The Problem Posed by New York's "20-Foot Clay": Which is Wrong – Published Dates, Presumed Glacial Events, or Strata Origins?

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Introduction

In his 1914 USGS Professional Paper 82 on "The Geology of Long Island, New York", Fuller published a map of the surface geology of Long Island, and in the text interpreted the regional glacial history (Figure 1). His mapping has been reinterpreted many times since, and these revisions are described in much greater detail in Sanders and Merguerian (1997). Each of the new interpretations generally fit in with the main known regional strata (shown in Smolensky & Others (1989) – Figure 2). However, when you consider the presence of a relatively obscure stratum that is commonly known as the 20-Foot Clay and usually lumped into the Upper Glacial Aquifer, for most of these versions either the presumed ages or origin of the Pleistocene strata no longer add up.

Figure 1 – Fuller's 1914 map of the surficial geology of Long Island, New York. The accompanying text described and interpreted the region's Pleistocene history.

The 20-Foot Clay

The 20-Foot Clay is an interglacial or interstadial marine clay that has been mapped in the subsurface along the south shore of Long Island in Suffolk and Nassau counties (Doriski & Wilde-Katz 1983) (Figure 3). At its northern edge it reaches up to elevation -20', hence the common name of 20-Foot Clay. It is likely the same stratum as Fuller's Vineyard Formation (Perlmutter & Geraghty 1963). In New York City references, the unit was mentioned as being part of the Upper Glacial Aquifer, but it was not actually mapped (Soren 1978, Buxton & Shernoff 1999). Data in MRCE archives confirms that it is a discontinuous unit that extends westward into Queens and Brooklyn (Figure 4).

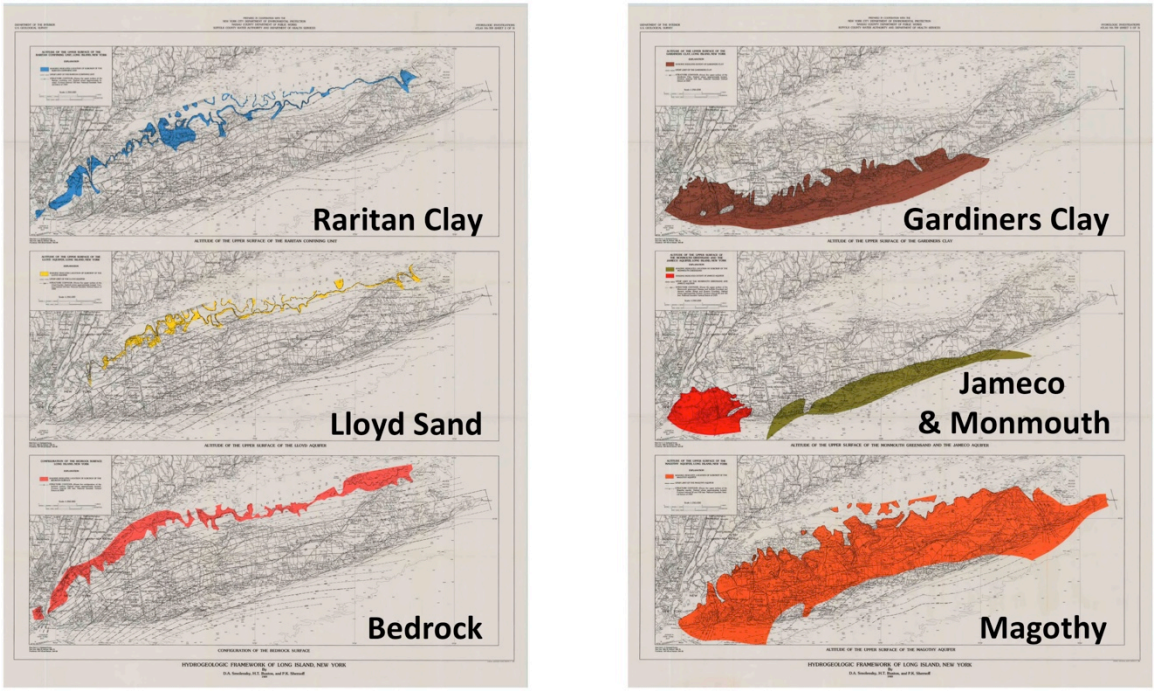

Figure 2 – Smolensky & Others (1989) maps the surface contours of the different strata below the Upper Glacial Aquifer in Long Island. The bedrock is overlain by Cretaceous coastal plains sediments – the Lloyd Sand, Raritan Clay, Magothy-Matawan and Monmouth formations. Pleistocene outwash (the Jameco Gravel) and then an interglacial marine clay (the Gardiners Clay) lie below the mix of strata that is generally referred to in USGS publications as the Upper Glacial Aquifer or "Upper Pleistocene Deposits".

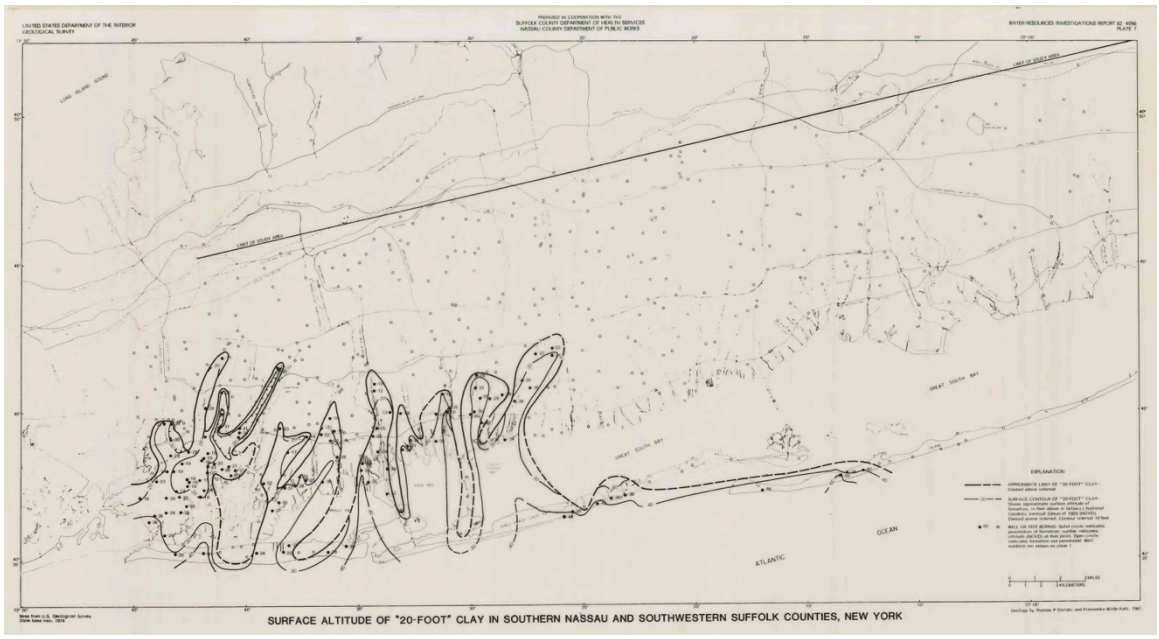

Figure 3 – Doriski & Wilde-Katz (1983) maps the presence and surface contours of the 20-Foot Clay in Nassau and Suffolk counties in Long Island. The 20-Foot Clay is an interglacial or interstadial marine clay within the Upper Glacial Aquifer. It is likely the same stratum as Fuller's Vineyard Formation.

