Evidence of Two Wisconsin Age Glacial Advances in a Bedrock Valley Below the New Yankee Stadium, Bronx, New York

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INTRODUCTION

Between 2001 and 2005 a geotechnical investigation was undertaken for the design of a new stadium for the New York Yankees (Figure 1). Located in the Bronx, across the street to the north of the old stadium, it sits above a deep bedrock valley carved into the bedrock and filled with multiple layers of glacial sediments. The stratigraphic sequence and engineering properties present indicate that the deposits were the result of two separate glacial advances.

Figure 1 – New Yankee Stadium built to the north of the old stadium. Photo taken in 2010 shows the old stadium starting to be demolished. Rock outcrops are present under the trees at the center right and center left edges of the photo. (Digital image from MRCE archives.)

BRIEF BACKGROUND GEOLOGY

New York City's geologic history, both bedrock and glacial, is quite complex and has already been described in detail in the references. A brief summary is provided here.

New York City's bedrock formed when Proterozoic basement rock and the overlying layers of Paleozoic sedimentary rocks were thrust and shuffled together during the Taconic Orogeny (Merguerian, 2008a; Moss, 2010). The layers were highly metamorphosed, with the very hard Fordham Gneiss basement rock, overlain by the softer Inwood Marble, and the typically hard Manhattan and Hartland Schists the dominant formations produced (Figure 2). Along the way the layers were tightly folded into a series of NE trending anticlines and synclines that plunge gently to the SW. This pattern is particularly visible on the geologic map in the Bronx and northern Manhattan, where the hard Fordham and Manhattan formations outcrop.

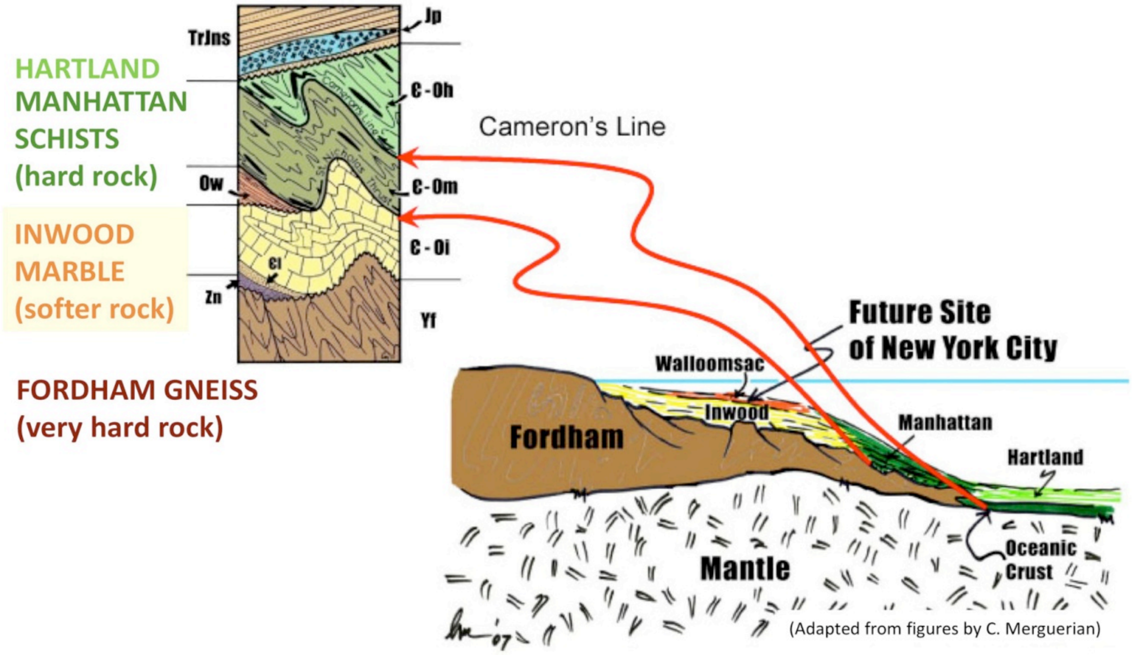


Figure 2 – Formation of New York City bedrock. Proterozoic basement rock (Fordham) and overlying Cambro-Ordovician sedimentary rocks were thrust and shuffled together and subducted during the Taconic orogeny. Primary formations produced by the high-grade metamorphism were the Fordham Gneiss, Inwood Marble, Manhattan and Hartland Schists.

The folded bedrock was later cut by generally NW trending faults (Figure 3). Erosion, most recently by glacial processes, then scoured out the softer rock, particularly along the easily weathered Inwood Marble and the faulted zones. As a result, the bedrock below the city is cut by numerous deep valleys that typically trend NE along the lithologic contacts, or NW along the fault zones. These valleys were then filled in with Pleistocene glacial deposits (Moss and Merguerian, 2008).

Much of the information about the region's glacial history comes from both surficial and subsurface mapping from nearby Long Island and New Jersey (Figure 4). In New Jersey deposits of Pre-Illinoian, Illinoian and Late Wisconsin age have been identified (Stone and others, 2002; Stanford, 2010). Long Island has sediments of Illinoian (Jameco Gravel), Sangamon (Gardiner's Clay) and Wisconsin (the earlier Ronkonkoma and later Harbor Hill) ages (Buxton and Shernoff, 1999). In NYC only glacial sediments of Late Wisconsin age are found at the surface.

