Use of Engineering Properties to Identify Multiple Glacial Advances in New York City's Subsurface

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INTRODUCTION

In New York City most of the surficial glacial deposits date to the Last Glacial Maximum, around 21Ka, with no sign of anything older (Figure 1). Relatively recent mapping in Connecticut (Stone and others, 2005) and especially New Jersey (Stone and others, 2002; Stanford, 2010) identify probable Illinoisan and likely older glacial layers below the LGM sediments (Figure 2). Geotechnical site investigations around the city (Moss and Merguerian, 2005, 2006, 2007, 2008, 2009) are revealing that multiple glacial layers of differing ages are also often present in the subsurface of New York City. This is of particular interest to engineers, since the different layers can have very different engineering properties, enough to affect foundation design. Conversely, geologists can use these properties to understand and interpret the geologic history of a site.

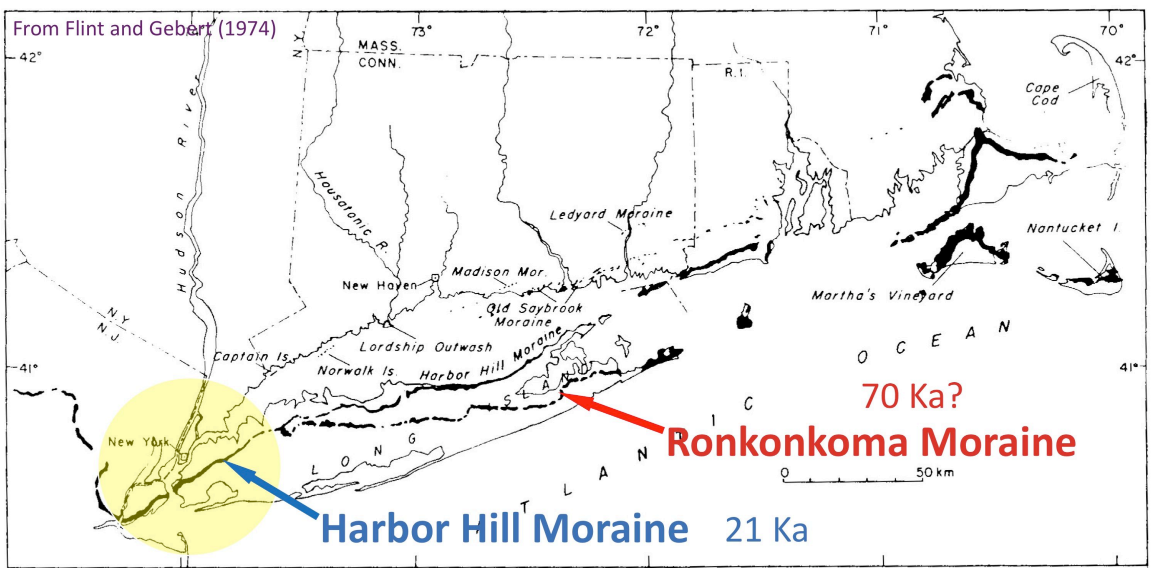

Figure 1 – Most of the surficial glacial deposits in the New York City area date to the Last Glacial Maximum, ~21 Ka. Older sediments are not seen at the surface.

There has been a long running debate about how many glacial advances crossed the NYC area, what direction they flowed in, what deposits they left behind, and when. Most of the region's detailed glacial mapping and research has focused on New Jersey and Long Island, with limited overlap across parts of the city. There has not been a lot of published research on the glacial history of the immediate New York City area. The city's surficial geology is mapped in the New York City Folio (Merrill and others, 1902). Glacial lakes and drainage paths connected to the ones found in NJ have also been mapped (Stanford, 2010; Stanford and Harper, 1991). Subsurface strata are described and contoured in Queens and Brooklyn (Soren, 1978; Buxton and Shernoff, 1999), but deposits above the Sangamon age Gardiner's Clay are all grouped together as "upper Pleistocene deposits" with little interpretation. Research by Sanders and Merguerian (1991, 1994, 1998; Merguerian and Sanders, 1996; Merguerian, 2003) is the most city specific and detailed overall, and describes a sequence of events that provides a good explanation for the many different deposits seen in New York City.

