

**PLEISTOCENE MULTI-GLACIER HYPOTHESIS SUPPORTED BY NEWLY EXPOSED  
GLACIAL SEDIMENTS, SOUTH TWIN ISLAND, THE BRONX, NEW YORK**

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**INTRODUCTION**

On 02 November 1996, during Hofstra University Geology Department's biannual Introductory Geology field trip to Pelham Bay Park in The Bronx, CM noticed that the intense storm of 19 October 1996 had undercut the coastal bluff at the south end of South Twin Island, exposing a brownish till beneath previously visible reddish-brown till. Subsequent to this short- but enlightening large-class visit, we revisited the site on 05 and 12 November 1996 to excavate-, clean up-, and sample a 2-m-high face that exposed four layers of Pleistocene strata, the lowest of which was found to rest on striated bedrock of the Hartland Formation.

Based on our previous studies of ice-eroded features on the bedrock here and elsewhere in southeastern New York, we found evidence of three glaciations, with ice flow from the NNE (Glacier I of Table 1), from the NNW (Glaciers II and/or III, which created the spectacular set of parallel striae oriented N32°W-S32°E at South Twin Island), and from the NNE (Glacier IV). We thought the storm and our shovels had exposed Till IV. The mineral composition- and color of the +0.5-phi fraction of the Pleistocene materials from the newly exposed section, however, seems to indicate otherwise. Only two contrasting suites are present in four distinct layers: (A) a reddish-brown layer in which well-rounded reddish-brown siltstone rock fragments predominate, and (B) three other layers. The freshness of the minerals rules out the presence of a till as old as Till IV. Thus, instead of a normal till-stratigraphic succession, our preliminary studies suggest that the newly excavated section displays deposits from two ice-advance directions (Nos. I and II and/or III), which have been imbricated by ice-thrust deformation.

