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Geoarchaeology
2008

GEOARCHAEOLOGICAL STUDY OF BURIED LANDSCAPES FOR THE PROPOSED 2ND AVENUE SUBWAY BETWEEN E 92ND AND E 99TH STREETS, NEW YORK, NEW YORK

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January 2008

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MANAGEMENT SUMMARY

This document presents the results of geoarchaeological investigations of buried landscapes on 2nd Avenue between E 92nd and E 99th Streets. Geoarcheology Research Associates (GRA) were contracted by the Metropolitan Transportation Authority (MTA) and its consultant DMJM+HARRIS•ARUP, JV (DMJM-HARRIS) to excavate a series of subsurface cores and to examine a set of previously collected cores associated with the project footprint. Objectives were to assess the archaeological potential of the buried landscapes associated with a historically documented estuary and marsh and/or near shore environments beneath it. The project area was known as Hellgate Bay until it was infilled and urbanized in the late 19th century. Investigations consisted of extensive background historical and geomorphic research, field collection of five (5) cores systematically placed along the linear project corridor, and laboratory studies focused on stratigraphic interpretations, radiometric dating, and pollen, macrofossil and molluscan identifications in support of environmental reconstruction. Stratigraphies of the primary cores were linked with an extensive collection of previously excavated geotechnical borings. The buried sequences revealed intact successions of bedrock, thin Pleistocene tills and deeper lacustrine deposits that are overlain by middle to late Holocene estuarine sediments. These borings register one of the only intact Late Quaternary sequences ever documented for Manhattan Island. Environmental studies of the Holocene deposits show that in the project area Hellgate Bay was a subaqueous mudflat. Accordingly the potential for preservation of archeological deposits is low. The southern segment of the project area at E. 92nd St preserves the eastern margin of the marsh and has a slightly higher

probability for archaeological preservation. Since archaeological deposits in the estuarine margins are likely to be thin and localized, continuous monitoring is not recommended.

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1. INTRODUCTION

Geoarcheology Research Associates (GRA) were contracted by the Metropolitan Transit Authority (MTA) and its consultant DMJM+HARRIS•ARUP, JV (DMJM-HARRIS) to undertake a geoarcheological assessment for the proposed 2nd Avenue Subway project. This project was undertaken to determine the potential of encountering buried surfaces in advance of a more extensive archaeological testing study by the Louis Berger Group (LBG). The objective of the GRA study was to identify and/or establish the integrity of buried surfaces that could have supported prehistoric occupation along the proposed subway footprint between East 99th and East 92st Street on 2nd Avenue (Figure 1). Indications of archaeological site potential include the presence of an estuarine marsh along the margin of the East River, which was built over and infilled during the late 19^{h} century. Preliminary review of engineering core borings logs by LBG disclosed not insubstantial accumulations of deposits identified as "organic" within the project area. The origins of such sediments were potentially traceable to sealed Holocene estuarine landforms and/or Late Pleistocene lacustrine basins (Schuldenrein et al, 2007; Newman et al., 1969). The New York State Historic Preservation Officer (SHPO) concurred and a geoarcheological investigation was conducted.

GRA was contracted to complete a study that consisted of:

- Coring and collection of five (5) continuous to semi-continuous columns from within the project corridor;
- Integration (if possible) of the field core stratigraphies with a series of 34 previously collected geotechnical core borings, stored at the MTA holding facility;
- Analysis of sediments from both phases of the work; such analysis includes sedimentological, geochemical, biotic and microfossil studies;
- Radiometric dating of sediments and preserved organic materials;
- Production of a synthetic report to include a comprehensive paleoenvironmental reconstruction and assessment of buried site potential.

This report presents the results of the GRA investigations. The study begins with a presentation of the research design, and is followed by a background section on the Late Quaternary history of the project area. The results of the coring and laboratory analyses are offered against this backdrop. Reconstructions of paleoenvironments and buried landscapes are then modeled, as a baseline to the assessment of buried archaeological site potential. Appendices provide the supporting data for the core sequences, dating chronologies, sediment studies and depositional histories, and the paleoenvironmental reconstructions.

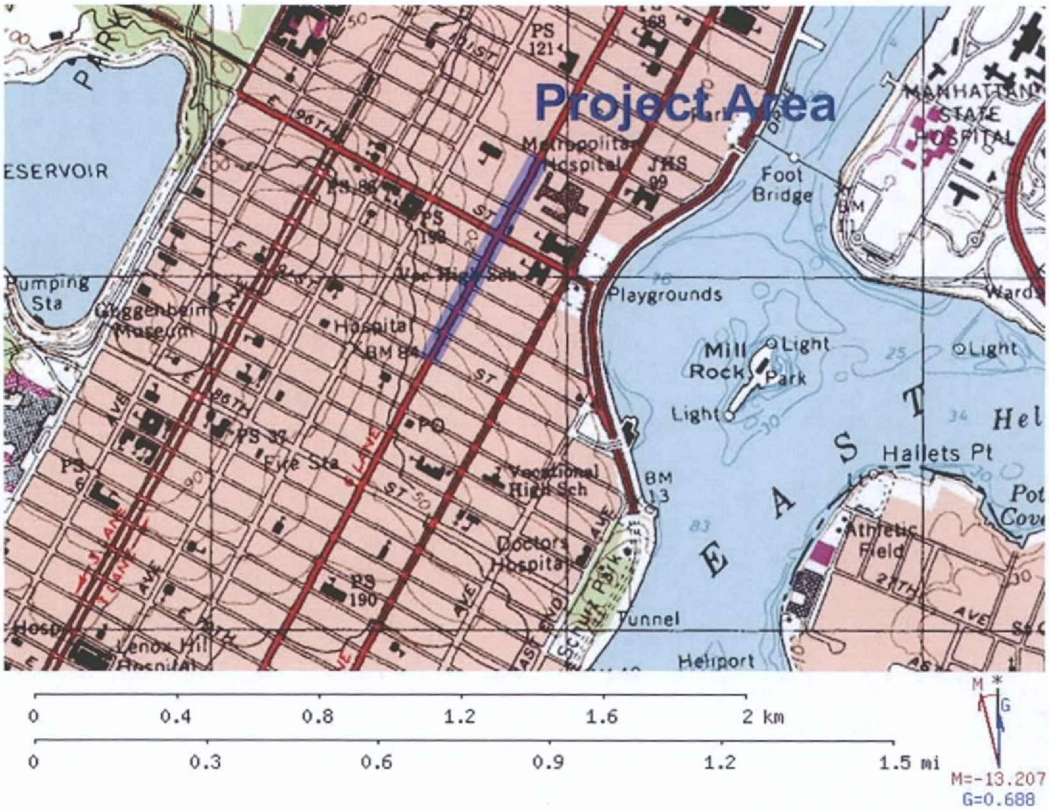

Figure 1. Project area map.

2. RESEARCH DESIGN

Previous Investigations

The buried landform under investigation in this project is an estuary, historically known as Hellgate Bay, located on the East River along the eastern margin of Manhattan. Estuaries are partially enclosed bodies of water formed where freshwater from rivers and streams flows into the ocean and mixes with salty sea water (Pritchard 1967). Estuaries and the lands surrounding them are places of transition from land to sea, and though they are influenced by the tides, estuaries are protected from the full force of ocean waves, winds, and storms by barriers such as reefs, islands, or land, which define an estuary's seaward boundary. Estuaries are complex systems with landforms that are reflective of differences in salinity, slope, tides, and biological activity. Most significantly, for assessment of archaeological contexts, the margins, biotic composition, and the structure of estuaries vary significantly with time. Because of fluctuating rates and patterns of sea level rise the topography and extent of the estuary will change through time. The landforms associated with the estuary reflect such changes in the nature of their depositional environments. Equally important is climatic variation, and especially fluctuations in precipitation quantities and seasonality, that alter the balance between freshwater inputs to the estuary (through river and stream discharges) and saltwater additions as a result of transgressions and landward encroachment of the shoreline. Thus, the ecology of estuaries is intricate and reflects a dynamic equilibrium between terrestrial and marine inputs. The zone of mixing between these two eco-zones creates the brackish environments that have been widely recognized by archaeologists as optimal resource and subsistence zones. In general, the Holocene has witnessed a net rise in sea level—both worldwide and locally within the New York Bight and the Hudson (see Schuldenrein et al, 2007 and references)--but climatic and edaphic changes coupled with the mechanics of ecological succession and localized environmental settings inhibit the modeling of archaeological site expectation. Accordingly, while it might be assumed that later prehistoric sites might be associated with the inner margins of an estuary (due to sea level rise), in many cases the opposite is true because of the unique configurations of landforms and resource zones on the outer edges of a shallow estuary (lagoons and barriers).

While familiarity with regional archaeological site geography and subsistence strategies can be excellent guidelines for modeling site expectation, their utility is compromised in urban environments. In Manhattan, decades and centuries of development have destroyed both the archaeological sites and the critical upper layers of estuarine landforms where evidence for them is likely to have been preserved. Nevertheless, careful stratigraphic and sedimentological observations can provide indications for the integrity and preservation of key subsurface estuarine components, especially marshes and nearshore environments (shorelines, tidal creeks, and pools). These would have been the loci for cultural activities that might provide evidence of human behavior.

A unique advantage for archaeologists working in marshes, swamps, or aquatic environments is the optimal preservation conditions afforded by hydromorphic, oxygen-depleted settings. Because of the net transgressive trend of sea level during the Holocene, cumulative sedimentation of peats and silt-rich organic mats seals in critical elements of the archaeological record. Items such as mussel shells and stone tools account for generally high recovery of non-perishable (and even otherwise perishable) material components at archaeological sites (Goldberg and MacPhail 2006:160-161). In the greater New York City area, there is infrequent, if not extensive, evidence that marshes and nearshore environments were habitats that prehistoric hunter-gatherers were drawn to for their rich food resources since the Early to Middle Archaic period (Cantwell and diZerega Wall 2001). These sites were the prime loci for aquatic resources such as shellfish, finfish and aquatic mammals, as well as terrestrial plant resources (berries and masts), and terrestrial game.

Finally, environmental archaeologists have a unique advantage working in brackish and estuarine settings since the procurement of paleoecological data is enhanced, in part, because of the same conditions accounting for excellent preservation of archaeological materials. Accordingly, the potential for recovering pollen is high and is indicative of the changing variety of vegetation types that populated the changing near shore setting through time. Foramanifera are also well preserved and attest to the variable balances between fresh and salt-water inputs feeding into the hydrologic system. Stratigraphies will also contain shifting proportions of terrestrial to marine-brackish shells and mollusks that register parallel transitions in the saline to fresh water balance. Proportional shell representation also provides dietary and subsistence information when found in conjunction with archaeological assemblages, thereby providing a picture of adaptive responses to environmental transitions.

The archeological record of New York City features a broad array of archeological sites on or near estuaries that have been variously examined for human ecological purposes (Figure 2). Recent examples with major prehistoric and stratified components include the sites of Dogan Point on the Hudson (Claassen 1995), and Old Place (Geoarcheology Research Associates 1996, 1997; Ritchie and Funk 1971) on Staten Island. The cultural sequences are typically Middle Archaic or later which is likely a function of both the development of marsh habitats during this time period and a limited sample size of earlier coastal sites due to submersion due to sea level rise. On the basis of foram and geophysical studies, it has been independently determined that peak meso-haline conditions in the Hudson estuary were reached around 6500 B.P. (Weiss 1974; Carbotte et al., 2004) thus affording populations access to oysters and plant resources fringing brackish waters. At Dogan Point substantial quantities of oysters were harvested from a nearby marsh at approximately this time. Shells were processed on the nearby upland terrain which features extensive and thick shell discard heaps. The site's locale represented an ecotonal setting, in close proximity to an estuary whose shifting resource base was a function of the shifting balance between stream and brackish hydrography. Old Place is situated downstream and featured a slightly different micro-environment. Here the local marsh preserved older Early Archaic terrestrial deposits because the marsh containing Middle and Late Archaic occupations aggraded over the older archeological deposit, effectively sealing them.

Archeological Sites and Ecological Study Areas

1. Dogan Point
2. Collect Pond / MCC Tunnel
3. Piermont Marsh
4. Hackensack
5. Old Place
6. Arthur Kill Marsh
7. Inwood Hill Park

Figure 2. Regional map showing project area, archeological sites, and paleoecological study areas mentioned in the text.

A comprehensive study assessing the geoarchaeology of marshes and related landscapes of greater New York City and New York Harbor has been recently synthesized (Schuldenrein et al., 2007), but there has been only one limited examination of a marsh and related landscape complex in Lower Manhattan, specifically in the vicinity of the old Collect Pond (Schuldenrein 2003; Yamin and Schuldenrein 2007). Historic maps and colonial accounts document not only the presence and duration of Manhattan's marshes, they also attest to their functions as cultural landmarks and their subsequent economic utility as Manhattan evolved from a colonial outpost to a commercial center between the 17^{th} and 19^{th} centuries (Cantwell and diZerega Wall 2001; Rothschild 1990; Yamin and Schuldenrein 2007). However, sustained industrial development along the shorelines of the island has either destroyed or buried the natural marshes.

The Collect Pond investigations in Lower Manhattan were based on two separate projects (Figure 3). The first, at Foley Square, involved the excavation of a single boring and a synthesis of a series of geotechnical cores (Schuldenrein 2003). The second was based on open investigations for the site of a tunnel at the Metropolitan Correction Center (MCC Tunnel) immediately to the east of Foley Square (Yamin et al., 1995; Yamin and Schuldenrein 2007). The integrated sequence is as follows (youngest to oldest):

- Historic fills and rubble (19^{th}-20^{th} centuries; 30 ft.)
- Collect Pond stream and pond deposit (17^{th}-19^{th} centuries; 3-5 ft.)
- Estuarine peats, silts and interfingered sands (4700-1200 B.P.; >8 ft.)

It should be noted that the base of the estuarine deposits, and specifically Middle Holocene peat deposits were not reached, such that the chronology of the Lower Manhattan estuarine succession cannot be definitively tied to regional sea level curves at this location. Typically a basal peat deposit in the range of 10,000-5000 B.P. is taken as a marker for the transgression across the Atlantic Inner Continental Shelf (Field et al., 1979). The Foley Square core does feature a relatively thick (.7 m) Late Holocene peat dated to 2500 B.P. (Schuldenrein 2003).

More generally, regional studies of marshes can be divided into two types:

- Geoarchaeologically based investigations that assess the potential for submerged archaeological sites within or adjacent to New York Harbor (Thieme 2003, Schuldenrein et al. 2007)

- Paleoecologically driven research by ecologists and geomorphologists to reconstruct estuarine chronologies and ecological diversity through time (Weiss 1974, Pederson et al 2005, Peteet et al 2007).

Geoarchaeologically based studies would require the retrieval of culture bearing horizons within a sealed context. It would then be possible to date and source the origins of the depositional environments that entrain the cultural deposits themselves as well as those registered by the sediments underlying or overlying them. As noted, the potentials for pinpointing chronologies and reconstructing depositional settings are strong because of the often highly organic nature of the sediments, the variability in sediment composition that can be readily linked to discrete estuarine sedimentation processes (near-shore, dominantly terrestrial, lagoonal, or combinations thereof), and finally, the diagnostic signature of an archaeological horizon through artifact typologies or dominance and preservation of subsistence remains. At Dogan Point, for example, two discrete oyster assemblages—separable by size and morphology--were associated with the Archaic and Woodland periods respectively, as were a limited collection of lithic tool and point assemblages (Claasen 1995). A recent study of the New York Bight was able to reconstruct shoreline positions and geomorphic processes to model the settlement geography and preservation contexts for discrete periods in prehistory (Schuldenrein et al., 2007).

The paleoecological studies have largely focused on using proxy data of preserved pollen and shellfish assemblages from marshes to infer past climate and environmental conditions. As discussed, peat horizons and marshes, irrespective of cultural enrichment, contain dateable sediment matrices and allow for vegetation and shell based climate and landscape reconstructions. The Piermont marsh along the Hudson is an example where variability in the rate and pattern marsh formation reflected sea level rise through the Holocene, effectively preserving a multifaceted record of environmental fluctuations (Peteet et al. 2007). Fossil oyster beds buried in the Hudson estuary have been studied and provide corroborating evidence of climate change (Carbotte et al. 2004).

The investigations for the 2nd Avenue Subway offer a unique opportunity to assess geoarchaeological potential from a buried landscape in Manhattan never before examined for such purposes. The study represents the first integrated human paleoecological study of an estuary in Manhattan. Most pristine landforms, once integral parts of preheistoric and early Euroamerican Manhattan, are largely destroyed. Reconstructions using historical maps, ecological analogy, and GIS modeling by Sanderson and Brown (2007) estimate that before European contact, 10% of Manhattan was once wetlands, with 8% of that salt and brackish marshes. The surface area of Manhattan currently sustained by marshes has fallen to <1%. The only remnants of natural marshes in Manhattan are at Inwood Hill Park on the northern tip of Manhattan (Barlow 1971, New York City Department of Parks & Recreation 2008). The rapid disappearance of the natural terrain only underscores the urgency for data recovery from this marsh. Along similar lines it is necessary to develop a methodology to study buried estuarine landscape segments that can be applied to similar settings both in Manhattan and in other heavily urbanized areas. It follows that this protocol can serve as a blueprint for complying with Section 106 regulations as the shore fronts of greater New York City undergo accelerated development.

Methods

In order to test the potential for deeply buried marsh and archeological deposits it was necessary to conduct subsurface testing. Geotechnical boring using a truck mounted split spoon auger was employed (Figure 3). The split spoon auger extracted 1½'' diameter samples in up to 2' long sections, with a continuous collection procedure. Cores were excavated to a depth of 60' unless bedrock was encountered. Upon extraction samples from the split spoon were photographed, collected in plastic bags, and stored in oriented sample boxes. Basic descriptions of the cores were made in the field. This collection strategy allowed the samples to be reoriented and examined at the GRA lab facilities for descriptions and sub-sampling for special studies.

Field investigations were conducted between May 18 and June 1, 2007. Five (5) localities were selected for geotechnical boring. The bores were sequentially named AB (Archeological Boring) -1 though -5 (Figure 4). Due to complications with access and buried utilities three (3) of the borings (AB-2, -4, -5A) had to be shifted from their planned locations. All relocations remained within the same city block of the originally planned boring. Sampling involved boring to a maximum depth of 65', with the use of a split spoon to allow the collection of a continuous sample. All cores except for AB-1 reached a maximum depth of 60'. Core AB-1 encountered consolidated bedrock at 25.5'. The samples collected were kept in ambient conditions and were transported to the GRA laboratory facilities, where the stratigraphy was documented and samples were collected for radiometric dating, pollen studies and mollusk shell identification. The cores were described using standardized pedo- and litho-stratigraphic terminology (USDA 1994; ISC 1990). A stratigraphy was devised for the project area, which identified six (6) Analytical Units (AU) (Table 1). These analytical units differentiate between depositional events or unconformities based on the chronology, lithstratigraphy, and biostratigraphy, which will be explained in greater detail with the core descriptions.

a)

b)

c)

d)

Figure 3. Photographs of field and lab methods: a) drill locality AB-4; b) drilling operation; c) sample in core tube; d) split sample in lab.

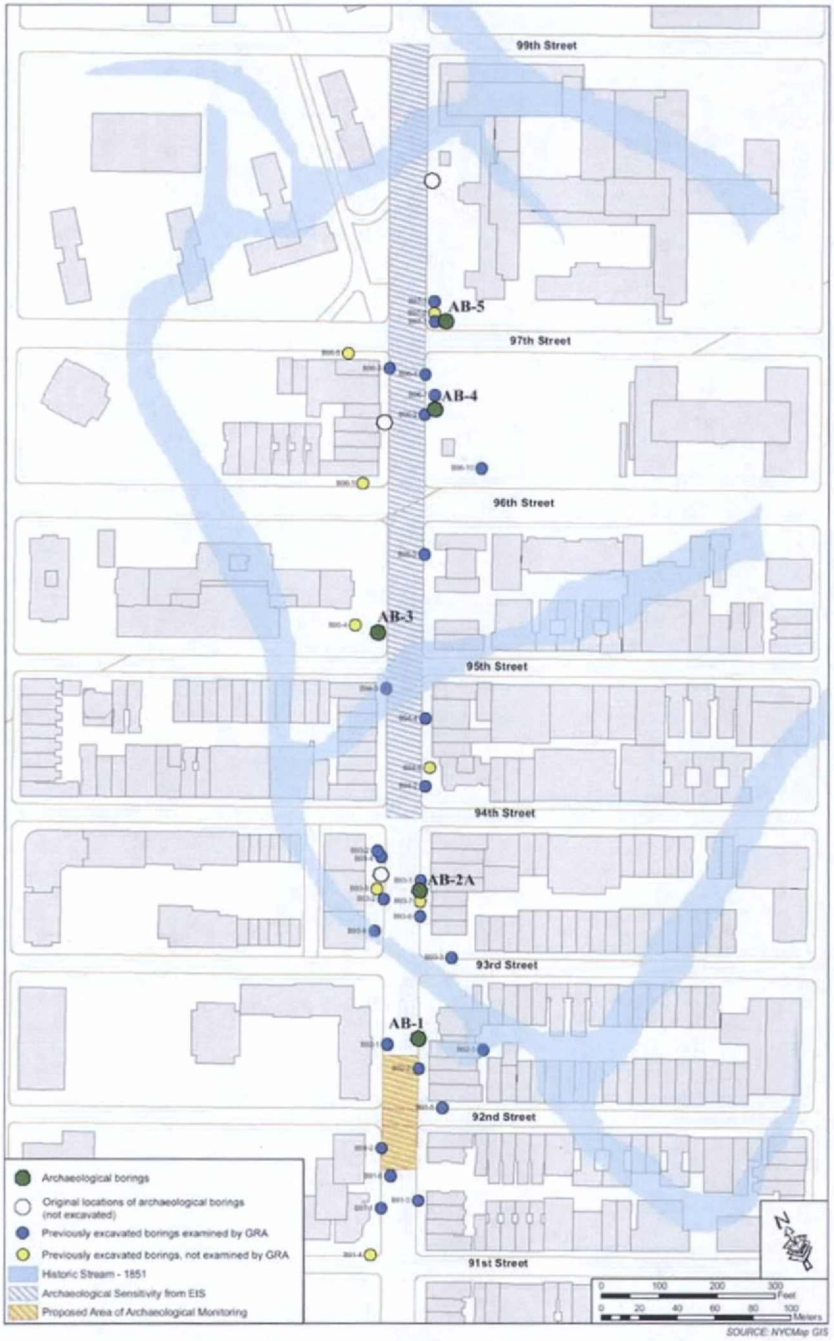

Figure 4. Core location map. The street grid is superimposed on a projection of the Historic Period stream as mapped in 1851 (Dripps 1851). Note locations of tidal and sub-tidal drainage channels.

