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Hunter Research, Inc. Project 06017

U.S. Army Corps
of Engineers
New York District

Geomorphology/Archaeological Borings and GIS Model of the Submerged Paleoenvironment in the New York/New Jersey Harbor and Bight in Connection with the New York and New Jersey Harbor Navigation Project, Port of New York and New Jersey

Draft Report

August 2007

Geoarcheology Research Associates
5912 Spencer Avenue
Riverdale, New York 10471

Under subcontract to and prepared in conjunction with:

Hunter Research, Inc.
120 West State Street
Trenton, New Jersey 08608-1185

Prepared for:

NEA
451 Presumpscot Street
Portland, Maine 04103

Under contract to:

U.S. Army Corps of Engineers
New York District
CENAN-PL-EA, 26 Federal Plaza
New York, New York 10278-0900

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Principal Investigator

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MANAGEMENT SUMMARY

Project Name. Geomorphology/Archaeological Borings and GIS Model of the Submerged Paleoenvironment in the New York/New Jersey Harbor and Bight in Connection with the New York and New Jersey Harbor Navigation Project, Port of New Jersey and New York

Project Location and Environmental Setting. The project area designation is the New York-New Jersey Port district and includes a series of navigation channels of the Upper Bay including Ambrose, Anchorage, Kill van Kull, Port Jersey, Newark Bay (South Elizabeth, Elizabeth, Elizabeth Pierhead, Port Newark Pierhead, and Port Newark channels), and Bay Ridge channels. Previous work has been done at these locations. New locations include Raritan Bay, Lower Bay, and the area west of a line connecting Jones Inlet (Long Island) and Long Branch (New Jersey).

Purpose and Goals. The primary objective of this investigation is to develop a model of the submerged paleoenvironment. The model will function as a planning document to assist the NYCOE and researchers in identifying areas that may have been suitable for prehistoric and historic settlement and also to delimit areas in which stratigraphic sequences and intact Late Quaternary landforms offer potential for preservation of prehistoric and historic surfaces and sites. This project will test and refine previous models of archaeological sensitivity thereby serving as a blueprint to guide the NYCOE in the mitigation of adverse impacts on parcels designated for channel improvements, maintenance and upgrading.

Investigation Methods and Results. Examination and consolidation of previous research was undertaken in advance of the present project. Prior to this study a preliminary model of archaeological sensitivity was assembled from baseline studies at select reaches in the Upper Bay (Schuldenrein 2006). The present study extends the project area to the Lower Bay and began with the systematic collection of cores aligned along three transects spanning the Lower Bay and two to supplement earlier data collection in the Upper Bay. The transects were selected on the basis of potential for yielding information in both closed and open marine and estuarine environments that were considered to have strong potential for intact Late Quaternary stratigraphy. The cores were identified for macrostratigraphy and were then dated and submitted for specialized analysis by biostratigraphers (pollen, microfauna, and malacology) and geologists (sediment stratigraphy and microstratigraphy). Geological and landscape analyses and radiometric dating are ongoing, as initial results are providing guidelines for detailed follow up testing. A key element in the study is the formulation of a revised sea level curve for the New York Bight. The need for this baseline work was identified as more detailed examination of the buried landform configurations and the stratigraphy underscored trends that had not been recognized by earlier stratigraphers and geomorphologists. The new data, and especially historic maps and Late Quaternary sequences are being integrated into a GIS platform to facilitate a multi-dimensional and integrated landscape model that accommodates the changes registered by the specialists working in each of the sub-disciplines. It also synthesizes the archaeological sensitivity model from a 3 dimensional perspective. The model tracks spatio-temporal trends in landscape availability in response to dynamically changing shore environments for the various periods in prehistory and early history.

Regulatory Basis. The U.S. Army Corps of Engineers (USACE), New York District is constructing navigation channels within the Port of New York-New Jersey to a depth of 50 feet. The Corps is the federal agency required to identify the cultural resources within the project area and evaluate their eligibility for listing on the National Register of Historic Places (NRHP). The Federal statutes and regulations authorizing the Corps to undertake these responsibilities include Section 106 of the National Historic Preservation Act, as amended through 1992 and the Advisory Council on Historic Preservation Guidelines for the Protection of Cultural and Historic Properties (36 CFR Part 800).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

INTRODUCTION

The U.S. Army Corps of Engineers (USACE), New York District, is responsible for maintainance of harbors and waterways and is actively involved in dredging existing channels and deepening others to allow greater access to the Port of New York and New Jersey (the Harbor Navigation Project) (**Figures 1.1, 1.2,** and **1.3**). Ongoing and anticipated changes involve widening and deepening channels to a depth of 50-feet in specific areas. As a Federal agency, the USACE, is required to identify cultural resources within its project areas and to evaluate their potential for eligibility for listing on the National Register of Historic Places (NRHP). Federal statutes and regulations identifying these responsibilities include Section 106 of the National Historical Preservation Act, as amended through 1992 and the Advisory Council on Historic Preservation Guidelines for the Protection of Cultural and Historic Properties (36 CFR Part 800). These responsibilities extend to both land based and submerged cultural resources. In terms of the Harbor Navigation Project, the shore and near shore areas of the New York and New Jersey harbors have been subject to filling or removal of former coastal past terrain segments that once sustained and preserved evidence of historic and prehistoric activities. A second critical aspect to understanding the systematics of archaeological preservation in the New York harbor complex has been the documented progressive encroachment of sea level on the adjacent land areas. Sea level has risen as much as 100 meters since the last glaciation of North America ended approximately 20,000 years ago. Rising sea level has progressively inundated the continental shelves and continues to rise, flood, and cover coastal lands. The postglacial rise in sea level has covered former land surfaces that were attractive as settlements for prehistoric peoples throughout this time period. While the probability of affecting "drowned" cultural resources seems remote, the potential for their identification and protection need to be considered. One of the most efficient methods for avoiding disturbance of submerged cultural resources is to identify and evaluate the former areas of greatest site potential in their former subaerial site settings. As land-based cultural resources studies address the potential for archeological sites on the basis of the geologic and geomorphic settings best suited for past settlement, so these same tools may be adapted to identifying potential underwater sites. One of the more effective methods of addressing the latter approach is through modeling the rise of postglacial sea level and the interaction between the sea and its contemporaneous coastal zone through time. Thus, the interface between land and sea and related coastal, riverine, and marsh environments can be tracked over time and space to provide clues to which of these loci have the greatest potential for in situ cultural resources. Similarly, the study of offshore stratigraphy from cores aids both to document the position and timing of past sea level stands and to provide fossil pollen and faunal samples for reconstruction of former vegetation and estuarine environmental changes.

As part of USACE's Section 106 compliance activities related to the Harbor Navigation Project, extensive background research was conducted to examine past studies and especially the logs of the numerous cores taken in the project area. In addition, a series of vibracores was taken in key locations within the Upper and Lower Harbors and Jamaica Bay

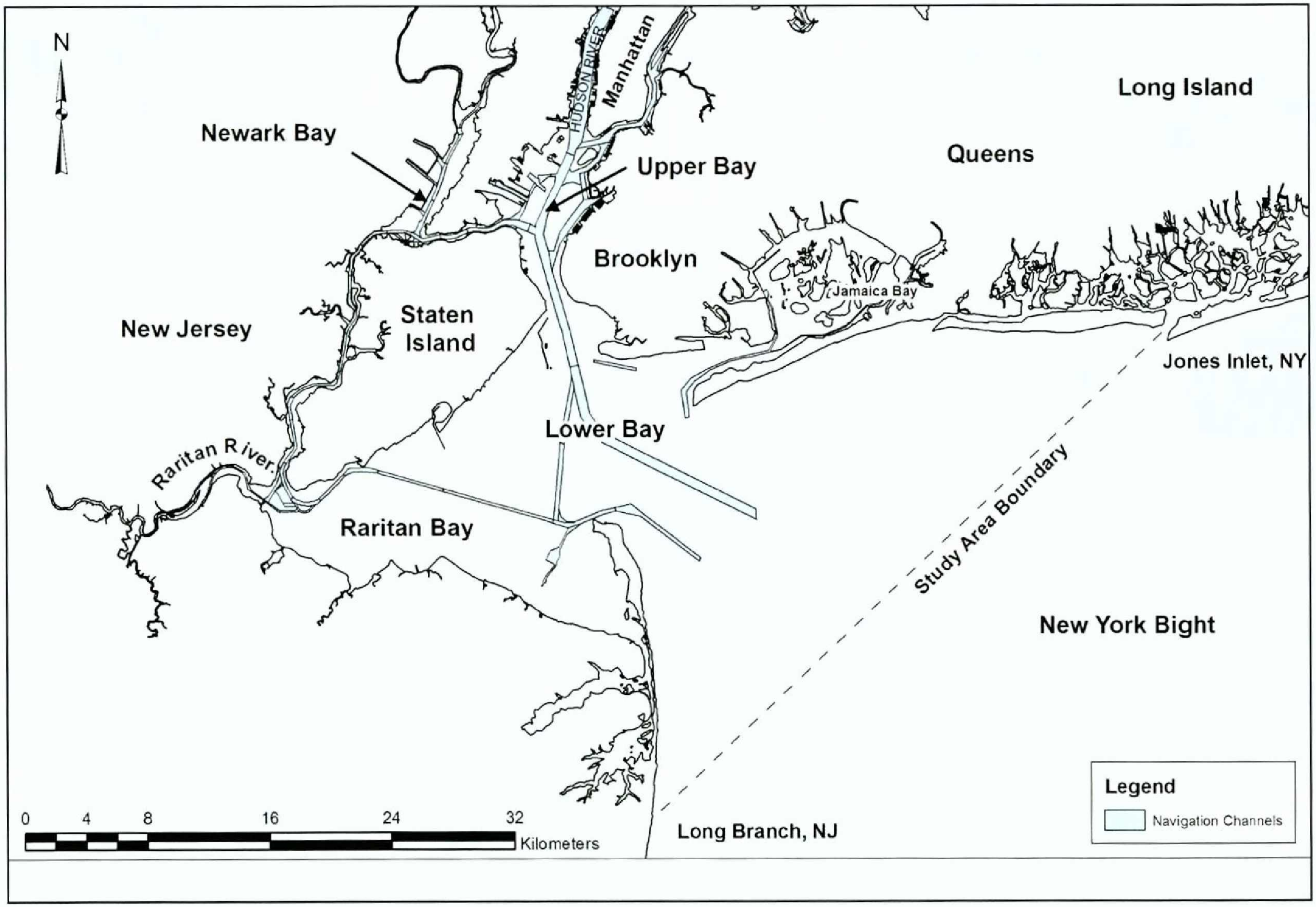


Figure 1.1: Location map for New York Harbor

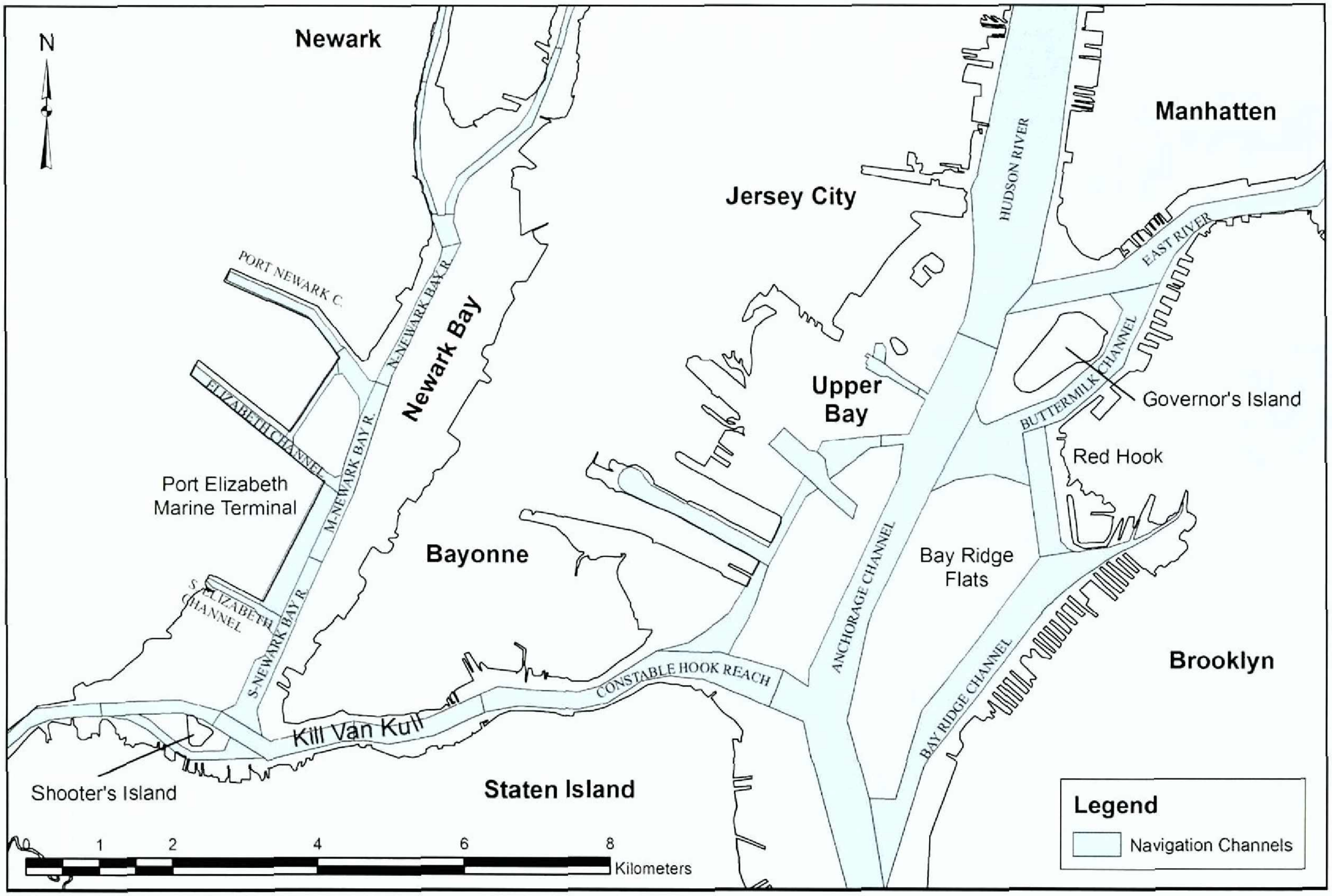


Figure 1.2: Upper New York Harbor and Newark Bay

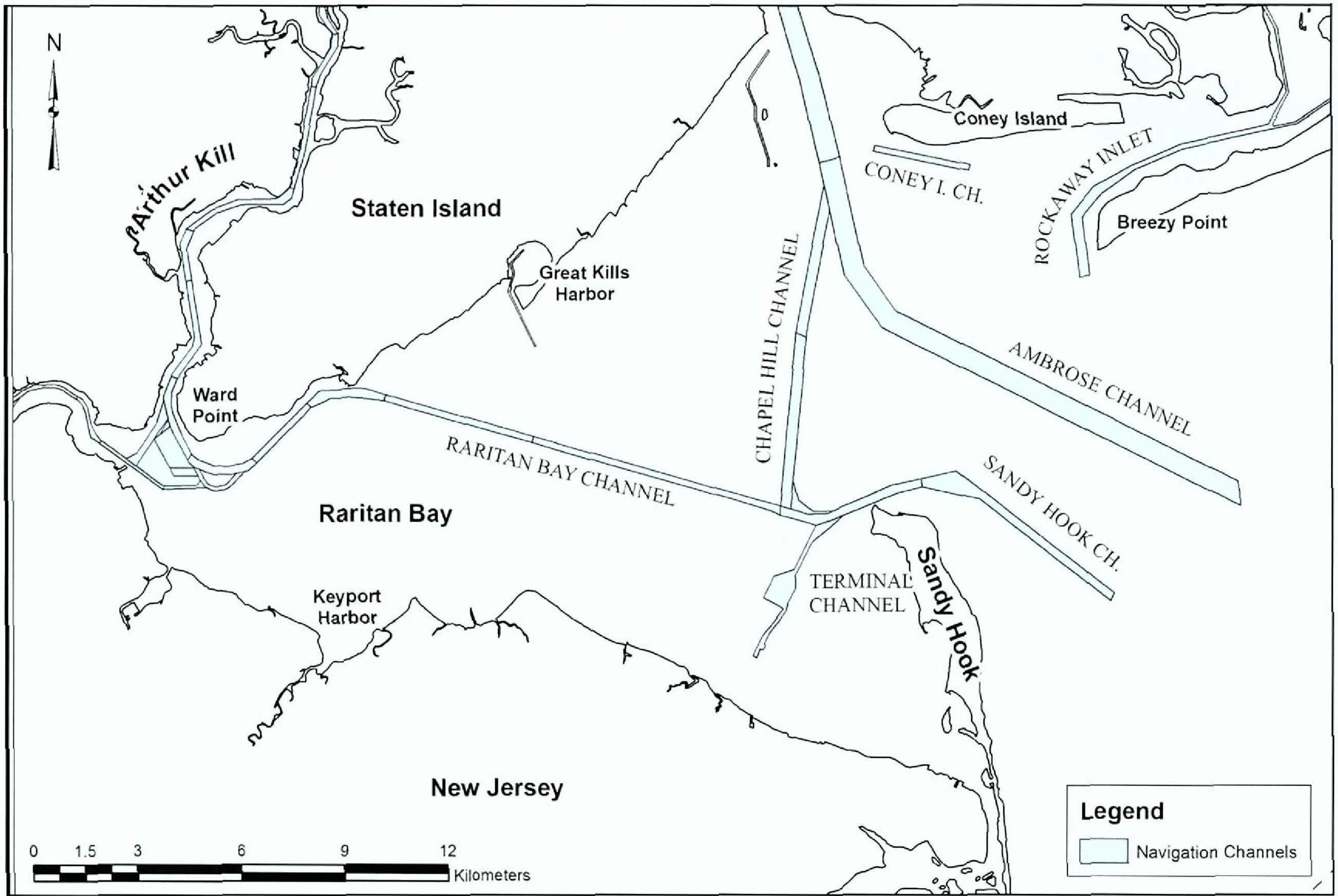


Figure 1.3: Lower New York Harbor and Raritan Bay

to aid in the description and dating of sediments, and to provide new samples for micropaleontological analyses. These recent cores, together with the records of cores from previous studies, helped to determine locations within areas of proposed deepening and widening that may preserve significant irreplaceable data on paleoenvironments as well as now submerged landforms.

Prior studies conducted by Geoarcheology Research Associates, Inc (GRA) related to submerged cultural resources in the New York – New Jersey harbor complex along with investigations performed by others that are on file with the New York District (USACE) provided data for this larger synthetic model of the now submerged landforms and the probability of their preservation. The model is important for determining areas of sensitivity for past Native American occupation. Previous work by GRA demonstrated the feasibility of archaeological sensitivity modeling and determined areas where additional data should be acquired. The present report is the culmination of working model concepts attained through these earlier studies. Apart from the acquisition and analysis of past reports and data, GRA designed and implementd a strategic subsurface exploration program. A total of 20 new vibracores were extracted to investigate stratigraphic and temporal relationships not addressed in previous geotechnical borings and cores, and to develop a more detailed relative sea level history than was formerly available.

On the basis of the material provided in the present study, together with the vast core database provided by the USACE, GRA has developed an inundation model of the Upper New York Harbor and Raritan Bay together with portions of the New York Bight and Jamaica Bay. The graphic model shows approximate prehistoric shoreline positions on a 1,000-year incremental basis that delineates former coastal landforms and helps to pinpoint the contemporaneous environmental settings now submerged beneath the harbor. The series of maps provided will help to visualize the characteristics of the changing New York and New Jersey shorelines in time and space while at the same time suggesting the habitats most conducive for past human settlement over this period.

The project GIS was used to georeference an 1844 U.S. Coastal Survey map of the New York Harbor region. Almost 12,000 bathymetric soundings were digitized from this map and a digital elevation model (DEM) of the seabed created via a kriging algorithm. This DEM formed the baseline for sea level regression images as it models the submerged landscape of the harbor region before industrial-era dredging activities dramatically transformed it. The GIS was also used to consolidate locational and stratigraphic information from geotechnical borings from a large number of previous studies along with those carried out under the aegis of the current one. Previous studies had recorded boring location in a number of different coordinate systems (e.g., NJ or NY state plane, UTM, unprojected latitude/longitude). These loci were reprojected into a single system and all available stratigraphic information was entered into a single database that was used within the GIS to visualize and analyze the information in three dimensions.

The present study envisions the submerged landscape of the New York Bight as a series of ancient land surfaces that sustained human populations since the arrival of people into the New World. The detection of these surfaces and their systematic destruction or preservation and burial is the purpose of the work in order to satisfy the obligations of the NYCOE under Section 106 of National Historic

Preservation Act (**Chapter 1**). A variety of previous studies have probed the subaqueous sediments underlying the Bight for paleoenvironmental and paleogeographic purposes. This present study is synthetic and proposes to integrate and refine previous models of the buried landscape into a comprehensive GIS based construct for buried site potential across the New York Bight (**Chapter 2**). The model is centered on a new paradigm for sea level rise that is derived from regional models for the Atlantic Coast bolstered by a coring program explicitly designed for this project (**Chapter 3**). The geological, bathymetric, geomorphic, and hydrographic foundations for the new landscape reconstructions are developed (**Chapter 4**) and the detailed paleo-environmental results are presented on the basis of the new corings for select portions of the Bight (**Chapter 5**). A systematic paleoenvironmental reconstruction for the Late Quaternary is then presented, largely driven by the new sea level curve, and by interpretations generated from biostratigraphic investigations of the sediment cores (**Chapters 6** and **7**). This construct is the basis for a proposed settlement model that plots the surfaces and landscapes that were sequentially available for settlement through time (**Chapters 8** and **9**). A series of results and recommendations concludes the presentation (**Chapter 10**).

Supporting data sets are incorporated as Appendices. Details of the most recent vibracores, including photographs and stratigraphies, appear at **Appendix A**. A compilation of all available marine radiocarbon dates are featured in a table at **Appendix B**. **Appendix C** is a contribution by Dr. Lynn Wingard on molluscan fauna from the most recent cores. **Appendix D** is a contribution by Dr. Benjamin Horton, who reports on the foraminifers. **Appendix E** presents a pollen analysis by Christopher Bernhard. Lithostratigraphic data are presented at **Appendix F**. Qualifications of all contributers appears at **Appendix G**. **Appendix H** is the final Scope of Work for this project.

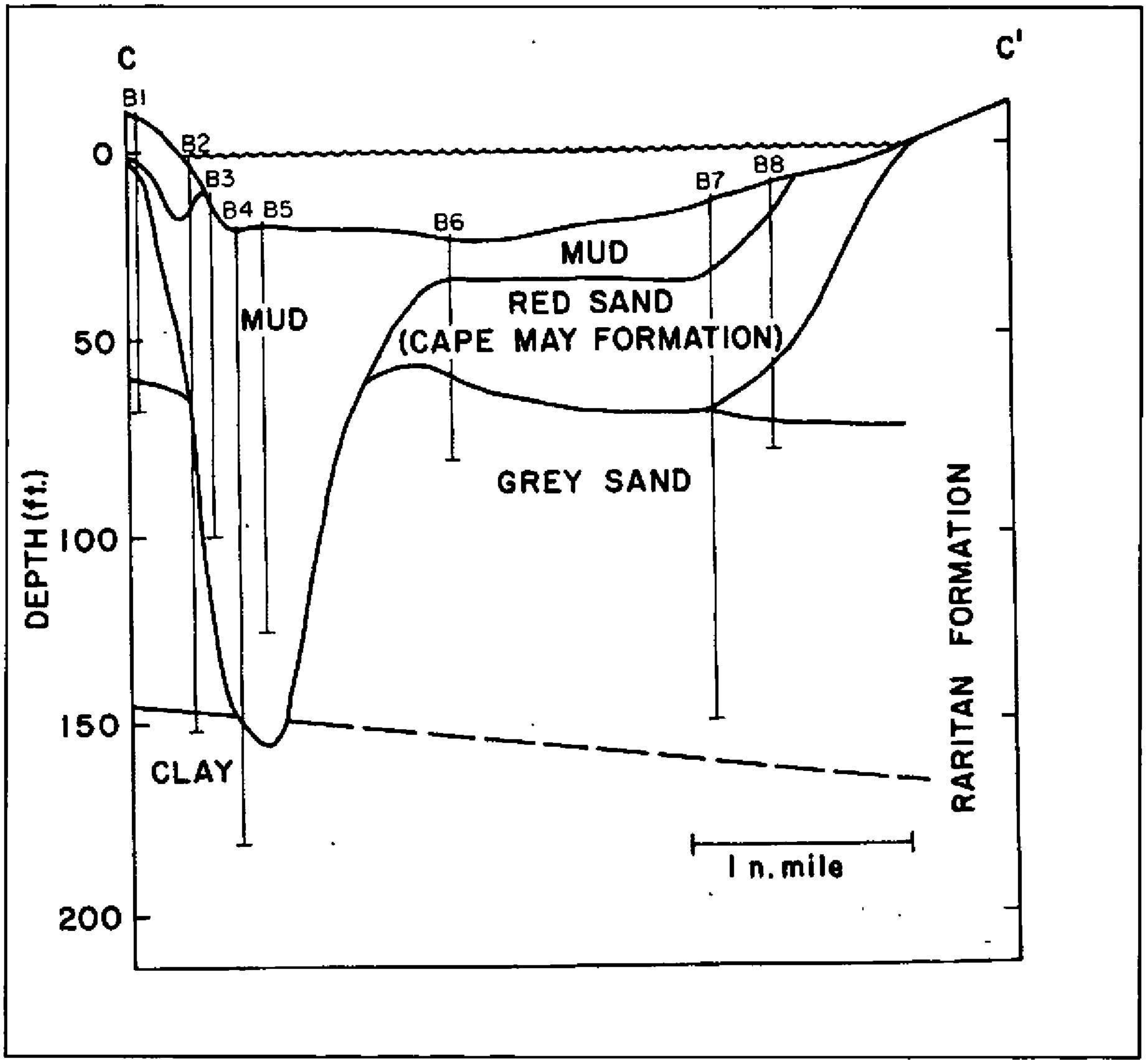
Chapter 2

RESEARCH DESIGN

Previous investigations of the New York Harbor, focused on evaluating the potential for submerged prehistoric and historic cultural resources for the New York and New Jersey Harbor Navigation Project, have relied heavily on the postglacial rise in sea level to identify, isolate, and explain relative site potential. The history of sea level rise is important because it facilitates reconstruction of the now-submerged former environmental zones, both riverine and marine, that were once most conducive to human habitation. It became clear during the evaluation of these earlier studies that the prevailing models for sea level change were dated and could not accommodate the chronologies and sequences that emerged from our expanding data base. Moreover, regional (Atlantic Coast) sea level models have produced curves that were more in line with our observations. Hence, the interpretations drawn from subsurface coring in the harbor for the purpose of environmental reconstruction were flawed. To remedy this shortcoming, GRA invested resources as part of the current study to develop a revised relative sea level model that is up to date and accurate for both geological and archeological researchers as well as engineers and planners.

The fieldwork, conducted in November 2006 and utilizing the vibracoring equipment of Alpine Ocean Seismic Survey, Inc., Norwood, NJ, investigated three specific areas, Raritan Bay, Upper New York Harbor, and Jamaica Bay. Raritan Bay was chosen to address two questions: (1) Given that much of the present array of cultural resource investigations has been aimed at the upper New York Harbor, GRA needed first hand knowledge of Raritan Bay to observe and assess the effect of rising sea level on coarse-grained sandy sediments in a relatively sheltered environment. And (2) previous investigations had cited a 1936 study (MacClintock and Richards, 1936 cited in Bokuniewicz and Fray, 1979) that showed early borings for a proposed bridge crossing from Staten Island (**Figure 2.1**). This model had been central to previous reconstructions of New York Harbor stratigraphies. A profile across Raritan Bay documented a deeply incised channel near the Staten Island shore filled with "mud." The channel was recorded as extending 150 feet below present sea level. Our interest here was to obtain a deep core from the "mud" fill of this channel for use in pollen, and foraminifer analysis and for radiocarbon dating of organics. We anticipated that the channel fill would contain a record of continuous deposition of fine-grained sediment that documented the postglacial rise in sea level. Radiocarbon dating of this deep sequence promised to aid in dating the marine transgression. We further considered that data from this core would make an important contribution as the original work has been cited by many past researchers and was apparently unstudied since 1936.

Nine 40-foot vibracores were extruded along two transects in Raritan Bay. These cores are discussed in detail in Chapter 6. A series of 5 vibracores was placed to reconstruct the MacClintock and Richards (1936) profile between Sequine Point on Staten Island and Conaskonk Point at Union Beach, NJ. The transects provided compelling evidence that the 1936 study was erroneous in its findings. There was no deeply incised channel in any of the locations shown in this early study. *Subsequent* researchers are warned to avoid further use of



Staten Island, NY Union Beach, NJ

2.1 Erroneous Subsurface Profile from Sequine Point, Staten Island, NY to Union Beach, NJ. (MacClintock and Richards, 1936 cited in Bokuniewicz and Fray, 1979).

that study. Four additional 40-foot vibracores were located along a transect normal to the shoreline at Keansburg, NJ. This series of cores was drilled to record the effects of the marine transgression on a sandy shore subjected to relatively low wave energy. As anticipated, reworked surficial sands were evident. Although we had hoped that wave energy here had been subdued sufficiently to preserve possible paleosols or other evidence of the prior sub aerial land surface, these could not be distinguished.

Upper New York Harbor investigations also utilized 40-foot vibracores. Two transects were located to address questions raised by earlier GRA studies centered on the Port Jersey area along the west bank of the Hudson River (Schuldenrein et al., 2001). A radiocarbon profile in that study showed an apparent anomalous stratigraphic arrangement of time horizons in estuarine silts and clays. Here cores taken at greater depths on the edge of the estuarine fill adjacent to the Anchorage Channel had younger ages that those further inland. This juxtaposition of ages was counter to our concept of dating the marine transgression. Our earlier report suggested that the anomalous and apparently inverted stratigraphy might relate to a period of lower sea level during the overall rise. Alternately, the inverted stratigraphy might reflect slumping of the channel edge.

A series of 40-foot vibracores taken in a similar setting provided an independent view of the stratigraphy and was geared to penetrate the estuarine fill to reach the pre marine-transgressive land surface. This transect was located south of the Liberty Island access channel on relatively undisturbed estuarine silt. Vibracores from shallow (6 ft, 1.8 m) to greater (51 ft, 15.5 m) depths broadly paralleled our earlier Port Jersey transect. Only the innermost core (C-1) penetrated the estuarine fill and furnished organics suitable for radiocarbon dating. The deeper core located along this transect (C-4) and drilled in 51 feet of water penetrated 40 feet of estuarine sediment. This core was expected to penetrate the estuarine fill and furnish basal organics to date early flooding of the Hudson Channel when relative sea level was 90 feet (27.4 m) lower than present. Ironically, core C-4 furnished a basal date of 2,520+/-40 B.P. (2,606 cal yrsbp). Our preliminary conclusion is that either estuarine sediment is "draped" over a preexisting irregular land surface and filling deep depressions or incised channels, or slumping of younger estuarine sediment has occurred to collect at the bases of the steep slopes on the edge of the Anchorage Channel. Nonetheless, core C-1 with a basal date of 5,660+/-40 B.P. (6,473 cal yrsbp) overlain with sediment dated at 5,000+/-40 B.P. (5769 cal yrsbp) has presented the greatest time depth for a continuous sedimentation record for microfossil analyses. Pollen, foraminifer, and macro molluscan studies were performed on this core.

Two additional 40-foot vibracores were taken in the Upper Harbor. These were drilled on the surface of the Bay Ridge Shoal. The purpose of these cores was to furnish a stratigraphic record of sedimentary deposition that could be correlated across the Anchorage Channel for comparison with sediments of similar type and depth described in an earlier GRA study of Port Jersey (Schuldenrein et al., 2001). Once again, radiocarbon dating produced unanticipated results. Wood fragments found at 33.4 ft (10.18 m) below mean sea level yielded a 1,880+/- 40 B.P. (1,806 cal yrsbp) date. Results of further pollen, foraminifer, and macro molluscan studies will assist in understanding this depositional history.

The final area of investigation in the current study was Jamaica Bay. Coring in this location was designed to provide the marine transgression history for the flooding of a sheltered embayment upon which salt marsh had developed. Our hope was that stratified peat deposits would help date the youngest portions of the marine transgression and anchor the young end of our developing relative sea level reconstruction. Bridge access to Jamaica Bay limited our investigation to 20-foot vibracores. Our objective was to obtain a series of five 20-foot cores leading from the surface of the Yellow Bar salt marsh southward into progressively deeper water and stratigraphically lower sediment packages. This operation was conducted on November 6, 2007. Falling tides prohibited reaching the surface of the Yellow Bar marsh, however, a continuous record of fine-grained sediment underlying the marsh was obtained. One radiocarbon date, 3980+/-40 B.P. (4432 cal yrsbp), at a depth of 32.14 (9.8 m) below mean sea level suggested the transgression history of this portion of the Long Island shore. Unfortunately, none of the five recovered cores included stratified peat deposits.

Our re-assessment of the range of available work, published and unpublished, underscored major inconsistencies in the data bases. In part, anomalies are attributable to methodological variability as well as fallacious interpretations generated from older sea level models. In the course of the present work, a primary goal was to upgrade previous and present observations and interpretations. In addition, our own reports provided significant data that enabled us to reconstruct the trends of relative sea level change over the past 10,000 years. Consequently, we have been able to present a highly detailed reconstruction for the past 3,000 years (Chapter 3).

Specialized analyses were undertaken as appropriate and by segment. Radiocarbon determinations were obtained for samples from the Liberty Island transect (4), the Bay Ridge Shoal (1), and Jamaica Bay (1). The limited number of samples was an indicator that many specimens were either contaminated or provided contexts unsuitable for dating (i.e. minimal organic materials). Samples from the Liberty Island transect and the Bay Ridge Shoal transect were submitted for specialized analyses of foraminifera, pollen, and plant macrofossils. Pollen and foraminifer specimens were productive and documented changing biomes and shifting margins of the estuaries during the Holocene. Forty-foot core C-1 from the Liberty Island transect was sampled at 30 cm (ca. 1 ft) intervals for analyses. Core D-1 from Bay Ridge Shoal was also sampled in this manner to furnish 40 samples. In all, eighty pollen and foraminifer samples were analyzed. Macromolluscan samples were taken from all cores to aid in the determination of contemporaneous water depths and habitat. Determination of a baseline stratigraphy relied on intensive study and sedimentological examination and mapping. Collective stratigraphic observations and supplementary specialized analysis allowed for reconstruction of the subsurface environments and landscapes by navigation channel (Chapter 9).

In addition to the vibracores collected as part of the present study, we have integrated the results from previous GRA harbor studies including the pilot for the present investigation (Schuldenrein et al., 2006), and the Port Jersey and Shooters Island: Newark Bay and Kill Van Kull (Schuldenrein et al., various). Other prior studies directed towards paleoenvironmental reconstruction for submerged sites included work by LaPorta et al. (1999) for portions of Raritan Bay, Arthur Kill, the inner New York Bight, and portions of the Upper Harbor, and by Wagner and Siegel (1997) in the Kill Van Kull. Boring logs with sediment descriptions were also recorded from the collection at the New York District USACE library along with pertinent geotechnical reports that were examined and plotted as part of this overview.

The following section summarizes the results of initial attempts to formulate a model of archaeological sensitivity based on a series of limited subaqueous testing efforts and the paleoenvironmental sequences and submerged landform histories outlined earlier. The model also incorporates the evidence for subaqueous disturbance that resulted from the past 150 years of navigation channel and near-shore dredging that has occurred within the New York Bight.

Georchaeological Investigations to Date

GRA performed four (4) sets of field investigations in the project area between 1999 and 2001 (Schuldenrein 2000a, 2000b, 2001). Supplementary investigations, in conjunction with harbor dredging were also undertaken by La Porta et al (1999), and by Wagner and Siegel (1997). Their results were integrated into the GRA reports and are referenced again in this presentation.

New York Harbor Study. An extensive set of subsurface borings for the New York Harbor area were analyzed for a pilot study which established a baseline stratigraphy indexed by radiocarbon analysis and foraminifer, pollen, and plant and macrofossil studies (Schuldenrein 2000a). The GRA team had access to a total of 114 borings extracted for geotechnical purposes. Additionally, curated samples were examined at the USACE New York District storage facility at Caven Point, New Jersey.

Geoarcheological field work was undertaken in November, 1998 and involved inspection and sampling of borings from two available drilling platforms. Standard geotechnical procedure was used to recover two-foot long split-spoon samples at every five feet in the uppermost sediments. This procedure was later modified to furnish a continuous series of two-foot spoons until the sediments appeared to be of Pleistocene age. Samples of bulk organic sediment and plant macrofossils were collected. It was noted that some of the uppermost sediments were contaminated with hydrocarbons and other hazardous materials. This was a function of the mixing of dredged materials plus the accumulation of effluents and discharge over the past 150 years.

Seven (7) borings were in the vicinity of the Newark Bay (NB) navigation channel work area, five (5) borings were in the vicinity of the Port Newark (PN); one (1) boring in Port Newark Point (PNP); and two (2) borings in the Elizabeth Channel (E) work area. Two (2) borings were described and sampled during fieldwork in the Claremont channel (CC); three (3) borings in Port Jersey (PJ); and five (5) borings in the Buttermilk Channel (BC). Borings in the other navigation channel work areas had been completed prior to fieldwork.

Thirteen (13) borings in the Anchorage Channel (ANC) work area were described and sampled at the Caven Point curation facility as were seven (7) from Stapleton (STA); and one (1) from Ambrose (AMB). The total number of borings integrated by GRA for its data base was 59. Fifty-two percent of the 114 borings collected for the New York and New Jersey Harbor navigation study.

Port Jersey Study. In addition to the four (4) vibracores taken near Liberty Island as part of the present study, five (5) cores on the Jersey Flats/Port Jersey navigation channel were reexamined. The cores were located along a transect from 12 to 30 ft water depths, according to the bathymetric contours. Based on the revised Holocene sea level rise model presented in Chapter 3, the "Jersey Flats" should have spanned habitable terrain along the Hudson River shore during periods as early as 6,000 B.P. (7,000 cal yrsbp). Thus, submerged cultural resources associated with the Late Archaic or older might be expected if occupation and site preservation were favored by subsequent environments of deposition within the estuary.

Shooters Island: Newark Bay and Kill Van Kull Channels. This earlier project involved subaqueous coring at four (4) locations in connection with mitigation activities at the site of the Arthur-Kill-Howland Hook Marine Terminal Channel project. Borings were spaced approximately 50 meters (164 feet) in each cardinal direction from a previous core (AK-95-5) that was formerly identified as having potential for Holocene landscape reconstruction (Wagner and Siegel 1997). Vibracore locations were recorded using a differential global positioning system and ship-board computer linked to the vibrator head. Depths of these four cores ranged from 7 to 18 feet, three of which provided Middle Holocene dates (ca. 6100-3000 B.P.).

The sequences were described lithostratigraphically and were examined for plant macrofossils. The data from these observations shows a documentation of relatively high-energy fluvial to near-shore facies directly overlying glacial till or outwash. Stratigraphies are diagnostic of changing estuarine and terrestrial balances in the Middle to Late Holocene. The macrofossil analyses suggested that brackish conditions emerged at approximately the beginning of the Middle Holocene (ca. 6,000 B.P.;[7,000 cal yrsbp]), and that by 4,000 B.P. (ca. 4500 cal yrsbp) an intertidal system was established at this location.

The muds at Shooters Island apparently accumulated at a rate of just over 1.0 meters per millennium. Sedimentation rates indicate a brackish intrusion at about 2 meters (6.5 feet) between 1000 and 2500 years B.P. The presence of oyster beds at the same depth is a confirming source of evidence for the same conditions at this depth. These observations are consistent with a 1 to 2 foot rise in sea level at the same time. Such a period of calm would explain the increase in submerged aquatic beds (preserved in the West Core at this depth). An increase in aquatic vegetation was documented at about 2 m in the South Core as well. The ongoing submergence of Shooters Island is the result of a sustained but subdued sea level rise over the course of the Holocene, beginning at about 6,000 years B.P. (7,000 cal yrsbp). After that time, estuarine clay and silt began to cap sequences. They signify landward marine transgression. Conditions became increasingly brackish until the system was completely intertidal ca. 4000 years B.P. Increased salinity up the sequence is also registered.

Baseline Model of Cultural Resource Sensitivity

The earlier studies of dredging impacts to the New York Bight produced a baseline model of archaeological sensitivity based on the relationships between cultural resource potential, dynamic landscapes of the past 20,000 years, and the impacts of dredging on former human landscapes. In general the geologic record offers a broad range of data because of several disciplines—geography, marine science, palynology, and sedimentology—have contributed variously to the data base. In contrast, the archeological information is considerably more uneven, since most investigations prior to the implementation of the National Historic Preservation Act (NHPA) were not systematic and the thirty years of subsequent research have produced limited results because of the complex logistics of both subaqueous archeological exploration and access to cultural deposits in urban and "made" landscapes.

Structuring a Model: Holocene Environments, Site Geography, and Historic Impacts

The formulation of the model of cultural resource sensitivity presented in previous work rests on synthesizing the following three sets of data.

Geomorphic and Paleoenvironmental Trends: Sea level rise is probably the most central factor accounting for changes in Holocene landscape and environmental history. It accounts for modifications to the shape, extent, and biotic potential of the former coastline during particular periods. It is reflected in distinct sedimentation modes during phases of sea level rise. Finally, the pattern of landscape transformation is indexed by dating the sediments associated with depositional environments along the coast.

As discussed earlier, postglacial sea level rise (after 12,000-10,000 B.P.) resulted in drowning of Continental Shelf, including areas that may have been occupied prehistorically **(Figure 2.2)**. The sea level rise to the general area of the New York Bight allows paleoshorelines to be plotted to suggest former areas of prehistoric occupation for our study area here. Between 6,000-2,500 B.P. sea level had risen to within 13 feet of its present level. Sea level continued to rise at the same rate over the following millennia although we now know that slight fluctuations above and below its mean trend took place. Since the 19th century it has been the impact of industrial age erosion and contemporary ocean circulation systems that have produced unique depositional patterns in the "made" landscapes of New York Harbor.

The habitable Coastal Plain land surface extended at least 60 miles onto the present continental shelf during the Paleo-Indian period (Bloom, 1983a: 220-222; Emery and Edwards, 1966; Stright, 1986: 347-350). The Kraft's *et al.* (1985) paleoshoreline reconstruction for the mid-Atlantic region suggests that there was still an additional ten miles of Coastal Plain at 9,000 B.P. (10,000 cal yrsbp). The succession of Middle Holocene shorelines rapidly approximated the present contours. All other factors considered, it would be expected that stratified shoreline occupations would have existed within the ten mile belt of the Middle Atlantic shore.

The overall pattern of sea level encroachment resulted in distinct modes of sedimentation that are reasonably well understood regionally, but poorly documented locally. The chronology of late glacial to post glacial sedimentation was initially explored by Newman et al. (1969) who identified the emergence if not the particular morphologies of the major pro-glacial lakes in the Hudson Valley. Most critically, the depositional signature for alternating clay and silt beds seasonally laid down in the individual lake basins was recognized. After 12,500 B.P. these beds were overridden by glacial meltwater sands whose distributions remain incompletely mapped. What is clear is that estuarine fines—finer sands, organic silts, and clays—typically cap sand deposits in many differentiated shoreline settings after 6,000 B.P. (ca 7,000 cal yrsbp). Thus the sands, or dateable organics in them, may date to between 10,000 and 5000 B.P. depending on the depth. But the absence of complete chronologies is complicated in the near channel settings by the ongoing dredging activities that have tended to redistribute the sands in various harbor settings.

The chronology of Holocene sedimentation remains poorly understood for

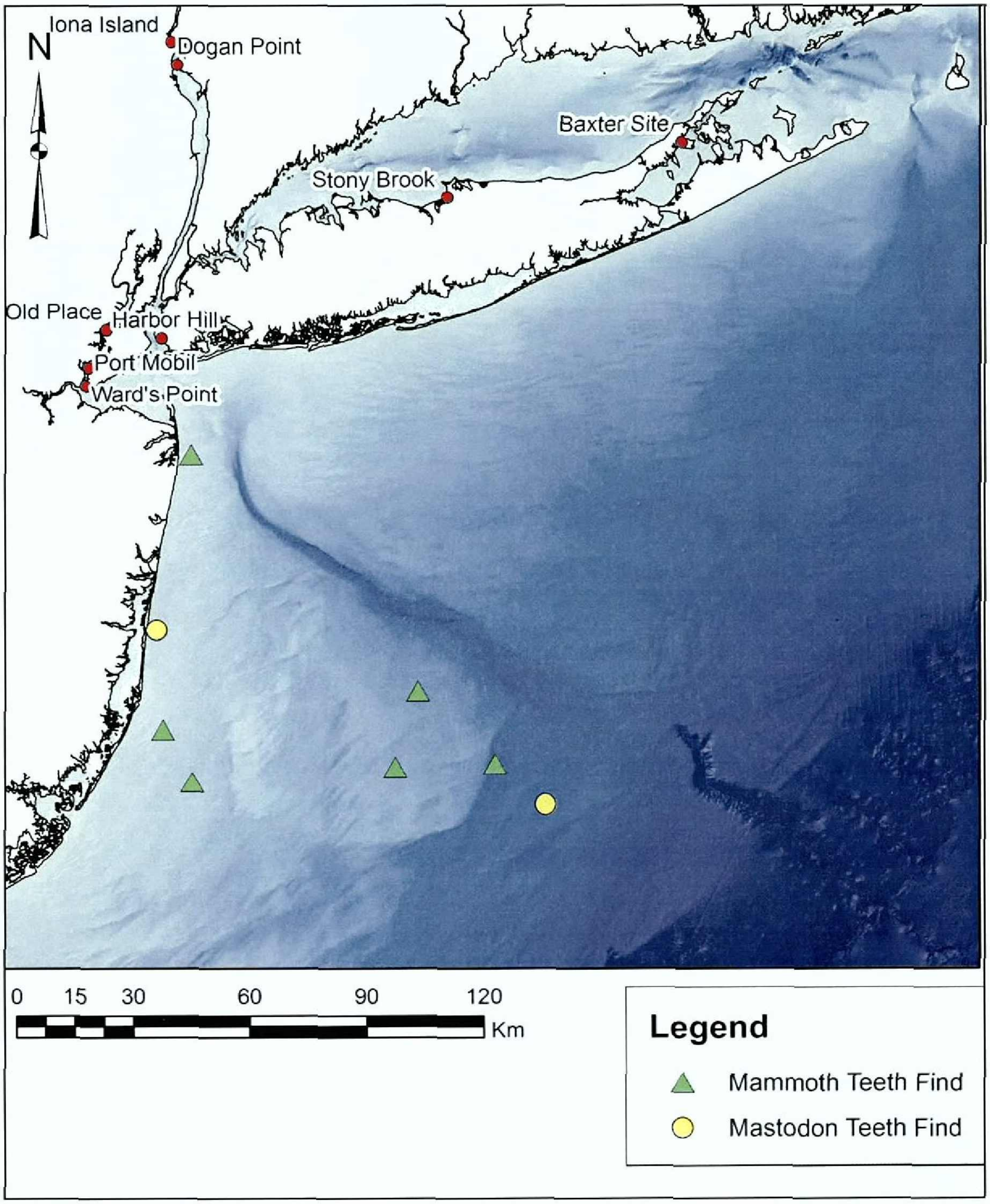


Figure 2.2: Mammoth and mastodon finds on the Continental Shelf and known Paleo-Indian and Early Archaic Sites.

the New York Harbor area, in part because of the extensive historic reworking of shore facies. Radiocarbon determinations document near shore transformations for the late Pleistocene and peak glacial environments. However, dated materials are rare for terminal deglaciation (especially on the coast); there is a gap in the sequence of dates between 19.000 and 9500 B.P. Early Holocene dates (ca. 10,000-6000 B.P.) are present but not abundant, while Middle and Late Holocene determinations are common. These data suggest that after 6,000 B.P. (ca. 7,000 cal yrsbp) regional and local landscape configurations begin to approximate those of the present.

Archeological Site Geography. Archeological models of site geography remain relatively poorly known for New York City to the present day (Cantwell and diZerega Wall 2001). This is because archeological investigation within the city environs has been impeded by urban constraints. The most relevant regional settlement models are those for the upstream seqments of the Hudson as well as from neighboring trunk drainages (i.e. Delaware and Susquehanna; see Funk 1976; 1993: Ritchie 1980). These constructs suggest that settlement trends are best reflected in the modifications to landscape caused by changing stream valley morphologies for terrestrial habitats and by rapidly rising sea level for near shore locations. In both situations, "available land" for occupation shifts in response to sedimentation patterns. That tendency was most pronounced during the Early Holocene (i.e. 10,000-6000 B.P. [11,500-7,000 cal yrsbp]). After the rate of relative sea level rise leveled off during the Middle Holocene, the newly exposed and lower gradient near shore surfaces opened up for colonization. A corollary to this effect of near shore stabilization is the increasing stasis of river systems which became confined to preexisting channels by 6000 B.P. (7,000 cal yrsbp) and whose floodplains subsequently mirror near-present configurations.

Post-glacial landscape transformation and dynamic geomorphic environments are a primary cause for the diffuse preservation records of early archaeological sites. Progressive stability of later Holocene environments accounts for settlement patterns that increasingly follow contemporary environmental zonations. Thus, the infrequent occurrences of Early Archaic sites everywhere in the Northeast are largely explained by their potential containment in sediments and river fills that are submerged or deeply buried and not accessible by typical survey strategies. In contrast, Late Archaic sites are considerably more abundant and accessible (Ritchie 1980), due to their alignment with contemporary floodplains; the geography of such floodplains has not changed dramatically in the past 3000 years. It has also been widely recognized that population densities for later prehistoric periods are higher as well. While there is evidence for both population reduction and dispersed settlement during various phases of the Woodland, such trends are explained more in terms of subsistence and scheduling variability rather than by environmental change (Funk 1993).

The absence of an extensive record of prehistoric occupation across the metropolitan New York City area is in no small measure a function of non-systematic survey and the uneven record of preservation and compliance. Projecting the Hudson Valley data onto the lower estuary it is noteworthy that for the Paleo-Indian period mammoth and mastodon finds were found on the continental shelf and south of the Hudson River channel (Fisher, 1955; Whitmore et al., 1967). Indications are that both of these large mammals were plentiful in valley flats that have since been drowned by sea level rise. However, the only known Paleo-Indian archeological contexts are in what were formerly upland locations at Port Mobil and Ward's Point on western Staten Island along the Arthur Kill.

Subsequently, the geography of site distributions may be characterized as one of progressive "landward migration", specifically to interior (north and west) locales in response to sea level rise. The bathymetric band between 10 and 30 feet (3 and 9 m) below present mean sea level should be particularly rich in inundated archeological sites of Middle to Late Archaic age and such sites could have extended across a broad band that would have attracted humans for periods of up to a thousand years prior to their submergence. It has been suggested that humans were frequenting northwestern Staten Island at least by the ninth millennium B.C. (Kraft, 1977a, 1977b; Ritchie and Funk, 1971), when spruce was beginning to decline relative to pine in the boreal forest. Early Archaic sites, currently bordering shoreline or salt marsh settings represent the vestiges of campsites in the boreal forest alongside small freshwater rivers or ponds. Their apparent low density and isolated distribution suggests that people were visiting them seasonally as part of an annual round, which also included more substantial base camps at locations now submerged within the harbor or on the continental shelf.

Until recently, the lack of diagnostic indicators for earlier Holocene paleo-environments accounted for inaccurate depictions of the Early Archaic. Reconstructions of salinity, water depth, and other factors affecting shellfish habitat within the early- to mid-Holocene estuarine waters would aid in environment and habitat reconstruction for rare Early Archaic sites. This would assist in explaining the sudden appearance of oyster-shell-bearing sites such as Dogan Point during the sixth millennium B.P. (Brennan, 1974, 1977; Claassen, 1995b). It is also possible that environmental conditions changed at this point to permit the combined procurement of faunal and floral resources whose previously disjunct distribution in coastal and interior settings required more "scheduling" of the annual round (Flannery, 1968). Continuation of residential mobility at least through the Middle Archaic is supported by Claassen (1995b), however, with an annual round which included both the shellfish, seeds, meat, and hides available at Dogan Point and other unspecified resources available from interior locations such as the Goldkrest site northeast of Albany.

Travel by canoes and other watercraft was common throughout the Northeast at least as early as 3,000 B.P. (3,100 cal yrsbp) as substantiated by Woodland culture assemblages found on Ellis Island and Liberty Island (Boesch, 1994; Pousson, 1986). Similar trends are suggested for the original portion of Governors Island (Herbster *et al.*, 1997) within New York Harbor. More systematic examination of Woodland period contexts is precluded by the diffuse distribution of such sites and their limited documented presence within the project area.

Settlement models for later prehistoric sites are varied, as they must account for the complex subsistence and settlement strategies characteristic of the later Holocene. Another factor accounting for selective preservation of Archaic and even Woodland age sites is depositional patterns in the near shore environment. As implicated earlier, drowning of terminal Pleistocene valleys, realignments of landscapes, and the establishment of new drainage lines during the early Holocene would have buried or severely reworked the limited sites of the Paleoindian and Early Archaic periods. Middle Archaic sites and settings within the Upper New York Bight of Middle Archaic age may have been vulnerable to the same processes of submergence and destruction. However, it is possible that during the Late Archaic (ca. post 6000 BP) isolated sites at 33 ft below mean sea level might have survived intact, since they would have been shielded from previous (alluvial or colluvial) disturbance processes. On Staten Island, many of the earlier period artifacts may have been eroded and redeposited far from their original context. However, later sites in unique settings may have remained intact. Typically, marine transgressions did not preserve archeological sites with undisturbed systemic context (Rapp and Hill, 1998: 78-79; Waters, 1992: 270-275).

Most models of sea level rise, even those developed in the '60's, account for short-term fluctuations in the overall transgressive regime. The initial rapid rate of sea level rise prior to 6,000 B.P. (7,000 cal yrsbp) suggests minimal disturbance due to wave action until sea level began to stabilize after 6,000 B.P. Rapid submergence of sites followed by rapid burial by sediment should actually preserve artifacts and their spatial patterning better than gradual inundation (Stewart, 1999: 571-574; Waters, 1992: 275-280). This hypothesis would apply for all sites from upper Late Archaic, Transitional and Woodland to historic periods. An overriding exception applies to subaerial and even currently subaqueous landscapes which have been extensively modified by historic erosion, re-contouring and development. The preservation contexts of all sites are therefore subject to post-depositional modifications.

Historic Impacts on the Channel Settings. Both episodic and cumulative effects of terrain modification during the Industrial period in the New York Bight cannot be underestimated. Historic impacts include modifications to the morphology of the coastline (by additions and removal of land) and impacts to the channel by depth and lateral extent. It is instructive to compare the overall differences between contemporary shore morphology and that of the 19th century in order to understand how historic modifications and land use patterns have affected the geography of the harbor.

Our earlier New York Harbor study (Schuldenrein et al., 2006) presented a pilot study of this kind, superposing the present navigation channels onto the positions of both the 1874 and present shoreline for most of the New York Bay navigation channels (Schuldenrein 2000a: Figures 12, 13, and 14). For Newark Bay, Port Newark, Port Newark Point and Elizabeth Channels, the plots illustrated that the eastern shore remains at approximately at the same location as that of the present, but the western shoreline is considerably modified. First, "made land" and docking slips were cut into the old land surface in three separate locations. Next, the shoreline itself was expanded harbor-ward (to the east) on the order of 2000 feet. On a larger scale, the segments encompassing Anchorage, Claremont, and Port Jersey Channels revealed similar changes, with the eastern shorelines remaining essentially the same as in 1874, but the western shorelines have been more intensively re-landscaped; they were relocated nearly one mile to the west. Finally, for the limited segment investigated along the Buttermilk Channel the eastern shore is largely the same, but Governor's Island has been built out significantly, extending its area by nearly one half.

The plots and records also documented significant impacts to the channels by extent and depth. Channel excavation typically extended flow lines to depths of 35-45 feet, although depths up to 55 feet have been projected for Ambrose and Anchorage Channels. For cultural resource planning purposes it should be noted that project impacts are critical not only for surfaces immediately underlying the channels (which would eliminate deposits younger than 7000 years) but also for adjacent tracts that may preserve intact buried surfaces.

Toward a Working Model of Cultural Resource Sensitivity

The baseline model for cultural resources sensitivity was developed in conjunction with the initial New York Harbor study (Schuldenrein 2000a: Figure 18). It was framed around a crude synthesis of subaqueous stratigraphies from geotechnical cores and an equally limited assessment of the integrity of the sediments recorded in those sequences. The follow up studies for the Shooters Island (and attendant Kill van Kull and Port Newark channels) (Schuldenrein 2000b) and Port Jersey (Schuldenrein 2001) have provided additional subsurface data and a refinement of sensitivity. Additional modifications derived from the GIS based mapping of bathymetry and re-analysis of the historic maps. Revised interpretations are incorporated into the present discussion.

A baseline composite cultural resource sensitivity plot for the project impact area was generated (**Figure 2.3**). The individual channels were identified, as were the locations of cores and borings excavated and examined to date. Sensitivity rankings were presented in terms of "Low", "Moderate-High" and "High" potential for sites, based on the conflation, by channel, of the data collected for assembling the paleoenvironmental, archeological, and channel impact histories. The key paleoenvironmental relationships used for ranking the sensitivity were presented along with more specific rankings of sensitivity by archeological component, by depth (below mean sea level) of expected occurrence per the shoreline histories discussed above. Impact areas referd not only to the navigation channels *sensu stricto* but to channel margins as well, since these are likely to be excavated and/or disturbed by channel widening activities and future ship traffic.

A relative scale for site preservation invoking High and Moderate probability was derived from the recognition of deposits below impact levels that correlate with shore, near shore, estuarine, or floodplain surfaces. These identify the range of buried surfaces that would have sustained human occupation during prehistoric time. For the earlier time frames (i.e. Paleo-Indian through Middle Archaic) rates of sea transgression were rapid and would have resulted in rapid burial of archeological deposits. Recognition of deposits likely to contain archeological evidence resulted in **Moderate** to **High** determinations. **Low** rankings were generally assigned to channel segments in which investigations disclosed presence of a proglacial lake deposit or glacial till, both of which are unlikely to contain archeological materials because of their subaqueous contexts or Pleistocene antiquity. Radiocarbon ages and the foraminifer data index the chronology and patterns of environmental change respectively. **Low** rankings were also assigned to segments in which bedrock was reached (i.e. Port Newark Point, Elizabeth Channel). For the later time frames (Late Archaic through historic), clear recognition of estuarine or fluvial, alluvial and near shore deposits was critical. These sediments document presence of a stable surface and/or potentially rich resource biome. The foraminifer data indicate shifts in resource zones that might be tracked by assessing types and frequency changes in the foraminifer types.

