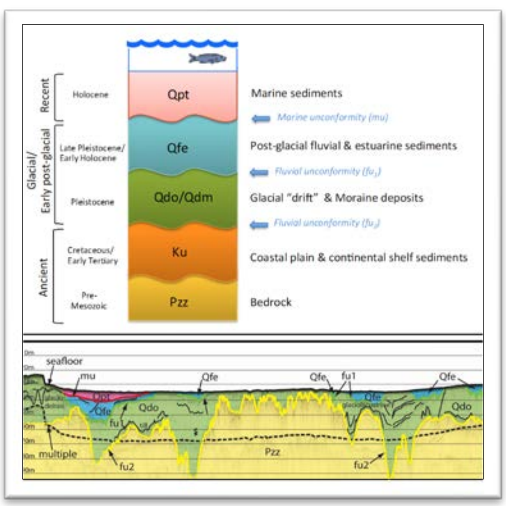
OCS Study
BOEM 2020-024

Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Ancient Native American Archaeological Sites in Submerged Environments:

Geoarchaeological Modeling



US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Ancient Native American Archaeological Sites in Submerged Environments:

Geoarchaeological Modeling

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DISCLAIMER

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ABOUT THE COVER

Left image: United States Geological Survey (USGS) stratigraphic framework of the subsurface continental shelf off Rhode Island.

Upper panel shows an idealized stratigraphic section with a simplified description of each stratigraphic unit after Needell et al. (1983a). Lower panel shows an excerpt of a seismic reflection profile obtained by the project team south of Narragansett Bay and interpreted according to the established stratigraphic framework illustrated in the upper panel. (Illustration by Carol Gibson and Brian Caccioppoli.)

Right image: BOEM Marine Archaeologist and Environmental Studies Coordinator, Melanie Damour, examines quartz chipping debris found at the newly identified “West Beach UW-1” (RI 2719) submerged site, Block Island, RI. (Photograph by David Robinson.)

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List of Abbreviations and Acronyms

APE	area of potential effect
AMI	Area of Mutual Interest
AMS	accelerator mass spectrometry
BITS	Block Island Transmission System
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
BP	before present
ca.	circa
CHIRP	compressed high intensity radiated pulse
cm	centimeter(s)
CML	Coastal Mapping Laboratory
CPT	cone penetration tests
CRMC	Coastal Resource Management Council
CTB	Cedar Tree Beach
DOI	Department of the Interior
DTU	dredge test units
ESPIS	Environmental Studies Program Information System
ESRI	Environmental Systems Research Institute, Inc
ft	foot/feet
fu_1, fu_2	post-glacial fluvial unconformity
GIS	geographic information system
GNSS	Global Navigation Satellite System
GRAPE	Gamma Ray Attenuation and Porosity Evaluator
in	inch(es)
km	kilometer(s)
kyBP	thousands of years before present
Ku	coastal plain and continental shelf sediments
LGM	Last Glacial Maximum
lb	pound(s)
m	meter(s)
mm	millimeter(s)
mu	marine unconformity
MGSL	Marine Geological Samples Laboratory
mm	millimeter(s)
MSL	mean sea level
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NIT	Narrangansett Indian Tribe
NITHPO	Narragansett Indian Tribal Historic Preservation Office
nT	nanoTesla
ROV	remotely operated vehicle
RSL	relative sea level
OCS	Outer Continental Shelf
OSV	ocean survey vessel
Qdm	glacial end moraine deposits
Qdo	glacial drift deposits
Qfe	post-glacial fluvial and estuarine sediments

Qpt	marine sediments
Pzz	pre-Mesozoic bedrock
RIHPHC	Rhode Island Historical Preservation & Heritage Commission
RI OSAMP	Rhode Island Ocean Special Area Management Plan
s	second(s)
TIN	Triangular Irregular Network
URI-GSO	University of Rhode Island-Graduate School of Oceanography
USACE	US Army Corps of Engineers
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VSP	visual sediment probe
yBP	year(s) before present
yr	year(s)

Lexicon

Some of the most common terms associated with submerged cultural sensitivity assessments have multiple meanings that can create significant confusion between research partners from diverse backgrounds. This lexicon clarifies the usage of these terms in this report.

Archaeological Site: *A geographic area where physical remains (i.e., features and artifacts) correlating to past human activity are present.*

Paleo: *A prefix meaning ancient*. Frequently used to refer to the geological past. For example, “paleoclimate” literally means “ancient climate.” “Paleo” is a general term that does not imply a particular time period in the past. The prefix “paleo” should never be confused with, or used interchangeably with the term “prehistoric,” which is offensive to Tribal communities, because it implies to them that their ancestral culture does not have a history.

Paleoenvironment: *Ancient environment,* describing the ecological and climatic characteristics of the ancient land surface. For example, an ancient land surface may be characterized by lakes and rivers, with vegetation indicative of cold climates. Note that this term refers to the natural environment only, without any implication regarding the cultural use or importance of the environment.

Paleotopography: *Ancient topography*, describing the physical configuration of the ancient land surface, frequently with respect to elevation. Note that this term refers to the natural environment only, without any implication regarding the cultural use or importance of a geographic area.

Paleolandscape: *The combination of the paleotopography and paleoenvironment of a geographic area*, *including the landforms of a region in the aggregate. A portion of territory that could have been viewed at one time from one place.* Using the term “paleolandscape” should imply a comprehensive understanding of the natural environment in a geographic area. Note that this term refers only to the physical characteristics of an area, not to the cultural use or importance of the area.

Paleolandscape Fragment: *A landform or portion of a landform that was part of a paleolandscape.* For example, a paleochannel is a paleolandscape fragment. It represents only a portion of a more complex landscape that may have been dominated by rivers, but also consisted of marshes, uplands, and other sub-environments.

Paleocultural Landscape: *An ancient landscape that was inhabited or modified by humans, and/or a landscape that is perceived by contemporary Tribal communities as having cultural importance to them since ancient times.*

Paleocultural Sensitivity: *The potential for paleocultural sites to be present within a given geographic area.*

Paleocultural Sensitivity Assessment: *An assessment in which cultural and environmental variables are examined to determine the potential for paleocultural sites to be present within a given geographic area.*

Paleocultural Site: *A site with evidence of ancient cultural activity or importance.*

Paleocultural Site Identification Survey: *A geoarchaeological survey done to identify paleocultural sites within a given geographic area.*

Reconstruction: *A representation of something that no longer exists or cannot be viewed directly based on scientific and cultural data obtained through evidence-based geoscientific, archaeological, and ethnographic research.* The focus of reconstructions can be geographically, chronologically, and culturally narrow or broad according to the types of data available and the needs and goals of the project.

Study, Survey, or Project Area: *The geographic location that is being investigated*, and where activities such as geophysical surveying or archaeological identification or investigation activities take place. These locations should not be called “sites” unless physical remains associated with past human history are present.

“Unless reliable paleoenvironmental reconstructions can be generated, it is clear that we must proceed with caution.”

(Kvamme 2006)

1 Introduction

1.1 Project Inception

The Outer Continental Shelf (OCS) of the United States is increasingly becoming the focus of renewable, oil, and gas development to meet the nation's energy objectives. Consideration of the effects this development may have on submerged Tribal historic properties is a legislatively mandated responsibility for Federal agencies, including the United States Department of the Interior's (DOI) Bureau of Ocean Energy Management (BOEM), which reviews and permits these undertakings. It is also a significant concern for individual States, Tribal Historic Preservation Offices (THPOs), other regulatory agencies, stakeholders, and researchers that participate in the environmental review process for offshore development projects. During BOEM's 2011 Atlantic Wind Energy Workshop, participants identified the development of geospatial databases of known submerged Tribal cultural sites, and the development of standardized methodologies for identifying them, as critical data needs (Cahill et al. 2011).

In response to these needs, the Coastal Mapping Laboratory (CML) at the University of Rhode Island's Graduate School of Oceanography (URI-GSO) and its research partners, the Rhode Island Coastal Resource Management Council (CRMC) and the Narragansett Indian Tribal Historic Preservation Office (NITHPO), submitted a joint proposal to BOEM in 2012 entitled, "Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Ancient Native American Archaeological Sites in Submerged Environments" (hereafter, "the project"). This proposal led to a cooperative agreement between URI and BOEM, with CRMC and NITHPO as research partners, to conduct a five-year study consisting of multidisciplinary investigations of five nearshore and offshore areas in Rhode Island waters. The overall goals of the project were to refine and enhance the following:

- The current understanding of submerged paleocultural landscape distribution on the Rhode Island OCS, especially landscapes of Tribal significance

- The identification of paleocultural landscapes of importance to southeastern New England Tribes

These goals were to be met through the development and testing of "best practices" for five interrelated processes that are considered essential for assessing cultural sensitivity of submerged environments and identifying submerged Tribal cultural sites: 1) paleoenvironmental reconstruction; 2) paleolandscape reconstruction; 3) Tribal engagement; 4) geoarchaeological modeling; and 5) model testing/submerged sites identification survey. This document focuses on the geoarchaeological modeling component of the project.

1.2 Document Context and Scope

Geoarchaeological modeling is based on the generally accepted theories that there is an association between past human activities and different types of paleolandforms and paleoenvironments, which results in a material culture expression sometimes preserved within the present landscape in a predictable manner. This association has been used with some success in terrestrial contexts onshore to develop models that predict where cultural materials may be located (Kvamme 2006; Verhagen and Whitley 2012). One of the objectives of the project was to examine whether geoarchaeological modeling could be applied effectively in the submerged environment to assist in making informed cultural resource management decisions for the OCS.

Initially, BOEM's scope for the project included the development of a predictive model for the Rhode Island OCS based on information compiled from a three-day workshop convened at the start of the project (CML, URI-GSO 2015). The workshop was designed to foster and support initiation of an open and respectful exchange of information, ideas, and values between representatives from the Tribal, agency, and research communities within a collaborative research partnership framework. Subject-specific presentations and discussion sessions for the workshop's first day included these topics: the project's legislative framework and BOEM's current survey guidelines, Tribal values and information, and current knowledge of impacts of sea level rise and marine transgression. Current methods for performing submerged paleolandscape reconstruction, predictive modeling, site identification, and excavation were also discussed. The second day of the workshop consisted of topical discussions intended to provide the necessary information for developing best practices for undertaking submerged paleolandscape reconstructions, predictive modeling of site locations, integrating Tribal oral histories into predictive models, identifying and reconstructing submerged paleolandscapes, and identifying and excavating sites. The third and last day of the workshop consisted of a private meeting and workshop debriefing for Tribal members, followed by a final open-forum discussion between the Tribes, BOEM, and URI project participants.

Although the workshop was an excellent venue for individuals from diverse backgrounds to interact and share information, it revealed significant gaps in the available geoarchaeological data and accessible Tribal oral tradition information considered necessary for completing the project's modeling effort. It also revealed that developing a standardized methodology for modeling was a more complex and challenging task than originally anticipated. Additionally, the workshop clarified that mutually beneficial and culturally sensitive relationships between the diverse groups engaged in the project needed further development before effective collaboration could take place. These challenges could not be fully addressed within a three-day workshop format.

In response to the results of the workshop, the project's modeling process was altered, and organized into the following six sequential steps:

1. Conduct a thorough literature review to understand the current state of knowledge regarding the use of archaeological predictive models in submerged environments

2. Conduct a detailed desktop study to synthesize the current state of geoarchaeological knowledge in the study area into geospatial format

3. Develop a modeling process that can be applied to any geographic area to assist with locating and characterizing preserved paleocultural landscapes

4. Develop regional sea level change and stratigraphic models to assist with locating and characterizing preserved paleolandscapes or paleolandscape fragments on the Rhode Island OCS

5. Apply the modeling process and model (developed in steps 3 and 4 above) to the project study area by conducting geoarchaeological investigations in five diverse case study areas

6. Develop recommendations about the use of predictive models in submerged environments, specifically with respect to identifying paleocultural landscapes of Tribal significance

This document presents the results of the tasks outlined above. Section 1 provides the context for the project's modeling task, and Section 2 provides a synthesis of the key geoarchaeological modeling concepts that are necessary to understand the potential applicability of terrestrial modeling to the submerged environments. Section 3 presents a process for submerged study area characterization that can be applied to a variety of geographic areas and used when diverse types, amounts, and resolution of data are available. Section 4 compiles the results of a comprehensive desktop study that was conducted in the project area as the basis for the modeling tasks in this report. Sections 5 and 6 present two regional models for the study area based on the data obtained through the desktop study. Section 7 summarizes the results of archaeological and/or geological investigations of five case study areas in Rhode Island waters and discusses the implications of these studies for geoarchaeological modeling of submerged environments. Finally, Section 8 identifies conclusions and recommended next steps to further refine the concepts presented in this report.

2 Geoarchaeological Modeling Overview

2.1 What is a Geoarchaeological Model?

The term “model” is used within a scientific research context to describe a wide variety of procedures and outcomes that vary significantly according to research subject and application. In this document, the term model is defined as an object, illustration, or process that helps to visualize or predict something, or to test a hypothesis. A model can be outcome-based, meaning that it is a digital or physical representation of something created for visualization purposes, or it can be process-based, meaning that it consists of a framework of steps and actions that can be applied to various datasets to test a hypothesis. For example, a representation of a planned building created by a 3D printer is an output-based model. As long as the user is comfortable with the technical specifications of the printer, the focus of the model is not the process that creates it, but the object that the printer produces. In contrast, a flowchart of geoprocessing steps necessary to identify the association between soil types and land use in a geographic area is a process-based model. The flowchart provides a structured framework of repeatable, interconnected steps. The resulting map, or output, of this type of model is important, but the framework used to create the map is considered to be the model, because it can be applied to a variety of different datasets to test diverse hypotheses. Data used in modeling can be quantitative or qualitative. Use of one over the other is dependent upon the amount and types of data that is available, and the purpose and goals for developing a model.

In archaeological research, a model is a conceptual tool that is used to assess and characterize “archaeological sensitivity”—that is, the relative probability of encountering an archaeological site within a given area. The outcome of these models, whether created from qualitative/phenomenological data or as a result of the processing of quantitative data using multivariate statistical analyses, are most often archaeological sensitivity maps that illustrate the horizontal extent of differentially defined sensitivities usually categorized into three zones: “high sensitivity,” where archaeological sites are most likely; “medium sensitivity” where sites are less likely; and “low sensitivity” where sites are unlikely. In practice, these maps are then used for a variety of purposes that include the planning of different types, resolutions, and extents of archaeological investigations and land-use planning and management (e.g., inventorying site types, site locations, and environmental characteristic of particular area and identifying gaps in those data, determining the historical significance and best use of an area, protecting and reducing natural and anthropogenic impacts to an area, etc.). Current environmental attributes are those most often correlated with archaeological site location data to model archaeological sensitivity. These environmental attribute data are often readily available in geospatial formats for use in digital archaeological modeling research. In the case of geoarchaeological modeling, environmental attributes that are considered also include those related to geology, geomorphology, and geochronology.

The inherent ambiguity of the term “model” requires that, in all cases, the type of model being produced, the processes used to create it, and the outcomes and products that are expected from it need to be clearly described and defined, as well as reproducible and testable. This type of clarification is not merely a matter of semantics, but is necessary for understanding and establishing the data requirements, goals, methods, workflow, and outcomes of a model.

2.1.1 Components of a “Good” Model

The accuracy with which an archaeological model predicts or characterizes a given phenomenon when tested through field investigation and data acquisition is a function of its performance or validity. By comparing model predictions against identified archaeological site locations, it is possible to determine, with specifiable confidence, how accurately a model performs. It is, in fact, this very approach that imparts confidence in a model and allows it to be used as a predictive tool. Iterative validation, evaluation, and field testing of a model are essential to demonstrating and improving the model's performance. Validation, or consistency testing, involves identifying any conceptual and factual errors that might have been incorporated into the model, such as errors in underlying theories, or unreliability and bias in the environmental and archaeological datasets. Evaluation, or performance testing, involves comparing model outcomes with existing archaeological knowledge and data and is generally accomplished using statistical methods. Finally, field investigation is essential to test and, if necessary, refine the original theories underlying the model (CML, URI-GSO 2015; Verhagen 2008; Verhagen and Whitley 2012). Additional elements of a "good" model or good modeling practice include the following:

- Transparency and reproducibility, resulting from clearly specified model-building steps
- Applicability to future situations
- The ability to be optimized to the available data set, allowing the best possible prediction based on available information
- The ability to specify uncertainties inherent in sensitivity predictions
- The ability to provide an explanatory framework to support why sensitivities are assigned as "low," "medium," or "high" (CML, URI-GSO 2015; Verhagen 2008; Verhagen and Whitley 2012)

2.2 Use of Predictive Models for Paleocultural Sensitivity Assessments

2.2.1 Overview of Theoretical Concepts

Although a comprehensive description of the theoretical aspects of predictive modeling in archaeological research is beyond the scope and purpose of this document (see Judge and Sebastian 1988), a discussion of basic theoretical concepts underlying the approach to assessing paleocultural sensitivity within the project's study areas is necessary. Predictive modeling's theoretical roots are traceable to the "New" or "Processual Archaeology" of the late 1960s, and the application of scientifically based statistical models for the prediction of site density based on the relationship between the characteristics of the natural environment with the location of human settlement, which were only ever applied to terrestrial archaeological contexts (Judge and Sebastian 1988; Verhagen and Whitley 2012). The general underlying theoretical basis for archaeological predictive modeling is that: 1) past human behavior is patterned with respect to natural and cultural/social environments; 2) we can learn something about ancient humans and past human behavior and their interactions with these environments by observing and recording the relationships between ancient human material residues (i.e., the archaeological record) and these natural and cultural/social environmental features; and 3) we can predict where sites may and may not be located based on these relationships and their observed patterning.

By the 1980s, and continuing up to the present, predictive modeling approaches had bifurcated into two primary lines of research, consisting of either a largely theoretical series of models based on the use of eco-systemic structures and relationships to identify spatial suitability, or a series of models based on extrapolating environmental variables from the landscape in a quantitative fashion, from which correlative statistical summaries could be built and applied to areas not yet surveyed (Verhagen and Whitley 2012).

The latter of these two approaches involving statistical extrapolation methods is often referred to as an "inductive," "correlative," or "data-driven" modeling approach. It compares known site data, usually acquired in a controlled survey area with "environmental" data sets, such as distance to water, soil type, slope, etc., and then extrapolates the correlations found to areas where no site information exists, usually by means of logistic regression. The role of archaeological theory on site location preference is very limited in these inductive models, with little or no attention paid to ideas on how people may have used and perceived the landscape in the past.

In contrast to the inductive modeling approach, "deductive," "explanatory," or "theory driven" approaches to modeling use archaeological site information to look for correlations for hypothesis testing purposes. Hypotheses of settlement location preferences are the basis for these models, which are created using relatively simple GIS-based analysis tools, such as weighted overlays. These models were mainly used in locations without much site information. Often, they are relatively unsophisticated models, to the point of being "intuitive" or "expert judgment" models based on *phenomenology*. Phenomenology is a qualitative research method that involves the direct investigation and description of the perceptions, perspectives, and understandings people have based on their experiences with a phenomenon of interest. By studying the perspectives of multiple participants, a researcher can begin to make generalizations regarding the phenomenon of interest from the perspective of those that have lived the experience. In this case, the phenomenon experienced has been the identification of submerged paleocultural landscapes and archaeological deposits within them. Virtually all of the archaeological modeling that has been done to date for the submerged environment may be described as phenomenological in nature.

Unfortunately, a dichotomy has arisen in the objectives of using predictive modeling in archaeology. On one hand, usually in the context of cultural resource management work, predictive models are employed as tools for minimizing field effort, rather than as explanatory research tools for understanding patterns in the spatial distribution of archaeological sites (Verhagen and Whitley 2012). Oftentimes, the primary intention of the application of predictive modeling is to enhance the cost-effectiveness of the research being done, rather than the investigation and explanation of spatial patterning of archaeological sites. These types of applications tend to be overly simplistic, ineffective, and ultimately not particularly useful for any audience. On the other hand, predictive modeling applications in academic research are often explanatory and useful, but only to a small group of scholars, and their complexity makes them impractical for environmental management.

Regardless of the type or degree of sophistication of the modeling that is developed and applied in a particular instance, clarity of what is being modeled is essential: a "systemic context" (the living behavioral state of past human groups or societies) or an "archaeological context" (the static, nonbehavioral state of archaeological materials comprising the physical record of archaeological study) (Kvamme 2006:13). From a cultural resource management standpoint, the goal seems to be the modeling of the latter. In approaching this goal, it is equally important to model and map where archaeological sites are unlikely to occur as it is to model and map where they are likely to exist.

2.2.2 Current Use of Geoarchaeological Models in Submerged Environments

At the time of their publication, BOEM's Office of Renewable Energy Programs' 2017 revised version of their "Guidelines for Providing Archaeological and Historic Property Information Pursuant to 30 CFR Part 585" represented the most current guidance and recommendations from a Federal agency regarding the use of geoarchaeological models in submerged environments. The purpose of these guidelines was to provide offshore renewable energy developers and their marine archaeological consultants with recommended methods for characterizing and identifying pre-contact period historic properties that could be affected by proposed offshore renewable energy development activities reviewed and permitted by BOEM. These pre-contact historic properties would be Native American cultural sites and archaeological deposits that dated from the time prior to European contact and were once part of a terrestrial landscape inundated by global sea level rise during the Late Pleistocene and Holocene and eligible for or listed in the National Register of Historic Places. The BOEM Guidelines were not intended as a one-size-fits-all methodology, but, instead, as a foundational framework for designing historic property identification surveys for specific areas and activities that would provide sufficient information for BOEM to fulfill its National Historic Preservation Act (NHPA) and National Environmental Policy Act (NEPA) review responsibilities. The 2017 BOEM Guidelines remain (as of 2019) the current and most widely utilized standard methods for geoarchaeological modeling in U.S. waters, in large part because most of the marine geoarchaeological work currently being performed there is associated with BOEM-reviewed offshore energy development activities.

BOEM's current geoarchaeological modeling guidelines adopt ideas and methods that have been developed during the course and as a result of this study, as well as those of the applied and academic research conducted since the 1970s to inform archaeological sensitivity assessment and submerged paleocultural site identification in the U.S. and abroad (e.g., Benjamin 2010; Benjamin et al. 2011; CEI 1977; Dunbar et al. 1992; Edwards and Merrill 1977; Evans 2016; Faught 1996, 2004, 2014; Fischer 1987, 1995; Fischer and Sørensen 1983; Flatman and Evans 2014; Flemming 2004; Gaffney et al. 2007; Gagliano 1974, 1977, 1983; Gagliano et al. 1982; Garrison et al. 2012; Gifford 1983, 1990; ICA 1979; Johnson and Stright 1992; Kelley et al. 2012; Pearson et al. 1986, 1989; Pedersen et al. 1997; Van Andel and Llanos 1984; Westley et al. 2011). However, it is primarily during the past two decades and especially over the last 10 years that focused interest in submerged paelocultural landscapes archaeology has grown and led to new research and fieldwork seeking to address current methodological, modeling, and theoretical questions in the discipline. Much of this more recent work has been driven in response to the anticipated impacts to the sea floor from current and planned expansion of conventional and renewable offshore energy infrastructure, as well as the expanded offshore sand and gravel resource extraction that is increasingly needed for shoreline stabilization due to a recent acceleration in the rise of global sea level. Greater recognition of the potential presence of previously unidentified submerged pre-contact period archaeological sites that could be impacted by the planned increases in federally permitted offshore activities has created an increasingly urgent need for better geoarchaeological maps and models for threatened areas of the sea floor—usable tools for identifying and characterizing paleocultural landscapes and the archaeological sites present within them—based on new geoarchaeological, paleontological, and indigenous cultural information and insights.

Substantively little has changed, however, regarding the fundamental need for more geoarchaeological data, since the publication of Benjamin et al's 2011 edited volume, *Submerged Prehistory*. As Benjamin et al. note in that volume, "the study of submerged prehistory is still in its infancy…" with "…countless inundated prehistoric sites, from marine, brackish, and freshwater environments worldwide…yet to be discovered and studied." More to the point, in regards to the current use of geoarchaeological modeling, is the problem that Peeters (2011) describes in the same volume—that the data points from which reliable (geoarchaeological) models for further research offshore can be produced is presently insufficient. Given this situation, an essential priority of the discipline must be the collection of more data. More experiences and observations from the field are needed from which phenomenologically based generalizations and testable hypotheses and models can be created. Beginning with the extremely limited data that is available, preliminary working hypotheses and "bold assumptions about what may be expected" need to be considered and coarse models developed and tested to refine them, so that it is possible to progress from a "primarily hypothetical world to a real one" in the future geoarchaeological models for the offshore environment (Peeters 2011).

Virtually all of the marine geoarchaeological studies conducted to date (2019) in the U.S. and abroad must be considered as developmental in nature and more narrowly applicable to the specific activites and areas for which they were designed. Collectively, though, they represent general progress towards achieving an accepted, standardized, systematic methodology that may be applied more broadly to the open-ocean offshore environment of the U.S. OCS. Synthesis of the different geoarchaeololgical modeling approaches coalesced in the BOEM 2017 Guidelines has produced several basic methodological elements currently being used in modeling. These elements include:

- Review of relevant geological and archaeological literature
- Reconstruction of sea level and shoreline location changes over time
- Characterization of onshore archaeological site types, ages, cultural affiliations, and distribution patterning for correlation with identified submerged paleolandscape types
- Analysis and interpretation of sub-bottom profiler and other types of remote sensing data, and geotechnical testing data (i.e., sediment cores and other types of sediment samples) to determine whether geomorphic features of the formerly subaerial landscape (e.g., terraces, flood plains, and river, bay, lagoon, and paleochannel margins, etc.), dating from the geological period(s) associated with human habitation, are preserved and buried beneath more recent marine sediments on the sea floor within the areas being studied
- Paleolandscape reconstruction that delineates areas of high potential for the presence of pre-contact archaeological sites based on the analysis and synthesis of the area's geomorphologies and documented onshore site patterning within those types of geological deposits.

Currently used geoarchaeological models developed for formerly glaciated locations and environments that have been tested and proven valid, or that are of particular interest because of the advancements they represent in their approach and methods, are few in number and are all European in origin. They include the long-standing "Danish Topographical Model" or "Danish Fishing Site Model," developed over 30 years ago for the nearshore coastal waters of Denmark (Fischer 1987, 1993, 1995), and more recently published models for the Netherlands (Vos et al. 2012) and Northern Ireland (Westley et al. 2014).

The Danish Topographical or Fishing Site model is a simple, non-quantitative, phenomenological model that was developed from interviews with elder local fishers and field surveys conducted in the mid-1980s and identified stratified layers of submerged paleolandscapes containing cultural features (e.g., a hearth) and artifacts dating from the Mesolithic (ca. 14,500 to 5,900 years before present [yBP]) and Kongemose (ca. 8,400 to 7,400 yBP) cultural periods. The presence of these submerged cultural features and artifacts was closely associated with the former topographic locations of ancient fishing sites where the trapping and netting of fish took place (e.g., at bay, river, and stream mouths, in narrows, and between nearshore islands and point bars [Fischer 1987, 1993, 1995]). The effectiveness of the Danish Fishing Site Model and its use of existing bathymetry as an indicator for predicting the possible locations of submerged cultural sites was tested at the time it was conceived and determined to have an efficacy greater than 80 percent (Fischer 1995). Widespread employment of the model during subsequent survey projects conducted throughout Denmark's coastal waters over the past four decades has proven similarly effective. Today, there are thousands of submerged Stone Age archaeological sites that have been identified in Danish waters by researchers and recreational scuba divers. Although the Danish Fishing Site Model has some limitations (non-quantitative, singular activity focus, the use of modern bathymetry as an indicator of paleolandscape topography, and sites that are exposed on the sea floor or have shallow burial depths), given that ancient coastal peoples worldwide have engaged in fishing activities, it seems likely that the Danish Fishing Site Model would nonetheless have broad applicability for identifying fishing site archaeological deposits in other regions of the world, including in U.S. waters.

Another geoarchaeological model with methodological elements of interest was developed recently by Vos et al. (2012) during a cultural resource management marine archaeological investigation conducted as part of a harbor deepening project in the coastal waters of the Netherlands. The study provides a current and more complex example of process modeling that is a distinctly articulated, systematic, phased approach. Most significantly, the model acknowledges one of the more pressing methodological limitations of underwater archaeological survey—that "an underwater archaeological study will be carried out with substantially less sampling than an equivalent terrestrial archaeological study." The Vos et al. (2012) model sought to address the issue by determining and testing areas with the highest archaeological potential, as determined through paleoenvironmental reconstruction and paleolandscape modeling, and the placement of archaeological finds known from terrestrial excavations into their paeloenvironmental context (Vos et al. 2012:940). Unlike the Danish Fishing Site Model, the Vos et al. (2012) model is not restricted to coastal or paleolandscape elements favorable to fishing, but instead focuses on examining the entirety of identified preserved paleolandsurfaces, and in the case of this particular study, paleolandscape geomorphologies that were initially deeply buried (20 m below sea level) prior to harbor dredging that took place as part of the project and removed 17 m of overlying marine sediments. The phases of the Vos et al. (2012) geoarchaeological modeling approach included the following:

- <u>Phase 1</u>: Desktop study of existing data and the development of a "Geological Layer Model" identifying paleolandsurfaces from those data and estimating the most likely approximate depth of possible archaeological remains (significantly, cone penetration tests (CPT), coincident and correlated with borehole data, were used)

- <u>Phase 2</u>: Full area site investigation, following harbor dredging down to 17 m below sea level, involving remote sensing (single and multichannel Compressed High Intensity Radiated Pulse [CHIRP] and "sparker" sub-bottom profiling and multibeam bathymetric survey), and additional CPTs and borings to update and refine the Geological Layer and Paleolandscape Models

- <u>Phase 3</u>: High-detail site investigation resulting in an archaeological potential map and preliminary archaeological site and depth selection

- <u>Archaeological Sampling</u>: Focused on high-probability locations identified in the previous research phases

Preliminary paleoenvironmental reconstruction conducted by Vos et al. (2012) identified depths below sea level that archaeologically relevant geological layers were most likely to be found. Use of resistance and friction parameters obtained from existing CPTs were correlated with existing boring data and then translated into identifiable indicators of specific lithological units and their interfaces. These were then grouped into a representative geological layer profile section model and a reconstructed digital surface model for the identified layers in the study area. This geological layer model provided a rough estimate of the layers and depth levels associated with the highest archaeological potential. In the case of the Vos et al. study area, the flanks of river dune sands deposited on the margins of rivers extending across a braided Pleistocene floodplain, and the bases of Early Holocene layers of deltaic peat and clay deposited subsequently onto the river dune sands as a result of rising sea level were identified as having the highest archaeological potential and chosen for archaeological sampling. Underwater excavation of three sampling locations, measuring 6 x 16 m, 9 x 12 m, and 2 x 3 m (in four areas), sieved through 10 mm and 2 mm mesh, resulted in the recovery of a very large number of finds (N=46,067). The finds consisted of charcoal, flint, and fragments of burned and unburned animal bones, and were the first *in situ* scientific proof for hominin occupation of the western Netherlands in the Early and Middle Mesolithic (Vos et al. 2012). Vos et al. (2012)'s systematic, phased, multidisciplinary, integrated-data approach is an example of a current geoarchaeological modeling effort that could have broader applicability elsewhere, including in the waters of the U.S.

Middle Holocene paleogeographic reconstructions and an archaeological site potential model developed for a coastal area in Northern Ireland by Westley et al. (2014) provide additional methodological advances for current geoarchaeological modeling in areas where marine sedimentation rates are relatively high and paleolandsurfaces are buried. Using legacy boring data, seismic profiles, and sediment cores, Westley et al. (2014) improved upon previous reconstructions that utilized modern bathymetry as a proxy for submerged and buried paleotopography (rendered potentially less accurate by the effects of post-submergence erosion or deposition) by employing a "backstripping" methodology in their digitial modeling to "remove" 2.5 to 10 m of accumulated modern marine sediments from identified buried paleolandscape surfaces in order to obtain a more accurate reconstruction of the past landscape. Westley et al. (2014) also utilized available sea level rise models to constrain the range of possible sea levels that they apply to their backstripped digital paleolandscape model to reconstruct marine transgression during the Early to Middle Holocene. Given the crucial role that paleolandscape reconstructions and marine transgression projections play in archaeological research by providing the physical context for predicting archaeological site locations produced by past human activities, Westley et al's methodological contributions to geoarchaeological modeling are important to consider.

2.3 Challenges with Modeling in Submerged Environments

Geoarchaeological modeling for study areas located in submerged environments presents challenges that are different from those that are encountered when developing archaeological models for terrestrial environments. These challenges are significant and presently preclude the application of sophisticated quantitative archaeological modeling approaches that have been developed and used for onshore study areas, due to the very limited number of identified paleocultural sites on the United States' continental shelf. The challenges include visibility, access, scale, and resolution. Seeing, surveying, identifying, accessing, and conducting archaeological testing of a submerged paleolandscape requires very different methodologies and produces different types of data than what is typical done for or available from the archaeological investigation of paleolandscapes on land. Unlike on land, where it is possible for a person to physically access, walk across, and visually observe broadly and identify a paleolandscape, and comparatively easy and inexpensive to complete comprehensive site assessments and archaeological surveys to identify archaeological sites within it, elements of the paleolandscape that are preserved in submerged environments are not easily visible. They are obscured by 1) the water in which they are submerged, both from the surface above the water, as well as below the surface due to limited underwater visibility; 2) overlying marine sediments that have accumulated on top of and buried them; 3) the massively transformative effects associated with the erosion and redistribution of sediments that occur during the marine transgression process and the geomorphological changes that occur post-submergence, which together result in the incomplete preservation of the submerged paleolandscape; 4) the equally incomplete present understanding of how much, what, where, and why remnants of the submerged paleolandscape are preserved; and 5) the absence of comprehensive, detailed, high-resolution mapping and visual documentation of the seafloor.

The amount of pre-existing high-resolution geologic and paleoenvironmental data that is publicly available for modeling the submerged environment is limited by the challenges associated with accessing, surveying, and identifying submerged paleolandscapes on and under the seafloor. Basic information about the extent and locations of preserved remnants of the submerged paleolandscape, the geomorphologic characteristics of those landscapes, the processes that lead to their preservation or destruction, and the submerged sites that would be found within them is all but absent from the literature. Modelers working in submerged contexts have almost no pre-existing archaeological site data available to them regarding the locations, types, dates, sizes, and distributions of archaeological sites in the submerged environment. In contrast, the onshore terrestrial environment has been continuously occupied by Native people for more than 10,000 years, and archaeological research on the material culture and available ethnohistorical records associated with that habitation has been ongoing for more than a century. Thousands of terrestrial cultural and archaeological sites have been identified onshore throughout the region as a result of surveys conducted by archaeologists who have most often been equipped with little more than a mode of transportation to get them to and from their study areas, a shovel, a trowel, a shaker-screen for sifting excavated soils, a camera, a field notebook and pencil, and a handheld GPS unit.

Submerged environment survey and site identification, on the other hand, requires use of research vessels, specially trained and educated marine scientists (i.e., oceanographers, marine geophysicists, marine geologists, archaeologists, paleontologists, etc.), and a suite of expensive marine surveying and sediment sampling equipment to conduct marine geophysical surveying and geotechnical sampling just to be able to access and "see" the seafloor/sub-seafloor and the sediments and stratigraphy that comprise it. In situations where conditions allow, actually observing the seafloor and conducting visual reconnaissance survey or targeted subsurface sampling/testing is possible only using specially trained and educated archaeological divers or archaeologist-guided and expensive remotely operated vehicles (ROV). Some offshore areas are characterized by marine conditions that make diving, ROV operations, or extensive on-site sampling/testing logistically problematic or impossible (e.g., where water depth is extreme, underwater visibility poor, high seas or strong currents prevalent, or where bottom composition interferes with the collection of high-resolution geophysical data or geotechnical sediment samples).

Other important challenges are related to scale and resolution. Although there is a significant amount of existing marine geological survey data and a substantial resulting body of literature describing, interpreting, and modeling post-glacial sea level rise and characterizing basic sea floor stratigraphy at multiple locations on the continental shelf, regional marine geological survey approaches followed to date are, by their nature, large in scale and coarse in resolution. Models for sea level rise are generally presented as smooth curves that average differences in data points and do not capture the episodic fluctuations, periods of "still-stand," and chaotic ways that sea level rise would have progressed in actuality across the variable terrain of the continental shelf's pre-submergence paleolandscape as it was inundated. Geophysical data acquired to develop the regional stratigraphic model for offshore sediments are generally acquired along widely spaced (e.g., 2 km apart) primary survey transects. Geotechnical sampling data complimenting the geophysical survey data can be limited. As a result, modeling the "human-" or "micro-scale" aspects of these paleoenvironmental changes is not yet possible without finer scale, higher resolution marine geological and archaeological data (Leary 2011:75-84).

For the submerged environment, the most immediately pressing question to be answered is not yet "Where and how did ancestral peoples interact with the formerly terrestrial paleocultural landscape?" but rather "Did any remnant elements of the paleocultural landscape that ancient people could have interacted with survive the inundation process intact and undisturbed?" If intact remnants of the now submerged paleolandscape are identified, a variety of additional questions must also be asked and answered:

- How disturbed are the surviving remnants of the paleolandscape?
- Is it possible to identify and discern primary, secondary, or tertiary contexts in preservedsubmerged paleolandscape sediment strata?
- How deeply are they buried?
- How far do they extend?
- What kinds of paleoenvironments are represented where cultural sites may have existed in the past, based upon what we know from the observed relationships of cultural sites and

paleoenvironments seen in the onshore archaeological record and as recorded in Tribal histories and traditions?

- Why have they survived?
- What are the geologic and oceanic conditions and processes that contribute to preservation?
- Can these variables be identified, measured and predicted?

Answering these questions will be essential for eventually developing the kinds of sophisticated quantitative archaeological predictive models for submerged environments that are presently available and being used in the archaeological sensitivity assessments of onshore study areas (see Verhagen and Whitley 2012).

In the case of developing a model for this project's study areas, the challenges included the basic ones of visibility, access, scale, and resolution, as outlined above. There is a limited amount of high-resolution marine geological data that is available for the Rhode Island OCS, particularly from Block Island southwards. Data available in the study area and northward is generally regional-scale reconnaissance-level survey data, except in a small number of areas that have been studied more intensively. Although the pre-existing regional data and its interpretation are of high quality, and their resolution is adequate for providing a regional geologic framework, it is inadequate for the purpose of identifying preserved remnants of the submerged paleolandscape. It is also inadequate for identifying specific elements of those preserved paleolandscape remnants that could then be correlated with similar preserved environments onshore and their associated archaeological and ethnohistorical data to assess and model their archaeological sensitivity. Meeting these challenges will require a combination of focused, high-resolution marine geophysical survey, geotechnical sediment sampling, sediment dating, analyses, and interpretation to further resolve the regional stratigraphic framework, to identify preserved remnants of the submerged paleolandscape, and to isolate specific environmental elements of it that can then be considered and modeled archaeologically.

2.4 Key Points

- The term "model" must be clearly defined in the context of each unique discussion or project.
- Unless specified, the term "model" in this report is defined as a process, object, map of two or three dimensions, or illustration that helps to visualize or predict something, or to test a hypothesis.
- In all cases, the type of model being produced, the processes used to create it, and the outcomes and products that are expected from it need to be clearly described and defined, as well as reproducible and testable.
- Iterative validation, evaluation, and field testing of models is essential to demonstrating and improving the model's performance, identifying any conceptual or factual errors, and assessing the reliability and any bias in the environmental and archaeological datasets used in the model's development.
- Geoarchaeological modeling in submerged environments presents unique challenges of visibility and access that are very different from those encountered when modeling in terrestrial environments onshore.
- Currently, the absence of archaeological site data and the limited amount of high-resolution comprehensive geological and geophysical data that exist for the submerged environment preclude applying quantitative terrestrial archaeological predictive models to underwater areas.

3 Development of the Project Modeling Process

3.1 Best Practices from Project Workshop

The initial project workshop summarized then-current (i.e., in 2013) approaches to assessing the archaeological sensitivity and predicting the potential for sites to be present within a given submerged study area. The resulting discussions that followed generated a number of ideas and general comments from the workshop's diverse group of participants representing academic research, applied sciences/industry, Federal and state agencies, and THPOs. A synthesis of the key "take away" messages regarding predictive models is presented below. A more detailed discussion is available in a separate project deliverable entitled "Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Native American Archaeological Sites in Submerged Environments: Best Practices" (Section 3.7) (Robinson et al. 2018).

- A model is only as good as the data that is used to create it, and a model incorporates assumptions and biases that directly affect the results of the model.

- The current amount of archaeological site data for the OCS is extremely limited. Only a handful of sites have been identified in submerged contexts offshore, and most of them have been close to shore and not in Federal waters.

- Models are a "best educated guess" simplification of reality and should never be viewed as reality.

- Models should never be the primary decision-making tool for cultural resource management.

- Models *must* be tested to assess their accuracy and should never be used without being tested.

- Models that attempt to identify ancient Tribal cultural sensitivity are incomplete without ethnohistorical input and cultural insights from contemporary Tribal peoples.

The project team incorporated all of these concepts into the development of the modeling process, the regional models, and the acquisition of new data for model testing that is discussed later in this document.

3.2 Defining the Scope of the Project Model

Given the inherent ambiguity in the meaning of the term "model" and the nature and scope of its application to addressing archaeological research problems, it is important to clearly define why a model is necessary, and the goals, processes, and expected outcomes of the model(s) being employed. It is also important to identify the potential issues and challenges that may be associated with the modeling task so that their impacts on the model are clearly understood at the beginning of the process.

The scope of the Submerged Paleocultural Landscapes Project models was established by the questions and responses summarized below. These questions provide a useful starting point for any modeling effort. Responses specific to the project are highlighted in bold.

1. What is the specific task that the model is being applied to?

    - **Developing a greater understanding of where culturally sensitive paleolandscapes and archaeological sites may be located on the continental shelf in southern New England.**

2. Why is a model necessary for this task?

    - **Modeling provides a starting point and theoretical framework for focusing research, testing hypotheses, and identifying and understanding observable patterning in the preservation and distribution of submerged paleolandscapes and their associated ancient Tribal archaeological sites. Focused research and hypothesis testing are necessary and especially important given:**
        - **The early developmental nature of submerged paleolandscapes archaeology as an emergent research discipline.**
        - **The extremely limited amount of baseline archaeological data available for the continental shelf.**
        - **The limited coverage and availability of high-resolution marine geological data.**
        - **The significant costs and logistical challenges associated with accessing, mapping, and sampling the sea floor.**

3. What is the definition of the term "model" as it will be applied to this task?

    - **An object, illustration, or process that assists with visualizing or predicting something, or is used to test a hypothesis. Multiple types of interconnected models can be used for a single task**.

4. What are the goals of the model(s) developed for this task?

    - **Develop a modeling process that is understandable by diverse groups of stakeholders.**

    - **Develop a modeling process that is applicable to multiple geographic areas, can be used when differing types and amounts of data are available, and that is applicable to "real life" circumstances.**

    - **Develop a tiered modeling process that begins with a thorough geological characterization of the study area on a regional scale, and progresses to a local assessment of paleocultural sensitivity by applying what is known from terrestrial archaeological research to predict the age(s), density, likely distribution, and types of sites that may associated with preserved paleolandscapes.**

    - **Address the unique challenges of working in submerged environments (see Section 2.5.2, and Question 8 below).**

    - **Avoid the pitfalls of previous predictive models that are not testable, not reproducible, and/or that use subjective environmental variables such as "near" (i.e., sites will be located *near* water bodies).**

5. What types of data will be used to develop the model(s)?

    - **Publicly available archaeological, geophysical, and geological legacy data for southern New England.**

    - **Archaeological, geophysical, and geological data previously collected by the project team and project collaborators.**

    - **Publicly available Tribal oral traditions and histories.**

- **Newly acquired archaeological, geophysical and geological data for the Greenwich Bay area, West Beach (Block Island), the Mud Hole, and northern Rhode Island Sound.**

6. What are the expected outcomes of the model(s)?

   - **A flow chart illustrating a modeling process that can be applied to diverse geographic areas.**

   - **Illustrations showing projected hypothetical paleoshoreline locations based on the application of sea level rise models to present bathymetry for the project study area at key times in the geological and archaeological past.**

   - **An improved understanding of the relationship between the broader regional subsurface stratigraphy and the local preservation of paleolandscapes that could be culturally sensitive.**

   - **An improved understanding of the pre- and post-inundation topographies and environments that preserve submerged paleocultural landscapes and the density, distribution, type, and time period of the archaeological sites likely to be present within them.**

   - **An improved understanding of the survey methodologies best suited to identifying, mapping, and reconstructing paleocultural landscapes in submerged environments.**

7. How will the model be tested?

   - **By conducting archaeological, geophysical, geological, and paleoenvironmental data acquisition and analyses of five case study areas representing diverse nearshore and offshore environments.**

8. What are the major challenges associated with model development for this task?

   - **The amount, resolution, and types of pre-existing data that are available will have a significant effect on the model.**

   - **Currently, there are very few submerged ancient Tribal archaeological sites that have been located on the continental shelf, so the modeling task cannot be based on archaeological data in the same way that it would be for terrestrial locations onshore with extensive archaeological datasets.**

   - **There is currently an incomplete understanding of how, why, and where paleolandscapes or paleolandscape fragments survived (or did not survive) the marine inundation process.**

   - **Characterizing the regional geology in submerged environments relies almost exclusively on remote sensing technology and interpretations of acoustic data.**

   - **Obtaining and analyzing sediment cores to ground-truth geophysical data, and developing an absolute age model with radiocarbon dates, is expensive, time consuming, and a significant drain on project resources.**

   - **Methods for culturally appropriate access and use of Tribal cultural knowledge in the model(s) requires additional attention and the development of trusting and mutually cooperative relationships.**

3.3 The Project Modeling Process

Identifying submerged paleocultural landscapes on the continental shelf requires a modeling approach that differs substantially from archaeological predictive modeling in terrestrial environments. Before potential cultural sensitivity can be assessed, the landscapes or landscape fragments that have survived post-glacial sea level rise, and that represent environments that could have been inhabited by ancient Tribal peoples, must first be located and characterized. Therefore, the modeling process requires a thorough understanding of subsurface geology and sea level change history on a regional scale, not just for a local study area.

The modeling process discussed in this document begins with a thorough desktop study to synthesize the current state of geoarchaeological knowledge in the study area and to assess the applicability of existing data to the modeling task. It then uses the compiled desktop study data to develop two types of regional geological models that are applied at the local level to five case areas. This approach differs substantively from previous approaches that have been applied in southern New England within the context of compliance archaeology projects, whose research focus is limited by design to within the localized vertical and horizontal boundaries of a proposed project's area of potential effect (APE). In addition, the modeling process presented in this report is unique because it does not assess paleocultural sensitivity based on the presence or absence of isolated geologic features, such as a paleochannels. Instead, once a regional geological framework is developed, geologic facies are identified that may represent the time frame and paleoenvironments associated with occupation by ancestral Tribal peoples.

Two types of models[1] are presented, which are organized in sequential tiers. Tier 1 is a process-based model that outlines all of the steps necessary to begin identifying and characterizing paleocultural landscapes in submerged environments. Because this model is a sequence of general tasks, it is applicable to any geographic location and can be used with varying amounts of data. Tier 2 models are illustrations and hypotheses that result from applying individual steps in Tier 1 to the regional project study area. Two Tier 2 models are developed for the southern New England continental shelf: 1) maps showing hypothesized paleoshoreline positions at key times in the past; and 2) illustrations that present a preliminary hypothesis about where preserved paleocultural landscapes may be located based on the subsurface stratigraphy of the region. Note that there is currently not enough geophysical data in the study area to create a regional geographic map of potential paleolandscape locations based on subsurface stratigraphy (see Section 4.1 of this report), so this model is not presented in the form of a map. Instead, it identifies basic geologic facies in representative seismic reflection profiles that may include strata in which are preserved archaeologically sensitive remnant elements of the submerged paleocultural landscape. Tier 2 models are applied to local case study areas, and are tested and revised by interpreting newly acquired data. Figure 3-1 is a flow chart illustrating the relationship between each of the models. Corresponding steps are summarized below.

1. Conduct a thorough desktop study to synthesize the geological and archaeological context of the study area. Identify previous research that has been conducted both regionally and locally. Assess the quality of the data and compile any legacy datasets that will be used for the project into a geospatial database. (An additional report produced as part of the Submerged Paleolandscapes Project, entitled "Developing Protocols for Reconstructing Paleocultural Landscapes and Identifying Native American Archaeological Sites in Submerged Environments: Best Practices," (Robinson et al. 2018) provides detailed recommendations about how to assess and compile legacy data).

[1] To review, a model as defined in this report is an object, illustration, or process that assists with visualizing or predicting something, or is used to test a hypothesis.

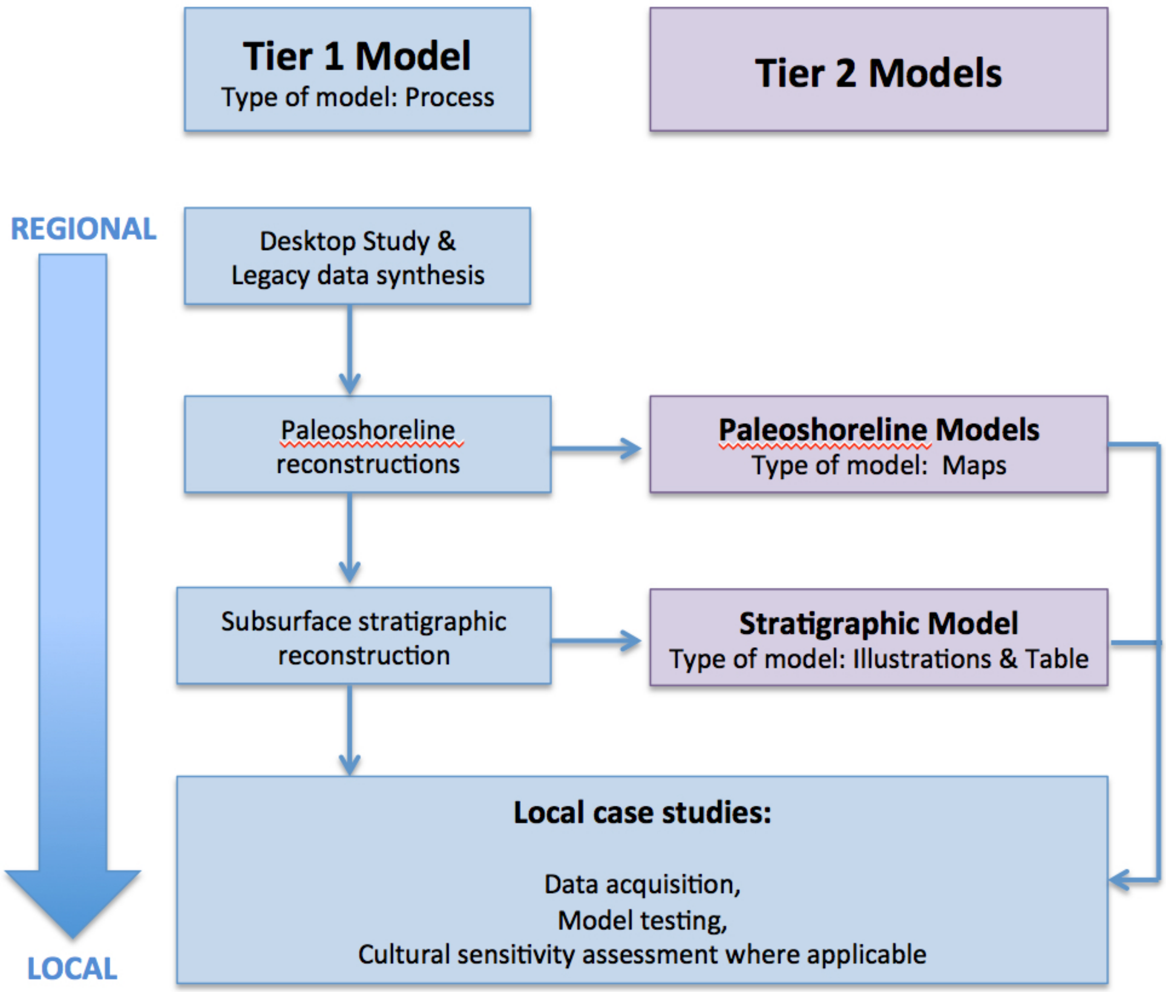


Figure 3-1. Flow chart showing the relationship between the models developed for this report.

2. Use exiting relative sea level change curves and the highest-resolution bathymetric datasets available to create preliminary reconstructions of approximate regional paleoshoreline position(s) applicable to the study area. This step has two purposes: 1) provide preliminary visualizations illustrating which portions of the study area may have been subaerially exposed at key times in the past that are associated with human habitation; and 2) visualize the difference between paleoshoreline positions resulting from various sea level models available of the study area. These visualizations should be regarded as hypotheses that require testing and verification at the local level.

3. Develop a regional stratigraphic model that identifies where paleolandscapes may be preserved based on the surficial and subsurface stratigraphy of the area. The goal of this step is to develop a broad understanding of the timing and processes associated with regional subsurface and surficial geology. It is essentoal to reconstruct and understand the complete subsurface stratigraphic sequence, beginning with acoustic basement and proceeding upwards to the seafloor. Focusing the reconstruction only on the depth likely to be impacted by a proposed construction project, or assuming that deeply buried sediments are too old to be culturally sensitive, may produce

inaccurate or incomplete assessments of potential cultural sensitivity. Using the reconstructed subsurface stratigraphic framework, identify the geological facies that represent the time frame in which humans could have inhabited the study area, and the types of paleoenvironments (lake, marsh, upland, etc.) that these facies are inferred to represent. Assess the extent to which those landscapes or landscape fragments appear to have been impacted by post-glacial sea level rise.

4. Test the model developed in step 3 at the study area(s). Acquire and interpret additional geophysical data and sediment cores to ground-truth the acoustic interpretations. If preserved paleolandscapes are identified, then conduct a paleoenvironmental assessment (examining sieved sediments for foraminifera, diatoms, pollen, etc.) to provide additional detail about the characteristics of the paleolandscape. If acquired and interpreted data demonstrate the presence of relict, preserved paleolandforms, then assess the paleocultural sensitivity of the represented landforms based on results from engagement and dialog with Tribal research partners, and from a review of the results of local and regional archaeological investigations of analogous landforms on shore.

Sections 4-7 of this report demonstrate how the modeling process discussed above was applied to the Submerged Paleolandscapes Project study area.

4 Application of Modeling Process to Project Study Area, Step 1: Desktop Study

The term “desktop study” refers to the compilation, synthesis, and summary of pre-existing, publicly available geophysical, geotechnical, archaeological, and cultural data and information about a given study area at the time when the investigation is initiated. Performance of a desktop study does not involve acquiring new field survey data. Conducting a thorough desktop study is a critical first step in the modeling process. Data that is synthesized as the result of a desktop study can be used to produce working regional models, which can then be tested with new data acquisition at local study areas. A separate report generated for the Submerged Paleolandscapes Project (Robinson et al. 2018) details “best practices” for conducting desktop studies and recommended content. The subject headings and discussion presented below follow these protocols.

4.1 Geographic and Temporal Limits of the Study Area

The modeling process and resulting models presented in this report were designed to apply to the southern New England continental shelf, and in particular to Rhode Island Sound and the eastern portion of Block Island Sounds. Figure 4-1 illustrates the specific areas that were targeted for new data acquisition, and/or analysis of legacy data. Archaeological, geophysical, and/or geological data from each of these locations were used to develop the models. Because one of the goals of the modeling process was to thoroughly understand the submerged subsurface regional geology of the study area, the project’s vertical depth of interest extends from acoustic basement as defined in seismic reflection profiles, upwards to the sea floor, and into the intertidal, beachface, backshore, and dune areas at Cedar Tree Beach (Greenwich Bay area) and West Beach (Block Island area). The time period for which paleocultural sensitivity and site potential was assessed extends from ca. 24,500 to 450 yBP, spanning the “Pre-Clovis” through “Late Woodland” pre-European contact archaeological periods.

Figure 4-1. Location of case study areas selected for model assessment and testing.

4.2 Tribal Engagement

An integral element of this project and modeling effort was the engagement with the Tribal communities who have cultural connections to the study area to discuss the study, to understand specific Tribal concerns and priorities associated with the project's study areas, and to incorporate Tribal suggestions, concerns, and priorities into the project's research. This engagement was realized through the formal research partnership that was established with the NITHPO at the start of the project, and through the informal collaborative relationships that were initiated and developed over the course of the study with Tribal representatives from the Aroostook Band of Micmacs, Lenape Indian Tribe of Delaware, Mashantucket (Western) Pequot Tribal Nation, Mashpee Wampanoag Tribe, Narragansett Indian Tribe (Niantic), Nipmuc Nation, Shinnecock Indian Nation, and Wampanoag Tribe of Gay Head (Aquinnah), who participated in the initial and interim project workshops, fieldwork, and report preparation and review.

4.3 Geologic Context

4.3.1 Overview

Mainland Rhode Island is composed of three general physiographic regions. The first, a narrow coastal plain with elevations of less than 100 ft, occurs along the shore and in the area around Narragansett Bay. The second, characterized by gently rolling uplands with elevations up to 200 ft, lies to the north and east of the Bay. A third region, comprising the western two-thirds of the state, consists of hilly uplands mostly between 200 and 600 ft in elevation. Narragansett Bay, a north-south trending estuary with approximately 420 miles of shoreline and multiple tributaries, dominates the eastern part of the state (Terwilliger Consulting, Inc. 2015).

Immediately offshore of Rhode Island, the Atlantic Ocean is divided into two areas: 1) Block Island Sound, which encompasses the area seaward of the southwestern coast of the state and north of Block Island; and 2) Rhode Island Sound, which is located south of Narragansett Bay and east of Block Island Sound. The water depth on the continental shelf in the study area ranges from intertidal at the coast to approximately 65 m offshore, with the deepest areas occurring as isolated basins that may represent portions of buried pre-glacial channels in the underlying bedrock (McMaster and Ashraf, 1973a, b, c). The seafloor consists of a mosaic of benthic environments characterized by mud, silt, sand, coarse sand, cobbles/gravel, and boulders associated with modern marine processes and Pleistocene glacial deposition (RI CRMC 2010). Some of the seafloor sedimentary environments are transitory and are subject to erosion, sediment transport, reworking, sorting and deposition by oceanographic processes, whereas others, such as deposits of glacial till, are more stable (RI CRMC 2010).

Much of Rhode Island’s contemporary terrestrial landscape results from glacial processes. The bedrock geology of the state consists of igneous, metamorphic, and sedimentary rocks that are between 136 and 570 million years old (Quinn 1997). Bedrock outcrops occur frequently around Narragansett Bay and in other isolated areas, but much of the landscape is draped by a heterogeneous blanket of glacial sediments that were deposited during multiple advances and retreats of the Pleistocene ice sheets (Terwilliger Consulting Inc 2015). A similar geological pattern occurs offshore in Narragansett Bay and on the continental shelf in the study area, where seismic reflection studies have identified glacial and modern marine sediments overlying pre-Mesozoic bedrock and Cretaceous coastal plain deposits (McMullen et al. 2009 a, b; Needell et al. 1983 a, b, c; Needell and Lewis 1984; Oakley 2012; O'Hara and Oldale 1980; Peck and McMaster 1991). The offshore subsurface stratigraphy of the study area is discussed in detail in Section 4.1.1 of this report.

Several glaciations and intervening non-glacial episodes are thought to have affected southern New England in the Pleistocene (Stone and Borns 1986; Boothroyd and Sirkin 2002). There is uncertainty regarding how many episodes of glacial ice sheet advance covered southern New England, but at a minimum, the Laurentide Ice Sheet advanced to the contemporary continental shelf during the Illinoian period (200–120 thousands of years ago), and again during the late Wisconsinan (Stone et al. 1998; Caccioppoli 2015). The late Wisconsinan ice sheet reached its terminal position south of Montauk, New York and Block Island approximately 26,000 yBP (Boothroyd and Sirkin 2002; Peltier and Fairbanks 2006). This event is associated with a global lowstand of sea level, which is estimated to have been approximately 120 m below present (Peltier and Fairbanks 2006; Oakley and Boothroyd 2012).

As the ice began to retreat northwestward from its terminal position after 26,000 yBP, a complex sequence of recessional moraines (Boothroyd and Sirkin 2002) were deposited across the study area, and remain significant features in the contemporary terrestrial and seafloor topography. Block Island is composed of a thick moraine complex deposited during this glacial episode (Boothroyd and Sirkin 2002).

Cosmogenic-nuclide exposure ages for these moraines provide an estimate of when the ice margin occupied those locations. The Charlestown moraine, a significant west/east trending topographic feature across the southern coast of Rhode Island, appears to have been deposited approximately 21,300 yBP (Balco et al. 2009; Balco and Schaefer 2006), and the Whale Rock End Moraine, located at the entrance to the West Passage of Narragansett Bay, is inferred to have been deposited between 20,300 yBP (Balco et al. 2009) and 20,550 yBP (Oakley and Boothroyd 2012). These dates indicate the continental shelf in the study area would have been ice free approximately 4,700–5,700 years after the ice had reached its terminal position south of Block Island (i.e., 21,300–20,300 yBP). By approximately 19,500 yBP, Narragansett Bay is inferred to have been ice free, although the ice remained in the watershed until at least 19,300 yBP (Oakley 2012; Oakley and Boothroyd, 2012).

Although portions of the continental shelf may have been subaerially exposed during the very early post-glacial period as the ice retreated, large glacial meltwater lakes occupied much of the study area, including what is now Narragansett Bay. These were formed by the impoundment of glacial meltwater behind bedrock outcrops, sediment dams, or blocks of stagnant ice as the ice sheet retreated (Bertoni et al. 1977; Lewis and Stone 1991; Lewis and DiGiacomo-Cohen 2000; Oakley 2012; Oakley and Boothroyd 2013; Caccioppoli 2015). Thick glaciolacustrine deposits associated with these lakes are visible in seismic reflection profiles throughout the study area (Needell et al. 1983 a, b, c; O'Hara and Oldale 1980; Klotsko and Driscoll 2018), suggesting that the lakes persisted for thousands of years (Uchupi et al. 2001), first as pro-glacial lakes fed by glacial meltwater, and then as meteoric lakes after the ice had completely receded from the area (J. Boothroyd, personal communication, June 5, 2012). Estimates of the geographical area occupied by the lakes have been developed by Oakley (2012), suggesting that they covered an extensive area of what is now the southern New England continental shelf. However, the exact locations of their shorelines, and how those shorelines changed over time, is not yet well constrained.

Drainage of the glacial lakes on the continental shelf and in the Narragansett Bay area is inferred to have occurred approximately 16,000 yBP, as post-glacial isostatic rebound elevated the land surface (Koteff and Larsen 1989; Koteff et al. 1993; Lewis and DiGiacomo-Cohen, 2000; Oakley 2012). Smaller lakes may have persisted in deep basins in the study area, but this hypothesis is based on contemporary geomorphology and has not been tested (J. Boothroyd, personal communication, June 5, 2012). Once the lakes drained, much of the study area was subaerially exposed prior to post-glacial sea level rise and is thought to have been characterized by fluvial and estuarine environments (Needell et al. 1983a, b, c). As sea level rose, marine inundation progressed from south to north, indicating that the Block Island, Mud Hole, and the Area of Mutual Interest (AMI) study areas on the contemporary continental shelf would have transitioned to marine conditions several thousand years prior to the Greenwich Bay study area in central Narragansett Bay. Illustrations of projected hypothesized paleoshoreline positions during the post-glacial period are presented in Section 5 of this report.

Although the general deglacial chronology presented above has been well established by a variety of interdisciplinary studies, the precise dates associated this chronology are still being refined. There is currently a lack of extensive radiocarbon ages and correlated varve sequences in southeastern New England (Oakley and Boothroyd 2013). In addition, the margins of error associated with varve chronology correlation, cosmogenic-nuclide (Balco and Schaefer 2006), and radiocarbon dating can range from hundreds to thousands of years. These margins of error should be clearly understood when identifying paleolandscapes that may have been available for occupation by ancient Tribal peoples. Additional chronological information specific to each of the five study areas, if available, is provided with the case studies discussed later in this report.

4.3.2 Development of an Offshore Regional Subsurface Geologic Framework

The five study areas identified for this project include a coastal/nearshore location in central Narragansett Bay (Cedar Tree Beach/Greenwich Bay), a coastal/nearshore island location approximately 12 miles offshore (West Beach, Block Island), and three submerged areas on the Rhode Island continental shelf (western Rhode Island Sound, Mud Hole, and the AMI) (Figure 4-1).

Although these areas are separated by tens of kilometers, they share the same regional geologic history that is key to identifying and characterizing preserved paleolandscapes. The distinction between terrestrial and submerged environments is obvious in the contemporary landscape, but ancestral Tribal peoples who occupied this area interacted with a landscape that was very different from contemporary conditions. Pleistocene glaciations lowered sea level substantially, with the result that part of what is now the submerged continental shelf off Rhode Island was once a continuation of the current terrestrial landscape, and was available for habitation. However, glacial processes, post-glacial marine inundation, and contemporary oceanographic conditions have either destroyed, significantly altered, and/or buried these ancient landscapes during and after submergence. Surviving paleolandscapes may not exist in a geographically continuous manner, and may be incomplete representations of the original ancient environment. Because these landscapes are now submerged and frequently buried beneath recent marine sediments, reconstructing their characteristics relies heavily on high-resolution seismic reflection profiling, which provides vertical acoustic "slices" of the sub-seabed. By identifying the ages, sedimentary units, and processes associated with the acoustic signatures visible in sub-bottom profiles, it is possible to identify where terrestrial paleolandscapes may be preserved, and what type of ancient environment (upland, marsh, lake, etc) they may represent.

