Long Island Geologists

Saturday June 29, 1991

Field Trip

Pleistocene Geology of Long Island's North Shore: Sands Point and Garvies Point to Target Rock

Figure 1. Physiographic sketch map of Long Island and vicinity showing the location of field-trip stops. (J. A. Bier, 1964.)

Notes for Field Trip by both trip leaders:

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INTRODUCTION

We have offered to lead this trip in order to lay before those interested in Long Island geology some implications (we would go so far as to assert, "far-reaching" implications) that follow from evidence we have discovered during the past several years on Staten Island and in Westchester County, chiefly, with respect to the number of and flow directions of the Pleistocene glaciers. We are convinced that as many as 5 continental glaciers spread into the New York metropolitan area and that each of them flowed from one of two contrasting directions, NNW to SSE and NNE to SSW. What we have to say is based on the following 3 propositions:

Proposition No. 1 in our interpretation may be paraphrased from a recent U. S. Supreme Court ruling on voting rights: "one person, one vote." In terms of tills, we would express this as "one glacier, one flow direction." (Farther along, we discuss all the caveats that go with this vision of "one glacier, one flow direction". Suffice it to say here, that if this point is accepted, then a series of drastic revisions in the Pleistocene geology of Long Island necessarily follows. Thus, the best strategy to be used by defenders of the status quo in Long Island's glacial geology is to try to "head us off at the pass" by denying our Proposition No. 1). "To the barricades!"

Proposition No. 2 holds that the youngest of the Wisconsinan glaciers, the Woodfordian, flowed from the NNE to the SSW. Flint (1961) demonstrated this in Connecticut; he named the youngest till there the Hamden Till. Our evidence, best seen at Croton Point Park, Westchester County, supports Flint's result: that is, the youngest glacier flowed down the Hudson Valley.

Proposition No. 3 holds that several pre-Woodfordian glaciers flowed from NNW to SSE. In Connecticut, Flint's (1961) Lake Chamberlain Till, which underlies the Hamden Till, is a product of a glacier that flowed from NNW to SSE. Glacier flow from the NNW to the SSE dominates Manhattan Island, and is especially well displayed in Central Park. What is even-more significant is the evidence that ice flowing from NNW to SSE deposited the Harbor Hill moraine. We think Woodworth's results in western Queens demonstrate this, but that further support comes from the distribution of erratics along Long Island's north-shore beaches. We will devote much of today's trip to a study of the erratics as they relate to this significant proposition.

BIG IMPLICATION: If ice flowing from the NNW to SSE deposited the Harbor Hill moraine, then the age of that moraine must be pre-Woodfordian. We do not know its age exactly, but concur with C. A. Kaye's (1964b) interpretation that the age of two prominent moraines on Martha's Vineyard (correlatives of those on Long Island?) are Early Wisconsinan and Illinoian. This represents a major downward shifting of the age assignments of Long Island's famous moraines. Such a proposed age shift is the only way in which we differ significantly from the stratigraphic results of M. L. Fuller (1914), who assigned both of these moraines to the latest Wisconsinan (in modern terms, Woodfordian).

Our next point is based on our new discovery at Garvies Point of a till containing decayed granite erratics resting on the Cretaceous. Without doubt, this contact is on a piece of material that has been displaced upward by ice-thrust deformation and subsequent to that, has slumped down to beach level. Nevertheless, whatever its post depositional vicissitudes have been, we think this ancient till matches Fuller's Mannetto Gravel and that it is the product of a glacier of

Early Pleistocene age. We have found a comparably old till containing decayed granitic stones on Staten Island and at Croton Point (Westchester Co.). Therefore, we think the small exposures that we have dug out at Garvies Point are very significant.

Our approach to the study of Long Island's glacial deposits has differed from that of most other workers. We are just now starting to become familiar with the details of the exposures and the subsurface relationships on Long Island. We compare what we have done with what the glaciers themselves did--cover the bedrock and transport blocks of it onto Long Island. As our main qualifications for daring to intrude into the hallowed precints of the study of the Long Island glacial deposits, we list only: (1) familiarity with the regional geologic relationships of many of the pre-glacial formations in the territory north and west of Long Island and related study of the tills and the directional features made by the flowing glaciers; and (2) possession of (and willingness to use) GI trenching tools (i. e., small shovels) and to expend whatever effort is necessary to "undress" an exposure of Quaternary sediments by stripping away the surficial layer of washed-down debris from higher up the slope and thus to disclose the Quaternary sediments "au naturel," so to speak.

To date, our studies have led us to diametrically opposite conclusions from all previous workers who have accepted the latest-glacial age for the Long Island terminal moraines. The interpretations involved are so contrasting that they can be described only as follows: both could be wrong, but only one of them can be right. Our results are directly contrary to those that have been published by others during the last 20 years or so and that have been given the "good mapmaking seal of approval" by the "establishment" in the form of a new state map (Cadwell and others, 1986).

While we were pondering over how we could possibly put together a case strong enough to instill some doubts in the minds of the "true believers" and were in the midst of preparing the guidebook for our "On-The-Rocks" trip to Montauk Point in November 1990, we found our road to "salvation." We inadvertently discovered what we consider to be a true "hidden treasure." From its innocuous title, one would never suspect that the paper written by H. C. Ricketts (1986) about two borings made near Kings Point (on Great Neck, west side of Manhasset Bay) amounts to a breakthrough and is (in our opinion) the most-significant paper written since Fuller's monograph of 1914. What Ricketts did that no one would ever suspect merely from reading the title of his paper is to obtain amino-acid racemization results from shell material from interglacial formations. Ricketts collected shell material from the two borings that penetrated the Gardiners Clay and from the shell beds exposed in the Port Washington sand pits, on Manhasset Neck, west side of Hempstead Harbor, He submitted these shells to Professor J. H. Wehmiller, of the University of Delaware, who is a specialist in determining the ages of shells by the changes with time (racemization) of the original amino acids. On the specimens collected by Ricketts, Wehmiller found D/L leucine values between 0.26 and 0.34, which implies that the age of the shells is about 225,000 years. (By comparison, a D/L value in shells from Nantucket that are thought to be 125,000 years old is about 0.20; Oldale and others, 1982.) After we knew about the Ricketts paper, we volunteered to organize and lead today's trip.

We have summarized our interpretations on a new correlation chart (Table 1). Despite our lack of chronologic data, we present it as a logical statement of our current thinking and as a guide for others.

OBJECTIVES

Our objectives for today's field trip for the Long Island Geologists are to take the participants to 3 localities on the north shore of Long Island (Figure 1, cover) to view evidence that we think requires a total revision in previously published interpretations of Long Island's glacial geology. We shall also see exposures of the Cretaceous strata, look at some evidence on the rate of retreat of the coastal cliffs, and study the relationships between the fans at the mouths of gullies eroded into the sediments of the coastal cliffs and the modern beach.

Specifically, our objectives are:

1. To examine the evidence for the proposition that the Harbor Hill Moraine was deposited by a pre-Woodfordian glacier which flowed from NNW to SSE. This will involve us in a study of the erratics on the north-shore beaches and discussions of their provenance.

2. To study an exposure of a till containing decayed granitic stones (equivalent of Fuller's Mannetto Gravel), and its contact relationships with the underlying Cretaceous.

3. To examine some exposed Cretaceous strata and to become familiar with two distinctive varieties of Cretaceous rocks, not exposed, that are common in the beach gravels: (1) a hematite-cemented conglomerate (erroneously identified by others as coming from the Silurian Green Pond Conglomerate); and (2) a fine-textured red sandstone (erroneously identified by others as coming from the Newark basin-filling strata).

4. To study the fans at the toes of the eroding bluffs and how fan sediments and beach sediments are interrelated. We shall use these fans as small-scale models for interpreting the widespread outwash underlying Long Island.

So much for the introductory comments for today's trip. Now on to a general summary of the bedrock geology to the northwest and north of Long Island and the specifics of glacial-flow directions.

BEDROCK IN SOUTHEASTERN NEW YORK AND CONNECTICUT

Viewed as a first approximation, any reasonable geologic intuition holds that the erratic boulders found along the north shore of Long Island come from the bedrock of Connecticut. The central point where our interpretation of the Pleistocene glacial deposits differs from that of most other workers has to do with the total number of glaciations and the flow directions of the glaciers. One of our important conclusions is that at certain times, glacial ice flowed rectilinearly (to use C. A. Kaye's term) from two contrasting directions [from the NW to the SE and from the NE to SW (Sanders and Merguerian, 1991)]. This can be demonstrated without any question in Westchester County, in Manhattan, and in western Queens, where glaciers flowing southeastward transported distinctive erratics from the rocks of the Newark basin and from the anthracite district of northeastern Pennsylvania. What is more, the color of the till deposited by such glaciers always bears the reddish-brown color of the Newark sedimentary strata.

Rocks virtually identical with those of the Newark basin are present in central Connecticut (Figure 2). Because of the geographic relationship between the northeastern termination of the belt of outcrop of the Newark rocks in Rockland County, New York, and the southern termination of the belt of outcrop of the rocks in the Hartford basin in New Haven harbor, Connecticut, a crystalline "corridor" exists through which a glacier flowing from NW to SE could pass, extend to Long Island, and not pass over Newark-age rocks, and thus the color of its till would not be the diagnostic reddish brown. We would expect the erratics to be different, as well. Note that in Figure 2 our Stops 1, 2 and 3 are, for our inferred NW to SE glacial flow, geographically located within the crystalline "corridor" of southeastern New York and western Connecticut.

In the following paragraphs, we review the distinctive features of the bedrock in southeastern New York and the state of Connecticut. Our objective is to help "soft-rockers" pinpoint distinctive kinds of bedrock so that the erratics found on Long Island's north shore beaches can serve as indicator stones.

Southeastern New York

The bedrock geology of southeastern New York state is dominated by a complexly deformed, metamorphosed sequence of autochthonous- and allocthonous Proterozoic Y through Cambro-Ordovician rocks which form the Manhattan Prong (Figure 3). The Manhattan Prong is bounded on the northwest by Grenvillian Proterozoic Y rocks of the Hudson-Reading Prong and to the east is in ductile-fault contact with essentially coeval, dominantly eugeosynclinal Cambro-Ordovician rocks of western Connecticut. The contact is marked by a zone of syntectonically intercalated, mylonitic rocks and is mapped as Cameron's Line.