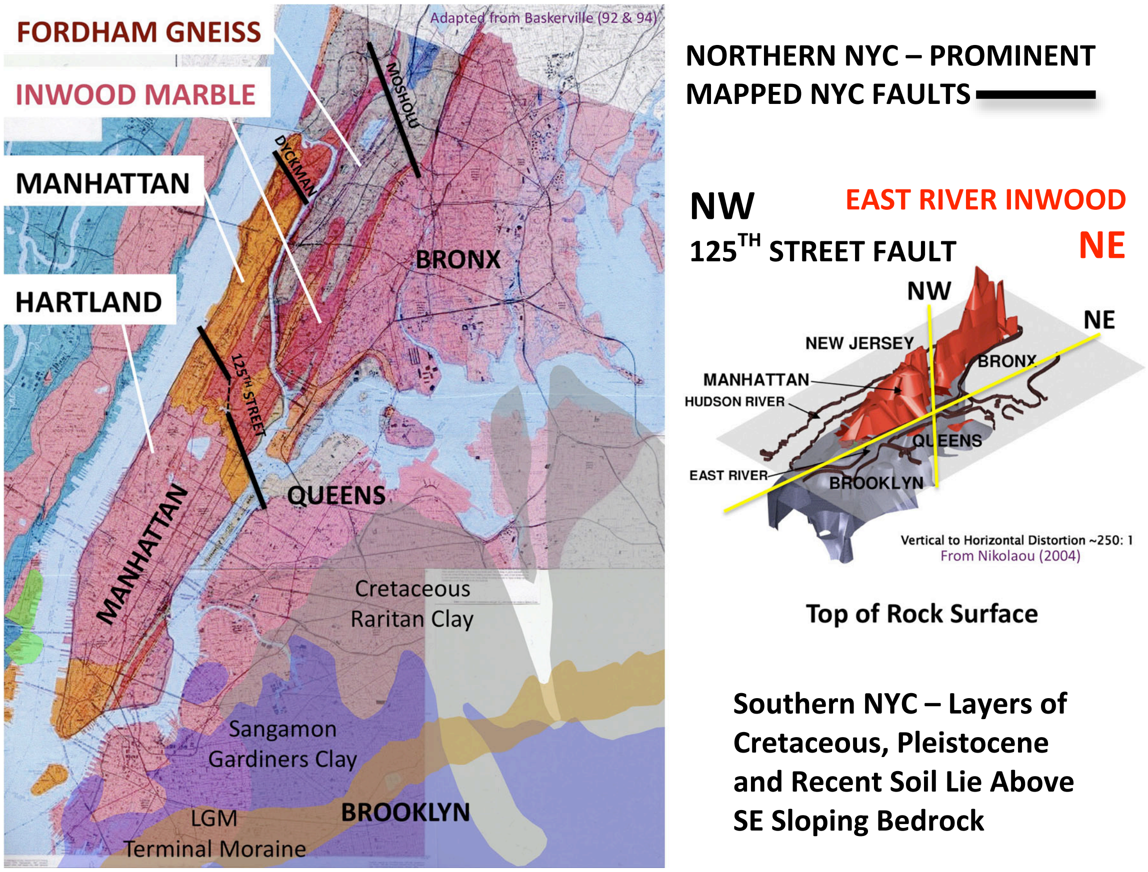
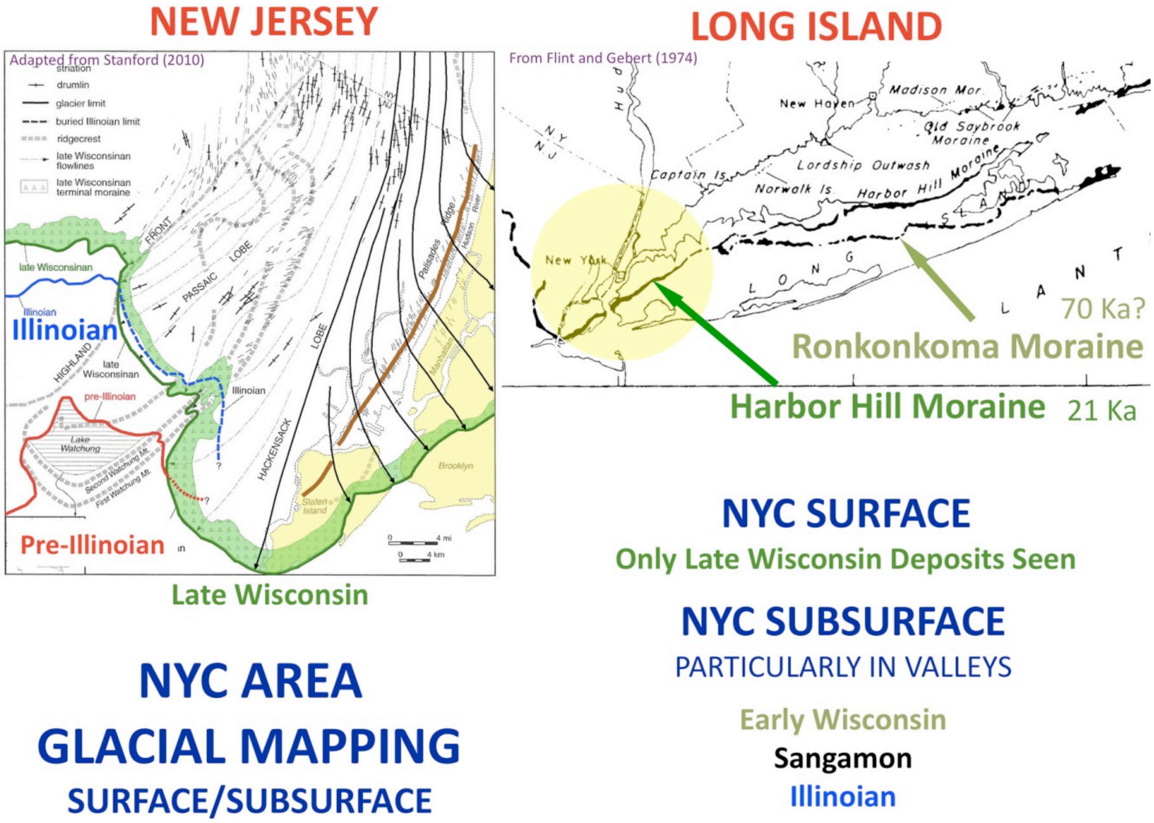