4.3.2.1 Foundation Studies

The subsurface stratigraphy of the inner continental shelf off southern New England consists of sediments deposited by Pleistocene and Holocene glacial and post-glacial processes, unconformably overlying Cretaceous/Tertiary deposits and pre-Mesozoic bedrock. This framework was established by a series of geophysical studies beginning in the mid-20th century (Ewing et al. 1940; Oliver and Drake 1951; Frankel and Thomas 1966; Schafer and Hartshorn 1965; Hoskins and Knott 1968; Savard 1966; Tagg and Uchupi 1967; McMaster et al. 1968; Grim et al. 1970; Oldale and Uchupi 1970; McMaster and Ashraf 1973a, b, c; Sirkin 1976; Bertoni et al. 1977; Gordon 1980; McMaster et al. 1980; McMaster and Fredrich 1985). Many of these investigations employed the technique of sequence stratigraphy, which involves identifying prominent acoustic reflectors in seismic reflection profiles, associating these reflectors with specific geological facies, processes, and time periods, and then correlating these units between tracklines to produce an inferred regional characterization of subseafloor sediments. In addition to providing a preliminary characterization of the subsurface acoustic signatures in southern New England continental shelf, these early studies also focused on establishing the relationship between the stratigraphic sequences seen in seismic reflection profiles and the bedrock and glacial geologic history that concurrent research established for the terrestrial environment in southern New England (Goldsmith 1962, 1982; Schafer 1961; Sirkin 1974, 1976, 1982; Hermes and Boothroyd 1981).

The conclusions resulting from this early research were refined by three extensive, high-resolution seismic surveys conducted by the United States Geological Survey (USGS) in Long Island, Block Island, and Rhode Island Sounds between 1975 and 1981 ("the USGS studies") (O'Hara and Oldale 1980; McMaster 1984; Needell et al. 1983a, b, c; Needell and Lewis 1984; Poppe et al. 2002, McMullen et al. 2009 a, b). Over 2,000 km (1,243 mi) of seismic reflection data was acquired in a systematic pattern (approximately 2-km trackline spacing) across the continental shelf off southern New England (Figure 4-2). Limited side-scan sonar data was also obtained along selected tracklines. Data acquired during these surveys defined the characteristics associated with acoustic basement in seismic reflection profiles; detailed the types, thicknesses, and regional distribution of the subsurface Pleistocene/Holocene glacial and post-glacial sedimentary sequences; and identified regional acoustic reflectors interpreted to represent significant unconformities between stratigraphic units. A series of associated maps was also produced to illustrate inferred depths to regional reflectors, and thicknesses of stratigraphic units throughout the study areas (O'Hara and Oldale 1980; Needell et al. 1983b; Needell and Lewis 1984; Poppe et al. 2002; McMullen et al. 2009 a, b). When combined with the earlier research, the results of these surveys produced a comprehensive, reconnaissance-level characterization of the geologic framework and depositional history of the inner continental shelf off southern New England (see Section 4.1.2 of this report) (Poppe et al. 2002; McMullen et al. 2009 a, b).

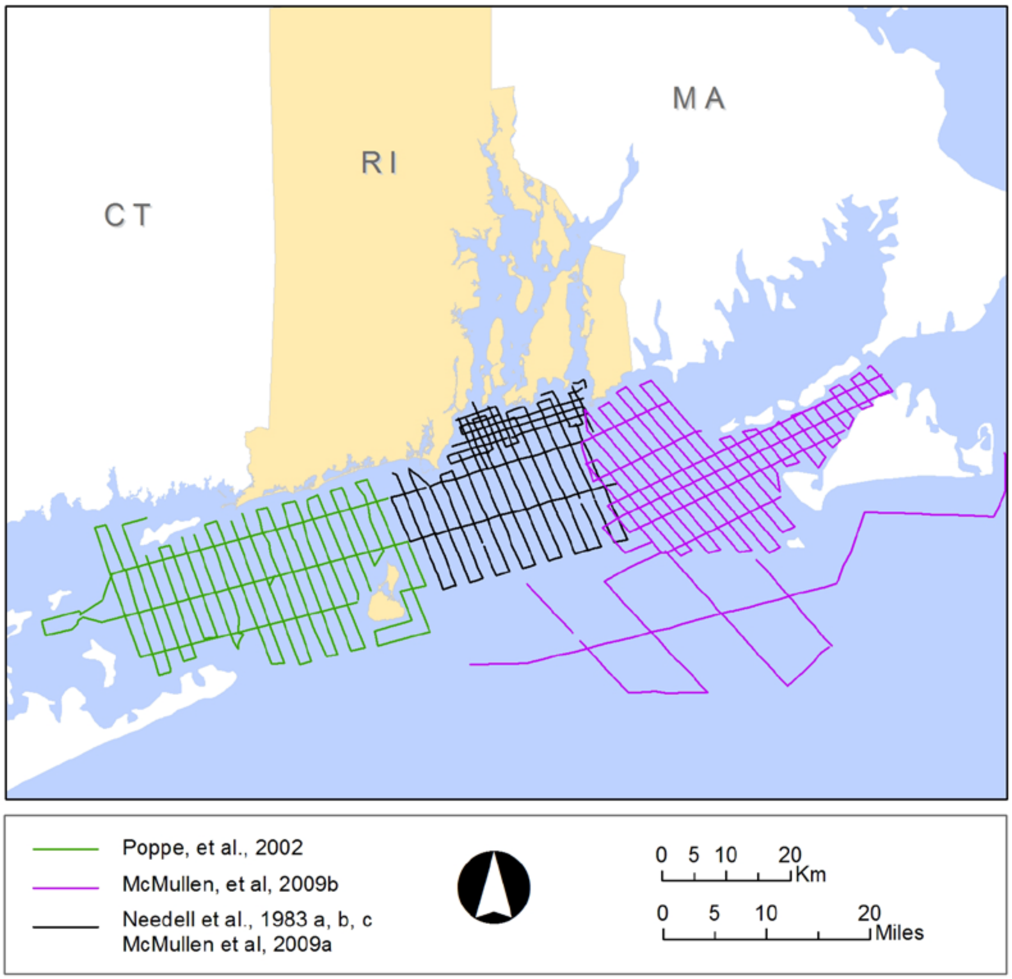


Figure 4-2. USGS seismic reflection profile tracklines surveyed between 1975 and 1981.

4.3.2.2 Validation of Acoustic Interpretations

Sediment cores and borings: The geological framework developed by the USGS foundation studies is primarily based on interpretation of seismic reflection profiles and the technique of sequence stratigraphy. "Ground-truthing" of the acoustic interpretations through analysis of sediment cores or borings has not yet been conducted in a systematic regional manner. Sixteen vibracores (Figure 4-3, purple dots) were acquired as part of the USGS geophysical survey off southeastern Massachusetts (Figure 4-2, closely spaced purple tracklines) to provide information about the geologic history of the area, identify potential sand and gravel resources (O'Hara and Oldale 1980, McMullen et al. 2009b) and to develop a local post-glacial sea level rise model for the area (Oldale and O'Hara 1980). Vibracores were not collected during either the Rhode Island Sound (Figure 4-2, black tracklines) or the Block Island Sound (Figure 4-2, green tracklines) survey. However, in 1988, 6 vibracores were obtained on USGS tracklines in Block Island and Rhode Island Sounds (Figure 4-3, blue dots) as part of a larger study to assess non-energy resources (sand, gravel, minerals) on the southern New England continental shelf and to investigate the subsurface geology in the area (Neff et al. 1989; Poppe et al. 2002). Three of these cores (Figure 4-3, cores 88-12, 88-13, 88-14) are within the Submerged Paleolandscapes Project study area and will be discussed in more detail in Section 6.1 of this report as part of an assessment of legacy data.

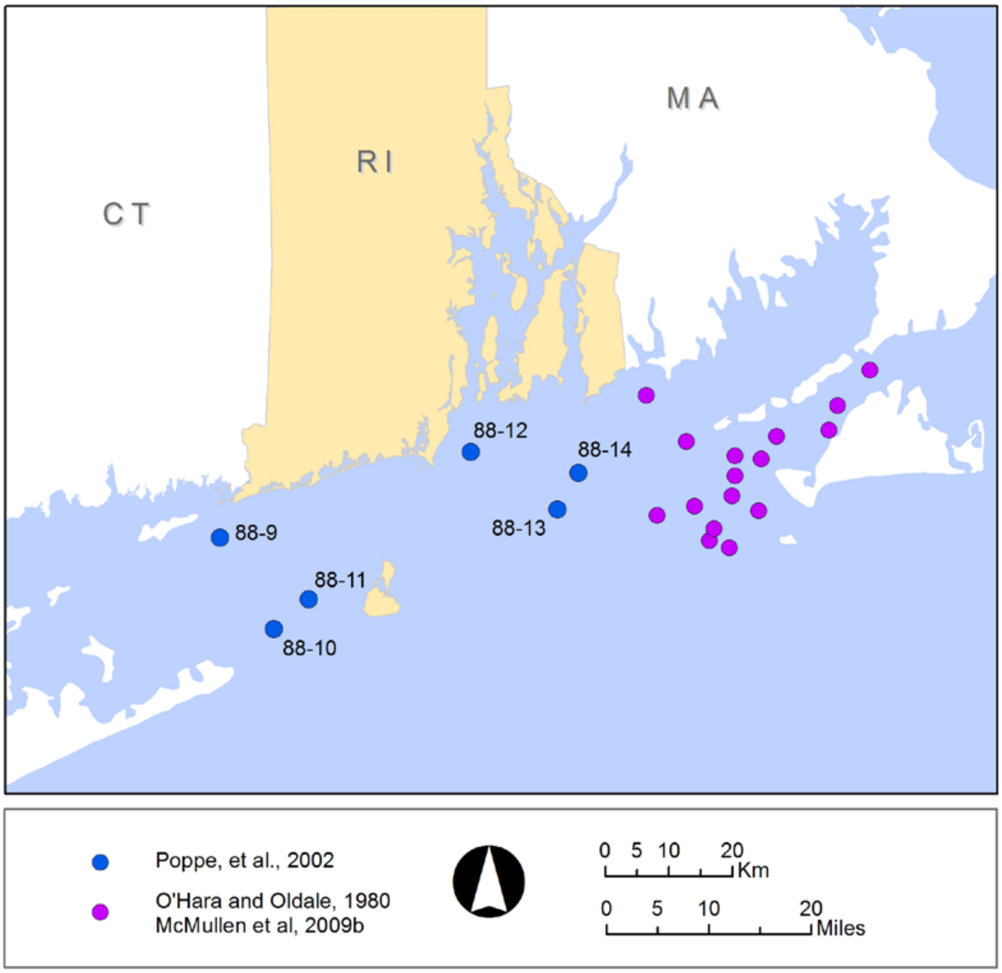


Figure 4-3. Vibracores obtained in the vicinity of the USGS seismic reflection data.
Purple dots show the location of cores obtained in 1976 to develop a sea level rise model of the area. Blue dots show the location of cores obtainted in 1988, as part of an unrelated study to identify minerals resources on the OCS.

Later studies that examined vibracore or borehole data from Rhode Island or Block Island Sounds include:

1. An investigation of the origin and evolution of Quaternary sediments in West Passage, Narragansett Bay using seismic stratigraphy, and multidisciplinary analyses of sediment samples obtained from borings collected near the Jamestown Bridge. Results of this study suggest a subsurface stratigraphic framework for western Narragansett Bay that is very similar to the framework developed for the Rhode Island continental shelf by the USGS studies, but a correlation between these two sets of findings was not made by the authors (Peck and McMaster

1991). The results of this study will be discussed in more detail in Section 6.3 of this report as part of the case study of Greenwich Bay.

2. A preliminary paleoenvironmental characterization of an approximately 15-km^2 area south of Block Island using CHIRP sub-bottom profiles and analyses of 9 sediment cores (Coleman and McBride 2008). This study focused on identifying relict geomorphic features interpreted from the CHIRP profiles and identified the associated depositional environments. No attempt was made to correlate these findings to the larger regional framework previously developed by the USGS.

3. A geoarchaeological marine site characterization study of a submarine cable linking a windfarm southeast of Block Island to mainland Rhode Island. Multibeam bathymetry, side-scan sonar, magnetic intensity measurements, vibracores, and shallow and intermediate sub-bottom profiles were acquired along the proposed cable corridor. Surface and subsurface conditions were assessed for engineering and design purposes, shallow hazards, and the potential impact of sub-seabed cable installation on submerged cultural resources. Analyses focused on characterizing conditions within a narrow APE centered on the proposed cable installation corridor (approximately 300 m wide horizontally on the seafloor with 3.3 m of subsurface depth) (Robinson 2012 a,b; Ocean Surveys Inc [OSI] 2012).

4. Two recent studies (Sheldon 2012 and Caccioppoli 2015) utilized cores and borehole data to extend the USGS subsurface stratigraphic framework south of the original USGS survey area. Results of these studies are discussed in Section 4.3.2.4 of this report.

Regional age control: In addition to the lack of systematic core data to verify the offshore regional geologic framework developed through sequence stratigraphy, comprehensive age control of the subsurface characteristics of the southern New England continental shelf have not yet been developed. Much of the interpretation of the processes and timing associated with the subsurface geological record is based on an overall understanding of the regional glacial and post-glacial history of the area, and correlation between the acoustic record and terrestrial outcrops. The only study (Oldale and O’Hara 1980) that applied absolute dates to the regional seismic reflection interpretations discussed above (Poppe et al. 2002; McMullen et al. 2009 a, b; Needell et al. 1983 a, b, c) was conducted using samples from vibracores collected in eastern Rhode Island Sound (Figure 4-3, purple dots), which were acquired to accompany the USGS geophysical survey conducted in that area (O’Hara and Oldale 1980; McMullen et al. 2009b). Radiocarbon dates were obtained from 22 peat and shell samples, with resulting ages ranging from > 35,000 yBP (referenced to 1950) for two fragments of Upper Cretaceous lignite occurring in glacial outwash deposits, to 830 ($\pm$ 200) for a shell fragment occurring in sand and gravel. Intermediate dates were obtained that defined approximately 1,000-year intervals between 13,500 ($\pm$ 1,000) and 1,340 ($\pm$ 200). This Late Pleistocene–Holocene chronology was used to produce a post-glacial sea level rise curve for southeastern Massachusetts (Oldale and O’Hara 1980) that is still referenced by contemporary researchers. Additional sources of regional age control include:

- Radiocarbon dates from borings collected in southwestern Narragansett Bay (Peck and McMaster 1991)

- Radiocarbon dates from shell and peat marsh samples, obtained to develop local sea level rise models (Engelhart et al. 2009; Engelhart 2010; Engelhart et al. 2011; Engelhart and Horton 2012; O’Hara and Oldale 1980)

- Four radiocarbon dates from shell material collected in sediment cores south of Block Island, obtained to assist with a preliminary paleoenvironmental characterization for the area (Coleman and McBride 2008)

- Correlations between varve sequences identified in cores from the Providence River (Upper Narragansett Bay), the North American Varve Chronology and cosmogenic exposure ages from glacial moraines (Oakley and Boothroyd 2013)

- Varve chronologies and cosmogenic-nuclide analyses of moraine deposits for southern New England (Balco et al. 2009; Balco and Schaefer 2006; Balco et al. 2002)

Each of the investigations discussed above was focused in small geographic areas on the Rhode Island continental shelf, and was not designed to systematically ground-truth the extensive seismic reflection dataset collected by the USGS between 1975 and 1981. Detailed re-examination and/or reinterpretation of these data could assist with refining the regional stratigraphic framework developed by the USGS, but is beyond the scope of the Submerged Paleolandscapes Project.

4.3.2.4 Follow-Up Research

The geologic framework produced by the series of foundation studies discussed above was developed through expert analysis of the stratigraphic record. Despite the lack of extensive coring studies or absolute age data, it continues to be the generally accepted interpretation of the stratigraphic sequences and associated processes that characterize the continental shelf off southern New England (see Section 4.1.2 of this report). Other subsequent research has helped to refine regional Pleistocene glacial and interglacial stratigraphy (Stone and Borns 1986; Stone and Sirkin 1996; Boothroyd and Sirkin 2002; Oakley 2012; Oakley and Boothroyd 2012; Oakley and Boothroyd 2013) and bedrock geology (Hermes et al. 1994) of southern New England, as well as provide important insight into the stratigraphy, depositional history and processes associated with the deglacial history of the region (Lewis and Stone 1991; Lewis and DiGiacomo-Cohen 2000; Oakley 2012; Oakley and Boothroyd 2013). Each of these follow-up studies contributed essential detail that is necessary to understand the regional subsurface record, but did not focus on ground-truthing the seismic reflection data collected earlier and did not result in substantial revisions to the existing geologic framework established by earlier research.

Only three investigations have specifically re-examined the regional geological framework developed by the USGS studies:

1. Goss (1993) refined the Quaternary geologic history of Block Island Sound by correlating well-log records and sedimentary facies visible in terrestrial outcrops on mainland Rhode Island to the seismic reflection data acquired in by the USGS seismic surveys. This study resulted in additional detail regarding the characteristics and processes associated with glacially derived sediment occurring stratigraphically above acoustic basement in the study area.

2. Sheldon (2012) conducted a multidisciplinary investigation utilizing seismic stratigraphy, and sedimentologic and lithostratigraphic analyses to investigate the subsurface stratigraphy of the continental shelf approximately 3 nautical miles southeast of Block Island, Rhode Island. The purpose of this investigation was specifically to ground-truth the subsurface stratigraphic framework derived from the USGS seismic reflection studies by examining newly acquired geophysical data and down-hole logs and core samples from eight approximately 70-m borings. The results of this study indicated that the regional subsurface stratigraphic framework identified by the USGS also extends south of the USGS study area on the continental shelf. Additional details regarding the Cretaceous and Late Pleistocene/Early Holocene depositional environments represented by the stratigraphic record are also provided by this study.

3. Caccioppoli (2015) provided similar confirmation of the regional framework south of the USGS survey area by examining CHIRP seismic reflection profiles and vibracore data obtained at "The Mud Hole," an anomalously deep depression located in southern Rhode Island Sound. This research was the subject of a Master of Science thesis conducted at the University of Rhode Island as part of Submerged Paleocultural Landscapes Project, and will be discussed in detail in Section 6.5 of this report.

None of these investigations listed above included absolute age determinations, although Sheldon (2012) used mineralogical analyses to confirm the age of the Cretaceous deposits occurring at the base of the stratigraphic sequence in the southern portion of the southern New England continental shelf.

4.3.3 Overview of the Subsurface Stratigraphic Framework of the Southern New England Continental Shelf

The research reviewed above resulted in the creation of a regional subsurface stratigraphic framework for the southern New England continental shelf. A simplified stratigraphic sequence consists of five geologic units (Needell et al. 1983a) separated by three regional acoustic reflectors interpreted to represent erosional unconformities. These deposits can be grouped into three general packages according to age (Figure 4-4).

As shown in Figure 4-4, two ancient units at the base of the stratigraphic sequence represent pre-Mesozoic bedrock (Pzz) and, in the southern part of the study area, Cretaceous continental shelf and coastal plain deposits (Ku). These two units are separated from the overlying sediments by a prominent acoustic reflector (fu_2) interpreted to be an unconformity representing approximately 64 million years of material that is absent due to erosion by Pleistocene glaciers. Above this unconformity are two sequences of Pleistocene/Early Holocene age deposited by glacial and post-glacial processes. The lowermost Pleistocene unit (Qdo and/or Qdm) was identified as "glacial drift" and is inferred to consist of till, morainal deposits, ice-contact sediments, outwash, glaciolacustrine deposits, and sediments deformed by overriding glacial ice (Needell et al. 1983a). This unit is separated from the younger one above it by a regional unconformity inferred to represent subaerial exposure of the landscape after the Wisconsinan ice retreated (fu_1). Late Pleistocene/Early Holocene sediments thought to be associated with fluvial and estuarine deposition (Qfe) occur above this reflector. At the top of the stratigraphic sequence, a third unconformity caused by marine inundation (mu) represents erosion of these fluvial and estuarine deposits by post-glacial sea level rise. Holocene marine sediments (Qpt) deposited by modern marine processes overly this unconformity (Needell et al. 1983a). Geographic variations in the presence, spatial extent, and composition of each of these stratigraphic units occur throughout the southern New England continental shelf. This stratigraphic sequence, and its importance with respect to reconstruction of paleolandscapes in the study area, will be discussed in more detail in Section 6 of this report, when a preliminary paleocultural sensitivity model is developed for the Submerged Paleolandscapes Project area.

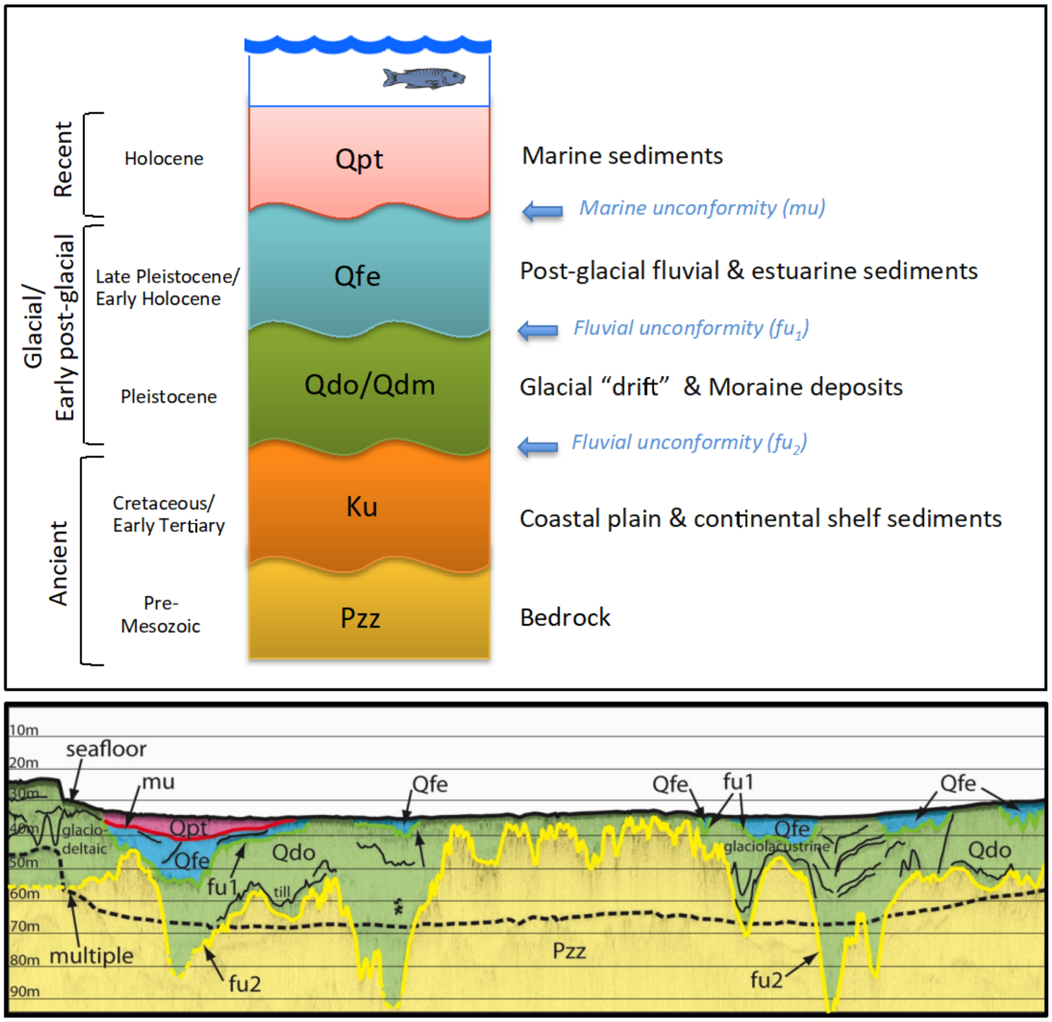


Figure 4-4. USGS stratigraphic framework of the subsurface continental shelf off Rhode Island. Upper panel shows an idealized stratigraphic section with a simplified description of each stratigraphic unit. Note that the thicknesses of the stratigraphic units in this illustration are not to scale. Lower panel shows an excerpt of a seismic reflection profile obtained by the project team south of Narragansett Bay and interpreted according to the established stratigraphic framework illustrated in the upper panel.

4.3.4 Key Points

- The terrestrial and submerged topography in the study area has been significantly impacted by Pleistocene glaciations. Understanding the processes and sedimentary deposits associated with glaciation, as well as the glacial and deglacial chronology of the region, is necessary to identify the location of potentially preserved paleolandscapes that could have been inhabited by ancient Native peoples.

- The overall deglacial chronology of the study area is well established, but there is currently a lack of region-wide absolute dates needed to develop a detailed timeline. Margins of error associated with varve chronology correlation, cosmogenic-nuclide, and radiocarbon dating can range from hundreds to thousands of years. These margins of error should be clearly understood when identifying paleolandscapes that may have been available for occupation by ancestral Tribal peoples.

- The subsurface framework of the southern Rhode Island continental shelf consists of five stratigraphic units and three regional acoustic reflectors thought to represent unconformities (Figure 4-4). This framework was developed by expert analysis of the stratigraphic record but is based primarily on decades-old, reconnaissance-level (approximately 2-km trackline spacing) seismic reflection profiles using the technique of sequence stratigraphy.

- Sediment cores have not been collected in a systemic manner to ground-truth the seismic reflection data, although the cores that have been obtained (O'Hara and Oldale 1980; Needell and Lewis 1984; Thomas 1985; Poppe et al. 2002; McMullen et al. 2009b; Sheldon 2012; Caccioppoli 2015) confirm the USGS geophysical interpretations at a regional level.

- Radiocarbon dates are available for samples collected from16 vibracores associated with the USGS survey in eastern Rhode Island Sound. Absolute dates to ground-truth the sequence stratigraphy in other areas of Block Island and Rhode Island Sounds are not yet available.

- Large data gaps significantly impact the current ability to develop a high-quality regional paleolandscape reconstruction for the continental shelf off southern New England, but a reconnaissance-level stratigraphic framework has been developed.

4.4 Sea Level Change History in the Study Area

4.4.1 Overview

An accurate reconstruction of Late Pleistocene and Holocene post-glacial sea level change is needed to identify the areas on the continental shelf that were once sub-aerially exposed and available for occupation by ancient Tribal peoples and to understand the extent to which these landscapes survived marine inundation. The following synthesis provides a regional overview of post-glacial sea level change in southern New England. A detailed discussion of specific sea level rise models applicable to the Submerged Paleolandscapes Project study area is presented later in this report.

The Laurentide Ice Sheet advanced across the New England landscape in the Late Wisconsin period, reaching its maximum extent approximately 26,000 years ago before beginning to retreat back out of southern New England. Retreat of the ice sheet approximately 26,000 yBP caused sea level to rise from its global lowstand approximately 120 m below present sea level and rapidly accelerate by 15 kyBP (Peltier and Fairbanks 2006; Oakley and Boothroyd 2012). There remains some uncertainty regarding how quickly isostatic rebound of the land surface began following the retreat of the ice sheet. Oakley and Boothroyd (2012) favor a delayed onset approximately 16 kyBP, whereas geophysical models support concurrent rebound and retreat (Roy and Peltier 2015). Regardless, by 16 kyBP, isostatic rebound was likely outpacing sea level rise for 2,000 years at the Late Wisconsinan terminal margin near Block Island. In coastal New England, uplift followed a 0.85 m/km rebound profile towards the northwest at 331 degrees, based on measurements of delta elevations representing formerly horizontal water levels in pro-glacial lakes (Koteff et al. 1993; Oakley and Boothroyd 2012).

By the Early Holocene, sea level was still rising rapidly in southern New England, and isostatic rebound had been mostly completed (Engelhart and Horton 2012; Oakley and Boothroyd 2012). From 8–4 kyBP sea level rise still remains poorly constrained, however reconstructions of sea level from basal sea level index points from salt marshes in Connecticut reveal sea level rise had slowed to 1.7 mm/yr between 6 and 4 kyBP (Engelhart and Horton 2012). The Atlantic Ocean began to inundate the stream systems cut into the drained lake-beds in present-day Long Island, Rhode Island and Block Island Sounds, marking a transition to an estuarine depositional environment. Estuarine sands, silts, clays, and freshwater peats are thought to overlie fluvial channel fill (O'Hara and Oldale 1980; Needell et al. 1983a, b, c; Needell and Lewis 1984).

A prominent transgressive wave-cut surface, often called the "ravinement," is observable in regional seismic reflection data (from Rhode Island Sound: O'Hara and Oldale 1980; Needell et al. 1983a, b, c; from Block Island Sound: Needell and Lewis 1984; from Long Island Sound: Lewis and Stone 1991), representing erosion of the landscape by post-glacial sea level rise. Fine-grained marine sediment conformably drapes the ravinement surface in deeper basins that are less prone to erosion by bottom currents. Shallower regions are more commonly covered with coarser reworked beach sand and gravel (O'Hara and Oldale 1980; Needell et al. 1983a, b, c; Needell and Lewis, 1984; Lewis and Stone, 1991).

4.4.2 Implications for Paleolandscape Reconstruction and Predictive Modeling in the Project Area

Sea level change curves have two significant implications for paleocultural sensitivity modeling. First, they are frequently used to develop hypotheses regarding the general location of paleoshorelines in the geologic past, and therefore can be used to identify areas on the continental shelf that may have been subaerially exposed and available for human habitation. Although this process can be generally instructive, the discrepancies discussed above between the various relative level rise models available for southern New England must be taken into consideration during their use, especially when developing illustrations of projected paleoshoreline positions. Even relatively small degrees of error in the vertical dimensions of sea level change curves can translate into significant horizontal variations in the reconstructed geographic positions of paleoshorelines. For example, at 4,000 yBP, relative sea level is estimated to be 7 m below its present level using the Roy and Peltier (2015) curve and 3 m below present using the Oakley and Boothroyd (2012) curve. The 4-m vertical discrepancy between these two curves will impact the projected hypothetical location of the paleoshoreline at this time by significantly more than 4 m horizontally.

Second**,** the amount and rate of sea level change has a significant impact on paleolandscape preservation and archaeological sensitivity (i.e., the potential for archaeological sites to be present). Sea level rise and the marine transgression of the land is a predominantly destructive process termed "shoreface retreat," wherein previously deposited sediments on land are eroded by powerful wave and current processes as the shoreline moves inland (Waters 1992). Because of the erosive force of water, much of the marine-transgressed landscape that was once terrestrial on the southern New England continental shelf has been significantly altered or destroyed through erosion that occurred during and after inundation. Slower rates of sea level rise allow for the greater development of coastal features, such as berms, barrier beaches, coastal wetlands, and marshes. These features together form an ecologically rich and diverse landscape abundant in plant and animal resources that would have been attractive for human utilization and habitation. Greater usage of this landscape would inevitably have resulted in a higher volume of material culture residue deposited into the archaeological record. In contrast, higher rates of sea level rise inundate and erode coastal areas more rapidly, thereby preventing the formation of coastal features typical of more stable shorelines. This, in turn, would lead to there being potentially less deposition of material cultural into the archaeological record, and, therefore, fewer sites. An exception to the generally destructive nature of rapid sea level rise are those isolated instances where the marine transgression of the land occurs by a process known as "stepwise retreat," during which coastal landforms and sediments are drowned suddenly and left in place as the surf and breaker zones jump from the active shoreline to a point further inland (Waters 1992). The exact rate of sea level rise associated with preservation or erosion of coastal features varies according to local pre-inundation topography, post-inundation bathymetry, prevailing wind, wave, and current regimes, and geomorphology and geology.

During the past 4,000 to 5,000 years, the northeast coast of the U.S. has remained relatively stable, with sea level rise rates of approximately 2 mm or less (Engelhart et al. 2011), which may assist with predicting where paleolandscapes could be preserved from that time period. Predictions become more difficult moving further back in time. It may be necessary to focus on specific time intervals where geologic information provides clues about possible landscape formation and preservation. Other time periods in which very rapid inundation occurred should also be examined, because rapid drowning of landscape features may protect them from erosion.

4.4.3 Key Points

- Sea level change reconstructions can assist with visualizing generally areas of the continental shelf that were subaerially exposed during key time periods of human habitation. Discrepancies between projected paleoshoreline positions for southern New England should identified and discussed in all illustrations.

- The presence or absence of preserved elements of paleolandscapes inundated by sea level rise is likely to be largely a function of localized variables, such as pre- and post-inundation topography/bathymetry, prevailing wind, wave, and current regimes, and geomorphology/geology. The amount and rate of sea level rise will also likely influence the extent to which paleolandscapes are preserved.

4.5 Paleocultural Context

A regional understanding of the archaeological and paleocultural context of the project's marine study areas, based on knowledge of ancient Tribal contact period human settlement and land use documented in the available archaeological record for the adjacent onshore area, as well as in shared accounts of the Narragansett's Tribal oral history, is important for understanding and modeling how the archaeological expression of these activities may be manifested in the submerged paleocultural landscapes potentially preserved offshore. Information sources particularly relevant for understanding this context synthesized and summarized in this document are the two recently produced archaeological reports on investigations conducted in coastal Rhode Island (the southern coast of mainland Rhode Island and the coast of Block Island) by McBride et al. (2016) and Waller and Leveillee (2016), prepared for RIHPHC and NPS as part of a Hurricane Sandy Disaster Relief Grant. Also informative were the transcribed contents of an interview conducted in 2010 by URI researchers with the late Dr. Ella Sekatau, former Narragansett Indian Tribal (NIT) Medicine Woman and Ethnohistorian, as part of the development of the Rhode Island Ocean Special Area Management Plan (URI 2010), as well as the comments by John Brown, NITHPO and Medicine Man, and Doug Harris, Preservationist for Ceremonial Landscapes and Deputy NITHPO, recorded in a 2012 documentary film prepared for the Rhode Island Deepwater Wind Energy Project (TPI 2012).

Pre-contact period cultural chronologies developed by archaeologists for the onshore portion of southern New England adjacent to the project study area are based on the presence and distributions of specific artifact types and the associated radiocarbon dates obtained at the archaeological sites where the artifacts were found. These archaeological data are compiled from the accumulated results of decades of academic archaeological research, professional cultural resource management surveys, and serendipitous reported spot-finds by the public and avocational archaeologists. From the distributions and dates of these catalogued cultural materials may be inferred patterns of past human behavior based on evidence of ancient land use, resource utilization, and, in some cases, elements of ceremonial practices. These patterns may then be used in assessments and modeling of the archaeological sensitivity (i.e., the likelihood for there to be cultural deposits) within a given project study area. Given that the only submerged sites known in the project study area were the few that were found during this study, virtually all of the archaeological data available for modeling in the offshore environment comes from the onshore terrestrial record. Consequently, it must be acknowledged that different, as-yet identified, site types, cultural materials, and represented time periods may exist in submerged contexts that are not found on shore.

Archaeologists working onshore in southern New England over the last several decades have developed a basic cultural chronology for the region that is essentially a theoretical model developed from inferences based on decades of archaeological research. This chronology is used to characterize and organize the region's human past during the pre-European contact ("Pre-contact") period. The chronology is divided into three principal archaeological time periods: "PaleoIndian" (ca. 12,500–10,000 yBP); "Archaic" (ca. 10,000–3,000 yBP); and "Woodland" (ca. 3,000-450 yBP). The latter two of these time periods is then subdivided into "Early," "Middle," and "Late" subperiods. An additional, distinct period—the "Transitional Archaic" (ca. 3,000-2,500 yBP)—is also included in the sequence between the Late Archaic and Early Woodland Periods. A "Late PaleoIndian" (ca. 10,000–8,000 yBP) Period is also sometimes included in discussions about southern New England's PaleoIndian Period. For this study and report, the reader is directed to McBride et al. (2016) and Waller and Leveillee (2016) for detailed descriptions of the Contact Period and Post-contact Period elements of the archaeological and cultural context chronology.

There is now unequivocal archaeological evidence of a human presence in the Americas predating the typical ca. 12,500 yBP start date for the onshore southern New England cultural chronology corresponding to an archaeological period called the "Pre-Clovis" (ca. 24,000–12,500 yBP) (Dillehay 1989; Halligan et al. 2016; Raghaven et al. 2015; Skoglund et al. 2015). However, the potential for cultural sites dating from the Pre-Clovis Period to exist within the limits of the Laurentide glacial ice sheet's maximum extent (corresponding with the locations of Long Island [New York], Block Island [Rhode Island], and Martha's Vineyard and Nantucket [Massachusetts]), must be considered extremely remote given of the massive impacts to the glaciated land surface that occurred as a result of the advance, retreat, and melting of the ice sheet. The same may not be said, however, of the potential for Pre-Clovis Period sites to be submerged and embedded in sediments further out on the continental shelf, beyond the limits of the Late Pleistocene southern New England glacial maximum, where it is possible there was a human presence that produced archaeological sites that survived inundation and are present within preserved remnants of submerged paleocultural landscape. Thus, the Pre-Clovis Period is included in the chronology here.

Hypothetically, the rapidly changing environment that characterizes the Late Pleistocene to Early Holocene time period should have produced an archaeological record of site types that is highly variable because of the need for flexible responses in social and resource utilization behaviors to the rapidly changing environmental conditions (Jones 1998). Increasingly, evidence of lowered water levels and an emergent correlation between large wetlands and major water bodies and ancient Native American archaeological sites suggests that water (inland and coastal) and its associated food resources were critical factors in site selection. Hypotheses are now proposed that assert large Early and Middle Archaic Period archaeological sites in proximity to large lakes, rivers, and extensive wetlands with inlets and outlets flushing their respective systems may have been more common on the coastal plain submerged by the rising sea level (McWeeney and Kellogg 2001), however, they are not represented in the terrestrial archaeological record onshore. It is perhaps for this reason that certain site types (especially large coastal occupations and very small interior camps and resource extraction locations) seem to be lacking or are very rare in the terrestrial archaeological record, as it presently known (Jones 1998). With few exceptions, virtually all documented PaleoIndian and Early Archaic Period finds reported throughout New England lack detailed contextual information. As archaeological data provides but a single lens through which to view, interpret, and understand past human and environmental histories, also incorporated into the archaeological and paleocultural context here are elements of the Narragansett Indian Tribe’s oral history traditions, as provided in the interview with Dr. Sekatau that was included in the Rhode Island Ocean SAMP (URI 2010), and as supplemented by Mr. Brown and Mr. Harris’s comments (TPI 2012). For example, Native oral traditions also point to a coastal focus for the ancestral Narragansett. According to Dr. Sekatau, “*Enishkeetompauog minnimussinnock*,” is a Native description that applied to the Narragansett and translates to “people of the small bays and inlets” (URI 2010). Dr. Sekatau also noted during her interview:

> *Our existence depended upon what the territories embraced directly from the salt water, marshes, and sweet [freshwater] waterways that flowed from inland springs, ponds, and seeps…The salt waters gave much to the Natives…The marshes around the sweet and the saltwater, and even mixtures of sweet-water joining saltwater, played a most important role in the existence of the Narragansett Indian peoples…They utilized saltwater fish, mammals, and shellfish, as well as the sweet-water fish, shellfish, and mammals. These creatures were used for food, clothing, parts of decorations, and shelter* (URI 2010).

Taken together, the available archaeological record for the adjacent onshore area and shared accounts of the Narragansett’s Tribal oral history provide an indication for the relationship between ancient human activity and the submerged paleocultural landscapes potentially preserved offshore that can be used to inform the archaeological sensitivity model.

4.6 Previous Modeling in the Project Area

Previous modeling efforts in the project area have been limited to preliminary assessments of pre-contact period archaeological sensitivity conducted as part of four different studies: 1) URI 2010; 2) Garrison et al. 2012; 3) Robinson et al. 2012a; and 4) Robinson et al. 2012b. The first study (URI 2010) was associated with the development of the Rhode Island Ocean Special Area Management Plan (RI OSAMP). Included in the RI OSAMP document (see Chapter 4: Cultural and Historic Resources) were a brief geological context; a transcription of an oral account of Narragansett Tribal history as provided during an interview conducted by the URI with (the now late) Dr. Ella Sekatau, Narragansett Tribal Ethnohistorian and Medicine Woman; and a brief paleogeographic landscape reconstruction accompanied by projected paleoshoreline location maps that applied the Peltier and Fairbanks (2006) sea level change model to existing bathymetry within the RI OSAMP study area. The paleogeographic landscape reconstruction indicated ancient people could have occupied the part of the continental shelf located within the limits of the RI OSAMP study area between about 12,000 and 6,000 yBP when sea level was modeled to be between about -55 to -6 m below its present level (Peltier and Fairbanks 2006). Narragansett Tribal oral traditions shared by Dr. Sekatau seem to agree with the accepted geoscientific data regarding sea level rise, as today’s Narragansett think about what was and how far the Atlantic Plains extended before the water covered them. Narragansett oral tradition also indicates the RI OSAMP study area was occupied by ancient Tribal peoples prior to the last glaciation, and that these people moved south with the last glacial advance and back northward to present-day Rhode Island as the glacier's retreated. Access to the “sweet” (i.e., fresh water) and salt waters along the coast was apparently very important to the ancient Tribal peoples, because of the abundance the waters offered them in terms of resources for food, clothing, and shelter. The marshes, in particular, seem to have played a most important role in the existence in the ancient and ancestral Narragansett peoples (URI 2010).

The second study (Garrison et al. 2012) was funded by BOEM to supplement and update two previous BOEM (then “Minerals Management Service”) studies of portions of the Atlantic OCS that were carried out nearly 40 years ago (ICA 1979; SAI 1981). These two studies collectively covered the area from the

Bay of Fundy to Key West and provided a broad overview of the geology, pre-contact period history, and sea level rise data that could affect submerged pre-contact period site preservation, as well as a predictive model for locating post-contact period shipwrecks. The Garrison et al. (2012) study built upon the ICA 1979 and SAI 1981 studies by exploring more recent research on pre-contact period settlement patterns, archaeological research, and relative sea level curves to refine the earlier predictive models for locating intact, submerged pre-contact archaeological sites and shipwrecks on the OCS. Sections 1.2.2 and 2.4 of the Garrison et al. (2012) report focused specifically on the southern New England region and summarized regional geology, sea level change, anticipated impacts from marine transgression, and conditions likely to lead to submerged paleolandscape and pre-contact period site preservation. The study also assessed general archaeological sensitivity for the OCS extending across Federal waters east of the southern New England region. The Garrison et al. (2012) assessment defined three categories of archaeological sensitivity based on the general projected locations of paleo-sea levels. The first category was "no sensitivity." The no sensitivity area lies below the projected -107 m sea level lowstand corresponding with the Last Glacial Maximum (LGM) of ca. 22,000 yBP and is an area presumed to have always been under water and never subaerially exposed in the archaeologically documented history of a human presence in southern New England. The second category was "Low Sensitivity." This area lies between the -107 m and -70 m sea levels, the latter of which corresponds to ca. 12,000 yBP and the time around which the onshore archaeological record provides the first evidence of a human presence in the region. The Low Sensitivity area recognizes that although there is not yet any archaeological evidence for a human presence in the region predating 12,000 yBP, it does not mean that it does not exist, particularly on the now submerged portions of the OCS that were south or east of the glacial terminus and exposed land prior to 12,000 yBP. The final category was "High Sensitivity." The high sensitivity area includes the portion of the shelf that extends between the -70-m sea level of ca. 12,000 yBP and the 3-mile nearshore limit of Federal waters, which corresponded closely with sea level at around 6,000 yBP. It is within this portion of the Garrison et al. (2012) southern New England study area that there was exposed land available for habitation by ancient Tribal peoples between ca. 12,000–6,000 yBP. These ancient peoples would have been associated with today's PaleoIndian, Early Archaic, and early part of the Middle Archaic archaeological periods.

The third and fourth studies (Robinson et al. 2012a and b) were conducted in support of the Federal and state permitting requirements associated with the development of Deepwater Wind's Block Island Wind Farm (BIWF) and Block Island Transmission System (BITS) projects. Both of these studies involved, for the first time, active participation of Tribal historic preservation specialists in the development of each project's marine geoarchaeological research design and in the execution of the field research and data analyses. Reporting produced from each study provided brief summaries of the geologic and paleocultural contexts, and interpretations and recommendations based on the examination of marine geotechnical samples (i.e., deep borings and vibracores). The studies processed marine geophysical data collected within each project's offshore APE. Robinson et al's (2012a and b) assessments ultimately concluded that though there was potential for submerged sites to be preserved within the BIWF and BITS project areas, review of geotechnical and geophysical data indicated that no archaeologically sensitive submerged paleolandforms were present within either project APE. However, indicators of preserved paleolandforms submerged and buried below the maximum depth of the BITS project's anticipated impacts were observed in the sub-bottom profiler data.

5 Application of Modeling Process to the Project Study Area, Step 2: Developing and Assessing Paleoshoreline Models

5.1 Introduction and Goals

Identifying culturally sensitive locations on the continental shelf first requires an understanding of where and when currently submerged areas may have existed as terrestrial landscapes that were available for human occupation. In southern New England, the amount and location of habitable land on the continental shelf was associated with the timing of Late Wisconsinan glacial ice retreat, and the rate and magnitude of post-glacial sea level rise. As described above, Garrison et al. (2012) developed a regional archaeological sensitivity model for the southern New England continental shelf by combining sea level rise hypotheses with archaeological information. Areas of the continental shelf that were submerged during the LGM were identified by Garrison et al. (2012) as having no sensitivity because they were never subaerially exposed and inhabitable land. Low sensitivity areas were those that were subaerial between the LGM and the PaleoIndian archaeological period, representing a time when areas of the continental shelf were subaerially exposed before the earliest archaeological record of human habitation in the northeast. High sensitivity areas were inferred to be subaerial and inhabitable beginning around 12,000 yBP, the time of the earliest dated archaeological evidence of human habitation in the region, up to ca. 6,000 yBP, the date corresponding to the approximate location of the subaerially exposed shelf and the Garrison et al. (2012) study area's shoreward Federal waters limit.

Inclusion of this type of modeling in research designs for marine archaeological compliance studies performed for offshore development projects is a growing concern. Models of hypothesized paleoshoreline locations are often developed by applying pre-existing sea level rise models to the contemporary bathymetric surface in a given study area using geospatial computer software. In theory, this type of modeling can be used to develop hypotheses regarding archaeological sensitivity based on the timing and extent of the shelf's exposure and potential inhabitability by humans. However, these types of models incorporate assumptions and sources of error have significant impacts on reconstructed paleoshoreline positions. The purpose of the following discussion is to apply this approach to create paleoshoreline models for the Submerged Paleolandscapes Project study area, evaluate the results, and provide recommendations about using this type of modeling for future paleocultural sensitivity assessments.

5.2 Relative Sea Level Change Models for Southern New England

The first step in reconstructing the hypothetical locations of paleoshorelines for the study area is to select a sea level change curve that can be used to estimate the location of the sea surface at key times in the past. The chronology, rate, and magnitude of relative sea level rise following glacial retreat is a function of the complex relationship between coastal topography, eustatic flooding, sedimentation, and isostatic rebound of the Earth's crust as the weight of the ice overburden is removed (McMaster 1984). Sea level change curves are developed using varying methodologies and data types, and incorporate these variables to different degrees. The purpose of this step is not to evaluate the detailed methodology used to construct each curve, but only to choose one that is considered the most robust curve for the rate and timing of sea level rise within the study area by researchers in the field.

The relative sea level (RSL) curves that have been developed for southern New England vary significantly. Four models are referenced most frequently:

1. **Roy and Peltier (2015):** These RSL curves were created to compare models of glacial isostatic adjustment with the extensive sea level indicator database developed by Engelhart et al. (2011) (see item 2 below). Specifically, iterative improvements of both the ice loading deglaciation history ("ICE-6G_C") and mantle viscosity ("VM6") models for the U.S. Atlantic coast were examined, with particular emphasis on assessing the influence of the glacial "forebulge" collapse on isostatic adjustment, and therefore on post-glacial sea level rise. Overall, Roy and Peltier's combination of the ICE-6C_C and VM6 models produced an RSL curve that is in good agreement with the Engelhart et al. (2011) (see item 2 below) database of index points. In the southern New England area (specifically the "Southern Massachusetts", "Connecticut," and "Long Island" regions in the Engelhart et al. [2011] study), the agreement is particularly good between 0 and approximately 4,500 yBP. For time periods earlier than approximately 4,500 yBP, Roy and Peltier's RSL curves indicate that sea level was lower than suggested by the terrestrial and marine-limiting data points. Therefore, the Roy and Peltier model may imply that more of the continental shelf was exposed before 4,500 yBP than the database of Engelhart et al. (2011) suggests.

2. **Engelhart et al. (2011):** This dataset consists of 492 RSL index points for the Atlantic Coast of the U.S. and 344 limiting dates, which constrain the minimum or maximum limits of former sea level. The majority of the index points are from 6,000 yBP to the present time, with only 7% older than 6,000 yBP, and most are derived from investigation of salt marshes. Sixteen regional sea level curves along the U.S. East Coast were produced using this extensive dataset. The "southern Massachusetts," "Connecticut," and "Long Island" curves are geographically closest to the Submerged Paleolandscapes Project study area. In this investigation, particular attention was given to strict quality control, consistent methodology between study areas, and accurate estimates of error (Engelhart et al. 2011), resulting in a robust dataset.

3. **Oakley and Boothroyd (2012)**: This RSL curve focuses on the area of the late Wisconsinan terminal ice margin south of Block Island, Rhode Island. It differs methodologically from Roy and Peltier (2015) as it is not dependent on ice sheet loading and the solid Earth geophysics associated with glacial isostatic adjustments, but instead considers the algebraic difference between delayed isostatic adjustment and a best-fit eustatic sea level curve. The uplift profile resulting from isostatic rebound is recorded by formerly horizontal water levels of pro-glacial lakes, which project onto a linear plane. Oakley and Boothroyd (2012) argue that no measurable isostatic rebound occurred prior to 16,000 yBP and may have been delayed as late as 14,000 yBP, due to projected water levels and drainage of Glacial Lake Hitchcock, which occupied the present-day Connecticut River Valley. The mechanism proposed for delayed isostatic rebound is that the lithosphere underlying southern New England behaved as a rigid "crustal block". This viewpoint is not in agreement with viscous mantle models, which favor contemporaneous uplift and ice retreat. In addition, the RSL curve proposed by Oakley and Boothroyd (2012) is in poor agreement with the Long Island and Connecticut RSL curves produced by Roy and Peltier (2015) from 4 to 0 kyBP, which is significant because of the excellent agreement of the Long Island and Connecticut RSL curves with the RSL index points over this time interval from the Engelhart et al. (2011) database. However, the Oakley and Boothroyd (2012) approach produced an important sea level change model that incorporates previously published data (Oldale and O'Hara 1980; van de Plassche et al. 1998; Donnelly and Bertness 2001; Peltier and Fairbanks 2006), with an expert understanding of deglacial geology and processes in southern New England.

4. **Oldale and O'Hara (1980)**: The RSL curve proposed by Oldale and O'Hara was constructed based on radiocarbon dating of terrestrial peats and marine shells identified in vibracore samples obtained from the continental shelf in eastern Rhode Island Sound. Each dated sample served as either terrestrial limiting (RSL below) or marine limiting (RSL above). This approach helps to

constrain sea level in space and time, and the proposed RSL curve represents a best fit of these limiting dates. Compared to the rigorous quality control measures applied for the RSL index points by Engelhart et al. (2011), each dated sample is subject to more error and uncertainty, including the assumption that the sample had remained in place following deposition. This curve was derived from a small study consisting of 22 radiocarbon dates, but is useful for constraining sea level change in the southeastern Massachusetts area.

Overall, the Roy and Peltier (2015) RSL curves appear to be most robust due to their agreement with RSL index points of Engelhart et al. (2011) and the overall performance of the latest geophysical models in all regions along the U.S. East Coast. However, the lack of index points earlier than approximately 6,000 yBP is problematic for testing these models. The Oakley and Boothroyd (2012) RSL model incorporated radiocarbon dates earlier than 6,000 yBP, including those from the Oldale and O'Hara (1980) study, and presents a RSL hypotheses that serves as an important comparison.

5.3 Paleoshoreline Reconstructions for the Project Study Area

Because multiple RSL curves for southern New England exist and vary significantly, two were selected as the basis for paleoshoreline reconstructions for the project study area. The Roy and Peltier (2015) curve was chosen because it incorporates the most recent geophysical understanding of post-glacial isostatic rebound and is also in generally good agreement with the sea level index point database of Engelhart et al. (2011). Use of this model effectively combines recent geophysical and geological data as applied to reconstructing sea level change. The Oakley and Boothroyd (2012) model was also selected because it was developed using an alternative view of post-glacial isostatic rebound and combines a detailed understanding of southern New England glacial geology with previously published sea level data (van de Plassche et al. 1998; Donnelly and Bertness 2001; Peltier and Fairbanks 2006), including the Oldale and O'Hara (1980) data from southeastern Massachusetts.

Ten paleoshoreline reconstructions were created that correspond with five archaeological time periods in southern New England:

1. 3,000 yBP: beginning of the Early Woodland Period
2. 6,000 yBP: beginning of the Late Archaic Period
3. 8,000 yBP: beginning of the Middle Archaic Period
4. 10,000 yBP: beginning of the Early Archaic Period
5. 11,000 yBP: mid-PaleoIndian Period

For each time period, two paleoshoreline reconstructions were created for comparison, one based on the Roy and Peltier (2015) RSL curve, and the other on the Oakley and Boothroyd (2012) RSL curve. Reconstructions were not developed for time periods more recent than 3,000 yBP because the comparatively small amount of sea level change that occurred in that time frame would not be easily visible on a regional map. In addition, reconstructions were not created for time periods earlier than 11,000 yBP because both the Roy and Peltier (2015) and Oakley and Boothroyd (2012) RSL models suggest that inundation of the project study area did not begin until approximately 11,000 yBP.

Roy and Peltier (2015) developed 16 RSL curves for distinct geographic regions associated with the Engelhart et al. (2011) index points. The closest regions to the Submerged Paleolandscapes Project study area are Connecticut and Long Island to the west, and southeastern Massachusetts to the east. Because the project study area does not correspond to any of these regions but occurs geographically in between them, paleoshoreline reconstructions based on the Roy and Peltier (2015) were created by averaging the sea levels from each of these three nearby regions at the desired age. Table 5-1 summarizes the paleoshoreline ages (represented in yBP) and corresponding sea level data (represented as meters below present) for each RSL model.

Table 5-1. Comparison of relative sea level models for southern New England used for paleoshoreline reconstructions in the project study area.
Estimates of RSL (meters below present) for five ages (years before present) based on the average of the Roy and Peltier (2015) models for Connecticut (CT), Long Island (LI), and southeastern Massachusetts (SE MA), and the Oakley and Boothroyd (2012) model for Block Island. RSL values in this table are approximations obtained from visual inspection of published graphs.

Age (yBP)	Roy & Peltier				Oakley & Boothroyd
	CT	LI	SE MA	Average	Block Island
3,000	4	4	4	4	2
6,000	15	17	16	16	6
8,000	33	36	34	34	13
10,000	48	53	49	50	30
11,000	55	64	57	59	50

Maps of hypothesized paleoshorelines were created for each time period using the information in Table 5-1, and ESRI's ArcInfo software. The "Northeast Atlantic 3 Arc-Second Coastal Relief Model" (National Geophysical Data Center 1999) was selected as the bathymetric base surface because it is available as a seamless raster grid for the entire study area, including Narragansett Bay. For each paleoshoreline reconstruction, the sea level value derived from the Roy and Peltier (2015) and Oakley and Boothroyd (2012) RSL curves was applied to the contemporary bathymetric surface to generate a new raster surface illustrating hypothesized areas of subaerial exposure and submergence. For example, the Oakley and Boothroyd (2012) RSL curve indicates that sea level near Block Island was approximately 6 m below present at 6,000 yBP. Using the ArcInfo "Raster Calculator" tool, the contemporary bathymetric surface was made "shallower" by 6 m, because water depths are inferred to have been shallower if sea level was lower. Areas of the contemporary bathymetric raster that emerged above 0 m in elevation as a result of this calculation are considered to be exposed land at 6,000 yBP, and areas below 0 m in elevation are considered submerged. The new raster was then color coded so that all areas above 0 m are shaded green, and all areas below 0 m are represented in blue. This process was completed twice for each of the ages listed in Table 5-1, once using the average Roy and Peltier (2105) sea level for Connecticut, Long Island, and southeastern Massachusetts, and again using the Oakley and Boothroyd (2012) RSL curve.

5.4 Results

Figures 5-1 through 5-5 illustrate the paleoshoreline hypotheses produced by applying two RSL curves to a contemporary bathymetry in the study area. The results using the Roy and Peltier (2015) and Oakley and Boothroyd (2012) data are presented side by side at each time interval for comparison. Although both RSL curves are based on a combination of carefully researched, high-quality geophysical and geological data, they produce substantially different paleoshoreline reconstructions, primarily as a result of differing hypotheses regarding the timing and extent of isostatic rebound in the study area. Both models indicate that most of the continental shelf in the study area was submerged by 6,000 yBP, and therefore uninhabitable after that time. However, they differ significantly regarding the submergence of the Narragansett Bay area at 6,000 yBP. According to the Roy and Peltier (2015) reconstruction, the northern part of Narragansett Bay, including Greenwich Bay, would have been exposed land at that time, whereas the Oakley and Boothroyd model suggests that much of the same area was submerged. Significant variation between the two models is visible at 8,000 yBP, when the Oakley and Boothroyd (2012) RSL curve results in most of the continental shelf in the study area being submerged, whereas the Roy and

Peltier (2015) model suggests that large areas were subaerially exposed and potentially available for human habitation. The discrepancies between the two models are even more pronounced at 10,000 yBP. These differences have a significant impact on identifying what areas of the continental shelf may have been available for human habitation at key times in the past, particularly for the earlier archaeological time periods when the absence of extensive RSL index points makes it difficult to test the models.

5.5 Implications for Predictive Modeling

The paleoshoreline reconstruction models illustrated in Figures 5-1 through 5-5 were viewed by the project team as graphical hypotheses regarding the general timing of when different parts of the overall study area may have been inundated and were, therefore, no longer part of a terrestrial landscape accessible for human habitation. The principal implication for these modeled time and geographically transgressive paleoshorelines is that the general position of the shoreline acts as a control over the possible ages, types, sizes, and predicted densities and distributions of archaeological sites that could be present within a particular area. Although there is the potential for sites dating from the earlier periods in the pre-contact period archaeological chronology (i.e., prior to ca. 11,000 yBP) to be present throughout this project's entire study area, there would be no potential for former habitation sites from periods post-dating the inundation of a progressively larger portion of the study area to be present. For example, based on the projected shoreline locations, there was essentially no potential for encountering, and no need to be considering and applying what is known from the archaeological record about, Woodland Period sites during the geoarchaeological investigations of the Mudhole or AMI study areas. Having even a general idea of where shorelines may have been located at particular times of interest in the past is a simple way of focusing attention and resources on a specific time period and range of expected site types and distributions.

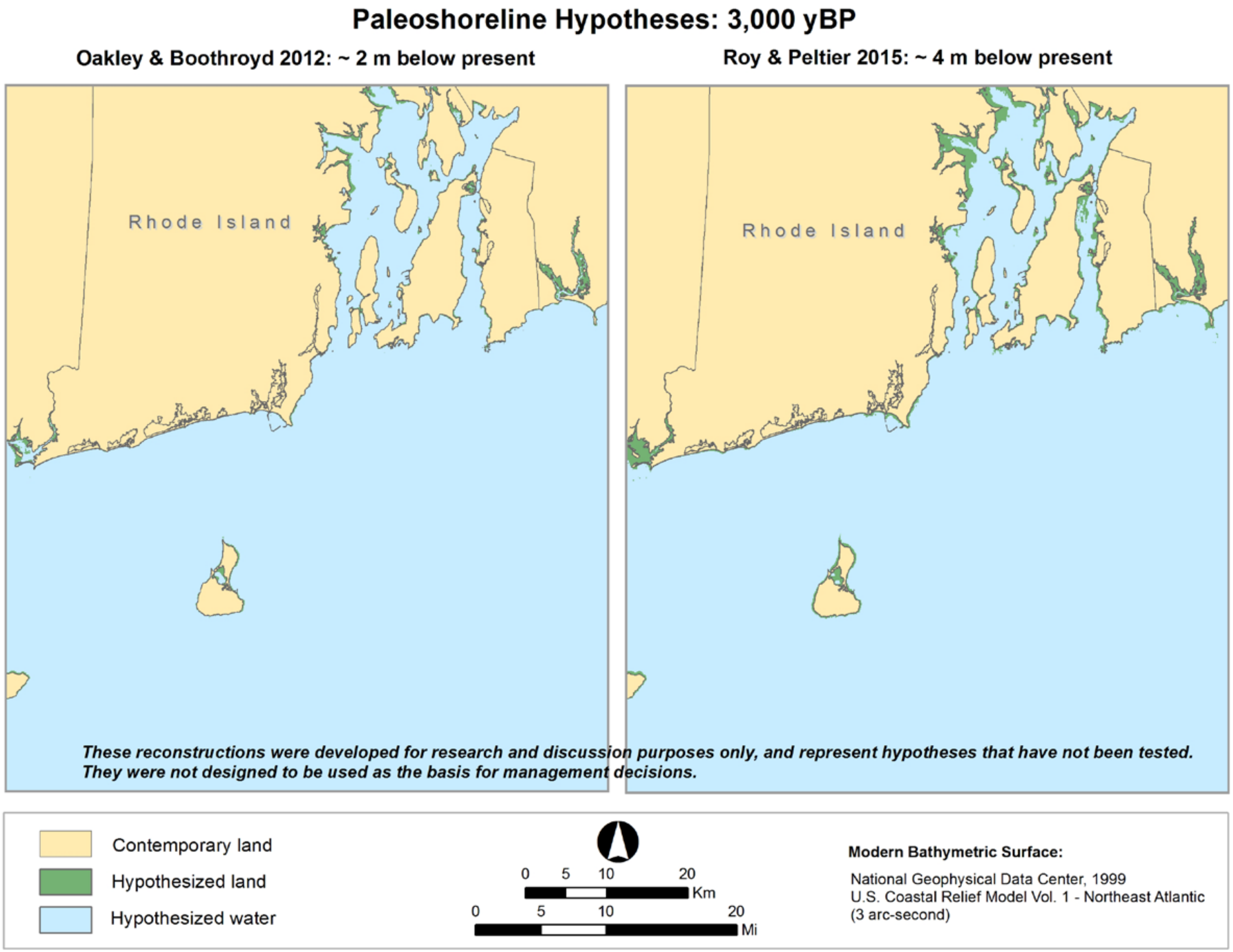


Figure 5-1. Paleoshoreline reconstructions for 3,000 yBP in the study area.

