DUKE GEOLOGICAL LABORATORY

Web: www.dukelabs.com
E-Mail: CharlesM@dukelabs.com

TRIPS ON THE ROCKS

Guide 13: Glacial Geology of Long Island, New York

Trip 15: 17/18 November 1990; Trip 39: 01/02 June 1996

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

Field Trip Notes by:

Charles Merguerian and John E. Sanders

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INTRODUCTION

This weekend's trip to Long Island (Figure 1, on cover) is devoted mainly to Layer VII, the Quaternary sediments (Tables 1 and 2), most of which were deposited by or in the vicinity of a continental glacier. The major question on today's agenda is: does the local record reflect the invasion by one glacier (presumably the latest, or Woodfordian) or by more than one? Geologists' answers to this question has varied from zero to four. William Mather (1843), who made the first geological survey of Long Island, did not know about glacial deposits. Thus, his answer was, by necessity, zero. In 1879, the glacial geologist Warren Upham described Long Island's two famous terminal-moraine ridges. Upham inferred that each moraine had been deposited by a separate glacier; thus, his vote was two. In 1883, T. C. Chamberlin argued that the same glacier had deposited both of these moraines. Thus, Chamberlin began the "one-glacier-did-it-all school." M. L. Fuller (1914) carried out a monographic study of the geology of Long Island. After visting all of the coastal-cliff exposures, sand pits, and studying samples- and records from all the water wells, Fuller concluded that Long Island had been subjected to four glacial episodes, the same four major glaciations that Chamberlin had found in the midwestern United States. From oldest to youngest, these are Nebraskan, Kansan, Illinoian, and Wisconsinan (Table 3). Fuller assigned the two terminal-moraine ridges to the Early Wisconsinan. In the mid-1930's, MacClintock and Richards (1936) led the multitude back to the "one-glacier-did-it-all" concept. Moreover, at some point, someone shifted the age of the terminal-moraine ridges upward from Fuller's Early Wisconsinan slot to latest Wisconsinan (subsequently designated as the Woodfordian).

Because of ice-thrust deformation, lack of exposures of interstratified glacial- and nonglacial sediments, general absence of materials useful in quantitative geochronometry (and arguments over the correct dates of certain shell-bearing units from which numbers have been derived), and sundry other complications, key points about Long Island's Quaternary record remain in dispute. We think that the field evidence overwhelmingly supports Fuller's interpretation. That being so, one might well ask, why have Fuller's results been trashed? We think we have found the answer to that question--and a very surprising answer it is! We shall come to that subject under the heading of nonstratigraphic age considerations. We return now to a general summary of Long Island during the Quaternary and the importance of the Quaternary sediments to Long Island's ability to sustain its large population.

The two major Quaternary environments of sedimentation on Long Island were: (1) a continental glacier and (2) one- or more lakes that formed during periods when the continental glacier melted. Till is the name for sediment deposited directly from a flowing glacier and outwash, a collective designation for sediments deposited by water from the melting of a glacier. Outwash may be deposited by streams or in lakes.

A lake adjacent to a glacier is known as a proglacial lake. The sediments of a typical proglacial lake are laminated and the laminae record the seasonal conditions (long, frozen-over period of 10 months or so and short, open-water period of about 2 months). During a typical "summer" season, light-colored laminated- and/or graded silts/sands are deposited. By contrast, during the long "frozen-over" season, dark-colored, fine clays settle to the bottom to form a nonlaminated- but graded layer. Whatever they consist of, sediments that are deposited in a year constitute what is known as a varve. A geologist skilled in the interpretation of varves can count them like tree rings and thus establish quantitative chronostratigraphic relationshps, for example the length of time the proglacial lake persisted. Varve counting was invented in 1912 by Baron Gerhard DeGeer, a Swede. Studies of local varved sediments have been made by Antevs (1922, 1928a, b), Reeds (1928, 1933), Ashley (1972, 1975), and Schove (1987). One of the most-comprehensive studies of varved proglacial lake sediments was carried out by Sauramo (1923) in southern Finland.

The four major components of the Long Island Quaternary record that will occupy our attention on this trip are: (1) the two prominent and world-famous terminal-moraine ridges that extend from the eastern- to the western end of Long Island (Figure 2); (2) the deposits, present under much of Long Island, of a large proglacial lake that we have proposed to name Lake Long Island; (3) the deeply incised N-draining "valleys" that form the bays and associated "necks" present along the coast of northwestern Long Island; and (4) localized bodies of till that are most prominent in the vicinity of Montauk Point.

We elaborate on each of these in the section entitled Geologic Background. In that section, we have also included some geologic background with respect to the modern ruckus about the "greenhouse effect" and "global warming."

The Quaternary deposits, particularly the coarse deltaic deposits of proglacial Lake Long Island and the underlying coastal-plain sands, form the aquifers that supply water to the people living on Long Island east of the Queens-Brooklyn line (i.e., residents of Nassau and Suffolk counties; in this discussion, in contrast to the views of many natives, including those who have made- and put up highway signs, who regard "Lon Gisland" as consisting only of Nassau and Suffolk counties, we consider that Queens and Brooklyn are parts of Long Island.). Queens/Brooklyn folk formerly depended on ground water, but their pumping finally exceeded the rate of recharge, the water table dropped, and salt water invaded the aquifers. Since 1910 or so, the Queens/Brooklyn water comes out of pipes connected to the New York City water reservoirs in the Catskills. Today, many wells in Nassau County are pumping ground water from the aquifers at the maximum safe limits. As a result, further population growth in Nassau County cannot take place unless additional supplies of water are found. (Not much imagination is required to envision the reply given to the emissaries from thirsty Nassau County who visited neighboring Suffolk County, drinking cups in hand, to seek some of Suffolk County's ground water!) Nassau County's water needs are a prime force driving the so-called Hudson River water-skimming proposal recommended by the U. S. Army Corps of Engineers in the report resulting from its congressionally mandated study of the regional water supplies in the northeastern states (prompted by the mid-1960s drought). As a result of the importance of ground water to Long Island, many geologic studies have been made based on the materials found in thousands of wells.