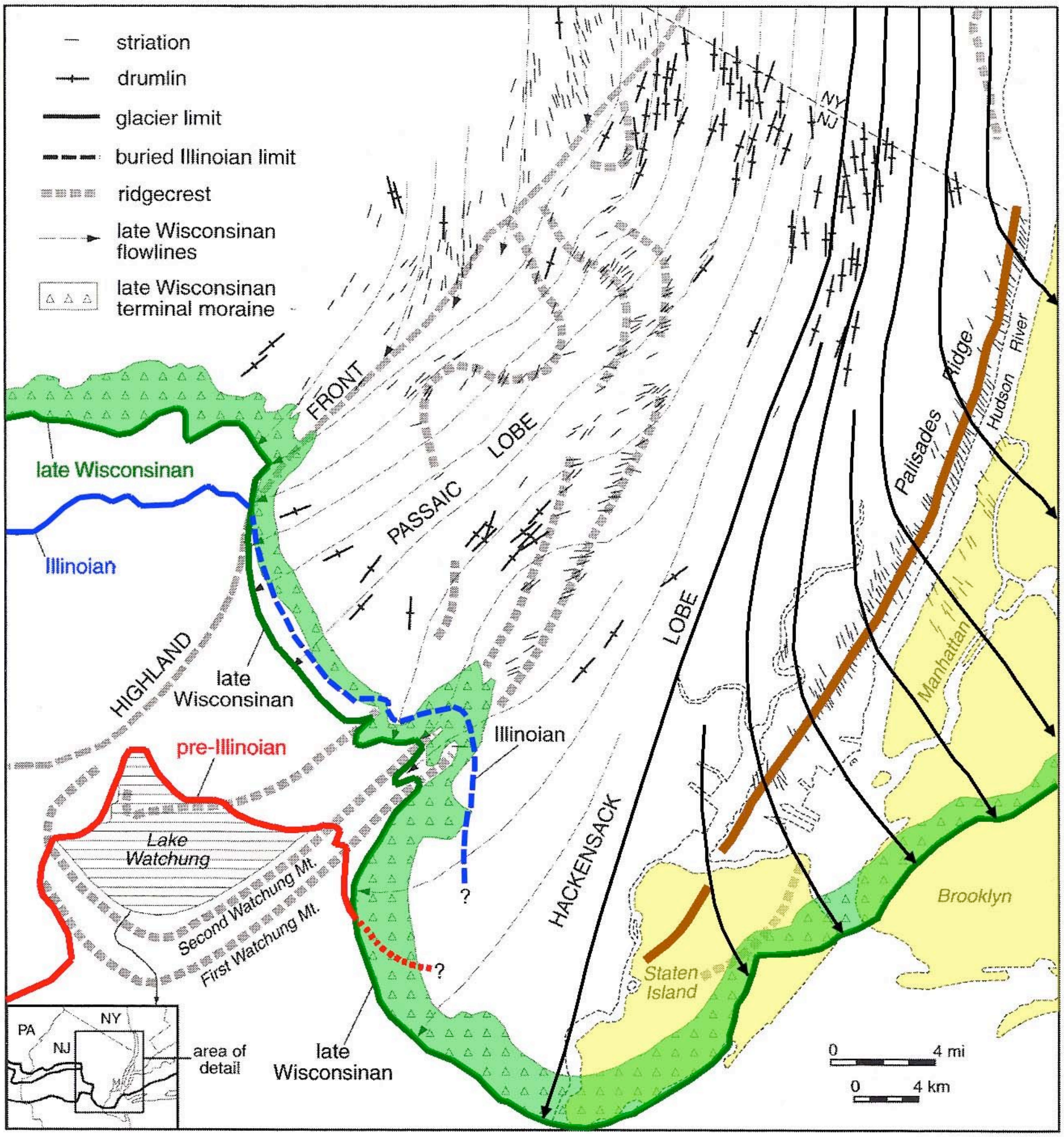

Figure 2 – Map showing the limits of the Late Wisconsinan, Illinoisan and pre-Illinoisan glaciations in New Jersey, and LGM glacial flowlines. In eastern NJ, ice flow followed the valleys and was partially confined behind the Palisades Ridge. Some ice, however, flowed over the Palisades and SE across NYC. Consequently, much of NYC's glacial deposits originated in NJ. Adapted from Stanford, 2010.

REGIONAL MAPPING

The Quaternary geologic map of Connecticut and Long Island Sound Basin (Stone and others, 2005) identifies older till, probably of Illinoisan age, below younger till deposited during the late Wisconsinan. The Surficial geologic map of northern New Jersey (Stone and others, 2002) also describes older till below younger till, and Stanford (2010) maps older glacial deposits south of the Wisconsinan terminal moraine. The older till, of Illinoisan and probably pre-Illinoisan age, is weathered, in some cases with the oldest clasts completely decomposed.

The New Jersey mapping indicates much of NJ's glacial flow came from the N to NNE and in eastern NJ followed the lowlands, further scouring out valleys between basaltic ridges. The Palisades ridge, a sill of diabase along the western bank of the Hudson River, acted as a partial barrier that largely separated the various NJ deposits from their counterparts in NY. Consequently, the glacial sediments on either side of the Palisades and their engineering properties are often quite different (Moss and Merguerian, 2005). However, there was some glacial flow over the Palisades and across NYC. As a result, a large percentage of the NYC glacial deposits originated in NJ. NJ mapping also indicated that the Wisconsinan ice started its initial retreat in the west, retreating later in the east (Figure 3). In NJ this caused the ice flow to shift from roughly north to flow from a more NNE direction. In NYC the NW flow over the Palisades and across the city shifted to flow from a more N to NE direction, moving down the NY river valleys.

