

CLASSIFICATION OF PLEISTOCENE DEPOSITS, NEW YORK CITY AND VICINITY--FULLER (1914) REVIVED AND REVISED

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INTRODUCTION

After the Pleistocene deposits in New York City and vicinity had been recognized as products of continental glaciation, debates arose and have continued over the number of times such now-vanished continental glacier(s) invaded our region. Late in the nineteenth- and early in the twentieth centuries, several authors cited evidence that SE New England had been subjected to at least two and probably three discrete ice advances (Shaler, 1866, 1886; Shaler, Woodworth, and Marbut, 1896; Upham, 1879a, b; 1880; 1889a, b, c; Woodworth, 1901; Clapp, 1908; Fuller, 1901, 1903, 1905, 1906). In the face of the case made by T. C. Chamberlin (1883, 1888, 1895a, b) for a "one-glacier-did-it-all" view, however, the multi-glaciation concept lost favor. The one-glacier view took over. (For examples, see references by Salisbury and co-workers in New Jersey.)

In 1914, the U. S. Geological Survey finally published M. L. Fuller's monograph on the geology of Long Island (based on field work completed nearly a decade earlier). 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 (Table 1).

In 1934, Woodworth and Wigglesworth published their monograph on the glacial deposits of Cape Cod and offshore islands. Their stratigraphic units closely matched those Fuller had found on Long Island; they accepted and reinforced Fuller's four-glacier interpretation. Almost immediately thereafter, revisionist-minded "Friends of the Pleistocene" (Flint, 1935; Fleming, 1935; MacClintock and Richards, 1936, 1937) cast aside the four-glacier classification of Fuller and of Woodworth and Wigglesworth and adopted the viewpoint that nearly all of the glacial features in our region had been made during the latest glacial episode, the "Wisconsinan" of modern terminology. This was, in effect, a return to T. C. Chamberlin's interpretation. The contemporary view among virtually all Pleistocene geologists (Schafer and Hartshorn, 1965; Muller, 1965; Koteff, Oldale, and Hartshorn, 1967; Sirkin, 1968; 1982, 1986, 1991; Sirkin and Mills, 1975; Cadwell, 1986, 1989) widely circulated in textbooks, discussed at conferences, and in popular accounts of the geology of Long Island (Schuberth, 1968; Isachsen, Landing, Lauber, Rickard, and Rogers, 1991) and of New Jersey (Widmer, 1964), is that the latest

glacier to visit our area, i. e., the "Woodfordian" glacier, deposited not only both of Long Island's terminal-moraine ridges but also produced all the other glacial features in the area. In short, they support the view that one glacier did it all. The one-glacier view had become so firmly entrenched that evidence to the contrary was cited as constituting the "two-till **problem**" (Pessl and Schafer, 1968).

But, despite the continued onward rolling of the "one-glacier" bandwagon, several investigators have published evidence comparable to that mentioned in a previous paragraph in support of a multi-glacial interpretation (Goldsmith, 1960; Flint, 1961; Kaye, 1964b, c, d; 1976, 1982; Pessl, 1966; Oldale, 1982; Oldale and Colman, 1992; Oldale and Eskenasy, 1983; Oldale, Valentine, Cronin, Spiker, Blackwelder, Belknap, Wehmiller, and Szabo, 1981; W. A. Newman and Mickelson, 1994; Muller and Calkin, 1993; Muller, Sirkin, and Craft, 1993).

Table not available.

Table 1. Pleistocene formations of Long Island showing Fuller's classification and two mid-1930's modifications to it proposed by revisionist-minded "Friends of the Pleistocene." In the "Fuller, 1914" column of Muller's original version of this table, the Harbor Hill Moraine and Ronkonkoma Moraine were shown as latest Wisconsin, the revisionist view. Fuller, however, assigned these two moraines to the Early Wisconsin, as shown here. (After E. H. Muller, 1965, tab. 2, p. 104.)

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. 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.