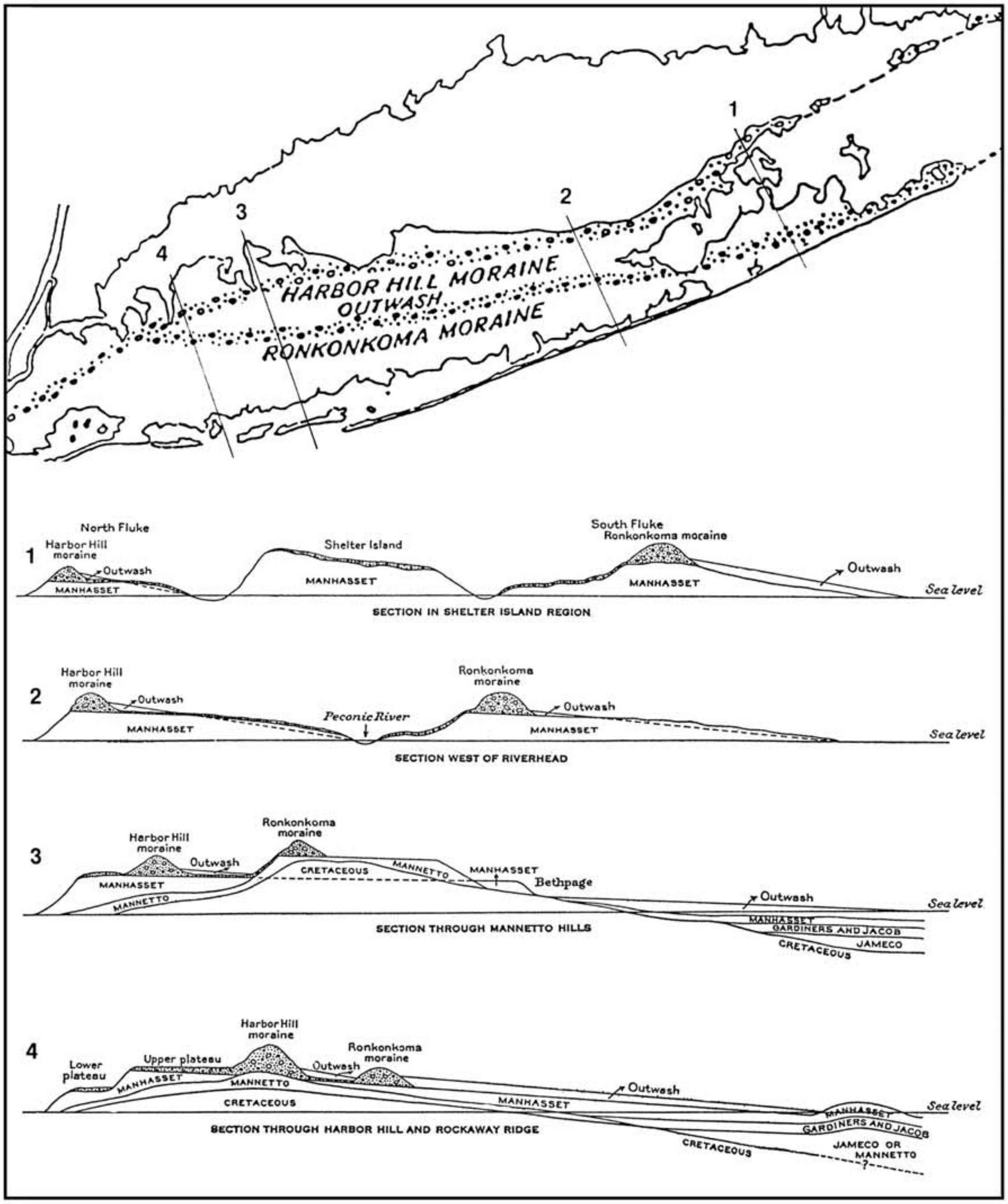


Figure 2. Map of Long Island showing the two prominent terminal-moraine ridges and profile-sections illustrating Fuller's interpretation of the subsurface relationships. Further explanation in text. (Map from A. K. Lobeck, 1939, fig. on p. 309 with location lines of Fuller's sections added by JES; profile-sections from M. L. Fuller, 1914, fig. 107, p. 120, rearranged to place easternmost section at top, westernmost at bottom.)

We summarize some important regional relationships about the bedrock, not only of our trip route, but also of the mainland N and NW of Long Island. Our knowledge of the bedrock in this territory has enabled us to test various flow models of the continental glaciers. A key point that we emphasize today is the effect of what we have called the "crystalline corridor" in western Connecticut and southeastern New York that intervenes between the two Newark-type basins: the Newark basin on the W and the Hartford basin on the E. As a result of this pattern in the bedrock, numerous parent areas are known that have yielded distinctive erratics to the glacial deposits (known as indicator stones if their parent bedrock ledges can be closely identified). Depending on the direction of flow of the ice, the indicator stones and the overall hue of their associated till are the basis for identifying various lateral facies changes in the composition of the Quaternary sediments on Long Island.

GEOLOGIC BACKGROUND

We begin our section on geologic background with a few remarks about the physiographic relationships on Long Island. Then comes material about the "layers" of the bedrock (Table 2). In the "layers" department, we include not only the formations belonging to the bedrock beneath the trip route, but include also a few remarks about distinctive kinds of bedrock (Layers I, II, and V) from the mainland northwest- and north of Long Island which have contributed to the erratics that have been eroded out of the glacial deposits and, after being cleaned up by being moved about on the beaches, are relatively easy to identify. Although most of the coastal-plain strata (Layer VI) do not qualify as being "bedrock," their distribution and characteristics are important factors in the geologic history of Long Island.