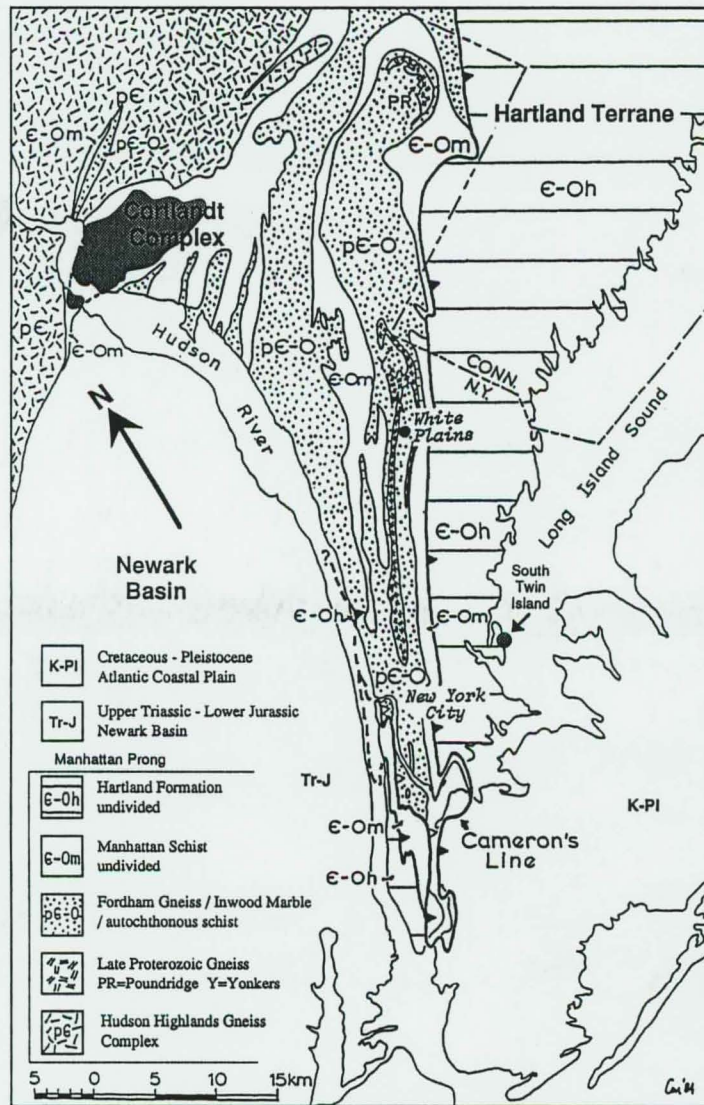
**REGIONAL GEOLOGY**

The bedrock in regions to the NW, N, and NE of South Twin Island, Pelham Bay Park, contain vastly different assemblages including Proterozoic- to Paleozoic metamorphic rocks and Mesozoic sedimentary redbeds and intercalated mafic igneous rocks. In addition, during the Cretaceous, coastal-plain strata extended inland for an unknown distance in southern New England. Although most of these onlapping coastal-plain strata have been eroded, remnants are present locally at the surface and are well known in the subsurface of NYC and vicinity.

Together, the crystalline metamorphic rocks of Manhattan and The Bronx underlie a northeast-trending physiographic province known as the Manhattan Prong (Figure 1), which contains deeply eroded sillimanite- and kyanite-grade Proterozoic- to Lower Paleozoic rocks, including gneiss, quartzite, marble, schist, and amphibolite that widen northward into the New England Appalachians. In eastern New York City and Long Island, they underlie nonconformably Cretaceous- and overlying Pleistocene (glacial) sediments.

The Manhattan Prong can be subdivided into two metamorphosed tectonostratigraphic belts. Forming the easternmost or **Taconian belt**, the Hartland Terrane (C-Oh) of Early Paleozoic age consists of muscovitic schist, gneiss, granofels, amphibolite, and minor coticule rocks. (See Figure 1.) Near the NY-CT state line, the terrane is in ductile-fault contact (along Cameron's Line) with structurally lower

but largely coeval Taconian allochthonous rocks (E-Om) mapped as the middle unit of the Manhattan Schist (Merguerian, 1983a, 1995, 1996). In NYC, the Manhattan Formation forms a kyanite-garnet grade sequence of dominantly massive biotitic gneiss, schist, and minor amphibolite. Together with their correlatives northward into Connecticut, Massachusetts, and Vermont, the Hartland- and Manhattan formations constitute a former oceanic terrane that collided with North America during the mid-Ordovician Taconic orogeny (Robinson and Hall, 1980; Merguerian, 1983b; Stanley and Ratcliffe, 1985). Rocks of the Taconian belt (E-Oh, E-Om) are in ductile-fault contact (along the St. Nicholas thrust; open thrust symbol in Figure 1) with autochthonous basement-cover bedrock units of Proterozoic- to Early Paleozoic age. These units, known from the base up as the Fordham Gneiss, Lowerre Quartzite, Inwood Marble, and overlying *in-situ* Manhattan Schist, are grouped together as unit pE-O in Figure 1.



**Figure 1** - Simplified index- and geologic map of Manhattan Prong showing the position of South Twin Island (study area), the distribution of metamorphic rocks ranging in age from Proterozoic to Early Paleozoic, Mesozoic basin-filling strata of the Newark Basin, and Cretaceous coastal-plain strata. Closed thrust symbols show Cameron's Line; open-thrust symbols show the St. Nicholas thrust. Most intrusive rocks, with the exception of the Cortlandt Complex, have been omitted. (Modified from D. G. Mose and Charles Merguerian, 1985, fig. 1, p. 21.)

Thus, on either side of the St. Nicholas-Cameron's Line thrust zone, an important Taconian structural boundary in the New England Appalachians, are exposed juxtaposed sequence of metamorphic rocks of roughly equivalent age. Both the autochthonous- and allochthonous units that crop out in Manhattan and the Bronx are strongly folded and truncated by a pre-Triassic planation surface that dips westward beneath the Hudson River.

To the west of the Hudson River, the deformed crystalline-basement rocks are nonconformably overlain by predominately red-colored sedimentary rocks and intercalated volcanic- (Watchung basalts) and intrusive rocks (Palisades Intrusive Sheet) of the late Triassic to early Jurassic Newark Supergroup. (See Figure 1.) The tilted- and eroded remnants of the Newark strata and the Palisades sheet, which are exposed along the west side of the Hudson River from Stony Point south to Staten Island, dip westward about 15°. Newark sedimentary strata were deposited in a fault-bounded basin to which the sea never gained access. Because of the arid continental setting which prevailed during their deposition, the bulk of the Newark strata developed a deep reddish-brown color, the result of hematite staining of original iron-bearing sediment. After the Newark strata had been deeply buried, they were elevated and tilted, probably the result of mid-Jurassic compressional tectonic activities (Merguerian and Sanders, 1994).