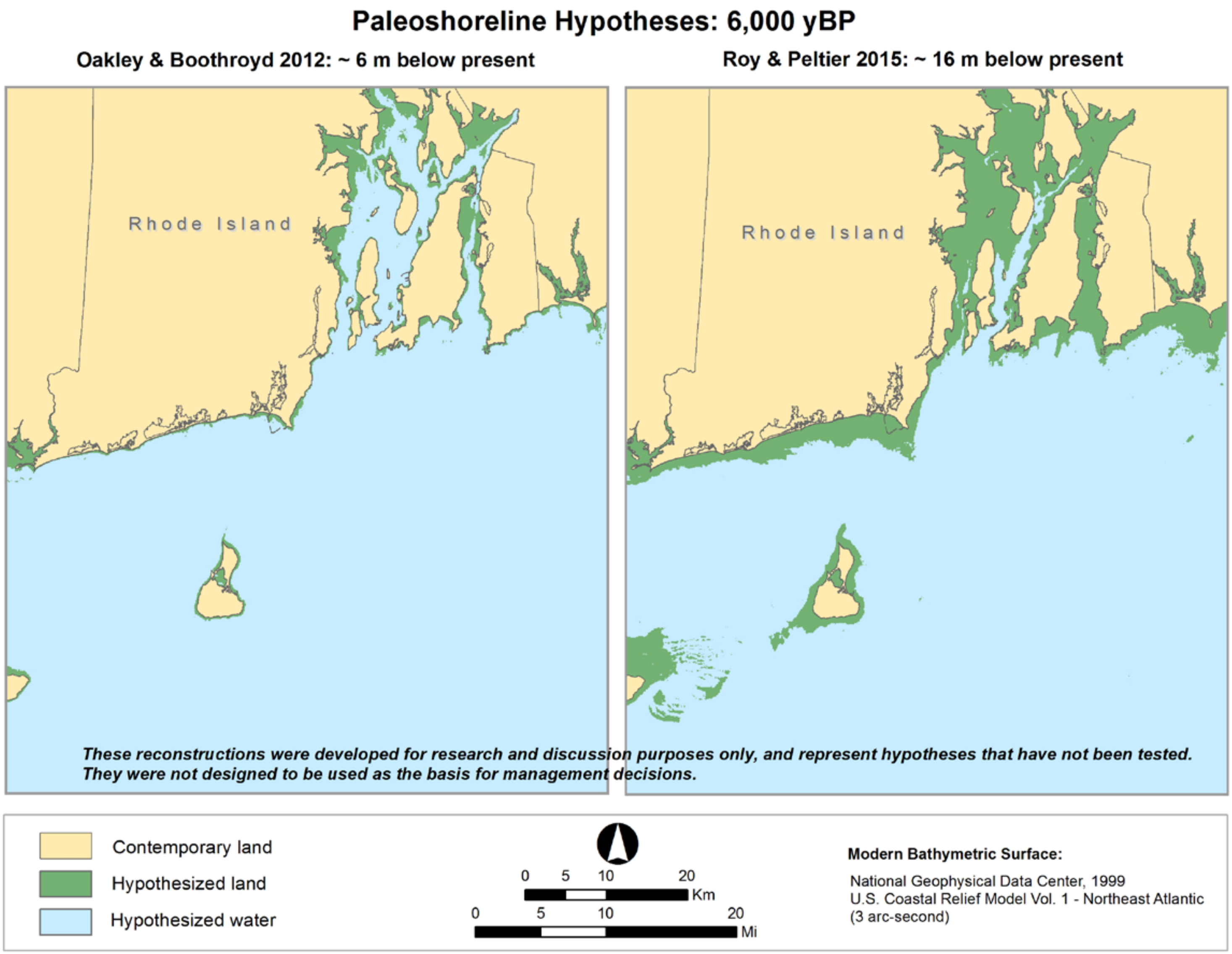


Figure 5-2. Paleoshoreline reconstructions for 6,000 yBP in the study area.3

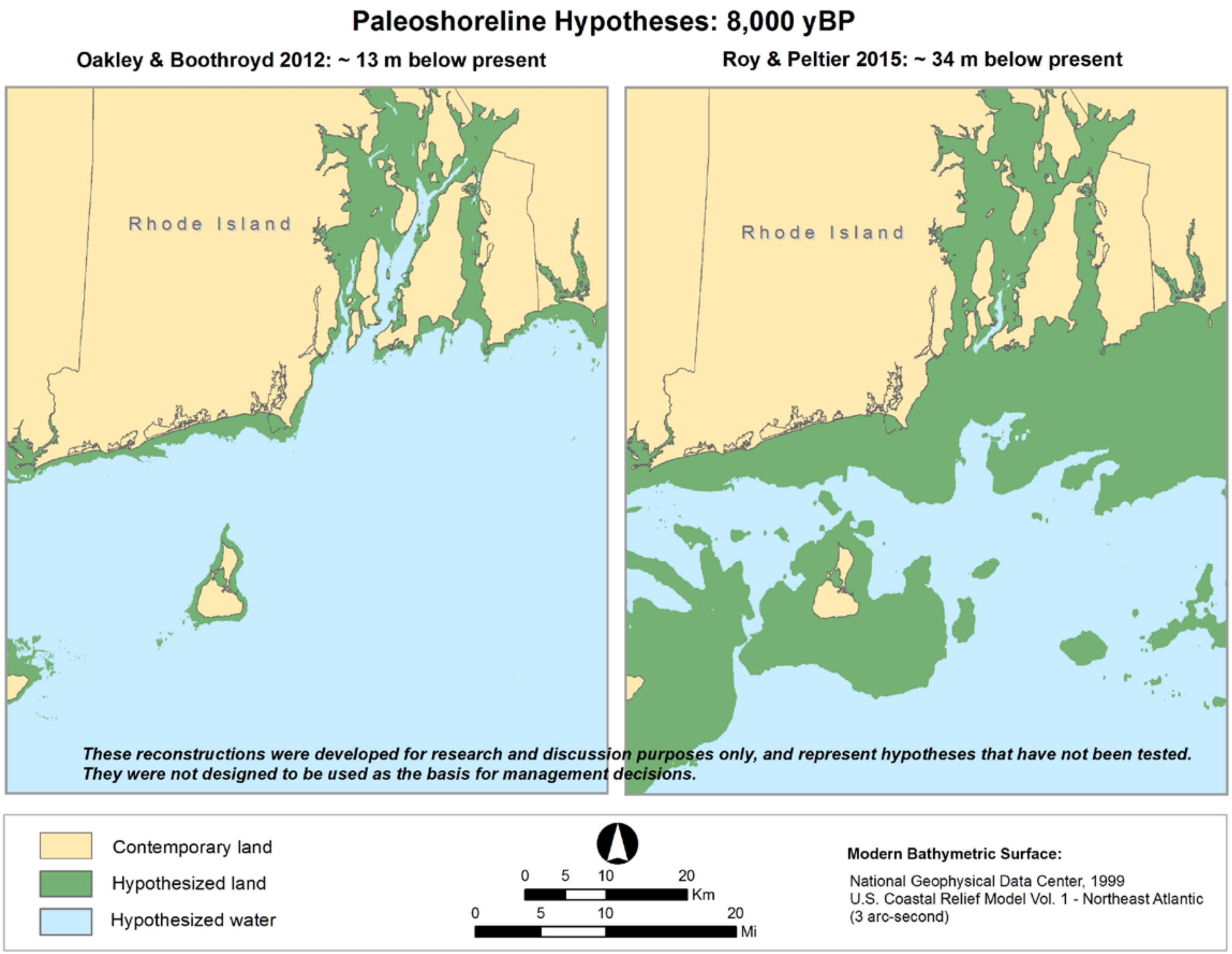


Figure 5-3. Paleoshoreline reconstructions for 8,000 yBP in the study area.

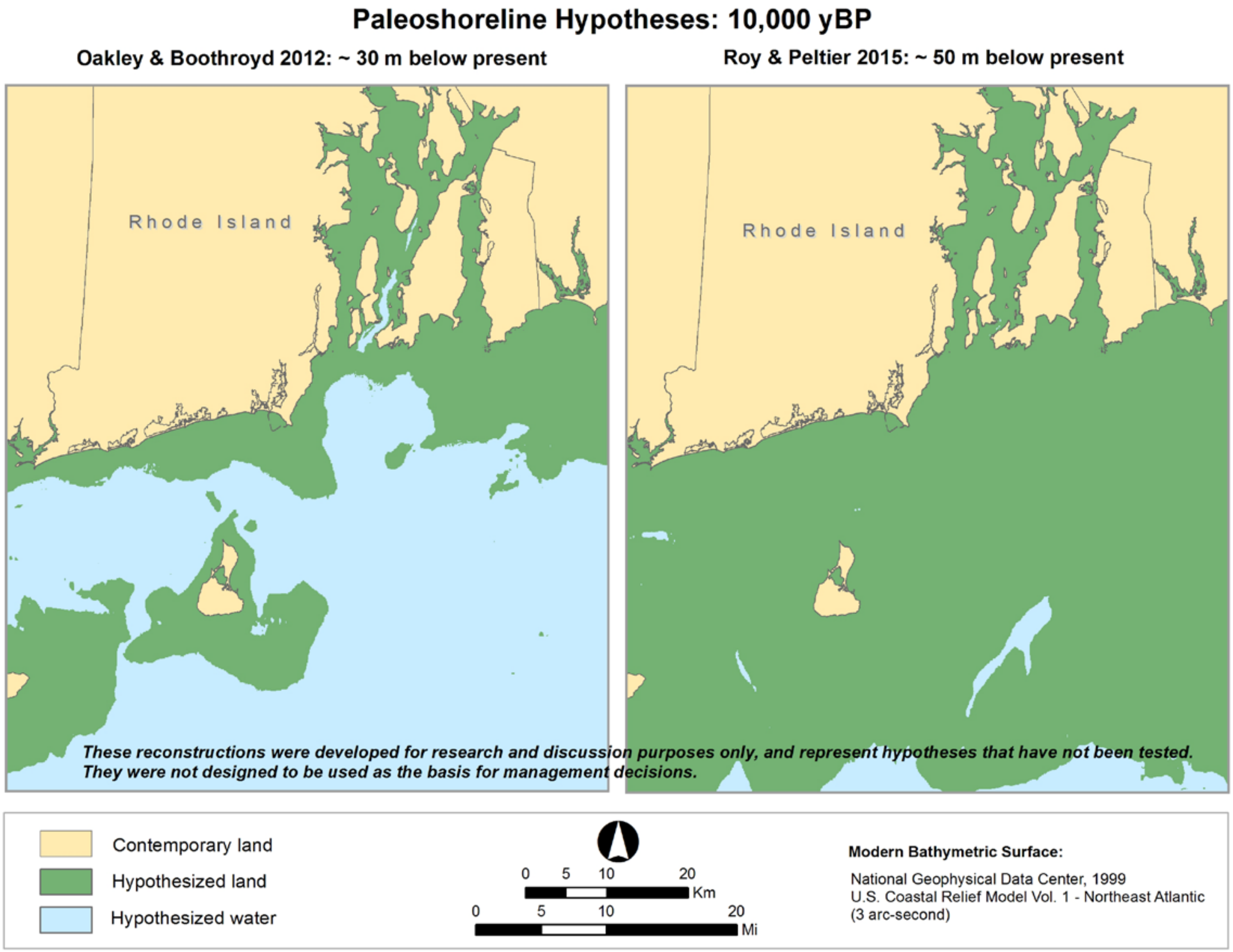


Figure 5-4. Paleoshoreline reconstructions for 10,000 yBP in the study area.

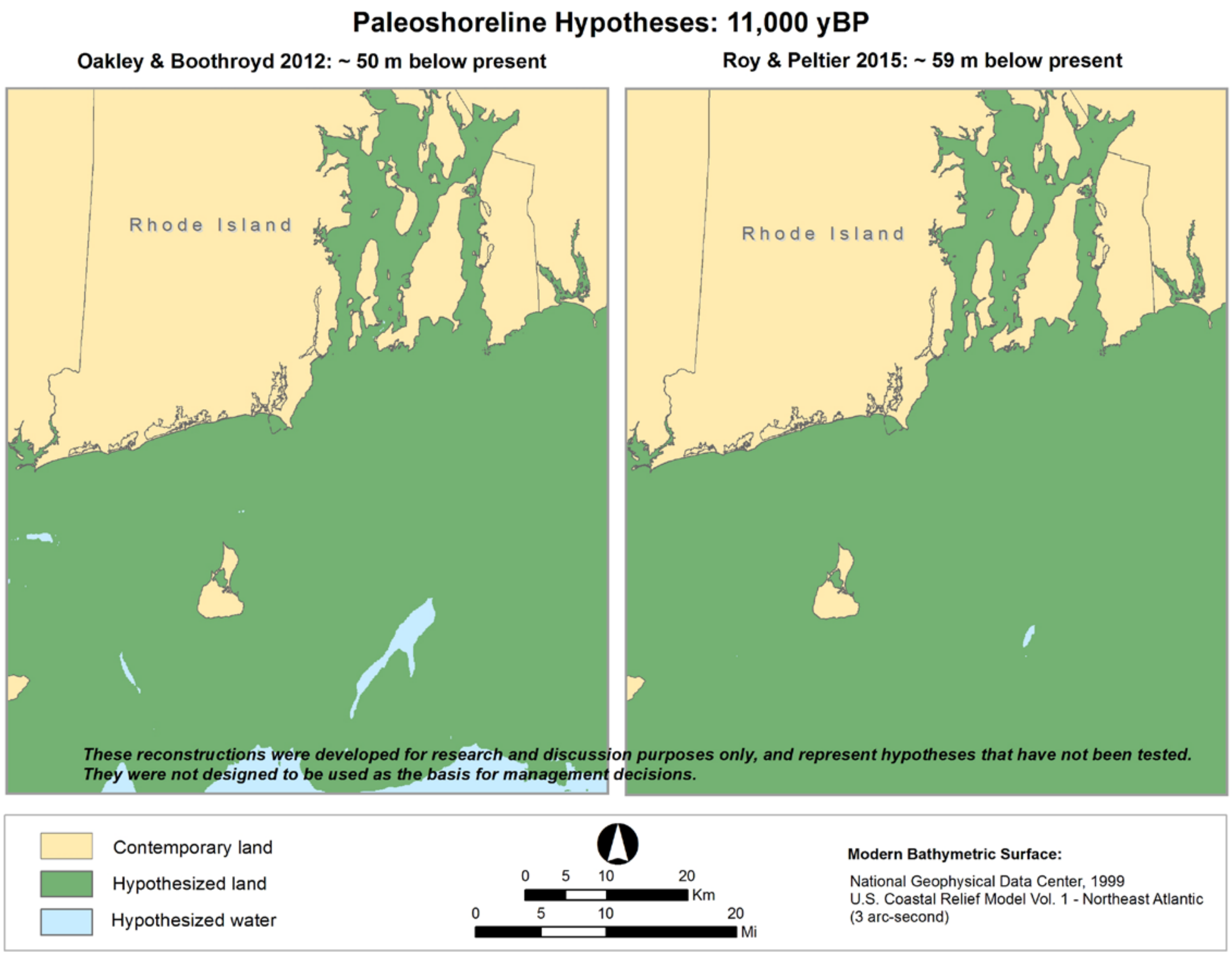


Figure 5-5. Paleoshoreline reconstructions for 11,000 yBP in the study area.

5.5 Recommendations

Although paleoshoreline models of this type are straightforward to generate with geospatial software, this type of model incorporates several sources of uncertainty:

1. **Methodological variations:** The development of sea level change models is an extremely complex process that incorporates several types of data and varying methodologies. For many study areas, one generally accepted model does not yet exist. Individuals who are interested in developing paleoshoreline reconstructions need to choose between available models, sometimes without a thorough understanding of how the models were constructed, the underlying assumptions, and margins of error.

2. **Lack of dataset access**: Obtaining an age and corresponding sea level through visual inspection of a printed graph, instead of from the numerical data used to construct the graph, is imprecise. However, many published papers provide only a summary graph of the sea level model, and the actual datasets are not available for general use.

3. **Uncertainty regarding the necessity of "backstripping"**: Applying sea level change curves to contemporary bathymetric surfaces assumes that the contemporary seabed is an accurate representation of the terrestrial paleolandscape. Seismic reflection profiles from the southern New England continental shelf (Needell et al. 1983a, b, c) indicate that previously terrestrial paleolandscapes have often been significantly altered by post-glacial sea level rise and frequently are buried beneath contemporary marine sediments. The contemporary bathymetric surface may display hints of any underlying preserved paleolandsurfaces but primarily represents contemporary oceanographic conditions. "Backstripping," a technique of digitally removing overlying Holocene marine sediments from seismic reflection profiles, can be applied to produce paleolandsurfaces that are potentially more accurate. Figure 5-6 illustrates an example of this approach for the Buzzards Bay area off the southeastern coast of Massachusetts (Foster et al. 2016). The differences between the contemporary bathymetric and backstripped surfaces are obvious, but the impact of these differences on regional paleoshoreline reconstructions has not yet been tested. In addition, backstripping and the subsequent creation of a continuous paleolandscape surface require an extensive database of closely spaced seismic reflection profiles, which are not available for many study areas.

4. **Sources of archaeological data**: The archaeological evidence of earliest human habitation in the northeast is only one source of information to constrain the time frame that previously terrestrial landscapes could have been inhabited by humans. Contemporary Tribal culture teaches that Tribal peoples have "always been here" and have always been an integral part of the landscape. Focusing only on the archaeological evidence of earliest human habitation in a region does not incorporate Tribal oral history or cultural values, and may incorrectly identify landscapes that are older than the "PaleoIndian" period as having no cultural sensitivity.

5. **Oversimplification of paleoenvironmental conditions:** Assessing cultural sensitivity based only on locations of marine submergence does not incorporate other paleoenvironmental conditions that would make portions of the paleolandscape uninhabitable. For example, in southern New England, extensive glacial lakes occupied the continental shelf immediately after glacial ice retreated. Submerged lacustrine areas would have been unsuitable for human habitation but would be displayed as "subaerially exposed" in paleoshoreline reconstructions based only on sea level rise models. Similarly, during the early post-glacial period in southern New England, some areas of the continental

shelf may have been exposed while others were still occupied by the retreating ice sheet, and would have not been available for human habitation.

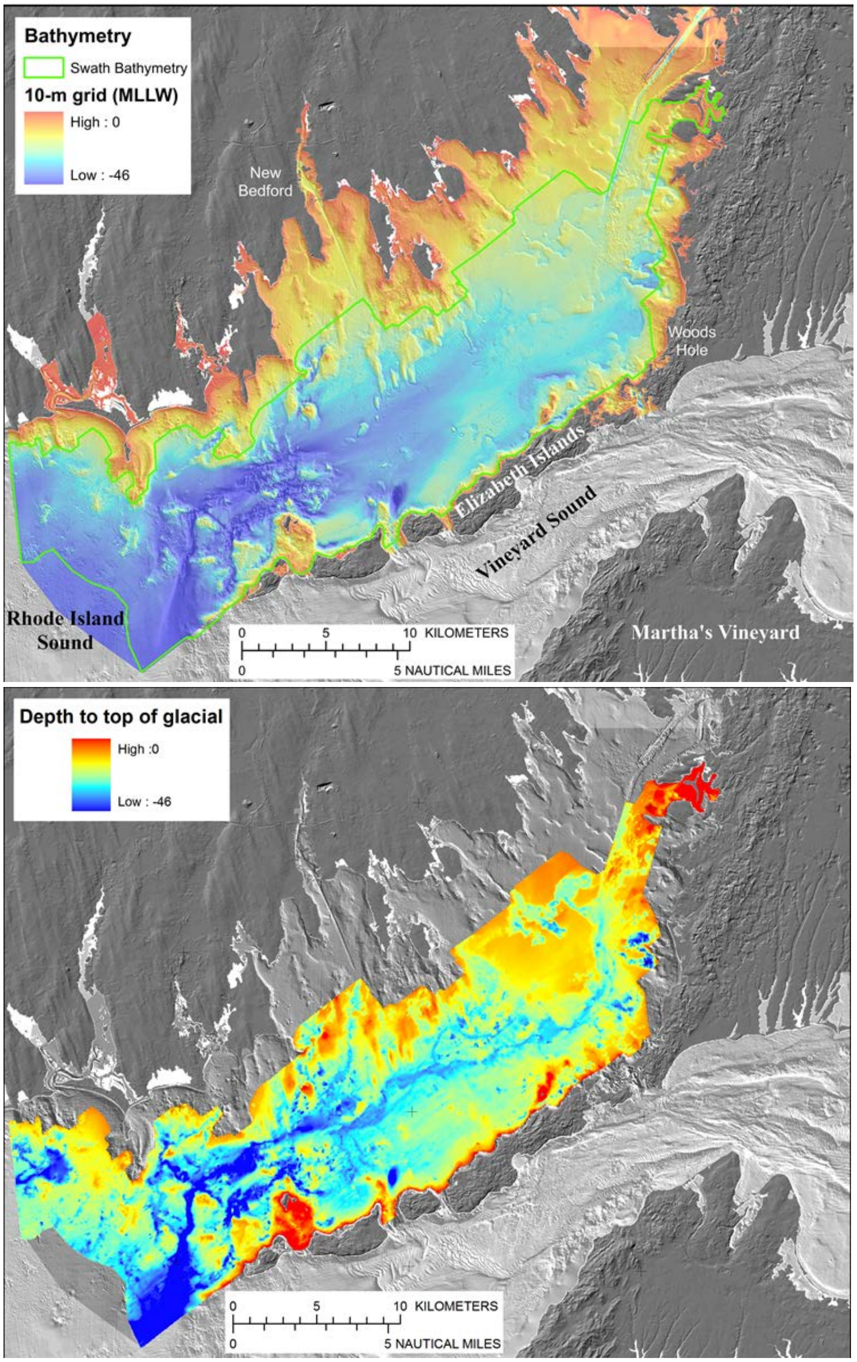


Figure 5-6. Comparison of a digital elevation model of the contemporary seafloor of Buzzards Bay, Massachusetts, (upper panel) with the elevation of the eroded surface of Pleistocene glacial drift in the same area produced by "backstripping" (lower panel).

The upper panel was developed from swath interferometric, multibeam, and single-beam bathymetry at a 10-m horizontal resolution. The lower panel shows the result of digitally removing the sediment that is located stratigraphically above the eroded surface of Pleistocene glacial drift. Image from Foster et al. 2016.

For these reasons, regional paleoshoreline reconstructions should be used cautiously, and should never be used as the basis for management decisions. These types of models should be regarded as one of many sources of information that can inform the assessment of potential cultural sensitivity in submerged areas, but must always be tested at the local level with geophysical, geological, and archaeological analyses.

5.5 Key Points

- In the Submerged Paleolandscapes Project study area, both the Roy and Peltier (2015) and Oakley and Boothroyd (2012) RSL curves suggest that the continental shelf was mostly submerged after 6,000 yBP. Significant uncertainty about the location of paleoshorelines exists prior to that time.

- Paleoshoreline reconstructions based on contemporary bathymetry and RSL curves incorporate several types of uncertainty and should be used with caution.

- Regional reconstructions of hypothesized paleoshoreline locations should never be used to make management decisions or to identify specific submerged areas that may or may not be culturally significant. These decisions should be made based on stratigraphic, sediment core, and paleoenvironmental analyses for a study area at the local level.

6 Application of Modeling Process to Project Study Area, Step 3: Developing a Regional Stratigraphic Model

6.1 Introduction and Goals

Once the Tier 1 model has been developed that estimates which parts of the continental shelf may have been subaerially exposed during the inferred period of human habitation, the next step is to develop a regional stratigraphic model that can be used to identify and characterize the geologic facies in the subaerially exposed areas that are most likely to contain culturally sensitive terrestrial paleolandscapes. Specifically, the goals of the stratigraphic model are as follows:

- Provide guidance about the process needed to characterize the subsurface stratigraphy in the study area

- Understand the regional geologic processes, facies, and chronology that are responsible for the regional pattern of subsurface stratigraphy

- Identify the geologic facies in seismic reflection profiles that meet the following criteria and are most likely to contain paleolandscapes that could have been inhabited by ancestral Tribal people:

    - Are associated with the timeframe that humans could have inhabited the area

    - Represent terrestrial paleolandscapes and paleoenvironments that were suitable for human habitation

Note that this model does not focus on identifying archaeological *sites*, but instead is designed to locate paleolandscapes or paleolandscape fragments that could contain sites. The outcome of the model is a table that ranks each of the regional stratigraphic units in the study area from “most likely” through “least likely” to contain paleolandscapes that could have been occupied by humans, based on the time frame and geological environments represented by each unit. Local testing of the model at five case study locations is described in Section 7 of this report.

The development of a stratigraphic model for submerged environments requires an expert understanding of the regional subsurface and surficial geology in the study area and a significant amount of high-quality seismic reflection data. As discussed in Section 4.1.1, the USGS developed a subsurface stratigraphic framework for the southern New England continental shelf based on geophysical data acquired between 1975 and 1981 (Figure 4-4). The survey conducted in 1980 south of Narragansett Bay (Needell et al. 1983a, b, c; McMullen et al. 2009a) provides reconsaissance-level subsurface coverage for much of the Submerged Paleolandscapes Project study area (Figure 6-1). However, because the dataset is almost 40 years old and has not been extensively ground-truthed, it was first necessary to assess its quality before using it as the basis for a stratigraphic model. The discussion below focuses only on the subset of the complete USGS dataset that was collected in 1980 south of Narragansett Bay (Needell et al. 1983a, b, c; McMullen et al. 2009a) (see Figure 6-1). However, because the USGS interpretations were based on the complete dataset collected between 1975 and 1981, this stratigraphic model is also pertinent to the entire southern New England continental shelf delineated by the surveying tracklines shown in Figure 4-4.

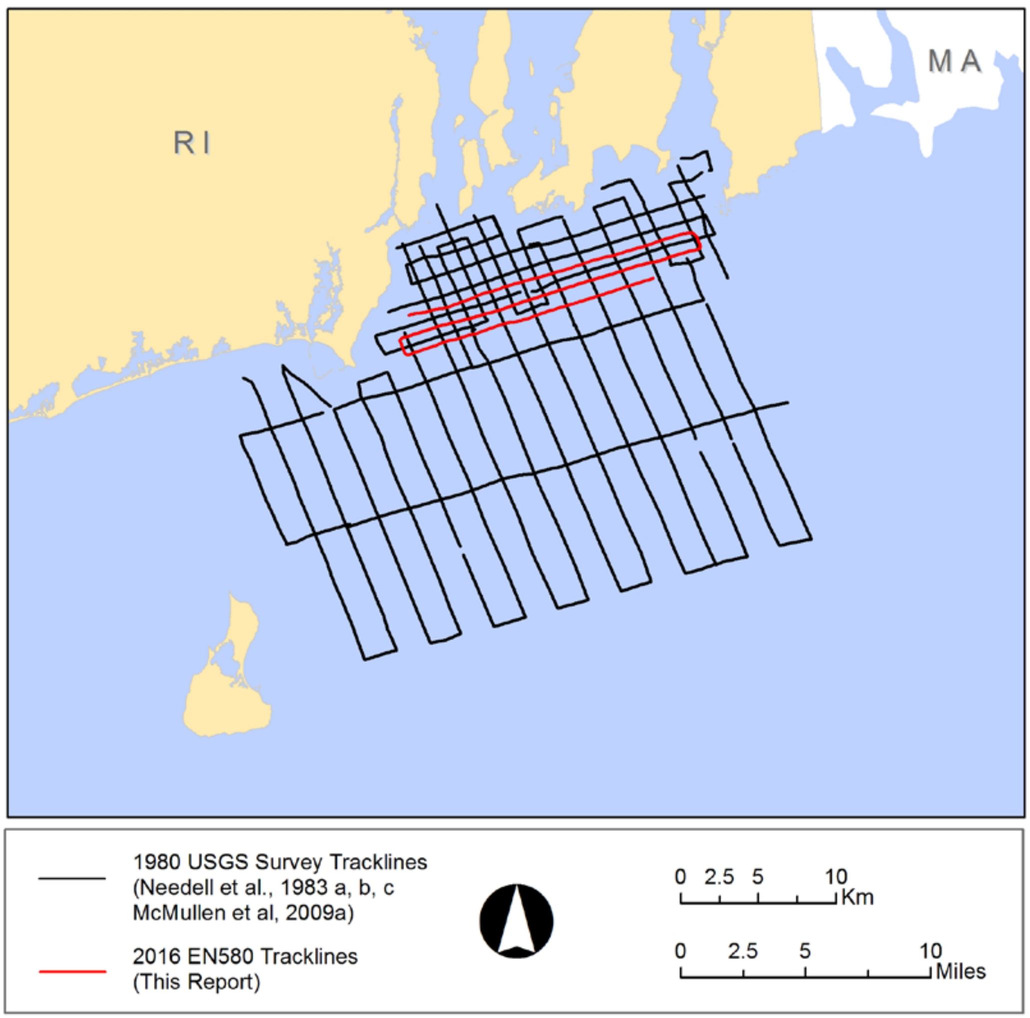


Figure 6-1. Seismic reflection tracklines from 1980 USGS legacy dataset (black) and 2016 EN580 follow-up cruise (red).

6.2 Field Methodology and Data Processing for Model Dataset

6.2.1 USGS Legacy Study: Rhode Island Sound

Approximately 580 km of seismic reflection and side-scan sonar data were collected simultaneously by the USGS in 1980, south of Narragansett Bay (see Figure 6-1) (Needell et al. 1983 a, b, c; McMullen et al. 2009a) at approximately 1–2 km trackline spacing. Seismic reflection data were acquired using a towed EG&G Uniboom system and were printed on an EPC Laboratories, Inc (EPC) recorder at a quarter-second sweep rate. The Uniboom system emitted acoustic pulses with frequencies of 400 Hz to 8 kHz. Acoustic energy reflected back to the ship from the sea floor and subsurface was detected by a hydrophone array and converted to an electric signal. The signal was then amplified and filtered to a 400- to 4,000-Hz bandpass. The resulting data have 1- to 2-m vertical resolution (McMullen et al. 2009a). The depth to prominent acoustic reflectors was determined using an assumed compressional wave velocity of 1,500 m/s for water and sediments of Holocene age and 1,800 m/s for sediments of Pleistocene age. Side-scan sonar data was acquired using an EDO Western system, with a 100m scan range on either side of the ship. Ship positioning was determined using Long Range Aids to Navigation (LORAN-C) navigation, with an absolute accuracy of 185 to 463 m (U.S. Coast Guard 1992). Navigation fixes were recorded manually every 15 minutes and at major course changes. Ship speed averaged about 9 km/h during the seismic surveys (McMullen, et al. 2009a).

In 2009, the USGS converted the original analog data from the 1980 study to digital format in response to ongoing interest in the dataset. Seismic data were scanned and converted to several universally readable digital image formats, as well as SEG-Y files. Navigation data were converted from LORAN-C time delays to latitudes and longitudes, summarized in space-delimited text files, and navigation tracklines were produced in ESRI ArcGIS format. These data, as well as associated maps and summaries, were released as an Open-File Report accessible to the public online (McMullen et al. 2009a). Because the original analog data had been converted and updated to digital format, and associated metadata was available, no additional data processing was necessary to utilize it for the Submerged Paleocultural Landscapes Project. Trackline files, seismic profiles, and metadata were downloaded from the online USGS Open-File Report (McMullen et al. 2009a) and imported into ArcGIS and SonarWiz for visualization, analysis and comparison with newly acquired data.

6.2.2 Project Follow-Up Study: EN580 Cruise

In 2016, the project team conducted a short seismic reflection survey in a portion of the study area previously studied by the USGS in 1980 (see Figure 6-1). The goals of this cruise were to 1) compare the resolution of the 1980 USGS survey data to data acquired with modern seismic reflection profiling equipment; 2) compare the geological framework interpretations made based on the 1980 data with interpretations based on newly acquired, higher resolution data; and 3) determine whether this legacy dataset could be used as the basis for a regional stratigraphic model to support paleolandscape reconstructions and paleocultural sensitivity modeling. Three test profiles (Figure 6-1, red lines) were acquired to fill data gaps between the 2-km trackline spacing of the 1980 survey and for comparison with the 1980 legacy data.

Surveying was conducted onboard the URI's R/V *Endeavor*, a 185-foot research vessel specifically equipped for scientific data acquisition. Seismic reflection profiles were obtained using an HMS-620 Bubblegun system operating in the 70–700 Hz frequency range, which allows 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.

Seismic reflection data was processed and analyzed using SonarWiz Version 6 (CTI) sub-bottom software package, which 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. Because 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.

6.3 Results

6.3.1 USGS Legacy Data

The results of the 1980 USGS geophysical survey south of Narragansett Bay are synthesized by three sources. The first (Needell et al. 1983a) is a concise, peer-reviewed journal article that summarizes the acoustic stratigraphy and interpreted geologic framework of the study area based on seismic reflection profiles and presents three maps showing 1) the hypothesized surficial geology of the study area (Figure 6-2); 2) the depth below sea level to the deepest acoustic reflector (Ku/fu_2) (Figure 6-3); and 3) the depth below sea floor to a prominent acoustic reflector interpreted to be the “post-glacial unconformity” (fu_1) (Figure 6-4). The second and third sources (Needell et al. 1983b, c) are USGS Field Study Reports that provide additional, larger maps and interpreted seismic reflection images. Illustrations of the thicknesses of glacial drift, end moraine deposits, and Holocene deposits (Needell et al., 1983b) are included in these reports and are available for online viewing and download as part of a USGS legacy digital data compilation (McMullen et al. 2009a). Each of these visualizations were created by interpreting the seismic reflection and side-scan sonar data acquired along 1- to 2-km survey tracklines and interpolating between the tracklines to construct a hypothesized regional representation of surficial and subsurface geology throughout the entire study area.

The USGS survey south of Narragansett Bay indicates that the subsurface geology in the Submerged Paleolandscapes Project study area consists of five stratigraphic units, separated by three prominent regional acoustic reflectors. These reflectors were interpreted to represent unconformities whose geologic nature was inferred from outcrops, bottom-sediment samples, and borehole data within the area, in adjacent areas, and from stratigraphic positions similar to geologic units in eastern Rhode Island Sound (O'Hara and Oldale 1980). The presence, characteristics, and composition of the stratigraphic units and unconformities are geographically variable but can be combined to form a generalized subsurface stratigraphic framework for Rhode Island Sound south of Narragansett Bay. The acoustic and geologic characteristics of each of these units, as interpreted by Needell et al. (1983a), is summarized in Table 6-1 in stratigraphic order (oldest units are listed at the bottom and youngest at the top of the table).

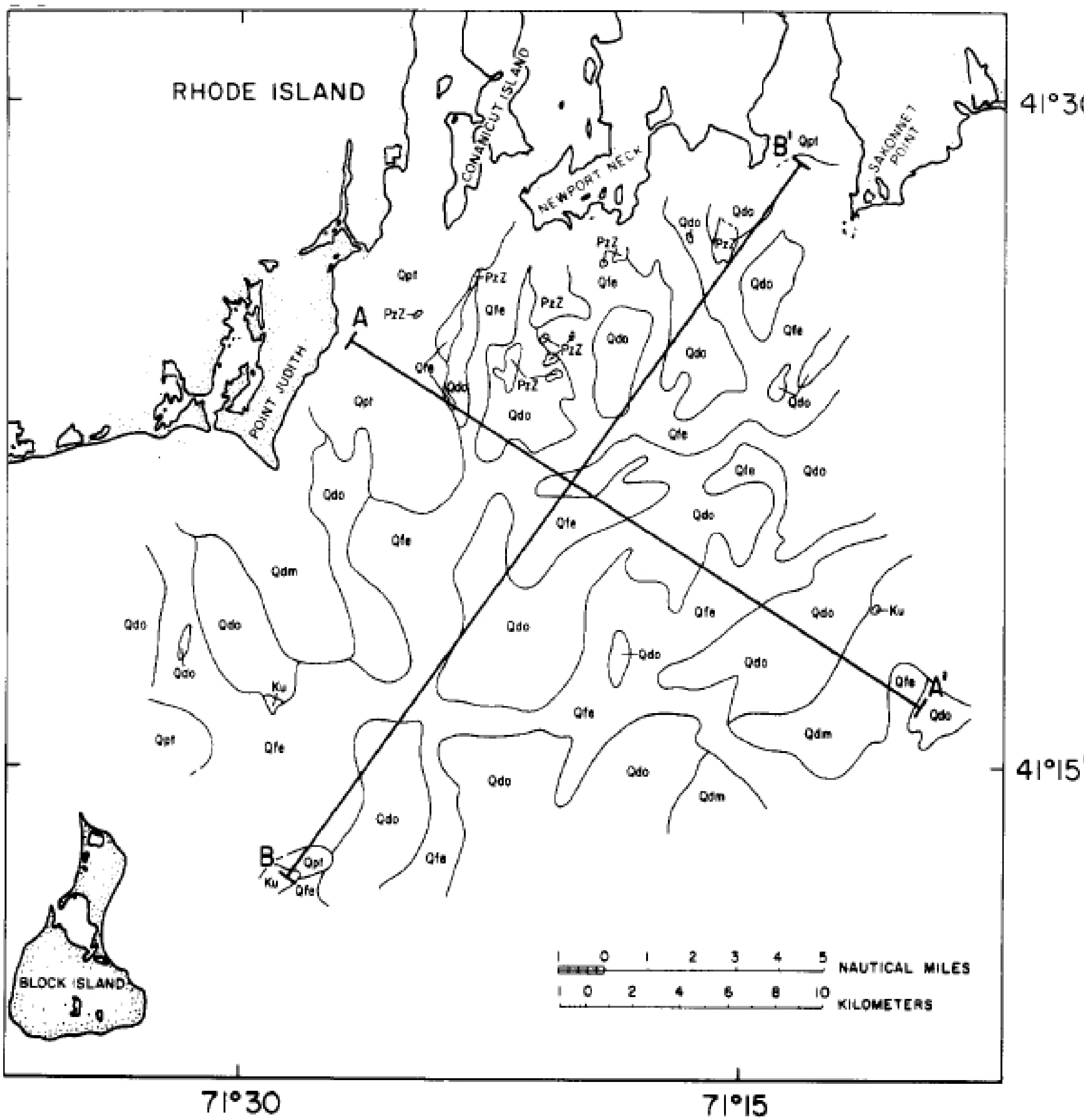


Figure 6-2. Surficial geology of western Rhode Island Sound from Needell et al. (1983a), developed from geophysical survey data.
Acoustic units represented by three-letter codes: PzZ - bedrock; Ku - coastal plain strata; Qdm - glacial end moraine deposits; Qdo - glacial drift; Qfe - fluvial and estuarine deposits; Qpt - marine deposits.

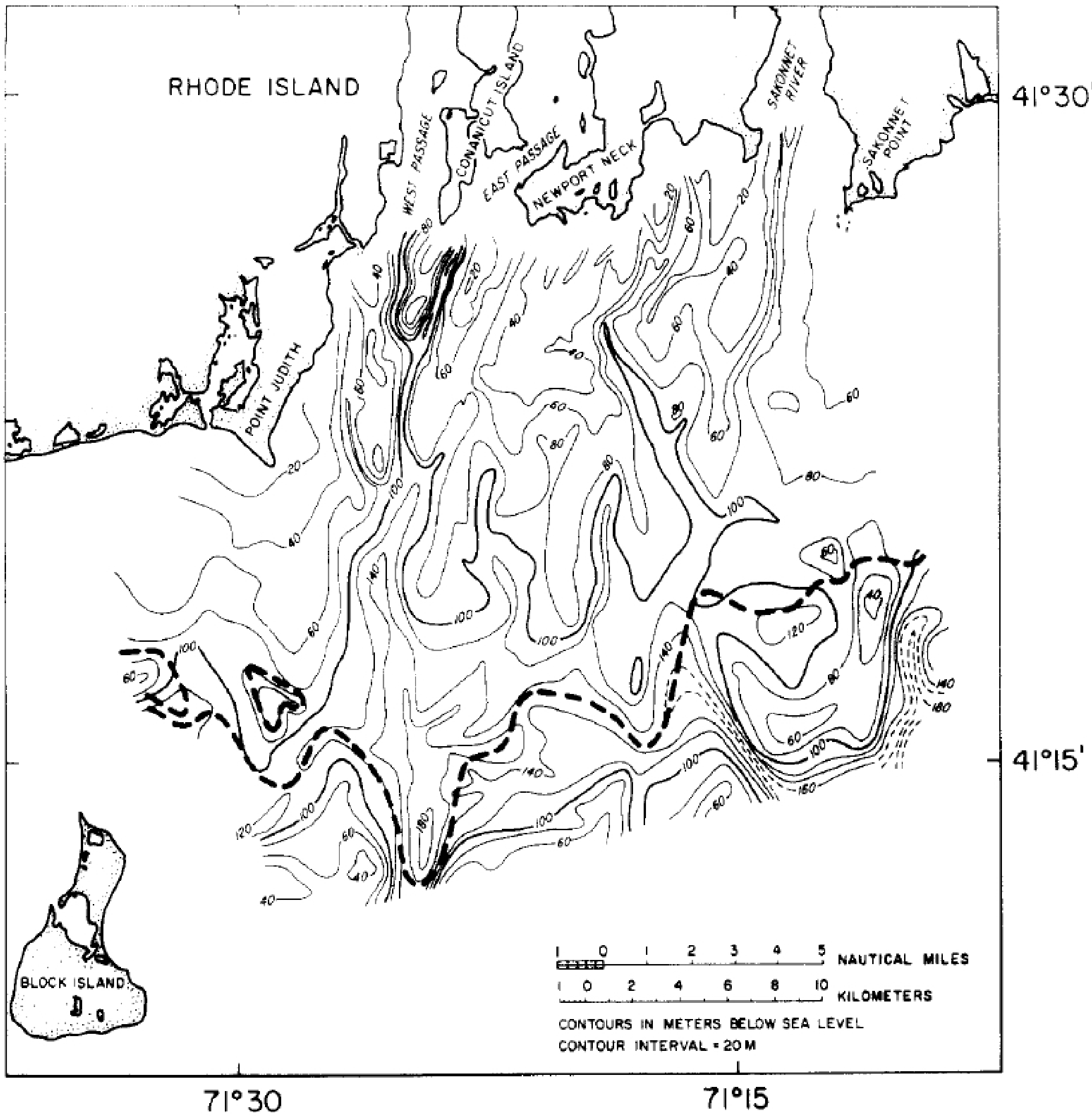


Figure 6-3. Depth below sea level to deepest acoustic reflector compiled from seismic reflection profiles, from Needell et al. (1983a).
North of the heavy dashed line, the reflector is inferred to be bedrock surface; south of the heavy dashed line, the reflector is inferred to be the surface of coastal plain and continental shelf strata.

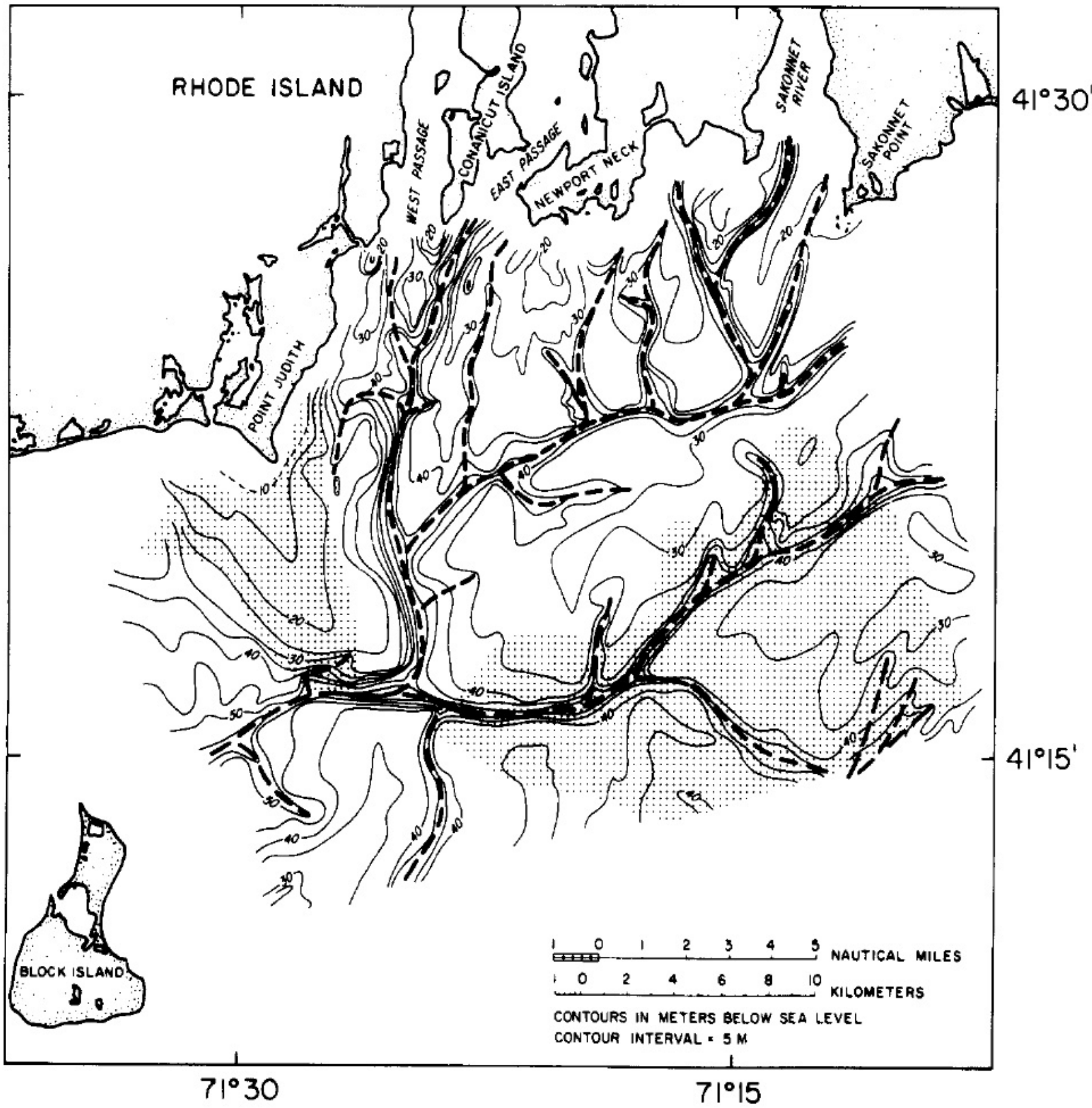


Figure 6-4. Depth below sea level to the post-glacial unconformity (fu_1) compiled from seismic reflection profiles, from Needell et al. (1983a).
Dashed lines indicate hypothesized thalwegs of post-glacial streams.

Table 6-1. Subsurface stratigraphic framework for the continental shelf south of Narragansett Bay, as described by Needell et al. (1983a, b, c).
Stratigraphic units are shown in white boxes, and regional reflectors are shaded with light orange. The thickness of each row in the table is the result of the table contents and is not representative of the relative thicknesses of stratigraphic units.

Feature Code	Interpretation	Age	Acoustic Signature and Notes
Qpt	Marine deposits	Holocene/Recent	• Geographically variable • Not always present
mu	Erosional unconformity caused by post-glacial marine inundation	Holocene	• Smooth, flat-lying reflector
Qfe	Post-glacial fluvial and estuarine deposits	Late Pleistocene/ Early Holocene	• Internal reflectors flat to gently dipping, or locally cross-bedded

fu$_1$	Erosional unconformity caused by post-glacial fluvial erosion of the landscape prior to marine inundation	Late Pleistocene	• Same as sea floor (mu) in some locations:
			  o Smooth, continuous reflector
			• When overlain by younger deposits:
			  o Reflector smooth to highly irregular and channelized

Qdo or Qdm	**Qdo**: Glacial “drift”
	• Till
	• Ice-contact drift
	• Glaciofluvial outwash
	• Glaciolacustrine
	• Ice-deformed drift
	
	Qdm:
	• End moraine deposits
		Late Pleistocene (associated with Late Wisconsinan glaciation)
		
		May be earlier Pleistocene in some areas
			• Acoustically variable
			  o <u>Ice-deformed drift</u>: highly irregular, short, discontinuous internal reflectors
			  o <u>Glaciofluvial outwash</u>: continuous, flat to gently dipping reflectors
			  o <u>Glaciolacustrine deposits</u>: well-laminated reflectors
			  o <u>End moraines</u>: acoustic signature dependent on geographic location; reflectors sometimes absent, sometimes continuous and well-defined, slightly irregular at top and base
			• Variable thicknesses
			• Geographically variable

fu$_2$	Erosional unconformity caused by glacial processes	Pleistocene	• Deepest identifiable reflector
			• Overlies Ku in southern study area
			  o Continuous, smooth in this area
			• Overlies Pzz in northern study area
			  o Strong, continuous, highly irregular in this area
			• Traceable from outcrops near shore

Ku	Coastal plain and continental shelf deposits forming a cuesta with a north-facing escarpment	Cretaceous/ Early Tertiary	• Only occurs in southern 1/3 of study area
Pzz	Crystalline bedrock	Paleozoic	• Limited or no acoustic penetration

6.3.2 Project Data—EN580 Survey

The seismic reflection profiles obtained by the project team in 2016 as a preliminary follow-up to the USGS survey south of Narragansett Bay are shown in Figure 6-5. The three additional seismic reflection lines were run with the same W-E orientation and in between existing USGS legacy data lines (Figure 6-1). The newly acquired seismic reflection data have the advantage of improved resolution and modern image processing software, allowing the existing framework to bias new interpretations would run the risk of missing previously unidentified features. For this reason, interpretations of these data were made in a manner consistent with the existing framework; however, the acoustic characteristics of each identified seismic unit were carefully considered before correlating with the older USGS data.

Several seismic units and erosional unconformities were identified and later correlated with the existing geologic framework.

- **Qpt:** Post-marine transgression marine sediment. Qpt is acoustically transparent or exhibits flat-lying to gently dipping internal reflectors. In most places, Qpt is a thin veneer of marine sediment (< 5 m), except near the western channel where thicknesses reach 10 m in Line 3, and was deposited post transgression in a low energy marine setting (Figure 6-5).

- **mu:** A flat-lying to gently dipping, laterally continuous reflector interpreted as an erosional marine unconformity (ravinement surface). Reflector mu is best observed in the western half of the seismic reflection lines and reaches its maximum depth of 47 m below sea level near the western channel cut by fu_1 in Line 3 (Figure 6-5). Marine transgression and wave-cutting are identified as the erosional processes leading to the formation of mu. Where mu is not buried below marine sediment, it is thought that the modern-day seafloor also comprises mu as it continues to erode or is depositionally inhibited by storm-induced bottom currents.

- **Qfe:** Post-glacial fluvial and estuarine sediment. Qfe exhibits some flat-lying and gently dipping internal reflectors, or otherwise acoustically featureless sediment, and ranges 5–25 m in thickness. Qfe unconformably fills the channels cut by fu_1, locally overlying Qdo.

- **fu_1:** A channelized, discontinuous, and irregular reflector interpreted as an erosional unconformity formed by post-glacial fluvial erosion that cuts channels into glacial deposits (Qdo). The channel depths reach a maximum of 55 m below sea level near the prominent westernmost bedrock channel, with several shallower channels towards the east varying in depths from 40–50 m below sea level.

- **Qdo:** Undifferentiated "glacial drift" composed of glaciolacustrine, glaciofluvial outwash, till, and ice-contact/ice-deformed drift sediment. Because this seismic unit spans several depositional environments, the acoustic characteristics vary drastically. Glaciolacustrine sediment is characterized by parallel, draped laminated internal reflectors and is the most recognizable and widespread in the seismic reflection profiles. Till exhibits more chaotic internal reflectors and are found locally draping the underlying bedrock. Qdo unconformably fills the large pre-existing bedrock valleys, found as deep as 100+ m and outcropping in some places at the seafloor. In places, the thickness of Qdo exceeds 60 m.

- **fu_2:** A strong and continuous reflector interpreted as an erosional conformity. It cuts and truncates Pzz, is highly irregular, and varies in depth from 30–100+ m below sea level. It is thought that fu_2 represents millions of years of erosion by a well-established fluvial drainage system that was possibly further eroded during Pleistocene glaciation.

- **Pzz:** Acoustic basement (no acoustic penetration) wherever present. Interpreted to be Paleozoic crystalline bedrock as it lies to the north of the coastal plain erosional remnant and associated cuesta. Because the area lies just to the south of Narragansett Bay, it is thought that Pzz represents a submerged portion of the Narragansett Basin bedrock.

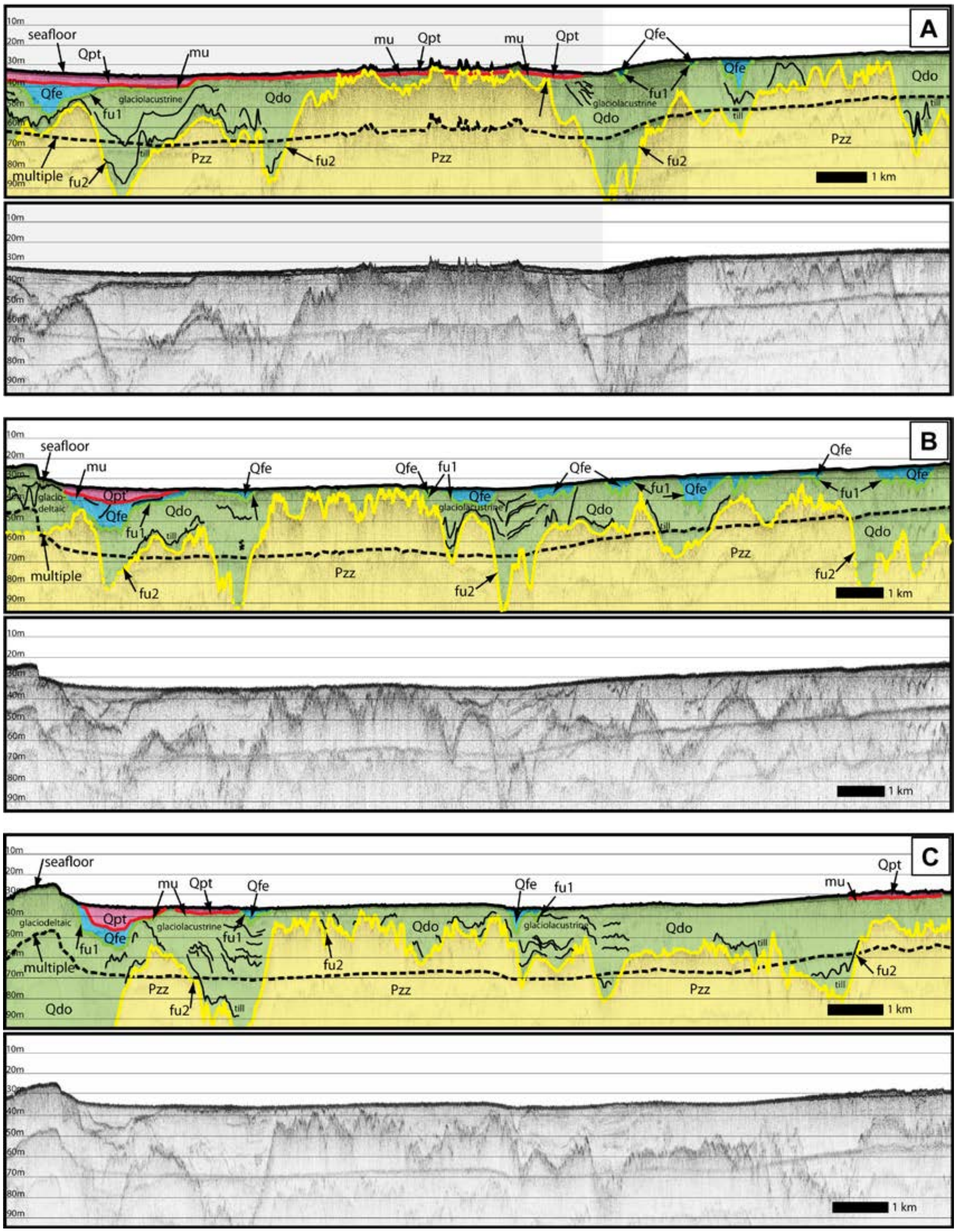


Figure 6-5. Interpreted seismic reflection profiles from research cruise EN-580.
Three west-east and parallel FSI Bubble Gun seismic reflection profiles were acquired in June 2016 aboard the R/V *Endeavor*. Profile 'A' is the northernmost line, and Profile 'C' is the southernmost line. Refer to Figure 6-1 for location of EN-580 seismic reflection profiles.

6.4 Discussion: Assessment of Legacy Data

The data acquired by the USGS reconnaissance cruises between 1975 and 1981 ("the USGS legacy data") continue to provide the generally accepted understanding of the regional subsurface geologic framework for the southern New England continental shelf. Before applying it to contemporary modeling efforts, two aspects of the dataset require assessment: 1) resolution and technical quality; and 2) geological interpretations.

6.4.1 Equipment Resolution and Technical Quality

Interpretations of seismic reflectors and units from the newly acquired EN-580 seismic reflection data discussed above are in good agreement with the USGS legacy data. Both datasets reveal the same general geological framework characterized by several episodes of erosion and deposition, including glaciation and marine transgression. The EN-580 data reveals finer scale detail compared to the USGS legacy data due to technological improvements in both acquisition and post-processing. Legacy data were analog records where all signal-to-noise improvements were performed during acquisition. Modern seismic reflection systems such as the Bubble Gun generate digital records where significant data quality improvements can be made by advanced image processing techniques in post-processing.

An additional comparison between Bubble Gun and legacy USGS seismic reflection data can be made using data obtained by the project team in for a concurrent project (BOEM-URI Grant and Cooperative Agreement M14AC00011, *Identification of Sand and Gravel Resources in Rhode Island While Working Toward a Better Understanding of Storm Impacts on Sediment Budgets*; Period of Performance: July 29, 2014–May 29, 2018). Bubble Gun seismic reflection data were collected in Block Island Sound during a geophysical cruise conducted in August 2015 (Figure 6-6). Although the primary objective of the study was to identify and characterize the thickness of sand and gravel deposits in Federal waters, a portion of the geophysical survey was specifically designed to re-run a legacy USGS seismic reflection trackline using the Bubble Gun to compare data quality, and to determine if new interpretations match the existing geologic framework. When comparing the two collocated datasets, it is immediately clear that the Bubble Gun provides much improved resolution (Figure 6-7). Acoustic basement, interpreted as crystalline bedrock in Block Island Sound, is easily identifiable in both the Bubble Gun and legacy data, with better detail gained from the Bubble Gun. Much greater disparities in resolvable detail are noticed in shallower sediments. The rhythmic character of glaciolacustrine sediment stands out much more clearly in the Bubble Gun data and the heterogeneity of glacial deposits (Qdo) is far more apparent. The lateral continuity of the post-glacial fluvial unconformity (fu_1) is also drastically more apparent and internal acoustic character of post-glacial fluvial/estuarine deposits (Qfe), and post-transgression marine sediments (Qpt) are more easily identified.

A similar assessment of USGS legacy seismic reflection data was recently described in Klotsko and Driscoll (2018). In this study, high-resolution CHIRP seismic reflection data from Block Island Sound revealed a Holocene-glacial sediment contact that was not imaged in the legacy data. For this reason, the thickness of glaciolacustrine sediment was underestimated in this study area prior to newly acquired CHIRP seismic reflection data. Although the newly acquired the CHIRP data provided new evidence supporting catastrophic lake drainage as opposed to gradual lake drainage, it did not change the general geologic framework from the legacy data at a regional scale.

Additional CHIRP seismic reflection data would be useful as there are significant improvements in resolution achieved with these higher frequency systems (10s of cm vertical resolution). Both the EN-580 and USGS legacy data used lower frequency seismic reflection systems that achieve better penetration, which are well suited to reconnaissance scale geological interpretations, especially where the seafloor geology is not well known. This advantage of better acoustic penetration in a wider range of sediment is offset by lower resolution, particularly with the first return from the seafloor which obscures the upper 1–2 m of sediment. CHIRP systems in fine-grained (fine sand, silt, clay) sediments produce excellent records; however, coarse-grained sediments can quickly attenuate the signal leading to insufficient acoustic penetration. Using only a CHIRP system when a geological framework is not well established makes it difficult to put observed reflectors into context. Supplemental CHIRP seismic reflection data could help to refine identification and interpretation of more archaeologically significant sediment, such as seismic units Qfe and Qdo, and should be considered in future surveys.

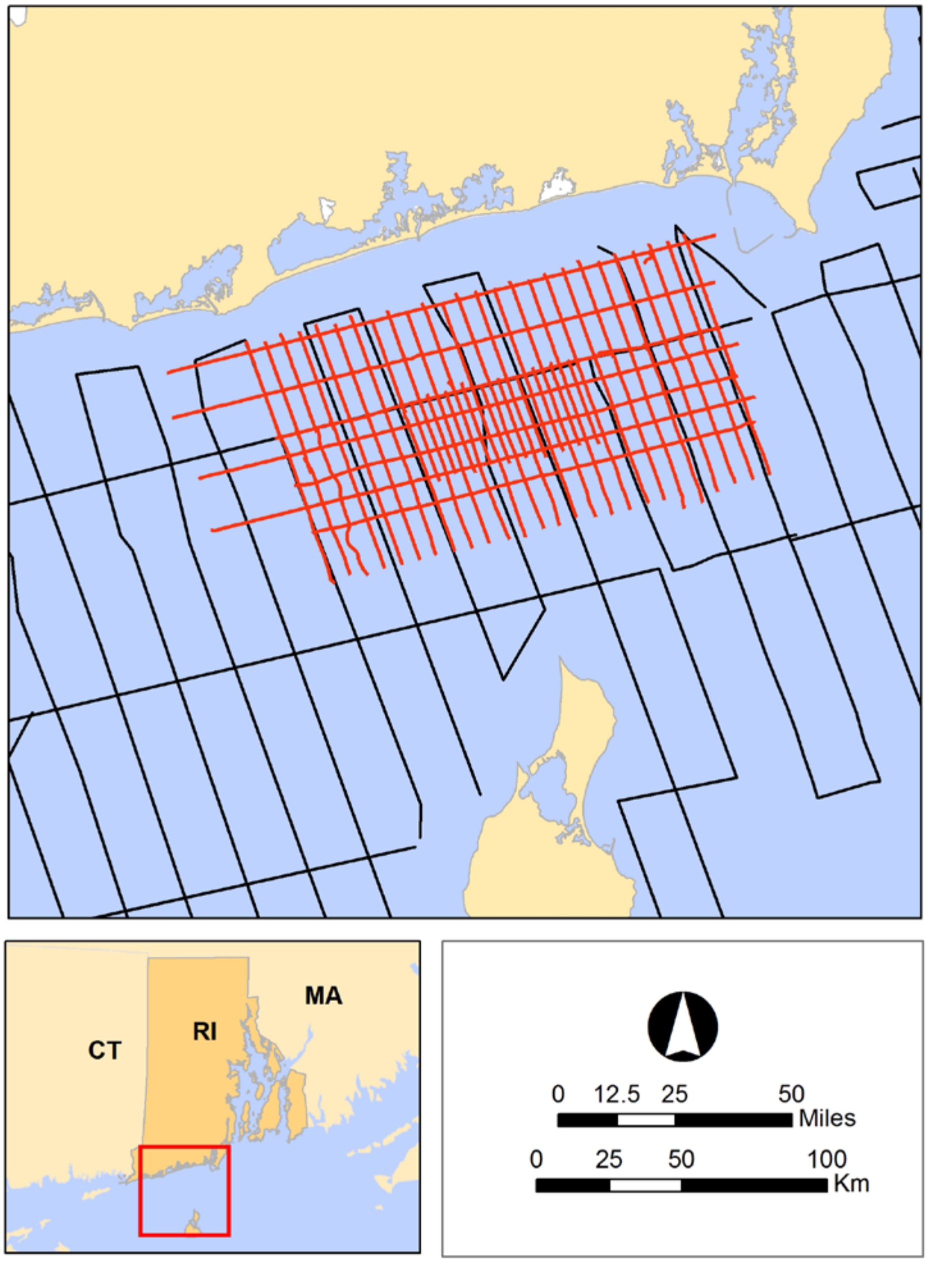


Figure 6-6. Seismic reflection survey tracklines in Block Island Sound.
Red survey lines were collected aboard the R/V *Endeavor* during research cruise EN-565 in 2015 and the R/V *Shanna Rose* in 2016. Black survey lines are part of the 1980 USGS legacy data.

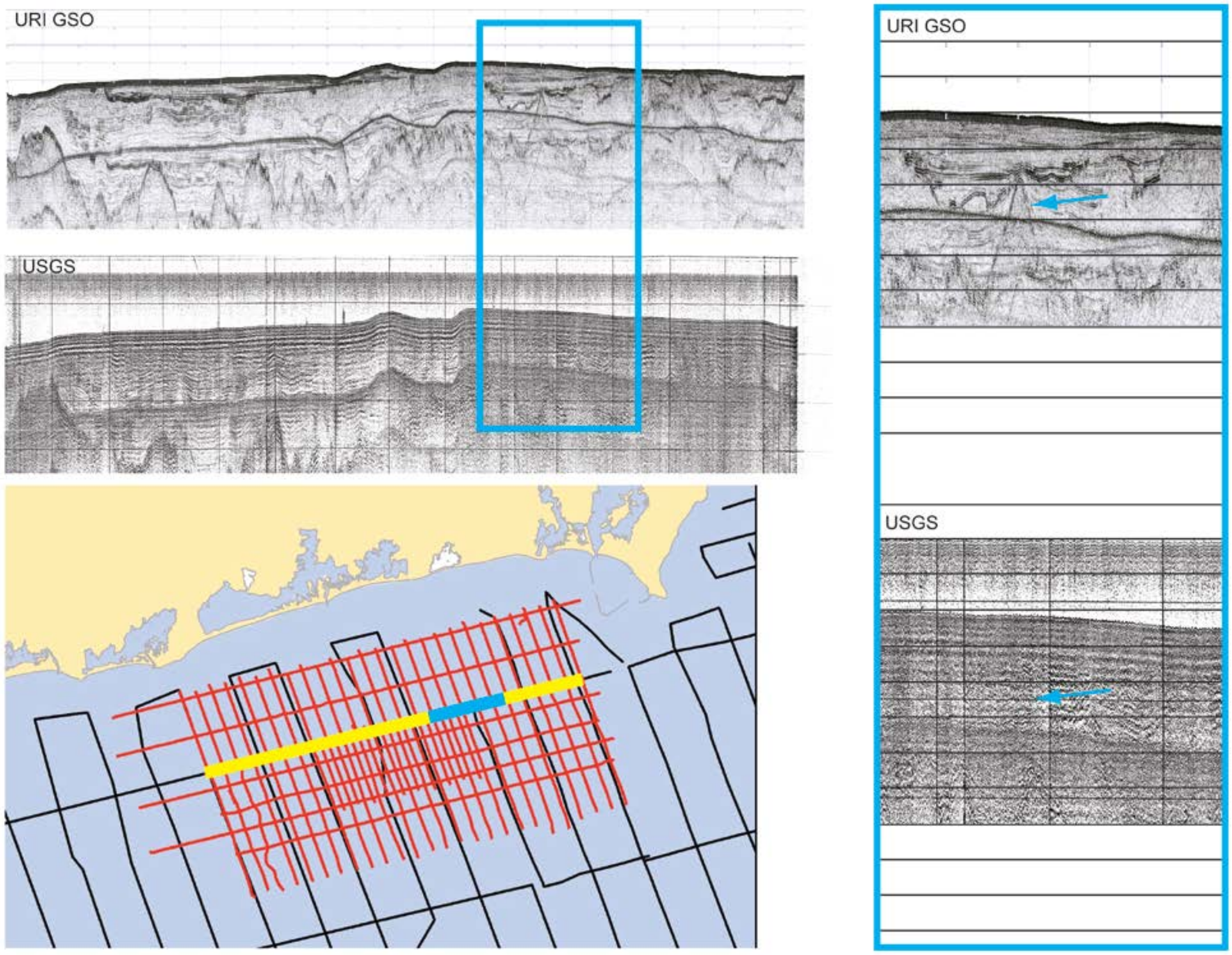


Figure 6-7. Comparison of seismic reflection profile resolution.
Yellow line in map delineates collocated seismic reflection lines. Blue frames delineate the region of comparison, also indicated as a blue line in map view. Blue arrows show a subsurface feature easily observed in the URI-GSO data that is undistinguishable in USGS legacy data.

6.4.2 Geological Interpretations

The subsurface stratigraphic framework developed by the USGS studies is based on early investigations of the bedrock and glacial history of southern New England (see Section 4.1.1.1 of this report) and expert interpretation of the acoustic record. Despite the improved resolution produced by contemporary seismic reflection profiling equipment, the newly acquired data discussed above supports the overall regional geological framework developed by the USGS studies. Subsequent research also supports the USGS regional framework, but the legacy interpretations of the acoustic dataset have never been ground-truthed in a comprehensive manner. Two recent studies (Sheldon 2012; Caccioppoli 2015) specifically sought to revisit the interpretations of the USGS legacy dataset by examining sediment core/borehole data and additional seismic reflection surveys; both confirmed the regional geologic framework presented by Needell et al. (1983a, b, c) but noted local variations. A third study (Klotsko and Driscoll 2018) identified glaciolacustrine deposits in CHIRP seismic reflection profiles that were not visible in a portion of nearby Uniboom data from the USGS legacy survey of Block Island Sound, but did not ground-truth this interpretation with cores or borings. These studies, and the comparison between newly acquired data and the USGS data discussed above, indicate that the USGS studies can be used as the basis for a preliminary regional stratigraphic model. However, caution should be exercised when applying it to site-specific paleolandscape reconstructions on a smaller scale. The following issues should be considered when using the dataset.