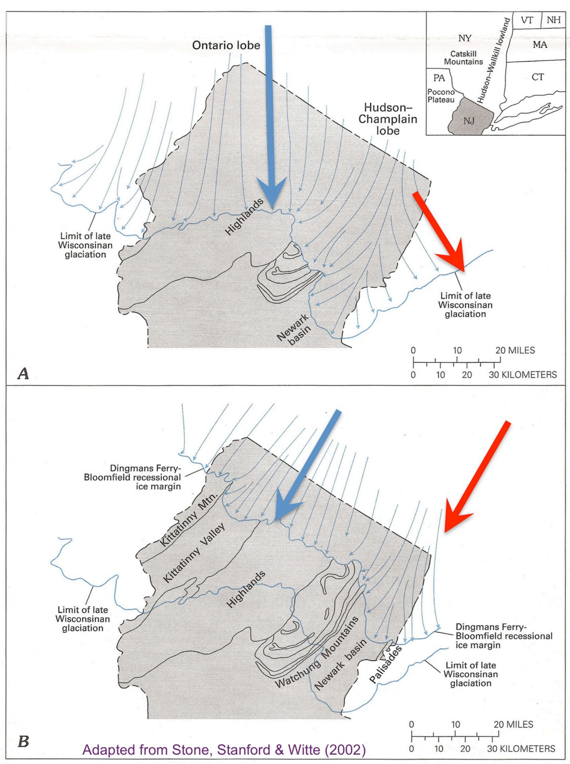

Figure 3 – Wisconsinan ice retreat started in the west, with ice retreating later in the east. As a result, ice flow across NYC shifted from the NW to a more N-NE direction, following the NY river valleys.

Along the western side of the Hudson in NJ, the rock is largely a distinctive mix of Mesozoic redbeds and basaltic igneous rocks, along with some zones of serpentinite (Figure 4). Across the Hudson in NY, the rock switches dramatically to generally micaceous metamorphics such as schist and gneiss, along with some marble. In eastern Queens and Brooklyn the rock is overlain by Cretaceous clay. Changes in the direction of glacial flow pick up these differences in the underlying bedrock.

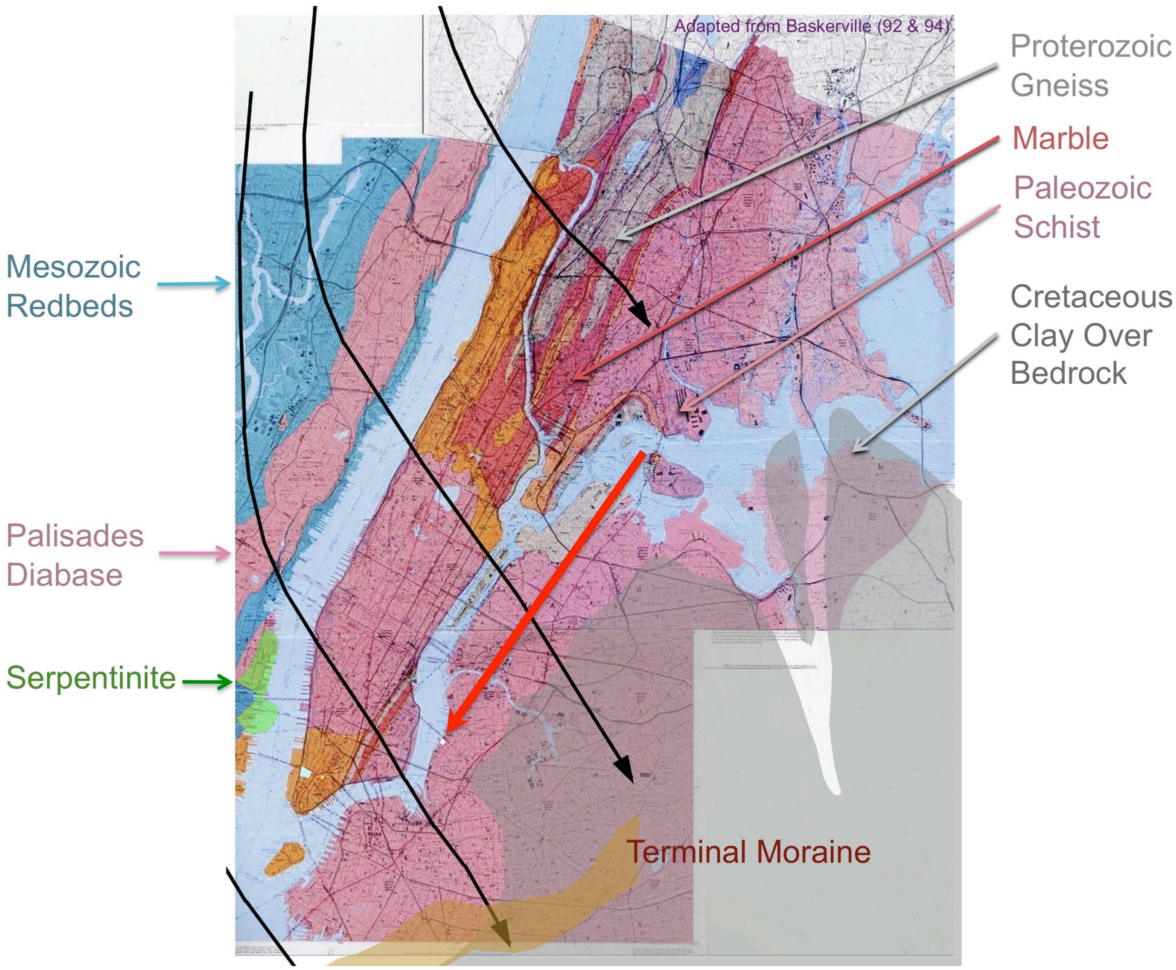

Figure 4 – LGM Glacial flow over the Palisades (black arrows) brought distinctive rock from NJ across the city. Recessional shift in flow to a more N-NE direction (red arrow) carried micaceous rock and Cretaceous clay over portions of the city.