Primary determinants for the probability rankings are sea level position and extent of disturbance by dredging. Two additional concerns include site probability by period and post-depositional modification. We assume that while site expectation might be considered

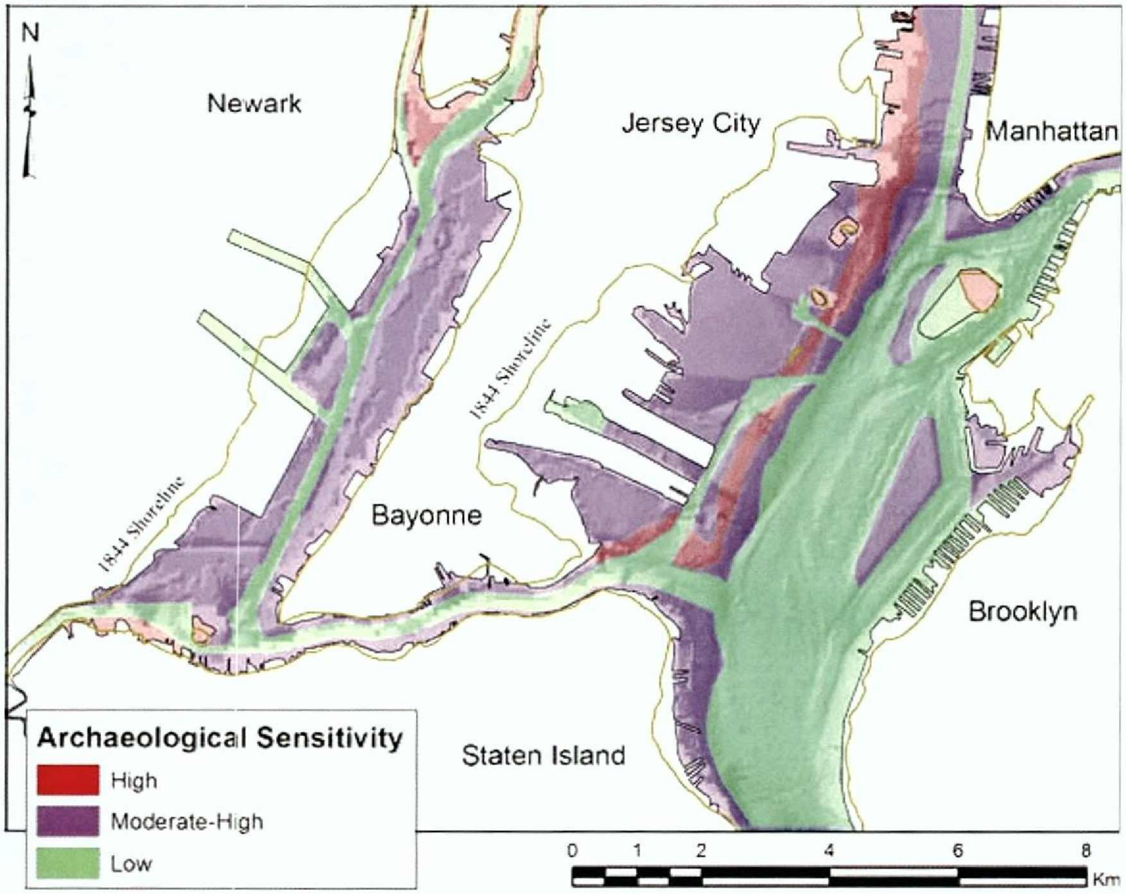


Figure 2.3: Example of archeological sensitivity denotation.

highest for late prehistoric components, integrity is compromised by their presumed location in those near shore settings most susceptible to disturbance by dredging and by earlier reworking by near shore geomorphic process during the long intervals of shore stabilization. Conversely, older sites, traditionally thought to be less dense and less likely to be preserved are more likely to be sealed at depths beneath dredging impact areas. Along similar lines, during the Early Holocene relatively rapid burial of earlier prehistoric components would have resulted in their optimal preservation contexts. In reviewing the geoarchaeological relationships, the following trends were suggested by the baseline site probability model.

1. *There is a relatively high potential for historic finds, even along channel reaches that are acknowledged to have low overall cultural resource potential.* This is because historic sites include contexts that may have been partially modified, but retain some integrity. Accordingly, even century old edifices constructed on "made land" are considered potentially eligible for the National Register of Historic Places (NHRP). Examples would include tanning yards that functioned along older shorelines that remain partially preserved in now submerged or disturbed settings.

2. *With some exceptions—Newark Bay, Claremont, Port Jersey and Anchorage Channel—most segments have Low expectations for later prehistoric remains.* Reference is made to post Late Archaic site potential and locations above the 20-40 ft bathymetric contours. The Low ranking reflects dredging disturbance to these channels and the probability of mixing of assemblages (i.e. Late Archaic and Woodland) on near shore surfaces during the Late Holocene, as sea level rise was stabilizing. Wave action and shifting beach margins of the estuaries would have affected land expanses and shapes along the coastline. Smaller sites would have been swept away well before historic times. Low-Moderate and Moderate rankings were assigned to locations flanking channels minimally dredged; here there remains a likelihood for Late Archaic and Woodland site survival.

3. *The Late Archaic marks a threshold for Moderate site potential.* As noted, by 6,000 B.P. (7,000 cal yrsbp) rates of sea level rise diminished and shorelines stabilized. Many sites could have been rapidly buried, thus resulting in retention of site integrity. Moreover, sites of this period are abundant, since in addition to the fact that landscapes began to approximate contemporary configurations, the changing coastlines marked the transitions to estuarine and highly differentiated micro-environments. These would have been excellent as well as prolific settlement loci. Stratigraphically, this portion of the vertical sequence is the break beneath which impacts by dredging were minimal. Thus, the potential for site preservation rises proportionately with increasing depth.

4. *Paleo-Indian to Middle Archaic site expectations are Moderate or Moderate-High in several channel segments.* Only Port Newark, Port Newark Point, and Buttermilk Channel have Low site potential rankings. The Low ranking was determined because elevations below 30 feet in these channels either encounter Late Pleistocene lake beds or bedrock. Moderate to High rankings are the product of stratigraphic exploration that either revealed a pristine glacio-fluvial facies (possible stream side location at Newark Bay), or Early Holocene near shore facies (Anchorage Channel; dated) or floodplain (Claremont, Port Jersey) contexts. Stapleton and Ambrose Channels, while not examined in detail, provide limited records of analogous Early Holocene sedimentation regimes. In all locations, with

the possible exception of Ambrose, the deposits with potential are below the limits of dredging.

Testing the Model

The above hypotheses are testable on several scales. Large scale refinements are generated by more detailed mapping. In the past few years, since the baseline New York Harbor investigations were undertaken, several agencies have completed the mapping and digitizing (GIS) of data sets bearing on local and regional surface geology.

Both the New York and New Jersey Geological Surveys have updated plots of the surficial geology of the coast and terrestrial landforms of the New York Harbor area. Present surfaces are either underlain by bedrock or surficial deposits of Late Quaternary age. In general the latter reach thicknesses of 1-20 m in marine, estuarine, and terrestrial contexts. Because of the complex record of glacial activity, the chrono-stratigraphy of the surface sediments is the key variable in assessing buried site potential for prehistoric deposits. Accordingly, accurate mapping is a key measure of the zonation of landform complexes likely to contain archaeological sediments of a given age.

Substantial refinement has been achieved in mapping complex subsurface lithologies. It has been provisionally possible to correlate between states by comparing descriptions of landform and sediment complexes in the vicinity of state lines and by generalizing unit designations. GIS data bases available in both states facilitate such tasks. Surficial geology maps provide an index for observations made over the course of the previous field testing. Ideally, the correspondences between the stratigraphies with broad landform/sediment complexes established by the mapping units would facilitate a stratigraphic sequence and chronology for the New York Harbor area.

Chapter 3

RELATIVE SEA LEVEL RISE ALONG THE MID ATLANTIC COAST

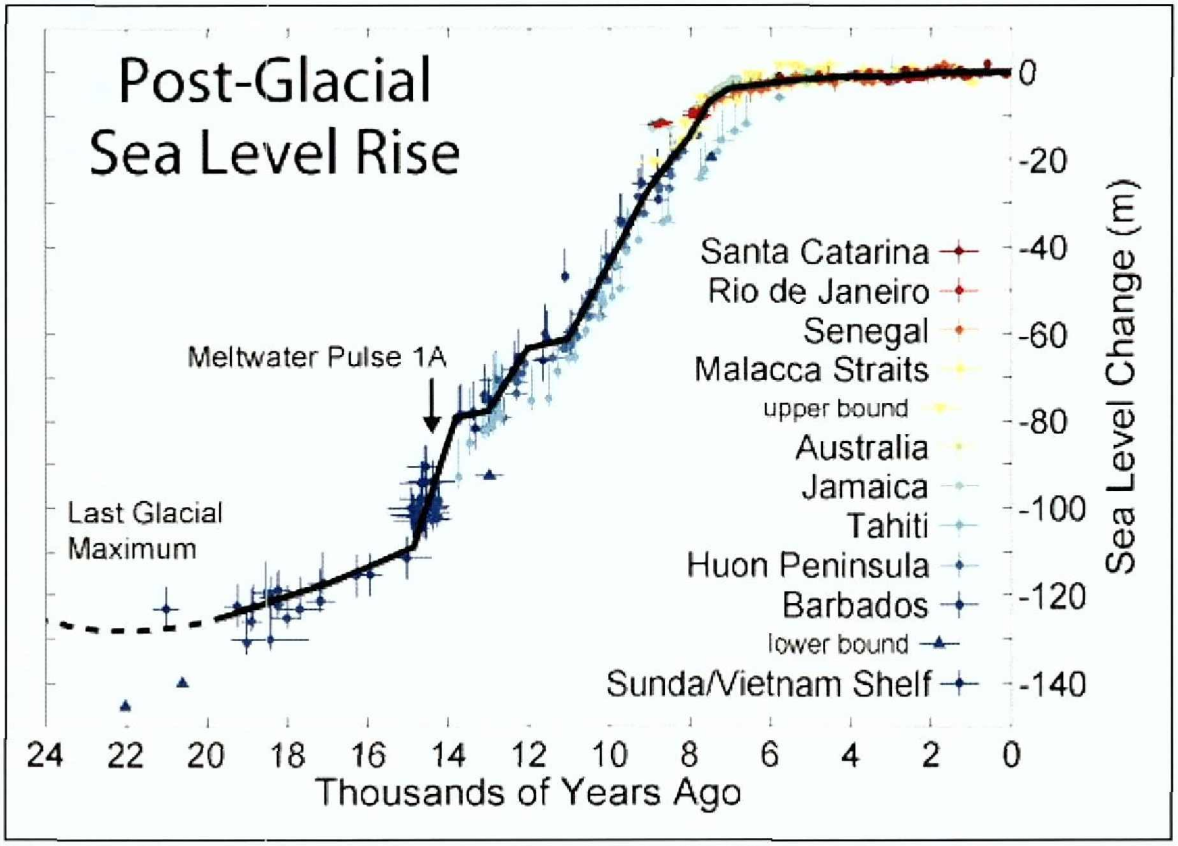
Global Eustatic Sea Level

Global sea level is ultimately controlled by climate change, which varies the volume of water available in the ocean basins. Simplistically we can think of sea levels being low during periods of glaciation when great volumes of the available earth's water were removed from the oceans and held in storage as ice on the continents. The converse was true when glaciers melted on the continents and returned water to the oceans once more. Geologic records from our continental shelves show sea level to have been at least 100 m (328 ft) lower than present during the last glaciation ca. 20,000 years ago. The change in volume of sea water in the ocean basins is termed the **eustatic** sea level.

Accurate determination of global sea level is more complex. Although studied over the past century, sea level records could only be reconstructed in detail after the advent of radiocarbon dating following World War II. Radiocarbon dated sea level records presented during the 1960's (Fairbridge, 1961, Shepard, 1965) generated subsequent decades of intense debate and research on sea level. Importantly, it appeared unlikely that eustatic sea level could be determined with accuracy because of the complexity of the changing size of the ocean basins due to sea floor spreading, or subsidence of the oceanic basins due to the mass of water returned from melting glaciers. Similarly, the temperature of sea water influenced its volume as well, with warming water giving rise to higher levels (steric effects). As a result, the study of sea level change was complicated by the changing position of the earth's crust with respect to the level of the sea and the level of the sea with respect to temperature and the continental shorelines. Current concerns with ongoing rise in sea level contend with the relative position of the sea relative to the land—hence **relative sea level**. Yet the impact of relative sea level on the continent shores requires a better understanding of eustatic sea level.

In recent years the eustatic sea level has been reconstructed with greater reliability through the study of "far field" sites. These are records of sea level change determined from islands "far field" from the complex crustal changes of the continents. In theory, radiometric dating of sea level sensitive markers (specific coral species, etc.) provide the basis for determining the "absolute" level of the sea with respect to its volume as varied by glacier melting and steric effects. The leading models for eustatic sea level are presented by Peltier (2002) and Fleming et al. (1998). Both models rely on estimates of the volumes of glacial meltwater returned to the ocean basins since the last glaciation. Peltier maintains that virtually all of the glacier ice had been returned to the ocean basins by 6,000 to 7,000 year ago suggesting that sea level has been stable since that time. Fleming and his colleagues have maintained that eustatic sea level has risen from 3 to 5 meters (ca. 10 to 15 feet) over the past 7,000 years. The arguments are not relative to this study other than to help understand the record of **relative** sea level changes on the Atlantic coast of the United States and Canada. It is important to recognize that during the melting of continental glaciers, the eustatic level of sea rose rapidly until ca. 7,000 years ago when the rate of rise decreased dramatically.

The pattern of eustatic sea level rise is shown graphically in **Figure 3.1**, which is the Fleming et al. (1998) compilation of sea level recorded from "far field" sites. This model illustrates a low sea level of 120 meters (394 ft) at the height of the last glaciation.



3.1 Eustatic Sea Level Determined from "Far Field" Sites (Fleming et al, 1998) (http://www.globalwarmingart.com/wiki/Image:Post-Glacial_Sea_Level_png)

Relative Sea Level Change along the Atlantic Coast

Tide gauges along the coasts of the U.S. and Canada provide historic records of relative sea level changes. It is clear, however, that there is great variation in the rates of sea level rise from one station to another. This is shown graphically in **Figure 3.2,** which illustrates the rates of relative sea level rise along the U.S. Atlantic coast from Key West, Florida to the Canadian border. Note that the rates of sea level rise recorded by the gauges are on the order of 1.5 to 2 mm/yr (0.06 to 0.08 in/yr) for the Florida peninsula and the New England coasts but rise to highs from 3 to 4 mm/yr (0.12 to 0.16 in/yr) for the Mid Atlantic coast. These are shown in comparison to the rate of global eustatic sea level rise proposed by Peltier (1995, 2000). Peltier (1995, 2000) and Douglas (1991) relate these anomalously high rates of relative sea level rise to ongoing postglacial crustal adjustments. More specifically, these authors point to subsidence along a zone peripheral to the southern limit of glaciation termed a proglacial forebulge. The forebulge represents an uplift of the earth's crust caused by simultaneous depression of the crust in the Hudson Bay region and Laurentian Highlands under great thicknesses of glacier ice. As the

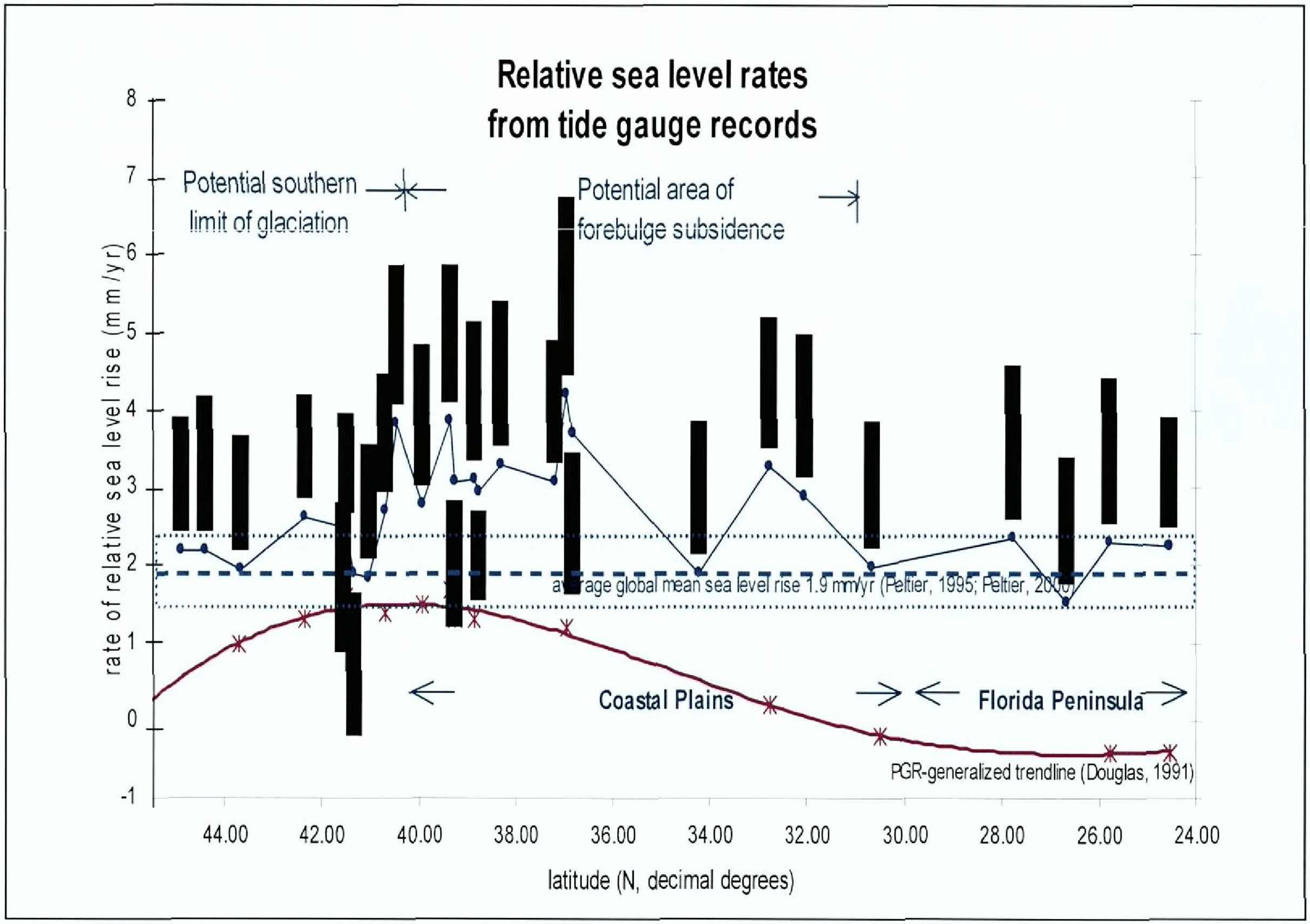


Figure 3.2: Relative rates of sea level rise along the Atlantic Coast as recorded by tide gauges. The rise in rates of subsidence (PGR) delineates the area of proglacial forebulge. (Larsen and Clark, in press)

crust in the former glacier ice center rises, the forebulge collapses and continues to do so. This ongoing process is termed postglacial rebound (PGR). Both Peltier and Douglas consider the rate of subsidence of the forebulge (labeled PGR) to be on the order of 1.5 mm/yr (0.06 in/yr). The pattern of subsidence rates is shown on **Figure 3.2** and delineates subsidence rising in rates from a minimum in the Florida peninusula to a maximum between Georgia and Long Island Sound while decreasing further north. In essence, since the crust is subsiding, this rate must be added to the global eustatic rate of sea level rise. Hence, the relative rates of ongoing sea level rise along the Mid Atlantic coast are on the order of 3 mm/yr (0.12 in/yr).

Comparative Holocene Sea Level Curves

The combination of eustatic sea level and forebulge subsidence provide an entrée for an understanding of postglacial relative sea level rise along the Mid Atlantic coast. But first it is necessary to show consistency between rates of relative sea level rise on historic and geologic time scales. **Figure 3.2** shows consistency in rates among New York, Philadelphia, and Washington, D.C. but only the first two sites have long enough periods of record to allow close comparison. Another site, Baltimore, MD, with a suitably long record can also be used. **Figure 3.3** shows a comparison of these three historic tide gauge records. All three of these are located on areas underlain by crystalline rocks that cannot be expected to show the effects of sediment compaction or anthropogencic subsidence due to groundwater withdrawal. These sites are in contrast to sites at Hampton Roads, VA, Atlantic City, NJ, and Sandy Hook, NJ, which show anomalously high rates of relative sea level rise. The latter two lie on the outer edge of the Atlantic Coastal Plain underlain by sedimentary rocks, while the former is located in a zone of probable anthropogenic subsidence due to groundwater withdrawal (Davis, 199_). The close agreement in the rates, trends, and patterns among these three tide gauge sites is striking. They form the comparative basis for building a Holocene relative sea level curve for the New York Harbor study area.

Detailed reconstructions of Holocene relative sea level are available from four critical areas: Chesapeake Bay, Delaware Bay, Long Island Sound, and Cape Cod Bay. Each of these sea level records are derived from radiocarbon-dated basal peat lying on sediments resistant to compaction. They represent the best sources for presenting the trend of Holocene sea level rise over the past several thousand years. The trends calculated from the radiocarbon-dated peat are shown below in **Figure 3.4**.

Consistent with the historic tide gauge records for the "bedrock-founded" sites in shown in **Figure 3.3**, the Clinton, CT, Barnstable, MA, including the Chesapeake Bay, show relative rates of sea level rise at 1.4 mm/yr while the sites at the mouth of the Delaware Bay show a greater rate: 2.0 mm/yr. The latter is likely affected by the thick sequence of less consolidated sediments and sedimentary rocks underlying this portion of the Atlantic Coastal Plain. Hence, the Delaware Bay sites seem to display regional compaction, while the Connecticut and Massachusetts sites are underlain by more consolidated sedimentary rocks (or crystalline rocks). Chesapeake Bay displays the 1.4 mm/yr rate, but lies at the inner edge of the Atlantic Coastal Plain where sediments and sedimentary rocks form a thin wedge lying on crystalline rocks of the Piedmont region similar to Philadelphia and New York City.

In terms of the eustatic sea level discussion above, these rates of are considered by Peltier (1997, 2002) and Douglas (1991) to represent

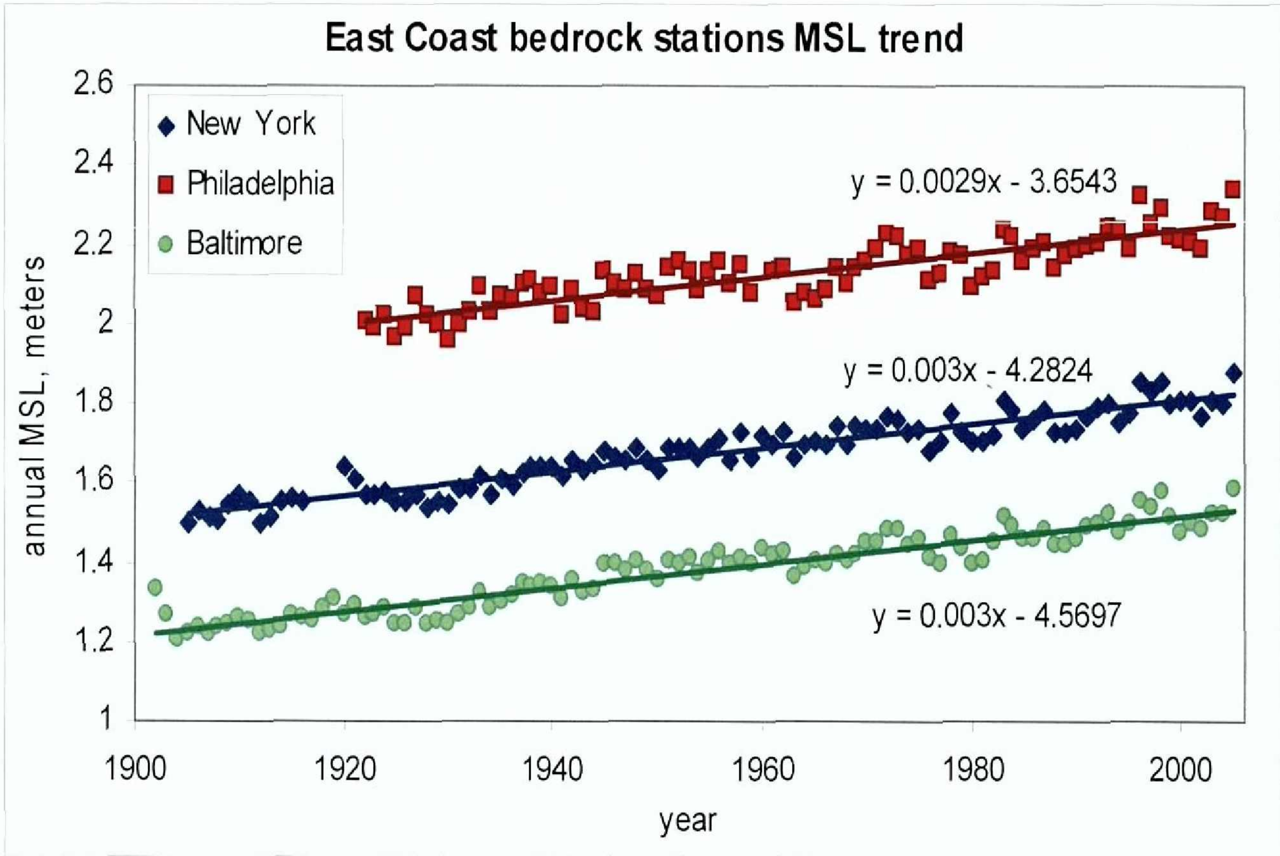
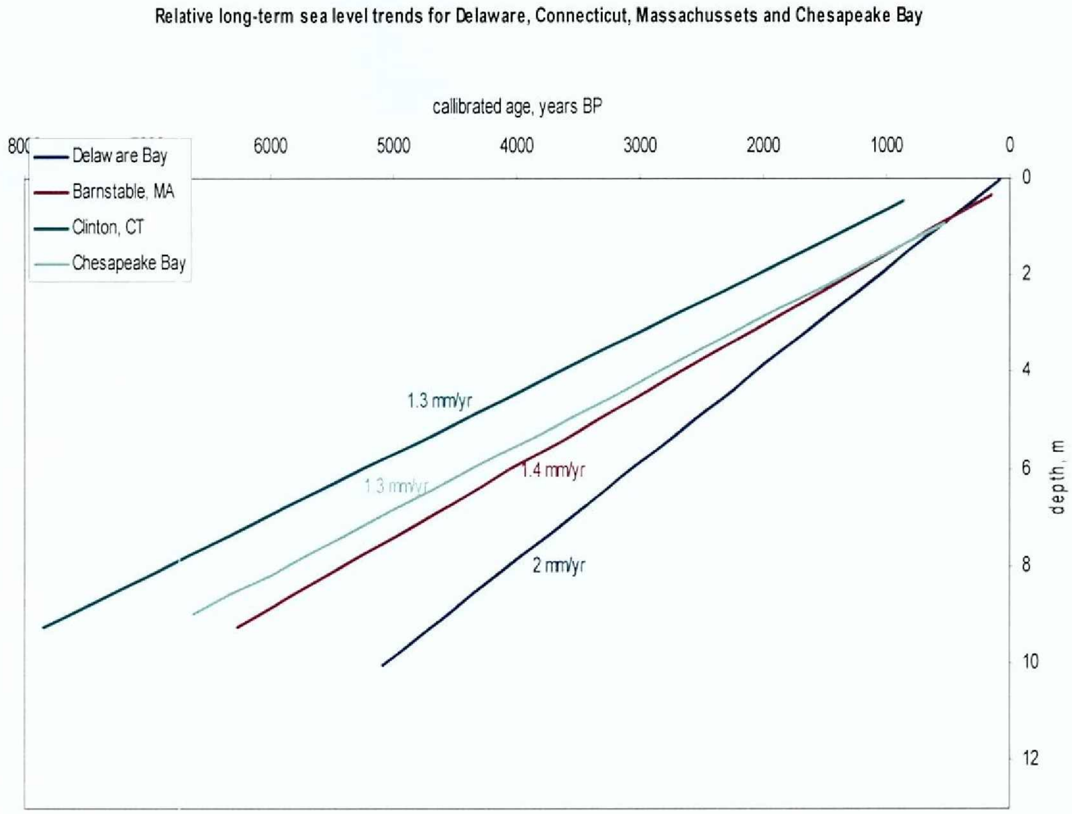


Figure 3.3. Comparison of tide gauges of long-term bedrock-founded sites. Each site shows a rate of rise of 2.9 to 3.0 mm/yr (0.12 in/yr).



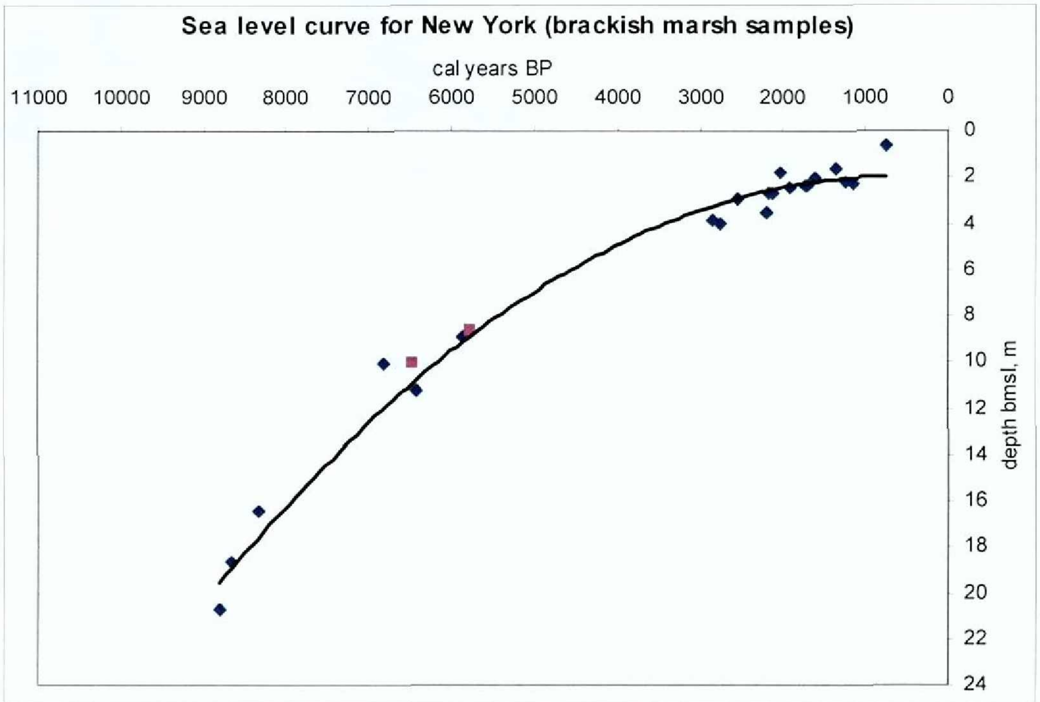
3.4 Comparative trends of Holocene sea level along the Mid Atlantic Coast (adapted from Larsen and Clark, 2006).

the rates of crustal subsidence along the eastern seaboard (**Figure 3.2**). For the purposes of constructing a sea level rise model for the New York Harbor area, the resulting curve of relative sea level should resemble the eustatic pattern shown in **Figure 3.1** lowered by consistent subsidence on the order of 1.4 mm/yr over at least the past 7000 years. In concept for New York Harbor then, we should expect a rising trend on the order of 1.4 to 1.5 mm/yr for at least the past 7000 years preceded by a more rapid rate of rise following deglaciation. In addition, since the current record of eustatic sea level has been presented in sideral (calendar) years, we must also maintain this consistency by calibrating radiocarbon ages determined as part of the present study as well as data contributed by other workers to build our model.

Development of an Accurate Local Relative Sea Level Curve

The Past 10,000 Years. Although the New York area researchers have figured prominently in discussing sea level histories (Fairbridge, 1961, Newman et al., 1969), few studies have been specific to New York harbor or the New York Bight. Psuty (1986) and Psuty and Collins (1986) presented a relative sea level reconstruction on the basis of dated stratigraphy from several New Jersey sites, including two from Raritan Bay. More recently, Stanley et al. (2004) have again discussed New Jersey data, but largely focused on the Cape May area which in some ways duplicates the longstanding work on Delaware Bay by Belknap and Kraft (1977) and synthesized most recently by Nikitina et al. (2000). These two complementary studies argue for a rate of relative sea level rise on the order of 2 mm/yr (as discussed above for the Lewes, DL, and Cape May, NJ area). Other important studies were conducted by Bloom and Stuiver (1963) on the salt marshes of the Clinton, CT area of Long Island Sound followed by Van de Plassche et al. (1998) and most recently by Varekamp and Thomas (1992, 1998). Further to the northeast, Redfield and Rubin (1962) provided a dated record of transgression at the Great Marsh at Barnstable, MA. The majority of work from the 1960's through the 1980's relied on radiocarbon ages. Refined calibration techniques for radiocarbon age dating have since impacted the interpretation of the early studies by allowing the direct comparison of the prehistoric sea level record to the historic data recorded by the tide gauges. Calibration of radiocarbon ages used in past sea level studies in the region points to different interpretations of the data originally presented. For example, earlier studies often showed sharp changes in the rate of sea level rise at various times in the past several thousand years marked by sharp break in slope of the curve (Psuty, 1986, Psuty and Collins, 1986, Redfield and Rubin, 1962). The break was generally considered to have occurred about 5000 years ago, we now relate this break in slope to be an artifact of uncalibrated radiocarbon dates. Few dated relative sea level curves are available from the New York area that extend beyond 6000 cal yrbp. The trend of the rate of rise since this time is nearly linear with probable departures of +/- 1 meter about the mean trend (Larsen and Clark, 2006). This seems to be consistent for the Mid Atlantic region where there are sufficient data to establish a trend.

During the course of the present study, 21 vibracores were taken in Raritan Bay, Jamaica Bay, and the Upper Harbor. Only a few of these provided sufficient organic material for radiocarbon dating of the marine transgression. Others, while datable, were from probable disturbed contexts or were from very young sediments. As a result, our team has compiled a collection of usable radiocarbon dates from pertinent cores taken by other researchers in the past as well as from cores taken by GRA in previous harbor area reports. Radiocarbon ages, calibrated to calendar years before the present, are shown in **Appendix B**. This table provides the elevations of the critical dates and stratigraphy in both meters and feet below mean sea level (m bmsl, and ft bmsl). Calibration is provided by the Oxford University (OXCAL) system available online (c14.arch.ox.ac.uk/ **oxcal**.html). The mid point of the calibration range forms the basis for plotting age versus depth to establish a sea level transgression curve for New York harbor. As basal peat ages furnish the only dependable measure for determining contemporaneous sea level elevations, only those samples labeled as basal peat or brackish marsh are used in the calculation. **Figure 3.5** illustrates this curve. Unlike the eustatic sea level curve (**Figure 3.1**), the relative rise of Sea level in New York harbor is a smooth curve extending 9000 years in the past. The data suggest a rising trend over the past 5000 years at a rate of between 1.4 and 1.5 mm/yr (0.05 and 0.06 in/yr). Prior to 5000 cal yrbp, the trend is more difficult to discern, largely due to the scarcity of earlier radiocarbon-dated stratigraphy. Three dated peats from the south shore of Long Island recorded by Field et al. (1974) and another from an incised stream channel along the eastern shore of Staten Island near Ward Point (LaPorta et al. 1999) suggest the rapid rise in sea level immediately following deglaciation, at a rate on the order of 2.6 mm/yr. The differing rates of rise are not consistent with the eustatic sea level and clearly do not exhibit the marked break in slope shown in **Figure 3.1**. Previously dated samples of wood from the Anchorage Channel (98ANC44) at 20.12 m bmsl/66 ft bmsl and basal peat overlying sand at 18.6 m bmsl/61 ft bmsl from

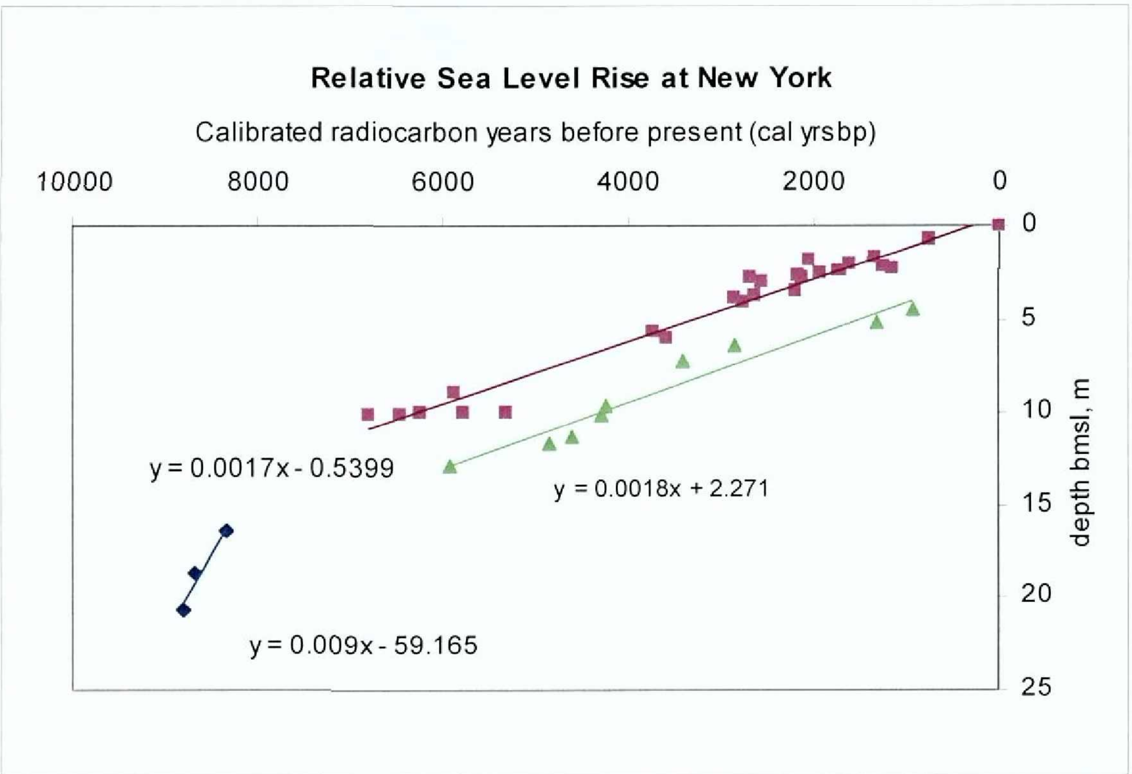


3.5 Relative Sea Level at New York Determined from 14C-dated Brackish Marsh Deposits and Peats.

the Jersey City viaduct (R15-4) reflect earlier ages but their interpretation is uncertain. In either case, the pre 5000 cal yrbp trend is poorly defined.

The lack of agreement with the eustatic curve is doubtless due to the smoothing program used to generate the curve using the common Excel program. Thus, the curve shown is a 2nd order polynomial best fit. **Figure 3.6** shows a comparison of linear trends calculated on pre and post 7000 cal yrbp samples shown above. Although there are few post 7000 samples, there is a clear dichotomy between the two groups. The trend calculated for the post 7000 cal yrbp samples shows a rate of rise of 1.6 mm/yr (0.63 in/yr) over this period and is consistent with rates derived from dated stratigraphy from Barnstable and Clinton marshes as well as Chesapeake Bay. The pre 7000 cal yrbp trend of 9mm/yr (0.4 in/yr) suggests the rapid rise following deglaciation and is in agreement with the 10 mm/yr (0.4 in/yr) rate for this period suggested by Flemming et al. (1998). Clearly, the curvilinear format is an artifact of the curve fitting technique and does not fit the current knowledge of eustatic sea level.

It is important to note that a recent study of submerged oyster reefs in Tappan Zee (Carbotte et al., 2004) has provided corroborating evidence for our interpretation of relative sea level change over the past 7,000 years. Shell dates, adjusted for dead carbon and subsequently calibrated, have been plotted in green on **Figure 3.6**. The calculated rate of relative sea level rise shown here is 1.6 mm/yr (0.63 inches/yr) and the trend calculated for the dated oyster reefs is 1.8 mm/yr (0.7 inches/yr) and comparable. This shows that living oyster communities adjusted to water depth and salinity were able to keep pace with the rate of sea level rise for at least a 5,000-year period for which we have data. Carbotte et al. (2004) also note that oyster growth was not continuous through time but showed distinct breaks in colonization. These authors propose that climate change and possible salinity changes related to sea level rise may have been contributing factors to periods conducive to oyster growth. These findings also reflect on distinct periods of oyster harvesting activity recorded in shell middens at Croton Point (Salwen, 1964, Newman et al., 1969) and Dogan Point (Claassen, 1995) that also point to periods when shellfish were not an important part of the diet at this particular site at these particular periods.



3.6 Comparison of Pre and Post 7000 cal yrbp Sea Level Trends. The green curve represents dated oyster reefs in Tappan Zee (Carbotte et al., 2004).

For our purposes, the relative sea level shown in **Figure 3.6** demonstrates the best agreement with the eustatic models argued by both Flemming et al. (1998) and Peltier (1995, 2000) and will be the interpretation used in this study to reconstruct the overall sea level rise history of the New York harbor area.

Detailed Reconstruction of the past 3,000 Years

Techniques for detailed reconstruction of relative sea level positions and rates of rise are in their infancy, however particularly cogent studies have been carried out in the New York area. Salt marsh stratigraphy is a key to determining short term and low amplitude fluctuations of sea level. Because many of our extant saltmarshes are relatively young—on the order of 2000 years or less—our knowledge is limited. Further, the field and laboratory studies required are labor intensive and therefore the results of the studies are not widely known. The concepts are straightforward. Saltmarshes are zoned with specific vegetation types dominant in specific tidal and salinity regimes. **Figure 3.7** demonstrates this concept. The intertidal zone located between mean high water (MHW) and mean low water (MLW) is most conducive to *Spartina alterniflora* and lithologically the sediment present contains high amounts of organic material in a matrix of clayey silt. Higher in elevation and away from the increasing reach of the tide, progressively less salt tolerant vegetation extends up imperceptibly gentle slopes. This progression often proceeds from *Spartina patens* through *Disticulus spicata* to *Scirpus americanus* or *olneyi* and *Juncus roemerianus*. In the more freshwater dominant areas upslope, the vegetation may give way to Typha sp., the common cattail and the invasive Phagmites sp. common to the marshes of New York area.

Because these plant types are salinity reliant, they respond to rising and falling water levels. Together with the underlying sediment, the pollen and seeds for each vegetation zone, as well as the microfauna living in the marsh, changes in past sea level can be tracked through time and space provided there is sufficient material for isotopic age dating. **Figure 3.7** demonstrates the zonation of vegetation and sediment in a tidal setting governed by a stable mean sea level. In this scenario, sediment accretion takes place along the edges of the marsh adjacent to tidal channels carrying suspended sediment. As sediment is added to the marsh edge, the marsh grows laterally and expands. The sedimentary zones or facies within the marsh also spread laterally forming near-horizontal stratigraphic units while simultaneously preserving the pollen and microfauna of the marsh surface. Abundant organic debris at the surface forms a saltmarsh peat layer underlain by organic silts indicative of the intertidal zone. This example can be considered the steady-state example of saltmarsh growth and expansion.

Sediment cores taken at sites A and B in **Figure 3.8** show the attitude of the facies and furnish the fossil record needed to reconstruct the contemporaneous environment. With the steady-state example in mind, the complexity of the saltmarsh to sea level variation can be better understood. **Figure 3.9** illustrates the changing vegetation positions and sedimentary facies during an episode of rising sea level. In this case both the vegetation and underlying sediment rise and move inland with a rising sea level. The sedimentary facies are no longer horizontal but rise and lap onto and cover previous deposits. Note for example the rise and movement of saltmarsh peat inland to overlie the previously deposited freshwater peat and land surface. Sediment cores taken in this scenario record the transgression of sea level onto the marsh.

For a falling sea level, the pattern reverses allowing the vegetation and stratigraphy to shift back to the lateral accretion model shown in **Figure 3.8**. Each transgression and regression of the sea surface is recorded stratigraphically in an interfingered sequence of lithologic units containing a fossil record of marsh history. Fletcher et al., (1993) recognized transgressive and regressive facies in saltmarshes at the mouth of Delaware Bay. These researchers identified five separate transgressive units over a 5000-year period, each separated by a period of regression during lowered sea level. Distinct periods of lower sea level were noted at 2200 and 800 BP.

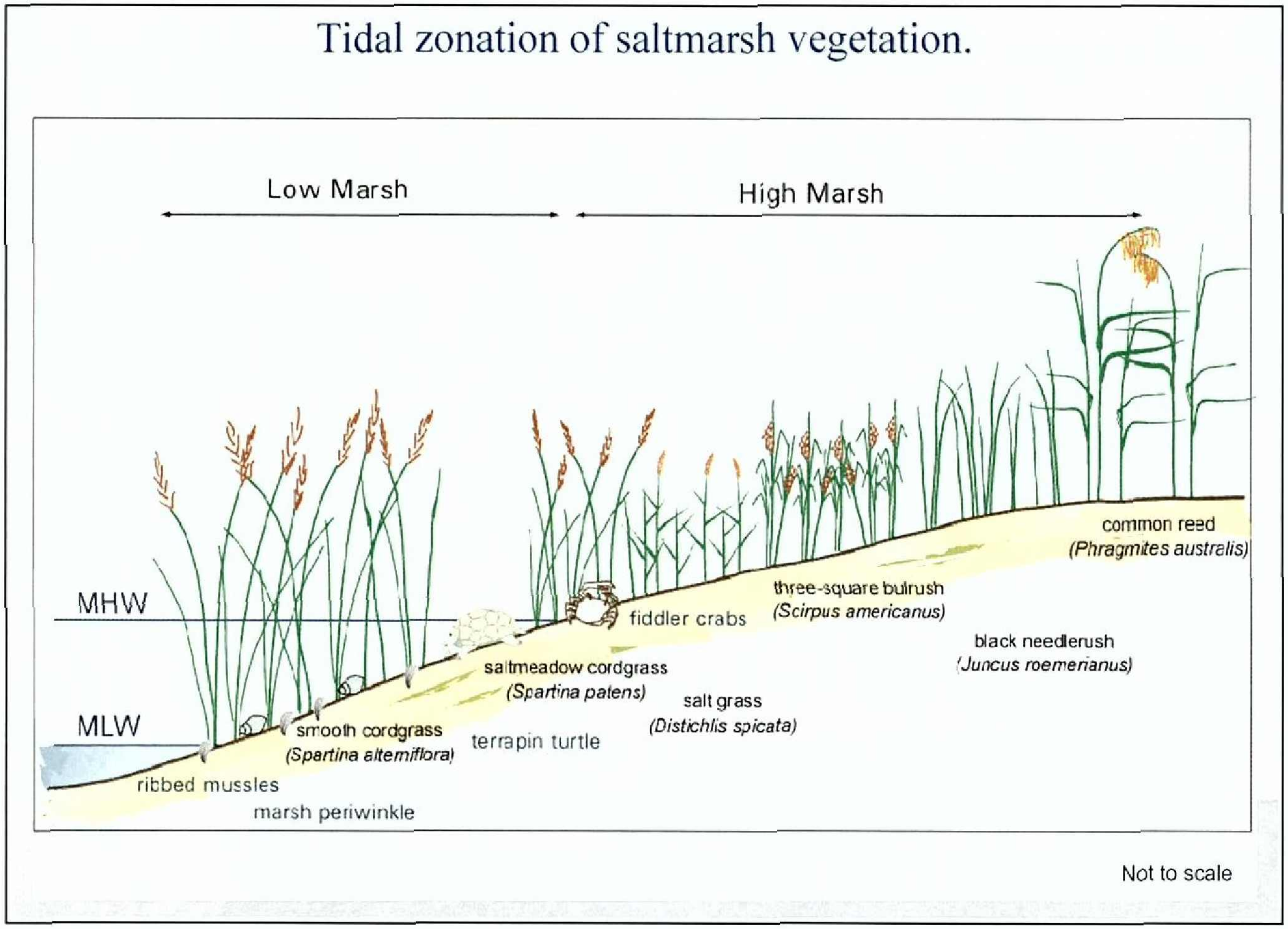


Figure 3.7. Zonation of saltmarsh vegetation (adapted from Larsen and Clark, in press).

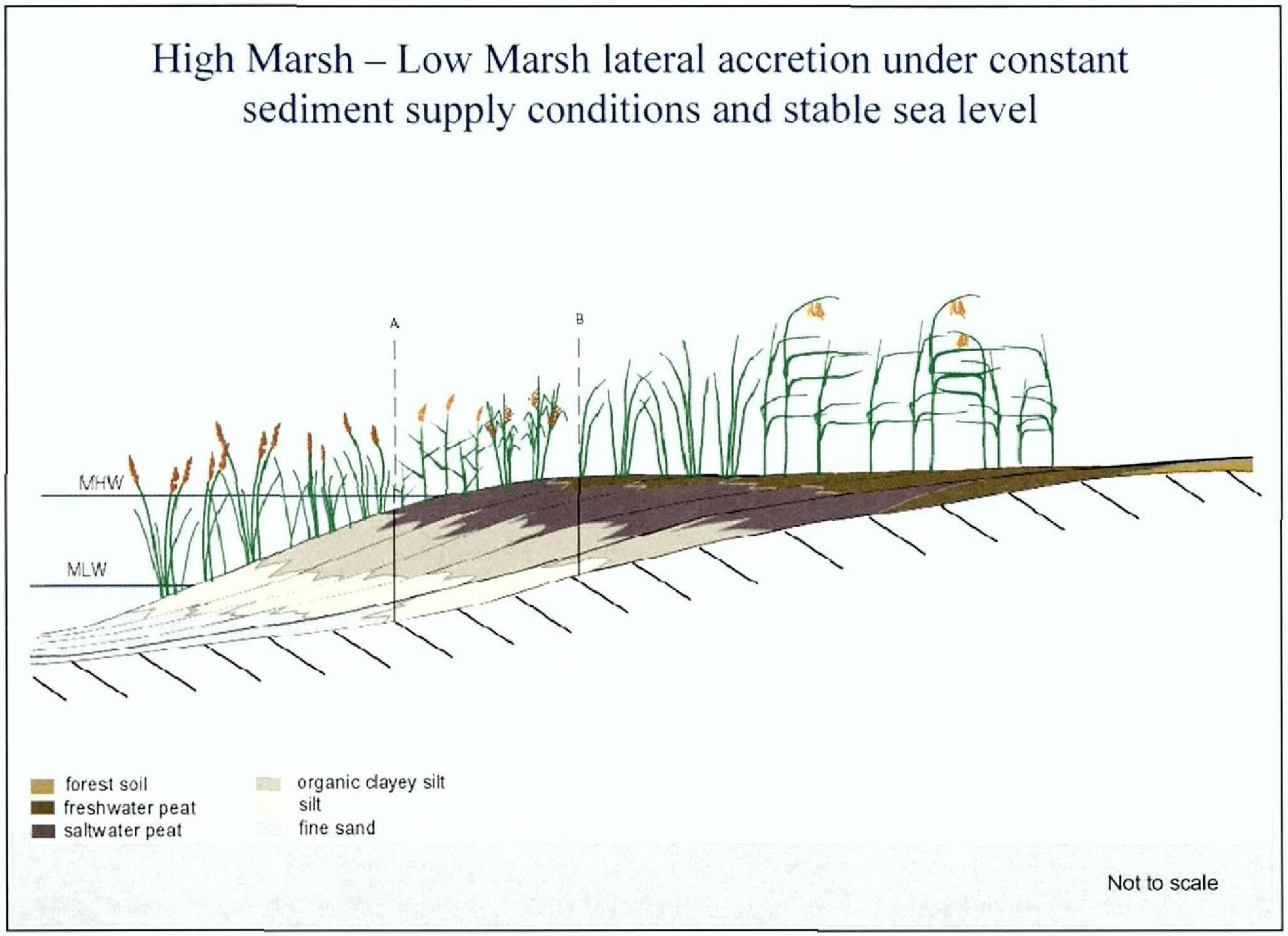


Figure 3.8. Lateral marsh accretion under constant sediment supply and stable mean sea level (adapted from Larsen and Clark, in press).

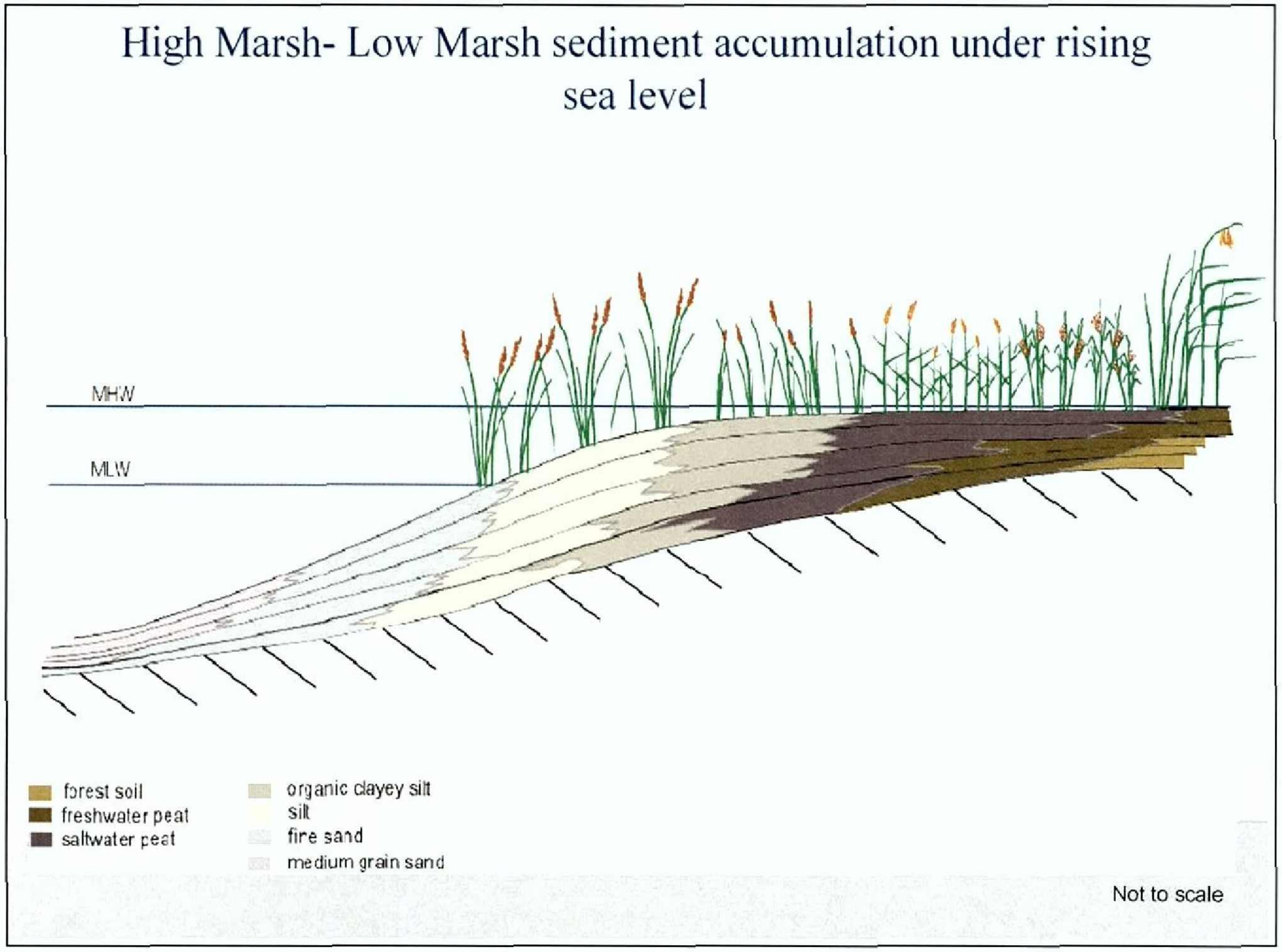
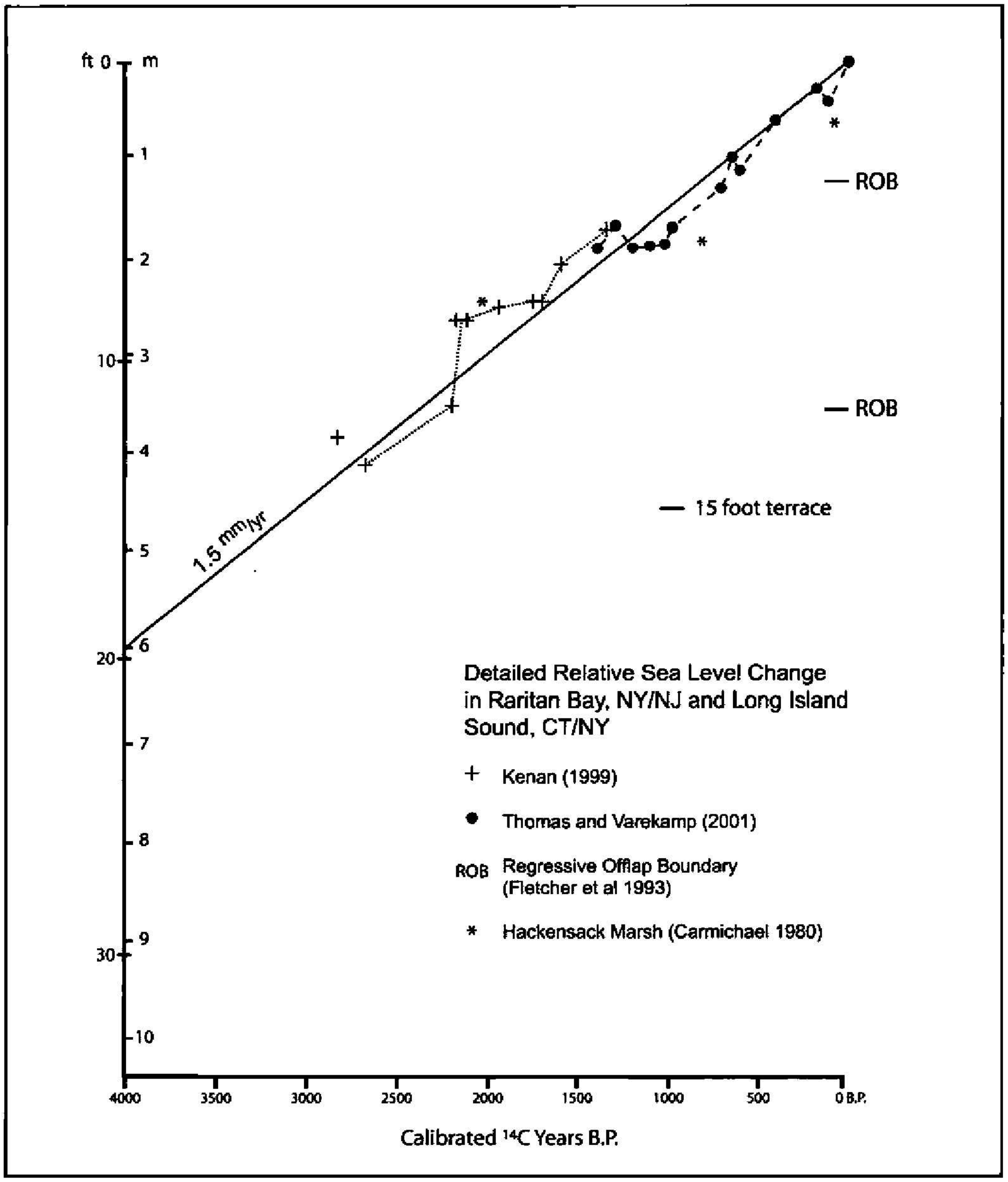


Figure 3.9. Saltmarsh response to sea level rise (adapted from Larsen and Clark, in press).