Figure 3 – The Taconic orogeny left the NYC rock formations tightly folded with a NE trend and a gentle SW plunge. This is particularly visible in the pattern of the map units in northern Manhattan and the Bronx. The city was later cut by brittle faults, commonly with a NW trend. Over time erosion, most recently by glacial action, scoured out softer rock, in particular the easily weathered Inwood Marble (red map layer) and the broken fault zones (prominent ones marked with black lines). The resulting deep valleys typically trend NE along the contacts or NW along the faults, and are filled with glacial sediments. To the south in Queens and Brooklyn (where rock surface drops steadily to the southeast) most of the bedrock is overlain by assorted Cretaceous and Pleistocene soils, including the interglacial Sangamon Gardiner's Clay. NYC's surficial glacial deposits all date to the Late Wisconsin.

After the city's surficial geology was mapped in the New York City Folio (Merrill and others, 1902), published mapping in the city shifted focus to Brooklyn and Queens, where the glacial strata above the Sangamon age Gardiner's Clay were grouped together and identified only as "upper Pleistocene deposits" (Soren, 1978). In and around the city, Sanders and Merguerian (1994, 1998; Merguerian, 2003) linked many of these units with events, however there are still few details known about NYC's full glacial history, particularly which events affected which parts of town and when. All that is clear is that most of the NYC surface sediments date to the Last Glacial Maximum (~21 Ka) and the subsequent glacial retreat, and they were initially deposited by ice flow coming from the NW. Recent subsurface investigations at locations around the city are identifying sites that have sediments from multiple glacial advances (Moss and Merguerian, 2005, 2006, 2007, 2009), allowing the opportunity to fine tune specifics about NYC's geology.



Adapted from Stanford (2010)

From Flint and Gebert (1974)

Figure 4 – Glacial deposits mapped in the New York City region. New Jersey has units that date back to a Pre-Illinoian glaciation, while Long Island has Illinoian, Sangamon and assorted Early to Late Wisconsin age sediments above Cretaceous soil. In NYC only Late Wisconsin deposits are found at the ground surface. Older strata that can provide details about the city's glacial history are found only in the subsurface, particularly in the protection of the valleys.

EVIDENCE OF MULTIPLE GLACIAL EVENTS

In the New York City area bedrock is near the ground surface in the north (with outcrops of the harder Fordham and Manhattan formations in the Bronx and northern Manhattan) and drops off gradually to the southeast (rock is over 1000' deep in southern Brooklyn and Queens). Where rock is deep, particularly in the protection of bedrock valleys, there is often evidence that more than one glacier advanced across the site (Moss, 2011).

Locations may contain multiple layers of glacial till and/or varved lake deposits (Figure 5). In geotechnical borings, changes in STP blow counts or preconsolidation values at a particular elevation can indicate that loading by glacial ice has densified the soil below. Changes in degree of weathering (both in the sediments and the bedrock buried below) and in other engineering properties (lithology, water content, seismic velocity, etc.) can also identify layers deposited or transformed at different times by different glacial events.