NEW YORK CITY SUBSURFACE

In NYC the bedrock drops off quickly to the south and east (Figure 5), and the city is cut by numerous valleys, some at least 300 feet deep. Valleys commonly trend NW, likely following scoured out fault zones, or NNE following the regional trend of folds and lithologic contacts. Geotechnical site investigations indicate there are multiple layers of glacial sediments present in the subsurface, particularly in the protection of the valleys.

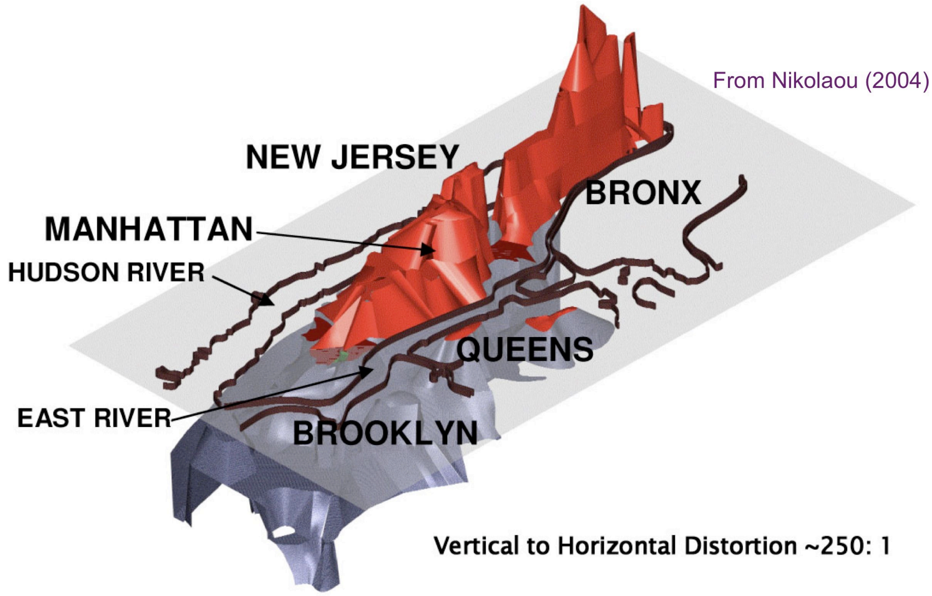

Figure 5 – Top of bedrock contour in Manhattan, Queens and Brooklyn. Rock drops off deeply to the south and east and in numerous valleys that cut through the city.

The typical NYC soil profile (Figure 6) consists of glacially scoured bedrock overlain by basal till, then layers of varved glacial lake silt and clay and/or outwash. Even when there appears to be one thick glacial stratum, it often consists of multiple separate layers. Additional till layers may not always be visibly present between them. Capping off the sequence, organic clays and peats are typically found along the rivers and streams, and miscellaneous fill covers much of the city.

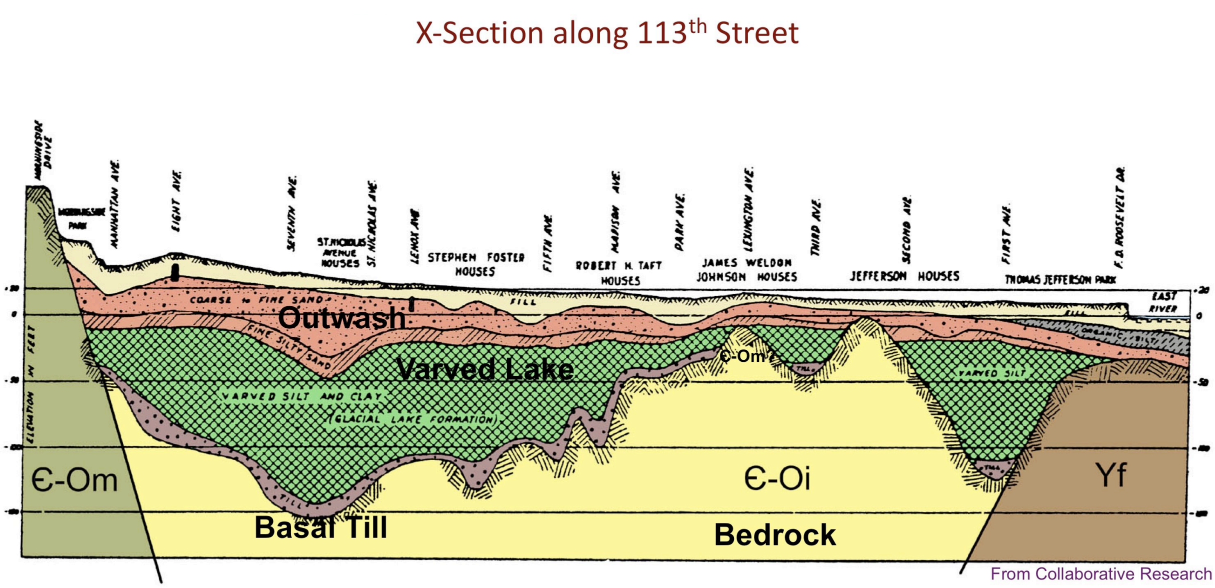

Figure 6 – Cross-section along 113th Street in Manhattan shows the typical soil profile in New York City. Thick layers are shown here, but in many locations the stratum may actually consist of multiple layers, each with different engineering properties.