We organize our discussion of the "layers" in the bedrock- and pre-glacial formations into three large groups, from oldest to youngest: (1) "basement" complex [Layers I and II] of ancient metamorphic rocks (ages generally greater than 350 million years, but possibly also including some as young as 230 million years; (2) the rocks constituting the filling of the Newark-type basins (Layer V); and (3) the coastal-plain strata (Layer VI).

We discuss the glacial deposits under the following headings: major components of the Quaternary record, facies changes in Quaternary sediments, and nonstratigraphic age considerations (including degres of weathering and extent of landscape dissection). At the end of this part we append a few remarks about geologicl perspectives on the "greenhouse effect" and "global warming."

We conclude with a few paragraphs devoted to the modern (=Holocene; some would say, "obscene") sediment being deposited along Long Island's coasts, including both the shores of Long Island Sound and of the Atlantic Ocean. Most of these sediments are not older than about 2,000 years; some of them may be as young as the most-recent storm.

Physiographic Description of Long Island

In this section, we try to digest Fuller's extensive treatise on the physiography of Long Island, which occupies 45 pages of his treatise and covers everything from the East River and the shape of Long Island Sound to the submarine channel of the Hudson River. Reference to Figure 2 will show the prodominant SSW-NNE elongation of the island and the whale-like outline and the two "flukes" or "forks" at the ENE end. This fundamental trend of the island is governed by the strike of the underlying cuesta of the coastal-plain Cretaceous strata, which was established as a result of the post-Miocene elevation of New England and subsequent fluvial erosion of a strike-valley lowland that subsequently became submerged to form Long Island Sound.

Thus, the Cretaceous "core" of Long Island is steep on the N and slopes gently toward the S (shown on Fuller sections that we have numbered as 3 and 4 in Figure 2) and is exposed (or nearly exposed) only locally along the NW coast and in the Mannetto Hills (located near the Nassau-Suffolk County boundary). Elsewhere, despite the cover of various layers of Quaternary sediments, the overall aspect of Long Island's N-S surface profile preserves the basic asymmetry of the top of the Cretaceous.

Many of Long Island's topographic features are related to the Quaternary sediments and are of depositional origin. For example, two widespread, nearly flat surfaces (Fuller's "plateaus") are associated with the most-extensive Quaternary formation, Fuller's Manhasset Formation (Figures 3, 4A, and 4B). Both are depositional tops, either of the whole Manhasset Formation (as in Figure 4C) or of the lower part of this formation (as in Figures 4A and 4B).

Plastered onto the depositional top of the Manhasset Formation (in most localities, as in profile-sections 1 and 2 of Figure 2) or on older units, such as the Mannetto or Cretaceous (as in profile-sections 3 and 4 of Figure 2), are the Harbor Hill and Ronkonkoma terminal-moraine ridges and associated aprons of outwash. These two moraines form the highest parts of Long Island, the so-called "backbone" or "spines" of the island (followed by the Long Island Expressway for much of its length). On the north fork, near its NE end, a moraine-like landscape consists of windblown dunes called "pseudomoraines" by Fuller (1914, p. 35).

Other distinctive features of Long Island physiographic aspect are various depressions, either open or closed. The open depressions include sundry shallow channels lacking modern streams that are present in the areas of outwash associated with the two terminal-moraine ridges and numerous steep-sided coastal embayments (Figure 4D). We discuss the coastal embayments and various filled channels in the upcoming section devoted to components of the Quaternary record.

Long Island's closed depressions range in diameter from a few meters to a kilometer or more and in depth from 1- to 10 or more meters. These are kettles, which formed when sediment buried a block of stagnant ice that had broken off from the glacier. Fuller (1914, p. 38-44) described Long Island's kettles in great detail and emphasized the important difference in resulting surficial aspect depending on whether the stagnant block of ice was small enough to be buried completely by the outwash (in which surface boulders are generally absent) or large enough to protrude through the blanket of outwash (surface boulders generally present). At present, many kettles form ponds or lakes. Lake Ronkonkoma, the type locality from which the Ronkonkoma Moraine was named, is an example of a kettle lake.

