DIFFERENT AND DISTINCT – IMPLICATIONS OF UNUSUAL GLACIAL STRATA IN BROOKLYN

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INTRODUCTION

In 2006 a boring investigation was conducted at a site in northwest Brooklyn. The project is located along the east side of the East River bounded by N. 5th Street, N. 7th Street, and Kent Avenue. The glacial deposits in the New York City area generally have similar characteristics. They may have the same grain size mix but different colors, or the same color and constituents with slight variations in the grain size range. The borings at this site, however, revealed a complex sequence of strata that included a couple of units that were unusual and distinctive, not typical of anything else in the area. The lead author has spent over the past 20 years with Mueser Rutledge Consulting Engineers sampling, reclassifying and testing soil and rock in the New York City area. In recent years projects in northwest Brooklyn have encountered some of the unusual strata. This particular site brings the distinctive units together in a way that begins to show how they are inter-related. The nature of these deposits has implications for the number of the glacial advances that affected the site and its surrounding neighborhood and their direction of flow (Figure 1).

Geologic Background

Over the years a basic understanding of the glacial stratigraphy of New York City has developed. A substantial amount of the knowledge of the glacial geology of the region, however, is based on research done in Long Island or New Jersey with comparatively little written specifically about the strata within New York City (Stone et. al. 2002, Soren 1978, Sanders and Merguerian 1998). This is especially true for the area in and immediately surrounding Manhattan.

The New York City area bedrock consists of a mix of complexly folded and faulted schist, gneiss and marble with occasional amphibolite, serpentinite and intrusive rocks. Basins to the northeast in Connecticut and west in New Jersey are filled with Mesozoic sedimentary rocks and basaltic intrusives. In places the rock is overlain by varying thicknesses of decomposed rock. In sections of Brooklyn, Queens and Staten Island the rock is covered with Cretaceous soil, primarily the Raritan Formation (Figure 2). Deltaic sand, gravel, silt and clay of the Lloyd Sand Member are overlain by the more extensive Clay Member. Less extensive deposits of the Magothy Formation and Matawan Group, deltaic sand, silt, clay and gravel, cover central and southern Queens and southern Brooklyn. During the Pleistocene, glaciers scoured away this rock and soil in some locations while depositing glacial strata above it in others. One major interglacial marine unit, the Gardiners Clay, was also deposited in Brooklyn and southern Queens (Figure 3).

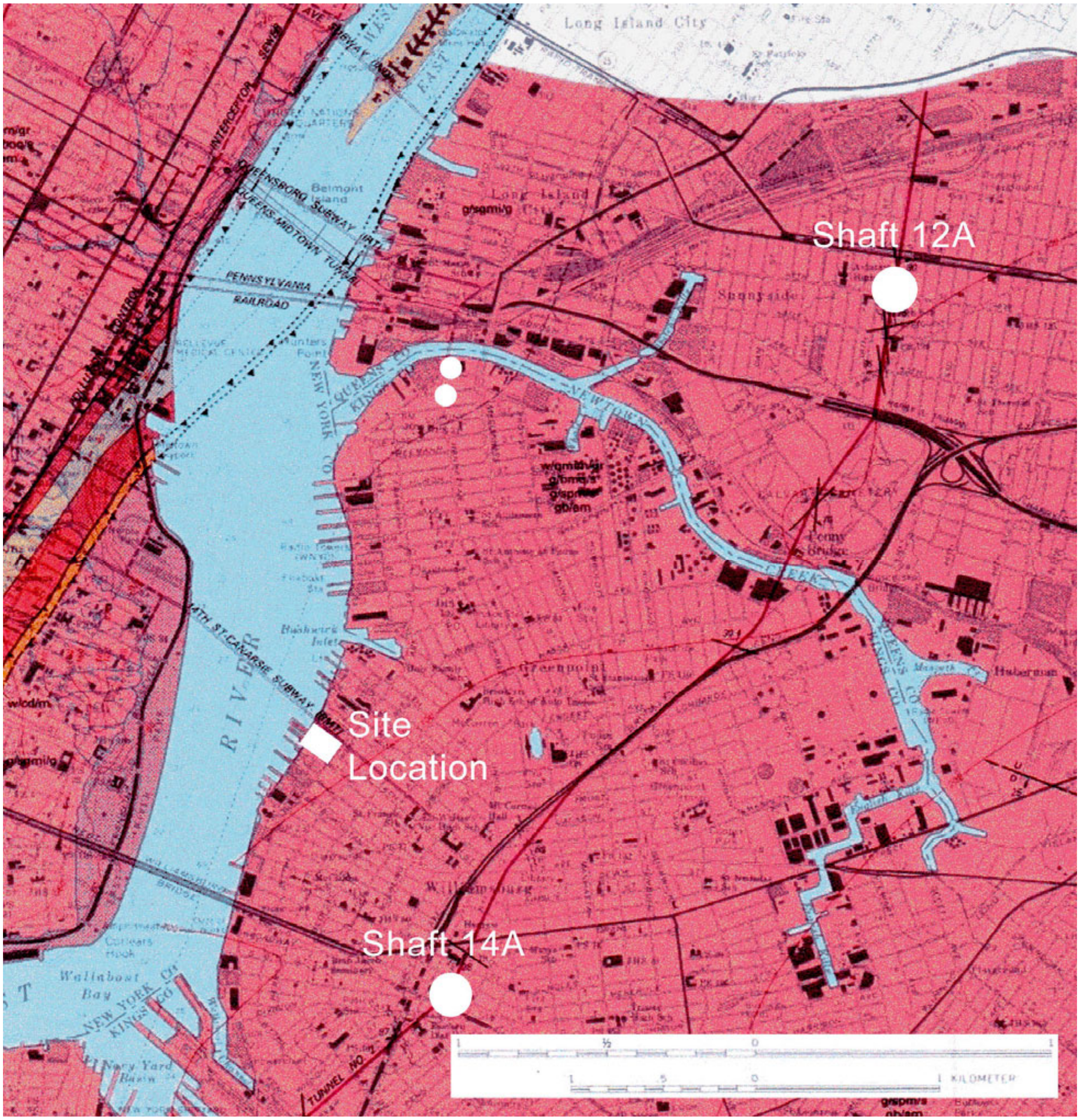

Figure 1 – The site location is marked in white. The unusual Silt stratum has been documented in the neighborhood in the past. The white dots show the locations where the unit was encountered during the excavation of a subway tunnel. The purple line shows the alignment of the NYC Water Tunnel No. 2 and the white circles show the location of tunnel shafts in the vicinity of a related silt deposit. Basemap from Baskerville (1994).