Table 1. Summary of stratigraphic Analytical Units (AU's)

AU-I: Manhattan Formation bedrock and glacial tills (Late Pleistocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Very dark gray (10YR3/1) gravelly silty sand to regolith, weathered micaceous sands and angular schist rock fragments, coarsening sands and rock fragments to contact with micaceous schist bedrock.	Underlying bedrock of Manhattan Formation schists capped with weathered bedrock and glacial till of sands and gravels.	n/a
Cores: AB-1, and numerous MTA cores below AU-II		

AU-II: Glacio-lacustrine deposits (Late Pleistocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Reddish brown (5YR4/3) silty very fine to fine sand to slightly sandy silt with only very occasional varves of 1-2" thick silty fine sand and fine sandy clayey silt, micaceous, abrupt lower boundary. The deeper MTA cores show these deposits overlay AU-I, and are up to *90'* to *160'* below the surface.	Weakly varved lacustrine sediments that formed the glacial lake Bayonne/Hudson complex during the Pleistocene. The sediments are coarser than typical lacustrine sediments, suggesting *higher energy deltas/fans* along the lake margins.	13570 $\pm$ 60 ^{14}C yr B.P. (Beta-232120); and 11' 21730 $\pm$ 120 ^{14}C yr B.P. (Beta-233892).
Cores: AB-2A, 3, 4, 5A		

AU-III: Fluvio-marine sands (Middle Holocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Light olive brown (2.5YR5/4) to dark gray (10YR4/1) silty sand to sand. Sand is a heterogeneous quartzitic (60%) and micaceous (40%) medium to coarse sand, with granule sized schist, white limestone, quartzite, and red siltstone rock fragments.	Complex deposits of post-lacustrine, high energy fluvial and beach sands deposited after the glacial lakes recede but before marshes develop.	5220 $\pm$ 50 ^{14}C yr B.P. (Beta-233887).
Cores: AB-2A, 3, 4, and 5A		

AU-IV: Marsh and tidal flat organic silts and clays (Late Holocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
A fining upwards sequence of organic very dark gray to dark gray (GLEY 3/N, 4/N) silty sands to very dark grayish brown (10YR3/2) clayey sands. Analytical unit is divided into three sub-units IV-a (Initiation of marsh), IV-b (marsh development), and IV-c (Historic stable marsh surface).	Prograding estuary that progresses from a freshwater to saltwater marsh, to a tidal mudflat. It developed during the Middle Holocene and stabilized during the Late Holocene.	3890 $\pm$ 40 ^{14}C yr B.P. (Beta-232119); 3760 $\pm$ 40 ^{14}C yr B.P. (Beta-233890); 3240 $\pm$ ^{14}C yr B.P. (Beta-233888); 3640 $\pm$ 40 ^{14}C yr B.P. (Beta-233891); 4020 $\pm$ 40 ^{14}C yr B.P. (Beta-233889); 230 $\pm$ 40 ^{14}C yr B.P. (Beta-232117); 230 $\pm$ 40 ^{14}C yr B.P. (Beta-232118).
Cores: AB-2A, 3, 4 and 5A		

AU-IV-a: Basal marsh silts and sands capped by weak soil (Late Holocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
At top is a very dark gray (10YR3/1) to (GLEY 3/N) organic slightly silty sand to clayey silt, organic (15%) partially decayed plant material to entirely decayed organic sediment that decreases in organics with depth. Below is a micaceous gray to very dark gray (10YR4/1, 3/1) silty sand that becomes sandier with depth. In AB-5 an abrupt transition from organics with grass materials at the top to a firm silty fine sand with partially decayed roots and common dark greenish gray (GLEY 4/1) mottling is suggestive of a stable surface with pedogenic alteration (Bg).	Transition from a higher energy (perhaps a beach or nearshore) environment to a tidal marsh. Higher organic matter accumulation suggests a stable marsh setting with the onset of marsh conditions. Freshwater fern pollen suggests it was either a freshwater marsh, or a freshwater marsh was nearby. Radiocarbon dates establish that the marsh initiated post 4 ka.	Dates are inverted, with a date of 3890 ± 40 ^{14}C yr B.P. (Beta-232119) from the organic horizon capping this deposit and 3760 ± 40 ^{14}C yr B.P. (Beta-233890) from the lower fining upward sand sequence in core AB-5A.
Cores: Upper organic portion found in AB-2A, 4, 5A, lower transitional sands found in AB-2A, 3, 4, and 5A		

AU-IV-b: Aggrading saltwater tidal marsh fines (Late Holocene)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Very dark gray to dark gray (GLEY 3/N, 4/N) organic sandy clayey silt to silty clay, micaceous, common (5% to 1% at base) partially decayed plant material of preserved stem fragments and few (1%) partially decayed fine hairy roots at base with *Ruppia maritima* seeds and, common (5%) shell fragments.	Tidal saltwater mudflat aggrading at a rate that matches sea level rise with a significant enough input of mineral sediment to not develop into a high organic (histic) peat, forms from between ~4 ka and 3 ka	3240 ± ^{14}C yr B.P. (Beta-233888) in the upper portion of this unit; 3640 ± 40 ^{14}C yr B.P. (Beta-233891) in the middle; and 4020 ± 40 ^{14}C yr B.P. (Beta-233889) at the base.
Cores found in: AB-2A, 3, 4, 5A		

AU-IV-c: Terminal marsh fringe silts, sands, and clays (Historic)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Very dark grayish brown (10YR3/2) organic slightly silty sand to slightly silty clay with many (30%) partially to well decayed plant fragments of wood, grass, and roots. Inclusions of upper historical fill material. Few (2%) small shell fragments were observed. A conformable contact with lower deposits in AB-5.	Stable historic subaqueous surface of the mudflat. Development of a histic (Oe horizon), organic horizon, however this surface was significantly impacted by historical processes.	230 ± 40 ^{14}C yr B.P. (Beta-232117); 230 ± 40 ^{14}C yr B.P. (Beta-232118).
Cores: AB-2A, and 5A		

AU-V: Basal fill (Historic)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Grayish brown (10YR5/2) medium to coarse sands with: minor (2%) component of possible rip-up and transported clays, common (30%) distinct slightly silty medium sand, and very occasional (1%) angular to subangular small pebbles.	The lack of disturbance and the uniformity of this deposit suggest a historical deposit of sands, possibly due to a historical erosion event or a high energy storm.	n/a
Cores: AB-2, 3		

AU-VI: Upper fill cap (Historic-Recent)

Description:	*Depositional Environment:*	*Radiometric Dates:*
Heterogeneous mixture of: road construction material (concrete, asphalt, cinders, gravels), fill (clean sands, silts, and cinders), buried construction materials (brick and wood fragments) and occasional domestic debris (ceramics, cinders, metal)	Typically the differing types of fill constituents are mixed (i.e. road construction material with fill material, fill material with domestic debris.	n/a
Cores: all cores between 0 and 16'		

The second phase of the field study included examination of the MTA's stored geotechnical borings. Sample inspections were undertaken between June 7 and 11, 2007 at the MTA storage facility. A total of thirty-nine (39) borings were studied. Detailed stratigraphic and sedimentological observations are presented in Appendix B. The samples from the borings were discontinous and stored in glass jars, thereby reducing their interpretive potential. Additionally, some of the borings recorded on the project area map (Figure 3) were either not present or could not be located at the storage facility. However, the overall sample size was sufficient to provide context for the in-field core excavations. The stratigraphy of the bores was integrated to that observed in the cores, and helped fill gaps in our understanding by refining facies relationships between deposits that were not present in all of the cores.

A total of thirty-four (34) specimens for radiometric dating were collected. Ten (10) of the samples were submitted to Beta Analytic Radiocarbon Laboratory (Beta) in Miami, Florida for analysis (Table 2). All samples were processed by accelerated mass spectrometry (AMS) either on bulk sediment or identifiable organic components. Calibration for the ^{14}C determinations was provided by the Oxford University (OXCAL) system (c14.arch.ox.ac.uk/oxcal.html). The mid point of the calibration range (2-sigma calibration) serves as the calibrate date, which is used in our interpretations and reported as cal yrs BP.

Paleo-environmental laboratory studies were completed on samples from the cores. Dr. Dorothy Peteet, a Senior Research Scientist at the Lamont-Doherty Earth Observatory at Columbia University, New York, NY undertook preserved pollen and macrofossil analysis to elucidate changes in paleo-vegetation regimes. A representative column sample from AB-5 with a total of ten (10) samples was analyzed and pollen was recovered from five (5) of the samples, as were identifiable seeds. Dr. G. Lynn Wingard of the U.S. Geological Survey, Reston, VA examined molluscan remains. A total of fifteen (15) shells from seven (7) locations within core AB-5 were sub-sampled. The results of these studies are discussed in the Paleoecological Studies section, and primary data and interpretations are provided in Appendices C (Palynological and Macro-fossil Analysis) and D (Molluscan Identification Analysis).

Table 2. Radiocarbon dates.

Beta Lab Number	GRA Lab Number	Core #	Analytical Unit	Depth below surface (ft)	Elevation above (+) and below (-) sea level (ft)	Material	Method	13C/12C Ratio	Cal 2-sigma age range, C^{14} yr B.P.	Conventional C^{14} yr B.P.	Calibrated (OxCal 4.0) yr B.P.
232117	RC-3	AB-2A	IV-c	18-20'	-2' to -4'	peat	AMS	-12.9	Cal BP 420 to 400 and 320 to 270 AND Cal BP 210 to 140 and Cal BP 20 to 0	230 ± 40 BP	212.5
232118	RC-8	AB-5A	IV-c	14-16'	-1' to -3'	wood	AMS	-26.2	Cal BP 420 to 400 and 320 to 270 AND Cal BP 210 to 140 and Cal BP 20 to 0	230 ± 40 BP	212.5
233888	RC-15	AB-5A	IV-b	18-20'	-5' to -7'	organic sediment	AMS	-22	Cal BP 3560 to 3380	3240 ± 40 BP	3471.5
233891	RC-33	AB-4	IV-b	24-26'	-11' to -13'	organic sediment	AMS	-22.2	Cal BP 4080 to 3850	3640 ± 40 BP	3970
233889	RC-26	AB-5A	IV-b	27-28'	-14' to -16'	organic sediment	AMS	-20.4	Cal BP 4580 to 4420	4020 ± 40 BP	4598.5
232119	RC-12	AB-5A	IV-a	28-30'	-15' to -17'	organic sediment	AMS	-25.4	Cal BP 4420 to 4230 and Cal BP 4200 to 4160	3890 ± 40BP	4291
233890	RC-32	AB-5A	IV-a	32-34'	-19' to -21'	organic sediment	AMS	-22.2	Cal BP 4240 to 4060 and Cal BP 4050 to 3990	3760 ± 40 BP	4113.5
233887	RC-13	AB-3	III	34-36'	-21' to -23'	organic sediment	AMS	-21.6	Cal BP 6180 to 6150 and Cal BP 6120 to 5900	5220 ± 50BP	6041.5
232120	RC-29	AB-5A	II	42-44'	-29' to -31'	organic sediment	AMS	-21.4	Cal BP 16500 to 15820	13570 ± 60 BP	16166
233892	RC-34	AB-3	II	50-52'	-37' to -39'	organic sediment	AMS	-24.9	*	21730 ± 120 BP	*

* Sample could not be calibrated because it is outside the calibration curve

3. GEOLOGICAL AND ENVIRONMENTAL SETTING

Physiography and Bedrock Geology

The natural (pre-urban) topography and physiography of midtown Manhattan is a function of geologic controls of the underlying bedrock and post glacial processes which dramatically reshaped the landscape. Orogeny and structural components are key as the terrain was initially shaped by rifts in the continental crust that trend from north to south. The Newark Basin is the primary geologic region to the west and the Atlantic Basin lies to the East. These first developed during the breakup of Pangea (Isachsen et al. 1991: 47-51). Manhattan Island contains the core of resistant rock material between the basins named the Manhattan Prong. The bedrock of the Manhattan Prong consists of the New York group of Lower Paleozoic and/or Precambrian schist, gneiss and marbles (Figure 5). The project area is situated on a northwest-southeast fault across Manhattan. The fault separates the relatively soft Inwood marble of the Harlem lowlands to the north from the more resistant mica schist of the Manhattan Formation to the south. A ridge of older resistant Fordham gneiss forms the uplands immediately west of the project area. The gneiss is not typically exposed in Manhattan, but it underlies the entire New York City region (Fischer et al. 1970, Schuberth 1968: 74-75, 82). The physical characteristics of these rocks and their surface expression have a direct bearing on the distributions of the subsequent Pleistocene glacial deposits.

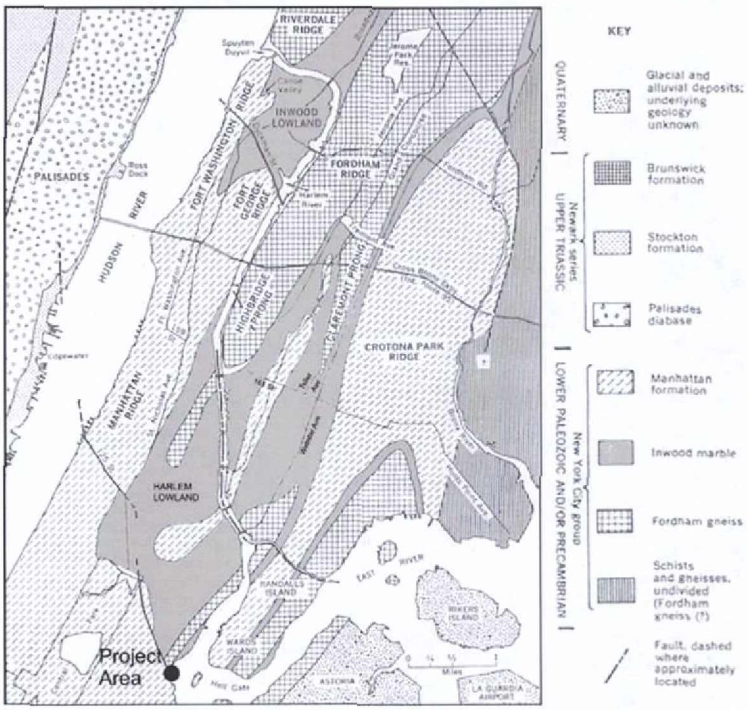

Figure 5. Geological map of Manhattan (modified from Schuberth 1968: Map 2).

Pleistocene Glaciations, Chronology, and Paleoecology

The Laurentide ice sheet advanced over the area at least twice during the Pleistocene Epoch, though the process chronologies of the advances remain uncertain (Ridge 2003; Sanders and Merguerian 1994). The Hudson-Mohawk Lobe of the latest or Wisconsinan ice sheet advanced to its southern terminus, the Harbor Hill moraine, by around 20,000 years before present (B.P.) (Sirkin, 1986: 14; Sirkin and Stuckenrath, 1980). As the glaciers retreated two processes drastically reworked the landscape. Initially recessional moraines formed at the margin of the glacier while it retreated. To the south and southeast of Manhattan the Harbor Hill moraines features glacial detritus that extended in an arcuate form across most of Long Island and much of Staten Island (Figure 6). Deposits of till behind the moraines blanketed the landscape in irregular fashion. The tills formed the parent material for later Holocene landforms (Cadwell 1991).

The second process was the formation of proglacial lakes, which filled deep preexisting depressions whose outlines were partially pre-determined by the bedrock geology but also by glacial incision and the cyclic retreats of the ice sheets. The Harbor Hill moraine effectively dammed the glacial meltwater and inhibited drainage into the Atlantic. Evidence for the lakes that formed at the melting glacial front takes the form of laminar to more massive silts and clays in the valleys of what are now the Hudson, Hackensack, and Passaic Rivers. A complex succession of glacial lakes including Lake Hackensack, and Hudson, as well as Bayonne occupied what is now the East River; their distributions have been recently remapped (Stone et al., 2002). 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. In the New York area the proglacial lake complexes were variously dammed 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 basin spilled into 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 stand of glacial Lake Hackensack drained through the moraine at Perth Amboy as its spillway was incised 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 was flushed 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 yr BP) (Stone et al., 2002).

These lakes were sustained, until a portion of the Harbor Hill moraine, at what is now the Verazanno Narrows, eroded. This allowed the impounded waters to empty into the Atlantic. Researchers disagree on the mechanism, but an outlet through the Harbor Hills moraine at the Narrows was opened, emptying Lake Hudson and giving 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 $\pm$ 600 B.P. (14,830 cal yr B.P.) as evidenced by marine and brackish marine microfossils preserved at the base of organic silts underlying peat bogs at Iona Island. There have been various interpretations as to the rate of drainage, and recent investigations suggest that it occurred rapidly (Donnelly et al. 2005, Theiler et al. 2007).

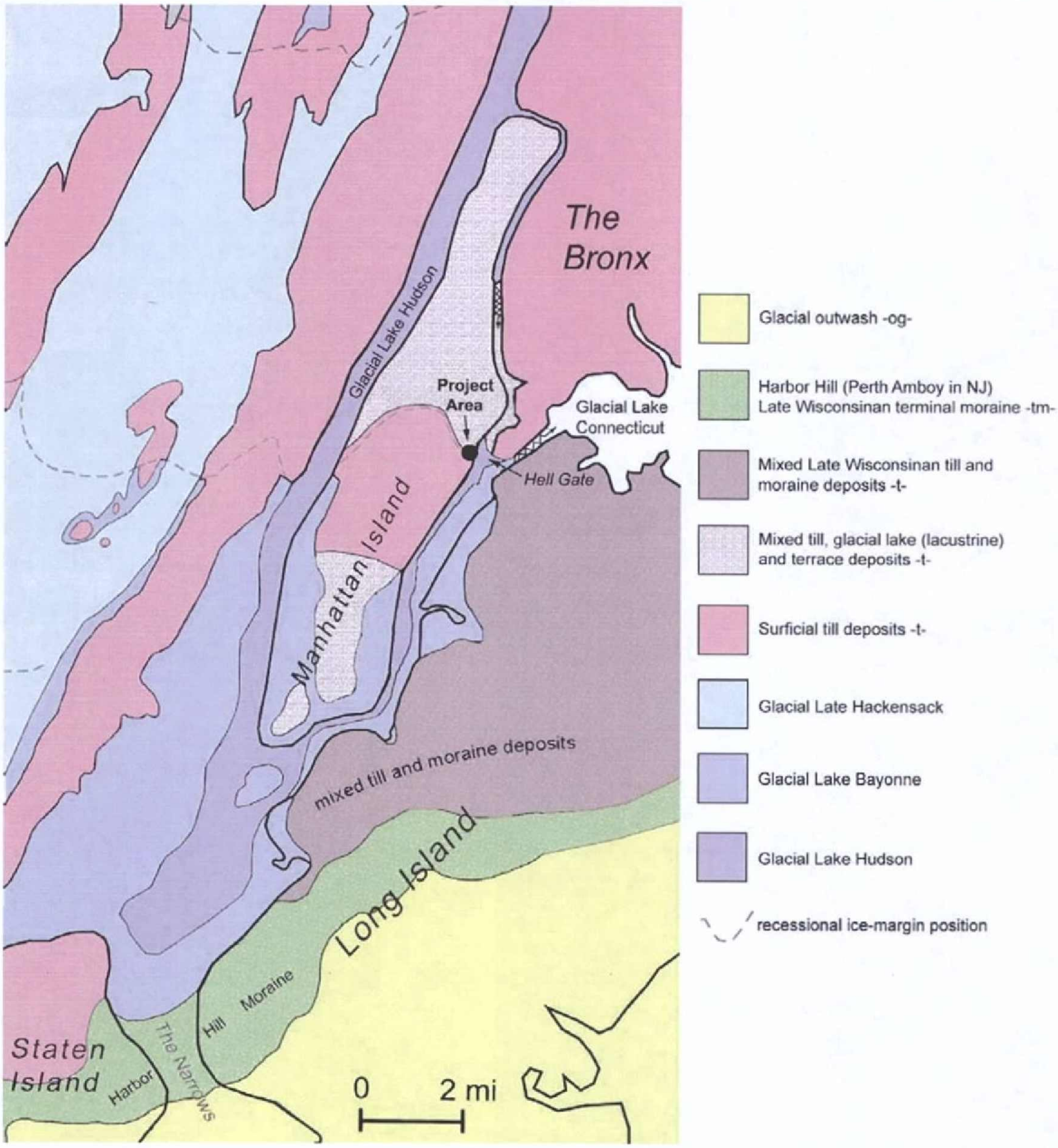

Figure 6. Surface geology and Pleistocene glacial lakes (Cadwell 1991 and Stone et al. 2002).

Sea Level Rise and the Emergence of the Holocene Estuary

The breaching of the Verazanno Narrows and sea level rise commensurate with the Holocene led to the development of estuarine environments in New York Harbor, the Hudson River and the East River. The earliest phases are poorly understood and our models of Early Holocene landforms are largely based on inferred sea level rise. Sea level rise is primary factor accounting for changes in Holocene landscape and environmental history within the project area. It accounts for modifications to the shape, extent, and biotic potential of the former coastline and is reflected in distinct sedimentation modes through different phases of sea level rise (Schuldenrein et al., 2007). Complicating matters further is the role of isostatic rebound, or the sustained uplift of post-glacial surfaces as the ice margins retreated northward and surface elevations readjusted. Rates of uplift have been difficult to determine, in part because the geophysics are incompletely understood and the precise timing of the retreating ice fronts and consequent surface responses are difficult to reconstruct with accuracy.

Such limitations notwithstanding, a variety of regional models have been advanced to model the rates and patterns of sea level rise over the past 10,000 years. Until the 1970's models drew almost exclusively on limited radiocarbon sequences of subaqueous deposits in New York Harbor and Long Island Sound bolstered by correlations with north and middle Atlantic models (see especially Newman et al., 1969). A recent update and revision of the sea level model for the New York Bight has been advanced and forms the basis of the current interpretations (Schuldenrein et al., 2007).

The revised model uses basal peat ages as the only dependable measure for determining correlations for shifting sea level elevations at locations where there is chrono-stratigraphic information. Integration of the results of local and regional sequences with the New York Harbor data set shows that the relative rise of sea level for the New York Bight is a smooth curve extending 9000 years in the past (Schuldenrein et al., 2007: Figures 3.5, 3.6). 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 yr BP, the trend is more difficult to discern, largely due to the scarcity of earlier radiocarbon-dated stratigraphy. However, there is a convergence of data sets for the earlier Holocene, indicating a pre-7000 cal yrbp transgression rate of 9 mm/yr (0.4 in/yr). The rapid rise following deglaciation is in agreement with the 10 mm/yr (0.4 in/ yr) rate for this period suggested by Flemming et al. (1998). In sum, the rate of sea level rise for the first 5000 years is about 8 times higher than that of the last 5000 years.

For geoarchaeological purposes, it should be noted that the recent study of submerged oyster reefs in Tappan Zee (Carbotte et al., 2004), about 20 miles (32 km) upstream of the project area has provided corroborating evidence for this interpretation of relative sea level change. Shell dates produced the absolute chronology for this study and resulted in a calculated rate of relative sea level of 1.6 mm/yr (0.63 inches/yr); the trend calculated for dated oyster reefs is 1.8 mm/yr (0.7 inches/yr). These data demonstrate that living oyster communities adjusted to water depth and salinity and were able to keep pace with the rate of sea level rise for at least 5,000 years. 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, an observation confirmed and refined on the basis of the shell midden and subsistence reconstructions at Croton Point (Salwen 1964, Newman et al., 1969) and Dogan Point (Claassen, 1995; Schuldenrein 1995). The archaeology showed that there were prehistoric periods when shellfish were not an important part of the diet.

The records for the past 3000 years show a refined chronology for transgressing and regressing sea level. The data argue for shorter term pulses that are related to both climatic and geomorphic changes. Fletcher et al., (1993) recognized transgressive and regressive facies in saltmarshes at the mouth of Delaware Bay. They 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. 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. 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 yr BP to 400 cal yr BP. Finally, an 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 yr BP. He too identified differing rates of relative sea level rise ranging from 2.0 mm/yr to 5.4 mm/yr. These regional records collectively point to the scientific value of salt-marshes 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. They obviously have critical implications for reconstructing human ecological relationships in later prehistory.

Figure 7 is a summary of the sea level model generated on the basis of the most recent New York Harbor model (Schuldenrein et al., 2007: Figure 6.1). Prehistoric periods are linked to chronological scale and document the linkage between oyster availability—based on salinity in the estuary--and the archaeological record. The data are compelling for last 5000 years, where archaeological information is accessible at depths up to 5 m. For the earlier (Early-Middle Archaic) periods sea level rise was steep and accelerated. Any surviving evidence would be overridden by many meters of sediment.

Relative Sea Level Rise at New York

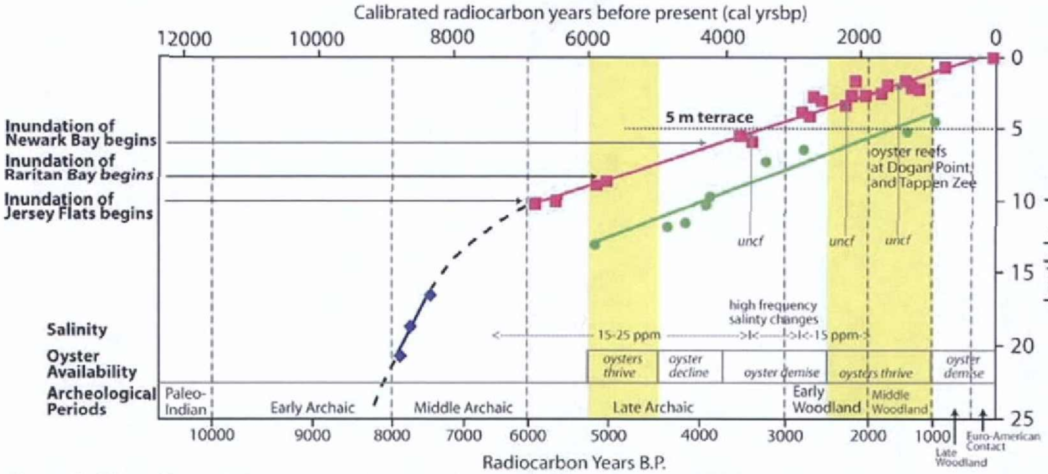

Figure 7. New York Harbor sea level curve (from Schuldenrein et al. 2007)

The Estuarine Landscape

Estuaries have characteristic landforms and vegetation patterns relative to salinity, slope, rate of sea level rise and the rate of sediment deposition. As stated previously sea level fluctuations are the overriding factor.