Reconnaissance-level trackline spacing: The 1980 USGS survey was conducted with a 1–2 km trackline spacing and, with the exception of a small area immediately south of Narragansett Bay, crossing lines are limited (see Figure 6-1). This resolution was designed for a comprehensive reconnaissance-level survey across a broad geographic area but is not adequate to develop a regional map of potential paleolandscape locations by correlating between survey tracklines. The coarse trackline spacing is particularly problematic because of the geographic variability and heterogeneity of sedimentary deposits noted in the interpretation of acoustic reflectors (Table 6-1 above). For example, stratigraphic unit Qdo is interpreted to represent sediments associated with several glacial depositional environments that are present in some geographic areas and absent in others. Unit Qfe represents both fluvial and estuarine sediments that are also present in some areas and absent in others. This type of geographic variability makes "connecting the dots" between widely spaced tracklines unwise without additional supporting data. A paleochannel or other landscape feature that is visible in one seismic reflection profile is not necessarily the same feature, or even the same age, as a similar one that appears in another profile 2 km away, although the regional processes that created both features may be related. The interpretive maps presented by the USGS studies (see Figures 6-2, 6-3, and 6-4) are illustrations of the *possible* regional distribution of stratigraphic units, but these interpolations are hypotheses that have not yet been tested. Until additional data can be collected to refine the characteristics and distribution of the subsurface stratigraphic units in Rhode Island Sound, regional-scale interpolations between widely spaced seismic reflection profiles should be avoided for modeling purposes. However, the data can be used to develop a preliminary regional stratigraphic model for the southern New England continental shelf that can be tested locally, as will be discussed in Section 6.5 of this report.

Limited sediment core data: Sediment cores or borings have not yet been acquired in a systematic manner to verify the interpretations of the USGS seismic reflection data. The geological interpretations for each stratigraphic unit are based largely on the analysis of acoustic signatures and the technique of sequence stratigraphy. The importance of analyzing sediment cores to ground-truth paleoenvironmental interpretations based on seismic reflection data is illustrated by the results of a 1988 coring study that was designed to assess non-energy (sand, gravel, and mineral) resources on the southern New England continental shelf (see Figure 4-3, cores 88-9 through 88-14) (Neff et al. 1989; Poppe et al. 2002). Three vibracores from this investigation were obtained in the Submerged Paleolandscapes Project area south of Narragansett Bay. Coring targets were selected based on the previous interpretations of the USGS seismic reflection profiles in the area, and sedimentological data was compared with the acoustic interpretations. Core 88-12 was chosen to gain information about the three uppermost acoustic units identified in a nearby USGS seismic reflection profile. Although the authors of this study (Neff et al. 1989) did not use the naming scheme of the USGS studies (see Table 6-1) to identify these units, they would represent Qpt, Qfe (estuarine), and Qfe (fluvial), respectively. Analysis of grain size samples and diatom floras from core 88-12 confirmed the previous acoustic interpretation (Neff et al. 1989), and a prominent contact visible in the core between Units 4 and 3 (Qpt and Qfe, respectively) appears to represent the Holocene marine unconformity identified as mu in the USGS studies (see Table 6-1).

Correspondence between the USGS acoustic interpretations and sediment core data at core locations 88-13 and 88-14 was less clear. The target of both cores was surficial Pleistocene glacial drift deposits, which had been inferred by Needell et al. (1983b) and Neff et al. (1989) to occur at these locations. Glacial drift deposits would correspond to unit Qdo using the naming scheme of the USGS studies (see Table 6-1 above). Instead, analysis of core 88-13 suggested that the upper 303 cm of sediments represented Holocene marine shelf deposits (Qpt) that may have been composed of reworked glacial sediments. This unit was underlain by sediments suggestive of a Holocene low energy estuarine basin (Qfe) or glaciolacustrine environment (Qdo). A sharp contact was identified in the core between these units, which may represent the regional acoustic reflector identified as mu by the USGS studies, although the exact depositional history of the lower unit was unclear. Results from core 88-14 also appear to contradict the acoustic interpretations. The target location was characterized by zones of parallel, wavy to flat-lying reflectors interspersed with chaotic reflectors. Analysis of core 88-14 indicated that a thin (approximately 46 cm) veneer of marine sediments overlies 303 cm of sediments of uncertain origin in this area, which were hypothesized to represent marine sediments composed of reworked glacial drift (Qpt) or possibly glacial outwash (Qdo). The contacts between facies in this core were gradational, suggesting that the regional acoustic reflectors identified in the USGS studies (Needell 1983 a, b, c; Table 6-1) may not occur in this area, or may not represent erosional unconformities.

Although these cores support the overall regional geologic framework proposed by the USGS studies, they indicate that direct correlation between the acoustic units visible in seismic reflection profiles and specific paleoenvironments at a local level require significant additional refinement. Because both the Qdo and Qfe units are interpreted to represent a variety of geographically variable depositional environments, analysis of sediment cores will be necessary to refine the acoustic interpretations and develop accurate paleolandscape reconstructions. In addition, verification that the three regional acoustic reflectors fu_2, fu_1, and mu represent unconformities cannot be confirmed without analysis of sediment cores.

Absence of absolute dates: Because sediment cores have not yet been acquired to support the USGS studies south of Narragansett Bay, absolute dates are not available to verify the ages of the stratigraphic units and unconformities identified by analyses of seismic reflection profiles. Approximately 16 vibracores were obtained as part of the 1975 USGS survey east of the 1980 study area (see Figure 4-3, purple dots) (Oldale and O’Hara 1980; McMullen et al. 2009b) and 22 radiocarbon dates were obtained from peat and shell samples acquired from these cores. These dates provide important time control for the stratigraphy of the continental shelf south of Massachusetts; however, applying them to the project study area south of Narragansett Bay requires correlation of local stratigraphic units across a large geographic area, which may be problematic due to the wide trackline spacing of the seismic reflection surveys and the apparent heterogeneity of sedimentary facies.

Acoustic resolution: As discussed above, the Uniboom system used for the USGS studies produced good results for characterizing the entire subsurface stratigraphic package in the study area, but it lacks detailed resolution in shallowly buried sediments. Identification of regional unconformities is necessary to understand the relative ages of depositional units. Distinguishing fu_1 from mu, and identifying their spatial extent, is problematic in some areas because these reflectors occur in shallow sediments with lower acoustic resolution. In addition, Klotsko and Driscoll (2018) identified glaciolacustrine deposits in Block Island Sound that are visible in CHIRP seismic reflection data but are not visible in nearby USGS Uniboom data, suggesting that the local resolution of the USGS legacy data may be variable.

6.5. Regional Stratigraphic Model

If the USGS legacy datasets are used with caution, they provide an important starting point for paleolandscape reconstruction and paleocultural sensitivity assessment in the project study area. A preliminary regional stratigraphic model can be developed to identify which subsurface geologic facies may contain paleolandscapes or paleolandscape fragments that were suitable for human occupation. This requires an understanding of the age, geological environments, and geological processes represented by the subsurface stratigraphy in the study area.

The subsurface stratigraphy identified by the USGS studies suggests that much of the geologic record of Rhode Island Sound is the result of Pleistocene and Holocene glacial and post-glacial processes.

Crystalline bedrock (unit Pzz) and Cretaceous/Early Tertiary coastal plain and continental shelf sediments (Ku) form the ancient base of the stratigraphic sequence, representing geological environments that are tens to hundreds of million years old. During the Pleistocene, multiple advances and retreats of glacial ice significantly eroded the ancient bedrock and Cretaceous sediments, resulting in a regional unconformity (fu_2). This unconformity represents several million years of missing sediments that were deposited between the Early Tertiary and Pleistocene Periods and were subsequently removed by glacial erosion. The Late Pleistocene (Wisconsinan) ice advance depressed the land surface and lowered sea level, resulting in subaerial exposure of much of what is now the continental shelf. A heterogeneous blanket of glacial “drift” sediments (Qdo) and end moraines (Qdm) were deposited across the continental shelf on top of unconformity fu_2 and the ancient basal units. During deglaciation, the continental shelf was occupied first by glacial lakes (portions of Qdo) that formed between the retreating ice and end moraines and then was exposed subaerially (unconformity fu_1) when the glacial lakes drained. This post-glacial, Late Pleistocene/Early Holocene landscape was characterized by streams flowing south and southwestward towards Block Island Sound, which eroded (fu_1) the earlier glacial and glaciolacustrine sediments (Qdo and Qfm) and produced fluvial deposits (Qfe). As sea level rose, post-glacial valleys were partly filled by fluvial, freshwater peat, estuarine, and salt marsh deposits (Qfe). Transgressing seas eroded the sea floor (mu), exposing the ancient basal bedrock and coastal plain outcrops in some places and depositing marine sediments (Qpt). In some parts of the contemporary sea floor south of Narragansett Bay, marine sediments are being deposited over the unconformity (mu) produced by the post-glacial marine transgression, but in much of the study area, bottom sediments may be composed of older geographic units (Needell et al. 1983a).

Table 6-2 presents a regional subsurface stratigraphic model that is applicable to the southern New England continental shelf and to Narragansett Bay, developed from the USGS legacy dataset. Although the USGS studies were focused on the southern New England continental shelf and did not extend into Narragansett Bay, several later investigations (McMaster 1984; Peck and McMaster 1991; Oakley 2012; Oakley and Boothroyd 2012; Oakley and Boothroyd 2013) suggest that the subsurface stratigraphy of Narragansett Bay is correlative with the continental shelf off Rhode Island. This is not unexpected, because the geologic processes that resulted in the stratigraphy of both areas were similar, despite variations in local topography. Therefore, the model below is applicable to the entire Submerged Paleolandscapes Project study area. Each geologic unit is presented in stratigraphic order (most recent at the top of the table and oldest at the bottom) and described according to the likelihood of containing paleolandscapes or paleolandscape fragments that may have been associated with occupation by ancestral Tribal peoples. The inferred age and paleoenvironment of each unit in the subsurface stratigraphy is summarized, along with associated rationale and cautionary notes. This table may be used in conjunction with Table 6-1 if additional information about the characteristic acoustic signature of each unit is desired. Note that the ranking system is based only on the inferred age and paleoenvironment of each stratigraphic unit and is not a cultural sensitivity assessment based on inferences about the behavior or preferences of ancestral Tribal people. The focus of this model is to identify geologic facies in the study area that are most likely to contain paleolandscapes or paleolandscape fragments that could have been occupied by ancient humans, not to make inferences regarding the importance of these landscapes to ancient or contemporary Tribal peoples. This is a regional model that must be tested and refined at each local study area to which it is applied.

Table 6-2. Regional subsurface stratigraphic model for the study area.

Qpt and mu:
Represents a marine or dynamic/erosional shoreface landscape unavailable for human habitation or unlikely to preserve its evidence.

Hypothesis: Qpt was deposited during the time period associated with human occupation of the study area but represents a submerged marine environment unavailable for human habitation. The reflector mu represents a marine shoreface environment that was dynamic/erosional and is therefore likely to be disturbed, with little potential for preservation of contextually intact cultural deposits.

Approximate Age: Marine inundation (date of inundation varies according to geographic location) to present

Rationale: The regional reflector mu (also called the "ravinement surface" by contemporary researchers) is interpreted to represent an unconformity produced by erosion of the subaerially exposed land surface by wave action as sea level rose and the shoreface transgressed across the landscape. Because the facies Qpt overlies mu, Qpt is inferred to be younger than the age of mu and marine in nature. The age of both of these units varies according to geographic location. Post-glacial sea level rise in the study area progressed from south to north, indicating that mu and Qpt are older at continental shelf locations and more recent in the Narragansett Bay area. Marine transgression of the study area appears to have begun approximately 11,000 yBP. Qpt and mu are inferred to have been formed after this time.

Paleolandscape Type: Marine (Qpt) and dynamic shoreface (mu)

Rationale: The USGS studies defined Qpt sediments as "marine deposits" associated with deposition in a submerged environment. Therefore, they represent a paleoenvironment unavailable for human habitation and only likely to contain cultural material associated with maritime cultural activity (e.g., vessel and fishing gear remains).

Qfe and fu_1:

Most likely to represent, or be associated with, elements of the paleolandscape that could have been inhabited and utilized by humans.

Hypothesis: Qfe was deposited during the time period associated with human occupation of the study area and may represent, or be associated with, archaeologically sensitive terrestrial paleolandscapes.

Approximate Age: < 16,000 yBP to marine inundation (date of inundation varies according to geographic location)

Rationale: The regional reflector fu_1 defines the base of Qfe sediments and was identified by the USGS studies as an unconformity resulting from subaerial exposure of the continental shelf that occurred after glaciers receded and the glacial lakes drained, but before marine inundation. Subsequent studies (Koteff and Larsen 1989; Koteff et al. 1993; Lewis and DiGiacomo-Cohen, 2000; Oakley 2012) indicated that drainage of glacial lakes on the southern New England continental shelf occurred approximately 15,000–16,000 yBP. Because the geologic unit Qfe overlies fu_1, it is assumed to be younger than the age of fu_1 and therefore less than approximately 16,000 years old. The earliest dated archaeological evidence of human habitation in southern New England is ca. 11,000 yBP, suggesting that Qfe represents sediments deposited during a time of possible human habitation.

Paleolandscape Type: Fluvial and estuarine

Rationale: The USGS studies concluded that Qfe represents fluvial and estuarine deposits associated with stream or river systems that developed on the subaerially exposed continental shelf prior to marine inundation. This hypothesis is based on the presence of channel-like features in the fu_1 reflector and qualitative correlation of the acoustic signature of this unit with acoustically similar valley fill deposits in nearby Martha's Vineyard Sound (O'Hara and Oldale 1980) and Buzzards Bay (Robb and Oldale 1977), which were ground-truthed with a small sediment core study. This facies is also hypothesized to contain estuarine deposits, resulting from the initial stages of marine inundation. Both fluvial and estuarine *sediments* are deposited in submerged environments, which obviously are unsuitable for human habitation. However, in a broader sense, fluvial and estuarine *systems* are complex landscapes that consist of a variety of environments, particularly at their margins and between them. For example, a landscape dominated by rivers also contains marshes and dry upland areas. Therefore, some of the sub-environments associated with fluvial and estuarine systems are likely to have been suitable for human habitation and use. Because Qfe currently is characterized only at a reconnaissance level, it is unclear what aspects of the fluvial and estuarine systems are preserved and included in this broadly defined sedimentary facies. However, the age range, deposition on the exposed shelf, and presence of fluvial and estuarine deposits in this facies suggests a paleolandscape that could have been occupied by and utilized by humans. Cultural deposits could also extend into fu_1.

Cautions:

- This facies has not been adequately defined with sediment cores, radiocarbon dates, and/or contemporary high-resolution seismic reflection data. It may represent a variety of geographically variable depositional environments, some of which are archaeologically sensitive and some of which are not.

- Acoustic resolution of the USGS seismic reflection data is sometimes poor in shallowly buried sediments, which interferes with a precise interpretation of this facies.

- The hypotheses that the fluvial component of this facies represent geographically continuous stream/river channels, and that fu_1 is a geographically continuous surface (Needell et al. 1983a, b, c), is based on qualitative correlation of features identified in seismic reflection profiles obtained at 2-km trackline spacing. Because Qfe appears to be geographically heterogeneous, this hypothesis must be tested by higher resolution surveys.

- The acoustic reflector fu_1 is an important marker for Qfe sediments, because it defines the base of the Qfe unit. However, its geographic continuity has not been examined in detail. In some areas, fu_1 and Qfe appear to be absent, and poor acoustic resolution in the upper part of the seismic reflection profiles interferes with detailed interpretation of the acoustic signatures.

Qdo, Qdm and fu_2:

Lower probability to represent paleolandscape elements associated with human habitation, except as outcrops in a younger landscape.

Hypothesis: Qdo and Qdm represent deposits formed on a landscape dominated by glacial ice. This landscape is associated with a time frame older than documented human habitation of the study area. However, if either Qdo or Qdm deposits persisted as outcrops in the post-glacial period, they could have been part of a landscape occupied by humans.

Approximate Age: 26,000–16,000 yBP?

Rationale: The reflector fu_2 is inferred to represent a regional unconformity produced by Pleistocene erosion of underlying bedrock and Cretaceous/Tertiary coastal plain deposits. Qdo and Qdm are located stratigraphically above fu_2, but below fu_1, indicating that they are associated with a time period in between these two features. Because there is some uncertainty about the number of glaciations that occupied southern New England during the Pleistocene, identifying a definitive age for Qdo, Qdm, and fu_2 is problematic. The USGS studies hypothesized that the Qdo and Qdm were largely associated with the Late Wisconsinan glaciation, which reached its terminal extent approximately 26,000 yBP in the study area. Qdo consists of both ice margin sediments deposited when glacial ice occupied the study area, and glaciolacustrine sediments deposited as the ice was receding northwards. Drainage of the glacial lakes in the study area is thought to have occurred approximately 16,000 yBP. Therefore, the Qdo and Qdm facies would have been deposited between approximately 26,000 yBP, when the ice was at its maximum extent, and 16,000 yBP, when the glacial lakes drained.

Paleolandscape Type: Glacial and early post-glacial

Rationale: The USGS studies indicate that Qdo is composed of a variety of deposits, including till, ice-contact drift, glaciofluvial outwash, ice-deformed “drift,” and glaciolacustrine sediments. Each of these deposits is associated with a landscape occupied by glacial ice. The time frame of these deposits is older than the documented archaeological evidence of human occupation in this area. If human occupation did occur in this time frame, the glacial landscape close to the ice margin (represented by deposits Qdo and Qdm) would have been an inhospitable (although theoretically possible) place for human habitation. During the early post-glacial period, glacial lakes occupied large areas of the continental shelf in the study area (represented by portions of unit Qdo), although the exact extent has not yet been defined. The glaciolacustrine deposits associated with unit Qdo also were deposited during a time frame prior to documented human habitation of the region, but if humans did occupy the area during this time, any exposed land around the glacial lakes could have been inhabited. Erosion of the Qdo surface would have been widespread. Preservation of any cultural deposits within it would have been localized and limited to preserved outcrops in younger sediments. Until additional evidence becomes available that humans occupied the study area prior to ca. 12,500 yBP, Qdo and Qdm are considered unlikely to represent paleolandscapes that were inhabited by humans. However, if either Qdo or Qdm deposits persisted as outcrops in the post-glacial period, they could have been part of a later landscape that was inhabited by humans.

Cautions:

- This facies has not been adequately defined with sediment cores, radiocarbon dates, and/or contemporary high-resolution seismic reflection data. It represents a variety of ice-contact and early post-glacial environments that are acoustically and geographically variable.
- The USGS studies hypothesized that Qdo and Qdm were associated with the Late Wisconsinan glacial period but also suggested that these deposits may have been associated with an older glaciation in some parts of the study area. Radiocarbon dates will be necessary to clearly define the chronology of these units.

Ku and Pzz:

Does not represent paleolandscape elements associated with human habitation, except as outcrops in a younger landscape.

Hypothesis: The stratigraphic units Ku and Pzz are associated with a time period that is millions of years older than the global human archaeological record. These units could only represent paleolandscapes occupied by humans if they persisted as outcrops with elements that were preserved when humans inhabited the study area.

Approximate Age: Tens-of-millions (Ku*) to > 245 million yBP (Pzz)

***** The unit Ku is identified as "Late Cretaceous–Early Tertiary" but has not been assigned a specific date.

> **Rationale:** The age of each of these units is inferred to correspond to bedrock identified and mapped on the southern New England mainland (Oliver and Drake 1951; Tagg and Uchupi 1967; Hermes et al. 1994).

Paleolandscape Type: Coastal plain and continental shelf (Ku) metasedimentary, igneous, and metamorphic bedrock (Pzz)

> **Rationale**: The geologic environments of these units is inferred to correspond to similar units identified and mapped on the southern New England mainland. Because they are significantly older than even the global archaeological record of human habitation, they cannot be associated with human habitation unless they occurred as outcrops in a younger landscape.

6.6 Key Points

- The USGS legacy studies resulted in the development of a subsurface stratigraphic framework for the southern New England continental shelf. This framework is based primarily on the technique of sequence stratigraphy and the interpretation of seismic reflection profiles obtained at approximately 2-km trackline spacing. The USGS interpretations have not been systematically ground-truthed with sediment core data or radiocarbon dates. However, the limited amount of subsequent studies that have been conducted in the study area confirm the regional stratigraphic framework developed by the USGS, while noting local variations in geologic facies and acoustic signatures.

- Comparison between the USGS legacy dataset and several newly acquired seismic reflection profiles indicates that contemporary geophysical surveying equipment produces higher resolution data but does not significantly alter the general subsurface stratigraphic framework for the southern New England continental shelf developed by the USGS.

- A regional stratigraphic model was developed for this project from the USGS legacy dataset, which identifies the geologic facies in the study area that are most likely to contain paleolandscapes or paleolandscape fragments that could have been occupied by ancient humans. Note that this model is based only on the inferred age and paleoenvironments of geologic facies. It is not designed to make inferences regarding how ancestral Tribal people interacted with those landscapes or the cultural importance of those landscapes.

- The stratigraphic model developed for this report is a regional model that must be tested and refined at each local study area to which it is applied. Ground-truthing of the model with contemporary high-resolution geophysical equipment, sediment core analysis, and radiocarbon dates is essential at each local study area.

- The cautionary notes included with the facies descriptions in the model should be carefully considered when the model is applied.

- Accurate application of the stratigraphic model to local study areas requires expert interpretation of the seismic reflection data by individuals who are experienced in interpreting geophysical data *and* who are thoroughly familiar with the regional geologic history of the study area. Interpretation of the sediment core data necessary to ground-truth the acoustic interpretations requires similar expertise. Applying the model without this level of expertise may result in inaccurate conclusions regarding the location, type, and preservation of paleolandscapes that may be of cultural significance to Tribal peoples.

7 Application of Modeling Process to Project Study Area, Step IV: Model Testing Through Local Case Study Analyses

Four case study areas were selected to test the Tier 1 and Tier 2 models discussed above and to refine data collection methodologies. A diverse range of environments was targeted in order to provide a variety of data types and data collection situations. The Greenwich Bay area (Figure 4-1) represents an interior study area in the central Narragansett Bay region, and its three sub-areas (Gorton Pond, Cedar Tree Beach, and the Greenwich Bay sub-seafloor) were targeted for multidisciplinary analyses (Figure 7-1).

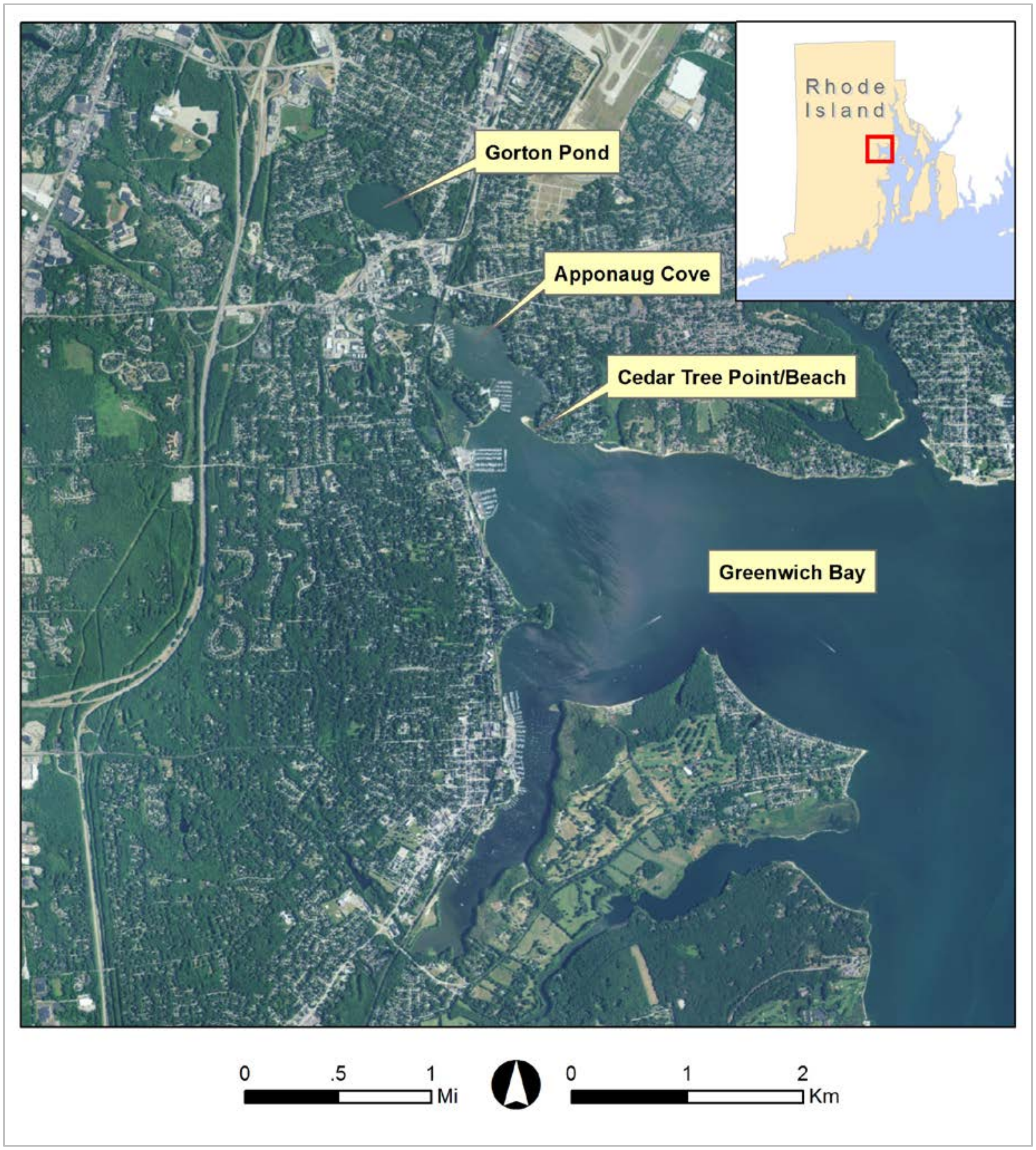


Figure 7-1. Location of study locations within the Greenwich Bay area.
Basemap: ESRI ArcGIS Online “World Imagery”

The nearshore location of the Greenwich Bay study areas simplified the logistics of field data collection and provided the project team with an accessible and cost-effective location for model testing and refinement. It also served as an analog for locations that are now submerged offshore but were once nearshore environments prior to post-glacial marine inundation. The West Beach (Block Island) study area (Figure 4-1) was chosen as a “data bridge” between the nearshore and offshore investigations. Block Island currently is located approximately 11 miles offshore of mainland Rhode Island and is therefore exposed to oceanographic conditions and associated with the offshore stratigraphic record, but the study area at West Beach is located in the beach, intertidal, and shallow subtidal zone. This combination of nearshore and offshore characteristics at West Beach provided an opportunity to investigate paleolandscape preservation and paleocultural sensitivity in a unique environment. The Mud Hole and AMI areas (Figure 4-1) served as offshore study locations that were targeted for geophysical and geological investigations to refine the test the offshore stratigraphic model and to understand whether elements of the formerly terrestrial paleolandscape survived post-glacial marine transgression. The specific goals of each study area are discussed in more detail below.

At each case study area, a primary goal was to educate Tribal research partners in the application and use of geophysical survey equipment and non-disturbance marine remote sensing survey methods. Fieldwork considered comments and recommendations that were voiced by Tribal participants during the project’s initial workshop in March of 2013. As such, the work progressed in three phases, progressing from the least to most in investigative techniques, with an overall goal of minimizing the disturbance to the seafloor as much as possible during the performance of all phases of the field investigations.

7.1 Greenwich Bay Area

7.1.1 Introduction and Goals

Archaeological and geological investigations in the Greenwich Bay area were focused in three locations: 1) Greenwich Bay itself, which is a major sub-embayment on the west-central margin of Narragansett Bay that drains into the larger Narragansett Bay estuary system; 2) Cedar Tree Beach, which forms the northwestern shoreline of Greenwich Bay; and 3) Gorton Pond, which is a small kettle pond located approximately 1 km (0.62 mi) from the Apponaug Cove, which forms the northwestern extent of Greenwich Bay (Figure 7-1). Hundreds of pre-contact period stone artifacts have been found by local residents in the exposed swash zone of Cedar Tree Beach. These artifacts do not exhibit significant marine growth or water-wear, suggesting that they originate from a nearby paleocultural landscape. Possible sources are archaeological deposits formerly situated in an ancient low-relief upland now being eroded by the northwardly migrating beach or in a partially eroded and buried submerged paleocultural landscape immediately offshore of the beach. The presence of a buried and submerged paleocultural landscape was suggested by detailed CHIRP sub-bottom sonar survey data acquired by the URI-GSO project team prior to the initiation of the Submerged Paleocultural Landscapes Project. These data depicted an acoustic reflector consistent with a marine bench or flat extending about 100 to 150 m off of Cedar Tree Beach out to the margin of a buried paleochannel near the current modern channel going across Greenwich Bay and into Apponaug Cove (Figure 7-2). This feature, combined with the large number of artifacts previously found and the protected environment within Greenwich Bay, presented a unique opportunity for conducting systematic, multi-phased geoarchaeological field investigations and field training.

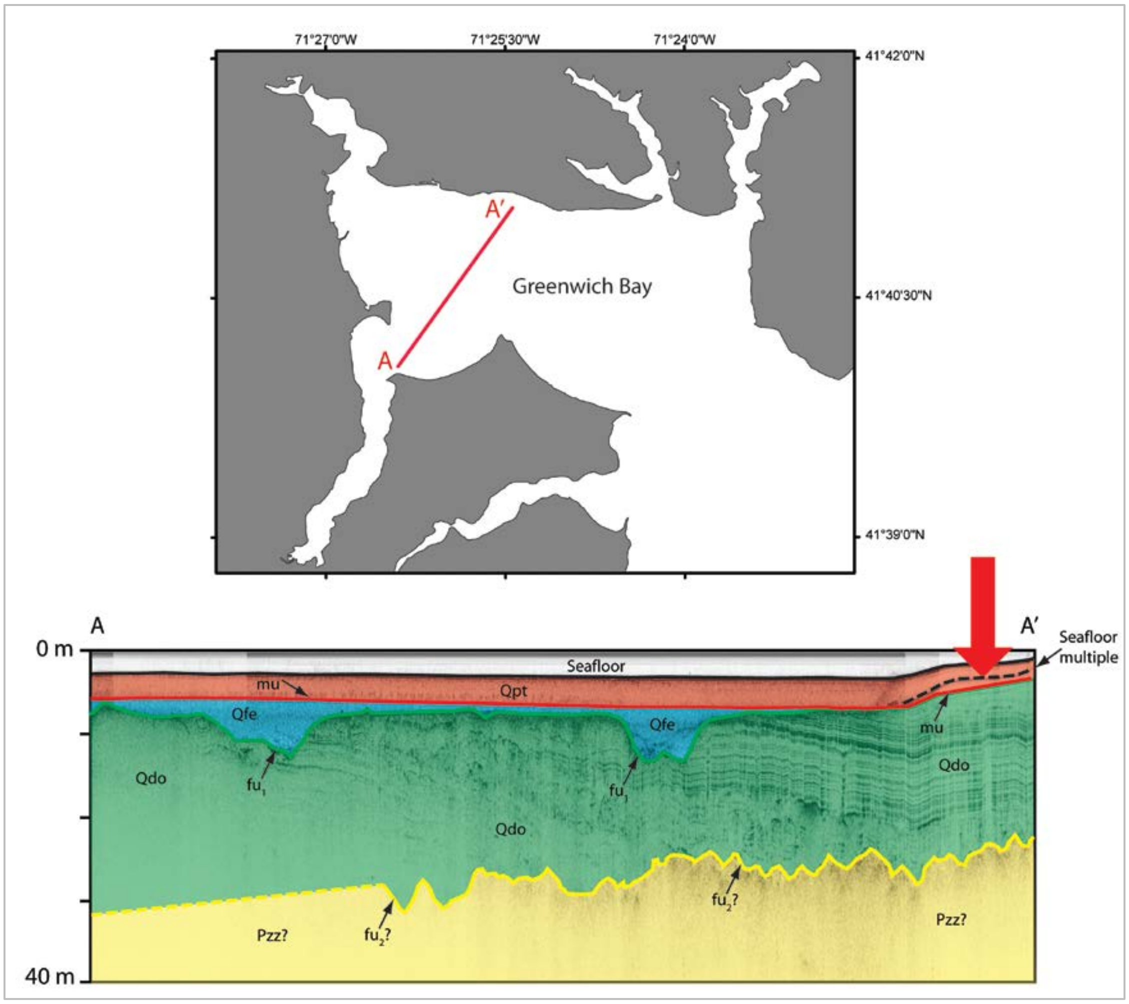


Figure 7-2. Seismic reflection profile obtained in the Cedar Tree Beach area prior to the initiation of the Submerged Paleocultural Landscapes Project.
Upper panel shows the location of the survey trackline. Lower panel illustrates the seismic reflection profile from this location. The red arrow shows the location of a marine bench that was hypothesized to represent a portion of a paleolandscape that may have been associated with the artifacts found on Cedar Tree Beach.

Each of the three locations within the broader Greenwich Bay study area was targeted for a specific purpose. The primary goals for each area are outlined below.

Greenwich Bay: Characterize the subsurface stratigraphy of Greenwich Bay to:

- Develop a hypothesis regarding the relationship between preserved Late Pleistocene/Early Holocene paleolandscapes and the archaeological evidence at Cedar Tree Beach.
- Test the stratigraphic model developed for the continental shelf of southern New England (Section 6 of this report) at an inland location to determine if the regional model is applicable to the Narragansett Bay area.

Cedar Tree Beach: Test and evaluate phased, systematic no- and low-impact geoarchaeological survey methodologies (close-interval [i.e., 1-m track line spacing] gradiometric survey, visual sediment probing, and excavation of 1 x 1 m underwater dredge test units [DTUs]) for identifying submerged paleocultural landscapes. In addition, test the hypotheses that:

- An element of the paleolandscape is preserved submerged and buried off of Cedar Tree Beach.
- This paleolandscape may have been utilized by pre-contact period inhabitants and, therefore, could be a source of some of the pre-contact period stone artifacts appearing in Cedar Tree Beach's swash zone.

Gorton Pond: Develop a paleoenvironmental framework for the Greenwich Bay area for approximately the past 15,000 years by investigating proxy indicators of vegetation change and fire frequency obtained from sediment core samples.

7.1.2 Cedar Tree Beach Archaeological Investigation

7.1.2.1 Introduction and Goals

The marine archaeological fieldwork conducted in the shallow waters off of Cedar Tree Beach was intended to meet multiple goals using a systematic, phased approach employing different types of low-impact surveying and subsurface sampling techniques to:

- Test the hypotheses that a) an element of the paleolandscape was preserved submerged and buried off of Cedar Tree Beach; and b) that this paleolandscape may have been utilized by pre-contact period human inhabitants and, therefore, could be a source of some of the pre-contact period stone artifacts appearing in Cedar Tree Beach's low-energy swash zone.
- Test and evaluate the combination of close-interval (i.e., 1-m track line spacing) systematic gradiometric survey, systematic and selective visual sediment probing, and selective excavation of 1 x 1 m underwater DTUs as methods of a phased approach to identifying and characterizing submerged paleocultural landscapes.
- Work with Tribal research partners to apply and use non-disturbance and low-disturbance marine remote sensing geoarchaeological survey methods.

7.1.2.2 Overview of Field Methodology

Field methodologies designed and employed in the Cedar Tree Beach study area (Figure 7-1) incorporated comments and recommendations voiced by Tribal and non-Tribal participants in the project's initial March 2013 workshop (CML, URI-GSO 2015). As such, the work progressed in phases from less- to more-invasive investigation techniques with an overall goal of minimizing the disturbance to the bay floor as much as possible during the performance of all phases of the Cedar Tree Beach field investigations. A more detailed description of the field methodologies employed at Cedar Tree Beach is included in the Project Field Report (Caccioppoli et al. 2018).

The first phase was a close-interval (1-m spaced survey transects) systematic gradiometric survey that was performed over a single 50 x 200 m study area, the northern edge of which was centered on the area where the greatest concentration of artifacts was found by Robin Cooney, long-time member of the Cedar Tree Point community. Similar gradiometric surveys performed in terrestrial contexts onshore have proven effective at identifying buried cultural sites, particularly stone-oven, fire pit, and kiln features, where subtle, localized changes in the Earth's magnetic field are detectable to gradiometers. Acquisition of high-resolution magnetic data within the study area was processed and contoured to reveal subtle, low-amplitude, anomalous deflections (possibly associated with cultural features) in the Earth's ambient magnetic field. Once located, these magnetic anomalies were then targeted for selective subsurface testing that included minimally invasive visual sediment probing, followed by, if warranted, selective excavation of 1 x 1 m underwater DTUs.

The gradiometric survey was conducted using a total field intensity Geometrics G-858 magnetometer operated in gradiometer mode (i.e., with two fixed magnetometer sensors oriented vertically on a boom and spaced about 1-m apart). The gradiometric survey was accomplished by walking across the exposed intertidal and submerged shallow sub-tidal portions of the nearshore mudflat off of Cedar Tree Beach at a spring low tide (i.e., the tide with the greatest distance between high and low tide that occurs when the Moon is either new or full, and the Sun, the Moon, and the Earth are aligned, strengthening their collective gravitational pull on the Earth's water). Prior to initiating the survey of each line, the end-points of planned survey track lines were acquired using a handheld Garmin GPS and marked with flagged stakes, so that the surveyor could use the stakes for visual referencing while walking and collecting data along the transects. A digital left-right indicator on the gradiometer unit also helped with tracking course heading along survey transects. The 1-m interval of the planned survey track lines optimized the density of coverage of the study area and increased the gradiometer's capacity to detect small features, such as might be caused by individual hearths. Gradiometer sensitivity was set at 0.01 nanoTesla (nT) or less, with data sampling set to 0.1 s. These settings yielded approximately one reading per 5 cm over-ground at normal walking/wading speeds of 1.5 m/s. Each magnetometer was fixed for gradiometric operation and was maintained at heights of 1 and 2 m above the harbor floor's surface. Positioning along surveyed lines was recorded in real time with the data from each magnetometer sensor. The quality of the acquired data was determined to be acceptable relative to the requirements of the survey, with minor magnetic noise typical of the Geometrics 858 system noted during data processing. None of the observed magnetic noise was significant enough to obscure magnetic features that were observable in the total field data or in the filtered data that was post-processed and plotted.

The second phase of the geoarchaeological field investigations performed in the Cedar Tree Beach study area involved the systematic subsurface testing the sediments, which was accomplished using two different methods. The initial subsurface testing method consisted of the systematic visual inspection and video documentation of subsurface sediments (in plan-view) at 33 locations distributed on a 20-m grid across the entire study area, and at 10 selective locations where magnetic anomalies of interest were identified in the post-processed magnetic data. The visual inspection of the subsurface sediments was achieved using a unique and minimally invasive technological approach termed "visual sediment probing," a technique first applied in a marine archaeological research context by one of this report's authors (Robinson) to ground-truth and identify the sources of marine magnetometer anomalies buried under the seafloor during the survey of a proposed submarine cable corridor off of Long Island, New York. Visual investigation of the Cedar Tree Beach study area's sediments using the visual sediment probe (VSP) was justified based on a) the results of the gradiometric survey that had identified multiple magnetic anomalies; b) the presence of the submerged and buried marine bench or flat seen in the pre-existing sub-bottom profiler data (Figure 7-2); and c) the presence of hundreds of pre-contact period artifacts that were found at Cedar Tree Beach. The principal goals of the visual sediment probing phase of fieldwork were the following:

- Determine the source of the magnetic anomalies identified during the gradiometric survey
- Determine whether or not the marine bench or flat had been previously a subaerially exposed paleocultural landscape with inherent archaeological sensitivity

- Determine whether or not excavation of 1 x 1 m subsurface underwater archaeological DTUs was warranted, and, if so, where

- Introduce and gain experience working with our Tribal research partners in developing minimally invasive, subsurface visual sediment probing technologies and field methods, and conducting data post-processing and interpretation

An average VSP probing depth of 2 m below the surface of the bay floor was targeted, as this depth was considered to be a realistic maximum depth for the planned next element of the subsurface testing (i.e., underwater excavation of 1 x 1 m DTUs) in the event that the VSP survey's results warranted it.

Based on the results of the VSP subsurface testing results, two probe points (selective VSP probe point "S2" and systematic VSP probe-point "B17") were selected for an additional phase of subsurface testing involving excavation of 1 x 1 m DTUs centered at their locations. Reacquisition of the precise locations of these VSP probe-points was facilitated by the presence of small depressions left behind in the bayfloor by the VSP probing. Excavation of 1 x 1 m underwater DTUs is, like all archaeological excavation, inherently destructive; however, it provided a larger physical "window" through which to observe, sample, and document the geoarchaeological record in plan and profile. From a scientific research perspective, as long as the excavation is conducted properly and well-documented, the information gained is generally thought to justify the destruction of the excavated portion of the investigated cultural site. This is a perspective that is not shared generally by Tribal people, for whom the Earth, and the ancestral cultural sites that are a part of it, have inherent spirituality that is best left undisturbed and protected from destruction. In essence, virtually all archaeological sampling or excavation is seen as an unwanted disturbance. Out of respect for the importance of this perspective, the originally planned underwater archaeological excavations of six 1 x 1 m DTUs was reduced to just the two DTUs, representing a nearly 70 percent decrease in the amount of disturbance to the seafloor caused by this particular phase of the geoarchaeological field investigation at Cedar Tree Beach. Justification for excavating these two locations was that they would provide information that would enable the further evaluation of the extent, nature, and content of the preserved, stratified, and formerly subaerial sediments within the full study area, and would provide an opportunity for evaluating the phased methodology employed in determining the presence/absence of paleocultural deposits at the two sampled locations. The field plan and the overall research design associated with the Cedar Tree Beach fieldwork included a contingency response plan covering the appropriate steps and coordination for addressing an unanticipated discovery of ancient human remains or a human burial, which was reviewed and approved by BOEM, the RIHPHC, and the NITHPO prior to the initiation of fieldwork.

Underwater excavation was conducted over three separate field deployments in June, July, and October of 2014 by a team of archaeological divers from URI-GSO, NITHPO, and BOEM working together to excavate two DTUs underwater by hand, assisted by an 8 cm-diameter induction dredge. A 1 x 1 m square x 30 cm tall x 7 mm thick clear plexiglass cofferdam was employed to prevent the less-consolidated uppermost sediment stratum of silty sand from slumping in during excavation. Excavation was conducted following natural stratum changes, or in 10 cm levels when individual strata exceed 10 cm in thickness. All excavated materials were screened through one of two different sizes (3 and 6 mm) of nylon mesh by attaching nylon mesh bags to the end of the dredge's exhaust hose. Excavators switched to the finer mesh bags once excavation depths approached the buried paleosol stratum that was targeted for testing. The mesh bag was changed with a new bag at each change in stratum, or each 10 cm level, as they were attained. Each dredge bag's contents were examined and sifted by topside personnel and evidence of artifacts and ecofacts were retained, bagged (to keep them wet), labeled, and then inventoried when brought back to the laboratory at URI-GSO for final processing, analysis, and cataloging of their contents. Upon completion of the excavation, the DTUs were backfilled with plastic bags of clean builder's sand. The plastic sand-filled bags were used to assist in identifying the excavated units in the event that additional archaeological excavation work is ever undertaken again in the Cedar Tree Beach study area. The upper 20 cm of the DTUs were then filled by dumping the clean builder's sand into the top of the unit, so that the plastic bags were not visible and the bay floor was as close to its natural appearance as possible.

7.1.2.3 Results and Discussion

The phased, systematic application of different types of no- and low-impact marine geoarchaeological surveying and subsurface sampling methods conducted at Cedar Tree Beach produced results that met the objectives and goals of the work that was planned. Geoarchaeological evidence acquired through the combination of close-interval systematic gradiometric survey, systematic and selective VSP probing, and selective excavation of two 1 x 1 m underwater DTUs confirmed that:

- A stratified element of the paleolandscape correlating with the marine bench or flat seen in sub-bottom data (see Figure 7-2) was preserved submerged and buried off of Cedar Tree Beach.

- Cultural materials were present in this element of the paleolandscape, thus indicating its utilization by pre-contact period human inhabitants and high potential for being a point of origin for some of the pre-contact period stone artifacts that have appeared in Cedar Tree Beach's low-energy swash zone.

- No- and low-impact marine remote sensing and subsurface testing geoarchaeological survey methods can be used effectively in identifying and characterizing preserved elements of the submerged paleocultural landscape and cultural deposits within them.

Gradiometric survey performed as the initial phase of marine geoarchaeological fieldwork identified numerous magnetic anomalies, visible as yellow and red areas in the plots of contoured magnetic data from the 2013 Greenwich Bay (Cedar Tree Beach) gradiometer survey comprising Figure 7-3. Some of these anomalies were clearly associated with visible modern, post-contact period ferrous metal cultural debris and structures (e.g., automobile parts and other debris, as well as the steel fasteners in the wooden groins extending into the water from the beach), while others were of the detectable size (i.e., approximately 0.5 to 3 m in duration) and intensity (i.e., 15 to 30 nT) to be suggestive of representing possible hearth or hearth-like paleocultural features, as indicated in reviewed literature on the subject (Jones and Munson 2005; Slater, et al. 2000).

Imaging subsurface sediments in the study area with the VSP provided an efficient and expedient, low-impact, first-pass approach for evaluating the gradiometric and sub-bottom profiler data. The VSP's unique perspective on subsurface sediments is different from that obtained from coring. The VSP allows researchers to see sediments in plan as each stratum is encountered (illustrated in the data presentation in Figure 7-4), rather than in profile, as sediments are seen in cores. Seeing the sediments in plan-view made it possible to more easily identify and image the formerly subaerial paleolandscape surface, which was clearly recognizable by its desiccated/sunbaked and cracked appearance, as shown in Figure 7-5. Indicators of subaerial exposure are detectable in the sediment profile of a split core (e.g., increased sediment density and color change due to oxidation) they are just less obvious. An additional unique capability of the VSP was its dynamic recording of the physical properties of sediments. These properties were observable as the internal water flow of the VSP washed over and through the probed sediments. A final benefit of the VSP was that it allowed for real-time monitoring, so that probing operations could be halted if evidence of a culturally sensitive feature was encountered (e.g., bone indicative of a possible human burial). Although VSP probing proved expedient and effective, it must be considered complimentary to, rather than a replacement for, subsurface sediment sampling/coring.

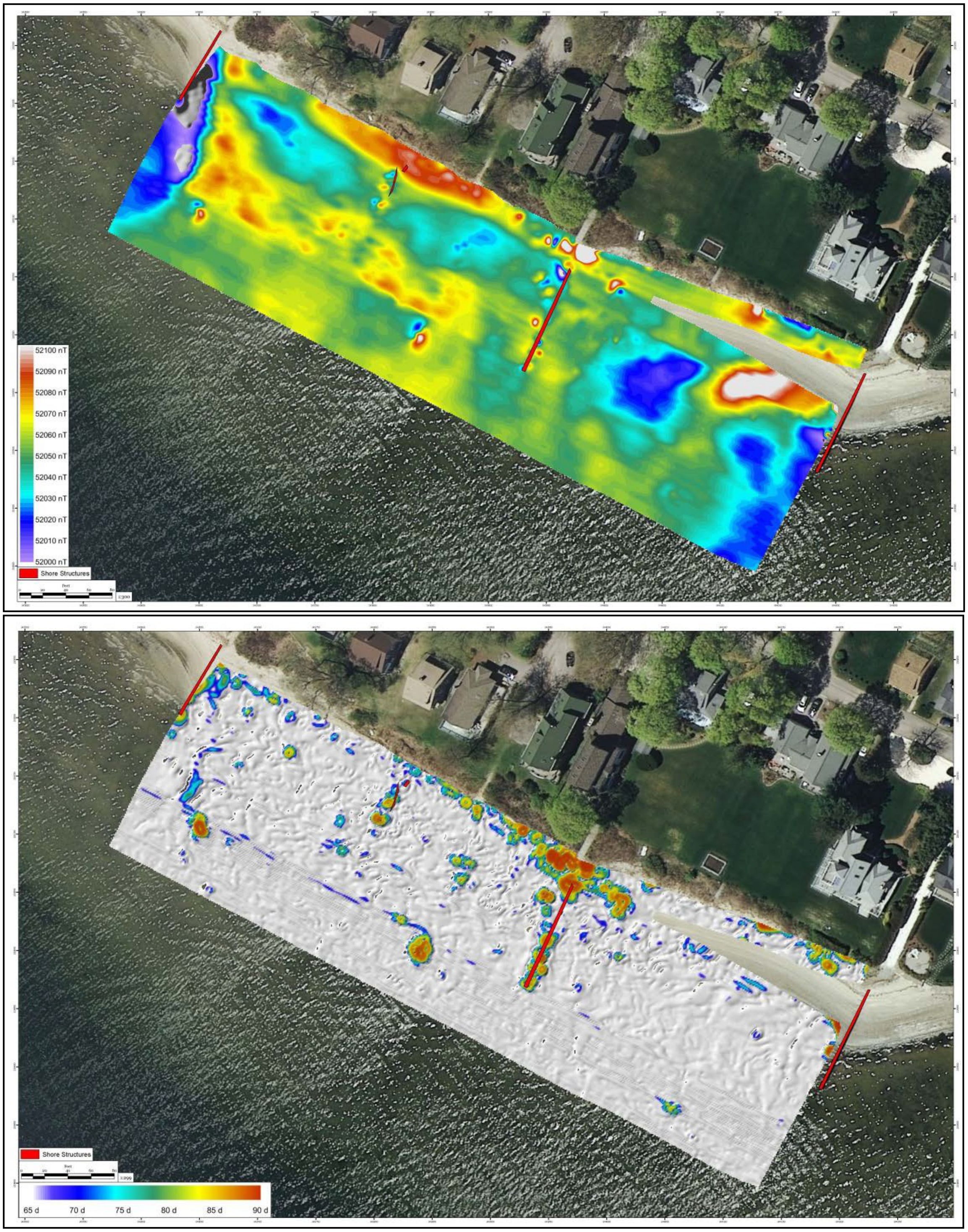


Figure 7-3. Plots of contoured magnetic data from the 2013 Greenwich Bay (Cedar Tree Beach) gradiometer survey.

The upper image presents the Earth's total magnetic field-strength data. The lower image presents the derivative of the magnetic gradient (i.e., the slope of the difference between magnetic readings), accentuating magnetic anomalies of potential interest that were targeted for VSP inspection.

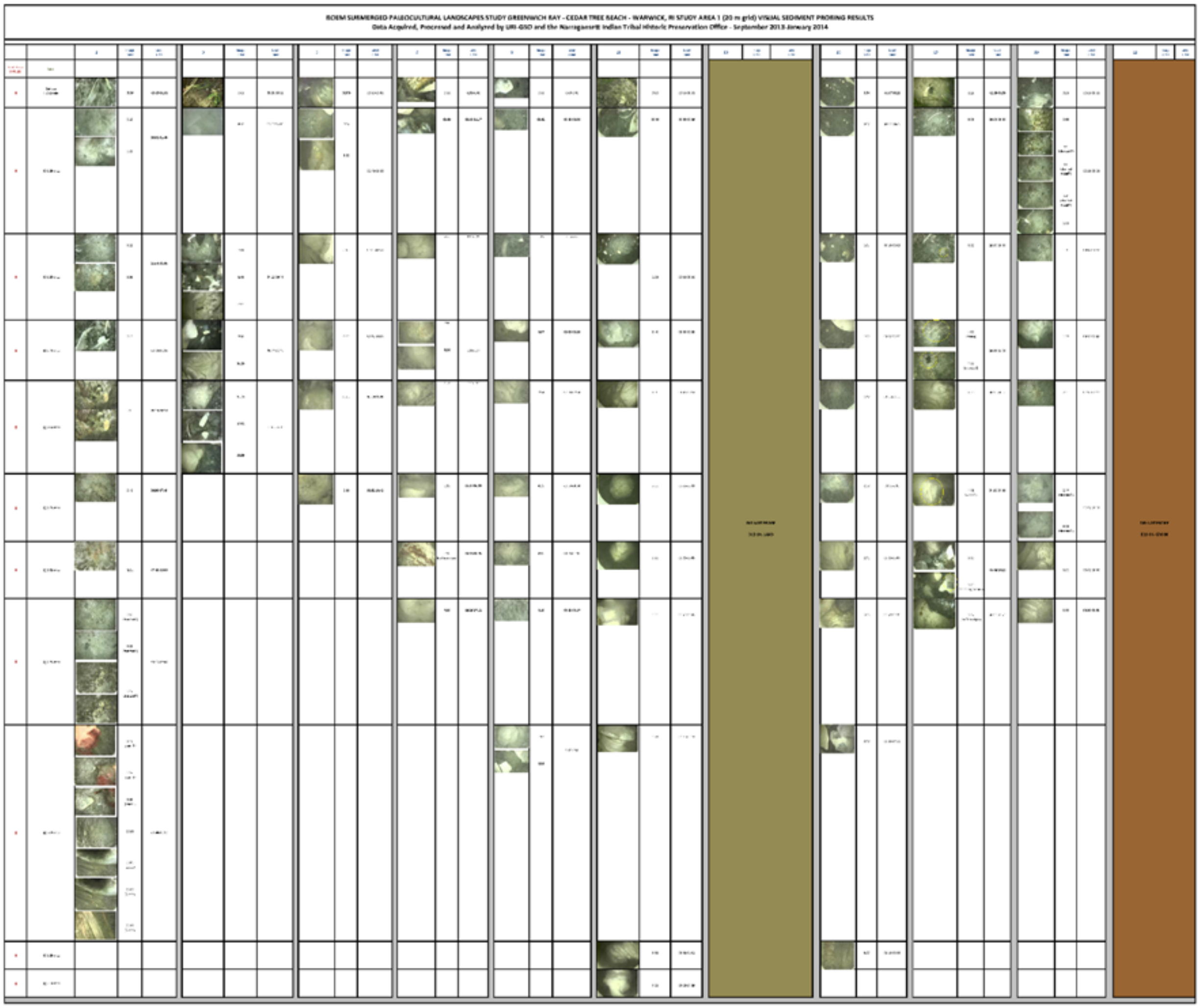


Figure 7-4. Example of plotted 2013 VSP survey data acquired at 20-m spaced probe points distributed along “Transect B” in the Greenwich Bay (Cedar Tree Beach) geoarchaeological study area.

Plot consists of sequenced plan-view images of changes to sediment strata recorded at each VSP probe point in 25 cm intervals down to a maximum target depth of 2 m below the surface of the bay floor. Images are frame-grabs from video that was recorded by a self-lit camera mounted in the tip of the VSP (a modified hydro-probe). The location of Transect B is illustrated in Figure 7-6 by the yellow dots in the row labeled "B."

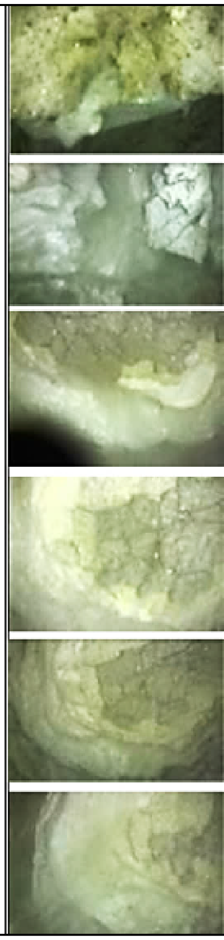
(-) 1.25 mbs		5:36 7:18 7:46 7:49 7:51 7:53	05:26-08:04	oxidized silty fine to medium sand with trace organics; varved silty clay desicated organic layer of peat; oxidized layer silty fine to medium sand; varved silty clay

Figure 7-5. Excerpted processed VSP data documenting the desiccated and cracked organic sediments comprising the formerly subaerial paleolandsurface stratum encountered at the location of Cedar Tree Beach "Selective Probe S2" approximately 1.25 m below the bay floor's surface.

In total, 41 VSP points were probed. Figure 7-6 shows the distribution of the systematic (20-m grid) and the 10 selective VSP probe point locations within the Greenwich Bay (Cedar Tree Beach) geoarchaeological study area. Only two of the systematic VSP locations targeted for investigation were not probed. One was at the location of a wooden groin and the other was located on shore. VSP data produced visual evidence of archaeologically sensitive, formerly subaerial sediments, as well as possible cultural features/artifacts. Formerly subaerial sediments were observed at several of the probed locations. Locations with evidence of paleolandsurfaces were organized hierarchically based on their predicted information potential. Two areas with the greatest information potential were selected for subsurface archaeological testing/excavation: VSP probe-point "S2" and systematic VSP probe-point "B17." These two points are located at opposite ends of the study area. Their positions and contents of interest are illustrated in Figure 7-7.

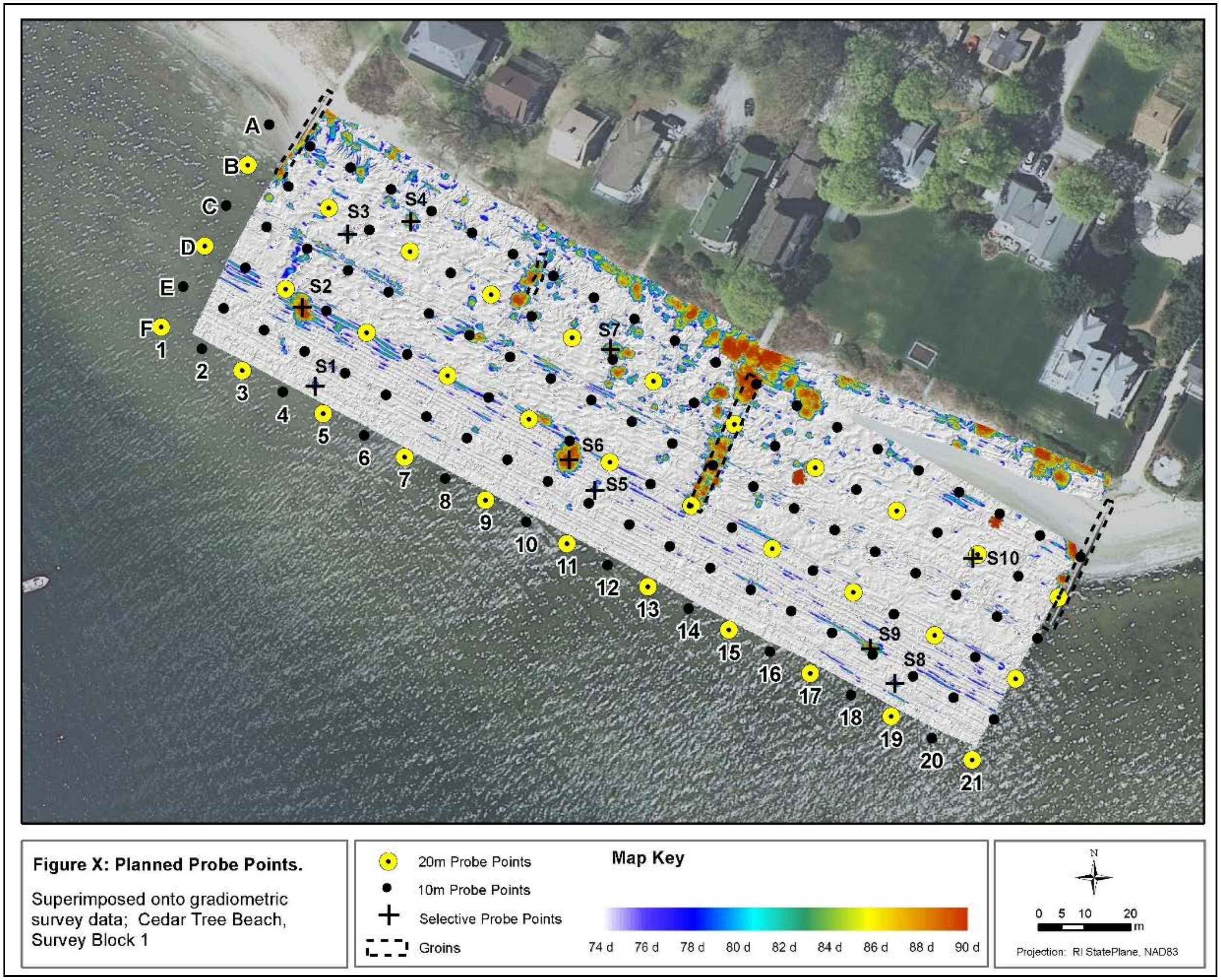


Figure 7-6. Distribution of systematic (20-m grid) and selective VSP probe point locations within the Greenwich Bay (Cedar Tree Beach) geoarchaeological study area.

VSP probe points are superimposed onto a plot of the gradiometric survey results. Magnetic anomalies appear as orange-red areas in the data and were selectively targeted for VSP inspection (note the locations of VSP Transect “B” and VSP Selective Probe “S2”).

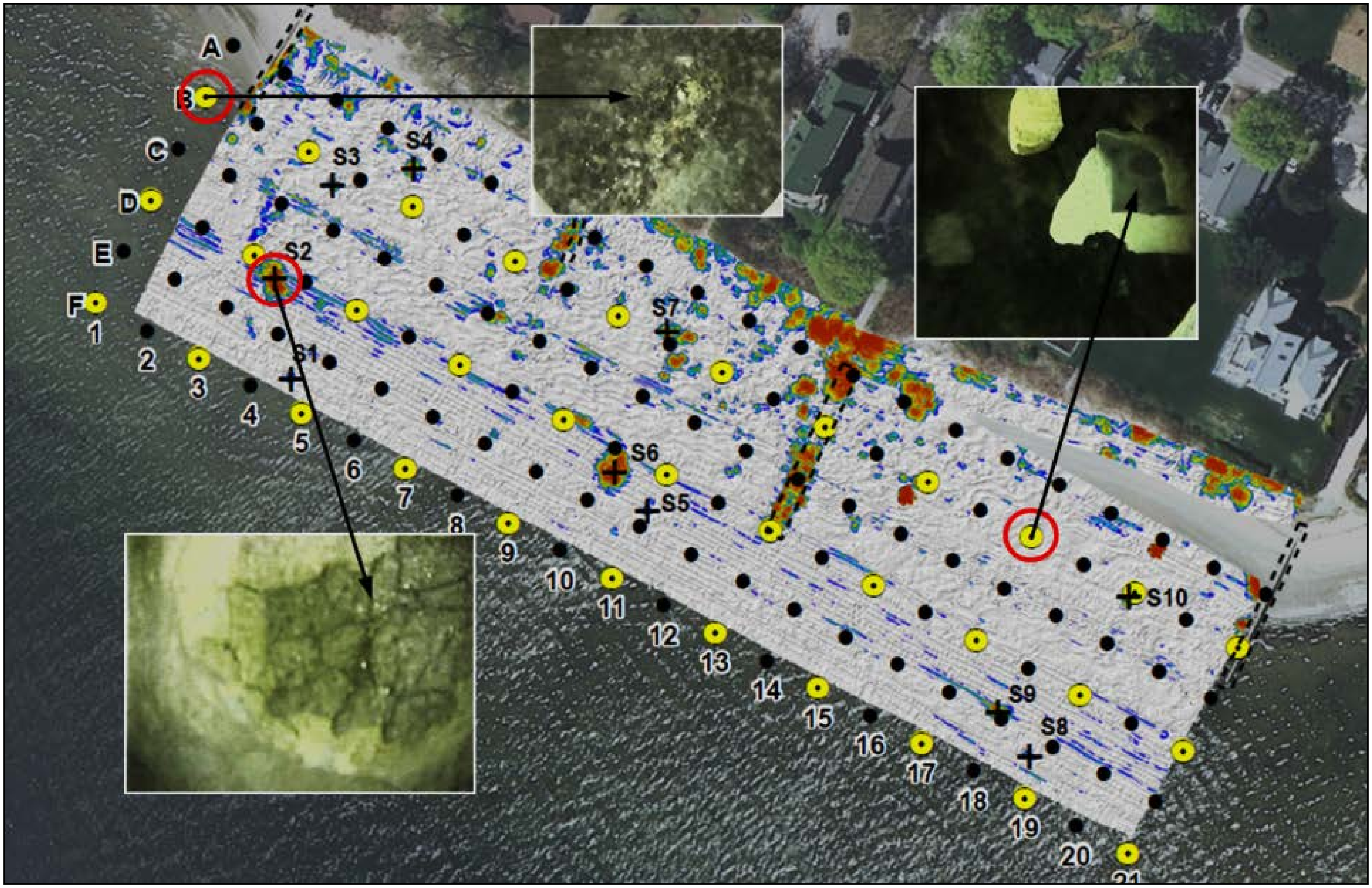


Figure 7-7. Visual features of interest (inset images) at Selective VSP Probe Point S2 and Systematic VSP Probe Point B17, which were subsequently examined through underwater archaeological excavation of 1 x 1 m DTUs at both locations.
Inset images show a thin, formerly desiccated, cracked organic layer of stratified paleosols preserved on top of a thick loess deposit at Selective VSP Probe Point S2 (lower left image), and what appears to be a small primary flake of a dark-colored chert chipping debris at the location of Systematic VSP Probe Point B17 (upper right image). The inset image at Systematic VSP Probe Point B1 includes what appears to be a thin layer of charcoal (this location was not subjected to underwater excavation).

VSP probe-point S2 was selected, because it contained a visibly oxidized, desiccated/sunbaked, archaeologically sensitive organic stratum at approximately 1.3 m below the surface of the sub-tidal bayfloor (see Figure 7-7). VSP probe-point B17 was selected, because it contained stratified organic sediments and what appeared to be a single piece of lithic chipping debris, as well as wood and charcoal approximately 1.5 m below the bayfloor surface (see Figure 7-7). Subsurface investigation of the two VSP probe-points, located at opposite ends of the Cedar Tree Beach study area, provided more broadly spaced windows into the stratigraphy of the area.