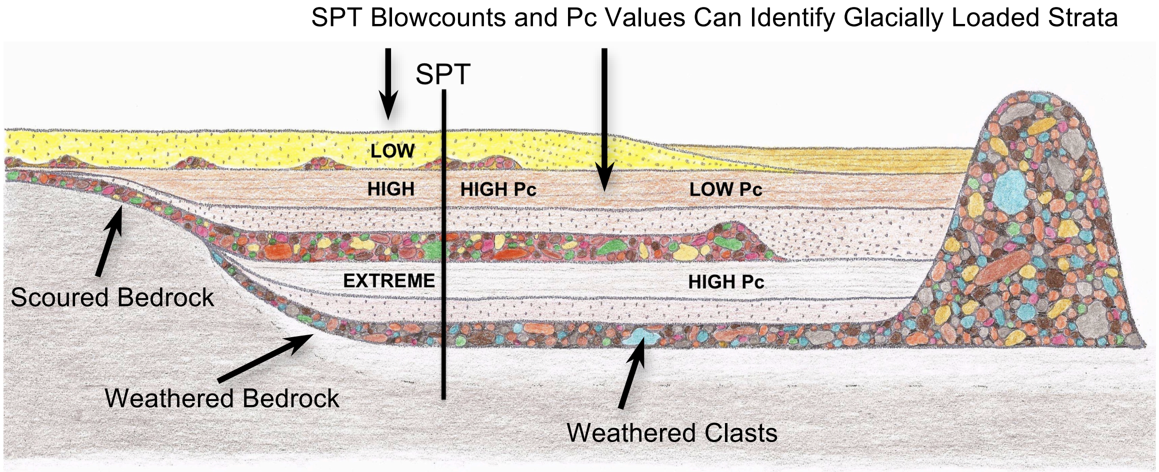
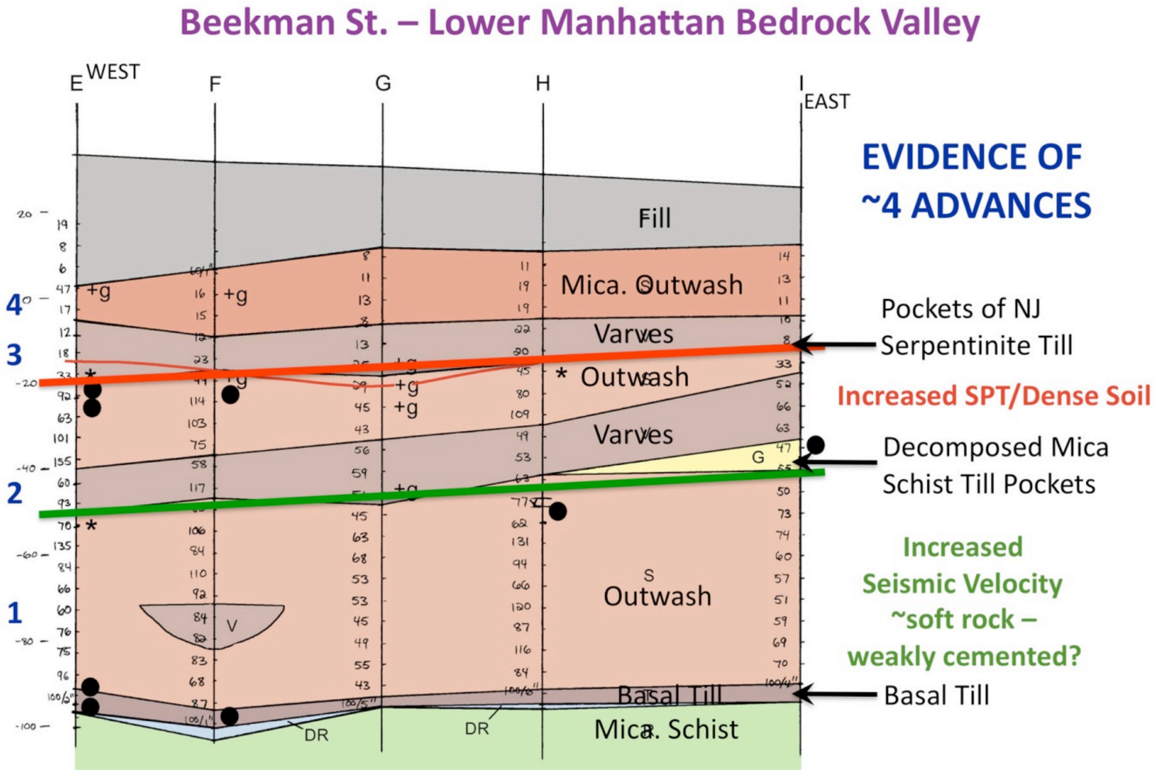


Figure 5 – Above: Schematic cross-section through multiple glacial strata, and their engineering properties. The presence of weathered bedrock +/or clasts is an indication of at least relative age. SPT blowcounts and preconsolidation values can provide specific information about the loading history of the different strata. Changes in landform and lithology mark different events +/or a change in flow direction. Changes in seismic properties can also identify changes in strata and possibly weathering and age.

Below: A valley in lower Manhattan exhibits many of the changes in strata and engineering properties typically seen in NYC that indicate a site has had multiple glaciations. Multiple layers of till and varved lake sediments, changes in lithology, lower strata densified by glacial loading while loose upper strata were not, older soil and buried bedrock showing a greater degree of weathering, property changes between layers (in this case the lowest strata have a significant increase in seismic velocity) are all present. Likely correlations; (1) Illinoian glaciation, (2) Ronkonkoma advance, (3) Harbor Hill advance, (4) micaceous pro-glacial outwash south of the Queens/Brooklyn/East River readvance.