Varekamp and Thomas (1992, 2001) analyzing foraminifers from the saltmarshes of the Connecticut shore of Long Island Sound constructed highly detailed records of sea level fluctuations over the past 1500 years. Significantly they identified differing rates of sea level rise with acceleration beginning as early as 1500 years ago. Perhaps more important, they showed a relatively long period of lowered sea level on the order of 30 cm (1 ft) lower than present from 1200 cal yrbp to 400 cal yrbp.

Another extensive and detailed study of saltmarsh stratigraphy was conducted along the Raritan River upstream from Raritan Bay by Kenen (1999). Kenen reconstructed an interval of fluctuating higher sea level on the order of 30 cm (1 ft) from ca 2500 to 1000 ca yrbp. He too identified differing rates of relative sea level rise ranging from 2.0 mm/yr to 5.4 mm/yr. A composite sea level record determined from the Kenen (1999) and Varekamp and Thomas (1992, 2001) studies is presented in **Figure 3.10**. The composite record points to the great scientific value of saltmarshes for unraveling the subtle changes in sea levels of the past and discerning differing rates of sea level rise and fall on a century-by-century scale. Such detailed records of sea level variation bridge the geologic and historic records to provide a context for both past and modern change in environment.



3.10 Detailed Reconstruction of Late Holocene Sea Level Variation.

Chapter 4

GEOLOGICAL AND ENVIRONMENTAL SETTING

The Late Quaternary landform history of New York Harbor area is function of bedrock geology and events associated with glacial history. The end of the Pleistocene (after 18,000 B.P.) is recorded extensively in the surface and subsurface deposits of the coast and near shore settings of metropolitan New York City and adjacent New Jersey and New York. Variable accumulations of sediment record the region's history of glaciation and deglaciation as well as submergence and emergence as ice sheets formed and global (eustatic) sea level changed during the past million years.

Regional geological and paleo-environmental studies are extensive. Relevant research has focused on bedrock geology (Isachsen et al. 1991; Schuberth 1968); late Pleistocene and (to a lesser degree) Holocene surficial deposits (Antevs 1925; Averill et al. 1980; Lovegreen 1974; Merguerian & Sanders 1994; Rampino & Sanders 1981; Reeds 1925, 1926; Salisbury 1902; Salisbury & Kummel, 1893; Sirkin 1986; Stanford 1997; Stanford & Harper 1991; Widmer 1964) as well as postglacial vegetation change (Peteet et al. 1990; Rue & Traverse 1997; Thieme et al. 1996) and sea level rise (Newman et al. 1969; Weiss 1974). More recently, there have been detailed studies of archeological preservation potential for the under-studied Holocene surficial deposits (GRA 1996a, 1996b; Schuldenrein 1995a, 1995b, 2000; Thieme & Schuldenrein 1996, 1998) and estuarine sediments (GRA 1999; LaPorta et al. 1999; Wagner & Siegel 1997).

Physiography and Bedrock Geology

The New York and New Jersey Harbor is an estuary formed within valleys deepened and widened by the advance and retreat of the great continental (Laurentide) ice sheet of the last Ice Age. The valleys occupy rifts which first developed during the separation of the North American and African continents beginning about 200 million years ago (Isachsen et al., 1991: 50-51). The Atlantic Ocean formed within the largest of these rifts while lesser rifts sliced through Paleozoic continental land masses and left isolated remnants such as the Manhattan Prong east of the Hudson River Valley. The Newark Group rocks underlying most of the Harbor Region formed from primarily alluvial sediments which filled the rifts as they were opening.

The Quaternary deposits of the Harbor Region rest unconformably on the Newark Group sedimentary rocks from upper Newark Bay east to the Hudson River. The Stockton, Lockatong, and Brunswick formations of the Newark Group consist of redbed sediments deposited in a Triassic basin which was subsequently faulted and intruded by igneous magma. The most significant intrusion occurred on the eastern edge of the basin at the Palisades sill, adjacent to the Hudson River of today. East of the Hudson River, the Manhattan Prong consists of outcropping Cambrian to Ordovician igneous and metamorphic lithologies of the New York City Group. Rare outcrops of gneiss or schist occur on Governors Island (Herbster et al., 1997; Schuberth, 1968: 82) and in Queens and Brooklyn, but these land masses consist primarily of Quaternary sediments or older marine units of the Atlantic

Coastal Plain. A northeast trending axial ridge of gneiss and serpentinite comprises the core of Staten Island against which tens of meters of glacial till were lodged by the Laurentide ice sheet.

Several contributing drainages to Newark Bay follow channels inherited from the great southwest trending Pensauken River system of probable Pliocene age (Stanford, 1997). Diversion of the Pensauken River into the Hudson Canyon between the Pliocene and the Pleistocene refocused continental shelf deposition from the Baltimore Canyon area (Poag and Sevon, 1989; Stanford, 1997) but the Pensauken deposits have been long since scoured way from the Harbor Region. Cretaceous and possible interglacial (oxygen isotope stage 5e) sediments occur at the Narrows but sediments older than the Wisconsinan glaciation are otherwise missing from the lower Hudson as a result of erosion following base-level fall (Weiss, 1974: 1567).

Pleistocene Glaciation, Chronology, and Paleoecology

Glaciers advanced across the region at least twice during the Pleistocene (Stanford, 1997; Sirkin, 1986). Both Illinoian (ca. 128-300 ka) and pre-Illinoian (> 300 ka) terminal moraines are mapped in northern New Jersey, and these ice advances may be represented by lower tills on Long Island such as the Montauk (Rampino and Sanders, 1981; Merguerian and Sanders, 1994). An abundance of gneiss clasts gives the older tills a "dirty" appearance and they can always be distinguished from late Wisconsinan deposits by the presence of some unweathered mudstone, sandstone, and igneous rock clasts in the late Wisconsinan deposits (Stanford, 1997).

The Hudson-Mohawk Lobe of the latest or Wisconsinan ice sheet advanced to its Harbor Hill terminal moraine by 20,000 years before present (B.P.) based on the evidence obtained from Port Washington on Long Island by Les Sirkin (Sirkin, 1986: 14; Sirkin and Stuckenrath, 1980). Some organic sediments from the preceding, warmer, interstadial period (oxygen isotope Stage 3) appear to have survived beneath or within the till and outwash, and several such sequences were identified in the earlier phases of the Harbor Study (Schuldenrein 2000a).

In addition to the oxygen isotope geochronology (Richmond and Fullerton, 1986) and the data from Port Washington on Long Island (Sirkin, 1986: 14; Sirkin and Stuckenrath, 1980) the age of the terminal Wisconsinan Harbor Hill moraine is constrained by basal postglacial radiocarbon dates from northwestern New Jersey of 19,340±695 B.P. (23,334 cal yrbp) in a bog on Jenny Jump Mountain (Witte, 1997) and 18,570±250 B.P. (21,941 cal yrbp) in Francis Lake (Cotter, 1983). Thieme and Schuldenrein (1998) recently obtained a date of 19,400±60 B.P. (23,061 cal yrbp) from a loamy sediment overlying glacial till along Penhorn Creek in the Hackensack Meadowlands. A pollen core from Budd Lake in northwestern New Jersey (Harmon, 1968) also provides supporting evidence for Sirkin's chronology of the Hudson-Mohawk Lobe. A sample of clay from 37 feet below surface was dated to 22,870±720 B.P. (23,003 cal yrbp) and contained a pollen assemblage dominated by pine (50-60%) and spruce (10-20%) with some oak (5-10%) and *Ambrosiae* dominant in the non-arboreal pollen. A boreal forest or park-like vegetation community is further indicated by pollen assemblages dated to 22,310±2070 B.P. (22,325 cal yrbp) and 22,040±550 B.P. (22,125 cal yrbp) from varved silt and clay in the Hackensack Meadowlands (Schuldenrein, 1992; Rue and Traverse, 1997) although reworked Cretaceous spores and pollen were also present. Pollen sequences documenting postglacial vegetation change have been registered in the initial New York Harbor study (Schuldenrein 2000a), as well as in the examinations of subsurface sequences at Jersey Flats (Schuldenrein 2001).

The terminal Pleistocene pollen record has been most informative for environmental reconstructions. Full glacial and late glacial pollen assemblages have been variously attributed to "tundra," "taiga," "spruce park," or "boreal forest" vegetation (Davis 1965, 1969; Deevey 1958; Martin 1958; Ogden 1959, 1965; Watts 1979). Several authors have also pointed out that the late Pleistocene vegetation may not have clear analogs in present-day plant communities (Davis 1969; Overpeck et al. 1985, 1992). Herb-dominated assemblages corresponding to the tundra Zone T of Deevey (1958) have been identified in basal samples of cores studied in the region (Sirkin et al. 1970; Peteet et al. 1990). A radiocarbon date of 12,840±110 B.P. (15,190 cal yrbp) (from Alpine Swamp Core A indexes the succession to the spruce-hardwood Zone A (Peteet et al. 1990: 224). Newman et al. (1969) obtained a comparable radiocarbon date of 12,500±600 B.P. (14,830 cal yrbp) for Zone A in their boring UH-1 from Salisbury Meadow on western Iona Island and Sirkin et al. (1970) report a radiocarbon date of 12,330±300 B.P. (14,459 cal yrbp) for Zone A in their boring SH-29 from a Coastal Plain bog west of Raritan Bay.

Spruce-dominated assemblages were present in the basal samples of five cores from the Lower Hudson River estuarine sediments analyzed by Weiss (1974), who obtained a radiocarbon date of 10,280±270 B.P. (12,024 cal yrbp) for the top of Zone A in a core beneath the Tappan Zee Bridge. Abundant spruce pollen was also characteristic of basal samples from borings for the Carlstadt Loop (Rue & Traverse 1997; 3DI 1992) and the North Arlington force main (Thieme & Schuldenrein 1996; Thieme et al. 1996) in the Hackensack Meadowlands. The basal North Arlington assemblage was interpreted to indicate scattered spruce trees on open, tundra-like terrain. An increase in "boreal" species such as spruce and paper birch between 11,000 and 10,000 B.P. was attributed by Peteet et al. (1990) to the Younger Dryas abrupt cooling of global climate.

A more direct cause of the migrations of plant species through the project area can be found in the irregular northwesterly retreat of the Laurentide ice sheet, as previously inferred from southern New England pollen records by Ogden (1959), Davis (1976), and others (Davis & Jacobson 1985; Gaudreau 1988; Gaudreau & Webb 1985). Zone B of Deevey (1958) is thus characterized by declining spruce and increasing pine pollen, with at least three species of pine potentially represented by grains which can be classified into at most two pollen "taxa." Davis (1976:19-21) maps the presence in the Harbor Region of *Pinus banksiana* (jack pine) and/or *Pinus resinosa* (red pine) by 11,000 B.P. and white pine (*Pinus strobus*) by 10,000 B.P. Hemlock, oak, birch, and alder pollen were also quite abundant in the Alpine Swamp Zone B assemblage (Peteet et al. 1990:222). With the change to essentially modern climatic conditions, there is a gradual shift toward an oak-dominated pollen assemblage (Deevey's Zone C), with basal dates of 9,000±100 B.P. (10,088 cal yrbp) in the Alpine Swamp core (Peteet et al. 1990) and 7,100±180 B.P. (7,962 cal yrbp) in the Tappan Zee core (Weiss 1974).

During the critical later phases of the Pleistocene, the hydrography at the glacial margin was dynamic and resulted in a glaciolacustrine landscape that involved cyclic retreats and transgressions of linear lakes that approximated the morphologies of structural valleys. A reconstruction of the terminal glacial geography is shown in **Figure 4.1**. Lakes Passaic, Hackensack, Hudson, and Flushing

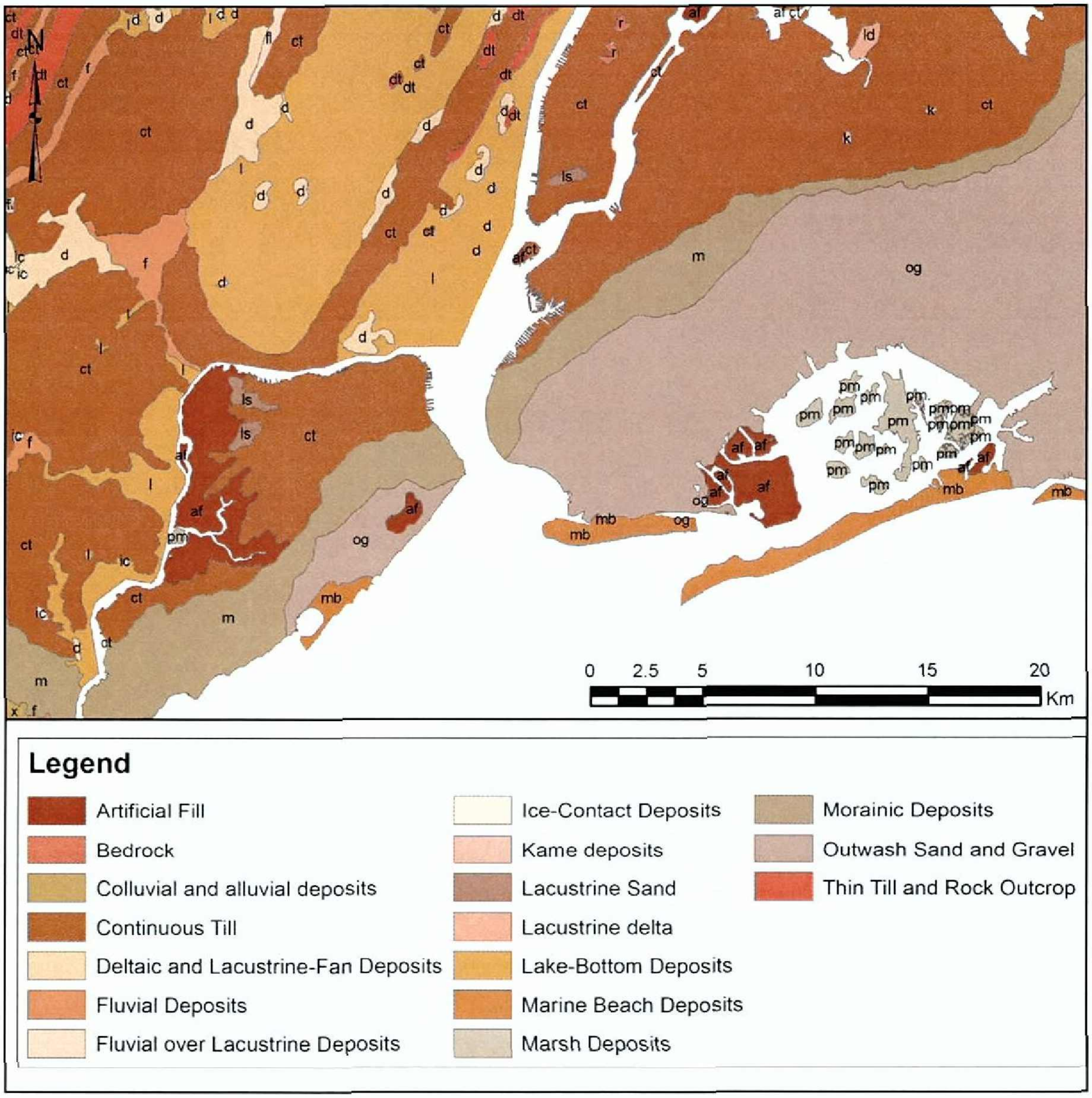


Figure 4.1. Surficial geology of the New York area.

variously crossed the terrain between Long Island and east-central New Jersey. In Newark Bay and the lower reaches of the Hackensack and Passaic River valleys subsurface stratigraphy has revealed uniform lake bed sequences beginning with deep, "varved" proglacial rhythmites (or paired laminations) (Antevs, 1925; Lovegreen, 1974; Reeds, 1925, 1926; Salisbury, 1902; Salisbury and Kummel, 1893; Stanford, 1997; Stanford and Harper, 1991; Widmer, 1964). Reddish brown muds derived from Newark Group rocks typify the thicker winter varves while the more heterolithic sandy varves were deposited as the ice melted during the summer. The top of the glaciolacustrine facies is typically an unconformable contact from 12-30 feet below the present land surface in the Hackensack Meadowlands (Lovegreen, 1974). At the last glacial maximum, approximately the time of deposition of the Harbor Hill moraine (**Figure 4.2**), nearly one percent of the Earth's water was transformed into glacier ice (Strahler, 1971). Eustatic sea level consequently plummeted, and a terrestrial coastal plain extended from 24 to 60 miles onto the present continental shelf along the Atlantic coast (Bloom, 1983a: 220-222; Emery and Edwards, 1966; Stright, 1986: 347-350). Sea level rise was extremely rapid in the period immediately following the retreat of the ice **(Figure 3.1)** as meltwater was delivered to the oceans basins from runoff and from pro-glacial lakes that were impounded by recessional glacial margins. Locally, the lower Hudson and Hackensack River Valleys were sequentially scoured and flooded (Reeds, 1925, 1926; Stanford, 1997; Stanford and Harper, 1991), forming much of the present-day topography surrounding New York and New Jersey Harbor. The basins left behind after the proglacial lakes drained were initially incised by meandering channels and then transformed into tidal marsh in the mid- to late-Holocene (Widmer and Parillo, 1959; Thieme and Schuldenrein, 1996; Carmichael, 1980; Heusser, 1949, 1963).

Critical to interpretation of the submerged sediments underlying New York Harbor is the glacial and sea level rise history of the Late Pleistocene and Holocene. New York lies at the southern limit of the last glaciation when glacier ice reached its final position approximately 18000 years ago (18,000 BP). The Harbor Hill moraine, extending across Long Island, Staten Island, and Middlesex County, New Jersey marks its terminus. Stone et al., (2002) show the lobate spread of glacier ice across New Jersey and New York (**Figure 4.3**). Stone (personal communication) notes that ice did not remain for an extended period at the terminal moraine, thus only small amounts of outwash were deposited at the outer edge of the moraine. This is of importance in interpreting the submerged deposits beneath the lower harbor and Raritan Bay.

Retreat of glacier ice from the terminal moraine supplied meltwater to proglacial lakes retained behind the moraines. Proglacial lakes occupied preexisting depressions determined by the bedrock geology as well as others created by deposition of glacial sediments. The levels of the proglacial lakes were controlled by the contemporaneous altitudes of spillways through adjacent lowlands or across channels cut into the terminal moraines. This was the case for the New York area where a series of proglacial lakes were retained behind the Harbor Hill moraine. The earliest of these lakes, Lake Bayonne, spread across the New York harbor area and East River while its broader extent occupied the lowlands west of the Palisades sill, including Arthur Kill, Kill Van Kull, and Newark Bay. Lake Bayonne drained southward across the terminal moraine through a spillway at Perth Amboy. The level of Lake Bayonne was controlled by a spillway altitude of 9 m (30 ft). A lower glacial Lake Hackensack of

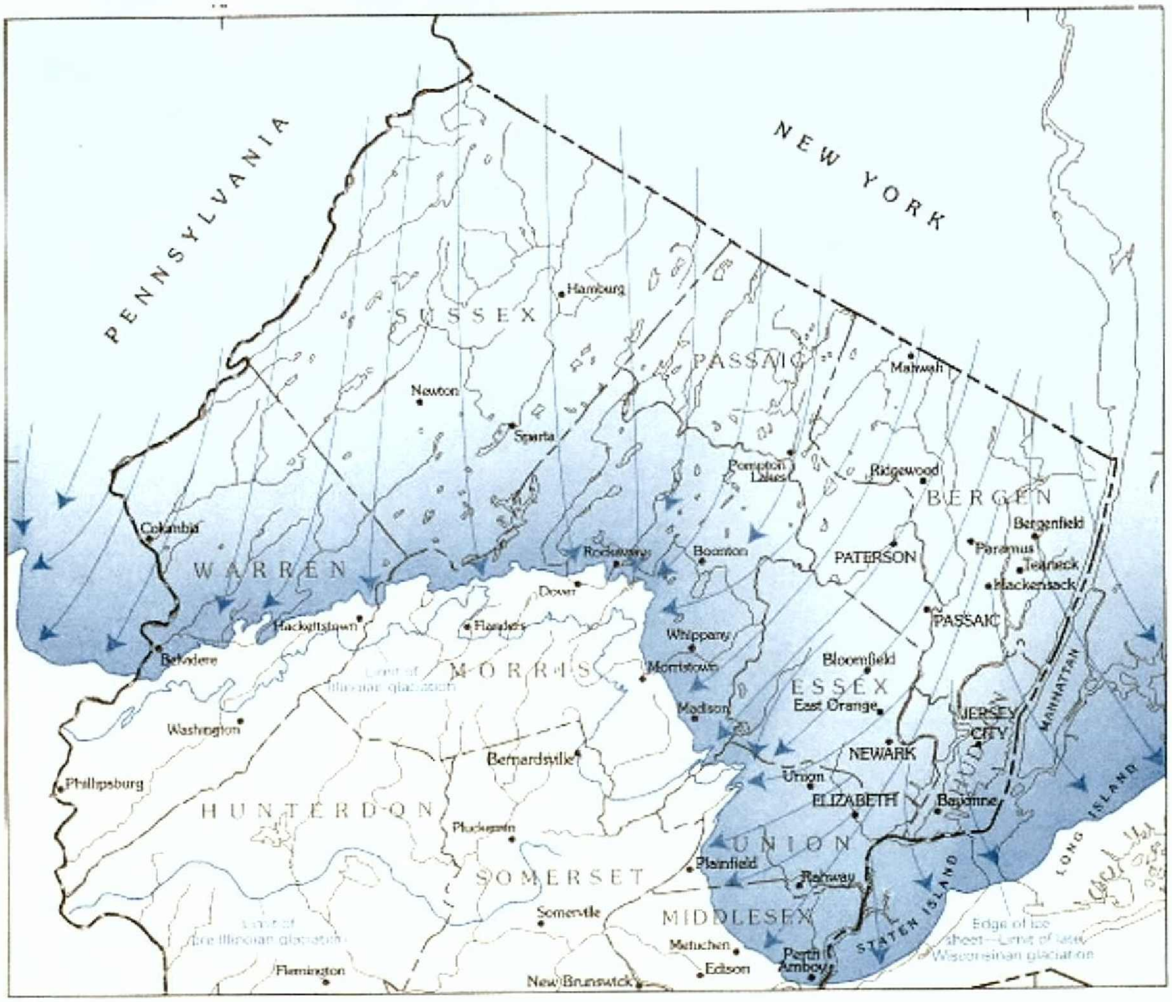


Figure 4.2. Glaciation of New York and New Jersey (Stone et al., 2002).

less area drained through the moraine at Perth Amboy as its spillway was eroded more deeply into the Harbor Hill moraine. Further ice retreat from western Long Island allowed additional lowering of lake level to the glacial Lake Hudson level which drained eastward through the East River at Hell Gate. This final lake was contained within the glacially scoured and deepened Hudson River channel that progressively expanded northward with ice retreat until the Mohawk valley lowland was deglaciated about 12,000 BP (13,875 cal yrbp) (Stone et al., 2002). **Figure 4.3** shows the location and extent of proglacial lakes in the study area.

The time of deglaciation of the Mohawk River lowland between 13,000 and 12,000 BP is a key time in the geologic history of the New York harbor area. About this time drainage of proglacial Lake Iroquois which occupied the Lake Ontario basin was free to drain directly to the Hudson River valley and add to the volume of proglacial Lake Hudson. Researchers disagree on the mechanism, but an outlet through the Harbor Hill moraine at the Narrows was opened at about this same time emptying Lake Hudson and gave rise to the present drainage pattern to the Hudson River. Newman and his coauthors (Newman et al., 1969) note that marine and brackish water filled the -27 m-deep channel of the Hudson River at 12,500 +/- 600 B.P. (14,830 cal yrbp) as evidenced by marine and brackish marine microfossils preserved at the base of organic silts beneath peat bogs at Iona Island. It is problematic whether the erosion of the outlet through the Harbor Hill moraine was gradual or catastrophic as recently proposed by Uchupi et al., (2001) and Thieler et al., (2006). Nonetheless, it is clear that flow from the Hudson River eroded a channel and valley across the exposed continental shelf to drain and deposit a delta on the outer shelf at a lowered sea level stand. Most challenging for our understanding of the Hudson River history is the lack of a clear explanation for a direct marine connection between contemporaneous sea level at the edge of the continental shelf and the upper Hudson River valley. For all intents and purposes, we consider the shelf to have been sub aerially exposed at this time. Differential isostatic adjustment of the earth's crust following deglaciation is the most reasonable process to suggest with downwarping and depression of the crust beneath glacier ice in the north and possible compensating uplift of the continental shelf to bring sea level in line with the upper Hudson River channel. Differential uplift of the crust along the upper Hudson Valley relative to the New York Harbor area on the basis of historic tide gauge data has been presented by Fairbridge and Newman (1969) but the complete relationship remains unclear. **Figure 4.4** is a three dimensional representation of the New York harbor area viewed from the south. The deeply incised channel of the Hudson River is well defined, as is the pre-dredging channel of Arthur Kill showing its incised outwash channel from Newark Bay to Raritan Bay that marks the overflow from proglacial lakes Bayonne and Hackensack. A broad wedge of sediment ostensibly derived from outwash from the ice front and carried by the Raritan River and Arthur Kill spillway fills Raritan Bay and spreads eastward with a lobate front into the New York Bight area. Splayed channels leading from the mouth of the main Hudson channel at the Narrows spread across the mouth of the lower harbor between Sandy Hook and Coney Island. The incised channels of the Raritan River and the Arthur Kill spillway appear to join near Perth Amboy and terminate near Great Kills where they appear to have been filled by littoral sediment derived from longshore drift from the northeast. The incised channels of these drainages were studied by Gaswirth (1999) and are discussed in a later section of this report. Earlier studies by Williams (1974) and Kondolf (1978) discuss the incised Raritan

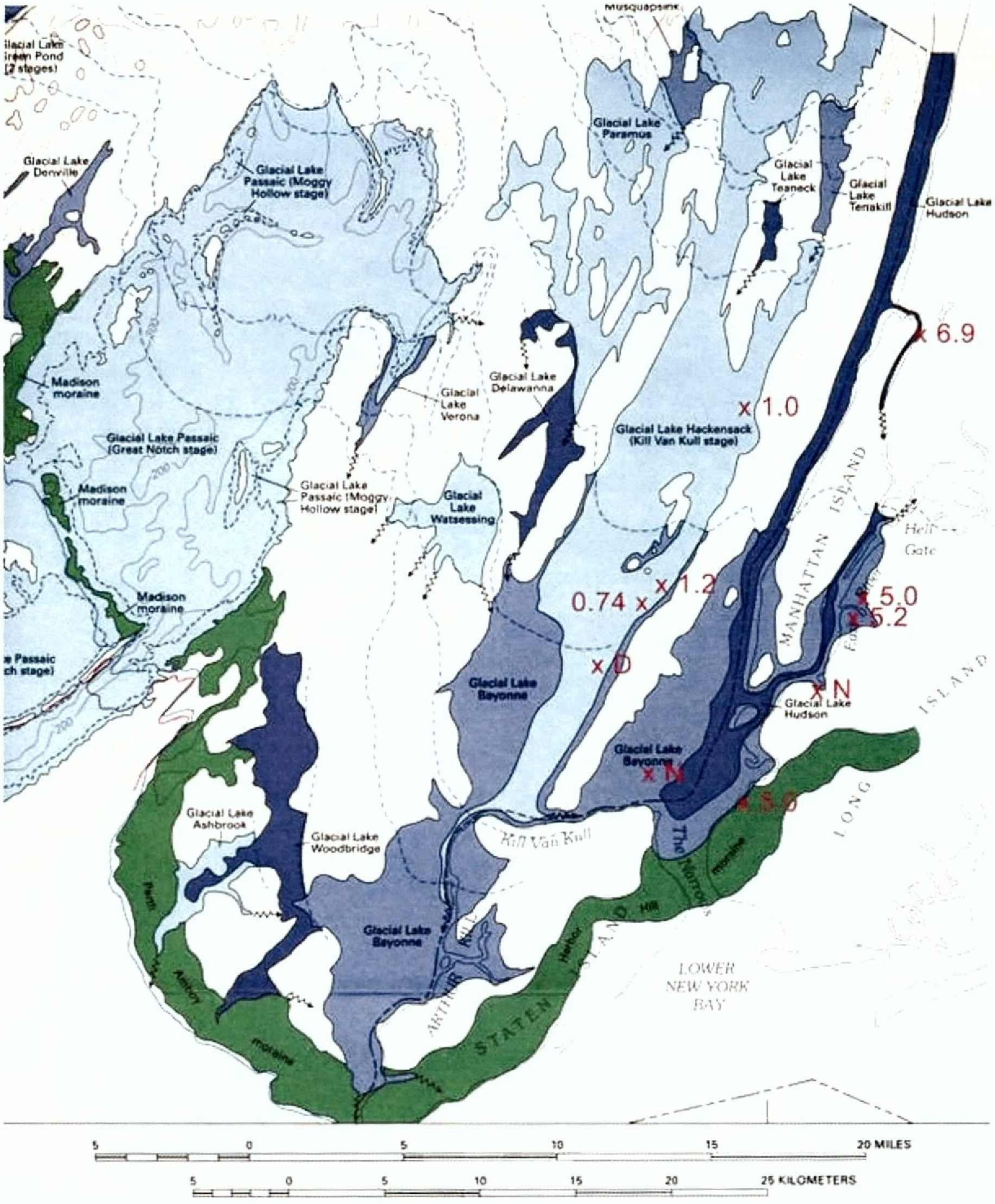


Figure 4.3. Proglacial lakes in the New York Harbor area (Stone et al., 2002).

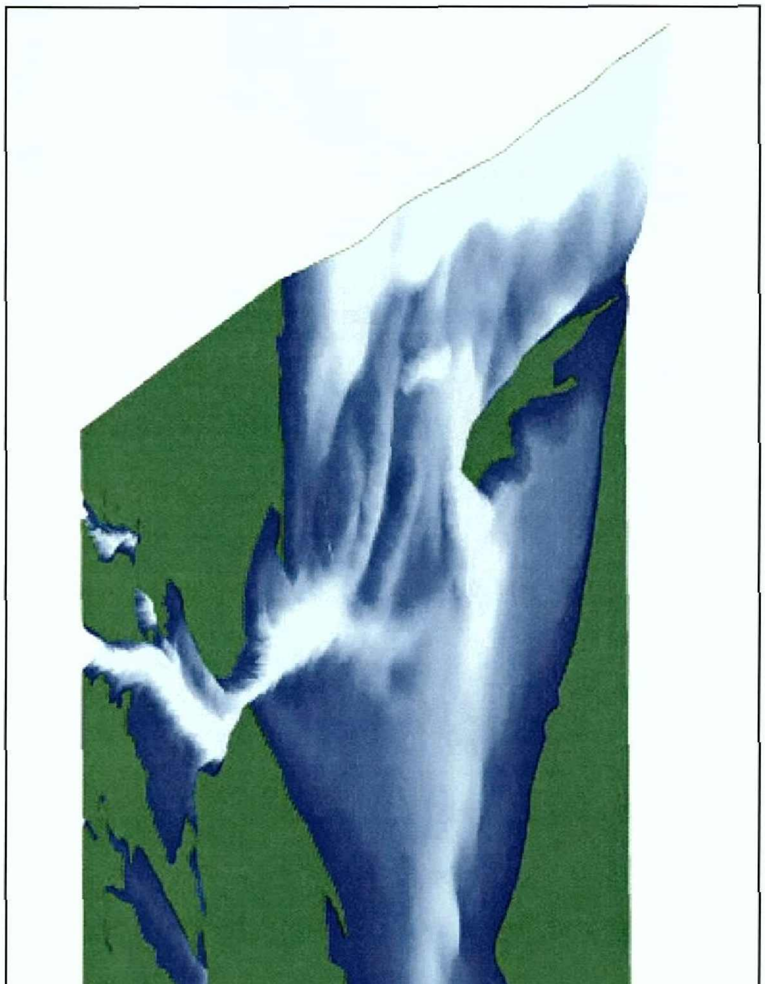


Figure 4.4. 1844 3D bathymetry of New York Harbor viewed from the south.

channel passing beneath Sandy Hook and draining to the continental shelf. Kondolf (1978) has suggested that the outer edge of the outwash sand body extending offshore Sandy Hook and Coney Island derives from beach sands and longshore transport from both the south and east along the New Jersey and Long Island shores, but **Figure 4.4** shows no indication of barrier island formation and points to its outwash related history. In fact, this figure suggests that the discontinuous shoal area east of Sandy Hook and noted as the False Hook on current navigation charts may be related to the outwash fan but truncated by tidal current flow around the tip of Sandy Hook.

Thieler et al. (2006) present a seismic reflection profile across the area east of the Narrows showing a deeply incised, but filled channel attributed to discharge of the Hudson upon erosion of the Harbor Hill moraine barrier **Figure 4.5**. This channel was cut to 45 m (148 ft) below present mean sea level in underlying Cretaceous sediments and is filled and overlain by 15 m of younger sediment. The depth of this incised channel relative to Thieler's observation of a subaqueous delta for the Hudson at the edge of the continental shelf (-110-120 m, -360-394 ft) underlines the need for a mechanism to reconcile this sea level position relative to the reflooded Hudson river channel at Iona Island.

One of the goals of the present study has been to develop an accurate record of relative sea level rise for the New York Harbor area for use in determining the submerged locations of probable prehistoric human habitation areas to be avoided by future navigation channel dredging. Derivation of the new sea level rise model is addressed in detail in a later chapter and coupled with a detailed submergence reconstruction for the study area. Our model is derived from existing and newly reported radiocarbon analyses from nearby submerged environmental settings acquired during this study or as part of previous GRA studies. We present a two part relative sea level history consistent with "far field" eustatic sea level studies (Fleming et al., 1998). We show a rapid rise in relative sea level at a rate of approximately 9 mm/yr (3.5 inches/yr) from at least 9000 cal yrbp until about 8000 cal yrbp when the rate decreases to a consistent 1.5 – 1.6 mm/yr (0.6 inches/yr) from 7000 cal yrbp until the present. The more detailed record of the last 2000 cal yrbp shows low amplitude century-scale fluctuations in sea level on the order +/- 30 cm until the period of historic tide gauge records. Our sea level model is also consistent with studies by Bloom and Stuiver (196) for the Connecticut shore, Redfield and Rubin (196) for Barnstable, Massachusetts, Belknap and Kraft (196), and Nikitina et al. (2001) for Delaware Bay as reexamined by Larsen and Clark (2006, and in prep.). Our new model (**Figure 3.6**) represents a significant refinement from the standard sea level curve that drew on the model formulated by Newman et al., (1969).

In general terms, our new relative sea level model can be hindcast to account for reflooding of the incised Hudson channel described by Thieler et al., (2006) for the Narrows at ca. 12,000 B.P. (13,875 cal yrbp) as well as the marine incursion of the upper Hudson Valley. It cannot, however, resolve the differential positions of the incised channel at the Narrows with the proposed delta at the edge of the continental shelf. Using the same data, we show progressive flooding of the main Hudson channel until its present configuration. The area currently known as the New Jersey flats begins to be flooded about 7000 cal yrbp. Oyster reefs begin to form upriver at Tappan Zee at this time as well and are found at successively shallower depths following the rising sea level (Carbotte et al., 2004). Marine water enters and progressively floods Raritan Bay and Newark

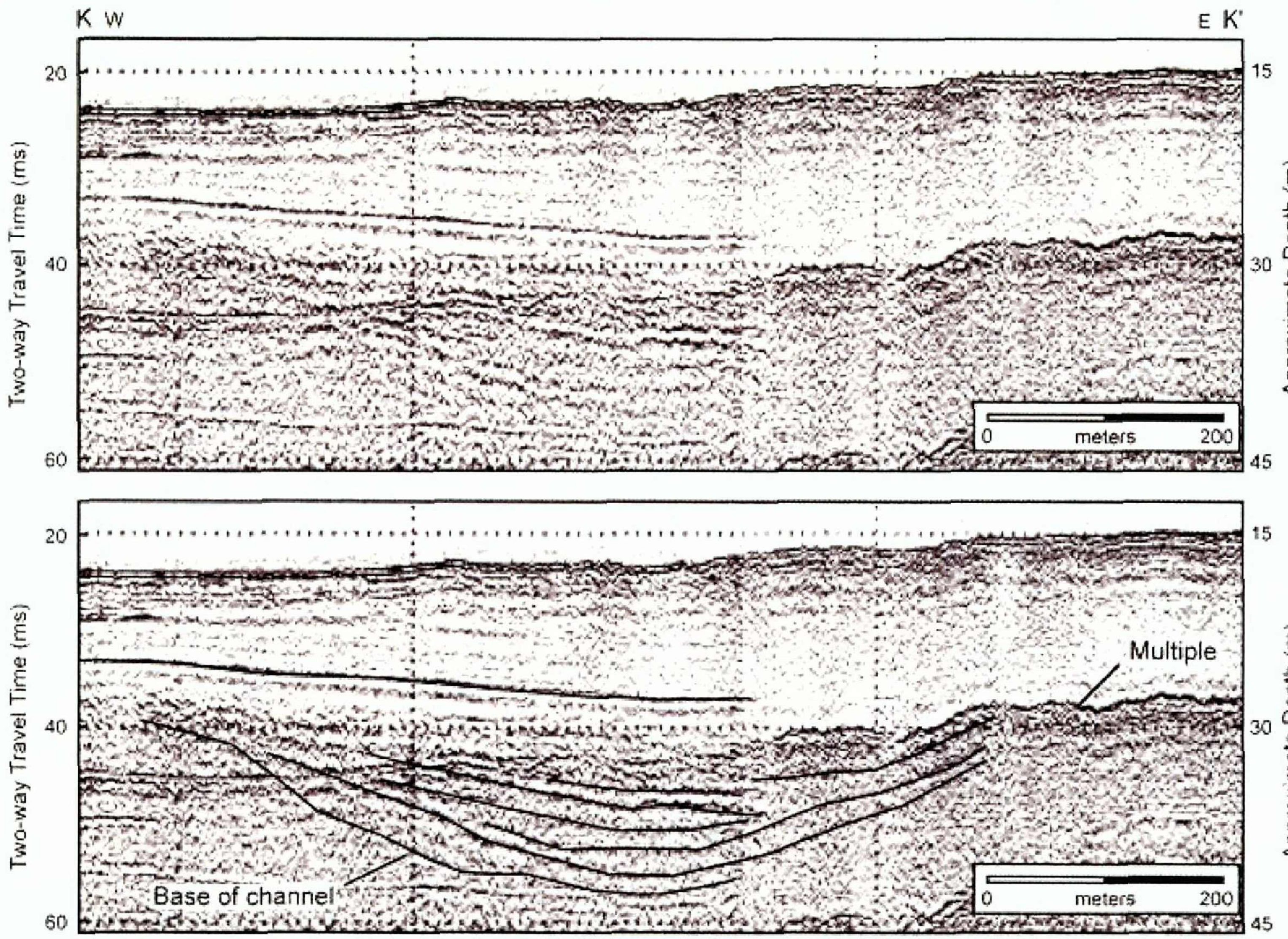


Figure 4.5. Seismic profile east of the Narrows (Thieler et al., 2007).

Bay about 6,000 cal yrbp. Significantly, we also recognize an erosional marine terrace at 5m below modern chart datum (MLLW). This terrace extends from Raritan Bay to Coney Island and includes Flynn's and Romer shoals as well as the East Bank and the False Hook east of Sandy Hook. This terrace indicates a prolonged hesitation in sea level rise between 2,000 and 3,000 cal yrbp. The terrace also limits the ages of the above shoals to predate this time. Marshes upstream from the present mouth of the Raritan River as well as the Hackensack marshes begin to become saline after 3,000 cal yrbp and subsequently develop into salt marshes. We suspect that portions of Jamaica Bay underwent a similar history but we lack the data.

Post-Pleistocene Geography

Recent studies on Staten Island (GRA, 1996a, 1996b), Ellis Island (Pousson, 1986), and Governors Island (Herbster et al., 1997; Thieme and Schuldenrein, 1999) suggest some of the complexity of Quaternary depositional environments in the lower Hudson River valley as well as the variable preservation of archeologically sensitive deposits. While the generic stratigraphy can be said to consist of Wisconsinan ice-contact and meltwater deposits capped by quartzose sheet sands, grain-size analyses of basal sands on Governors Island indicated a combination of glaciofluvial, ice-contact, and fluviomarine deposition (Thieme and Schuldenrein, 1999).

There is very little evidence of soil formation or stability of Holocene shorelines until after 7,000 cal yrbp, although some submerged contexts may in fact be present within the harbor itself. As proposed for the northeastern United States in general by Nicholas (1988, 1998), Mid-Holocene terrestrial sediment packages have occasionally been identified in the project vicinity at the margins of freshwater ponds or marshes (e.g. Thieme and Schuldenrein, 1996). The most recent example of this is at the Collect Pond in lower Manhattan (Schuldenrein, 2000). Early- to mid-Holocene sediments are virtually absent in the estuarine valley fills, however.

In Newark Bay and the lower reaches of the Hackensack and Passaic River valleys there is a different and more uniform sequence that was discovered at the interface of the terminal Pleistocene glacio-lacustrine varves discussed earlier. Here, Late Holocene peat often overlies the contact except for where sediment was stored by one of the pre-estuarine river systems. In North Bergen Thieme and Schuldenrein (1998) identified a stratigraphic column wherein a fining upward alluvial sequence—sandy loam to fine silt—indicates deposition on the natural levee of a meandering stream (Brown, 1997: 70-81; Waters, 1992: 134-135). A buried soil within this Holocene floodplain facies was dated to 3,650±70 B.P (3,977 cal yrbp) while plant stem fragments from overlying tidal marsh were dated to 1,130±60 B.P (1,075 cal yrbp). (Thieme and Schuldenrein, 1998).

A representative section for the submerged depositional contexts of landforms in the general New York Harbor area is shown in **Figure 4.6.** This is also a general model for shoreline evolution, chronology and stratigraphy and it is reinterpreted from our earlier GRA reconstruction at Jersey Flats (Schuldenrein 2001). As shown, core locations JF-1 and JF-3 are separated by approximately 600 meters across which the harbor floor steps from approximately -10 feet to -20 feet MSL. Much of this change occurs at a step or terrace "riser" immediately landward of the JF-3 location. The model postulates three time transgressive surfaces along an East to West transect between Port Jersey and Anchorage Channel. At this location, an indicator of this development is a series of Aligena shell beds that register still stands of the sea. They record a certain depth of water (for the sediment-water interface) that has advanced landward as a barometer of sea level rise. The core sequence did not definitively isolate the Pleistocene-Holocene contact but a date of 9,400±150B.P. (10,690 cal yrbp, Beta-127019) for Anchorage Channel boring 98ANC44 (Schuldenrein et al., 2000a: Appendix 3) is a reasonable temporal benchmark.

Early-Middle Holocene sedimentary sequences are projected from regional chronologies and the relative sea level model developed in the present study. Based on this relative sea level curve, a transgressive shoreward coastline has some measure of support from dates at JF-1 (3,460±70 B.P.; [3,736 cal yrbp], Beta-150701) and JF-6 (3,360±70 B.P.; [3,586 cal yrbp Beta-15074). The model assumes that the inverted sequence at JF-3 is completely disturbed, perhaps by mixing of the recent subtidal sediments or, alternatively by channeling and dredging activities in the historic past. Thus, recent and localized scour and fill along the terrace riser probably accounts for the thin intercalations of dark gray clay and grayish brown sand from 7 to 9 feet below the sediment-water interface in core JF-3a.

The upper portion of the sequence identifies the Late Holocene shoreline, reworked by historic tidal scour and fill. This portion of the sequence, extending to depths of at least 3 feet, is consistent for all the cores. At Jersey Flats, the pollen and other biostratigraphic evidence suggests that uppermost core stratigraphy everywhere appears to be contemporaneous with Euro American settlement and the present shoreline position. In the study it was determined that the JF-4 core location has the best potential for preserving deposits which predate the postglacial marine transgression and estuary formation within the lower Hudson valley. Paleoecological analysis indicated that JF-4 preserves the most intact vegetation succession. If intact early- to mid-Holocene sediments are actually present, and particularly if these are from a terrestrial fluvial depositional environment, the JF-4 core location would have moderate to high potential for submerged cultural resources.

More generally, buried soils are the most sensitive indicators for stable surfaces and are thus the most critical measures for subsurface prehistoric cultural resources (Holliday, 1992: 101-104; Rapp, 1998: 34-36; Waters, 1992: 74-77). Buried soils have been identified primarily within the interval 4,000-2,000 B.P. (4,527-1,982 cal yrbp) for terrestrial settings in the project vicinity (GRA, 1996a, 1996b; Herbster et al., 1997; Schuldenrein, 1995a, 1995b, 1995c; Thieme and Schuldenrein, 1998, 1999). In some locations, such as on Governors Island and the north shore of Staten Island, the buried soils are at or even slightly below mean sea level. Earlier as yet undocumented soil forming intervals may be represented by stratigraphy which has been submerged, although no buried soils were definitively identified from geotechnical borings during the present study.

Chapter 5

SEDIMENT CORES

This chapter describes the sediment lithologies observed during the inspection of split cores. Examination of the cores took place in the Alpine Ocean Seismic Survey, Inc. storage facility in Norwood, NJ rather than in the field to ensure optimal recovery under controlled conditions of samples for paleoecological (i.e. pollen, foraminers, and shell) and radiometric (radiocarbon dating) analyses. The recovery of these cores was critical for developing a paleoecological and chronological framework (**Chapter 7** and **Appendices C, D**, and **E**).

In all, twenty one (21) cores were collected. Five transects, located in Raritan Bay, the Upper New York Harbor, and Jamaica Bay were selected for vibracoring. The core samples were extracted into flexible, semi-opaque poly tubing and immediately sealed to prevent contamination and to maintain stable conditions (**Figure 5.1**). Coring locations, water depth, penetration depth, and actual recovery were recorded. The percentages of recovery relative to penetration depth varied by transect relative to differences in lithology. The depth of penetration versus recovery for each core are presented in core stratigraphic descriptions (**Appendix A**), while averages by transect are presented below (**Table 5.1**). Transects A and B, which are located in Raritan Bay, had generally poorer recovery than transects C, D, and E, which are located in Upper New York Harbor and Jamaica Bay. This is probably due to lithology differences between the coarser sands (which are prone to compaction in vibracore sampling) found in the Raritan Bay transects as compared to the generally higher clay content encountered in the Upper New York Harbor and Jamaica Bay transects. The core was described using the recovered samples with no retrofitting of the stratigraphy to the penetration depths.

Table 5.1. Average Penetration and Recovery by Transect

Transect Name	Average Penetration (m)	Average Recovery (m)	Percentage Recovered
A. Seguine Point–Union Beach	9.88	6.00	61%
B. Keansburg	11.05	8.19	74%
C. Liberty Island	10.93	9.60	88%
D. Bay Ridge Flats	12.00	10.38	86%
E. Yellow Bar Marsh	5.85	5.02	86%

Figure 5.1. Core recovery, Raritan Bay.

After recovery the cores were stored and examined at the Alpine Ocean Seismic Survey, Inc. storage facility in Norwood, New Jersey (**Figure 5.2**). The cores were not refrigerated. The cores were split, the litho-stratigraphy was documented, and paleoecological and radiometric dating samples were collected by GRA staff. Litho-stratigraphy here refers to the description of principal sediment characteristics of discrete layers and the identification of major stratigraphic unconformities between deposits. Results of the radiocarbon dating are found in **Chapter 3**, while special studies of shells, foraminfers, and pollen are found in **Appendices C**, **D**, and **E**. A split of each core was resealed (**Figure 5.3**) and archived at the Army Corps of Engineers storage facility at Caven Point, NJ. The core lithologies and interpreted stratigraphy are presented below by project area and transect.

Raritan Bay

Seguine Point – Union Beach Profile (Cores A0-A5). A total of five (5) localities (A-0 to A-4) were vibracored (**Figure 5.4**). Seven cores were obtained at the five localities because two localities required additional cores to maximize recovery. Core locality A-2 had the upper 5.14 m recovered in one core (A-2/R1) while a second core was collected from approximately 5.10 m to approximately 7.70 m below the water/sea bottom contact. Core locality A-3 was also sampled by multiple cores due to poor recovery, largely due to complications associated with attempting to core through lithologically dissimilar strata. Core A-3/R1 recovered a representative sequence; however though the sample penetrated 10.67 m only 4.57 m was recovered. In order to better sample the deposits a second series of cores A-3/R2-3 was conducted. This two-stepped coring consisted of taking one core from the upper coarser sandy sediments, then taking a second core that began collection below the coarse sandy sediments. This method provided a 12.5 m long core sample that was more representative of the sediments.

The cores provide an approximately 6.2 km cross section of Raritan Bay from Seguine Point, Staten Island, NY on the north to Union Beach, NJ on the south (**Figure 5.5**). As mentioned in Chapter 2, this location was chosen to duplicate the results of an often cited geologic cross section across Raritan Bay made in 1936 as part of bridge construction study (McClintock and Richards, 1936, cited in Bokuniewicz and Fray, 1979; Gaswirth, 1999, and Thieler et al., 2006). Recovered cores ranged in length from 2.65 m to 12.5 m. Descriptions can be found in **Appendix A**. No radiocarbon samples were collected from the samples because no potentially datable carbon was observed in the cores. Six (6) shell samples from the cores were examined (**Appendix C**).

The cores along the Seguine Point to Union Beach transect in Raritan Bay encountered four (4) litho-stratigraphic units:

Stratum IV:	Very dark gray reworked sandy marine sediments
Stratum III:	Truncated, stacked, fining upwards glacio-fluvial sequences with polygenetic phreatic weathering at its lower contact
Stratum II:	Poorly sorted glacial till
Stratum I:	Highly weathered Cretaceous clays and sands

Figure 5.2. Processing core samples, Alpine Ocean Seismic Surveys, Inc.

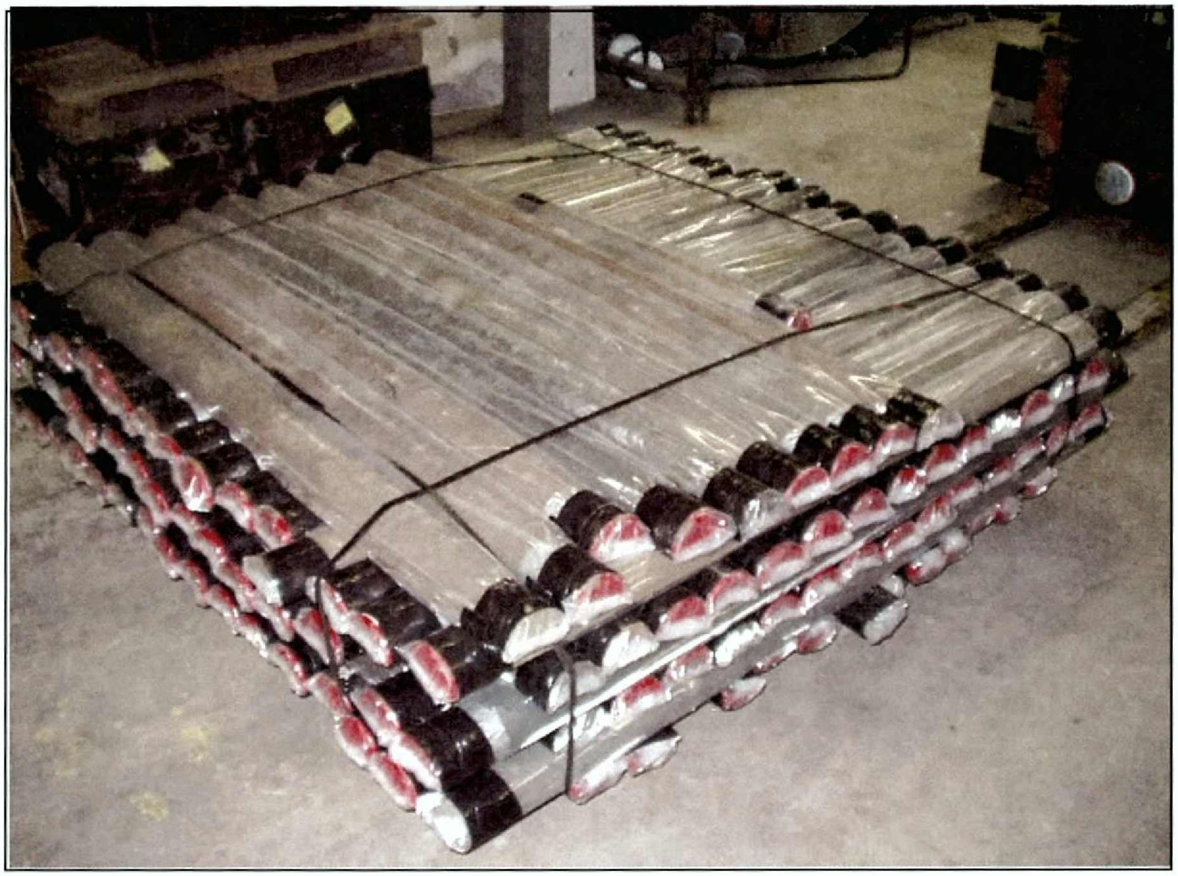


Figure 5.3. Cores prepared for curation at the Caven Point facility.

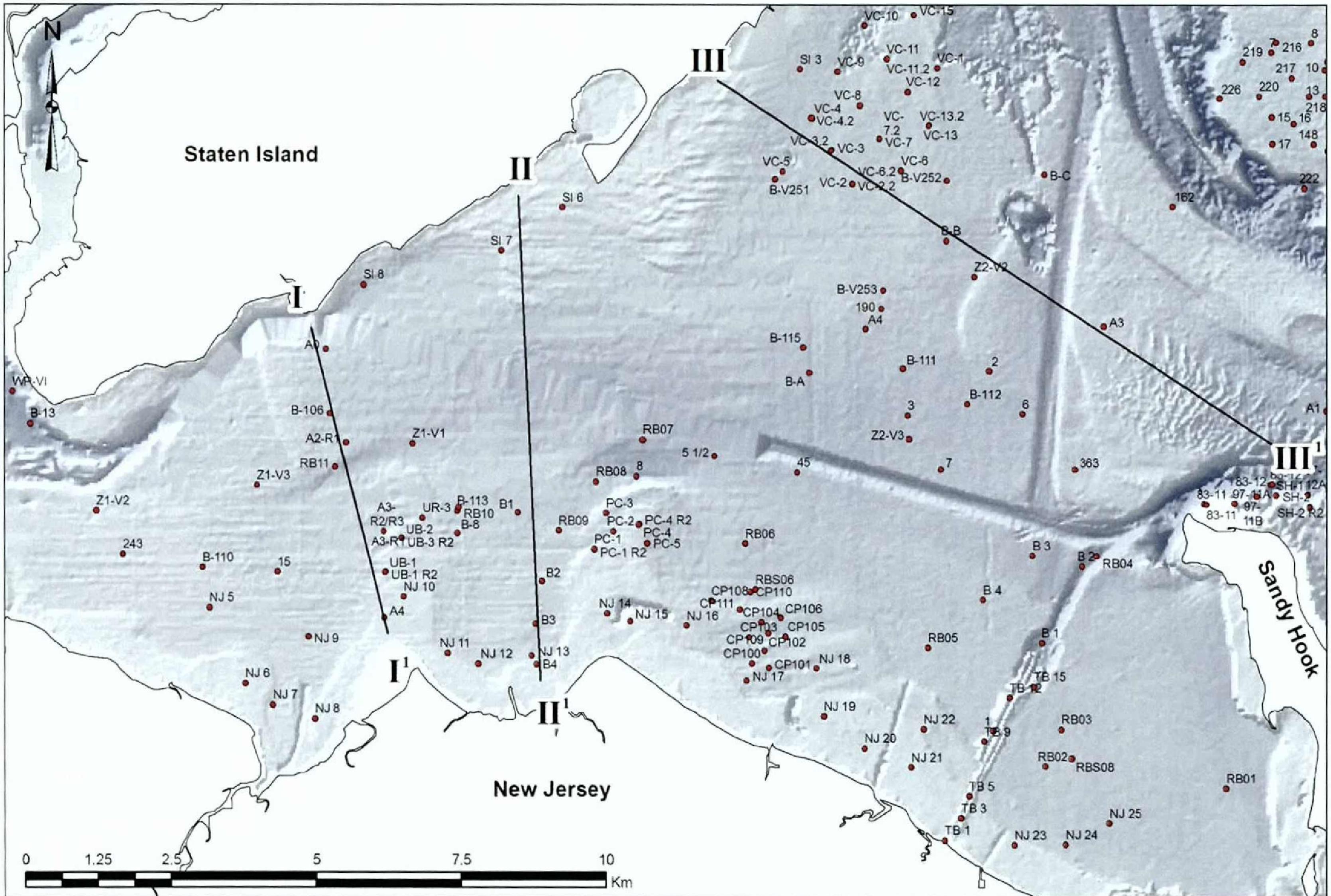


Figure 5.4. Raritan Bay transects along profiles I-I' and II-II' and assembled study core locations.