ENGINEERING PROPERTIES

Engineers routinely test the properties of a soil to assess its behavior, analyzing density, strength, permeability, liquifaction and settlement, amongst other qualities. Geologists can use the same data to analyze the site's history. Differences in the engineering properties of the deposits can be used to separate and interpret the strata (Figure 7). Consolidation tests may give specific values for previous glacial loads on the soil. SPT blow counts can also provide information about the soil's previous loading history. In particular, a sudden increase in SPT blows below a certain elevation across a site indicates the strata below may have been glacially loaded, while the layers above were not. Intervening till layers are not always visibly present, but are often found at that elevation nearby. These property differences are commonly seen in NYC, with changes often occurring over relatively short distances vertically and/or laterally.

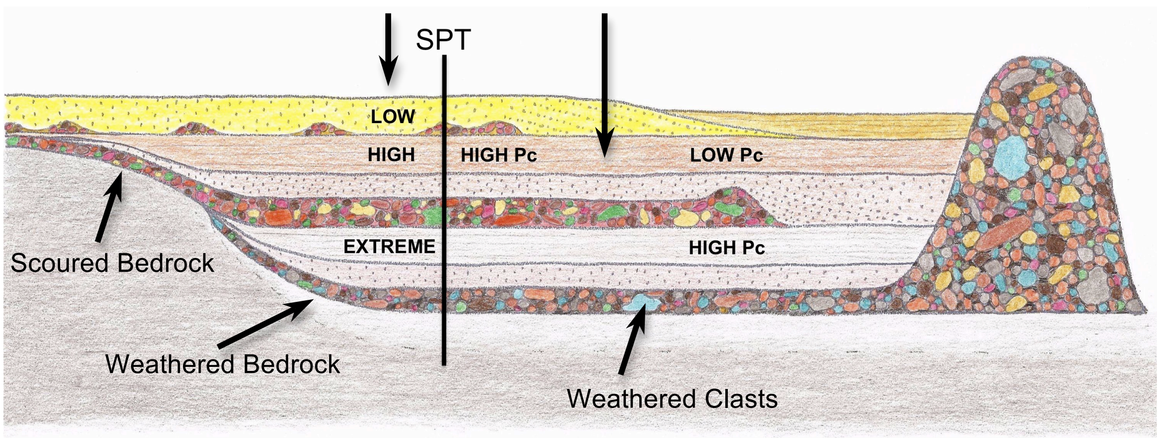

Figure 7 – Schematic cross-section through multiple glacial strata, and their engineering properties. While much of NYC's bedrock has been scoured clean by glacial action, in some sheltered locations younger glaciations flowed over and buried the older deposits, rather than eroding them and the underlying rock away. This has happened repeatedly in some areas, leaving behind multiple glacial layers. 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.

Since much of the NYC bedrock surface has been scoured by glacial ice, there's generally not a lot of chemically weathered rock present, though exceptions exist. Particularly in the shelter of valleys, older deposits are often over-ridden by newer glacial advances rather than being scoured away completely by them. In turn, the older sediments protect the underlying bedrock from erosion. If the soil has been in place long enough to weather and/or allow the underlying bedrock to decompose, the degree of weathering may provide information on the relative age of the stratum.

Changes in the seismic properties of the soil may also identify layers of differing age or with a different level of weathering and/or cementation.

Since NYC was in the terminal zone of multiple glaciations, minor shifts in stratigraphy may reflect short-term events within a glaciation. However, significant changes in landform or lithology are likely produced by different glacial events or changes in glacial flow.

FEATURED SITES IN BRIEF

The unusual geology found at several sites in NYC has been described in much greater detail previously; Beekman Street in lower Manhattan (Moss and Merguerian, 2006), The Edge in Brooklyn (Moss and Merguerian, 2007), and the World Trade Center Site (Moss and Merguerian, 2008, 2009), so only key details are provided here. Each location (Figure 8) provides information about the glacial history of NYC, but when taken together a better understanding of the events and timing starts to emerge. It should be noted that while each site has multiple features that are unusual (making it easier to correlate them) the same features and/or property changes are often found elsewhere in the neighborhood or across the city.