SITE GEOLOGIC HISTORY

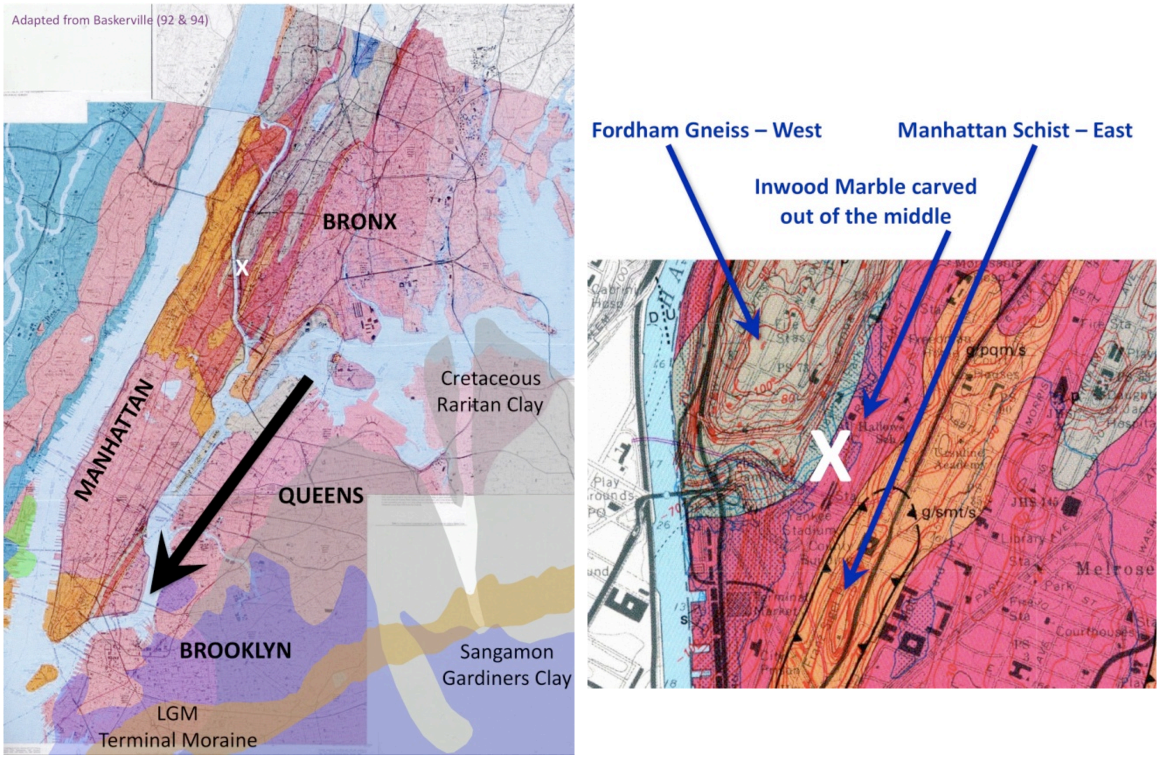
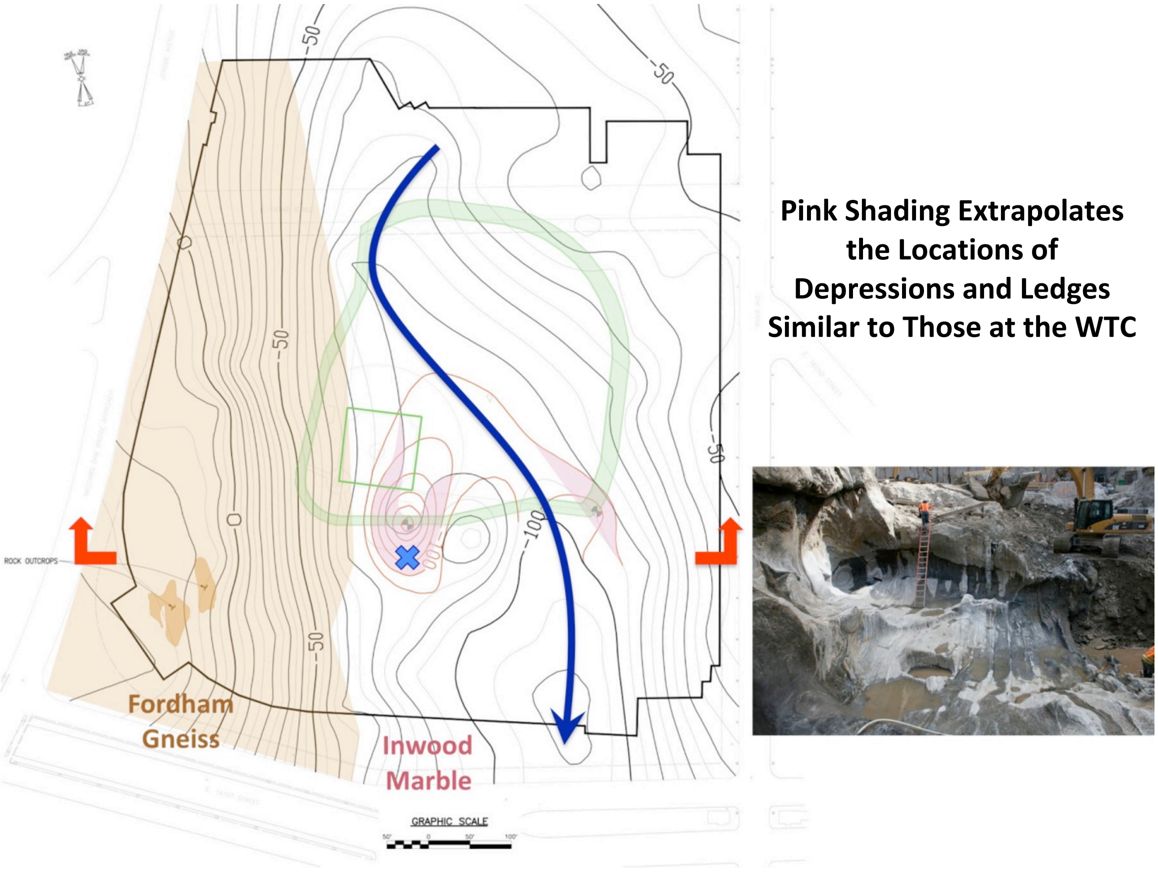


Figure 6 – The new Yankee Stadium site (white X) is located in the Bronx above the Fordham Gneiss/Inwood Marble contact. Fordham Gneiss outcrops to the west, Manhattan Schist to the east (red spots among the rock contours denote outcrops). The soft Inwood Marble found between the 2 harder formations has been eroded away, forming a valley.