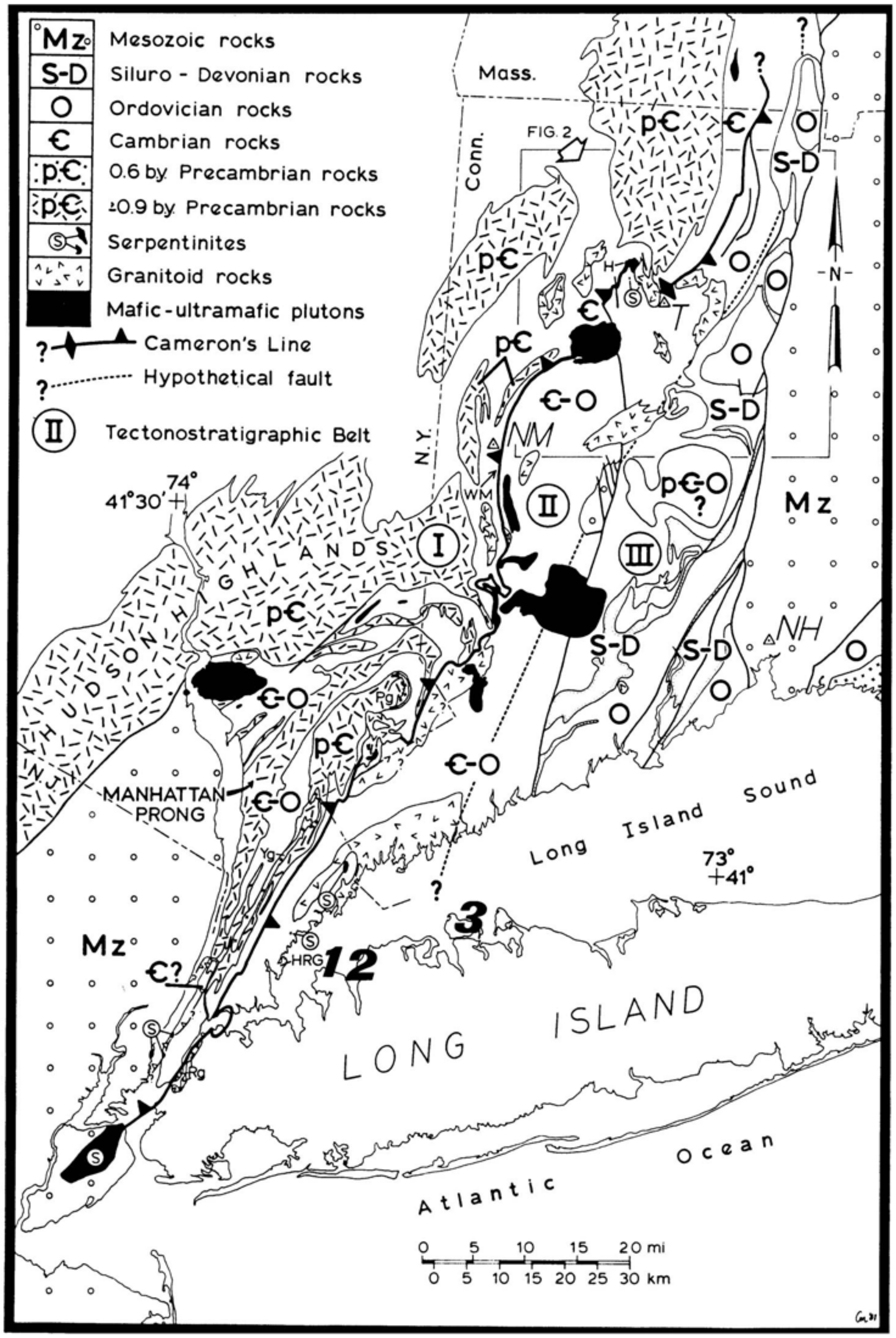

Figure 2. Geotectonic map of western Connecticut and southeastern New York. The location of our three field-trip stops and their geographic relationships to the crystalline "corridor" are shown. (Merguerian, 1983.)

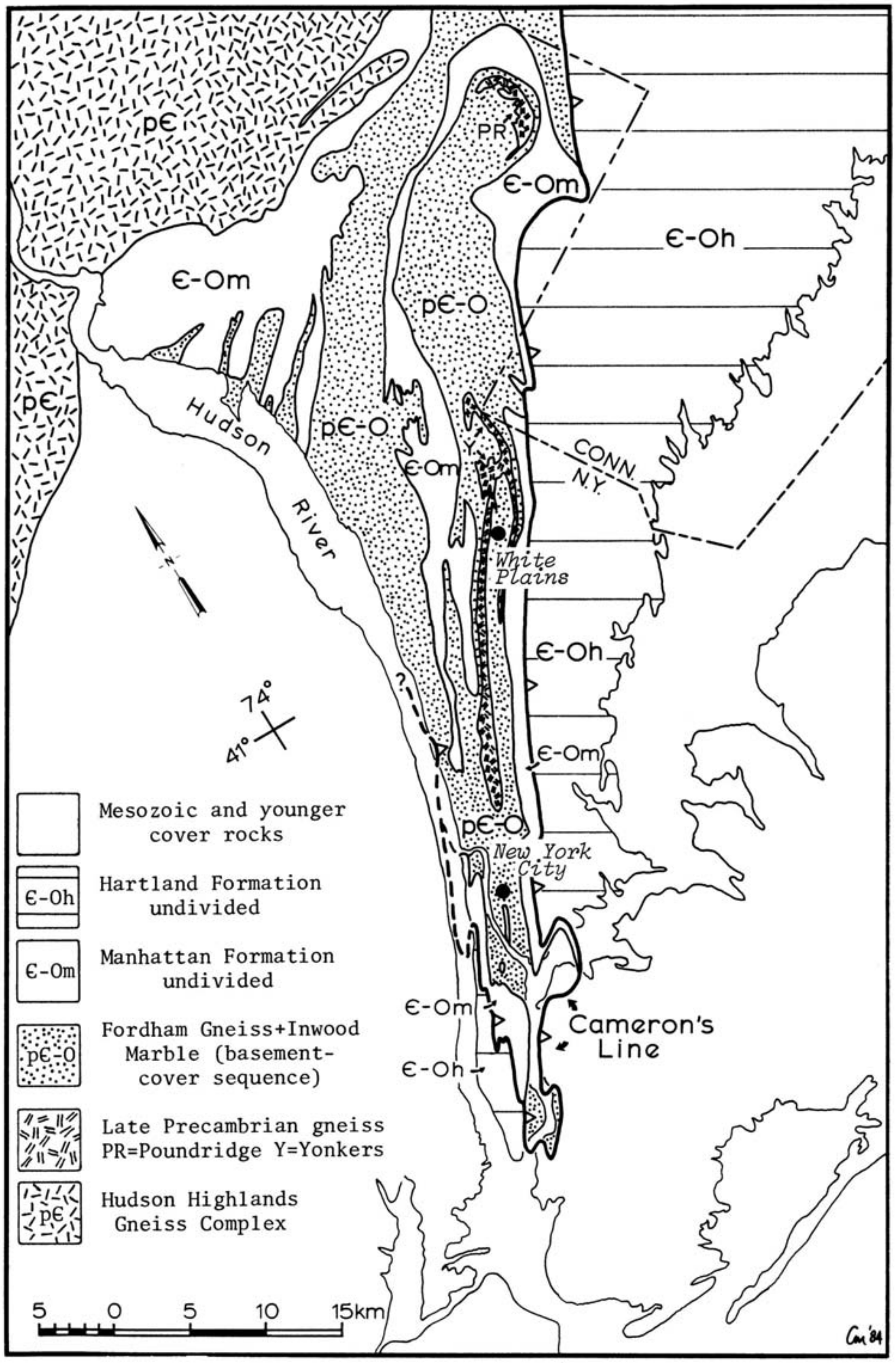

Figure 3. Simplified geologic map of Manhattan Prong showing the distribution of metamorphic rocks ranging in ages from Proterozoic to Early Paleozoic. Most intrusive rocks have been omitted. (Mose and Merguerian, 1985).

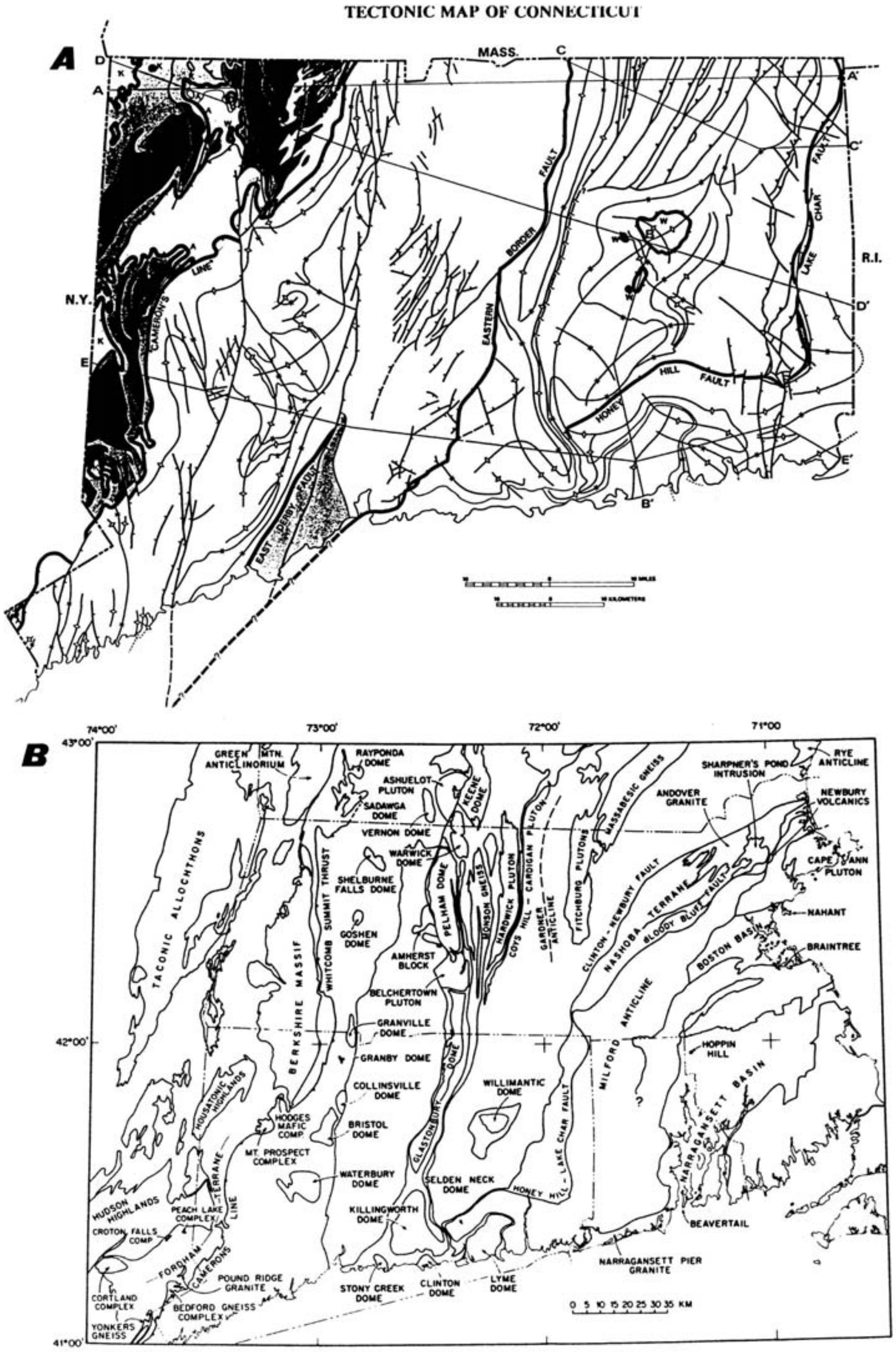

Figure 4. Maps of Connecticut and southern New England showing major tectonic features and rock bodies.