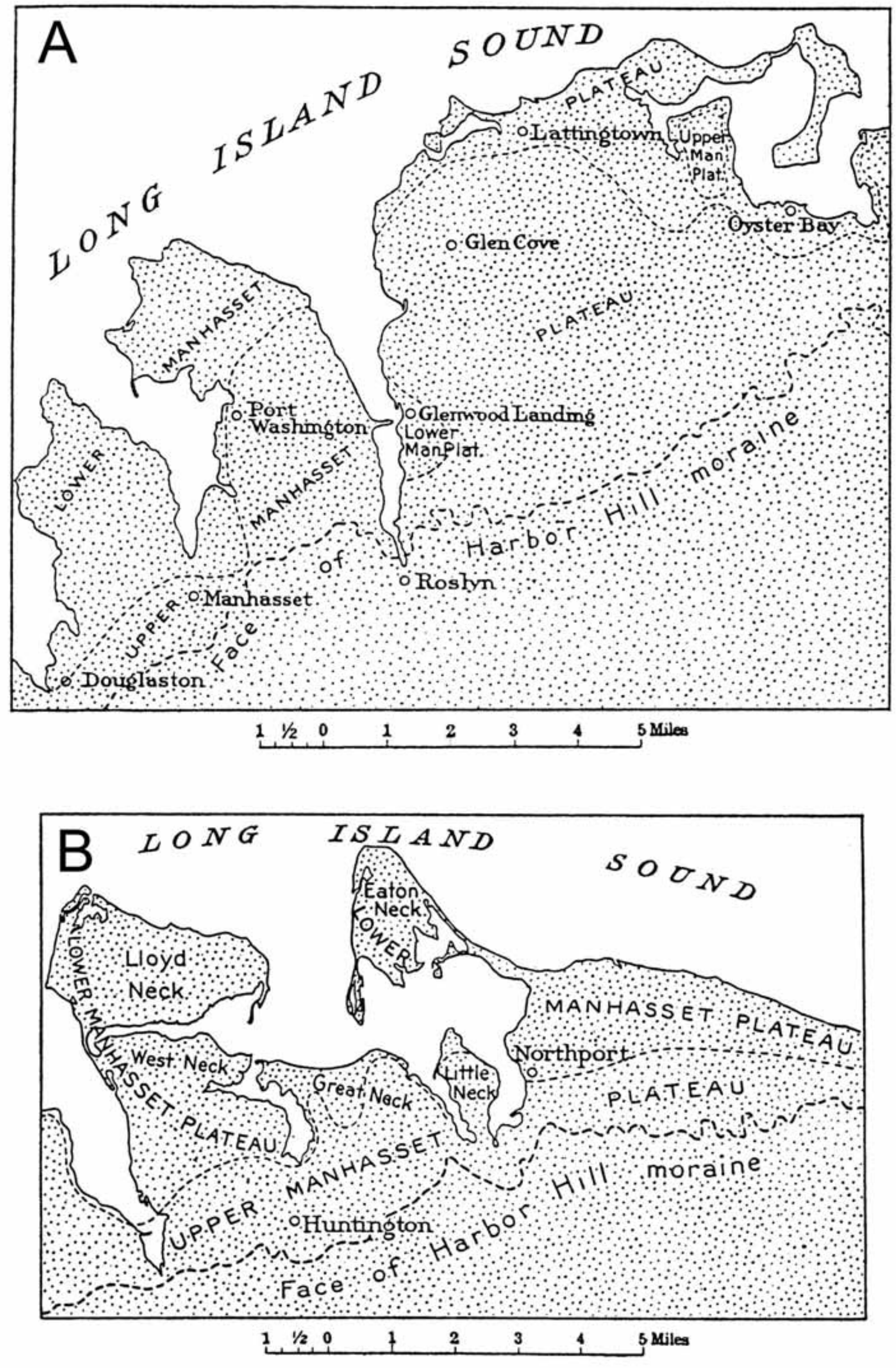


Figure 3. Sketch maps of two sectors NW coast of Long Island showing locations of two "plateau" surfaces (lower- and upper Manhasset, formed by depositional tops of lower- and upper parts of the Manhasset Formation, respectively) and the Harbor Hill Moraine. (M. L. Fuller, 1914, A, fig. 7, p. 30; B, fig. 8, p. 31.)
A. Douglaston to Oyster Bay.
B. Huntington-Northport area.