Existing geologic maps (Baskerville, 1992) indicate that the new Yankee Stadium site in the Bronx is located on the western limb of a southward plunging syncline (Figure 6). Fordham Gneiss outcrops to the west, while Manhattan Schist outcrops to the east. The more easily weathered Inwood Marble, sandwiched between the two formations, has been eroded out, forming a bedrock valley filled in with sediments. The new stadium was built above the Fordham Gneiss/Inwood Marble contact. This posed a challenge to engineers to design a foundation built on hard bedrock along the west side and over 150' of sediments along the east (Wisniewski and others, 2011). The numerous borings made during the geotechnical investigation for the project provide new details about the nature of the valley and the different glacial deposits that fill it. The following sequence of events are identified at the site:

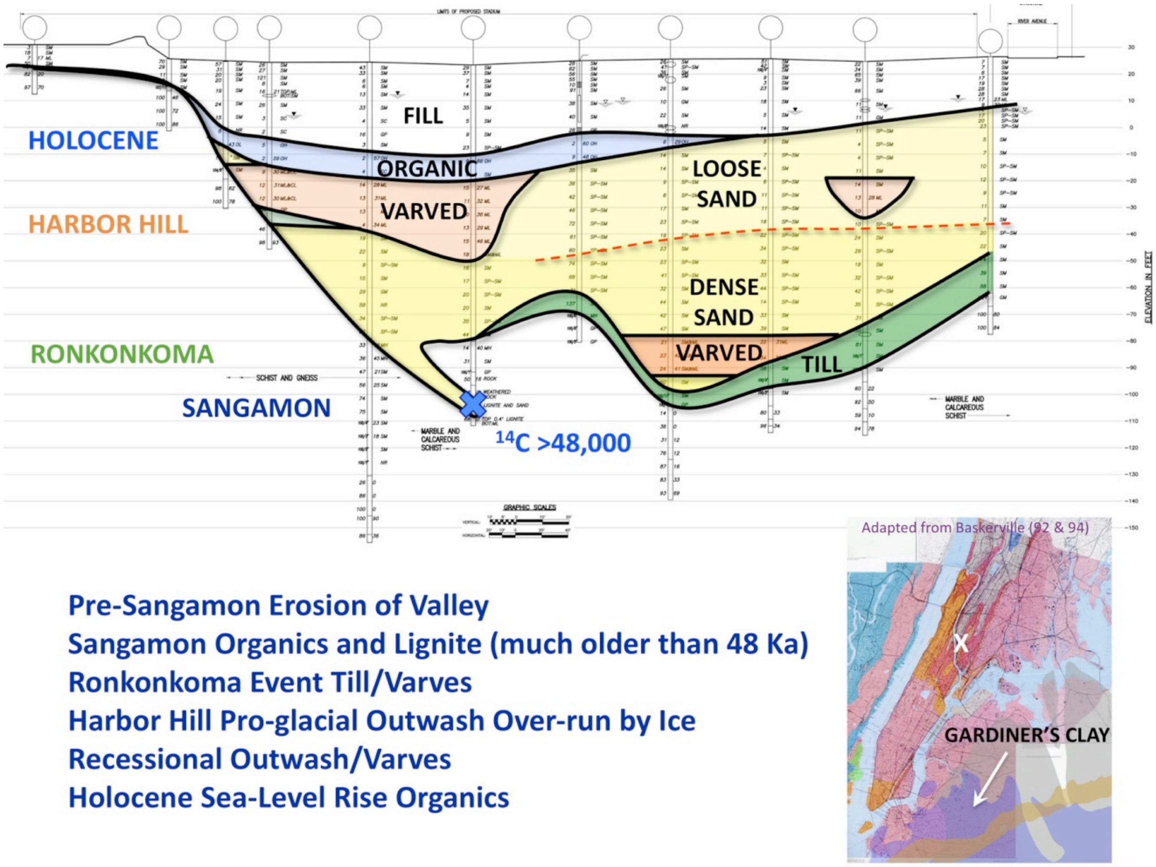
Pre-Sangamon age erosion scoured out the marble along the Fordham/Inwood contact (Figure 7), producing a deep narrow valley that contains depressions and ledges that are probably similar to the whirlpools and ledges seen at the softer schist/harder pegmatite contact below the World Trade Center site. Since plungepools and potholes are often associated with glacial meltwater, the valley's last deep erosion likely took place during the Illinoian glaciation.



Pink Shading Extrapolates the Locations of Depressions and Ledges Similar to Those at the WTC

Figure 7 – Bedrock surface contours below the site based on borings made for the geotechnical investigation. The brown area is underlain by Fordham Gneiss, with outcrops in the SW corner. The area to the east, shown in white, is underlain by the Inwood Marble. Red lines show contours drawn for the bedrock surface below 2 ledges and the pink shading extrapolates their extent. The ledges are probably similar to the whirlpools seen below the World Trade Center site (photo at right). Red arrows mark the location of a cross-section cut through the site (see Figure 8). The blue X marks the location of a boring that encountered wood buried under the ledge. (Digital image by C.J. Moss)

The valley then filled in with Sangamon age sediments (Figure 8), including organic clays and wood analogous to the Gardiner's Clay scattered across the region to the south. Lignite preserved under a deep ledge at the southern downstream end of the basin was ^{14}C dated at >48,000 BP (at NOSAMS-WHOI). While a specific age could not be assigned, test results suggested that the wood was "older" rather than "younger" (A. McNichol, personal communication, 2011), making a Sangamon age reasonable. The deeper bedrock was highly weathered or decomposed, also suggesting the valley bottom was last eroded during an earlier glacial event.



