Stratigraphy Across the Hudson River, Tarrytown – Nyack, NY
Updated From Borings for the New NY Bridge Replacing the Tappan Zee

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Introduction

In 2002, 2006 and 2012 a total of 28 land and 85 water borings under the inspection of MRCE were made in and along the Hudson River to produce geotechnical data reports leading to the construction of the New NY Bridge to replace the Tappan Zee Bridge. The investigation for the construction of the original Tappan Zee Bridge identified the general stratigraphy and revealed that bedrock drops to around elevation –740' near the western edge of the river. The new borings allow a much better definition of the upper glacial and estuarine strata present at the Tarrytown-Nyack section of the river, which is roughly 2.8 miles wide. The new borings did not go deep enough to explain why the western rock is cut so deep, or what sediments are present in the channel directly above the rock.

Background Geology

Bedrock below the east side of the Tappan Zee Bridge is the Proterozoic Fordham Gneiss. Above it to the west is the Triassic Brunswick Formation, undivided, part of the Newark Supergroup (Figure 1).

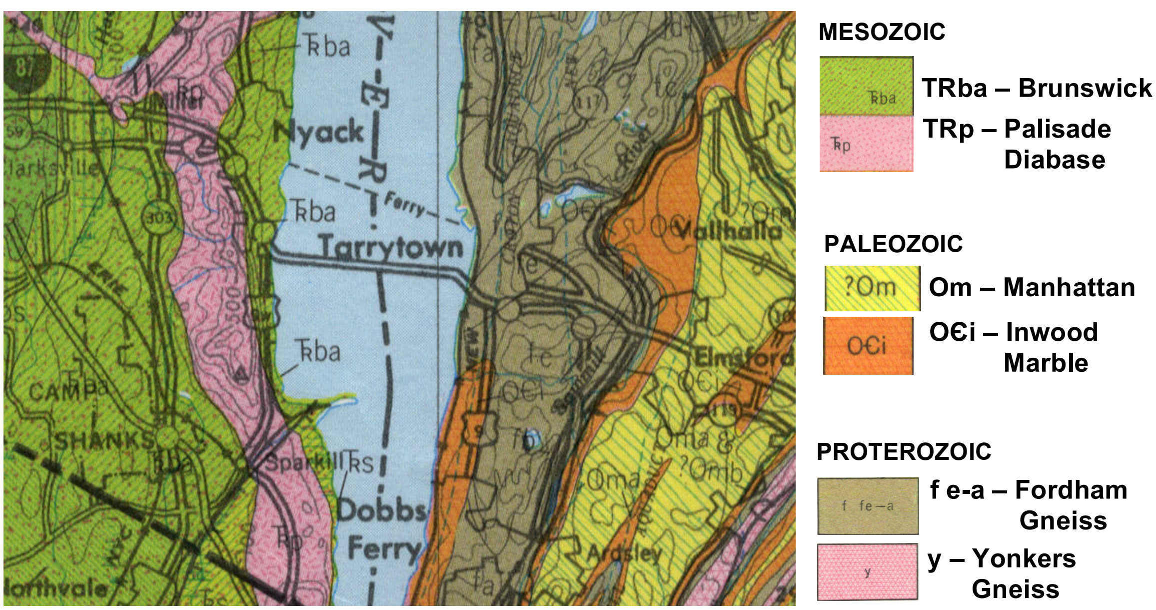


Figure 1 – The Geologic map of New York: Lower Hudson Sheet shows the rock formations below the Tappan Zee Bridge. The Proterozoic Fordham Gneiss (f e-a) is the formation present along the east shore of the river, the Triassic Brunswick Formation ($T_R$ba) is along the west shore. Formations mapped nearby, such as the Paleozoic Inwood Marble and Manhattan Formations and the Mesozoic Palisade Diabase, were not found in the Hudson River borings. (Modified from Rickard & Others (1970).)

Two very detailed references from Stanford (2010a & 2010b), fortunately published before the final Tappan Zee geotechnical investigation, provide a great deal of information about the geologic history of the Lower Hudson River since the Miocene, so I will only provide a brief summary of pertinent items here.

The Hudson River has changed its course many times in the past, but has been present along the Tappan Zee stretch since at least the Pliocene. The amount of erosion along the river likely increased during the Pleistocene as a result of glacial processes. Sediments to the south in New Jersey and New York City/Long Island indicate there were at least 3 separate glacial advances across the region (Figure 2). The first glaciation is pre-Illinoian. The timing is uncertain, but deposits in NJ suggest an age greater than 788 Ka, possibly belonging to a glaciation in the Pliocene around 2–2.5 Ma. The Illinoian advance (~150 Ka – MIS 6) left behind sediments in both NJ and Long Island. Most of the glacial deposits found in the region date to the Wisconsin, and are associated with the late Wisconsin advance (~21 Ka – MIS 2) and the subsequent glacial retreat.