A. Tectonic map of Connecticut showing Cameron's Line and three major terranes. (John Rodgers, 1985.)

B. Tectonic sketch map of southern New England showing major domes, folds, and faults. (P. Robinson and L. Hall, 1980, fig. 3, p. 78.)

Cameron's Line, which skirts the New York - Connecticut state boundaries, separates rocks of the Manhattan Prong to the west from coeval rocks to the east that were deposited in a dramatically different paleogeographic setting. Rocks to the west of Cameron's Line include the metamorphic rocks of the Manhattan Prong consisting of the Proterozoic Y Fordham Gneiss, the Proterozoic Z Yonkers and Poundridge gneisses and coeval rift-facies strata mapped as the Ned Mountain Formation, the Cambrian Lowerre (Cheshire) Quartzite, the Cambrian-to-Ordovician Inwood (=Woodville, and Stockbridge) marbles, and overlying Middle Ordovician Manhattan Schist (Unit A) and correlative Annsville Phyllite. In addition, these basement-cover rocks are structurally overlain by allochthonous rocks of the Taconic sequence and their metamorphosed, dominantly massive southerly equivalents (the Manhattan Schist and related amphibolite (Units B and C), the Waramaug Formation, and locally, the Hartland Formation). Farther north, beyond the Hudson-Reading Prong in New York State, less-metamorphosed lithostratigraphic equivalents of the Early Paleozoic rocks are found including the Wappinger carbonates, the Walloomsac slate and shale, the Normanskill graywackes and shale, and rocks of the Taconic allochthons.

Extending toward the southwest of the Hudson River valley from southeastern New York into New Jersey, are Mesozoic igneous- and sedimentary rocks of the Newark basin. (See Figure 2.) Distinctive in their reddish-brown color, the west-dipping sedimentary strata range in age from Late Triassic to Early Jurassic and are time- and lithostratigraphic equivalents of rocks of the Hartford basin of central Connecticut (as discussed below). The west-dipping Palisades Sill, which forms a prominent ridge on the west side of the Hudson River valley from the New York Bight to the vicinity of Stony Point, New York, is a medium- to coarse-grained diabase that was originally intrusive into the the Newark strata based on baked contacts above and below the sill. Basaltic lava flows of the Watchung mountains and intercalated red-brown Jurassic sedimentary rocks crop out farther westward and up-section in New Jersey in an outcrop belt that extends beyond the New York State border. Many of these Mesozoic rocks are found as erratics on Manhattan Island. Near the Ramapo fault, the border fault on the western edge of the Newark Basin, distinctive clast-supported fanglomerates occur which bear Paleozoic boulders eroded from above the Hudson-Reading Prong and from areas to the north- and northwest of the highlands, cemented in a red-brown matrix.

Given the varied lithologies found in southeastern New York and adjacent regions of New Jersey, erratics from these areas could only be deposited on Long Island by a glacier that flowed from the northwest to the southeast.

Connecticut

Connecticut, like all of Caesar's Gaul, can be subdivided into three parts (physiographic provinces, geotectonic terranes, or whatever). These are western, central, and eastern terranes, respectively (Figure 4).

The Western Terrane

(1) The western terrane includes mostly metamorphic rocks that form part of the central crystalline core of the Appalachians. The age range of these rocks is from Proterozoic Y through Lower Paleozoic. Although volumetrically most of the metamorphic rocks are metasedimentary units, some distinctive igneous rocks (both intrusive and extrusive) are present as are some distinctive mylonites associated with a large-scale regional overthrust known as Cameron's Line (Figures 2, 4).

We begin with the contrasting metasedimentary rocks found adjacent to Cameron's Line and then summarize some of the distinctive mylonitic rocks and igneous rocks. In westernmost Connecticut north of the "panhandle", rocks of the Manhattan Prong crop out. As they were described above we will not discuss them here.

East of Cameron's Line, the bedrock formations differ significantly from those of the Manhattan Prong to the west of this line. To the east, the Cambrian-to-Ordovician Hartland Formation is the dominant formation underlying the crystalline highlands of western Connecticut. The Hartland Formation consists of a thick sequence of dominantly well-layered muscovite-rich schist, gneiss, amphibolite, and intercalated mafic- to felsic metavolcanic- and metavolcaniclastic rocks (Merguerian, 1983). Throughout the Hartland terrane of western Connecticut, local bodies of unique ferruginous- and manganiferous garnet-quartz granofels (coticules) are found as highly laminated rocks within the sequence (Merguerian, 1980, 1981). The Cambrian-to-Ordovician Hartland Formation is unconformably overlain by Siluro-Devonian metamorphic rocks of the Straits Schist.

To the east of the panhandle area of southwesternmost Connecticut, Silurian-to-Devonian metamorphic rocks occur as the Straits Schist to the south and north of the Cambrian (?) gneisses of the Waterbury Dome. (See Figure 4.) Farther east and cropping out in the vicinity of New Haven, in the extreme southeastern corner of the western terrane, are relatively low-grade (chlorite to garnet) schistose-, phyllitic-, and metavolcanic rocks of the Allingtown and Maltby Lake volcanics (Fritts 1962, 1963). These rocks are a part of the Middle Ordovician Bronson Hill-Ammonoosuc volcanic terrane which trends northeasterly through Connecticut, Massachusetts, and New Hampshire. Thus, as initially pointed out by Crowley (1968) and elaborated on by Merguerian (1983, 1985), in a transect extending from northwest to southeast across the western terrane, the interpreted protoliths of Paleozoic metamorphic rocks of the western terrane of southeastern New York and western Connecticut become less "continental" and more "oceanic"; an abrupt lithologic change occurs at Cameron's Line. (See Figures 2, 4.)

CM interprets Cameron's Line as a thrust fault within a deep-seated subduction complex that formed during the medial Ordovician Taconic orogeny adjacent to the Early Paleozoic shelf edge of eastern North America. This might explain the northwest- to-southeast imbrication of early Paleozoic shallow-water "continental" (Fordham-Lowerre-Inwood-Manhattan A plus correlative) lithologies with transitional slope- and rise- lithologies (Manhattan B and C, Waramaug, and parts of the Hartland Formation), from purely deep-water (including volcanic) rocks found west of the New Haven area. Thus, according to many workers, the juxtaposition of these largely coeval belts occurred during the arc-continent collision of the Taconic orogeny and resulted in telescoping of the continental-margin sequence and overthrusting of the volcanic arc and its fringing oceanic- basin deposits (Merguerian, 1983).

The rocks along the Taconic suture (Cameron's Line) form an impressive zone of mylonitic rocks that experienced abnormally high shear strain under deep burial during the Taconic arc-continent collision. Mylonites, or ductile-fault rocks, bear unique metamorphic textures that can be easily identified in the field by their highly-laminated appearance and distinctive microtextures under the microscope.

With respect to the Taconic orogeny, local plutons are both synorogenic and post-tectonic. The older group of synorogenic plutons cut across Cameron's Line in western Connecticut and southeastern New York. These include a series of mafic- to ultramafic plutons (now largely metamorphosed) that are similar in mineral composition and texture to the Cortlandt Complex of Peekskill, New York (On-The-Rocks Trips #10 and #14). In the panhandle area of southeastern New York and southwestern Connecticut, high-grade Ordovician granitoid- and dioritic orthogneisses (including various phases of the Harrison Gneiss, Brookfield Diorite Gneiss, and Bedford Augen Gneiss) are in great abundance. Similar metaplutonic rocks including norite, hornblendite, and pyroxenite occur farther north near Litchfield and Torrington, Connecticut and are known as the Mount Prospect and Hodges Complexes and the Tyler Lake Granite (Cameron, 1951; Merguerian, 1977, 1985). Together, these orthogneisses represent late syn-orogenic plutons that were intruded into the developing suture zone during the waning stages of the Taconic orogeny (Merguerian, Mose, and Nagel, 1984). As such, these mineralogically and texturally distinct metaplutonic rocks should serve as valuable indicator stones.

The younger group of post-orogenic intrusives include Devonian lamprophyre and potash feldspar-phyric (meaning a porphyritic rock containing feldspar phenocrysts to translate for those of who have not been exposed to the "new" petrologic language) Nonewaug Granite. Other plutonic rocks of still-younger ages include isolated bodies of Permian syenite, -adamellite, and -dacite porphyry. Of additional help, we are investigating the distribution of economic ore deposits in the crystalline terranes to the north- and northwest of Long Island in an effort to locate scarce, but highly useful indicator stones. During an On-The-Rocks field trip in November, 1990, one such erratic, containing sulfide ore minerals, was found eroding out of the Montauk Point "till".

The Central Terrane

The rocks of the central terrane consist of Mesozoic sedimentary- and igneous rocks filling the Hartford basin. The Hartford basin-fill rocks underlie a north-south-trending lowland in the central part of Connecticut. This lowland continues northward into Massachusetts (Longwell, 1922, 1928, 1933, 1937). To the west, the basin-filling rocks lie in fault-modified unconformable contact with Paleozoic metamorphic rocks of the western crystalline terrane. On the east, the basin filling rocks end abruptly at the basin-marginal fault (On-The-Rocks Trip #18). East of this fault are the rocks of the eastern crystalline terrane of Connecticut and Rhode

Island. [In this discussion, we include the Mesozoic rocks found in an isolated half-graben known as the Pomeraug Basin within the western terrane. (See Figure 2.)]

Lithologically distinct, the strata filling the Mesozoic basins consist predominantly of east-dipping, red-colored sedimentary rocks and intercalated basalts with local intrusive mafic rocks (for example, the Buttress and West Rock dolerites). Correlative with the Upper Triassic to Lower Jurassic Newark Supergroup of New Jersey (On-The-Rocks Trip #5), the rocks of the Hartford and Pomeraug Basins include the New Haven, Shuttle Meadow, East Berlin, and Portland formations consisting of red- to maroon-colored micaceous arkose and quartzose sandstone and siltstone, shale, and local conglomerate and fanglomerate, together with subordinate black shale and local dolostone, and intercalated dark-colored mafic volcanic rocks of the Talcott, Holyoke, and Hampden basalts.