The unit is typically a gray organic silty clay, with trace amounts of shells and peat. Sand layers and lenses are occasionally present within it. As in Long Island, the layer is laterally discontinuous, absent where the underlying strata rose above the then existing sea-level or where subsequent erosion removed it from above. Where it is located along the coastline below Coney Island and the Rockaways, the stratum is generally found between elevations –40' and –100', with a thickness ranging up to 50' thick (Figure 4). As measured by SPT blow counts, the sand below the clay stratum tends to be significantly more dense than the sand above it.

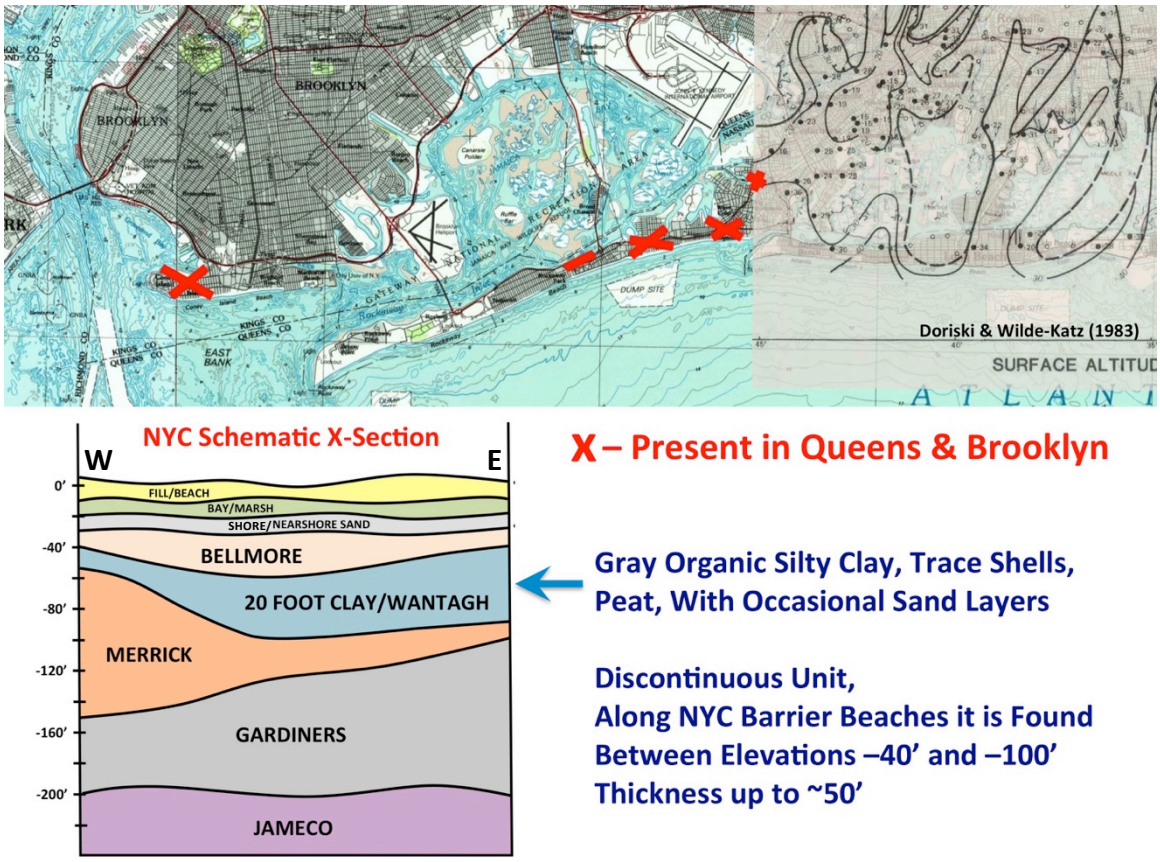

Figure 4 – Data in MRCE archives confirms that the 20-Foot Clay is a discontinuous unit that extends westward into Queens and Brooklyn. Red X's show locations where its presence is confirmed. The schematic W-E cross-section below the NYC shoreline is very simplified, but it illustrates how the clay, in places 50' thick, can be a significant stratum that should be taken into consideration in a subsurface investigation. Rampino & Sanders (1981) renamed the stratum the Wantagh Formation and named the sand layers usually found below (Merrick Fm.) and above it (Bellmore Fm.). In USGS publications these 3 formations are usually just grouped together as part of the Upper Glacial Aquifer. (Modified from Doriski & Wilde-Katz (1983) and USGS Long Island West (1984) and Newark (1986) quadrangles.)

Rampino and Sanders (1981) studied the stratum and adjacent strata in more detail in the general vicinity of Jones Beach (Figure 5), renaming the clay the Wantagh Formation. In places they were able to identify layers of barrier island sediments within the stratum, similar to the modern coastal environment. At the time of deposition, the local paleoclimate appears to have been temperate, but possibly a bit cooler than present day.