Later, during a high stand of sea level, Cretaceous sediments of the Atlantic coastal plain covered the New York City area and parts of southern New England, including both the Newark- and Hartford Basins. Found today almost exclusively in the subsurface of New York City and Long Island, Cretaceous deposits consist of variegated muscovite-rich sands, silts, clays, and armored ironstone strata. Pre-glacial erosion and glaciation have stripped most of the Cretaceous from their former up-dip extensions.

### **Geology of South Twin Island, Pelham Bay Park**

**Bedrock Geology.** The locality we describe below at the south end of South Twin Island (*UTM Coordinates: 602.4E; 4524.9N, Flushing quadrangle*), consists of glaciated exposures of the Hartland Formation immediately to the north of Orchard Beach in The Bronx (Figure 2). Described by Leveson and Seyfert (1969), and Seyfert and Leveson (1968, 1969), these steeply oriented high-grade metamorphic rocks include sillimanite-bearing gneiss and -schist, and garnet amphibolite all showing ample evidence for partial melting to produce migmatites, and syn- to post-tectonic pegmatites. The rocks, a metamorphosed deep-water sequence of interlayered shales, turbidites, volcanic- and plutonic rocks, were formerly named the Hutchinson River Group, but are now mapped as the Hartland Formation (Baskerville, 1982). Field studies by Merguerian in 1981-1983 indicate that the rocks have been affected by four phases of superposed folds which have created complex interference patterns, ideal for the purposes of student instruction.

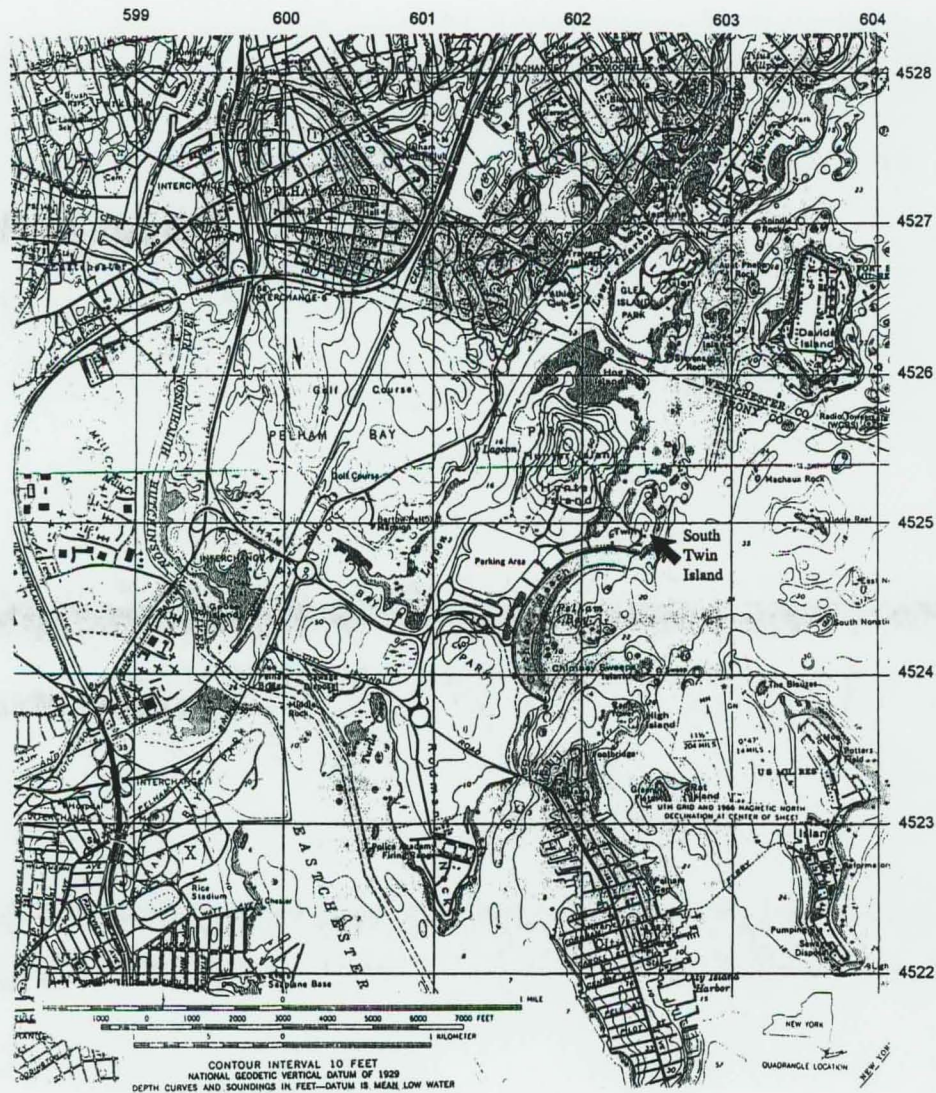
In contrast to coeval metamorphic rocks cropping out in New York City, the Hartland Formation of Pelham Bay Park is of higher metamorphic grade and consists of well-layered migmatitic feldspathic gneiss, biotite schist, and subordinate amphibolite, with no massive carbonate- nor associated Proterozoic-basement rocks. On North Twin Island, however, pinkish marble occurs as 1-m-scale boudins within sheared Hartland amphibolites, but these are isolated blocks (perhaps olistoliths?) rather than the thick-layered sequences typical of the Inwood Marble and correlatives.