There are generally four landform settings that dominate the landscape (Figure 8) (Rabenhorst 2001, Schuldenrein et al. 2007, Warren 1995):

1) *Offshore intertidal zone*. This comprises the terrain below mean low tide which is entirely submerged. This zone typically has coarser sediments (silts to sands) with lower organic content and vegetation adapted to subaqueous conditions, such as widgeon grass (*Ruppia m.).*

2) *Low marsh zone*. Reference is to surfaces between the mean daily high and low tide. They are subject to the daily tides. This zone is typically rich in vegetation, primarily Smooth Cord-grass (*Spartina alterniflora)*. The sediments are typically fine grained (clays and silts). Deposition is regulated by the vegetation mat's slowing tidal currents that allows the suspended sediment to settle. There is a significant organic component from decaying vegetation as well that can lead to the formation of peat deposits.

3) *Middle marsh zone*. This is the segment that experiences seasonal inundation by spring high tides. It is higher in elevation and removed from the increasing reach of the tide. Vegetation is less salt tolerant and distributions extend up imperceptibly gentle slopes. The lateral succession typically proceeds from *Spartina patens* through *Disticulus spicata* to *Scirpus americanus* or *olneyi* and *Juncus roemerianus*. As in the low marsh zone, sediments are typically fine grained with a high organic component.

4) *High marsh/terrestrial margin.* It typically features higher freshwater input and only experiences occasional tidal inundation, such as during the high astronomical tide and storm surges. In the more dominant freshwater 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. The sediments are a mixture of high organic freshwater peats and silty clays.

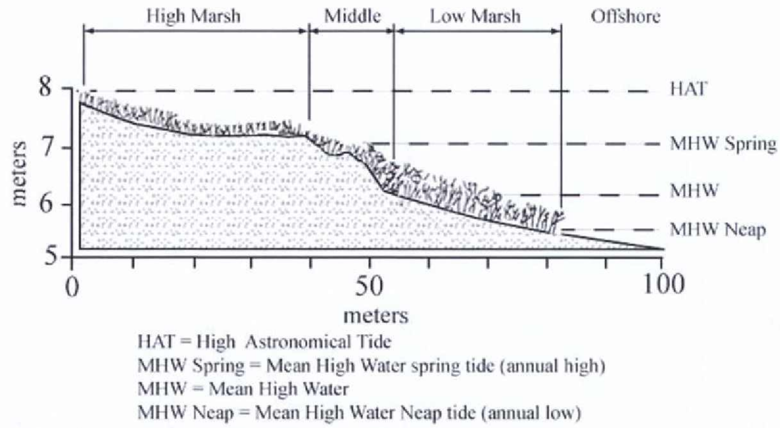

Figure 8. Classification of marsh zones (based on Rabenhorst 2001).

Estuarine environments began forming in the New York Harbor, the East River and up the Hudson during the Holocene (Schuldenrein et al. 2007: 93-107). Environmental reconstructions of sea level rise and the corollary geomorphic landforms indicate that by 8000 cal yr BP the Hudson had a connection to the Long Island Sound via the East River at Hells Gate, with a sea level -52' below current sea level. As discussed, sea level continued to rise rapidly until approximately 5000 cal yr BP, upon which the preservation of oyster beds and the initiation of marsh deposits across the region indicates that the conditions began to stabilize and the balance between the terrestrial and brackish landscapes began to assume a modern character. At this time the East River began functioning as a tidal strait between Long Island Sound and the New York Harbor, with continued input of freshwater from the Hudson River and minor tributaries. Sea level continued to rise but there were pulsations and minor regressive cycles. By 1000 cal yr BP major environmental transitions had been completed.

Historical Context of the Project Area

The primary source of information on the project area comes from *The Historical Guide to New York City*, published in 1906 (Bolton and Hall) and historic maps, such as the Viele map (1874) as seen in Figure 9. The project area is located in an area that was known as Hellgate Bay. Hellgate Bay is south of the Harlem Plains, where the village of Harlem was founded in 1637 by Dutch immigrants. The project area is described as "meadow lands" and "salt flats", which were owned by the Dutch church. A differing source (Riker 1904:691) states that during the 17th century the property was owned by the Waldron family. The historical maps depict the project area as marshlands with channelized drainages. The pattern of these channels consists of a backchannel around the margins of the estuary with the uplands that are connected by a series of tidal channels that connect the bay to the East River. The regular spacing of these channels suggests they may have been historically channelized, however no documentation of this process was identified. The marsh was bound to the north by a slight rise that had the indigenous name of *Rechawanes*, which is interpreted to mean Great Sands (Riker 1904: 122) that formed a drainage divide. This interfluve separated Hellgate Bay from one of the larger creeks in the area, variously known through time as Montagne's Creek, Mill Creek, and Harlem Creek (Bolton and Hall 1906).

A place name that has stood the test of time is Horns Hook, which is the name of the promontory to the south of the marsh that in part protects the area from the irregular currents at Hells Gate. The uplands immediately to the southwest of the project area have also been known as Rhinelander's or Observation Point (Bolton and Hall 1906). The area no longer retains this name of Hellgate Bay as it was infilled before the 20th century. A large powerhouse of the Metropolitan Railroad Company was built at the location (Bolton and Hall 1906), which has since been replaced by mixed urban development of hospitals, schools, businesses, and residences.

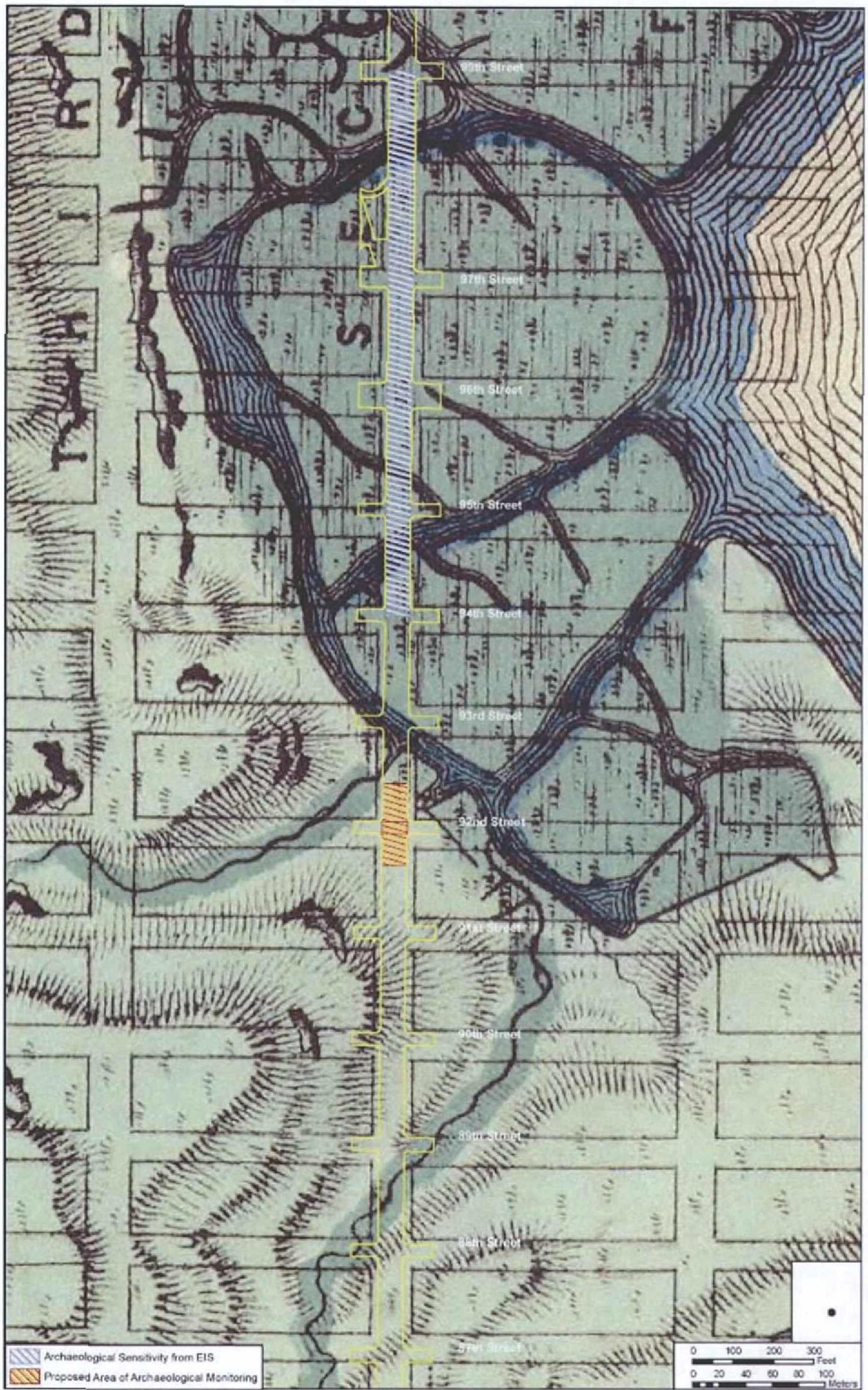

***FIGURE 1:* Overview of the Second Avenue Subway, Northern Section of Phase I, Project Area in 1865 *and with the* Original Shoreline Depicted**

Figure 9. Viele map (1874) of project area. Note tidal drainages that were probably reconfigured and rechanneled in the historic period.

4. SEDIMENT CORES

GRA Cores

A total of five (5) cores were excavated, collected, and examined by GRA for this study. Formal descriptions of each core are presented below, followed by a synthesis of the stratigraphic interpretation of the composite cross section. Core locations were determined from proposed boring maps, as well as coordinates from a GPS field unit, USGS topographic maps, and Google Earth imagery. The detailed descriptions of the cores can be found in Appendix A. Recovery was incomplete for the cores as shown in Figure 10).

Depths for the cores are registered in feet below ground surface. As discussed the stratigraphic framework is structured by Analytical Units (AUs), numbered sequentially from older to younger units (bottom to top), and are distinguished as lithostrata. Lithostratigraphy describes and organizes deposits based on lithologic character and stratigraphic relations (ISSC 1994). More broadly the lithostrata represent changes in the depositional environment through time. The textural and structural properties of a particular deposit differentiate the lithostrata from one another. One of the lithostrata, AU-IV, is further subdivided into three biostratigraphic zones (designated a, b, and c; bottom to top), based on fossil content, and specifically shell populations that varied in type and frequency within the parent marsh sediment.

Lithostratigraphic relations between cores are illustrated in Figure 11. Locations for paleo-environmental and radiometric samples (dates in ^{14}C years) are also shown.

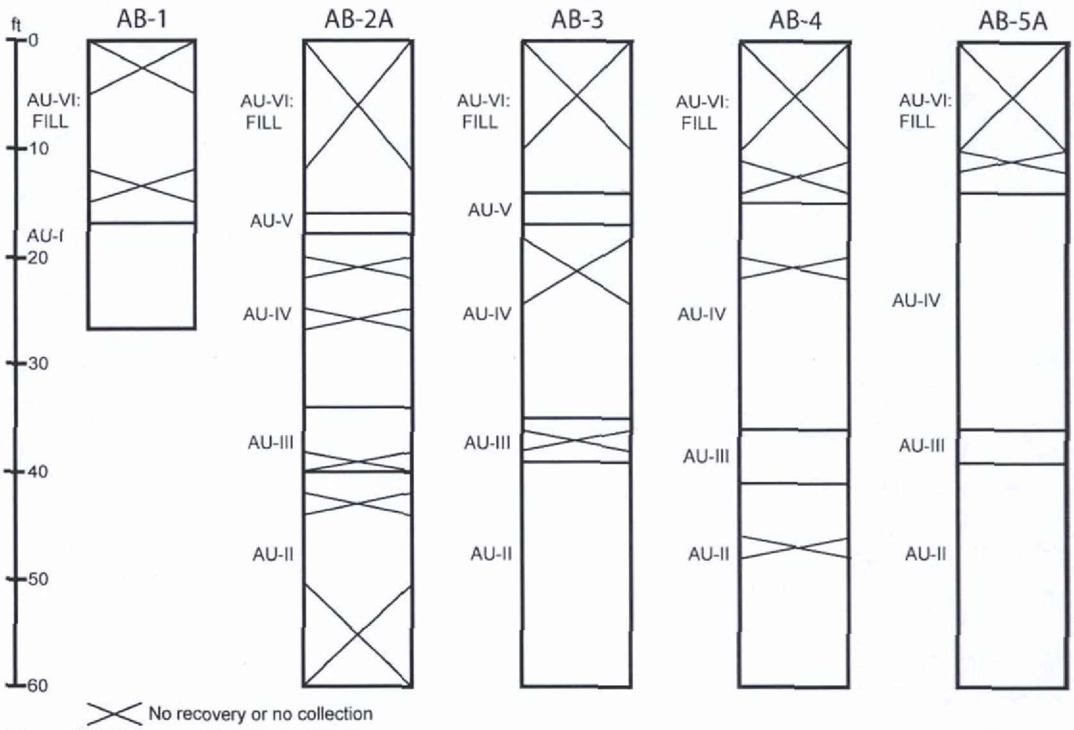

Figure 10. Recovery by core.

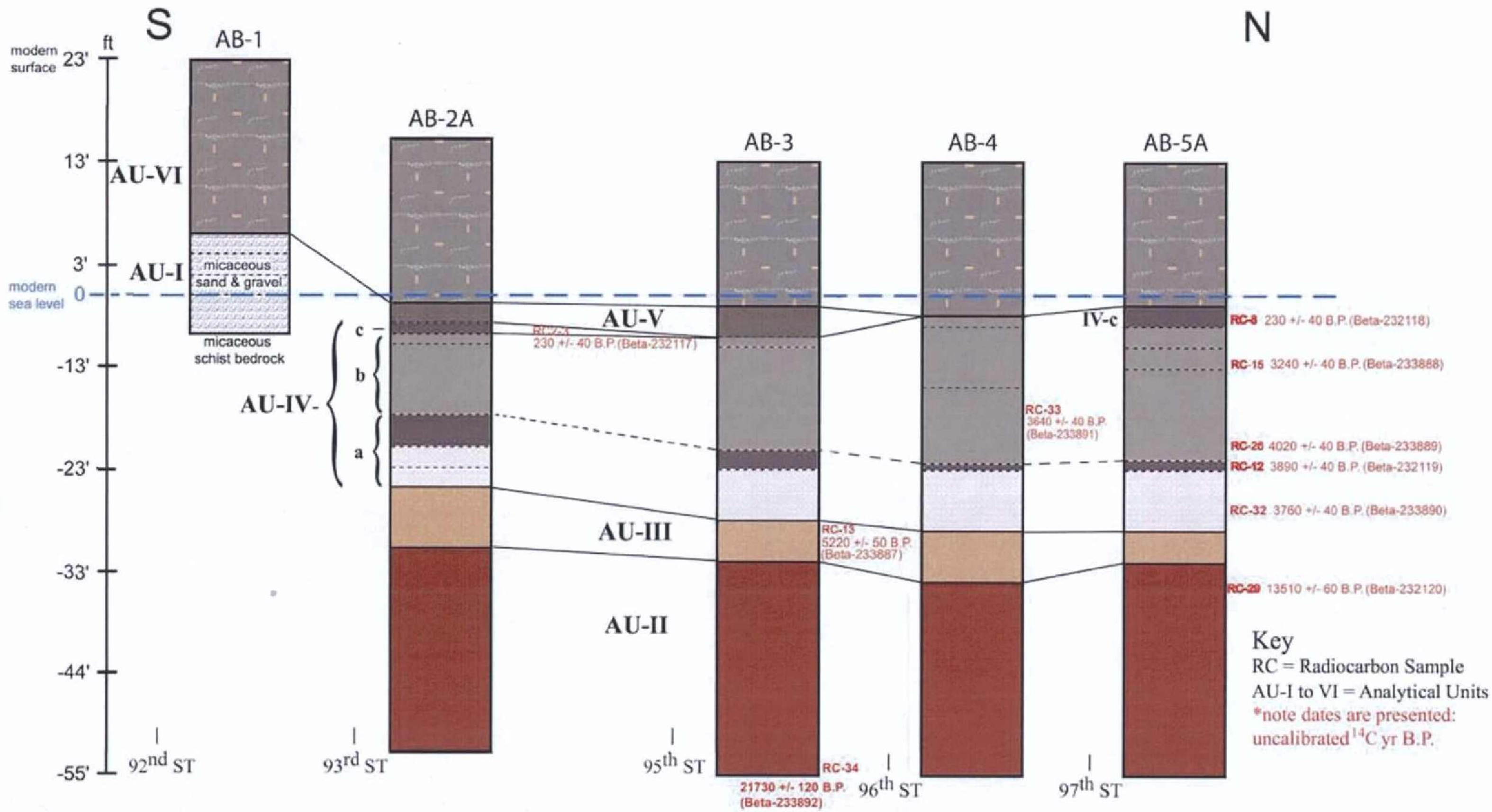

Figure 11. Cross section of cores with radiocarbon dates.

AB-1		Surface elevation above sea level:		23'
Location:	**between E 92nd and E 93rd St.**	*Maximum depth of core below surface/sea level:*	**25'6"**	**n/a**

Core AB-1 was located on the east side of 2nd Avenue approximately 120 feet north of E 92nd Street (Figure 4). Recovery was good, with a sample recovered from all cores except between 13' and 15'; rock obstructions impeded penetration (Figure 10). Core AB-1 was the only core that did not contain marsh deposits. It encountered a sequence of rubble fill to a depth of 17' (AU-VI) underlain by gravelly sands of micaceous till and weathered bedrock. The latter is underlain by unconsolidated schist bedrock; 23.5'- 25.5' (AU-I) (Figure 11, Appendix A). The gravelly sands and unconsolidated bedrock between 17' and 23.5' were heterogeneous with a generally fining upward sequence of micaceous dark gray (10YR4/1) to very dark gray (10YR3/1) gravelly silty sands to clayey sandy silt. No marsh deposits or cultural materials were observed in these deposits. No special samples were collected.

AB-2		Surface elevation above sea level:		16'
Location:	**between E 93rd and E 94th St.**	*Maximum depth of core below surface/sea level:*	**60'**	**44'**

Core AB-2A was emplaced on the east side of 2nd Avenue approximately 123 feet north of E 93rd Street (Figure 4). The core was intended to be on the western side of 2nd Avenue. Core location was finalized because of logistic concerns involving subsurface utility networks and construction concerns. The core had moderately good recovery. No recovery was achieved for sections 20-22', 24-27', 38-40', 42-44', and 54-56'. The length between 50 and 60' was disturbed, and no cultural materials were encountered in intact, undisturbed deposits (Figure 10).

This core exposed a depositional sequence that was representative of the project area substrate (Figure 11, Appendix A). The underlying bedrock (AU-I) was not reached. From 40 to 60' below ground surface were the reddish brown (5YR4/3) fine sandy silts of AU-II. Core specimens retrieved from 50' to 60' were disturbed by intrusive bentonite muds, likely sourced to a nearby well. AU-III was encountered from 34' to 40', and consisted of heterogeneous quartzitic and micaceous sands of a yellowish brown (10YR5/4) slightly silty clayey sand grading to a reddish brown (2.5YR5/4) silty sand. The upper silty sand is possibly reworked AU-II sediment. Between 27' and 34' AU-IV-a was identified. It consisted of a very dark gray (10YR3/1) to gray (GLEY N 5/) organic clayey silt from 27' to 30' that represents the first stable period of the marsh. Below the silts is a possible hydromorphic Cambic soil at 30' to 32'. The matrix consisted of a gray (GLEY 5/) organic (15%) silty clay with pedogenic development in the form of common (15%) faint fine very dark gray (GLEY N 3/) clayey silt mottling and a slight rubefied hue (3Bg horizon). The base of the unit from 32' to 34' sees a transition (3BC) into coarser sediments of gray (10YR5/1) slightly silty sand with weak mottling. AU-IV-b was found from 19' to 27' and consists of a very dark gray (10YR3/1) to very dark gray (GLEY N 3/) organic sandy silts to slighty sandy clays. Preserved organics in the form of roots and grass fragments increase in frequency up through the profile from 5% to 10% of the matrix, with very few shell fragments. AU-IV-a is a thin deposit of black (10YR2/1) organic slightly silty clay from 18.5' to 19'. The organic content is 20% of the matrix and consists of partially decayed plant material with a disaggregated grass mat. A sample of organic sediment from the contact between AU-IV-a and -IV-b was dated by AMS to 230 $\pm$ 40 BP (212.5 cal yr BP) (Beta-232117). A pollen sample from this level yielded no preserved remains (Appendix C). From 16' to 18' the historic sediment cap of AU-V sealed in the marsh deposits. The horizon consisted of grayish brown (10YR5/2) slightly silty sand with rip up clays and occasional small pebbles. The core was capped by historic fill and rubble from 0-16'.

AB-3		Surface elevation above sea level:		13'
Location:	between E 95th and E 96th St.	*Maximum depth of core below surface/sea level:*	**60'**	**47'**

Core AB-3 was located on the west side of 2nd Avenue approximately 23 feet north of E 95th Street (Figure 4). The core had relatively poor recovery with no samples from 18-24', 26'-28' and 36-38' (Figure 10). No cultural material was observed in any of the buried, intact deposits. Two (2) radiocarbon samples were analyzed from this core.

The core preserved a near complete stratigraphic succession for the project terrain. However, horizon AU-IV-c is absent (Figure 11, Appendix A). The underlying bedrock of AU-I was not encountered. AU-II is at depth from 39' to 60' and consists of a reddish brown (5YR4/3) slightly sandy. An AMS speciment from 50' to 52' dated to 21730 ± 120 BP (Beta-233892). AU-III was a dark gray (10YR4/1) slightly silty heterogeneous coarse sand between 35' and 39'. The only date from AU-III in the project area was procured from the top this unit in AB-3. Organic sediment dated to 5220 ± 50 BP (6041.5 cal yr BP) (Beta-233887). From 28' to 35' AU-IV-a consisted of a dark gray (10YR4/1) sand with 5% organics). The matrix did contain the strong organic signature and sticky consistence of the organic marsh deposits. No signs of pedogenesis were observed. Localized erosion may account for the poor expression of AU-IV-a or, more probably, it was lost in the section of cores 26' to 28' that had negligible recovery. Recovery of AU-IV-b was also minimal between 18' and 24'. Intact AU IV-b matrix was obtained from 24'-26' and at the contact with AU-IV-c at 17'-18'. The limited sample contained very dark gray (GLEY N/3) slightly silty clay with typically enriched (3%) and partially decayed organic fragments and (3%) shell fragments. AU-IV-c was observed between 17'-18' as a black to very dark gray (10YR2/1, 3/1) organic slightly sandy clayey silt with a partially disaggregated but preserved grass mat (10% by volume). The basal historic fill of AU-V was at 14'-17', preserved as a grayish brown (10YR5/2) slightly silty sand with rip-up clays and small pebbles that grades upward to the historic fill cap. AU-VI extended from 0 to 14'.

AB-4		*Surface elevation above sea level:*		**13'**
Location:	**between E 96th and E 97th St.**	*Maximum depth of core below surface/sea level:*	**60'**	**47'**

Core AB-4 was located on the East side of 2nd Avenue approximately 93 feet north of E 96th Street (Figure 4). The core was relocated from the west to the east side of the roadway. There was no recovery from 11-14', 20-22', and 46-48' (Figure 10). One (1) radiocarbon sample and three (3) shell samples were analyzed.

This core contained all stratigraphic units except AU-V and the historical marsh surface of AU-IV-c (Figure 11, Appendix A). The underlying bedrock of AU-I was not encountered. AU-II extended from 41' to 60' and is a reddish brown (5YR4/3) slightly sand silt. AU-III is from 36' to 41' as a dark reddish gray (2.5YR4/1) silty sand to sand dominated by heterogeneous quartzite and micaceous granules and similarly sized rock fragments. AU-IV-a marks the transition from sands to marsh organics (peaty silts and sands) between 29.5' and 36'. The deposit is capped by a thin 6" organic horizon of very dark gray (10YR3/1) silty clay sand with disaggregated plant and vegetation matter (root stems and fleshy fragments). That matrix is underlain by a dark reddish gray to weak red (2.5YR4/1, 5/2) fining upward silty sand to sandy clay. Unlike the other locations, the AU-IVa here has few shell and organic fragments in these transitional deposits. AU-IV-b extends from 15' to 29.5' and is a very dark gray (GLEY N/3) silty clay to clayey silt with an increase in partially decayed grasses and roots from 0% to 10% of the matrix at the top. Shell fragment density is consistently at 5% throughout the unit. An AMS sample from 24' to 26' was dated to 3640 ± 40 BP (3970 cal yr BP) (Beta-233891). The core was missing AU-IV-c. AU-VI fill material extends 0-15' to the unconformity with the marsh matrix of AU-IV-b.