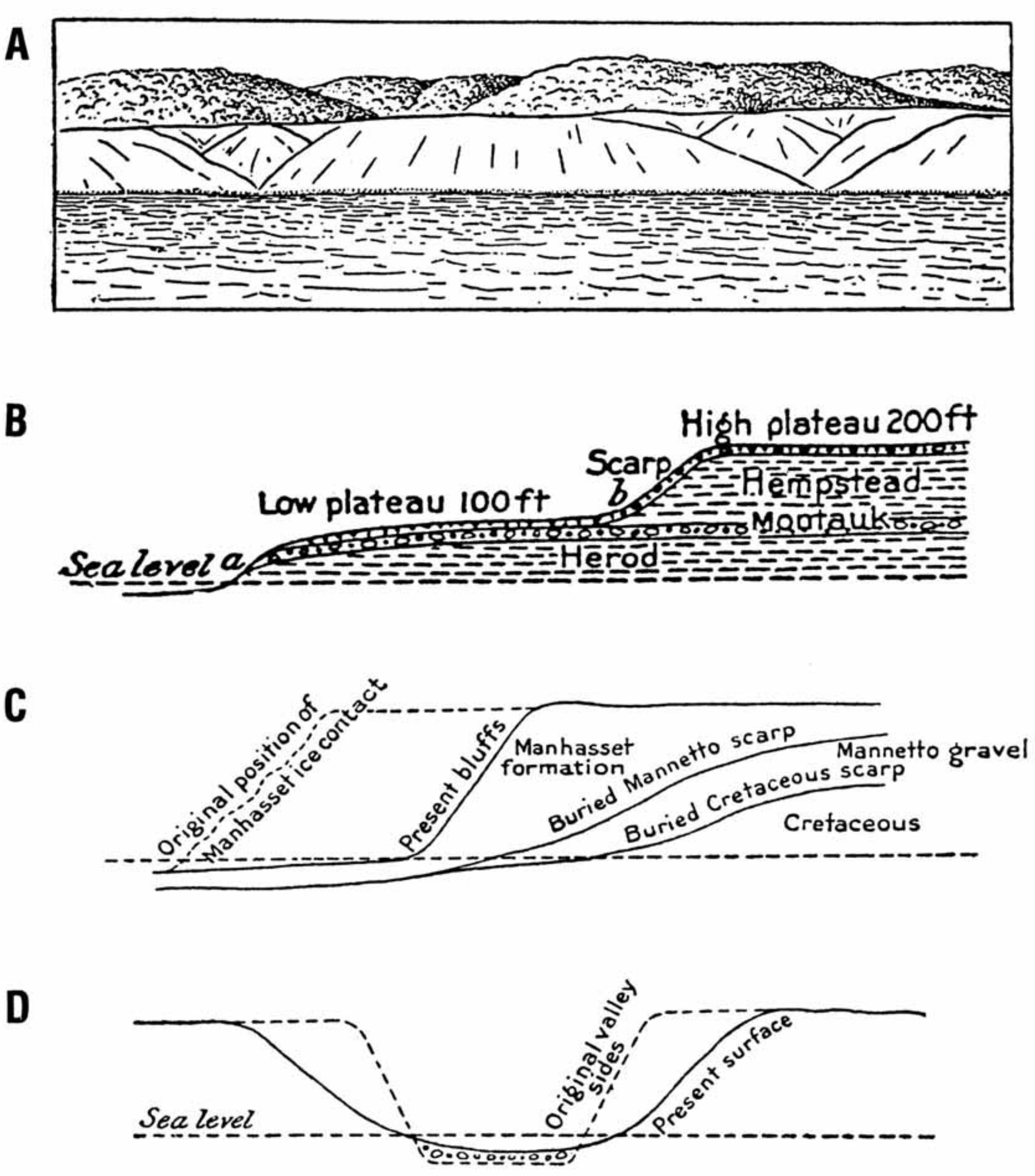


Figure 4. Fuller's sketches of some of Long Island's prominent physiographic features. (M. L. Fuller, 1914, A, fig. 3, p. 22; B, fig. 9, p. 31; C, fig. 5, p. 25; D, fig. 6, p. 26.)
A. View of north-shore bluff of Long Island from Long Island Sound emphasizing the depositional top surface of the lower part of the Manhasset Formation (Manhasset "plateau;" flat surface at elevation +100 ft. in middle) beyond which is the higher, irregular landscape of the Harbor Hill Moraine.
B. Schematic N-S profile-section through coastal region of NW Long Island showing Long Island Sound (at L), modern coastal bluff (a) and two "plateau" surfaces (depositional tops of lower- (Herod-Montauk members) and upper (Hempstead Member) of the Manhasset Formation, respectively, both veneered with younger glacial sediments (of Early Wisconsinan age according to Fuller). Scarp at b is thought to be a modified ice-contact scarp, where the ice stood while the Hempstead Member was being deposited.
C. Schematic N-S profile-section through north-shore bluff, E Long Island, showing relationships among Cretaceous core (lower R), buried Mannetto scarp, and present-day bluffs, cut in Manhasset Formation with estimated original ice-contact position (at L). No "low plateau" is present as in NW Long Island.
D. Schematic E-W profile across typical north-shore coastal embayment, western Long Island, showing relationship between present surface and inferred original valley sides.

The "Basement" Complex of Layers I, II and V

Found exposed in many parts of southeastern New York, solid bedrock which underlies the tall buildings of New York City and is encountered in the various tunnels (shallow ones for vehicles and subway trains and deep ones for water conduits), ranges in age from about 350 million years to 1,100 million years. Collectively, the rocks form a "basement" complex upon which Triassic- and Jurassic Newark-Hartford basin-filling-, Cretaceous coastal-plain-, and subsequent Pleistocene (chiefly glacial) sediments accumulated. The "basement" complex includes many kinds of metamorphic rocks and has provided the garnets and other dark-colored "heavy" minerals (specific gravities greater than 2.80) that are locally abundant within the quartzose sands on many of Long Island's beaches. The "basement" complex extends beneath the coastal-plain cover of Long Island, underlies buried Mesozoic basins beneath Long Island Sound (discussed later), and is exposed at the surface the western- and eastern upland areas of Connecticut (Figure 5).

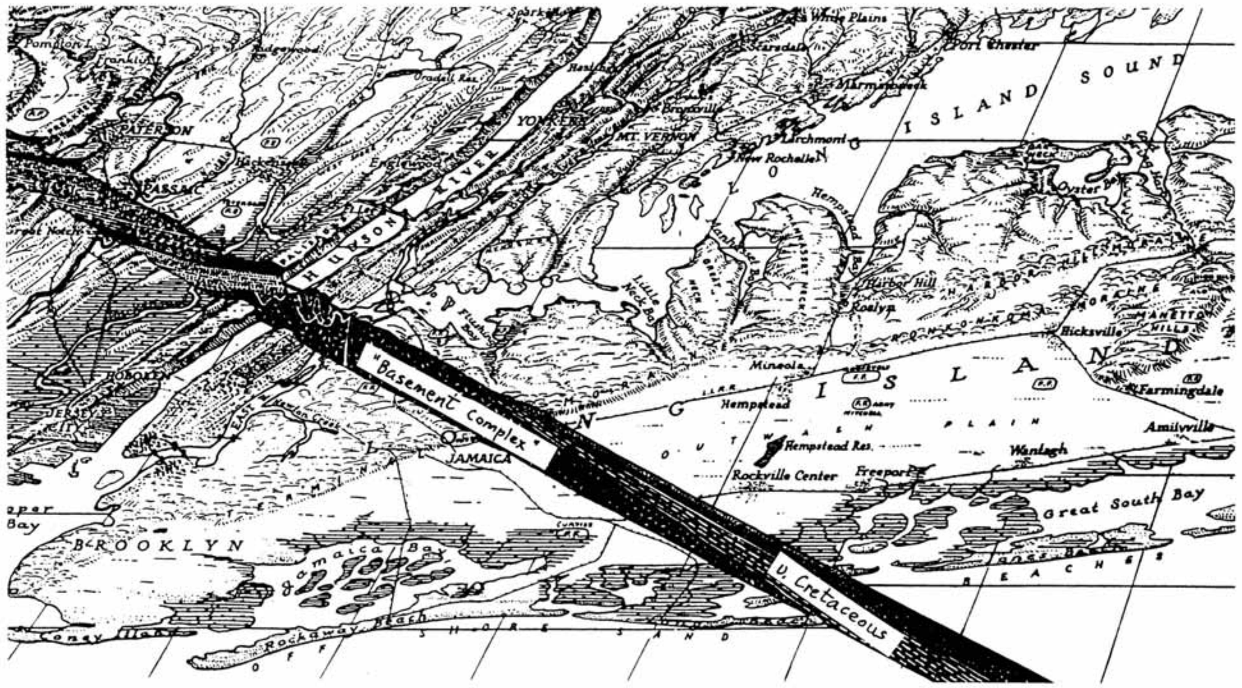


Figure 5. Physiographic block diagram of western Long Island and adjacent areas showing relationship of Upper Cretaceous strata to "Basement complex." (E. Raisz.)