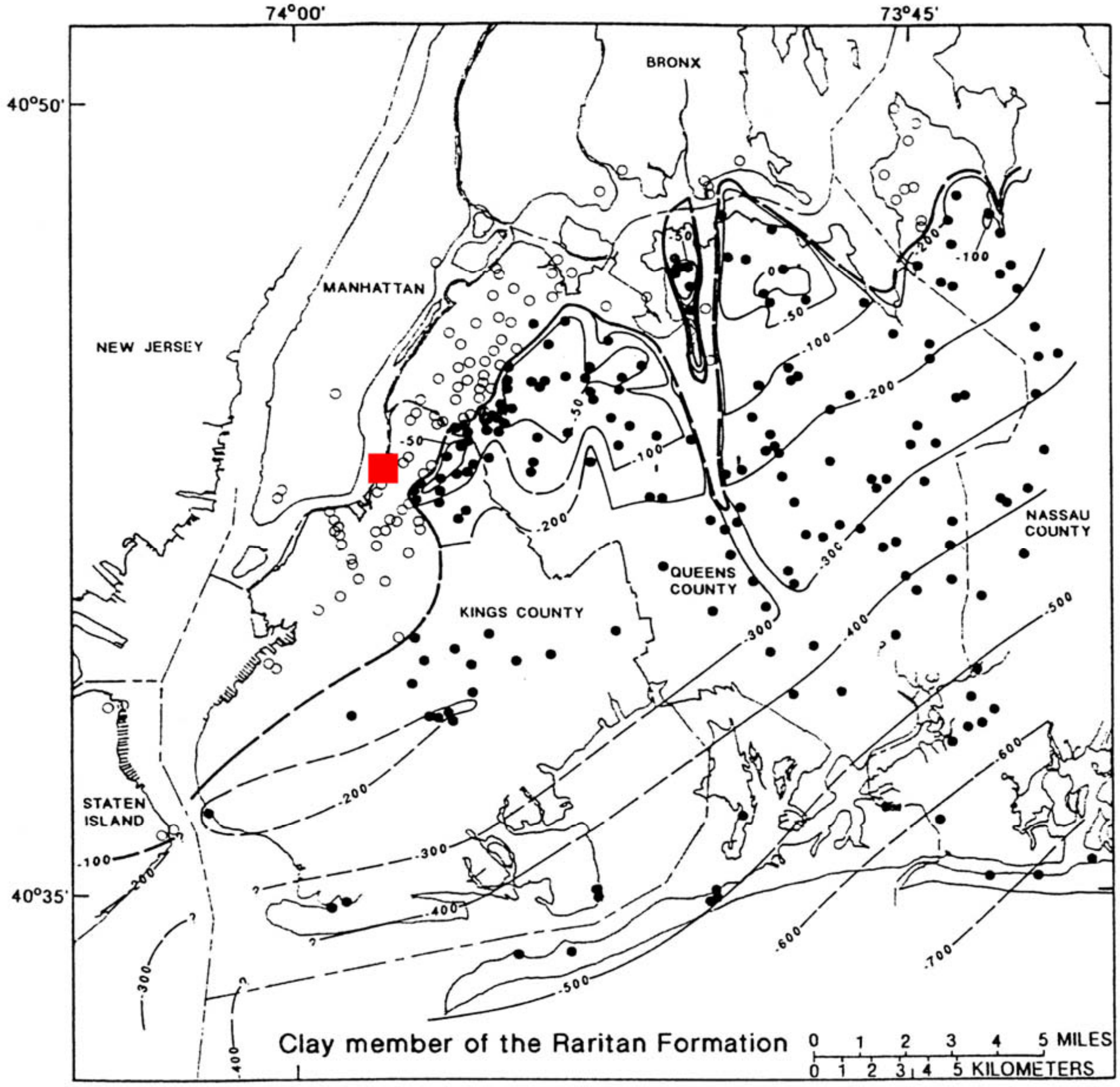

Figure 2 – Contour map showing the location and surface elevation of the Raritan Clay. The black dots show boring locations where the stratum was encountered, open circles are locations where the unit was not found. The formation's landward edge is found to the northeast and east of the site (red square). Raritan Clay found in the Clay Till had to have come from a glacier flowing from the northeast. (After Buxton and Shernoff 1995.)

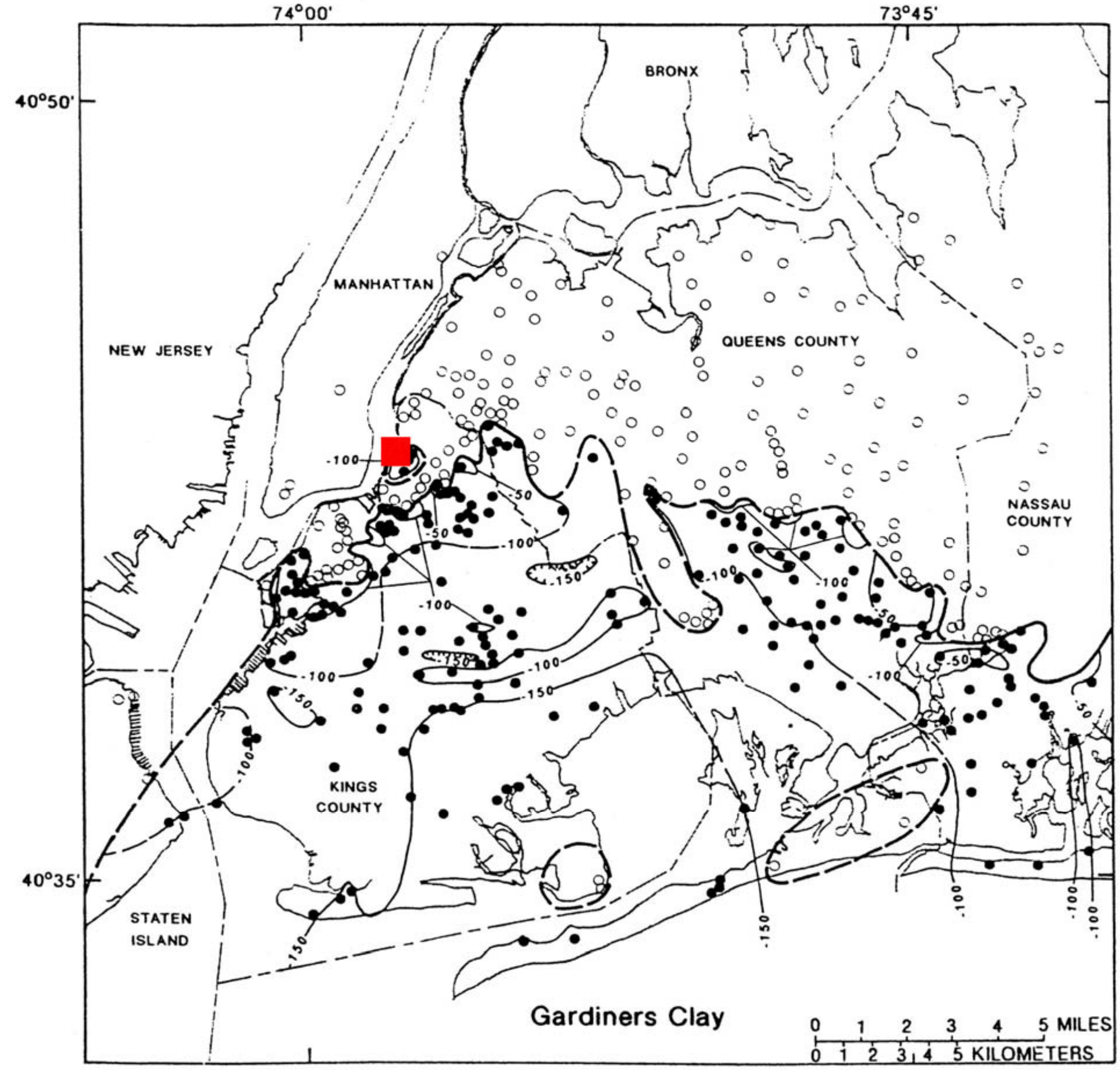

Figure 3 – Contour map showing the location and surface elevation of the Gardiners Clay. The black dots show boring locations where the stratum was encountered, open circles are locations where the unit was not found. The formation's landward edge is found immediately to the northeast and east of the site (red square). The more limited distribution of the Gardiners Clay is one reason it is a less likely source of clay for the Clay Till. (After Buxton and Shernoff 1995.)

Research by Sanders and Merguerian (1991, 1994, 1998) describes five previous glaciations found to affect the New York City area. They used stratigraphy and orientation of landforms and striations along with matching distinctive "marker" stones in till with their source area to determine the number and direction of flow of the glaciers (Table 1).

Age	Till No.	Ice-flow Direction	Description; remarks
Late Wisconsinan ("Woodfordian"?)	I	NNE to SSW	Gray-brown till in Westchester Co., Staten Is., Brooklyn, & Queens (but not present on rest of Long Island); Hamden Till in CT with terminal moraine lying along the S coast of CT; gray lake sediments at Croton Point Park, Westchester Co.
Mid-Wisconsinan (?)			Paleosol on Till II, SW Staten Island.
Early Wisconsinan(?)	II	NW to SE	Harbor Hill Terminal Moraine and associated outwash (Bellmore Fm. in Jones Beach subsurface); Lake Chamberlain Till in southern CT.
Sangamonian(?)			Wantagh Fm. (in Jones Beach subsurface).
	IIIA	NW to SE	Ronkonkoma Terminal Moraine and associated outwash (Merrick Fm. in Jones Beach subsurface).
Illinoian(?)	IIIB		Manhasset Fm. of Fuller (with middle Montauk Till Member; in lower member, coarse delta foresets (including debris flows) deposited in Proglacial Lake Long Island dammed in on S by pre-Ronkonkoma terminal moraine.
	IIIC		
Yarmouthian			Jacob Sand, Gardiners Clay.
Kansan(?)	IV	NNE to SSW	Gray till with decayed stones at Teller's Point (Croton Point Park, Westchester Co.); gray till with green metavolcanic stones, Target Rock, LI.
Aftonian(?)			No deposits; deep chemical decay of Till V.
Nebraskan (?)	V	NW to SE	Reddish-brown decayed-stone till and -outwash at AKR Co., Staten Island, and at Garvies Point, Long Island; Jameco Gravel fills subsurface valley in SW Queens.
			Pre-glacial (?) Mannetto Gravel fills subsurface valleys.