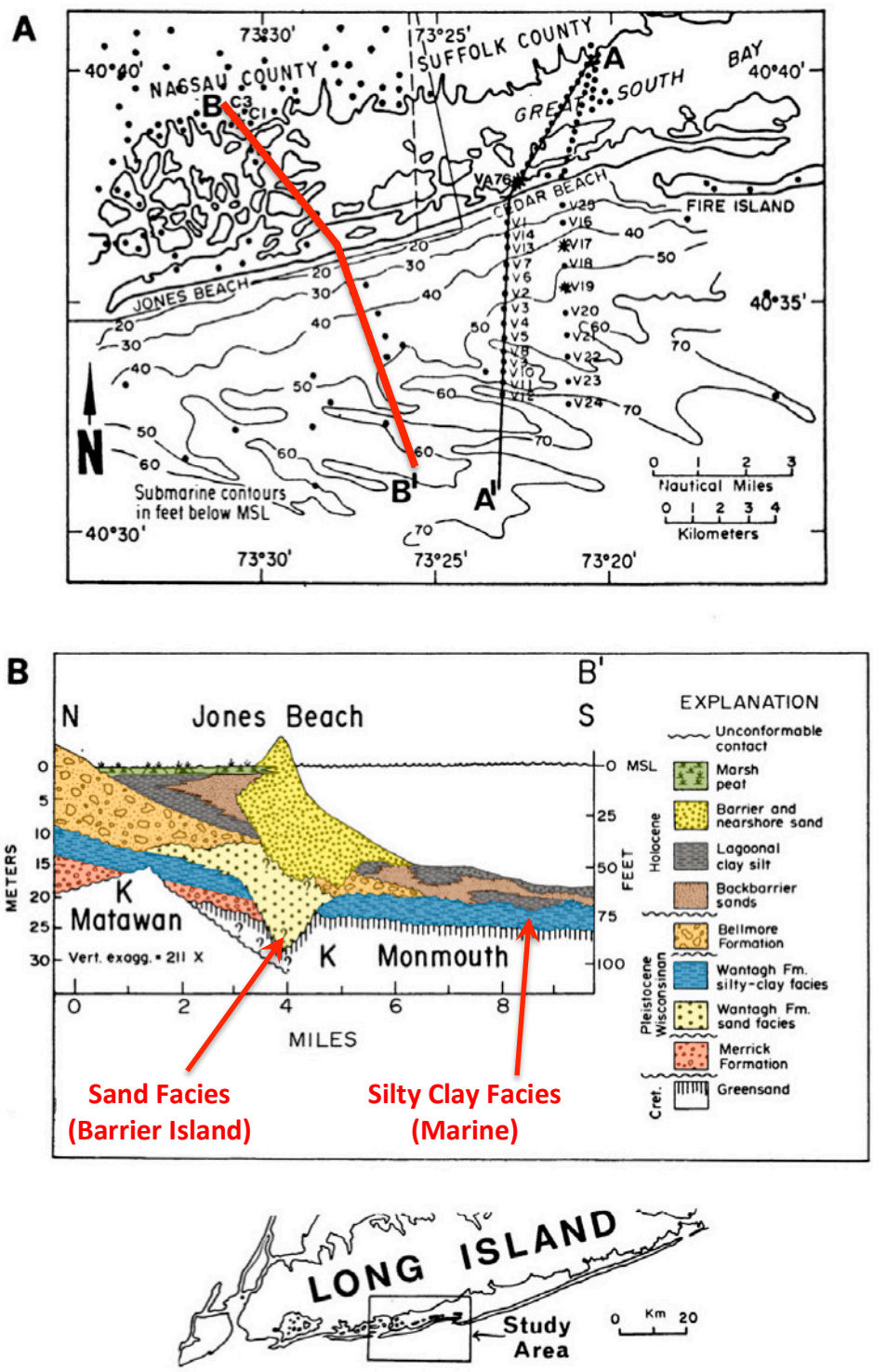

Figure 5 – Rampino & Sanders (1981) studied the 20-Foot Clay and surrounding strata in greater detail in the vicinity of Jones Beach, renaming the unit the Wantagh Formation. Cross-section B-B' shows the strata in a N-S onshore-offshore direction. The Wantagh's silty-clay facies is the marine clay portion of the stratum, the sand facies is barrier island sand within it. The Merrick outwash? is found below, and the Bellmore LGM outwash lies above the Wantagh. (Modified from Sanders & Merguerian 1997.)

Long Island Stratigraphy

In Long Island, assorted Cretaceous coastal plains sediments were deposited over the crystalline bedrock. The basal Lloyd Sand is overlain by the Raritan Clay, which is in turn overlain by the Magothy-Matawan and Monmouth formations (Figure 6). Subsequent erosion cut into the Cretaceous soils, in some places scouring down into the bedrock. An assorted mix of Pleistocene glacial and interglacial sediments were then deposited above the older strata.

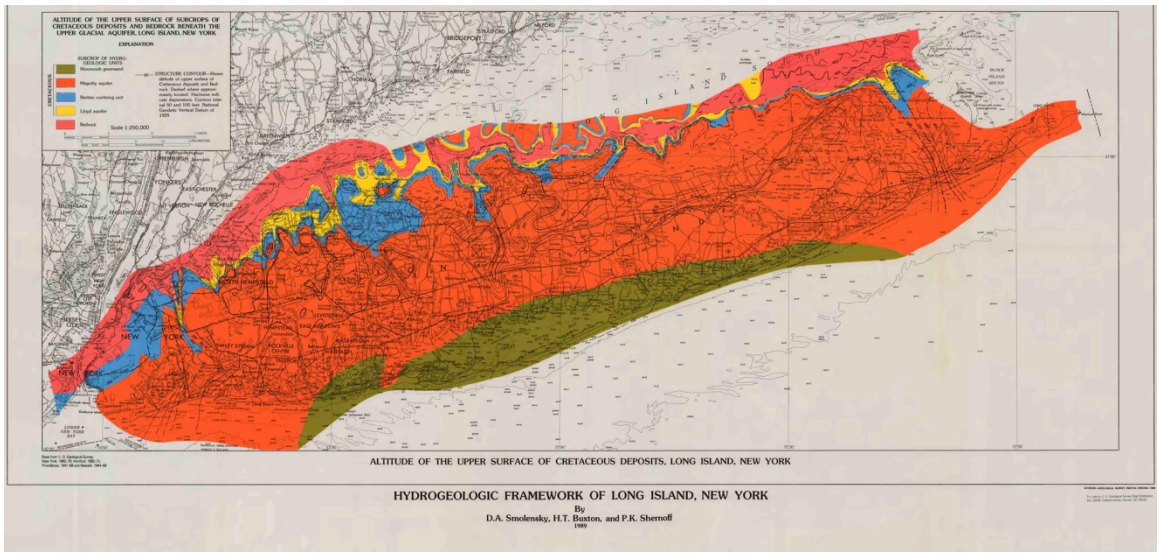

Figure 6 – Smolensky & Others (1989) contours the top of the pre-Pleistocene surface on Long Island, which consists of bedrock covered with layers of Cretaceous sand and clay.