AB-5		*Surface elevation above sea level:*		**13'**
Location:	**between E 97th and E 99th St.**	*Maximum depth of core below surface/sea level:*	**60'**	**47'**

Core AB-5 was located on the East side of 2nd Avenue approximately 6 feet north of E 97th Street (Figure 4). The core was intended to be further north up the block; however it had to be relocated because the potential for encountering contaminants associated with a petrochemical plant. The core was relocated to the southeastern corner of E 97th Street, but it had to be moved yet again because a subsurface obstruction prevented the continued excavation. A final attempt was successful and it had the best recovery of all five archeological borings, with no recovery from only 10-12' (Figure 10). Because of its optimal recovery this core was most extensively sampled for radiometric dating, pollen, molluscan, and sedimentological analysis. A total of six (6) radiocarbon samples were analyzed, as were nine (9) pollen samples, and four (4) shells.

All of the identified AUs were identified in the core except for AU-I and AU-IV-c (Figure 11, Appendix A). AU-II was identified at 39' to 60' and is a reddish brown (5YR4/3) slightly sandy silt. A bulk sediment sample from near the top of the deposit at 42' to 44' was dated to 13,570 ± 60 BP (16,166 cal yr BP) (Beta-232120). Above this deposit from 36' to 39' is AU-III. It is a brown (10YR4/3) slightly silty sand dominated by micaceous and quartzite grains. AU-IV-a is at 29' to 36' and consists of very dark brown (10YR2.5/1) organic silt with some partially decayed sections of grass mat from 29'-29.5'. Organic matrix was dated by AMS to 3890 ± 40 BP (4291 cal yr BP) (Beta-232119). Below this marsh deposit is a gray (GLEY N 5/) silty sand from 29.5' to 30' with a weak and gleyed 2Bg horizon. The matrix features common (15%) dark greenish gray (GLEY N 4/1) mottles. It grades from 30' to 36' to a downward coarsening gray (10YR5/1) sand. The latter is displaced by silty sands and brown (10YR4/3) slightly silty sands, possibly representing beach or near shore deposits. Organics from a bulk sample of these sands was dated by AMS to 3760 ± 40 BP (4113.5 cal yr BP) (Beta-233890). AU-IV-b consisted of a relatively uniform dark gray (GLEY 1 N 4/) marsh silts and clays at 16' to 29'. The organic content decreases down the profile from 5% organics (partially decayed grasses and roots) to <1% at 26'. Shell fragments are found throughout at a relatively uniform (5%) proportion of the matrix. Two bulk samples from AU-IV-b, one from the upper portion of the deposit (18' to 20') and another from the lower portion (27' to 28'), were dated by AMS. The upper sample provided a determination of 3240 ± 40 BP (3471.5 cal yr BP) (Beta-233888) while the the lower was assayed to 4020 ± 40 BP (4598.5 cal yr BP) (Beta-233889). From 14' to 16' is a very dark grayish brown (10YR3/2) organic silty sand with an abundant plant and vegetal component (30% by volume) including partially to well decayed grass, wood, and root fragments. Historic fill is incorporated into the top of this deposit, while a few (2%) small shell fragments are present. A sample of wood was dated by AMS to 230 ± 40 BP (212.5 cal yr BP) (Beta-232118). This historical marsh surface is capped from 0 to 14' by historical fill.

MTA Cores

As noted, a total of thirty nine (39) borings were examined at the MTA core storage facility. Each jar, which typically presented a 2' length of core, was examined and correlated to the Analytical Units (AU) scheme developed during the GRA field effort. No paleoenvironmental specimens were analyzed from the MTA cores. The descriptions of these cores can be found in Appendix B. Due to the large number of MTA cores and the interpretive restrictions imposed by limited inspections and discontinuous sampling and preservation, the cores are described by block. They are indexed and compared to the closest GRA cores.

90th and 91st Street Blocks

Since no GRA cores were excavated from either of these blocks and the stratigraphies are similar, cores from 90th and 91st are discussed together. Samples from three (3) cores on 90th Street (B90-1, B90-2, and B90-4) and five (5) cores from 91st Street (B91-1, B91-2, B-3, B-5, and B-6) were examined (Figure 3, Appendix B). The sequences are analogous to AB-1, although it is noted that AB-1 is located on 92nd Street. The cores have a general sequence of 10' to 15' of fill (AU-VI) above 5' to 10' of unconsolidated bedrock (AU-I), and are underlain by micaceous schist bedrock from 15' to 25'. The unconsolidated portions of AU-I have some indications of preserved surfaces, in the form roots and organic matter from 15' to 17', in sediments below the fill (Core B90-1). Weak, possibly pedogenic mottling was observed in samples from 21' to 23' and 25' to 27' in Core B91-3. The bedrock trends deeper from 90th to 91st street at 20' to 30'. This reflects the slope of the ancient landform.

92nd Street Block

Three cores from the MTA collection (B92-1, B92-3, and B92-3) (Figure 4, Appendix B) were examined and compared to the one GRA core from 92nd street (AB-1). Cores B92-1 and B92-2 had upland stratigraphy similar to that observed in AB-1. These cores featured succession of fill (AU-VI) from 0 to 15', unconsolidated sands of AU-I from 15' to approximately 25', underlain by schist bedrock. B92-3 differed and is the first core that preserved marsh deposits. Below the fill (0-22') AU-IV-b and AU-IV-a matrix were encountered from 25' to 32'. Sands of AU-III were identified in a sample from 35' to 37'; however the deepest sample in the collection from 40' to 42' was a brown (10YR4/3) slightly clayey silt that is not analogous to AU-III or AU-II, and unfortunately there were no deeper samples in the collection. The core is important because it establishes the southern edge of the marsh and it correlates to the location of a channel identified in the Dripp (1851) and Viele (1874) maps (Figures 4 and 9).

93rd Street Block

A total of six (6) MTA cores were examined from 93rd street (B93-1, B93-2, B93-3, B93-4, B93-6, and B93-8) (Figure 4, Appendix B). Core stratigraphies are analogous to AB-2A, but because their depths extended to bedrock they provide insights into the underlying structural geology and the thickness of the glacio-lacustrine deposits of AU-II. The top of the underlying schist bedrock dips from 60' on the southern end of the block in B93-3, to 90' at B93-1. The latter location is adjacent to AB-1 in the middle of the block, to 100' on the northern edge of the block at B93-4. Accounting for slope from south to north, the top of AU-II extends uniformly 40-45' below the top of the ground surface, regardless of depth to bedrock.

94th Street Block

GRA did not bore on 94th street; therefore the four (4) MTA cores from this street (B94-1u, B94-2, B94-3, and B94-4) (Figure 4, Appendix B) are our only record for this block. These cores have a generalized stratigraphy similar to the other cores, however the fill is typically deeper (to approximately 25') and the bedrock dips significantly deeper. Only core B94-1u was bored to the depth of bedrock (AU-I), which was encountered at a depth of 150'. The red silts of AU-II still have their upper limits at 40', therefore the glacio-lacustrine deposits have a thickness of up to 110'.

95th Street Block

A total of three (3) MTA cores were examined (B95-2, B95-3, and B93-3); however there were two samples with the same label (B95-3) (Figure 4, Appendix B). The stratigraphy of the cores was similar to that observed in GRA core AB-3, with a typical sequence of marsh deposits and transitional sands over glacio-lacustrine silts (AU-IV to AU-II). None of the MTA cores were excavated to the depth of bedrock, and instead terminated in AU-II at 122 (B95-2) and at 112' (B95-3).

96th Street Block

A total of ten (10) MTA cores were examined (B96-2, B96-3A, B96-4, B96-6, B96-7, B96-8, B96-9, B96-10, B96-12, and B96-13) (Figure 4, Appendix B). The cores were similar to that observed in AB-4, and like the cores on the 95th street block, none of the cores extended to the underling bedrock.

97th Street Block

A total of three (3) MTA cores were examined (B97-1, B97-3, and B97-5) (Figure 4, Appendix B). The cores had a similar stratigraphy to AB-5A, and one of the cores (B97-3) extended to bedrock at 165'.

108th and 109th Street Blocks

Two (2) MTA cores from well outside the project (B108-1 and B109-1) (Appendix B) area were examined to provide exposures of outside of the marsh, on uplands just to the north of the presently infilled and recontoured landscape of Pension's/Harlem Creek. The cores recovered a stratigraphy markedly different from what preserved in the general core suite because they did not preserve evidence for the marsh (AU-IV) nor did they encounter bedrock (AU-I). Significantly, however, the red silts of the glacio-lacustrine unit (AU-II) were identified. AU-II is overlain by sands and gravels, texturally similar to both the heterogeneous sands of AU-III and to the unconsolidated portions of AU-I as observed to the south of the marsh. These sediment complexe,s from roughly 20' to 50'-60', may represent a heterogeneous mixture of glacial till and outwash sands that cannot be indexed to any sedimentary suite observed in the core transect excavated along the project corridor.

5. PALEOECOLOGICAL STUDIES

Paleoecological studies were undertaken to supplement the landform history developed from the stratigraphic and radiometric results. Palynological and macrofossil analyses were performed, as was a malacological study. Results for each are presented in Appendices C and D respectively. Both provided insights into patterns and chronologies of sea level rise and climatic change.

A sedimentological analysis is also in progress and will facilitate a more comprehensive interpretation of the estuarine depositional patterns through time. These will also aid in the differentiation of discrete landform components of the complex buried estuary. Summary paleoecological observations are presented below.

Palynological and Macrofossil Analysis

The macrofossil and pollen research document time-transgressive trends in vegetation for the estuarine micro-environment through time. These trends have paleo-climatic implications. Because of the sensitivity of paleo-biotic indicators, even short term climatic pulses can be indexed.

The pollen data are most diagnostic of the climatic signal. The pathway of pollen from plants to a buried deposit is complex and the pertinent aspects of palynology relative to the study are summarized.

There are three aspects of pollen mobilization that account for its interpretive potential: dispersion, transport, and preservation. Dispersal is central to pollen's appearance in the sedimentary record (Figure 12) (Faegri et al. 1989). Gravity initially deposits pollen locally near the source plant. Local diffusion and wind transport accounts for the settlement and storage of pollen locally. Finally regional pollen components are transported over greater distances and altitudes. Additional factors such as climate, vegetation distributions, and the actual weight of the pollen grains impact the dispersion and transport of pollen, and thereby have an impact on the quality of the record. In marsh settings pollen settles in the subaqueous environment, variously transported in by tides and currents.

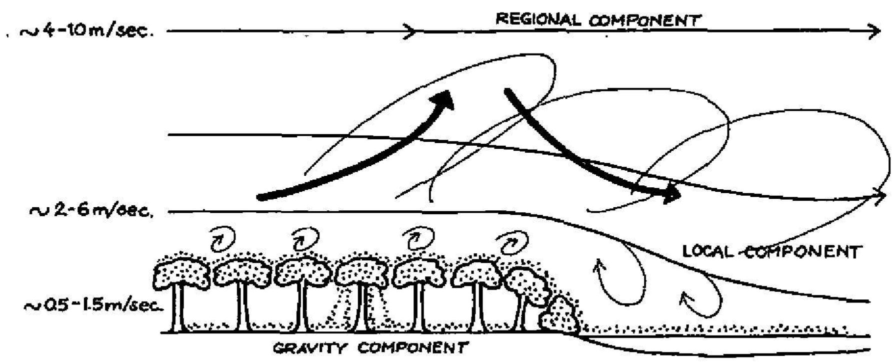

Figure 12. Pollen dispersion model (from Faaegri et al 1989: 24 and Figure 2.10)

Marsh preservation is generally good because: vegetation slows the water column allowing pollen to settle to the bottom; sustained low energy deposition seals in the pollen grains; and the saturated, reduced environments hinder the destruction of pollen grains. Finally, organic-rich marsh deposits are typically acidic, with a low pH that hinders the microbial activity of bacteria and fungi which feed on pollen.

The macrofossil and pollen sampling column for this study was AB-5A and extended from depths of ca. -11 to -22'. All specimens recovering pollen were contained within AU-IV-b, the aggrading salt-water marsh facies. The sampling column is well dated to 4600-3200 B.P. It is noted that Loss-on-Ignition assays (LOI), undertaken in conjunction with the pollen processing, found organic matter concentrations on the order of 2-5%, considered to be very low in comparison with other Hudson marshes that contain 20-40% organics.

The major local findings of the study were that:

- Seeds of *Ruppia maritimia* (widgeon grass) were found throughout AU-IV, which suggests submergence in a brackish estuarine mud. *Ruppia m.* habitat is the shallow (subtidal) sea bed or tidal channels that tolerate a wide range of salinities from 0 to 70 ppt (La Peyre and Rowe 2003);
- General absence of seeds and relatively low pollen counts from salt marsh species (such as Cyperaceae and Gramineae) suggests that the depositional environment was not that of a vegetated salt marsh, but rather an estuarine mud or a mud flat;
- The presence of *Pteridium* (brackenfern) and *Osmunda* (fern) pollen, which are both not salt tolerant species, at the lowest levels of AU-IV-b suggests there was a nearby freshwater wetland;
- The overall trend was to more saline conditions over the ca. 1200 year interval of marsh margin sedimentation.

At the regional level the pollen and macrofloral analysis found:

- High concentrations of charcoal and *Carya* (hickory) throughout the history of the marsh (AU-IVb) which suggest warmer drier conditions than the modern historical period;
- The warmest/driest periods are registered both at the base of the horizon (4600 B.P.) and the top (3200 B.P.) but there is evidence for intervening cool/moist and warm/moist pulses based on arboreal pollen representation.
- Higher salinity seems to be tied to drought conditions

Molluscan Analysis

The molluscan analysis consisted of the identification of ten (10) shells from core AB-4 and five (5) from AB-5A by Dr. G. Lynn Wingard (Appendix D). Interpretations of inferred ecological habitats based on the species identified were also presented. The samples were all recovered from variable depths in units AU-IVa and AU-IVb.

Three molluscan genera were identified: *Macoma, Nassarius,* and *Argopecten.* Identification on the species level was limited by fragmentary preservation contexts in some cases. Provisional indications are that the *Macoma* species is either *M. balthica* or *M. calcarea,* while the *Nassarius* species were likely *N. trivittatus, N. vibex* or *N. obsoleta.* The sample of *Argopecten* could not be identified on the species level.

The *Nassarius* and *Macoma* species are endemic to cold water shallow estuarine environments, most probably a mudflat. *Macoma* species are found from intertidal to deeper water, while the *Nassarius* is found primarily in shallow water mud-flats. The *Nassarius* species tolerate salinities ranging from mid-estuarine to marine at (15-25 ppt). The *Argopecten* observed is generally found in deeper, clearer water, and it was probably transported during a tidal inundation, as it is not indigenous to estuaries.

Summary

The ecological studies provide additional lines of evidence that contribute to understanding the landforms within the project area. The data suggest that the marsh deposits of AU-IVb represent a subaqueous mudflat that was completely saturated. It does not appear to have been a tidal micro-environment that sustained a salt grass marsh.

6. SYNTHESIS

Nearly forty years ago, a seminal paper by Newman et al. (1969) outlined the first comprehensive Late Quaternary history for the landscapes in and around New York City. The model was structured around an overarching sequence beginning with bedrock (typically gneiss and schist), overlain by lake beds and or till, then by various estuarine facies and capped by urban fill. These sequences were projected to extend up to several hundred feet across most of the New York metropolitan area, conditional on local topographies, erosional processes, and the accelerated pace of urban development. The outlines of this stratigraphic framework have largely been confirmed by limited but increasingly sophisticated geological and geomorphological investigations. Over the past few decades, methodological advances, specifically in paleo-environmental research, radiometric calibration and now Geographic Information Systems (GIS) have refined the baseline sequences on the local level (see Schuldenrein et al., 2007 and references). Most significantly, it is possible to reconstruct relatively high resolution chronologies with limited subsurface exploration bolstered by site specific, efficient analyses techniques. This approach was applied to the geoarchaeological study for the 2nd Avenue subway project.

The objective of the study was to assess the buried archaeological site potential along a 9 block linear corridor, for which a buried historic marsh provided the only firm basis for site preservation. While the avenues for paleoenvironmental investigation were extensive, the data bank for assessing shore or near shore archaeological site preservation was more limited. Prehistoric site distributions in and around New York City suggested that prehistoric cultural components—spanning the 10,000 year range of the Holocene—are either sparse or have been located serendipitously at shoreline locales where landscapes have not been impacted by late Euroamerican urbanization. In their recent summary of the archaeology of New York City, Cantwell and di Zerega Wall (2001: 13) note that "....(larger sites) located at the confluences of rivers, along sheltered shorelines, on well drained soils, or near fresh water....were often destroyed in the early years of the city's modern history."

Thus, while it was clear that the prospects of encountering a prehistoric or even historic site along the 2nd Avenue footprint was inherently low, the stronger possibility of synthesizing both the depositional sequence and the chronology would facilitate construction of a model of archaeological probability. That model, in turn, serves as a scientific basis for assessing preservation potential not only for the location itself but for particular occupations as well. The model hinges on the accuracy of the landscape reconstruction. The balance of this section begins by summarizes the stratigraphic and landform sequences underscoring the paleoenvironmental model. It proceeds with a time transgressive paleo-landscape reconstruction. The final subsection is an assessment of buried archaeological site potential based on the landscape model.

Landscape History

The 2nd Avenue subsurface geoarchaeological testing program presents a variant of the Late Quaternary Hudson Valley evolution keyed to the site of the former Hell's Gap Marsh along the margins of the East River. Six (6) lithostrata register the local landscape history beginning with the presence of the Late Glacial Maximum (LGM) Pleistocene lake and upland tills; its subsequent disappearance; the emergence and sustained evolution of an estuary regulated by marine shoreline cycles during the Middle to Late Holocene; and finally the Euroamerican settlement and rapid overhaul of the natural shoreline during the industrial and commercial phases of neighborhood development. While the sequence is chronicled by unconsolidated sediments, and the radiometric materials that date them, there are temporal gaps of equal or longer duration, attesting to extensive intervals of non-deposition. For example sustained erosion and long term edaphic adjustments account for the absence of early post-glacial sediments while the missing record of the pre-Euroamerican estuary may be attributable to large scale reclamation projects and relandscaping during the historic to recent periods. Additional concerns, for the estuary in particular, include geomorphic process and patterns of net sediment accretion vs. loss over the course of a particular geomorphic cycle. While the landform chronology developed below is structured primarily on the sediment history, reference is also made to processes and time frames during which erosion and/or non-deposition should be factored into the history.

The paleo-geographic time line developed begins with the semi-schematic stratigraphic profile that links the Analytical Units (AU's) over the 0.25 mile (0.4 km) length of the project transect (Figure 13). Chronologies for the Analytical Units (AU's) are indexed and referenced by calibrated ages (Figure 14). The most detailed chrono-stratigraphies and reconstructions were developed for estuarine environments that evolved over the interval 4600-3200 B.P. Figure 15 illustrates the regression line for sea level rise that documents the succession of Middle to Late Holocene development along the Hells Gap estuary. The curve was generated on the basis of the radiocarbon dates; the fit with the recently revised sea level model for the New York Bight is compelling (Schuldenrein et al., 2007).

The foregoing data sets allow for the generation of a series of chronologically based hypotheses as follows:

1. **Upland terrain of the project area (south of the middle of the E 92nd and E 93rd St block) is underlain by regolith and glacial till with no preserved Holocene deposits. Age: ca. 20,000 B.P.**

   South of 93rd St. AU-I represents the Manhattan Formation micaceous schist infrequently capped by a thin sandy Late Pleistocene till. The bedrock and till veneers were identified across the project area, both on the upland margins of Hellgate Bay and under thick proglacial lake sediment. There are unconsolidated portions of the mica schist found on the upland margins in the form of micaceous sands and gravels.

The presence of quartzite sands and generally poorly sorting suggests that glacial tills interfinger with the unconsolidated regolith. South of E 92nd street the bedrock till complex directly underlies historic fill.

2. **Thick proglacial lake deposits unconformably underlie the Middle Holocene estuary. Age: ca. 23,000-14,800 B.P.**

Cores from E 92nd to E 97th street are dominated by thick packages of red silts, fine sands, and clays (AU-II). Accumulations are typically 120' thick and extend to depth of -30' (bsl). Bedding, sedimentology and structure conform to observed varved proglacial deposits in Newark Bay and the lower reaches of Hackensack and Passaic River valleys (Lovegreen 1974, Stanford and Harper 1991). The reddish color of the matrix is derived from Newark Group rocks that were eroded and transported by glaciers and laid down in the lake basin. Most recent mapping assigns the basin to the glacial Lake Bayonne-Lake Hudson complex (Stone et al., 2001: Figure 3). It is subjacent to and separated from the former Lake Hackensack by the Palisades sill. In the New Jersey meadowlands the uppermost (Lake Hackensack) deposits were typically 12' to 30' below surface; the deeper elevation conforms to equivalent Lake Hudson sediments in the 2nd Avenue cores. The dates of 16,166 cal yr B.P. and 21,730 ^{14}C B.P. are both consistent with the antiquity of Lake Hackensack and pre-date the estimated breaching of the Narrows at 14830 cal yr B.P. Accordingly, the draining of the Lake Hudson would have been through the opening of Long Island Sound via the Harlem River and Hells Gate. The lack of preserved macrofossils, shell, and pollen preclude more refined Late Pleistocene paleoenvironmental reconstructions.

3. **Extensive post-glacial erosion and hydrological overhauls. This resulted in a depositional hiatus following the emptying of the post-glacial lakes. Lacustrine terraces framed the margin of the East River when sea level fell below -30'. Hiatus: >12,000-6000 B.P.**

Following the emptying of the glacial lake basins, two factors accounted for the reconfiguration of the landscape: 1) the drop and subsequent rise of sea level over a 10,000 year period; and 2) the renascent fluvial system that scoured, eroded, and eventually began to construct new alluvial plains within the basins of the former glacial lakes. The revised model of sea level rise for New York Harbor shows that by 8000 yr B.P. (uncalibrated) sea level stood at -72' (~22 m) (Figure 15). Stream channels such as the Harlem River would have incised through lacustrine sediments towards that adjusting base level. Deep channel scouring across the abandoned lake plain was a dominant process, evidenced locally in the deep channels in the East River and the Hudson, and especially at Hells Gate. Just offshore of

Hellgate Bay to the east of the project area the modern sea bottom is between -80' and -96' (NOAA 1990). Such a difference in elevation suggests the project area likely escaped erosion during the Late Pleistocene and Early Holocene, and Hellgate Bay remained a high terrace overlooking alluvial landscapes that were subject to the increasing encroachment of brackish, salty sea water as sea level rose. The terrace could have been a terrestrial surface that supported vegetation during this period. However there was no evidence for buried surfaces in the cores, perhaps a function of sustained erosion during the Early to Middle Holocene.

4. **By the Middle Holocene sea level has risen to the point where it was encroaching the eroded relict Lake Hudson terrace. A heterogeneous coarse sand of nearshore, fluvial (antecedent Harlem Creek?) or multi-source facies associated with the *rising shoreline is laid down atop the older Pleistocene* deposits Age: ca. >6000 B.P.**

   Sea level models show that the early Middle Holocene witnessed a rapid transgression with elevations rising from -72' at 8000 yr B.P. to -30' by approximately 5500 yr B.P. (Figure 15). This corresponds to the date of 5200 BP (6050 cal yr BP) and elevation -21' to -23' at the top of heterogeneous coarse sand deposits of AU-III. These sands may represent deltaic or fan sedimentation at the mouth of terrestrial streams and the encroaching shoreline. A rising sea level would have raised the base level of the small creeks draining Manhattan and diminished stream gradients. This change in slope likely altered stream patterns from incised single channels to multiple braided channels that spread over a larger area and buried the lacustrine terrace. More significantly, they would have initiated a mosaic of estuarine and near shore environments in the brackish zone.

5. **Middle Holocene landscape evolution involved the transformation from a nearshore to an estuarine environment. After the initial transformation *diminished* rates of sea level rise promoted stabilization and equilibrium of freshwater and saltwater inputs. The estuary slowly encroached landward creating a saltwater marsh. The initial marsh micro-environment features distal aquatic and wetlands zones. Progressive transgression expands the brackish zone. It is eventually submerged and develops into a subaqueous mudflat. *Pollen assemblage indicates the climate was warmer than today.***
   Age: ca. 6000-3500 B.P.