We have found five main reasons for resurrecting- and modifying Fuller's (1914) classification: (1) provenance data indicate that the latest-Wisconsinan ("Woodfordian" of authors) glacier, which flowed from NNE to SSW, **did not reach most of eastern Long Island** but deposited a terminal moraine along the S coast of CT (Ellis, 1962; Flint and Gebert, 1976) and thus was not responsible for depositing the main body of the feature known as the Harbor Hill Moraine on Long Island (Fig. 1); (2) provenance- and structural data support the interpretation that the glacier which did deposit the main body of the Harbor Hill Moraine on Long Island

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Figure 1. Sketch map of southern New England and vicinity, including adjacent islands showing locations of end-moraine ridges (black). We think that only the Old Saybrook and related moraines are products of the "Woodfordian" glacier that flowed from NNE to SSW. According to us, this moraine (of Glacier I in our proposed classification) was limited to coastal Connecticut as far W as the Norwalk Islands and extended southward so as to cross western Long Island (Queens and Brooklyn) only SW of these islands. (R. F. Flint and J. A. Gebert, 1974, fig. 4, p. 187.)

flowed regionally from NNW to SSE (Fig. 2) and was of pre-"Woodfordian" age (we offer no new data but accept Fuller's "Early Wisconsinan" assignment); (3) subsurface data from the vicinity of Jones Beach (Rampino, 1978 ms.; Rampino and Sanders, 1981) suggest an "Illinoian" age for the glacier that deposited the Ronkonkoma Moraine (earlier than Fuller's "Early Wisconsin"), and Gilbert-type deltas (G. K. Gilbert, 1885, 1890) 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 a feature required for impounding a large Proglacial Lake Long Island (we think this feature probably was a now-eroded, pre-Ronkonoma terminal moraine but admit that it could have been an upbulged part of what is now the sea floor that was elevated as a peripheral bulge but disappeared after the ice had melted); (4) the new-, and to us convincing, chronostratigraphic information that supports 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. Wehmiller, 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) two much-weathered tills, not yet dated but presumably of Early Pleistocene ages, that we have discovered: a younger one at Croton Point, Westchester Co., NY; and an older one at Garvies Point, Long Island; and in SW Staten Island.

Figure not available.

Figure 2. Sketch map of Connecticut, adjacent parts of New York, Rhode Island, and part of SE Massachusetts showing inferred regional SE-directed flow pattern in the glacier (No. II of our classification, Early Wisconsinan?) that deposited the Harbor Hill Moraine. (After J. H. Wilson, 1906, Plate II, fig. b, with N and E sides cropped.)

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 (Table 2).

Table not available.

Table 2. Proposed classification of Pleistocene deposits in southeastern New York and vicinity according to our interpretation that these deposits have resulted from 5 glacial invasions, assigned roman numerals counted down from the top.

Because we lack evidence for assigning absolute 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.

In this paper we present some highlights of the bedrock underlying areas north and west of Long Island that have provided distinctive indicator stones to the Pleistocene deposits and outline the components of our proposed classification.

HIGHLIGHTS OF BEDROCK UNDERLYING AREAS NORTHWEST AND NORTH OF LONG ISLAND

The bedrock underlying the regions to the northwest and north of Long Island contains vastly different assemblages including Proterozoic- to Paleozoic metamorphic rocks from the central parts of the Appalachians and Mesozoic sedimentary redbeds and intercalated mafic igneous rocks that are remnants of the fillings of the Newark and Hartford basins, respectively. In addition, during the Cretaceous, coastal-plain strata, whose modern-day outcrop edge extends across NE New Jersey and is buried beneath the Pleistocene sediments of Long Island, extended inland for an unknown distance in southern New England. Although NW and N of the outcrop edge, most of the onlapping coastal-plain strata have been eroded, remnants are present locally at the surface and are well known in the subsurface of New York City and vicinity.