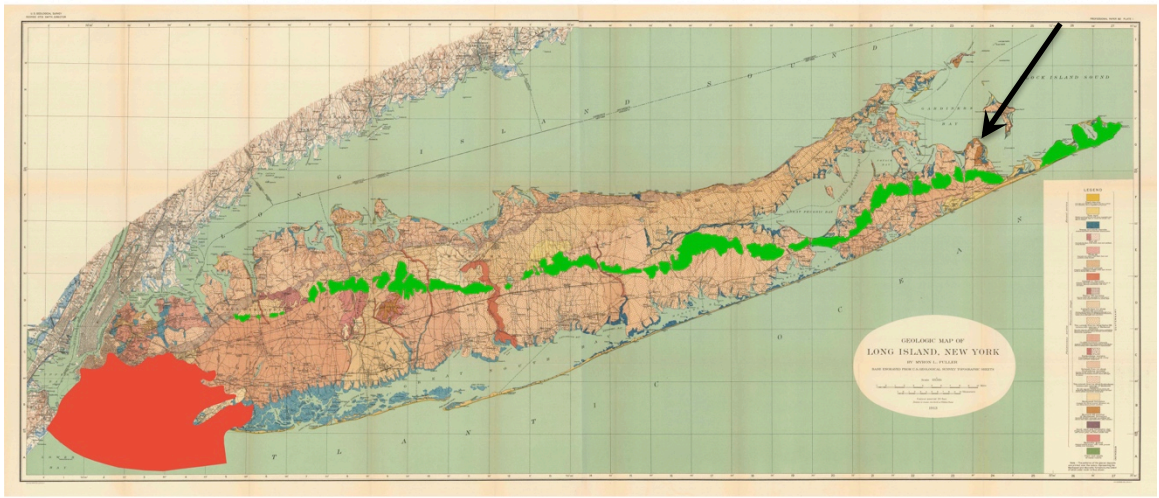

Figure 7 – Jameco Gravel and Montauk Till. The Jameco Gravel (red overlay) is an outwash sand mapped in western Long Island, and is usually considered Illinoian age. Fuller's Montauk Till is mapped in eastern Long Island in the general vicinity of, and below, the Ronkonkoma moraine (green overlay). See arrow – brown map unit is too small to see clearly at this scale. Slivers of it are also exposed by coastal erosion along the north shore of Long Island. This stratum is also generally considered to be Illinoian age. (Modified from Smolensky & Others (1989) and Fuller (1914).)

Stratigraphically the lowest Pleistocene stratum is the Jameco Gravel outwash (Figure 7), which is mapped in western Long Island. Its age is pre-Illinoian or Illinoian, though more recent published references generally lean toward an Illinoian age (Buxton & Shernoff 1999). In eastern Long Island Fuller's Montauk Till and related strata are found in the vicinity of, and below, the overlying Ronkonkoma moraine. Slivers are also exposed by coastal erosion along the north shore of Long Island. This till is also generally associated with an Illinoian glaciation (Stanford 2010b).

The Gardiners Clay is found to the south and west of the Ronkonkoma moraine and above the Jameco outwash (Figure 8). It is an interglacial marine clay that is generally considered to be Sangamon in age (MIS 5). This age is uncertain however, since there is a huge range in the published dates from the stratum. Amino acid racemization dates suggest deposition during MIS stages 9 through 5 (Wehmiller & Pellerito 2015), which corresponds to an age range of 337 ka to 71 ka (Lisiecki & Raymo 2005). One U-Th date of 130 ka from a coral fragment in marine sand on Nantucket suggests that the region's interglacial deposits are Sangamon. ^{14}C dates from the unit skew younger, with an age range of ~22 ka to >43 ka (Cadwell & Others 1991). While the different sets of dates converge on the Sangamon they can't actually confirm it. To confuse the issue further, the stratum resembles both deeper Cretaceous sediments and the overlying 20-Foot Clay, and in some places these other strata were likely mis-mapped as Gardiners. Dates taken from different stratigraphic units, rather than just sampling the Gardiners, may be a possible explanation for the wide range in ages.

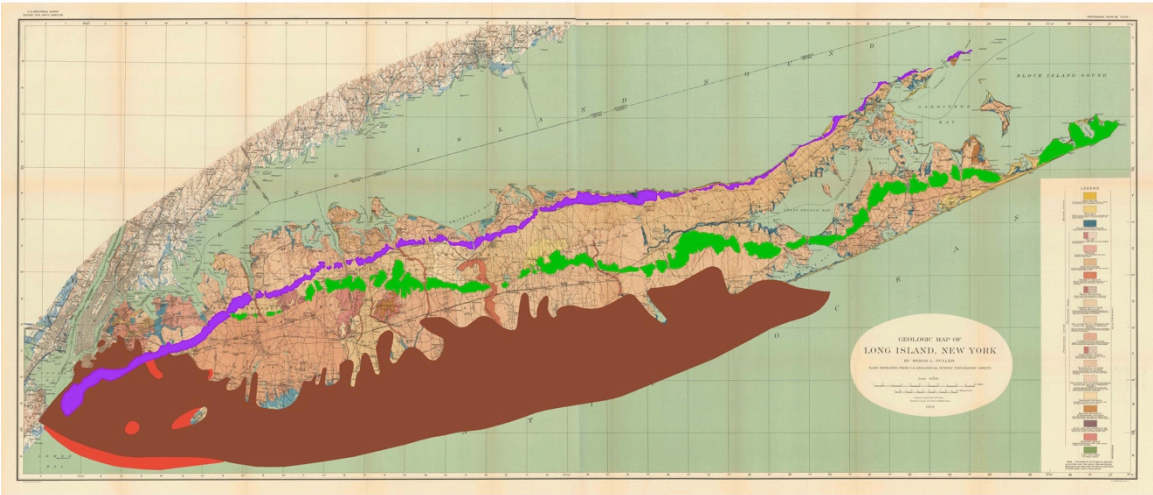

Figure 8 – The Gardiners Clay (brown overlay) is found to the south of the Ronkonkoma moraine, above the Jameco Gravel. It is an interglacial marine clay that is usually considered Sangamon age. Strata of the Upper Glacial Aquifer lie above the Gardiners – first the Merrick outwash? sand, then the 20-Foot Clay/Wantagh marine clay, then the Merrick late-Wisconsin outwash sand. To the north, running the length of Long Island are terminal moraines, which are also grouped with the Upper Glacial Aquifer. A Wisconsin age glacial advance built up the Ronkonkoma moraine (green overlay), the ice retreated and then readvanced to form the late-Wisconsin LGM Harbor Hill/Roanoke Point moraine (purple overlay).

In most USGS publications the Pleistocene sediments above the Gardiners Clay are grouped together as the Upper Glacial Aquifer or Upper Pleistocene Deposits. The strata

are mentioned in the text, but not mapped separately. A lower sand layer that is identified as outwash in essentially every reference lies above the Gardiners (Figure 9). Rampino and Sanders (1981) named this stratum the Merrick Formation and indicated that its characteristics were entirely consistent with an outwash origin. The marine, interglacial or interstadial 20-Foot Clay/Wantagh Fm. lies above this sand. Dating is very limited, but one AAR date places it in MIS 5 (130 – 71 ka) or possibly early MIS 3 (~57 ka), while ^{14}C dating gives an age of ~28,150 BP. A layer of outwash (Rampino's Bellmore Formation) lies above the 20-Foot Clay/Wantagh, and can be traced back to the late-Wisconsinan outwash on the surface of Long Island.