Table 1 – Proposed classification of the Pleistocene deposits of New York City and vicinity. (From Sanders and Merguerian 1998, Table 2.)

The USGS surficial geological map of northern New Jersey (Stone et. al. 2002) shows where the Wisconsinan terminal moraine created a dam across New York Harbor. As a result, glacial Lakes Bayonne and Hudson, along with their associated spillways formed behind the moraine. Varved sediments were deposited in these lakes until a breach of the dam (Merguerian 2003) allowed them to drain (Figure 4).

Site Stratigraphy

Regionally, the bedrock is found near the ground surface to the north of the site in Long Island City, Queens and from there, dips steadily to the southeast (Figure 5). To the west and northwest along the shoreline of Manhattan the rock lies around elevation -80 feet and drops even deeper under the East River. The nearest documented Cretaceous soil is the Raritan Clay, a unit whose northernmost extent in Brooklyn and Queens follows a NE–SW trend. Resembling the underlying bedrock surface the Raritan also dips steadily to the southeast. The Raritan is present to the northeast of the site and is closest approximately 1 mile to the east. (See Figure 2.)

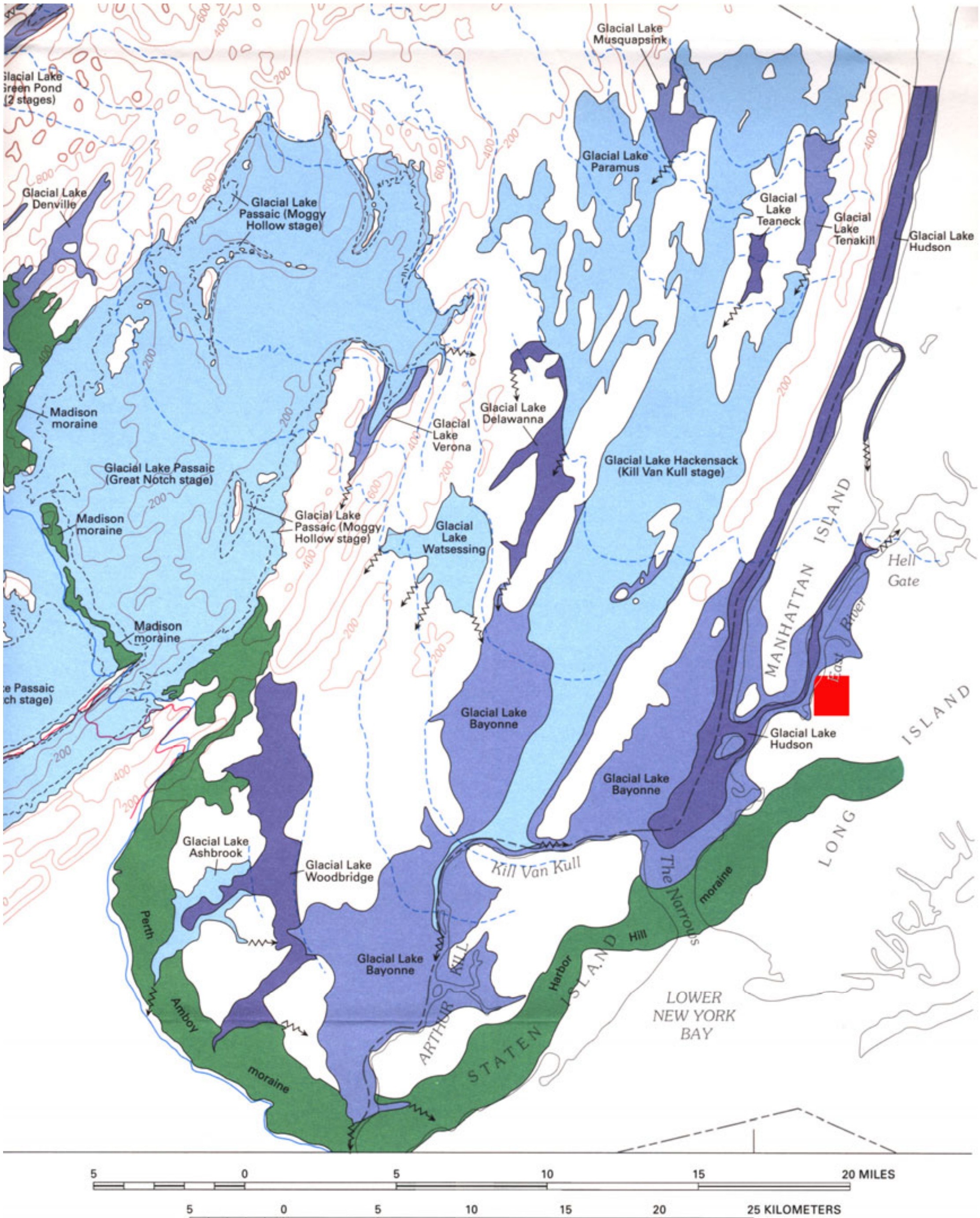

Figure 4 – The map shows the northward location of the site (red box) with respect to the Wisconsinan Harbor Hill terminal moraine, which formed a dam across The Narrows. Glacial lakes Bayonne and Hudson formed behind it, their locations controlled by spillways that drained the lakes. Varved sediments were deposited in the lakes until a catastrophic breach at The Narrows drained them. It is possible that the terminal moraine acted as a dam for more than one glacial advance. (Basemap adapted from Stone et al. 2002.)