   Atop the sands of AU-III the successive facies of AU-IV are progressively more estuarine. AU-IV-a fines upward signaling a stable surface (at approximately -15' to -17') above the coarser, more poorly sorted beach sands. The initial estuarine sediment features a high organic sediment and muck, as well as limited pedogenic soil development in the form of a weakly gleyed (Bg) horizon. The recovery of pollen from ferns that require freshwater environments at the base of the marsh deposits indicates that the marsh was either freshwater or very near a freshwater setting during its early formation. Ages for the initiation of deposit cluster around 3800 B.P. (4200 cal yr BP) (Figure 14). Even though dates are not stratigraphically consistent for the unit (IV-b), they are within several hundred years of each other and variability is attributable to extensive lateral mobilization of sediment in the tidal zone. Age ranges correlate with sea level at -21' at 3500 B.P. The ongoing transgression resulted in a landward displacement of the landform: the former marsh became a subaqueous mudflat (AU-IV-c). Evidence for this transition to a mudflat is demonstrated by marked decrease in organic content; the lack of freshwater or saltwater marsh species in the pollen assemblage; subaqueous seeds of *Ruppia m.*; mollusk species typical of near shore and deep water, subtidal mudflats; and gleyed sediments indicative of hydromorphism.

6. **The mudflat progrades to match sea level rise until approximately 3000 B.P. The surface stabilizes after this period and vegetation and organics accumulate on the stable mudflat surface into the Historic.**

Age: 3500 B.P.-3000 B.P.
***Hiatus:* 3000 B.P.-1650 A.D**

The youngest age from the top of AU-IV deposits is 3200 B.P. (3500 cal yr BP) and represents the end mudflat aggradation. The mudflat ceased to accrete at approximately -5' to -7' below modern sea level. Here the sea level curve at Hellgate Bay deviates from regional sea level rise model for New York Harbor. At 3000 B.P. (uncalibrated) the regional model indicates sea level was at -15' the level does not attain that for Hellgate Bay until 1000 B.P. (Schuldenrein et al. 2007: Figure 14). More generally, the radiocarbon dates for the 2nd Avenue estuarine sequence (Figure 14) implicate surfaces that were up to 2 m higher in the estuary's early phases (6000 B.P.) but the plots converge after 3000 B.P. (compare regression plots in Figure 15). Reasons for the variability may involve dating errors but may also be attributable to local sedimentation, subsidence, or rebound. After 3000 B.P. the mudflat is no longer aggradational and instead a relatively thin horizon of organic material begins to accumulate on the stable sea floor (AU-IV-c). That thin horizon is of early Euroamerican age and verifies that there is no sedimentation across the project area until that time.

7. **Historical sedimentation of sands caps portions of the mudflat. Hellgate Bay is subsequently infilled with rubble and domestic debris in the late 19th century.** **Age: 1650 A.D.-Present**

During the historic period limited mudflat segments and peat lenses were overridden by fine sands. A variety of processes could have accounted for sedimentation including storm surges, urban runoff; coarser sands may be derived from current activity as well. The area was dramatically altered by the infilling of the Bay during the late 19th century. Rubble and domestic debris were observed in the fill material, which ranged from 10' to 20' thick.

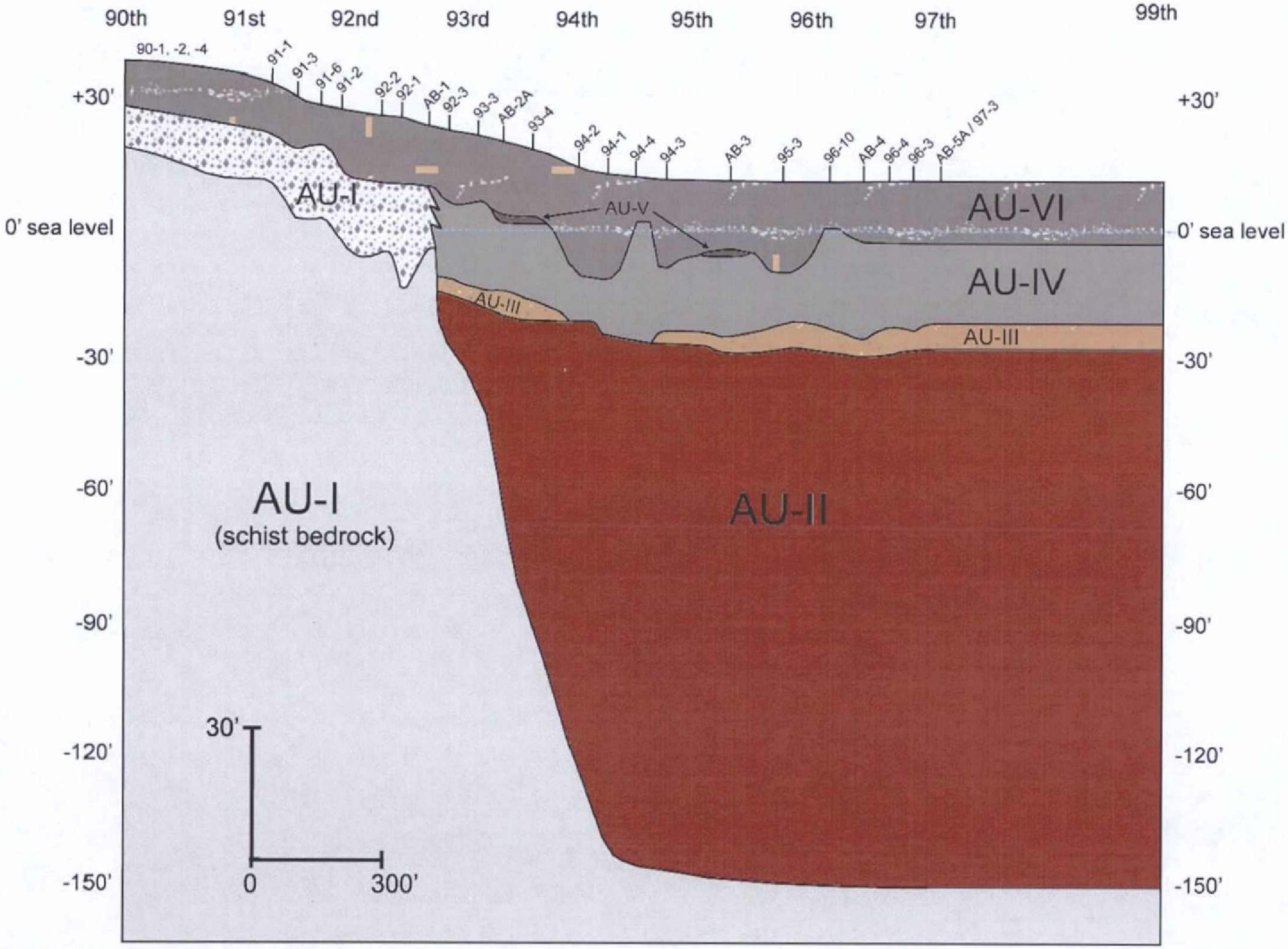

Figure 13. Schematic cross section of project area.

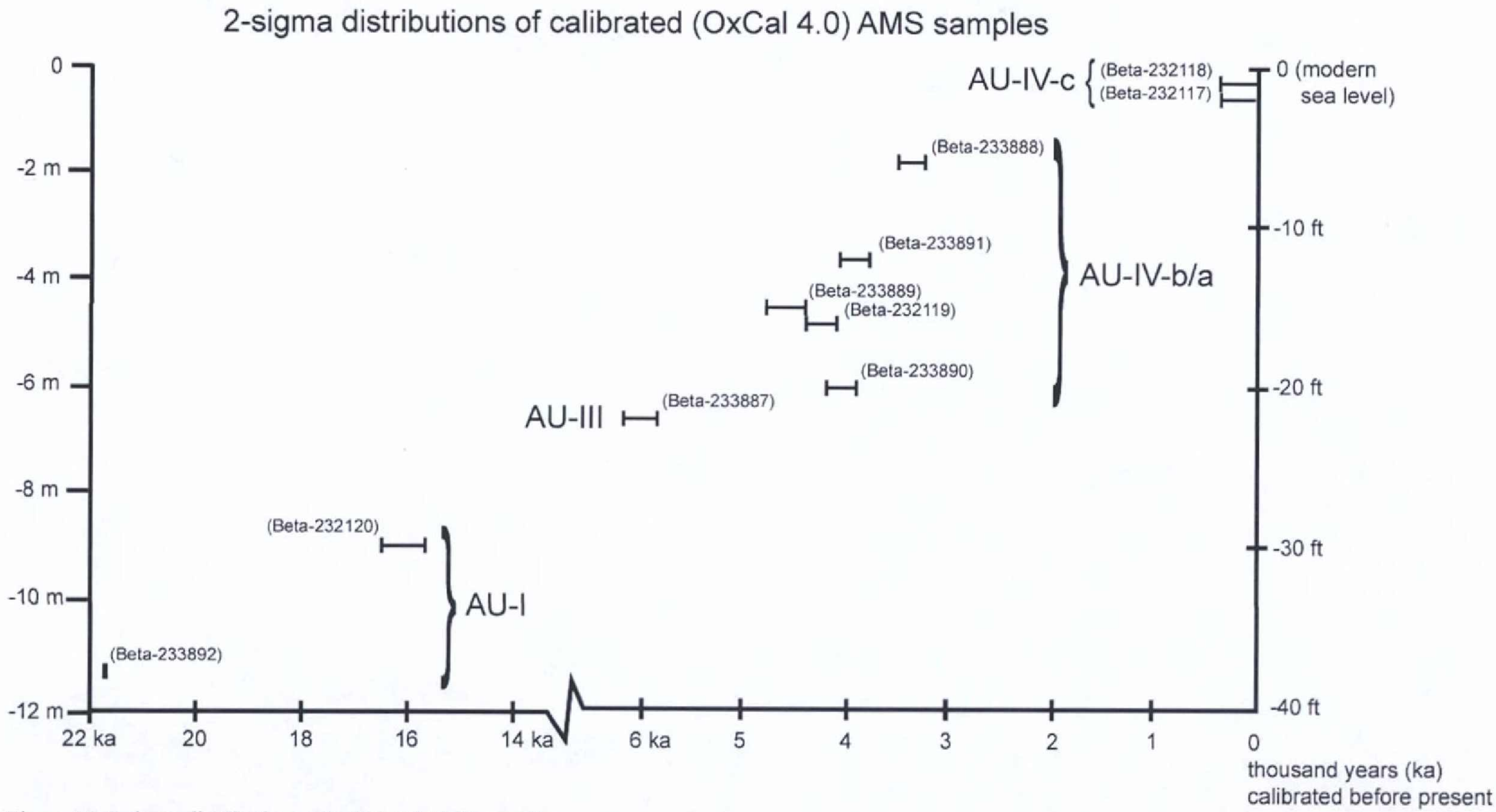

Figure 14. 2-sigma distributions of calibrated AMS samples.

Relative Sea Level Rise at New York Harbor with Sea Level Rise at 2nd Avenue Subway

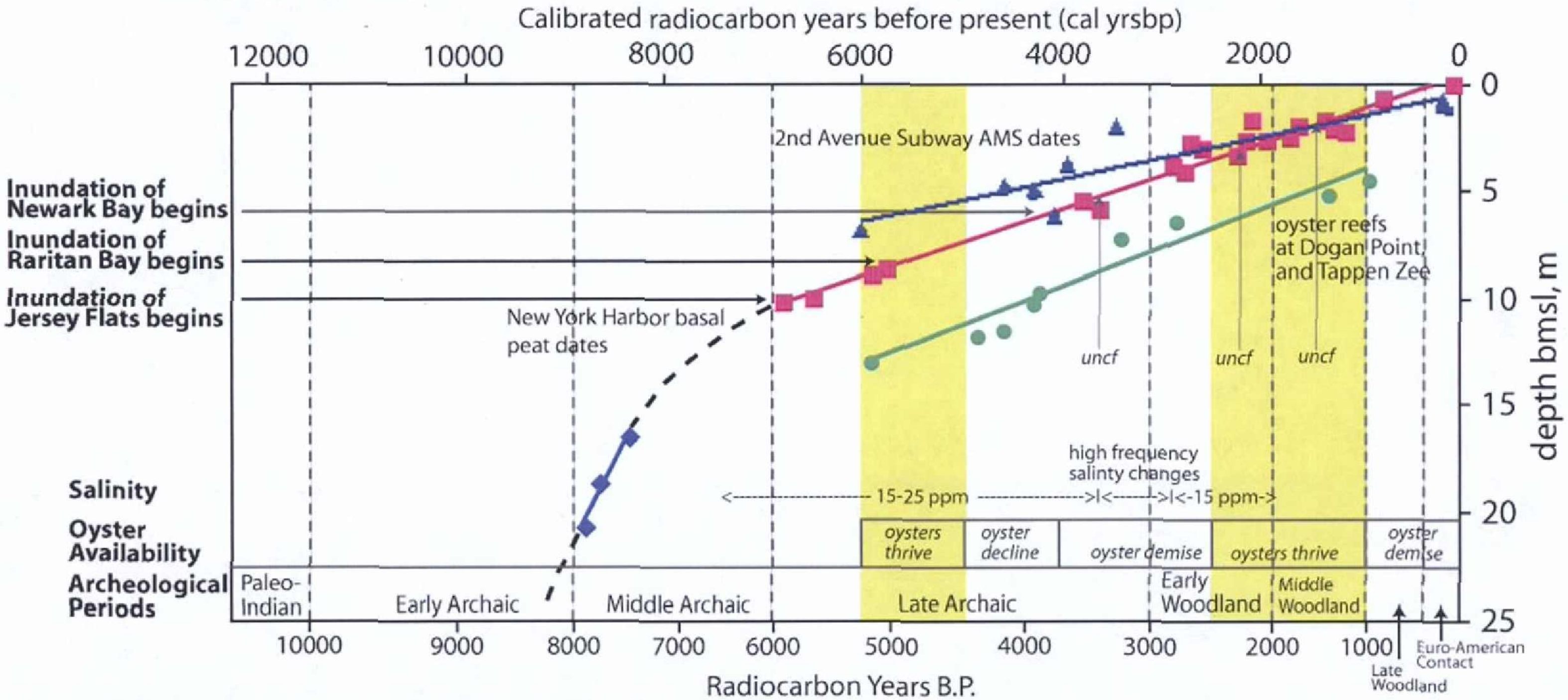

Figure 15. Regional sea level model with AMS dates from the 2nd Avenue subway.

Landform Modeling

The incorporation of project stratigraphies with regional landform histories allows for the generation of a diachronic model for the evolution of the Hellgate Bay. This is depicted in time transgressive, graphic representation of landscape form and process (Figure 16). "Time slices" were created using a combination of modern elevation data, historical bathymetry, historical landform maps and projected sea level information. A digital elevation model (DEM) for the Central Park Quadrangle (USGS 7.5 minute series topographic maps) was used as the base that was modified within a Geographic Information System (GIS) to reflect the pre-landfill topography of parts of the Harlem plain. Bathymetry was digitized from a georeferenced digital image of the "Navigation Chart of Hell Gate and its approaches" (1875) retrieved from the image archives of the Historical Map and Chart Collection, Office of Coast Survey/National Ocean Service/NOAA. This chart was considered more accurate than modern bathymetric data, as it predates most of the late 19th and early 20th century dredging activities. The location and outline of the historic period's low-lying wetlands was digitized from a georeferenced image of the map "Sanitary & Topographical Map of the City and Island of New York" (Viele 1874). The elevation of this wetland was lowered for older time periods in accordance with information generated in the course of this study's subsurface investigations. The shoreline for each period reflects the sea level curve depicted in Figure 15.

This model generated eight (8) temporal projections for landform evolution (Figures 16a-h). A brief synopsis of the key landform developments is described for the individual time frames.

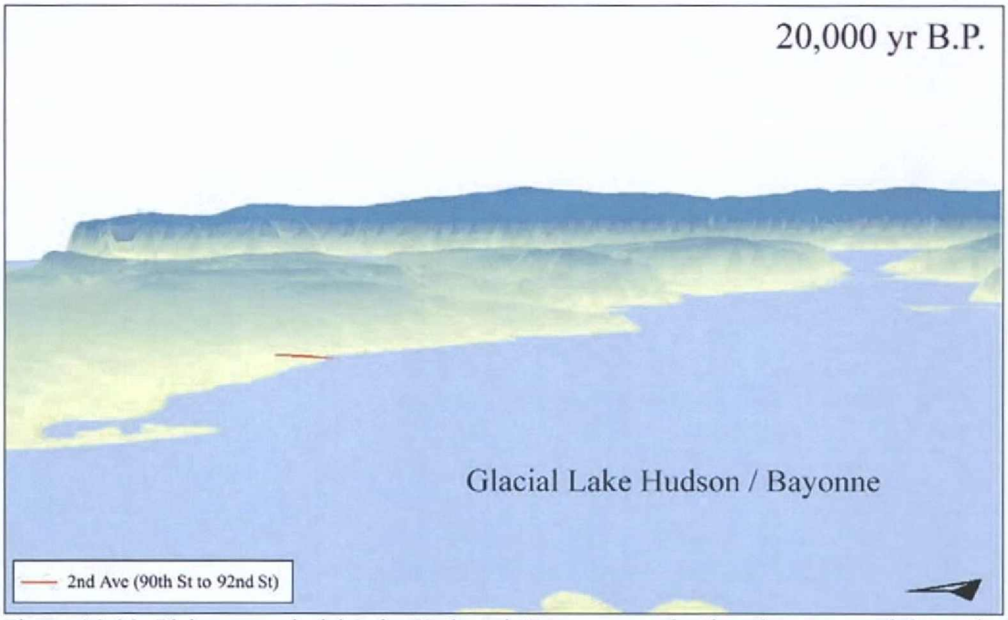

Figure 16 (a). Pleistocene glacial Lake Hudson / Bayonne complex inundates most of the project area. Regional models suggest that lake elevations are approximately 9 m (~30 ft) higher than modern sea level. The terrain above 92nd street was submerged; the segment between 90th and 92nd streets was not. This is consistent with our findings, as lacustrine sediments were not found between 90th and 92nd streets, and were prominent in all cores to the north.

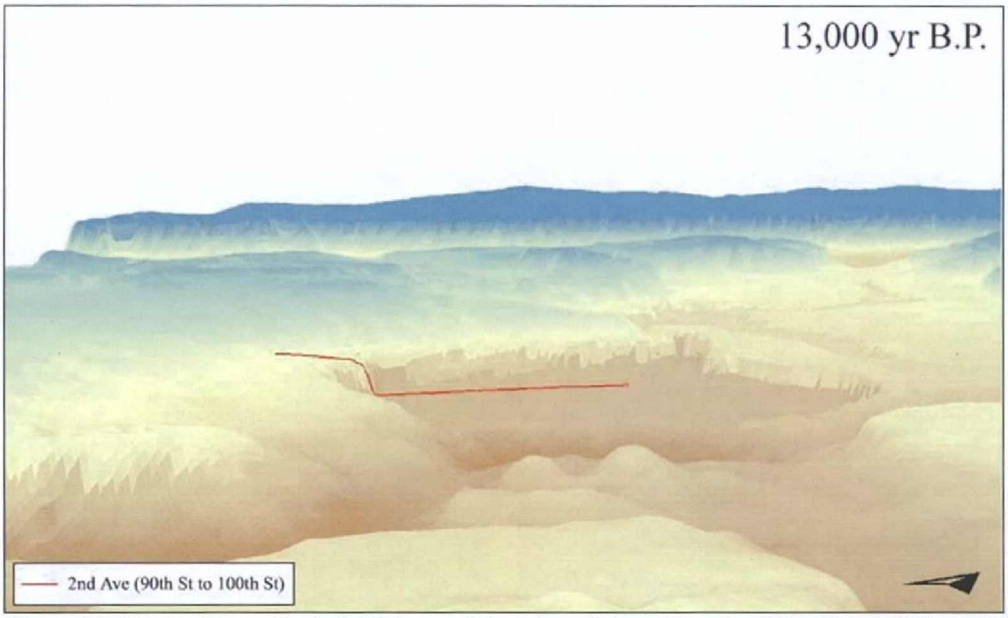

Figure 16 (b). Drainage of glacial lakes and incision of lacustrine deposits. By 13,000 yr B.P. the proglacial lakes had drained, and sea level was -72' below modern levels. Exposed, steep sided terraces flanked the ancestral trenches of the Harlem and East Rivers. The project area was perched above the floodplain. It is probable that small tributaries from Manhattan drained across the project area, although no evidence for these was observed in the cores.

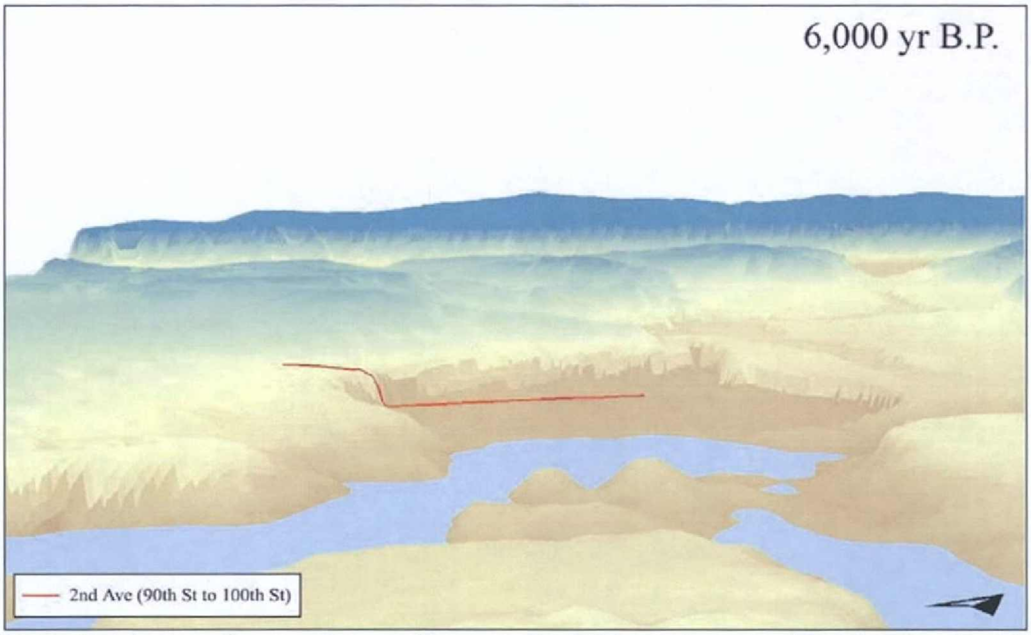

Figure 16 (c). Emerging near shore environment. By 6,000 yr B.P. sea level had risen to a level (-35') where marine waters encroached onto the surface of the lake terrace. During this very dynamic time period a complex of freshwater fluvial sands and transgressing marine deposits began aggrading atop the lacustrine terrace surface.

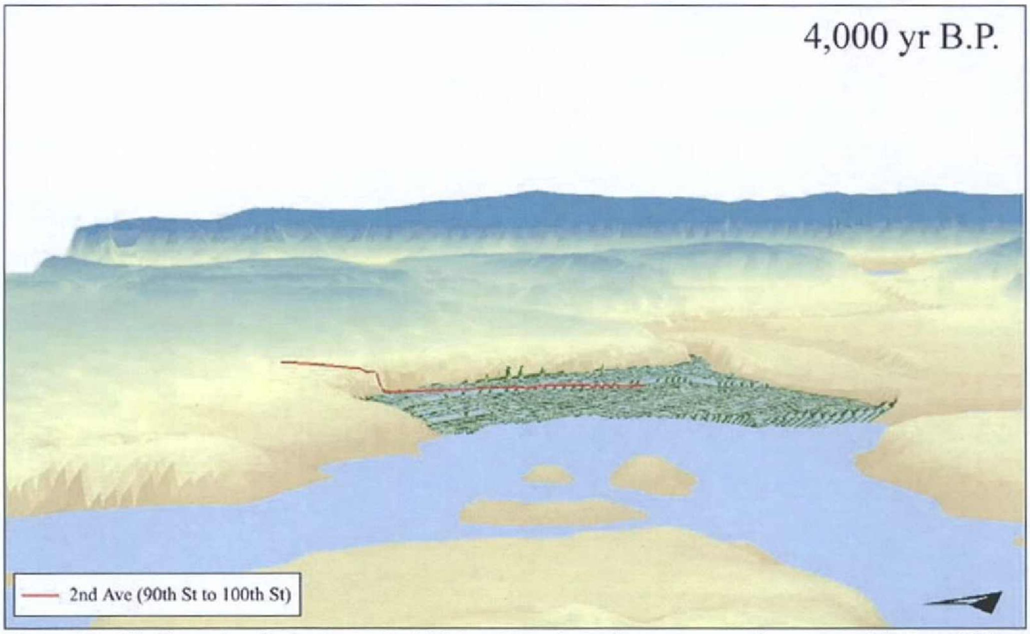

Figure 16 (d). Estuarine formation. At 4,000 yr B.P. the entire terrace surface was subject to tidal cycles, as sea level had risen to between -21' and -24'. Organic muck, peat, and silts suggest the formation of marshes, which would have transgressed across the project area commensurate with rising sea level. The presence of freshwater pollen species indicates that at these early stages of estuarine formation the marsh still had a significant freshwater component. This would have been a habitat optimally suited for prehistoric (Late Archaic) activity, with convenient access to marine and terrestrial resources.