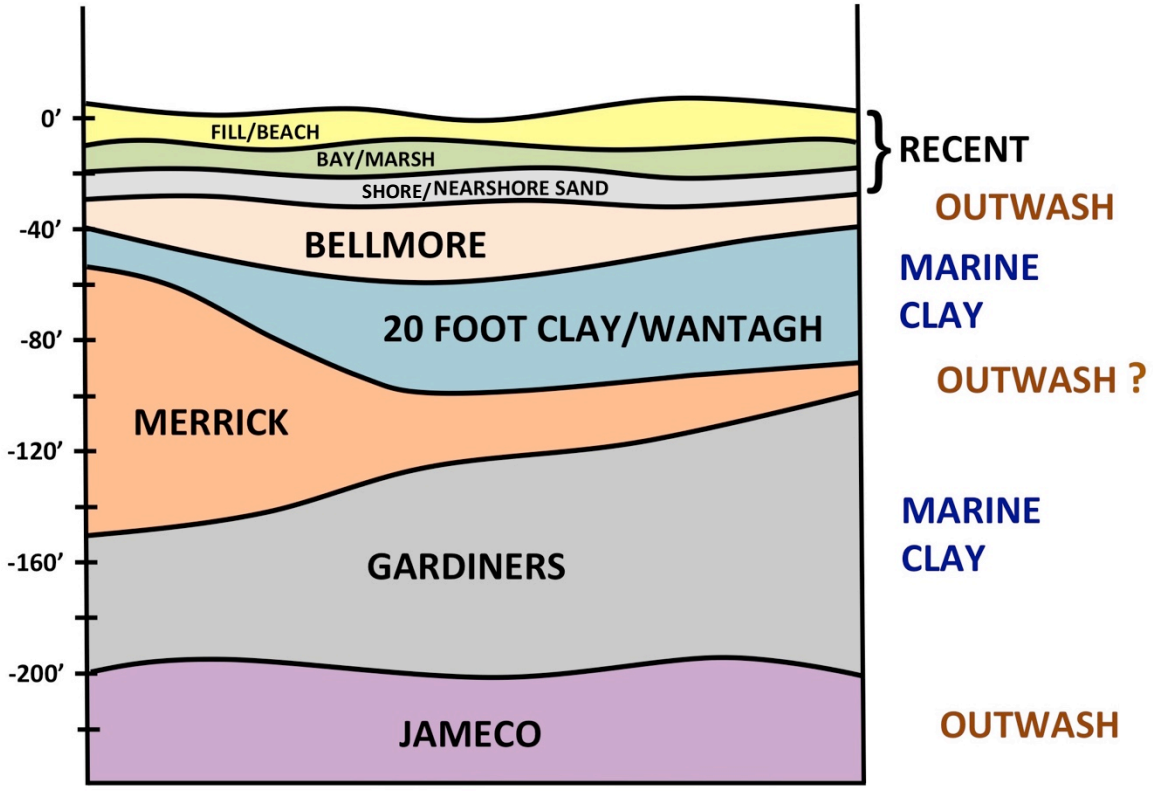

Figure 9 – Pleistocene and recent strata along Long Island's south shore. The Upper Glacial Aquifer lies above the Jameco Gravel and the Gardiners Clay. South of the terminal moraines, the Gardiners is overlain by the Merrick outwash? sand, the 20-Foot/Wantagh marine clay and then the LGM Bellmore outwash sand. With Holocene sea-level rise these deposits were reworked and covered with recent shoreline/nearshore, beach and back-bay sediments.

Terminal moraines run the length of Long Island to the north of these strata and are also grouped in the Upper Glacial Aquifer (Figure 8). The Wisconsin age Ronkonkoma Moraine runs along central Long Island and forms the south fork of Long Island. The ice front retreated an unknown distance from this position and then readvanced to build up the late-Wisconsin Last Glacial Maximum (LGM) Harbor Hill Moraine that cuts across New York City, and heads eastward to link with a series of moraines to form Long Island's north fork. There is still confusion regarding the precise ages of, and relationships between, these glacial advances, along with the associated outwash and possible interstadial strata that are found along the south shore.

Some references consider the Montauk Till to be associated with the Ronkonkoma moraine and advance, assigning to it either an Illinoian (Sanders & Merguerian 1998) or Early Wisconsin (Mills & Wells 1974) age. Some link the Merrick outwash with the Ronkonkoma advance (Rampino & Sanders 1981) and place the 20-Foot Clay/Wantagh as an inter-stadial between the Ronkonkoma and Harbor Hill advances (Soren 1978).

To top off the stratigraphic sequence, offshore and along the shoreline recent Holocene barrier island, back-bay, marsh and beach deposits often rework and cover the older glacial sediments.

Possible Interpretations

When you consider all of the strata present on Long Island there are a few ways to interpret the region's Pleistocene history, depending on which assumptions you want to make, and what sets of published ages you want to give more weight to.

1 – Revise the Presumed Ages of the Strata

If it is believed that only one Wisconsin age glaciation (the late-Wisconsin LGM event) directly affected the New York City region, then published ages of the deeper strata need to be revised older (Figure 10). The Bellmore Fm. is outwash from the late-Wisconsinan advance. Below it, the marine 20-Foot Clay/Wantagh Fm. is the Sangamon interglacial deposit. The underlying Merrick Fm. is the Illinoian outwash, the Gardiners Clay is from the pre-Illinoian interglacial, and the Jameco is outwash from a pre-Illinoian glaciation. The older AAR dates reported in the UDAARDB database (Wehmiller & Pellerito 2015) tend to support this interpretation.

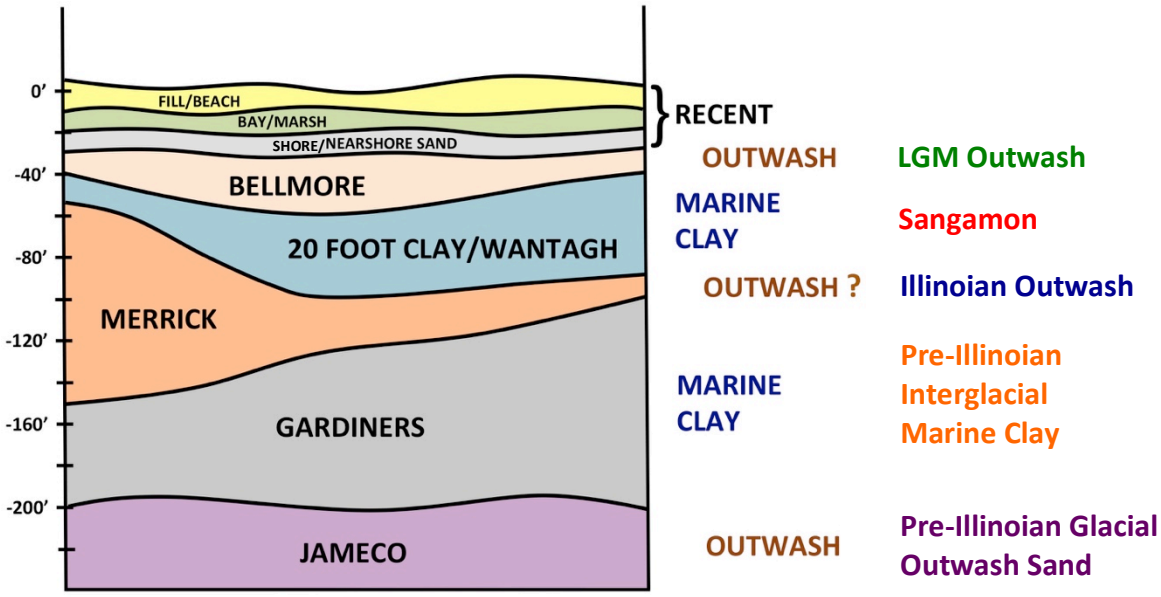

Figure 10 – If the late-Wisconsin LGM advance was the only Wisconsin age glaciation in the NYC area, then the presumed ages of the strata have to be revised older. In particular, the Gardiners becomes a pre-Illinoian interglacial deposit and the Jameco becomes outwash from a pre-Illinoian glaciation.