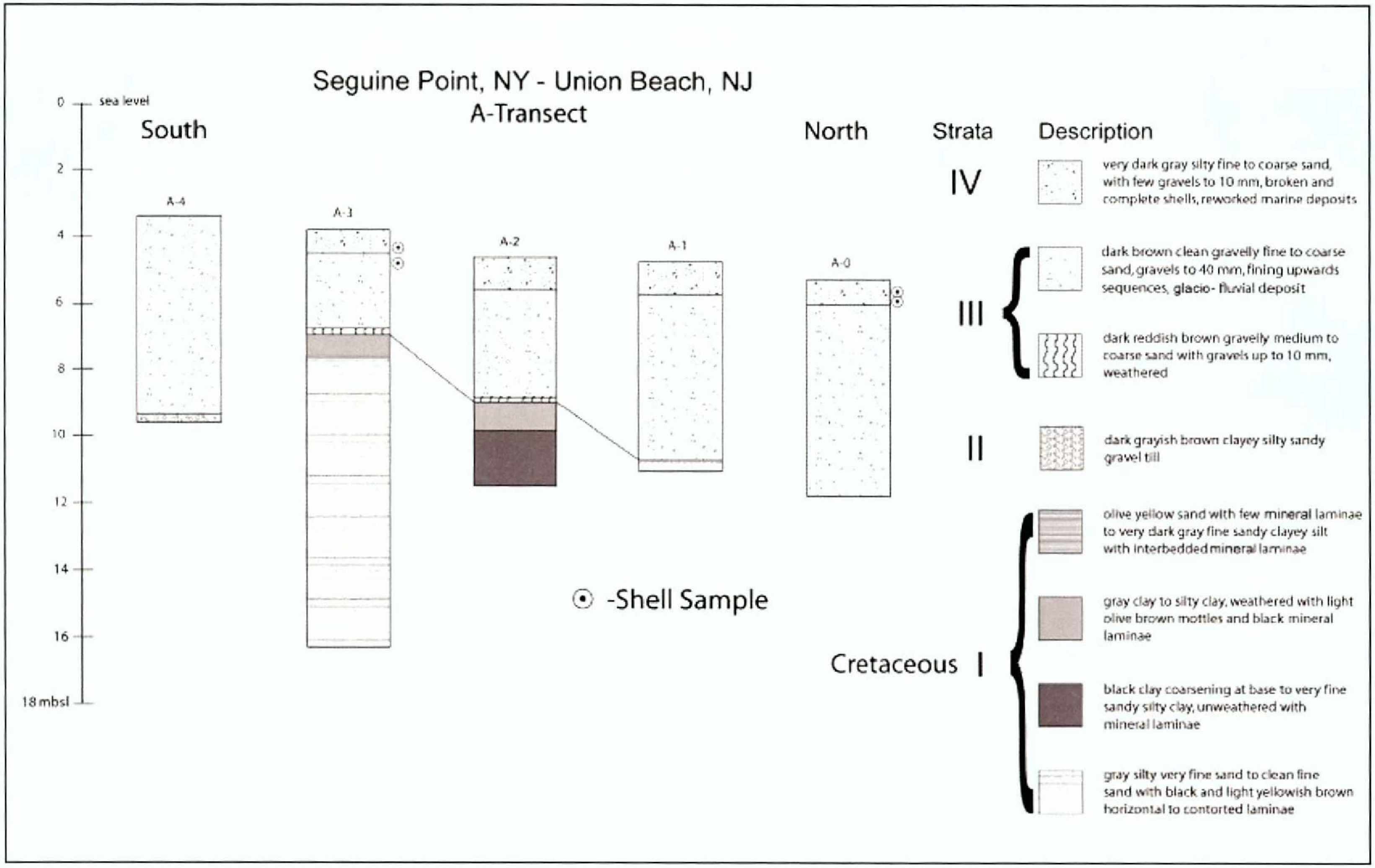


Figure 5.5. Seguine Point-Union Beach transect.

The uppermost sediments (**Stratum IV**) are reworked marine deposits to a depth of 1 meter. They consist of very dark gray (10YR3/1) silty, fine to medium sand with broken shell fragments. These deposits were found in all the cores except for A-4 at the southern end of this transect. The thickness of this uppermost deposit ranges from 2.26 ft (0.69 m) to 3.2 ft (0.98 m). The deposits are texturally similar to the underlying sandy fluvial deposits, however the presence of marine shell and organics indicate that the extant fluvial sediments were likely reworked by sea level transgression through the Holocene. Six marine mollusk samples were recovered from Core A-0 and A-3 and identified as to depositional environment (**Appendix C**).

Below the marine deposits are truncated, but otherwise undisturbed, dark brown (7.5YR3/2) clean poorly sorted gravelly fine to coarse sand of **Stratum III**. The gravel fraction is sub- to well rounded, and range in size from 10 to 40 mm. Fining upward sequences were found in these deposits, indicating a series of high energy fluvial events, which may be associated with fluvio-glacial conditions. The deposits ranged in thickness from approximately 2.26 m to 4.95 m. No paleosols or textural unconformities which would suggest preserved stable surfaces during this depositional period were observed. Core A-0 terminated at 6.5 m below the sediment/water interface in these fluvial sediments without encountering a deeper stratigraphic break.

A thin weathering horizon is found at the base of Stratum III where the horizon comes into contact with the lithologically dissimilar, heavily weathered Cretaceous clays of Stratum I. This horizon exists in Cores A-2 and A-3. In A-2 it is expressed as a 0.13 m thick horizon of dark reddish brown (5YR3/4) hard fine to coarse sands with few well rounded and up to 10 mm in size cemented gravels. In Core A-3 the horizon is 0.10 m, and is manifested as a color change from brown (7.5YR4/2) to reddish brown (5YR3/4) in a gravelly medium to coarse sand that is otherwise similar to the overlying deposits. The reddening of sediment color indicates pedogenic alteration due primarily to the weathering of iron (Fe). This saturated condition is likely a function of water collecting atop the impervious Cretaceous clays, weathering the base of Stratum III.

Underlying Core A-4 on the southern end of the "A" transect near Conaskonk Point, NJ is dark grayish brown 2.5Y4/2 clayey silty sandy gravel. This lithology was only observed in core A-4, and is identified as **Stratum II.** This poorly sorted deposit is similar to a diamict or glacial till.

A major stratigraphic unconformity was observed beneath the sandy fluvio-glacial deposits of Stratum III in cores A-1, A-2, and A-3. **Stratum I** is identified as a deeply weathered unconsolidated Upper Cretaceous clays, silts and sands. The Cretaceous deposits are southeast dipping quartz rich clay and sand deposits which form aquifers and aquicludes (Gaswirth, 1999). The locations of cores A-0, A-1, and A-2 are mapped as Raritan Formation, while cores A-3 and A-4 fall within the Magothy Formation (Gaswirth, 1999; Minard, 1969). The upper portion of this deposit is a 0.5 to 1.0 m thick deeply weathered gray (2.5Y6/1) clay with weak olive yellow (10YR6/6) weathering stains and black mineral lamellae. In core A-2 the clayey sediments continued with an additional 1.5 m thick dark gray (10YR4/1) clay that coarsened to very fine sandy silty clay at the base. Below these clays a gray (2.5Y6/1) well sorted fine sand with distinct laminations was observed in A-3. The fine sands of this lower portion of the Cretaceous deposit are interbedded with distorted, possibly by injection, subhorizontal to broken vertical black

(10YR2/1) and light yellowish brown (10YR6/4) organic and mineral silty fine laminae.

Figure 5.6 shows an interpretation of the stratigraphy along the Seguine Point-Union Beach transect I-I'. The five new vibracores obtained from the present study as well as an additional core from an earlier Union Bay study (Alpine, 1998), UB-3 are plotted on a bathymetric profile across Raritan Bay in the same location as the 1936 stratigraphic profile by McClintock and Richards (1936) cited by Bokuniewicz and Fray (1979) and discussed in Chapter 2 (**Figure 2.1**). Their figure was scaled and our boring locations were selected to resample the deep incised valley shown. Our **Figure 5.6** shows the actual subsurface conditions and negates the often used information attributed to these authors. The cores along this transect show the surface covered by a thin veneer of silty fine to coarse grained sand. North of Conasconk Point this fine to coarse sand overlies medium to dark brown to reddish brown coarse sandy gravel that fines upslope to a clean fine to coarse sand. Downslope and near the center of the bay, the gravel gives way to reddish brown medium grained sand that extends northward across the bay to the edge of the Raritan Bay West Reach channel. The reddish brown color and coarse grain size of the sediments are normally attributed to Pleistocene outwash sediments (Bokuniewicz and Fray, 1979; Gaswirth 1999). These coarse sediments overlie weathered stiff clay on the north that generally is considered to represent the Cretaceous Raritan Formation. To the south stiff clay overlies a thick sequence of gray silty very fine sand with black and light yellowish brown subhorizontal laminae. The clay and underlying fine sand are considered to be the Cretaceous Magothy Formation (Gaswirth, 1999). Core UB-3 in the central portion of the bay and approximately above Gaswirth's (1999) proposed buried paleochannel of the Pleistocene Raritan River shows brown fine and medium sand overlying gray silty and gravelly sands. We suggest that the gray sands at the base of this boring represent reworked Cretaceous Magothy Formation which displays similar characteristics. Thus, **Figure 5.7** shows an unconformity outlining an incised sand filled channel as well as a Cretaceous surface sloping from south to north beneath the bay. Clearly there is no evidence of a deep "mud-filled" channel extending ca. 150 feet (45 m) below present sea level. Two shallow troughs are present on the floor of the bay at this location. Both of these troughs may mark the position of former incised outwash channels. We have labeled the northern trough the Pleistocene Arthur Kill paleochannel and the central trough the Pleistocene Raritan paleochannel. The age of these channels is problematical as Gaswirth obtained only one radiocarbon date for the sediments at the base of her Pleistocene valley fill. This date was 31,740 +/- 1830 B.P. thus the paleochannel may predate the final glaciation of the area.

Keansburg Profile (Cores B1-B4). Four (4) vibracores were collected along the Keansburg profile (**Figure 5.4**) using a Vibracore as shown in **Figure 5.7**. The cores are located along a transect beginning at Keansburg, NJ and continuing to the northwest for 3.1 km across the southern half of Raritan Bay (**Figure 5.8**). Core recovery ranged in thickness from 2.65 m to 12.5 m. Depths to the Raritan Bay bottom ranged from 3.32 m to 4.51 m below sea level in cores B-4 though B-2 on the southernmost portion of the profile, while core B-1 was far deeper at 11.28 m. No radiocarbon samples were analyzed from the Keansburg Profile. Two (2) shell samples were collected, one shell from 0.15 m below the top of core B-1, and one shell from 1.35 m below the top of core B-3. Descriptions can be found in **Appendix C**.

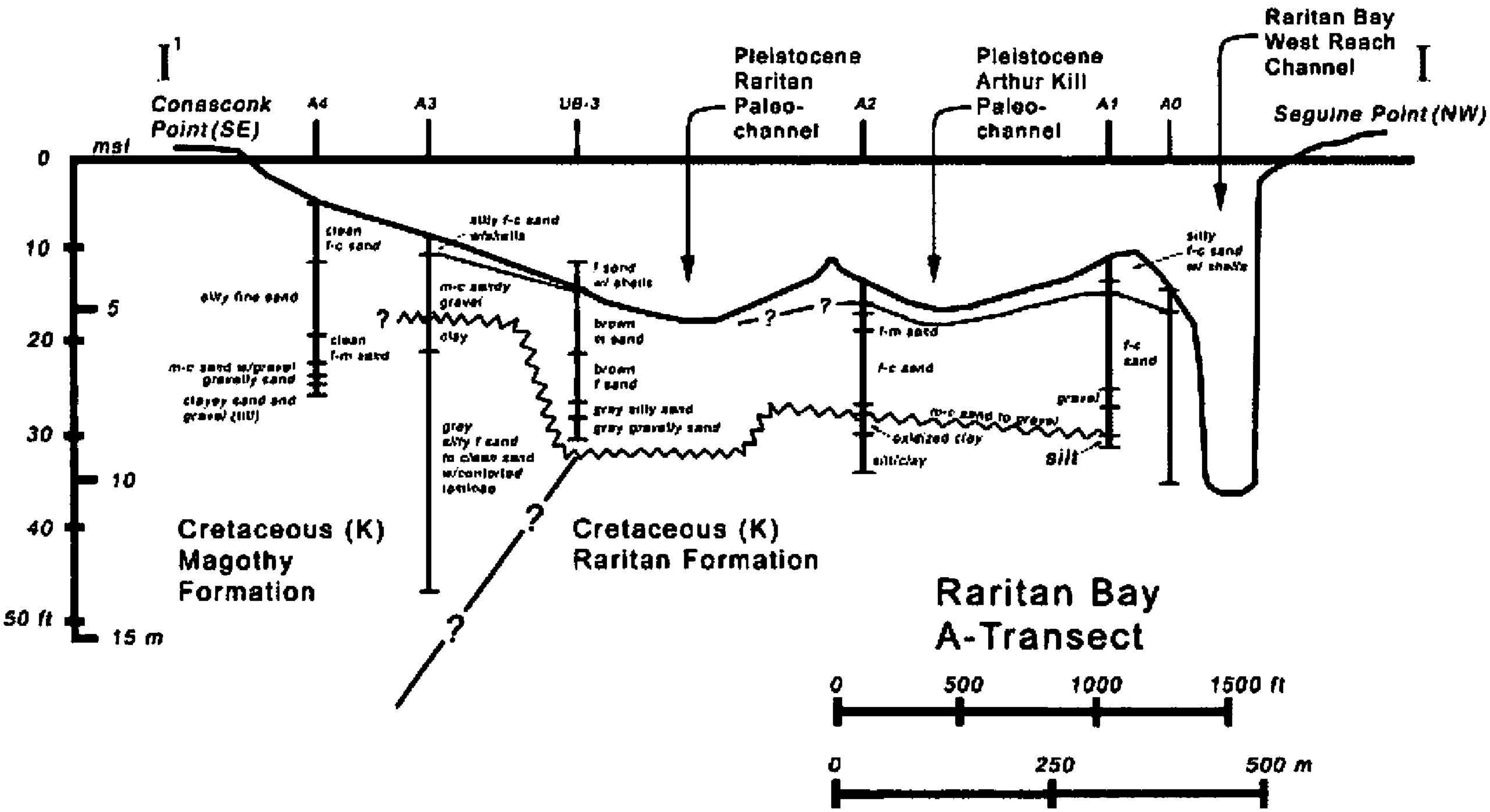


Figure 5.6. Stratigraphic profile I-I', Seguine Point to Union Beach.

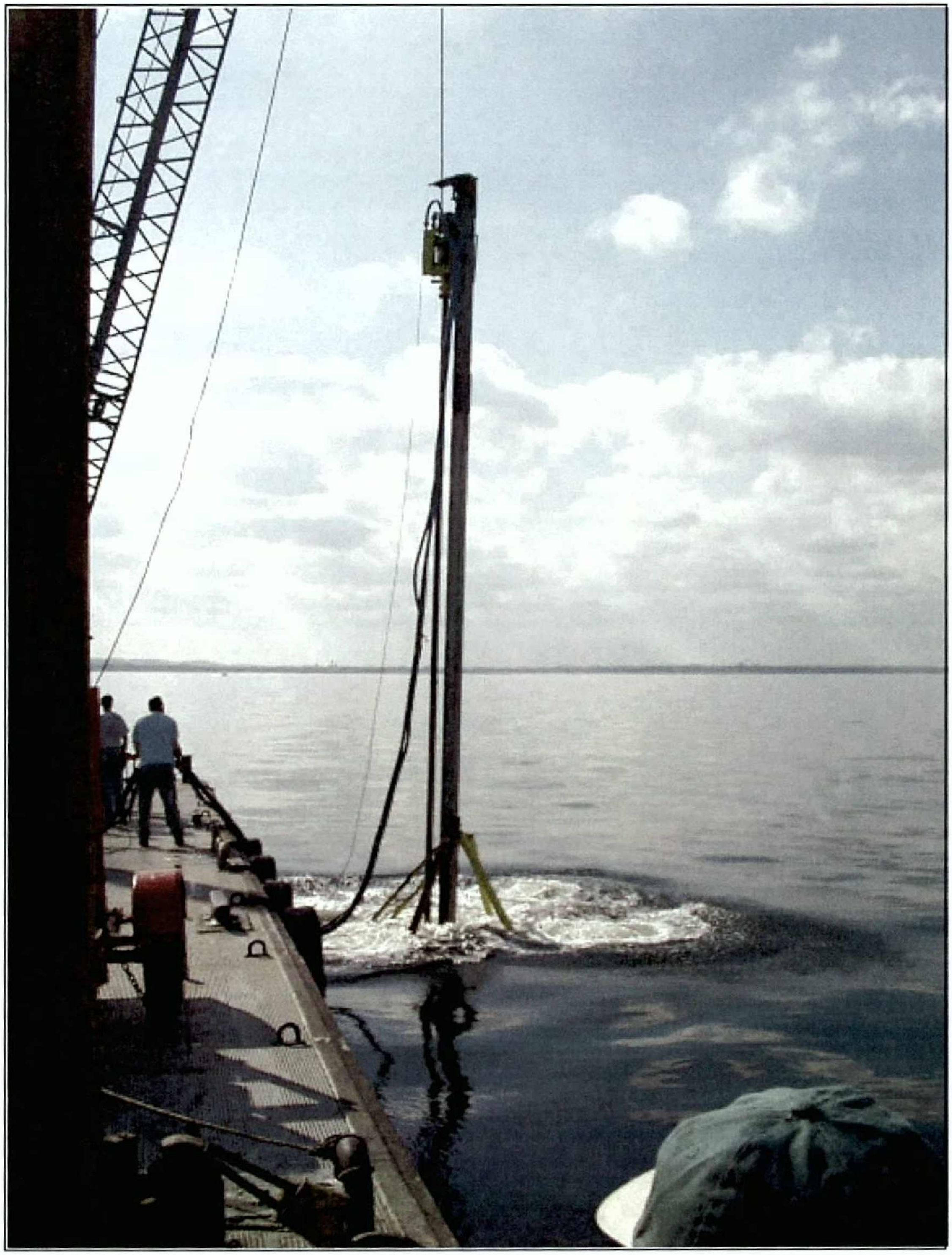


Figure 5.7. 40-foot vibracore, Raritan Bay.

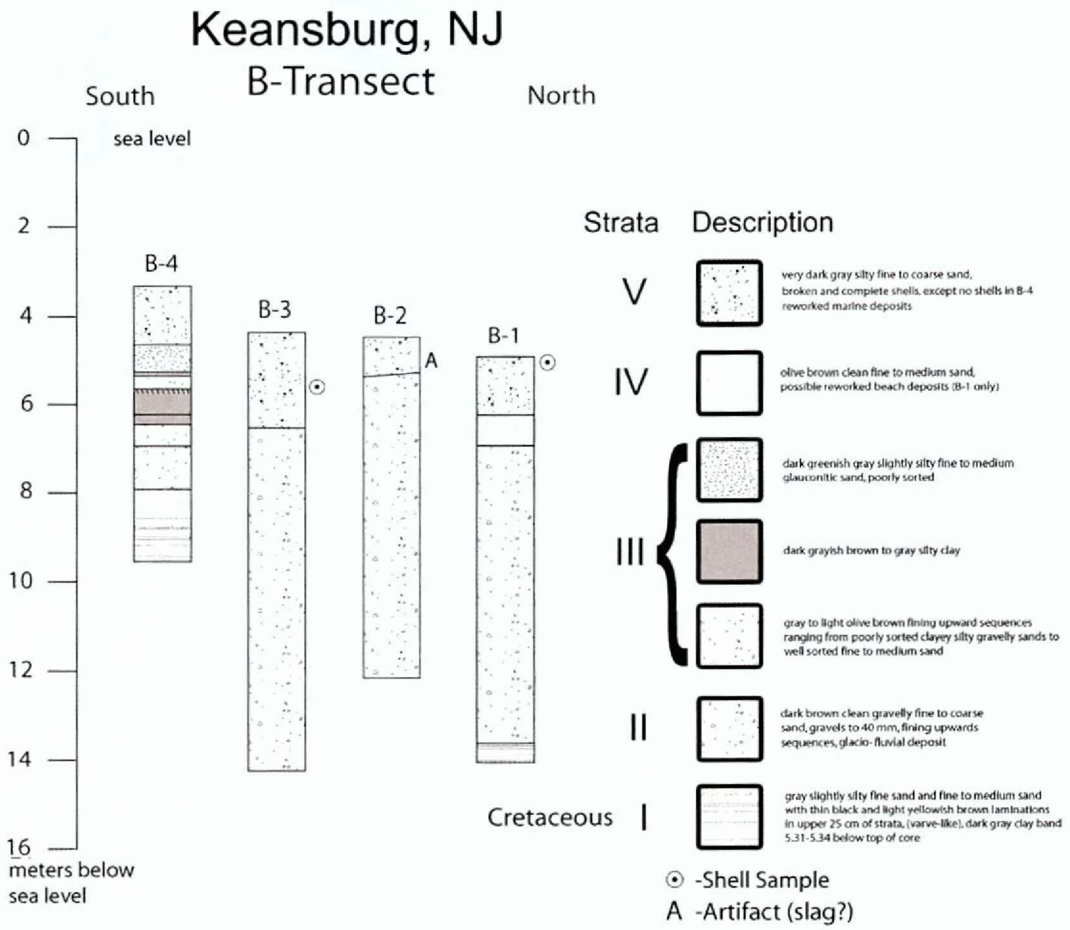


Figure 5.8. Keansburg transect.

The cores along the Keansburg transect in Raritan Bay encountered four (4) litho-stratigraphic units:

Stratum V: Very dark gray reworked clayey, silty, sandy marine sediments

Stratum IV: Olive brown clean fine sand, possible reworked beach (B-1 only).

Stratum III: Complex of glaconitic sands, weathered clays, and well sorted brown sands associated with colluvial and alluvial settings along submerged portions of Waackaack Creek (B-4 only).

Stratum II: Truncated, stacked, fining upwards fluvial sequences with polygenetic phreatic weathering at its lower contact

Stratum I: Highly weathered Cretaceous sands

Stratum V consisted of a very dark gray (10YR3/1) clayey sandy silt to silty fine sand ranging in thickness from 0.80 m to 2.15 m. Occasional fine broken shell fragments are found throughout this stratum in cores B-1 to B-3. Two slag-like fragments were found in core B-2 between 0.45 and 0.89 m, indicating historical deposition of these deposits. Core B-2 has a dark yellowish brown (10YR3/4) clean fine to medium sand overlying Stratum V, which, considering the historic object immediately below in Stratum V, suggests that this sand deposit are very recent.

Stratum IV consisted of olive brown (2.5Y4/3) clean fine to medium sand, with a thickness of 0.70 m, between 1.3 and 2.0 m below the water/sea floor bottom interface. This Stratum was only observed in B-1. These clean sands may represent a preserved reworked beach surface, which implies a period of stability during the Holocene transgression. The B-1 core is the only setting with a potentially preserved beach deposit atop the truncated glacio-fluvial deposits.

Stratum III is a complex series of sediments and soils found only in Core B-4 that are more likely associated with submerged portions of Waackaack Creek than buried paleochannels of the ancestral Raritan River. The deposit ranges from between 1.35 m and 3.62 m below the top of the core. The top of the deposit from 1.35 m to 1.93 m is a dark greenish gray (GLEY1 4/1) slightly silty fine to medium glauconitic sand. Sand continues below this horizon from 1.93 to 2.11 m with an olive brown poorly sorted clayey silty gravelly sand. From 2.11 m to 2.31 m is a dark gray (10YR4/1) silty clay with organics. Below the clay from 2.31 m to 2.38 m is a reddish gray (2.5Y5/1) fairly well sorted fine to medium sand, with abrupt contacts above and below. From 2.38 m to and irregular contact at 2.85 m to 3.05 m is a dark grayish brown (10YR4/2) silty clay with a weathered reddish yellow (7.5YR6/8) oxidized zone in the upper five (5) cm of the horizon. The dark grayish brown (10YR4/2) silty clay continues from 2.85 m to 3.05 m contact to 3.23 m. From 3.23 m to 3.62 m is a fining upward sequence of black (10YR2/1) very silty fine to medium sand with gravels at the base that fines upwards to a sandy silt. This undated sequence of deposits appears to represent a wedge of alluvium and colluvium at the southern margin of Raritan Bay. Stratum III can be interpreted as a fining upward fluvial deposit capped by alluvial overbank muds, which experienced limited pedogenic weathering. The deposits were then capped by glauconitic sands, which may derive from colluvial wash or a high energy fluvial deposit from weathering glauconitic bedrock, which can be found in the upland portions of the Waackaack Creek drainage.

Stratum II is analogous to Stratum III as identified in the Seguine Point to Union Beach transect. Sediments range from fining upward sequences of olive brown (2.5Y4/3) clean coarse to fine sand in core B-1, to brown (10YR5/3) interbedded clean fine to medium sands to gravelly sands with gravels up to 30-40 mm in core B-2. Stratum II is found in all of the cores, including a 0.95 m thick package of these deposits between the underlying Cretaceous Stratum I sands below and the Stratum III complex of deposits associated with the submerged Waackaack Creek.

Stratum I was identified at the base of Cores B-1 and B-4. Unlike the expression of the Cretaceous deposits along the Seguine Point – Union Beach transect these deposits are not capped by deeply weathered clays. Instead these deposits are analogous to the gray sands observed deep in Stratum I along the Seguine Point – Union Beach transect. The sediments are gray (10YR5/1) well sorted fine sand with common, horizontal to subhorizontal distinct black (10YR2/1) 5 mm to 15 mm thick lamina.

The Keansburg transect extends further east and "downstream" in the drowned valley of the Raritan River. **Figure 5.9** shows a continuation of the characteristic reddish brown fine to coarse sand and gravel of the Pleistocene valley fill present in the Seguine Point – Union Beach transect, II-II'. These deposits underlie the southern slope of the bay and are known as the "Keansburg Sands" as reported by Bokuniewicz and Fray (1979) although our line of vibracores lies in an area mapped as West Raritan mud in their report. The Pleistocene sands and gravels were penetrated in cores B-1 and B-4 where the same gray fine grained sand with black and yellowish laminae that were encountered in cores A-1, A-2, and A-3 indicating the Cretaceous Magothy Formation. Although Gaswirth (1999) maps the area of B-4 to be underlain by Cretaceous Merchantville Formation, the sediments are more similar to the Magothy sands however. The submerged floodplain of the ancestral Raritan River begins to show fluvial characteristics. For example prominent breaks in slope suggest the presence of terrace at -20 ft (-6 m) below sea level. This may signify a hesitation in rise in sea level at this position. Evidence of the rising sea level is also present as a thin wedge of clean, olive brown fine to medium sand that appears to have been a transgressive beach deposit that appears to pinch out upslope. A similar unit of very dark gray silty fine to coarse sand appears to pinch out at -15 ft (-4.6m) between cores B-1 and B-2. Another noticeable break in slope is present on the north side of the bay at -15 ft (-4.6m) at the base of a sand apron associated with the Orchard Shoal. We show the probable position of southeastward dipping Cretaceous formations below the Pleistocene outwash and alluvium. The central portion of the drowned Raritan River valley is generally underlain by estuarine clayey silt that covers Pleistocene sand and gravel. Gaswirth's (1999) core RB08 is projected on to our cross section and marks the position of the radiocarbon sample with the 31,740 +/- 1830 B.P. age at the base of the Pleistocene gravel. This limits the age of the overlying deposits.

Submerged Terraces in Lower New York Harbor. Close examination of NOAA Chart 12327 of New York Harbor shows clear indications of continuous terrace surfaces at approximate -15 foot (-4.6 m) depth that extend from the area east of Great Kills across the harbor to the East Bank shoal offshore Coney Island. The terrace is also present on the surface of Romer Shoal and Flynns Knoll. **Figure 5.10** is a cross section of a portion of this area drawn southeastward from Great Kills towards Sandy Hook and across Flynns Knoll, III-III'. The

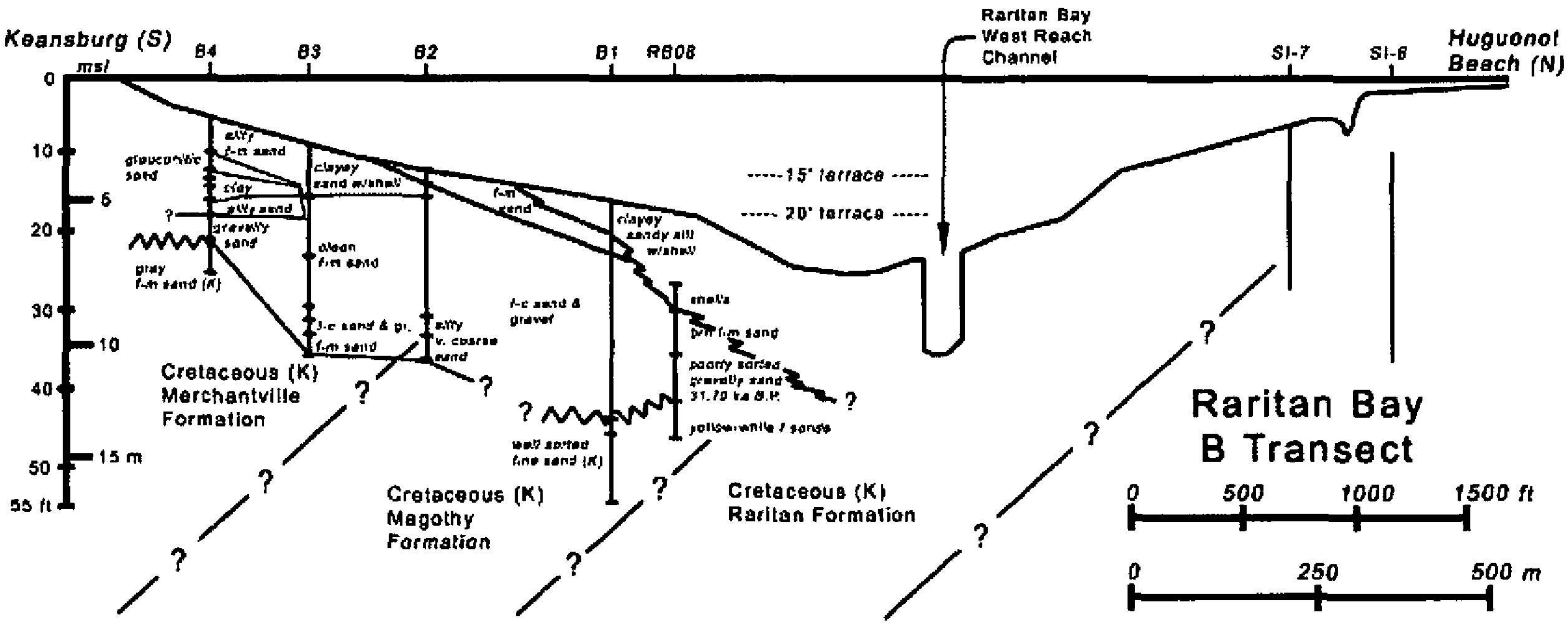


Figure 5.9. Stratigraphic profile II-II', Keansburg to Hugenot Beach.

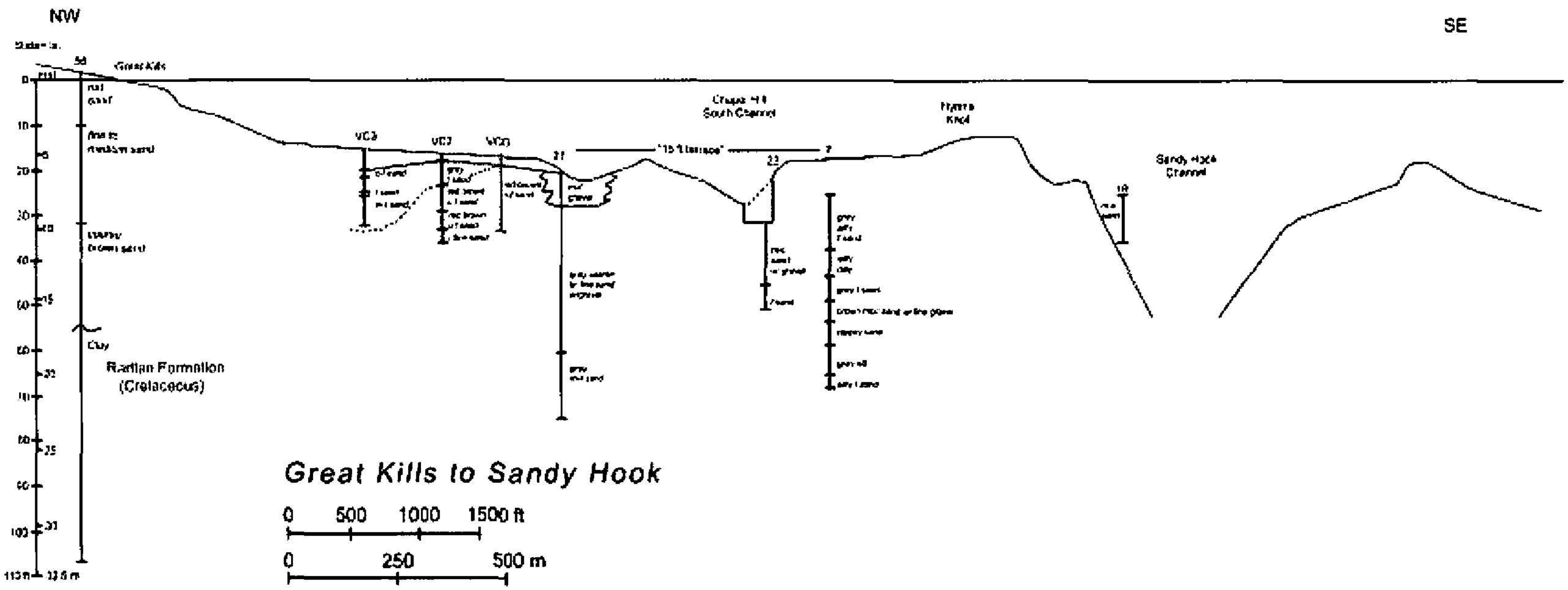


Figure 5.10. Great Kills- Sandy Hook profile III-III.'

submerged topography shows clear evidence of a -15 ft (-4.6 m) terrace between the base of the Orchard Shoal across the surface of Flynns Knoll. We suggest this as an erosional terrace indicative of a temporary "stillstand" in sea level rise, or a low fluctuation similar to that shown in the detailed sea level curve shown in **Figure 3.10**. This depth also relates to the break in slope described above. Since the surface is continuous and traceable across the lower harbor, we consider it evidence for the relative stability of the deposits underlying this portion of the harbor. Other researchers (for example Williams and Duane, 1974, and Bokuneiwicz and Fray, 1979) have considered the lower harbor to have been a "sink" for sediments moving in longshore transport along the Long Island and New Jersey shores. Also, Williams (personal communication) has pointed to sand waves at the harbor entrance as indications of sediment movement into the harbor from offshore. The presence of terraces, however, suggests that the sediments beneath the lower harbor have had a relatively stable surface for at least 3,000 years dated on the basis of our sea level curve (**Figure 3.6**). Relative stability of the surface of the lobate fan of sediment spreading out from Raritan Bay and the Narrows supports an idea of this fan as preexisting outwash feature reworked by channels from the ancestral Hudson River and Raritan River and later sculpted by tidal current action. This hypothesis requires additional study.

Upper New York Harbor

Liberty Island Profile (Cores C1-C4). Four (4) localities (C-1 to C-4) were sampled with a total of four (4) cores extracted using a vibracore (**Figure 5.11**). The Liberty Island transect was located south of Liberty Island (**Figure 5.12**) and was oriented along a northwest to southeast azimuth. The cores provide an approximately 0.85 km cross section of the western half of Upper New York Harbor, from the Jersey Flats to the west to the margins of the Anchorage Channel in the center of the Harbor to the east (**Figure 5.13**). Cores C-1 and C-2 were located on the Jersey Flats, at a shallow depth of 1.95 m and 2.90 m below sea level. Cores C-3 and C-4 are located on the margin of the Jersey Flats and at the base of the slope to the Hudson Anchorage, with depths of 8.84 m and 15.79 m below sea level. The recovered cores range in thickness from 8.4 m to 11.48 m. Detailed descriptions can be found in **Appendix A**. Samples for radiocarbon dating, shell identification, and pollen analysis were collected from this transect. Foraminifer and pollen samples were collected from core C-1 (**Appendices D** and **E**). A total of three (3) radiocarbon samples were collected from cores C-1 and C-4. A total of sixteen (16) shell samples from the across transect were examined (**Appendix C**).

The cores along the Liberty Island transect in Upper New York Harbor encountered three (3) litho-stratigraphic units:

Stratum III: Black oily clay muck, recent historical disturbances and limited biological activity

Stratum II: Very dark gray clayey silt, marsh deposits with common marine shell fragments and shell hash lenses. Historic ceramic recovered in upper portions of the stratum. The extremely young radiocarbon ages determined for the deposit suggests it has slumped down from the upper slopes to fill an incised depression along the west side of the Anchorage Channel.

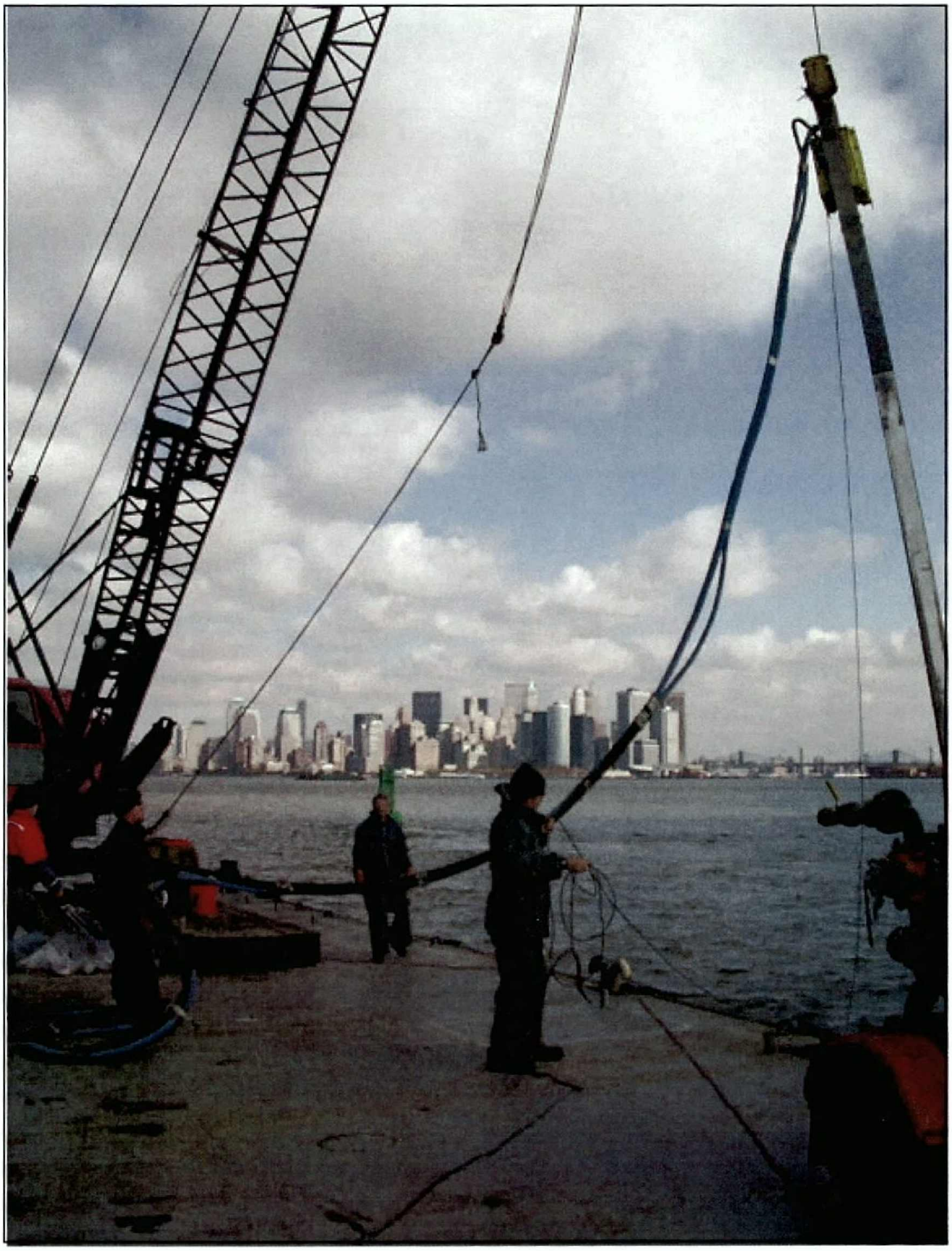


Figure 5.11. Coring along the Liberty Island transect.

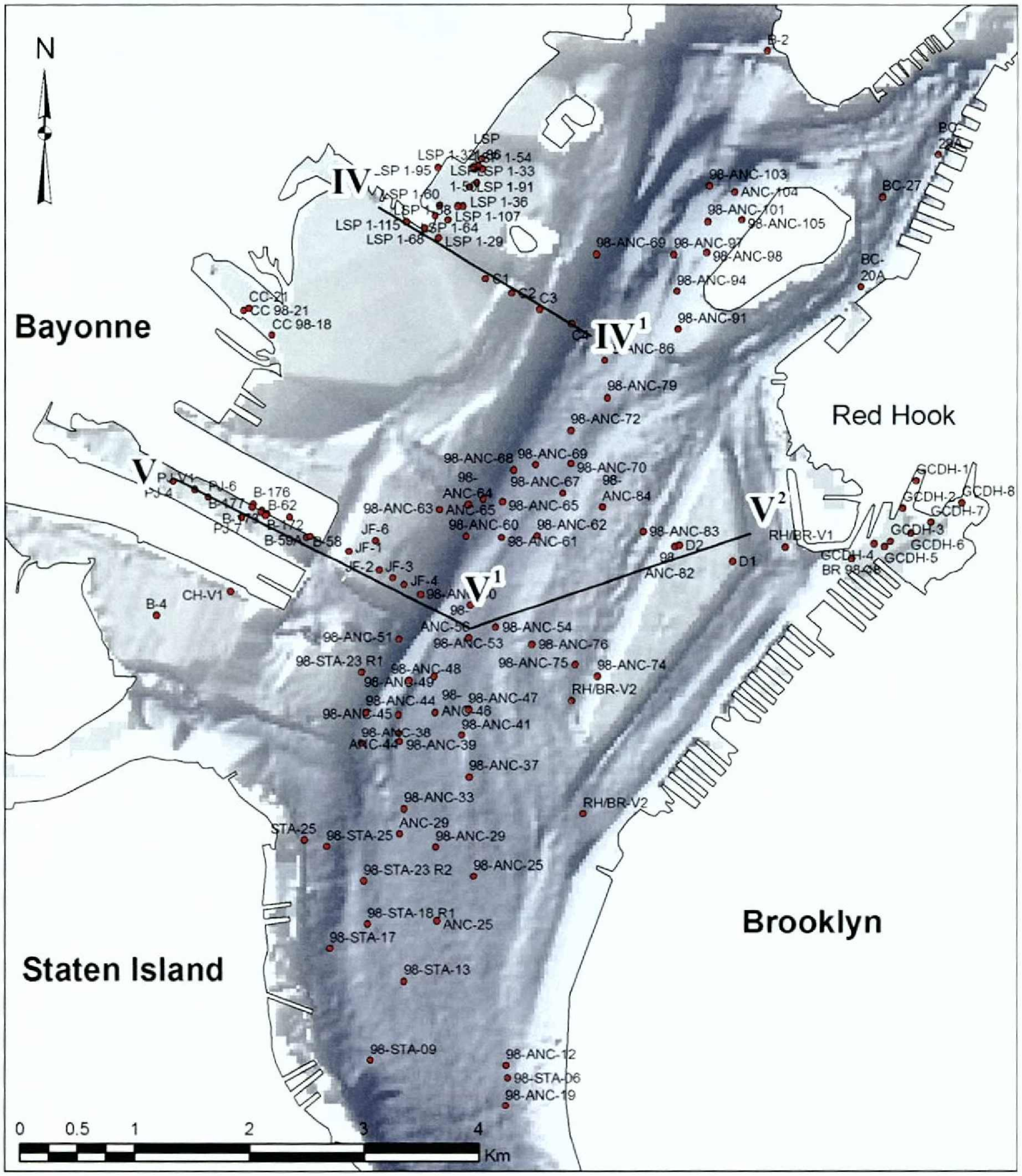


Figure 5.12. Upper Harbor core locations showing new cores along profiles IV-IV' and V-V.'

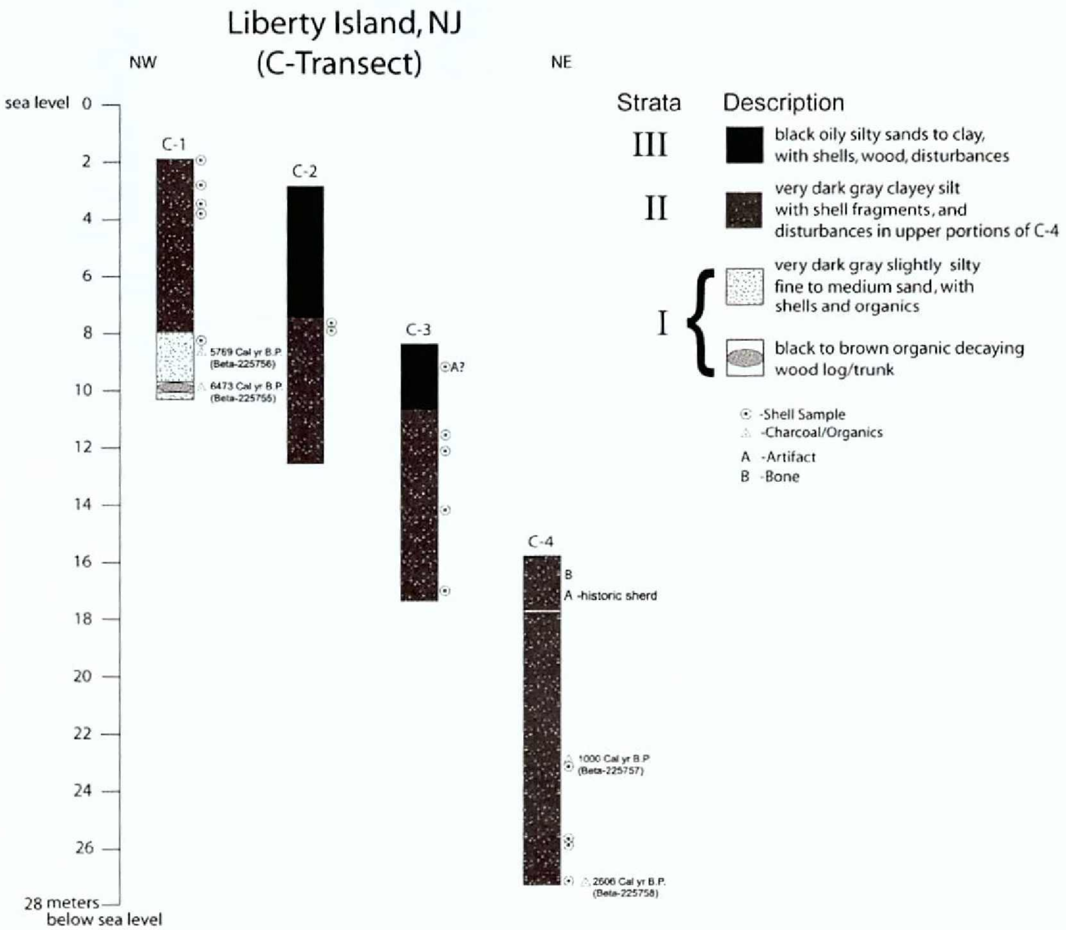


Figure 5.13. Liberty Island transect.

Stratum I: Very dark gray silty fine to medium sand, that becomes cleaner with depth, common marine shell fragments, and partially decayed organics.

Stratum III was only identified in cores C-2 and C-3. It ranges in thickness from 2.25 m thick in C-3 to 4.60 m in C-2. It is a black (10YR2/1) oily clay muck that has a scent of H_2S, diesel, and oil. In C-3 there are clay intrusions and shell fragments, however the shell fragments are in far lower concentrations than the undisturbed deposits of Stratum II. One small slag fragment was identified in this stratum of the obviously historically disturbed stratum.

Stratum II was identified in all four cores. The stratum consists of a very dark gray (10YR3/1) clayey silt with common shell fragments of oyster and mussel. The deposits are estuarine deposits. Cores C-2, C-3, and C-4 reached their terminal depths within Stratum II. It is 6.05 m thick in core C-1, and is present at the surface. This suggests that core C-1 is relatively undisturbed profile as opposed to the cores with the Stratum III overburden. The stratum has seen only limited historical disturbance, however the orientation of the stratum along the slope of the Hudson Anchorage Channel in cores C-3 and C-4 indicates that Stratum II has slumped deep into the Anchorage Channel due to colluvial processes. Core C-4 has two temporal controls from Stratum II. A historic ceramic sherd was recovered 1.4 m below the top of the core. A radiocarbon date from a sample 7.25 m below the channel bottom, which was already 15.79 m below the water surface was dated at 1090 +/- 40 BP (1000 cal yrsbp, Beta 225757). This young date so deep below the floor of the Anchorage Channel indicates that Stratum II sediments have been transported down slope to this depth and location or alternatively that young sediment has filled a deep depression at the base of the adjacent slope.

Stratum I was only identified in core C-1. A 2.35 m thick section of this Stratum was observed from 6.05 m to 8.40 m below the Harbor bottom at the base of core C-1. It consists of a very dark gray (10YR3/1) silty fine to medium sand with common marine shell and decayed organics. The sands become cleaner with depth. The abundant organics in this horizon facilitated the analysis of two radiocarbon samples. From near the top of Stratum I wood located 6.70 m below the top of the core dated to 5000 +/- 40 BP (5769 cal yrsbp, Beta-225756). From a depth below the top of the core of 7.78 m to 8.15 m a decayed log was recovered. A section of wood from the outer rings of the log dated to 5660 +/- 90 BP (6473 cal yrsbp, Beta-225755) These mid-Holocene dates and the relationship between the overlying clayey marine sediments and the underlying coarser sands of Stratum I represent the timing of inundation of the land surface by sea level rise.

The Liberty Island transect is put into its broader stratigraphic context in **Figure 5.14** that shows cores C-1 through C-4 plotted along an east-west section (IV-IIV') drawn on bathymetry derived from NOAA Chart 12327. Additional borings (LSP 1-118, LSP 1-105, LSP 1-68, and LSP 1-107) obtained from the New York District USACE core library are projected on to an expanded profile along the Liberty Island channel. The profile shows the surface of what has been collectively called the "Jersey Flats," known historically for its oyster beds. The "flats" extend westward from the edge of the Anchorage Channel to shallow water at the head of the channel. Our new vibracores are shown at the entrance to the channel south of Bedloe's Island. The figure outlines the surface of the "flats" underlain by dark gray organic silt that pinches out in a peat deposit at the edge

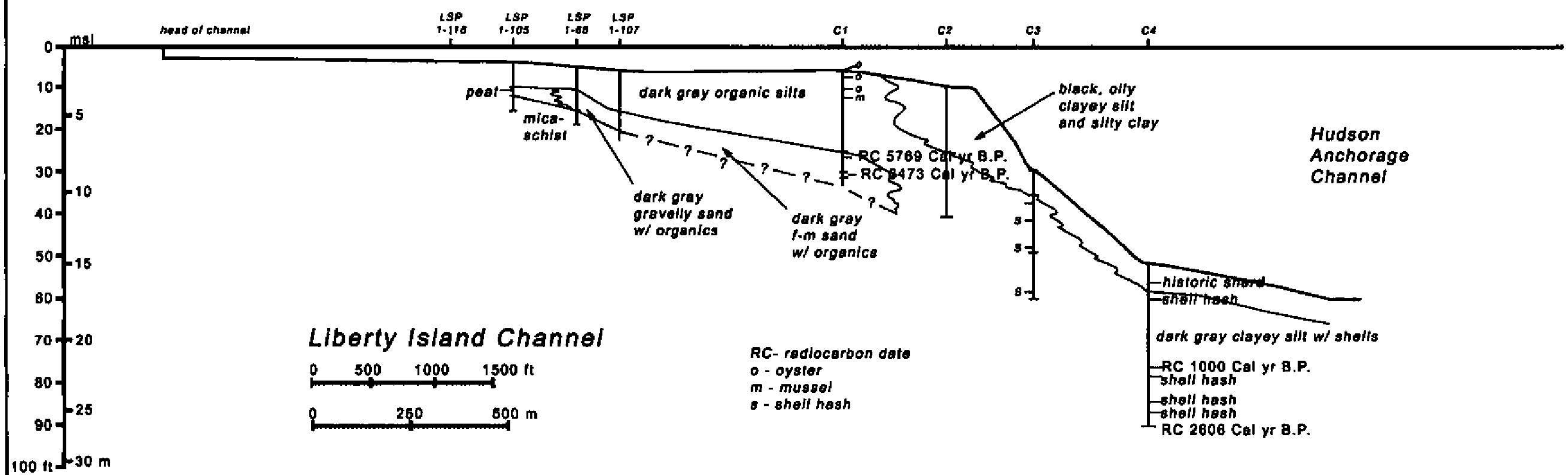


Figure 5.14. Liberty Island stratigraphic profile IV-IV.'

of a former saltmarsh deposited on the surface of crystalline rocks (LSP 1-105, LSP 1-68). The organic silt is underlain by dark gray gravelly sand lying on the surface of the crystalline rocks. This sand represents the reworked surface of more extensive fluvial sand underlying the Hudson River channel. The organic silt thickens to the east while maintaining the shallow depths of the flats. The flats terminate between cores C-2 and C-3 where the landform drops off into the deeper water of the Anchorage Channel. With the exception of core C-1, our Liberty Island core recovered dark gray clayey silt for their entire ca. 40-foot (12.2 m) lengths. Cores C-3 and C-4 both contain shell rich zones. Core C-4 shows wood in mid depth dated at 1,090 +/- 90 B.P. (1,000 cal yrsbp) and a basal date of 2520 +/- 40 (2,606 cal yrsbp). The historic ceramic sherd location is shown at the base of a black, oily clayey silt deposit that has a maximum thickness at the edge of the flats in core C-2. Anomalously young radiocarbon ages such as those in core C-4 may derive from slumping of younger deposits from the edge of the adjacent steeper slopes. The location and depths of two radiocarbon-dated wood samples obtained from the sand underlying the estuarine clayey silt in core C-1 are also shown. The wood, dated at 5,000 +/-40 B.P. (5769 cal yrsbp) and 5,660 +/ - B.P. (6473 cal yrsbp) is shown in its stratigraphic position. These dates, representing drowned river edge forest, provide limits on the timing of the inundation of the western edge of the Hudson River channel.

Bay Ridge Flats Profile (New cores D1-D2). Two (2) cores (D-1 to D-2) were obtained (**Figure 5.11**) from the Bay Ridge Flats. The transect was located on the east side of Upper New York Harbor on the Bay Ridge Flats on an east to west azimuth located west of Brooklyn, and south of Governors Island in Gowanus Bay. The two cores provide an approximately 0.50 km cross section of the Bay Ridge Flats (**Figure 5.15**). The recovered cores ranged in length from 9.7 m to 11 m. Detailed descriptions are found in **Appendix A**. Samples for radiocarbon dating, shell identification, and pollen analysis were collected from this transect. Pollen and foraminifer samples were collected from core D-1 (**Appendices E** and **D**). The radiocarbon sample collected from the core D-1 yielded a date of 1880 +/- 40 /B.P. (1806 cal yrsbp, Beta-228847). One shell sample from core D-1 was collected for identification (**Appendix C**).

The cores of the Bay Ridge Flats transect in Upper New York Harbor encountered two (2) litho-stratigraphic units:

Stratum II: Modern sand bar deposits of very dark grayish brown slightly silty fine to medium sand interbedded with horizons of black oily clays to sands with inclusions of wood and shell fragments

Stratum I: Estuarine deposits of very dark gray fine sandy clayey silt and sand fining with depth to silty clay, with common marine shell fragments and shell hash lenses

The modern **Stratum II** sand bar deposits consisted of very dark grayish brown (10YR3/2) slightly silty fine to medium sand. These sands were interbedded with historical disturbances of black (10YR2/1) oily clays and sands that included shell and wood fragments. Stratum II ranged in thickness from 2.20 m in core D-1 to only 1.25 m in core D-2.

Stratum I consists of estuarine deposits analogous to sediments identified as Stratum II in the Jersey Flats transect on the west side of New York Harbor. These deposits consist of very dark gray (10YR3/1) fine sandy clayey silt

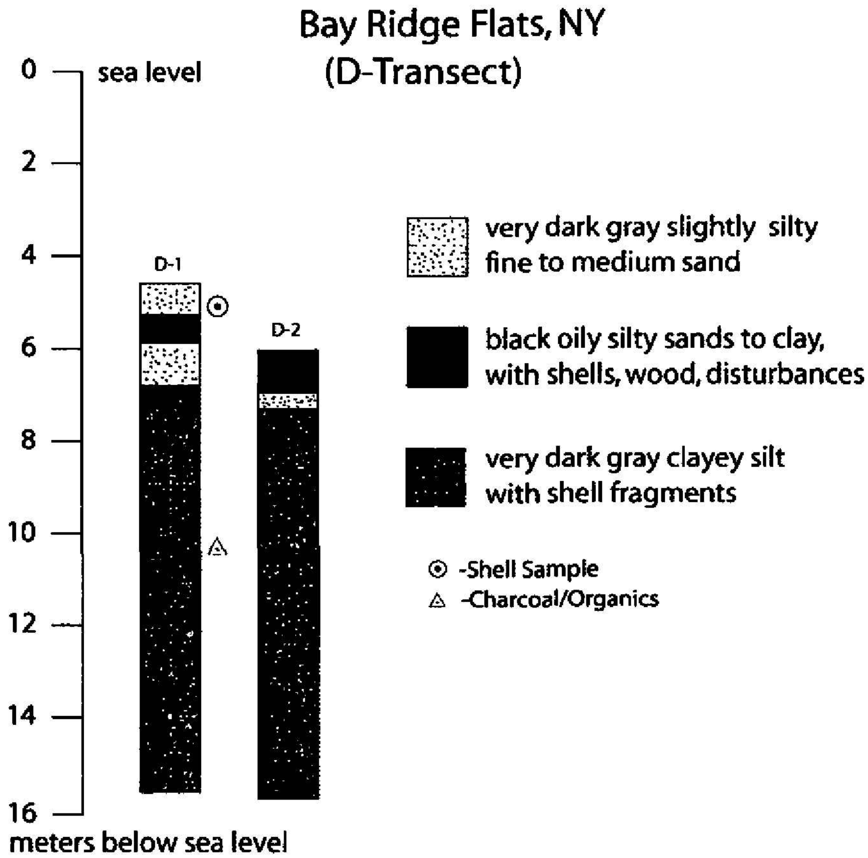


Figure 5.15. Bay Ridge Flats transect.

that fines to a silty clay with depth. Shell concentrations range from occasional shell fragments throughout the recovery as seen in core D-2 to multiple distinct shell hash concentrations in core D-1. A sandstone pebble was recovered in core D-2 at a depth of 4.05 m. The lack of soils, coarse fragments, or cultural material precludes the identification of this pebble as a cultural object. Stratum I was the basal deposit encountered in both cores, which reached maximum depths below the Harbor bottom of 11 m and 9.7 m below surface, respectively.