**Glacial Geology.** The surface of the bedrock at Pelham Bay Park has been greatly modified by the effects of glaciation in the form of parallel striae and grooves oriented N32°W-S32°E, crescentic marks, glacial polish, and roche-moutonnée structure. The glaciated bedrock is overlain by Pleistocene sediment and glacial erratics some of which are **indicator stones**.

Table 1 - Proposed new classification of the Pleistocene deposits of New York City and vicinity

Age	Till No.	Ice-flow Direction	Description; remarks
Late Wisconsinan (Woodfordian?)	I	NNE to SSW	Gray-brown till in W. Queens, Westchester Co., Staten Is., gray lake sediments at Croton Point Park, Westchester; non-reddish till in Queens but not present on most of Long Island; Hamden Till in CT with terminal moraine lying along the S coast of CT.
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.)
Illinoian(?)	IIIA	NW to SE	Ronkonkoma Terminal Moraine and associated outwash; Merrick Fm. (in Jones Beach subsurface).
	IIIB		Manhasset Fm. of Fuller (with middle Montauk Till Member; in lower member, coarse delta foresets including debris flows) deposited in Lake Long Island.
	IIIC		Pre-Ronkonkoma terminal moraine creates dam to S of LI.
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 meta-volcanic stones, Target Rock, LI; Mannelto Gravel fills deep valley in SW Queens.
Aftonian(?)			No deposits; valley erosion and 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.

As mentioned, from our previous work (Sanders and Merguerian, 1991, 1994a, 1994b, 1995; Sanders, Merguerian, and Okulewicz, 1995; and Merguerian and Sanders, 1996) we know that in New York City, glacial sediments deposited by ice flowing from NNW to SSE (**across** the Hudson Valley) are characterized by their distinctive reddish-brown-color, the result of grinding over hematite-rich sedimentary rocks from the Newark Basin. By contrast, sediments deposited by glaciers that flowed from the NNE to the SSW (**down** the Hudson Valley) are associated with yellow-brown- to brownish-gray tills, the result of glacial scour of non-hematite-bearing rocks underlying the "crystalline corridor" of metamorphic rocks exposed between the Newark- and Hartford basins (Sanders and Merguerian, 1994b). Each of the flow directions resulted in a system of crosscutting glacial features and diagnostic indicator stones, easily identifiable in the field.



**Figure 2** - Topographic map (contour interval 10 feet) of Pelham Bay Park and vicinity, The Bronx, New York City, showing two small drumlins, with long axes oriented NNW-SSE on the golf course. Arrow (below label for Interchange 6) shows inferred direction of glacier flow, which is the same as the orientation of the dominant set of striae eroded on the bedrock surface that is being uncovered by wave erosion at Twin Island. (Copied from Mount Vernon and Flushing 7.5-minute topographic quadrangle maps of the U. S. Geological Survey.)