Excavation of the 1 x 1 m DTUs' S2 and B17 terminated at depths of 1.5 and 1.8 m, respectively, below the bayfloor surface. The sidewalls of both DTUs were fragile and proved challenging to maintain. The stratigraphic sequence and visual evidence of a formerly subaerial paleolandscape surface observed in VSP S2 at 1.35–1.45 m below the bayfloor surface were confirmed by the excavation of DTU S2. Examination and sorting of the archaeologically excavated paleolandscape surface stratum in DTU S2 produced the first pre-contact period artifact—a single piece approximately 1.5 x 2.0 cm of high-quality quartz chipping debris—discovered as a result of a multi-phase, systematic geophysical/geotechnical survey of a submerged context (Figure 7-8). This discovery constituted a major technical find and project achievement, as it confirmed the presence of cultural materials within a documented, intact, stratified paleosol deposit identified by the research team, which was composed primarily of Tribal field specialists and data analysts.

Figure 7-8. Quartz chipping debris recovered during the underwater excavation of Greenwich Bay (Cedar Tree Beach) Selective VSP Probe Point Dredge Test Unit S2.
These cultural materials were encounted in a submerged and buried, contextually intact, freshwater wetland paleolandsurface stratum that was located 135–145 cm below the surface of the bayfloor surface (photographs by David S. Robinson [URI-GSO]).

Underwater archaeological subsurface testing in DTU B17 encountered a stratified, organic-rich, formerly subaerial paleolandsurface stratum overlying a loess sediment layer (oxidized at its upper limit) at approximately the same depth below the seafloor (1.3–1.45 m as was seen in the systematic VSP data acquired at B17 and was found preserved in DTU S2. Preserved paleolandscape sediments in DTUs B17 and S2 (approximately 200 m apart), as well as observations from other VSP probe points across the study area, suggested the stratified paleolandscape surface may have been more extensive within the Cedar Tree Beach (CTB) study area (and possibly beyond it) than originally thought, based on the project's 2013 VSP probing alone.

As in the case of DTU S2, roots from an as-yet identified species of paleo-vegetation were preserved in their original growth position extending from the formerly subaerial paleolandsurface stratum into the upper surface of the underlying loess sediments. Unlike the relatively few roots seen in DTU S2, however, DTU B17 contained a relative abundance of them, as well as greenish-colored leaves/blades that were visible above the rootlets in the organic paleolandsurface stratum's matrix. The finer and more dispersed roots of the vegetation observed in DTU B17 were different than the comparatively robust and densely packed roots of the common reed (*Phragmites*), which were observed and documented in sampled exposed peat deposits present onshore on CTB. Instead, they bear a closer resemblance to those of widgeon grass (*Ruppia maritima*), a salt-tolerant freshwater grass that grows in oxygenated sediments of fresh to brackish, non-turbid shallow water in coastal marshes. The presence of the *in situ* paleo-vegetation mat in its original growth position is significant, as it is a strong indicator of the lack of inundation-related disturbance to the paleolandsurface's sediment matrix in which it was found.

Macro- and microscopic examination and sorting of materials excavated from the paleosols in DTU S2 and B17, combined with observations from the visual sediment probing data and from the DTU's during excavation, produced some basic results that are significant to the project, paleoenvironmental reconstruction, and modeling. Pre-contact period artifacts (i.e., quartz chipping debris) were recovered from a submerged and stratified, formerly subaerial paleolandsurface deposit that was identified through systematic, phased field research and data analysis by a joint-team of Tribal and non-Tribal researchers. This tells us that not only was a stratified paleolandsuface deposit preserved in Greenwich Bay, but that it contained cultural materials that were preserved in that stratified context as result of the activities of the ancient Native people who were occupying that now submerged and buried paleolandsurface at CTB.

In addition to the cultural material recovered through underwater archaeological excavation, an assemblage of paleobotanical macrofossils was also recovered and identified. This assemblage included: a goosefoot (*Chenopodium*) seed; a grape seed; acorns; a maple seed; and numerous pondweed (*Potamogeton*) seeds, visible in Figure 7-9, as well as miscellaneous fragments of twigs, bark, and charcoal. Images of as-yet identified paleo-vegetation in its original growth position in the paleolandsurface stratum was documented in HD underwater video and samples of this vegetation were recovered from each excavated DTU (S2 and B17). Microscopic examination of the sediment sample recovered from the interface between the paleoslandsurface stratum and underlying loess in DTU S2 revealed no indications of a marine environment (e.g., the presence of foraminifera). The combined presence of desiccated and cracked organic-rich paleolandsurface sediments overlying a deposit of loess that were observed in the VSP, the absence of foraminifera or any other marine floral or faunal remains, and the presence of pond weed seeds, along with terrestrial floral materials (e.g., acorns, maple seed, walnut or hickory shell husks, etc.), displayed in Figure 7-10, together suggest preservation of a paleoenvironment that was a topographically low and frequently wet, but sometimes exposed, muddy area (i.e., a flood plain) that was a resource-rich, intermediate environmental zone—a potential zone of intensive human activity—that was situated between adjacent uplands and the freshwater stream or small river that once occupied the natural channel in Greenwich Bay.

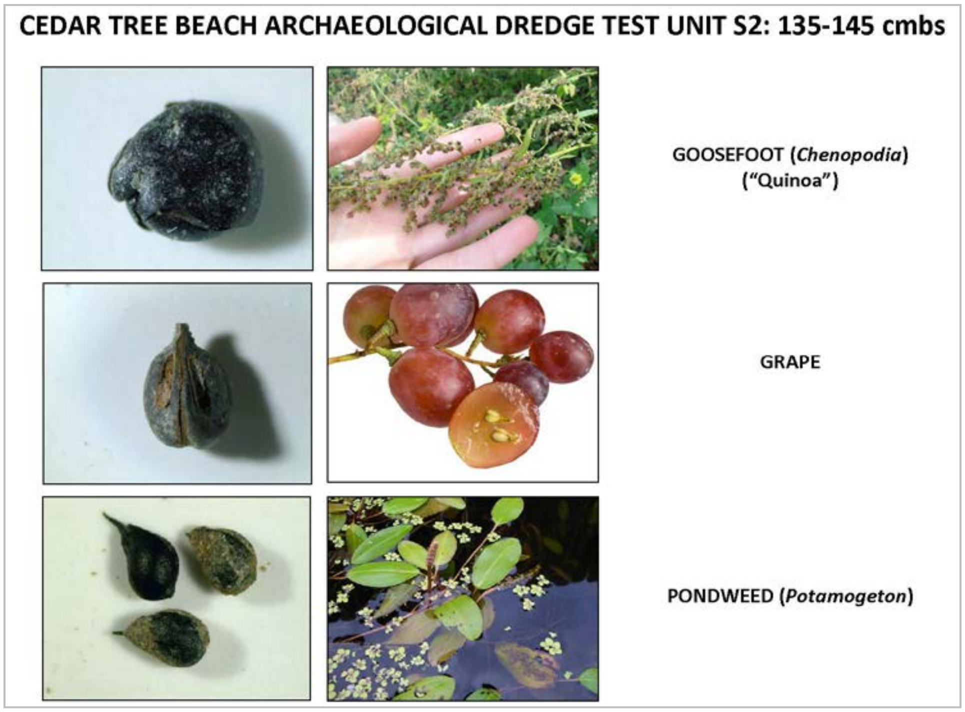


Figure 7-9. Plant macrofossils (left column images) recovered during the underwater archaeological excavation of Greenwich Bay (Cedar Tree Beach) Selective VSP Probe Point Dredge Test Unit S2.

These macrofossils were encountered in a submerged and buried, contextually intact, organic, freshwater wetland paleolandsurface stratum that was located 135–145 cm below the surface of the bayfloor.

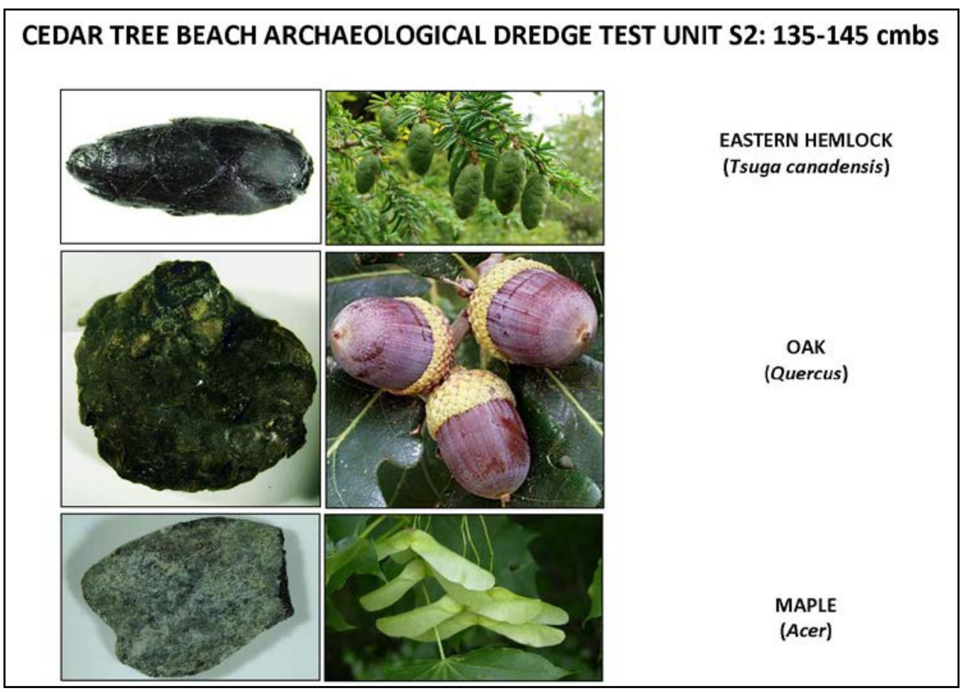


Figure 7-10. Tree macrofossils (left column images) recovered during the underwater archaeological excavation of Greenwich Bay (Cedar Tree Beach) Selective VSP Probe Point Dredge Test Unit S2.

Macrofossils were encountered in a submerged and buried, contextually intact, organic, freshwater wetland paleolandsurface stratum located 135–145 cm below the surface of the bayfloor.

7.1.3 Greenwich Bay Geological Investigation

7.1.3.1 Introduction and Goals

Greenwich Bay is a shallow (2.6 m mean depth), 12-km^2 estuary, with connection to the West Passage of Narragansett Bay. Cedar Tree Beach, described in Section 7.12 above, is located on the northweast coast of Greenwich Bay (Figure 7-11).

Figure 7-11. Overview map of the Cedar Tree Beach study area (top panel) and Greenwich Bay (bottom panel).
Aerial imagery prepared by the URI Environmental Data Center, and projected in the NAD83 Rhode Island State Plane Feet 3800 coordinate system.

The purpose of the geological surveying in Greenwich Bay was to support the archaeological investigations at Cedar Tree Beach by identifying and characterizing submerged preserved terrestrial deposits and/or paleolandscapes offshore of Cedar Tree Beach and to determine if the subsurface stratigraphic framework established for the southern New England OCS applies to Greenwich Bay. In addition, geophysical surveying was conducted in order to investigate how improving seismic reflection profile trackline spacing affects paleolandscape reconstruction where high-resolution data exist.

7.1.3.2 Geologic Setting and Previous Work

The preferential erosion and lowered topography of the Rhode Island Formation led to the establishment of a south-flowing drainage system through Narragansett Bay during the Tertiary Period, representing nearly 60 million years of erosion (McMaster 1984). A prominent bedrock valley referred to as the (proto-) Blackstone River was traced from north of Providence through Greenwich Bay, connecting to a trunk valley in the west passage of Narragansett Bay (Upson and Spencer 1964). Subsequent modification by Pleistocene glaciation resulted in the widening and deepening of drainage valleys, followed by deposition of up to 40 m of Quaternary sediments in upper Narragansett Bay, mostly filling the drainage valleys (McMaster 1984). This thick sequence of sediment is composed of ground moraine tills, stratified outwash, and glaciodeltaic and glaciolacustrine deposits (Peck and McMaster 1991). The glacial deposits enclosing Greenwich Bay are described by Boothroyd and McCandless (2003), with glacial deltaic deposits to the north and south of Greenwich Bay, ice-marginal deposits to the west, and coarse tills to the east.

Twenty-four CHIRP seismic reflection profiles collected by URI-GSO in 2006 from Greenwich Bay and interpreted by Morissette (2014) describe the post-glacial depositional environments and sediments of now submerged Greenwich Bay. Acoustic basement was constrained as bedrock or where shallow, a progradational glacial fan. A thick sequence (typically > 30 m) of glaciolacustrine deposits was found to overlie acoustic basement throughout the bay, consisting of both proximal and distal seismic facies. The rhythmic internal reflectors draping the underlying topography are consistent with glaciolacustrine sediments identified in most of Narragansett Bay (Peck and McMaster 1991; Boothroyd and McCandless 2003; Oakley 2012).

Morissette (2014) reports the existence of paleochannels incising glaciolacustrine sediments. These paleochannels form a tributary system, consistent with seismic reflector R2 reported by McMaster (1984) and a regional fluvial unconformity fu_1 (O'Hara and Oldale 1980; Needell et al. 1983a, b, c; Needell and Lewis 1984). The presence of paleochannels is associated with the drainage of Glacial Lake Narragansett, which likely did not begin until the onset of isostatic rebound, but remains poorly constrained (Oakley 2012). A paleo-stream originating from modern-day Apponaug Cove passed just to the south of Cedar Tree Beach, joining a trunk channel approximately midway through Greenwich Bay (Morissette 2014).

Glacial deposits are truncated by a diachronous ravinement surface representing marine transgression through Greenwich Bay. Inundation of Greenwich Bay was at first confined to the paleo-streams, progressively flooding the subaerially exposed lakefloor. The timing of marine inundation of Greenwich Bay is somewhat contested. Based on the RSL curve generated by Oldale and O'Hara (1980), McMaster (1984) proposed an inundation age of 5,500 yBP. A study by Vinhateiro et al. (2007) reported an AMS-dated shell from a sediment core collected in western Greenwich Bay dated to 6,500 yr BP. Morissette conservatively placed the age of paleo-streams as > 6,000 yBP.

Estuarine sediments overlie the ravinement surface and were deposited as Greenwich Bay transitioned to an estuary during the Holocene. In the seismic reflection profiles, estuarine sediment is nearly acoustically transparent suggesting the fine-grained nature of these sediments (Morissette 2014). Benthic geologic habitat mapping by Oakley et al. (2012) details the surficial geology of Greenwich Bay. The deeper, central basin of Greenwich Bay appeared as a featureless, low backscatter region in the side-scan imagery and is reported as fine-grained silts. Near the mouth of Greenwich Bay, sand sheets with some tidal/wave bedforms are predominant. Along the margins of Greenwich Bay, a shallow (< 1 m) depositional platform composed of sand, some gravel and shells can be traced to the beaches. Cedar Tree Beach falls under this categorization and marks the westernmost extension of the northern depositional platform. The coves of Greenwich Bay are primarily dredged channels or composed of clay, silt, and organic matter.

In Morissette (2014), three-dimensional paleolandscape reconstructions were attempted using the 2006 CHIRP seismic reflection dataset with 300-m line spacing. Reflectors including acoustic basement, paleochannels and the ravinement surface were digitized using CTI SonarWeb software and interpolated in ESRI ArcGIS software, producing continuous surfaces. Morissette reported the prevalence of interpolation artifacts that arose due to the widely spaced seismic reflection profiles and the absence of perpendicular crossing lines. Nevertheless, the general morphology of the paleolandscapes was captured in these interpolated surfaces.

7.1.3.3 Overview of Field Methodology

Cedar Tree Beach

During the spring and summer of 2015, a seismic reflection survey was performed within the Cedar Tree Beach study area at 20-m line spacing perpendicular to the shoreline, and crossing lines paralleling the shore (Figure 7-12). Due to shallow bathymetry along this depositional platform, and the importance of collecting data as near to the beach as logistically possible, the survey was conducted at high tide. The data were acquired using a surface-towed “catamaran” style Benthos CHIRP III seismic reflection system and an Applanix POS MV inertially aided navigation system. All data were logged using SonarWiz 5 acquisition software. Data quality was monitored during acquisition and parameters were modified in the field as needed (see field report for additional details). A total of six vibracores (Figure 7-12) were also collected along Cedar Tree Beach, using a pontoon boat as a coring platform. A submersible Rossfelder P-3 vibracoring head was affixed to a 4-in PVC tube, into which the sediment was recovered. Successful vibracores were capped and transported to the URI-GSO Marine Geological Samples Laboratory (MGSL) and stored near 4°C in a sediment core refrigerator.

The physical properties of each vibracore were logged and imaged using the non-destructive Geotek MSCL system. Parameters logged at a 1-cm resolution included Gamma Ray Attenuation and Porosity Evaluator (GRAPE) density, magnetic susceptibility, electrical resistivity, compressional wave (P-wave) velocity, and travel times. Initial core descriptions were recorded noting observed changes in color (referenced to the Munsell system of color notation), lithology, grain size, and presence of organic matter.

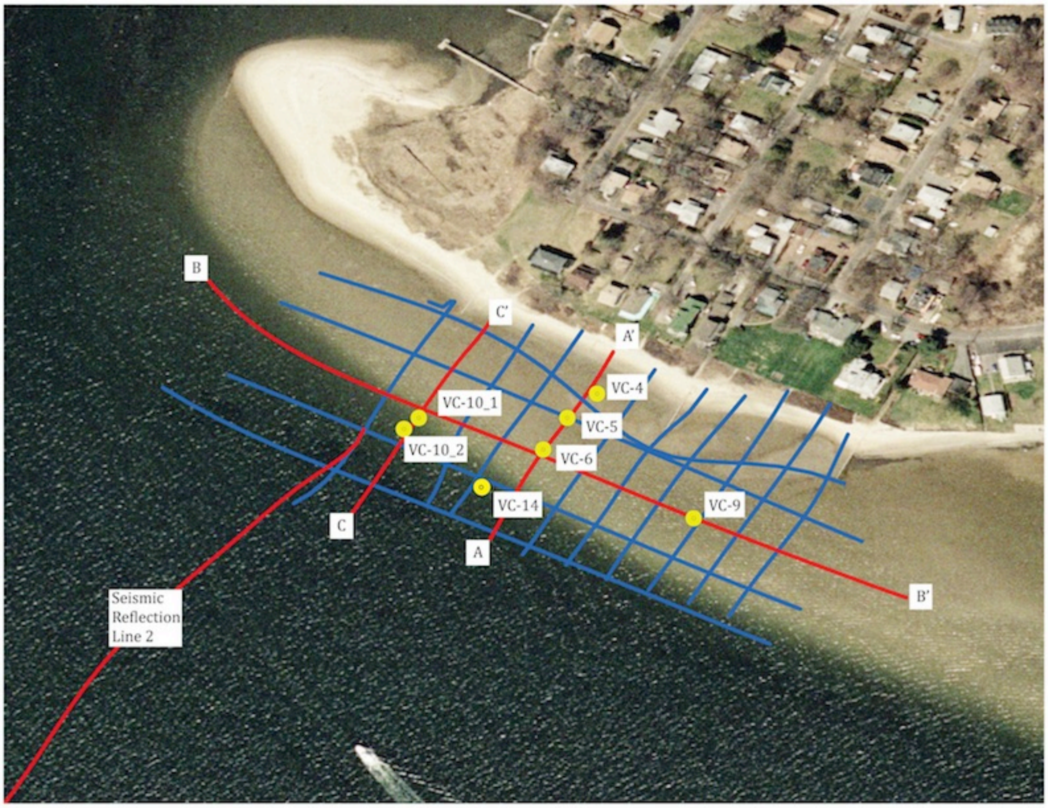


Figure 7-12. Seismic reflection survey lines from the Cedar Tree Beach study area and the locations of collected vibracores.
Survey lines are shown with red and blue lines. Vibracores are shown with yellow dots. Survey lines A-A', B-B' and C-C' overlap vibracore transects and are discussed in further detail. Seismic reflection line 2 was collected in 2006 and provides a stratigraphic framework for Greenwich Bay.

3-D Paleolandscape Reconstruction of Central Greenwich Bay

A total of 25 NE-SW trending CHIRP seismic reflection profiles (100- to 200-m line spacing) and 7 perpendicular crossing profiles (300-m line spacing) were collected in June–July 2015. The seismic reflection system, software, and acquisition techniques were the same as the Cedar Tree Beach survey (see Caccioppoli et al. 2018 for detailed description). The new CHIRP seismic reflection data supplements a 2006 CHIRP survey such that when combined, the data achieves 100-m line spacing and 300-m crossing line spacing throughout Greenwich Bay.

Raw digital seismic reflection data were imported into CTI SonarWiz 6 processing software. Each seismic reflection profile was bottom tracked and signal gains were applied to improve image quality. A subset of 13 NE-SW trending seismic reflection profiles and 3 perpendicular crossing lines located in central Greenwich Bay were selected for paleolandscape reconstruction. These 16 seismic reflection lines were selected due to excellent seismic penetration and relative absence of gas-bearing sediment.

Seismic reflector fu_1 was identified and digitally traced in each seismic reflection profile using SonarWiz 6 software (Figure 7-13). The thicknesses of traced reflectors fu_1 were then calculated and exported as points (delimited xyz text files). The depth of reflector fu_1 was then converted from milliseconds to meters using an assumed two-way travel velocity of 1,500 ms^{-1}, a value that is valid for unconsolidated saturated sediment and in agreement with previous p-wave seismic velocity findings from a sediment core in Greenwich Bay (Vinhateiro et al. 2007).

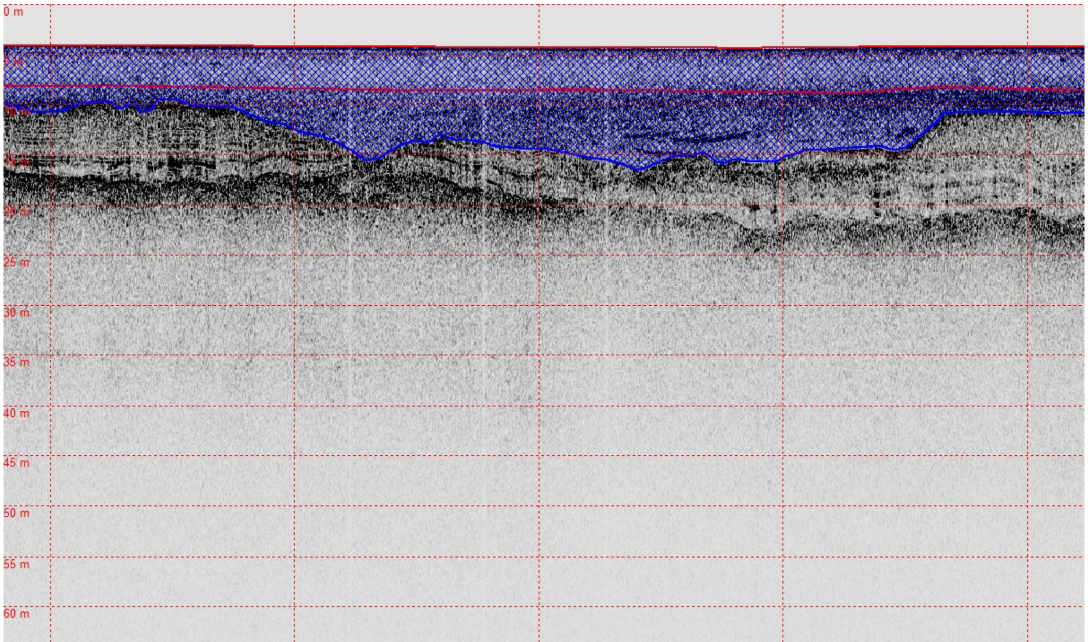


Figure 7-13. Example CHIRP seismic reflection profile from Greenwich Bay.
Shaded blue area shows depth to reflector fu_1, treated as a thickness and exported an ".xyz" file for use in the interpolated paleolandscape surface.

The processed xyz point text files were brought into a geospatial environment using ESRI ArcMap 10.2 as points with elevations. The points were then interpolated as a continuous surface using the Terrain interpolation method. Terrains are a robust, specialized variant of Triangular Irregular Network (TIN) surfaces that are well suited for datasets exceeding many thousands of points such as those generated by sonar and LiDAR. The terrain was then converted to a raster using the Terrain to Raster Conversion toolset. The resulting raster represents the depth to reflector fu_1 below mean sea level (MSL).

This outlined procedure was repeated, generating three interpolated surfaces. The first surface contains all interpreted seismic reflections lines within our study area. The second surface is based on the on all NE-SW oriented seismic reflection lines, excluding perpendicular crossing lines. The final surface uses only the older CHIRP seismic reflection lines collected in the original 2006 survey.

7.1.3.4 Results and Discussion

7.1.3.4.1 Cedar Tree Beach

Seismic Reflection Profiles and Correlation with Previous Studies

The combination of very shallow water depths and a highly reflective seafloor resulted in the poor performance of the CHIRP seismic reflection system. Best penetration occurred in the westernmost study area, where water depths were slightly deeper and surficial sediments finer. Two reflectors were identified in the CHIRP data. The deepest reflector observed is south dipping and discontinuous, and reaches a depth of approximately 5 m (seismic line C-C') (Figures 7-12, 7-14). This reflector is also observed in seismic line B-B' at approximately 1.5 to 2.5 m depth (Figures 7-12, 7-15). A shallower, prominent flat-lying reflector is observed 1 to 1.5 m below the seafloor in the western portion of the seismic line (Figure 7-14).

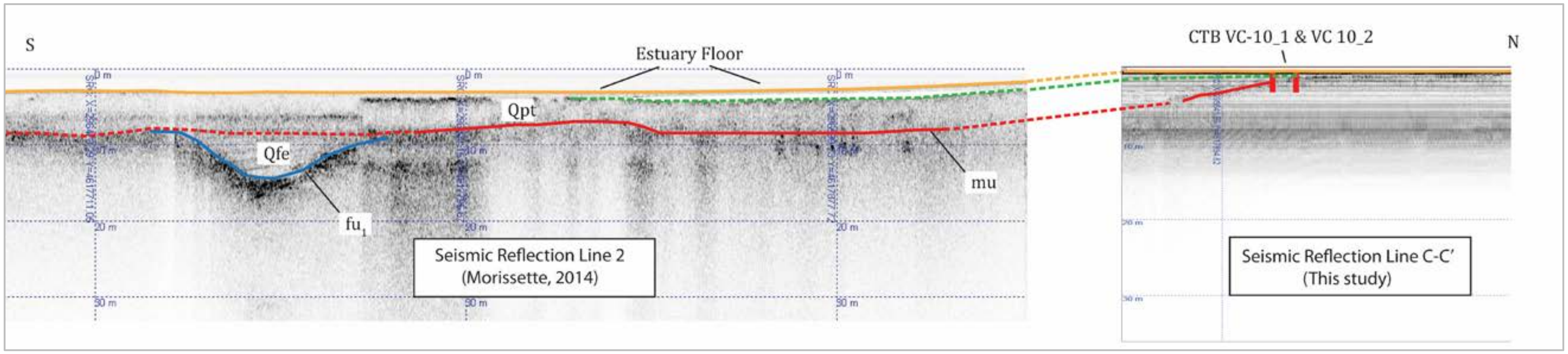


Figure 7-14. Processed seismic reflection line C-C', with interpreted seismic reflectors and correlated with seismic reflection line 2 from Morissette (2013).
See text for explanation of reflectors and interpretations of lithology

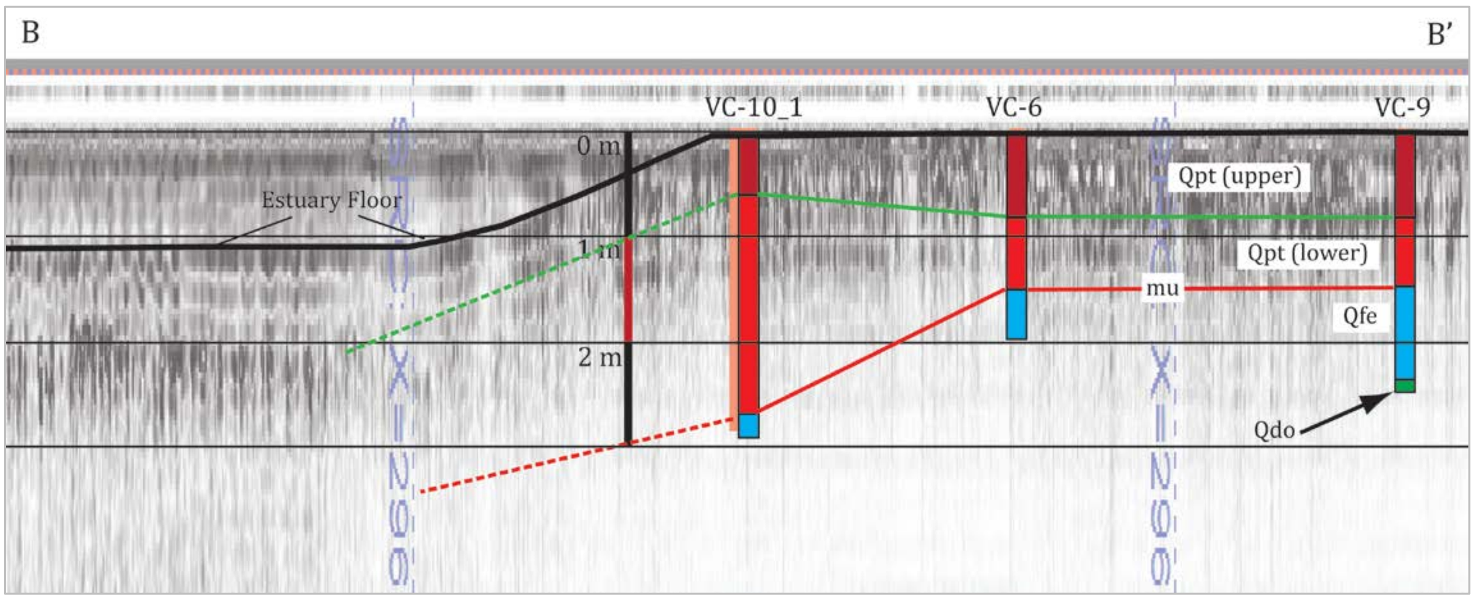


Figure 7-15. Seismic reflection line B-B' with W-E vibracore transect.
See Figure 7-12 for location of seismic line. Dark red, red, blue and green core sections represents Lithology 1, 2 3 and 4, respectively. See text for explanation of reflectors and interpretations of lithology.

Despite limited penetration, the two identified reflectors were correlated with the regional stratigraphic framework and with reflectors reported in Morissette (2014). The deepest seismic reflector identified was the lithological change at the marine unconformity (mu), representing Holocene marine transgression and the truncation of underlying glaciolacustrine sediments (Figure 7-14). The marine unconformity is referred to as the ravinement surface (R1) in Morissette (2014). The shallowest reflector identified in seismic reflection profiles B-B' and C-C' is represented by a dashed green line in Figure 7-14. This reflector has not been described in previous studies, likely due to its shallow depth and confinement to the depositional platform. This reflector lies ~1 m below the estuary floor and represents a change in physical properties within the estuarine sediment.

Several other reflectors and sedimentary units were only observed in seismic reflection line 2 from Morissette (2014) and were correlated with the regional stratigraphic framework. A well-defined paleochannel, referred to as PC in Morrissette (2014) and part of reflector fu_1 in the regional stratigraphic framework, dissects glaciolacustrine sediment (Figure 7-14). Filling these channels is post-glacial fluvial sediment and estuarine sediment, referred to as Qfe in the regional stratigraphic framework (Figure 7-14). Overlying the marine unconformity (mu) and Qfe is marine sediment (Qpt in the regional framework). The reflector mu exists at a depth of approximately 6–8 m below present sea level in seismic reflection profile 2, and more or less parallels the depth of the estuary floor. Extrapolation of mu to the north, and approximately following the slope of the estuary floor results in good depth agreement with a reflector identified in seismic reflection profile C-C' (this study) (Figure 7-14).

Physical Properties and Stratigraphic Correlation of Vibracores

Physical properties from the seven vibracores were plotted using Delta Graph 5 software (Figures 7-16 to 7-22). Additionally, a down-core plot of reflection coefficient was calculated for each vibracore. The trends in magnetic susceptibility, P-wave travel time, GRAPE density, and reflection coefficient were analyzed based off the plotted data and four distinct lithologies were identified and are discussed below.

Several distinct lithologies have been identified through the analysis of seismic reflection profiles collected for this study, correlation of seismic reflection data with previous studies, and analysis of physical properties of vibracores.

Lithology 1: Estuarine Deposition Modified by Anthropogenic Processes

Previous studies have established the usefulness of magnetic susceptibility for stratigraphic correlation of coring sites (Bloemendal et al. 1988; Corbin 1989). Changes in the concentration of magnetic minerals in sediments are responsible for changes in measured magnetic susceptibility values, therefore, as sedimentation rates increase at a given site, fluxes of magnetic material will covary based on the concentration of magnetic minerals. Corbin (1989) used this relationship as a proxy for sedimentation rates in Narragansett Bay. Piston cores analyzed in Corbin (1989) from Apponaug Cove and Greenwich Bay show a very similar trend in magnetic susceptibility, with high values within the upper 40–60 cm, and trending towards a low background value down-core. Vibracores collected from Cedar Tree Beach exhibited high amplitude variability with up to four distinct peaks in magnetic susceptibility, with the core logging sampling interval of 1 cm. These peaks were absent from the piston cores in Corbin (1989), which is likely due to the difference in sampling interval (3-cm subsamples). Additionally, the amplitude of peaks in magnetic susceptibility increased with nearness to shore.

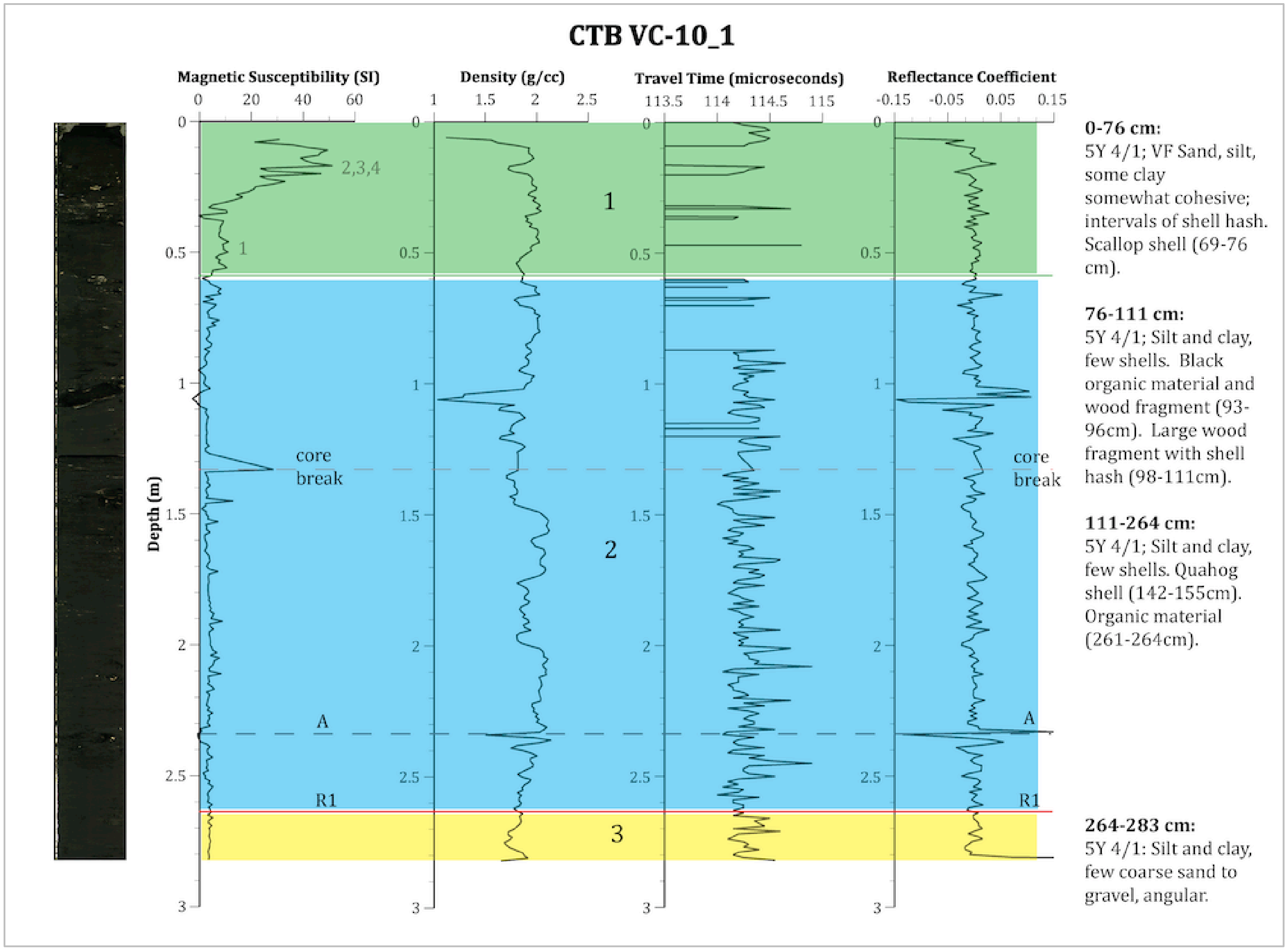


Figure 7-16. Physical properties and initial core descriptions of vibracore CTB VC-10_1.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Dashed black line labeled “A” is a tie point with CTB VC-10_2 and CTB VC-14. Red line (R1) indicates a change in lithology characterized by the presence of coarse sand and gravel. See text for interpretations of lithology.

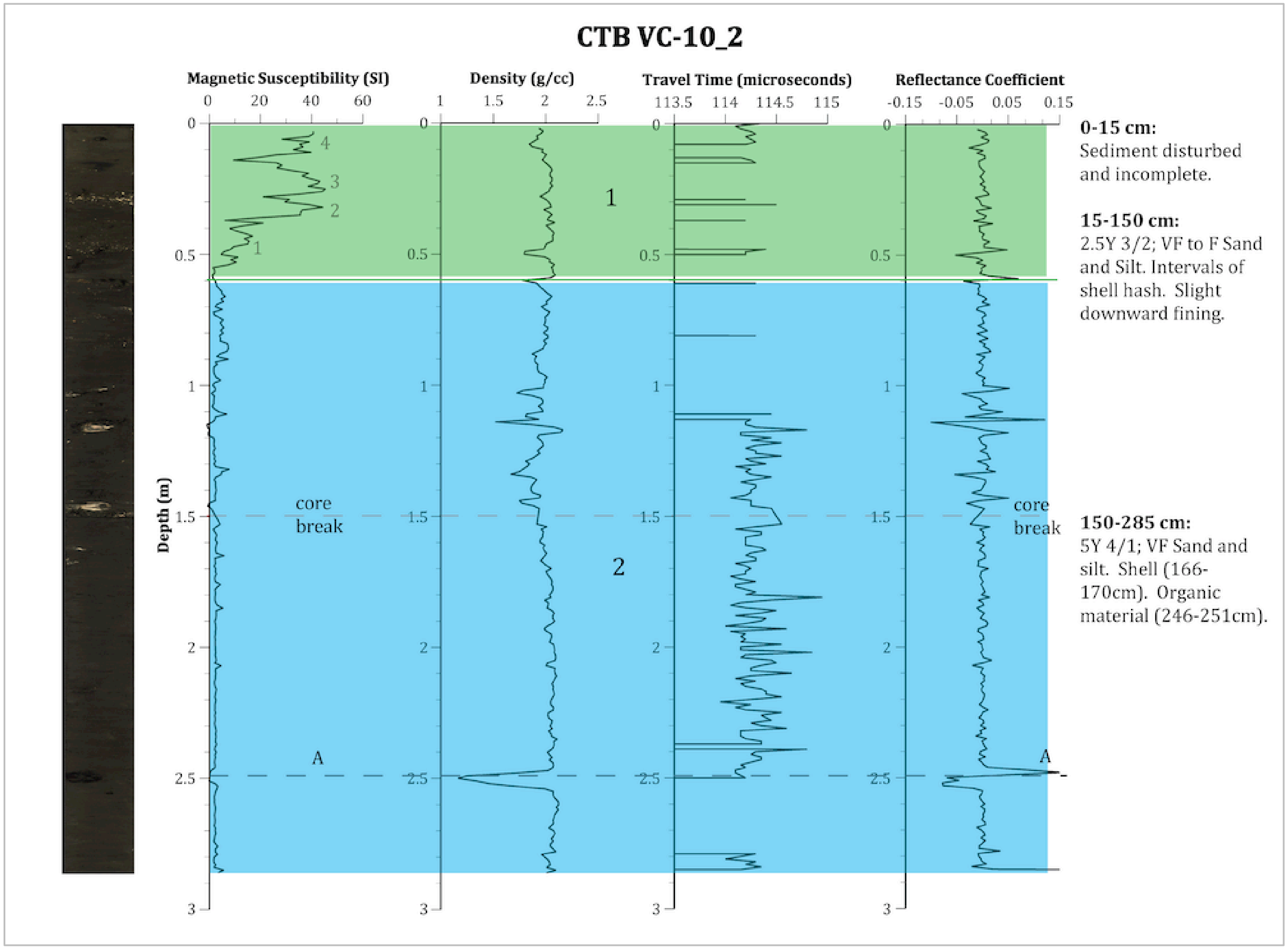


Figure 7-17. Physical properties and initial core descriptions of vibracore CTB VC-10_2.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Dashed black line labeled "A" is a tie point with CTB VC-10_1 and CTB VC-14. See text for interpretations of lithology.

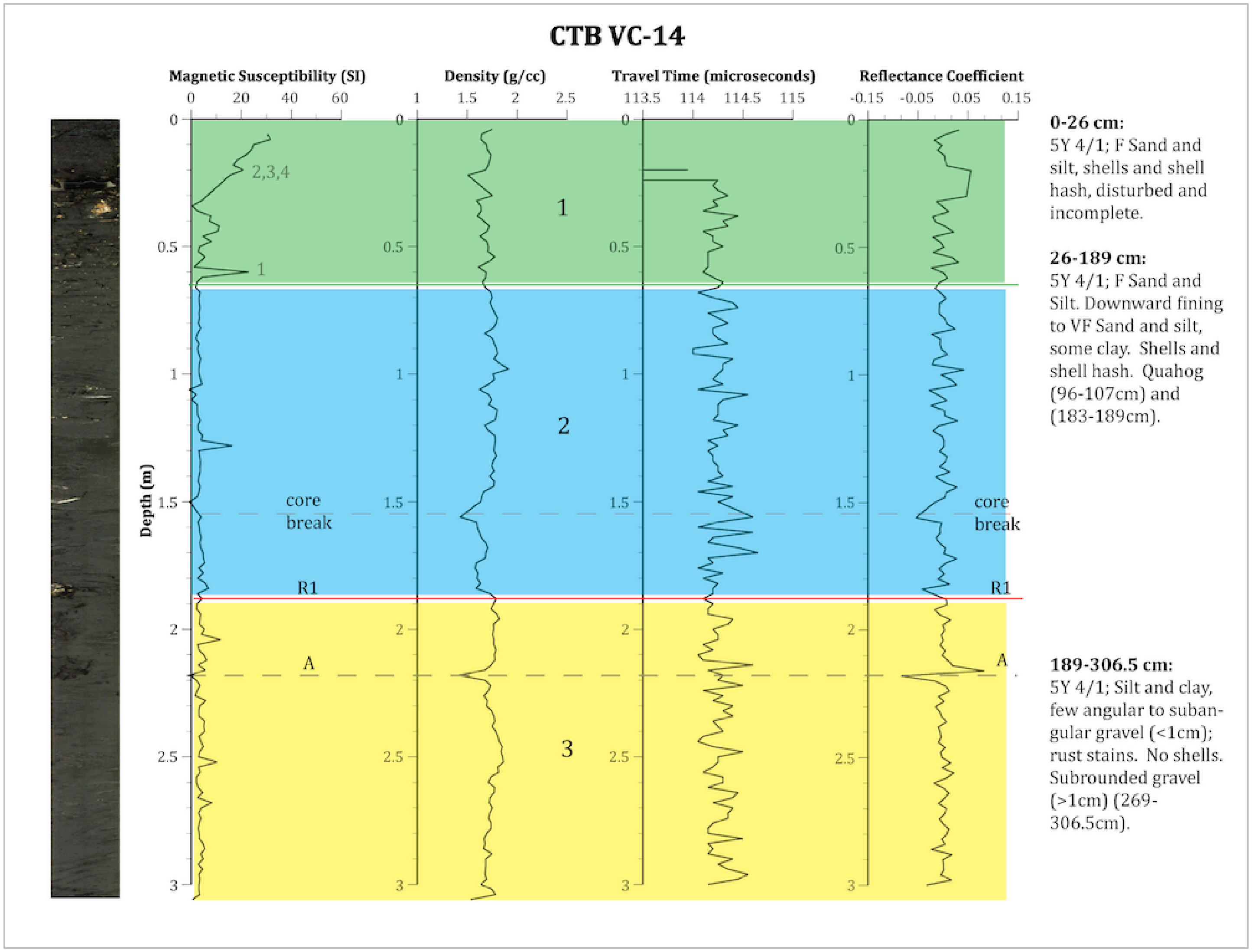


Figure 7-18. Physical properties and initial core descriptions of vibracore CTB VC-14.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Dashed black line labeled “A” is a tie point with CTB VC-10_1 and CTB VC-10_2. Red line (R1) indicates a change in lithology characterized by the presence of coarse sand and gravel. See text for interpretations of lithology.

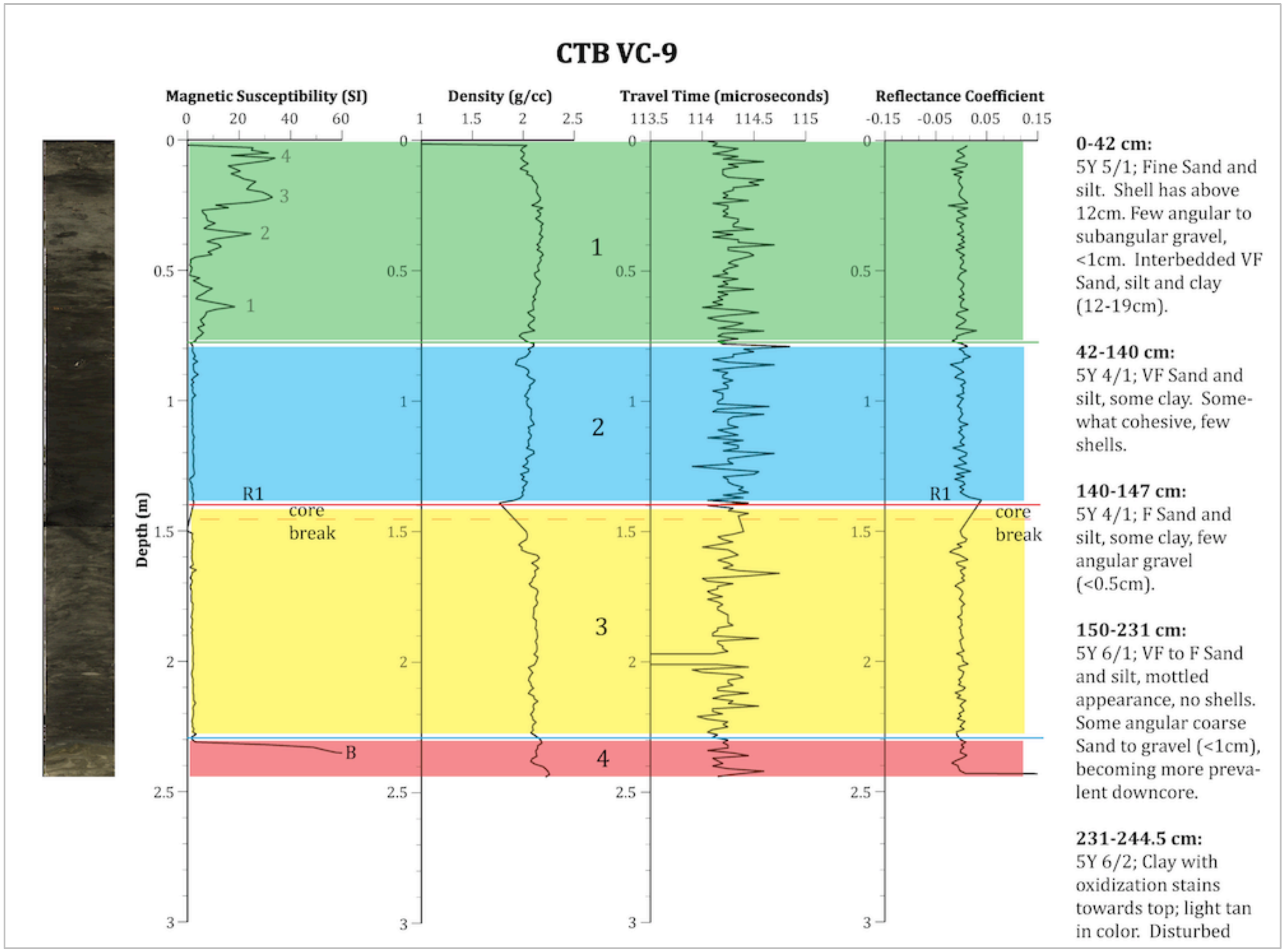


Figure 7-19. Physical properties and initial core descriptions of vibracore CTB VC-9.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Red line (R1) indicates a change in lithology characterized by the presence of coarse sand and gravel. Blue line represents a change in lithology. See text for interpretations of lithology.

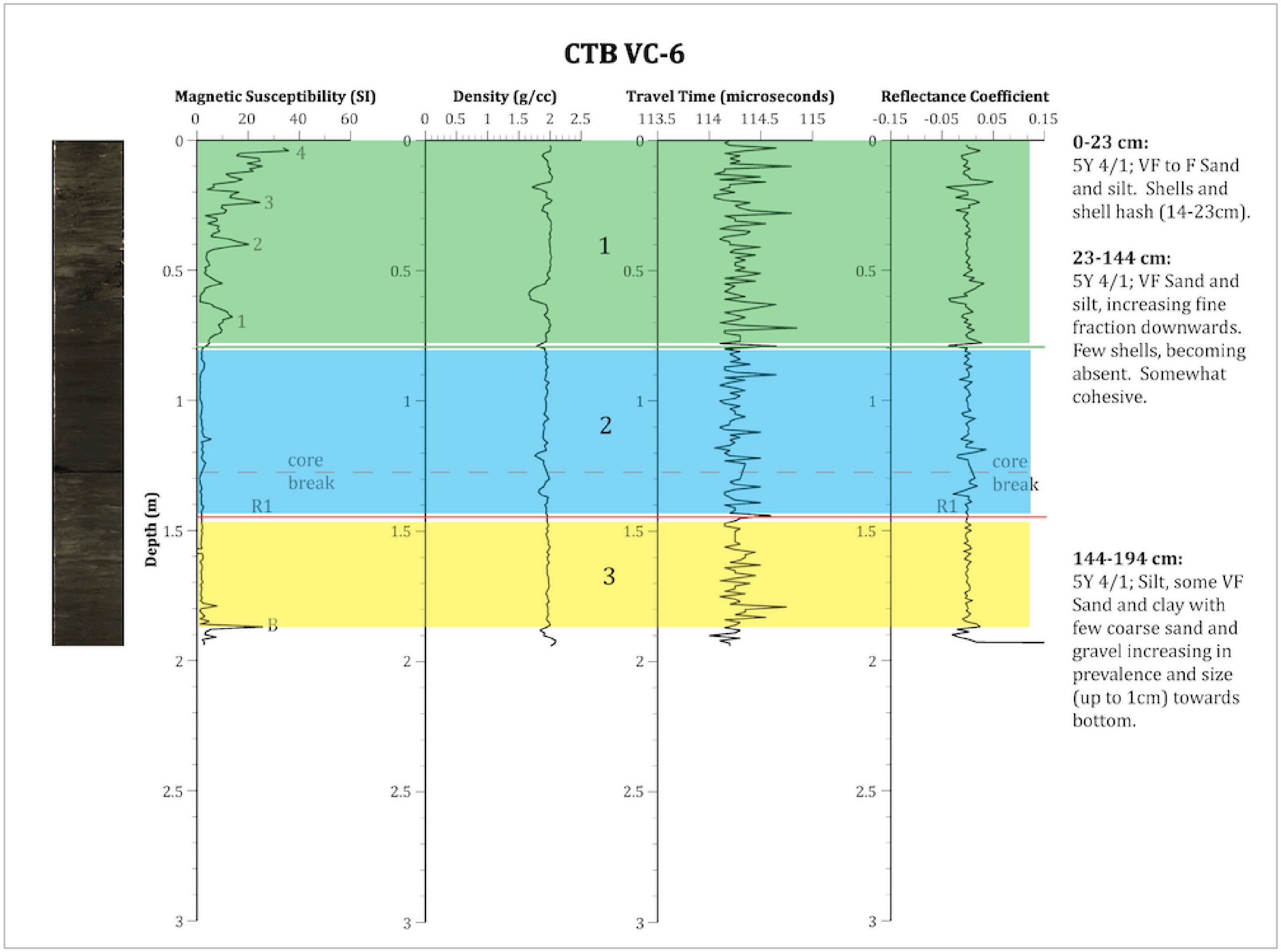


Figure 7-20. Physical properties and initial core descriptions of vibracore CTB VC-6.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Red line (R1) indicates a change in lithology characterized by the presence of coarse sand and gravel. See text for interpretations of lithology.

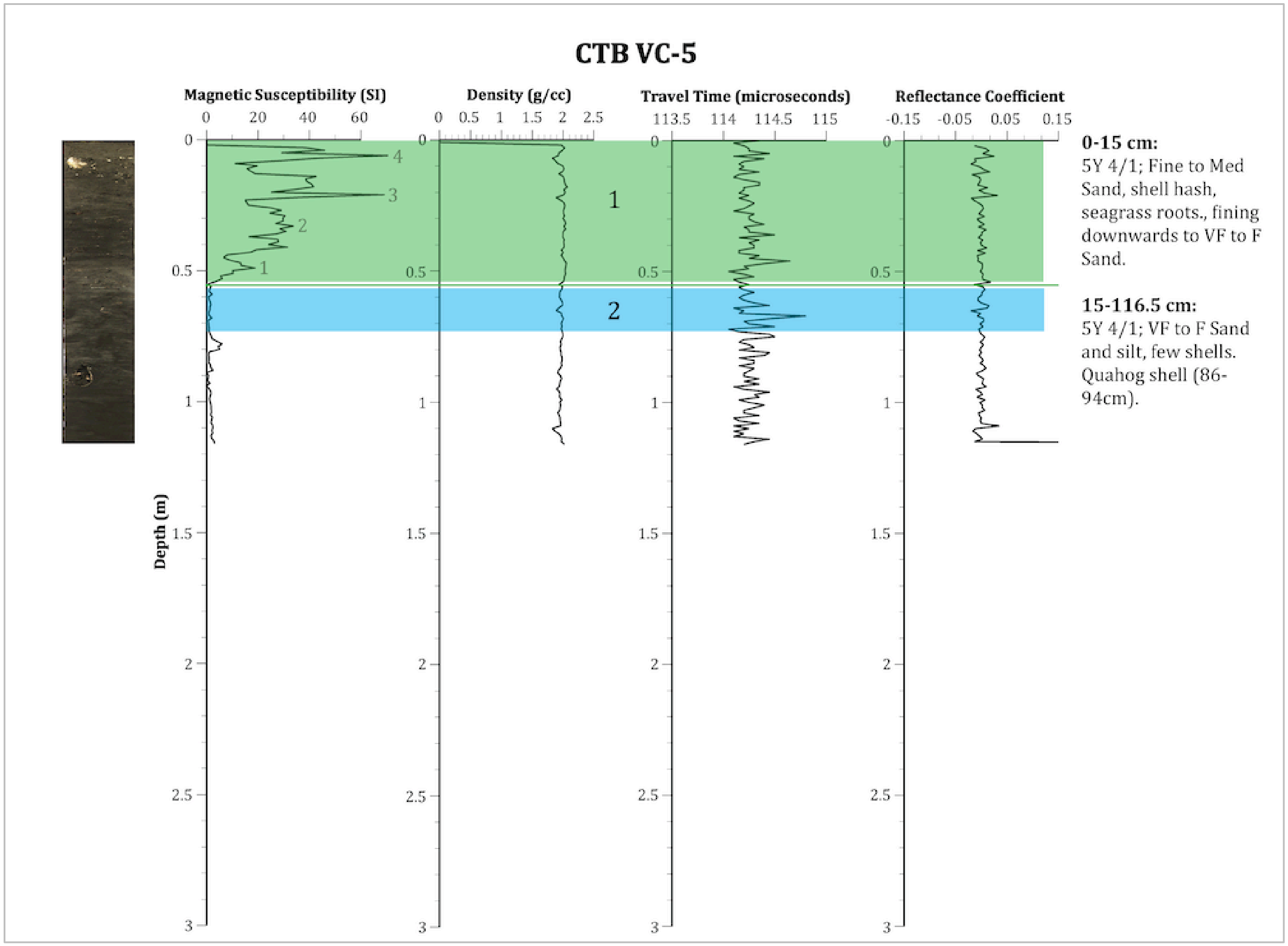


Figure 7-21. Physical properties and initial core descriptions of vibracore CTB VC-5.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. See text for interpretations of lithology.

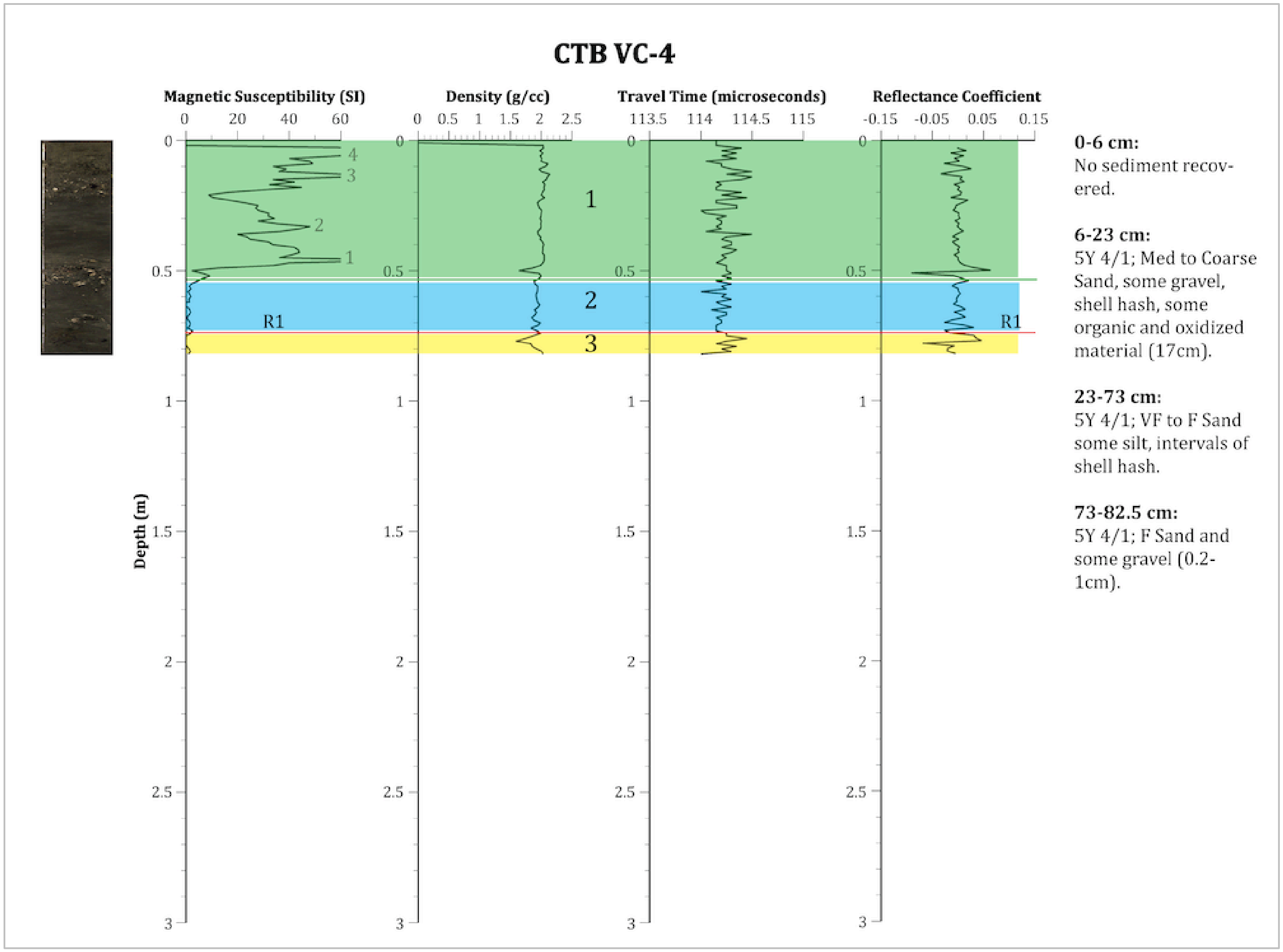


Figure 7-22. Physical properties and initial core descriptions of vibracore CTB VC-4.
Numbers refer to correlated peaks in magnetic susceptibility. Green line represents a down-core transition to background values of magnetic susceptibility. Dashed red line represents a core break. Red line (R1) indicates a change in lithology characterized by the presence of coarse sand and gravel. See text for interpretations of lithology.

Corbin (1989) reported that metal concentrations reached background values at a depth very similar to magnetic susceptibility and occurred at the interface of two distinct lithologies. Similarly, magnetic susceptibility of the vibracores from this study reached background values at a distinct density change, indicated by a high amplitude peak in the reflection coefficient. The base of Lithology 1 is correlated with the tie point in Corbin (1989), where magnetic susceptibility and metal concentrations reach background values, which was dated to approximately 1880 A.D. (138 yBP). This age serves as minimum age of the base of Unit 1, as the increase in magnetic susceptibility predated the increase in metal concentrations in the Apponaug Cove and Greenwich Bay piston cores. The increase in magnetic susceptibility and sedimentation rates are the result of land clearance by European settlers, which increased erosion rates and changed the composition of sediments entering Greenwich Bay (Corbin 1989). A well-established proxy for European settlement and land clearance is the "*Ambrosia* rise," the presence of ragweed pollen grains representing a vegetation shift due to European settlement. Morissette (2014) reporting on an unpublished study by King et al. (1993) identified an age of ~340 yBP for the *Ambrosia* rise specific to Gorton Pond, a freshwater kettle pond < 2 km from Cedar Tree Beach. It is therefore proposed that 340 yBP is a maximum age of the base of Unit 1. According to the radiocarbon-dated *Rumex* pollen rise observed in sediment cores from Succotash Marsh, East Matunuck, RI, the date of land clearance in southern New England occurred ~209–281 yBP (1734–1806 A.D.). This date range is closer to the widespread and regional European-style agricultural land clearance ca. 1,700 (Donnelly and Berntness 2001). Based on initial core descriptions, grain size of Unit 1 decreases with distance from the shoreline, with numerous marine shells and shell hash present. The base of this lithology is correlated with green reflector from seismic reflection line 2 (Figure 7-14), representing an upper facies of marine sedimentary unit (Qpt).

Lithology 2: Open Estuarine Deposition

Based on initial core descriptions, sediment within this unit fines downward, with increasing fraction of silt and mud. Shells become less common down-core through this lithology. In vibracore CTB VC-10_1, a scallop shell was preserved at the very top of this lithology (Figure 7-16). In Greenwich Bay, scallops are an indicator species for good water quality. Prior to anthropogenic eutrophication, Greenwich Bay supported a thriving scallop fishery. Declines in eelgrass due to eutrophication have greatly reduced scallop populations (John King, personal communication, October 25, 2015). This lithology is correlated with sedimentary unit Qpt from the regional framework and represents the onset of open estuarine deposition within the Cedar Tree Beach study area, truncated at the top by the onset of estuarine deposition modified by anthropogenic activities in surrounding upland areas.

Lithology 3: Ravinement and Onset of Estuarine Deposition

The identification of Lithology 3 is dependent on observations of coarse-grained sediments during initial core descriptions. In most cores, sub-angular to angular coarse sand to gravel are sparsely embedded within this unit, becoming more prevalent towards the bottom of this lithology. Lithology 3 ranges in down-core depth from 73 to 189 cm and is shallowest near shore. The coarse sand and gravel do not exhibit distinct layering in any of the cores. It is hypothesized that rising sea level left a coarse lag deposit prior to onset of estuarine deposition that was subsequently mixed with finer grained sediment by bioturbation.

The top of Lithology 3 is correlated with seismic reflector mu from seismic reflection line 2, representing the marine unconformity (ravinement surface) (Figure 7-14). In the down-core plots of reflection coefficient there are no prominent reflectors that are associated with the ravinement. However, the ravinement surface is clearly observable in seismic reflection profiles 2 and C-C' (Figure 7-14). This disparity most likely arises from the differing vertical resolutions between the Geotek MSCL system and the CHIRP seismic reflection system. The absence of high amplitude reflectors representing the ravinement in the core is likely due to the small (1- to 2-cm) sampling interval of the Geotek MSCL system and the lack of a distinct layer of coarse sand and gravel due to bioturbation effects. Conversely, the 20- to 40-cm vertical resolution of the CHIRP seismic reflection system is thought to average the acoustic impedance of sparsely distributed coarse sand generating a weak reflector.