The basins are internally cut by a myriad of faults and, as discussed below, trend southward and project into Mesozoic grabens in the subsurface of Long Island and the New York Bight that have been identified by samples from drill holes and data from geophysical surveys (Klitgord and Hutchinson, 1985; Hutchinson, Klitgord, and Detrick, 1986; Hutchinson and Klitgord, 1988). The distinctive color and lithology of these rocks make them ideally suited for use in analysis as indicator stones and as sources for the generation of red-colored tills but similarity with rocks of the Newark Basin complicates direct correlation. All is not lost however, as the presence of low-grade (chlorite- and epidote-bearing) schist and metavolcanic rocks as erratics in concert with these distinctive Mesozoic lithologies would identify a unique Connecticut source as such low-grade rocks of volcaniclastic parentage do not occur in the vicinity of the Newark Basin of New Jersey.

The Eastern Terrane

The crystalline rocks to the east of the basin-marginal fault along the east side of the Hartford Basin underlie eastern Connecticut and Rhode Island. The bedrock formations here include exceedingly complex suites of metamorphic- and metaigneous rocks that range in age from Proterozoic through Permian. They have been cut by a regionally important ductile shear zone having the unlikely but nonetheless real name of Lake Chargoggagoggmanchauggagoggchaubunagungamaugg - Honey Hill Fault Zone [also known as the Lake Char - Honey Hill Fault Zone], which separates metavolcanic-, metaplutonic-, and metasedimentary rocks of the Bronson Hill-Ammonoosuc terrane to the north and west from Proterozoic Z gneisses and Permian intrusive rocks of the Avalonian terrane to the south and east. The Proterozoic Z rocks include the Plainfield Quartzite (a distinctive vitreous feldpathic +/- biotite quartzite), the Waterford Group, and the Sterling Plutonic Group. Many unusual porphyritic gneisses are present within this sequence that should serve as excellent indicator stones.

The Ordovician rocks of the Bronson Hill - Ammonoosuc volcanic terrane include the Monson Gneiss and overlying Middletown and Brimfield formations as well as the Glastonbury Gneiss. These rocks are overlain by Silurian and Devonian metamorphic rocks of the Bolton Group and cut by the Devonian Maromas Granite Gneiss. To the east, correlatives include the

Ordovician Quinebaug, Tatnic Hill, and Brimfield formations and overlying Siluro-Devonian units known as the Hebron Gneiss and equivalents.

Intrusive into these crystalline rocks are many plutons ranging in age from Ordovician to Permian. The distinctive rocks among this group on the Connecticut side of the Lake Char - Honey Hill Fault Zone include the Ordovician Preston Gabbro (+/- diorite), the Devonian Lebanon Gabbro (+/- diorite), and unnamed Devonian norite, diorite, and granitoid gneiss. In places where the mafic rocks are in close proximity to the Lake Char - Honey Hill Fault Zone, the rocks have been transformed into distinctive mafic mylonites. To the east of the Lake Char - Honey Hill Fault Zone are Permian intrusives known as the Narragansett Pier Granite (including a mafic phase) and the Westerly Granite, both distinctive lithologies.

Thus, given the complexities of the geology of the state of Connecticut, there appears to be room for identification of distinctive rocks and lithologic assemblages in the erratics that we will examine on our trip this weekend. Pleistocene boulder chasing is an exercise that best demonstrates the necessity of having a well-rounded knowledge of all fields in geology in order to arrive at a satisfactory conclusion.

DIRECTIONS OF GLACIER FLOW

The directions of flow of a former glacier can be determined easily and unambiguously in the field by recording the azimuths of features eroded on bedrock by the flowing ice (such as striae and grooves, and the long axes and slope asymmetry of roches moutonées and rock drumlins), by plotting the distribution of erratics (especially indicator stones), and by recording certain asymmetrical properties of glacial deposits (such as directions of orientations of elongate clasts and the long axes of drumlins).

In the nineteenth century, the raw data on ice-flow marks on the bedrock were collected systematically. Indeed, many papers dealing solely with data on striae on bedrock surfaces were published. Before long, the novelty of such papers wore off. And a worn-off geologic novelty is like yesterday's newspaper. Novel or not, the straightforwardness of the directional data disappear when one begins to interpret them. If all the flow-directional data in a given region are about the same, interpretations are not controversial. But, if more than one set of flow-directional indicators have been found, then that is another story. In the following paragraphs, we review the evidence that in the New York City region, more than one set of ice-flow indicators can be demonstrated. After we have reviewed these, we take up their interpretation.

Glacial striae on bedrock surfaces

Perhaps the easiest of the ice-flow indicators to record are the directions of striae and grooves on the bedrock. In New York City, such a survey was first carried out in 1828-29 by L. D. Gale (Mather, 1843). As was common in his day, Gale supposed that the grooves and scratches had been made by water currents, perhaps assisted by icebergs. The presumed significance of water is implied in the use of the term diluvial. Gale's report written in 1839 and entitled: "Geological Report of New-York; New-York island" was published in Mather (1843). Gale's results on flow directions appear on p. 209-210).

Details of Gale's observations are contained in our On-The-Rocks guidebook for Trip 15 to Montauk Point (On-the-Rocks guidebooks from our past season's trips are available from Duke Geological Laboratory - See order form at the back of this guidebook). To summarize, Gale's measurements led him to conclude that he had observed the effects of two contrasting flow directions, (a) nearly all the "diluvial scratches and furrows" indicated flow from the NW to the SE and (b) the displacement of indicator erratics (an anthophyllite-bearing rock and a white limestone) implied transport from the NNE to the SSW. Despite the apparent contrast in flow directions, Gale interpreted his data in terms of a single event, which he expressed as "the diluvial current." Gale tried to show how the changes in flow of a single such current could account for both the regional trends of the scratches and furrows on the smoothed bedrock and the displaced indicator erratics. In this regard, Gale began a pattern that would be followed by most subsequent students of the "diluvial" deposits: trying to account for all the disparate observations by invoking only a single transport event. But Gale's single transport event differed significantly from the one favored by later investigators. Gale concluded that his single "diluvial current" had flowed from NW to SE and he sought aberrations in this flow direction to account for the displacement from NNE to SSW of indicator erratics. In contrast, the single flow event for most later workers was taken to be from the NNE to the SSW; they invoked aberrations to explain the scratches and furrows that trend NW-SE.

That great genius of Connecticut geology, James Gates Percival, was well acquainted with both the bedrock and what we would now refer to as the Pleistocene deposits. He classified these as "Diluvium," or the "unstratified materials," which he contrasted with the Alluvium, "those arranged in strata." Percival (1842, p. 453-456) cited many examples of distinctive rocks that had been displaced from NW to SE. "The greater part of the Diluvium was apparently deposited by a general current, traversing the surface from N. N. W. to S. S. E. This is satisfactorily indicated both by the bowlders, scattered over the surface, or imbedded in the diluvial earth, and by the smaller fragments included in the latter, as well as by its general character (sic)." (Percival, 1842, p. 453). Percival emphasized that knowledge of the composition of the bedrock was absolutely essential to reconstructions of the directions of the "diluvial currents:"

"In order to determine the direction of the diluvial currents, a particular knowledge of the local character (sic) of the rocks, as indicated in the account already given of the different local formations, is indispensable. Several of these local formations are so peculiar in the character (sic) of their rocks, that the latter cannot be mistaken, to whatever distance they may have been transported. These, by the distribution of their bowlders and fragments, furnish conclusive evidence that the more general (sic) direction of the diluvial current was S. S. E. (Percival, 1842, p. 454)

Despite the numerous examples he cited that demonstrate transport from NW to SE, Percival reported that some rocks had been moved from NNE to SSW. As did Gale in Manhattan, Percival supposed that this transport to the SSW had resulted from local deflections of the general diluvial movement to the SSE:

"Although the general direction of the diluvial current was apparently S. S. E., yet in some instances, from local obstructions, its course was deflected to a S. S. W. direction. This is most distinctly obvious along the Western border of the larger Secondary formation, where blocks and fragments of the Trap and Sandstone of that formation are accumulated, sometimes quite abundantly, in such a direction from their apparent source." (Percival, 1842, p. 457).

Striated bedrock lending further support for glacial flow from the NW or NNW to SE or SSE was found by Woodworth (1901) in Long Island City.

Salisbury and assistants (1902) found that the predominance of ice-flow indicators showed glacial flow from the NNW to the SSE over the Palisades. By contrast, such indicators demonstrated that glacial flow over the Watchung ridges had been predominantly from the NNE to the SSW. In his interpretation of these indicators of contrasting directions of ice flow, Salisbury argued that within the margins of an ice sheet are localized zones within which the ice-flow paths are faster than elsewhere. Accordingly, the ice-flow "streamlines" are thought to be crowded close together, as in the sketch map of the region surrounding Lake Michigan (Figure 5). On either side of such supposed zones of concentrated flow, the ice tends to spread out toward each side. In applying this concept to the New York metropolitan area, Salisbury inferred that during the latest glaciation of the New York City region, the axis of fastest-flowing ice had not been down the Hudson Valley, as one might expect on the basis of valley size, but rather had followed the Hackensack Valley to the west (Salisbury and assistants, 1902). From this inferred zone of concentrated flow down the Hackensack Valley, they thought that the ice had flowed toward the south-southeast over the Palisades ridge and Manhattan, and toward the south-southwest over the crests of the Watchung Ridges in New Jersey (Figure 6). Salisbury admitted that the regional distribution of erratics of the distinctive Silurian Green Pond Conglomerate from northwestern New Jersey constituted an anomaly to this explanation of marginal-flow divergence within a single glacier as the cause of the divergent orientations of the glacial grooves and -scratches. Salisbury acknowledged that another succession of events which could explain the distribution of erratics of Green Pond Conglomerate involved two glaciations. He considered this possibility briefly, but rejected it.

Hanley and Graff (1976) found numerous places in Central Park, Manhattan where the bedrock has been prominently striated by glacial ice that flowed from the NW to the SE (Figure 7).

Indicator stones

Indicator stones implying flow from NW to SE have been found on Staten Island by Hollick (1908, 1915) and at the Brooklyn Botanical Garden (Gager, 1932, based on petrographic results by Robert Balk). Erratics of Green Pond Conglomerate (Silurian, northwestern New Jersey) and of Pennsylvanian anthracite from near Scranton, Pennsylvania have been found on Staten Island (Friedman and Sanders, 1978; Figure 8).