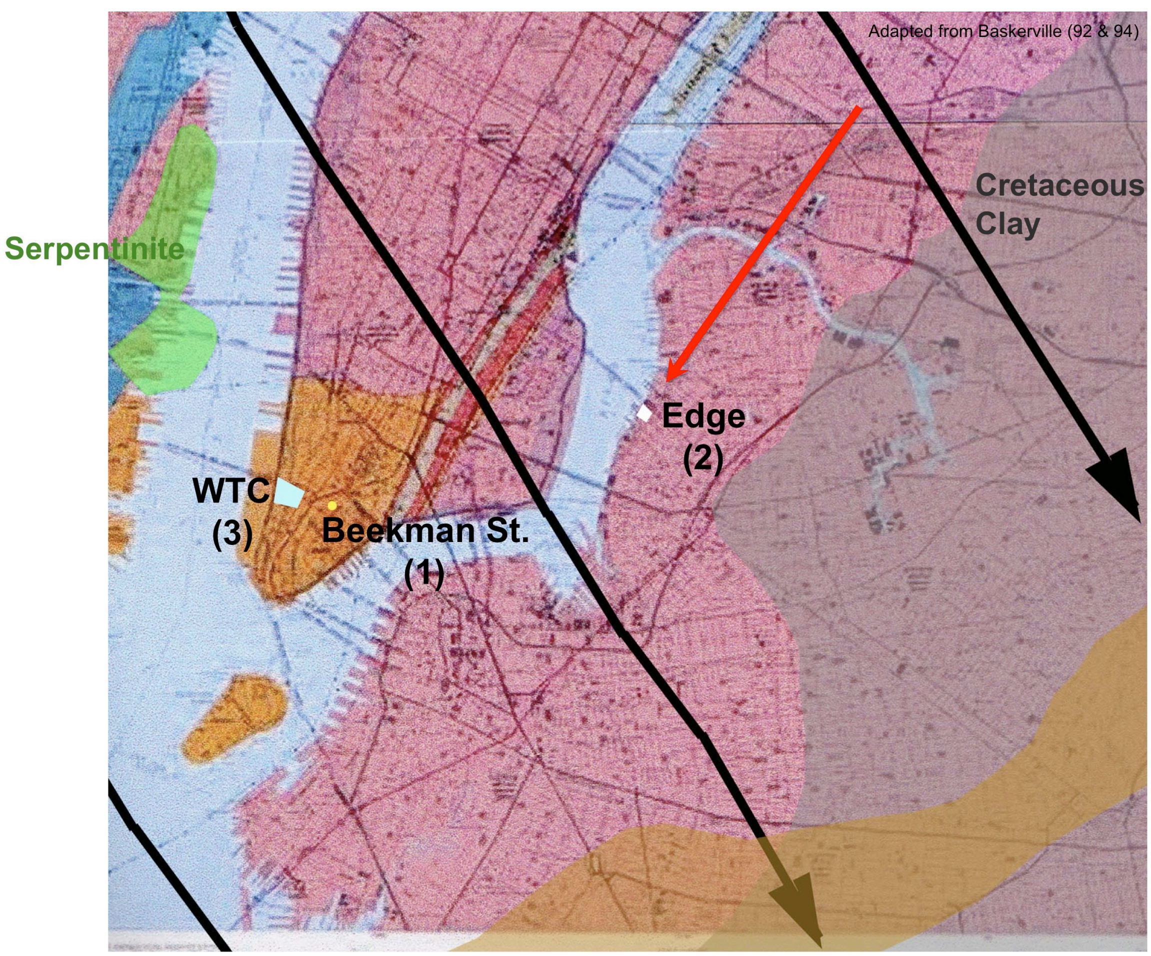

Figure 8 – Featured site locations. 1st is a site on Beekman Street in lower Manhattan, 2nd is at the Edge of Brooklyn, and 3rd is the World Trade Center site.

Beekman Street – Bedrock Valley in Lower Manhattan

A site in SE Manhattan on Beekman Street (Figure 9) lies above a bedrock valley filled with deposits from what appears to be at least 4 different glacial advances. The site has schistose bedrock overlain with thin zones of decomposed rock. Above this is a thin layer of locally derived till. This is topped with a sequence of outwash sand, then glacial lake varves, outwash, varves, then a darker and more micaceous outwash overlain by fill. Pockets of till containing decomposed schist are found at the base of the lower varved layer and till pockets with NJ serpentinite are at the base of the upper varves. Across the site SPT blow counts increase dramatically below the upper varves/till, and in places even more so below the lower varves/till. Stratified drift below the lower till has cross-hole seismic shear wave velocities more typical of weak rock rather than soil, possibly from weak cementing in an older, more weathered stratum. The pockets of decomposed bedrock below and till above could be the source of the cement.