The ravinement surface is a diachronous feature, and therefore the depth at which it is observed corresponds to an inundation age based on RSL rise. A previously unpublished study created an age model for an approximately 7-m sediment core collected in western Greenwich Bay (Vinhateiro et al. 2007) (Figure 7-23). Calibrated radiocarbon-dated shells determined a basal age of ca. 6,500 yBP. The depth of the ravinement surface at the southern edge of the Cedar Tree Beach study area is estimated to be approximately 5.50 m below present-day sea level. Based on the age model produced by Vinhateiro et al. (2007), submergence of Cedar Tree Beach would have begun approximately 6,000 yBP. This closely agrees with the RSL curve constructed for Block Island by Oakley and Boothroyd (2012), which yields an inundation age of ca. 5,800 yBP (Figure 7-23). Comparison with RSL curves for southern New England constructed by Roy and Peltier (2015) yields a much younger inundation age, approximately 3,300 yBP (Figure 7-23). The Connecticut RSL curve presented in Roy and Peltier (2015) was determined as appropriate for Greenwich Bay, RI, based on the measured distance (ca. 2,450 km) from the approximate center of mass of the Laurentide Ice Sheet near the western shore of Hudson Bay. A plot of the rates of Late Holocene RSL rise against the distance from the ice sheet center of mass presented in Engelhart et al. (2009) yields a subsidence rate of ca. 1 mm/yr at a distance of 2,450 km, a rate which is nearly identical to that of Connecticut (1.1 ± 0.1 mm/yr). The predicted RSL curves from geophysical models fit well with robust RSL indicators, especially from 4,000 to 0 yBP (Roy and Peltier 2015). For this reason, an inundation age closer to 3,300 yBP must be strongly considered.

Lithology 4: Terrestrial / Glaciolacustrine Deposition

Lithology 4 was only recovered in vibracore CTB VC-9, however, characterization of the physical properties associated with this boundary suggests that several vibracores likely penetrated, or came very close to penetrating this lithology (Figure 7-19). At 231 cm sediment depth, a light tan silt and clay unit with oxidation stains and a disturbed appearance was recovered, to a depth of 247 cm. A very high amplitude magnetic susceptibility peak and prominent reflection was observed within this lithology, where background values predominated in the overlying lithology. CTB VC-6 also shows a high amplitude peak in magnetic susceptibility at the very bottom of the vibracore, at a down-core depth of approximately 188 cm (Figure 7-20). These two vibracores have a similar density trend at peak in magnetic susceptibility, characterized first by a sharp decrease in density, followed by a sharp increase in density, occurring over a 10-cm interval at the bottom of the core.

Lithology 4 is inferred to be non-estuarine deposits, and is likely glaciolacustrine sediment (Qdo in the regional stratigraphic framework). Morissette (2014) reported very thick sequences (up to 42 m) of varved pro-glacial lake floor sediments truncated by the ravinement surface. Lithology 4 represents the top of the glacial deposits. Oxidized sediment may represent a period of subaerial exposure, as the pro-glacial lake in Greenwich Bay was drained, and streams cut in to the exposed lake floor as is indicated by the paleochannel identified in seismic reflection line 2.

Due to the poor performance of the CHIRP seismic reflection system along the Cedar Tree Beach depositional platform, no seismic reflector is correlated with this change in lithology.

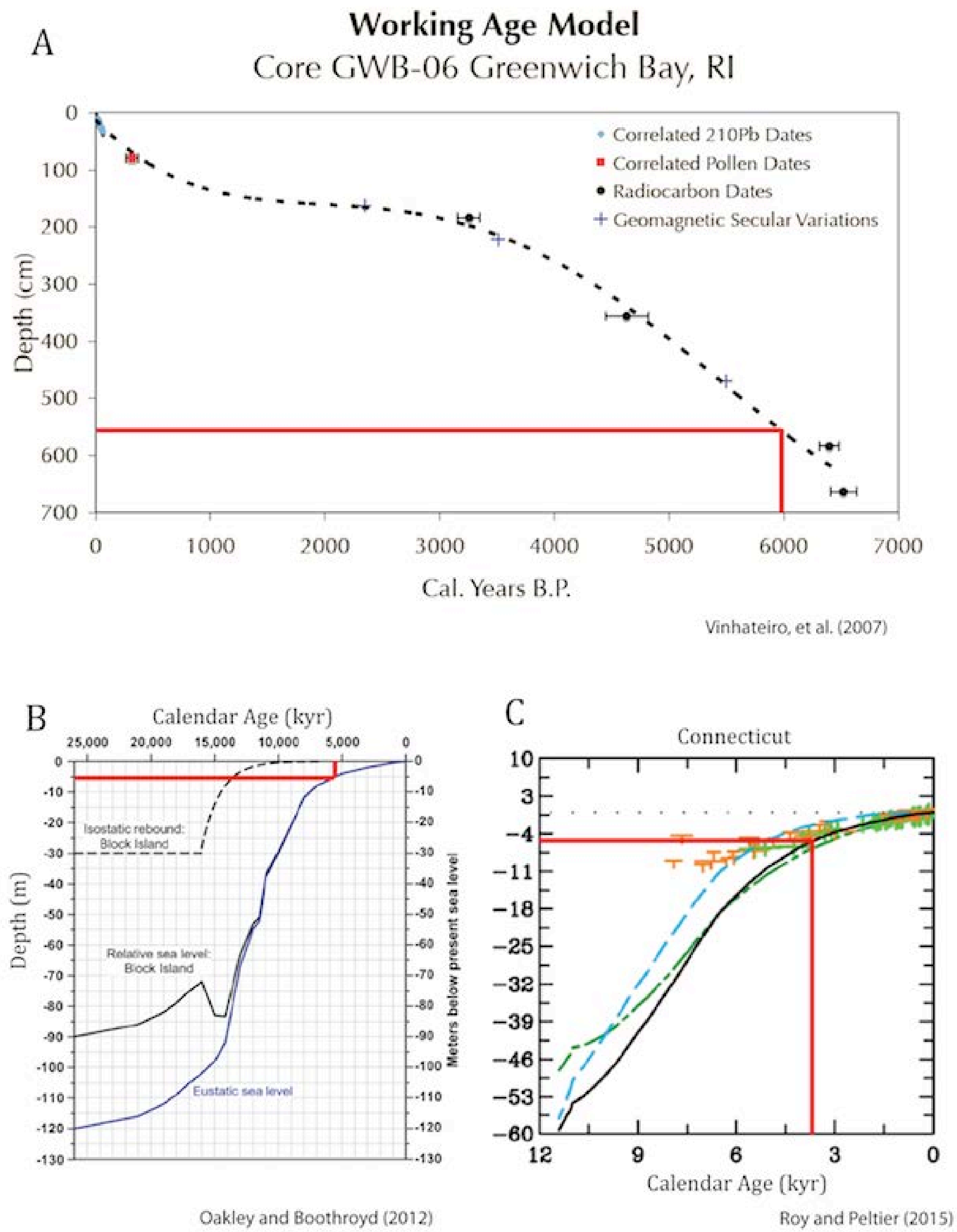


Figure 7-23. Comparison of an age model for Greenwich Bay (A) and relative sea level curves for southern New England (B, C).

The horizontal red lines intersect a depth of 5.5 m below present sea level, representing the depth of the ravinement surface at the seaward edge of the Cedar Tree Beach study area. The Greenwich Bay age model agrees more closely with the RSL curve produced by Oakley and Boothroyd (2012), with an inundation age of ~5,800 yr BP.

7.1.3.4.2 3-D Paleolandscape Reconstruction of Central Greenwich Bay

The methodology outlined above describes the process of generating three-dimensional (x, y position and z elevation) continuous surfaces from reflectors traced across seismic reflection profiles. When a seismic reflector has inferred geological attributes, the 3-D expression of the reflector represents a paleolandscape. Paleolandscapes are best visualized like bathymetry, where depth contours are filled and colorized displaying the variation in depth across the study area. In the case of a paleolandscape, the generated surface represents the depth to a sub-seafloor feature (instead of depth to seafloor for bathymetry).

As is intuited, increasing the number of seismic reflection profiles from which the 3-D paleolandscape reconstruction is based results in a much more detailed continuous surface (Figure 7-24). When only four seismic reflection profiles were incorporated into the reconstruction (Figure 7-24c), depths exceeding 11 m form a broad trough and appears to follow the trend of bathymetric contours (Figure 7-23, nautical chart basemap). However, as additional seismic reflection lines are incorporated, this broad trough becomes more discontinuous and irregular (Figure 7-24 a, b). Without crossing lines incorporated into the reconstruction (b), an apparent sill separates two deeper basins. Incorporating the crossing lines (Figure 7-24a) reveals that the deeper basins are narrowly connected by a channel. Because this channel axis is aligned with the trend of the crossing line, it is absent in both reconstructions b and c, despite being nearly 100 m in width. This example illustrates the importance of crossing lines when planning paleolandscape reconstructions.

The fu_1 reflector is a prominent regional seismic reflector described throughout this report (Figure 7-13). It represents a fluvially eroded terrestrial surface underlain by glacially deposited sediment. Throughout Greenwich Bay, fu_1 truncates glaciolacustrine sediment that was deposited when Glacial Lake Narragansett occupied Greenwich Bay following the retreat of the Late Wisconsinan icesheet. As the post-glacial lake occupying Greenwich Bay and, more broadly, Narragansett Bay drained, the lakebed was subaerially exposed and subsequently was fluvially eroded. The fu_1 reflector and paleolandscape represents what remains of the subaerially exposed lakebed.

Within this study area subset in Greenwich Bay, there does not appear to be a strongly developed dendritic drainage pattern, but a partially interconnected series of basins. This is in general agreement with the paleochannels mapped by Morissette (2014); however, a better-defined tributary drainage system was described as occupying Greenwich Bay than is observed in this reconstruction. Similar post-glacial drainage features have been described in southern New England and were attributed to spring-sapping erosion from high water tables immediately following lake drainage (e.g., Uchupi and Oldale 1994; Boothroyd and August 2008).

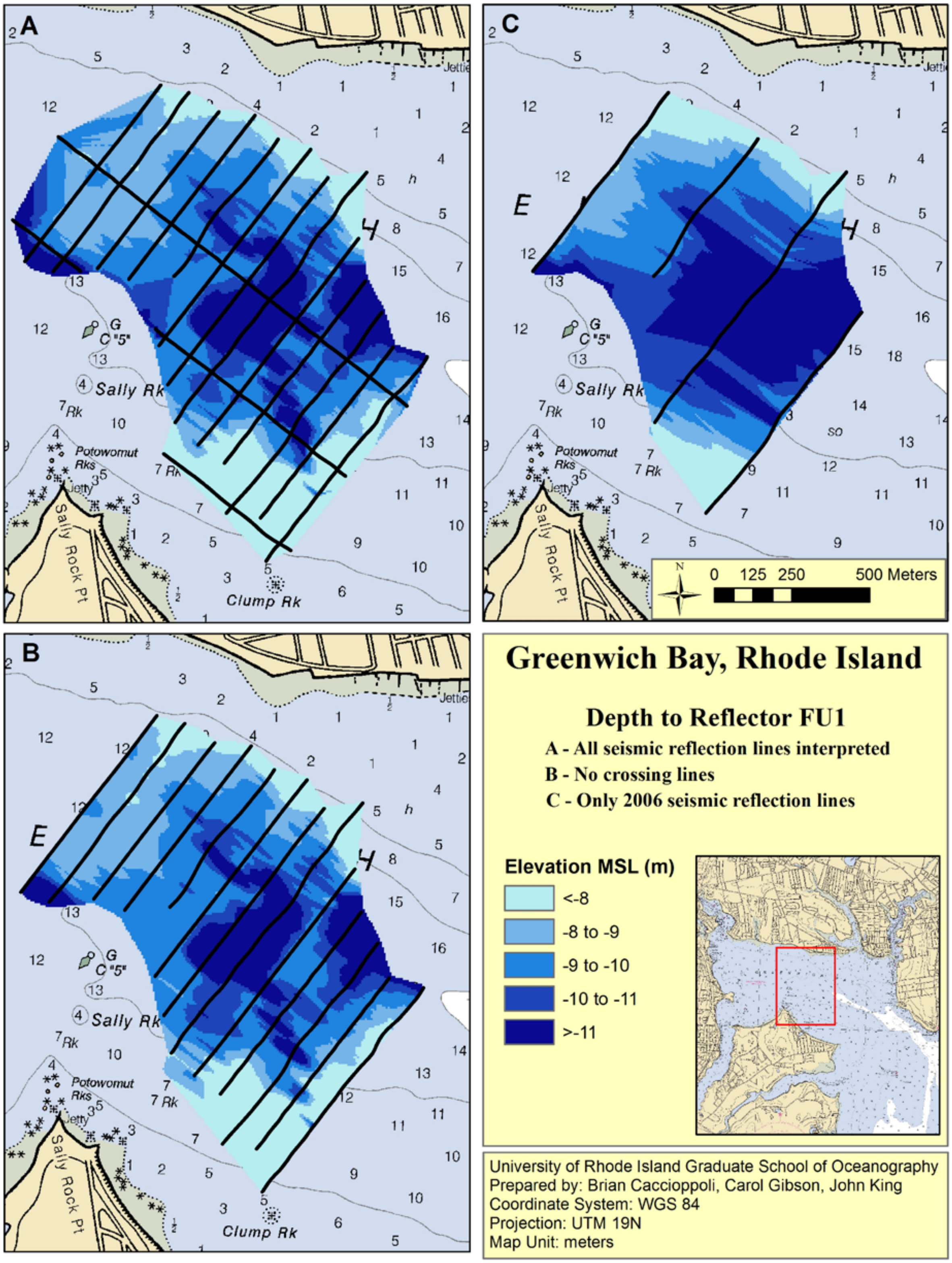


Figure 7-24. Visualizations of interpolated depths to reflector fu$_1$ (post-glacial fluvial unconformity) using seismic reflection profiles obtained at three trackline spacings.

7.1.4 Gorton Pond Paleoenvironmental Investigation

7.1.4.1 Introduction and Goals

Gorton Pond is a 13.7 m deep freshwater glacial kettle lake located at the headwaters of Greenwich Bay in Warwick, Rhode Island (Figure 7-25). The sedimentary record contained within the lake is potentially approximately 19,000 years old, based on the estimated age of the associated glacial moraine (Morrissette 2014). Several core locations (Figure 7-25) were sampled in order to obtain a long regional paleoenvironmental record for use in the Submerged Paleolandscapes Project. The results of studies from a long core from the deep basin in Gorton Pond are summarized in Morrisette (2014). Additional cores were subsequently taken in shallower basins to test for lake level changes (Figure 7-25). The water depths at the core locations are summarized in Table 7-1.

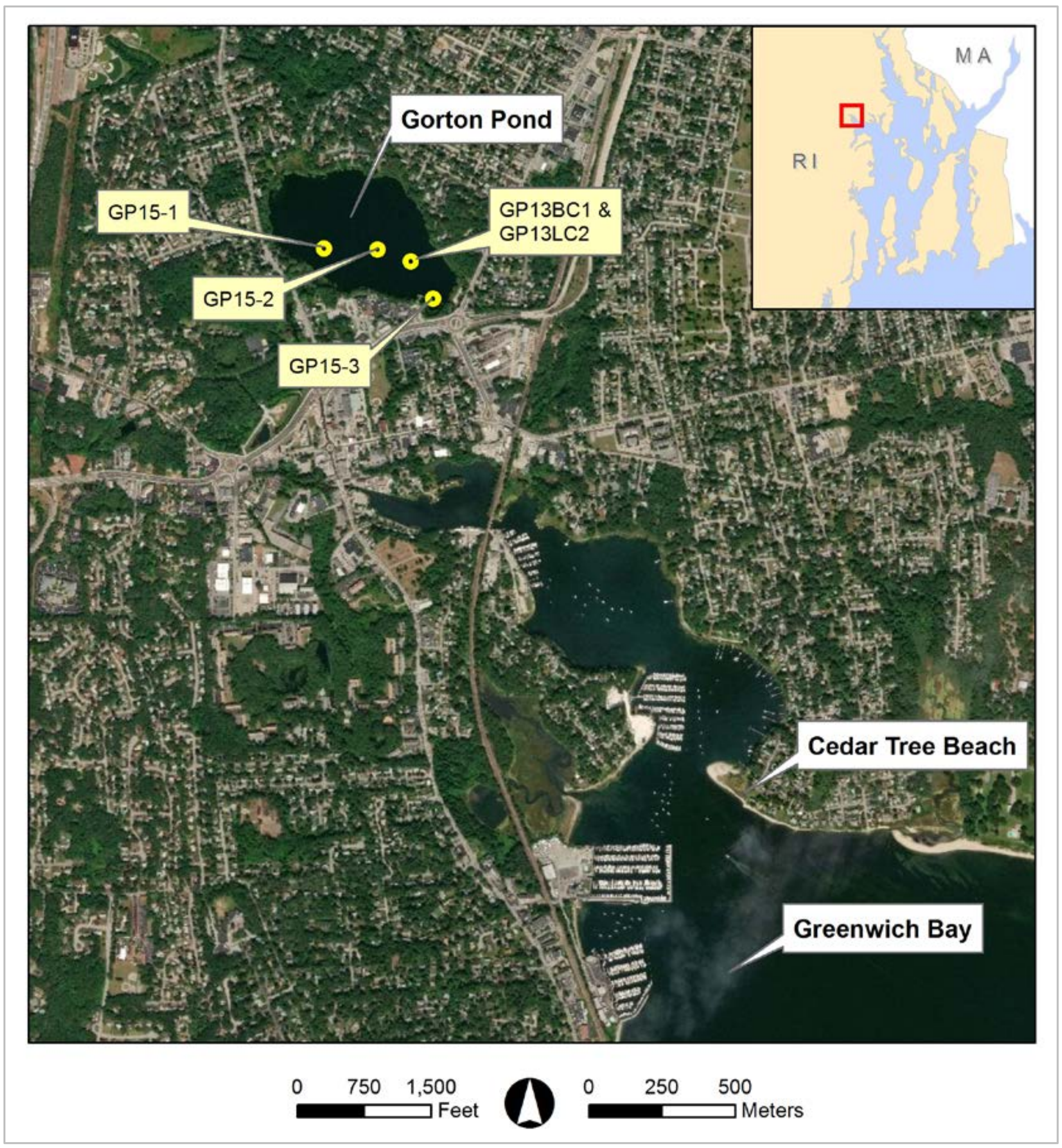


Figure 7-25. Location of Gorton Pond cores.
The location of cores obtained within Gorton Pond are illustrated by yellow dots, with call-out boxes indicating core names.

Table 7-1. Water depths of Gorton Pond Cores.

Core Location	Water Depth (m)
GP13	13.0
LC1 & LC2	13.0
15-1	3.8
15-2	9.6
15-3	5.5

The primary goals of the Gorton Pond studies were to:

- Develop a paleoenvironmental framework for the Greenwich Bay area for approximately the past 15,000 years, by investigating proxy indicators of vegetation change and fire frequency obtained from sediment core samples.
- Test the efficacy of proxy indicators for detecting climate change and human activity in the sedimentary record, and try and distinguish changes in the paleoenvironmental record that were due to climate change from those that might indicate human activities within the watershed.

7.1.4.2 Geological Setting and Previous Work

Gorton Pond is a kettle pond that formed from the melting of calved ice blocks that were originally buried beneath glacial derived sediments and are often found with either glacial moraines or glacial outwash plains (Morrisette 2014). Previous glacial geology summarized in Morrisette (2014) indicates that the age of the basal sediments in Gorton Pond is between 17,800–18,800 calendar years old. Little multi-proxy paleoenvironmental work had been conducted on Rhode Island kettle lakes prior to Morrissette (2014). Studies of Gorton Pond and an additional kettle pond known as Silver Lake, located about 30 km south of Gorton Pond near the south coast of Rhode Island, were conducted as part of the Submerged Paleolandscapes Project as a follow-up to Morrissette (2014).

7.1.4.3 Geological Setting and Previous Work

The field methodology used to study Gorton Pond is summarized in Morrisette (2014) and Caccioppoli et al. (2018). In short, a piston coring system (Glew et al. 2002) was deployed from a 10 m pontoon boat in the summer of 2013 to obtain a approximately 1.2 m surface core, and an approximately 6.4 m long core from the deep basin of the lake. During the winter of 2015, additional cores were obtained using the same coring methods in shallower basins from a frozen ice surface (Caccioppoli et al. 2018). These cores were obtained to detect major climate-induced lake level fluctuations during the Holocene period.

7.1.4.4 Results and Discussion

The majority of the results from multi-proxy studies of the long core from the deep basin of Gorton Pond are summarized in Morrisette (2014). One important result was the construction of a hydrogen isotope paleotemperature curve for the region that spans from the present back to approximately 16,000 calendar years ago (Morrissette 2014). Subsequent studies have been done to construct a paleo-vegetation record or the same interval. A summary pollen diagram for Gorton Pond is shown in Figure 7-26. The chronological information used to estimate the age model is shown in Table 7-2.

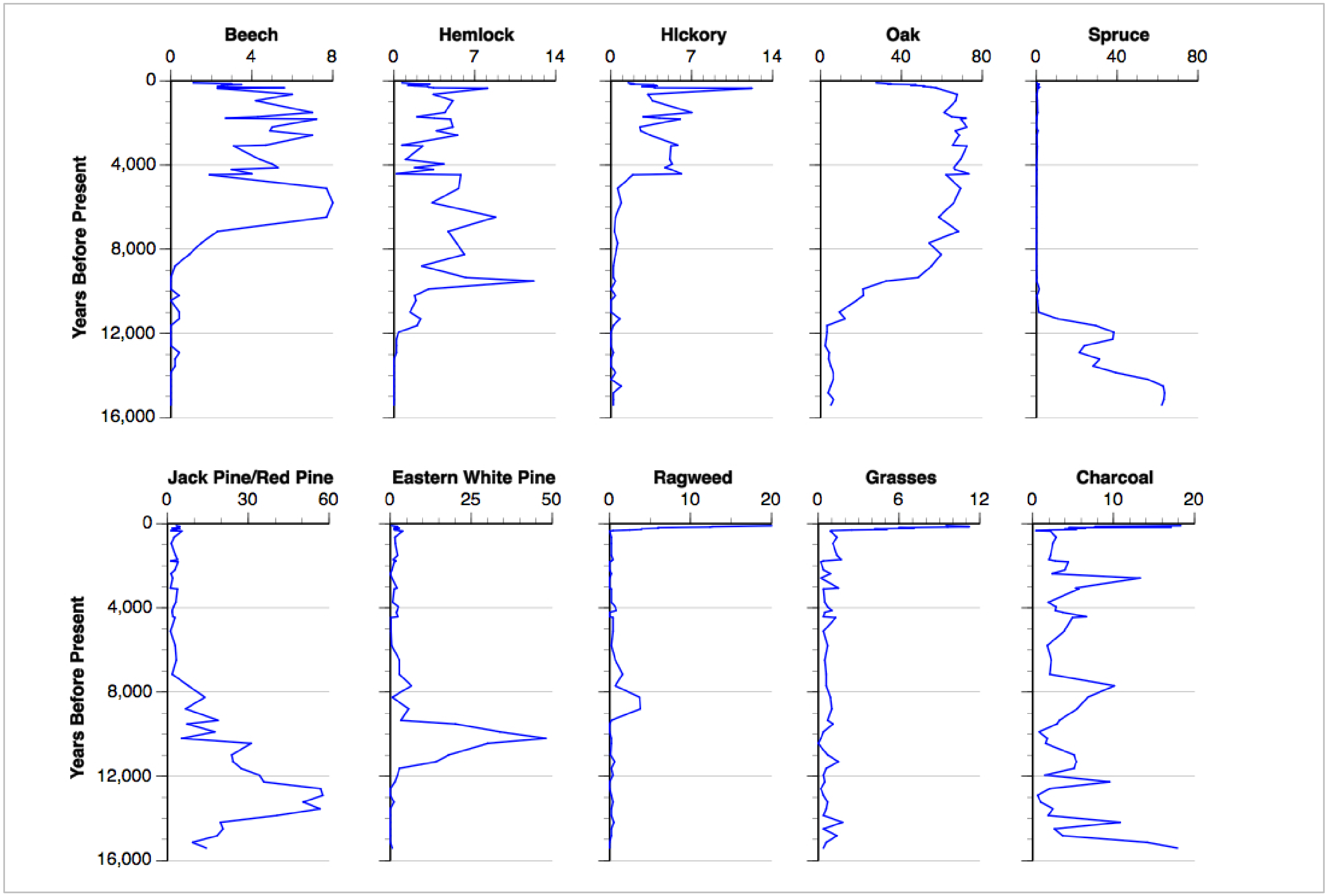


Figure 7-26. Summary pollen diagram for Gorton Pond.
Pollen type and charcoal are shown on the x axis as percentages of the total grains counted at each depth interval. The age model is estimated from the pollen datums and radiocarbon dates shown in Table 7-2.

Table 7-2. Datums used for Gorton Pond age model.

Composite Depth (cm)	14C Age (yBP)	Error (± years)	Calendar Age (yBP)	Error (± years)
0	0	0	0	0
110 (Ragweed rise)	--	--	338	25
180	1,840	30	1,859	87
303	6,140	30	7,117	103
416	9,570	40	10,986	182
475	10,310	40	12,165	123

Previous studies (Delcourt and Delcourt 2004) have shown that intervals of elevated percentages of ragweed pollen, an indicator of forest clearance/disturbance, in conjunction with elevated inputs of charcoal, are evidence of human activities within the watershed. Two major intervals, between 9,200–7,000 years ago and 400 yBP–present, of contemporaneously elevated ragweed pollen and charcoal inputs are shown in Figure 7-26.

The lithological results from the depth transect of cores summarized in Table 7-1 are interesting because core 15-1, obtained at 3.8-m water depth, contains a sand layer at 3.35-m depth in the core (Figure 7-27). This sand layer indicates that the core site was dry at that time and that the lake level was more than 7 m lower in the past. Studies are ongoing but the sediments above the sand layer are approximately 1,000–1,500 years old. Therefore lake levels in Gorton Pond were more than 7 m lower than present at that time. The lack of a comparable layer at site 15-3 located in 5.5 m of water indicates that the drop in lake level was more than 7 m but less than approximately 9 m.

The increase in ragweed and charcoal during the interval of 400 yBP to present is coincident with the contact period and time of European settlement and subsequent development in the Gorton Pond watershed. This time interval is one of well-documented forest clearance and extensive human disturbance (Morrisette 2014). The interval between 9,200–7,000 years ago is one of relatively stable temperatures (climate) as indicated by hydrogen isotope studies (Morrisette 2014). For this reason the observed increase in ragweed pollen and charcoal input to Gorton Pond may be indicative of an earlier interval of disturbance within the watershed by indigenous people (Delcourt and Delcourt 2004).

Late glacial and Holocene lake level fluctuates of up to 20 m have been observed in a high-resolution study of Sluice Pond in southern Massachusetts (Hubeny et al. 2015). The Sluice Pond lake level record is shown in Figure 7-28. The interval between 5,500–1,000 years contains two times of lake levels that are 10–15 m lower than present, separated by a short interval approximately 3,000 years ago that had lake levels that were 5 m lower than present. In addition, lake levels up to 10 m lower than present have been observed during the interval between 5,500–1,000 years ago have been observed by King et al. (2015) in Silver Lake, located in southern Rhode Island. For these reasons the approximately 7–9 m drop in lake level in Gorton Pond that ended 1,000–1,500 years ago is interpreted to be part of a regional time of significantly drier climate in southern New England.

The sediments of Gorton Pond contain two intervals of extensive human disturbance within the watershed as indicated by ragweed pollen and charcoal inputs. The younger interval of disturbance is well-documented in the written historical record. Further work on the older interval is underway to look for cultural material, e.g., microdebitage. The sediments of Gorton Pond and other regional lake records document dramatic changes in lake level during the Holocene. The interval 5,500–1,000 years ago is one of drier climate. Further work is underway to examine the possible relationship between human populations and climate prior to, during, and after this dry interval.

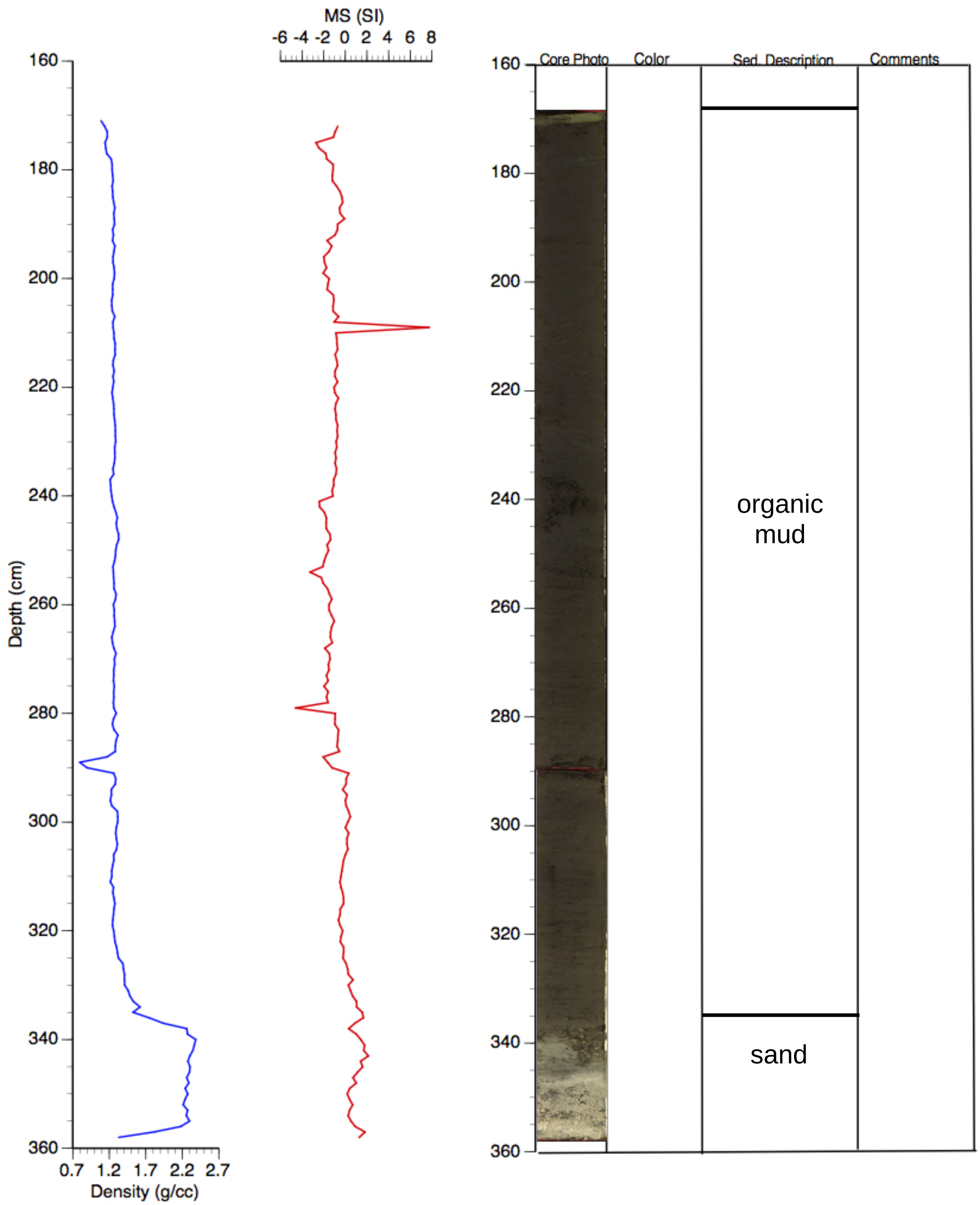


Figure 7-27. Core log from Gorton Pond Livingston core 15-1.
Core was obtained in 3.8-m water depth. Down-core density and magnetic susceptibility (MS) are shown at left, compared to the core image and description at right.

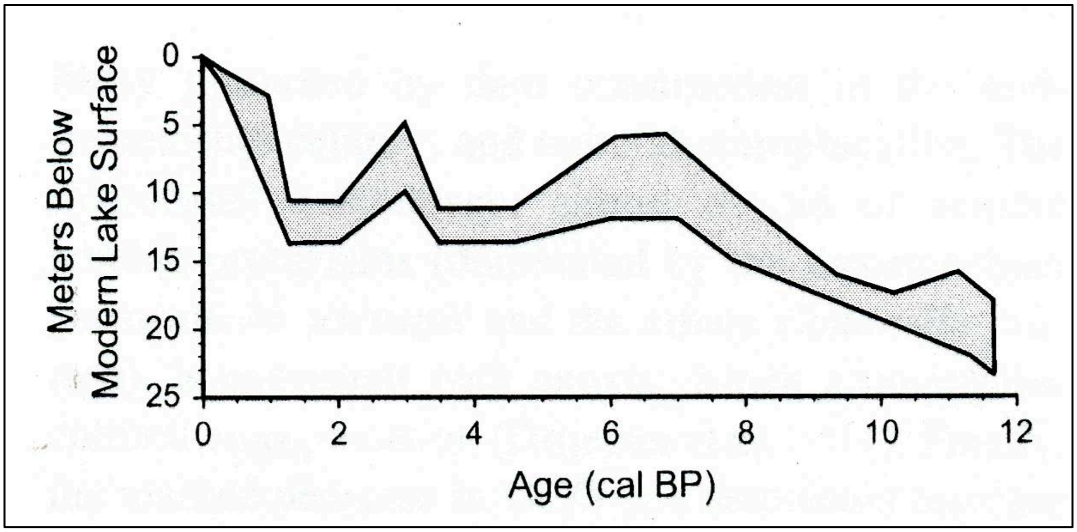


Figure 7-28. Lake level reconstruction for Sluice Pond, Massachusetts.
Diagram from Hubeny et al. (2015).

7.1.5 Implications for Predictive Modeling

7.1.5.1 Archaeological Investigations

The phased, systematic application of different types of Tribally sensitive no- and low-impact marine geoarchaeological surveying and subsurface sampling methods (i.e., close-interval systematic gradiometric survey, systematic and selective VSP probing, and selective excavation of underwater DTUs) conducted on a localized scale at Cedar Tree Beach demonstrated that:

- Identifying, characterizing, and documenting preserved elements of the submerged paleocultural landscape is technologically possible and logistically feasible.

- Identifying cultural deposits preserved within the preserved paleolandscape is technologically possible and logistically feasible.

- It is possible for submerged and buried sediment strata associated with a resource-rich, archaeologically sensitive element of the formerly subaerial paleolandscape located in the intermediate environmental zone (e.g., a floodplain) between a freshwater stream/small river and adjacent uplands to survive the marine transgression process intact within protected, lower-energy, shallow water, estuarine embayment environments.

- The root mat of thick peat deposits that can form along coastal areas on top of terrestrial strata as sea level rises and shorelines move inland act as a protective layer inhibiting erosion and destruction of the underlying paleolandscape surface.

The implication of these findings to modeling is that elements of similarly situated paleolandscapes located at the margins of former water bodies can be preserved underwater, and, consequently, may have higher archaeological sensitivity than other types of sea floor strata.

7.1.5.2 Geological Investigations

Several seismic reflectors representing unconformities and sedimentary sequences were identified in the extensive seismic reflection surveys in Greenwich Bay. Previous work by Morissette (2014) did not conform to regional geologic framework nomenclature, despite similar findings. The inconsistent nomenclature between these previous works can be challenging, and therefore we have summarized the correlated reflectors and sedimentary sequences below. For the discussion of predictive modeling, the regional geologic framework nomenclature developed by the USGS legacy studies (Sections 4 and 6, and Figures 4-4 and 6-5 in this report) will be used for consistency purposes within this report.

- **Qpt:** Post-transgression marine sediment. The uppermost sediment identified in seismic reflection profiles from Greenwich Bay is post-marine transgression estuarine/marine sediment. It is easily identified by its nearly acoustically transparent character and was referred to as U4 in Morissette (2014). This sediment overlies the ravinement surface and is correlated with the Qpt post-transgression marine sediment in regional geologic framework studies.

- **mu**: Ravinement surface. The ravinement surface, an erosional unconformity due to wave-cutting during marine transgression was identified throughout Greenwich Bay. It has been referred to as the R1 reflector in Morissette (2014) and is correlated with the mu reflector reported in regional geologic framework studies.

- **Qfe:** Fluvial and estuarine sediments. Fluvial and estuarine sediment filling paleochannels associated with reflector fu_1 and unconformably overlying glaciolacustrine sediment were not discussed in previous works. This sediment is confined to the paleochannels and underlies the ravinement surface and is referred to as Qfe in regional geologic framework studies.

- **fu_1**: Post-glacial fluvial unconformity. Previous work by Morissette (2014) describes reflectors interpreted as paleochannels that were eroded into the underlying glaciolacustrine deposits. This post-glacial fluvial unconformity is ubiquitous throughout the sub-seafloor geological framework of Narragansett Bay, Block Island, and Rhode Island Sounds and is referred to as fu_1 in several earlier studies (e.g., Needell et al. 1983a, b, c). Although fu_1 is described as a continuous drainage system connecting the upper portions of Narragansett Bay to the present-day continental shelf, the paleolandscape reconstruction of fu_1 within Greenwich Bay suggest that the connectivity may not have been completely continuous in the central basin of Greenwich Bay (Figure 7-24).

- **Qdo:** Glaciolacustrine sediments. Glaciolacustrine sediments with thicknesses of up to ~40m were identified in Greenwich Bay. Morissette (2014) separated glaciolacustrine into several different seismic units (U1, U2, U3), suggesting that there were slight differences in depositional environments and conditions. More broadly, the glaciolacustrine sediment is correlated with the "Qdo" depositional sequence described in regional geologic framework studies.

Of the described sedimentary units and reflectors observed within Greenwich Bay, only two are most likely to be paleoculturally sensitive. At the base of the stratigraphic unit, acoustic basement is inferred to consist of bedrock or stratified glacial deposits, which underly Greenwich Bay and served as the basin where glacial meltwater formed a glacial lake. Thick deposits of glaciolacustrine sediment overlie acoustic basement, suggesting that acoustic basement had not been subaerially exposed since before Wisconsinan glaciation. Also unlikely to be culturally sensitive is Qpt, as it represents sediment that had been deposited after marine conditions had been established in Greenwich Bay. Only Qdo and Qfe are likely to be paleoculturally sensitive in Greenwich Bay. Glaciolacustrine sediment (Qdo) would only become sensitive following lake drainage and subaerial exposure of the lakebed. Similarly, Qfe may be culturally sensitive, particularly any sediment deposited in a fluvial environment. Although fluvial processes are erosional at stream thalwegs, deposition can occur at the margins and in a floodplain, particularly as stream levels lower. Any improvements in seismic reflection profile spacing only improves paleolandscape reconstruction and should be considered when planning paleocultural sensitivity assessments.

7.1.6 Key Points

- Several different depositional sequences were identified in seismic reflection profiles in Greenwich Bay:
  - Acoustic Basement: bedrock or deltaic sediment (Pzz in the regional geologic framework)
  - Units 1–3: glaciolacustrine sediment (Qdo in regional geologic framework)
  - Unit 4: estuarine sediment (Qfe and Qpt in regional geologic framework)

- Two reflectors were identified in seismic reflection profiles in Greenwich Bay:
  - Paleochannel: post-glacial fluvial erosion (fu_1 in regional geologic framework)
  - R1: ravinement surface (mu in regional geologic framework)

- Non-marine sediment "Lithology 4" was recovered in a single vibracore from Cedar Tree Beach and is inferred to be glaciolacustrine sediment (Qdo).

- Marine inundation at Cedar Tree Beach occurred when sea level reached -5.5 m below present-day sea level and is constrained between 6,000 and 3,300 yBP.

- Significant improvements in 3-D paleolandscape reconstruction of the post-glacial fluvial unconformity (fu_1) surface occurred when reducing seismic reflection profile spacing from 300 m to 100 m and when incorporating crossing lines (spaced 300 m apart in this case).

- It is possible to identify, characterize, and document preserved elements of the submerged paleolandscape and cultural deposits within them.

- Resource-rich, archaeologically sensitive, topographically low, margins of former water bodies on the paleolandscape can survive the marine transgression process intact, particularly when jacketed by a thick vegetative root mat and when situated in protected, lower-energy, shallow water, estuarine embayment environments.

- The sediments of Gorton Pond and other regional lake records document dramatic changes in lake level during the Holocene. The interval 5,500–1,000 years ago is one of drier climate.

7.2 Block Island: West Beach

7.2.1 Introduction and Goals

7.2.1.1 Geologic Background

Block Island is a 5.8-km wide by 9.3-km long island situated 14.9 km south of mainland Rhode Island and 22.8 km northeast of Montauk Point, New York. It is surrounded to the northwest by Block Island Sound, to the northeast by Rhode Island Sound, and to the south by the Atlantic Ocean (Figure 7-29).

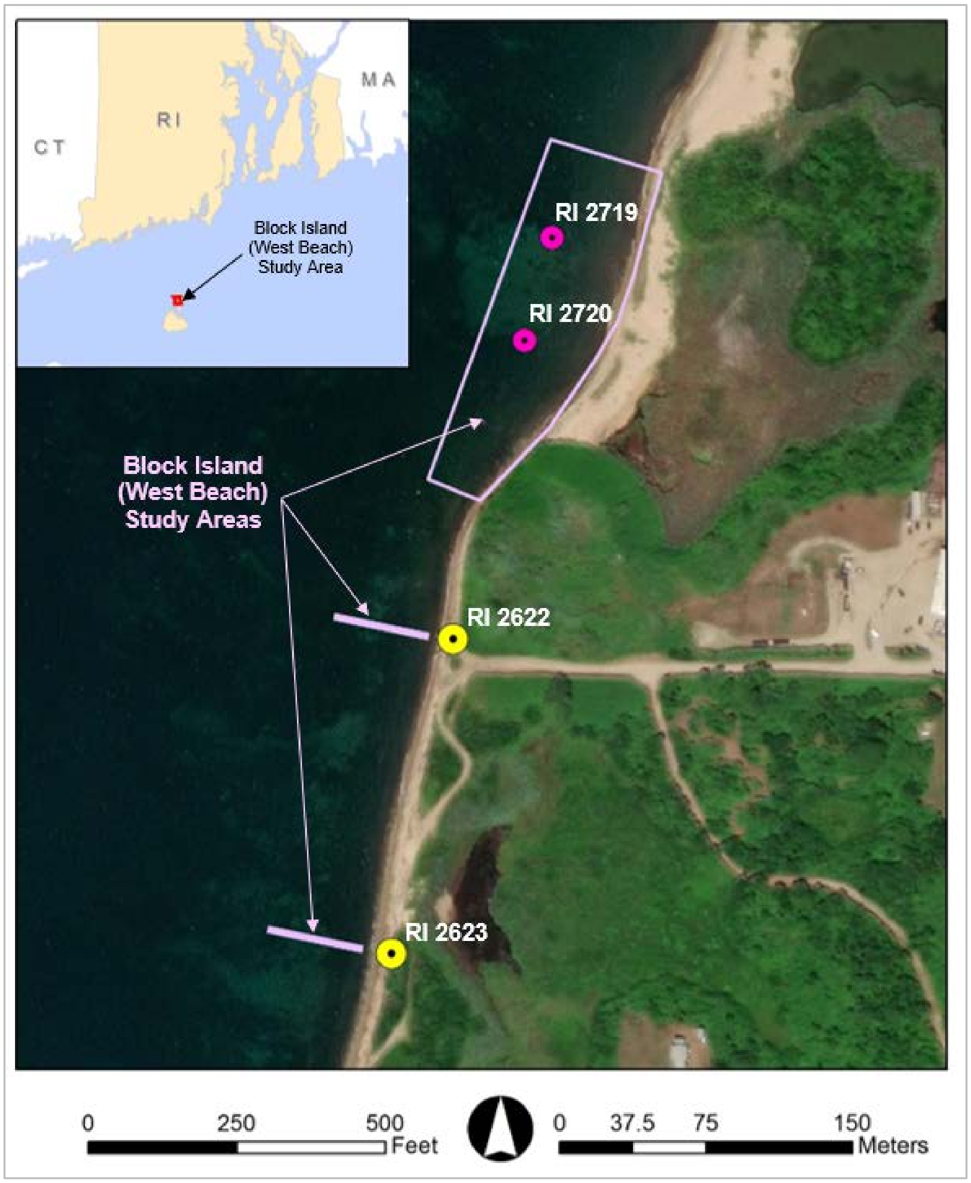


Figure 7-29. Block Island (West Beach) geoarchaeological study area locations.
Note locations of URI-identified subtidal archaeological sites (RI 2719 and RI 2720) and Mashantucket Pequot Museum and Research Center-identified terrestrial archaeological sites (RI 2622 and RI 2623).

Much of the island's geology was shaped and deposited by the Wisconsinan glaciation as a recessional moraine just north of the terminal end moraine that formed immediately south of Block Island about 21,000 years ago. Block Island is part of a west-east trending series of moraines and glacially created islands in southern New England that extend from Long Island, New York, to the west and to Nantucket, Massachusetts, to the east (Figure 7-30) (McBride et al. 2016).

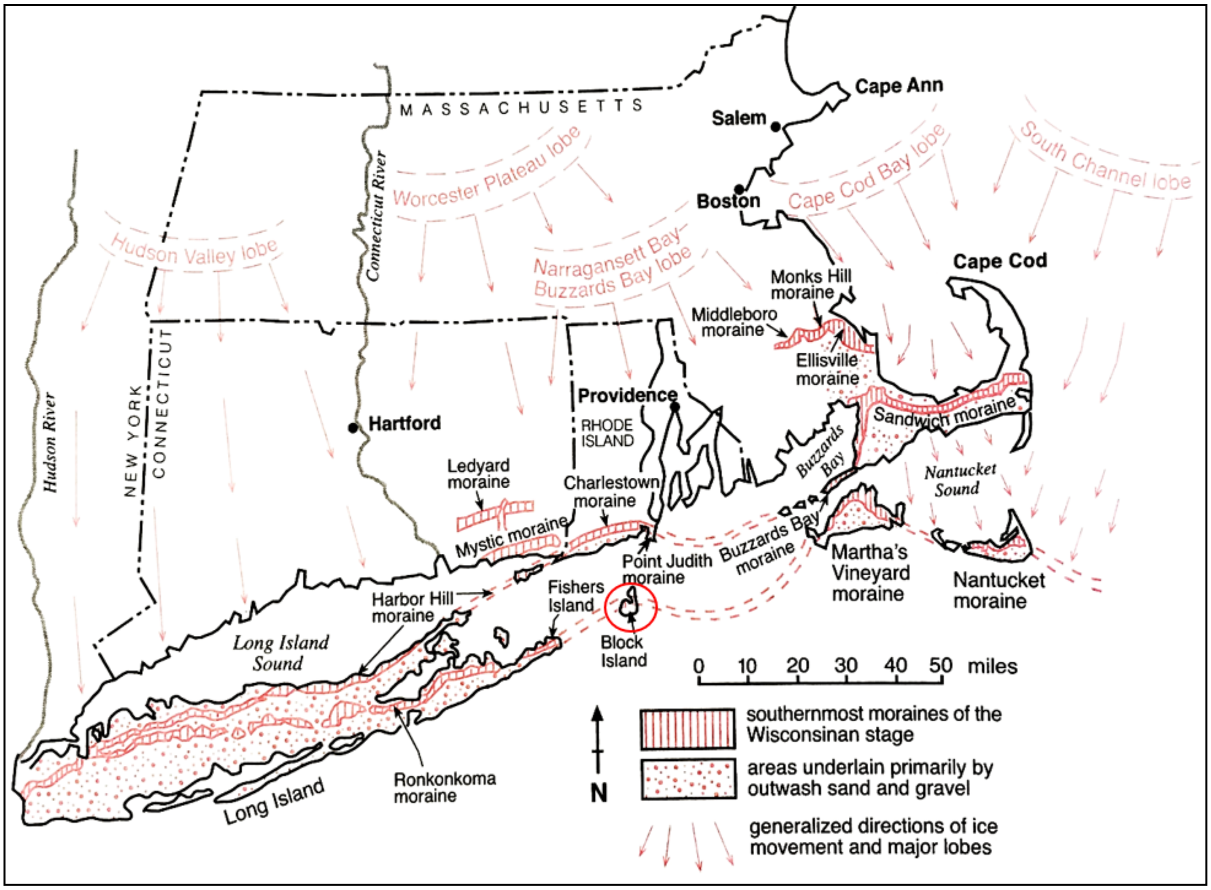


Figure 7-30. Map showing the location of Block Island (circled in red) relative to regional moraine locations across southern New England.

Source: after Skehan 2001, as modified from Mather 1952, Koteff 1974, and Larson 1982

Block Island is composed of stratified morainal material (i.e., rock debris ranging in size from boulders to gravel to sand) deposited at the interlobate contact of the Hudson-Champlain and Narragansett Bay-Buzzards Bay glacial ice lobes (McBride et al. 2016; Boothroyd and Sirkin 2002). The island's north and south ends are morainal deposits. They are divided by the Block Island's "Great Salt Pond" but joined by two barrier spits on the east and west sides of the pond. The northern of these two upland areas, where the West Beach study area is located, is called "Corn Neck." Corn Neck is a recessional moraine that occupies an area of about 2.5 km². Its elevation rises gradually from the south to northeast reaching a maximum of 42.7 m above sea level. Its topography has been described as "hummocky" and is dotted with kettle ponds and coastal ponds.

Sediments on Corn Neck consist of a sheet of upper glacial drift overlying an older, lower drift sheet deposited by an earlier glaciation, as well as masses of Cretaceous sediment. The younger drift covers most of the island and is characterized by glacial deposits and landforms associated with the Late Pleistocene melting and receding of the Laurentide Ice Sheet. The uppermost element of this glacial sequence consists, in part, of a type of till known as "melt-out" till, which was deposited during the final wasting of the area's glacial ice. After the ice receded, the climate remained cold, and strong winds blew across the barren, recently exposed land surface adjacent to the ice. Wind-blown silt or "loess" was swept off of the exposed glacial deposits and redeposited as an "eolian mantle" of sediment on top of the melt-out till. This eolian mantle overlies most of the glacial deposits in southern Rhode Island, including the upland till mantle and lowland morphosequences (Boothroyd and Sirken 2002). A layer of loess 1-m thick can be found in places on Block Island, including in the West Beach study area. As the climate warmed and glacial ice receded further northward, the barren sediments on the surface of the deglaciated landscape weathered and became vegetated. Organic components accumulated on the surface of the loess and gave rise to a silty-sandy variety of organic soil known as "loam." In places along the coast, as sea level rose and beaches migrated inland, sand dunes formed on top of this old soil ("paleosol") surface. Organic soils rich in partially decomposed organic plant debris were formed in lowlands, wetlands (swamps and marshes), and ponds that were significantly different in composition than paleosols in the upland areas. Pollen, spores, seeds, needles, leaves, and other tough plant structures are preserved in these layers of highly organic "peat." Many glacial lakes have been filled-in with lake bottom sediment and then covered with peat. These layers of sediment provide a record of post-glacial vegetation and climate in their assemblages of tree, shrub, and herb pollen (Sirkin 1996). Elements of all of these various strata are present within the West Beach study area (Figure 7-31).

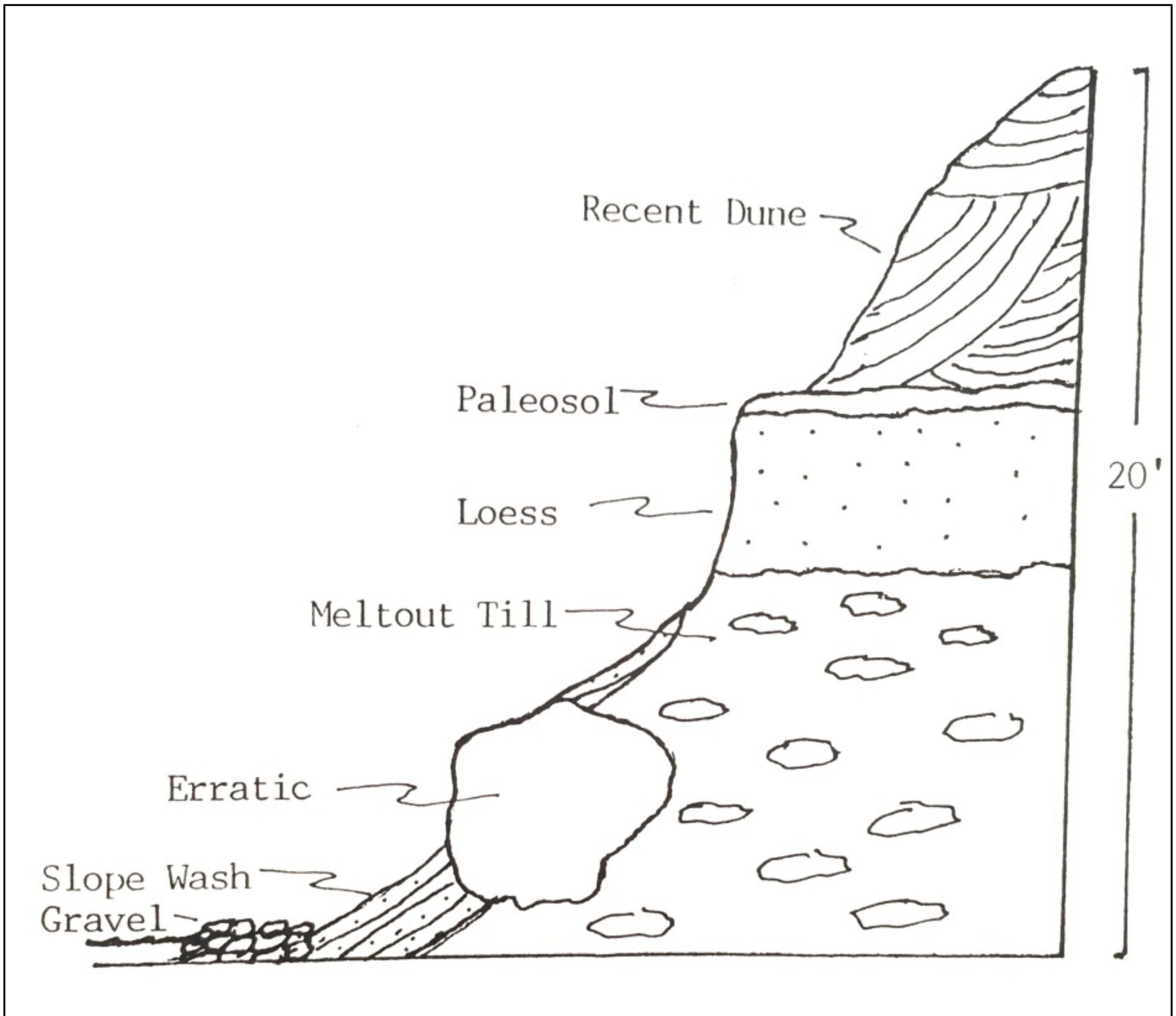


Figure 7-31. Representative stratigraphic sediment profile of the upland sections in the Block Island (West Beach) study area (Sirkin 1996).

7.2.1.2 Justification and Goals

The West Beach study area was selected for marine geoarchaeological reconnaissance field investigations as part of the project because of its unique combination of environmental, geological, and archaeological variables. West Beach is located on the western shore of the northern or Corn Neck moraine end of Block Island on a low- to high-energy beach that is a much more dynamic environment than exists in the Cedar Tree Beach/Greenwich Bay study area. West Beach faces the coastal waters of Block Island Sound where there is 25 km of fetch from winds out of the northwest. Westerly winds are dominant on Block Island 9.7 months out of the year between September and July. Southerly winds dominate during the remaining 2.3 months of the year from July to September.

The West Beach study area's onshore component includes preserved elements of a low-relief, coastal upland paleocultural landscape that are preserved at two previously identified locations, Rhode Island Historical Preservation & Heritage Commission- (RIHPHC-) registered archaeological sites, RI 2622 and RI 2623. These archaeological sites are interpreted to be the cultural material residue left behind by activities that took place at ancient Native seasonal (likely Springtime) fishing camps dating from the Early to Middle Woodland archaeological periods (ca. 3,000–1,000 yBP) (McBride et al. 2016). Portions of upland paleocultural landscape elements preserved at West Beach and the intact stratigraphy above and below them were exposed in plan and profile after the dune deposits overlying them were stripped and eroded by wind and waves associated with Hurricane Sandy in 2012. The preserved upland paleocultural landscape elements are backed and interspersed by lowlands containing fresh water wetlands and small, shallow, freshwater ponds. Seaward elements of West Beach's upland paleolandscape areas are eroded and completely absent from the beach, the intertidal, and the subtidal portions of the study area. In contrast, large highly organic peat and paleosol deposits, some containing tree stumps and root mat still in growth positions (also presumably exposed by Hurricane Sandy), are preserved onshore in the intertidal and in the subtidal—the places corresponding to what had been lowlands, wetlands, and coastal ponds that were/are interspersed between the onshore uplands. The presence of nearby onshore archaeological deposits, the apparent preferential preservation of the lower elevation paleocultural landscape elements (i.e., remnants of lowlands—wooded wetlands, marsh, and pond basins), and the unknown extent of their preservation offshore together made the location attractive for conducting marine geoarchaeological investigations. The overall goals of these investigations were to learn more about the nature of the preservation of these paleocultural landscape elements and the archaeological deposits they contained out in West Beach's subtidal zone.

The goals of the 2015–2016 reconnaissance investigations were met by accomplishing the following fieldwork objectives:

- Examine and preliminarily map visually (with the recorded observations of archaeological divers and underwater video documentation), as well as through marine geophysical remote sensing survey, West Beach's exposed intertidal and subtidal paleolandscape elements and obtain small samples of organic materials within them for radiocarbon dating.

- Obtain sediment cores from Wash Pond and West Beach's subtidal paleolandscape elements for paleoenvironmental analysis and radiocarbon dating to assess how much, if any, of these archaeologically sensitive upland coastal geological features and their cultural deposits were preserved in the water.

- Visually examine and video-document transects extending out into the subtidal zone coastal from West Beach's previously identified onshore back-beach dune locations of archaeological sites RI 2622 and RI 2623 to assess the preservation of the different paleolandscape strata and the possible extent of the archaeological sites offshore.

7.2.2 Field Methodology

Marine geoarchaeological field investigations conducted for the project in the West Beach study area included the following methods:

2015:

- May 29, June 14: onshore walk-over survey of the beach, GPS mapping, and intertidal organics small sample collection of intertidal tree stumps and exposed peat deposits

- June 21–27: geoarchaeological visual examination/video documentation, GPS mapping of subtidal transects, subtidal organics small samples collection, and collection of subtidal artifacts discovered *in situ* (two pieces of small stone chipping debris) by archaeological divers from BOEM and URI

- June 25: depth survey and sediment coring in Wash Pond (shallow fresh water pond backing West Beach)

2016:

- May 2–14: onshore, intertidal, and subtidal geoarchaeological visual examination/video documentation; GPS mapping; and subtidal organics small sample collection by archaeological divers from BOEM and URI

- May 3–9: vessel-based geophysical remote sensing survey of the subtidal zone with Edgetech 6205 side-scan sonar system, Benthos CHIRP III sub-bottom profiling system, and Applanix POS MV positioning system

- June 16: geoarchaeological visual examination/video documentation of subtidal area and collection subtidal artifact discovered *in situ* (one large piece of stone chipping debris) by archaeological divers from NITHPO and URI

Detailed descriptions of the field methodologies employed at West Beach are included in the Project Field Report (Caccioppoli et al. 2018).

7.2.3 Results

Initial walkover surveys of the West Beach study area documented five areas of intertidal peat deposits (designated “Peat Areas 1 through 5”). Several of the peat deposits appeared to extend out into the water a significant distance (ca. 50 m) beyond the low-tide level, based on the dark appearance of the seafloor in areas of exposed peat, which contrasted with the otherwise lighter-colored sandy areas of the seafloor. The northernmost of these exposed intertidal peat areas contained three tree stumps distributed roughly perpendicular to the axis of the beach, as well as multiple small sapling stumps, all of which were in growth positions (Figure 7-32). The tree and sapling stumps were also surrounded by tree root mat, which presumably helped hold together the sediment matrix in which they had grown. The exposed peat was observed to contain rocks and woody fragments (roots and branches of varying diameter and size) embedded in it. The observed stratigraphy in the areas of the intertidal with exposed peat consisted of 1) an overlying upper layer of coarse sand, gravel, cobbles, and boulders; 2) a middle layer of peat; and 3) a lower layer of brown (oxidizing to gray) loess with organic inclusions.

Figure 7-32. Northernmost intertidal peat deposit with tree stumps in original growth positions within the Block Island (West Beach) Study Area.
The AMS dates for the peat were ca. 900 yBP. Dates for the stumps closest to shore and furthest offshore were CAL BP 430–375 and CAL BP 730–670, respectively. (Photograph by David S. Robinson [URI-GSO]).

Examination of the preserved paleocultural upland stratigraphy at the locations of archaeological sites RI 2622 and RI 2623 revealed a stratigraphic sequence consistent with that described by Sirkin (1996:141, Figure 25) for a "twenty-foot bluff, West Beach." The observed stratigraphy consisted of a variable-thickness veneer of overlying recent dune sands, underlain by a thin paleosol layer of dark brown to black organic sandy loam. The sandy loam paleosol layer overlays a thick stratum of a lighter-colored, brown loess. The thick visible basement stratum consisted of a hard, concrete-like, glacial melt-out till. The stratigraphic profile observed where archaeological site RI 2623 is located included the paleolandscape's upland feature containing the RI 2623 cultural deposit. This upland feature extended northward, sloping downward into a topographic depression or lowland area (Figure 7-33).

Figure 7-33. Representative profile of the eroded and exposed profile of the coastal wetland and upland topography onshore in the Block Island (West Beach) Study Area.
Note the wetland basin filled-in by displaced beach sand and cobbles (left side of the image) and the dune-topped low-relief upland low-relief bluff (right side of the image) with its distinct, but thin, dark organic paleosol stratum overlying a thick loess stratum, which overlies a thick melt-out till stratum at its base. This particular upland location corresponds with the location of a Middle Woodland Period archaeological site (RI 2623) identified by archaeologists from the Mashantucket Pequot Museum & Research Center in 2015 (McBride et al. 2016). (Photograph by David S. Robinson [URI-GSO]).

Within this lowland were highly organic sediments associated with a wetland or pond margin that transitioned into highly organic lagoonal mud indicative of a shallow pond basin. This variable paleolandscape profile provided an excellent proxy for interpreting the multiple exposed paleolandscape strata visible in a more planar orientation in the intertidal and subtidal zones that were then investigated by the project's diving archaeologists.

Fieldwork performed by BOEM, NITHPO, and URI archaeological divers in the intertidal and subtidal zone of the West Beach study area focused mainly on the visual exploration, mapping, and characterization of the subtidal area's surface. Portions of the subtidal zone that were examined included the areas seaward of the five exposed intertidal deposits of peat, as well as subtidal areas seaward of the RI 2622 and RI 2623 onshore archaeological sites. A 100-m long x 50-m wide subtidal survey area, oriented along the axis of the beach and extending southward from the location of the northernmost exposed intertidal peat deposit, was mapped by the archaeological divers. Systematic visual survey of this subtidal area was accomplished by installing a 100-m long baseline tape onshore, parallel to the axis of the beach, from which a series of 10-m spaced, 50-m long, tape-measure survey transects were extended perpendicular to the baseline out into the water. Each of these transects was surveyed visually and video-documented by the archaeological divers who also recorded their observations on underwater slates. The GPS positions of the ends of the baseline and survey transects, as well as features of interest (marked with a buoy), were recorded at the surface using a handheld Garmin GPS, which reported positional accuracies of +/- 2.5 m.

In addition to the systematic visual survey of the seafloor, the archaeological divers also performed *non-patterned* visual survey and exploration of the subtidal zone. During this phase of the subtidal area's examination, two pieces of quartz chipping debris were found *in situ*, embedded in the subtidal portion of the northernmost peat deposit (i.e., the deposit containing the intertidal tree stumps) (Figure 7-34). The find was video-documented underwater in real time when it was discovered and its GPS location recorded. The identified artifacts were then recovered by URI, photo-documented, inventoried, and are presently in storage at the URI-GSO CML until a permanent repository is designated by the RIHPHC. The site where the artifacts were found, "West Beach UW-1," was reported to the RIHPHC and added to their archaeological site inventory as RI 2719, the state's first registered subtidal ancient Native archaeological site; cultural material found in a subtidal context off of Cedar Tree Beach is considered to be an extension of the previously identified intertidal "Cedar Tree Point" site (RI 2311).

Additional non-patterned visual survey conducted seaward of the southernmost of the five exposed intertidal peat deposits encountered a broad expanse of multiple exposed and stepped submerged paleolandscape strata extending from the seaward margin of the exposed area of intertidal peat out about 100 m offshore into water approximately 5 m in depth. Video documentation and radiocarbon dating of this seaward progression of the stepped sub-tidal strata recorded a stratigraphically and paleoenvironmentally differentiated sequence of lowland (wetland margin/pond basin) sediments that was similar to that which was observed onshore in the exposed profile of upland, wetland, and pond basin stratigraphy at RI 2623. Progressing from the sea towards shore, in the subtidal was observed glacial melt-out till, an overlying eolian mantle of loess thickening towards shore, topped by organic paleosols associated with both a wooded wetland margin and a pond basin (Figure 7-35). Overlying the wooden wetland margin paleosols were three distinctly separate peat layers. Micro- and macro-fossil elements of these distinct peat layers record their transition from two freshwater marsh environments to a salt marsh environment. Radiocarbon-dated samples from multiple elements of this preserved subtidal remnant of West Beach's paleocultural landscape provided evidence of the sequencing and timing of the area's transition from a wooded low area, to a marsh, to a beach, and then to an inundated marine environment. These dates, organized from shallowest water depth/closest to shore, to the deepest depth/furthest from shore were reported by BETA Analytic as: 735–870 cal yBP; 1,295–1,225 cal yBP; 3,330–3,290 cal yBP; and 6,635–6,580 cal yBP.

Figure 7-34. Quartz chipping debris constituting the West Beach UW-1 Site (RI 2719) discovered embedded in subtidal, exposed, and stratified organic paleosols in the Block Island (West Beach) study area.
Photographs by Melanie Damour (BOEM) (upper image) and David S. Robinson (URI-GSO) (lower image).