The Bay Ridge cores were taken to provide possible correlation of deposits of similar depth and form across the main Anchorage Channel and to obtain a more complete record of the depositional history of the harbor than was possible in our earlier study of the Port Jersey (Schuldenrein et al., 2001). **Figure 5.16** places these two cores in stratigraphic context with more detailed subsurface information available from the Port Jersey area. A composite profile (V-V') across the Anchorage Channel includes cores obtained in our earlier study (Schuldenrein et al., 2001) as well as several geotechnical boring logs obtained from the New York District USACE core library. The Port Jersey cores are projected on to a common profile to better understand the subsurface relationships. Like the Liberty Island channel, this portion of the Jersey Flats is marked by shallow water extending westward to the now covered historic shoreline of this embayment. For example, historic fill is shown above gray, clayey estuarine silt in geotechnical borings B-172, B-62, B-59A and B-58. Here again, the western flank of the Anchorage Channel is characterized by a steep slope dipping eastward to the floor of the channel. The greater amount of sediment underlying the flats at this location is estuarine silt that thins to the west. It overlies brown, fine to coarse grained fluvial sands representing Pleistocene outwash deposits. These outwash sands, in turn overlie the irregular surface of crystalline rocks at depth. An incised channel in the crystalline rocks filled by Pleistocene gravels is shown in borings B-172, B-62, B-59A, and B-58. Radiocarbon ages were determined from three previous GRA borings. JF-1 provided an age of 3,460 +/-40 B.P. (3,736 cal yrsbp). Estuarine silt from JF-6 was dated to 3,360 +/-40 B.P. (3,586 cal yrsbp). These two dated cores provide a reasonable timing for the time of inundation for this portion of the flats. Two other dates obtained from core JF-3, 1,970 +/-60 B.P. (1,927 cal yrsbp) and 2,360 +/-70 B.P. (2,606 cal yrsbp), were considered anomalous and came from the edge of the channel. These also suggested movement and redeposition or young sediment along the flanks of the channel. The Anchorage Channel as shown is asymmetrical with the deepest portion on the west at the base of the slope to the Jersey Flats. The channel is underlain by thick gray, estuarine clayey silt that is underlain by fluvial sand and gravel. The Bay Ridge Flats rise to the east and represent the final remnant of a more extensive shoal area now isolated by dredged navigation channels. Cores D-1 and D-2 are shown in relative position. One radiocarbon date obtained from wood in mid core D-1, 1,880 +/-40 (1,806 cal yrsbp) is anomalously young given its depth and location. The depositional history of the Bay Ridge Flats, given that age determination is unclear, requires further investigation.

Jamaica Bay

Yellow Bar Marsh Profile (Cores E1-E5). Five (5) cores (E-1 to E-5) were taken in Jamaica Bay (**Figure 5.17**). The sampling strategy used differed from the other areas studied. Due to the shallow water depth in Jamaica Bay a smaller barge was used which collected shorter cores. Core recovery ranged from 3.90 m to 5.65 m. The transect was oriented on a northeast to southwest azimuth

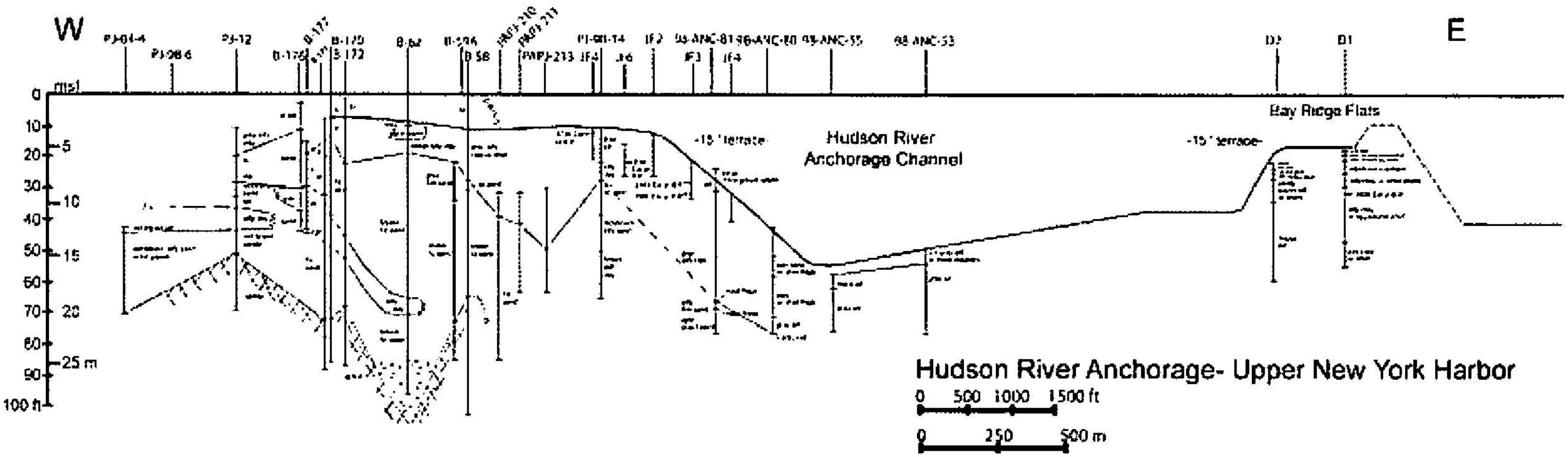


Figure 5.16. Port Jersey-Bay Ridge Flats stratigraphic profile V-V.'

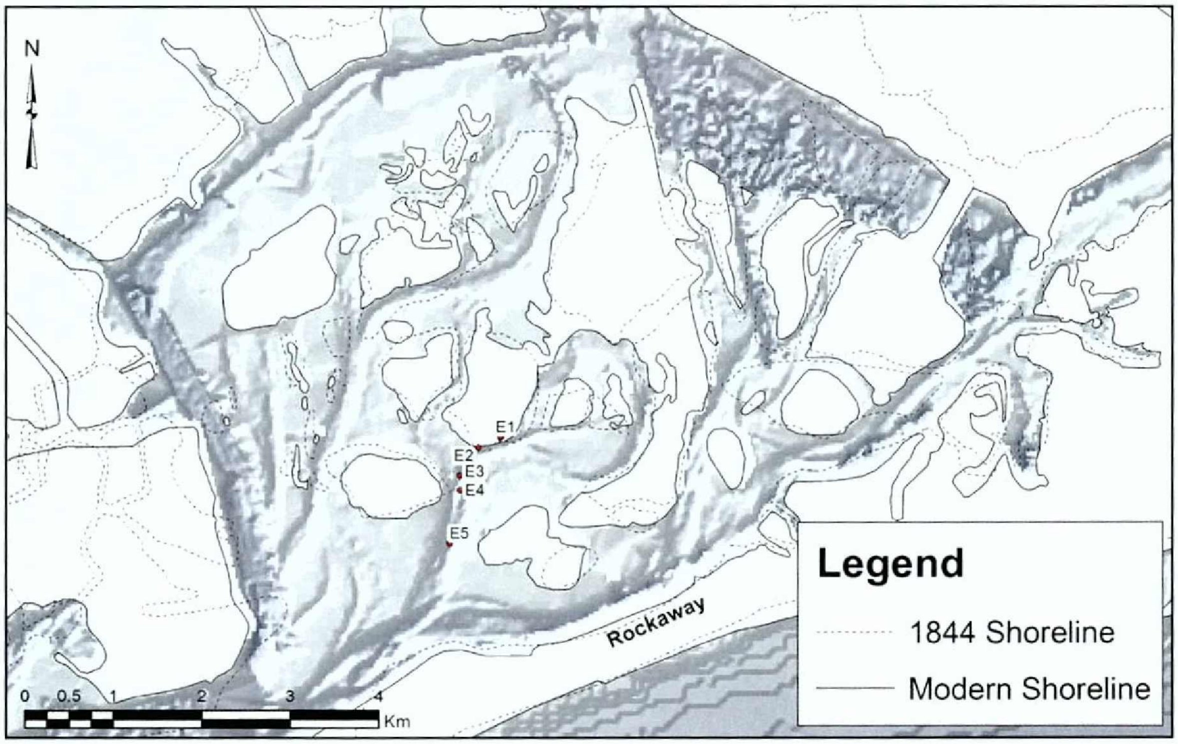


Figure 5.17. Jamaica Bay core locations.

from the southern end of Yellow Bar Hassock to south of Ruffle Bar between Ruffle Bar and Little Egg Marsh (**Figure 5.18**). The bottom depths of Jamaica Bay varied greatly between core locations. Cores E-1 and E-2 were located on the edge of the Yellow Bar Hassock, and were very shallow. Water depths ranged between 0.76 m and 0.88 m. Cores E-3, E-4, and E-5 were located in the channel between Ruffle Bar and Little Egg Marsh. Water depths were 6.68 m, 6.10 m, and 6.89 m respectively.

The Yellow Bar Marsh cores from Jamaica Bay encountered six (6) litho-stratigraphic units:

Stratum VI:	black oily silty clay with disturbed organics
Stratum V:	gray well sorted bar sands
Stratum IV:	gray sand with bedded black mineral lamellae found only in the channel
Stratum III:	very dark gray sands above marsh deposits with shell fragments.
Stratum II:	marsh deposits of very dark gray fine sandy silt to clayey silt with shell fragments
Stratum I:	gray silty fine sand below marsh deposits with shell fragments

Stratum VI was only recovered in cores E-3, E-4, and E-5 in the channel. The black (10YR2/1) oily organic silty clay ranges in thickness from 0.42 m to 0.80 m. The stratum was only present at the top of the cores at the interface of the water and Bay floor bottom. The stratum had a faint H_2S smell and abrupt lower boundary. These observations coupled with the stratigraphic position on the bay bottom, and the oily texture of the deposit suggests that the deposit is a historically recent deposit. The upper 0.10 m of core E-2 is a disturbed dark gray (10YR4/1) sand, but it lacks oily deposits.

Stratum V was recovered in cores E-3, E-4 and E-5.

Stratum IV was only recovered in cores E-3, E-4, and E-5 in the channel. The deposits were a gray (10YR5/1) fining upward sequence of medium to fine sand with occasional 10 mm thick very dark gray subhorizontally dipping silt lamina (10YR3/1). This deposit was identified as the terminal deposit in core E-5, while cores E-3 and E-4 had a gray to very dark gray (10YR5/1, 3/1) fine to coarse sands lacking laminae. Wood fragments were recovered at a depth of 2.52 m below the top of the core E-3 (9.2 m below sea level). A radiocarbon analysis dated this sample to 3980 +/- 40 B.P. (4432 cal yrsbp, Beta-228848). This sample recovered from a channel is not considered *in situ*.

Stratum III was recovered in E-1 and E-2.

Stratum II was also identified in cores E-1 and E-2 on the southern end of the Yellow Bar Hassock. Stratum II is a dark gray to very dark gray (10YR4/1,3/1) clayey silt that coarsens upwards to a clayey silty fine sand. Shell fragments are found throughout the stratum, with three (3) shell hash lenses in the upper clayey silty fine sand portions of stratum II in core E-2. The stratum was encountered 1.48 m and 1.65 m below the sea floor bottom. Core E-1 was the only core that exposed the full thickness of the deposit (2.12 m) while core E-2 terminated in stratum II at 4.88 m below the Bay bottom. Stratum II is analogous to organic clayey marsh deposits of stratum II in the Liberty Island transect and stratum I in the Bay Ridge Flats transect in the New York Harbor.

Stratum I was only recovered in the base of core E-1. It consisted of a gray (10YR5/1) silty fine sand with shell fragments that extended from a depth of 3.60 m below surface to the base of the extracted core at 3.90 m. This stratum is analogous to Stratum I identified in the Liberty Island transect in the New York Harbor. In both settings gray fine sand with shell is found below marsh deposits of organic clayey silts. This facies relationship conforms to model of marsh formation under rising sea level.

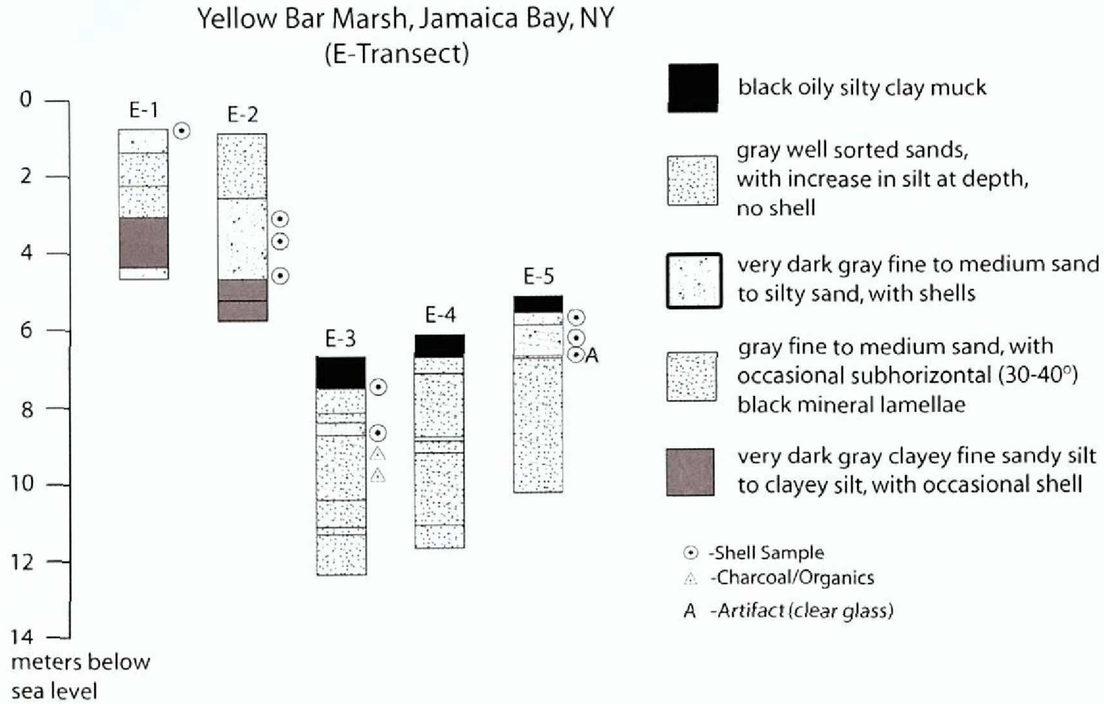


Figure 5.18. Yellow Bar Marsh transect.

Chapter 6

PALEOECOLOGICAL OVERVIEW

Tracing the history of past environmental change in the New York Harbor area is a key to evaluating the potential for past human habitation. Sediment lithology is a clue to the depositional environment in which deposits were laid down, but the biological evidence is more informative in many ways. As an example, we are able to reconstruct the past record of temperature and salinity changes through detailed analyses of foraminifera. Similarly we are able to derive clues to past floral communities in the region through pollen records preserved in cores. The latter especially give an idea of the ages of sediments in subsurface through comparison with more complete regional pollen records. Both pollen and microfauna such as foraminifers provide a general view of past environmental conditions. Pollen in New York Harbor, for example, is not only derived from ongoing pollen rain throughout the area, but also pollen transported downriver from areas of different vegetation far upstream in the Hudson. Pollen analysis is a regional indicator at best. Benthic foraminifers, on the other hand, are bottom dwellers and populate the bottom sediments of the marine environment in which they are found. They too can be transported by tidal currents to give mixed assemblages. Most useful for discerning the immediate environmental setting for sediments is the macromolluscan fauna consisting of gastropods and of bivalves like oysters and pelecypods. These larger bottom dwellers give an immediate record of the environmental setting of the sediment studied.

Previous Studies

Past paleoecological studies conducted by GRA as part of the New York Harbor project have utilized all of the above approaches. Past analyses have utilized the expertise of Dr. Ellen Thomas (foraminifers) and Dr. Richard Orson (pollen and macro mollusks). Their reports appear in past studies of Shooters Island and the Jersey Flats. Their work is the foundation for the present study. Different researchers have been utilized for the present report. We have also utilized previous work on pollen and microfossils by LaPorta and his coworkers. Macromollusks have been identified by Dr. Georgiana Lynn Wingard, pollen by Christopher Bernhardt and foraminifers by Dr. Benjamin Horton. Dr. Wingard has studied mollusks along the entire Atlantic coast. Christopher Bernhardt has similar experience. Dr. Horton is an internationally known researcher specializing in sea level rise through the use of foraminifer studies. Since our previous work, several important studies have been completed by Lamont-Doherty Earth Observatory on the Hudson estuary. The latter studies give more immediate information on pollen, sedimentation, salinity changes, and shellfish (oyster) colonization further upstream in the Tappan Zee area. Radiocarbon ages from salt marshes as well as submerged oyster reefs in Tappan Zee have formed an independent check on the relative sea level history presented here. Many of the recent Lamont-Doherty findings relate directly to past and present GRA studies.

Past GRA paleoecological studies were site specific while the present study seeks to present a broader view of past environmental changes in New York Harbor. Two Upper Harbor cores were chosen for study. These cores, C-1, and D-1, were from opposite sides of the harbor i.e. Liberty Island and the Bay

Ridge shoal. The former was chosen because it promised the greatest time depth. Core C-1 yielded a basal date on wood of 6473 cal yrsbp overlain by another date on wood of 5769 cal yrsbp. Provided this 40-foot core was not disturbed, we anticipated virtually the complete environmental history over this time span. Core D-1 was chosen as a check on core C-1 as it had a similar surface elevation and promised to represent the same sedimentary sequence. Both cores were 40 feet in length. They were sampled at 30 cm (ca. 1 ft) intervals. Surprisingly, core D-1 was age dated at 1806 cal yrsbp at a depth of 33 feet. It was clear that the two cores did not correlate temporally across the harbor. A detailed analysis of these cores is presented in Chapter 6 and Appendix 1.

The Shooter's Island cores were from shallow water at the entrance to Newark Bay. They extended little more than 18 ft (5.5 m) below mean sea level. All cores terminated in fluvial gravelly sands that were overlain by estuarine clayey silt. First and foremost, the analysis attested that there had been no upland or tidal marsh vegetation present in the core. Fluvial gravelly sands graded to fine sands at a depth of 16 ft (4.9 m) were inundated at least since 3200 cal yrsbp on the basis of our relative sea level curve (**Figures 3.6 and 3.10**) and had remained underwater since that time. At 11 ft (3.4 m) depth, oysters began to appear about 2200 cal yrsbp and an oyster reef was in place at 6.5 ft (2.0 m) by 1320 cal yrsbp. Presence of oysters pointed to an increase in brackish water (salinity) at the mouth of Newark Bay. While increased salinity could result from decreased freshwater runoff from the Passaic and Hackensack rivers, this same period corresponds with rise in sea level (**Figure 3.10**) at the same time period and in concert with thriving oyster habitat further upstream in Tappan Zee (Carbotte et al., 2004). The oyster reef was overlain by sediments with remnants of submerged aquatic vegetation pointing to a shallower water column and a possible decrease in the marine submergence rate. Here again the change in molluscan fauna and vegetation are contemporaneous with a fall in sea level corresponding with the onset of the Little Ice Age. Thus this significant change may result from both climate and sea level driving forces. In the upper 3 ft (1 m) of the core, surf clams appear pointing to deeper water conditions in the last 500 years.

Another paleoecological analysis of cores from the Jersey Flats explored a different environment on the steep slope on the western edge of the Anchorage Channel. Two cores were studied but core JF-2 provided the most complete data set. Cores here did not extend to bottom of the estuarine fill, but rather began with subtidal habitats. At a depth of 11 ft (3.3 m) the presence of the pelecypod Eastern *Aligena* and the gastropod *Sayella fusca* suggested that the water was brackish. By 8.8 ft (2.65 m) periwinkle (*Littorina irrorata*) fragments are found suggesting low tide zones or marshes in the vicinity. From 8 ft (2.65 m) to 7.2 ft (2.7 m) the development of a "clam bar" indicated this site was near the head of tide or at least was in a low tide zone. From 6.5 to 3.5 ft (2.0 to 1.0 m) there were few clams consistent with a deepening water column consistent with rising sea level. This core was topped by a final "clam bar" populated by surf clams and pointed to deeper water conditions.

Detailed Studies from Tappan Zee

Lamont-Doherty research on Tappan Zee is important here. Perhaps most important for the submerged cultural resource potential focus of the present study is work by Carbotte and her coworkers (Carbotte et al., 2004) on submerged oyster reefs. Work by Pekar et al., (2004) documents salinity changes in the lower Hudson estuary over the past 7,000 years. Pollen work by Pederson et al., (2005) and

Peteet et al., (in press) gives us long term records of vegetation and climate change in the project area as well as the history of salt marsh development in response to relative sea level changes.

Pekar and his coworkers infer paleosalinity reconstructions on the basis of benthic foraminifera and associated biofacies. They show an initial high summer time salinity of 20 to 25 ‰ beginning at about 6,000 years ago decreasing to 10 to 15 ‰ by 2,000 years ago. Diminished salinity has also been attributed to greater effective moisture at Dogan Point that resulted in higher stream discharge at a time when sea level rise had slowed somewhat (Schuldenrein 1995). The latter salinities are generally consistent with the modern salinity range. A period of high frequency salinity changes marked the transition to lower summer time salinity at about 3,600 years ago. The sedimentation rates in Tappan Zee were relatively low and similar to the rate of relative sea level rise although they note that rates were lowest over the past 2,400 years in shallow water but with increased rates in further downstream between 2,300 and 1,300 years ago. They attribute variations in sedimentation rates to migrations of the saltwater wedge of water migrating up and downstream from the mouth of the estuary. The Lamont-Doherty researchers refer this wedge of saltwater intrusion at the ETM or Estuarine Turbidity Maximum. This can be thought of at the zone where fine grained sediment (largely clay minerals) carried downstream by the Hudson flocculate and tend to drop out of the water column. They thus suggest that estuarine sedimentation can be highly localized suggesting complex depositional patterns.

The development of oyster reefs in the Tappan Zee (as well as Shooters Island, see above) has not been continuous. Carbotte et al., (2004) have noted that oysters thrived between 6,100 and 5,600 cal yrsbp and 2,400 to 500 cal yrsbp, but virtually disappeared between 5,000 and 4,000 cal yrsbp associated with the onset of a cooler climate. They also point to a more recent demise of oysters in the estuary between 900 and 500 cal yrsbp that may have accompanied cooler climates of the Little Ice Age. Radiocarbon dated oysters from these researchers core SD30, which has the most continuous record in their study has been incorporated into our relative sea level model (**Figure 3.6**) as it reflects the same rate of rise and corroborates our reconstruction. More detail on the changing rates of relative sea level rise is also contained in their data. For example, the data show a clear low phase and decrease in the rate of rise in sea level between 5,000 and 3,500 cal yrsbp with a rate of 2 to 4 mm/yr at the end of this phase. Overall, however, the long term rate or relative sea level rise shown by the Tappan Zee oysters is on the order of 1.7 to 1.8 mm/yr as is our calculated rate.

The Tappan Zee oyster studies also provide a background to archeological investigations at Croton Point (Newman et al. 1962) and at Dogan Point (Brennan, 1974 and Claassen, 1995). Shell middens at Dogan Point for example, show that oyster harvesting by Late Archaic populations began as early as 6,000 cal yrsbp. Distinctly large oysters characterize the base of the shell midden at Dogan Point and date between 5,900 and 5,100 cal yrsbp (Brennan, 1974, Little, 1995). Smaller oysters are dated in two distinct horizons at the site (5,100 to 4,000 and 1,800 and 1,500 cal yrsbp) separated by a 2,000-year hiatus. While the archeological interpretation might suggest changes in dietary patterns or cultural groups (the hiatus is contemporaneous with the end of the Late Archaic period and includes the more agriculturally oriented Early Woodland period), the hiatus is also present in the fossil record and points to significant temperature and salinity changes in the estuary less conducive to oyster growth.

A detailed study of the Piermont Marsh (Pederson et al., 2005) not only provides us with a regional view of vegetation and climate changes over the past 2,000 years, but also the contemporaneous changes within the marsh. These in turn reflect upon changes in the local watershed as well as the ongoing changes in sea level as the marsh attempts to keep pace with rising sea level. One of the key findings of this study has been the suggested correspondence between high concentrations of charcoal and the timing of the Medieval Warm Phase (1,200 to 700 cal yrsbp). The authors attribute these concentrations of charcoal to drought conditions and possible frequent fires in the watershed related to warmer climate conditions in the region. They also show changes in sedimentation rates over the past 2,000 years. Significantly, they show a decrease in sedimentation rate to .3 mm/yr during the Medieval Warm Phase, subsequently increasing to 2.9 mm/yr and 5.9 mm/yr and then decreasing to the background rates of 1.1 and 1.4 mm/yr. The overall sedimentation rate for the Piermont Marsh core is ca. 1.8 mm/yr consistent with the rate of relative sea level rise determined from the Carbotte et al., (2004) oyster reef trend and the sea level model presented in this report. Also important from our standpoint is the varying trends and rates in sedimentation documented by Pederson and her colleagues. Close examination of her sedimentation results suggest an overall decrease in rates between 1,000 and 300 cal yrsbp. When viewed against her background sedimentation rate of 1.8 mm/yr between 1,600 and 1,000 cal yrsbp her study suggests an overall period of lower sedimentation rates that correspond with the period of lower relative sea level presented by Thomas and Varekamp (2001) from Connecticut salt marshes and used here in **Figure 3.10**. It would appear on this basis that the pollen studies of Piermont Marsh not only track changes in climate and local runoff, but also are an independent marker of relative sea level change in the Hudson estuary.

An additional study by Slagle et al. (2006) discusses infilling of the estuary. The authors begin by noting their identification of three distinct unconformities that represent erosion surfaces or periods of non deposition in the sedimentary record at Tappan Zee. Maximum ages for the unconformities are 3,655, 2,200, and 1520 cal yrsbp. They also identified two sedimentary facies apparently overlapping the above unconformities. A deeper sedimentary unit identified as a delta and dated ca 1,700 years accumulated at rates of 2 to 4 mm/yr and lapped onto the 2,200 cal yrbp surface of erosion or non deposition. Identification as a delta suggests sediment contribution from a nearby fluvial source. A shallower depositional facies accumulated at a slower rate of 1 to 2 mm/yr and tended to cover the above delta deposit. The data suggest that the shallow flats at Tappan Zee are no longer depositional sites but are rather characterized by alternating periods of erosion and deposition sensitive to small fluctuations in sea level and climate conditions.

Applications to New York Harbor

The detailed paleoecological studies conducted by Lamont-Doherty provide an extremely useful context for the past studies of mollusks, foraminifers, and pollen conducted for cultural resources purposes by GRA and other researchers. By necessity, our studies are coarse-grained in comparison. It is useful however to view the findings of those earlier studies at Shooters Island and the Jersey Flats against the Tappan Zee context. This is shown graphically using our relative sea level reconstruction as a background. **Figure 6.1** shows the relative sea level trend juxtaposed

Relative Sea Level Rise at New York

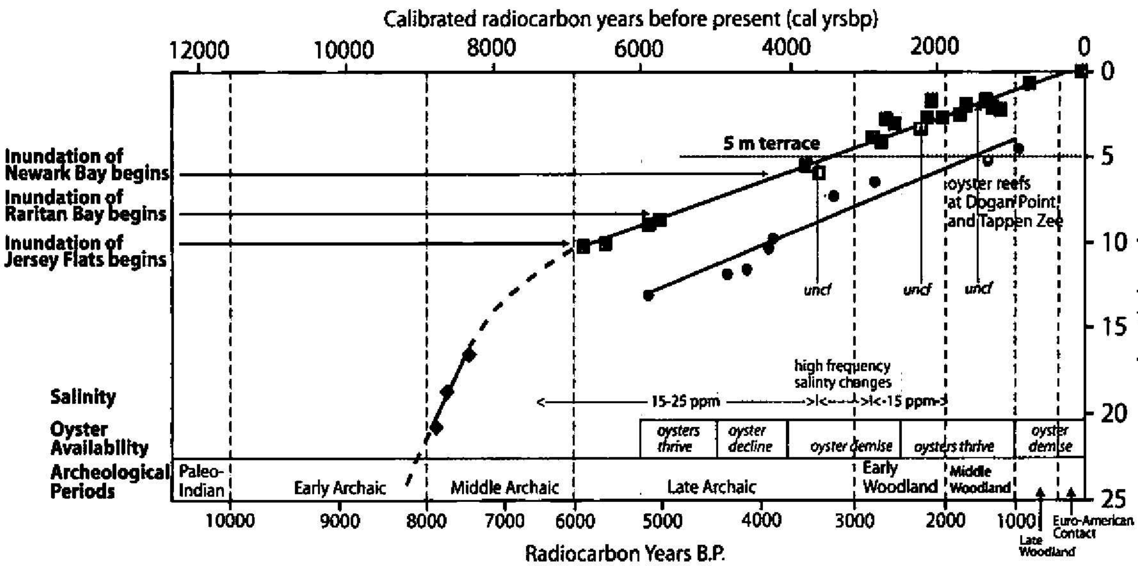


Figure 6.1. Relative sea level compared with Tappan Zee oysters, salinity, and unconformities

with the Carbotte et al. (2004) radiocarbon dated oyster sequence from their core SD30. Also shown are the approximate times for the inundation for the Jersey Flats (ca. 6,000 cal yrsbp), Raritan Bay (ca. 5,000 cal yrsbp) and Newark Bay (ca. 3.500 cal yrsbp). We assume on the basis of radiocarbon dates from the deeply incised channel of the Hudson at Iona Island as well as one from the incised outwash channel of Arthur Kill that the main incised channel of the Hudson River was inundated by brackish water as early as 12,000 radiocarbon years B.P. (ca. 14, 500 cal yrsbp). The figure also shows as background the intervals of active oyster growth at Tappan Zee.

The inundation history of the Jersey Flats appears to parallel that at Tappan Zee with the earliest basal radiocarbon dates of 6,473 and 5,769 cal yrsbp at Liberty Island corresponding with the earliest appearance of oysters further upstream. This marks the intrusion of marine water on to the shallower flanks of the Hudson both in the Harbor and upstream. The inundation also is in tandem with the observed increase in salinity to 25 °/oo subsequently decreasing to 15 °/oo by 3,500 cal yrs bp. At Shooters Island oysters begin to populate the entrance to Newark Bay at about 2,200 cal yrsbp also in agreement with the return of oysters at Tappan Zee after at least a 1,000 year hiatus.

In summary, we are beginning to develop an understanding of the paleoecology of the New York Harbor as well as the Hudson estuary that will enable other researchers and specifically cultural resources specialists to better interpret the submerged locations within the harbor with the greatest potential for former prehistoric coastal marine adaptations and possible settlement sites.

Chapter 7

ENVIRONMENTAL RECONSTRUCTION AND PREHISTORIC LANDSCAPE

The following portion of our study is designed to present a graphic characterization of the inundation of the New York Harbor study area for aid in understanding both its sedimentary history and in the determination of the potential for submerged prehistoric archeological sites. A digital elevation model (DEM) showing topography merged with shorelines and bathymetry from the earliest dependable charts (New York Bay and Harbor and Environs, U.S. Coast Survey, 1844) has been constructed from U.S. Geological Survey topographic data and a laborious digitization of the 1844 bathymetry and shoreline data as part of this study. The resulting model (**Figure 7.1**) shows the harbor study area in 1844 prior to dredging and significant land fill operations. Highly important for future Federal interests are the original shoreline positions for both the Jersey Flats and Jamaica Bay which have undergone extensive modification over the past 150 years.

To conceptually set the stage, **Figure 7.1** shows the deeply incised channel of the Hudson River upstream from the Narrows as well as the incised channel of the East River through Hells Gate to Long Island Sound. The original shorelines for the Jersey Flats and Jamaica Bay are useful markers. The Hackensack and Passaic rivers enter Newark Bay from the north and the incised channel of the precursor of the Hackensack River is visible and drains to the Hudson through the Kill Van Kull. South of the Narrows the Hudson channel gives way to a more subdued topography characterized by an array of splayed channels separated by interfluves that have historically been shoals limiting access to the harbor and directing maritime traffic into Raritan Bay through a deeper channel at the tip of Sandy Hook. Although indistinct, the channels at the mouth of the Narrows apparently drain eastward to the edge of the incised Hudson Shelf Valley and ultimately to the Continental Shelf. Arthur Kill is inundated but shows that its incision begins at Newark Bay, the position of the former glacier ice front and subsequent proglacial lake that drained through its channel. The mouth of the Raritan River lies at the left of the figure at the west edge of Raritan Bay. Deeper water outlines the general course of the ancestral channel of the Raritan River beneath the bay and merging with the Hudson channel north of Sandy Hook. The Navesink and Shrewbury rivers enter their conjoined estuaries behind the barrier island at the base of Sandy Hook. Sandy Hook has not prograded to its modern position.

Using our relative sea level model (**Figure 3.6**) it is now possible to view a lower sea level at its 9,000 cal yrbp position (- 72 ft, -22m), and expose the landscape (**Figure 7.2**). We can progressively innundate the New York Bight and upper and lower harbors on an incremental 1,000 year basis. **Figure 7.2** shows the landscape at 9,000 cal yrsbp. This period postdates the draining of the proglacial lakes held behind the Harbor Hill moraine that ostensibly incised the Hudson Shelf Channel across the Continental Shelf at a lowered sea level stand. The Hudson, Raritan, Hackensack, and possibly Arthur Kill rivers drain across reworked outwash from both the Raritan River and the leading edge of the Harbor Hill Moraine. We are uncertain as to the sequencing of the former Hudson channels shown, thus we show four identifiable channels draining to the

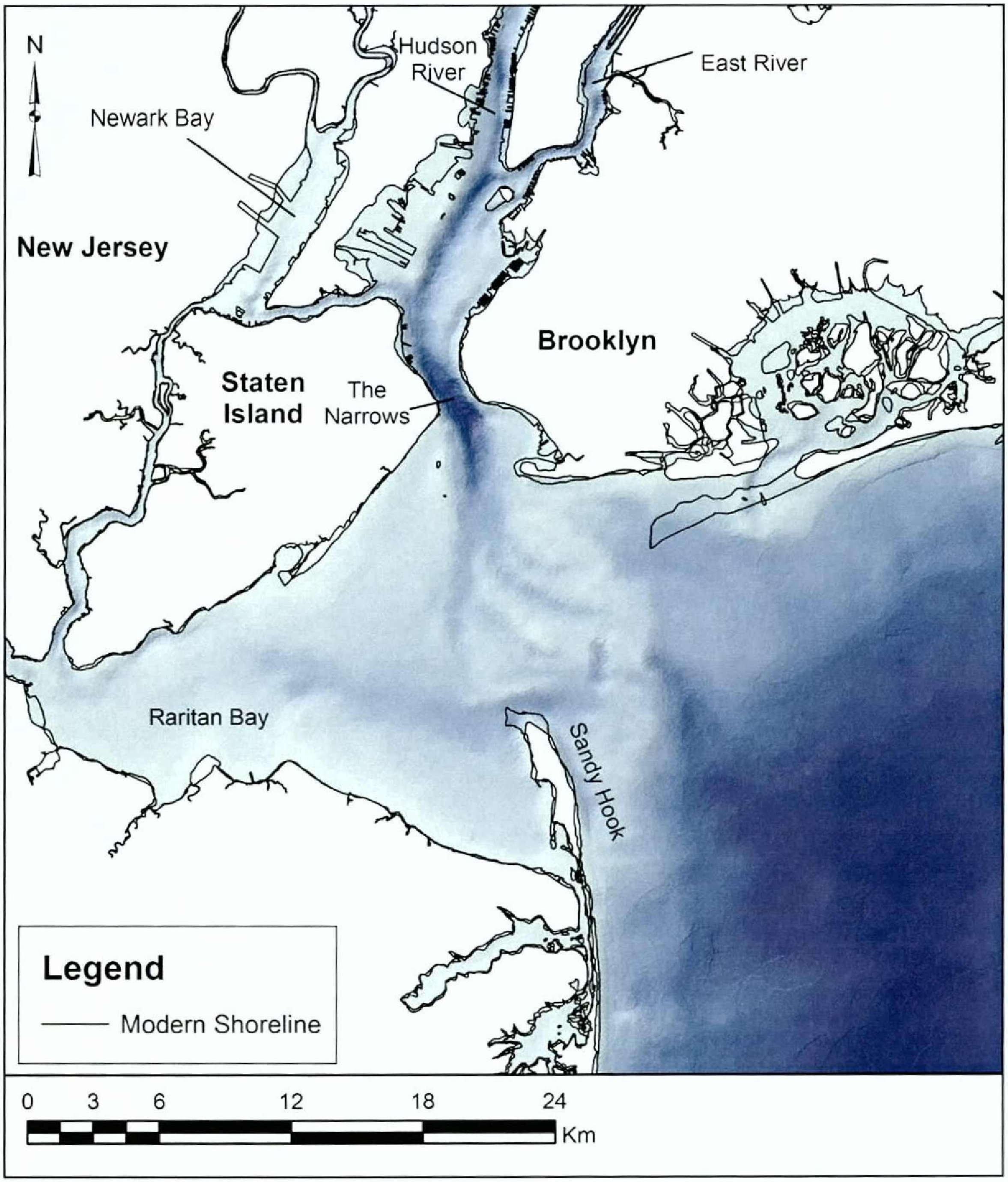


Figure 7.1 1844 Bathymetry of project area showing modern shoreline.

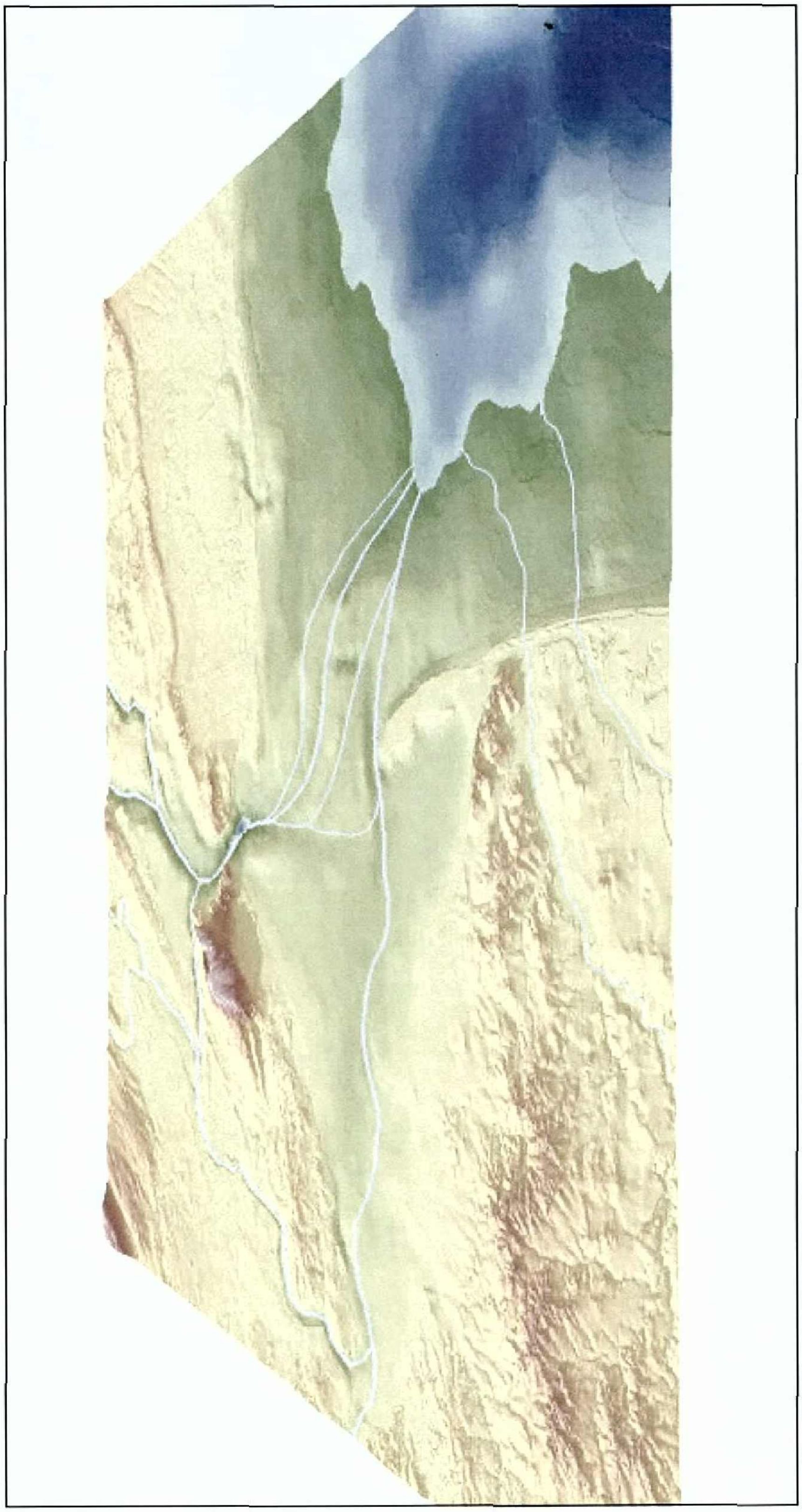


Figure 7.2. Sea level ca 9,000 cal yrsbp (ca. 8,000 B.P.) at -72 ft (22 m), Early Archaic

head of the Hudson Shelf Channel. We are also uncertain as to the configuration of the ancestral Raritan River as earlier work by Gaswirth (1999) and focused on the outflow from high volume glacial outwash channels shows the Raritan to pass beneath the midpoint of Sandy Hook. For ease of presentation we show the Raritan River following the lowest trough across present Raritan Bay to join the Hudson and drain directly into the Hudson Shelf Channel. The Navesink and Shrewsbury rivers drain directly to the contemporaneous shoreline to the east. That said the figure shows the landscape at the time of transition between the Early and Middle Archaic archeological periods. We can think of any Early Archaic prehistoric occupation (11,500 to 9,000 cal yrsbp) as extending further seaward onto the exposed shelf. Inland we know that both Paleo-Indian and Early Archaic archeological sites are found on Staten Island where they possibly overlooked game migration routes along the Raritan River and Arthur Kill. Any evidence for earlier Paleo-Indian occupations extends from the present subaerial land surface to a shoreline deeper and farther to the east. Preservation of sites in the Early Archaic through Paleo-Indian periods might be expected to be deeply buried along the floodplains of the incised river channels. Alluviation of floodplains is expected along all incised river drainages.

By 8,000 cal yrbp (**Figure 7.3**) with sea level at -52 ft (16 m) the landscape is little changed reflecting upon the relative steepness of slopes draining to the Hudson Shelf Channel. River channels further inland follow their earlier courses. This is the height of the Middle Archaic period characterized by small groups of hunter-gatherers utilizing riverine systems. **Figure 7.4**, the relative sea level position at 7,000 cal yrsbp at -35 ft (-11 m) marks the transition between the Middle Archaic and Late Archaic periods. By this time sea level has risen to edge of an apparent outwash fan extending seaward from Raritan Bay and the Narrows. There are clear connections between the main Hudson channel and Long Island Sound through the East River and Hells Gate. We continue to show multiple channels draining the Hudson to the Bight. For the first time however, the remnants of former Hudson channels begin to become evident at the edge of the outwash fan. A deeper embayment extends inland to join the northernmost of the channels across the fan. A second channel to the south exits the fan at a similar reentrant. The interfluve between these channels suggests that the outwash fan predates the opening of the Hudson channel at the Narrows and that flow from the Hudson eroded channels at the edge of the fan. This apparent incision suggests that these channels are the earliest in the sequence as incision points to preceding lower sea level. Thus it would seem that channels across the fan migrated from north to south through time. In terms of the archeology, the now submerged land surface between the modern shoreline and that of 7,000 years ago was potentially occupied by Late Archaic through Paleo-Indian groups.

At this juncture, the rate of relative sea level rise has slowed to an average rate of about 1.5 mm/yr (0.06 in/yr). By 6,000 cal yrsbp (**Figure 7.5**) coastal environment settings begin to stabilize. This marks the initiation of oyster growth as far upriver as Tappan Zee and probably on the Jersey Flats as well as marine water transgressed up the flanks of the main Hudson channel reworking fluvial sand and gravel by wave action. While we still don't clearly understand the direct connection between the Hudson channel and the open water of the Bight, runoff from the Hudson River drainage basin was clearly sufficient to maintain an open channel subject to tidal current. This is the time of onset for increased salinity at Tappan Zee. The Raritan River together with possible flow from Arthur Kill crosses the open

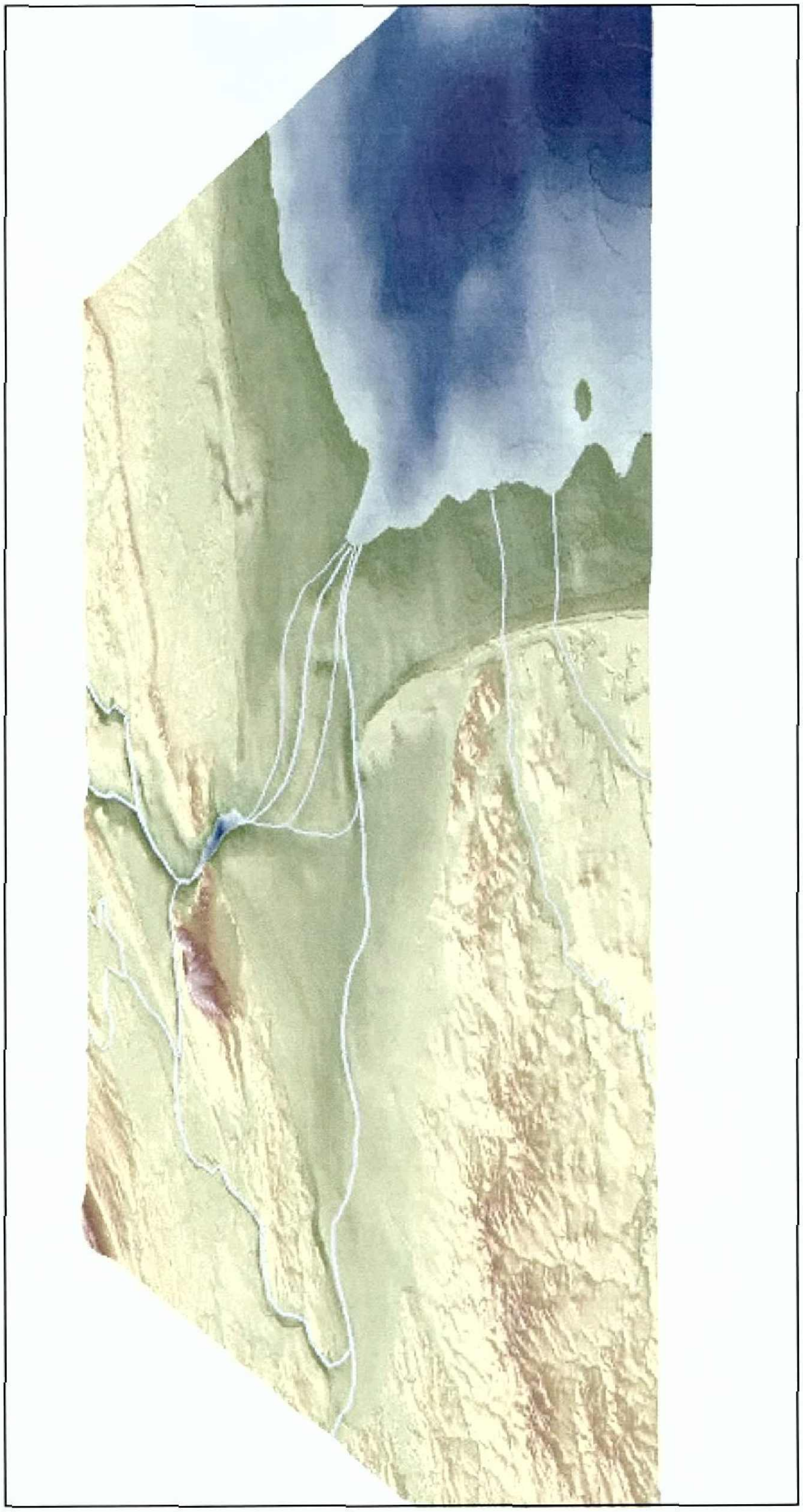


Figure 7.3. Sea level ca 8,000 cal yrsbp (ca. 7,000 B.P.) at -52 ft (16 m), Middle Archaic

Figure 7.4. Sea level ca 7,000 cal yrsbp (ca. 6,000 B.P.) at -35 ft (10.7 m), Middle Archaic to Late Archaic transition

Figure 7.5. Sea level ca 6,000 cal yrsbp (5,200 B.P.) at -30 ft (9 m), Late Archaic

surface of the outwash fan to reach open marine water east of present day Sandy Hook. The Hackensack and Passaic rivers drain directly into the main Hudson channel through Kill Van Kull. There continues to be a direct deep water connection between Long Island Sound and the Hudson via the East River and Hells Gate. Virtually all of present Raritan Bay, the seaward edge of the outwash fan across to present Coney Island, the Jersey Flats, and land surface between Brooklyn and Manhatten were all exposed and open for Late Archaic prehistoric habitation.

At 5,000 cal yrsbp (**Figure 7.6**) as sea level has risen to within 25 ft (7.6 m) of the present mean sea level, the active channels of the Hudson seem to be better defined emptying offshore through two probable channels. The lower portion of the Raritan River now begins to flood and become defined as a narrow estuary although the Raritan River and Arthur Kill still maintain separate channels emptying into this narrow estuary. Farther to the north the Hackensack and Passaic rivers continue to be active emptying into the Hudson via the Kill Van Kull. This sea level stand marks the beginning of a thousand year period of oyster decline in Tappan Zee for yet unknown reasons but possibly related to salinity changes. Since 7,000 cal yrsbp when direct linkage between Long Island Sound and the Hudson appears to have begun, dissimilar tidal regimes apparently begin to interact and influence tidal currents in the upper and lower harbor. Here again the area is open to Late Archaic period use by bands of hunter gatherers utilizing riverine and coastal settings.

Over the succeeding 1000 years, sea level rises to the -20 ft (-6 m) level (**Figure 7.7**). A fully flooded Hudson estuary is recognizable as it spreads out from the confines of the main incised channel and into an expanding estuary in the central portion of present Raritan Bay. Interfluves separating the previous splayed channels of the Hudson across the outwash fan now begin to appear as distinct islands recognized as linear shoals on early pre dredging maps of New York Harbor. One of these islands east of modern Sandy Hook occupies the eastern edge of the outwash fan at the mouth of the outer harbor. This feature is known on navigation charts as the "False Hook". We suspect that another similar island underlies Sandy Hook and acted as a platform for the spit to develop on as longshore sediment was moved northward along the New Jersey barrier island system. There is some indication that the incised channel of the Kill Van Kull begins to flood at this time to reach the mouth of the Hackensack River in the vicinity of present Shooters Island. This period, ca 4,000 cal yrsbp, marks the final years of the Late Archaic period and the probable transition to a form of horticulture to add to the hunting and gathering subsistence pattern. Perhaps concomitantly this also marks a period of oyster demise at Tappan Zee that possibly removed a significant shellfish resource for the prehistoric diet.

By the end of the Late Archaic period at 3,000 cal yrsbp (**Figure 7.8**) and the transition to the more agriculturally based Early Woodland period, sea level stood at -15 ft (-4.6 m). The outer edges of the outwash fan have been inundated by this time leaving narrow linear islands that mark the location of the present Flynn Knoll and Romer Shoal. The present East Bank shoal off Coney Island is exposed above sea level as well. Marine water has extended further into Raritan Bay to begin to define the southern shoreline of Staten Island as the Raritan River drains to the bay through the incised former outwash spillway channel of Arthur Kill. Marine water also flooded the deep Arthur Kill channel. Continued flooding of the Kill Van Kull deepened marine water there and extended further upstream to become

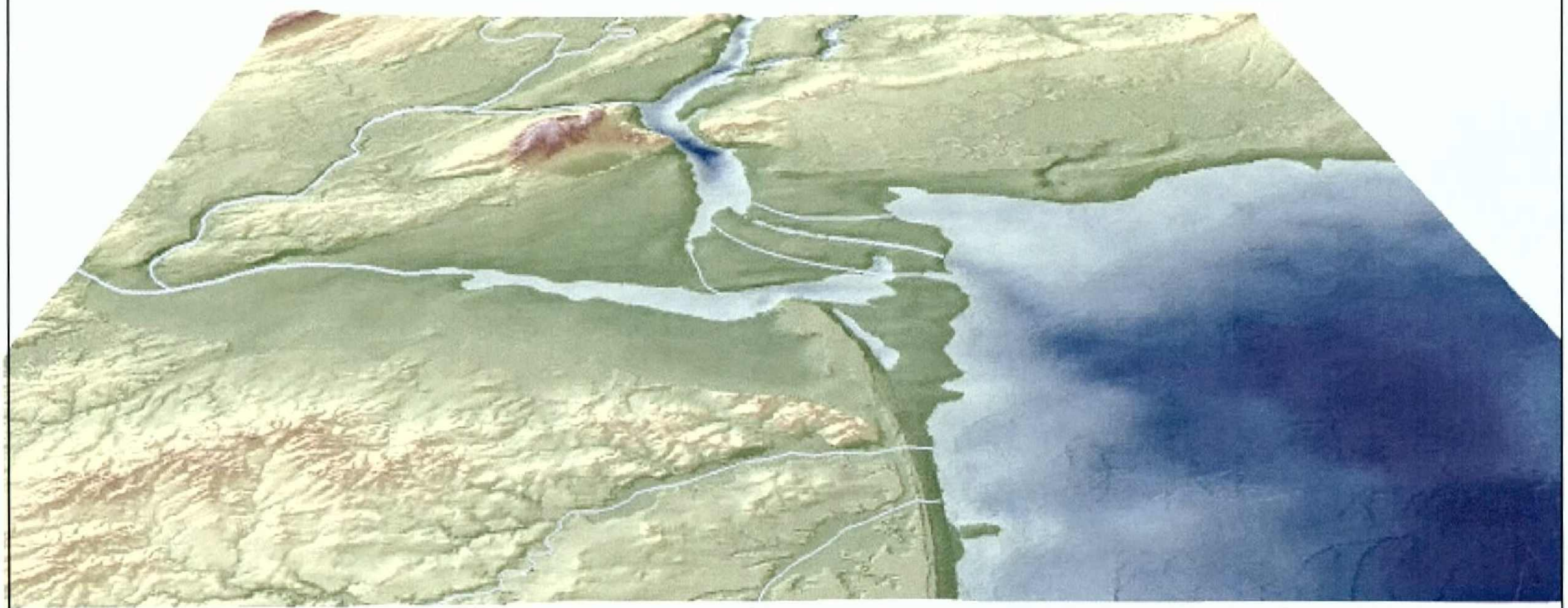


Figure 7.6. Sea level ca 5,000 cal yrsbp (ca. 4,500 B.P.) at -25 ft (7.6 m), Late Archaic

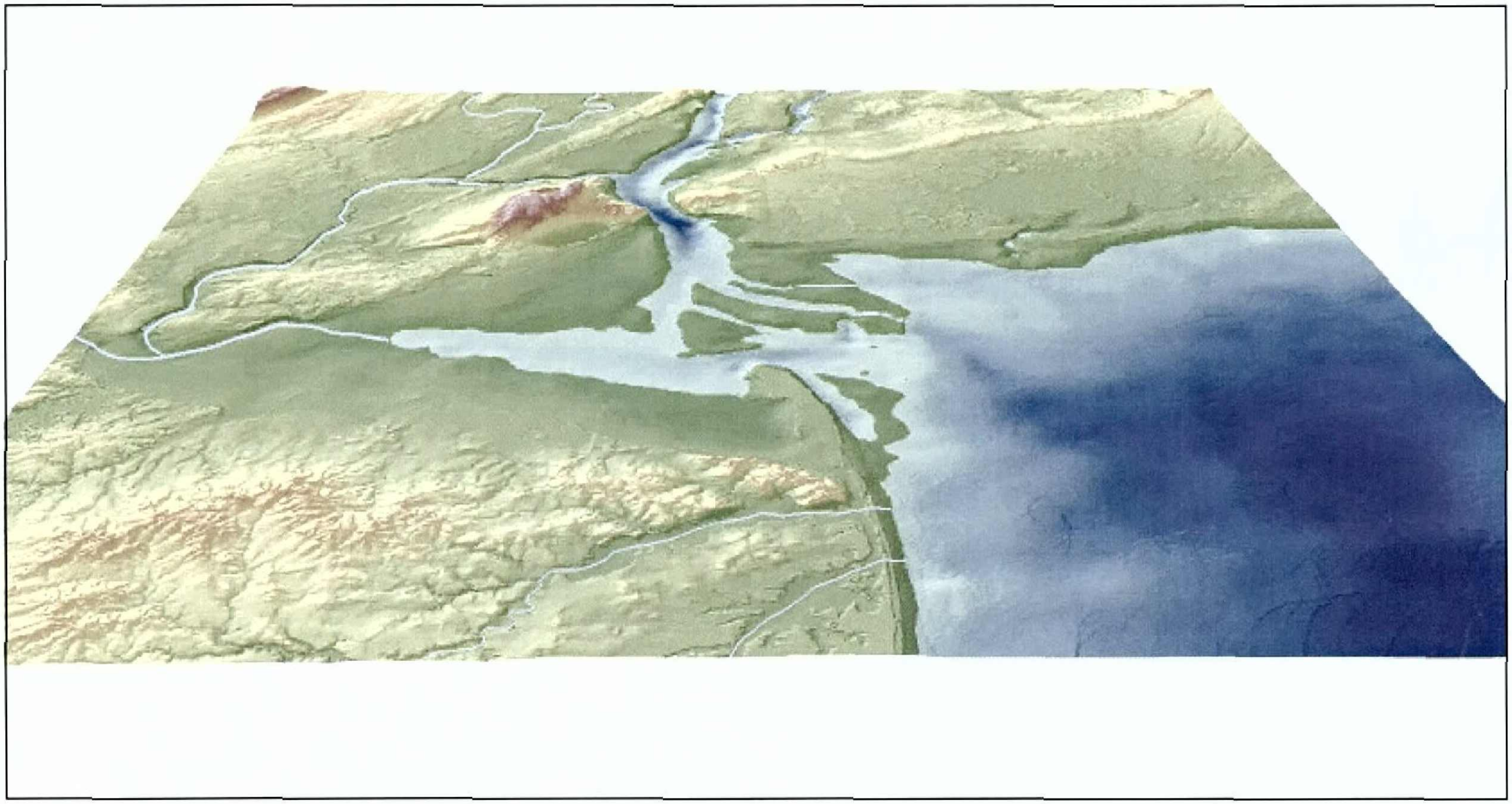


Figure 7.7. Sea level ca 4,000 cal yrsbp (ca. 3,700 B.P.) at -20 ft (6 m), Late Archaic

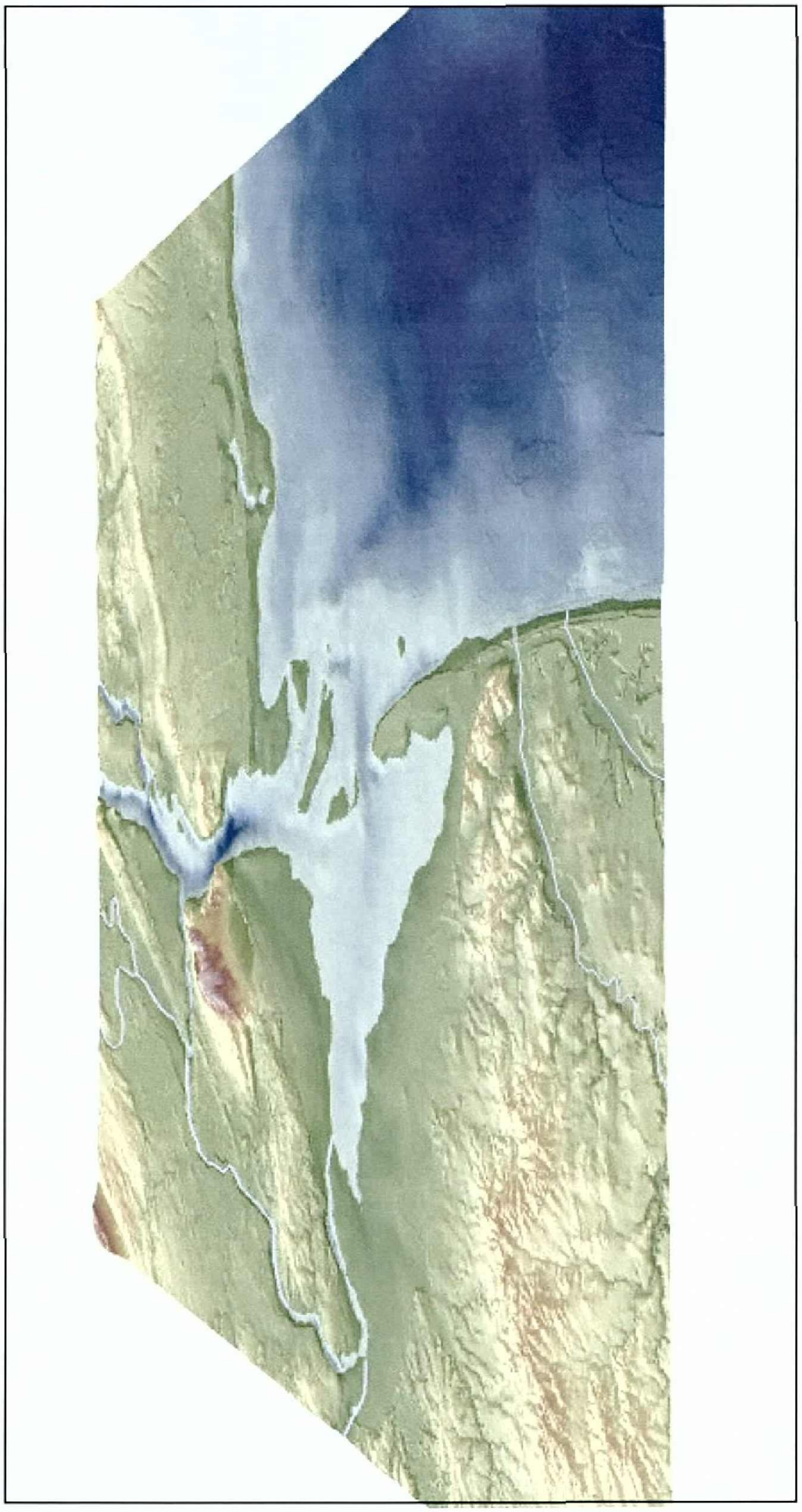


Figure 7.8. Sea level ca 3,000 cal yrsbp (ca. 3,000 B.P.) at -15 ft (4.5 m), Late Archaic to Early Woodland transition

the mouth of the Hackensack River at the southern end of present Newark Bay. The Hudson estuary continues to invade the sloping edges of the main channel in the area of the Upper Harbor and widen the channel. Distinct islands now occupy shoals off Brooklyn near Bay Ridge. Inundation of the Jersey Flats also continues at this time although it is not shown in this image as sedimentation had largely filled this area by 1844, the date of this bathymetry. Archeological occupation of the landscape below modern sea level was available for use by Paleo-Indian through Woodland period groups.