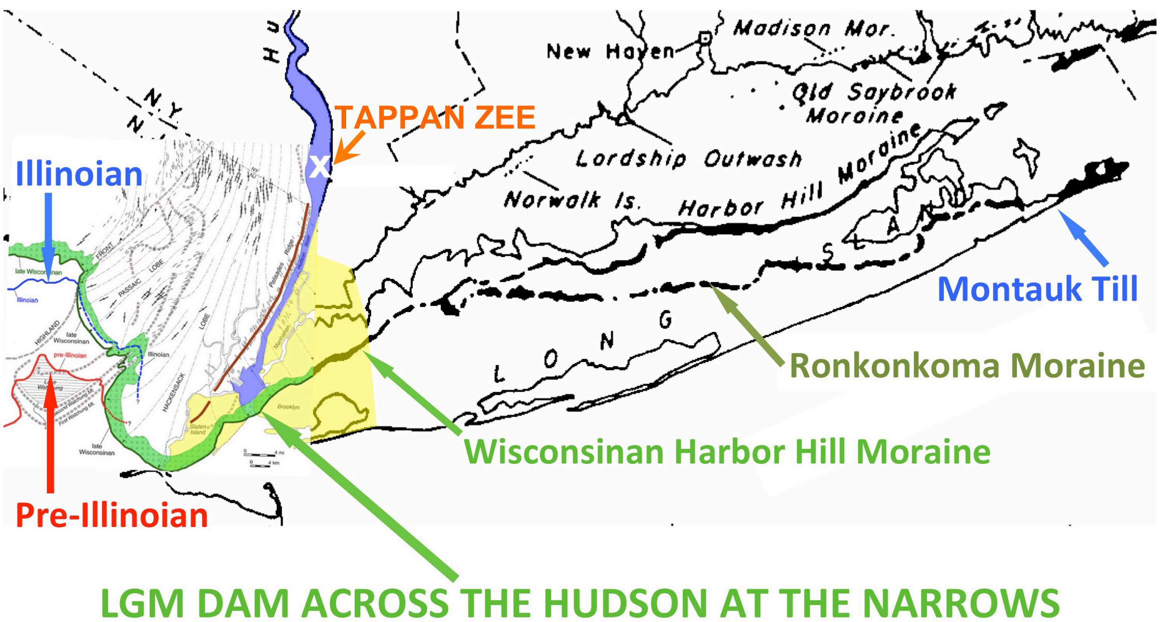


Figure 2 – Sediments in New Jersey and New York City/Long Island indicate that there were at least 3 glacial advances across the region. The limits of a pre-Illinoian advance are shown in red. Presumed Illinoian deposits are labeled in blue. Most of the glacial sediments found in the region date to the Wisconsin (labeled in shades of green), and are associated with the late Wisconsin advance and the subsequent glacial retreat. The Ronkonkoma Moraine and related deposits most likely date to an earlier Wisconsin advance that retreated an unknown distance before the ice readvanced to the LGM Harbor Hill position. The Harbor Hill Moraine crossed the Hudson at the Narrows where it formed a dam. (Modified from Stanford (2010b) and Flint and Gebert (1974).)

At the Last Glacial Maximum (LGM) the Harbor Hill terminal moraine built up across the mouth of the Hudson at the Narrows. As ice started to retreat (~20 Ka) the moraine acted as a dam and a series of somewhat interconnected glacial lakes formed from the meltwater trapped behind it. Glacial Lake Bayonne was the first to develop over the lower Hudson (Figure 3). When the ice retreated north of Hell Gate in the East River

(~19 Ka), an outlet opened up into Long Island Sound. Lake Bayonne was now free to drain into the Sound and glacial Lake Connecticut, where the water would then flow through the Race (between the east end of Long Island and Connecticut) to the Atlantic. With a new outlet available, the level of Lake Bayonne dropped and split into 2, forming Lake Hackensack to the west of the Palisades ridge and Lake Hudson to the east of the Palisades. Now with 2 outlets, Lake Hackensack drained southward through the Arthur Kill, and flowed eastward through the Kill van Kull at the north end of Staten Island down into Lake Hudson, which then flowed northward down into the Sound.