Pre-Sangamon Erosion of Valley
Sangamon Organics and Lignite (much older than 48 Ka)
Ronkonkoma Event Till/Varves
Harbor Hill Pro-glacial Outwash Over-run by Ice
Recessional Outwash/Varves
Holocene Sea-Level Rise Organics

Figure 8 – Sequence of geologic events seen in a West-East cross-section through the site (location marked in Figure 7). The wood trapped under the ledge is older than 48 Ka and is likely a contemporary of the Sangamon age Gardiner's Clay found to the south (blue shading on map). The overlying glacial strata were deposited by the Ronkonkoma and Harbor Hill glacial advances. Holocene sea-level rise left behind organic soils that were covered with fill.

The glaciation associated with the Wisconsin age Ronkonkoma advance scoured out the sediments not trapped under ledges, and deposited basal till above the bedrock across the site. Its retreat left behind glacial lake varved deposits that filled in depressions in the till. The subsequent Harbor Hill advance filled the valley with pro-glacial outwash sand that was then overrun by the glacier. The soil below (from roughly El. -40' at the north end to El. -50' to the south) was densified by glacial loading. Retreat of the glacier left behind layers of less dense, unloaded varved lake sediments and outwash.

Post-glacial stream flow through the valley and Holocene sea-level rise into the neighboring Harlem River filled the center of the valley with organic river clay. Man-made fill was later placed across the site.

GEOLOGIC IMPLICATIONS

As the Harbor Hill ice receded, the direction of ice flow shifted (Stone and others, 2002). Instead of flowing across the city from the NW, ice started to flow more from the north (Figure 9). Evidence from several sites across the city indicates that a minor glacial readvance from the NNE moved over NW Queens and Brooklyn, flowing down along the East River to the south (Moss, 2011; Moss and Merguerian, 2007). Details of this event are still unclear, a topic for further research.