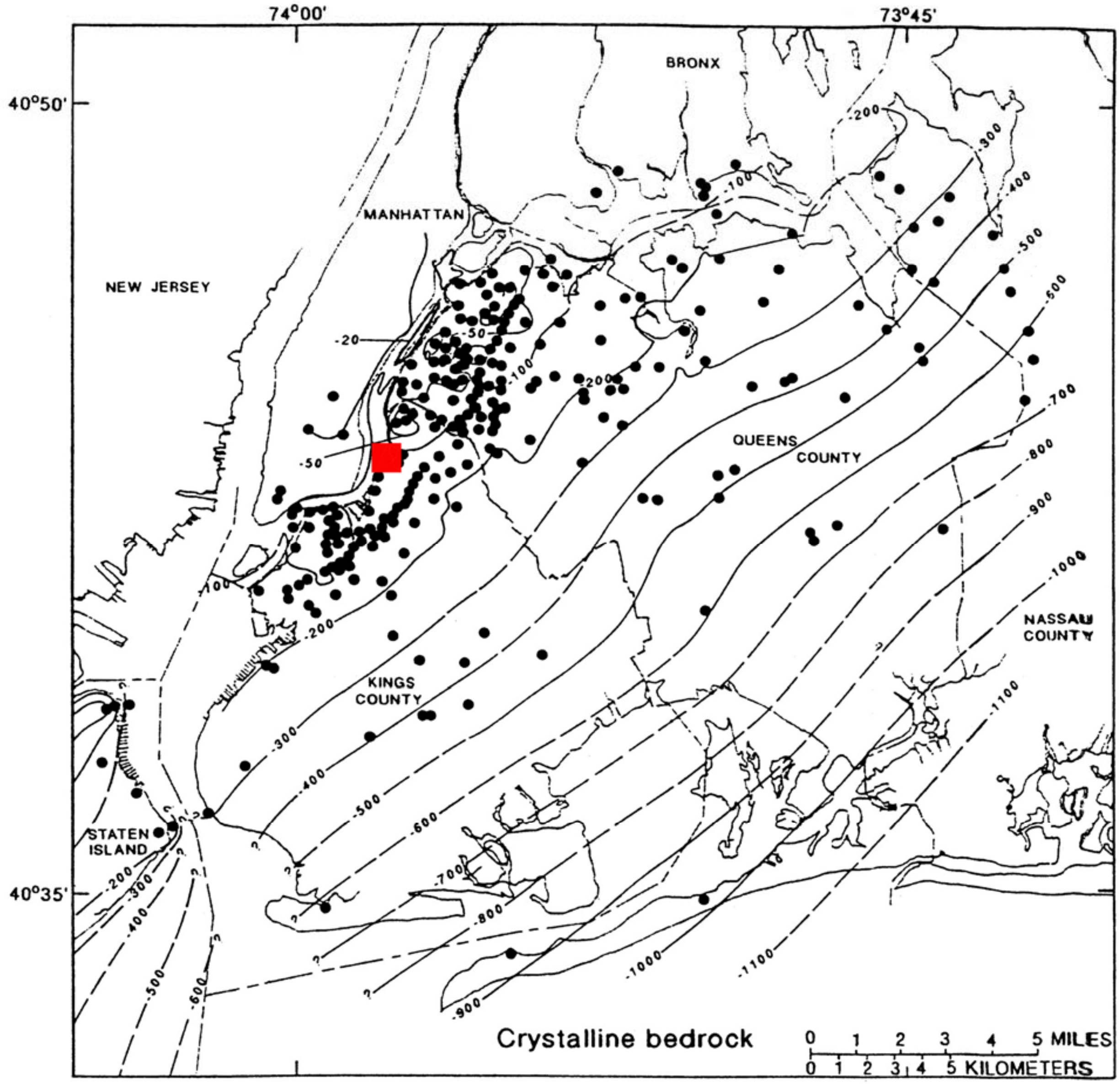

Figure 5 – Contour map showing the surface elevation of the bedrock. The black dots show boring locations where the rock was encountered. Rock is near the ground surface north of the site (red square) in Queens and drops steadily off to the southeast. The Silt stratum is clearly derived from local rock flour or decomposed bedrock. The source of the sediment is most likely the rock to the north. (From Buxton and Shernoff 1995.)

The site studied in Brooklyn has many different layers of glacial strata overlying rock (Figure 6). The general stratigraphy of the site shows the rock overlain by a layer, often quite thick, of decomposed rock. In turn, almost every boring that went to decomposed rock hit a very unusual stratum of glacial silt above that. The silt contains a wedge of glacial lake soil and is capped with pockets of till. Glacial lake deposits cover much of the site and a distinctive clayey till lies above that. Mixed glacial sediments blanket the location. Layers of recent organic clay are found above this along the East River, and miscellaneous fill covers the whole site.

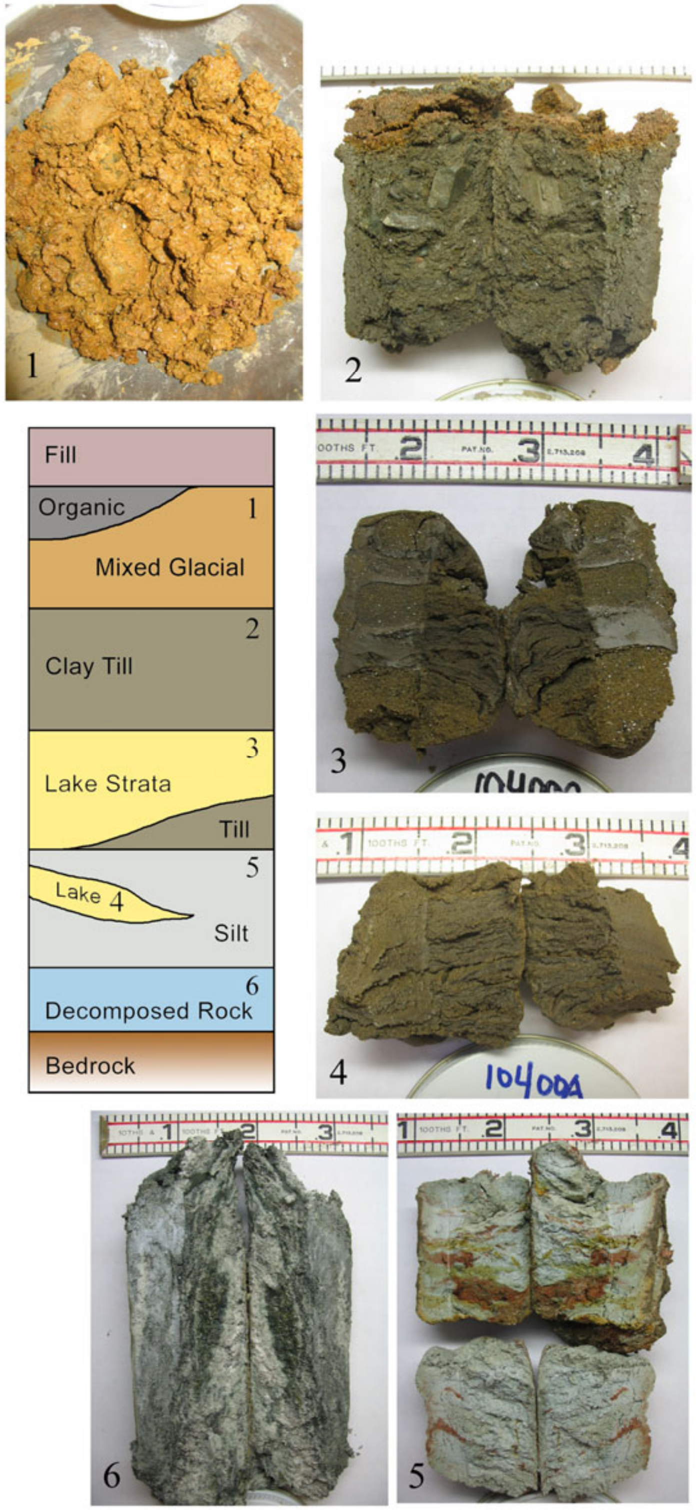

Figure 6 – A schematic cross-section showing the general relationships between the strata at the site. Photographs show some of the typical soil samples. **1** – A sample of till from the mixed glacial stratum. **2** – A sample of clay till. **3** – A sample of varved sand and clay from the lake stratum. **4** – A sample of varves from the lower lake stratum. **5** – A sample of the silt stratum. Note the stratification. **6** – A sample of decomposed rock. Near vertical relict foliation is still visible.

Bedrock – The bedrock at the site is mapped by Baskerville (1994), incorrectly we might add, as the Hartland Formation. The bedrock is actually Fordham Gneiss and consists of predominantly gray and black gneiss with occasional zones of gneissic schist, hornblende gneiss, and pegmatite intrusives. Rock is at a highpoint in the northwest corner of the location at approximately elevation -73' and, following the regional trend, drops off quickly to the south and east (Figure 7).

Decomposed Rock – The decomposed rock layer consists of the undisturbed natural bedrock that has been chemically weathered to the consistency of a soil. Relict rock structure is often still visible. The soil ranges from clayey silt to silty sand with rock fragments. The colors are a mix of light blue, gray, yellow, green and red. The material is generally very dense, with Standard Penetration Test (SPT) values usually greater than 50 blows per foot.

Silt Layer – The Silt stratum is a very unusual and distinctive layer that underlies virtually all of the site. It is composed of clayey silt with varying amounts of fine to coarse sand. Pieces of cemented silt are relatively common throughout the stratum. They tend to be concentrated at the base or particularly at the top of the unit. In places the soil has the grain size mix and soil structure typical of the local basal till. The colors are usually pastel shades of gray, blue, green, yellow, brown, red, pink and white, and samples are often mottled. The soil structure ranges from massive to horizontally layered. Soil density is quite variable, but SPT values average less than 50 blows per foot. It is clear that the soil is in some way derived from either the local decomposed rock or rock flour. Towards the northwest corner of the site a fairly thin layer of glacial lake sand, silt and varved silt and clay is present within this silt layer. In scattered locations, pockets of till of varying composition lie on top of the silt stratum.

The precise origin of the deposit is not certain. The presence of areas with basal till soil structure suggest that parts of it were ice deposited, or at least over-run by glacial ice. The occurrence of scattered pockets of till of varying composition (including Clay Till) on top of the Silt unit supports this notion. Where the structure is laminated and/or it has no coarse grains it may have been deposited in a glacial lake environment. This is backed up by the presence of a stratum of "conventional" glacial lake sand and silt at the northwestern end of the site, indicating that at least a portion of the unit was covered by a lake. The presence of cemented silt indicates that the soil was exposed to cementing agents. This suggests that at some point the material may have been above the water table, possibly desiccated, or exposed to cementing agents flowing in through more permeable soil nearby. No sign of surface weathering or soil development occurs suggesting that either such a layer was eroded by later glacial activity or that the unit was covered with new glacial material before there was enough time for significant weathering.