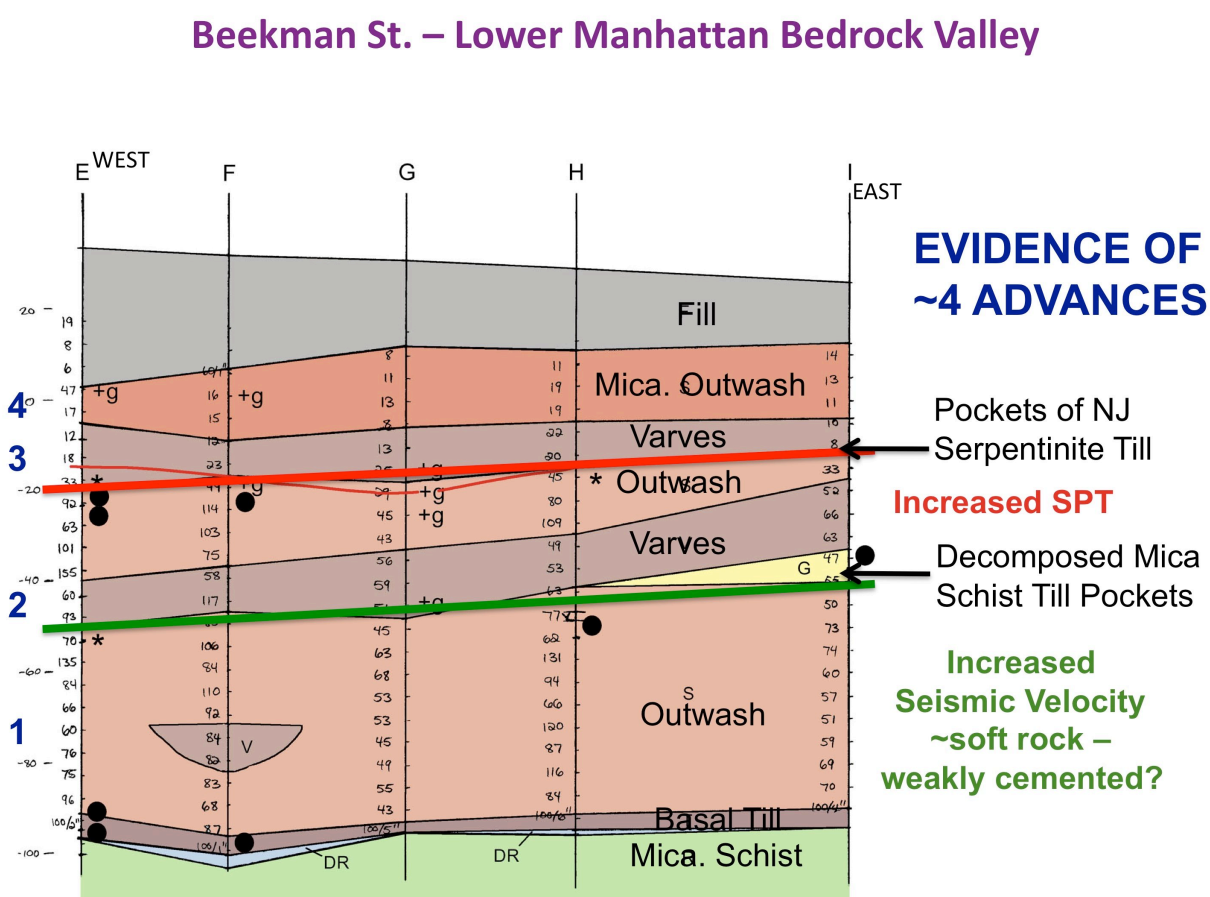

Figure 9 – Cross-section along the southern end of the Beekman Street site. The strata provide evidence of at least 4 different glacial advances. The lower outwash (1), showing signs of weathering +/or cementation, is likely much older than the overlying strata. Although the till at the bottom of varved layers (2) and (3) is thin and discontinuous, the change in engineering properties and lithology indicates glacial loading during different advances. The darker, more micaceous, less dense outwash at the surface (4) reflects a shift of glacial flow over micaceous rock, but the site itself was south of the areas that were glacially loaded.

The Edge of Brooklyn

Repeated glacial advances generally scoured the NYC bedrock clean, but NW Brooklyn (Figure 10) has unusually thick decomposed rock above gneissic bedrock. This is overlain by an odd, dense clayey silt layer derived from decomposed rock, which was possibly deposited in a glacial lake. Above this lie thin till pockets, then more typical glacial lake sediments, then a thick, dense clay till that contains Cretaceous clay found only to the NE. This is overlain by a mixed glacial ablation deposit the color of till derived from rocks found to the north and NE. The upper till layers end at, and just south of, the site, indicating they were deposited by a less extensive glacial advance.