Together, the crystalline metamorphic rocks underlying the region of interest consist of sillimanite- and kyanite-grade Proterozoic- to Lower Paleozoic rocks, including gneiss, quartzite, marble, schist, and amphibolite (Baskerville, 1992, 1994; Rodgers, 1985; Drake and others, 1996). Distinctive igneous rocks of Late Ordovician age are present, notably in the Cortlandt Complex near Peekskill, Westchester Co., NY (Ratcliffe, 1981; Ratcliffe, Bender, and Tracy, 1983).

Two bodies of Mesozoic-age strata nonconformably overlie these deformed crystalline-basement rocks (Fig. 3). The Mesozoic rocks (of Late Triassic-Early Jurassic ages, Olsen, 1978; Froelich and Olsen, 1985; Lyttle and Epstein, 1987) consist predominantly red-colored sedimentary strata but include intercalated sheets of both intrusive-and extrusive dark bluish-gray mafic igneous rocks whose fresh color is masked by a thin limonitic

coating from the oxidation of thin film of joint-facing pyrite and whose textures range from that of basalt to that of pegmatitic gabbro.

West of the Hudson River, from Stony Point, Rockland Co., NY, south to Staten Island and beyond, is the type area of the Newark Supergroup (Froelich and Olsen, 1985). Here, the strata dip predominantly to the NW, usually at angles of about 15° or less (Lytle and Epstein, 1987). The tilted and eroded edge of the sheet of resistant intrusive rock near the base of the sedimentary strata forms the Palisades ridge. Comparable tilted, eroded edges of sheets of resistant volcanic rocks that are intercalated high up in the stratigraphic succession form the Watchung ridges of north-central New Jersey.

The Mesozoic sedimentary and igneous rocks filling the Hartford Basin underlie a north-south-trending lowland in the central part of Connecticut that continues northward into Massachusetts. The strata composing the filling the Hartford basin show many similarities with those filling the Newark basin in New Jersey and adjacent Pennsylvania (Sanders, 1963). Both consist predominantly of red-colored sedimentary rocks and intercalated sheets of mafic igneous rocks both intrusive and extrusive. In contrast with the Newark basin, the regional dip of the preserved remnants of the Hartford basin-filling strata is to the E. The tilted edge of the resistant intrusive sheet near the base of the Mesozoic rocks in the central Connecticut belt forms West Rock. The Connecticut equivalents of the Watchung extrusives are the volcanic rocks of the Talcott, Holyoke, and Hampden basalts. These underlie curvilinear ridges that are near the top of the preserved sedimentary strata in southern CT, but are present near the middle of the succession in central CT.

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Figure 3. Regional sketch map of part of NE USA showing locations of preserved remnants of strata that filled Mesozoic nonmarine basins (Newark basin in NY, NJ, and PA; Hartford basin in CT and MA; light gray tone). Parallel line segments show how glacial ice flowing regionally from each of the observed dominant directions would distribute diagnostic erratics to Long Island. P = Peekskill, NY, near unique Cortlandt Complex of coarse ultramafic igneous rocks. (Base map from J. E. Sanders, 1963, fig. 7, p. 513.)

A. Flow from NNW to SSE deposits reddish-brown till and erratics of Mesozoic rocks in extreme W and extreme E Long Island, but throughout a substantial stretch along the N shore of Long Island, downflow from the "crystalline corridor" between the two belts of Mesozoic rocks, did not deposit any reddish-brown till. The distribution of erratics in the Harbor Hill Moraine and in the Ronkonkoma Moraine proves these moraines were deposited by ice flow from NNW to SSE, as shown in Fig. 2.

B. Flow from NNE to SSW, as in the "Woodfordian" glacier, distributes erratics from the Hartford basin to the WSW. The absence of reddish-brown till and associated Mesozoic erratics in the Pleistocene deposits exposed along the N shore of Long Island WSW of the S end of the Hartford basin proves that the "Woodfordian" ice could not have deposited the main bodies of Long Island's two famous terminal-moraine ridges.