At the northern end of South Twin Island, a thin reddish-brown till, consisting of rounded boulders set in a matrix of poorly sorted sand, silt, and clay, undercut by storms in April of 1993, rests on bedrock exhibiting NW-SE-trending glacial grooves. Also at the extreme north end of South Twin Island, the bedrock shows evidence of having been sculpted by two glaciers, the initial one flowing from NNE to SSW (Glacier IV of Table 1) and the second from the NW to the SE (Glacier III or II). On display here is what we have described as a "roche-moutonnée structure," that is the up-flow part of a typical roche moutonnée but where the typical down-flow jagged face has been smoothed by a second glacier flowing at a high angle to the first. Present near the S end of South Twin Island are two large boulders of ultramafic rock which were deposited by Glacier I. (See Table 1.) These large erratics are interpreted to be indicator stones from the eastern funnel of the Cortlandt Complex, located due N near Peekskill, NY. (See Figure 1.)

Before the 1996 storm and our shovels had unearthed the new exposures, only reddish-brown till (base not exposed) could be seen at the south end of South Twin Island.

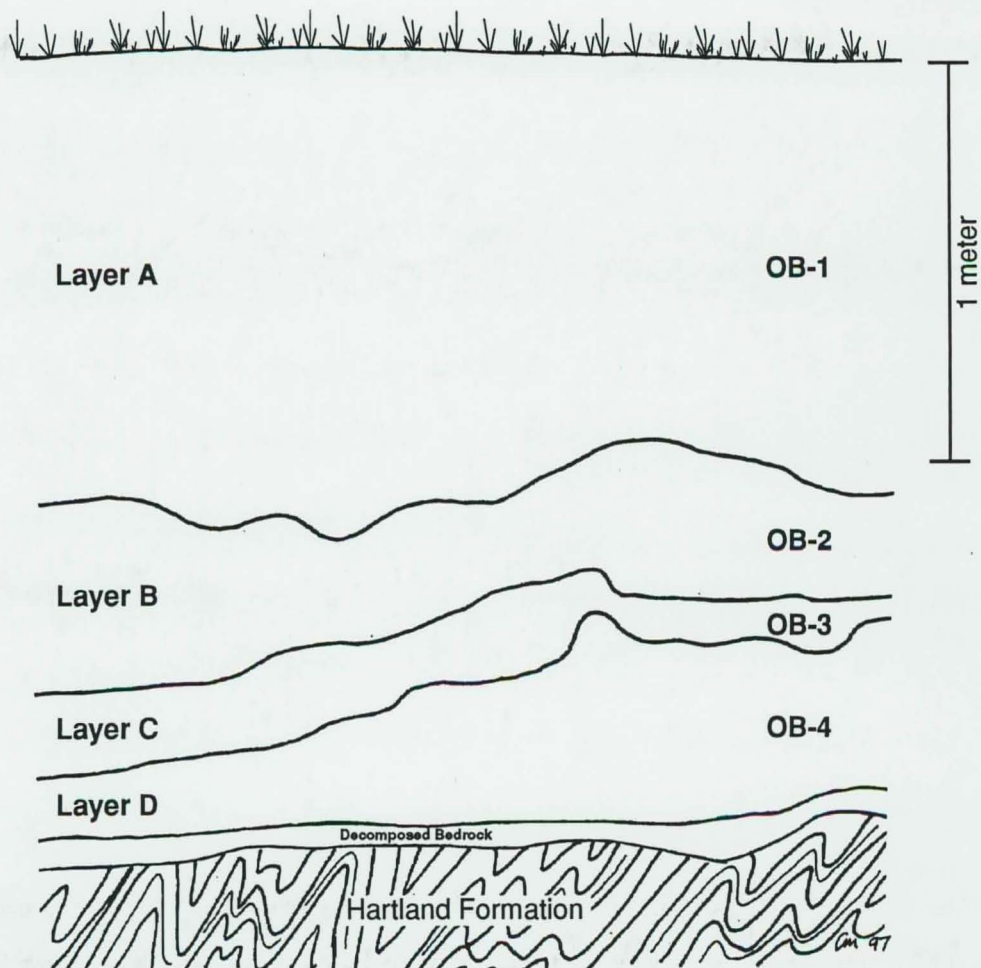
### NEWLY EXPOSED GLACIAL DEPOSITS

By cleaning up the storm-eroded face from the top of the low bluff to the striated bedrock surface we have found Pleistocene units (Figure 3) that together compose roughly 2 meters of nonlithified sediment. From the top down, they include a layer of massive clast-poor bouldery reddish-brown clay-rich till, about a meter thick, which has always been exposed at this locality. This unit (Layer A in Figure 3) is underlain by an irregular layer (~13 cm thick) of pebbly brown till (Layer B). Our excavations indicate that the exposed brown till is underlain by an undulating 5- to 12-cm-thick layer of reddish-brown silty outwash (Layer C) containing friable well-rounded granules of Newarkian siltstone. These layers are, in turn, underlain by a 22-cm-thick layer (Layer D) of pebbly brown till (nearly identical to the second layer) which grades downward into a 4-cm-thick layer of granular reddish disintegrated bedrock that rests on striated biotite-schist and -gneiss of the Hartland Formation.

One haunting difficulty with the interpretation of the layers we exposed involved the possibility that these materials are nothing more than the *Recent* (one might insert the term *Obscene*) work of Robert Moses, who is known to have modified this area by filling in low places. JES investigated this possibility by contacting New York City's Parks Commissioner, Henry J. Stern, to find out to what extent Moses had modified the area of our research. His reply, dated 22 January 1997, stated that "the main categories of fill used in the gargantuan 'reclamation' projects of the Moses era were usually of the following four types: 1) hydraulically dredged sand; 2) sanitation debris (household trash); 3) construction and demolition debris consisting primarily of brick, concrete, and stone rubble; and 4) coal ash and cinders. The four fill types sometimes appear as pure, discrete deposits, other times in various combinations. Each is also usually associated with a distinctive weed flora comprising primarily Phragmites and Artemisia."