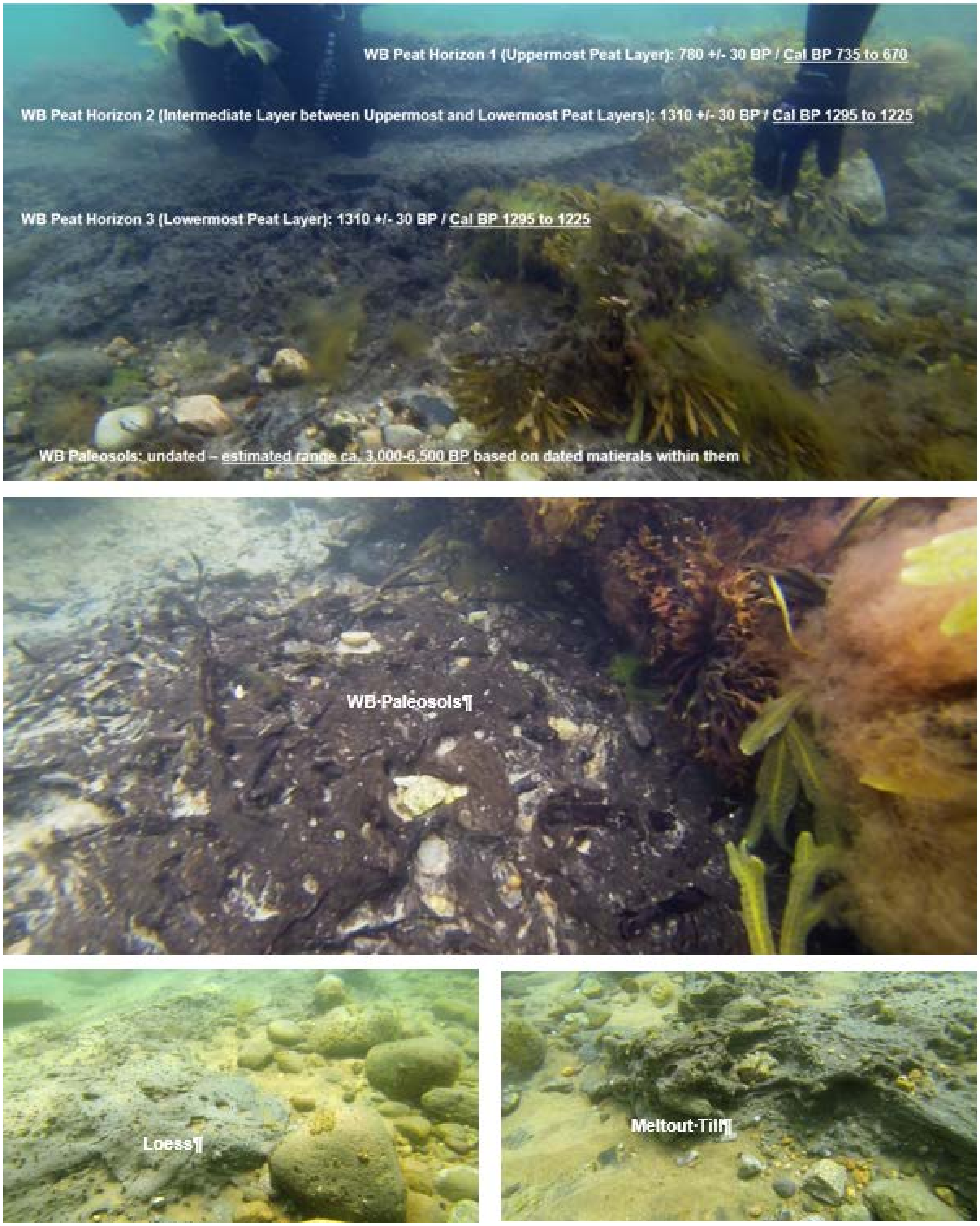


Figure 7-35. Exposed and preserved submerged stratigraphy within the Block Island (West Beach) Study Area in the vicinity of the West Beach UW 2 Site (RI 2720).
Photographs by David S. Robinson (URI-GSO)

Embedded in the surface of the organic paleosols corresponding to a preserved subtidal remnant lowland area of the paleolandscape were four tree stumps in growth positions surrounded by extensive tree root mat (Figure 7-36). Next to one of the four stumps was about a 2-m long toppled trunk section lying embedded in the paleosols. Also observed and documented in the surface of the organic lowland paleosol was a possible hearth feature, consisting of about a 1-m diameter area of burned ground surface (Figure 7-37). Microscopic analysis of a sample of sediments from within this possible hearth feature found evidence of heated sediments and charcoal. Embedded in this burned area was a large piece of well-preserved, naturally shaped/broken, and charred wood. The burned area of the paleolandsurface and charred wood were surrounded by a concentrated assemblage of small cobbles that appeared to have been heated. Also present and associated with the possible hearth feature was a large primary flake of quartz chipping debris embedded in the surface of unburned organic paleosols, less than 1 m away from the possible hearth feature (Figure 7-37). This artifact and possible hearth feature together comprise the "West Beach UW-2" site, which was also reported to RIHPHC and entered into their archaeological site inventory as RI 2720, the second subtidal ancient Native archaeological site registered in Rhode Island waters.

Details about these different paleolandforms, the conditions that allowed them to be preserved, and the prevailing paleoenvironmental conditions that were represented on site were all noted and considered during the performance of the West Beach marine geoarchaeological fieldwork. Small samples of the different strata represented in the paleolandforms, including the exposed, burned surface of the paleosols within the potential hearth feature, the tree stumps, and the paleosols from which they had grown were collected for micro- and macroscopic analysis and AMS radiocarbon dating.

In addition to the systematic and non-patterned archaeological diver survey of the West Beach underwater archaeological sites, two 50-m transects extending seaward of the onshore low-relief upland areas containing archaeological sites were visually examined and video-documented to assess how much, if any, of these archaeologically sensitive upland coastal geological features and their cultural deposits were preserved across the beach and subtidal zone, and out into the water. In both cases, it was evident that the upland geological stratigraphy and the archaeological deposits that they contained had been completely removed by erosion. Only a small area of the basement stratum of glacial melt-out till was observed exposed from beneath marine sediments a short distance out into the water off of the RI 2623 location.

Coring operations were conducted in two locations within Wash Pond at locations that were 1) near its deepest central area that was thought to contain the thickest sediment record; and 2) on the pond's western edge, just beyond the slope of the over-wash sand deposit (Figure 7-38). These locations were chosen to provide the most complete paleoenvironmental and storm records possible. Both biological cores recovered adequately long sections and terminated in a stiff layer, precluding the need for additional cores of this type in the pond. Although biological core WP15-2Bio missed the sediment-water interface, WP15-1LC did not. A Livingston core was also taken at the western coring site, managing two drives for a cumulative recovered length of 130 cm. This core started from a depth of 74 cm (the upper section already represented by the biological core from this site) and consisted of two drives (74–176 cm and 176–204 cm). The water depths at the two coring sites were similar at approximately 2.1 m, the maximum observed depth of the pond. The Wash Pond cores were found to contain highly organic lagoonal mud with outwash sand in the upper sediments, particularly in the core sample from the more western coring site. These results indicate that Wash Pond is likely to have been one of the numerous seaward-reaching topographic lows interspersed between topographic highs in the northern Block Island paleolandscape that filled with water over time and remained wet as West Beach's inland-migrating dune zone formed a dam along the depression's western edge and trapped water within it.

Figure 7-36. Archaeological diver examining extensive subtidal area of preserved and exposed tree stumps and root mat visible embedded in the exposed surface of paleosols present in the vicinity of the West Beach UW-2 Site (RI 2720).
Photographs by David S. Robinson (URI-GSO).

Figure 7-37. Charred wood (top image), burnt ground surface (middle image), and quartz chipping debris (bottom image) comprising the identified elements of the subtidal West Beach UW-2 Site (RI 2720).
Photographs by David S. Robinson (URI-GSO).

Figure 7-38. Location of sediment cores obtained at Wash Pond, Block Island, Rhode Island. WP15 designates the core name. The abbreviations “Bio” or “Liv” lindicates the type of coring system used. “Bio” is a biological-type coring system with < 2m coring capacity, which is optimized for use in flocculent or loosely compacted sediments and is designed to retrieve the sediment-water interface intact. “Liv” is a Livingston-type coring system, which can obtain longer cores by recovering 1–1.5 m core sections through multiple drives in the same cased hole.

Marine geophysical remote sensing survey operations in the subtidal portion of the West Beach study area utilizing the Edgetech 6205 side-scan sonar system, Benthos CHIRP III sub-bottom profiler system, and the Applanix POS MV positioning system were run at a trackline spacing of 30 m with the side-scan sonar system’s range set at 25 m, producing a total potential swath width of 50 m, dependent on water depth. The CHIRP sub-bottom profiler was run at a 63-ms repetition rate and towed 10–15 m aft of the survey vessel’s stern. The side-scan sonar system was successful in acquiring high-resolution acoustic imaging (side-scan and bathymetric data) (Figure 7-39) from the surface of the sea floor in the subtidal portion of the West Beach study area, with bedforms, such as scour marks and sand waves, easily observed in both datasets. The CHIRP’s penetration was limited due to the coarse seafloor geology (i.e., sand, gravel, cobbles, and boulders) visibly prevalent in the area, as well as the thin or absent veneer of sediments overlying the hard basement stratum of concrete-like glacial melt-out till observed in the area by the project’s archaeological divers.

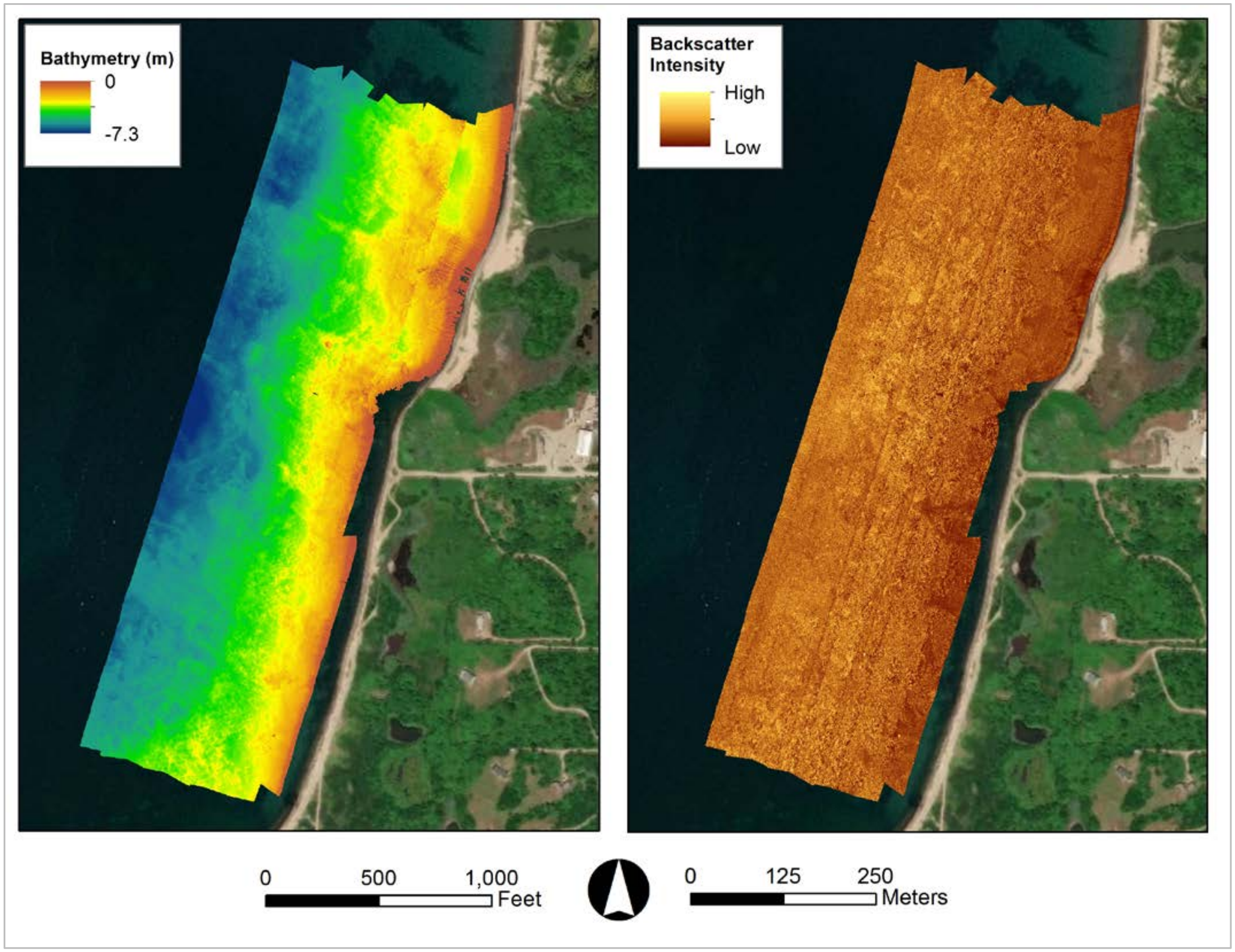


Figure 7-39. Bathymetry and side-scan sonar mosaic from West Beach study area, Block Island, Rhode Island.
Both images benefit from magnification to visualize the details of the data.

Coring locations within the subtidal portion of the West Beach study area were selected after reviewing the processed side-scan data to identify fine-grained areas. When arriving at the coring locations, it was determined that the seafloor geology was too coarse for both biological cores and vibracores. After physically probing the seafloor in numerous locations to find sites adequate for coring, coring operations were abandoned, and no cores were collected.

7.2.4 Implications for Predictive Modeling

Terrestrial archaeologists conducting site identification surveys in 2015 along West Beach were able to observe, examine, and identify archaeological sites onshore within the upland and lowland paleolandscape stratigraphy in the back-beach zone that was recently exposed in plan and profile by Hurricane Sandy's powerful winds and waves. The project's diving archaeologists were able to observe in West Beach's intertidal and subtidal zones the preserved lowland element of this same paleolandscape stratigraphy, presumably exposed and visible also because of the recent erosion caused by Hurricane Sandy. The implications for predictive modeling resulting from the geoarchaeological investigation of the West Beach study area may be summarized as follows:

- Sea level rise and the concomitant process of shoreface retreat appears to have the greatest impact on upland geological formations, which were observed at West Beach to be completed eroded and absent from the explored intertidal and subtidal stratigraphy.

- In contrast, lowland elements of the paleolandscape (i.e., the margins and basins of coastal ponds, marshes, and swamps) were found to be preserved. Preservation of these lowland areas is hypothesized to be the result of multiple factors that include the following: the degree of protection afforded by their local pre-inundation topographic situation; the rate of sea level rise and the slope of the seafloor—rapid inundation through stepwise retreat of the shoreface causing the erosive surf zone to jump inland of the flooded topographic low; the infilling and burial of the submerged low by displaced upland sediments; and the armoring effect of the thick root mat of peaty deposits in the upper stratigraphy of lowlands.

- Well-drained, upland paleolandforms are typically among the most archaeologically sensitive areas identified in onshore archaeological predictive models. Their absence from the intertidal and subtidal stratigraphy indicates that any model developed for a submerged oceanic context is going to need to be significantly different from existing models developed for onshore contexts. Greater consideration needs to be given to the types and range of past human activities that may be represented in the archaeological record found in the preserved elements of the paleolandscape's lowlands and margins of water bodies when modeling archaeological sensitivity in a submerged context.

7.3 The Mud Hole

7.3.1 Introduction and Goals

The Mud Hole is an anomalously deep (up to 60 m) elongated depression in the seafloor at the southern edge of the Rhode Island Sound, located approximately 15 km southeast of Block Island, RI (Figure 7-40). The long axis of the trough is oriented approximately SW-NE, measuring 30 km in length and approximately 8 km wide along the shorter axis. The trough is shallower and broader towards the north, becoming deeper and branching into two distinct channels towards the south. Adjacent to the Mud Hole's west and east margins are submerged segments of the Block Island-Martha's Vineyard terminal end moraine, which delineate the maximum extent of Late Wisconsinan glacial ice. These end moraine segments are the result of glaciotectonic upthrust of older sediment and till (Poppe et al. 2012) and currently form bathymetric highs compared to the surrounding seafloor, at approximately 30- to 35-m depth. The Mud Hole interrupts these broad ridges as a bathymetric low.

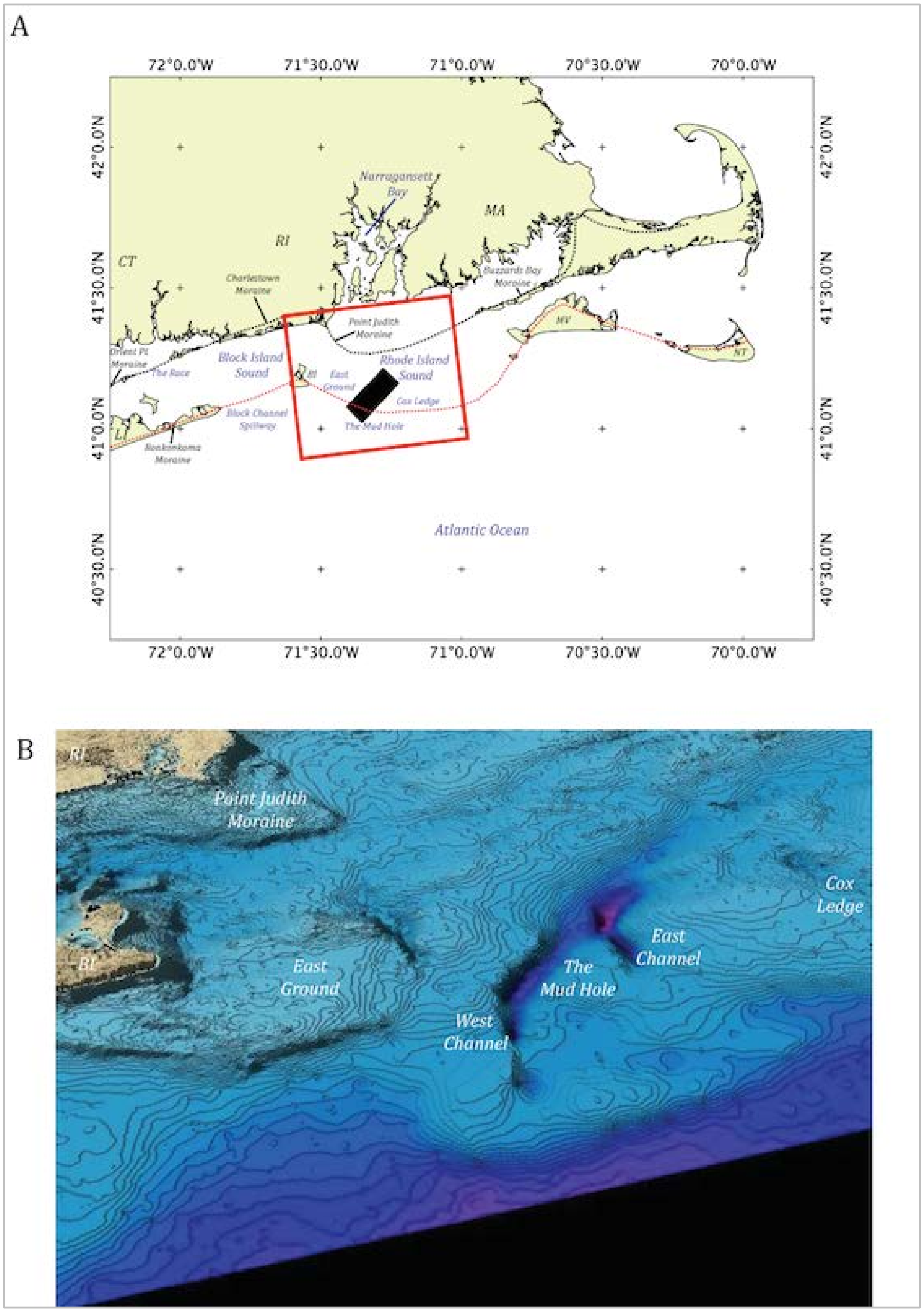


Figure 7-40. Illustrations of the Mud Hole study area.
(A) Overview map showing the position of the Mud Hole (black inset), Late Wisconsinan terminal end moraine (dashed red line), recessional end moraine (dashed black line), and adjacent water bodies. (B) Fledermaus scene depicting the bathymetry of the Mud Hole and related bathymetric features.

The deglacial chronology of the Rhode Island Sound can be summarized in three distinct phases, with the Mud Hole potentially playing a key role in determining how the paleolandscape transformed.

1. **Formation of Glacial Lakes:** Glacial ice began its retreat from its maximum extent at the terminal end moraine. Meltwater became trapped north of the terminal end moraine, forming large glacial lakes in the Rhode Island, Block Island, and Long Island Sounds (Bertoni et al. 1977; Lewis and Stone 1991). Lake levels were controlled by erosion at spillways and isostatic rebound. There is ample evidence that glacial lakes had formed behind the terminal end moraine in present-day Rhode Island, Block Island, and Long Island Sounds; evidence includes direct sampling (e.g., Bertoni et al. 1977) and inferences from seismic reflection data (e.g., Needell et al. 1983a, b, c; Lewis and DiGiacomo-Cohen 2000). The proximity of the Mud Hole to the southern edge of glacial lake Rhode Island and its low topography have led to the hypothesis that it served as a spillway for glacial lakes that once occupied present-day Rhode Island Sound following the retreat of glacial ice (Oakley 2012).

2. **Drainage of Glacial Lakes**: It is reported that glacial lakes of the inner continental shelf mostly, if not completely drained by approximately 15,500 yBP, leading to subaerial of exposure of the lakefloor (Lewis and DiGiacomo-Cohen 2000). Isostatic rebound likely accelerated lake drainage. As erosion at the Mud Hole continued, lake levels would have continued to lower. With the Mud Hole serving as a topographic low, it may have remained a small post-glacial lake longer than the rest of the Rhode Island Sound.

3. **Marine Transgression:** Rising eustatic sea level during deglaciation advanced the shoreline from its -120 m position at the edge of the continental shelf to its modern-day position. Due to its depth, the Mud Hole would have been inundated earlier than the rest of the Rhode Island Sound, and may have also transitioned to a quiescent marine setting, diminishing the erosional effects of marine transgression and leading to better chances of preserving older sediments. Conversely, if the Mud Hole served as a chokepoint for the proto-Rhode Island Sound, tidal currents may have scoured and deepened the Mud Hole.

Critical to understanding the potential for preservation of terrestrial paleolandscapes and/or paleocultural resources is whether the Mud Hole was deepened prior to or following marine inundation. It was hypothesized that deepening of the Mud Hole by fluvial processes would have caused it to flood more quickly during marine transgression, creating an environment more conducive to preservation. If additional deepening occurred due to tidal scour, much of the underlying sediment may have been eroded, with little potential preservation of terrestrial paleolandscapes or paleocultural resources. The potential for the preservation of pre-inundation sediments sets the Mud Hole apart from most other areas of the inner continental shelf, where it is expected that up to 2 m of sediment may have been eroded due to marine transgression (Koteff et al. 1993). For this reason, the Mud Hole was selected as a study site to assess paleocultural sensitivity in an offshore setting.

The following goals were outlined to help address the Mud Hole's paleocultural sensitivity and potential for preservation of paleolandscapes:

- Determine how strongly the seismic stratigraphy from the CHIRP seismic reflection data correlates with the existing geologic framework for the Rhode Island Sound

- Investigate if the high-resolution geophysical data support the hypothesis that the Mud Hole served as a spillway

- Better understand how significantly episodes of erosion and deposition have modified the post-glacial landscape

7.3.2 Field Methodology

A suite of geophysical data including interferometric side-scan (swath bathymetry and backscatter) and CHIRP seismic reflection data were collected in August 2012 on the EPA operated Ocean Survey Vessel (OSV) Bold. The combined Teledyne Benthos C3D/CHIRP III pole-mounted sonar system allowed for simultaneous collection of interferometric and sub-bottom data, respectively. Data from a total of 37 survey lines spaced 500 m, trending WNW–ESE, surveyed perpendicular to the deep channel-like portions of the Mud Hole were collected (Figure 7-41). No data from crossing lines (lines run perpendicular to the trend of the survey) were obtained. Side-scan swath width was approximately 500 m, providing nearly complete coverage of the study area. Bathymetric swath width was significantly narrower than side-scan swath width, depending on water depth. Data acquisition was controlled by OIC GeoDAS software for the interferometric side-scan data. Chesapeake Technologies SonarWiz software was used for CHIRP seismic reflection data acquisition. Position, heading, attitude, heave and velocity data were obtained by an Applanix POS MV Inertially aided Real-Time Kinematic Global Positioning System. Nearly 260 km of sub-bottom data and ~130 km^2 of interferometric side-scan data were collected. CHIRP seismic reflection data achieved a maximum of 90 m penetration. The system produced a CHIRP waveform with a 2–7 kHz frequency band transmitted at a 1/8 second repetition rate. Raw data were recorded in SEG-Y format. Interferometric side-scan raw data were recorded in .OIC file format (Ocean Imaging Consultants proprietary file format).

Vibracoring operations took place in August 2015 during the RIEP EN-565 cruise aboard the R/V *Endeavor*. The cruise began with geophysical surveying in Block Island Sound on an unrelated effort. On August 25, and the R/V *Endeavor* transited to the Mud Hole study area and coring operations began. Prior to deployment, the Rossfelder P-3 Vibro-Percussive coring system was prepared and assembled. Plastic core liners were inserted into the 6-m core barrels. The core barrel, cutter, and catcher were assembled and attached to the vibracore head. To ensure that the entire vibracoring assembly remained upright in deep water during deployment and recovery, a purpose-built assembly with a series of weights and floats was utilized. The entire coring assembly was then deployed aft of the stern, using a cable winch run through the stern A-frame. Two deck-mounted air-tugger winches were used in tandem to prevent the coring assembly from swinging with vessel motion. As the vibracoring system was being deployed, diligent field notes were kept noting latitude/longitude, water depth, time, and measurements of cable tension. Just before the vibracoring system reached the bottom, the system was powered on. The cable out and cable tension were monitored to determine when a full core/refusal was achieved. Before recovery, the vibracore system was powered off. Once on deck, the core barrel assembly was removed from the vibracore head, and the core liner extruded from the core barrel. The recovered sediment length was measured, and the core was packaged and placed in cold storage. These vibracoring methods were repeated at each subsequent station. Coring operations were continued during daylight hours and lasted until Thursday, August 27, with 16 cores attempted and 15 successfully recovered (Figure 7-42). At the end of coring operations, each vibracore was cut into 1.5 m segments and was labeled and packaged for transport back to URI-GSO.

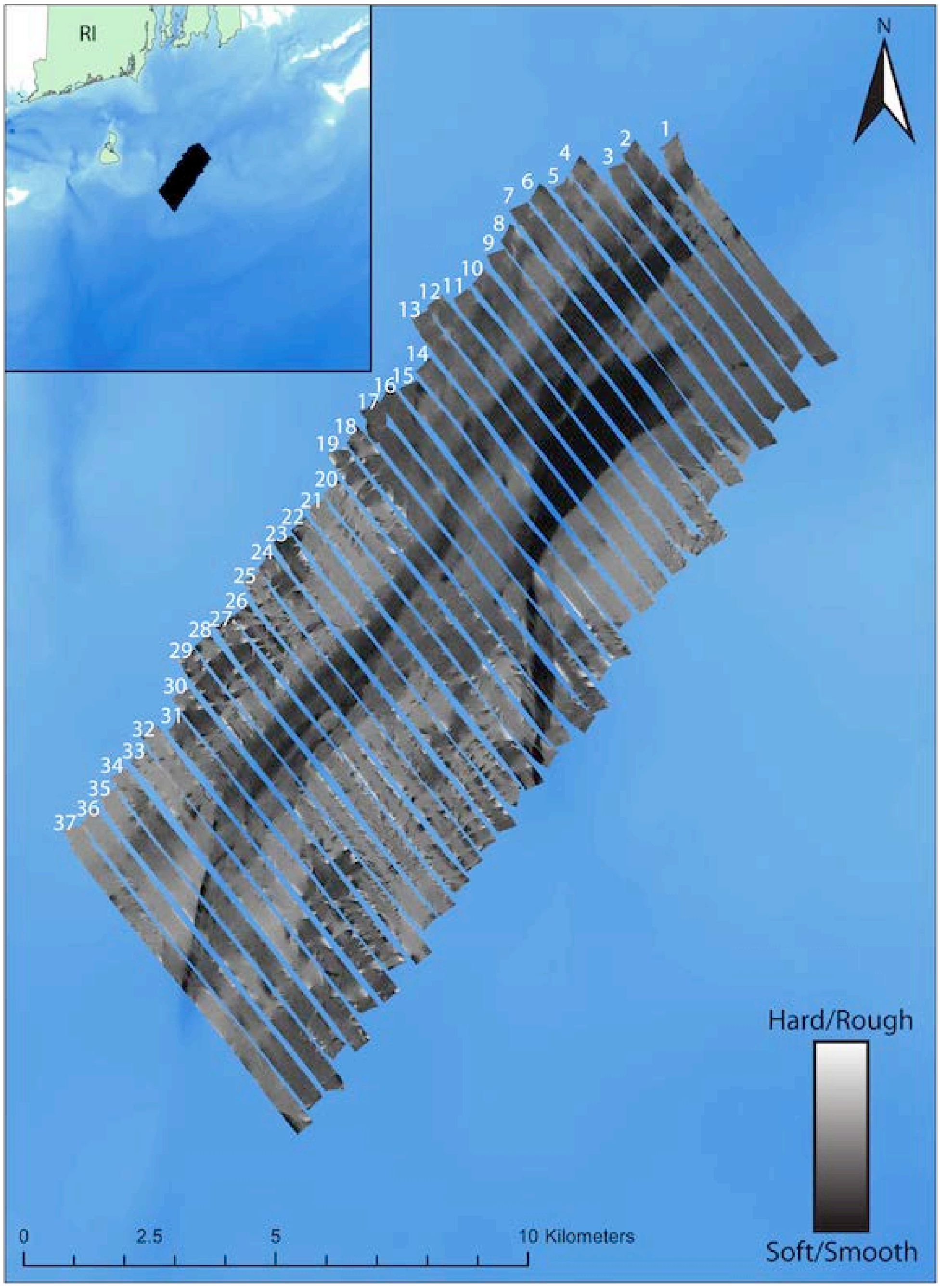


Figure 7-41. Coverage map of high-resolution geophysical data collected by the URI Graduate School of Oceanography in August 2012.

The data includes interferometric sonar and CHIRP seismic reflection profiles. Shown in this figure is a mosaic of side-scan imagery overlaying the RI Ocean SAMP RI Coastal Bathymetry raster dataset produced by the University of Rhode Island's Environmental Data Center. Numbers correspond to the survey lines, referred to within this text.

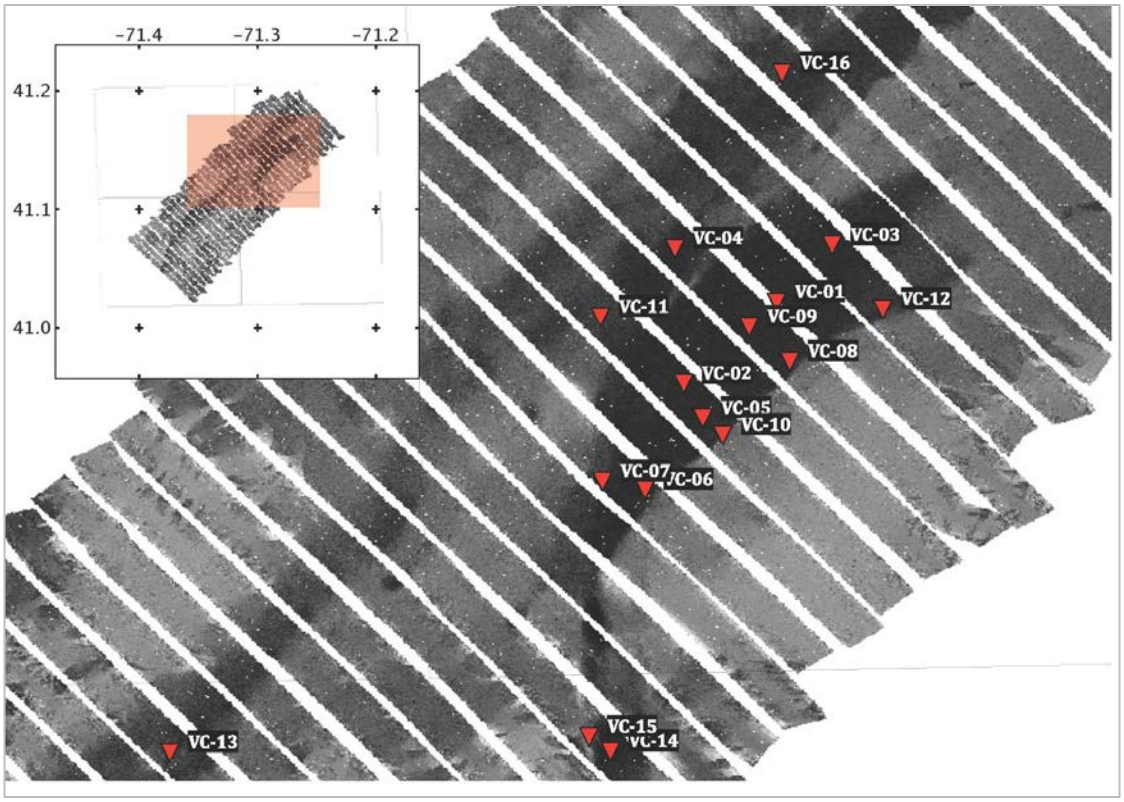


Figure 7-42. Map showing the locations of vibracores collected by the R/V *Endeavor* (cruise EN-565) from the Mud Hole study area.

7.3.3 Results

7.3.3.1 Data Processing

Sub-bottom profiles were processed in 2015 using Chesapeake Technology Inc. SonarWiz 5 processing software. Navigation data were inspected and fixes were calculated for each of the 37 sub-bottom profiles where applicable. Each profile was bottom tracked and processed to adjust for signal attenuation and improve signal to noise using signal gains. Attempts were made to process out a persistent diagonal striping data artifact across all seismic images with no success. A 1,500 ms^{-1} sound velocity was used for all seismic images, a valid value for saturated and unconsolidated sediment. Seismic reflectors identified in each processed image were traced using the SonarWiz Digitize Reflectors tool. The reflectors were also displayed in map view such that the 2D spatial extent and continuity of the reflectors could be ascertained.

Side-scan data had been previously post-processed shortly following the *Bold* 2012 cruise using OIC CleanSweep. Each swath was bottom tracked, and across track signal gains were applied to compensate for signal attenuation. Look-up tables were used to compensate for along-track variability in color. Side-scan swaths were mosaicked at 1-m pixel resolution and exported as a GeoTIFF spatially referenced in the Universal Transverse Mercator (UTM) Zone 19N projected coordinate system. Two interpretative maps were generated in ESRI ArcMap 10 software: backscatter and surficial sedimentary environments by delineating changes in backscatter and bedforms respectively (Figure 7-43, Figure 7-44).

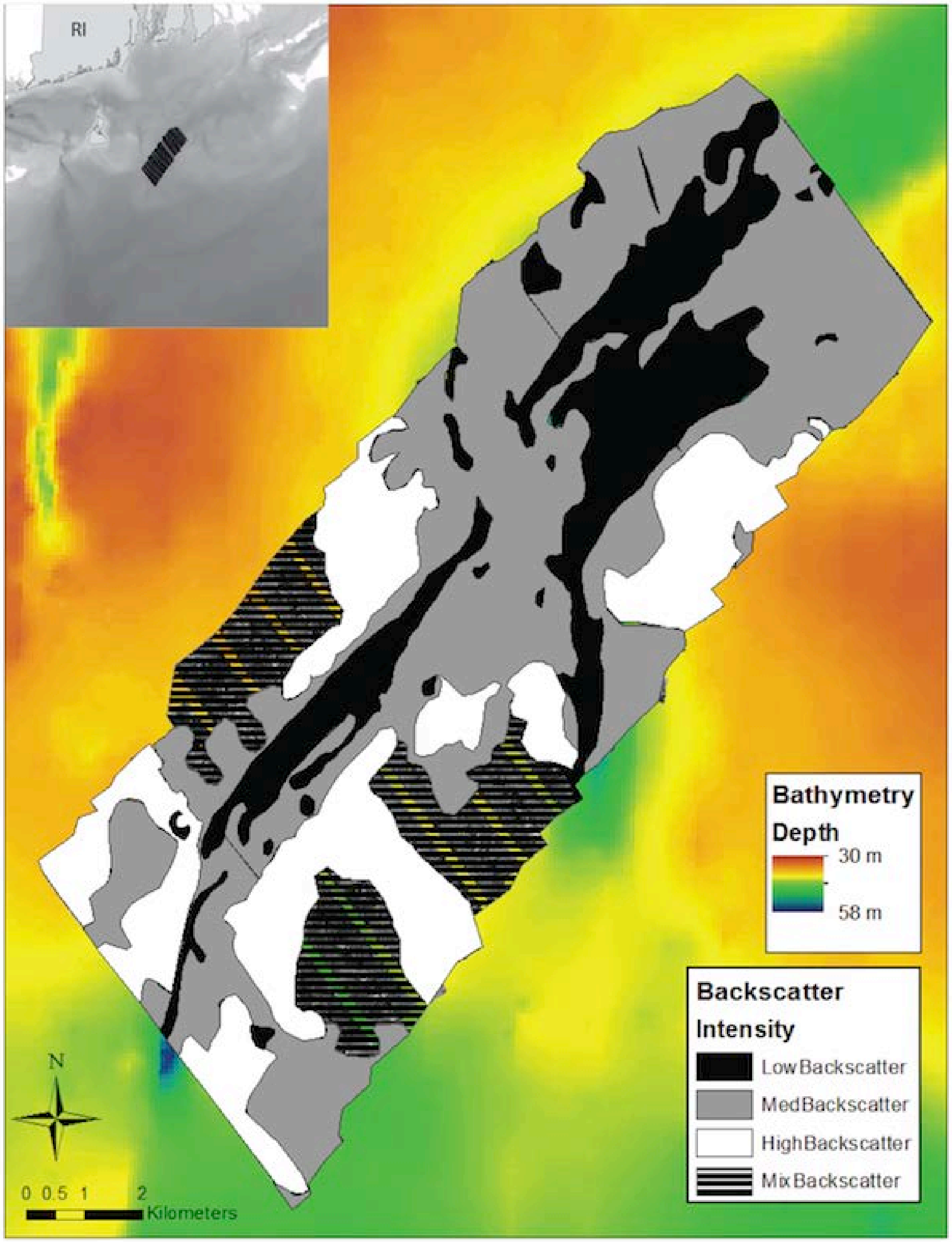


Figure 7-43. Characterization of backscatter intensity from side-scan imagery.

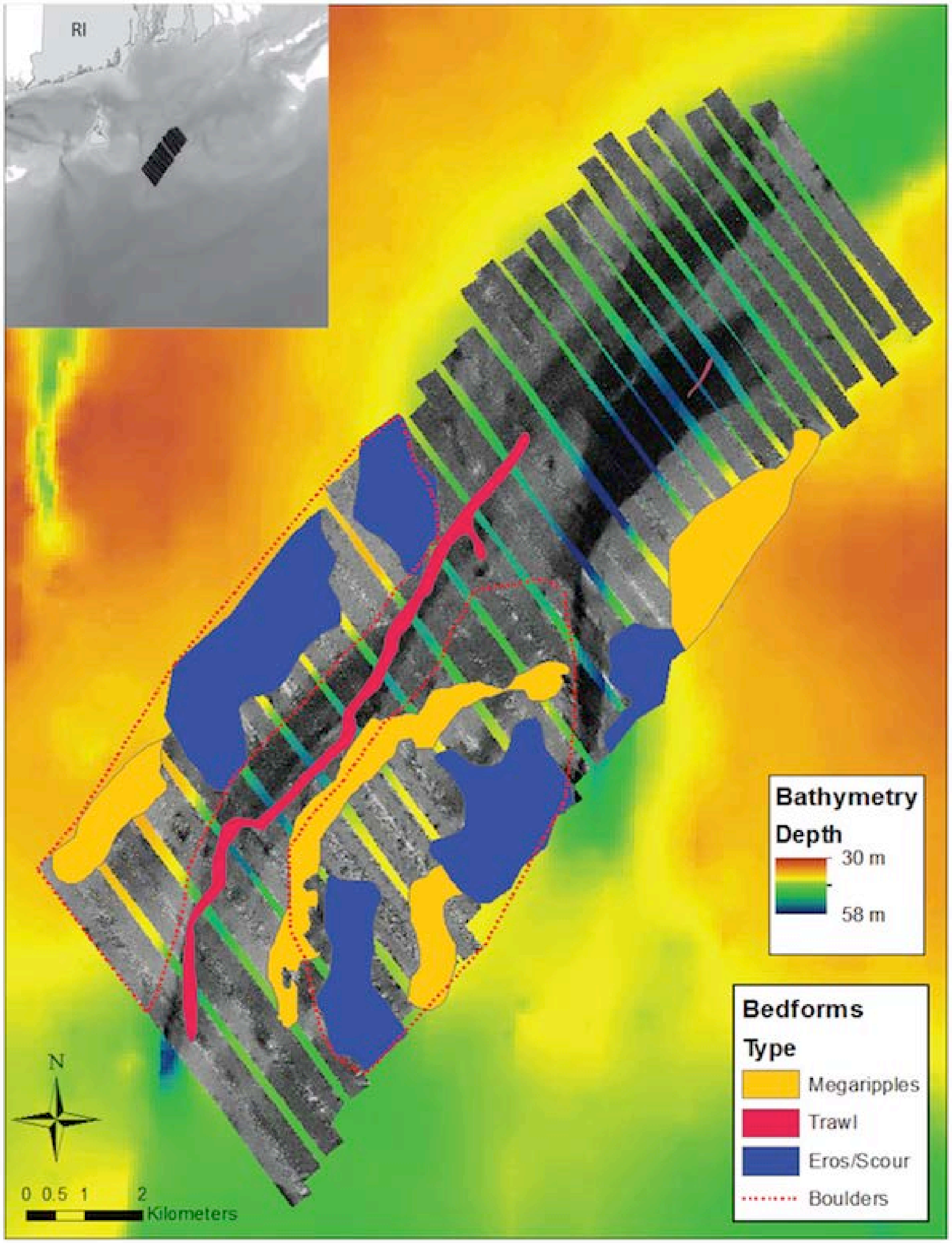


Figure 7-44. Mapped spatial extents of sedimentary features identified in side-scan imagery.

Several types of bedforms and sediment features were identified in the side-scan mosaic. Megaripples, defined as sandwaves with wavelengths between 2–20 m, and crest-to-trough heights of 0.6–2 m were prominent in shallower portions (< 40 m depth) of the study area. Megaripples indicate a sedimentary environment in which the seafloor is being actively reworked due to unidirectional current flow. The WNW–ESE trend of the megaripple crests suggests a NNE migration direction, likely due to storm-induced bottom currents. Erosional outliers and scour depressions were commonly observed in the souther half of the study area, at depths shallower than 40 m and in areas of mixed backscatter intensity. These scour depressions were characterized by having higher acoustic backscatter compared to the surrounding seafloor and are crescent shaped. It is speculated that the coarse, rough seafloor causes turbulent bottom current flow, enhancing erosion and inhibiting deposition. Boulders are distributed primarily in the southern portions of the study area, with the exception of the deepest locations. They can be identified in the side-scan imagery as highly reflective points, creating a speckled seafloor appearance. Trawl marks were also identified in areas of low backscatter and are mostly confined to the deepest, fine-grained portions of the study area, where sediment reworking and deposition allow for preservation of these anthropogenic features.

7.3.3.2 Identified Sediments and Correlation with Geologic Framework

Several seismic reflectors and seismic units were identified within the Mud Hole study area. Acoustic penetration was highest where surficial sedimentology was predominantly fine-grained. In coarse sediment, particularly in the southern portion of the study area, signal attenuation limited penetration approximately 5–10 m below seafloor. Identified reflectors and sedimentary units were correlated to the regional seismic stratigraphy developed in earlier studies (Needell et al. 1983a) and the naming convention remains consistent.

Ku and Reflector fu$_2$: Ku is the lowest observed sedimentary unit within the Mud Hole study area. The internal character is unknown due to lack of acoustic penetration beyond reflector fu$_2$, and thus only the surface of Ku can be characterized. Ku varies in depth from nearly outcropping (Figure 7-45) to greater than 90 m below sea level, where it can no longer be resolved. Ku is interpreted to be the highly eroded coastal plain remnant. The coastal plain strata are composed of semi-consolidated to unconsolidated marine sands, silts, and clays that were primarily deposited in the Late Cretaceous Period (Flint 1963; McMaster et al. 1968; Sheldon 2012). Early lower resolution but more deeply penetrating seismic reflection studies report parallel internal bedding distinctive of coastal plain sediments, none of which was observed in this study (McMaster et al. 1968). Correlation with Ku is therefore limited to stratigraphic position and expected depth to the truncated surface. Previous works within the Rhode Island Sound report a similar depth to the coastal plain surface in the vicinity of Block Island (McMaster and Ashraf 1973c).

The deepest reflector identified within the study area, fu$_2$ is inferred to be an erosional unconformity, incising Ku. The surface is strongly reflective and strongly attenuates the seismic signal. Reflector fu$_2$ is only traceable in the northern half of the study area due to lack of acoustic penetration elsewhere. It is characterized as a smooth, shallowly westward dipping surface in the northern study area becoming a deep channel. The character of fu$_2$ becomes more obscured towards the south and eventually is no longer visible due to the coarse surficial geology attenuating the CHIRP seismic signal. fu$_2$ represents the fluvially eroded surface of the underlying coastal plain strata during eustatic sea level lowstands of the Late Tertiary and Early Quaternary periods and subsequent widening and deepening by episodic glaciations during the Pleistocene Epoch. North of the Mud Hole, Fu$_2$ forms the north facing cuesta. The possibility that reflector fu$_2$ could represent an erosional contact between the most recent glacial deposits and pre-Wisconsinan glacial deposits has been considered, and without direct sampling cannot be fully ruled out. However, the alignment of the valley axis defined by fu$_2$ and the direction of glacial advance suggests that the most recent Wisconsinan glaciation would have likely removed most if not all of the earlier glacial deposits and continued to widen and scour the pre-glacial valley. In addition, pre-Wisconsinan glacial deposits have only been found locally outcropped on the outer islands (Long Island, Block Island, Martha's Vineyard, Nantucket), due to glaciotectonic upthrust of pre-glacial material (Poppe et al. 2012). The study area is dissimilar to this geologic configuration, and thus the interpretation that fu_2 represents an erosional unconformity separating pre-glacial and glacial deposits is favored.

Sedimentary Unit Qdo, Qdm, and Discontinuity fu_1: Sedimentary unit Qdo unconformably overlies Ku and shows considerable thicknesses (up to 45 m). The internal character of Qdo exhibits continuous parallel internal reflectors (Figure 7-45). The thickness of seismic unit Qdo is generally controlled by the depth of fu_2, and thus the deposits are thickest where fu_2 assumes a deep incised valley configuration. Regional seismic reflection studies have considered glacial deposits as one seismic unit, Qdo; however, these studies recognized that the glacial deposits (Qdo) are made up of unconsolidated tills, stratified outwash and glaciolacustrine deposits (O'Hara and Oldale 1980; Needell et al. 1983a, b, c; Needell and Lewis 1984). The closely spaced, rhythmically layered, continuous internal reflectors draping the underlying topography are diagnostic of glaciolacustrine sediments. Qdo is interpreted to be pro-glacial delta/lakefloor deposits composed of varved silt and clay. As the ice sheet retreated, meltwater became impounded north of the terminal moraine deposits, flooding areas of low topography

Sedimentary unit Qdm overlies discontinuity fu_2 south of seismic reflection line 18. Acoustic penetration is significantly reduced due to coarse surficial geology, making it difficult to determine the thickness of Qdm; however, the internal character is observed in several sub-bottom profiles as discontinuous stratification and chaotic and parabolic internal reflectors (Figure 7-46). Qdm is composed of unconsolidated till and glaciotectonically upthrust sediment deposited as portions of the terminal end moraine as the Late Wisconsinan ice sheet reached its terminal position approximately 26 kyBP.

Reflector fu_1 truncates Qdm, forming two distinct paleochannels (west and east). The depth of fu_1 is approximately 60 m and nearly constant wherever observable in the study area. Both the western and eastern paleochannels are observed in the southern half of the study area and become progressively narrow towards the south. The reflector fu_1 represents a fluvial unconformity that cuts into the underlying glaciolacustrine sediment as glacial lakes drained through the spillways to the south. At the Mud Hole, fu_1 represents the spillway that cuts through the end moraine (Qdm).

Sedimentary Unit Qfe, Discontinuity mu, and Seismic Unit Qpt: Sedimentary unit Qfe overlies reflector fu_1, partially filling the paleochannels. The base of Qfe is strongly reflective, with hummocky, chaotic, and discontinuous internal reflectors. This lowermost channel fill obscures the true channel depth. Acoustically transparent sediment overlies the strongly reflective fill, and is < 5 m in thickness. Qfe is interpreted as a transgressive sequence consisting of channel-fill sand, silt and clay, freshwater peat and marsh, and estuarine silt and clay (O'Hara and Oldale 1980; Needell et al. 1983a, b, c; Needell and Lewis 1984). Qfe represents a transition from an erosive fluvial environment to an estuarine depositional environment as marine inundation began. It is likely that the lower portion of Qfe partially fills the spillway channels with channel-fill gravel, sands, and silts. Presumably diachronous estuarine deposits composed of finer silts and clays overlie the emplaced channel fill, as sea level began to inundate the study area.

Reflector mu is a prominent reflector in the northern half of the study area characterized as a continuous, smooth surface that truncates seismic unit Qdo. This reflector forms a channel beginning with seismic reflection line 8 (reaching a maximum depth of 70 m) to line 16 (up to 60-m depth); it is not observable in any lines to the south. Reflector mu represents the wave-cutting ravinement with marine transgression and tidal scour in the eastern channel where depths reach 70 m.

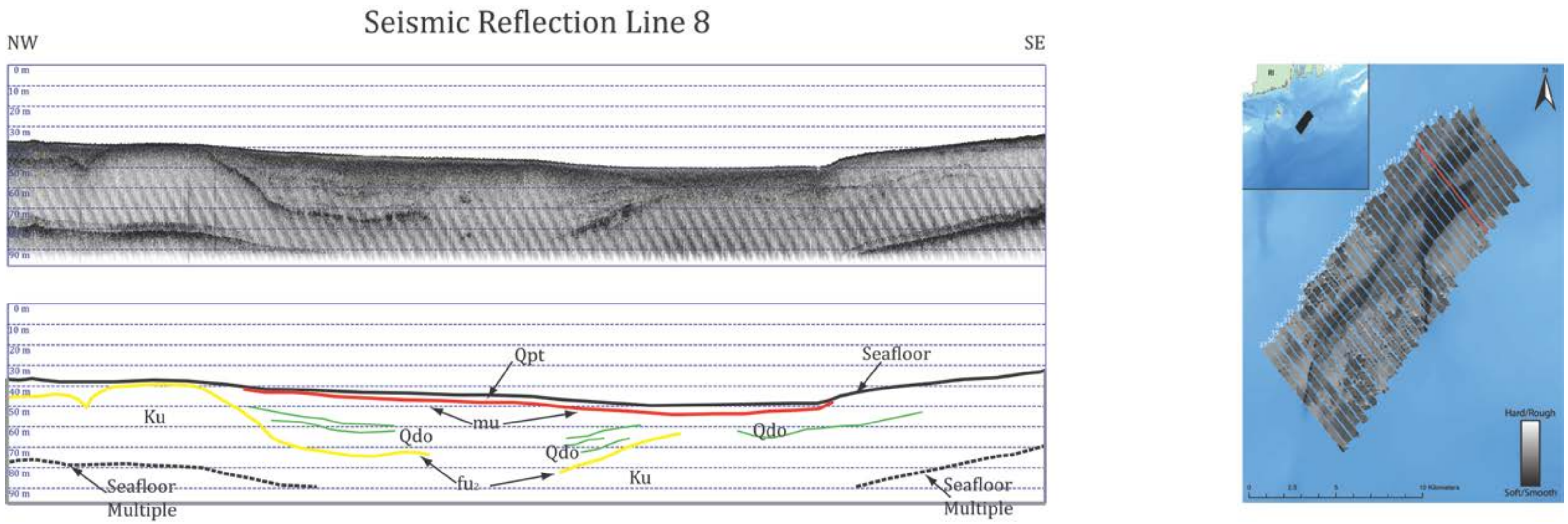


Figure 7-45. Processed seismic reflection line 8, with interpreted seismic reflectors.
Trackline location is highlighted in red on the index map at right. See text for explanation of discontinuities and seismic units.

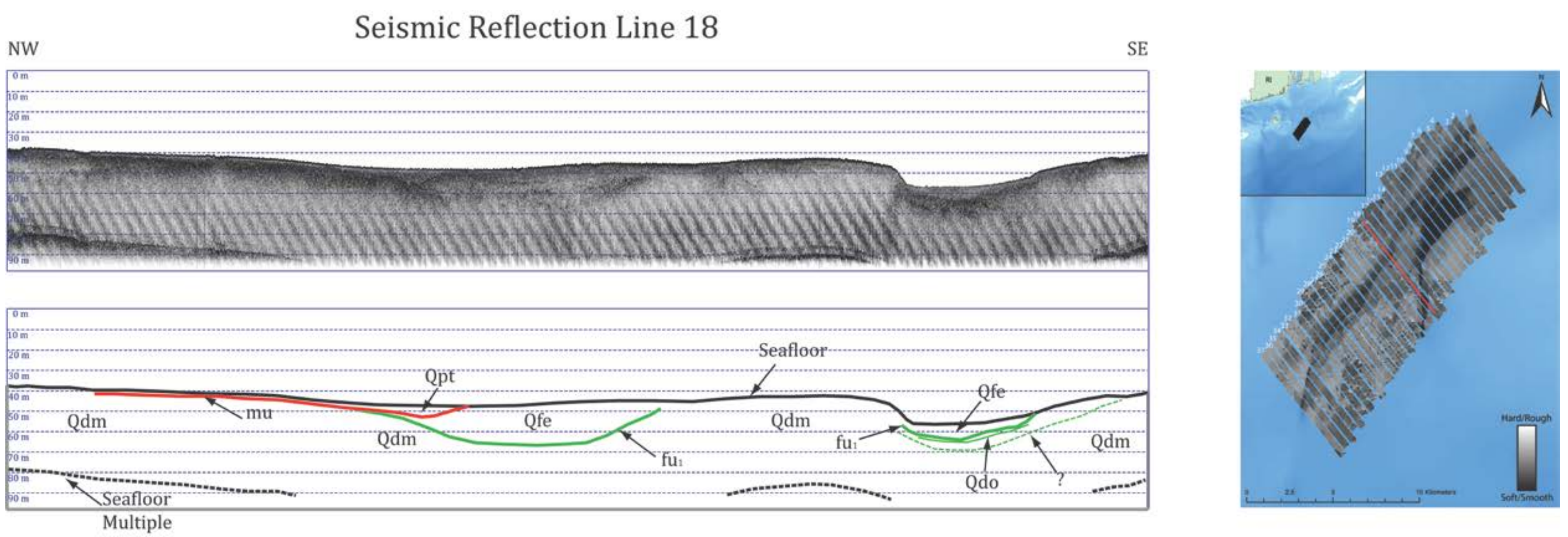


Figure 7-46. Processed seismic reflection line 18, with interpreted seismic reflectors.
Trackline location is highlighted in red on the index map at right. See text for explanation of discontinuities and seismic units.

Sedimentary unit Qpt is nearly acoustically transparent and homogenous though some discontinuous, flat-lying internal reflectors occasionally are seen. With the exception of the channel cut by mu, where Qpt thickens ~12 m and most of this seismic unit is no thicker than 1–2 m. Qpt is not observed where seafloor depths < 40 m. Qpt is interpreted as a drape of fine-grained sand and silt deposited as the Mud Hole transitioned to a low energy marine setting during the Holocene. Qpt was directly sampled by vibracores and found to contain fine sand and silt, shells, and shell fragments (Figure 7-47).

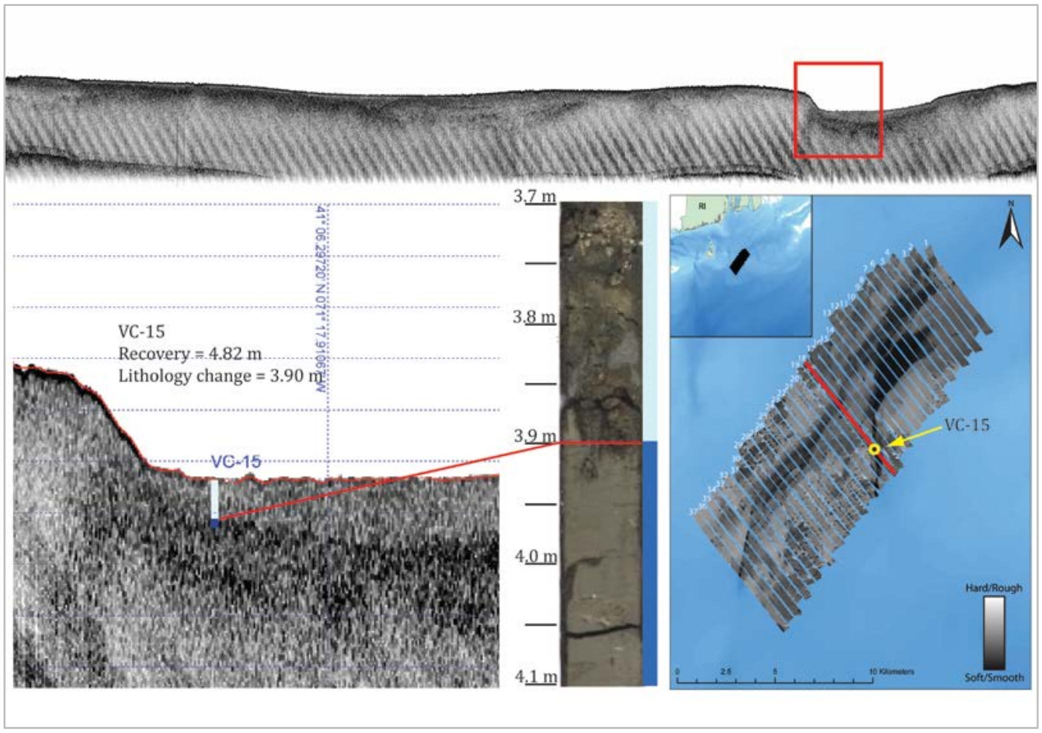


Figure 7-47. Vibracore VC-15 location and depth plotted against seismic reflection line 18.
A lithology change from marine/estuarine sediments to glaciolacustrine sediments occurs at a sub-bottom depth of 3.90 m.

7.3.4 Implications for Predictive Modeling

Several of the sedimentary units and reflectors observed within the Mud Hole study area can be considered for paleocultural sensitivity. Ku and fu_2 underlie glacially deposited sediment, and therefore do not represent a landscape that would have existed during human habitation. Qpt is also disqualified from sensitivity as it represents sediment that had been deposited after marine conditions had been established at the Mud Hole. Qdm is potentially sensitive; however, assessment of surficial geology and bedforms indicate that the moraine deposits have been reworked by modern bottom currents. Preservation potential is thus thought to be low. These constraints leave only Qdo and Qfe as potentially sensitive sedimentary units with some caveats. Qdo, characterized as glaciolacustrine and moraine sediment, would only become sensitive following lake drainage and subaerial exposure of the lakebed. Assuming the lake had drained completely from the Mud Hole, ravinement and subsequent tidal currents (mu) eroded and reworked the terrestrial landscape. It appears that the disturbance may have been accentuated in the east channel of the Mud Hole, where up to 10 m of Qdo may have been eroded. The depth of the east channel reaches 70 m, shallowing southward to 60 m at the spillway. This positive N-S gradient is incompatible with stream drainage, and it is thought that tidal scour occurred before sea level overtopped the adjacent moraine segments. Similarly, Qfe has some potential for sensitive sediments, particularly any sediment identified as fluvial. Fluvial processes are erosional at stream thalwegs, or during high flow, but can form stratified deposits at the margins and in a floodplain.

In addition to the spatial considerations for paleocultural sensitivity, there are also temporal considerations that rely on a well-constrained deglacial chronology. The Mud Hole study area is first considered to be habitable when glacial ice had retreated north of the study area. A conservative estimate of the onset of habitability is 21,000 yBP, when the ice margin was well north of the Mud Hole at the Charlestown-Point Judith recessional end moraine position (Oakley and Boothroyd 2012). The end of habitability is controlled by RSL rise and inundation of the study area. Earliest inundation, and the establishment of estuarine conditions at the Mud Hole is constrained between 12,800 and 10,700 yBP based on the southern New England RSL curve and backstripping of marine sediments (Table 7-3). Full inundation of the Mud Hole study area occurred when sea level reached -35 m, constrained between 10,800 to 8,000 yBP. The date range from 21,000–8,000 yBP represents the maximum period of time in which habitable conditions existed at least in part of the Mud Hole study area, however, the habitability of one particular location would likely have been transient as the basin evolved. The following outlines the limitations to habitability in three distinct phases in the evolution of the Mud Hole while considering the large uncertainties that exist with the timing of marine inundation.

Table 7-3. Sea level rise models for the study area.

Publication	Location	Calendar Age (yBP)		Methods
		60 m below sea level	35 m below sea level	
Oldale & O'Hara 1980	SE Massachusetts	10,966 to 10,708	8,845 to 8,294	• Radiocarbon-dated peat and shells from vibracores • Calibrated agebased on original radiocarbon data were calculated by Caccioppoli (2015) using the CALIB v.7.1 software (Stuiver et al. 2019) • Range reflects error (2-sigma)
Oakley & Boothroyd 2012	Block Island	12,800	10,800	Best-fit curve of previous RSL studies and delayed onset of isostatic rebound based on paleolake water levels
Roy & Peltier 2015	Connecticut	11,500	8,400	Mantle viscosity model (VM6) and deglaciation model ICE-6G_C combined with Engelhart et al. (2011) RSL curves reconstructed from salt marshes
Roy & Peltier 2015	Long Island	10,800	8,000	Mantle viscosity model (VM6) and deglaciation model ICE-6G_C combined with Engelhart et al. (2011) RSL curves reconstructed from salt marshes

Phase 1: Formation of Post-Glacial Lake 21,000 yBP to 16,000 yBP: As the ice retreated from the recessional end moraine position 21,000 yBP, meltwater lakes were already forming in present-day Rhode Island Sound north of the end moraine segments. Lake water level control was shifted to the Mud Hole by 21,000 yBP with coalescence of Glacial Lakes Block Island and Rhode Island (Oakley 2012). Fluvial erosion formed the west and east spillway channels in the southern Mud Hole, the path through which the lakes drained towards the Atlantic Ocean. The Mud Hole study area was part of Glacial Lake Rhode Island, constraining the habitable area to the topographic highs along the moraines.

Phase 2: Accelerated Lake Drainage 16,000 yBP to 12,800 yBP: The interpreted acceleration of isostatic rebound of the glacially depressed land surface occurred ~16,000 yBP. The rebound tilted the land surface, accelerating the drainage of Glacial Lake Rhode Island. Glacial Lake Connecticut was drained by 15,500 yBP (Lewis and DiGiacomo-Cohen 2000), and because of the interconnectedness with Glacial Lake Rhode Island, a similar timing for drainage of Glacial Lake Rhode Island is inferred. Prior to marine inundation, much of the study area would be considered habitable if pro-glacial lake levels lowered significantly.

Phase 3: Transition to Estuarine Conditions 12,800 yBP to 8,000 yBP: According to local RSL rise curves, marine inundation reached the spillway depth of -60 m between 12,800 and 10,800 yBP and began to infiltrate the eroded spillways at the southern extent of the Mud Hole study area. Estuarine conditions that were originally confined to the thalwegs of the channels, inundated further into the proto-Rhode Island Sound. Tidal constriction due to the topographically higher moraines likely enhanced tidal scour of the eastern channel, eroding up to 10 m of glacial lakefloor sediment, to 70 m depth (10 m below spillway depth). Full marine conditions were established between 10,800 and 8,000 yBP, when sea level had risen to ~35 m below present, overtopping the glacial moraines and relaxing tidal constriction. Habitability of the Mud Hole study area began as early as 12,800 yBP after the complete drainage of Glacial Lake Rhode Island and prior to the beginning of marine inundation, and declined until the study area was fully inundated and uninhabitable.

7.3.5 Key Points

- The Mud Hole was selected as a submerged offshore study site for establishing best practices for assessing paleocultural sensitivity.

- 37 CHIRP sub-bottom profiles, side-scan, and 15 vibracores were obtained from 2012–2015 over two research cruises.

- The seismic stratigraphy from the CHIRP seismic reflection data correlated easily with the existing Rhode Island Sound geologic framework in Needell et al. (1983a, b, c). Several sedimentary units were identified:

    - **Ku**: Unconsolidated coastal plain sediment of Late Cretaceous age

    - **Qdo**: Glacial sediment from Late Wisconsinan glaciation, with potentially older glacial deposits, including glaciolacustrine, glaciofluvial, till and stratified outwash

    - **Qdm**: Glacial moraine sediment composed of till and stratified glacial outwash

    - **Qfe**: Post-glacial fluvial and estuarine sediment deposited after glacial lake drainage and as marine transgression began to flood the Mud Hole

    - **Qpt**: Marine sediment deposited when sea level had risen and the Mud Hole transformed into a low energy depositional basin

  Several seismic reflectors were also identified at the Mud Hole:

    - **fu_2**: Fluvial unconformity, incision of the coastal plain remnant during Tertiary and Early Quaternary Age, and additionally scoured by Pleistocene glaciation

- fu_1: Fluvial unconformity, incision of the Late Wisconsinan glacial surface during drainage of glacial lakes

- **mu**: Marine unconformity, ravinement due to Holocene marine transgression and locally due to tidal scour

- There is ample evidence that the Mud Hole served as a spillway for Glacial Lake Rhode Island. Two distinct channels were identified with spillway depths 60 m below present-day sea level. These channels cut through terminal end moraine segments, though they may have been modified by tidal currents during marine inundation.