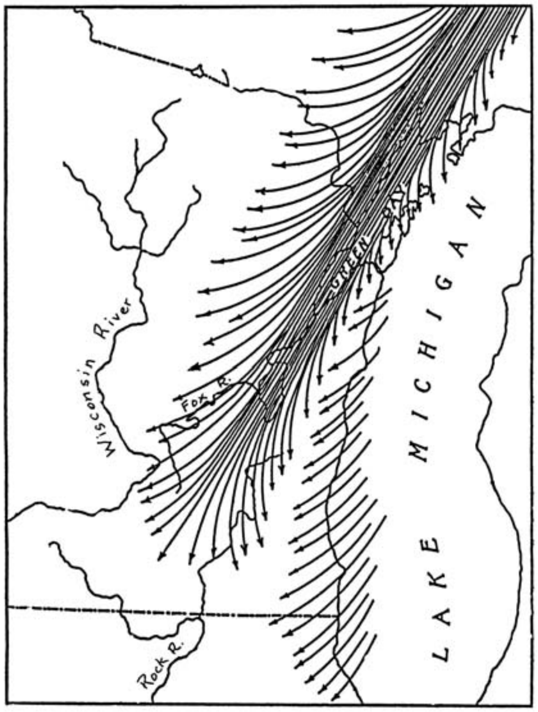

Figure 5. Sketch map of area west of Lake Michigan (mostly in Wisconsin, but including parts of Michigan and Illinois), showing concept of divergent flow from a narrow zone (centered above Green Bay, Wisconsin) of rapid flow within an ice sheet. (R. D. Salisbury, 1902, fig. 31.)

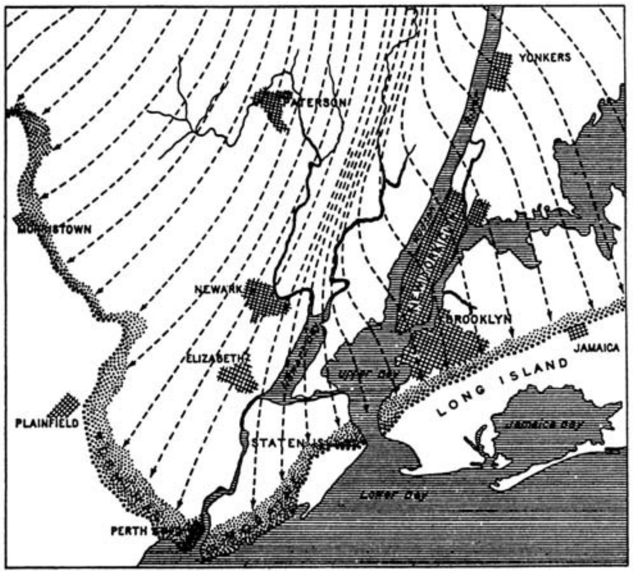

Figure 6. Sketch map showing lobate margin of a terminal moraine (Harbor Hill?) in New York City and vicinity with inferred divergent directions of flow of the most-recent continental glacier. (R. D. Salisbury, in Merrill and others, 1902, fig. 12, p. 13; also 1908, fig. 11; also, H. B. Kümmel, 1933, fig. 13, p. 66.)

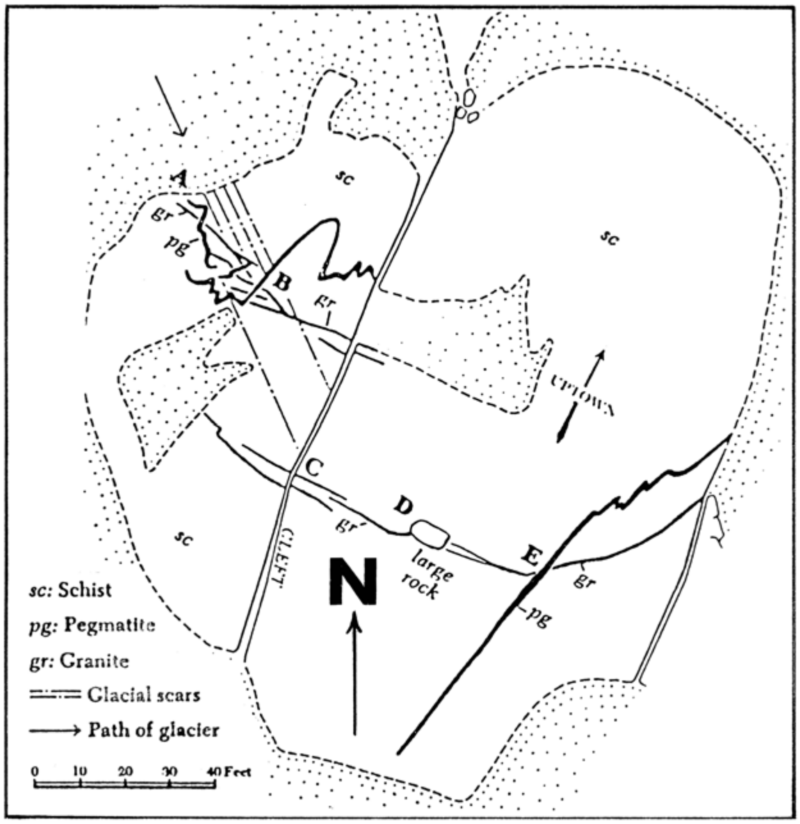

Figure 7. Sketch map of the geology of Umpire Rock, Central Park, New York showing directions of glacial striae oriented NW to SE. (After Hanley and Graff, 1976, p. 43; modified by JES.)

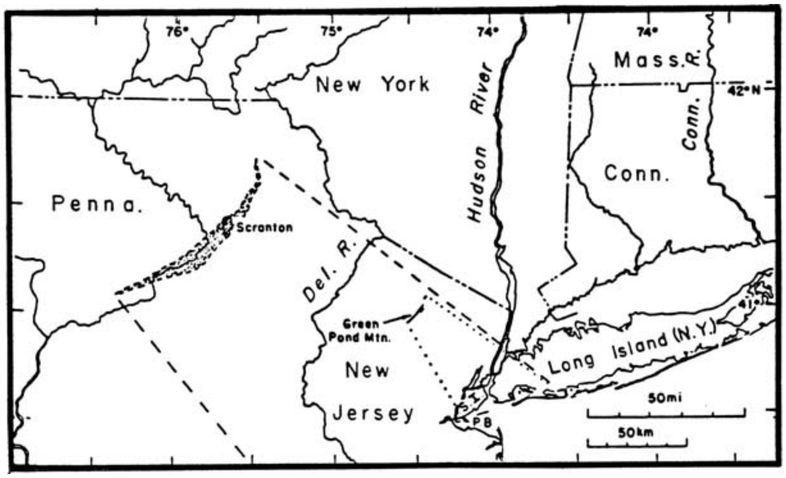

Figure 8. Distinctive erratics found in till in New York City, (1) anthracite from northeastern Pennsylvania, and (2) Green Pond Conglomerate from northern New Jersey, support interpretation of rectilinear flow of glacier from NW to SE. Stippled area, outcrops of anthracite coal; S. I. = Staten Island; P. B. = Princess Bay. (Friedman and Sanders, 1978, Figure 2-1, p. 27.)

After he had analyzed the Pleistocene stratigraphy of the Boston area, Kaye (1982) wrote the following paragraph under the headings of directions of glacial flow:

> "The direction of ice flow in the Boston Basin and adjoining uplands was studied by means of the orientation of striations (sic) and grooves on the bedrock surface, the orientation (sic) of the long axes of drumlins, the direction of transport of erratics in till, and the direction of thrusting and and overturning of bedding in glacially deformed drift. These data range through 360° in azimuth. Analysis of this confusing message shows the existence not of an ever-shifting ice current but of at least four separate and distinct ice currents of different ages. Three of these flowed fairly rectilinearly, but one (the last) was multicomponent and marked by strong lobation" (1982, p. 31).

Kay numbered these tills from I (oldest) to IV (youngest). Tills I, II, and III flowed from the NW to the SE, the mean direction being S23°E +/- 1° for Till I; S64°E +/- 18° for Till II; and S31°E +/- 2° for Till III. Till IV was from the NNE.

The regional geologic relationships in the New York City region are especially helpful with regard to ice-flow reconstructions. The distribution of the reddish-brown bedrock in the strata filling the Newark basin lying west of the Hudson River provides an especially valuable indicator with respect to ice flow across the Hudson Valley in contrast to ice flow down the valley. In many localities east of the Hudson River, it is possible to distinguish distinctive tills and outwash on the basis of color. Any reddish-brown sediments resulted from action of ice that flowed across the Hudson River. By contrast, sediments that are yellowish brown or gray were deposited as a result of glaciation by ice that flowed down the Hudson Valley.

If one grants that the ice-flow indicators presented imply flow from both the NNW and the NNE, then several interpretations are possible. Three ideas are analyzed here: (1a) that changing meteorological conditions caused the sites of maximum snow accumulation to form "ice domes" on the top of the glacier and that flow direction responded to the changing zones of maximum ice thickness, thus enabling the flow directions within a single ice sheet to shift with time; (1b) that the margin of the ice sheet was characterized by lobes within which the ice flowed with contrasting directions; and (2) each set of flow directions was made by a single glacier having only one dominant flow direction.

(1a) Changing meteorological conditions and shifting ice domes.

The theoretical background in support of the concept that changing meteorological conditions could shift the locus of maximum snow accumulation to build ice domes and that as a result, one and the same continental ice sheet could display multiple flow directions was proposed at the time when the modern version of the Laurentide Ice Sheet was advocated (Flint, 1943).

According to Flint, the Laurentide Ice Sheet began as one or more snowfields in the highlands of northeastern Canada. With continued additions of snow, an ice cap appeared and it began to spread southward and westward. The azimuth from the northeastern Canadian highlands to New York City is 195° or along a line from N15°E to S15°W. After this ice cap had become a full-fledged ice sheet and had attained something close to its full thickness, it is presumed to have itself become a factor in localizing where further snow would fall. Flint inferred that the ice sheet could divert the flow of moisture-bearing winds from the Gulf of Mexico and thus would have acted as an orographic source of precipitation. In other words, the ice sheet forced the air to rise and to be cooled and thus to drop its moisture. Enough snow is therefore thought to have been heaped up at various localities near the outer margin of the ice sheet and thus to have formed ice domes whose relief altered the direction of flow. Thus, the initial direction of regional rectilinear flow toward the SSW as a result of snow supply from northeastern Canada, could change locally to centers of quasi-radial flow under of the influence of the ice domes each of which could display divergent flow patterns, including zones of flow from NNW to SSE. During retreat, the above-described situation would be reversed. The factors responsible for radial ice-dome flow, including sectors from NNW toward the SSE, would cease to operate and those causing rectilinear flow toward the SSW to resume their former preeminence. The predicted pattern of flow for each advance of such an ice sheet, therefore, would involve three phases in the following order: (1) rectilinear flow from the NNE toward the SSW; (2) quasi-radial flow from the glacier-marginal ice domes, but locally from the NNW toward the SSE; and (3) rectilinear from the NNE toward the SSW.

Flint opposed the multiple-glacier hypothesis because he was convinced that if two glaciers had flowed over an area and both had extended their influence deep enough to polish and scratch the bedrock, then the younger glacier would obliterate all traces of the older one. Accordingly, he argued that all the striae must have been made by only one glacier, the youngest one.

(1b) Ice lobes at glacier margin.