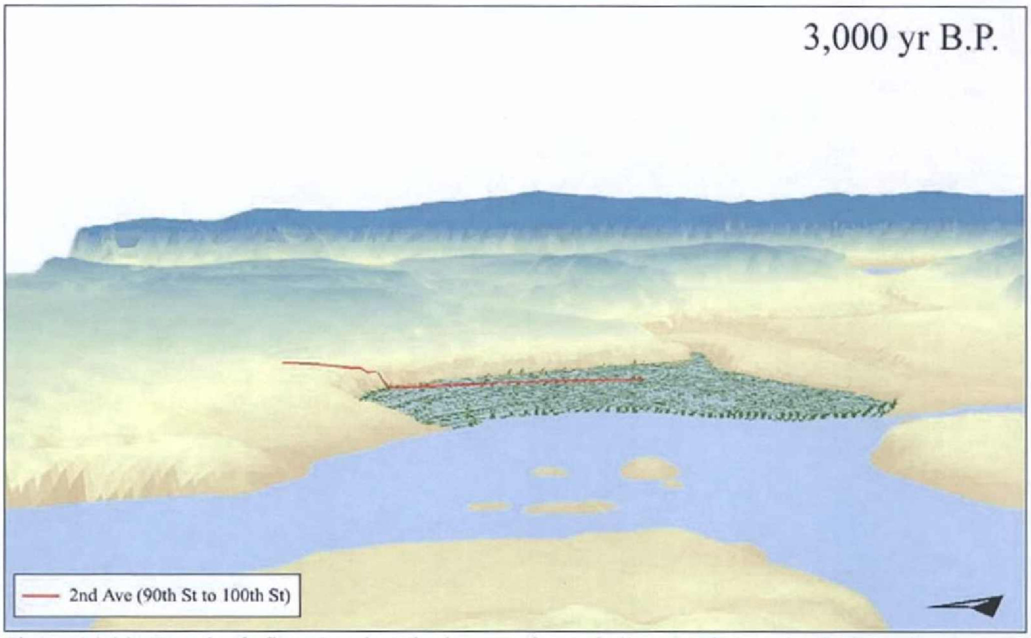

Figure 16 (e). Zoned salt flats. Landward advance of mesohaline marsh (proximal) and subaqueous saline mudflat (distal). By 3,000 yr B.P. marsh biomes continued to develop and the majority of the project terrain consisted of subaqueous mudflats. From 4,000 to 3,000 yr B.P. estuarine sedimentation is registered by mineral and organic sediment, reflecting pulses in sea level rise. Shortly after 3,000 yr B.P. the mudflats had stopped aggrading, in response to general deceleration in of sea level rise. The environment would have remained attractive to later prehistoric groups (Transitional Archaic to Woodland).

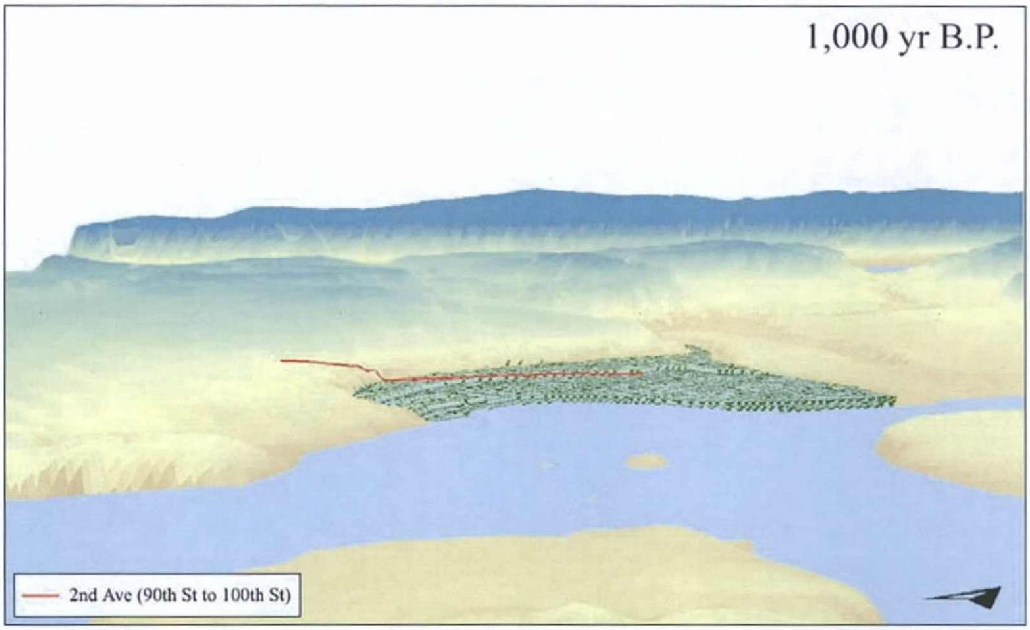

Figure 16 (f). Stabilized subaqueous saline mudflat. At 1,000 yr B.P. the landscapes emerging around 3,000 yr B.P. reached a homeostatic state. This is signaled by the minimal accumulations of organic material on the mudflat bottoms.

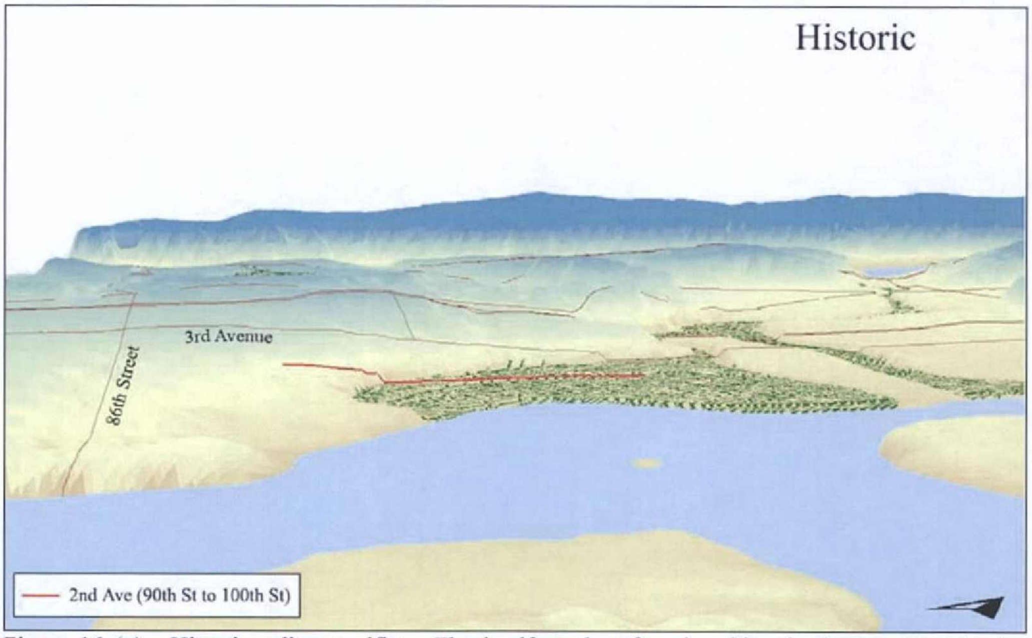

Figure 16 (g). Historic saline mudflat. The landform is referred to historically as a "meadowlands". During the early Euroamerican period surfaces were level, subject only to tidal cycles. Thin and diffuse organic lenses and minor peats implicate changing (humanly influenced) edaphic conditions as subaqueous vegetation communities expanded across the landform.

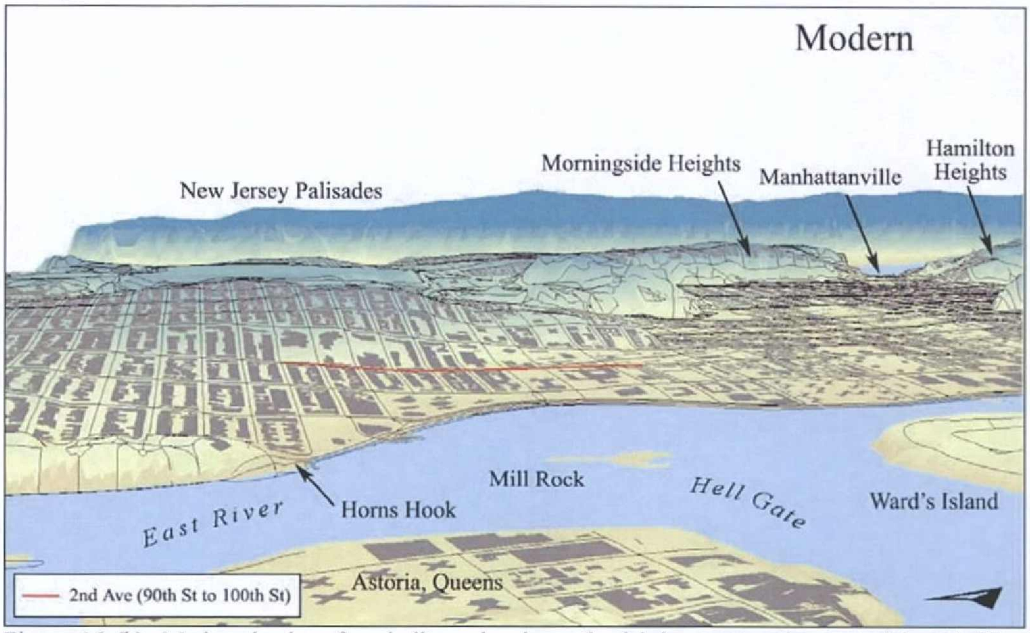

Figure 16 (h). Modern land surface built up by domestic debris, construction material, and fill. The infilling during the late 19th century reclaimed the major land segments of Hellgate Bay. The landform was capped with approximately 10' to 20' of fill material to raise shore elevations 13' to 15' above sea level.

Archaeological Assessment

The assessment of buried archaeological sites for a given project area is dependent on a series of inter-related variables:

- Footprint (3 dimensional) of the project impact area
- Methods of subsurface testing
- Previously documented archaeological record
- Age of buried deposits
- Composition, thickness, and preservation potential of buried deposits
- Degree of impact and disturbance to the substrate

Each of these variables is discussed in turn. A summary discussion provides an overall assessment of buried site potential.

Footprint of the Project Area

The dimensions of the impact zone were 0.25 miles (1300 ft. [400 m], south-north, along 2nd Avenue) by 75 ft. ([23 m] east-west). More significantly, the depth of the impact zone is 65' (20 m). Across the transect a mantling fill extends to depths of 15-20'. Bedrock capped by a thin veneer of regolith and glacial till spans the southernmost 10% of the length of line while over 50 vertical feet of Late Quaternary sediment is preserved across 90% of the length of line.

This thickness of deposit calls attention to archaeological sensitivity.

Methods of subsurface testing

A split spoon hydraulic coring device was utilized for in field data collection and sample recovery. This was the most feasible means for deep excavation in one of the densest urban landscapes in the world, where sub-surface probing of any kind required extensive planning and preliminary clearances (for utilities and related underground impediments). Recovery of sediment from upper horizons was discontinuous and incomplete because of consistence of the subsurface fill. The intact Holocene and late Pleistocene deposits yielded more complete sediment columns. For archaeological purposes, discontinuous cores are not optimal for data recovery. Coring is most efficient for previewing depositional contexts, recovery of paleoenvironmental specimens (pollen, macro-botanical remains, mollusks) and radiometric specimens. In this case, the core recoveries were sufficient to formulate sedimentary history, to develop a landform model (in conjunction with regional mapping) and to frame the chronology of the buried landscape.

Archaeological recovery would not be anticipated unless large scale cultural features (villages; burials; or substantial processing stations) underlay the project footprint.

Previously documented archaeological record

The archaeological data base for New York City generally identifies a significant number of historic sites on the edges and margins of slackwater, marsh, and near shore locations in Lower Manhattan. A number of prehistoric sites have been found along the coastline of Staten Island. These include Ward's Point, Port Mobil, Bowman's Brook and Old Place. Inwood and Tubby Hook are in Upper Manhattan and Clason's Point in the Bronx, again in proximity of the shore (Cantwell and diZerega Wall 2001: Figures 1.1 and 1.2). The Staten Island sites are generally associated with greater antiquity (Early to Late Archaic) and their preservation is typically attributable to their unique geographic setting along an intact late Pleistocene till ridge overlooking the shoreline. The Staten Island shore has also been one of the last to be developed within New York City proper.

Most of these prehistoric sites are linked to resource-rich estuarine landscapes with distal freshwater (ie. wetlands) components. Artifact assemblages nearly always include shell (oyster) elements as well as diagnostic points and lithics. Farther up the Hudson locations such as Dogan Point preserve evidence of complex resource procurement strategies, again centered on oyster and shell based economies. Perhaps most significantly, these are multi-component sites whose occupations reflected changing resource bases conditioned by environmental dynamism and succession (Claasen 1995; Schuldenrein 1995).

The regional evidence suggests that shoreline occupations of the Archaic period or subsequent would be situated in this setting. There is a more limited possibility for preservation of historic sites.

Age of buried deposits

The age range of the intact deposits dated for the 2nd Avenue subway project is approximately 22,000 (AU-II) to 200 B.P. (AU-IVc). Of these deposits, the lowermost 20-25' are lacustrine sediments (AU-II) which document the presence of a closed lake basin during the glacial period. They pre-date the generally accepted time frame for human presence in North America and could not otherwise have sustained human activity.

Holocene sediments immediately underlie the historic fills (AU-VI) and include a fluvial facies (AU-III; ca. 5500 B.P.); two late Holocene estuarine and organic sediment complexes (AU-IVa,b; 4200-3200 B.P.); and one thin organic facies of historic age (AU-IVc; 230 B.P.).

These dates are consistent with regional Archaic and early Euroamerican time frames in settings that have yielded archaeological sites in the greater New York City area.

Composition, thickness, and preservation of buried deposits

Because of their antiquity and type, the lowermost (lake) sediments (AU-II) preclude archaeological preservation. The uppermost (fill) deposits (AU-VI) are not intact. The fluvial facies (AU-III) conforms to the Late Archaic period but it is a thin deposit (1-3') and generally represents a stream or near shore sediment laid down under high energy conditions. The basal estuarine matrices (AU-IVa, b; up to 10' thick) represent low energy depositional matrices and correspond to environmental conditions—salt marsh flanked by aquatic (wetlands) biomes--during which prehistoric peoples utilized the resource rich estuary. Sites are likely to be oyster middens and food processing stations. The upper estuarine complex (AU-IVc; discontinous, <1') represents a peat and its expression is not sufficient to form an assessment of potential.

The most likely preservation of archaeological materials is confined to AU-IVa and AU-IVb. These deposits are 5-10' thick and are typically encountered between 15-25' beneath the present ground surface across the project area north of 93rd St. Settlement archaeology suggests, however, that cultural deposits are likely to be thin and feature a broad and irregular lateral distribution.

Degree of impact and disturbance to the substrate

The extent and thicknesses of the fills (AU-V and AU-VI) are the most critical factors in assessing the preservation potential of upper portion of the sediment columns. The uppermost deposits of AU-IVb are dated to ^{14}C 3240±40 B.P. The unconformity at the top of the overlying early historic age estuary, suggests that its integrity has been compromised by late 19th and 20th century fill activity. Laterally discontinuous lenses of the Euroamerican peat indicate that any later prehistoric horizons (Woodland to Contact period), if they existed at all, would have been adversely impacted by development activities.

Later prehistoric and early Euroamerican components, those recording cultural activity higher up in the stratigraphic column, have almost certainly been obliterated by historic fill and relandscaping. There is preservation potential for Middle to Late Archaic occupations.

Table 3 summarizes the integrated landform interpretations with the project preservation of archaeological components by time frame. Sea level projections are also presented. An archaeological probability assessment for subsurface site preservation is made on a ranked scale for ***high***, ***moderate***, ***low*** and ***no*** probability. Determinations were made on the strength of the variables identified above.

Negligible to ***low*** probabilities are assigned to the Paleoindian component since the dated landforms (Lake Hudson) pre-date human arrival, and, further, that the lake basin proper could not have preserved intact cultural remains. There is a ***low*** probability for Early and Middle Archaic sites because the landforms dated to that period are high energy loci that would have eroded sites; moreover, any sites of that time frame would have been small and featured minor assemblages susceptible to extensive reworking and displacement. A ***moderate*** preservation ranking is given to the Late Archaic component since the estuarine micro-environment—sustaining salt and freshwater resources—is both an optimal preservation and settlement locus. Nevertheless, the likelihood for encountering sites is tempered by an expectedly diffuse site distribution and restricted site signature (ie. small shell mounds, food processing station).

Table 3. Chrono-stratigraphic summary.

Years B.P. (before present) uncalibrated	Archeological Period	Regional sea level model (ft) (Schuldenrein et al. 2007)	Analytical Unit	Landform	Archeological Probability
0-500	Historic	0	V-VI	marsh meadows infilled in 19th cent.	moderate
1000	Late Woodland	-5'	IV-c	stable brackish mudflat	low
2000	Middle Woodland	-10'			
3000	Early Woodland	-15'			
4000		-21'	IV-b	brackish marsh transitions to a subaqueous mudflat	low to moderate
5000		-25'	IV-a	freshwater marsh and shoreline transitioning to brackish marsh	moderate
6000	Late Archaic	-30' -35'	III	fluvial-shoreline environment	low
7000		-52'		initially an eroded surface of lacustrine terrace deposits (post-breaching of Narrows) that eventually sees a complex of high-energy beach and fluvial channel deposits as rising sea level reaches surface of terrace	low
8000	Middle Archaic	-72'			
9000					
10000	Early Archaic				
11000 to 12000	Paleo-Indian				none-low
12000 to 15000	Pre-Cultural/ Pre-Clovis?		II	Pleistocene glacial lake, breaching of the Narrows and Long Island Sound	none
15000+	Pre-Cultural			Pleistocene glacial lake (freshwater)	none

7. RECOMMENDATIONS AND CONCLUSIONS

Geoarchaeological studies to test for buried cultural deposits along the footprint of the proposed 2nd Ave. Subway Line (92nd to 99th Street) disclosed intact Holocene deposits linked to the former Hellgate Bay estuary. The 10-15' thick organic and silt rich sediment documented the locale's transformation from an emerging to stable and diverse brackish environment for the interval 4600-3200 B.P. This period is co-incident with the Late Archaic period in northeastern prehistory. It is a time when shellfish and other marine and terrestrial resources formed the subsistence for the prehistoric inhabitants of what is now Manhattan Island.

An assessment of the preservation potential for Late Archaic archaeological sites is conditioned by a number of variables. To develop a baseline for such an assessment, the present study advanced a model of landscape formation keyed to the results of a comprehensive coring program and follow up geomorphic and paleo-environmental analyses. A battery of ten (10) radiocarbon dates facilitated a detailed chronology for the model.

It was demonstrated that the earliest sediments preserved in the cores are over 20,000 years old and document the presence of the Glacial Lake Hudson-Bayonne complex. The lake basin emptied approximately 14,000 years ago in conjunction with the northward retreat of the glaciers. The dated cores indicate that following a hiatus, new stream environments began to form before 6000 B.P. and in conjunction with the decelerated rise in sea level which was approximately -35 ft. (-7 m) below the contemporary stand. Sea level rise continue to slow thereafter so that by 4000 B.P. levels were up to -25 ft. At that time the estuary forming along the retreating continental shelf began to stabilize and included a mosaic of freshwater (wetlands) and salt tolerant (brackish) environments. Peak estuarine conditions extended to at least 3200 B.P. After that time the stratigraphic sequence in the cores is largely truncated. Two (2) additional radiocarbon determinations, at 230 B.P., or contemporaneous with the Euroamerican settlement were taken from a thin, discontinuous peat; their significance is not clear. Overlying fill sediments indicate major landscaping activities during the 19th century.

The buried landscape segments dated by these deposits suggest first and foremost that there is limited archaeological sensitivity for a Late Archaic occupation. It is emphasized that no primary evidence for this occupation was identified, but simply that time equivalent sediments of the environments favored by these populations were recognized. In landscape terminology, the terrestrial slopes of the marsh, identified in cores from the middle of 92nd street and north, at depths of 20-33' below street surface. These slopes would have been adjacent to the marsh and could have served as loci for prehistoric cultural activities, such as habitations or processing areas for estuarine food resources (shellfish, mammals, and finfish). It should also be noted that generally Late Archaic shoreline sites are limited in size, depth, and type such that the likelihood of encountering such a site simply because the conditions are appropriate for its presence are small.

As discussed above, the potential for sealed site preservation for other components can be unequivocally determined. The presence of Paleoindian sites is obviated by the lake basin, and the erosive action of drainage in the late glacial to post-glacial periods. Early to Middle Archaic sites would be expected on alluvial landforms but evidence for these landscape segments is either missing or minimal; high energy stream settings are not probably preservation loci. Finally, Woodland to Contact period sites, likely to be entrained in the upper sediments of the estuarine column, were either removed or destroyed by fill emplacements and relandscaping in the 19^{th} and 20^{th} centuries.

In sum, the only sealed and preserved sediments with archaeological potential are those of the estuarine depositional complex dated to ca. 4200-3000 B.P. No evidence of archaeological remains were identified. Moreover, archaeological deposits in the estuarine margins are likely to be thin and localized. For this reason, continuous monitoring is not recommended.