- The post-glacial landscape has been modified significantly by several geological processes. First, drainage of Glacial Lake Rhode Island through the topographic low at the Mud Hole caused fluvial erosion in the spillway channels. Marine inundation appears to have further scoured the east channel of the Mud Hole, likely due to tidal scour when sea level had not fully overtopped the end moraine segments. This is evidenced by a marine backstripped depth of 70 m in the east channel, suggesting 10 m of localized erosion in that channel. Elsewhere, ravinement was probably negligible. There are thick marine deposits in the basin of the Mud Hole, exceeding 6 m thickness as is observed in the CHIRP sub-bottom data as well as verified by vibracores.

- Spatial and temporal constraints were placed on paleocultural sensitivity in the Mud Hole. Qdo, Qdm, and Qfe are considered to be potentially paleoculturally sensitive. The degree to which they are sensitive is dependent on how these sediments were modified by marine inundation and tidal/bottom currents. Qdm, composed of end moraine sediment, was likely eroded by ravinement and reworked by modern bottom currents. This is supported by the presence of bedforms in surficial geology. Qdo and Qfe where there was limited fluvial erosion (fu_1) or marine erosion and reworking (mu) are likely the most sensitive.

- Human habitation at the Mud Hole would have theoretically been possible following the retreat of glacial ice. By 21 kyBP, glacial ice had retreated to the Charlestown-Point Judith-Buzzards Bay end moraine position, which serves as a conservative boundary for human habitation at the Mud Hole. Glacial lakes formed in the present-day Rhode Island Sound and Mud Hole, and were thought to have fully drained by 15.5 kyBP. Between 12.8 and 8 kyBP, marine inundation progressively transitioned the Mud Hole to a shallow estuarine marine setting. Therefore, between 15.5 and 12.8 kyBP, the Mud Hole is thought to have been most conducive to human habitation.

7.4 The AMI

7.4.1 Introduction and Goals

The AMI is located in Federal waters approximately 25 km SE of Block Island and 45 km due south of the Sakonnet River (Figure 7-48). The study area is nearly square: 15 km (N-S) by 15 km (W-E). Water depths generally increase from north to south through the study area ranging from approximately 35 to 55 m. The bathymetry is generally featureless and absent of any large-scale features. The Mud Hole is immediately adjacent to the northwest of the study area. The northern portion of the AMI encompasses a submerged segment of the Block Island-Martha's Vineyard terminal end moraine consisting of deposits from the Late Wisconsinan icesheet at its furthest extent. It is here where the shallowest portions of the study area are found. Towards the south, depths increase with distance away from the end moraine segment.

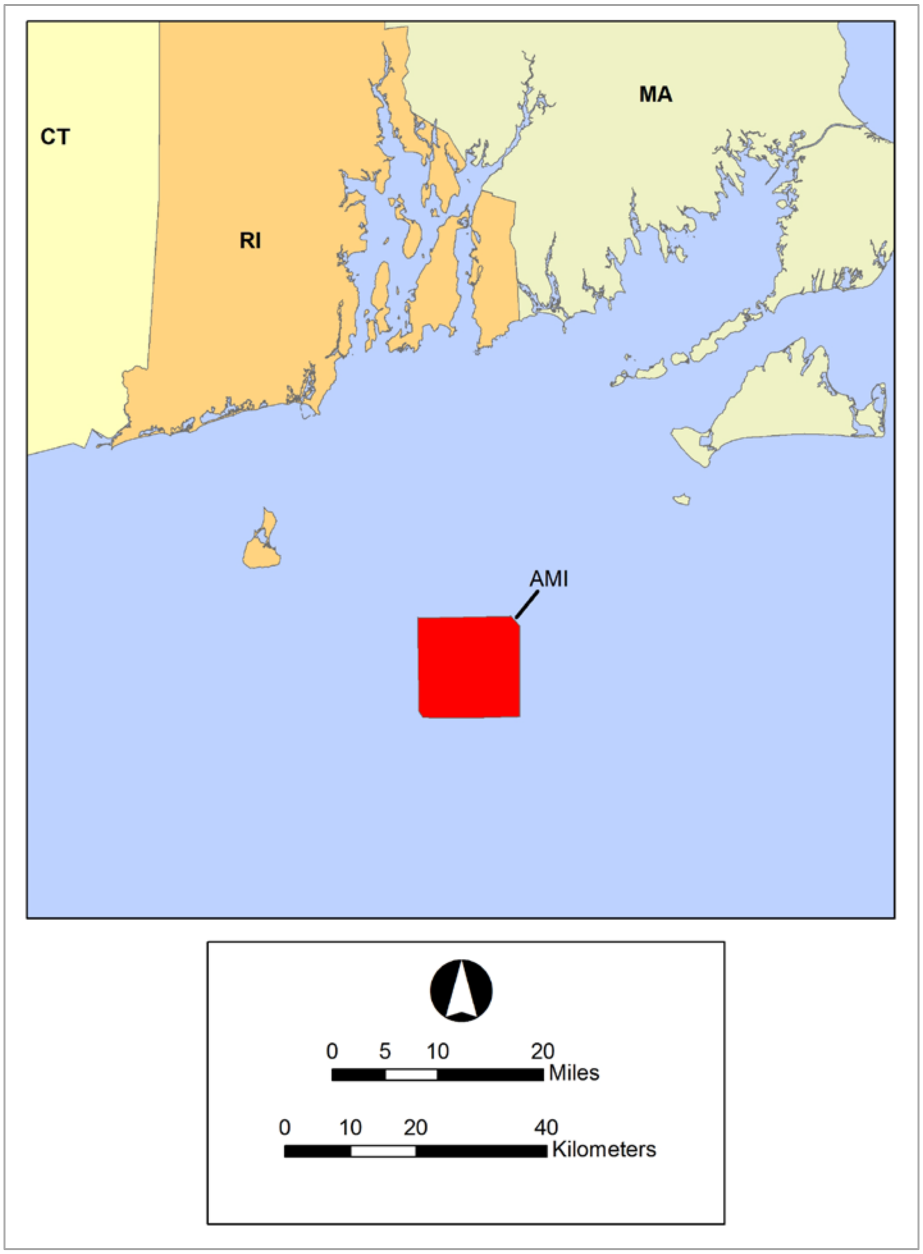


Figure 7-48. Location of the Area of Mutual Interest (AMI) study area.

The primary goal of the AMI study area was to investigate whether bathymetry can be used as a proxy for underlying paleolandscapes and to assess paleocultural sensitivity. Studies that rely exclusively on bathymetry for paleolandscape reconstructions with the assumption that the seafloor expression closely resembles the subsurface geology should be met with skepticism. Investigation of the AMI study area using a CHIRP seismic reflection system set out to address if areas with featureless bathymetry are indicative of a featureless subsurface. Similarly, the goal of this study was to determine if bathymetry can fully mask the presence of buried paleolandscapes in submerged areas. The results of these goals will help us judge just how predictive bathymetry is of underlying paleolandscapes.

7.4.2 Field Methodology

Interferometric side-scan (swath bathymetry and backscatter) and CHIRP seismic reflection data were collected in August 2011 on the EPA operated OSV *Bold*. The combined Teledyne Benthos C3D/CHIRP III pole-mounted sonar system allowed for simultaneous collection of interferometric and sub-bottom data. Trackline spacing for the survey was 150 m, trending NW–SE. Side-scan swath width exceeded trackline spacing leading to a full coverage dataset. Data acquisition was controlled by OCI GeoDAS software for the interferometric side-scan data. Chesapeake Technologies SonarWiz software was used for CHIRP seismic reflection data acquisition. Position, heading, attitude, heave, and velocity data were obtained by an Applanix POS MV Inertially aided Real-Time Kinematic Global Positioning System. Nearly 225 km^2 of interferometric side-scan data were collected. CHIRP seismic reflection data achieved a maximum of 90-m penetration. The system produced a CHIRP waveform with a 2–7 kHz frequency band transmitted at a 1/8-s repetition rate. Raw data were recorded in SEG-Y format. Interferometric side-scan raw data were recorded in ".OIC" file format (Ocean Imaging Consultants proprietary file format).

7.4.3 Results

7.4.3.1 Data Processing

Sub-bottom profiles were processed using Chesapeake Technology Inc. SonarWiz 5 processing software. Navigation data were inspected and fixes were calculated for each sub-bottom profile where applicable. Each profile was bottom tracked and processed to adjust for signal attenuation and improve signal to noise using signal gains. Attempts were made to process out a persistent diagonal striping data artifact across all seismic images with no success. A 1,500-ms^{-1} sound velocity was used for all seismic images, a valid value for saturated and unconsolidated sediment. Due to the limited amount of acoustic penetration achieved by the CHIRP seismic reflection system, very few seismic reflectors were identified, most of which were not spatially continuous. For this reason, reflectors were not systematically traced and interpretation of the subsurface was greatly impeded.

7.4.3.2 Characterization of the Seafloor and Subsurface

The CHIRP seismic reflection system performed poorly due to coarse surficial sediment. In most places, acoustic penetration was approximately 0–10 m, except in several noteworthy areas. Several channel-like features (Figure 7-49) were identified with some continuity in adjacent lines, none of which can be confidently correlated with any of the regional reflectors.

The majority of identified reflectors within the AMI study area are shallow (10–15 m below seafloor) and laterally discontinuous. A channel-like feature was identified and observed in three adjacent lines (Figure 7-49). Much of the seafloor geology appears to be coarse, with many boulders observed along the seafloor, especially near Cox Ledge. Rhythmic laminated sediment is occasionally observed in the northwest AMI, near the Mud Hole and Cox Ledge, and interpreted to be glaciolacustrine deposits (Figure 7-50). Some profiles also show a thin veneer of acoustically transparent sediment, interpreted to be fine-grained marine sediment. The lack of lateral continuity of identified reflectors as well as the lack of acoustic penetration makes subsurface geological interpretation not possible within this study area. A lower frequency seismic reflection system would provide better acoustic penetration in this area, where coarse surficial sediments impeded the CHIRP signal.

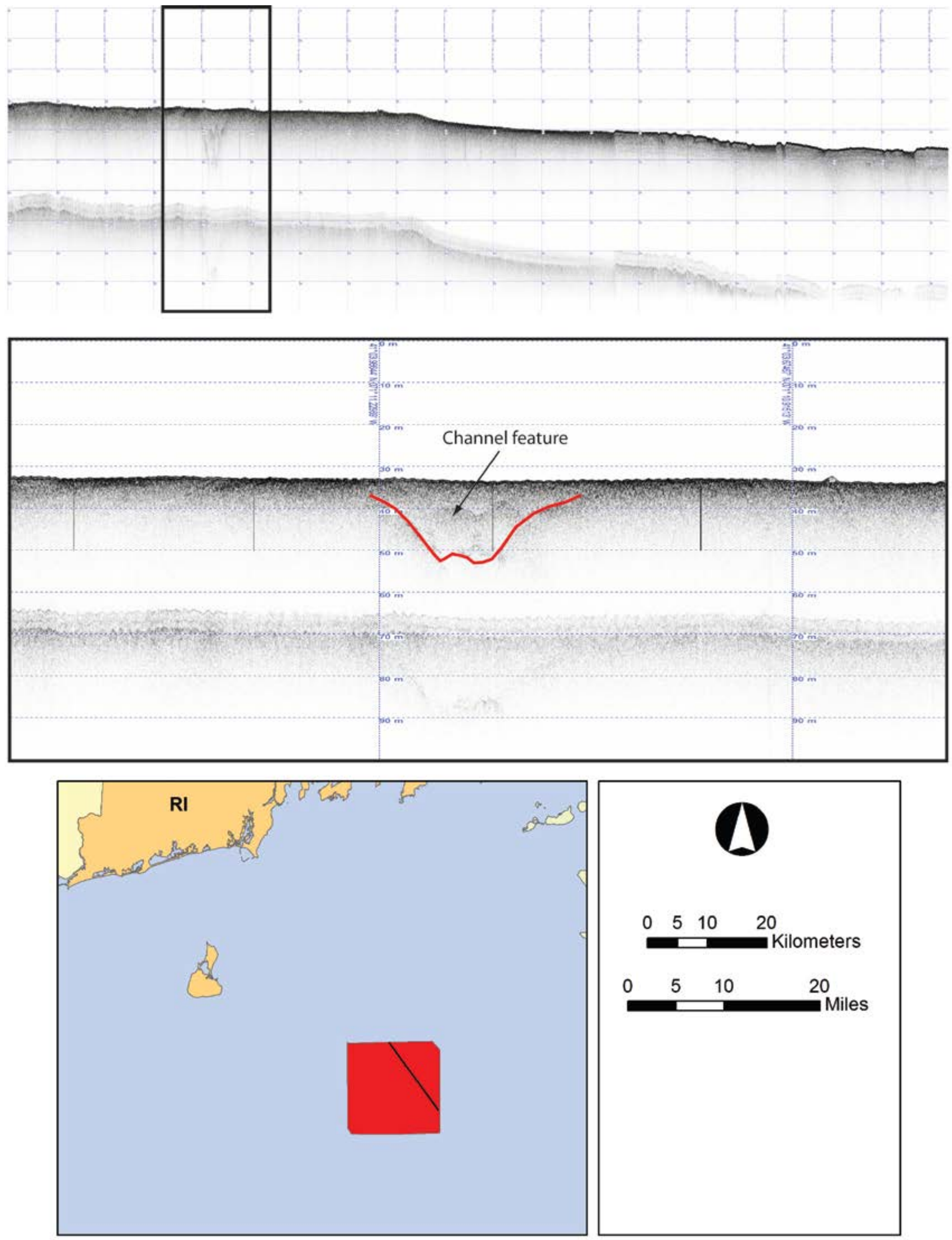


Figure 7-49. Channel feature from the AMI CHIRP seismic reflection data.
Top panel shows the full extent of the seismic reflection profile. Black inset is an expanded view, shown in the middle panel. A discontinuous channel feature is seen within this profile.

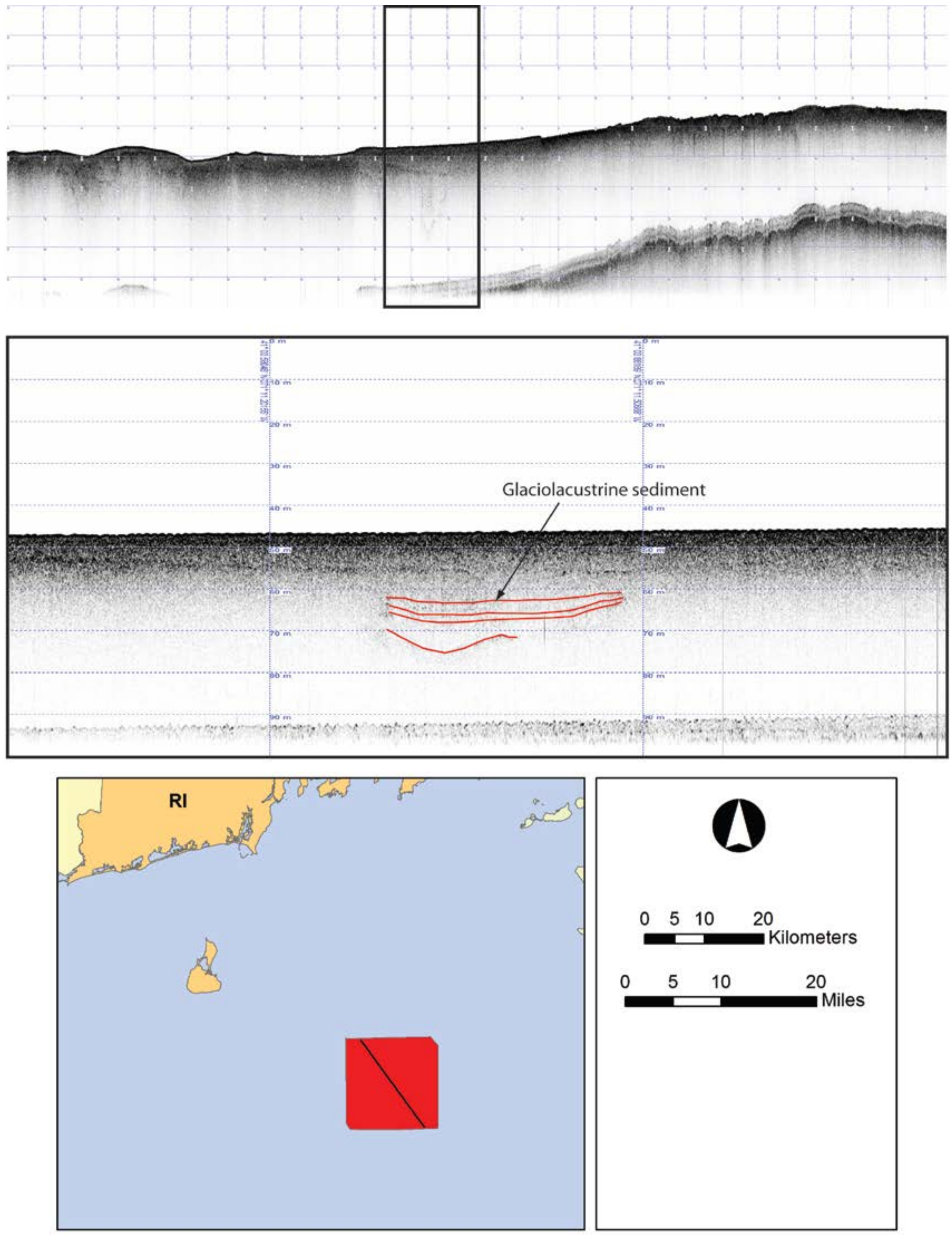


Figure 7-50. Glaciolacustrine sediment from the AMI CHIRP seismic reflection data.
Top panel shows the full extent of the seismic reflection profile. Black inset is an expanded view, shown in the middle panel. Discontinuous, parallel reflectors are interpreted as glaciolactustrine deposits.

7.4.4 Implications for Predictive Modeling

Although the CHIRP seismic reflection system performed inadequately in the AMI, several lessons were learned that are significant when designing future surveys for predictive modeling purposes.

- Bathymetry is not a reliable predictor of subsurface geology. In many places, a drape of contemporary and/or reworked marine sediment buries older and potentially more archaeologically sensitive sediments. This can range from a thin veneer to locally much thicker deposits where there are buried channels. The bathymetry only reveals the modern marine landscape, which has no significance for predictive modeling of paleolandscapes.

- In areas of unknown surficial geology, it is recommended that two seismic reflection systems be used to characterize the subsurface. In favorable conditions, a CHIRP system can produce very high-resolution (< 1 m vertical) records, revealing finer scale changes than other lower frequency systems. It is for this reason that the CHIRP is often favored and recommended by regulating bodies for marine archaeological survey. Where surficial geology is coarse (medium sand and coarser) the CHIRP signal is often attenuated very quickly, with almost no penetration below the seafloor. A lower frequency system like the Bubble Gun achieves far better penetration in coarser sediment with some compromise in vertical resolution. Running the two systems simultaneously is preferable when there is no frequency band overlap between the systems as this offers several benefits. First, the data are collocated allowing for redundancy. The ability to better contextualize and interpret the subsurface is also greatly benefited by two systems. Spatial changes in sediment distribution within a study area may lead to variable performance of the CHIRP. Having a lower frequency system that performs well in all environments will help interpretation consistency throughout the study area. Even where the CHIRP works well, it may be difficult to interpret the CHIRP data within the geologic framework without a more complete record (e.g., identifying all sediments above crystalline bedrock).

8 Conclusions

The processes and datasets necessary to identify areas of cultural sensitivity in submerged environments differ significantly from those utilized in terrestrial environments. In terrestrial environments, information from a wide range of identified archaeological sites can be used to create hypotheses about how ancestral Tribal people interacted with the landscape, and the remnants of those ancient landscapes can be visited and analyzed by researchers and contemporary Tribal representatives, in most cases with relative ease. On the continental shelf, very few Tribal archaeological sites have been identified. Previously terrestrial paleolandscapes that could have been inhabited by ancestral Tribal peoples are hidden from view by marine waters and are frequently buried beneath meters of recently deposited sediments. In addition, paleolandscapes that may have once been suitable for human habitation often have been significantly altered by post-glacial marine transgression and modern marine processes, and may have been eroded and be entirely absent from the offshore geological record, or exist only as geographically discontinuous fragments of formerly terrestrial strata and paleoland surfaces. Conversely, the greater preservation of organic elements of cultural sites in submerged contexts may make what is known of archaeological site types and assemblages from terrestrial contexts a poor proxy for modeling offshore site types and distributions. Identifying and reconstructing paleolandscapes in submerged environments is completely dependent on geophysical remote sensing techniques and the analysis and correlation of sediment coring data, except in cases where oceanographic conditions also allow for visual investigation and subsurface sampling by scientific divers or ROVs. For these reasons, applying traditional or advanced archaeological predictive modeling concepts and techniques to the continental shelf is problematic.

Modeling cultural sensitivity in submerged environments requires a unique approach that distinguishes between models designed to understand cultural systems and those designed to understand natural, non-human systems. Although these two types of models may be related, they should not be viewed as interchangeable. Models of cultural systems seek to recreate how ancient peoples interacted with and viewed their landscape, so that locations of material culture deposits can be predicted. Models of natural systems are focused only on understanding how the non-human, natural world functions and has changed over time. Currently, the primary question to be answered about Tribal cultural sensitivity on the continental shelf is not how ancient Tribal peoples interacted with their landscape, but instead whether any of the landscapes that they could have interacted with have been preserved and, if so, what type of landscapes they were, and where they are located. Answering the latter question requires the development of models for natural systems only. Attempting to apply a cultural sensitivity model to a landscape first requires the identification and characterization of that landscape. For submerged environments on the continental shelf, this is the current challenge.

This report discusses the state of knowledge regarding archaeological predictive modeling both in terrestrial and submerged environments, and discusses the difficulties with applying terrestrial cultural sensitivity models to the continental shelf. In response to increasing offshore energy development pressures and the immediate need to understand where submerged paleolandscapes might be located to avoid impacting them, a new approach involving the development of a regional stratigraphic model is presented for use as a guide for the comprehensive geological characterization of local study areas within the region. This regional model approach was designed to assist with identifying where submerged, culturally sensitive paleolandscapes are likely to be located and to inform detailed geoarchaeological analyses at a study area of interest, rather than to make inferences about how ancestral Tribal peoples interacted with those landscapes, or their cultural importance. Although the regional stratigraphic model presented in this report focuses on the southern New England continental shelf, the following principles and process used to construct it can be applied to any location:

1. Reconstruct the entire subsurface stratigraphic framework of a study area from acoustic basement upwards to the seafloor. In this preliminary step, avoid focusing only one one facies or on one type of landform.

2. Thoroughly understand the geological processes and chronology responsible for each stratigraphic unit in a regional context.

3. Identify the geologic facies (if any) that are a) associated with the time frame of human habitation in the area; and b) represent terrestrial environments that could have been inhabited by humans.

4. Conduct detailed paleoenvironmental reconstructions and archaeological surveys of the facies identified in step 3 above.

This process places each study area in a well-characterized regional context that can be refined at the local level. The emphasis on developing a regional context differs substantively from previous approaches that have been applied in southern New England within the context of compliance archaeology projects, whose research focus is limited by design to within the localized vertical and horizontal boundaries of a proposed project's APE. In addition, the modeling process presented in this report is unique because it does not assess paleocultural sensitivity based on the presence or absence of isolated geologic features, such as a paleochannels. Instead, once a regional geological framework is developed, geologic facies are identified that may represent the time frame and paleoenvironments associated with occupation by ancestral Tribal peoples.

For now, until a more comprehensive understanding is developed regarding the extent to which paleolandscapes are preserved on the continental shelf and the circumstances that lead to their preservation, this approach is recommended to provide the most accurate understanding of where submerged paleolandscapes with the potential to contain cultural sites may be located. Although a substantial amount of additional research is needed to improve the geoarchaeological understanding of submerged environments, conducting this research provides excellent opportunities to improve the capacity for agencies, researchers, and Tribes to determine collaboratively the presence/absence of submerged paleocutural landscapes in a positive, culturally sensitive, and mutually satisfactory manner.

In addition to developing a regional stratigraphic model that can assist with identifying where paleocultural landscapes may be located, this report presents the results of more localized geological and archaeological analyses at five case study areas in nearshore and offshore Rhode Island waters. The regional stratigraphic model was tested at each location where applicable within the southern New England region, specifically, at Cedar Tree Beach (Greenwich Bay area) and West Beach (Block Island), where submerged ancient Tribal cultural material was identified in the locally preserved expressions of what appears to be the regional geological facies Qfe. Qfe was identified in the stratigraphic model as most likely to contain paleolandscapes or landscape fragments of cultural significance because it appears to represent terrestrial environments that existed on the OCS after the large post-glacial lakes drained (approximately 16,000 yBP) but before marine inundation (date depends on location). Geophysical and geological investigations at the Mud Hole indicated the stratigraphic model was applicable south of the geographic area associated with the USGS legacy surveys on which it was based, and a similar conclusion was reached at Greenwich Bay, located north of the USGS survey area. This suggests that the model can be applied across a broad geographic region. It can also be used to assist with paleocultural landscape identification at the local level if it is ground-truthed with high-resolution seismic reflection surveys using both CHIRP and Bubblegun systems, sediment core analyses, and, when logistically feasible, scientific diver or ROV visual investigation and subsurface sampling.

Several surveying methodologies were also explored and refined at the case study areas. The acoustic quality of the USGS legacy seismic reflection profiles was compared to data acquired with current geophysical systems at a test location south of Narragansett Bay, and the current BOEM recommendation to use CHIRP seismic reflection systems to characterize the subsurface stratigraphy of a study area was investigated at Greenwich Bay, the Mud Hole, the AMI. This methodological research will assist with accurately collecting the geophysical and geological data needed to develop effective and accurate paleolandscape reconstructions in the future.

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Appendix A: Pre-contact Cultural Chronology for Project Study Area

A.1 Pre-Clovis Period (ca. 24,500–12,500 yBP)

The timing of the initial peopling of the eastern seaboard remains a question among archaeologists and is a topic of debate between them and the region's Native peoples. Archaeologists cite the accumulating body of genetic and radiocarbon-dated archaeological evidence that support their hypotheses. These hypotheses center on the idea that ancient human populations migrated into the Americas from northeastern Asia over land and by water along interior and coastal routes in multiple migratory pulses spanning a period lasting more than 10,000 years (Dillehay and Meltzer 1991; Erlandson 2002; Fiedel 2001; Jablonski 2002; Kraft et al. 1983; McBride et al. 2016; Powell 2005; Ridge 2004). In contrast, Native oral traditions from the region indicate to Native peoples that they have always been here, since time immemorial (CML, URI-GSO 2015), and that people of southern New England and Rhode Island returned to the area as glaciers receded—implying they had been present before the area's glaciation—a position stated unequivocally by the Narragansett Indian Tribe's Dr. Sekatau: "We the Narragansett People, know that our peoples evolved on this side of the world and did not come from elsewhere" (URI 2010).

By the start of the Pre-Clovis Period, glacial ice had reached its point of maximum advance southward and stretched east-to-west across today's Long Island, Block Island, Martha's Vineyard, and Nantucket islands, and the waters now between and north of them. With all of New England covered by glacial ice, there would have been no opportunity for cultural materials from this period to have been deposited into the archaeological record of the ice-covered landscape. At the start of the period, however, sea level was more than 100 m below its current level and the coastline was out near where the edge of the continental shelf is today, approximately 150 km to the south of the present southern New England coastline. Remains of terrestrial plant life (e.g., large chunks of peat-like deposits containing multiple kinds of organic materials and interspersed with wood fragments) and terrestrial and coastal animal life (e.g., mammoth, mastodon, and walrus) are reported to have been found serendipitously in bottom-dragging offshore commercial fishing gear over the last 50 years as far offshore as Georges Banks (i.e., 100 km) (Edwards and Emery 1966; Emery et al. 1965; Emery et al. 1967; Whitmore et al. 1967). These finds have provided intriguing clues about the former nature and possible preservation of elements of a now submerged paleolandscape that once was exposed on today's continental shelf and available for human occupation. Equally compelling is the NIT's oral tradition, as recalled by Mr. Harris based on what he heard said by Dr. Sekatau, which was that "…more than 15,000 years ago, that the ocean waters began to rise overnight and inundate our villages and people had to evacuate" (TPI 2012). This oral tradition of the Narragansett comports with the marine geological record indicating that during the course of this period, global temperatures generally rose, glacial ice melted, and the ice sheet's margin retreated northward. As the glacier melted, water returned to the world's oceans, and sea level rose rapidly. With this rapid rise in sea level, more and more of the shelf progressively became submerged, and the positions of the paleoshorelines retreated rapidly inland, as well.

Archaeological research has produced data that has led most archaeologists to conclude that following the retreat of thick glacial ice from the region between 18,000 and 16,000 yBP, the subaerially exposed portions of the now submerged study area, if inhabited, were probably initially populated by bands of highly mobile ancient people. Again, the timing of the post-glacial population of the Eastern Seaboard by ancient Native peoples is a topic of debate. Contributing to this debate are the discovery of apparent cultural strata and artifacts predating the PaleoIndian archaeological Period Clovis culture or fluted point tradition, such as those found at the "Topper Site" in South Carolina and the "Cactus Hill Site" in Virginia. The latter of these two sites is situated on a river terrace within the coastal plain, highlighting the fact that environments such as these were attractive for occupation. Similarly, an averaged date of 15,960 radiocarbon years BP from reported cultural strata at the Meadowcroft Rock Shelter Site in Pennsylvania predates accepted Clovis dates in the Northeast by nearly 3,000 years (Adovasio 1993). The advance and subsequent retreat of thick glacial ice across southern New England ca. 15,000 to 16,000 yBP is often assumed to have eradicated any evidence for Pre-Clovis occupation of the region, and no Pre-Clovis finds are known from onshore (or offshore) contexts in New England or in Rhode Island.

A.2 PaleoIndian Period (ca. 12,500 to 10,000 yBP)

The earliest unequivocal archaeological evidence for human habitation of New England is associated with two PaleoIndian Period Clovis Culture sites dating from ca. 11,000 yBP: the 11,120 ± 180 radiocarbon years BP "Vail Site" in Maine (Gramly 1982), and the "Sands of the Blackstone Site" in Massachusetts with an averaged date of 10,903 radiocarbon years BP (Leveillee 2016). Traditional archaeological interpretations of PaleoIndian Period settlement and subsistence patterns are that ancient peoples of the period were generally organized into small groups of nomadic hunters that hunted large migratory animals, such as mastodon, caribou, bison, or elk (Dragoo 1976; Kelly and Todd 1988; Snow 1980; Waguespack and Surovell 2003). PaleoIndian Period subsistence data from archaeological sites in the New England-Maritimes (Meltzer and Smith 1986; Spiess et al. 1998) and the Great Lakes (Stothers 1996) regions indicate people living then hunted mainly caribou. The relative absence of migratory or megafaunal animal remains from PaleoIndian Period archaeological contexts in southern New England has caused some to question the "specialized subsistence model" in the region (Dincauze 1993; Ogden 1977). The late archaeologist, Dr. Dena Dincauze (1990), argued that PaleoIndian Period people living in southern New England were more generalized in their subsistence strategies, hunting and gathering opportunistically available animal and plant species. Jones and Forrest (2003) have concurred with Dincauze, arguing that the higher abundance of small PaleoIndian Period encampments relative to larger base camps in the region may be characteristic of a PaleoIndian Period settlement and subsistence pattern wherein hunters and foragers had adjusted to resource unpredictability likely tied to climatic shifts. Resource-rich freshwater glacial ponds and wetlands were widely distributed across the deglaciated New England landscape and likely supported a relatively abundant and more climatically stable diversity of plant and animal species suitable for human consumption and use. Following the thinking of Jones and Forrest, smaller groups would have been better equipped than larger groups, via adaptive flexibility, to utilize available resources in southern New England.

PaleoIndian Period sites and artifacts are comparatively rare in New England's archaeological record. Tool assemblages from southern New England PaleoIndian sites typically include non-local (chert and jasper) lithic materials and extra-regionally (e.g., Massachusetts, New Hampshire, Maine) available rhyolites. The places where PaleoIndian Period sites and artifacts are found suggests that settlement and subsistence activity of that time were focused along interior post-glacial wetlands, glacial lakes, and riverine settings. Known PaleoIndian Period artifacts from southern Rhode Island are limited to an isolated fluted projectile point find from along the shores of Chapman Pond in Westerly (Turnbaugh 1980), fluted projectile point finds and a spurred end scraper from the Great Swamp Management Area of South Kingstown (George et al. 1993) and a single fluted biface from the South Wind Site (RI 1006) located on Wickford Harbor in nearby North Kingstown (Leveillee and Van Coughyen 1990). No PaleoIndian sites have been identified on Block Island, but fossil evidence for the presence of elk on the island during the period, and Dr. Sekatau's statement that her ancestors in the region "hunted very large animals, including migratory elk" (URI 2010), suggests that there may have also been an as-yet archaeologically identified PaleoIndian Period presence there (McBride et al. 2016:79).

A.3 Archaic Period (ca. 10,000 to 3,000 yBP)

The Archaic Period is interpreted from the archaeological record to have represented a time of increasing population and settlement complexity by ancient Native peoples within the southern New England woodlands. The Archaic has been subdivided into Early, Middle, and Late subperiods. Paleoenvironmental and archaeological evidence indicates there were increased diversification of food resource utilization and the establishment of Tribal territories during the Archaic Period. Archaic Period peoples appear to have subsisted primarily through hunting and gathering with a settlement pattern characterized by exploratory forays and seasonal relocations within circumscribed territories (Dincauze 1975).

A.3.1 Early Archaic Period (ca. 10,000 to 7,500 yBP)

The Early Archaic Period coincided with the commencement of the Holocene Epoch, ca. 10,000 years ago. The Early Holocene was marked by warmer and drier conditions than the preceding Pleistocene Epoch. The Early Archaic Period archaeological record indicates ancient people of this time had a generalized subsistence base hunting available animals, including deer and elk, and harvesting a wide range of woodland and wetland vegetation and nuts, particularly hazelnuts, which tended to grow near wetlands, and wetland tubers (cattail, bulrush, water lily, and arrowroot) (Dumont 1981; Forrest 1999, Kuehn 1998; Meltzer and Smith 1986; Nicholas 1987). Early Archaic Period sites identified in southern New England and in Rhode Island have typically been concentrated around large glacial lake basins, the perimeters of ponds, marshes, and very productive wooded wetlands, particularly at the headwaters of major rivers (Pfeiffer 1986; Taylor 1976; Turnbaugh 1980). The association of Early Archaic Period sites with wetland locations implies that wetland environments were one of the most important loci of human activity during the Early Archaic Period (Jones and Forrest 2003; Nicholas 1987).

Early Archaic Period bifurcate-based projectiles are made almost exclusively from non-local and extra-regional lithic materials. This suggests that people living during the Early Archaic Period either were comparatively highly mobile or maintained active trade networks in the region (Waller and Leveillee 2002). Recent archaeological data from Connecticut (Forrest 1999) and the Gulf of Maine region of northern New England (Robinson 1992) suggest that some southern New England Early Holocene populations utilized a distinct quartz lithic technology producing quartz “microliths” for use in composite tools (Forrest 1999). The ubiquitous nature of quartz in regional artifact assemblages raises the possibility that some Early Archaic sites and assemblages are being misidentified as later occupations. The settlement patterning of the microlith tool-makers appears markedly different from that of the Early Archaic Period’s bifurcate-based stone projectile-makers in that it includes large “residential” base camps with subterranean pit houses occupied for extended periods of time (ca. 8,800 to 8,200 yBP). The archaeological evidence of subterranean pit houses found at the “Sandy Hill Site” on the Mashantucket Pequot reservation in southeastern Connecticut is an example of one of these Early Archaic large residential base camps (Forrest 1999; Jones and Forrest 2003). Small, short-duration sites resulting from logistical forays undoubtedly supplemented larger residential sites in the Early Archaic settlement patterning. Jones and Forrest (2003) interpret the Early Archaic’s semi-residential settlement pattern in southeastern Connecticut as an adaptive response to more predictable and readily abundant resources. The identification of a semi-subterranean pit house associated with a LeCroy Bifurcate complex at the Weilnau Site in Ohio (Stothers 1996), and the more recent discoveries of two pit houses dated to 7,830 ± 130 and 8,110 ± 90 radiocarbon years BP at the Whortleberry Site in Dracut, Massachusetts (Dudek 2005), may imply a previously unknown/unrecognized degree of sedentism for the Early Archaic Period peoples in portions of the Northeast and Great Lakes regions. Paleobotanical remains (acorns, hazelnuts, blackberry/raspberry, and goosefoot) from the Whortleberry Site suggest a summer occupation that possibly extended into the winter. Apparent differences in identifiable artifact assemblages (quartz microlith composite tools v. bifurcate-based projectile points) and settlement systems suggests the possibility that two distinct Early Archaic Period populations occupied the southern New England landscape during the Early Holocene (Forrest 1999).

Archaeological evidence of Early Archaic habitations in Rhode Island is scarce, consisting of low-density recoveries of diagnostic bifurcate-based projectiles from the nearby Pawcatuck River Drainage in Washington County (Turnbaugh 1980) and from the Bear Swamp in Exeter (Waller and Leveillee 2002). The large Congdon Collection gathered in proximity to the Great Swamp in South Kingstown contains Kirk corner notched and bifurcate-based projectiles, both of which are diagnostic of the Early Archaic Period. In addition to temporally diagnostic projectile points, an Early Archaic presence in South Kingstown may be indicated by an uncalibrated radiocarbon ages of 8,510 ± 90 radiocarbon yBP from the Bouchard Site along Glen Brook in Usquepaug (Davin 1985) and 8,510 ± 140 yBP from the village of Rocky Brook. The low frequency of Early Archaic finds is suggestive of brief occupations by highly mobile peoples (Waller and Leveillee 2002). On Block Island, the Historical Society has a number of Early Archaic projectile points in its collections. Unfortunately, all of these points lack specific provenience information. The points are distinct from those found on the Rhode Island mainland in that they are all made from quartz and quartzite, presumably from locally available beach cobbles. In contrast, the lithic materials used in Early Archaic Period points found on the mainland are made almost exclusively from lithic materials from outside of southern New England. By the Early Archaic, Block Island was separated from the mainland, although only by a short distance easily crossed in a canoe. It may be that there was a resident population of people living on Block Island during the Early Archaic who were not participating in extra-regional exchange networks (McBride et al. 2016).

A.3.2 Middle Archaic Period (ca. 7,500 to 5,000 yBP)

The Middle Archaic Period is generally correlated with the beginning of a warmer and wetter Atlantic climatic phase and a broadening of ecosystems at about 7,500 yBP. The appearance of oak, hickory, beech, and chestnut forests provided more predictable and stable plant and animal food resources to humans living in the area during this period. A dramatic increase in the number of Middle Archaic Period sites in southern New England indicates resident populations in the region were firmly established by ca. 7,500 yBP. Overall, Middle Archaic Period culture is conceptualized as having been based primarily on hunting and gathering with more permanent residential bases from which foraging activities were conducted within circumscribed territories that may have coincided with major river drainage systems. Middle Archaic sites are commonly associated with waterfalls in major river drainages, as well as with wetlands and coastal settings. Large base camps established along extensive wetland systems, the appearance of heavy chipped-stone woodworking tools (possibly used for making log boats), net sinkers, and the common presence of fish remains in the archaeological record of Middle Archaic sites all point to water-focused subsistence (Bunker 1992; Dincauze 1976; Dincauze 2000; Doucette 2005; Doucette and Cross 1997; Jones 1999; Maymon and Bolian 1992; McBride et al. 2016).

Models of settlement for the Middle Archaic suggest two types of sites. The first reflects large group activities sited on flood plains and low terraces of major rivers and streams and in association with marsh, swamp, and estuarine environments to maximize access to a diverse, abundant, and predictably reliable resource base. The second reflects small group activities, such as hunting and gathering forays from base camps or staging areas that are located in a broader range of environmental settings. Smaller logistical camps and hunting-and-gathering sites supplemented the base camps. Subsistence activities reflected at these sites included the harvesting of anadromous fish, hunting and foraging, and fishing and shellfish collection. An increase in the complexity of seasonal rounds is conjectured based on the broad range of resources available throughout the period (McBride 1984). Adzes, gouges, and axes suggest heavy woodworking and possibly the making and use of dugout canoes and other wooden structures.

A preference for regionally available lithic raw materials (quartzite and rhyolite) with lesser amounts of locally available materials, namely argillite, is reflected in the site collections databases. The correlation between regional lithic material types and Middle Archaic materials led Dincauze (1976) to theorize that Native American band or Tribal territories were established within major river drainages, and that the scheduling of subsistence activities, such as the seasonal pursuit of anadromous fish species, may have developed in response to territoriality (Dincauze and Mulholland 1977).

The location of many of Rhode Island's known Middle Archaic sites indicates the region's interior wetland environs were especially targeted for settlement. Documented Middle Archaic sites are more numerous in Rhode Island relative to the earlier periods. Non-local and extra-regional lithic materials such as quartzite and varieties of rhyolite dominate Middle Archaic assemblages. Middle Archaic sites have been identified along the shores of Larkin Pond (Waller and Leveillee 2001) from the Gallo 2 Site in South Kingstown (Leveillee 1998) and the Great Swamp Management Area (Leveillee and Lance 2008). Middle Archaic Period archaeological sites are very common on Block Island, and the materials from them are well represented in the collections of the Block Island Historical Society and of local collectors. Their locations indicate a marked preference for the larger wetlands on the island, including the salt ponds, when they were freshwater ponds. Middle Archaic artifacts were all recovered from "multicomponent sites" (i.e., sites with artifacts and features dating from more than one archaeological period), indicating some continuity in the use of the larger freshwater wetlands on the island from the Middle Archaic through the Woodland archaeological periods (McBride et al. 2016). However, as McBride et al. (2016) note, it is important to consider that the paleoenvironmental contexts of these Middle Archaic and Woodland components would have been quite different. The location of the coast would have been many hundreds of meters further away during the Middle Archaic Period than it was during the Woodland Period. Consequently, the Middle Archaic Period sites would have been associated with inland wetlands and ponds, while the nearby Woodland Period sites would have been proximal to the ocean and coastal wetlands and ponds.

A.3.3 Late Archaic Period (ca. 5,000 to 3,000 yBP)

The Late Archaic archaeological period correlates with a time of adjustment to environmental change and apparent population increase with sites associated with the period both larger and more numerous than during previous periods. The climate continued its warming trend and became somewhat drier, reaching a period of maximum oscillation between about 5,000 and 3,000 yBP. A particularly high density of Late Archaic sites is associated with large wetland systems after about 4,200 yBP (McBride et al. 2016). Vegetation during the Late Archaic archaeological period is dominated by a fully temperate deciduous forest, which included more hickory and pine and less oak. This resulted in a more open forest canopy with a higher carrying capacity. The period also correlates with the marked decrease in the rate of sea level rise. Stabilization of sea level appears to be associated with increased populations of shellfish, anadromous fish, and other riverine, estuarine, and marsh resources, which were better able to become established with more stabilized sea levels. As a result, the archaeological record from the Late Archaic reflects a more intensive focus on the high-yield and highly predictable food resources associated with riverine and estuarine environments, particularly the collection of oysters and clams. A mosaic of archaeological sites created as result of multi-generational land use provides evidence of intensive and repeated reuse of the Northeast's swamps and wetlands and repetitive longer-term occupations of lands near large interior wetland basins and along regional waterways (McBride et al. 2016). The focus on fishing and shellfish gathering is evident in the large shell middens found along the coast (Kraft 1985).

This apparent transition to a coastal focus could be the result of the stabilization of sea levels and coastlines (relative to earlier periods) and a concomitant establishment of resource-rich marshes and estuarine systems with extensive shellfish beds that were attractive to Late Archaic populations. Alternatively, it could also be the result of a data filtering bias. This data filtering bias could be attributed to the preferential preservation of shell as compared to other resources, such as fish bone. It could also be attributed to the current terrestrial bias in the archaeological data due to the virtual absence of underwater archaeological research and subsurface testing and excavation conducted to date within the former coastal areas that were exposed during earlier cultural periods, but are now submerged (Westley and Dix 2006).

Late Archaic Period archaeological sites are well represented on Rhode Island's mainland. The density of Late Archaic archaeological deposits and an apparent reliance on locally available lithic materials (quartz, quartzite, and argillite) is suggestive of increased Native American sedentism for the period (Dincauze 1975). Seasonal and multi-occupation Late Archaic campsites were created as a result of the harvesting of an expansive variety of resources. Shellfish harvesting and use, first observed during the Middle Archaic, appears to have intensified, perhaps because as the rate of coastal inundation decreased, estuaries, more extensive salt marshes, and tidal mud flats were established (Braun 1974; Lavin 1988). The overlapping mosaic of archaeological sites created during generations of land use attest to intensive utilization of the Northeast's swamps and wetlands and occupation along regional waterways, particularly after around 4,200 yBP. The high density of Late Archaic sites in a wide range of habitats, coupled with the large number of artifacts attributed to the period, is suggestive of a large regional population utilizing a broad spectrum of resources (Dincauze 1975; McBride 1984).

The Late Archaic archaeological period is associated with three distinctive archaeologically defined cultural "traditions": the "Laurentian," the "Small Stemmed," and the "Susquehanna." Each tradition is identified by its well-defined time periods based on radiocarbon-dated sites and associated diagnostic tools, distinct lithic tool morphologies/technologies and preferences for different types of raw materials, settlement patterns, and ceremonial practices, all of which have been documented archaeologically.

The Laurentian Tradition is the earliest cultural expression of the Late Archaic archaeological period in the Northeast. Materials associated with Laurentian occupations include woodworking tools (hones and adzes), ground slate points and knives, ulus, simple bannerstones, and broad-bladed and side-notched projectile points (Ritchie 1980:79). Lithic materials used in Laurentian Tradition tool manufacture include quartzites, volcanics, and some argillites. Laurentian Tradition sites in southeastern Connecticut and Rhode Island contained very high percentages of Plainfield Formation quartzite, obtained primarily from bedrock outcrops or cobbles found in eastern Connecticut or far western Rhode Island. Laurentian Tradition site distributions on the mainland in the region imply an interior settlement focus associated with small, mobile groups of hunter-gatherers who occupied sites for short-durations while targeting specific resources, and moved their site locations on a fairly regular basis within well circumscribed territories (McBride 1984; McBride et al. 2016). Laurentian Tradition cultural materials have been recovered from multiple mainland sites in Rhode Island, which include South Kingstown's RI 781 and Gallo 2 sites and an Otter Creek projectile point find in the Great Swamp Management Area, and the Bear Swamp 2 Site in Exeter, dating from 3950 ± 70 radiocarbon yBP (Waller and Leveillee 2002). An apparent focus on uplands led Ritchie (1980) to suggest an essentially interior riverine adaptation for Laurentian groups; however, one of the most significant Laurentian Tradition sites discovered and investigated archaeologically in southern New England to date is the recently identified Harbor Pond Site (RI 2554) out on Block Island, the presence of which suggests a broader focus that included coastal areas (Waller 2013). Located in very close proximity to Harbor Pond, Trims Pond, and the Great Salt Pond (which would have been a freshwater pond at the time), the site contains one of the largest and most varied lithic assemblages (projectile points, a ground-stone axe, a ground-stone celt, and drills) ever identified in a Laurentian site in southern New England. Equally significant are the sources of the raw materials used to make the tools in this assemblage. Although the majority of the Block Island Harbor Pond Site assemblage was made from quarried Plainfield Formation quartzite identical to what is found on mainland sites, the presence of cortex on quartzite debitage from the site indicates the utilization of raw materials obtained from beach cobbles on the island. The Harbor Pond Site provides evidence that suggests there was a year-round Late Archaic resident population of Laurentian Tradition people on Block Island by at least 5,000 yBP (and maybe earlier) (McBride et al. 2016).

The Small Stemmed tradition is a Late Archaic cultural tradition that appears to continue into the Woodland Period (Mahlstedt 1985). Regional archaeological data indicates Small Stemmed tool-makers relied on a quartz cobble tool technology (McBride 1984). Quartz cobbles from glacial outwash, riverbeds, or coastal contexts were the most common sources of raw material for Small Stemmed chipped-stone tools. In addition to quartz, Narragansett Basin argillite was also utilized preferentially for the production of Small Stemmed projectile points in Rhode Island. The database of Late Archaic Small Stemmed tradition sites in Rhode Island is quite extensive (e.g., RI 781, RI 247, RI 1116, RI 2008, etc.). The distribution of these points suggests that the Small Stemmed tool-makers occupied an environmental niche focused on the region's interior wetlands (Waller and Leveillee 2002). The Small Stemmed tradition settlement pattern is consistent with that described by McBride (1984) for Connecticut with large base camps concentrated along the well-drained, resource-rich banks of streams, ponds, and interior wetlands, supplemented by task-oriented, short-duration sites where specific resources were sought (Waller and Leveillee 2002). The occurrence of Narragansett Bay argillite at Small Stemmed tradition Native American archaeological sites in the region indicates the importance that this lithic raw material played in the Late Archaic Small Stemmed settlement patterning. Small Stemmed projectile points are well represented from all of the collections from Block Island and are often recovered from the island's multicomponent sites that also yield Laurentian Tradition and Woodland Period artifacts (McBride et al. 2016).

A.4 Transitional/Terminal Archaic Period (ca. 3,600 to 2,500 yBP)

The Transitional Archaic Period bridges the Archaic and Woodland periods and is recognized in southern New England through Susquehanna tradition cultural materials and sites. An extensive trade network, increased burial ceremonialism, and stone tool making technologies markedly different from the antecedent Late Archaic traditions characterize the Transitional Archaic Period. Radiometric and stratigraphic information from some southern New England archaeological sites indicate the Susquehanna tradition was temporally contemporaneous with the Late Archaic Small Stemmed tradition sites (Filios 1989, 1999). The Susquehanna tradition in southern New England commenced with the Atlantic Phase (ca. 3,600 yBP) and terminated with the Orient Phase (ca. 2,600 yBP), coincident with the beginning of the Early Woodland Period (ca. 3,000–1,600 yBP) (Dincauze 1972; Ritchie 1980). The peoples associated with these phases, although differing in some ways from one another, shared similar cultural commonalities (lithic technologies, cultural materials, and/or settlement and subsistence data) to place them within the collective Susquehanna archaeological tradition.

New technological developments associated with the Susquehanna tradition included the manufacture of steatite vessels and broad-bladed tool forms (Atlantic, Susquehanna Broad, Coburn, and Orient Fishtail projectile points/knives), which either developed out of the local populations or were introduced to the region by peoples migrating into New England. Steatite bowl use, technology, and trade had its beginnings approximately 3,600 years ago following the Atlantic Phase, peaked between 3,400 and 2,900 yBP, and fell into disuse by the end of the Orient Phase, perhaps because of the introduction and widespread use of ceramic vessels (Sassaman 1999). Regionally available steatite outcrops included the Oaklawn steatite quarry in Cranston, the Manton Avenue Quarry in Providence, and the Ochee Springs steatite quarry in Johnston. Broad and thin Susquehanna tradition bifaces were ideally suited for knives and possibly woodworking implements and are in marked contrast to the more linear, elongated, narrow, and thicker piercing Small Stemmed projectiles. Susquehanna tradition chipped-stone tools were commonly manufactured from a variety of lithic materials that included regionally available rhyolites, quartzite, and non-local cherts. A reliance on readily available lithic materials, such as quartz, argillite, and some rhyolites, is apparent by the final Orient Phase of the Susquehanna tradition. The manufacture and use of heavy steatite vessels by Susquehanna tradition peoples implies a trend towards increased sedentism by resident populations. The predominance of non-local lithic materials in Susquehanna tradition cultural assemblages implies the existence of a broad exchange network between different Susquehanna Tradition peoples across the region (McBride et al. 2016).

The Transitional Archaic settlement pattern on the mainland was oriented towards coastal or riverine settings with a subsistence base focused on the acquisition of riverine or estuarine flora and fauna that included fish, nuts, and small- to medium-sized mammals (Pagoulatos 1988). There is also evidence of increased use of floodplain seed plants, such as Chenopodium (goosefoot) (McBride et al. 2016). Susquehanna tradition sites are markers of the Transitional Archaic Period and are best known from regional cremation cemetery complexes, such as the Vincent, Watertown Arsenal, and Millbury III sites in Massachusetts (Dincauze 1968; Leveillee 2002), and the Bliss and Griffin sites in Connecticut (Pfeiffer 1986). Transitional Archaic Period burials in Rhode Island are reported in the Pawtuxet River drainage from the Flat River Site in Coventry (Fowler 1968), from Charlestown (Fowler 1964), and at the West Ferry Site in Jamestown (Simmons 1970). Susquehanna artifacts have been recovered from the South Wind Site along Wickford Harbor (RI 667) in North Kingstown; from Deerskin Landing in Perryville; and from the RI 1854, Peninsula, and RI 1371 sites in Charlestown (Waller and Leveillee 2016). Transitional Archaic sites are also prevalent around noted steatite quarries, such as the Furnace Hill Brook and Phenix Avenue sites near the Oaklawn steatite quarry in Cranston (Waller and Leveillee 1998). On Block Island, Susquehanna Tradition projectile points are common in Block Island collections; however, no Susquehanna tradition occupation sites have been isolated from the multicomponent sites identified on the island. Other than diagnostic projectile points, the only other Susquehanna tradition-associated artifact found on Block Island was a steatite stone bowl fragment (McBride et al. 2016).

A.4.1 Woodland Period (ca. 3,000 to 450 yBP)

The Woodland archaeological period was a time of very dynamic development for southern New England's indigenous peoples and generally involved a transition from a more mobile foraging way of life towards a more sedentary existence (McBride et al. 2016; Waller and Leveillee 2016). The Woodland Period has traditionally been interpreted as reflecting an abandonment of the Archaic subsistence pattern of hunting/gathering/fishing, replacing, or supplementing it with the adoption of horticulture and ceramic technology (Snow 1980). However, the transition from the Archaic Period into the Woodland Period does not reflect a strictly linear evolution from one stage to the next. Radiometric and stratigraphic data indicate that a Susquehanna tradition presence overlapped in time with the Late Archaic Small Stemmed tradition and Early Woodland Period, and the archaeological record supports a continued diversification of food resources, an increased reliance on shellfish and maritime resources, refinement in pottery manufacturing, the maintenance of long-distance trade and exchange networks, and eventually year-round coastal or riverine settlement with evidence for horticulture. It is during the Early Woodland Period (ca. 3,000 to 1,600 yBP) on the mainland that the first documented evidence appears in the archaeological record for the regular and seasonal harvesting of shellfish and non-anadromous fish, marking a trend towards the increased reliance on coastal and maritime resources that continues throughout the entirety of the Woodland Period. The Woodland Period settlement and subsistence patterns reconstructed for the population on Block Island, as well as the observed lithic technology, are very different from those for the people inhabiting the mainland coast, exhibiting a much stronger maritime subsistence focus than that which is found in mainland sites, even after the adoption of maize horticulture (McBride et al. 2016). Faunal assemblages from Block Island Woodland Period sites indicate an overwhelming orientation to marine mammals, migratory birds, and fish of coastal and marine species with the only terrestrial resource occurring in high numbers being mast products, such as hickory, hazel, and acorn nuts (McBride et al. 2016). Block Island Woodland Period Lithic technology is also significantly different than that of the mainland and is described as an "expedient technology" that includes very few form tools as compared to what is found in mainland sites (Tveskov 1992; McBride et al. 2016). Although there is a wide variety of lithic raw materials abundantly available in cobble form on Block Island's beaches, there appears to have been little effort expended to make or curate more formal tools (e.g., knives, scrapers, or drills) during the Woodland Period (McBride et al. 2016). Tools do not appear to have been made carefully for durability and longevity, but, instead, appear to have been considered expendable and were made quickly and easily by splitting and modifying readily available beach cobbles to produce a usable edge or tip for scraping, cutting, or piercing. Like the Archaic Period, the Woodland archaeological period is also subdivided into Early, Middle, and Late subperiods.

A.4.2 Early Woodland Period (ca. 3,000 to 1,600 yBP)

Early Woodland Period settlement patterns on the mainland were characterized by medium-sized seasonal camps situated in a variety of ecological zones (uplands, river valleys, and coastal zones). Early Woodland peoples do not seem to have been as mobile as were the people of the Archaic Period, but still organized their movements to follow changes in the seasonal abundance of resources. Coastal habitation sites and shell midden deposits found along saltwater and estuarine margins from Maine to New York reflect the increasing dependence on shellfish and other marine resources during the Early Woodland Period. On the mainland, there are generally fewer identified Early Woodland Period sites as compared to those from earlier periods. This may be related to a problem of determining what constitutes diagnostic artifact assemblages for the period (Juli and McBride 1984). The positive association of some Small Stemmed projectile points with Early Woodland radiocarbon dates indicates that some Early Woodland assemblages have been misidentified as older Late Archaic materials. Early Woodland archaeological deposits have traditionally been identified through the presence of Meadowood, Lagoon, and Rossville type projectile points, as well as grit-tempered, cord-marked Vinette I ceramic styles in the absence of radiocarbon dates. The under-representation of Early Woodland Period occupations in the regional archaeological record has also led to speculation that there was a population decline for the period (Dincauze 1974; Lavin 1988). Fiedel (2001) hypothesized that either climatic or environmental changes, sociocultural change, or epidemics may have contributed to an "Early Woodland collapse." Recent paleoenvironmental analyses of sediment cores recovered from Sluice Pond (Lynn, Massachusetts) (Hubeny et al. 2015), Silver Lake (South Kingstown) (King et al. 2015), and Gorton Pond (Warwick) (for this project) (John King, personal communication, 2016) seem to support a climate change-related hypothesis, as analyses of sediments from all three ponds indicate a significant period of warmer and drier climatic conditions persisted for a majority of the time between ca. 5,100 and 1,300 yBP. Nevertheless, the regional database of archaeological data appears to support the idea of a population decline for the period (Fiedel 2001).

Settlement appears to have intensified along the estuary margins of Narragansett Bay and Rhode Island's south coast during the Early Woodland Period. This intensification seems to correspond with decreased rates of sea level rise and coastal inundation, and the resultant stabilization of shorelines, approximately 3,000 years ago. Radiocarbon dates ranging from 2,720 +/- 120 yBP to 2,110 +/- 120 yBP obtained from the Greenwich Cove shell midden site on Greenwich Bay/Narragansett Bay, indicate shell-fishing intensified around Narragansett Bay during the Early Woodland. Small- to medium-sized temporary or seasonal Early Woodland archaeological sites have been identified all around Narraganset Bay. They follow a settlement pattern that is typical for the mainland in other parts of southern New England, but very different from the pattern identified on Block Island associated with large, semi-permanent or permanent occupations with a stronger maritime subsistence focus than found on mainland Early Woodland sites. These villages were complimented by temporary and task-specific sites throughout the interior of the island associated with ponds and wetlands. Dating from as early as 2,700 yBP, the identified Block Island Early Woodland Period sites represent the first permanent villages in southern New England until after the advent of maize horticulture on the mainland ca. 1,500 years later. Very few Early Woodland projectile points have been identified on Block Island. Archaeological excavations there at the Early Woodland Period village site (RI 1428) recovered over 10,000 artifacts and pieces of debitage. Almost all were of quartz, indicating a strong preference for it that lasted through the Middle Woodland Period on the island (Tveskov 1992, 1997).

A.4.3 Middle Woodland Period (ca. 1,600 to 1,000 yBP)

Middle Woodland Period archaeological site distribution throughout the region on the mainland reflects a continued focus on coastal or riverine ecosystems with a trend towards fewer, but larger, seasonal camps along rivers, large wetlands, and coastal zones with a corresponding increase in small, temporary and task-specific sites in the interior (Hecker 1995; McBride et al. 2016). The introduction, adoption, and subsequent intensification of horticulture in the Northeast has been interpreted by archaeologists as substantially altering previously established settlement and subsistence patterns of Archaic Period hunters and gatherers (Snow 1980). Horticulture had important impacts on the Native subsistence and settlement base for southern New England, as it initially supplemented and later supplanted the pre-existing focus on hunting and gathering of the Middle Woodland Period. The earliest evidence of domesticated agricultural products in the region dates to around 1,000 yBP, coincident with the end of the period, suggesting a "late" reliance on horticulture (Bendremer and Dewar 1994). More recent analyses of food residues from cooking pots suggest that maize and squash were present in the Finger Lakes region of New York as early as around 1,350 yBP (Hart et al. 2003). Middle Woodland Period sites in southeastern New England are commonly marked by a high occurrence of non-local chert, jasper, and various amounts of hornfels from the Blue Hills area south of Boston (Luedtke 1987; Ritchie and Gould 1985). The use of Boston Basin lithics and exotic cherts and jaspers is in contrast to the almost exclusive use of quartz and argillite materials dating to the Early Woodland Period, except on Block Island, where the preference for quartz and argillite persisted through the Middle Woodland Period. The relative frequency of "exotic" raw materials from Middle Woodland sites implies the existence of long-distance exchange networks extending from Labrador to Pennsylvania and beyond (Dragoo 1976; Fitting 1978; Snow 1980). Through established trade networks, southern New England's Native cultures remained peripheral to, though influenced by, the prominent Hopewell culture situated in America's midwestern region (Kostiw 1995).

Middle Woodland components are known from both interior and coastal settings in Rhode Island, but are more common along the coast. Middle Woodland Period cultural materials were recovered from the RI 1818 shell midden archaeological site located along the western edge of Point Judith Pond in South Kingstown. Small limited-focus Middle Woodland Period archaeological deposits are documented at the Hoskins Park Site (RI 1007), RI 670, RI 141, the ER Site, and the Habitat Site in North Kingstown, while a Middle Woodland site dating from 1,650 yBP was reported from the Walmsley Lane Site near Tower Hill on the North Kingstown and South Kingstown town line (Harrison and Leveillee 1996). Hornfels chipping debris collected from the YMCA Site (RI 141) located on the northeast shore of the Pettaquamscutt River in Saunderstown (North Kingstown) is also likely to Middle Woodland Period in age. Very few Middle Woodland points have been identified on Block Island. This may be a result of the island's population's making and use of bone points of various types, which were more effective than stone points for hunting large marine species, such as seal and sturgeon (McBride et al. 2016).

A.4.4 Late Woodland Period (1,000 to 450 yBP)

The nature and distribution of Late Woodland Period settlement and subsistence patterns contrast sharply with the preceding Middle Woodland patterns. Coastal and estuarine resources continued to be a focus for coastal groups, but with introduction of maize horticulture, sedentary villages appeared for the first time in riverine and coastal areas on the mainland (McBride et al. 2016). Late Woodland Period settlement types reconstructed from archaeological evidence in coastal areas included specialized resource procurement sites (shell middens, hunting and processing camps, lithic workshops, etc.), small domestic sites, and larger semi-permanent and permanent hamlet and village sites (McBride 1984). Maize horticulture was the most important element of most Late Woodland subsistence economies between ca. 800 and 700 yBP (McBride et al. 2016). With intensive maize horticulture came the need, refinement, and advances in storage technology to ensure that ample maize would be available through the winter months and that a sufficient supply of seed crop would be available for the next season. Increased reliance on storage led to be people being more tethered to specific areas and localized regions. The result was decreased mobility, wherein residential mobility was abandoned in favor of logistical mobility, with a corresponding increase in the quantity of logistical temporary and task-specific sites within a community's territory, as interior upland and coastal resources were sought be small groups on behalf of their associated village (McBride et al. 2016).

Increasing populations and the reduction in communal mobility influenced the development of formative Late Woodland territories and increasingly complex social structures. Social complexity, the formation of political alliances, and the establishment of Tribal territories appear to have developed during the period (Mulholland 1988). Many researchers believe "intensive" maize horticulture must have been inextricably linked with population growth and Native American sedentary settlement, reasoning that only such a productive subsistence economy could reliably support large communal populations. McBride and Dewar (1987) have countered, arguing that large settlements could have developed independently of horticulture, especially in ecologically rich settings such as coastal environments and estuaries, where there is a rich and reliable maritime or estuarine (fish and shellfish) base.

The Late Woodland Period is associated with an improvement in ceramic technology and production. Late Woodland artifacts represented in the regional archaeological record include triangular Madison and Levanna type projectile points and cord-wrapped, stick-impressed, and incised ceramics. Diagnostic Levanna projectile points were most often manufactured of quartz, argillite, as well as rhyolites derived from the Lynn Volcanic Suite and Blue Hills Area of northeastern Massachusetts and the Boston Basin, respectively; or coastal cobbles that were carried in glacial drift. The Midwestern trade in cultural items continued into the Late Woodland. However, the importance of the Late Woodland's Midwestern trade had diminished relative to that of the preceding Middle Woodland.

The Late Woodland Period is well represented along the margins of South Kingstown's and southern Rhode Island's salt water estuaries. Large concentrations of Late Woodland materials have been recovered from settlement sites, such as the Potters Pond Site and larger resource extraction sites, such as RI 1818, and around Great Salt Pond on Block Island. Native American settlements that arguably qualify as "villages" have recently been the focus of archaeological investigation near Ninigret Pond in Charlestown and along the upper Point Judith tidal estuary in Narragansett (Leveillee et al. 2006). Low-density recoveries of Late Woodland projectiles are also reported from southern Rhode Island's interior. Nevertheless, the relatively fewer Woodland sites and low-density recoveries from the interior might be reflective of seasonal relocations of peoples for hunting and collecting purposes as the ancestral Narragansett Indians began to establish their characteristic coastally based settlement pattern (Waller and Leveillee 2002). A cluster of Late Woodland archaeological sites that include domestic village and ceremonial mortuary sites discovered since 2,000 indicates the formation of an ancestral Narragansett homeland at the headwaters of the Point Judith Pond saltwater estuary in South Kingstown and Narragansett during the period (Harrison and Leveillee 1996; Leveillee et al. 2006; Waller 2000; Waller et al. 2018).

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