Lake – Across much of the site, except for a portion of the southwest corner, the silt layer is covered with glacial lake sediments. The glacial lake deposits consist of interlayered brown fine to medium sands and silts with occasional varves of silt and silty clay.

Clay Till – Another very distinctive layer, a clayey till deposit, covers the entire area. It has the typical glacial till mix of fine to coarse sand with silt and clay and gravel, cobbles and boulders. It also contains trace amounts of lignite. The color is predominantly gray or brown, though it is in places yellow, red or green. Occasionally the other colors are swirled through the gray. What stands out is the prevalence of the gray lignitic clay matrix. This material is almost certainly derived from the local and lignitic Raritan Clay. The clay was scoured up by the over-riding glacier, mixed with whatever other soil the ice picked up along the way, and then dropped along this stretch of western Brooklyn. No obvious sign of weathering or decomposition in the gravel portion of the till was found suggesting it is the product of one of the more recent glacial events, rather than one of the older advances.

Mixed Glacial – Covering much of the site, the uppermost glacial stratum is an interlayered mix of till, outwash, lake sands, and varved silts and clays. The colors range among yellow-brown, brown, and red-brown. This is most likely the mix left behind as a melting glacier retreated.

Organics – In spots along the East River the glacial sediments were covered with a layer of recent organic silts and clays.

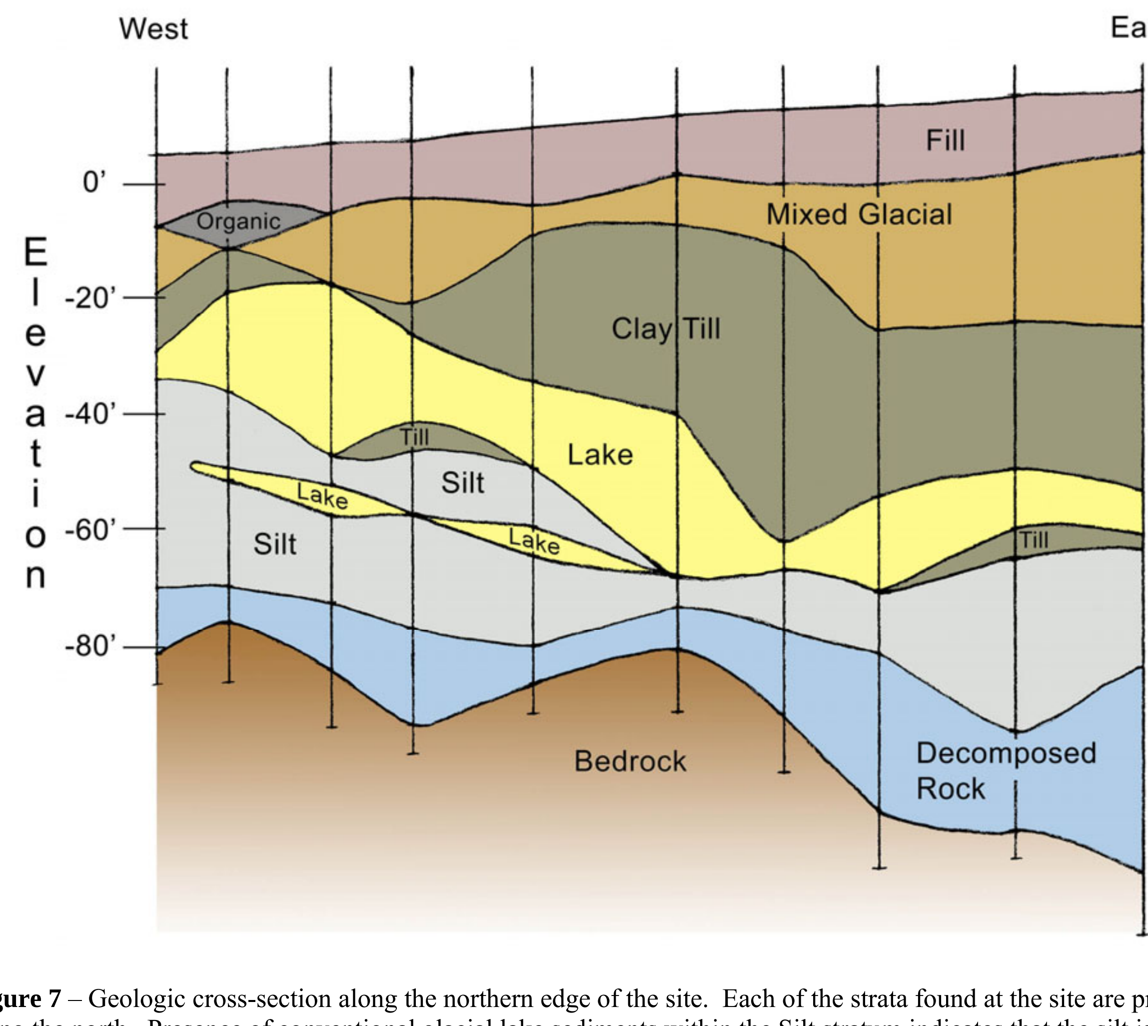

Figure 7 – Geologic cross-section along the northern edge of the site. Each of the strata found at the site are present along the north. Presence of conventional glacial lake sediments within the Silt stratum indicates that the silt is a glacial deposit rather than a residual soil. Pockets of till above the Silt layer suggest that the silt was overrun by glacial ice. Retreat and/or readvance of the ice left behind a more significant layer of lake sediments, which were later overrun by the glacier that deposited the Clay Till. Retreat of the ice left the site blanketed with the Mixed Glacial ablation till.

Glacial Processes

After the advance, stagnation, and retreat of a glacier numerous diagnostic deposits and landforms are left behind (Edwards 1978). As ice accumulates in a glacier's source area it starts to shear internally under its own weight and flow downstream. Particularly in temperate regions, there is often a layer of water at the base of the glacier resulting from seasonal temperature changes, geothermal heat, friction and pressure melting. This water can act as a lubricant speeding up the glacial flow. It also carries finer grained sediments scoured from the substrate or melted out of the ice away from the glacier to be deposited further downstream. When the water refreezes material from the substrate is enclosed in the ice, plucked loose, sheared up into the base of the glacier as it flows, and is carried downstream (Figure 8).