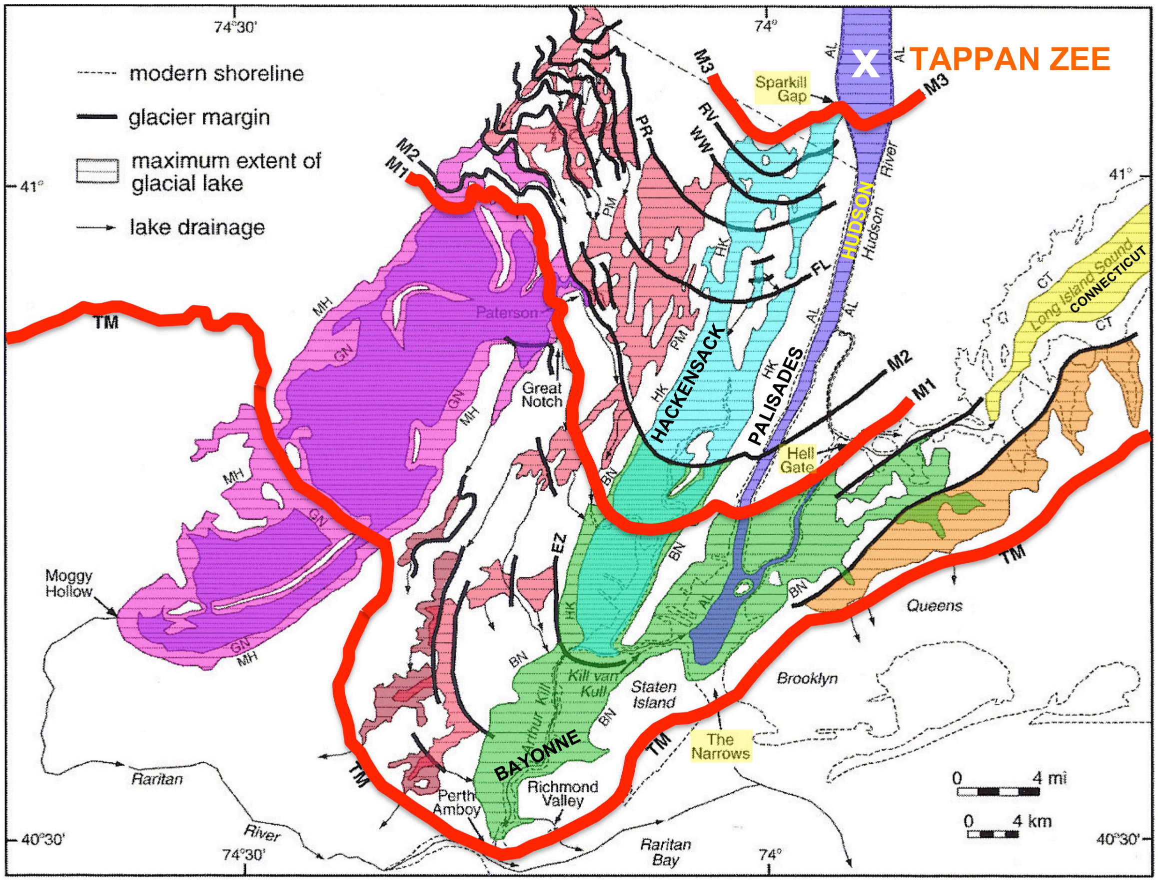


Figure 3 – Recessional ice margins and associated glacial lakes, northeast New Jersey/southeast New York. When the ice retreated from the terminal moraine (TM) the first glacial lake to form over the Hudson was Lake Bayonne (colored green). When the ice retreated north of Hell Gate (M1) an outlet opened to Lake Connecticut (colored yellow) in Long Island Sound. The level of Lake Bayonne dropped, separating into Lake Hackensack (light blue) west of the Palisades ridge and Lake Hudson (dark blue) east of the Palisades. In addition to an outlet at Arthur Kill, Lake Hackensack drained through Kill van Kull down into Lake Hudson, which flowed through Hell Gate down to Long Island Sound, en route to the Atlantic. When ice retreated north of Sparkill (M3) a new outlet opened, allowing Lake Hackensack to drain northward into Lake Hudson through Sparkill Gap. Tappan Zee is located only 2.25 miles north of Sparkill Gap. (Modified from Stanford (2010b).)

With further retreat another outlet opened (~18 Ka), and Lake Hackensack started to drain northward into the Hudson at Sparkill Gap, which is located roughly 2.25 miles to the south of Tappan Zee (Figure 3). When isostatic rebound caught up to Sparkill Gap, what was left of Lake Hackensack leveled off, ponded up, and then ~13 Ka eventually reversed direction and once again its water flowed southward.

Meanwhile, the ice continued its northward retreat until it passed Moodna Creek (Figure 4), which allowed the Lake Wallkill – Augusta Stage to pour into the Hudson (~15.5 Ka). This initial flood, along with the subsequent inflow of water from other significant lakes and tributaries opening upstream, caused the dam at the Narrows to breach and erode down. This allowed Lake Hudson to drain, and the lower Hudson was once again free to flow directly into the Atlantic. To the north, the Hudson valley was still isostatically depressed, so a glacial Lake Hudson/Albany continued to exist upstream. As the valley to the south rose upward as a result of isostatic rebound, the newly flowing river cut its channel down into the older glacial lake sediments. Until isostatic rebound caught up, the old lake bottom became the dam and outlet for the lakes to the north. Eventually a rising relative sea-level brought estuarine conditions into the lower reaches of the river.