Satisfied that our massive clay-rich clast-poor uppermost layer (Layer A in Figure 3), which crops out continuously along the entire eastern shore of South Twin Island **was not fill**, our sampling of the four Pleistocene layers were numbered according to the following scheme from the top down:

- Layer A (youngest) = Sample OB-1
- Layer B = Sample OB-2
- Layer C = Sample OB-3
- Layer D (oldest) = Sample OB-4



**Figure 3** - Sketch of the four units of Pleistocene sediment exposed at the south end of South Twin Island, Pelham Bay Park, The Bronx. The four layers, which were excavated by the authors in November 1996 following an intense coastal storm on 19 October 1996, rest on a bedrock surface exhibiting N32°W-oriented striae.

The samples from the four layers have been analyzed by standard sieve- and binocular techniques. Samples were soaked for two days in water after which they were sonified for 10 minutes and subjected to wet sieving through a 230-mesh sieve to separate the silt- and larger-sized fractions from the clay. The pebbles-, sand- and silt-sized fractions were carefully dried and passed through a dry sieve stack for 10 minutes in a Tyler Ro-tap machine to separate out the various size fractions (by 0.5-phi increments) that allowed binocular microscopic examination and x-ray analysis (in progress) of the samples. We concentrated our attention on the fraction caught on the +0.5-phi sieve (smaller than 1 mm and larger than 0.7 mm).

### LABORATORY RESULTS

As mentioned, the mineral composition and color indicate that all four samples can be assigned to only two contrasting suites: the reddish-brown layer (Layer C) in which well-rounded reddish-brown siltstone rock fragments predominate; and the three other layers (Layers A, B, and D). In general, the

distinctive features of the samples are displayed by the coarser fractions that include the still-recognizable rock fragments. In the smaller fractions, progressively more ground-up quartz is present. The minerals in all samples appear fresh and unaltered suggesting a relatively young age.

A visual estimate of the 0.5-phi fraction of Sample OB-3 indicates 50% siltstone rock fragments, 40% quartz, and 10% micas (biotite>muscovite), metamorphic rock fragments (mostly sillimanitic schists), and white plagioclase. Also included are traces of green hornblende and pink garnet. By contrast, the 0.5-phi fraction of Samples OB-1, OB-2, and OB-4 totally lack any siltstone rock fragments. Quartz and biotite are the predominant minerals, but the proportion changes among the samples. In OB-1 quartz forms 60%; in OB-2, 50%; and in OB-4, only 30%. Biotite changes from 20% to 40% to 60% in the corresponding samples, respectively. White plagioclase forms about 10% in all three samples. Sillimanite is a common accessory in Sample OB-1 and garnet is a prominent accessory in Sample OB-4.