New York harbor begins to attain its near modern configuration by 2,000 cal yrsbp (**Figure 7.9**) when sea level stood at -10 ft (-3 m). Islands are still present at the mouth of the harbor and occupy the locations of the present East Bank and Romer Shoal. The former West Bank shoal (now largely removed by dredging) also appears as a distinct island. GRA investigations of Raritan Bay and the Lower Harbor have identified an apparent "still stand" or low fluctuation along the rising trend of sea level between 3,000 and 2,000 cal yrsbp marked by erosion surfaces at -15 ft (-4.6 m) that define the islands shown on this image. Temporally this period of "still stand" seems to correspond with a long period of oyster "demise" in Tappan Zee that ended fairly abruptly before 2,000 cal yrsbp and near the close of the Early Woodland period when oysters again become prevalent. This correspondence suggests that lower salinity associated with a fall in sea level and retreat of the salt water wedge in the estuary may have occurred. By 2,000 cal yrsbp sea level has back flooded Arthur Kill to its pre dredging depth at its headwaters near present Newark Bay. The Raritan River empties directly into Raritan Bay which is still confined within the earlier and now drowned channel of the river. We suspect that Sandy Hook may have begun its formation at about this time. In the Upper Harbor the Bay Ridge Shoal is present as a distinct island between Manhattan and Brooklyn. The Kill Van Kull continues its expansion of marine water along the lower reach of the Hackensack River and may have extended as far upstream as Newark along its incised channel. We know little about Jamaica Bay at this juncture beyond the 1844 configuration of the Rockaway Beach barrier island. **Figure 7.9** does show back barrier channels leading inland to the present Jamaica Bay marshes as well as shoals on either side of the inlet. The shoreline pattern shown in **Figure 7.9** marks the time of transition from Early Woodland to Middle Woodland periods with an increased dependence on agriculture. Concomitantly, the Tappan Zee studies (Carbotte et al.,2004) point to the return of oysters to the estuary perhaps suggesting more favorable temperature and salinity conditions at the end of the low phase or "still stand" in sea level during the preceding 1,000 years. Coastal settlements were likely prevalent during this period along small drainages entering the harbor areas. Late Archaic through Middle Woodland use of shellfish (oysters) has been documented by Claassen (1995) for Dogan Point north of Tappan Zee. Her summary of similar shell bearing sites along the lower Hudson also points to this subsistence pattern and timing. Thus, shell middens associated with this and earlier shoreline positions may have been common along now submerged tributary drainages.

Throughout the subsequent 1,000 years (**Figure 7.10**) continued rise in sea level now clearly presents a more recognizable landscape, shoreline, and riverine drainage pattern. One thousand years ago, sea level was about 5 ft (1.5 m) lower than the present level. Newark Bay has been flooded to the confluence of the Hackensack and Passaic rivers and connected to the Hudson through Kill Van Kull. The Jersey Flats are now clearly inundated. The

Figure 7.9. Sea level ca 2,000 cal yrsbp (ca. 2,000 B.P.) at -10 ft (3 m), Early to Middle Woodland transition

Figure 7.10. Sea level ca 1,000 cal yrsbp (ca. 1,000 B.P.) at -5 ft (1.5 m)

Arthur Kill channel has been flooded to nearly connect with Kill Van Kull and Newark Bay. The mouth of the Raritan River is now inundated indicating the spread of estuarine conditions upstream from Raritan Bay. The southeastern shore of Staten Island remains exposed. Our studies of Raritan Bay suggest that an earlier barrier island system and spit similar to the modern Great Kills spit may have existed at this time. Most of the islands capping the shoals at the entrance to the harbor are now largely gone with remnants present on the Romer Shoal, the West Bank, and at the entrance to the Rockaway inlet and entrance to Jamaica Bay. Inundation of preexisting lowlands at the present mouth of Jamaica Bay apparently begins at this point marking the onset of conditions conducive to salt marsh growth and development. Archeologically, this image and shoreline configuration corresponds with the transition between Middle Woodland and Late Woodland periods. It closely approximates the conditions present in the few centuries prior to European entry into the area in the 17th century.

Figure 7.11 is a return to the historic condition, albeit ala 1844. In the Upper Harbor the Jersey Flats are fully inundated as are the Bay Ridge shoals. Governors Island, Bedloes Island, and Ellis Island all remain above sea level. Paulus Hook stands out prominently in its former pre land filling configuration at Jersey City. Newark Bay is directly connected to the Upper Harbor and Raritan Bay through Arthur Kill and Kill Van Kull. In the Lower Harbor, Raritan Bay, and the Bight the shoreline and submerged landscape shown by bathymetry are visible in the pre dredged condition. Significant in terms of modern concerns over wetland loss due to sea level rise is the flooding of Jamaica Bay over the preceding 1,000 years and development of extensive salt marshes.

New York Harbor has obviously changed since 1844. Historic sea level has risen approximately 1 ft (30 cm) since the beginning of the 20th century (**Figure 3.3**) and extensive harbor modifications have been made since the harbor was mapped in detail in 1844. **Figure 7.12** displays those changes through a comparison between the 1844 bathymetry and that of 1984.

Relative changes in depth between these two defined periods are shown in shaded colors with reds indicating increasing depth over the period and greens reflecting decreasing depth. Lighter shades denote lesser magnitude changes. Thus, dark reds clearly show areas of historic dredging within the Upper Harbor and the Ambrose channel. Subordinate dredged navigation channels are shown in red in Newark Bay, across the entrance of Raritan Bay (the Raritan Bay East Reach and Chapel Hill channel), and at the entrance to Arthur Kill at Perth Amboy. Other dredged channels link the Navesink and Shrewsbury rivers to Raritan Bay through a back barrier channel at the base of Sandy Hook. Dredged channels define the periphery of Jamaica Bay where they replaced former salt marshes. Lighter shades of pink outline areas of slight deepening and probably the result of historic sea level rise. Nonetheless these areas outline important bottom features. For example, the meandering former channel of the Pleistocene Raritan River (Gaswirth 1999) can be seen outlined in pink along the southern shore of Raritan Bay and leading to Sandy Hook where it drained prior to the deposition of the spit. Similarly, greens show areas of decreasing depth as in the case of shoaling or other deposition. The deep greens shown in the upper Hudson and East rivers are areas of no data, while those offshore at the head of the Hudson Shelf Channel represent areas of historic dumping. Green around Breezy Point at the entrance to Rockaway Inlet and Jamaica Bay indicates shoaling caused by

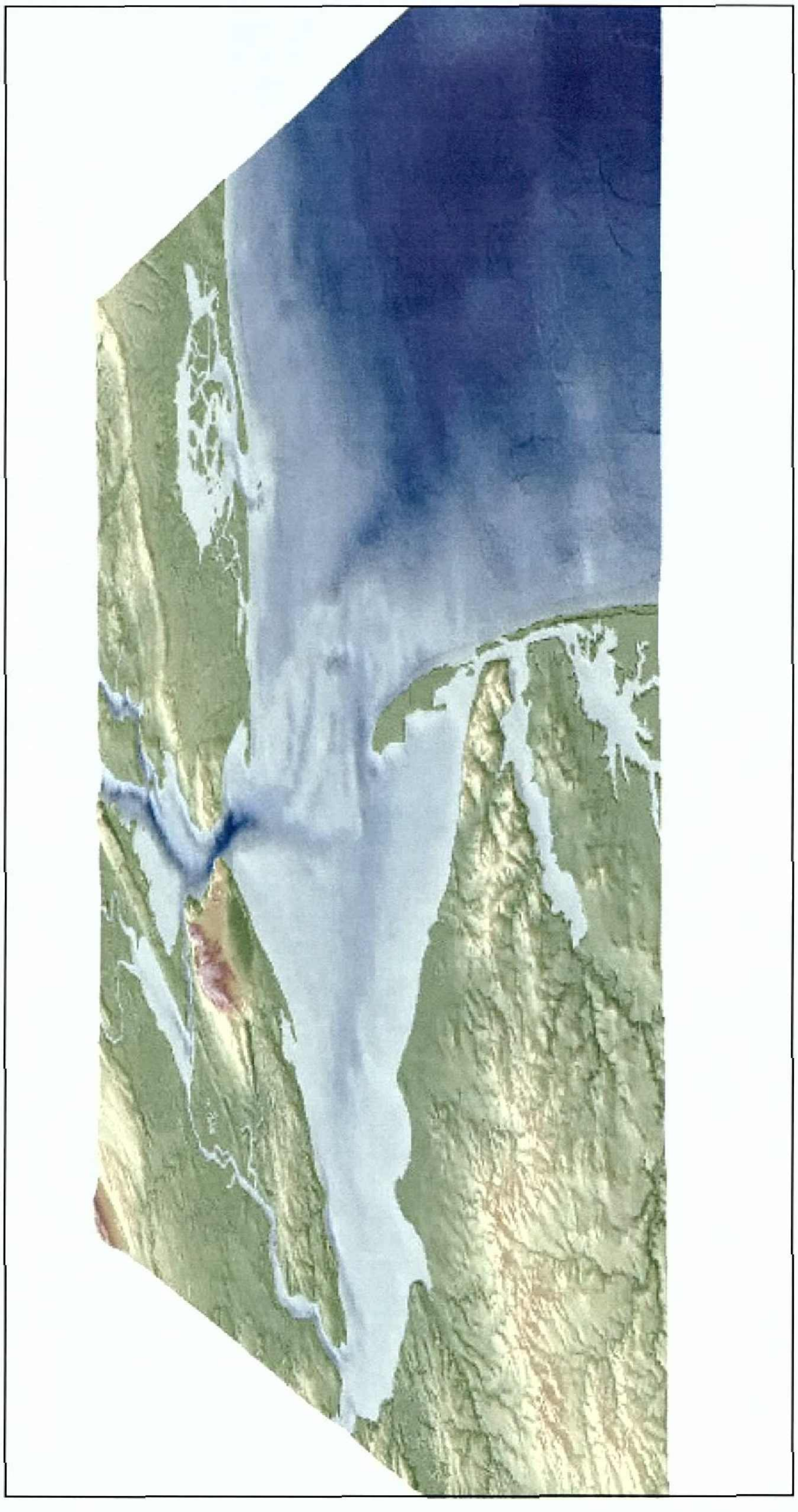


Figure 7.11. 1844 sea level and shoreline model

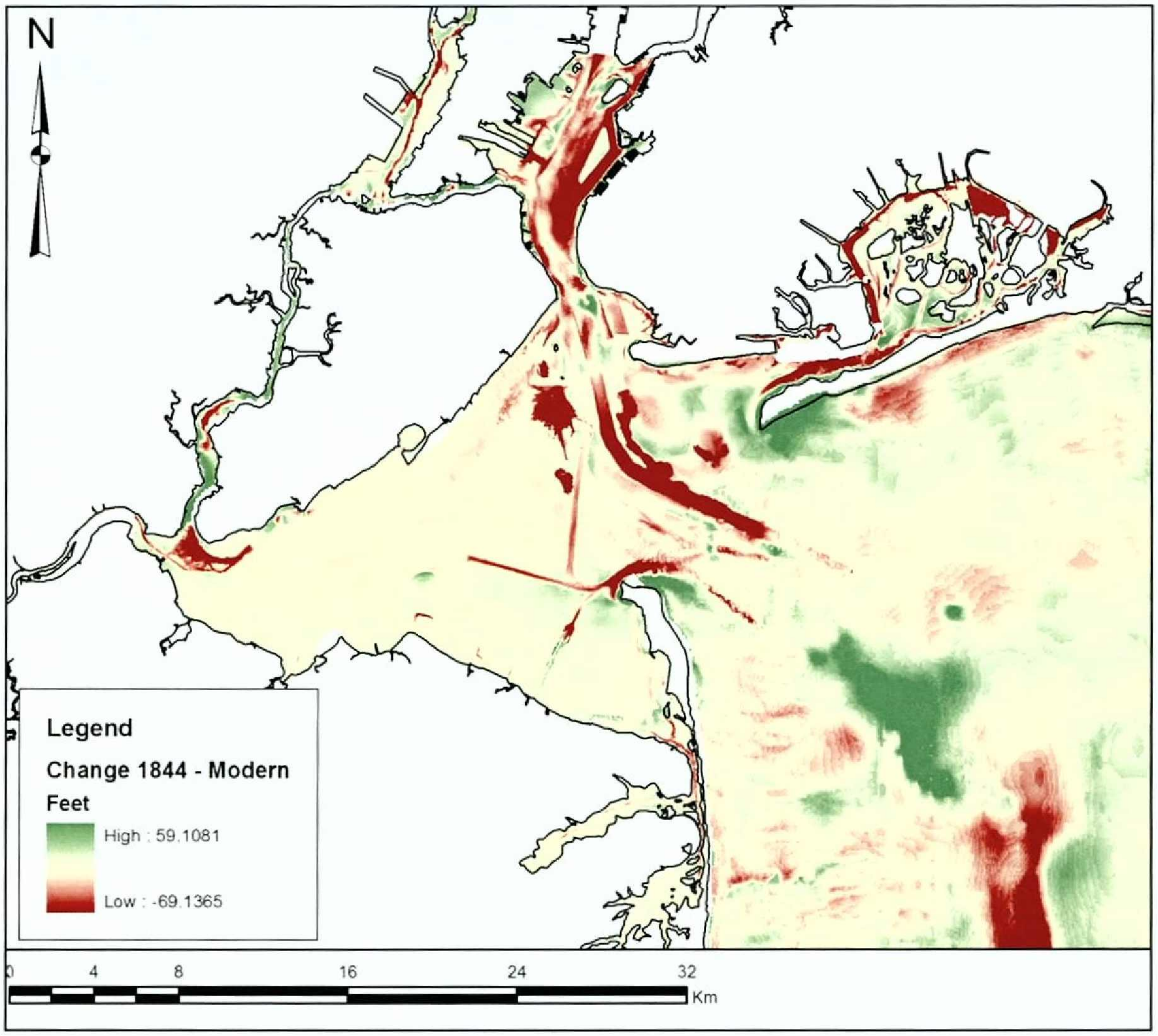


Figure 7.12. Historic bathymetric change 1844-1985

westward longshore transport of sediment along the south shore of Long Island while red indicates maintenance dredging of the Rockaway Inlet channel.

The model we have developed here is a static one. For example we know that coastal sedimentary processes are highly dynamic and capable of distributing sediment in complex ways. We have chosen a simple method as a starting point for understanding the sea level transgression history for New York Harbor. The data presented in this section outline as succinctly as we can at this juncture the types of coastal environmental changes we can reconstruct using our developing knowledge of the relative sea level history.

Chapter 8

THE ARCHEOLOGICAL GEOGRAPHY OF HUMAN SETTLEMENT AND SITE PRESERVATION

In general prehistoric deposits are sparsely distributed within both naturally deposited sediments and their weathered counterparts or soil as large segments of the pristine landscape have been removed and new landforms constructed. As this study shows, even submerged surfaces have been either overridden or exhumed, with reworked materials often capping deeply scoured substrate. Next, because of the scale of historic activity in the area, surficial materials of the 19th, 20th, and 21st centuries reflect human impacts on the landscape which, over the past 100-150 years have caused more widespread changes to landform relations than the natural events in the last ten millennia since the earliest human occupations. Accordingly, much of the regional sediment cover, both terrestrial and submerged, reflects the effects of industrial-age and subsequent human activity on the near shore environment. To date, interpret, and assess the cultural resource potential of these deposits it is necessary to understand the chronologies and patterns of occupation in along the shifting margins of New York Harbor.

Prehistory. There is minimal evidence for prehistoric activity in areas that are currently submerged, although there are limited efforts underway to reconstruct potential site environments on the continental shelf (Merwin, 2002). However, data to date are questionable and testing programs are neither extensive nor systematic. There is no significant submerged site database for prehistoric sites in the New York Harbor area.

The earliest accepted occupations of the present New York Harbor area would have begun during the Paleo-Indian cultural period, ca. 11,500-8,000 years B.P. (13,390-8,890 cal yrbp). As discussed earlier, relative sea level was at least 50 feet to 120 feet below present throughout the period (**Figure 2.2**) and the habitable Coastal Plain land surface extended from 24 to 60 miles to the edge of the continental shelf (Bloom, 1983a: 220-222; Emery and Edwards, 1966; Stright, 1986: 347-350).

Mammoth and mastodon finds on the continental shelf and within the Hudson River channel (Fisher, 1955; Whitmore *et al.*, 1967) indicate that both of these large mammals were sufficiently abundant to have permitted focal hunting adaptations. Recent Paleo-Indian site excavations in the Northeast suggest a more varied subsistence, however (Adovasio *et al.*, 1977, 1978; Gardner, 1977, 1983; Funk and Steadman, 1994; McNett *et al.*, 1985). Exploitation of marine fish and shellfish in settings now submerged beneath the harbor would not be surprising given the broad-spectrum diet of plants, birds, small mammals, and freshwater fish now suggested for Paleo-Indian in the Northeast.

Early prehistoric occupation begins with a series of sites with diagnostic artifacts from either the Late Paleo-Indian or Early Archaic (10,000-8,000 B.P. [11,600-8890 cal yrbp]) cultural periods. The most unique landscape preserving (relatively) extensive evidence for these earliest prehistoric periods is the western shore of Staten Island (Kraft, 1977a, 1977b; Ritchie and Funk, 1971). Intact landforms survive because to date they have largely escaped development. At Port Mobil, fluted points, end and side scrapers, and unifacial tools were among over 51 lithic artifacts recovered from a sandy slope between 20 and 40 feet (6 and 12 meters) above sea level. Fluted points were also found on Charlestown Beach south of Port Mobil. Projectile points classified as Kirk, Kanawha, LeCroy, and Stanly have been recovered from the Hollowell and Ward's Point sites at the island's southwestern tip of the Island. The Old Place site near the crossing of the Goethals Bridge appears to be primarily a Middle Archaic (8,000-6,000 B.P.[8890-6900 cal yrbp]) through Late Archaic (6,000-3,000 B.P.[6900-3150 cal yrbp]) encampment, although a radiocarbon date of 7,260±140 B.P., 8106 cal yrbp (I-4070) was obtained on hearth charcoal associated with Stanly, LeCroy, and Kirk points.

Early prehistoric sites represent only a very small portion of settlement networks, which extended across Harbor Region surfaces, subsequently by sea level rise. The rate of transgression slowed at approximately 7,000 cal yrsbp (Fairbanks, 1989, Peltier, 2001, Fleming et al. 1998). This timing accounts for the abundance of Late Archaic sites in settings that are now at or slightly below present shoreline positions. Of five inundated sites along shores or tidal stream banks on Long Island reported by Stright (1990), all are Late Archaic or Woodland period encampments.

The magnitude of landscape change diminished significantly after the Middle Holocene. Between 5000-3000 B.P., as this study has confirmed, near shore environments began to stabilize. Exploitation of shellfish and other marine resources was a definite specialization among Late Archaic hunter-gatherers of coastal New York and New Jersey (Brennan, 1974; Kraft and Mounier, 1982; Ritchie, 1980: 165-167). Although Brennan (1977) argued for antecedents extending back to the Early Archaic, his only evidence was the date of 6,950±100 B.P., 7786 cal yrbp (L-1381) from the deepest level of the Dogan Point shell midden (Little, 1995). Dogan Point did have a small Middle Archaic component, as evidenced by both the radiocarbon chronology and presence of Neville, Stark, and other large side-notched projectile points (Claassen, 1995a). The main shellfish gathering period, however, dates from 5,900-4,400 B.P., 6730-5070 cal yrbp (Claassen, 1995b: 131) and thus correlates with other shell midden sites in the Lower Hudson such as the Twombly Landing site below the Palisades near Edgewater, New Jersey (Brennan, 1968).

While site densities increase variability in settlement geography and site structure While site densities increase variability in from the Late Archaic onward. As noted by Funk (1991:51), shell matrix and shell bearing sites on Martha's Vineyard (Ritchie, 1969), Nantucket (Pretola and Little, 1988), Fishers Island (Funk and Pfeiffer, 1988), and Long Island (Ritchie, 1980: 164-178; Stright, 1990: 442-443) are all younger than 4,500 years. Older shell middens may once have existed, however, along coastlines that are now beneath the sea. In addition to the more ephemeral hunting camps of the earlier cultural periods, this type of prehistoric culture resource is likely to be preserved in several contexts within the Harbor navigation channels.

The transition between the Archaic and Woodland periods in the Northeast is marked by the presence of ceramics and, in many areas, by the first remains of cultivated plants. The Woodland period is generally divided into three stages, Early (3,000-2,000 B.P. [3145-1982 cal yrbp]), Middle (2,000-1,000 B.P.[1982-902 cal yrbp]), and Late (1,000 B.P. to European contact). In coastal New York, however, the Windsor and East River "traditions" were defined by Smith (1950, 1980) as distinct ethnic groups manifested in several contemporaneous phases.

The North Beach phase of the Windsor tradition is contemporaneous with shell-bearing Terminal Archaic sites of the Orient phase. In several sites on Long Island, Windsor ceramics have been found associated with steatite vessels and Orient fishtail points. After the Middle Woodland the Clearview phase of the Windsor tradition is succeeded by the Late Woodland Sebonac phase. Sebonac sites are most common in Connecticut, although the phase is named for a site on eastern Long Island excavated by Harrington (1924).

Later Windsor tradition sites coincide with the earliest, Bowmans Brook phase of the East River tradition on Staten Island (Smith 1950, 1980). Bowmans Brook begins ca. A.D. 1000 and its geographic range eventually included western Long Island, Manhattan, and the lower Hudson River Valley (Ritchie, 1980: 268-270). The type site on the northwestern shore of Staten Island was investigated by Skinner in 1906 (Skinner, 1909: 5-9; Smith, 1950,: 176-177).

Larger features were characteristic of Woodland sites generally. Pits filled with shell and other refuse ranged from four to six feet in diameter and from three to six feet in depth. The pottery is either stamped or incised and tempered with grit or occasionally shell.

The Late Woodland to Euroamerican transition is registered locally by the Clasons Point phase of the East River tradition (ca. A.D. 1300). The type site on the north side of the East River in the Bronx was excavated by Skinner in 1918 (Skinner, 1919: 75-124; Smith, 1950: 168-169). The few known village sites are approximately an acre in size and are located on higher landforms well above any tidal submergence (Ritchie, 1980: 270-272). The pottery is typically shell tempered but there is a wide range of both vessel forms and surface decoration. European trade goods have been found in the upper levels of some Clasons Point phase sites.

History of the Harbor and the Navigation Channel Network. Historic maps shed light on the nature of the Harbor transformation over the past four centuries since Euroamerican colonization. **Figure 8.1** illustrates the geography of New York Harbor during the mid-19th century. That shoreline was somewhat, but not substantially different from that encountered by Florentine navigator Giovanni da Verrazano who sailed between the straits that now bear his name in 1524. Locally Verrazano's voyage initiated European exploration that culminated in the colonization of Upper New York Harbor. Trade goods from this period have been found in the upper levels of some Clasons Point phase sites (Ritchie, 1980: 270-272) and the native inhabitants are known to have been Algonquin relatives of the Delaware (Homberger, 1994: 16). They sold the island they called Manahattan to the Dutch for trinkets in 1626 and moved west of the Bronx River.

Dutch settlement was first localized near the tip of Manhattan island, commanding naval access to both the Hudson River and the East River (Homberger, 1994: 20). By 1639, Dutch plantations thinly lined the East River and three small villages on Long Island were combined to form Breukelen in 1642 (Homberger, 1994: 30). Buildings on the East River waterfront were constructed on an unstable and muddy shoreline until after Peter Stuyvesant became Director-General in 1647 (Homberger, 1994: 32); there is considerable potential for early historic as well as prehistoric archeological contexts beneath the present piers and seawalls (Cantwell and deZerega Wall 2001).

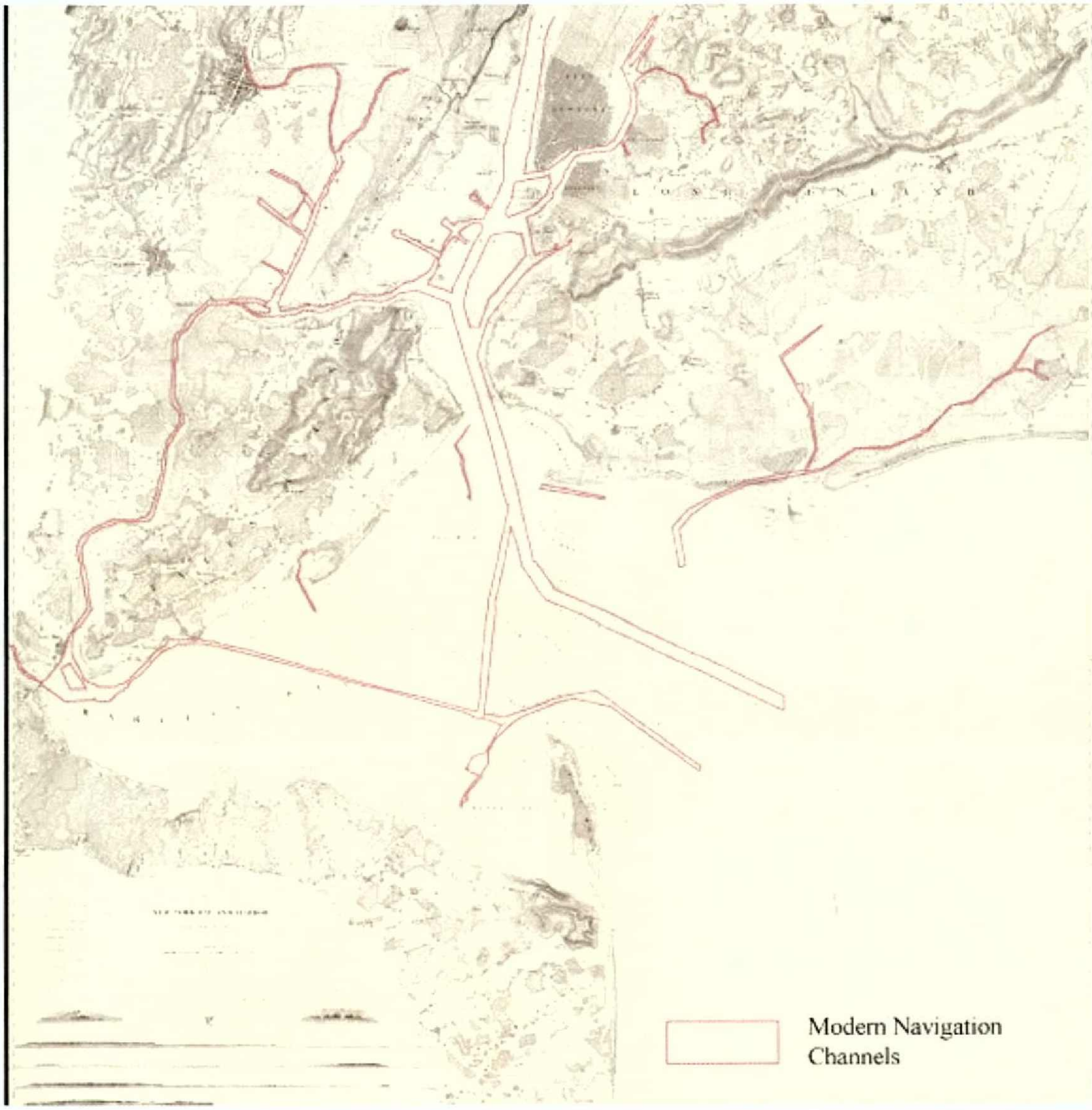


Figure 8.1. Contemporary dredging since 1844

Dutch commercial activity and settlement of the Upper Bay expanded steadily because of the virtually land-locked harborage, well protected from ocean gales, that was afforded by the Narrows between Brooklyn and Staten Island. At its most constricted point, this passage is less than three-quarters of a mile wide, where it is presently spanned by the Verrazano-Narrows Bridge (Water Resources Support Center, 1988). Historically, this constriction does not appear to have changed significantly **(Figure 8.2)**. The natural geography of the New York and New Jersey Harbor region nonetheless posed certain challenges for early maritime commerce. Unlike the naturally deep harbors of Boston, Quebec and Norfolk, which could accommodate any vessel afloat during the eighteenth and early nineteenth centuries, the lower portion of New York Harbor had a controlling depth of 21 feet at low tide and the upper bay contained numerous areas of shoals and treacherous currents. Prior to the first dredging of the harbor, larger vessels could approach New York only through the Main Ship Channel, which required navigation of a narrow passage between Sandy Hook and a series of shoals that blocked most of the Lower Bay (Albion, 1939; Newberry, 1978). Smaller vessels could utilize the Swash, "Fourteen Feet," or East (later known as Ambrose, see below) channels. Only isolated channels in Upper Bay (Buttermilk Channel) were considerably more hospitable for commerce. In 1837, Lieutenant R. T. Gedney conducted a Coast Survey study that charted an outer alternative channel that still bears his name.

Public funding for harbor improvemenet was initiated with a New York City municipal appropriation of $13,861 in 1851. The effort was designed to remove rocks and reefs in the Hells Gate entrance to the East River. This effort was supplemented two years later by a federal appropriation of $20,000 (Albion 1939:28). However, most efforts at Harbor improvement during this period were privately funded and poorly coordinated. The dredging of underwater property was under the jurisdiction of the New York City Street Commissioner and the unregulated construction of piers and wharfs was found to be a hindrance to the economic potential of the harbor (Homans, 1859; New York State Harbor Encroachment Commission, 1864). In 1870, the city and state legislature established the New York City Department of Docks, appointing General George McClellan of Civil War fame to serve as engineer-in-chief. Since all of the new wharfs and piers would ultimately be owned by the municipality, the Department of Docks represents the first sustained attempt at municipal ownership and administration of port facilities in the United States. In 1921 this agency was renamed the Division of Surveys and Dredging. McClellan's first task was to invite public proposals and comment with a view of developing a Master Plan for piers, wharfs, and seawalls around the island of Manhattan. The subsequent processes of seawall construction and landfill reconfigured the geography of Manhattan Island to its present shape. It is now thirty percent larger than the landform initially encountered by the first Dutch settlers.

McClellan's plan called for the excavation of some six hundred soil borings around the entire perimeter of Manhattan. As described in the 1871 Annual Report, these borings were performed by various techniques, including: hand rod, Woodcock, and artesian well boring machine (Betts, 1997; New York City Department of Docks, 1872). At least some of the logs from these borings are apparently still held in the New York City Municipal Archives.

Ultimately Harbor maintenance and enhancement was bolstered by federal assistance. Municipal and federal efforts worked in conjunction with each other. In 1872 Congress commissioned a survey of Buttermilk Channel,

Figure 8.2. Dutch settlement on the Hudson 1639.

Figure 8.3. Governors Island and the Buttermilk Channel 1844.

the narrow passage between Governors's Island and the City of Brooklyn **(Figure 8.3).** The survey located a large shoal with a minimum depth of 9.5 feet at the junction with the East River. This shoal was in the track of navigation, making it unsafe to maneuver large vessels in the vicinity of the Brooklyn wharves. The proposed dredging was conducted from October 1 through November 3, 1884 (U.S. Bureau of Engineers, 1885). The shoal was removed to a depth of 24 to 26 feet below mean low water in a zone extending 850 feet from the wharves. The estimated cost of this work was $210,000. By 1976 Buttermilk Channel had been enlarged to a width of 1,000 feet and a depth of 34 to 40 feet below mean low water (Hammon, 1976).

On July 5, 1884 a congressional appropriation of $200,000 facilitated a survey for deepening Gedney's Channel, marking the first attempt to improve a navigation channel in the Lower Bay (Edwards, 1893; U.S. Engineer Bureau, 1886). That project was the first large-scale dredging project in New York Harbor, and formed the basis for subsequent channel maintenance programs in support of commercial boat traffic. Perhaps the key long term component of the appropriation was funding of a detailed survey of the lower New York Bay. Detailed investigations included current and tide records, borings to a depth of three feet below bottom, and detailed bathymetric maps showing the location of the -24 foot contour in 1835, 1855, 1881, and 1884. Despite dramatic changes in the configuration and location of several landforms, for example the Sandy Hook peninsula, the bottom profile had changed very little between 1835 and 1884. The survey also found that in 1884 the minimum depth in Gedney's Channel at mean low tide was 22.3 feet. The mean high tide rose to 4.8 feet, giving a controlling depth at high tide of 27.1 feet. The report noted that the largest steamships running out of New York drew 28 feet when fully loaded, but few vessels were loaded to capacity. The 1886 Engineers Report also discussed options for creating a safe navigable channel along or near Spuyten Duyvil Creek between Manhattan and the Bronx. This project would not come to fruition until the completion of the Harlem River Ship Canal in 1923.

The Gedney's Channel dredging contract was awarded to Elijah Brainard at a cost of 54 cents per cubic yard. The program commenced on September 26th, 1885, and by the beginning of November, 1886 303,869 cubic yards had been dredged from the channel (Edwards, 1893). On the basis of the Engineer's Report (U.S. Engineer Bureau, 1886: 737-739) it is possible to reconstruct the stratigraphic sequence encountered during the dredging. The dredging first encountered a bed of live mussels ranging from six to ten inches thick. Some of the mussels were quite large and large quantities of dead shells and a very fine powder of pulverized mussel shells was also encountered. The mussel layer was underlain by a stratum of "pea gravel" to which the mussels often adhered. Beneath the upper stratum of pea gravel the dredging encountered interbedded layers of fine sand and water-worn quartz gravel. The gravel ranged in size from "the size of a pea to the size of a goose egg." About 70% of the gravel was classified as "pea gravel." The dredging also encountered a few large pieces of water-worn sandstone, the largest of which measured 13 by 8 by 5 inches. Finally, at the western end of the channel the dredging encountered a stratum of very compact "blue clay" at 33 to 35 feet beneath mean low water. The report notes that this clay is "evidently a very old formation." By 1889 the dredging program had resulted in an unobstructed navigable channel with a 30-foot controlling depth at mean low water and a depth of 34.8 feet at high tide.

Increased harbor traffic coupled with the large size of vessels that utilized the Harbor resulted in additional harbor development. On June 3, 1896 Congress authorized a survey with a view to providing a 35-foot channel at mean low water from the Narrows to the sea. It was recommended that the East Channel be dredged to maintain a channel of 40-foot depth and 2,000-foot width. The funds were appropriated by the River and Harbor act of 1899. The East Channel was renamed by an Act of Congress in 1900 to "Ambrose Channel," in honor of Mr. John Wolf Ambrose, who had worked diligently for the improvement of New York Harbor. The channel continues officially to be known by this name (U.S. Engineer Bureau, 1939). The project was completed in 1914, providing a mean low water controlling depth of 40 feet and a width of 2,000 feet. A total of approximately 66,000,000 cubic yards of material was removed under the project.

The Federal Rivers and Harbors Act gave the U.S. Engineers Bureau (now the U.S. Army Corps of Engineers) control over all navigable waters in the United States in 1888. The Bureau was given the charge to establish bulkhead and pier head lines. With the 1898 consolidation of Greater New York under a single municipal government, the Department of Docks also became responsible for city-owned ferries and ferry terminals and was renamed the Department of Docks and Ferries (Betts, 1997; Hoag, 1911). Meanwhile, the development of the New Jersey portion of the harbor lagged, in part because of the lack of a comprehensive, cooperative approach to waterfront use. A 1914 report by the New Jersey Harbor Commission, entitled "New Jersey's Relation to the Port of New York" noted that New York City's waterfront development had cost more than one-hundred million dollars and that waterfront development produced annual revenue in excess of four and one-half million dollars. The report recommended creation of a permanent New Jersey Harbor Commission with statutory authority to regulate all waterfront development in the state.

Following World War I, it was becoming increasingly apparent that the long-standing New York-New Jersey animosity was hindering unified development of New York Harbor. In 1921 the Port of New York Authority was created as the first interstate agency permitting compacts between states. It assumed responsibility for Harbor maintenance since the port included portions of New Jersey and New York. In 1972 the name of the agency was changed to the Port Authority of New York and New Jersey (Port of New York Authority, 1946; Port Authority of New York and New Jersey, 1996).

As dredging of the recently renamed Ambrose Channel was nearing completion, the River and Harbor Act of March 4, 1913, authorized a survey for a channel 40 feet deep and 2,000 feet wide as an extension of Ambrose Channel through Upper Bay. The funds for the dredging were appropriated by the Act of August 8, 1917. Commonly known as the Anchorage Channel, this project was completed in 1929. A similar large-scale project was initiated in the Stapleton vicinity, located above the Narrows on the northeast shore of Staten Island. This area offered a substantially undeveloped stretch of waterfront approximately 6,300 feet in length (U.S. Engineer Bureau 1939). Piers over 1,000 feet long could be constructed in this area, where the natural water depth at the pier head line exceeded 40 feet. By 1939, most of the navigation channels had already been covered by maintenance programs. Only the Port Elizabeth, Port Newark, and Port Jersey areas remained relatively undeveloped.

The most recent maintenance efforts have included the removal of drift and debris from shorelines of the entire New York Harbor (Hammon, 1976; U.S. Army Corps of Engineers, 1971). The New York Harbor Collection and Removal of Drift Project ultimately recommended the removal or repair of 2,230 timber and steel vessels, 100 dilapidated piers, wharves, and miscellaneous shore structures, and 23.6 million cubic feet of timber drift and debris (Hammons, 1976: 32). One of the highest concentrations of derelict vessels was located in the Port Jersey Channel. The drift removal project was initiated in 1976, in conjunction with development of Liberty State Park in Jersey City.

The sequence of historic modifications to New York Harbor's shoreline and bathymetry is shown in **Figure 8.4** These projections were generated from historic maps that were assembled, digitized, and analyzed using geo-referenced GIS data sets. The 1844 shoreline **(Figure 8.5)** has been superposed on the existing coastal contours of the Upper Bay. The projection shows that the harbor and near shore margins effectively conformed to the boundaries of the natural landscape. Following the mid-nineteenth century, as barge and boat traffic increased shipping facilities were built up and filling activities resulted in coastal modifications extended the once natural landforms bay ward, especially in Brooklyn and Manhattan. The most significant expansions to the shipping facilities were engineered along the former isthmus between the Lower Hackensack/Newark Bay and Hudson Rivers. This is the landform bounded by the Arthur Kill Channel, Newark Bay, and Elizabeth channels to the west; the Kill Van Kull to the south; and most dramatically by the Port Jersey and Claremont Channels to the east. The east-west reach of the peninsula was nearly doubled by landfill attendant to commercial and port expansion.

Figure 8.5 shows the steep flanks of the incised Hudson River channel. The difference between the early and contemporary bathymetry of the harbor is a function of accelerated rates of infilling initiated by near shore sedimentation due to consistent dredging and channel widening. **Figure 7.12** underscores the changes to bathymetry for the Upper and Lower Bay since 1844. This GIS based plot establishes a framework for examining the depth of dredging along the channels over the past 150 years. The contemporary plot verifies the long-term maintenance of the Ambrose channel, the main transport artery into the metropolitan area. Accordingly, the deepest portions of this channel extend from –24 to –32 feet. Most navigation channels are at least –10 to –13 feet in depth. **Figure 7.12** shows that, on average, over the past 150 years Ambrose channel has undergone a net deepening of 5-12 feet, largely in the southeastern approach to New York City and along the key traffic lines north of the Narrows and into the approach to Manhattan. Deepening in the latter area is not confined to present channels but to surrounding portions of the bay floor as well. In general, the result of long term channel maintenance across the New York Harbor has resulted in lowering of the bay floor by an average of 3-4 feet.

The bathymetry of the Lower Bay was not greatly modified during the mid-20th century. **Figure 8.4** shows that the Ambrose channel was substantially widened to the east and significantly deepened in its north end. However, across the greater reach of Raritan Bay floor depths remained intact at 5-13 feet. It is critical to note, however, that sustained and scheduled dredging activities, especially over the past 50 years were directed at maintenance (and not necessarily deepening and widening) of channels for navigation purposes. Thus, the GIS maps do not offer indications of the frequency of dredging but provide a time-transgressive picture of net changes to the

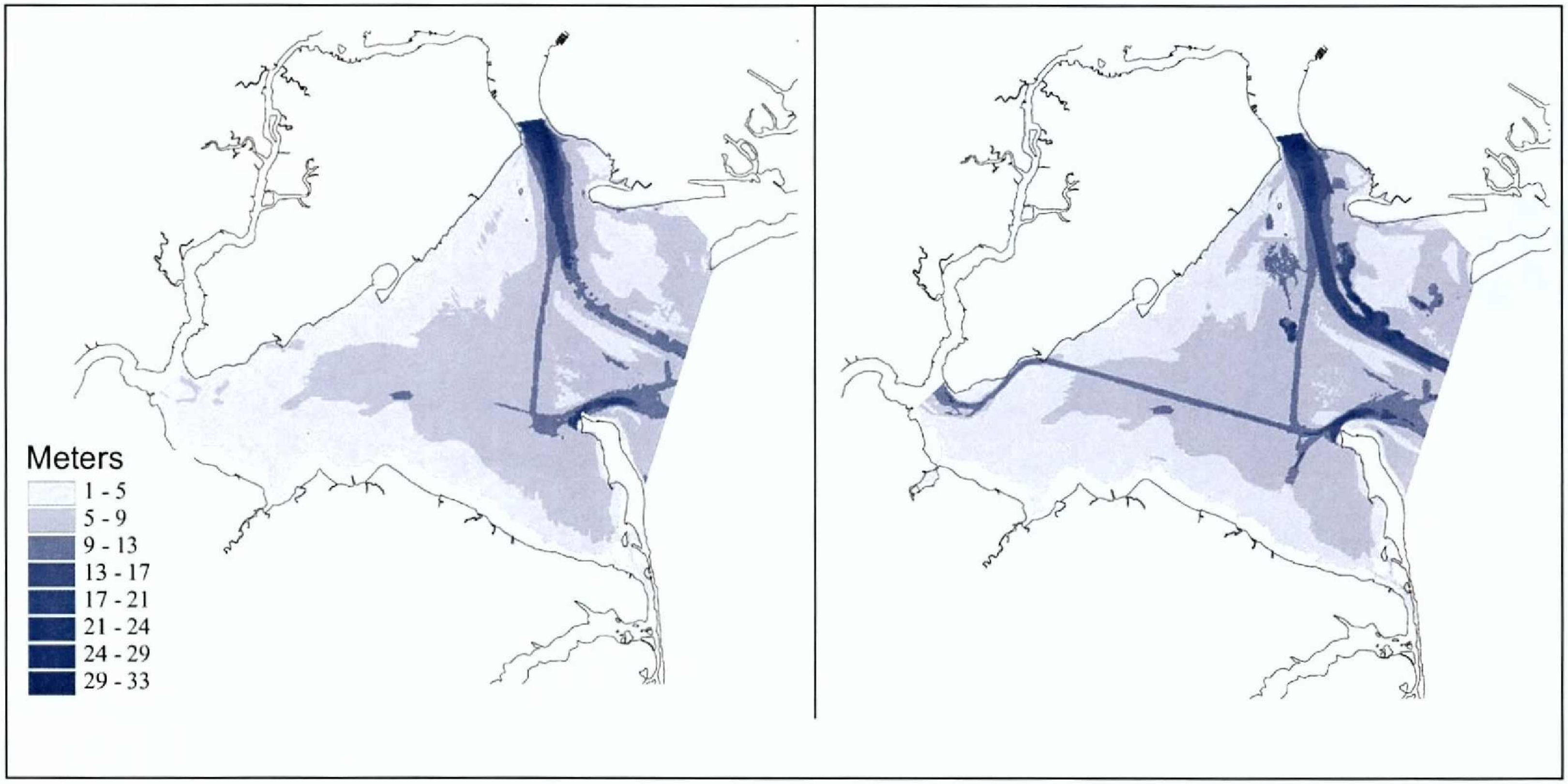


Figure 8.4. Historic dredging 1934 to 1980.

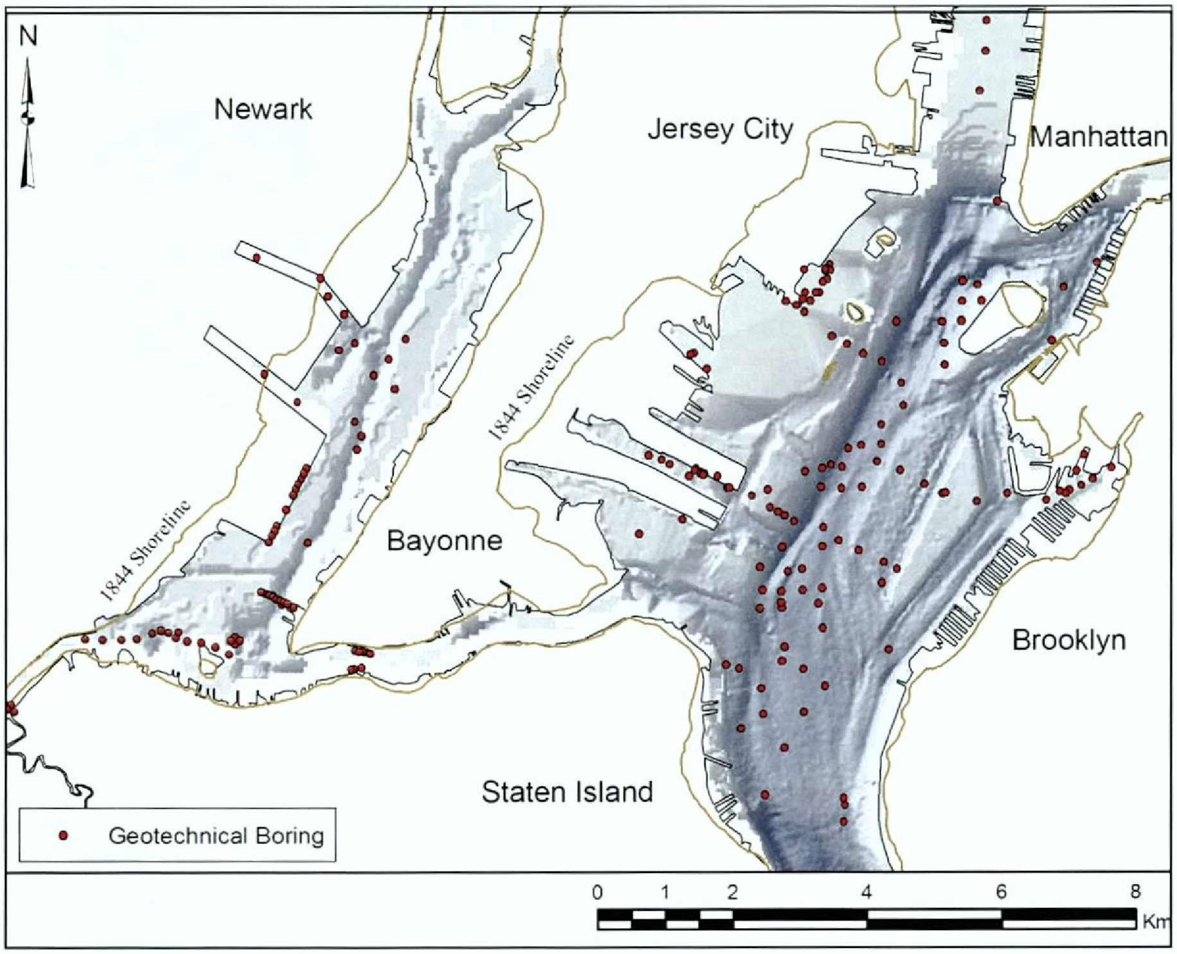


Figure 8.5. Shoreline change in the Upper Harbor since 1844.

morphology of the bay floor. Records suggest that stringent monitoring of patterns and frequency of sedimentation dictate the schedule of dredging based on volume and congestion of vessel traffic. Weights of vessels also impact dredging timetables and procedures.

GRA's initial studies (Schuldenrein et al., 2000a, 2000b, 2001, 2006) proposed that most of the active navigation channels have been dredged below the elevation of any terrestrial surfaces younger than 7,000 B.P. Many were presumed to preserve no Holocene surfaces whatsoever. It is not necessarily the case that all sediments beneath the channel floors are Pleistocene or older, however, since thick estuarine packages of Holocene age have been reported throughout the harbor (Carmichael, 1980; Heusser, 1949; LaPorta et al., 1999; Lovegreen, 1974; Newman *et al.*, 1969; Weiss, 1967, 1974; Wagner and Siegel, 1997). In some cases the contexts of Holocene packages, even when dated, may represent secondary displacements of thick and possibly even contaminated organic or hydrocarbon-enriched sediment packages (Schuldenrein 2001).

Our long term research suggests that archaeological compliance and management planning must be mindful of account an understanding of dredging schedules and strategies. The present research in particular demonstrates that systemic mobilization of sediments in shoreline environments is an essential component in the evaluation of their archeological potential. These issues are as critical as geomorphological and paleoenvironmental data. This research has demonstrated that ancient and contemporary sedimentation processes allow for the refinement and expansion of the baseline model for archaeological sensitivity . It is hoped that our model for archaeological sensitivity in the historically dynamic submerged environments of New York Harbor will serve as a guide to planners concerned with mitigating impacts on cultural resources discussed in the following sections.

Chapter 9

ASSESSING THE POTENTIAL FOR SUBMERGED PREHISTORIC SITES

Previous Work

The pilot study that preceded this report (Schuldenrein et al. 2006) focused on the development of an archaeological sensitivity model for Upper New York Harbor. It developed a methodology for defining zones of **High**, **Moderate**, and **Low** Potential on a channel-by-channel basis. Site potential was determined from information provided from cores taken as a part of that and previous GRA studies as well as other cultural resource investigations and study of samples from geotechnical borings curated at the USACE storage facilities at Caven Point, NJ. Potential was evaluated using the criteria presented in **Chapter 2**. Most signifcantly, however, the initial model was based on a sampling of only those channel segments that were scheduled for immediate mitigation. Accordingly, it was not possible to consider the entire New York Bight as a macro-landscape from which the systematics of archaeological geography and site preservation could be generated.

Those individual channel evaluations showing zones of site potential are presented again in this chapter as part of a synthesis of potential for the entire New York Harbor study area. With the exception of two channels, the Ambrose Channel, and Port Jersey, we expand the criteria for assignment of potential as presented in that report. On the basis of our more recent investigations, we have downgraded the Ambrose Channel to Low potential and the entire Port Jersey area to Moderate potential.

Our present study looks in detail at the Lower Harbor. We have broken this area into zones: Raritan Bay including Arthur Kill; Long Island and the Narrows including the Ambrose Channel; the inner Bight; and Jamaica Bay. While Jamaica Bay was not a specific part of the Scope of Work, we have included it as an area significant to broader USACE concerns as well as pivotal to the development of a sea level model which is prerequisite to understanding the structure of the submerged landscape and its archaeological potential.

The generalized impact of relative sea level rise on the study area is evident from the graphics included in **Chapter 8**. Although we are aware that reworking of the landscape has taken place during inundation of the area and by wave and tidal current action, it is clear that major portions of the former land surface has been preserved, albeit under a veneer of later sediment.

Raritan Bay and the Arthur Kill Channel

Figure 9.1 is a detailed digital bathymetric model of the Lower Harbor bounded by Great Kills on the north, Sandy Hook on the east, and the mouth of Arthur Kill on the west Long Island on the east. Apart from the obvious dredged navigation channels, traces of three prominent landscape features are visible on the floor of the bay. First and foremost, prominent traces of meanders are visible offshore Union Beach and Keansburg, New Jersey in positions consistent with the pattern shown by Gaswirth (1999) for the former Pleistocene Raritan River outwash channel. This same meandering regime is also identifiable in **Figure 8.12** underscoring a sinuous channel reach abutting the

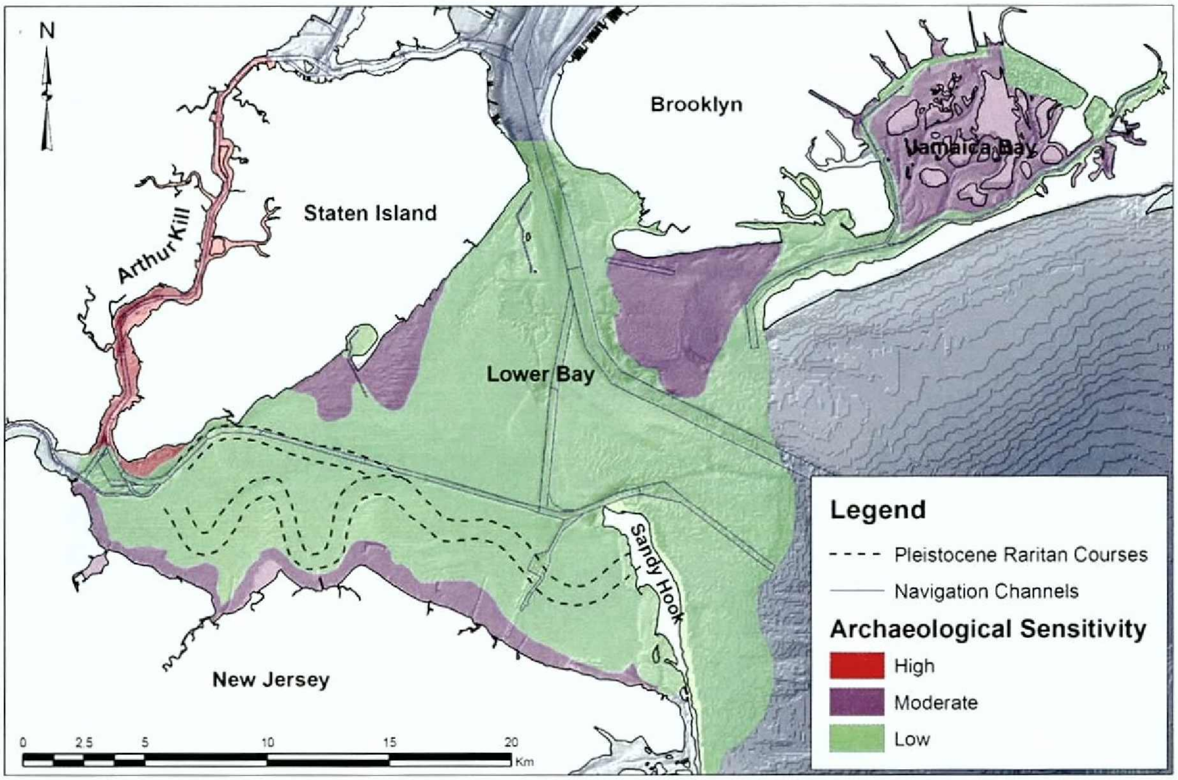


Figure 9.1. Composite map of archeological potential superimposed on bathymetry of the Lower Harbor and Inner Bight

south shore of the bay and apparently exiting the bay under Sandy Hook through a channel identified offshore in seismic profiles by Williams and Duane (1974). The approximate course of this former Raritan River channel is shown in **Figure 9.1**. Also identified by Gaswirth (1999) and discernible here is the course of the former trench of the Pleistocene Arthur Kill that carried overflow from proglacial lakes retained behind the Harbor Hill moraine. While not the "mud" filled channel proposed by McClintock and Richards in 1936 (**Figure 2.1**), the former Arthur Kill channel appears to be close to shore at Seguine Point and beneath the dredged West Reach navigation channel. We show this channel joining the former Raritan River channel in a mid bay position as suggested by Gaswirth (1999).