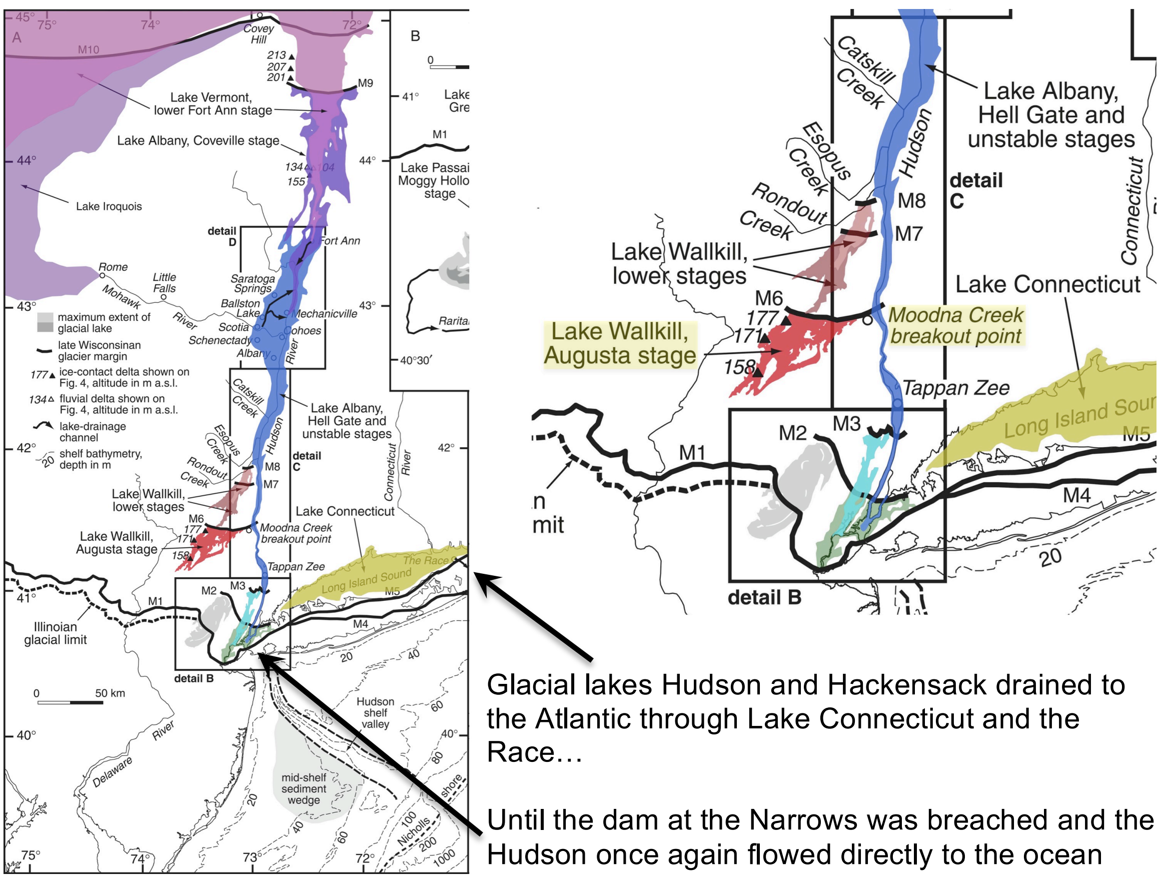


Figure 4 – Hudson Valley glacial lakes. When ice retreated north of Moodna Creek the Lake Wallkill – Augusta stage (colored red) flooded into Lake Hudson (colored dark blue). This flood, along with the subsequent inflow from lakes and tributaries opening upstream, breached and then eroded down the moraine dam at the Narrows. The lower Hudson River was once again free to flow directly into the Atlantic, rather than looping around Long Island. When the valley to the south rose upward due to isostatic rebound, the newly flowing Hudson cut its channel down into the glacial lake sediments. The former lake bottom, including the Tappan Zee stretch, became the new dam and outlet for the lakes to the north until the rising sea-level caught up, bringing estuarine conditions upstream. (Modified from Stanford (2010a).)

Prior to construction of the Tappan Zee Bridge, 23 seismic refraction profiles, in addition to 34 borings, were made to identify the strata and depth to bedrock along the bridge alignment (Worzel & Drake 1959). The borings did not reach the deeper sediments or bedrock in the western half of the river, but the seismic profiles indicated that at its deepest point top of rock was at roughly elevation – 740' (Figure 5). The investigation was not able to determine why the rock was cut so deep. The presence of a fault and/or glacial erosion in a fjord setting were suggested possible causes.

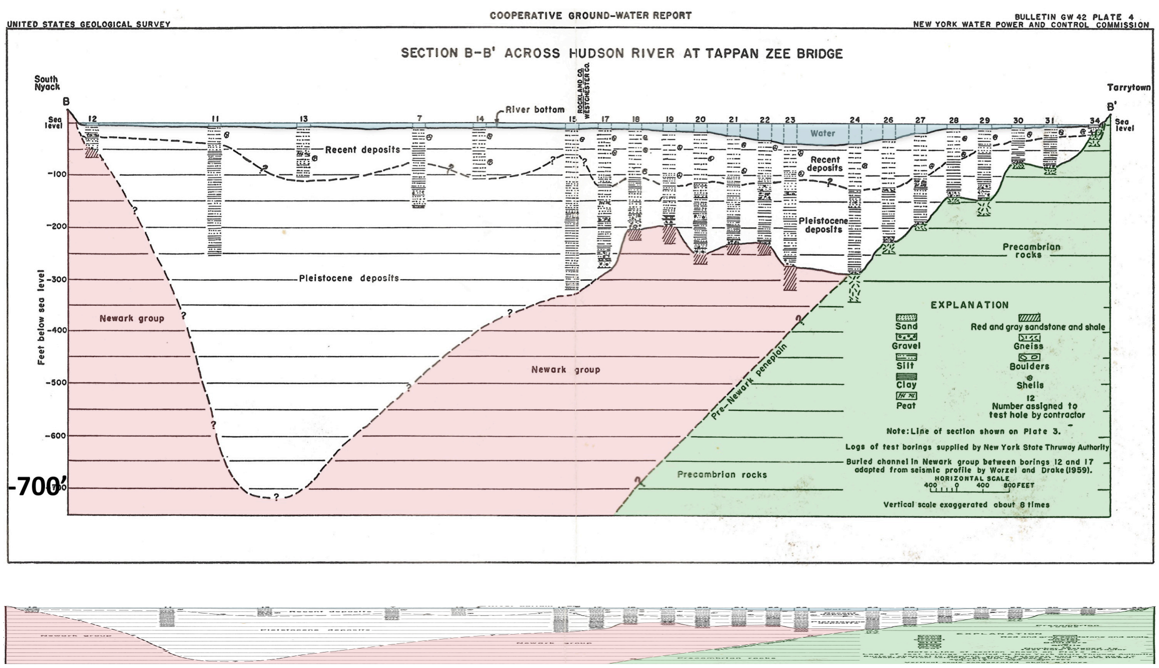


Figure 5 – Cross-section using data from the original Tappan Zee Bridge investigation. Seismic refraction profiles indicated the bedrock drops to around elevation –740' near the western edge of the river. Note that the vertical scale is roughly 8 times the horizontal scale, so while the rock drops steeply on the west side of the river it probably isn't the "cliff face" that is implied at an exaggerated scale. The image below is stretched to roughly a natural scale. (Modified from Perlmutter (1959).)

Strata Present

In 2002, 2006 and 2012 a total of 28 land and 85 water borings under the inspection of MRCE were made in and along the Hudson River. These borings went as deep as elevation –395'. 30 CPT soundings were also made, reaching up to ~302' deep. There were also some additional borings made by others for the contractors that went as deep as elevation –442'. The cross-section shown (Figure 6) follows the northern alignment of the new bridge being built directly to the north of the existing Tappan Zee Bridge.