2 – Add an Extra Glaciation-Interstadial in the New York City Region

If the Gardiners Clay is assumed to be Sangamon age, then there are strata in the New York City area present from an extra glaciation (Merrick Fm. – MIS 4?) and interstadial (20-Foot Clay/Wantagh Fm. – MIS 3?) prior to the LGM advance (Figure 11). The mix of dates is closer to supporting this interpretation, especially if the younger "Gardiners" dates, particularly the ^{14}C dates, actually came from samples taken from the younger 20-Foot Clay/Wantagh formation (or its age equivalent stratum from the north shore of Long Island and Long Island Sound). However, the most recent references generally do not place glacial ice this far south during MIS 4, or relative sea-level only ~20 feet below current levels during MIS 3 (Figure 13).

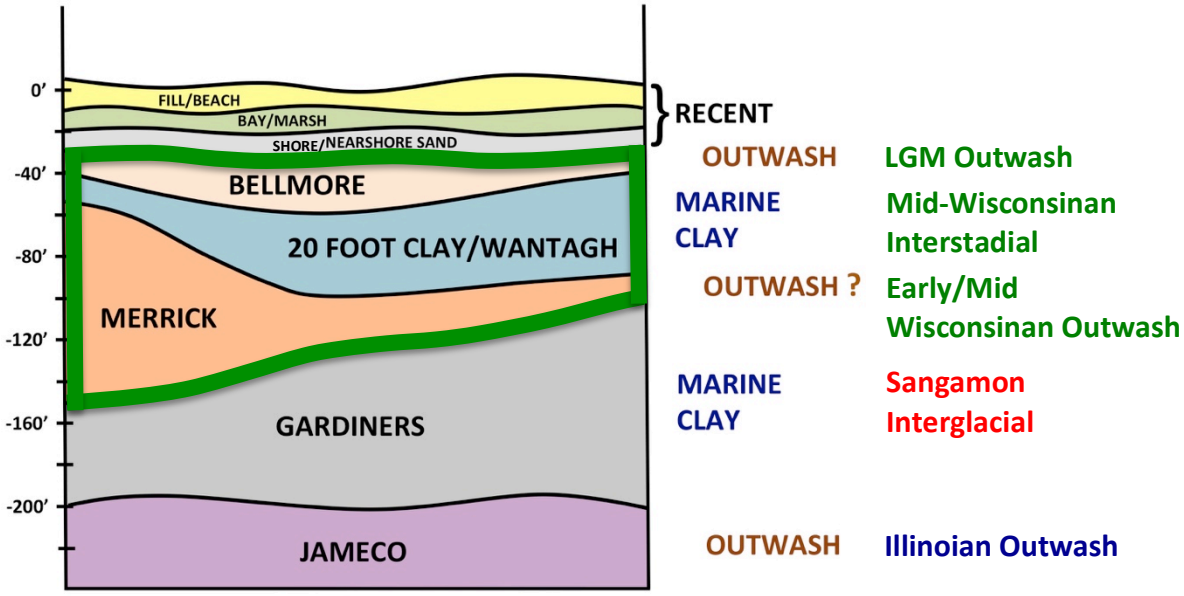

Figure 11 – If the Gardiners is Sangamon in age then an early to mid-Wisconsinan glaciation and interstadial needs to be added to the NYC region in order to deposit the Merrick outwash and the 20-Foot/Wantagh marine clay after the Sangamon and before the LGM advance.

3 – Change the Origin of the Merrick Outwash Stratum

The only possible scenario that would place the Gardiners in the Sangamon without adding another glaciation, is that both the Gardiners and Wantagh formations are Sangamon in age and the Merrick between them is not outwash at all (Figure 12). Presumably as sea-level rose and fell and the shoreline shifted, a sheet of laterally continuous sand was deposited by migrating streams, beaches and barrier islands.

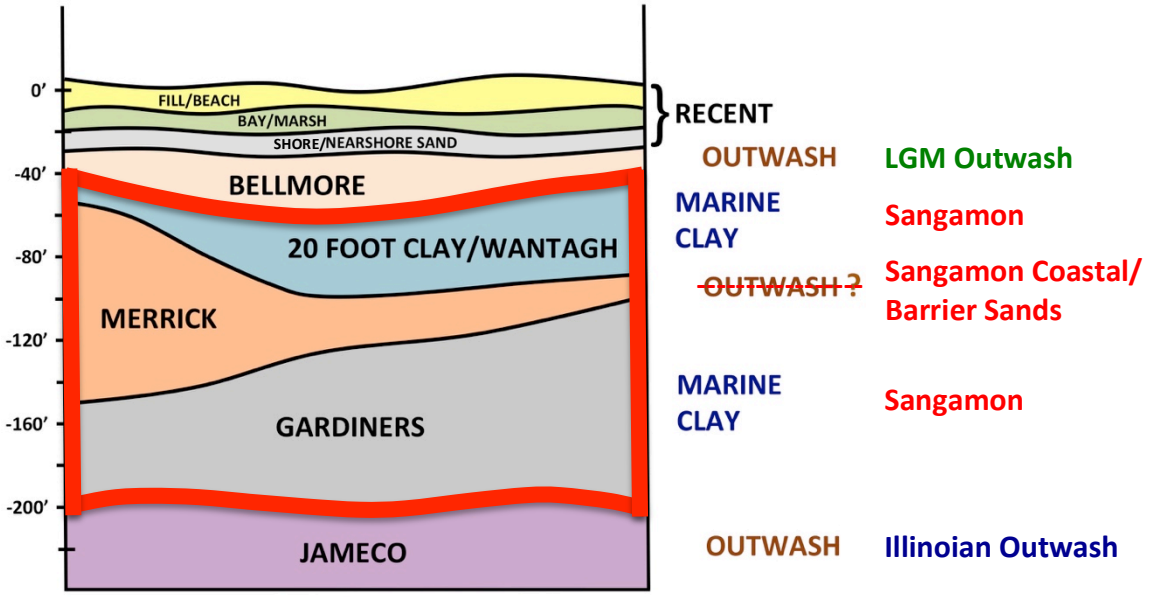

Figure 12 – If both the Gardiners and 20-Foot Clay/Wantagh formations are Sangamon in age, then the Merrick formation between them is not glacial outwash at all. Presumably as sea-level rose and fell migrating streams, beaches and barrier islands left behind a laterally continuous sheet of sand.