The types of exposed rocks composing the "basement" complex form only at temperatures and pressures that prevail deep within the Earth (in the range of 20 to 25 kilometers). Accordingly, the exposure of such rocks at the Earth's surface means not only that the territory in which they are found sank to great depths long enough for the metamorphic reactions to take place, but also that it was afterward re-elevated and its former cover eroded (Figure 6). The age of 350 million years (Ma) marks the last time that many of the rocks of the complex were heated to temperatures high enough to cause their minerals to recrystallize and to drive out the gaseous radioactive-decay products so that their isotopic "clocks" were re-set to zero. In some localities, late in the Paleozoic Era (during the terminal-stage Appalachian orogeny), some radiometric "clocks" were reset to zero and many older metamorphic rocks were subjected to metamorphic conditions where lower-temperature "retrograde" minerals replaced higher-temperature "prograde" minerals.

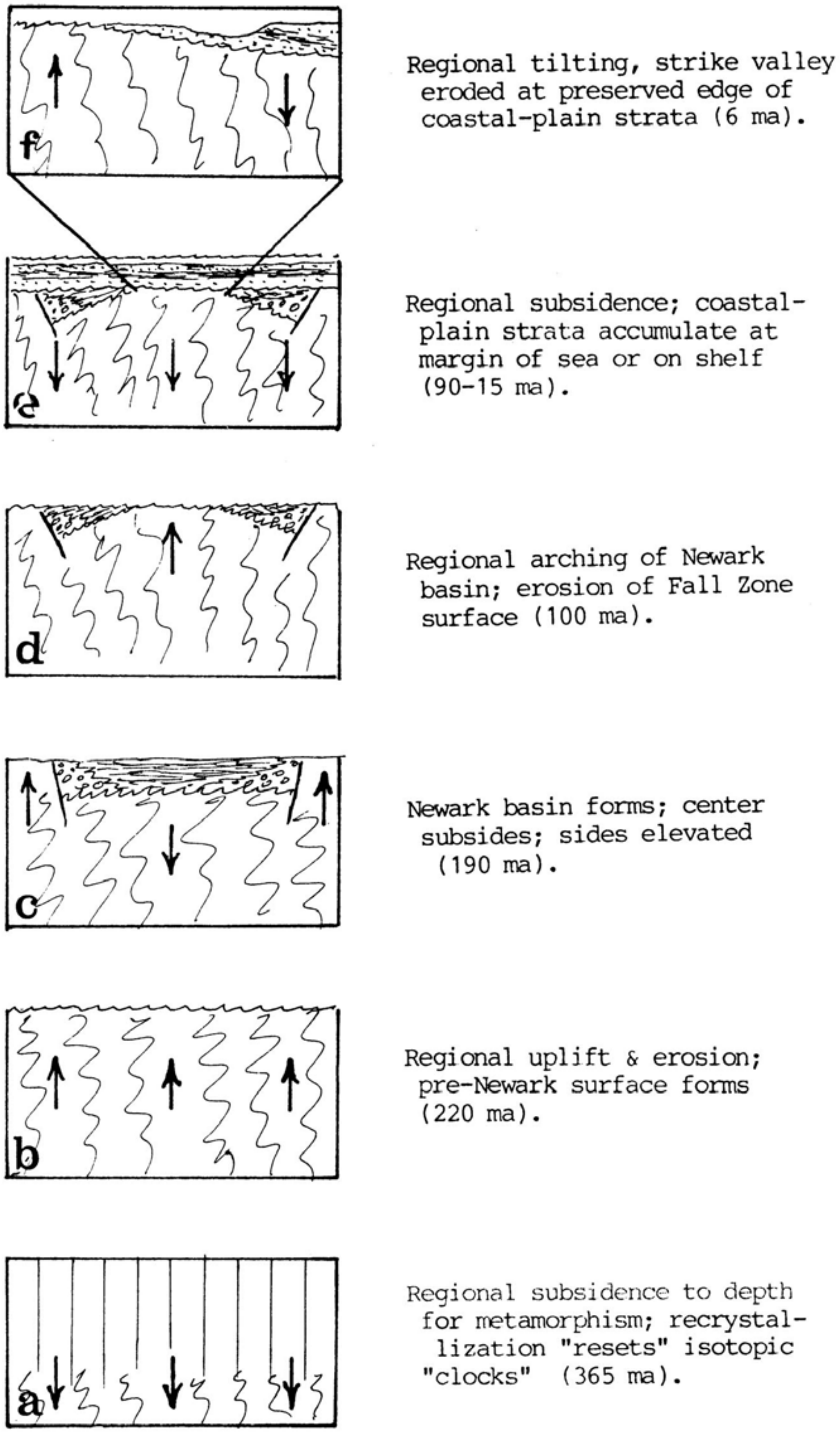


Figure 6. Schematic profile-sections showing stages in development of Long Island and vicinity. (JES.)

The post-Paleozoic history of ups and downs of the complex (See Figure 6.) involves its reappearance ("sunning") at the Earth's surface about 220 Ma (at the beginning of the episode of subsidence of the Newark-Hartford Basin); another sinking of part of it is equal to the thickness of the Newark strata (possibly as much as 10 kilometers) plus closely coupled zones (upland areas) that were elevated to provide the coarse sediment forming the fill of the Newark Basin; and a post-Newark, pre-coastal plain elevation amounting to whatever was the amount of Newark subsidence plus another amount great enough to cause the formerly horizontal Newark strata to acquire their present-day gentle dips.