Another version of how a single glacier could create flow indicators having several directions is based on the behavior of ice lobes. Such lobes characterize the terminus of a valley glacier that has spread beyond the confining bedrock valley walls. Although the main flow direction of ice in a valley glacier is parallel to the trend of the valley, within the terminal lobe, the spreading ice creates divergent flow paths.

(2) One ice sheet, one flow direction.

Our field studies made mostly off Long Island, have led us to conclude that in the New York metropolitan area, the evidence about glacier-flow directions supports the view that each ice sheet was characterized by a single dominant flow direction (Figures 9, 10). In other words, the pattern was one ice sheet, one flow direction. Table 2 shows the relationships as we envisage them.

We make no claim that we have proved that our interpretation is correct and that it should, therefore, supersede all others. Our scheme lacks a chronologic basis; we are vulnerable to all the pitfalls associated with that oft-used method of "counting down from the top." But, given the current state of affairs in local Pleistocene geology, we believe that our beliefs should be considered by the believers of contrasting sets of beliefs. Our interpretation contains specific, checkable consequences with regard to the provenance of the tills.

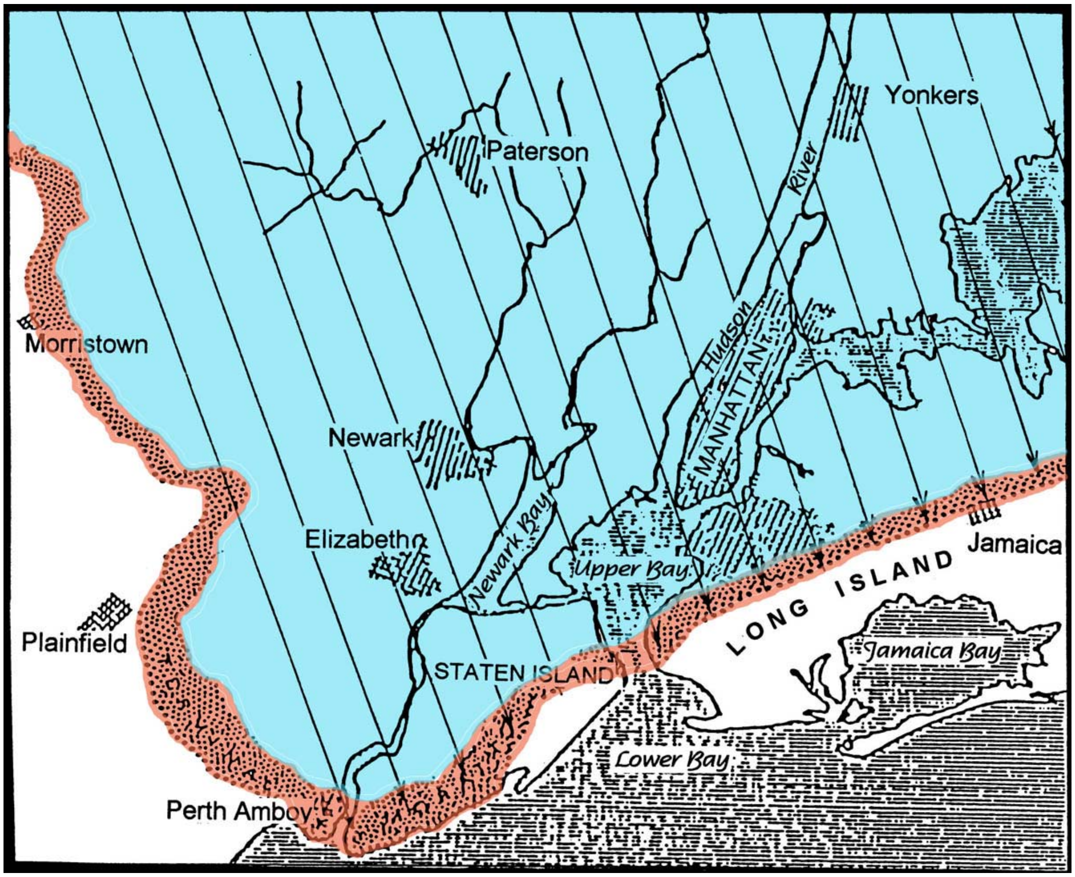

Figure 9. Rectilinear flow from NW to SE of glacier older than the latest Wisconsinan. This glacier flowed across the Hudson Valley and deposited red-brown till and -outwash on the east side of the Hudson River. (J. E. Sanders).

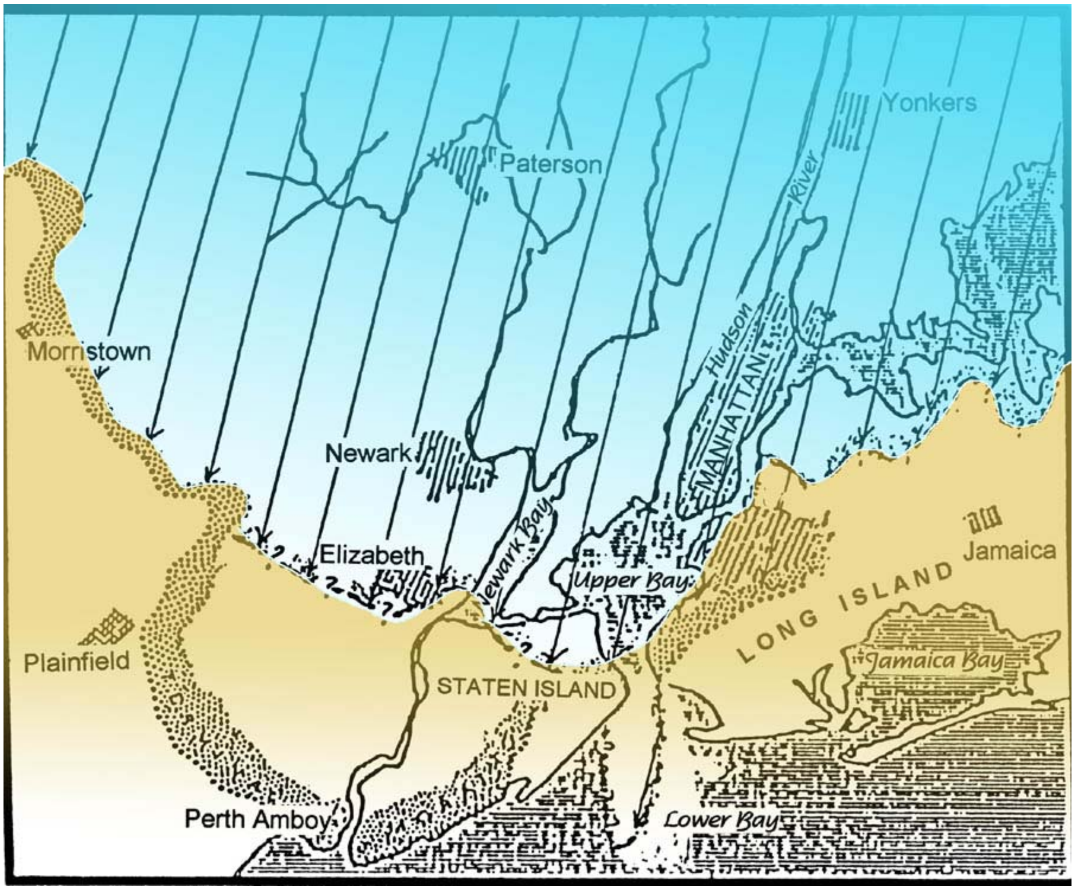

Figure 10. Inferred flow pattern of latest Wisconsinan glacier, down the Hudson and Hackensack lowlands from NNE to SSW. This glacier affected only westernmost parts of Long Island; elsewhere, its terminal moraine was along the south coast of Connecticut. (J. E. Sanders).

DESCRIPTIONS OF LOCALITIES ("STOPS")

STOP 1 - Outwash, till, and loess in coastal cliff; fans and beach sediments at Sands Point Museum and Preserve, Sands Point. UTM coordinates = 609.9E/4524.3N, Sea Cliff 7 1/2-minute quadrangle. (We are indebted to Herb Mills, County Parks Naturalist, who hopes to be able to join us and who has been helpful in arranging permissions for us to visit the Sands Point Preserve.)

Much of the present preserve was formerly part of the Sands Point U. S. Naval Station. To the west of the wooden stairs at the end of trail 3, archeological artifacts including arrowheads, coins (late 1700s), square hand-made nails, and pottery have been found.

Take trail #3 (numbers on painted markers) to beach past kettle lake. Note abundant erratics including possible blueschist boulders.

Four topics are of special interest here: (1) provenance of the erratics on the beach; (2) stratigraphy of the Pleistocene sediments, (3) erosion of the bluffs, and (4) relationships of the modern beach sediments to the older deposits and to sediments eroded from them.

Provenance of erratics on the beach

The most-diagnostic erratic we have found here so far is the block of middle Ordovician Normanskill graywacke (from the Appalachian-Hudson valley) near the place where the trail leads down to the beach. An early lesson that needs emphasizing here is how to distinguish between the blocks of concrete having local beach gravel as aggregate and the Upper Cretaceous hematite-cemented conglomerate. A careful search of the concrete will show that some of these hematite-cemented conglomerates were among the stones used in the aggregate. Notice that in these Cretaceous conglomerates, the rock usually breaks around the rounded, white quartz pebbles. This is a simple, but diagnostic way to tell these local Cretaceous conglomerates from the Lower Silurian Green Pond metaconglomerate in which the rock breaks across the quartz pebbles.

Other distinctive erratics whose provenance we have not yet established include mylonitic rocks and various granitic- and dioritic gneisses, schist, gneiss, amphibolite, and pegmatite.

Absent here are any Upper Triassic-Lower Jurassic rocks (red sandstones, feldspathic conglomerates, dolerites, etc.) from the Newark basin fill, from the Hartford basin fill, or from the Southbury outlier.

Stratigraphy of the Pleistocene sediments

Beneath slope-wash cover, the cliff face consists of horizontally stratified outwash sand and -gravel with mafic minerals, and rounded white quartz pebbles. Outwash is overlain by till(?) and a layer of coarse reddish loess, 1 m thick, which undoubtedly was derived from a red till. We have not dug out this entire bluff, but have scraped away the slope-wash cover from near the top. We do not have anything definitive to say about the stratigraphy here but remind everybody that we are not far from the famous Port Washington sand pits, where Mills and Wells (1974) and Sirkin and Mills (1975) have described spectacular effects of ice-shove deformation involving both the Pleistocene and underlying Cretaceous.

Erosion of the bluffs

Herb Mills has been studying the rate of retreat of the coastal cliffs here. He told us about the history of the iron rods, 40 feet long, some of which can still be seen sticking out of the cliff sediments at the east end of the beach, but many of which have fallen down to the beach. These rods were buried at a shallow depth along the top of the bluff, at right angles to the trend of the bluff. Herb does not know their exact purpose, but infers that they were emplaced for the purpose of anchoring some structure or other. At any rate, in 1970, he first noticed that the ends of these rods were starting to stick out of the bluff. By 1990, the cliff had retreated southward approximately 40 feet, giving an average rate of 2 ft/yr.