None of the new borings went deep enough to hit the ~740' deep bedrock in the western ~40% of the river, or the overlying till in the western ~30%, so there are still some unknowns. Bedrock along the eastern ~25% of the river is the Proterozoic age Fordham Gneiss. At Tappan Zee it covers the range from gneiss to schist, with occasional zones of hornblende gneiss and granitic intrusions. To the west, the basement rock is overlain by the Triassic Brunswick Fm., which at the site is typically a fine to coarse-grained sandstone, siltstone or occasionally conglomerate (Figure 7). The river has 2 channels scoured into the rock. In addition to the deep western cut, there is a shallower channel on the eastern side of the river that is centered over the contact between the 2 different rock types.

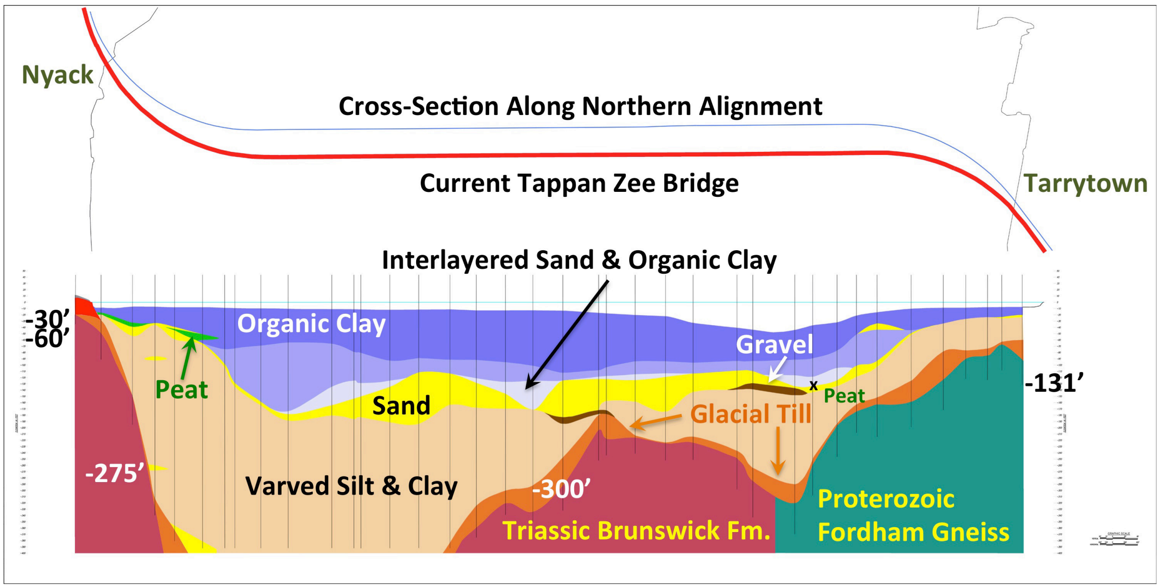
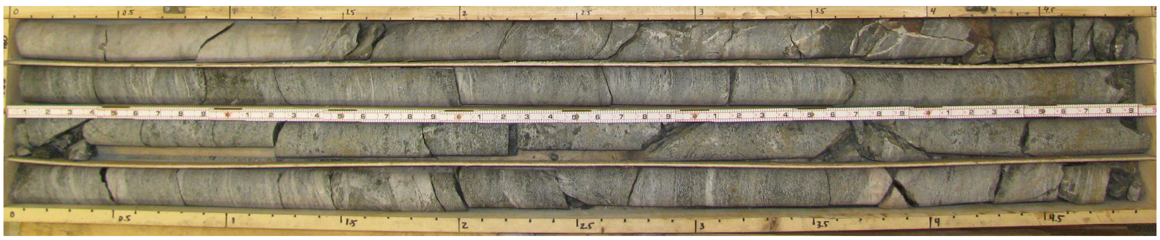


Figure 6 – Stratigraphic cross-section along the northern alignment of the New NY Bridge that will replace the Tappan Zee. Bedrock consists of the Proterozoic Fordham Gneiss (dark green), overlain to the west by the Triassic Brunswick Fm. (red). Glacial till (orange) generally covers the rock. Glacial lake varved silt and clay (beige) filled the valley up to ~ El. –20'. Thin sand layers (yellow) are present on the west side below, and extending into, the varved soil. After Lake Hudson breached at the Narrows a new channel was scoured into the lake sediments. Thin gravel layers (brown) are present above the scoured surface on the east side of the river, and the width of the channel is covered with a layer of sand. As sea-level rose estuarine conditions worked their way upriver from the Atlantic. Initially organic silty clay mixed and interlayered with the river bottom sand (light blue). The channel then filled with organic silty clay with decreasing amounts of sand (medium blue) and increasing amounts of peat and shells (dark blue). Between elevations –60' and –30' thin sand layers extend from both shores into the river, and peat (green) is off the west shore. A thin peat layer is also present on the east side of the river just above the river sand at the base of the estuarine organics (black **x**).

(C) Glacial Till

(B) Brunswick Formation



(A) Fordham Gneiss

Figure 7 – Typical Tappan Zee bedrock and overlying till. (A) Proterozoic Fordham Gneiss basement rock. (B) Triassic Brunswick Formation that was deposited above the Fordham. (C) Glacial till found directly above the bedrock – a mix of grain sizes ranging from boulders to clay.

Where rock was encountered it was generally covered with a layer of glacial till; a red brown to brown to gray brown clay, silt, sand, gravel and boulders mix. Across the entire width of the river the till is overlain by a thick layer of varved glacial lake clay and silt that extends up to approximately El. –20' along the shorelines. The varves consist of a mix of gray silt, clayey silt, silty clay and clay with trace amounts of brown or red brown fine sand and silt partings. Just above the till the color shifts from gray to gray brown to brown, then to red brown at the till. A few small layers of sand are present at depth in the varved stratum at the western edge of the river, including a layer at El. –275'. CPT soundings indicate that there is a greater amount of silt and fine sand (or soil that behaves as such) below this elevation. Varve counts in select samples suggest that the soil does indeed become slightly more silty/sandy. Lab tests indicate that the soil becomes denser, with a lower void ratio, below El. –300'.