Both of these drainage trenches are filled by 10 to 15 feet (3 to 4.5 m) of later sediment which also appears to cover the red brown Pleistocene sands and gravels over much of the bay. Our study only penetrated the Raritan River channel in one location, B3, on our Keansburg transect where the Cretaceous surface has been cut to a deeper level than our adjacent core B4. The channel is filled by gray fine to medium sand at core B3. Our sea level inundation model indicates that the floor of Raritan Bay did not begin to become inundated until about 5,000 years ago and did not reach its near modern shoreline position until 2,000 years ago. This has critical archaeological implications. The submerged landscape was exposed for Woodland through Paleo-Indian occupations. Given the presence of Paleo-Indian and Early Archaic archeological sites on Staten Island along the Arthur Kill, it is highly likely that the former Pleistocene-age drainage lines were cut across terrestrial terrain and carried water from the uplands at this time. It is also possible that these early sites represented camps frequented by hunters following game along the former Pleistocene drainage channels. That said, none of our cores yielded evidence of clearly identifiable floodplain sediments or soils associated with these channels. These channels were apparently not inundated until quite late. We do not know when or how they were filled, whether by subsequent fluvial sediment or by reworked marine deposits during the transgression. At some time drainage shifted to the central part of the present Raritan Bay as shown in our sea level models in the preceding chapter. Whether this was forced by progressive progradation of Sandy Hook to the north or some other mechanism is unclear. Nonetheless, this feature is so prominent that it cannot be overlooked and must be assigned a Low potential for submerged Late Archaic through Paleo-Indian sites.

Figure 5.9 shows a cross section of Raritan Bay at Keansburg, New Jersey. This section shows that sediments bearing marine shells represent only a thin 5-foot (1.5 m) veneer overlying the Pleistocene fluvial sediments beneath the bay. Perhaps significantly there were no marine shells identified in core B-3 from the suggested fill of the buried Raritan outwash channel. Of note, however is the suggested presence of identifiable -20 and -15 (-6 and -4.5m) terrace features along the later talweg of the submerged Raritan River. These features are dated relatively to 4,000 and 3,000 years ago respectively, and correspond with the final portion of the Late Archaic period. Significantly, this period also corresponds with the documented demise of oyster colonization (Carbotte et al., 2004) further upstream. We considered that the oyster demise might be related to "stillstands" or lower sea level at periods up river that altered the salinities necessary for oyster growth. It is not clear whether these same conditions would have applied to the mouth of the estuary immediately adjacent marine water. Yet, we need to consider this area, as well as that flanking the banks of this former narrow estuary of the Raritan River to have a Moderate potential for submerged sites.

As a caveat, however, this zone lies at a depth greater than the currently dredged operational depth of the West Reach Channel to be 35 feet below mean lower low water (MLLW). Therefore, it should pose no problems unless deeper navigation channels are required in the future.

The north shore of Raritan Bay presents a somewhat different scenario. Identifiable offshore Great Kills are shoals referred to as Old Ochard Shoal, on NOAA chart 12327. The south shore of Staten Island is the high wave energy shore of the bay. This is indicated by groin fields showing westward longshore sediment transport giving rise to a former spit across the mouth of Great Kills, now marked by a structurally protected spit forming the entrance to Great Kills harbor. Close examination of the navigation charts coupled with the landform expression on the above chart suggests that the area offshore Staten Island to a depth of -15 ft (-4.6m) may represents a drowned barrier island analogous to those along the shore of Long Island that terminated at the Old Orchard Shoal. As a result, we have given this portion of the shore of the bay a Moderate potential for submerged sites. We note that this is also an area sensitive for shellfish harvesting suggesting that it may have also been a popular prehistoric shellfish harvesting area during the Woodland period. Similarly, the importance of shellfish harvesting may preclude the sediments on this side of the bay being disturbed for other purposes.

Also important *vis a vis* the Staten Island shoreline is the known presence of Early Archaic and Paleo-Indian sites in the vicinity of Wards Point at the mouth of Arthur Kill. This same location was noted in LaPorta et al. (1999) as having a submerged peat bed beneath the dredged channel dated at 7950 +/-70 B.P. (8,803 cal yrsbp) which places it in the Early to Middle Archaic range. We suggest that the early sites in this vicinity indicate use of freshwater marshes at the mouth of Arthur Kill as a subsistence resource. As a result, we assign a High potential for submerged site presence and preservation in this general area. This is and has been an important area for maintenance of a navigation channel subject to further dredging. Given the richness of wetlands and salt marshes as a habitat for waterfowl and as a spawning area for various marine species, the Arthur Kill becomes an area of prime importance for deeply buried or submerged cultural resources. The great expanses of marshes that once covered the northwestern shore of Staten Island and nearby New Jersey in association with the number of early archeological sites in the area attest to the importance of wetlands as a human subsistence resource. Peteet and Pederson (in press) report a basal peat date of 11,100 B.P. for a Staten Island freshwater marsh. This early date places added importance on the Arthur Kill area. As result, we consider Arthur Kill and its fringing marshes to have high archeological potential along the full length of its channel.

Traditionally, stream mouths, or the confluence of streams, have been important loci for Native American settlement in historic times and in evidence prehistorically. In Raritan Bay, stream mouth areas are most prevalent along the south shore of the bay where they are often associated with salt marshes. The south shore accordingly should be highlighted as an area of interest for the preservation of submerged sites. This shore is a low wave energy area conducive to site preservation. We have assigned the nearshore portion of the south shore of the bay to the category a Moderate potential.

Western Long Island, the Narrows, and Ambrose Channel

For ease of organization, we have grouped these three areas into a single category. The pre-dredging topography described from the

1844 navigation chart shows that the channel at the Narrows was originally flanked by a western shoal termed the West Bank and another on the east was described as the East Bank. The East Bank was shown as contiguous with Coney Island and Gravesend Bay. Coney Island was clearly an active barrier island with a back barrier salt marsh much like those father to the east today. The Ambrose Channel provided a direct deep-water access to the harbor when it was dredged between the East Bank and the West Bank through the former East Channel. To the south of the modern Ambrose Channel lie the Romer Shoal and Flynns Knoll separated by the Swash Channel. In our assessment of the submerged landforms, we have considered the various shoals and historic channels across the mouth of the Lower Harbor to be relicts of a previous Hudson River channel network now capped by a veneer of later sediment. As mentioned earlier, the presence of submerged terraces and especially the -15 foot terrace suggest that the surface of these landforms have not been greatly disturbed for as least the past 3,000 years. This terrace can be identified on the surface of each of these shoals as well as the West Bank and East Bank.

The channel at the Narrows lies below the planned depth for navigation and is not considered to present difficulty with respect to cultural resources. We should add, however, that Charles Dill of Alpine Ocean Seismic Survey, Inc. describes peat deposits from a core approximately 30 feet (9 m) beneath the bottom in the vicinity of the Narrows. Large areas of the West Bank and Gravesend Bay have been dredged for sand and gravel for use in construction projects. Both the West Bank and East Bank were mapped as being underlain by fine to medium-grained sands by (Bokuniewicz and Fray 1979); and this is corroborated by our research into core records. In our sea level rise model, the surfaces of shoal areas were not inundated until after 2,000 cal yrsbp and have doubtless undergone sorting and redistribution of surface sediment since that time. The East Bank shoal is contiguous with the mainland at Coney Island and would have been available to prehistoric populations for occupation. The West Bank shoal is also contiguous with Staten Island although it has been substantially destroyed by dredging operations.

On the basis of our sediment studies and our sea level rise model, we consider the East Bank to be the only area with archeological potential, which we assess to be of Moderate likelihood. The Romer Shoal and Flynns Knoll doubtless extended above the water surface as islands in the past. It remains unclear as to whether these were inhabited or not. In our view, they are of less importance than other sites in Raritan Bay, thus we assess them as Low potential areas. The dredged Ambrose Channel was classified as moderate to high potential in our earlier report, on the basis of limited core information. If we limit our consideration to the existing dredged channel, recent seismic profiles across the Lower Harbor by Thieler et al., (2007), show the Pleistocene channel of the Hudson east of the Narrows to have incised to a depth of ca. 150 feet below present sea level; it was overlain by ca. 50 feet of younger sediment. Dredging has already removed the overlying sediment package over much of its length. Thus, the Ambrose channel can be downgraded to Low potential. **Figure ??** is the color coded map of archeological potential for the central portion of the Lower Harbor.

Jamaica Bay

Jamaica Bay fell within the overall project area but it was not specified in the Scope of Work. GRA undertook investigations here to provide potential information on the formation of salt marshes during the ongoing marine transgression. Jamaica Bay falls within purview of the U.S. National Park Service as part of Gate-way National Recreation Area. Work was performed under Permit # GATE-2006-SCI-0019. As noted earlier, we were unable to obtain cores from the actual marsh surface at the Yellow Bar Marsh as anticipated due to water depths. Personal communication with Dorothy Peteet of Lamont-Doherty Earth Observatory as well as Peteet and Pederson (in press) confirms our sea level rise conclusion that the formation of salt marshes in Jamaica Bay is a very young event. We concur with Peteet and Pederson that the marshes here are less than 1,000 years old and that the current marsh has developed in a pre-existing depression on the surface of glacial outwash. The outline of this depression as well as the centripetal drainage network entering it can be plainly seen on the digital elevation models in our chapter on environmental reconstruction using the sea level model. Consequently, Jamaica Bay does not appear to be a classic back barrier salt marsh like that at South Oyster Bay behind the Jones Beach barrier island. Jamaica Bay is a clear anomaly. Other than relatively thin estuarine silt layers covered by fine sand adjacent to the Yellow Bar marsh the five cores taken in this location did not give any indication of submerged land surfaces within 40 feet (12 m) of present sea level. Marine shell fragments were not recovered lower than 30 feet (9 m) below present sea level although the bedding on the well sorted fine-grained sands below the marsh suggest a littoral history. However, our deepest core was obtained from an active channel deposit.

Pending further investigation, it is hypothesized that the fine-grained sands decrease in thickness towards the edges of the Jamaica Bay depression and its former shoreline now circumscribed by a dredged channel. Archeologically the pre sea level rise surface beneath the Jamaica Bay salt marshes would have been available for prehistoric occupation extending from the Woodland back to the Paleoindian periods. On this basis, we suggest that Jamaica Bay, with the exception of the present dredged channels, that have obviously been reworked historically, be considered to have Moderate potential for prehistory beneath the existing marsh. We recommend that future dredging activities for navigation or marsh restoration consider the presence of deeply buried sites.

The Inner New York Bight

The Inner New York Bight as currently referenced comprises the area seaward from Sandy Hook and extending from Long Branch, New Jersey on the south to Jones Inlet on the Long Island shore and east of Jamaica Bay. Various geotechnical borings have been taken along the barrier islands, for the purpose of evaluating offshore sand and gravel resources for beach nourishment and restoration. The locations of core logs examined for this study are shown in our compiled maps of boring and core locations. Extensive work was done in the vicinity of Sea Bright, New Jersey as well as offshore Jones Beach. Our earlier discussion noted the presence of evidence of Pleistocene megafauna on the continental shelf south of the Hudson Shelf channel suggesting the possible presence of Paleo-Indian hunters in the same area during the low Pleistocene sea level low stand. More pertinent to our study are the shallower waters nearer to the present shoreline. **Figures 7.2** and **7.3**, for example show an approximate shoreline position for 9,000 and 8,000 cal yrsbp. The exposed landscape offshore the barrier island systems mark the general areas available to both Early and Middle Archaic as well as Paleo-Indian hunters in the Inner Bight area and at depths consistent with the future navigation channel needs in New York Harbor. It is only after 7,000 cal yrsbp, when the rate of sea level rise slowed, that environmental settings along the coasts began to stabilize so that shellfish colonization and coastal fisheries pattern could become predictable as subsistence resources. This type of resource establishment is exemplified by the dated colonization of oysters in Tappan Zee at about this time.

In terms of the Inner Bight, **Figure 7.5** gives and insight into the former landscape. The shoreline outlines the outer edge of the outwash fan spreading out from the Raritan Bay and the Hudson River valley. The major portion of this fan passes beneath Sandy Hook and extends southward to the Navesink River. Like much of Raritan Bay, this area was progressively inundated so that Late Archaic groups most likely utilized the coastal and marine resources of this narrow portion of the shore. Like Late Archaic groups at Croton Point and Dogan Point as far up the Hudson River at Tappan Zee we can expect similar types of subsistence strategies to have been practiced along the coast. Were this stretch of the shore in a sheltered environment, we would assess it as having moderate to high potential for submerged sites. However, this is a high wave energy shore. Accordingly, we suggest that *in situ* archeological evidence has been disturbed or eroded over the past 6,000 years. This portion of the shore is considered to have **Low** archeological potential. The coastal areas of the Long Island shoreline offshore the present barrier islands do not present areas as extensive as those near Sea Bright, New Jersey. The narrow bands of areas exposed during lower sea level along the Long Island shore are likewise exposed to high wave energy, thus we extend our assessment of **Low** potential to this portion of the Inner Bight as well.

Figure 9.1 presents a composite map of archeological potential for the Lower Harbor including Raritan Bay and extends eastward to include Jamaica Bay and the Inner New York Bight.

Upper New York Harbor and Newark Bay

Newark Bay. The Newark Bay navigation channel has been studied intensely to determine the geotechnical problems associated with dredging to required future channel depths. These have involved the depth and attitude of the bedrock surface that underlies the channel as well as deeply incised Pleistocene sediment filled channels in the bedrock surface (Beda et al., 2003). Our study by necessity looks beyond the confines of the narrow channel and its feeder channels to Port Newark, Port Newark Point, and the Elizabeth Channel. The pre-engineered topography and bathymetry shown in the 1844 charts, stratigraphic study of cores from Kill Van Kull, and our relative sea level model show that Newark Bay was occupied by the meandering channel of the prehistoric Hackensack River until about 4,000 years ago when it began to be inundated by rising sea level. We can anticipate that brackish marshes began forming along the edges of the valley edges and spread laterally with rising sea level and expanding in area to fill the present basin. Carmichael (1980) has described the later portion of the present Hackensack marshes and notes changing vegetation and salinity changes.

Archeologically, the Hackensack River valley, now covered by the marshes, might have afforded rich subsistence base for Paleo-Indian through Late Archaic groups that were situated on higher terrain along the valley margins. The expanding fringes of the marshes can be considered to have offered the same resource base to Woodland period groups as well. The main dredged channel has been assigned a Low potential while we extend a Moderate potential to the marsh peripheries. The Port Newark and Elizabeth Channels maintain their Low potentials as previously dredged channels. Port Newark Point is included within the overall Moderate potential category given to New Bay outside the main channel.

Upper New York Harbor. For the purposes of this discussion of archeological potential, the Upper Harbor includes contiguous channels and areas. These are the Anchorage Channel, Claremont Channel, Port Jersey, Buttermilk Channel, and Stapelton Channel.

Thirteen cores were examined as part of our previous investigation to better understand the Anchorage Channel. Critical to that study was a radiocarbon date on organic fragments from weathered fluvial deposits at 66 feet below sea level in core 98ANC64, overlain by thick estuarine silt and clay that floors the Hudson in this area. A determination of 9,400 +/-150 (10,690 cal yrsbp) suggested the dated deposits were of a potential Early Archaic affinity and appeared to represent a riverine environment. Other cores from the Anchorage Channel also contained organics from fluvial sands beneath the estuarine fill (98AC80 and 98ANC81) from between 70 and 90 feet below sea level. This was an indication that there was a potential for relatively old prehistoric sites at depth. The depth of the channel at these locations is on the order of 60 feet below sea level and below proposed future dredging requirements or plans. We assigned the Anchorage Channel a Low priority on this basis although we call attention to these potentially important future sites for further investigation.

Our present study adds a context to the Anchorage Channel cores because of the revised sea level model. **Figure 5.17** is a cross section of the Hudson from Port Jersey to the Bay Ridge Flats and across the Anchorage Channel. It is clear from this section that the organic zones at the base of the estuarine silt are continuous with the underlying former land surface composed of crystalline bedrock covered in turn by Pleistocene fluvial gravels. Radiocarbon ages from the silts point to a time of deposition between 3,500 and 3,700 years ago for the upper portions of the Jersey Flats. Anomalously young ages were found on the slope of the Jersey Flats in core JF-6. Across the harbor another anomalously young date on wood fragments, 1,880 +/-40 B.P. (1,806 cal yrsbp) was found in our new core D-1 from the Bay Ridge Flats at a depth of 33 feet below sea level. An additional cross section, Figure 5.15 along the Liberty Island channel, gives a better representation of the depositional history in the harbor. Here a marine transgression on to a former land surface is more clearly defined with estuarine silt overlapping fluvial outwash sands with *in situ* trees. These are dated at 5,660 +/-90 B.P. (6473 cal yrsbp) and 5,000 +/-40 B.P. (5769 cal yrsbp) and give a reasonable indication for the inundation of the western shore of the harbor. Examination of the bathymetry in the harbor also identifies a highly contaminated black oily mud, in our core C-2, as the product of relatively recent filling of an early dredged channel. This disturbed edge of the Jersey flats was given a High potential in our earlier report, but we now downgrade it to Moderate, in keeping with the remainder of the Jersey Flats. We now classify the Jersey Flats including the Claremont and Port Jersey channels as Moderate potential. We do not yet understand the depositional history of the Bay Ridge Flats, thus, we have given it a Moderate potential.

Across the harbor in the vicinity of the Bay Ridge Flats there is evidence for recent dredging along the west side that has removed formerly intact sediment. That area is now included in the expanded Low potential area of the Anchorage Channel. Along similar grounds, we retain a classification for the Low potential for the Buttermilk Channel.

The individual study areas of the Upper Harbor are included on a map of composite archeological potential in **Figure 9.2** This map in overall planning for compliance requirement for future specific projects. Most importantly, these maps together with the information furnished in this study provide a needed context to view the complex environmental history of the New York Harbor area.

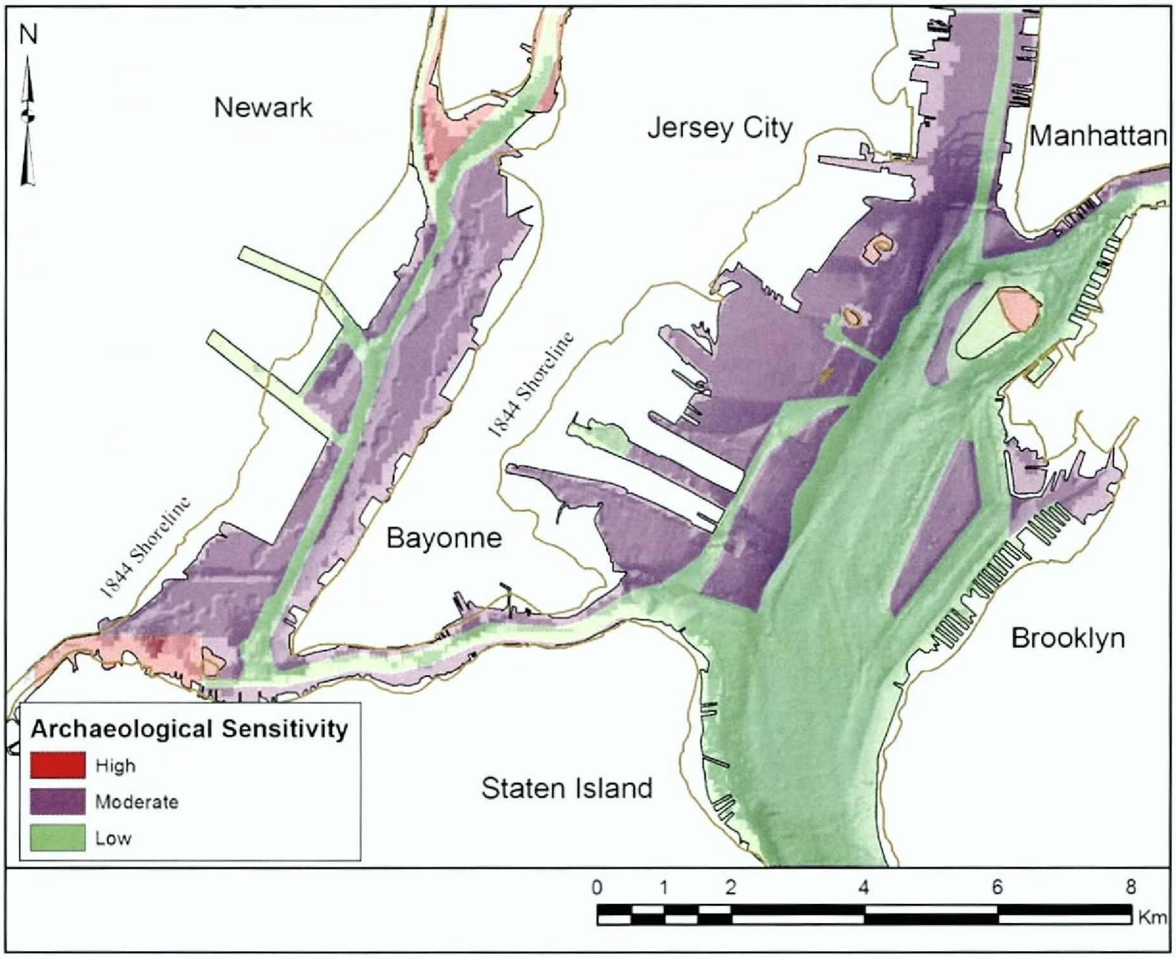


Figure 9.2. Composite map of archeological potential superimposed on bathymetry of the Upper Harbor and Newark Bay

Chapter 10

CONCLUSION

The objectives of this project has been the development of a model of submerged paleoenvironment within the Upper and Lower Harbor segments of the New York Bight. The model is to serve as a blueprint for assisting the NYCOE and researchers in isolating and delimiting areas that might have been available for settlement during the various periods of the prehistoric and historic past.

This report is the culmination of a near decade long effort in assembling and assimilating data sets that provided clues on the systematics of submerged landscapes and archaeological preservation, but were insufficient to provide a comprehensive framework. The formulation of an overarching model, one that would allow planners and managers to develop archaeological site prediction modules in advance of Harbor improvement projects, was partially precluded by the project by project planning imperatives of the NYCOE. In other words, Section 106 Compliance had typically been invoked to mitigate the impacts on a particular segment of the Bight. Discussions with NYCOE in 1998 resulted in a long term mitigation strategy that addressed both the near term requirements of the Section 106 process (ie. the need for immediate mitigation efforts at Harbor Channels on schedule to be impacted) and longer term goals that would allow planners to benefit from an inductively based, Bight-wide, model of archaeological sensitivity that could be utilized for future oriented management plans.

Practically, the implementation of that strategy involved the formulation of an inductive model of archaeological sensitivity that was built on identifying the integrity of buried or "drowned" landforms (ie. terraces, meander belts) and identifying potentially sealed and intact surfaces for the terrain delimited by the impact zone (ie. Jersey Flats, Shooter's Island). The key elements in determining integrity were the development and dating of litho-stratigraphies for the impact zones. These sequences were assembled through systematic coring, designed and implemented by GRA personnel, and supplemented by available geotechnical boring records. Bio-stratigraphic records provided an additional data base and archaeological sensitivity maps were prepared for each project zone based on data bases and the dating of buried organic horizons. While archaeological sites, sensu stricto, were never identified, laterally continuous facies for Late Holocene estuarine deposits, and occasional alluvial sequences provided a guideline for recognizing "available surfaces for occupation" for given slices of prehistoric time. While each project had its own Scope of Work (SOW) the application of a consistent investigative methodology geared towards assessing the integrity of Holocene columns and dating stratigraphic breaks allowed us to expand our inductive model and refine the stratigraphies across broader reaches of the Harbor.

Five such studies were undertaken and in 2006 the NYCOE issued an SOW to assimilate the results of the project specific investigations and to create archaeological sensitivity modules for the 14 reaches and channels of the New York Bight that had been investigated to date for these purposes (Schuldenrein 2006: Figure 5.1). These modules were examined synthetically and a series of recommendations were made that would allow the expanding sensitivity model to be projected across the Bight as a first step in designing the long-term planning document that is the product of the present report.

The Research Design and methodology underlying this synthesis is straightforward. They emerged from the need to develop a comprehensive model for landscape evolution in the subaqueous terrain, which in turn, provides a reliable measure of prehistoric geography. The individual modules structured in the earlier report were incomplete, driven by an uneven record of subsurface geological data and, perhaps even more significantly, by a sea level model that was both dated and partially obsolete. Accordingly, an unanticipated need for fine-tuning the archaeological sensitivity paradigm involved a complete rebuilding of the sea level curve for the Holocene marine cycles of the New York City area. While the recommended Research Design identified in the earlier report rightly pointed out the need for collecting additional paleogeographic and environmental data, it was originally thought that this was for purposes of "filling in gaps" that would link up the individual modules. In the course of collecting the data, however, the potential for updating the New York area sea level curve became a focus of the data collection effort. Accordingly, the present report has emerged as a more reliable construct for both paleogeography and archaeological sensitivity.

The data collection effort was concentrated in the Lower Bay and its upstream periphery, areas that were determined to have the greatest potential for preserving intact submerged Quaternary sequences. The cores also sampled the most diverse micro-environments housed in the subaqueous terrains. Limited coring upstream allowed us to refine and rethink the initial sequences, those developed in the earlier phases of the New York Bight research, and to retrofit these observations into what is now emerging as the first comprehensive model of Late Quaternary landscape evolution for this part of the world. Ongoing sedimentological and bio-stratigraphic studies will allow us to complete a more systematic reconstruction of the submerged terrain with a degree of detail previously unattainable. This is because 3-dimensional mapping, the use of historic maps and the integration of observations into GIS formats has allowed us to construct the buried landscape on a segment by segment basis. While this remains incomplete, our framework is sufficiently comprehensive to identify broad spatio-temporal trends in Late Quaternary landscape evolution.

Against this backdrop the new model of archaeological sensitivity has emerged. It is illustrated in **Figure 10.1**. This represents the most accurate depiction of archaeological site sensitivity based on the sets of comprehensive geoarchaeological and stratigraphic analyses assembled and synthesized in the present analyses (including specialized studies still in progress). **Figure 10.1** has also utilized GIS templates for historic mapping and data sets that have been digitally manipulated to filter out shoreline and subaqueous disturbance patterns. The latter task has still not been completed. But our final product will allow prehistorians and Quaternary scientists to model the Harbor terrain prior to and as a result of extensive Euroamerican impacts. This approach enables planners to anticipate potential effects on cultural resources in channel reaches slated for widening and dredging.

A major emphsis in this study has been the application of GIS to facilitate multi-layered mapping in the depiction and interpretaion of patterned changes in geomorphology, paleogeographic groupings, and archaeological site distributions. The GIS model began with terrain elevation models that charted near shore and subaqueous elevations and incorporated recently mapped surface geology data. They then assimilated baseline sedimentological and

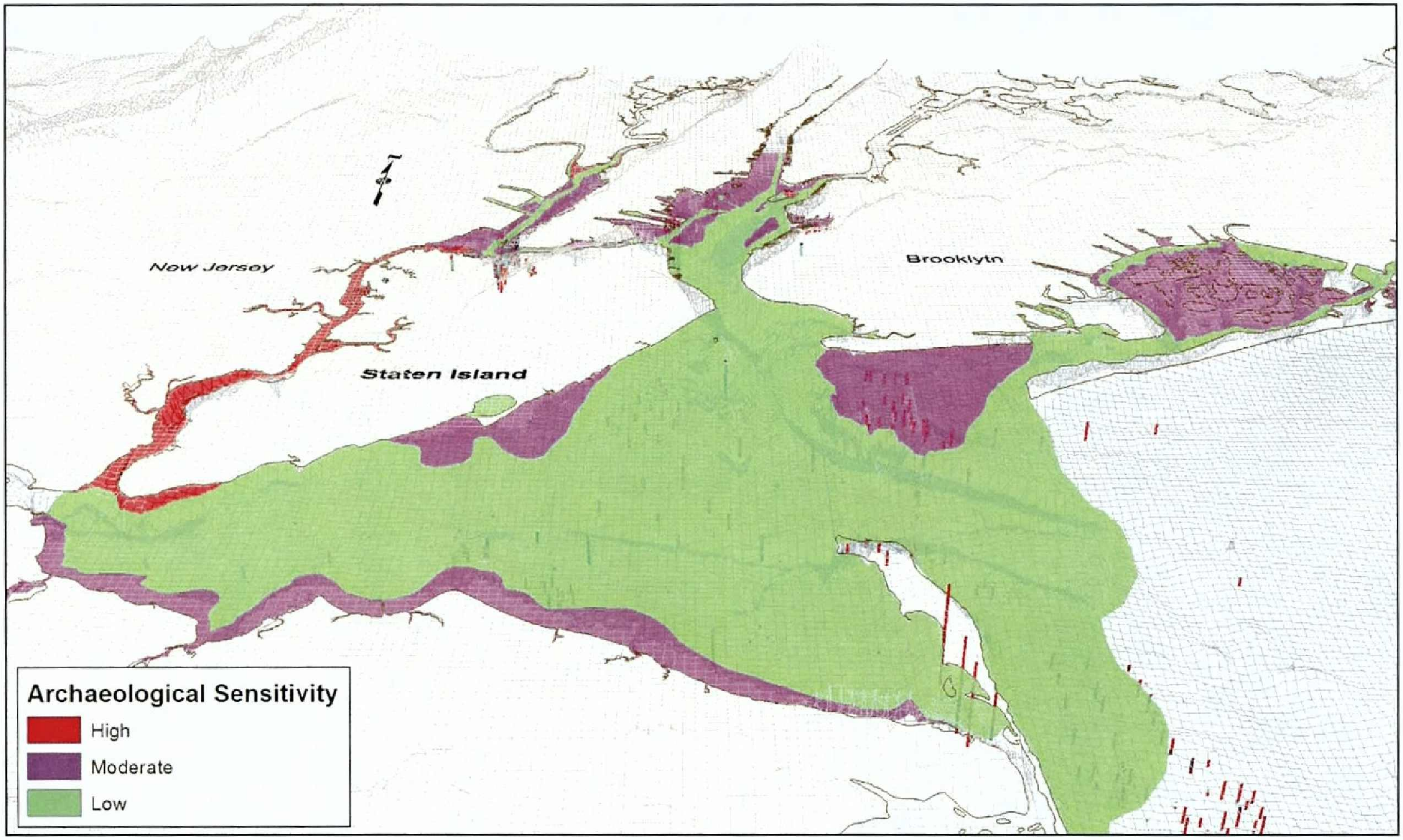


Figure 10.1 3D view of sensitivity model and borings.

stratigraphic data, combining previously assembled information sets with those obtained from the new field work. Digitized versions of the data modules were then produced. A total of 25 image sets depict the composite interpretations of our data in this platform. Additional data processing will result in supplementary presentations for the bio-stratigraphic and lithostratigraphic interpretations when these are completed.

The original proposal for the present study proposed seven (7) specific GIS based products as follows (Schuldenrein 2006: 6-4 ff):

(1) *Historic terrain and bathymetric plots.* We presented the 1844 bathymetric plots of the New York Bight as a baseline for documenting subaqueous contours. We proposed to develop additional time based projections and were able to do so.

(2) *Shoreline models for prehistoric and historic terrain.* We were able to generate sea level curves tracking shoreline contours and migrations by millennial intervals. These track changing configurations of terrestrial (stream lines), estuarine, marsh, and marine margins for these time frames. The original plan was to obtain resolution at 500 year intervals but the present model is configured on the basis of the reworked sea level curve and provides considerably more accurate projections.

(3) *Surficial geology of the shore and subaqueous terrain of the Bight.* The initial study illustrated the maps that were available for various sections of the Bight. These were so diverse and based on such a broad variety of sedimentological and geomorphic criteria that comprehensive integration would require a complete reworking of primary data sets. We were able to generate a GIS model for surface and subsurface Quaternary landforms, including those that are a product of or were affected by marine transgressions and regressions. It is possible that additional refinements can be incorporated.

(4) *GIS plots of subsurface lithostratigraphy.* The layer involves plots of the late Quaternary lithostratigraphy based on an assimilation of the bore logs, first by the individual channel reaches and subsequently for the entire project area. This proved to be the most complex task for the GIS because lithostrata are not furnished, nor can they be readily transformed to a single data set. This is because even though there are GIS based plots of cores by texture, the prospect of grouping these lithostratigraphically is minimal without a more fundamental sorting of landforms. The latter is not yet possible.

(5) *GIS plots of biostratigraphy.* The layer integrates the foram, macrofossil, and pollen records to sort out habitats through time. This is an independent measure of the zonation of nearshore environments established by the shoreline model (item 2 above). Additional information may be forthcoming, but here again, the variability in data reporting and an absence of reliable baseline stratigraphy may render this task difficult.

(6) *GIS plots and simulation of prehistoric and historic site geography*. This construct projects likely settings of sites based on known patterns of settlement in near shore environments through time (ie, for Paleoindian, Archaic, Woodland, Contact and historic periods) based on the model of changing nearshore environments through time. It is then "fitted" against the submerged landscape model developed for this study. A first iteration of this was successfully implemented.

(7) *Projection of a refined model of archaeological sensitivity*. The baseline models were refined on the strength of the present investigations. The predictive model for the major navigation channels and surrounding areas is advanced and illustrated in Figure 10.1.

Summarily, our field and analytical work has produced a dynamic human ecological model that began with inputs from our original model, was progressively enhanced through systematic collection, and refined into an integrated model. The GIS filter allowed us to produce a dynamic model for environmental change and human geography that is still evolving. It can and will continue to help structure planning decisions for cultural resource planners.

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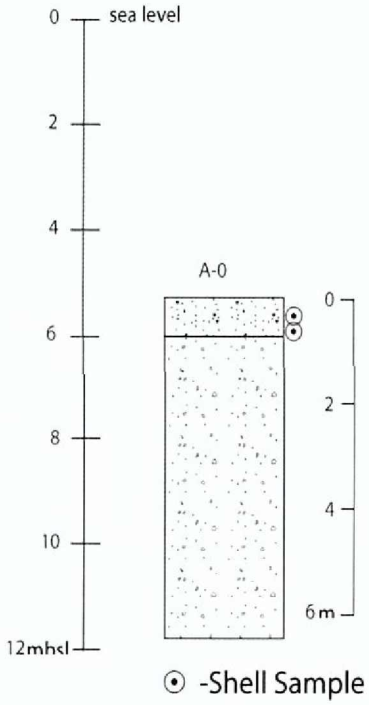
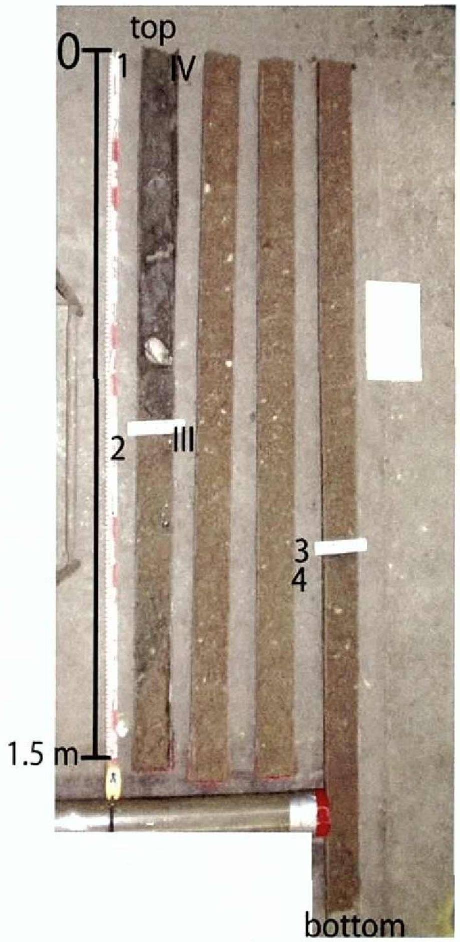
APPENDIX A

Borings (cores and data)

Core A-0

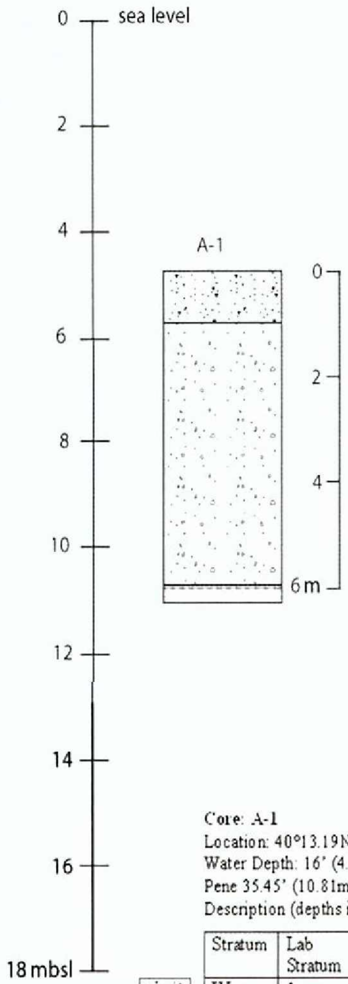


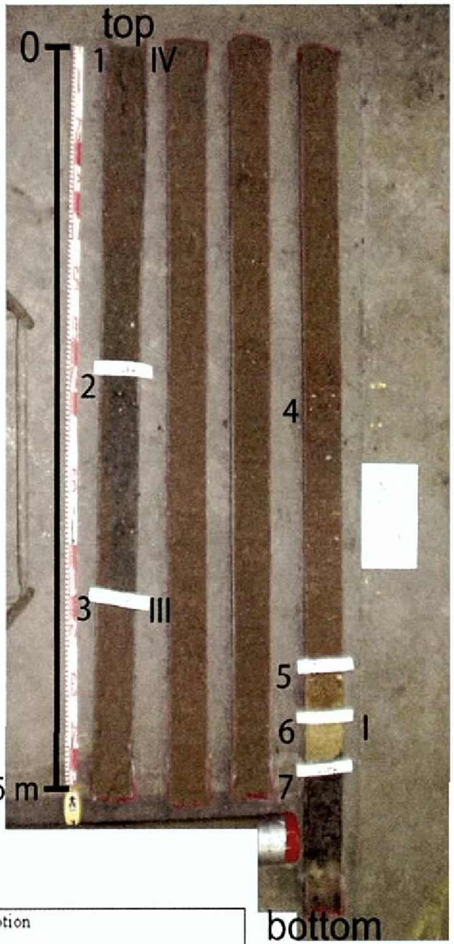


Core: A-0
Location: 40° 30.26N 74°11.59W
Water Depth: 17.8' (5.43m)
Pene 39' (11.89m), Recov. 21' (6.40m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
IV	1	0-0.75	10YR3/1	clayey silty fine to coarse sand, with intact clam shells and broken shells with greatest concentration in upper 0-15 cm, abrupt lower boundary
III	2	0.75-5.75	7.5YR4/2	clean poorly sorted gravelly fine to coarse angular to subangular sand, with well rounded to subrounded gravels to 5-10 cm, abrupt lower boundary
	3	5.75-5.78	7.5YR3/1	silty fine sand, abrupt lower boundary
	4	5.78-6.50	7.5YR4/3	slightly poorly sorted gravelly silty fine to coarse sand with rounded to subrounded gravel to 5-10 cm

Core A-1

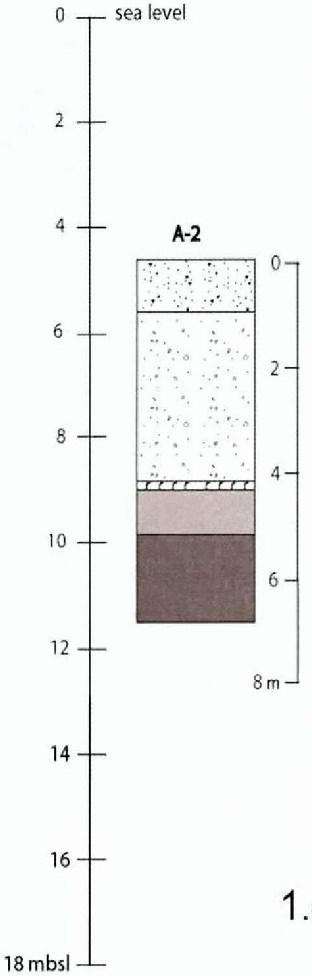


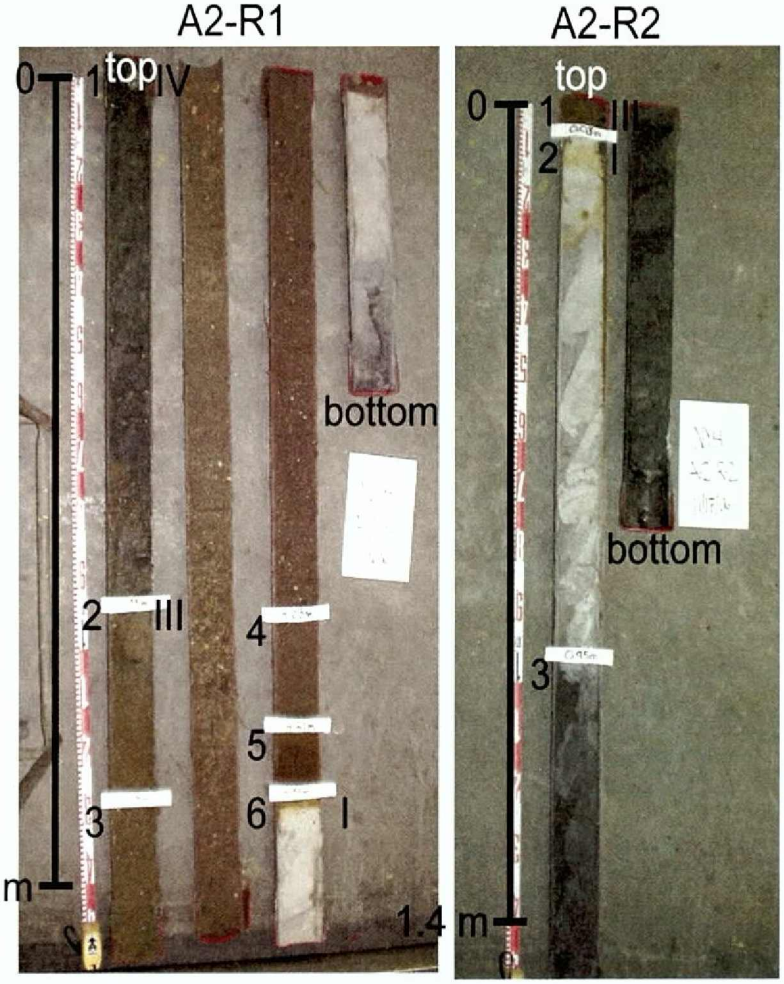


Core: A-1
Location: 40°13.19N 74°11.53W
Water Depth: 16' (4.88m)
Pene 35.45' (10.81m), Recov 12.6' (3.84m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
IV	1	0-0.65	10YR4/2	slightly silty fine to medium sand, with broken shell fragments, abrupt lower boundary
	2	0.65-0.98	10YR3/1	silty fine to medium sand with broken shell fragments, abrupt lower boundary
III	3	0.98-5.30	7.5YR3/2	clean poorly sorted gravelly rounded to subrounded fine to coarse sand, with few subrounded gravels up to 15 mm, with well sorted fine sand from 2.0-2.60, 3.70-4.30, abrupt lower boundary
	4	5.30-5.82	7.5YR4/2	gravelly slightly silty poorly sorted fine to coarse sand, with subrounded gravels up to 10 mm, abrupt lower boundary
	5	5.82-5.95	7.5YR4/3	fine to medium sandy gravel, with rounded gravels to 20 mm, abrupt lower boundary
I	6	5.95-6.00	2.5Y6/6	fine sand, with weak organic laminations, 2 weak 1 mm thick lamina, 1 distinct 2 mm thick lamina near base, abrupt lower boundary
	7	6.00-6.20	10YR3/1	fine sandy clayey silt, with fine horizontally interbedded discontinuous lamina

Core A-2





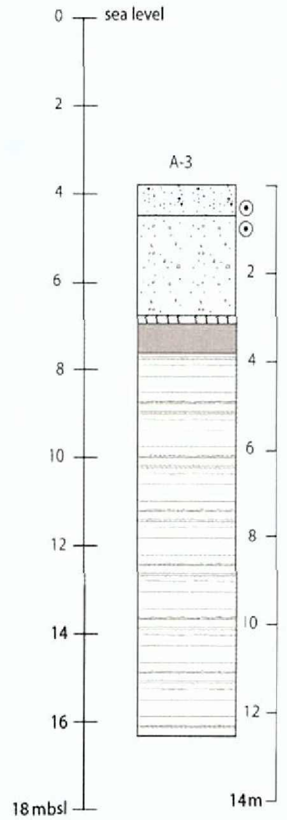
Core: A2-R1
Location 40°29.40N 74°11.35W
Water Depth: 15.5' (4.72m)
Pene 21.24' (6.47m), Recov 16.7' (5.10m)
Description (depths in meters below core top)

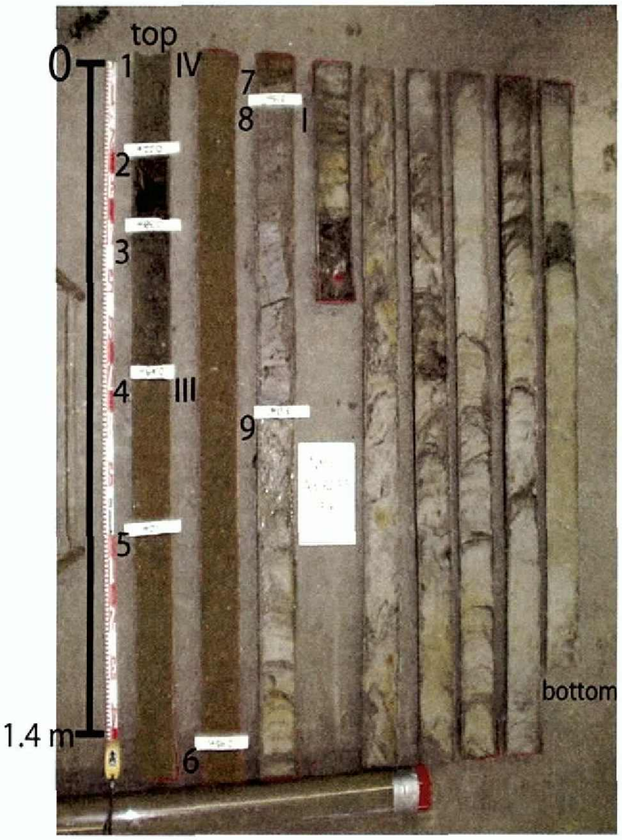
Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
IV	1	0-0.95	10YR3/1	gravelly silty clayey fine to coarse sands, poorly sorted gravels subrounded to well rounded up to 10 mm, clam shell on top only, abrupt lower boundary
III	2	0.95-1.30	7.5YR3/2	well sorted fine to medium sand, no shell, abrupt lower boundary
	3	1.30-4.03	7.5YR4/3	gravelly poorly sorted fine to coarse sand with subrounded gravel up to 40 mm, well sorted fine sand from 1.85-2.48, abrupt lower boundary
	4	4.03-4.21	7.5YR3/2	fine to medium sand, poss elluvial, abrupt lower boundary
	5	4.21-4.35	5YR3/4	medium to coarse sand, few subrounded to well rounded gravels to 10 mm, poss illuvial, abrupt lower boundary with 3 cm transition of weathered clay
I	6	4.35-5.14	2.5Y6/1	clay with weak 10YR6/6 weathering stains to approx 4.65 m, below is 10YR4/1 clay with some 10YR6/6 yellow weathering stains, and some dark 10YR3/1 indistinct mottles

Core: A2-R2
Location 40°29.40N 74°11.35W
Water Depth: 15.5' (4.72m)
Pene 24.7' (7.53m) w/ jet down to 18 (5.49), Recov 6.7' (2.04m) below jet
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
III	1	0-0.08	5YR3/4	fine to coarse sand, with few well rounded 5 mm gravels, hard, moderately cemented, abrupt lower boundary
I	2	0.08-0.92	2.5Y6/1	clay, from top (0.08 to 0.25) is 10YR6/8 moderate to strong weathering, from 0.08-0.13 matrix is weathered to 2.5Y6/4, below from 0.13-0.25 weathering is distinct wavy horizontal to subhorizontal fine filaments and nodules, gradual lower boundary
	3	0.92-2.65	10YR3/1	clay at top, slightly coarsening to a very fine sandy silty clay at base with very fine charcoal flecks diffuse throughout upper clay portion

Core A-3

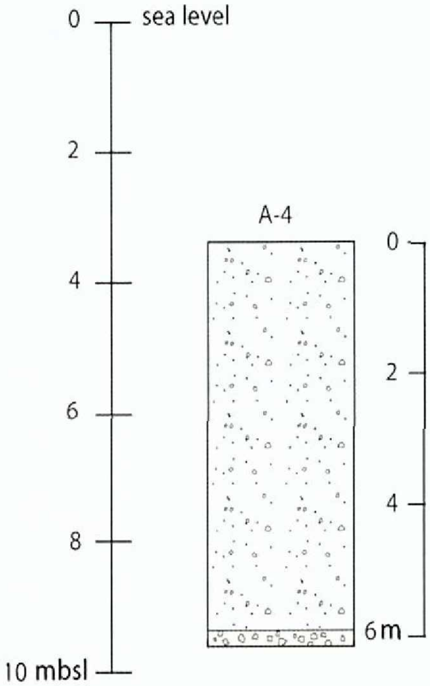


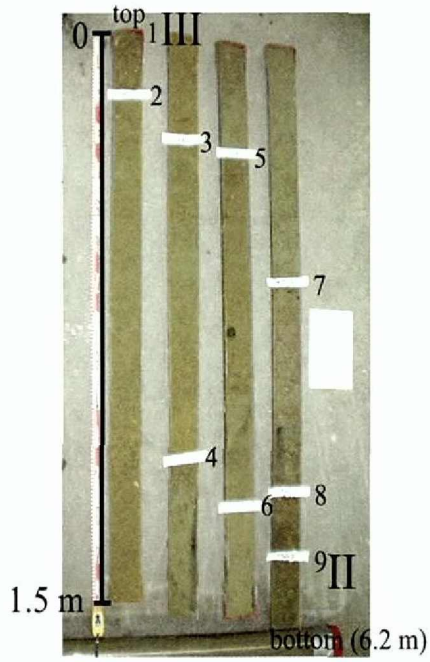


Core: A-3 R2/R3
Location: 40°28.58N 74°10.9W
Water Depth: 13.1' (3.99m)
Pene R2: 34.28' (10.45m), R3: jet to 18' (5.49m), drill to 39' (11.89m) Recov R2: 16.8', R3: 24.1' (7.35m), total recovery 41' (12.50m)
Description (depths in meters below core top)

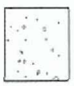
Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
IV	1	0-0.22	10YR3/2	poorly sorted fine to coarse sands, with occasional well to subrounded gravel to 5 mm, few broken shell fragments, abrupt lower boundary
	2	0.22-0.38	10YR2/1	silty fine to medium sand, with common broken and complete shells, abrupt lower boundary
	3	0.38-0.69	10YR3/2	slightly silty fine sand, common broken shell with highest concentration at base, abrupt lower boundary
III	4	0.69-1.0	10YR5/2	fine to medium sand with occasional well rounded gravels to 15 mm, no shell, abrupt lower boundary
	5	1.0-2.95	7.5YR4/2	gravelly medium to coarse sand, common, poorly sorted subangular gravels to 20 mm, moderately well sorted fine to medium sand from 1.85-2.18, abrupt lower boundary
	6	2.95-3.12	5YR3/4	gravelly medium to coarse sand, subrounded gravels up to 60 mm, abrupt lower boundary
	7	3.12-3.15	10YR5/3	silty clayey fine sand, abrupt lower boundary
I	8	3.15-3.81	2.5Y6/1	clay, with very few, very weak 10YR5/6 indistinct fine mottles to depth with moderate amount of 10YR2/1 weak, fine horizontal lamina throughout, abrupt lower boundary
	9	3.81-12.50	2.5Y6/1	silty very fine sand with 10YR2/1 and 10YR6/4 lamina, 3.81-4.22: lamina contorted, disturbed, possibly by injection; 4.22-5.05: slightly silty very fine sand with distinct horizontal lamina of 10YR6/4 silty very fine sand and 10YR4/1 silty clay; 5.05-8.15: slightly silty very fine sand contorted irregular subhorizontal to vertical, possible disturbances due to coring, abrupt lower boundary, 8.15-9.85: horizontally bedded fine sand with few fine 10YR2/1 and 10YR6/4 fine 5 mm thick lamina, gradual lower boundary; 9.85-10.05: subhorizontal distinct 10YR2/1 3 mm lamina; 10.05-11.10: very fine sand with occasional 10YR2/1 distinct fine (3mm) and 10YR6/4 indistinct (5 mm) lamina, clear lower boundary; 11.10-11.60: very fine sand, occasional slightly contorted 10YR2/1 lamina increasing in lamina thickness and frequency to a "stacked sequence" between 11.45-11.60, abrupt lower boundary; 11.60-12.50: clean very fine sand with very few (~2-3) lamina

Core A-4

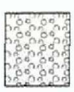




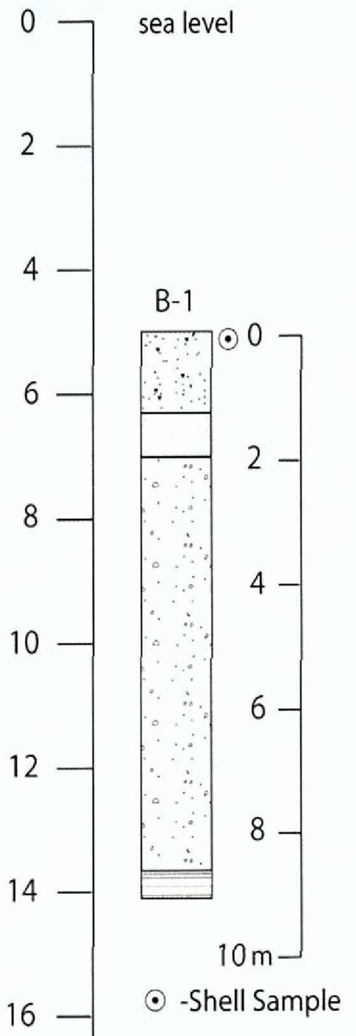
Core: A-4
Location: 40°27.79N 74°10.9W
Water Depth: 11.5' (3.51m)
Pene 34' (10.36m), Recov 20' (6.10m)
Description (depths in meters below core top)

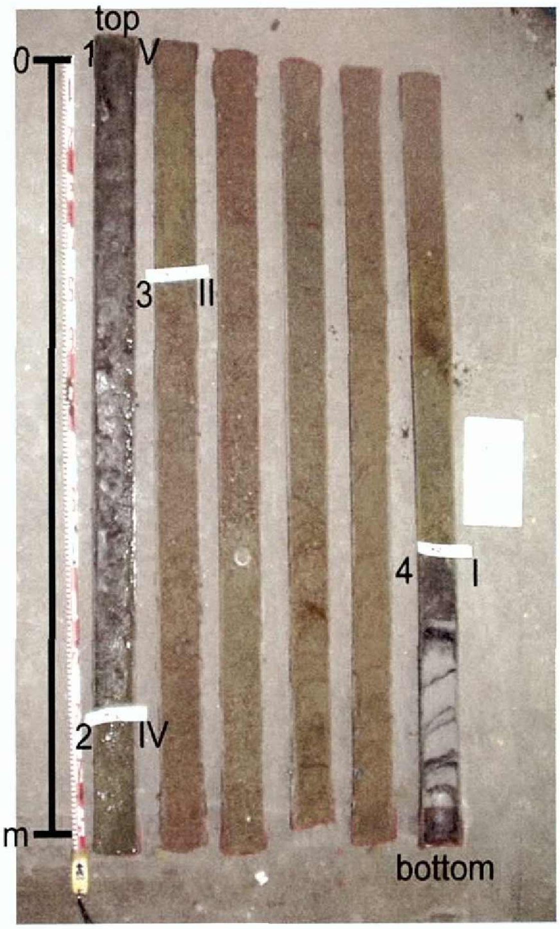


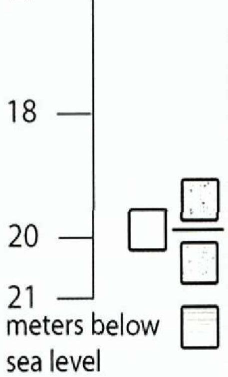
Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
III	1	0-0.20	10YR5/4	fine to coarse gravelly sand, with gravels up to 40 mm at top, abrupt lower boundary
	2	0.20-1.80	10YR5/4	clean fine to coarse sand, fining upward from medium to coarse at base to medium to fine at top, occasional gravel up to 40 mm at base, abrupt lower boundary
	3	1.80-2.65	2.5Y4/3	fine to medium sand fining upward to fine sand at top, well rounded gravel up to 20 mm at base, abrupt lower boundary
	4	2.65-3.40	2.5Y4/2	silty fine sand, with thin gravel lense at 3.15, abrupt lower boundary
	5	3.40-4.26	2.5Y4/3	fine to medium sand, to coarse silty sand at base, angular red crystalline rock at 3.85, abrupt lower boundary
	6	4.26-5.21	2.5Y5/2	clean fine to medium sand, fining upwards from coarse to medium sand at base, abrupt at base
	7	5.21-5.75	2.5Y5/3	medium to coarse sand with fine gravel, fines upward from coarse sand to fine gravel at base, gravels up to 70 mm, abrupt lower boundary
	8	5.75-5.95	5YR4/3	fining upward gravelly coarse sand to medium to coarse sand at top, gravels to 70 mm, weathered, forms into lower gravelly till, abrupt lower boundary
II	9	5.95-6.20	2.5Y4/2	*clayey silty sandy gravel (till)*