Our preliminary results suggest that our newly excavated section displays deposits from two ice advances (Nos. I and II and/or III) which have been imbricated by ice-thrust deformation.

### DISCUSSION

A long-standing debate about the Pleistocene glacial history of the New York City region is whether the glacial features hereabouts were caused by the advance- and retreat of one continental glacier or by more than one such glacier. A key factor involved in this debate is direction of flow of the glacial ice. One of our chief contributions to knowledge of the local Quaternary record is an emphasis on the features by which the direction of flow of a former glacier can be established. We follow the principle that a continental glacier can be characterized locally by a distinctive flow direction. (See Table 1.) Application of this principle has led us to resurrect, but to modify in several important respects, M. L. Fuller's (1914) four-glacier classification of the Quaternary deposits of Long Island.

Starting in the mid-1930's revisionist-minded "Friends of the Pleistocene" cast aside Fuller's four-glacier classification and adopted the viewpoint that nearly all of our local glacial features were made during the latest glacial episode, the "Wisconsinan." The contemporary view among Pleistocene geologists, widely circulated in textbooks, discussed at conferences, and in popular accounts of the geology of Long Island, is that the latest glacier to visit our area, i. e., the "Woodfordian" glacier of many authors, deposited not only both of Long Island's terminal-moraine ridges but also produced all the other glacial features in the area. In short, one glacier did it all. We disagree with this concept and include a brief summary of our stratigraphic basis for resurrecting- and modifying Fuller's classification, which depends on evidence found at localities outside The Bronx.

Fuller found deposits that he interpreted as products of 4 glacial advances; between some of the glacial sediments, he found nonglacial strata. In order of decreasing age, Fuller (1914) recognized the following six major units of the Pleistocene on Long Island: (1) the Mannelto Gravel, (2) the Jameco Gravel, (3) the Gardiners Clay, (4) the Jacob Sand, (5) the Manhasset Formation (which Fuller diagnosed as consisting of two units of outwash, the basal Herod Gravel and upper Hempstead Sand/Gravel, that are separated by a middle Montauk Till) and (6) the two world-famous terminal-moraine ridges and associated outwash plains to the south of each: the older Ronkonkoma and younger Harbor Hill, which overlie the Manhasset Formation. (See Table 1.)

Our five main reasons for resurrecting- and modifying Fuller's (1914) classification are: (1) provenance data indicating that the latest-Wisconsinan ("Woodfordian" of authors) glacier, which flowed from NNE to SSW, did not reach most of eastern Long Island; (2) provenance- and structural data supporting the interpretation that the glacier which deposited the Harbor Hill Moraine flowed regionally



from NNW to SSE and was of pre-"Woodfordian" age (we accept Fuller's "Early Wisconsinan" assignment); (3) subsurface data from the vicinity of Jones Beach suggesting an "Illinoian" age for the glacier that deposited the Ronkonkoma Moraine (earlier than Fuller's "Early Wisconsin"), and Gilbert-type deltas in the Herod Gravel Member of Fuller's Manhasset Formation (Sanders, Merguerian, and Mills, 1993; Sanders and Merguerian, 1994b) that not only absolutely destroys the basis for the revisionists' "Wisconsinan" age reclassification of Fuller's Manhasset Formation but also requires Fuller's non-lacustrine paleoenvironmental analysis to be significantly modified by including the requirements for impounding a large lake, probably requiring a now-eroded, pre-Ronkonoma terminal moraine; (4) the new-, and to us convincing, chronostratigraphic information supporting Fuller's "Yarmouthian" age of the Gardiners Clay that H. C. Ricketts (1986) collected from two borings made near Kings Point (on Great Neck, west side of Manhasset Bay) on which J. H. Wehmler, of the University of Delaware, found D/L leucene values between 0.26 and 0.34, which implies that the age of the shells is about 225,000 years [225 Ka]; and (5) our discovery of two much-weathered tills, not yet dated but presumably of Early Pleistocene ages.