The focus of this weekend's trip is an examination of Layer VII (Pleistocene Glacial Deposits), but an important product of glacial deposition is the transportation of erratic blocks of bedrock and deposition of colored tills from regions that may be far removed from Long Island. We have described the rocks of this basement complex in the guidebooks of several of our previous On-The-Rocks Trips and thus we will confine our remarks here to a description of the potential source terrains for the distinctive kinds of rocks that are found as erratics weathering from tills found on Long Island. Our joint studies of glaciation in the Hudson valley have been greatly strengthened by identification of erratic indicator stones from geologically unique, "point-source" exposures of distinctive lithologies and correlation of colored tills with regional up-glacier soil profiles. Our preliminary examination of glacial erratics on the north shore of Long Island (particularly Stops 1, 2, and 3) indicates the presence of many unique sedimentary-, metasedimentary-, metaigneous-, and ductile-fault rocks traceable to geologically complex terrains of southeastern New York, Connecticut, and possibly Rhode Island (present at Stop 6?).

In the following paragraphs, we review the distinctive features of the bedrock in southeastern New York State and the state of Connecticut. (See Tables 1 and 2.) Our objective is to help "soft-rockers" pinpoint distinctive assemblages of bedrock so that certain erratics found in the till or along local bouldery beaches can indeed serve as indicator stones. In this way we extend the "facies concept" to include groups of boulders in much the same way a paleontologist would use assemblages of fossils for purposes of biostratigraphic correlation.

Western Crystalline Terrane, SE New York and Western Connecticut

Highly metamorphosed- and lithologically distinct Paleozoic rocks are found nestled between the Newark Basin of New Jersey and New York and the Hartford Basin of Connecticut and Massachusetts (Figure 7). We refer to this region herein as the Western Crystalline Terrane. This "crystalline corridor" of the Appalachians constitutes a lithically unique source terrain between the Mesozoic Newark- and Hartford basins.

Geology of the "Crystalline Corridor"

The bedrock of southeastern New York State is dominated by complexly deformed, metamorphic- and metaigneous rocks that underlie the Manhattan Prong and adjacent areas of western Connecticut (Figure 8). The ages of these rocks range from Proterozoic Y through Devonian. Many of the rocks sequences have been overthrust, but some more than others. Included are some distinctly allocthonous rocks of the low- to moderate metamorphic grade Taconic sequence that have been overthrust many km to the NW from their original depositional sites. For ease of discussion, we will subdivide the "crystalline corridor" into two belts: (1) the Manhattan Prong of southeastern New York and, (2) the highlands of western Connecticut. These two belts are separated by a regionally important middle Ordovician ductile shear zone mapped as Cameron's Line. Work by Merguerian (1983, 1985) and many others have traced this contact from western Connecticut into New York City.

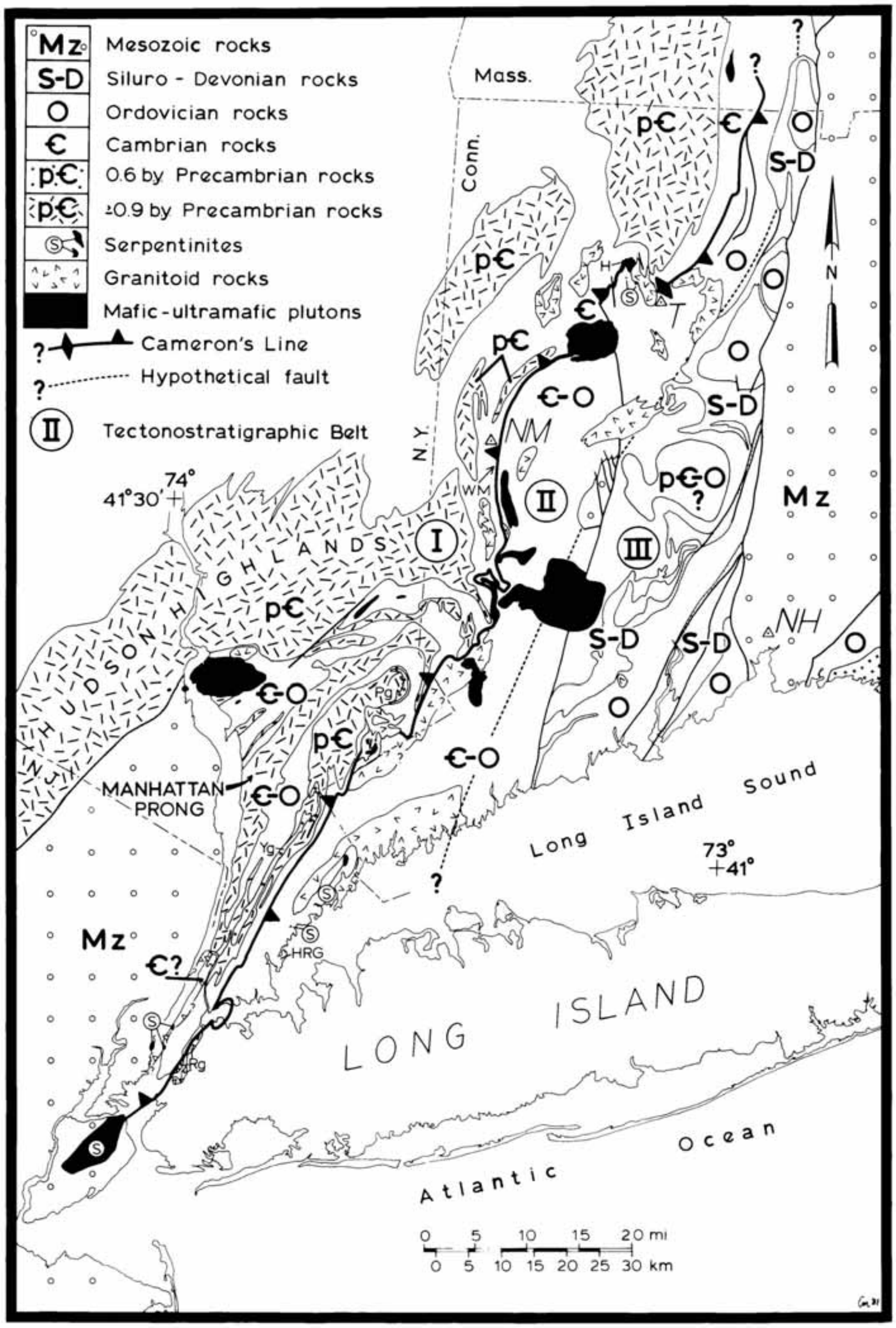


Figure 7. Geotectonic map of the "crystalline corridor" of western Connecticut and southeastern New York showing major rock units. Shown in black are distinctive mafic-ultramafic plutons, parents of many indicator stones in Quaternary sediments. (Charles Merguerian, 1983, fig. 1, p. 342.)