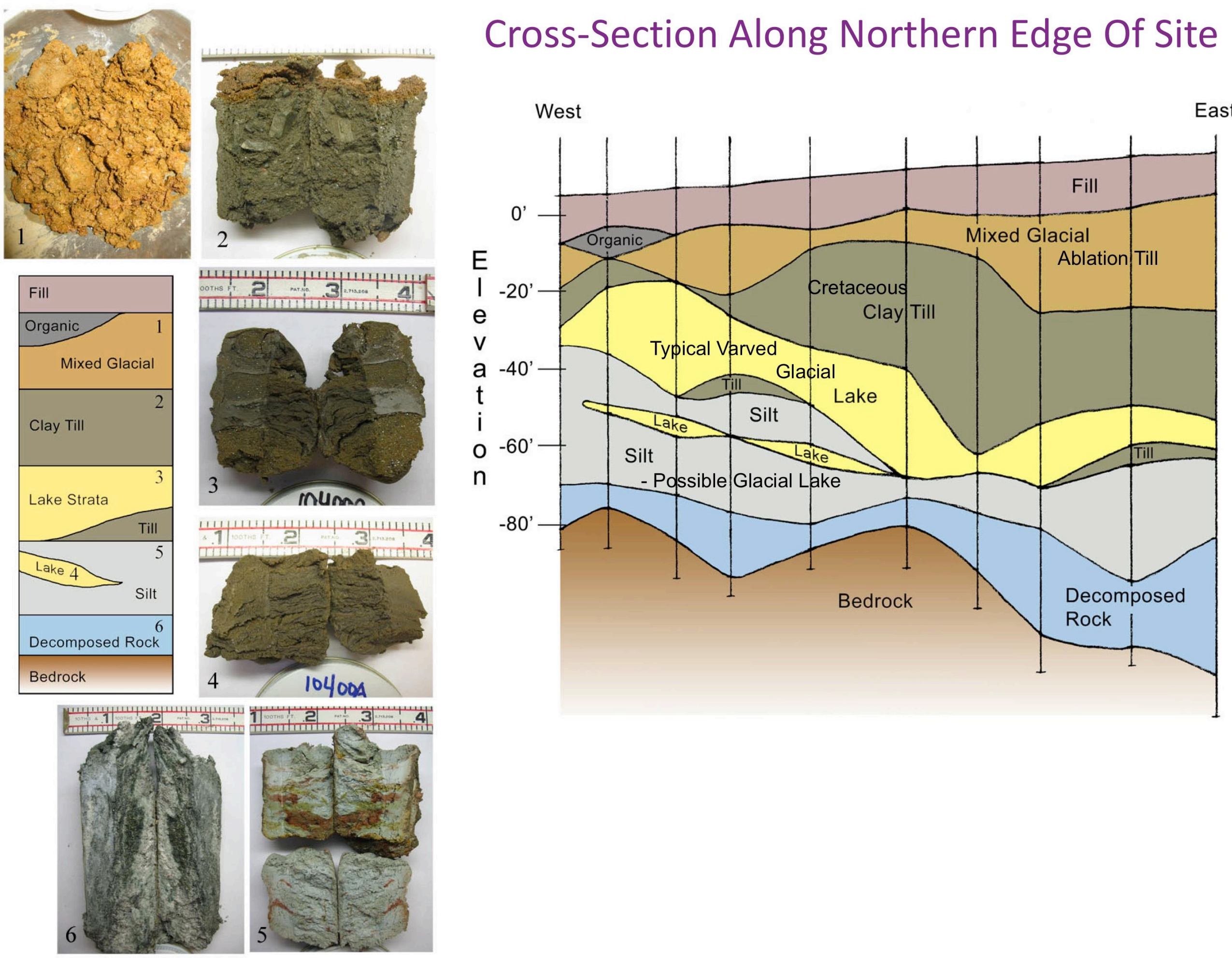

Figure 10 – Cross-section along the northern end of the Edge site in Brooklyn and photos of typical soil. The site has evidence of at least 2 different glacial advances. The extreme degree of bedrock weathering suggests that the lowest strata are associated with a much older event. The presence of upper till layers that reflect source material found only to the north and NE of the site indicate that during LGM recession the ice flow over NYC shifted direction to come from the NE, mirroring the shift seen in NJ. The upper till layers end just to the south of the site (which is NE of the Beekman Street site), marking the extent of the limited readvance.

The World Trade Center Site – Lower Manhattan

At the WTC site (Figure 11) plunge pools and potholes were scoured 40 feet deep into the bedrock and filled with an incredibly dense till native to NJ, indicating a glaciation from the NW. A silt layer 2/3 of the way up in the till contained a tree branch ^{14}C dated at 49,500 (+3050/-2205) BP. The plungepools were carved in an event (likely glacial) prior to the deposition of till during a glaciation older than LGM.

49,500 BP +3050/-2205

Figure 11 – World Trade Center site in lower Manhattan. A – 40' deep scoured plungepools. B – Filled with glacial till. C – Piece of wood dated at 49,500 BP. D – Found 2/3 of the way up, in a silt layer. E –Located within the dense till native to NJ, indicating flow from the NW.

CONCLUSIONS

While the surficial glacial deposits date to the Late Wisconsin, a lot of NYC sites have older – possibly much older – layers present in the subsurface. Currently it's often not possible to link each stratum to a specific event, only to a range of choices. More sites will have to be investigated and correlated across the city – ongoing research – to get a better idea of which older strata are found where, and to establish the actual timeline.

EVENT	Beekman St.	Edge	WTC
Recessional/ Readvance	Mica. Outwash	Mixed Glacial Cret. Clay Till	
LGM - 21Ka	Varves Serpentinite Till	Glacial Lake Thin Till	Upper Glacial
Early Wisconsin	Outwash	Silt Thick Dec Rock	~50 Ka Deep Till
Sangamon	Varves Dec. Schist Till		Reported Shells
Illinoisan	High Seismic Velocity Outwash Basal Till		Plungepools
Pre-Illinoisan?			

Older advance associated with weathering

Advance from NW before 50,000 BP

LGM advance from NW

Limited later readvance from NNE

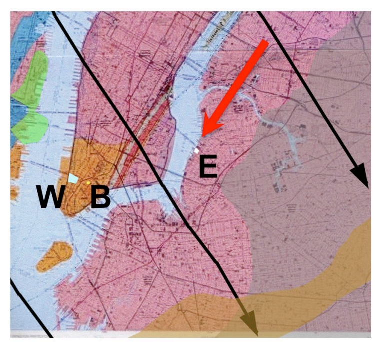

Figure 12 – Table showing possible correlations between each site stratum and glacial event. Red line in front of a stratum spans the possible glacial events it most likely is associated with.

Several general events can be identified in the subsurface, however, from the evidence from different sites (Figure 12). NYC has subsurface deposits from an older advance associated with weathering – probably Illinoisan, possibly older. There is an advance from the NW that took place before 50 Ka – probably Early Wisconsin, possibly Illinoisan. The LGM ~ 21Ka is well documented across the region and is responsible for most of the near surface deposits. During its recession a limited glacial readvance from the NNE covered a smaller portion of the city that includes the vicinity of the East River.

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