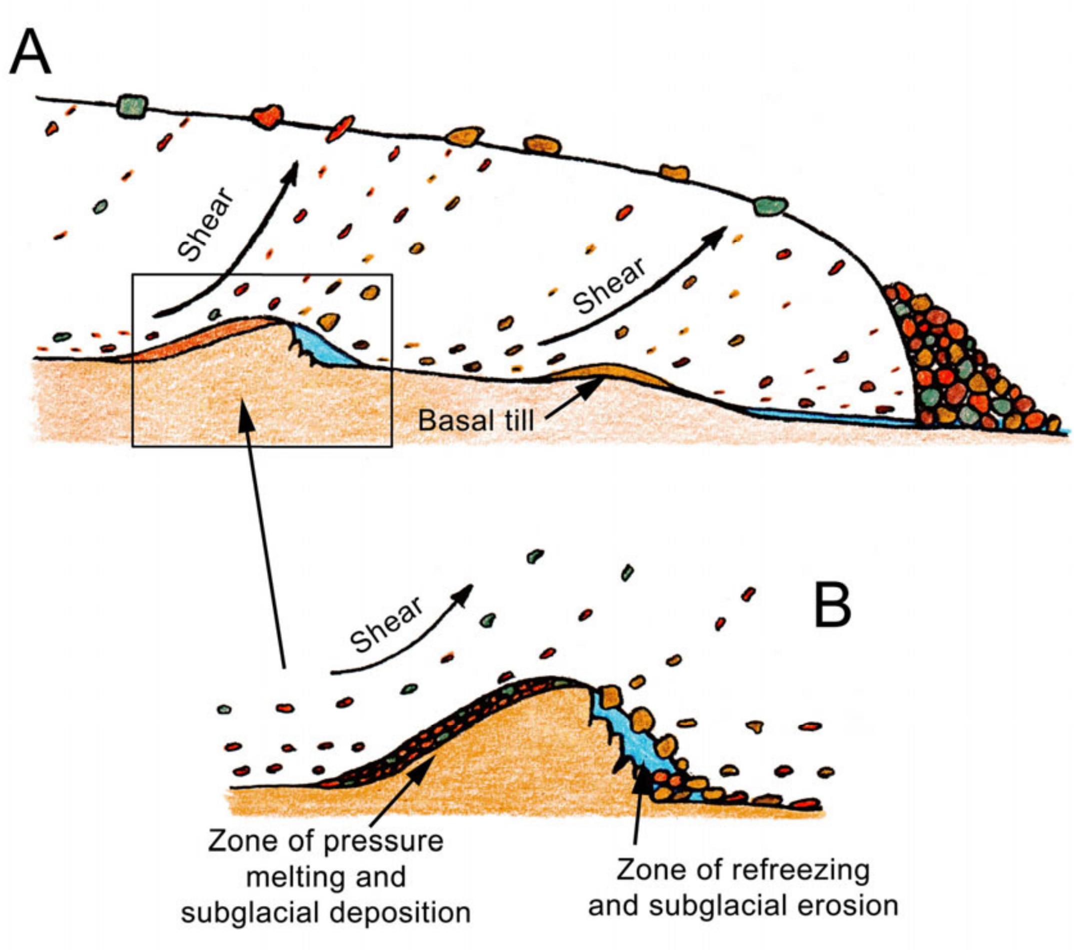

Figure 8 – **(A)** Schematic cross-section of an advancing glacier. When glacial ice encounters an obstruction or freezes to the substrate it flows by shearing. In a temperate climate there is often a layer of water at the base of the ice, which speeds its flow. It also carries fines away from the glacier and deposits them further downstream.
(B) Close up of the base. When glacial ice melts, for example behind an obstruction where there is pressure melting, debris carried by the ice is released and deposited as basal till. When the water refreezes, for example beyond the obstruction in a zone of lower pressure, material in the substrate is frozen to the base of the glacier, sheared up into the ice, and carried downstream. The sediment may remain near the base (subglacial), or it can be transported up into the ice (englacial), eventually even reaching the surface (supraglacial).

Recently acquired debris is closest to the base of the glacier, while material that has traveled a greater distance is more likely to have been sheared further upward into the glacial ice, possibly even resting on top of the glacier (Dreimanis 1976). When the basal ice melts or an obstruction is encountered sediments carried near the base are deposited as basal till. Loaded by the ice above and thrust into voids or behind obstructions, the basal till is often a dense mix of all the sediments found near the base of the glacier.

At the terminus of the glacier the amount of melting ice is roughly equal to the amount of new ice flowing in. The glacial debris flowing in is built up into a terminal moraine at the ice front. Meltwater flowing from above and below the glacier carry sediments beyond the terminus in streams, which deposit outwash sands and gravels (Figure 9). Grain-size typically gets finer with distance from the glacier. If a structure, such as a previous terminal moraine, creates a dam downstream a pro-glacial lake forms. This typically fills with the finest grained sediments such as fine sands and seasonally varved silt and clay.

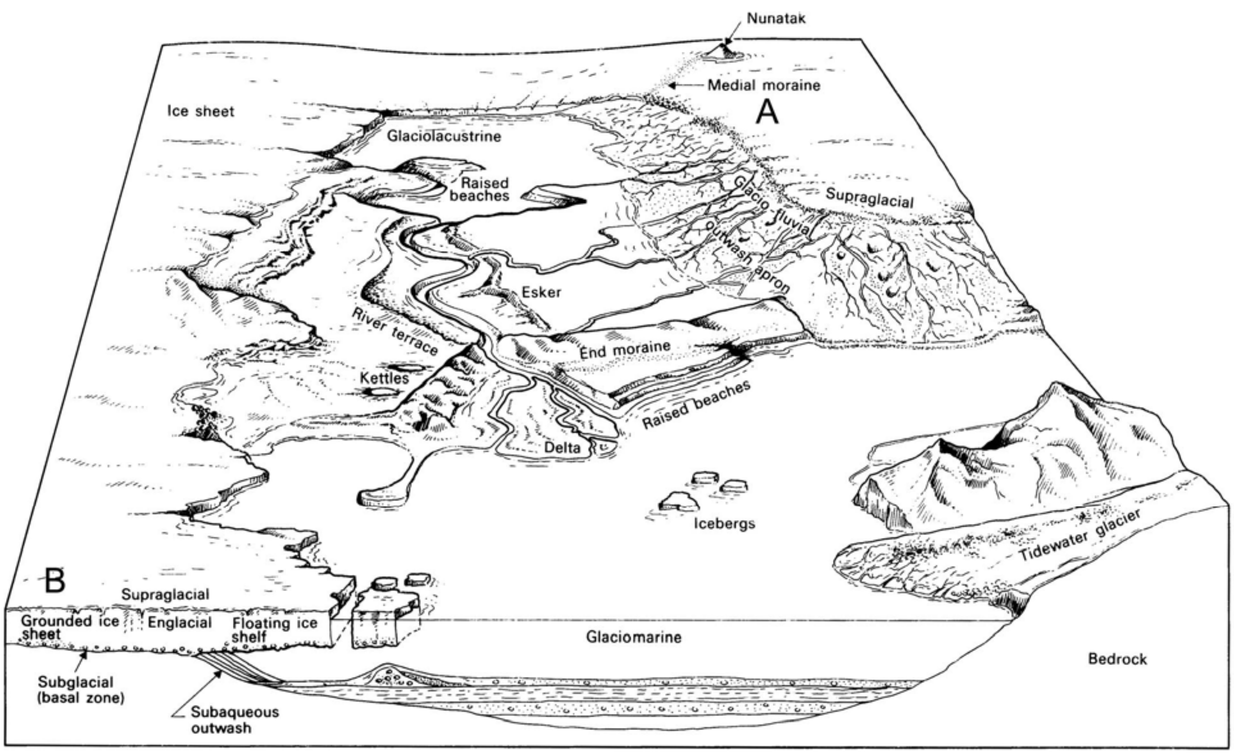

Figure 9 – The figure shows common glacial environments, their relationships to each other, and their associated landforms. Deposits most commonly found in the New York City area come from the landscapes portrayed in the upper right corner (A) and lower left corner (B). **(A)** Moraines (recent or past) create a dam allowing meltwater to form a proglacial lake which fills with fine-grained varved deposits. Heading upstream towards the glacier the sediment becomes more coarse-grained as you approach the outwash fans built up by streams in front of the ice. Various forms of glacial till are deposited directly by the ice. **(B)** Basal till is deposited from debris carried at the base of the ice (subglacial). Ablation till is deposited when the glacier melts, releasing sediment carried within (englacial) and upon (supraglacial) the ice. (From Edwards 1978.)

As climate conditions change and the amount of ice melting exceeds the amount of ice advance the glacier starts to recede. Sediment still contained in the ice is lowered to the ground as the ice melts out from below. This forms a blanket of ablation moraine overlying the basal till (Figure 10). Although derived from the same glacier, this stratum can be quite different from the underlying ground moraine. The components may have traveled a greater distance, possibly reflecting a source area further upstream. Given the circumstances, they are generally affected by meltwater. As a result, fines are often washed away downstream or into local depressions, and the soil remaining behind may be locally stratified. Pockets of lingering ice result in the formation of structures such as kettles and kames. Final melting of the stray ice can deform and disturb the deposits it is in contact with, resulting in slides of flow till. The varied nature of the glacial processes and resulting deposits can leave behind an interlayered mix of strata such as till, outwash and varves. The bulk of the deposits were not loaded by ice so the ablated material is generally not as dense as the underlying basal till.