Each varve sequence may consist of distinctly separate layers or may grade continuously from a fine sand parting or seam upward through silt into a clay. Varve thicknesses vary greatly, but in general are thicker at depth (for example at El. –271' the measured varve sequences are up to 4 inches thick) becoming thinner closer to the top of the stratum (Figure 8). Across much of the river the glacial lake sediments were scoured out, as deep as ~El. –192', following the breach of Lake Hudson at the Narrows.

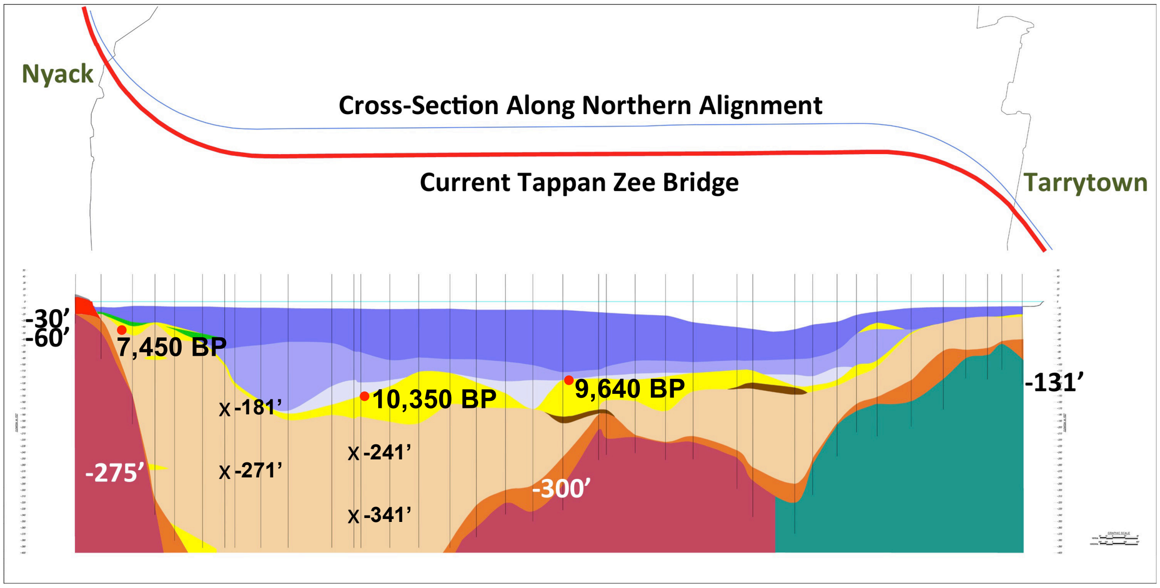
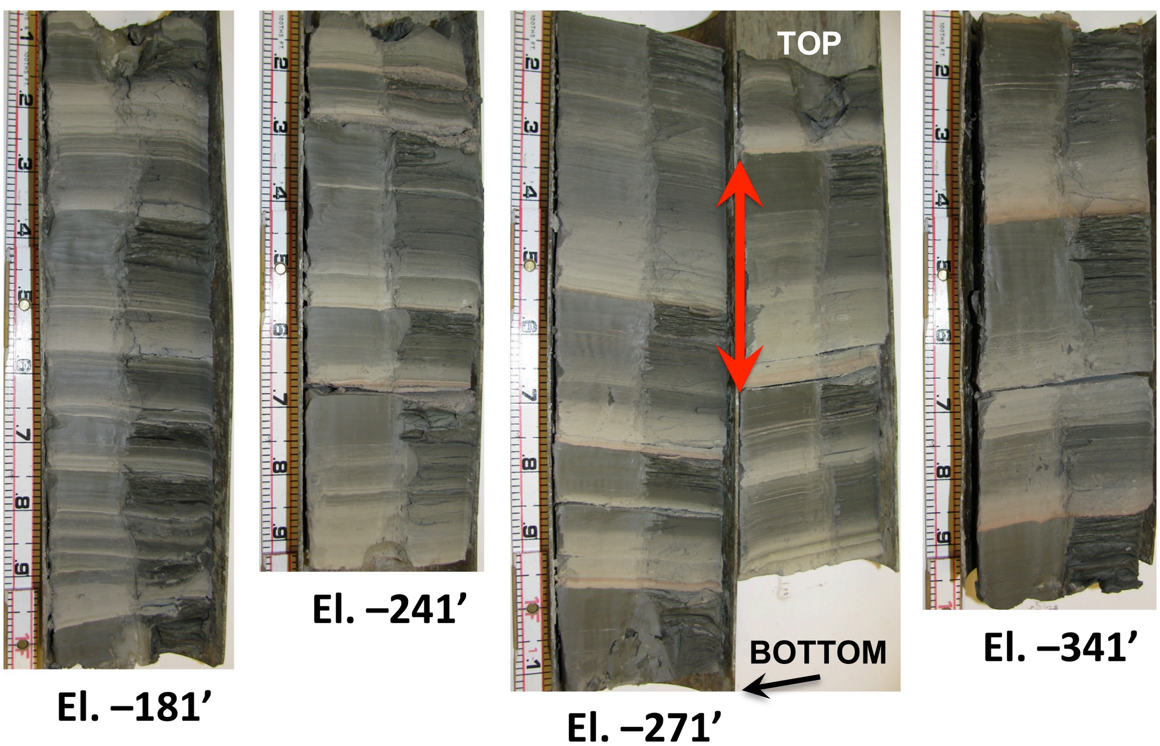