Relationship of the modern beach to the older deposits and to sediments eroded from them.

Along the base of cliff exposing the Pleistocene sediments, a modern beach has accumulated. At the mouths of each of the tiny watercourses or larger channels, where rainwater is concentrated into surface flows that erode the Pleistocene sediments, a fan is present. On Wednesday, 07 November 1990, fans of two generations, each truncated on their seaward sides by a steep scarp, were clearly visible. But the storm on Saturday, 10 November 1990, changed all this. On Saturday, 17 November 1990, no traces of the the former fans remained. A fresh new set of fans that were coarser and larger than the previous two had been deposited, entrenched by stream channels, and their distal margins truncated. Since mid-November 1990, this set of convex-up coarse fans has been largely obscured. They have been cut by gullies, and their distal margins have been eroded and covered by a new generation of fans consisting mostly of sand.

We think that these small fans are useful to study, not only for themselves and their relationships to the eroding coastal bluffs and adjacent beach sediments, but also because we think that they provide useful small-scale models of what was happening during much of the Pleistocene when Long Island's blanket of outwash was being deposited. In order to visualize the conditions of deposition of Long Island's Pleistocene outwash, one needs only to increasee the scale from these small fans by two or three orders of magnitude; to reverse their orientation (from being at the ends of channels flowing north to the ends of channels flowing south); and to replace the coastal bluff a few tens of meters high with the terminus of a continental glacier perhaps several kilometers high. Place the terminus of the glacier out in the lowland that is now Long Island Sound, and let the fans composed of outwash be spread southward away from it (Figure 11).

On 17 November 1990, the former beach had been stripped away, and a thin (only a millimeter or two thick) veneer of dark-colored heavy minerals rested on a surface that dipped northward (toward Long Island Sound). Beneath that thin layer of dark-colored heavy minerals were brown-weathering sands that dipped steeply southward. We infer that these south-dipping sands are upthrust Cretaceous. On 22 June 1991, we dug a small trench through the beach sediments and exposed these south-dipping (Cretaceous?) sands/clays once again. The thickness of the beach sediments covering them was about 25 cm. We plan to dig still-another trend to expose the base of the beach sediments.

Walk back to vans and prepare to go to Stop 2.

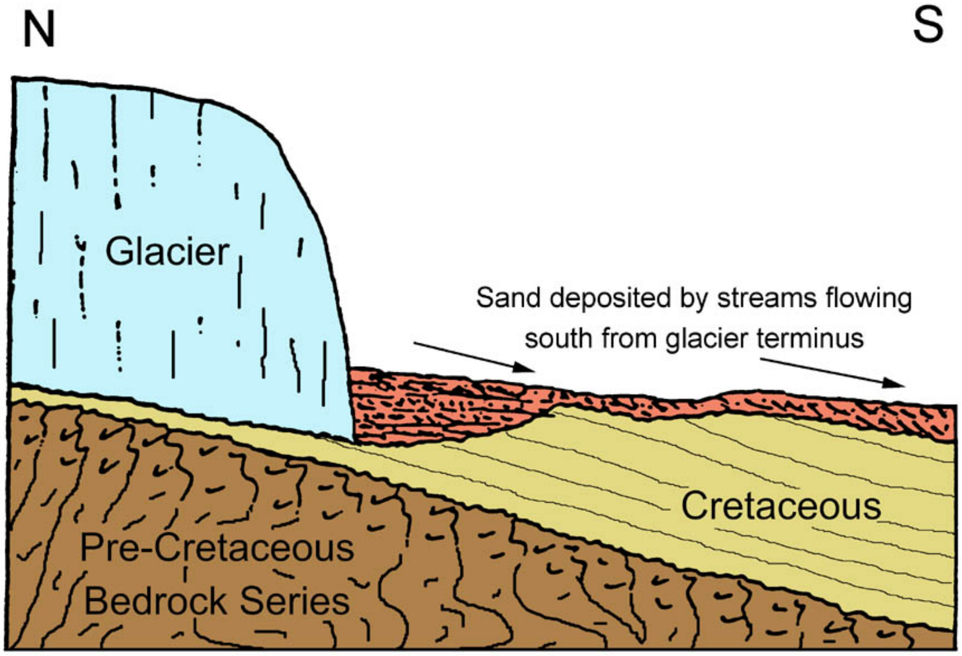

Figure 11. Restored profile-section from Connecticut to Long Island showing terminus of continental glacier standing in what is now Long Island Sound and spreading compositionally mature outwash sand and gravel southward to bury the Upper Cretaceous strata of Long Island. Extension of Cretaceous beneath glacier is schematic, but is based on the lack of feldspar in much of the Long Island outwash. (Drawn by J. E. Sanders in 1985 using regional relationships shown in W. deLaguna, 1963, fig. 2, p. A10.)

STOP 2 - Cretaceous clays and sands; Lower Pleistocene outwash and till; and postglacial loess at Garvies Point Museum and Preserve, Glen Cove. UTM coordinates = 613.5E/4523.7N, Sea Cliff 7-1/2 minute quadrangle.

For permission to visit, contact Ms. Kathryne Natale [Chief; tel. (516) 671-0300 or Mr. Douglas Winkler (Asst. Curator) (same #)]. Garvies Point Museum and Preserve, Barry Drive, Glen Cove, N.Y. 11542.

Many points of geologic interest are here, including numerous excellent exhibits on the geologic history of Long Island inside the museum itself. Outside are three large erratic boulders and various glacial landforms. By walking down the trail one comes to a set of stairs that leads to the beach at the base of bluffs that are retreating by slumping and by wave erosion at their toe.

En route to the beach we shall make a brief stop at the three large erratics. We shall not bother with the interesting landforms, but proceed directly to the stairs leading to the beach.

Two chief features exposed in the slumped- and eroding bluffs south of the stairs here are: (1) the Cretaceous strata; and (2) the Lower Pleistocene till containing decayed granite clasts (the Manetto of Fuller). In addition, the boulders on the beach contain a large variety of erratics.

Cretaceous strata

The exposed Cretaceous consists of varigated clays and sands with lignite seams and layers of charcoal (products of Cretaceous forest fires). Stratigraphy as found in slump block to south of wooden stairs is:

Yellow-brown sand with local cross strata, underlain by
Whitish clay,
Red-purple clay with local lignite at base, and
Gray clay.

Lower Pleistocene sediments

The Cretaceous is overlain by a reddish till consisting of deeply weathered granitic boulders, Cretaceous ironstones, and manganiferous residue at contact with underlying outwash. At the right side of the face that we shall clean off for study is a large groove in the underlying Cretaceous. Of significant importance, the orientation of this groove indicates ice flow from the NW or even WNW.

In the currently fashionable "one-glacier-did-it-all" concept, Fuller's Jameco Gravel and Manetto Gravel, have been reassigned to younger ages. For example, Sirkin wrote:

These two units "probably do not represent pre-Wisconsinan glacial (sic) or interglacial deposits but may be Wisconsinan outwash. Another unit, the Gardiners Clay, was believed to represent an Early Pleistocene interglacial (Fuller, 1914) and was subsequently placed in the Sangamonian Interglacial Stage (MacClintock and Richards, 1936). In historical usage, a variety of fine-grained sediments of both fresh water (sic) and marine orgin have been called the Gardiners Clay. These strata, which have been observed in surface exposures and well sections, can vary considerably from the original fossiliferous marine sediments of the type section (Upson, 1968; Sirkin and Mills, 1975). Gustavson (1976) has shown that certain so-called Gardiners Clay units contain fossil faunas quite unlike the fauna from the type section, while Sirkin and Stuckenrath (1980) indicate that some strata identified as Gardiners Clay could be of Portwashingtonian age, particularly in the absence of radiometric ages for either the original or the presumably correlative units.

"The inclusion of such strata in the Woodfordian moraines only show that they predate (sic) the Woodfordian advance. As a surface deposit, the Manetto Gravel, although well weathered, is probably Woodfordian outwash (Sirkin, 1971), derived from deeply weathered granite and granite gneiss in Connecticut. The Jameco Gravel and the Gardiners Clay as recognized in well section are undoubtedly post-Cretaceous and probably represent Late Pleistocene deposits that are older than the overlying glacial deposits" (Sirkin, 1982, p. 38).

For reference, we include Fuller's original description (1914) of the Mannetto Gravel:

(p.80) Mannetto Gravel

Name

"The Mannetto gravel was named from the Mannetto Hills (West Hills), on the crest of which just west of Melville some of the best exposures of this gravel on the island were found. (See section, p. 68.)"

Character (sic)

"The Mannetto gravel, as is indicated in the table on page 21, is the earliest of the Pleistocene deposits. It consists of stratified (sic) and in some places cross-bedded gravels composed mainly of well-rounded pebbles of quartz from half an inch to an inch in diameter mixed with coarse yellowish quartz sand, but carrying everywhere a few deeply weathered granitic pebbles and scattered large bowlders of crystalline rock, also deeply weathered or disintegrated. It includes a few thin intercalated beds of yellowish clay. The granitic fragments can usually be crushed by the finger or by a slight blow of a hammer, and even the quartz is far more friable than fresh fragments. The quartzose (sic) and stained character (sic) of the gravels, the deep weathering of the pebbles, and the complex flow and plunge (sic) structure are the distinguishing features of the formation.

(p.81) Source of Material

"The great predominance of quartz in the Mannetto gravel is at variance with the composition of the later glacial deposits, in which granites are very abundant. It seems likely that this predominance arises from the nature of the formations of the Coastal Plain farther north. Highly quartzose Cretaceous beds probably extended across what is now Long Island Sound, overlapping the metamorphic rocks of Connecticut, and, being nearest, furnished a large part of the materials of the Mannetto gravel, as compared to the relatively small portion fornished by the more remote (sic) granitic rocks.

(p.82) Outcrops in the interior of the island

"Melville.--The finest exposure of the Mannetto yet found is that in the southern half of the West or Mannetto Hills, outside of the moraine. In these hills the Mannetto gravel appears to form an extensive terrace ranging from about 270 to 330 feet in height. The formation could be best seen in 1903 at the side of the road leading from Melville to the crest a mile west of that village. There 40 feet of somewhat irregularly stratified but not cross-bedded (sic) buff (sic) to orange-colored gravel, mainly quartz with a few rotten granite and ferruginous sandstone fragments, was found resting on the pre-Pleistocene deposits. Essentially horizontaly gravels of the same type, though somehwat less stained, are seen at intervals to the base of the hill, their relations (sic) being as shown in figure 57."