Discussion

There is little consensus between published references regarding the Long Island stratigraphy and glacial history. More recent U.S.G.S. papers and maps that cover New York City or Long Island, such as Buxton and Shernoff (1999) and Smolensky and Others (1989), generally follow the geologic history described by Soren (1978). These consider the Jameco to be probably Illinoian age, the Gardiners to be probably Sangamon, and the 20-Foot Clay is an interstadial marine deposit between the late-Wisconsin glacial advances that produced the Ronkonkoma and Harbor Hill moraines. However, according to even more recent references late-Wisconsin ice arrived in the area after 24 kyr BP and reached its maximum by 20 kyr BP (Stanford 2010a), not enough time for an interstadial sea-level to rise to a near modern level (Figure 13). The region was isostatically depressed during the LGM, but not likely enough to bring the area beyond the ice margin below a sea-level of -120 meters (~ -400').

Older references often placed the Ronkonkoma advance in the early to mid-Wisconsin (Mills & Wells 1974), or placed the 20-Foot Clay/Wantagh after an early Wisconsin (Rampino & Sanders 1981, Stone & Borns 1986) or Illinoian (Sanders & Merguerian 1998) glacial advance responsible for depositing the Montauk Till and associated outwash. These interpretations would allow sufficient time for the necessary amount of sea-level rise, but would either add an additional glaciation to the region, or push back the presumed ages of the underlying strata.

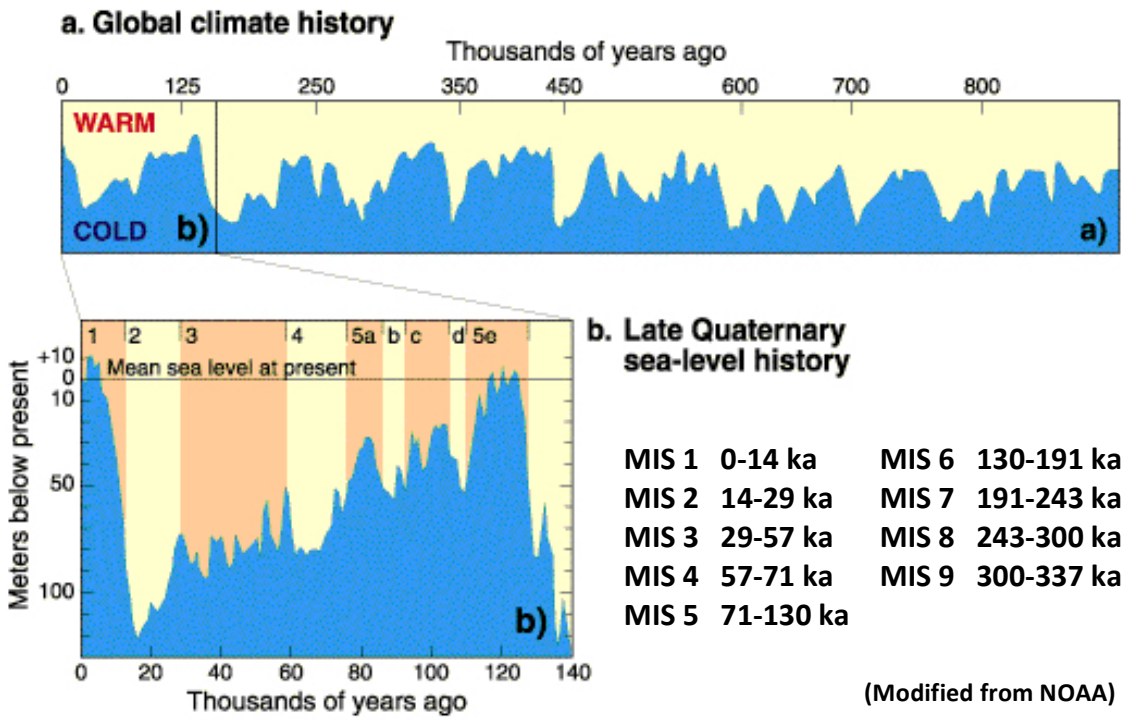

Figure 13 – Estimated global Pleistocene sea-level. The sediments that make up the 20-Foot Clay/ Wantagh Fm. are typically deposited at or fairly close to sea-level. The last time sea-level was estimated to be within 20 feet (~6 meters) of the current level was during MIS5e, roughly 120,000 years ago. The region would have had to have been isostatically depressed to a significant extent, roughly 75 meters, during MIS 3 to approach the estimated sea-level. The ages associated with the more recent Marine Isotope Stages are shown in the lower right corner. (Modified from NOAA, National Climatic Data Center website, MIS ages obtained from Lisiecki & Raymo, 2005.)

While it is possible that the Merrick Fm. is not actually an outwash deposit, this option seems the least plausible. It is more likely that the ages and events currently associated with the strata are incorrect. Additional research and/or mapping is needed to determine the actual age and relative stratigraphic positions of the formations in question. There appears to be a clear discrepancy between the published AAR and ^{14}C dates, with little overlap. There is also debate if the Montauk Till and outwash is associated with the Ronkonkoma glacial advance, or if it was deposited in an earlier glaciation. Until these issues are addressed, it is unclear which parts of the standard map references are reliable.

Acknowlegments

I would like to thank the partners at Mueser Rutledge Consulting Engineers for allowing me to publish information from the company archives. I would like to thank John Wehmiller for his considerable help in providing information from the University of Delaware Amino Acid Racemization Database and answering questions about understanding and interpreting the results. I would like to thank Herb Mills for his help describing and discussing Long Island glacial geology with me, and answering my many questions about it.

References

Buxton, Herbert; and Shernoff, Peter, 1999, Ground-water resources of Kings and Queens Counties, Long Island, New York: U.S. Geological Survey Water-Supply Paper 2498, 113 p.

Cadwell, D. H.; Connally, G. G.; Dineen, R. J.; Fleisher, P. J.; Fuller, M. L.; Sirkin, Les; and Wiles, G. C, 1991, Surficial geologic map of New York: Lower Hudson Sheet: New York State Museum, Map and Chart Series 40, scale 1:250,000.

Doriski, T. P.; and Wilde-Katz, F., 1983, Geology of the "20-Foot" Clay and Gardiners Clay in southern Nassau and southwestern Suffolk counties, Long Island, New York, U.S. Geological Survey Water-Resources Investigations Report 82-4056, 17 p.