Figure 8 – Glacial lake varve and ^{14}C date sample locations. The X's mark the locations of the varved silt and clay samples shown below. The varves consist of a mix of gray silt, clayey silt, silty clay and clay with trace amounts of brown or red brown fine sand and silt partings (more visible in the sample from El. –341'). Just above the till the color shifts from gray to gray brown to brown, then to red brown at the till. Each varve sequence may consist of distinctly separate layers or may grade continuously from a fine sand parting or seam upward through silt into a clay. Varve thicknesses vary greatly, but in general are thicker at depth (up to ~4 inches thick in the undisturbed tube samples that were taken, see red arrow) becoming thinner closer to the top of the stratum. Each number on the ruler = 0.1 feet. The red dots show the locations and ^{14}C dates of 3 Tappan Zee basal organic/peat samples tested as part of other research. (Digital images by C. J. Moss.)



A thin layer of gravel covers the eastern half of the river above the scoured varved sediments. A layer of river bottom sand lies above this across most of the river. As relative sea-level rose and estuarine conditions moved upriver, the river bottom sand became mixed and interlayered with, and then eventually overlain by thick deposits of organic silty clay. The soil directly above the sand, particularly in areas where channels were cut down into it, generally contains a higher percentage of reworked sand and inorganic glacial silt and clay mixed in and/or interlayered with the estuarine organic clay. A thin peat layer is present at El. –131’ in the eastern half of the river in between the sand and deep organic clay. Moving upward, the soil becomes softer, water content rises, shells and scattered pockets of peat appear and the fine sand partings decrease. Along the shorelines there are layers of peat (on the western shore) and fine sand extending into the river roughly between the elevations of –30' and –60'. The softest soil and the greatest number of shells tend to lie above this sand/peat level.

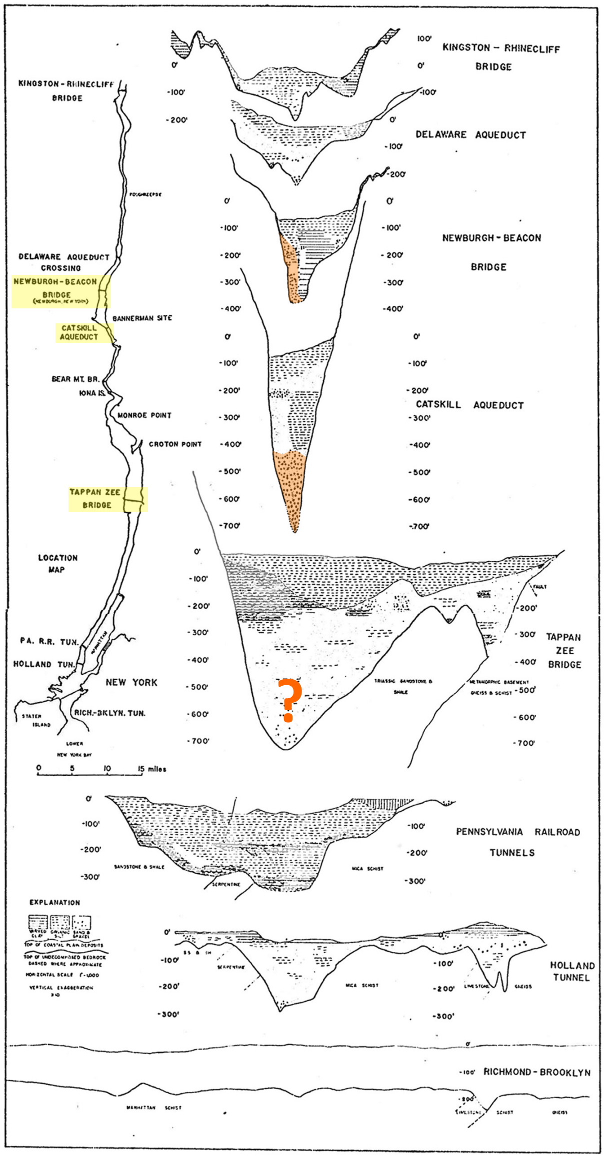
Interpretation

There was nothing unusual in the bedrock that was recovered to the east or west of the deep channel that would indicate why the western side of the river was eroded so deeply. The rock was entirely “typical” for both of the rock types; no unusual degree of jointing, shearing, alteration, or weathering was present. Unfortunately, the deepest portion of the valley remains a mystery.

At least 2 other stretches of the Hudson that are somewhat nearby also have unusually deep bedrock (Newman & Others 1969). At the Newburgh – Beacon Bridge crossing rock on the western side of the river drops to almost El. –400’. The rock drops to over El. –700’ at the Catskill Aqueduct crossing at Storm King (Figure 9). In both locations the deepest part of the river is filled with a thick layer of till, described as a boulder till at Storm King. Because the Tappan Zee borings did not go deep enough, it is still unknown what type of soil fills the deep valley. Some locations in New York City that have deep bedrock valleys or depressions, such as the World Trade Center site (Moss & Merguerian 2009), also have an especially boulder rich till at the base. Consequently, a bouldery till is a strong candidate for the type of soil present at the deepest part of the valley at Tappan Zee.

The glacial Lake Hudson sediments present at Tappan Zee were deposited after ice retreated to the north (shortly after Sparkill Gap opened ~ 18 Ka) and before the Lake Wallkill flood (~15.5 Ka) started a period of erosion that cut a channel down into them. Above El. –275’ the glacial lake sediments are quite consistent across the site. There are no dramatic changes in color, soil type, or engineering properties that would mark a sudden change in the sedimentary source or a significant glacial readvance. The more silty/sandy soil below El. –275’ is confined to the western channel in the rock.