"South end of Mannetto Hill.--Many sections of the Mannetto can be seen about the south end of the Mannetto Hills, especially in the vicinity of Bethpage, Plainview, and Farmingdale...

"Among the points at which the Mannetto gravel was recognized were the small projecting ridge east of the road half a mile northwest of Plainview, the sand pit just northeast of the Bethpage clay pit, sections on the east-west road a mile south of Plainview, and the cut made by the east-west road through the till a quarter mile north of Bethpage Junction. At the last-named locality a fine unconformity, marked by a zone stained by iron and manganese, was seen between the Mannetto and the overlying Manhasset. The steeper slopes of the Mannetto Hills are commonly covered with talus defying identification."

Half Hollow Hills.--From road sections it seems probable that a large part of the mass of the Half Hollow Hills also is made up of the Mannetto gravel, although no typical outcrops were discovered. Yellowish sands, however, such as occur in this formation at many places, were seen in several road cuts. The top of these hills appears to consist of later Pleistocene material, abounding in large and relatively fresh granitic fragments."

(p.83) Outcrops on the coast

"Lloyd Neck.--On the north side of Lloyd Neck the Mannetto was apparently removed by the erosive action of the Montauk ice, no indication of it being seen over the Cretaceous outcrops at that place. Back of the south end of the beach southwest of Lloyd Point and at the base of the bluff just north of Lloyd beach, talus slopes, seemingly of Mannetto materials, are seen. The section at this point is given to show the character of the clayey phase of the formation.

Section north of Lloyd Beach	**Feet**
Montauk till member of Manhasset formation (?): Interstratified yellowish clay and sand with an occasional erratic up to 6 inches in diameter	2
Mannetto gravel:	
Dark-gray clay	1.5
Bright-yellow clay	1
Yellow clay with ferruginous sand and pebble layers	2
Fine quartz gravel with iron and manganese stains; weathered granitic pebbles	5

"The beds are folded on east-west axes, the dips ranging from 5° to 30°."

We think that the till containing the decayed granitic stones correlates with Fuller's Mannetto gravel. We concur that the Mannetto is of Early Pleistocene age (based on the state of decay of its stones) and thus find no merit in Sirkin's assertion that the age of the Mannetto gravels is Woodfordian.

As for the MacClintock and Richards (1936) reassignment upward to the Sangamonian of the Gardiners Clay (assigned to the Yarmouth Interglacial by Fuller), which has become established "dogma," we refer the reader to Ricketts (1986).

Erratic boulders

The beach is littered with boulders of great variety and distinctive types include:
plagioclase-phyric gabbro with xenoliths,
amphibole-phyric lamprophyre,
potash feldspar phyric granitic gneiss,
mylonitic granitoid gneiss,
augen gneiss,
epidote amphibolite,
potash felspar pegmatite,
mica-rich red shale (Cret.),
hematite-cemented conglomerate (Cret.),
and many others.

As at Sands Point, no erratics of Triassic-Jurassic Newark-type basin fill rocks are present.

Unfortunately, we do not yet know the provenance of these boulders, some of which are very distinctive. The augen gneiss may be from the Bedford Gneiss of Westchester County and the epidote amphibolite is probably from the Orchard Beach area of Pelham Bay Park.

STOP 3 - Target Rock - Tills, outwash, hogwash, loess and erratic boulders. UTM coordinates = 632.0E/4531.8N, Lloyd Harbor 7-1/2 minute quadrangle.

In our pre-trip visit to Target Rock, we were not able to study these exposures that were described in 1975 by Sirkin and Mills. We are eager to have a look at them, but if we do get to all of them, we will be seeing them for the first time. From what we did see, we disagree with the provenance of the stones inferred by Sirkin and Wells. We include extensive quotations from Sirkin and Mills (1975, Trip B-5, p. 316-322).

Guide to trip from stairway to the beach and extending NW along the shore of Huntington Bay.

Stop 1: Ca. 100 m NW of stairway.
(p. 319)
Beach upward: outwash, till, outwash, and loess.
From top downward:
Loess: ca 1 m. thick.

Outwash: "Stratified sand and gravel (outwash?) forms a lens pinching out to the southeast and thickening to about 2m to the northwest. The height of the cliff diminishes southward as this unit pinches out."

Till: "A compact, brown till (a sandy loam with abundant cobbles and boulders) about 1 m thick overies the outwash."

Glacial outwash: "approximatley 5m of glacial outwash composed of stratified sand and gravel."

"On the beach there is an abundance of cobbles and boulders. Diabase and purple-red puddingstone conglomerate erratics, along with till fabrics and other rock compositions suggest a northwesterly source are for the till. The diabase may be derived from the Palisades and the puddingstone from lower or middle Paleozoic conglomerates such as the Green Pond Conglomerate found near the New York-New Jersey border northwest of the Palisades."

"Between Stops 1 and 2, cobbles begin to appear in the loess and the stratified unit above the till thickens and then thins until the loess is nearly resting on the till."

Stop 2. Actively slumped section in the topographic high; added relief supplied by thickening to about 8 m of sediments above the till.

"These //(p.320) stratified layers exhibit small scale (sic) cross bedding and bedding rippled by translational waves overturned to the southeast. This unit is characterized by clay, silt, and fine sand at the abase which is somewhat obscured by slumping. It coarsens upward into fin and medium sized (sand). Overall this unit probably represents sedimentation in a proglacial lake that aformed between the ice just to the north and the upland to the south."

"On the beach a number of predominantly dark colored (sic) erratics of mafic composition have been eroded from the till. Some of these rocks resemble the Harrison Gneiss found to the north and northwest in southern Westchester and Connecticut."

Stop 3: in two parts, A and B.

Stop 3A: "low cliff where well exposed (sic) lake silts may be observed."

"Here the basal unit of interbedded, fine grained (sic) silts and sands are well exposed. These beds are somewhat disturbed and have small folds that are overturned to the southeast, and represent additional evidence of minor glacial deformation due to overriding by the ice."

Stop 3B: (description omitted).

Stop 4: The low cliff at the northern point of the beach.

Two tills exposed here; erratics are more felsic than farther south.

"This upper till is of limited extent and seems to grade southward into proglacial deposits. It was probably deposited during the 'Necks' stillstand, with a different source areas than the underlying till. While (sic) correlation with other local tills has not been resolved, the lower till may be the equivalent of the upper or late Wisconsinan till (the Roslyn Till) in Port Washington. The differing source areas between the two (possible) late Wisconsinan tills may be due to their interlobate position and the stacking of Hudson Valley and Connecticut lobe deposits as the ice front fluctuated."

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Table 1. Correlation chart of Pleistocene deposits in New York City and vicinity.

Fuller (1914) names		**S. Long Is.**	**Staten Is.**
(see note below)		**subsurface**	**Westchester Co.**
STAGE	**UNIT**		
	Woodfordian		Till **LII**
WISCONSIN			Paleosol
	Harbor Hill Mor.	Bellmore Fm.	Till **KIII**
		(=Roslyn Till)	
Sangamon	Vineyard unconf.	Wantagh Fm.	
		(="20-ft clay")	
	Ronkonkama Mor.	Merrick Fm.	Till **KII**
	Hempstead Gravel		
ILLINOIAN	Montauk Till		
	Herod Gravel		
Yarmouth	Jacob Sand		
	Gardiners Clay		
KANSAN	Jameco Gravel		Till **KI**
pre-KANSAN	Manetto Gravel		Till **LI**
(w/decayed granite			
stones)			

[Note: Fuller did not use the term Woodfordian and thought that the Harbor Hill and Ronkonkoma moraines were of late Wisconsinan age. We have shown our correlation, not Fuller's for these two moraines. Southern Long Island subsurface from Rampino, 1978 ms.; Rampino and Sanders, 1976, 1980, 1981a, b; Staten Island and Westchester Co. by JES and CM recent field work. We adhere to Fuller's original assignment of the Gardiners Clay to the Yarmouth Interstadial, as supported by Ricketts, 1986 (based on amino-acid racemization results of shells by J. H. Wehmiller, University of Delaware) rather than placing the Gardiners in the Sangamon as proposed by MacClintock and Richards 1936 (and followed by the multitude since then). The designation of tills by K or L based on direction of flow (K for tills from the NW, from the Keewatin center; and L for tills from the NNE, from the Labrador center) and Roman numerals based on age (I for oldest, II, and III, for successively younger tills) follows Sanders and Rampino (1978 abs.). JES and CM have found an ancient till containing decayed granite stones on both Staten Island and Long Island. This finding confirms Fuller but requires assertions made by Sirkin that such ancient tills are not present on Long Island to be revised.) A significant JES/CM departure from Fuller (and everybody else) is the recognition that the youngest Wisconsinan till, the Woodfordian, is younger than the two prominent terminal-moraine ridges on Long Island.]

Table 2. Inferred relationships among Pleistocene tills in southeastern New York and vicinity (Sanders and Rampino, 1978 NE section, GSA abstract; Sanders and Merguerian field observations, 1989-90; 1991 NE section GSA abstract).

Glacial episode	Inferred ice-flow dir.	Evidence and remarks
[Youngest]		
IV Till (Yellow-brown; gray)	**NNE to SSW** (down Hudson valley)	Excavations in Westchester Co.'s sewage-treatment plant in Ludlow area of southern Yonkers and for former Otis Elevator Co. plant near Yonkers RR Sta; exposures at Croton Point and elsewhere. [This is the Woodfordian of newer usage; we infer that the Woodfordian glacier did not reach most of Long Island but rather built a terminal moraine along the north shore of Long Is. Sound. If so, then it had little to do with the terminal-moraine ridges on most of Long Island. It may have crossed parts of Queens and Brooklyn.]
III Till (red-brown)	**NW to SE** (across Hudson valley)	Same as for II, but locally overlying red-brown outwash (not in itself a necessary proof of a deglaciation). This glacier is inferred to be the same one that Woodworth (1901) found had built the inner moraine in Long Island City (western Queens), a feature now known as the Harbor Hill Moraine. This may be the Roslyn Till of Sirkin (1977).
II Till (red-brown)	**NW to SE** (across Hudson valley)	Surface exposure at Prince's Bay, Staten Island; NW part of Croton Point, Westchester Co., NY. JES (1974) inferred that this till was deposited by the same glacier that heaped up the Ronkonkoma Moraine on Long Island.
I Till (gray or yellow-brn.)	**NNE to SSW** (down Hudson valley)	Exposure at Teller's Point, Croton Point Park, Westchester Co.,NY.; resting on Cretaceous, Garvies Point L.I.; cut at entrance to AKR Excavating Co., SW Staten Island; contains decayed stones; ice sheet responsible for shaping NS-trending rock drumlins in Manhattan, at Bear Mountain, South Twin Island, etc.
[Oldest]		

Sanders, J. E.; and Merguerian, Charles, 1991b, Pleistocene geology of Long Island's north shore: Guidebook for the Long Island Geologists, 29 June 1991, 40 p.