Core B-1



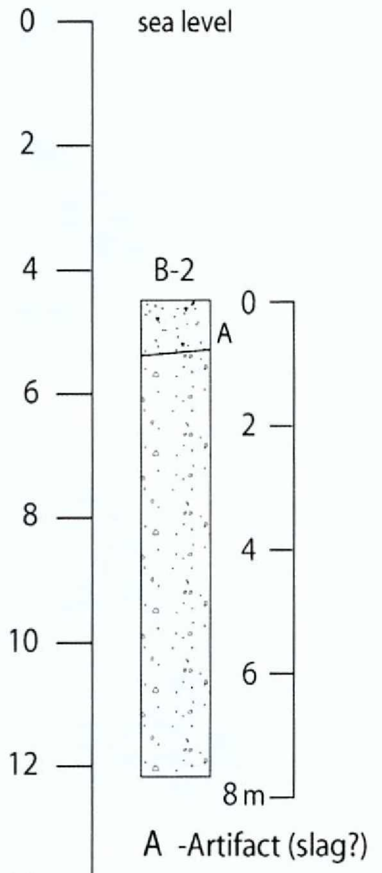


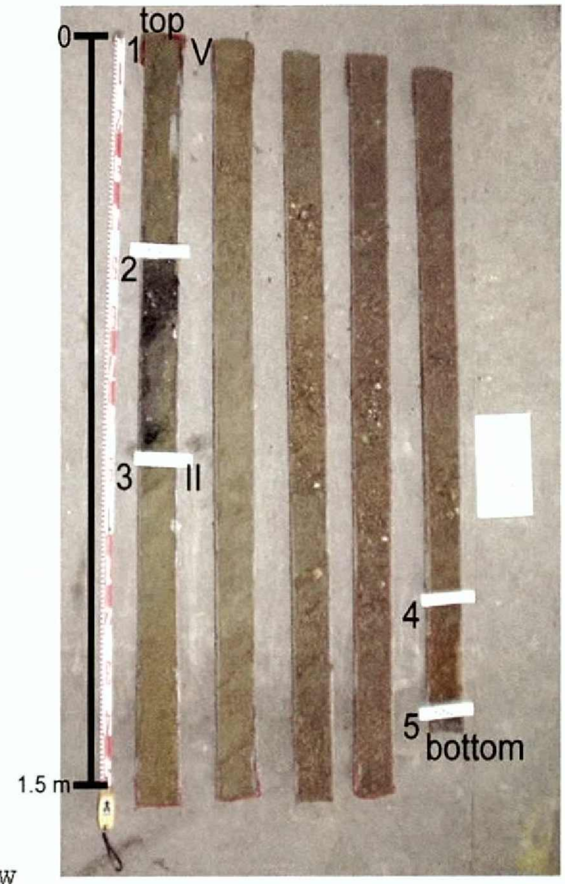


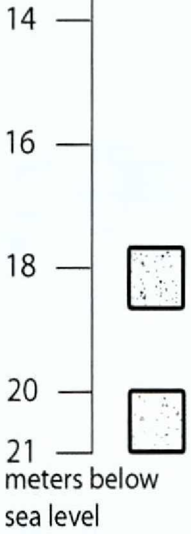
Core: B-1
Location: 40°28.74N 74°09.26W
Water Depth: 16.5' (5.03m)
Pene 37' (11.28m), Recov 30'6" (9.30m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
V	1	0-1.30	10YR3/1	clayey sandy silt, with occasional fine broken shell throughout, abrupt lower boundary
IV	2	1.30-2.01	2.5Y4/3	clean fine to medium sand, poss. reworked beach? abrupt lower boundary
II	3	2.01-8.68	2.5Y4/3	clean fine to coarse sand, with fining upward sequence of poorly sorted fine to coarse sands to moderately well sorted fine to medium sands, weathered sandstone boulder at 8.25, abrupt lower boundary
I	4	8.68-9.15	10YR5/1	well sorted fine sand with common, horizontal to subhorizontal distinct 10YR2/1 5 mm to 15 mm thick lamina, 20 mm thick 10YR2/1 lamina couplet at 8.88, lower portion 8.82-9.15 include few gravels in moderately sorted fine to medium sand

Core B-2



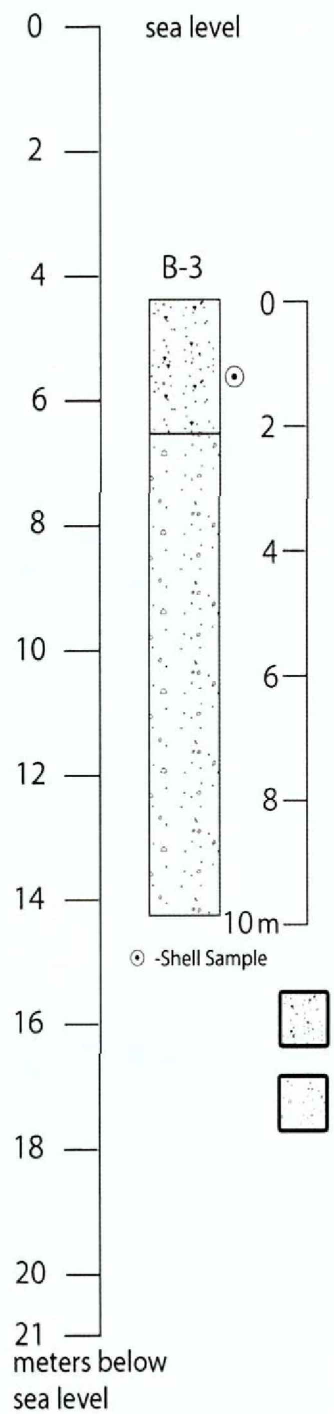


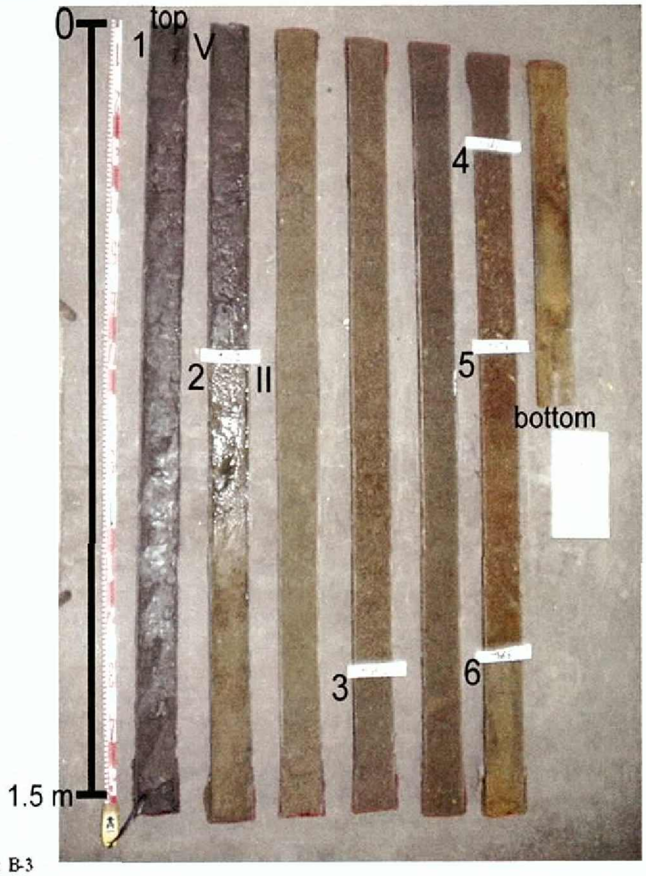


Core: B-2
Location: 40°28.11N 74°08.98W
Water Depth: 14.8' (4.51m)
Pene 34' (10.36m), Recov 24'6" (7.47m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
V	1	0-0.45	10YR3/4	clean fine to medium sand, abrupt lower boundary
	2	0.45-0.80/0.89	10YR3/1	silty fine sand with common small broken shells and 2 black slag-like cultural objects, abrupt lower boundary
II	3	0.80/0.89-7.30	10YR5/3	interbedded clean fine to medium sands to gravelly sands with gravels up to 30-40 mm
	4	7.30-7.50	5YR4/4	coarse sandy gravel, gravels up to 5 cm X 2 cm, abrupt lower boundary
	5	7.50-7.60	2.5Y4/1	very silty fine sand

Core B-3

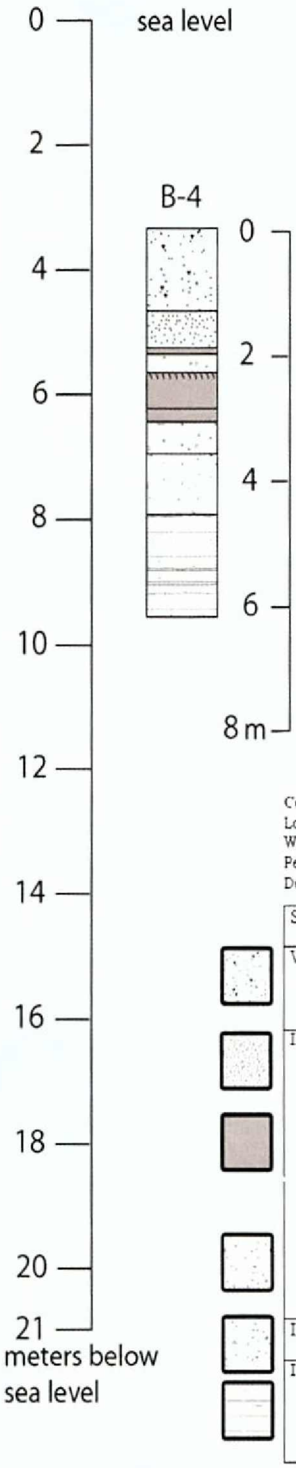


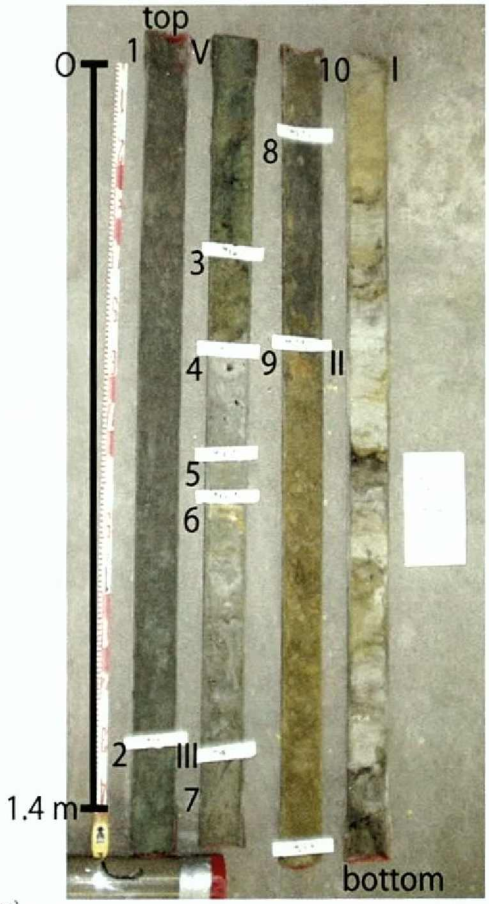


Core: B-3
Location: 40°27.72N 74°09.06W
Water Depth: 14.4' (4.39m)
Pene 40' (12.19m), Recov 32'4" (9.86m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
V	1	0-2.15	10YR3/1	clayey silty sand with shell fragments throughout, gradual lower boundary
II	2	2.15-5.85	10YR5/3	clean fine to medium sand, 5.35-5.85: *poorly sorted* fine to coarse sand up to granules and few gravels to 15 mm, abrupt lower boundary
	3	5.85-7.85	10YR4/2	well sorted medium sand, interbedded with gravelly medium to coarse sand, few gravels to 10 mm, abrupt lower boundary
	4	7.85-8.25	10YR3/3	poorly sorted fine to coarse sand, with granules and rounded gravels to 30-40 mm
	5	8.25-8.89	5YR4/3	poorly sorted fine to coarse sand with common gravels from granule to well rounded gravels to 30 mm, abrupt lower boundary
	6	8.89-9.90	7.5YR5/4	well sorted fine to medium sand, with distinct gravel lens from 9.45-9.58 which includes weathered sandstone fragments

Core B-4

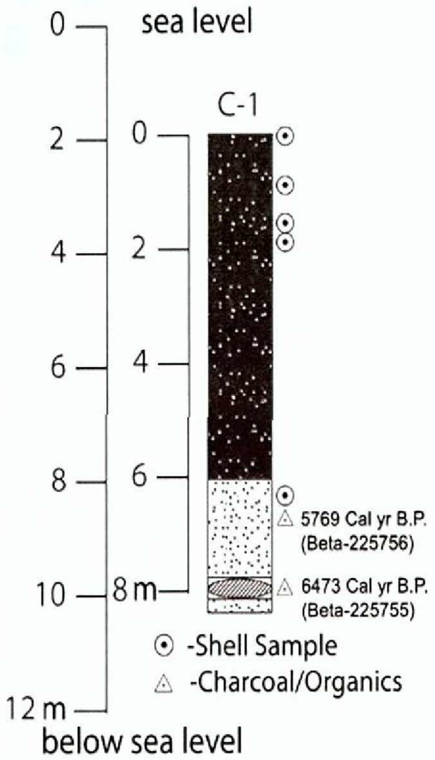




Core: B-4
Location: 40°27.35N 74°09.05W
Water Depth: 10.9' (3.32m)
Pene 34' (10.36m), Recov 20' (6.10m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
V	1	0-1.35	10YR3/1 at base to 10YR3/2 at top	silty to slightly silty fine to medium sand, coarsening upwards from base, abrupt lower boundary
III	2	1.35-1.93	GLEY1 4/5GY	slightly silty fine to medium glauconitic sand
	3	1.93-2.11	2.5YR4/3	poorly sorted clayey, silty, sandy gravelly sand
	4	2.11-2.31	10YR4/1	silty clay with organics, abrupt lower boundary
	5 6	2.31-2.38 2.38-2.85/3.05	2.5Y5/1 10YR4/2	fairly well sorted fine to medium sand silty clay with 7.5YR6/8 oxidized zone in upper 5 cm
	7	2.85/3.05-3.23	10YR4/2	slightly silty clay, abrupt lower boundary
	8	3.23-3.62	10YR2/1	very silty fine to medium sand with gravel at base, fining upwards to sandy silt, abrupt lower boundary
II	9	3.62-4.57	2.5Y5/3	poorly sorted gravelly sand with gravels up to 5 cm
I	10	4.57-6.12	2.5Y6/1	slightly silty fine sand and fine to medium sand with thin 10YR2/1 and occasional horizontally bedded oxidized 2.5Y6/4 laminations in upper 4.57-4.82, dark gray clay band from 5.31-5.34

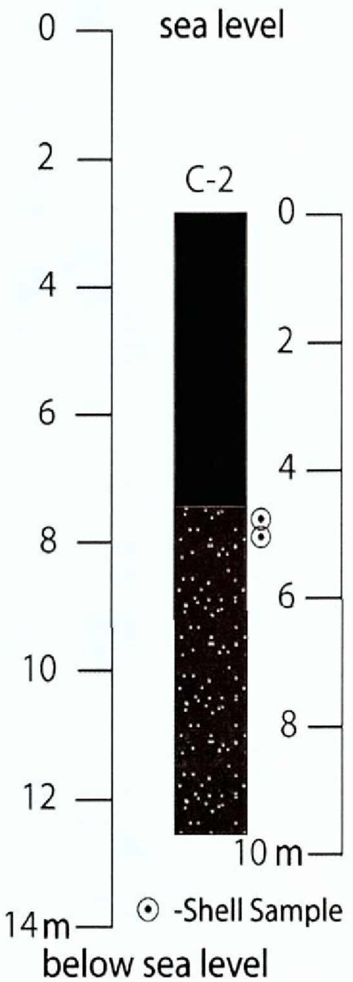
Core C-1



Core: C-1
Location: 40°41.19N 74°02.98
Water Depth: 6.4' (1.95m)
Pene 30' (9.14m), Recov 27'3" (8.31m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
II	1	0-6.05	10YR3/1	slightly silty clay, very occasional small whole shells, including oyster and mussel, clear lower boundary
I	2	6.05-7.78	10YR3/1	silty fine to medium sand, becomes cleaner with depth, shell fragment and one wood branch, abrupt lower boundary
	3	7.78-8.15	-	organic decaying wood partially decayed black to brown, possibly a wood log decaying in place, abrupt lower boundary
	4	8.15-8.40	10YR3/1	silty fine to medium sand, possibly darker because of organics

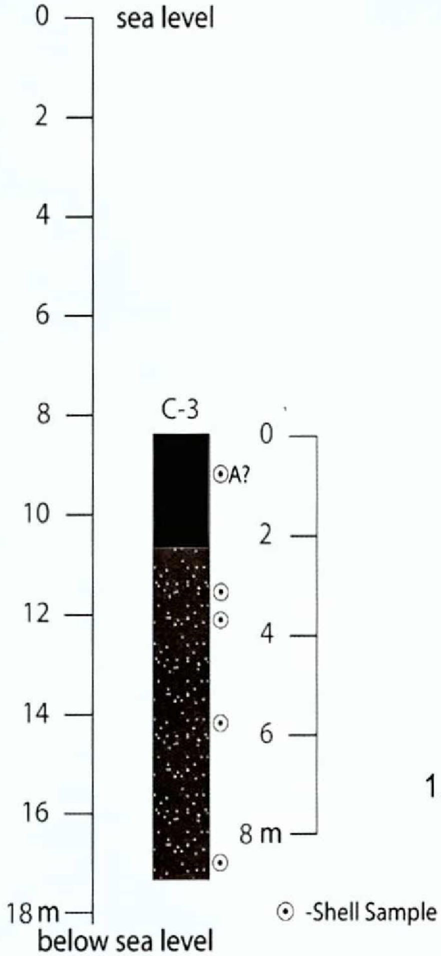
Core C-2

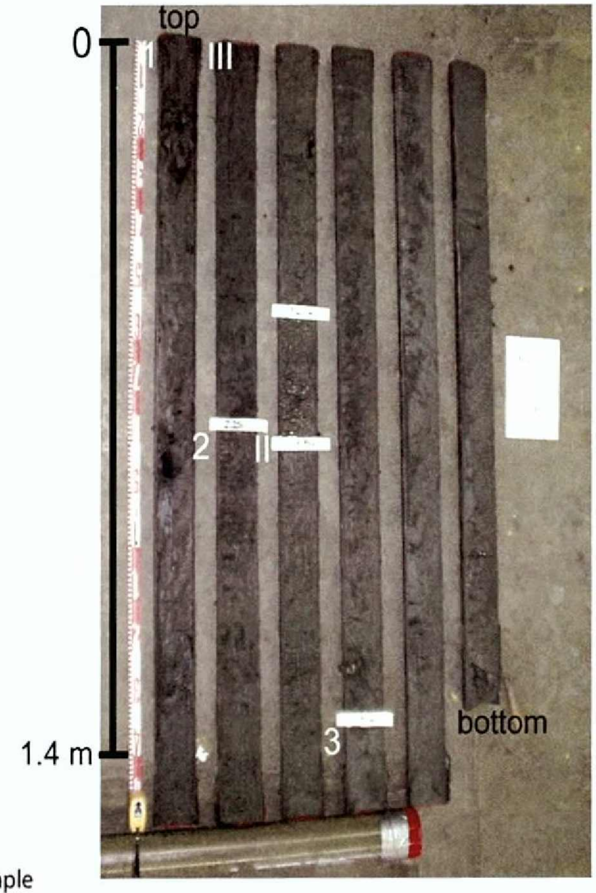


Core: C-2
Location: 40°41.12N 74°02.82W
Water Depth: 9.5' (2.90m)
Pene 35.8' (10.91m), Recov 31.8' (9.69m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
III	1	0-4.60	10YR2/1	oily clay muck, no shell, H_2S smell, abrupt lower boundary
II	2	4.60-9.70	10YR3/1	silty clay with fine shell fragments throughout

Core C-3

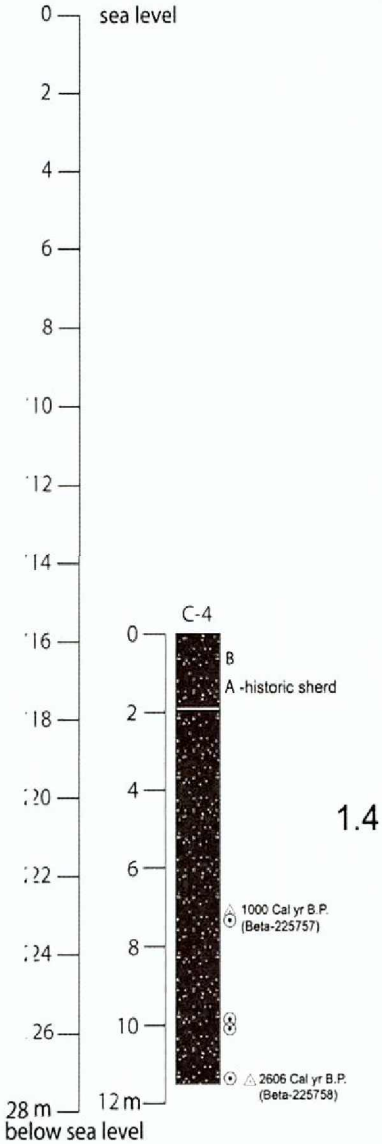


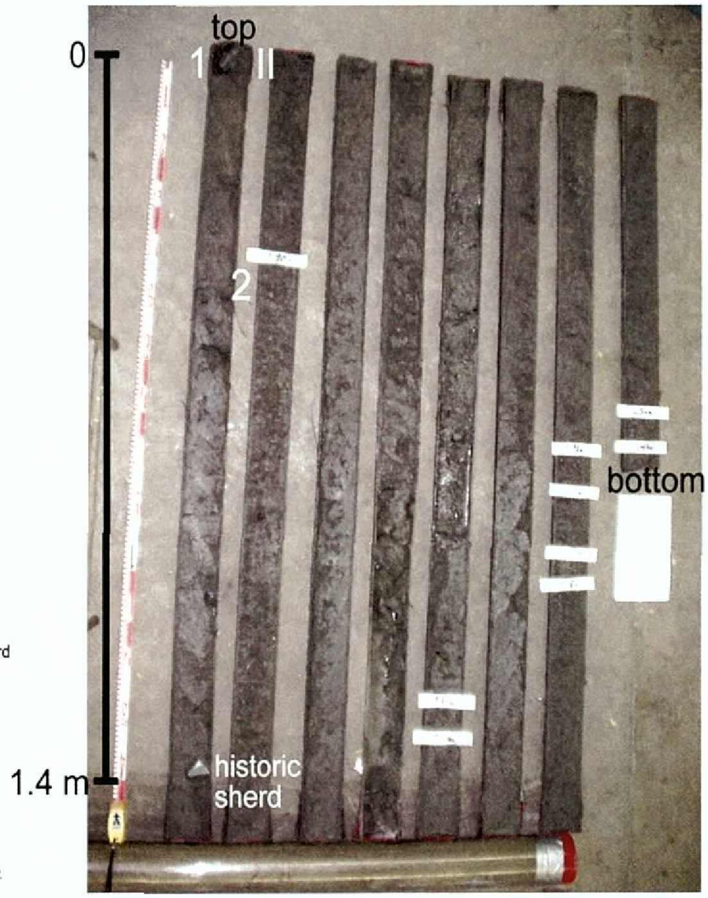


Core: C-3
Location: 40°41.04N 74°02.65W
Water Depth: 29' (8.84m)
Pene 38.26' (11.66m), Recov 29.26' (8.92m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
III	1	0-2.25	10YR2/1	oily clay muck, very occasional shell fragments, inclusions of brown clay streaks, weak diesel/oil smell, abrupt lower boundary
II	2	2.25-5.95	10YR3/1	silty clay with shell fragments throughout, including shell hash lenses, abrupt lower boundary
	3	5.95-8.95	10YR4/1	clay, very occasional broken shell fragments, shell concentration of small broken fragments from 8.65-8.70

Core C-4

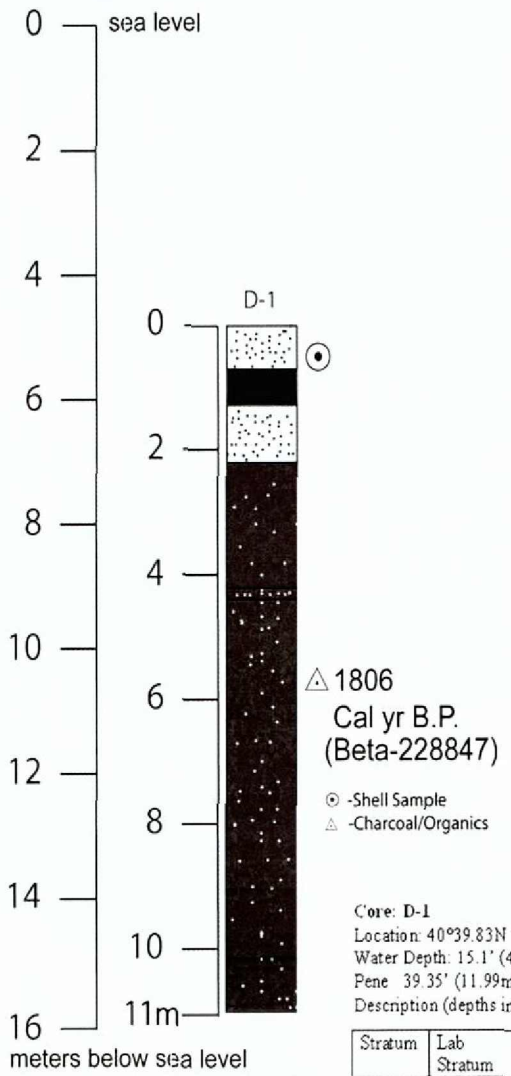


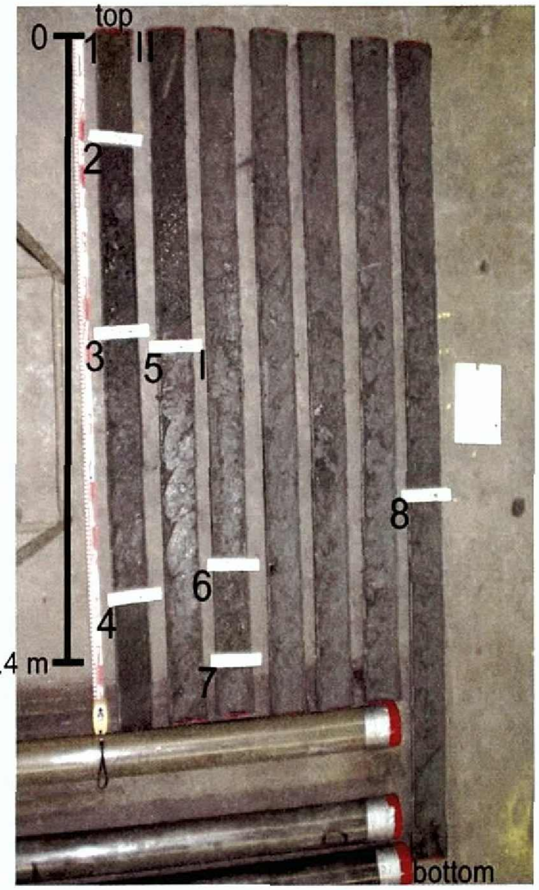


Core: C-4
Location: 40°40.97N 74°02.45W
Water Depth: 51.8' (15.79m)
Pene 39.38' (12.00m), Recov 37.4' (11.40m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
II	1	0-1.90	10YR2/1	silty clay, with 10YR3/1 subhorizontal clay inclusions (ie disturbance) very occasional shell fragments, 0.60: fish bone, 1.40: ceramic sherd, abrupt lower boundary
	2	1.90-11.48	10YR3/1	silty clay with distinct shell hash lenses of small broken shell with occasional small broken shell found throughout, voids from 5.55-6.10 and 6.85-7.00 due to core slipping from tube during collection, organics collected from 11.60

Core D-1

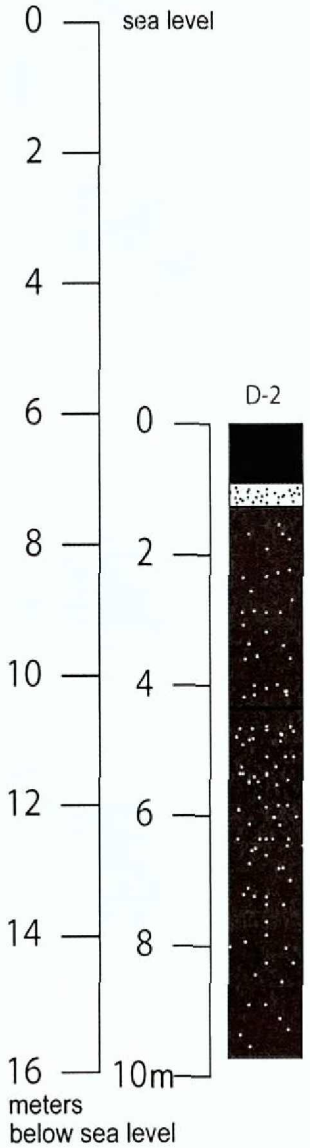


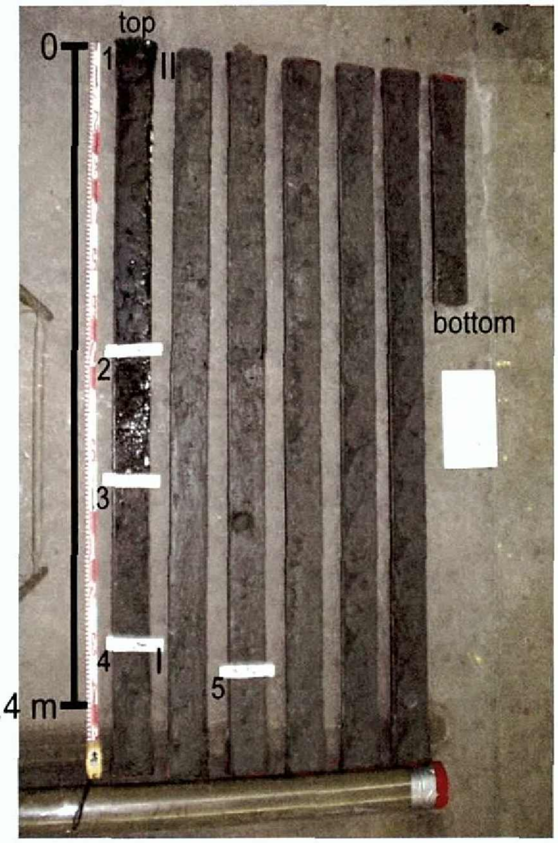


Core: D-1
Location: 40°39.83N 74°01.47W
Water Depth: 15.1' (4.60m)
Pene 39.35' (11.99m), Recov 36.2' (11.03m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
II	1	0-0.25	10YR3/2	slightly silty fine to medium sand, abrupt lower boundary
	2	0.25-0.68	10YR2/1	slightly silty fine to medium sand with large shell fragments, has oily smell, smooth lower boundary
	3	0.68-1.25	10YR3/1	silty fine to medium sand, no shells
	4	1.25-2.20	10YR3/1	slightly silty fine to medium sand, very occasional snail shell fragment, 1 clay filled burrow, gradual lower boundary
I	5	2.20-4.22	10YR2/1	silty clay, with shells, including small clam, abrupt lower boundary
	6	4.22-4.40	10YR3/1	clay, increased shell concentrations, abrupt lower boundary
	7	4.40-10.18	10YR3/1	silty clay, occasional shell fragments throughout
	8	10.18-11.00	10YR3/1	silty clay, no shell

Core D-2

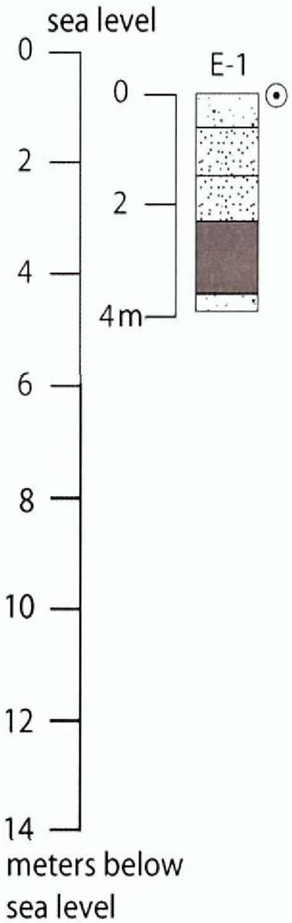


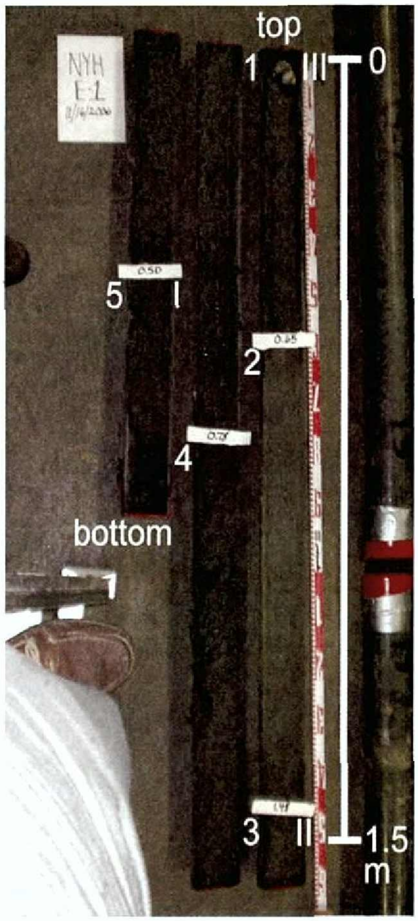


Core: D-2
Location: 40°39.91N 74°01.80W
Water Depth: 19.9' (6.07m)
Pene 39.37' (12.0m), Recov 31.9' (9.72m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
II	1	0-0.65	10YR2/1	oily clay, no shells, abrupt lower boundary
	2	0.65-0.90	10YR2/1	oily clayey silty fine to medium sand, with shells, wood, abrupt lower boundary
	3	0.90-1.25	10YR3/1	slightly silty medium sand
I	4	1.25-4.35	10YR3/1	fine sandy clayey silt with occasional shell fragments throughout, sandstone pebble at 4.05, gradual lower boundary
	5	4.35-9.70	10YR3/1	clayey silt with occasional shell fragments

Core E-1

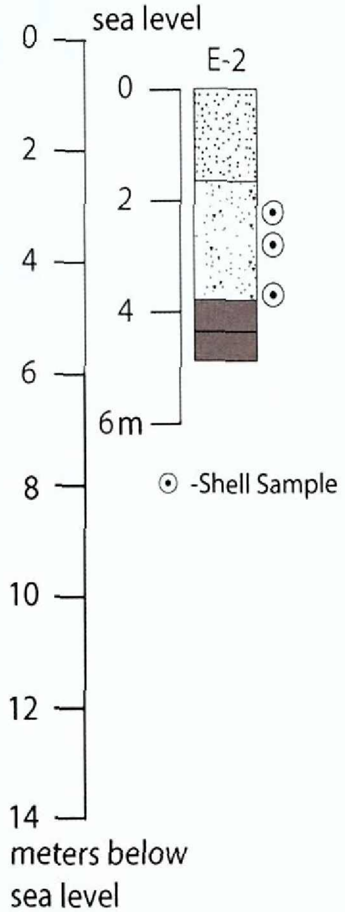




Core: E-1
Location: 40°36.22N 73°50.58W
Water Depth: 2.5' (0.76m)
Pene 15.9' (4.85m), Recov 12.9' (3.93m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
III	1	0-0.60	10YR3/1	fine sandy clayey silt grading to fine sand at base, clam at surface
	2	0.60-1.48	10YR5/1	well sorted subangular fine to medium sand grading to silt at top and bottom, gradual lower boundary
II	3	1.48-2.30	10YR3/1	clayey silty fine sand, gradual lower boundary
	4	2.30-3.60	10YR3/1	clayey fine sandy silt, gradual lower boundary
I	5	3.60-3.90	10YR3/1	silty fine sand with shell fragments

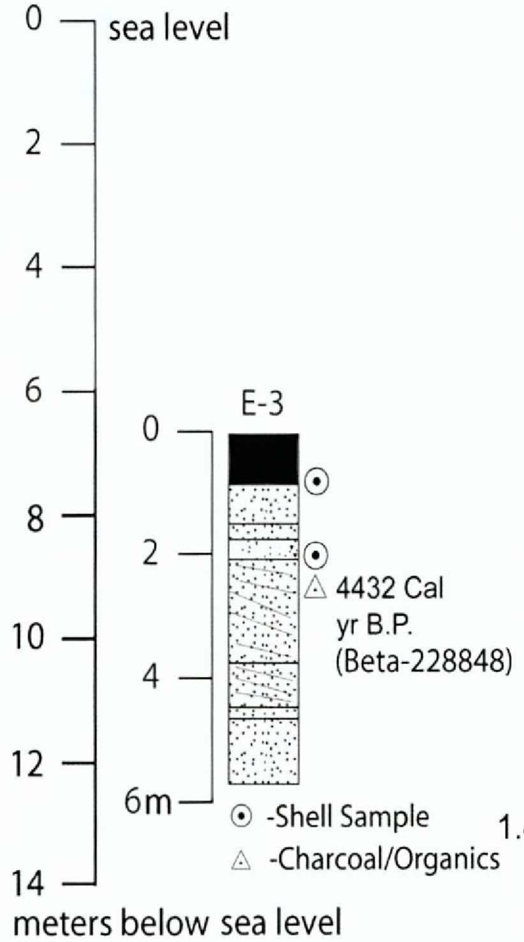
Core E-2

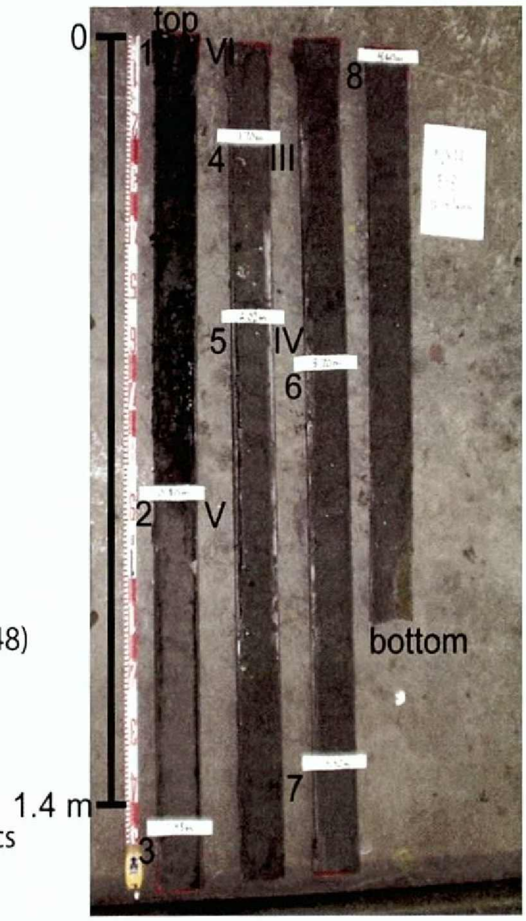


Core: E-2
Location: 40°36.16N 73°50.76W
Water Depth: 2.9' (0.88m)
Pene 20' (6.10m), Recov 16.8' (5.12m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
VI	-	0-0.10	10YR3/1	Disturbed, dark gray silty fine sand
	1	0.10-1.65	10YR5/1	well sorted fine sand, clear lower boundary with an increase in silt with depth
III	2	1.65-3.80	10YR4/1	clayey silty fine sand, saturated, three shell hash lenses, clear lower boundary
II	3	3.80-4.35	10YR3/1	clayey silt, small shell fragments
	4	4.35-4.88	10YR3/1	clayey sandy silt

Core E-3

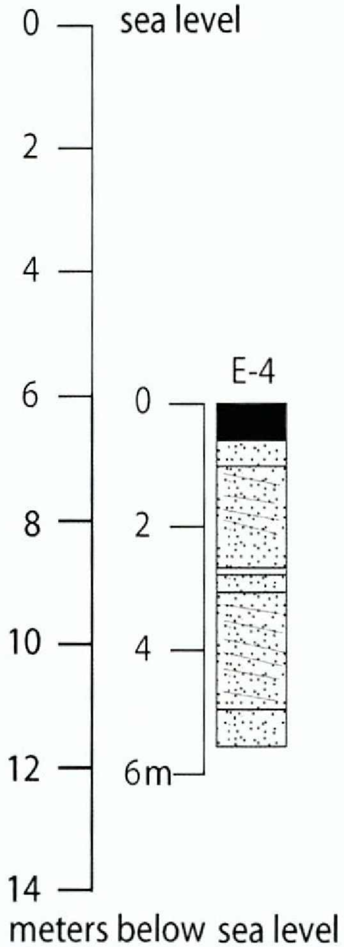


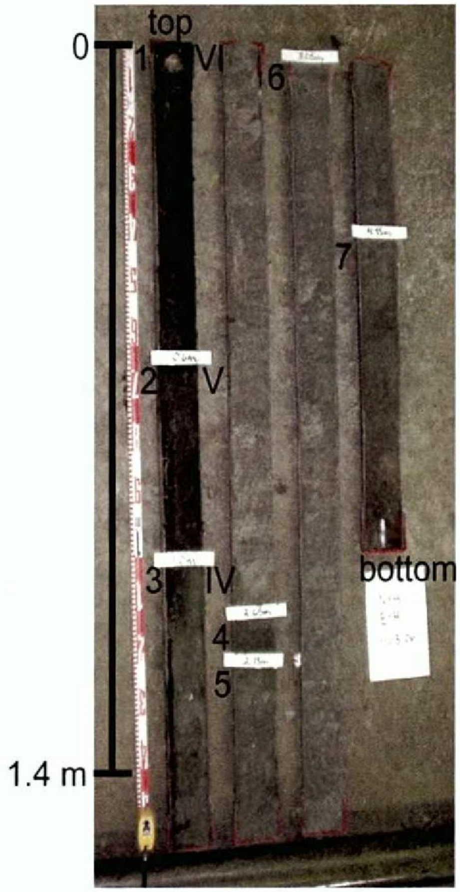


Core: E-3
Location: 40°35.99N 73°53.91W
Water Depth: 21.9' (6.68m)
Pene 20' (6.10m), Recov 18.5' (5.64m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
VI	1	0-0.80	10YR2/1	organic silty clay muck, abrupt lower boundary
V	2	0.80-1.45	10YR5/1	fine sand
	3	1.45-1.70	10YR5/1	medium to coarse sand
III	4	1.70-2.03	10YR5/1	fine to medium sand, with shell hash including jingle shell at base of strat
IV	5	2.03-3.70	10YR4/1	fine to medium sand, with occasional 5 mm thick 10YR3/1 silt lamina subhorizontal dipping 30-40°, with organic fragments collected for 14C and ID
	6	3.70-4.40	10YR4/1	coarse sand, interbedded with occasional 10YR3/1 10 mm thick silt lamina, subhorizontal dipping 30-40°
	7	4.40-4.60	10YR5/1	fine sand
	8	4.60-5.65	10YR4/1	medium to coarse subangular to subrounded sand

Core E-4

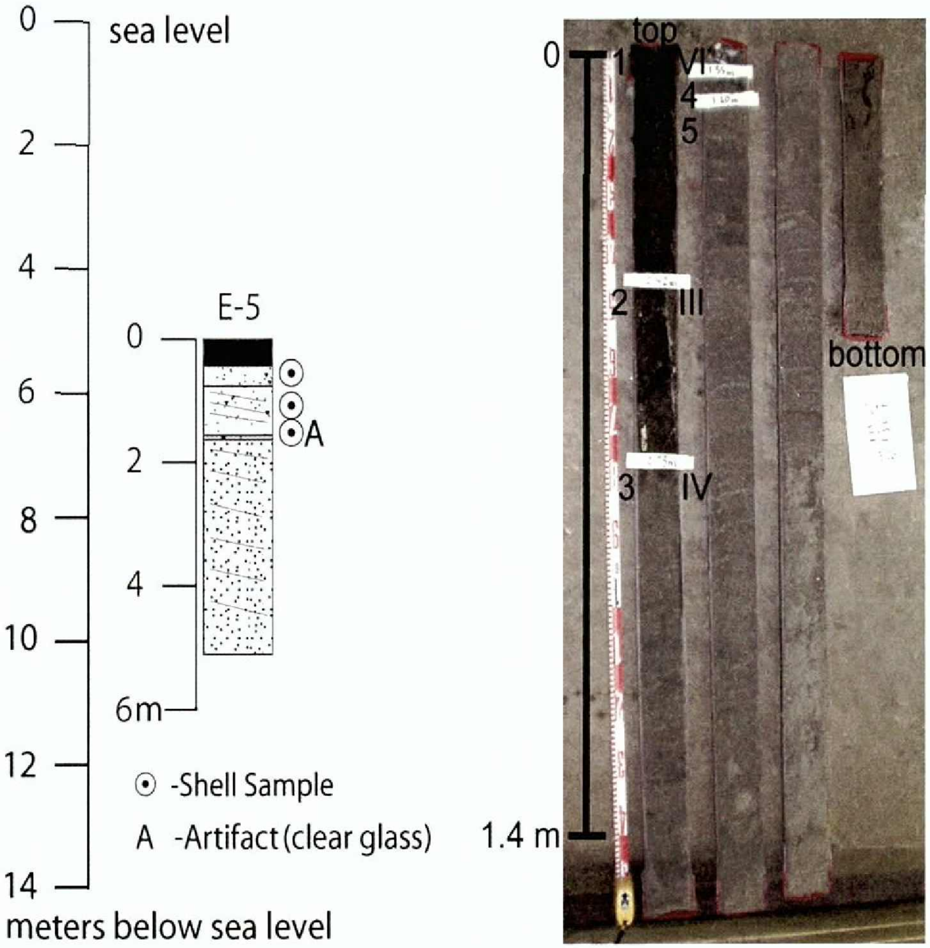




Core: E-4
Location: 40°35.99N 73°50.91W
Water Depth: 20' (6.10m)
Pene 20' (6.10m), Recov 18' (5.49m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	Description
VI	1	0-0.60	10YR2/1	organic silty clay muck, smell of H_2S
V	2	0.60-1.00	10YR3/1	organic silty fine sand
IV	3	1.00-2.65	10YR5/1	fining upward sequence of medium to fine sand, with fairly indistinct fine subhorizontal dark mineral lamellae above 2.30, abrupt lower boundary
	4	2.65-2.75	10YR5/1	slightly clayey silty fine sand, with small shell fragments, abrupt lower boundary
	5	2.75-3.05	10YR5/1	fine to medium sand
	6	3.70-4.40	10YR5/1	fining upward from medium to fine sand, with fairly indistinct fine subhorizontal dark mineral lamellae, abrupt lower boundary
	7	4.95-5.55	10YR3/1	slighty silty fine to coarse sand with medium sands dominant

Core E-5



Core: E-5
Location: 40°35.57N 73°51.00W
Water Depth: 22.6' (6.89m)
Pene 20' (6.10m), Recov 16.8' (5.12m)
Description (depths in meters below core top)

Stratum	Lab Stratum	Depth (m)	Munsell Color	*Description*
VI	1	0-0.42	10YR2/1	organic silty clay muck, smell of H_2S, clear lower boundary
III	2	0.42-0.75	10YR3/1	silty fine sand, with shell fragments including razor clam, abrupt lower boundary
IV	3	0.75-1.55	10YR5/1	fining upward sequence from fine to medium sand at base to fine sand at top, occasional fine subhorizontal lamina of dark minerals, shell hash with oyster and gastropod shells at base, abrupt lower boundary
	4	1.55-1.60	10YR4/1	silty fine sand with shell and broken glass, abrupt upper and lower boundary
	5	1.60-5.10	10YR5/1	well sorted fining upward sequence from fine to medium sands at base to fine sand at top, very occasional horizontal to subhorizontal dark mineral lamellae

APPENDIX B

Radiocarbon Ages

Location	Elevation mbmsl	ftbmsl	Material	Lithofacies	Age 14C yrs BP	Calibrated Age cal yrs BP Oxcal	Mid Point	Lab Number	Source
Anchor Channel - 98ANC44	20.12	66	wood	Fluvial sand	9400+/-150	11121 - 10258	10690	Beta 127019	Schuldenrein et al., 2000
Arthur Kill - WP-VI	20.73	68	peat	Fluvial sand	7950+/-70	8998 - 8607	8803	?	LaPorta et al. 1999
Arthur Kill - Shooters Is.	2.3	7.55	wood	Fluvial sand	3040+/-120	3549 - 2881	3215	Beta 137984	Schuldenrein et al., 2000
Arthur Kill - Shooters Is.	4.6	15.09	bulk sediment	Estuarine silt	4340+/-80	5285 - 4655	4970	Beta 137986	Schuldenrein et al., 2000
Arthur Kill - Shooters Is.	2.56	8.4	bulk sediment	Estuarine silt	6100+/-60	7162 - 6798	6980	Beta 137985	Schuldenrein et al., 2000
Hackensack Marsh -	0.1	0.33	reed muck	Freshwater marsh	240+/-110	489 - minus 3	241	RL-1030	Carmichael, 1980
Hackensack Marsh -	0.7	2.3	sedge peat	Brackish marsh	810+/-110	935 - 556	746	RL-1031	Carmichael, 1980
Hackensack Marsh -	1.8	5.91	sedge peat	Brackish marsh	2060+/-120	2338 - 1740	2039	RL-1032	Carmichael, 1980
Hackensack Marsh -	2.8	9.19	woody peat	Forested wetland?	2610+/-130	2992 - 2350	2671	RL-1033	Carmichael, 1980
Hackensack Marsh -	2.3	7.55	peat	Freshwater marsh?	2025+/-300	2742 - 1384	2063	I-510	Heusser, 1962
Jersey City, NJ - R15-4	2.2	7.4	organics in silt	Estuarine silt	1320+/40	1304 - 1175	1240	Beta 171330	Schuldenrein 2006
Jersey City, NJ - R15-4	8.9	29.1	organics in silt	Estuarine silt	5130+/-40	5986 -5749	5868	Beta 171331	Schuldenrein 2006
Jersey City, NJ - R15-4	10.1	33.1	shell	Estuarine silt	4670+/-50	5580 - 5306	5443	Beta 171332	Schuldenrein 2006
Jersey City, NJ - R15-4	10.1	33.1	organics in silt	Estuarine silt	5980+/-50	6943 - 6678	6811	Beta 171333	Schuldenrein 2006
Jersey City, NJ - R15-4	16.6	54.3	peat	Freshwater marsh?	9140+/-70	10497 - 10198	10348	Beta 171334	Schuldenrein 2006
Pine Creek Marsh, NJ	2.71	8.7	basal peat	Brackish marsh	2130+/-60	2315 - 1951	2133	Beta 76536	Kenen, 1999
Pine Creek Marsh, NJ	2.1	6.7	basal peat	Brackish marsh	1690+/-70	1809 - 1412	1610	Beta 76537	Kenen, 1999
Pine Creek Marsh, NJ	3.85	12.5	basal peat	Brackish marsh	2710+/-60	2986 - 2744	2845	Beta 79340	Kenen, 1999
Pine Creek Marsh, NJ	2.7	8.7	basal peat	Brackish marsh	2170+/-70	2335 - 2001	2168	Beta 79341	Kenen, 1999
Pine Creek Marsh, NJ	2.42	8	basal peat	Brackish marsh	1780+/-70	1866 - 1547	1706	Beta 79342	Kenen, 1999
Pine Creek Marsh, NJ	3.54	11.5	basal peat	Brackish marsh	2210+/-70	2348 - 2041	2195	Beta 79343	Kenen, 1999
Pine Creek Marsh, NJ	1.67	5.47	basal peat	Brackish marsh	1410+/-80	1518 - 1175	1347	Beta 79344	Kenen, 1999
Pine Creek Marsh, NJ	2.42	8	basal peat	Brackish marsh	1820+/-80	1896 - 1566	1731	Beta 90574	Kenen, 1999
Pine Creek Marsh, NJ	2.48	8.2	basal peat	Brackish marsh	1970+/-80	2121 - 1726	1923	Beta 90575	Kenen, 1999
Pine Creek Marsh, NJ	4.06	13.5	basal peat	Brackish marsh	2690+/80	3003 - 2518	2760	Beta 90577	Kenen, 1999
South Shore Long Island	18.6	61.02	peat	Brackish marsh	7750+/-125	8980 - 8361	8671	I-5880	Field et al., 1979
South Shore Long Island	16.4	53.8	peat	Brackish marsh	7585+/-125	8641 - 8057	8349	I-?	Field et al., 1979
Liberty Island C-1	8.7	28.54	wood	Wood in fluvial sand	5000+/-40	5893 - 5644	5769	Beta 225755	This report
Liberty Island C-1	10.1	33.14	wood	Wood in fluvial sand	5660+/-90	6651 - 6295	6473	Beta 225756	This report
Liberty Island C-4	23.04	75.6	wood in silt	Estuarine silt	1090+/-40	1073 - 927	1000	Beta 225757	This report
Liberty Island C-4	27.26	89.46	organics in silt	Estuarine silt	2520+/-40	2746 - 2466	2606	Beta 225758	This report
Bay Ridge Flats D-1	10.18	33.41	wood	Estuarine silt	1880+/-40	1897 - 1715	1806	Beta 228847	This report
Jamaica Bay E-3	9.8	32.14	organics in sand	fine to med sand	3980+/-40	4567 - 4296	4432	Beta 228848	This report
Jersey Flats JF-1	5.6	18.3	organics in silt	Estuarine silt	3460+/-40	3839 - 3633	3736	Beta 150701	Schuldenrein et al., 2005
Jersey Flats JF-6	5.96	19.56	organics in silt	Estuarine silt	3360+/-40	3692 - 3480	3586	Beta 150704	Schuldenrein et al., 2005
Jersey Flats JF-3	9.7	31.8	organics in silt	Estuarine silt	1970+/-60	2112 - 1741	1927	Beta 150703	Schuldenrein et al., 2005
Jersey Flats JF-3	8.7	28.6	organics in silt	Estuarine silt	2360+/-70	2706 - 2180	2443	Beta 150702	Schuldenrein et al., 2005
Thomas Paine Park B-1	2.3	7.5	peat	Brackish marsh	1220+/-60	1282 - 989	1136	Beta 130393	Schuldenrein et al., 2001
Thomas Paine Park B-1	3	10	peat	Brackish marsh	2490+/-60	2735 - 2364	2550	Beta 130394	Schuldenrein et al., 2001
Sandy Hook, NJ	27	88.6	organics in silt	Estuarine silt	9860+/-300	12566 - 10502	11534		Minard, 1969
Tappan Zee, SD30	4.4	14.44	oyster	Estuarine silt	1940+/-35*	*	927	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	5.11	16.77	oyster	Estuarine silt	2370+/-60*	*	1307	Zurich	Carbotte et al., 2004
Tappan Zee, SD30	6.38	20.93	shell	Estuarine silt	3720+/-50*	*	2853	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	7.2	23.62	shell	Estuarine silt	4160+/-35*	*	3425	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	9.66	31.69	shell	Estuarine silt	4800+/-65*	*	4244	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	10.1	33.14	shell	Estuarine silt	4820+/-65*	*	4287	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	11.31	37.11	shell	Estuarine silt	5060+/-40*	*	4608	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	11.63	38.16	shell	Estuarine silt	5250+/-65	*	4851	NOSAMS	Carbotte et al., 2004
Tappan Zee, SD30	12.86	42.19	shell	Estuarine silt	6150+/-65*	*	5931	NOSAMS	Carbotte et al., 2004

Location	Elevation mbmsl	Elevation ftbmsl	Material	Lithofacies	Age 14C yrs BP	Calibrated Age cal yrs BP Oxcal	Mid Point	Lab Number	Source
Tappan Zee, SD30	13.61	44.65	oyster	Estuarine silt	6270+/-70*	*	6058	Zurich	Carbotte et al., 2004
Tappan Zee, SD11	3.62	11.88	oyster	Estuarine silt	2560+/-35*	*	1522	LLNL	Carbotte et al., 2004
Tappan Zee, SD11	5.18	16.99	shell	Estuarine silt	4230+/-40*	*	3473	LLNL	Carbotte et al., 2004
Tappan Zee, SD11	9.64	31.63	shell	Estuarine silt	6295+/-45*	*	6133	LLNL	Carbotte et al., 2004
Tappan Zee, LWI-79	6.32	20.73	oyster	Estuarine silt	3050+/-60*	*	2091	Zurich	Carbotte et al., 2004
Tappan Zee, LWI-25	4.88	16.01	oyster	Estuarine silt	1765+/-55*	*	728	Zurich	Carbotte et al., 2004
Tappan Zee, LWI-56	5.35	17.55	oyster	Estuarine silt	3280+/-65*	*	2346	Zurich	Carbotte et al., 2004
Tappan Zee, LWI-4	11.96	39.24	oyster	Estuarine silt	2135+/-60*	*	1164	Zurich	Carbotte et al., 2004
Tappan Zee, CD02-08	12.31	40.39	oyster	Estuarine silt	2080+/-40*	*	1028	LLNL	Carbotte et al., 2004
Raritan Bay RB-08	11.7	38.39	wood fragments	coarse sand	31740+/-1830			Beta 90133	Gaswirth, S.B., 1999
Arthur Kill Marsh	8	26.2	peat	Freshwater marsh	11100	13189 - 12873	13031		Peteet et al., in press
Piermont Marsh	13.7	45	peat	marsh	5700	6719 - 6299	6509		Peteet et al., in press
Croton Marsh	**10**	**32.8**	**peat**	**marsh**	**4630**	**5589 - 5040**	**5315**		**Peteet et al., in press**
Iona Marsh	**10**	**32.8**	**peat**	**marsh**	**5500**	**6494 - 6002**	**6248**		**Peteet et al., in press**