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APPENDIX A: GRA CORE DESCRIPTIONS

AB-1 ELE =23'

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates	Comments
VI	0-17					a		FILL
	17-19	10YR3/1	GCSSi	1gr	slst	a		micaceous medium sand to granule sized gravels (3%), moist, large pebble size rock fragment of micaceous schist at base
	19-21	10YR4/1	slSCSi	1ab	slst	a		few (3%) medium sand grains, moist, soft, sands increase in % and size (to coarse sized) with depth
	21-23	10YR4/1	SiS	gr	slst	c		medium to coarse sand of mica grains
	23-23.5	10YR3/1	slSiS	gr	l	a		sand grains are angular to subangular mica grains that coarsens with depth and includes occasional (3%) 10YR7/2 and 5YR5/6 subangular to subrounded coarse quartzite sand grains, few (2%) medium pebble sized angular to sub-angular schist rock fragments with some cementing of sand grains on rock surface
I	23.5-25.5	10YR3/1	R	na	na	na		micaceous schist, mica grains up to coarse sand sized, bedrock

Texture: Si = silt; L = loam; C = clay; S = sand; O = organic; F = fine; M=medium; G = gravel; R = regolith
Structure: 1 = weak; 2 = moderate; 3 = strong; f = fine; m = medium; c = coarse
gr = granular; mass = massive; strat = stratified; sbk = subangular blocky; ab = angular blocky; pr = prismatic; pl =platy; col = columnar; dist. = disturbed/no structure
Consistence: fri = friable; sl = slightly; v = very; l = loose; fi = firm; st = sticky; ss = strongly sticky
Boundary Distinctness: a = abrupt; c = clear; d = diffuse; g = gradual; s = sharp
Boundary Topography: s=smooth; w=wavy; i = irregular; b=broken

AB-2A ELE =16'

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
VI	0-16		GSiS			a		FILL
V	16-18	10YR5/2	slSiS	3gr	slfi	a		grayish brown (10YR5/2) medium to coarse sands with minor (2%) distinct fine light brownish gray (10YR6/2) silty clay and common (30%) distinct slightly silty medium sand, very occasional (1%) angular to subangular small pebble
IV-c	18.5-19	10YR2/1	OslSiC	pl	fri-st	a	230 ± 40 BP (Beta-232117)	high organic (20%) partially decayed plant material (primarily grass fragments)
IV-b	19-20	10YR3/1 to 2/1, GLEY N/ 3	OslSCSi	2pl	slst	c		organics common (2-10%) partially decayed plant material with preserved grass-reed fragments, micaceous
IV-b	20-27	10YR3/2	OSSi	2pl	fri	a		sand grains occasional to common (up to 15%) up to large sand grain sized, organics few to common (5%) fine to very fine undecayed hairy roots, poor recovery with no sample 20'-22', wash between 24'-26', micaceous
IV-a	27-30	10YR3/1 to GLEY N 3/	OCSi	2pl	fi	c		high organic (15%) partially decayed plant material (grass fragments) that decrease in amount with depth to 2% at 30', micaceous
IV-a	30-32	GLEY N 5/	OSiC	2pl	fi	c		organics few (5%) and becoming more fully decayed with depth, with common (15%) faint fine GLEY N 3/ clayey silt mottling towards base, micaceous
IV-a	32-34	10YR5/1	slSiS	gr	fri	na		with few (5%) 10YR4/2 fine masses, medium rounded sand grains, micaceous

AB-2A continued

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
III	34-40	10YR5/4, 2.5YR5/4	slSiCS to SiS	gr	fi-fri	a		At 36' 10YR5/4 slSiCS grades to 2.5YR5/4 SiS with sands up to coarse sized, mixed micaceous and quartzite grains
II	40-48	5YR4/3	slSSi	mass	fi	a		sand grains fine to very fine, with common (10%) faint fine 5YR4/3 mottles between 46'-48', micaceous
	48-50	5YR4/3	R			na		only recovery gray soft quartzite sandstone fragment
DIST?	50-60	10YR3/2	slSiS	gr	fri	na		poorly sorted sands, disturbances (inclusions of bentonite mud) possibly from adjacent well, micaceous

AB-3 ELE =13'

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
VI	0-14					a		FILL
V	14-17	10YR5/2	slSiS	mass	fi	a		medium to coarse sands (coarse sands dominate) with minor (2%) distinct fine light brownish gray (10YR6/2) silty clay and common (30%) distinct slightly silty medium sand, very occasional (1%) angular to subangular small pebble, upper portions mixed with historical wash/fill
IV-c/b	17-18	10YR3/1, 2/1, GLEY N/ 3	OslSCSi	2pl	slst	c		organics common (2-10%) partially decayed plant material with preserved grass-reed fragments, micaceous

AB-3 continued

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
	18-24					a		empty 18'-20', wash 20'-22', 22'-24'
IV-b	24-28	GLEY N/ 3	slSiC	2pl	fi	na		dispersed (3%) broken small shell (bivalve) fragments, and few (2-3%) small fine partially decayed fine organic fragments, micaceous, wash 26'-28'
IV-a	28-30	10YR4/1	S	1pl	slfi	a		very fine to fine sand, few (2%) partially decayed fine organic fragments, micaceous
IV-a	30-35	10YR4/1	S	1pl	slfi	a		fine to medium sand with few (2%) granule to small pebble of micaceous schist rock fragments
III	35-39	10YR4/1	slSiS	gr	l	a		clean coarse sand up to granule sized moderate poorly sorted sub-angular to rounded grains, mixed micaceous and quartzite grains with quartz dominant
II	39-60	5YR4/3	slSSi	mass	fi	na	21730 ± 120 BP (Beta-233892	slightly very fine to fine sandy silt with varves of 1-2" thick silty fine sand and fine sandy clayey silt beginning at48' and occuring approximately once every 2' to terminal depth, micaceous

AB-4 ELE =13'

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
VI	0-15					a		FILL
IV-b	15-16	GLEY N/3	CSi	1pl	fi	c		common (10%) undecomposed organics of grasses-reeds
IV-b	16-22	GLEY N/3	SiC	1pl to sbk	fi	c		moderate (5%) undecomposed organics of grasses-reeds, shell (5%) broken and complete, micaceous

AB-4 continued

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
IV-b	22-29.5	GLEY N/3	SiC	1pl to sbk	fi	a	3640 ± 40 BP (Beta-233891)	few (0-2%) organics of well decayed grasses and fine hairy roots, 5% shell fragments broken and complete, micaceous
IV-a	29.5-30	10YR3/1	OSiCS	1pl	fi-fri	c		organics nearly completely decomposed, with only limited (2%) partially decayed organics at top, no shell, micaceous
IV-a	30-36	2.5YR4/1, 5/2	SiS to SC	1pl	fi	a		fine to medium sand at top becoming coarser (medium to coarse) sand to 34', occasional (2%) shell fragment and few (2%) fine distinct organic mottle, from 34'-36' becomes 2.5YR5/2 sandy clay with few (2%) coarse sand, micaceous
III	36-41	2.5YR4/1	SiS to S					heterogeneous quartzite (60%) and micaceous sand, sand range from medium to coarse grained, subangular to well rounded clasts up to granule sized rock fragments of mica schist, white limestone, quartzite, and red siltstone, silty sand 37'-39'
II	41-60	5YR4/3	slSSi	mass	fi	na		with 2" thick sandy clayey silt varve at 53', micaceous

AB-5 ELE =13'

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
VI	0-14	FILL				a		FILL
IV-c	14-16	10YR3/2	OSiS	1pl	fi	g	230 ± 40 BP (Beta-232118)	many (30%) partially to well decayed very dark brown (10YR2/2) plant fragments of wood, grass, and roots. Top of organics have inclusions of upper fill material, few (2%) small shell fragments
IV-b	16-18	GLEY N4/	SiC	2pl	fi	c		common (5%) partially decayed plant material with preserved grass-reed fragments, common (5%) shell fragments, micaceous
IV-b	18-20	GLEY N4/	SiC	2pl	fi	c	3240 ± 40 BP (Beta-233888)	few (3%) partially decayed plant material with preserved grass-reed fragments, common (5%) shell fragments, micaceous
IV-b	20-29	GLEY N4/	slSiC	2pl	fi	c	4020 ± 40 BP (Beta-233889)	few (1%) partially decayed fine hairy roots decreasing to no roots at 26', common (5-7%) shell fragments and complete shell, few (1%) well rounded granules 22'-24', micaceous
IV-a	29-30	10YR2.5/1, GLEY 4/1 10Y	OSlSiS	1pl, 1sbk	fi	c	3890 ± 40 BP (Beta-232119)	organic silt with many (5%) partially decayed plant materials with preserved grass fragments to 29.5', at base is gray slightly silty fine sand with common (15%) faint, dark greenish gray (GLEY 1 4/1) matrix, with decayed roots only in upper 3" of the lower horizon, possible buried soil, micaceous
IV-a	30-36	10YR5/1, 4/3	SiS, slSiS	gr	fi, l	c	3760 ± 40 BP (Beta-233890)	firm silty fine sand 30-32', silty fine to coarse poorly sorted sand 32-36', micaceous

AB-5 continued

Analytical Unit	Depth (ft)	Munsell Color	Texture	Structure	Consistence	Boundary	RC Dates (uncalibrated)	Comments
III	36-39	10YR4/3	slSiS	gr	fri	a		heterogeneous quartzite and micaceous medium to coarse sand
II	39-60	5YR4/3	slSSi	mass	fi	na	13570 ± 60 BP (Beta-232120)	with 2" thick silty sand to clayey varves at 48.5', 54.5', 58', micaceous

Texture: Si = silt; L = loam; C = clay; S = sand; O = organic; F = fine; M=medium; G = gravel; R = regolith

Structure: 1 = weak; 2 = moderate; 3 = strong; f = fine; m = medium; c = coarse

gr = granular; mass = massive; strat = stratified; sbk = subangular blocky; ab = angular blocky; pr = prismatic; pl =platy; col = columnar; dist. = disturbed/no structure

Consistence: fri = friable; sl = slightly; v = very; l = loose; fi = firm; st = sticky; ss = strongly sticky

Boundary Distinctness: a = abrupt; c = clear; d = diffuse; g = gradual; s = sharp

Boundary Topography: s=smooth; w=wavy; i = irregular; b=broken

APPENIX B: MTA CORE DESCIRIPTIONS

B90-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
VI	10-12	
	15-17	10YR5/3 w, 10YR6/3 d, *slightly fine sandy* silt, firm bsa parting to single grain, faint organic matrix
	20-22	10YR5/4 medium to coarse sand (micaceous) with gray schist rock fragments
	25-27	silty sand (10YR6/3 d, 10YR4/3 w) micaceous sand, firm
I	30-30.3	weathered micaceous schist bedrock fragments

B90-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	10YR5/3 w, 10YR6/3 d, slightly fine sandy silt, firm bsa parting to single grain, faint organic matrix
VI	8-10	
VI	10-12	silty sand 10YR6/3 d, 10YR3/3 w, w/ occasional micaceous gravel and occasional roots
	12-14	gravelly micaceous schist bedrock fragments in gritty sand
	14-15.5	
	16-16.4	weathered micaceous schist bedrock fragments
I	20	

B90-4

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	3-5	FILL: sandy gravels
	5-7	
VI	7-9	
	11-13	10YR4/3 slightly silty fine sand, micaceous
	15-17	
	20-20.5	10YR4/3 slightly silty medium sand with occasional small pebble sized schist rock fragments
	20.5-20.8	weathered gravelly sandy schist bedrock
I	25-26.2	

B91-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: brown sand
	8-10	
VI	10-11.5	
	15-17	10YR4/3 very fine well sorted sand, soft
I	20-21.5	very fine sand continues, schist bedrock at base

B91-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: brown sand
VI	8-10	
	10-12	10YR3/2 silty sand, schist bedrock fragments, micaceous
I	15	schist bedrock

B91-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: brown sand
	8-10	
VI	10-12	
	21-23	10YR4/3 fine sand, soft loose micacaeous, with weak faint 10YR4/3 weathering fine filaments
	25-27	10YR4/3 medium to fine sand, soft loose micacaeous, with weak faint 10YR4/3 weathering fine filaments with distinct diffuse 10YR3/2 fine weathering stains
	30-32	weathered coarse sand (micaceous) with schist bedrock fragment
I	35	schist bedrock

B91-5

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: with common micaceous gravels
	8-8.3	
	10-10.4	
VI	15-17	
	20-22	10YR4/3 fine sandy silt, micaceous
	25-27	weathered coarse sandy schist
	30-30.4	
I	35-37	bedrock

B91-6

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL
	8-10	10YR4/3 fine sandy silt, soft, micaceous
	10-12	
I	15-15.2	AU6: weathered coarse sandy schist

B92-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	8-10	FILL: sandy gravel with brick fragments
	13-13.5	
VI	15-15.5	
	25-27	10YR4/3 gravelly micaceous sand with schist rock fragments
	30-32	10YR4/6 gravelly micaceous silty sand with schist rock fragments
	35-37	transition to 10YR3/4 fine to medium sand, soft, well sorted heterogeneous (micaceous 70%, quartzitic 30%)
I	45-47	weathered gray gravelly sandy schist bedrock fragments

B92-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: sandy gravel
	8-10	empty
	10-12	FILL: sandy gravel
	15-17	empty
VI	20-22	10YR6/3 silty fine sand
I	30-32	10YR5/4 yellowish brown gritty gravelly sand with micaceous angular schist rock fragments

B92-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	1-2	FILL
	2-4	
	4-6	
	6-8	
	15-17	FILL- gritty organic gray clay mix
VI	20-22	empty
IV-b	25-27	GR CLY W/ORGANICS w/shell
IV-a	30-32	ORGANIC CLY, well preserved partially decayed peat/organics, sample collected, at base is GLEY 2.5/1 (10Y) silty clay with only few organics
III	35-37	AU-4
?	40-42	10YR4/3 slighly clayey silt (no deeper samples or rock samples on shelve)

B93-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: heterogeneous
	8-10	
	10-12	
	15-17	
	20-21	FILL: disturbed fill with inclusions of organic gray silty clay
	21-22	
VI	25-27	
IV-b	30-31	black organic silty clay
	31-32	transitional sandy clay
IV-a	32-32.5	empty
III	35-37	heterogeneous brown sand
II	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	67-69	
	70-72	
	75-77	
	80-82	
	85-86.9	
	90-90.8	weathered gravelly sand schist bedrock
I	95-97	

B93-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	7-9	FILL: browish gray gravelly silty sand
	9-11	
	11-13	
	13-15	
	15-17	empty
	17-19	FILL
	20-22	
VI	25-27	
	30-32	transitional gray clayey sand
IV-a/III	35-37	
	40-42	empty
	45-47	
?	47-49	
	50-52	RED SILT
	55-57	
	60-62	empty
II	65-67	RED SILT

B93-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
VI	10-12	
	15-17	GRY CLY W/ORGANICS
	20-21.2	
	21.2-22	
	25-27	
	30-31.2	
IV-b	31.2-32	
	35-37	10YR5/4 f. sand w/ few 5% med. sands
IV-a/III	40-42	10YR6/3 silty f-c sand, up to well rounded granules, 70% quartzitic, 30% micaceous sand grains
	45-47	RED SILT
	50-52	
	55-57	10YR6/4 silt, highly micaceous
II	60-61.2	10YR6/3 gravelly silty weathered micaceous schist bedrock

B93-4

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	5-7	FILL
	7-9	
VI	11-13	
V-VI	15-17	10YR5/3 (w) fine silt
V-VI	20-22	10YR4/3 (w) fine sandy silt, soft micaceous (possibly fill)
V-IV	25-27	transitional gray brown silty clay sand (micaceous)
IV-a/b	30-31.5	black high organic silty peat
IV-b	31.5-32	dark gray silty clay, with decreasing organics
III	35-37	heterogeneous (quartzitic and micaceous) brown medium sand
II	40-42	RED SILT

	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
	100-102	weathered schist bedrock
	105-106.9	
I	110-112	

B93-6

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
	15-17	empty
VI	17-19	FILL
	20-22	GRY CLY
	25-27	empty
IV-b	30-32	GRY CLY
IV-a	35-37	gray slightly clayey sand to AU-4 brown silty clayey sand
III	40-42	coarse brown sand
	45-47	RED SILT
	50-52	
	55-57	
	60-62	
II	65-67	
	70-72	
	75-76.3	weathered gravelly schist
	80-81.7	rock fragments in micaceous silty coarse sand
I	85-86.3	

B93-8

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	5-7	FILL: gravels, brick, tan fine sandy silt
	7-9	
	9-11	
VI	15-17	empty
IV-c	20-22	GR CLY: black organics in gray clay
IV-b	30-32	GR CLY
IV-a	35-37	transitional silty clayey sand
III	40-42	coarse sand
	45-47	RED SILT
II	50-52	
I	55-57	gray shist bedrock fragments in micaceous sand

B94-1u

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	8-10	FILL
	10-12	
	12-14	empty
	15-17	FILL
VI	25-27	
IV-c	30-32	black gray high organic silty clay common large organic fragments
IV-b	32-34	gray silty clay, hard
IV-a	35-37	transitional gray silty sand
II	37-39	
	40-42	RED SILT
	45-47	
	50-52	
	60-62	red fine sand
	65-67	red silty fine sand
	70-72	
	75-77	RED SILT
	80-82	
	85-87	
	90-92	red clayey silt
	95-97	
	100-102	RED SILT
	105-107	
	115-117	red clayey silt
	120-122	RED SILT
	125-127	red clayey silt
	130-132	
	135-137	
	140-142	
	145-147	
	150-151.5	10YR5/3 very silty fine sandy silt, hard firm parting to loose weathered micaceous schist rock fragments in sand
	151.5-152	
I	155-156.4	

B94-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	
	8-10	
	10-12	
	12-14	FILL
	14-16	
	20-22	
VI	25-27	
IV-b	30-32	GR CLY
IV-a	34-36	TRANS CLY SND gray clayey fine sandy silt w/ organics
	40-42	
	45-47	
	50-52	RED SILT
	55-57	
	60-62	
	65-67	
	67-69	empty
	70-72	
	75-77	
	80-82	
	85-87	RED SILT
	90-92	
	95-97	
II	100-102	

B94-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
	15-17	
	20-22	
VI	25-27	empty
IV-a	30-32	transitions from gray silty clay to gray silty clay sand
III	35-37	hetero transitional *sand*
	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	very fine sandy silt (5YR3/2 (w))
	65-67	RED SILT
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
II	100-102	

B94-4

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
VI	10-12	
	15-15.25	GRY CLY W/ORGANICS
IV-b/c	15.25-15.5	
	20-22	GRY CLY W/DECREASING ORGANICS
	25-27	
	30-32	
IV-b	35-37	
	40-42	RED SILT
	45-47	
	50-52	
	55-57	
II	60-62	

B95-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
	15-17	
VI	20-22	
IV-b	24-26	gray organic clay
IV-a	28-29.2	well developed black peat
IV-a	29.2-30	gray organic silt
IV-a	30-32	gray very fine sand
III	35-37	brown hetero sand
	40-42	*RED SILT*
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	red clayey silt
	80-82	RED SILT
	85-87	
	90-92	
	95-97	red clayey silt
	99-101	RED SILT
	105-107	
	110-112	
	115-117	
II	120-122	

B95-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
	12-14	
	14-16	
	16-18	
	18-20	
VI	20-22	
	25-27	GR CLY
IV-b	30-32	
III	35-37	brown (10YR4/3) medium sand, clean, well sorted, mixed 75% quartzitic, 25% micaceous
	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
	100-102	
	105-107	
II	110-112	

B95-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	18-20	FILL
IV-b	30-32	gray transitional clayey sand
III	35-37	heterogeneous brown medium sand
	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
	100-102	
	105-107	
II	110-112	

B96-2

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
VI	15-17	
	20-22	gray clay with moderate organics and shell
IV-b	25-27	
	29-29.8	dark black high organic silty clay, moderate organics
IV-a	29.8-31	transitional gray silty clayey sand
	35-37	heterogeneous brown coarse sand
III	40-42	heterogeneous brown well sorted medium sand
	45-47	RED SILT
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
II	100-102	

B96-3B

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL: brown reddish gravelly sand
	8-8.3	
	8.3-10	
	10-12	
VI	15-17	
	20-22	gray silty clay with organics and shells
IV-b	24-26	
	28-30	transitional gray clayey sand
IV-a	30-32	
III	35-37	heterogeneous brown sand
II	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-90.9	
	90.9-92	
	95-97	
	100-102	

B96-4

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	28-30	mixed brown fine sand, well sorted, clean, soft
	30-32	dark grayish brown (2.5Y4/2) slightly very fine sandy slightly clayey silt, soft, loose, few micaceous grains, clean
	35-37	mixed brown fine sand, well sorted, clean, soft
III	40-42	yellowish brown (10YR5/4) fine sand, clean, well sorted, soft
	45-47	Red fine sandy silt
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	
II	100-102	

B96-6

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
VI	10-12	Fill w/ disturbed organic dark gray silty clay at base
	15-17	GR CLY W/ORGANICS w/shell
	21-23	
IV-b	25-27	
IV-a	30-32	TRANS SANDY CLAY gray sandy clay
III	35-37	mixed (quartz and mica) gray sand w/ some organics
	40-42	RED SILT silty fine sand to fine sand
	45-47	7.5YR4/2 fine to medium sand of with common well sorted quartzitic granules to small pebbles, with few shell and organics and weak asphalt/tar scent, possible disturbance/seep?, typical red fine sandy silt at base
	50-52	red fine sandy silt
	60-62	
	65-67	
	70-72	
	77-79	
	80-82	
	85-87	sandy silt
	95-97	sandy clay silt
	100-102	clayey silt
	107-109	silty clay to silt
II	110-112	silt

B96-7

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
VI	15-17	
IV-c	20-22	blackish gray high organic silty clay
IV-b	25-27	dark gray silty clay w/ shells & organics
IV-b/-a	30-32	at top: gray silty clay, at base: dark black to gray highly organic silty clay
	35-37	at top: 10YR4/3 clayey silty fine sand, at base: heterogeneous silty f-c sand
IV-a/III	40-42	empty
	45-47	RED SILT
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	72-75	
	80-82	
	85-87	
	90-92	
II	95-97	

B96-8

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
VI	15-17	empty
	20-22	dark gray clay with shell and organics
	25-30	
IV-b	30-32	
	35-37	at top: 10YR4/3 clayey silty fine sand, at base: heterogeneous silty f-c sand
IV-a/III	40-42	empty
	45-47	RED SILT
	50-52	
	55-57	
	65-67	
	70-72	
	75-77	
	80-82	
	90-92	
II	95-97	

B96-9

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL
	8-10	
IV-b	20-22	GR CLY
	25-27	
IV-a	30-32	brownish gray clayey sand
	35-37	
	40-42	empty
II	45-47	RED SILT
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	93-95	
	95-97	

B96-10

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL
	8-10	
	10-12	FILL: gritty organic fill
IV-b	15-17	GR CLY: organic gray clay w/shell
	20-22	
	25-27	

B96-12

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL
	8-10	
	10-10.1	empty
	13-15	FILL: oily with historic high organic fill
V/IV-c	15-17	FILL: high organic gritty sand at top, a high organic gray clay at bottom
IV-b	20-22	GRY CLY
	23-25	GRY CLY gray clay with shell and decrease in organics

B96-13

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	17-19	FILL (gritty, high organic sand)
IV-b	25-27	GRY CLAY W/ ORGANICS w/shell
IV-a	30-32	transition olive gray sandy clayey silt
II	50-52	RED SILT
	60-62	
	80-82	
	85-87	
	90-92	

B97-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	FILL: gravelly clayey fill
	12-14	
VI	15-17	
	20-22	organic gray silty clay
	25-27	
IV-b	29-30	
IV-a	30-30.5	high organic black silty clay
	30.5-31	transitional gray clayey sand
	31-32.4	
IV-a/III	32.4-33	
III	35-37	heterogeneous coarse sand to fine granules (mixed quartzitic and micaceous)
	40-42	RED SILT
	45-47	
	50-52	
	55-57	
	60-62	
	65-67	
	70-72	
	75-77	
	80-82	
	85-87	
	90-92	
	95-97	red sandy silt
	100-102	RED SILT
	105-107	
	110-112	
	115-117	
	120-122	
	125-127	
	130-132	
	137-139	
	140-142	
	145-147	
	150-152	
	155-157	
	160-160.5	
	161-162	
II	172-172.1	

B97-3

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	6-8	FILL
	8-10	
	10-12	
	12-14	
VI	14-16	
	16-18	GRY CLY
	18-20	empty
	20-22	
	22-24	GRY CLY
	25-27	GRY CLY: decrease in organics
	27-29	
IV-b	30-32	
IV-a	32-24	10YR4/3 (w) silty f-c sand
	35-37	brown 10YR4/2 (w) well sorted heterogeneous sand
III	40-42	empty
	45-47	RED SILT
	47-49	
	50-52	
	55-57	
	57-59	
	60-62	
	65-67	
	67-68	
	136.5-137	highly micaceous red silt
	145-147	
II	155-157	
I	165-165'2"	micaceous schist bedrock fragments

B97-5

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
	55-57	RED SILT: clayey silt
	65-67	RED SILT: silty clay
	76-78	RED SILT: clayey silt
	85-87	
II	92-94	

B108-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL: gravelly sand
	8-10	
	10-12	
	12-14	
	14-16	
V /III?	20-22	10YR5/3 heterogeneous (quartzitic and micaceous) fine to medium sand
	40-42	
	45-47	
III	50-52	10YR3/2 fine sand micaceous
	55-57	
	60-62	
II	65-67	red silt with micaceous fine sand
	80-82	
	85-87	
	90-92	

B109-1

ANALYTICAL UNIT	DEPTH (ft)	DESCRIPTION
VI	6-8	FILL: sands and gravels
	8-10	
	15-17	
?	20-22	7.5YR4/3 well sorted medium sand, soft loose
	25-27	10YR5/3 medium to few coarse sand, heterogeneous (70% quartzitic, 30% micaceous) sand with few (1%) subrounded quartzitic pebbles
	35-37	10YR4/3 silt, loose, soft, micaceous
III	40-42	10YR3/3 fine to medium sand heterogeneous (60% micaceous 40% quartzitic)
	45-47	
	50-52	10YR4/2 silty fine sand, slightly firm parting to single grain fine sand
II	55-57	*red fine sandy silt*
	60-62	
	62-64	
	64-66	

APPENDIX C. Pollen and Macrofossil Analysis

By
Dr. Dorothy Peteet
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10 samples processed, counted, and analyzed for pollen, spores, macrofossils and LOI, all from Core AB-5A (Figure 2).

I. Plant Macrofossils

Methods

2cc of sediment each, soaked and heated to almost boiling using 5%KOH for disaggregation, then screened using water. The greater than 500 micron fraction examined under the dissecting microscope, while the smaller fraction was used for palynology (Table 1).

Results

Table 1. Macrofossil recovery by sample.

P-21	Lots of pebbles, sand, charcoal. Plant fragments...sedge? Transparent balls..unidentified
P-3	Silty clay, lots of unidentified transparent balls
P-4	Silty clay with white shell fragments, *Ruppia maritima* seed, unidentified transparent balls
P-7	Silty clay with *Ruppia maritima* seeds, unidentified transparent balls
P-10	Silty clay with *Ruppia maritima* fragments
P-12	Silty clay with *Ruppia maritima* whole seeds
P-2	Sandy, quartz and mica, no visible shells
P-18	Sandy, quartz
P-19	Slightly reddish sand, quartz
P-15	Very reddish pink sand

Samples P-3, P-4, P-7, P-10 and P-12 all contained *Ruppia maritima* (widgeongrass) seeds or fragments of seeds (Figure 1), which are also contained in the remainder of these same 5 samples and could be possibly be used for C-14 dating. The plant is an obligate aquatic, living in medium salinity waters in a pH from 5.4-8.5 (USDA website). While it is possible the seeds could be used for AMS dates, because the plant is underwater, it probably takes some of its carbon from the water, and may give a C-14 date which includes the reservoir age of the water, which in the Hudson River ranges from 400-1200 years from dating on 1950's shells (Peteet and Rubenstone, unpub). The documentation of seeds of this plant is consistent with a brackish estuarine mud habitat.