Our proposed classification of the Pleistocene deposits of the New York City region is close to Fuller's but differs in that we recognize products of five (not four) glacial advances. (See Table 1.) Because we lack evidence for assigning ages to the products of these various glacial episodes, the best we can do is count them down from the top. Accordingly, we designate each of the tills (and its formative glacier) by a roman numeral, starting with I, the youngest, at the top, and ending with V, the oldest, at the bottom.

According to us, **Glacier I** flowed from NNE to SSW and did not reach most of Long Island; it deposited the fields of drumlins in Rockland County, NY and the yellowish-brown till forming a single drumlin at Enoch's Nose, Croton Point Park, Westchester County, NY; the Hamden Till in south-central Connecticut; and a terminal moraine along the S coast of Connecticut (SW of the Norwalk Islands, it crossed what is now Long Island Sound and covered Queens, Brooklyn, and at least some of Staten Island). At Pelham Bay Park, it deposited the ultramafic Cortlandt erratics and the brown tills (Layers B and D), which rest on reddish-brown outwash (Layer C) and locally cuts down to bedrock. (See Figure 3.) These layers have been repeated by ice-thrust deformation. The uppermost layer (Layer A) has probably been affected by ice-thrust mechanisms, as well. At present we are not sure about the timing of this event but based on the freshness of the component minerals, infer that it occurred during Glacier I time. A possible Glacier I/II interglacial deposit is the paleosol capping the reddish-brown till in the coastal bluffs of SW Staten Island.

**Glacier II**, flowing from NNW to SSE reached all of Long Island and deposited the Harbor Hill Moraine and reddish-brown till at Croton Point Park and other localities on the E side of the Hudson River in Westchester County and New York City (including our Layer A till at Pelham Bay Park); and possibly also the Lake Chamberlain Till of south-central Connecticut. Glacier II/III interglacial marginal-marine sediments include the Wantagh Formation of the Jones Beach subsurface (the "20-foot clay" of geologists from the U. S. Geological Survey Water Resources Branch).

**Glacier III**, the most-extensive of them all, also flowed from NNW to SSE and featured three fluctuations; its earliest advance deposited a now-vanished and -submerged terminal-moraine; the ice front then retreated and a regionally extensive proglacial Lake Long Island formed in which the lacustrine sediments forming the lower member of Fuller's Manhasset Formation were deposited; a subsequent readvance deposited the Montauk Till; and after another retreat and deposition of outwash sediments, a final readvance deposited the Ronkonkoma Moraine. Glacier III/IV interglacial deposits include the Gardiners Clay.

**Glacier IV** flowed from the NNE to the SSW, deposited a gray-brown till exposed at water's edge, Teller's Point, Croton Point Park and in the lower part of the coastal bluff at Target Rock National Wildlife Refuge, Long Island; and sculpted many rock exposures in the Hudson Highlands, in northern Manhattan, and in the New York Botanical Garden and the roche moutonnée structure at the N end of Pelham Bay Park, both in The Bronx. We have not found any Glacier IV/V interglacial deposits.

**Glacier V** flowed from NNW to SSE and deposited the much-decomposed reddish-brown tills resting on the Upper Cretaceous coastal-plain strata at the AKR Excavating Company, SW Staten Island, and at Garvies Point, Long Island.

### CONCLUSIONS

Preliminary laboratory study of sieved samples from the newly exposed section of Pleistocene sediments at South Twin Island indicates only two kinds of materials that we assign Tills I and II (and/or III) of our resurrected-modified Fuller classification. We had hoped the laboratory studies might reveal additional stratigraphic evidence with respect to the number of glaciations which we had previously inferred from studying features eroded on the bedrock and by identifying indicator stones. Unfortunately, our preliminary sedimentologic investigations have not reconciled the order of superposition of the four Pleistocene layers as an uninterrupted stratigraphic succession. Rather, our findings suggest that the four layers sampled have probably been repeated by ice-thrust tectonics. With shovels in hand, we await the next storm.

### ACKNOWLEDGEMENTS

Our continued studies of the glacial geology of the New York City area have been supported by the Geology Department of Hofstra University. We are indebted to our colleague Prof. J Bret Bennington for his expertise in computer drafting of Figures 1 and 3 and to Mr. Henry J. Stern, Commissioner, New York City Parks Department for his timely response to our inquiry. In the field, along with our two student coauthors, Christopher Merguerian dug and collected rocks for analysis and throwing.

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