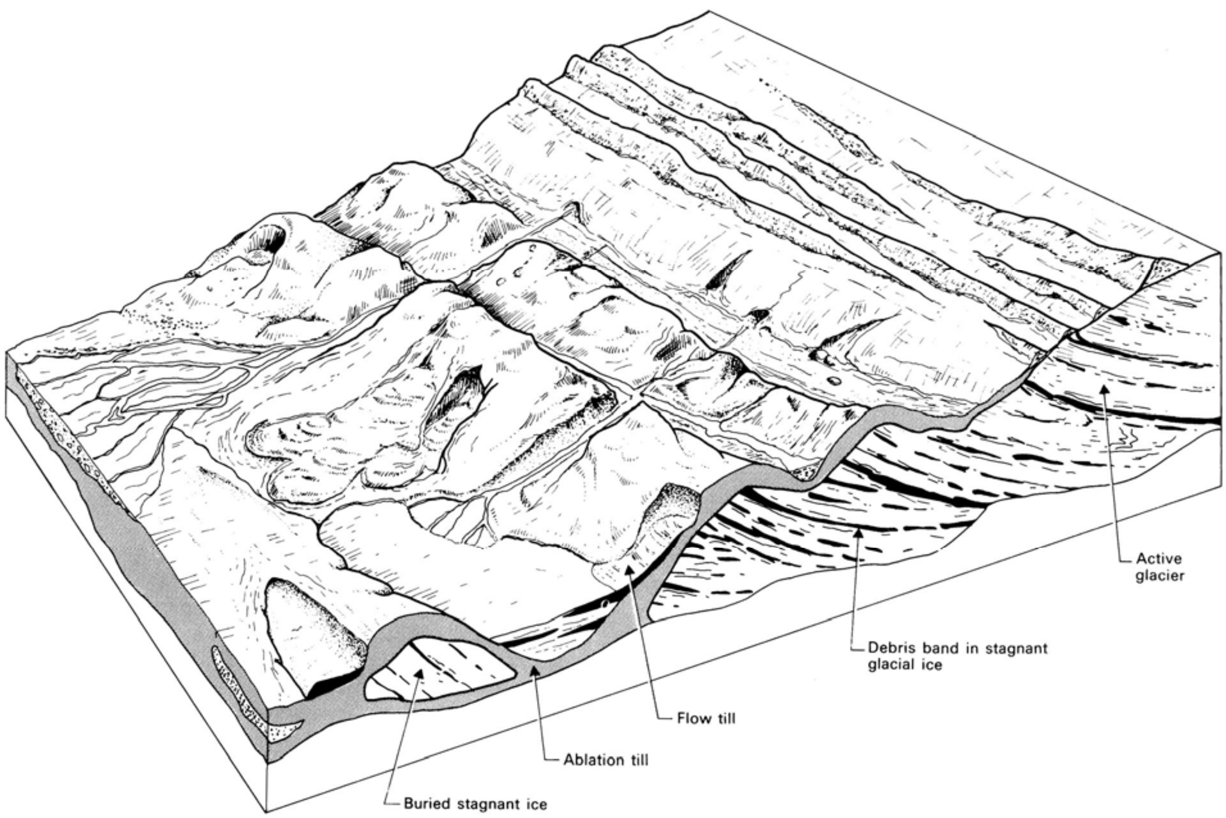

Figure 10 – In the terminal zone of a glacier the melting ice releases its sediment to be lowered or dropped to the ground, or to be carried away by meltwater and redeposited downstream. A wide variety of deposits such as till, outwash and varves are produced as a result. Rather than forming regional strata, the units are frequently found mixed and interlayered in localized zones. (From Edwards 1978.)

Not only are all of these units associated with each other laterally in a glacial landscape, but over time as glaciers advance, retreat, and sometimes readvance the deposits can build up vertically, offering a glimpse into the glacial history of a site. While an advancing glacier can erode away all pre-existing sediments in its path, it can also override and preserve them. A very basic example would involve a till-bearing glacier with outwash sediments being deposited directly in front and a varved glacial lake further downstream. As the glacier advances, outwash sand starts to flow into the pro-glacial lake, covering the varved lake sediments. In turn, the glacial ice starts to flow over the outwash covering it with basal till. As the glacier stagnates and the ice melts out, a varied mix of ablation till blankets the basal till. As the ice recedes farther northward these recent deposits may be covered by outwash flowing from the glacier now located upstream. If the old terminal moraine is topographically high enough so that it forms a dam then it can allow meltwater to fill up a lake. In this case varved strata may eventually cap the site.

Previous References/Discussion

The Silt stratum has been documented in the neighborhood in previous literature. (See Figure 1.) It was recognized in the excavation of the subway tunnel (currently the G line) under Manhattan Avenue in Brooklyn, just south of Newtown Creek (Kerr 1930). The decomposed bedrock was blanketed with an irregular layer of white kaolinite clay, which in turn was covered with glacial outwash sand. Other locations in the city had documented kaolinized clay in pegmatites, which was subsequently eroded by glacial action and capped with glacial drift. It was assumed that the Brooklyn white clay was the remnant of a residual soil not eroded by later glacial action.

Observations that Kerr made are actually explained better if the stratum is glacially reworked, rather than residual soil. “The kaolin on Long Island is limited to the surface or near surface portions of the rock, and is not encountered in the deep tunneling operations beneath the city.” This is because he is seeing only the decomposed rock surface or the reworked and redeposited material derived from it. The soil does not reflect any natural, in place deep weathering. “The alteration is apparently not restricted to one particular phase of the granodiorite, but extends laterally across both the granodiorite and the pegmatites by which it is cut.” Indicating the material was reworked and re-deposited rather than forming in-place. “The distribution of the areas is erratic and seemingly without relation to the present topography.” The present topography is due to subsequent glacial action. “Portions of the underlying rock in which one would expect recent weathering action to be most active are often least altered.” This is because the expected portions of bedrock were in fact altered, then eroded by glaciers, leaving intact rock behind. The clay is a newer glacial deposit.

Borings and shafts constructed for the City Water Tunnel No. 2 also encountered unusual deposits in southern Queens and northern Brooklyn. (See Figure 1.) Blank (1978) describes a layer of decomposed rock and residual soil between Shafts 12A and 14A which he interprets as an ancient laterite formed prior to the deposition of Cretaceous sediment. It is not clear from his descriptions if the white clay was present, but if it was originally more widespread the deposit is a likely source material. The unit includes a layer at the top of the decomposed rock that contains concretions and oolites. In places its upper surface was suncracked (Figure 11). The Silt layer has cemented silt which may reflect desiccation and at other sites nearby it also includes oolites.