Consolidation tests were performed on undisturbed soil samples taken from a range of locations and depths across the river. Test results in the varved stratum indicate that if glacial Lake Hudson was filled with sediment up to roughly (what is now) El. –20’ prior to the Narrows breach, then the varved soil that remains is now over-consolidated just below the scoured surface, normally consolidated in the center of the stratum and significantly over-consolidated below El. –350' (Figure 10). There aren't enough data points to be certain, partly because there are several mechanisms that can lead to over-consolidation (Moss & Merguerian 2005) and in theory a complex mix of them could be involved here, but this pattern generally suggests that after the lake drained the near-surface clay became subaerially exposed and at least slightly desiccated. It is possible the over-consolidation below El. –350' may be the result of glacial loading +/or desiccation.



NEWBURGH – BEACON BRIDGE

CATSKILL AQUEDUCT CROSSING AT STORM KING

THOUGH STILL UNKNOWN, A BOULDERY TILL IS A LIKELY CANDIDATE FOR THE DEEPEST SOIL AT TAPPAN ZEE

Figure 9 – Profiles at Hudson River crossings. Like Tappan Zee, bedrock is also unusually deep at the Newburgh – Beacon (almost El. –400') and Catskill Aqueduct (deeper than El. –700') river crossings. In both locations the deepest part of the river is filled with a thick layer of till, described as a boulder till at the Catskill Aqueduct Storm King crossing. A bouldery till is a strong candidate for the type of soil present at the deepest part of the valley at Tappan Zee. Note that the vertical scale is exaggerated roughly 10 to 1. (Modified from Newman & Others (1969).)

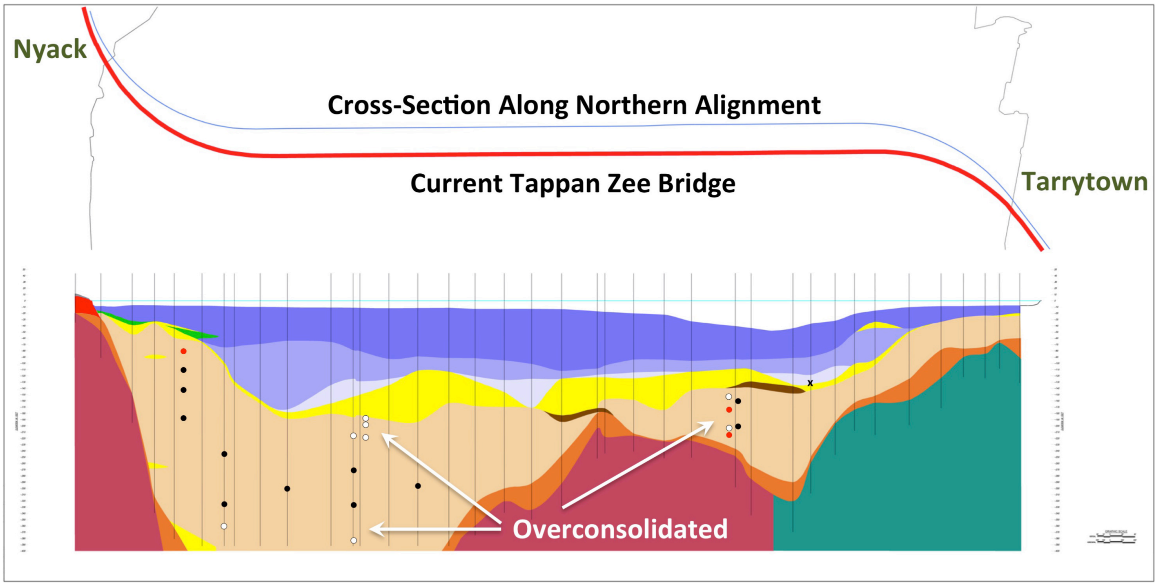


Figure 10 – Test results in the varved stratum indicate that if glacial Lake Hudson was filled with sediment up to roughly El. –20' prior to the Narrows breach, then the varved soil that remains is now over-consolidated just below the scoured surface, normally consolidated in the center of the stratum and significantly over-consolidated below El. –350'. Black dots mark locations of normally consolidated test samples, red dots are slightly overconsolidated, and white dots are significantly overconsolidated. This pattern generally suggests that after the lake drained the near-surface clay became subaerially exposed and at least slightly desiccated. It is possible the over-consolidation below El. –350' may be the result of glacial loading +/or desiccation.

After the Narrows was breached estuarine conditions worked their way upstream. Shoreline marsh deposits, where present, became submerged and organic silty clay mixed with and then eventually covered over the river bottom sand, ultimately filling up the channel. The upper sand and peat layers that are present within the organic clay (~ El. –60' to –30') were deposited along the shorelines at the point where the scoured sides of the glacial lake channel flatten out and the river widens. It is unclear to what extent the change in slope, increased width of the river or possible changes in the rate of relative sea-level rise contributed to the formation of these strata. Since the Pleistocene, it is likely that changes in the rates of global sea-level rise and local isostatic rebound combined to produce an uneven rate of local relative sea-level rise.

Carbon dating of organic samples was not specifically part of the scope of the geotechnical investigations. Some samples, however, were tested as part of other research (Figure 8). From 2 of the 2002 borings, Donnelly (2005) obtained ages of 10,350 +/- 65 ^{14}C BP (~ El. –150.5') and 9640 +/- 60 ^{14}C BP (~ El. –127') from samples at or near the base of the organics. A sample from 1 of the 2006 borings was tested as part of an archaeological study (Schuldenrein & Others 2010) and got a date of 7450 +/- 50 ^{14}C BP (~ El. –52.5') from the deeper peat stratum near the western shore. These ages are in ^{14}C years and are not the calibrated dates.

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