The distinctive colors and compositions of the Mesozoic rocks make them ideal indicator stones and pigments for distinctive reddish-brown tills. However, by themselves, erratics from the Newark basin cannot be distinguished from those from the Hartford basin. At least locally, however, the associated non-Mesozoic rocks provide useful diagnostic clues. For example, low-grade phyllites, -schist, and -metavolcanic rocks containing chlorite and epidote are present in the western Connecticut terrane W of the S end of the Hartford basin (Fritts, 1962; Burger, 1967). No such low-grade rocks of volcanoclastic parentage are present in the vicinity of the Newark Basin of New Jersey. Therefore, erratics of such low-grade volcanoclastic rocks associated with distinctive Mesozoic rocks would **uniquely** identify a Connecticut source.

COMPONENTS OF OUR PROPOSED CLASSIFICATION OF PLEISTOCENE DEPOSITS

As mentioned, from our previous work (summarized in Sanders and Merguerian, 1997) 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 a glacier's 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. Each of the flow directions resulted in a system of crosscutting glacial features and diagnostic indicator stones, easily identifiable in the field.

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 (Flint, 1961); and a terminal moraine along the S coast of Connecticut [SW of the Norwalk Islands (Ellis, 1962), it crossed what is now Long Island Sound and covered Queens (Woodworth, 1901; Brooklyn (Lyell, 1852), and at least some of Staten Island). Based on evidence from the Catskills (Rich, 1935), we can infer that the "Woodfordian" glacier was thinner than most, if not all, of its predecessors (top at alt. 3900 ft vs. ice thick enough to cover all of the Catskills and all other high parts of New England). 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; and possibly also the Lake Chamberlain Till of south-central Connecticut (Flint, 1961). Glacier II/III interglacial marginal-marine sediments include the Wantagh Formation of the Jones Beach subsurface [Rampino (1978 ms.); Rampino and Sanders (1981)].

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 II and/or Glacier III (we do not know which; it could have been both) brought anthracite erratics from NE Pennsylvania into the New York City region. Such ice flow explains the results that Zen and Mamay (1968), who accepted the consensus view of only a single direction of Pleistocene ice flow from the NNE to the SSW, found so puzzling.

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 sculpted 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

The main bodies of Long Island's two famous terminal moraines contain unmistakable provenance evidence that they were deposited by ice that flowed regionally from NNW to SSE. Because the "Woodfordian" glacier, our No. I, is the glacier most geologists accept as being responsible for these two moraines, flowed from NNE to SSW and stopped along the S coast of CT; it reached only westernmost Long Island (Queens and Brooklyn) and adjacent parts of Staten Island. Accordingly, the main body of the Harbor Hill Moraine **could not have been deposited by the "Woodfordian" glacier** but rather must have been deposited by ice flowing from NNW to SSE. We think the glacier responsible for depositing the main body of the Harbor Hill Moraine was our No. II (of probable Early Wisconsinan age, as Fuller believed). The subsurface Wantagh Formation, a marginal-marine deposit, may be of Sangamonian age. The most-extensive

local Pleistocene unit is Fuller's Manhasset Formation, which is probably of Illinoian age. It consists of two deposits of large proglacial lakes separated by the Montauk Till (our units IIIA, IIIB, and IIIC). We conclude that a terminal moraine of pre-Ronkonkoma age (deposited by our Glacier IIIC), which we correlate with the Martha's Vineyard-Nantucket moraines and bouldery shoals in between, served as the dam to impound Proglacial Lake Long Island in which the lacustrine parts of the Manhasset Formation were deposited. We accept Wehmiller's finding that the Gardiners Clay is of Yarmouthian age (as assigned by Fuller) and **not of Sangamonian age** as supposed by MacClintock and Richards (1936) and their host of followers. The ages of two pre-"Illinoian" tills (our Nos. IV and V) that contain much-decayed stones are not well constrained. We guesstimate their assignments as "Kansan" (?) and "Nebraskan" (?), respectively.

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