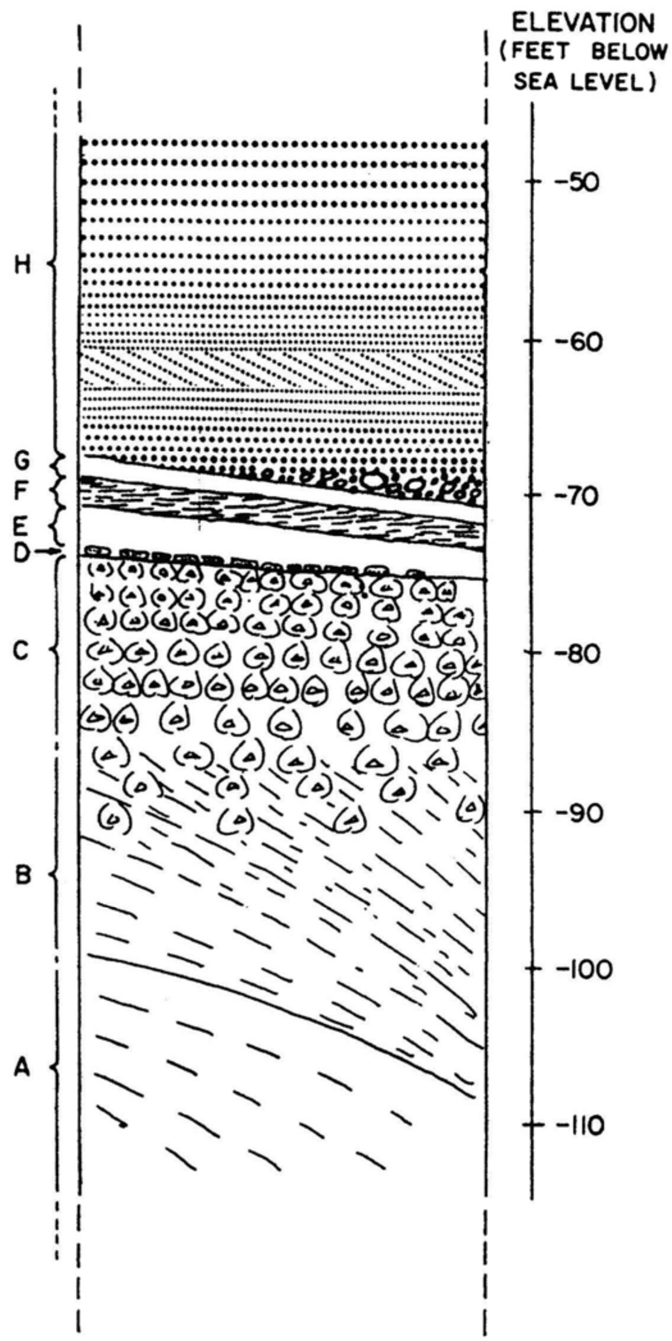

Figure 11 – Geological section through part of Shaft 14A of NYC Water Tunnel No. 2. (See Figure 1 for location of shaft.) This soil is possibly a source of sediment for the **Silt strata** of this report. **A.** Sound rock; gneiss, laminated mica schist type, medium- to fine-grained; narrow, irregular, dark-brown and white bands. **B.** Decayed gneiss (saprolite), chiefly clay; contains bronzed biotite and residual garnet; preserves faint gneissic structure; merges imperceptibly upward into C. **C.** Concretionary rock (duricrust, ferricrete). **D.** “potato layer”; suncracked polygonal blocks of hard, brown, fine-grained sandstone, resembling potatoes. **E.** Stiff gray to brown clay; containing fragments of lignite. **F.** Stiff, mottled red and gray clay; apparently horizontally stratified. **G.** Stiff gray clay; contains much very fine mica. **H.** Glacial outwash sand and gravel; stratified and, in places, cross stratified. Figure and caption from Blank 1978.

The fine-grained portion of the Clay Till is almost certainly derived from the Raritan Clay. The Raritan Clay in the New York City area is described as light to dark gray, brown-red, pink, red, and gray-white clay, silty clay, and clayey to silty fine sand. Disseminated lignite and pyrite are common and calcareous concretions may be present. The Gardiners Clay is described as fossiliferous gray-green and dark gray clay. Disseminated lignite is common and vegetation may be present (Soren 1978, Suter 1949). The two descriptions have enough of an overlap that it is not always possible to diagnose which formation is present in a boring. In the New York area when reddish Cretaceous clay is encountered it is distinctly the Raritan. It is frequently overlain by a stiff gray to black or dark brown clay that contains significant amounts of lignite and no visible shells. In New Jersey (Wolfe 1977) the red Raritan is overlain by gray clays that contain abundant lignite and concretions of siderite. It is likely that most, if not all, of the New York City lignitic gray clay that overlies red Raritan clay is also part of the Raritan Formation, rather than Gardiners Clay. There is a documented outcrop of gray Raritan clay along the shoreline in Whitestone, Queens (Soren 1978).

Gray clay containing shells and/or lacking abundant lignite may be Gardiners Clay but it is not clear whether the Gardiners Clay occurs to the north of the Brooklyn site. Buxton and Shernoff (1995) show a small deposit just to the east and southeast at around elevation -100 feet, and the main body of the stratum starting about 1 mile to the east at about elevation -50 feet. (See Figure 3.) It is possible that Gardiners once lay to the north and the entire body was scoured up and incorporated into the gray clay till. The abundance of lignite, the lack of shells, and the presence of occasional swirls of red, yellow and white Raritan clay mixed in with the gray suggests that the clay portion of the till is really the Raritan. The presence of Raritan in locations lying to the north of the site, particularly in outcrops, also makes it a more likely candidate for the source of the clay matrix.

The topography of each of the strata at the site is generally fairly smooth and even except for the Clay Till layer which has a more hummocky surface and variable thickness compared to the other units. The overlying Mixed Glacial stratum blankets the Clay Till, filling in most of the depressions and leaving behind a fairly level surface. It is most likely the drift left behind when the glacier retreated. The highly varied and interlayered mix suggests that it was deposited in the terminal zone of the waning glacier. In one of the borings that contained a till deposit a piece of gravel within the till was composed of marble. In the New York area, unless a site lies on or directly southward of an area underlain by the Inwood Marble, marble is not noticeably present in the till.

Local Context

This assemblage of strata is not unique to this site. The Silt stratum has been found in locations ranging from 1 mile to the north and almost 1.5 miles to the northeast to 0.5 mile to the south. Blank's lateritic soil was found scattered between Shafts 12A and 14A of NYC Water Tunnel No. 2, which ranges between 3 miles to the northeast and 1 mile to the southeast of the Brooklyn site. (See Figure 1.) Borings made in the past by others suggest the silt layer may be found in the vicinity of Shaft 12A. One report called it a varved glacial lake stratum, which is consistent with what we see at the Brooklyn site.

The Clay Till layer has been found over a similar area, ranging from 1 mile to the north to roughly 1.5 miles to the northeast, a small amount is 0.5 mile to the south and there is possibly some over 1.5 miles to the east. An area to the east has gray clay till directly over the most likely source clay (which was mapped as Gardiners but appears to be consistent with the gray Raritan). An interesting note about this particular site is that gravel incorporated into the till also contained small quantities of marble.

IMPLICATIONS AND CONCLUSIONS

The Silt stratum is a cryptic unit. Deposits found to the east and northeast of the site suggest that the bedrock grades upward into decomposed rock, which in turn grades up into a possible residual soil. (See Figure 11.) At the site, the Silt stratum is clearly glacially scoured and reworked soil derived from the local decomposed bedrock and possibly the residual soil. The rock grades upward into decomposed rock with relict rock structure still visible. The overlying Silt layer shows signs of horizontal stratification and contains interlayers of glacial deposits. SPT values indicate that the soil is significantly less dense than the underlying decomposed rock, further indicating that the unit is reworked rather than an in-place ancient residual soil. At other sites in the neighborhood the deposit occasionally contains slivers of lignite implying that the associated glacier passed over Cretaceous clay up slope. This suggests that the layer was deposited in a glacial lake in advance of the glacier responsible for the overlying Clay Till. Because the unit is so locally derived it is not exactly clear what direction the glacier that deposited it came from. Likely source bedrock at a comparable or higher elevation is found at the site and directly to the north. Possible source residual soil is found to the east and northeast. Sources of Cretaceous lignite are also found to the northeast and east.

The Clay Till is a more conventional glacial deposit. Its significance lies in its ability to indicate the most recent direction of glacial flow over northwest Brooklyn. Local glacial advances are known to have come from either the northwest or the northeast. (See Table 1.) A primary constituent of the stratum is Cretaceous Raritan Clay. The immediately underlying stratum is an obviously post-Cretaceous glacial deposit. Consequently, the soil had to have been transported to the site from elsewhere. No evidence of Raritan clay exists in the general vicinity to the west or northwest of the Brooklyn site. Rather, the landward edge of the formation is present to the northeast and east. This suggests that the only direction the glacier could have come from is the northeast.

The overlying Mixed Glacial stratum is most likely the ablation till associated with the Clay Till. Its constituents likely traveled a greater distance than the more locally derived basal Clay Till. The predominantly yellow-brown and brown colors are typical of the crystalline metamorphic source rocks to the north and northeast. Little of the red-brown material typical of the advances is known to have originated from the northwest. One of the pockets of till within the unit contained a piece of gravel composed of marble. Marble bedrock is found mainly to the north of the site. The only potential sources to the northwest are narrow bands at much lower elevations, mainly in the East River.

It is known that an early, pre-Ronkonkoma and Harbor Hill glacier advanced from the northeast. It is unlikely, given the dominance of these two later events, that large swaths of at least two strata associated with this earlier glaciation could still survive intact, and have no conclusive sign of the later glaciations remaining above them. It is most likely that at least the Clay Till and Mixed Glacial strata were deposits associated with the Woodfordian glacier of Sanders and Merguerian (1998).

Not enough stratigraphic units are preserved at the site to define the precise glacial history, but some events are likely. Previous glaciations appear to have scoured the area down to the bedrock, decomposed rock or residual soil. High ground, possibly relict from a previous glaciation, allowed a lake to form in advance of an approaching glacier. This lake was filled with glacially reworked soil ultimately derived from the local bedrock, thus creating the Silt stratum. This was apparently overrun by glacial ice that deposited pockets of till. Retreat and/or readvance of this ice allowed the area to be covered with conventional glacial lake sediments. A significant glacial advance from the north or northeast left the site covered with the Clay Till, and upon its retreat the overlying Mixed Glacial ablation deposit was formed.

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