Fuller, M. L., 1914, The geology of Long Island, New York: U.S. Geological Survey Professional Paper 82, 231 p.

Lisiecki, L. E.; and Raymo, M. E., 2005, A Pliocene-Pleistocene stack of 57 globally distributed benthic $d^{18}O$ records, Paleoceanography, v. 20, PA1003, doi: 10. 1029/2004PA001071.

Merrill, F. J. H.; Darton, N. H.; Hollick, Arthur; Salisbury, R. D.; Dodge, R. E.; Willis, Bailey; and Pressey, H. A., 1902, Description of the New York City district: United States Geological Survey Geologic Atlas of the United States, New York City Folio, No. 83, 19 p.

Merguerian, Charles; and Sanders, J. E., 1996, Glacial geology of Long Island: Guidebook for On-The-Rocks 1996 Fieldtrip Series, Trip 39, 01 + 02 June 1996, Section of Geological Sciences, New York Academy of Sciences, 130 p.

McMullen, K.Y.; Poppe, L.J.; Twomey, E.R.; Danforth, W.W.; Haupt, T.A.; and Crocker, J.M., 2007, Sidescan-Sonar Imagery, Multibeam Bathymetry, and Surficial Geologic Interpretations of the Sea Floor in Rhode Island Sound, off Sakonnet Point, Rhode Island, U.S. Geological Survey Open-File Report 2007-1150, http://woodshole.er.usgs.gov/pubs/of2007-1150/html/figures.html

Mills, Herbert C.; and Wells, Paul D., 1974, Ice-Shove Deformation and Glacial Stratigraphy of Port Washington, Long Island, New York, Geological Society of America Bulletin, vol. 85, no. 3, p. 357-364.

Moss, Cheryl J., 2009, Boulder till filled plunge pools found at the World Trade Center site, NYC, NY, Geological Society of America Abstracts with Programs, v. 41, no. 3, p. 35.

Moss, Cheryl J., 2011a, Geotechnical Evidence of Multiple Glacial Advances in New York City's Subsurface, Geological Society of America Abstracts with Programs, v. 43, no. 1, p. 95.

Moss, Cheryl J., 2011b, Use of Engineering Properties to Identify Multiple Glacial Advances in New York City's Subsurface: in Hanson, G. N., Chm., 18th Annual Conference on Geology of Long Island and Metropolitan New York, 9 April 2011, State University of New York at Stony Brook, NY, Long Island Geologists Program with abstracts, 13 p.

Moss, Cheryl J., 2015a, New York's "20-Foot Clay" Conundrum: Which is Wrong – Published Dates, Presumed Glacial Events, or Strata Origins?, Geological Society of America Abstracts with Programs, v. 47, no. 3, p. 82.

Moss, Cheryl J.; and Merguerian, Charles, 2009, 50 Ka Till-Filled Pleistocene Plunge Pools and Potholes Found Beneath the World Trade Center Site, New York, NY: in Hanson, G. N., chm., Sixteenth Annual Conference on Geology of Long Island and Metropolitan New York, 28 March 2009, State University of New York at Stony Brook, NY, Long Island Geologists Program with Abstracts, 19 p.

NOAA, National Climatic Data Center website: http://www.ngdc.noaa.gov/paleo/ctl/clisci100k.html#sea

Perlmutter, N. M.; and Geraghty, J. J., 1963, Geology and Ground-Water Conditions in Southern Nassau and Southeastern Queens Counties Long Island, N.Y., Geological Survey Water-Supply Paper 1613-A, 205 p.

Sanders, J. E.; and Merguerian, Charles, 1994b, Glacial geology of the New York City region, p. 93-200 *in* Benimoff, A. I., *ed*., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E.; and Merguerian, Charles, 1997, Geologic setting of a cruise from the mouth of the East River to the George Washington bridge, New York Harbor: New York, NY, American Rock Mechanics Association, NYRocks 97, hosted by Columbia University Field-Trip Guidebook, 147 p.

Sanders, John E.; and Merguerian, Charles, 1998, Classification of Pleistocene deposits, New York City and vicinity – Fuller (1914) revived and revised: p. 130-143 *in* Hanson, G. N., *chm*., Geology of Long Island and Metropolitan New York, 18 April 1998, State University of New York at Stony Brook, NY, Long Island Geologists Program with Abstracts, 161 p.

Smolensky, D.A.; Buxton, H.T.; and Shernoff, P.K., 1989, Hydrologic framework of Long Island, New York: U.S. Geological Survey Hydrologic Investigations Atlas HA-709.

Soren, Julian, 1978, Subsurface geology and paleogeography of Queens County, Long Island, New York: U. S. Geological Survey Water-Resources Investigations 77-34 Open File Report, 17 p.

Stanford, Scott D., 2010a, Onshore record of Hudson River drainage to the continental shelf from the late Miocene through the late Wisconsinan deglaciation, USA: synthesis and revision, Boreas, vol. 39, p 1–17.

Stanford, Scott D., 2010b, Glacial Geology and Geomorphology of the Passaic, Hackensack, and Lower Hudson Valleys, New Jersey and New York, p. 47-84 in Benimoff, A. I., ed., New York State Geological Association 82nd Annual Meeting Field Trip Guidebook, Staten Island, NY, 24-26 September 2010, 190 p.

Stone, J.R.; Schafer, J.P.; London, E.H.; DiGiacomo-Cohen, M.L.; Lewis, R.S.; and Thompson, W.B., 2005, Quaternary geologic map of Connecticut and Long Island Sound Basin: U.S. Geological Survey, Scientific Investigations Map SIM-2784, scale 1:125000.

Suter, Russell; deLaguna, Wallace; and Perlmutter, N.M., 1949, Mapping of geologic formations and aquifers of Long Island, New York: State of New York Water Power and Control Commission with the U. S. Geological Survey, Bulletin GW-18, 211 p.

Swarzenski, Wolfgang, 1963, Hydrogeology of northwestern Nassau and northeastern Queens Counties Long Island, New York: U. S. Geological Survey Water-Supply Paper 1657, 88 p.

Wehmiller, John F.; and Pellerito, Vincent, 2015, An Evolving Database for Quaternary Aminostratigraphy, GeoResearch Journal, in press.

Wehmiller, John F.; and Pellerito, Vincent, 2015, Database of Quaternary Coastal Geochronologic Information for the Atlantic and Pacific Coasts of North America, Open File Report No. 50, Delaware Geological Survey.

Moss, Cheryl J., 2015b, The Problem Posed by New York's "20-Foot Clay": Which is Wrong – Published Dates, Presumed Glacial Events, or Strata Origins?: in Hanson, G. N., Chm., 22th Annual Conference on Geology of Long Island and Metropolitan New York, 11 April 2014, State University of New York at Stony Brook, NY, Long Island Geologists Program with abstracts, 13 p.