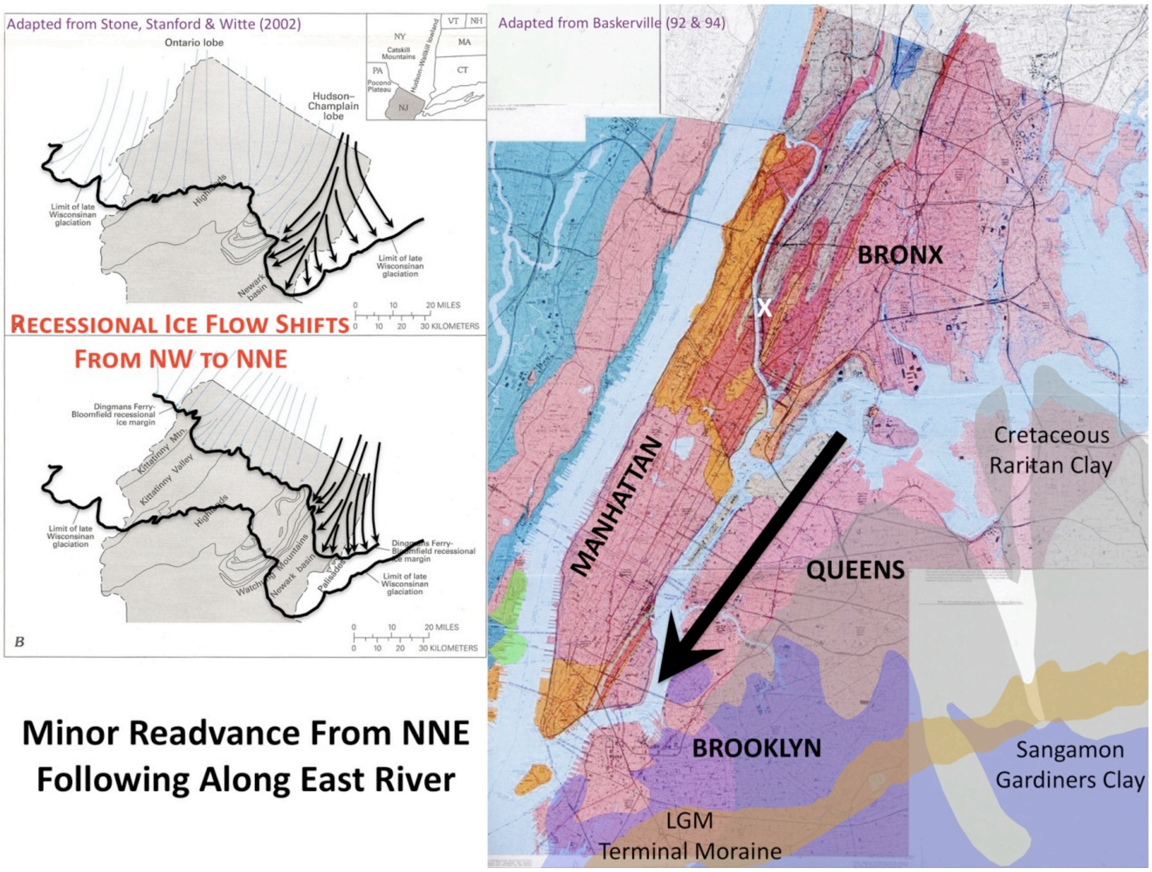
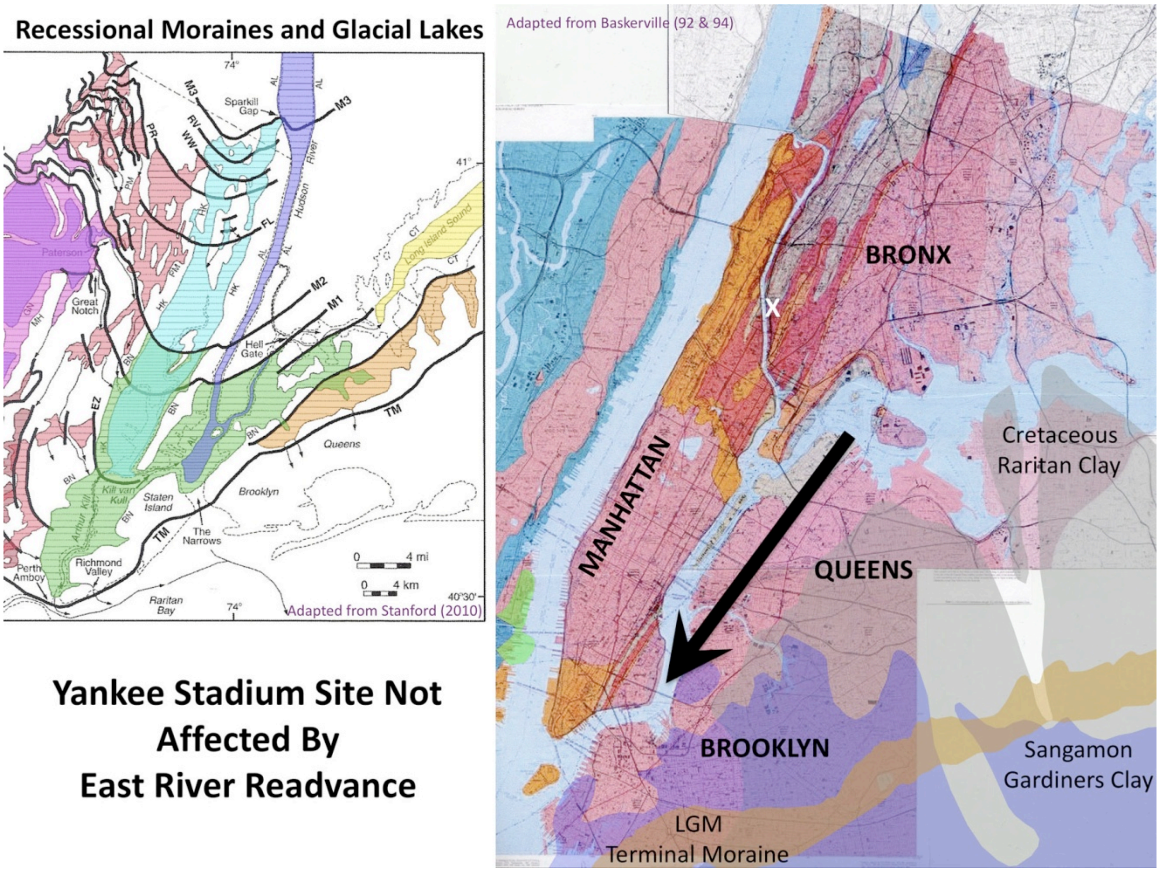


Figure 9 – During the Late Wisconsin advance ice flowed across the city from the NW. As LGM ice receded the direction of ice flow shifted to flow from the north or NNE. Several sites around the city have evidence of a minor readvance across northwestern Queens and Brooklyn that flowed along the East River.

The Yankee Stadium site has sediments from an interglacial event, followed by two substantial glacial advances. There is no sign of a third glaciation and additional ice loading, so this section of the Bronx apparently was not affected by the late readvance (Figure 10). Either the Queens readvance took place while the Bronx was still under ice, or its glacial ice flow was confined to the vicinity of the East River and did not extend further to the northwest.



Yankee Stadium Site Not Affected By East River Readvance

Figure 10 – The Yankee Stadium site in the Bronx was not affected by the Queens late glacial readvance. Either the site was still under ice when the readvance occurred (as suggested by the position of recessional moraines) or the ice had receded to the north and the readvance was confined to the vicinity of the East River.

An alternate timeline is technically possible, though current evidence suggests less likely. If the lignite and organics were deposited during a Ronkonkoma/Harbor Hill interstadial that dates to well before 48,000 BP, then the lower glacial strata belong to the Harbor Hill event and the thick upper strata belong to a readvance. If this is the same as the Queens readvance, then the ice retreated north into the Bronx before starting a more significant readvance across the city. If this is a separate event, then there were multiple readvances across different neighborhoods of the city during the LGM final retreat.

The “20 Foot Clay”, found in the subsurface along the south shore of southeast Queens and Long Island (and named for its depth), is the only mapped unit in the city currently attributed to the interstadial. Odds favor the organics in a Bronx valley being a contemporary of the more prevalent and equally deep Sangamon Gardiner’s Clay, rather than the more limited interstadial “20 Foot Clay” found at the opposite end of the city at a much higher elevation.

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