Figure 1. Photograph of *Ruppia m.* seed, magnification X180, seed is approximately 2 mm in size.

II. Palynology

Methods

2 cc from each of the 10 samples listed above were screened for plant macrofossils (greater than 500 micron) and the remaining material greater than 7 microns was retained on a screen for pollen analysis. An exotic tablet of *Lycopodium* was included in order to plot pollen accumulation values. The samples were then prepared for microscopic pollen analysis using standard techniques (Faegri and Iversen, 1975). This process includes continuous screening to remove the clays before proceeding with treatment (including heating and many centrifuges) of HCL to rid the sample of carbonates, HF to rid the samples of silica, and acetolysis to rid the samples of more labile organic matter.

Samples were screened again with 7 micron screens to rid the samples of clays, then suspended in alcohol washes for dehydration before mounting in silicone oil for ease in rotating grains on the microscope slide. At least 350 grains were counted per sample, and all counts were calculated as percentages and graphed using Tiliagraph (Grimm, 1992)

Results

Only 5 of the 10 samples contained pollen for analysis. The samples P-21, P-2, P-18, P-19, and P-15, when mounted on slides, contained silica but almost no pollen at all. This lack of pollen may be due to the larger grain size of these sands and pebbles instead of clays.

The samples P-3, P-4, P-7, P-10, and P-12 all contained abundant charcoal, and individual grains were full of black unidentified substance, possibly fungi. This made counting more difficult, but the major pollen types were easily identifiable and very few unknowns were encountered. The samples are described from lowermost (oldest) to uppermost (youngest) in the chart below (Table 2) with an inferred relative climate, and graphed in Figure 3.

Discussion

In general, the 2nd Ave. Subway samples all have very distinctive high amounts of charcoal compared to modern pollen samples, indicative of burning. They clearly do not have significant amounts of *Ambrosia* (ragweed) or other weedy pollen, and are thus are older than European impact. The closest regional match for high charcoal is pre-European age sediments in the Hudson River Marshes (JoCo, Yellow Bar, (unpublished) and Piermont (Pederson et al., 2005). In Piermont we found evidence of a strong Medieval Warm Interval (800-1350 AD) with high charcoal, and relatively high percentages of *Carya* (hickory) and *Pinus* (pine) vs. *Quercus* (oak). However, in Piermont, the *Carya* percentages never reach greater than about 12%, and the 2nd Ave. Subway P-12 sample contains twice this amount. The climatic inference is that these samples overall indicate a relatively dry, warm climate compared to today, with the stratigraphically lowermost indicating the warmest and driest conditions. High charcoal supports this climatic inference.

Table 2. Pollen, spore and charcoal recovery by sample.

P-3	*Pinus* maintaining 24%, *Quercus* increasing to 38%, *Carya* about 14% and *Tsuga* declining to 10% suggests slightly less moist environment than previously. Chenopodiaceae and *Plantago* may indicate disturbance on the upland, or nearby salt marsh flora. Charcoal relatively high, indicative of fires.
P-4	Slight decline in *Pinus* to about 24%, *Quercus* maintaining 32%, *Carya* declining to 12% and *Tsuga* increasing to maximum of about 14% indicates a relatively warm, moist environment. *Plantago* possibly suggests disturbance, and highest charcoal suggests increased fires.
P-7	Highest *Pinus* percentage of all samples (26%) and intermediate *Quercus* percentage (37%) with 15% *Carya* and increasing *Tsuga* (11%) suggests a relatively warm but moist environment, with lowest charcoal of all samples. Polypodiaceae ferns are present.
P-10	Lowest *Pinus* percentage of all samples (19%) and highest *Quercus* percentage (42%) with increasing *Tsuga* (8%) and much less *Carya* (12%) than previous sample. Presence of *Alnus, Liquidambar, Fagus*, and *Castanea* suggest a more moister, cooler climate than previous sample.
P-12	Most distinctive sample – highest percentages of *Carya* (23%) but low percentages of *Pinus* (21%), *Tsuga* (4%), *Quercus* (32%). Suggests driest, warmest climate…a lot of charcoal indicative of drought and burning. Greatest occurrence of *Pteridium* and *Osmunda* fern (both facultative wetland species) spores, possibly colonization of nearby wetland.

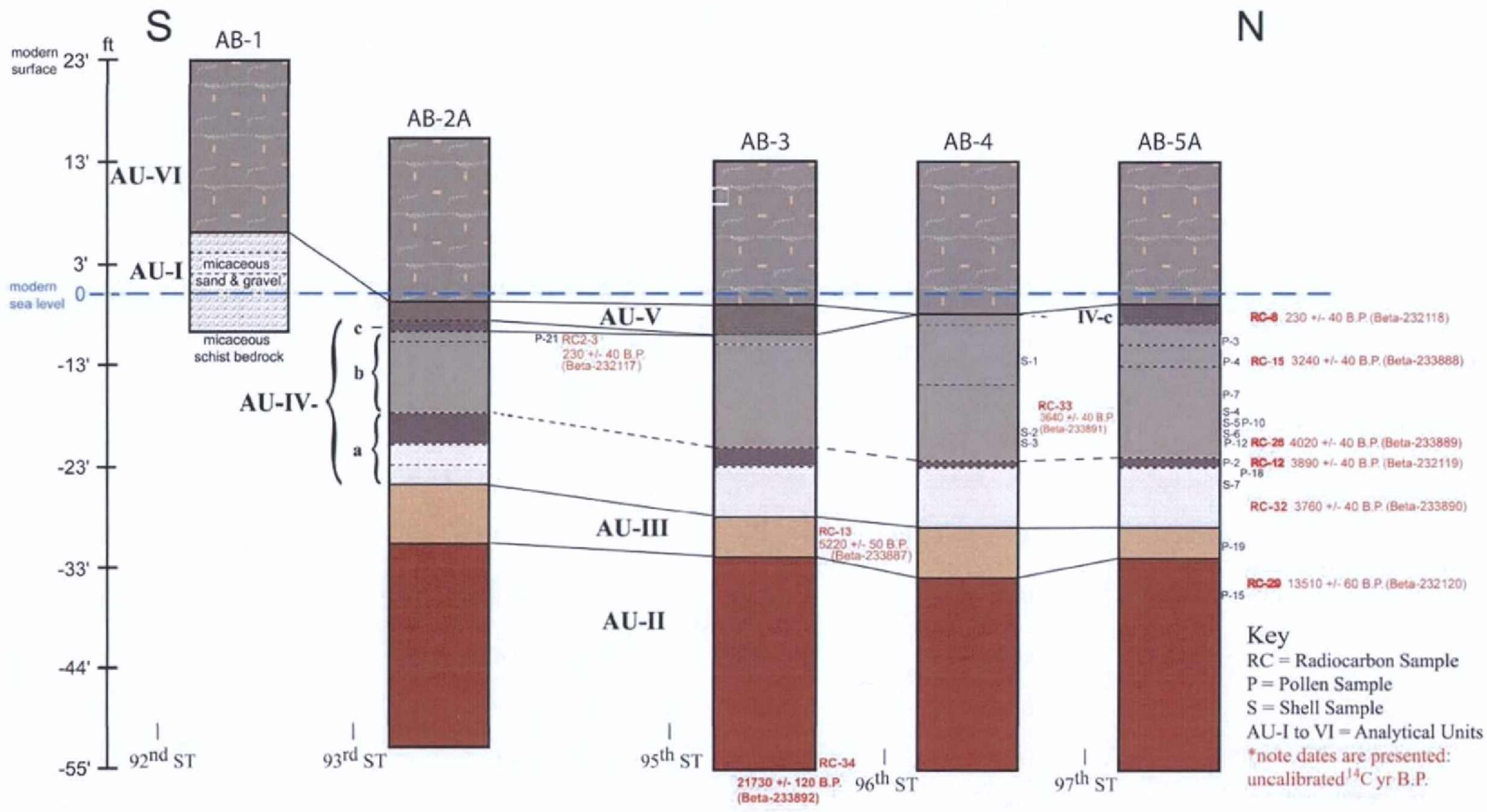

Figure 2. Cores with pollen and shell samples.

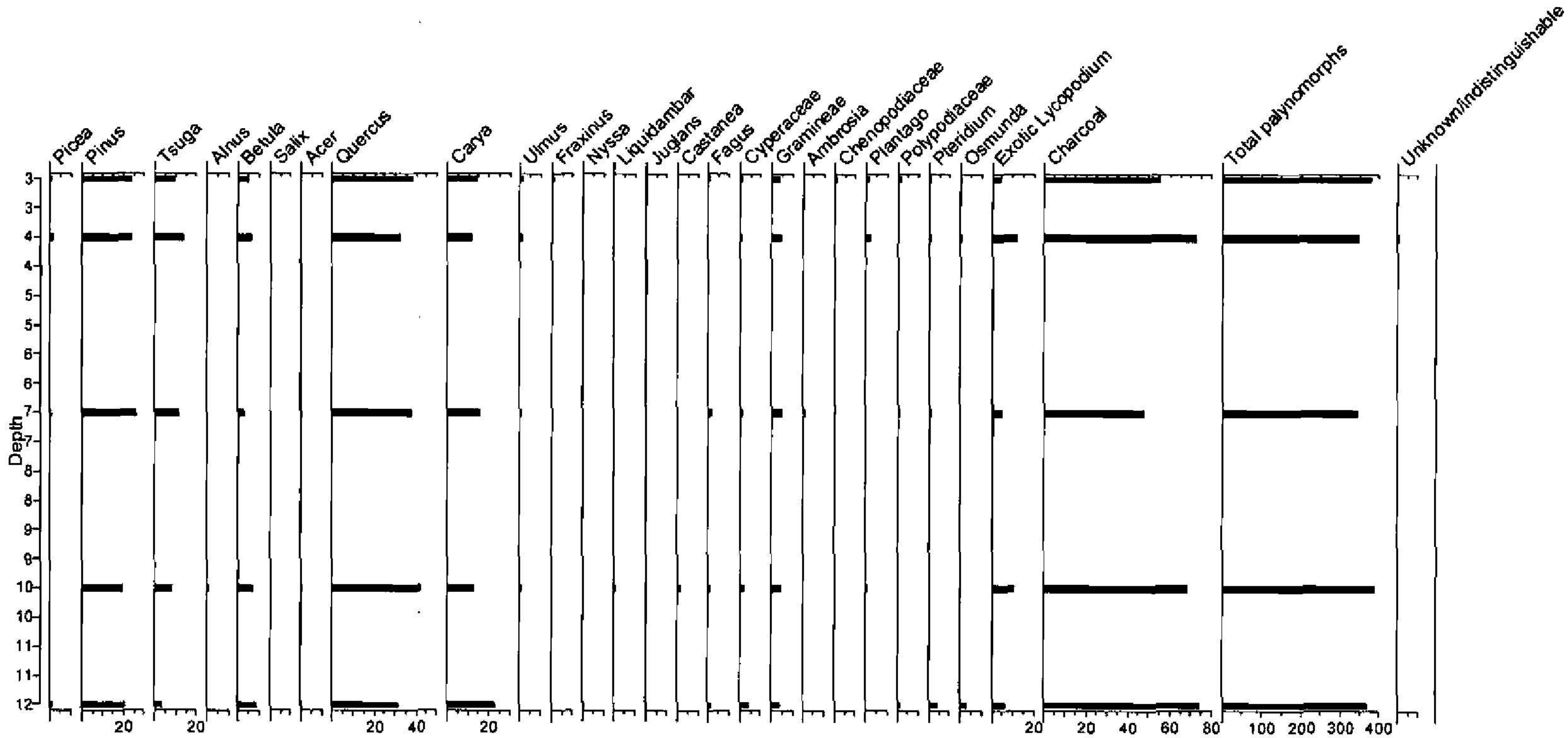

Figure 3. Pollen and spore percentages from 2nd Ave. Subway samples.

Discussion

In general, the 2nd Ave. Subway samples all have very distinctive high amounts of charcoal compared to modern pollen samples, indicative of burning. They clearly do not have significant amounts of *Ambrosia* (ragweed) or other weedy pollen, and are thus are older than European impact. The closest regional match for high charcoal is pre-European age sediments in the Hudson River Marshes (JoCo, Yellow Bar, (unpublished) and Piermont (Pederson et al., 2005). In Piermont we found evidence of a strong Medieval Warm Interval (800-1350 AD) with high charcoal, and relatively high percentages of *Carya* (hickory) and *Pinus* (pine) vs. *Quercus* (oak). However, in Piermont, the *Carya* percentages never reach greater than about 12%, and the 2nd Ave. Subway P-12 sample contains twice this amount. The climatic inference is that these samples overall indicate a relatively dry, warm climate compared to today, with the stratigraphically lowermost indicating the warmest and driest conditions. High charcoal supports this climatic inference.

Shifts in percentages of *Pinus* and *Quercus* of 5% may not be really indicative of a real climate shift, as modern samples year to year probably vary in this amount. However, I have noted a possible shift in inferred climate with relatively minor shifts in the pollen percentages in the chart.

As noted in the chart, the pollen and spores percentages indicate that the most distinctive sample is the lowermost in the set (P-12) which has the lowest *Tsuga* (hemlock*)* (4%) and the highest *Carya* (23%) percentages. Comparing 2nd Ave. Subway samples with the nearby Hudson salt marsh sediments from Jamaica Bay (JoCo and Yellow Bar) and Arthur Kill, Staten Island (unpublished), it is interesting that the pre-European impact percentages of *Pinus* (about 20%), *Quercus* (30-40%), and *Tsuga* (5-10%) are all very similar in all of these sites, although *Tsuga* is a bit higher in P-4 and P-7. In contrast, *Carya* percentages in the 2nd Ave. Subway samples range from 12-23%, which are all higher than the typical *Carya* percentages of 5-10% in the Hudson marshes.

Very low Cyperaceae (sedge) and grass (Gramineae) amounts are present in the samples, suggesting they are not of salt marsh origin. This inference is supported by the macrofossil evidence of *Ruppia* seeds and very low LOI indicative of inorganic estuarine mud.

Exotic *Lycopodium* counts do not vary significantly (6-12%), suggesting that the total pollen counts do not vary substantially among the five samples, and pollen concentrations variation will be insignificant.

In sum, the assemblages from the five estuarine mud samples suggest a warm, dry climate relative to today in NYC, and the dating control to date suggests this occurred prior to the last millennium. This data is interesting in that preliminary data from Piermont prior to recent millennia also shows indications of a higher salinity environment and drought conditions.

III. Loss-on-Ignition

All 10 samples were burned according to Dean (1974) which includes drying overnight at 100°C followed by one hour of high temperature ignition. These samples were burned at 450 °C instead of 650°C to prevent organic matter in clays burning off (Jim Simpson, personal communication, LDEO). The results in Figure 4 show that all samples which contained pollen and spores (P-3, P-4, P-7, P-10, P-12) have very low % organic matter (2 -5%), especially compared to Hudson River marsh samples of about 20-40%. The samples that had no pollen were even lower, with less than .5% organic matter, excepting P-2 and P-21, which had higher amounts. P-2 and P-21 probably did not have pollen and spores due to the larger grain size of sand and pebbles.

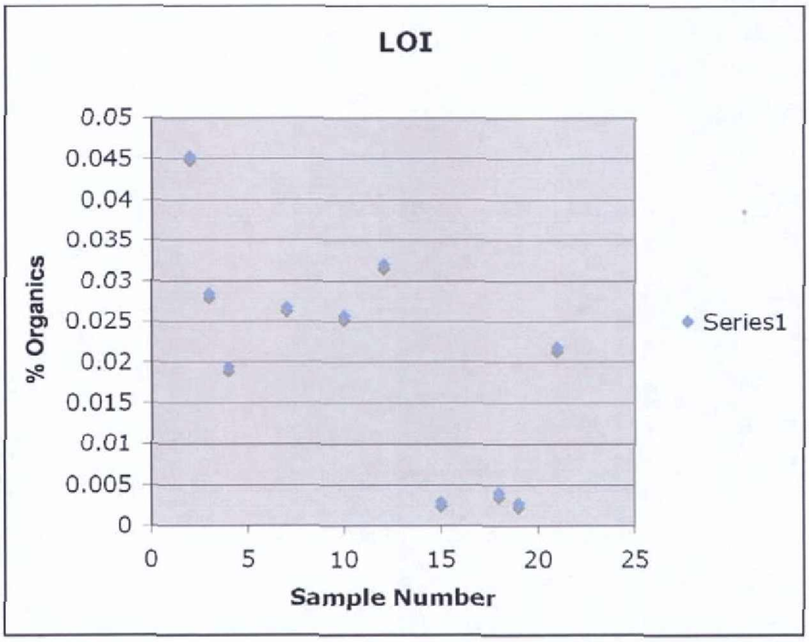

Figure 4. Loss-on-ignition for Subway samples

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APPENDIX D. MOLLUSCAN IDENTIFICATIONS

by
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7 Samples from 2 cores, see Figure 1.

Sample Preparation/Condition:
No sample treatments were necessary in USGS lab. Shell samples were selected and packaged by Geoarcheology Research Associates. Unfortunately, they were shipped in a FedEx Envelope intended for documents, and the aluminum foil in which the shells were wrapped did not provide enough protection. Almost all samples appear to have been flattened/crushed during shipment.

Given the condition of the specimens, identifications could only be made to generic level in most cases. Ecologic information on species was derived from a number of sources.

Findings:
Two genera constitute the majority of the shells examined from both cores: *Nassarius* and *Macoma*. The preservation of the shells prevents confident assignment to species level; however, the members of these genera tend to indicate similar environments. The *Macoma* present is either *M. balthica* or *M. calcarea*. The primary features that distinguish the two species are the pallial sinus scar and the overall size of the adults. Neither feature can be determined from the shells present, but the fragments in some samples appear to be from fairly large shells – larger than normal for *M. balthica* – which indicates these may be *M. calcarea*. Both species are relatively common cold water estuarine forms occurring from intertidal to deeper water. *M. balthica* ranges as far south as Georgia, but *M. calcarea* does not occur south of Long Island Sound. They live infaunally feeding on micro-organisms in the detritus and suspended in the water column. They are tolerant of high sedimentation rates, and generally prefer softer, finer grained substrates.

Nassarius vibex, and *N. obsoleta* are considered shallow water mud-flat species. *N. obsoleta* relies more on micro-organisms and detritus in the sediment for food, whereas *N. vibex* scavenges for food. Salinities range from mid-estuarine to marine (15-35 ppt). *Nassarius trivittatus* cycles seasonally between onshore and offshore, but can also be found on mud-flats in warm weather.

The only other taxon present in the samples is a fragment of *Argopecten* – the Bay Scallop. Typically *Argopecten* are found in clearer, deeper, less muddy estuarine water than the other two taxa, but this single specimen may have been washed in from more open water.

In sum, the presence of the *Macoma* and *Nassarius* seem to indicate deposition in a shallow estuarine environment, most likely a mud flat with salinity in the range of 15-35 ppt.

Samples from **Core AB-4** were identified as follows:

Sample #	Sample Depth	Shell Depth	Identification	Notes
1	18-20 ft	19'	*Macoma* sp.?	3 fragments of adult shell - match species from other samples
		~19.5'	*Nassarius* sp. cf. *N. trivittatus*	Very worn broken adult
2	26-28 ft	~26.5'	*Macoma* sp. cf. *M. calcarea*	Almost intact, but worn and missing part of hinge
		~26.75'	*Nassarius* sp.	Worn adult
		~26.75'	*Macoma* sp. cf. *M. calcarea*	Hinges visible but not pallial line
		27'	*Macoma* sp?	Fragments only
3	26-28 ft bottom	27.25'	? possibly *Macoma*	Crushed
		27.5'	*Nassarius* sp. cf. *N. obsoleta*	Worn broken adult
		27.6'	*Macoma* sp. cf. *M. calcarea*	Fragmented adult; hinge visible
		27.5'	*Argopecten* sp.	Fragment of shell margin

Samples from **Core AB-5A** were identified as follows:

Sample #	Sample Depth	Shell Depth	Identification	Notes
4	24-26 ft	~24.75'	? probably *Nassarius*	Shell crushed and crumbled
5	26-28'	~26.25'	*Nassarius* sp. cf. *N. vibex*	Worn broken adult
6	26-28 ft bottom	~27.25'	Indeterminate Gastropod	Small, non-descript fragments
7	32-34'	33.5'	*Nassarius* sp. cf. *N. vibex*	Worn adult
		~33.5'	*Macoma* sp. cf. *M. calcarea*	Hinge visible, fragmented

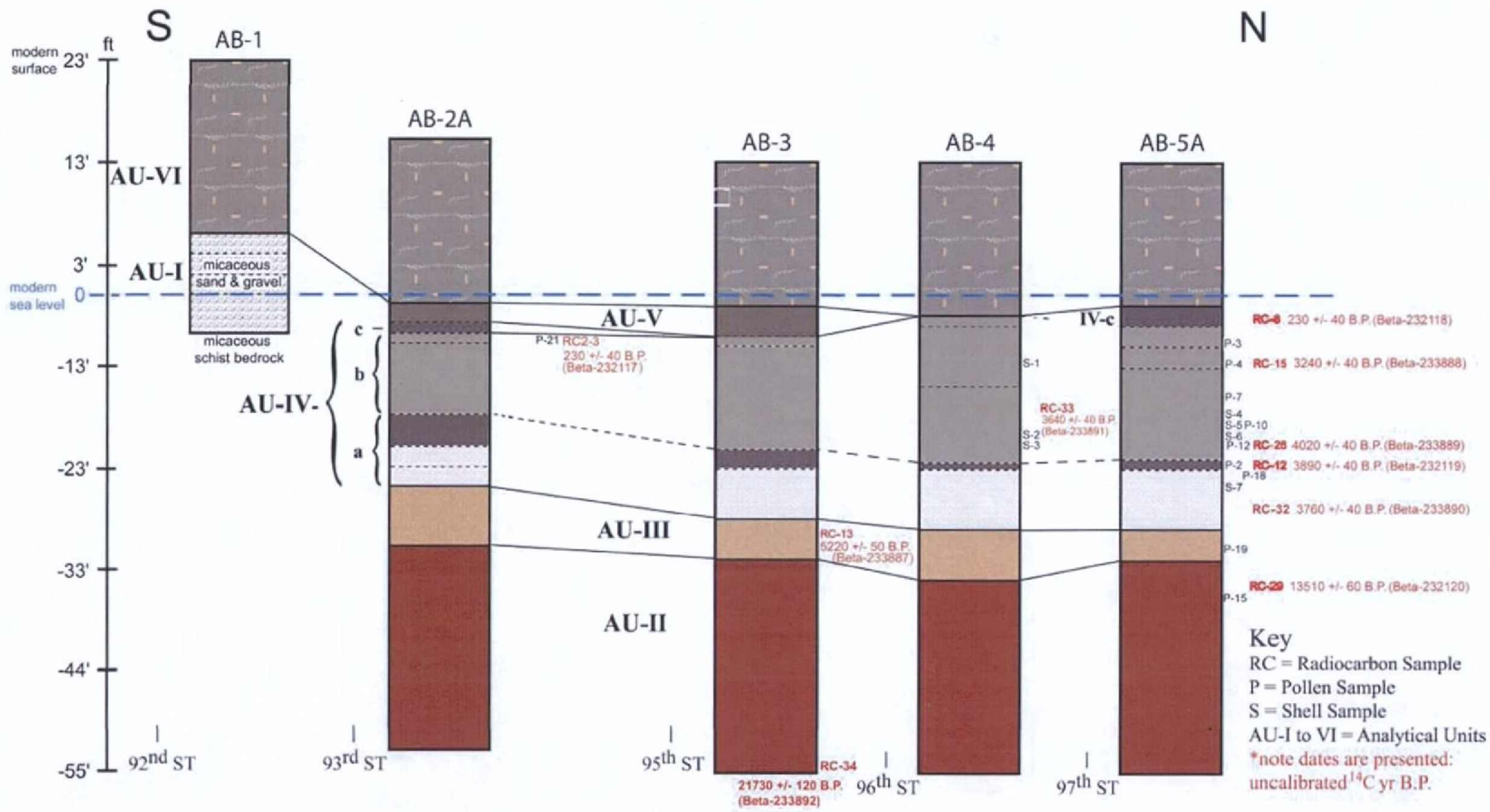

Figure 1. Cores with shell and pollen samples.