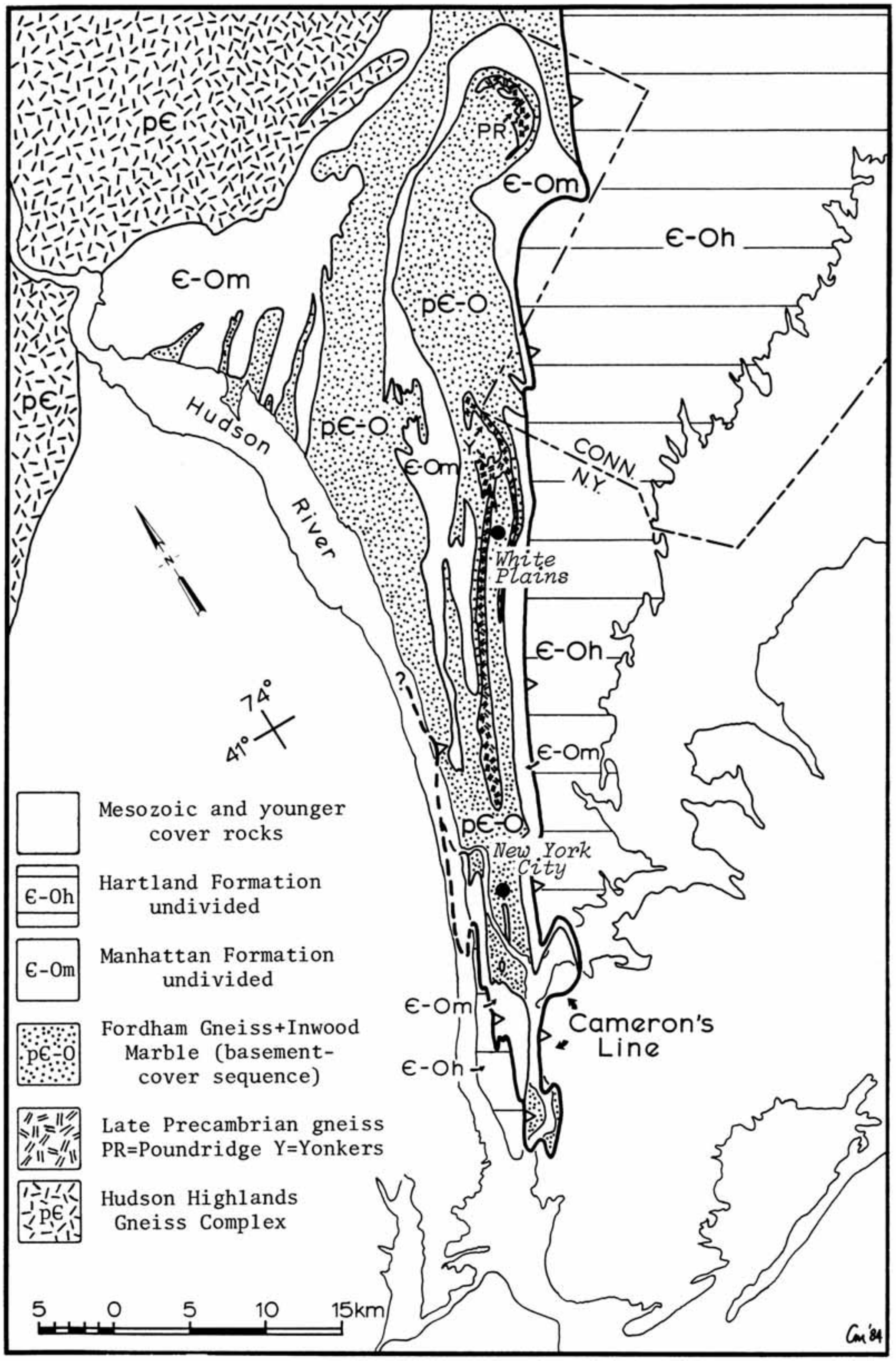


Figure 8. Simplified geologic map of Manhattan Prong showing the distribution of metamorphic rocks ranging in ages from Proterozoic to Early Paleozoic. Most intrusive rocks have been omitted. (D. G. Mose and Charles Merguerian, 1985, fig. 1, p. 21.)

The Manhattan Prong

The Manhattan Prong, which extends from New York City northward into New England, is bounded on the northwest by Grenvillian (1.1 Ga) Proterozoic Y rocks of the Hudson-Reading Prong (pꞒ in Figure 8) which constitute Layer I. (See Table 2 for Layer descriptions.) On the east is a ductile-fault contact (Cameron's Line) marked by a zone of highly sheared and syntectonically intercalated, mylonitic rocks. Cameron's Line, which skirts the New York-Connecticut state boundary, separates Layer II rocks of the Manhattan Prong to the west from coeval rocks to the east that were originally deposited in a dramatically different paleogeographic setting (shallow water [Layer IIA(W)] vs. continental rise and deep-sea floor [Layer IIA(E)]).

Formerly deposited as sediments under shallow-water shelf conditions, Lower Paleozoic metamorphic rocks of the Manhattan Prong found to the west of Cameron's Line include the Lower Cambrian Lowerre (=Cheshire) Quartzite, the Cambrian-to-Ordovician Inwood (=Woodville, and Stockbridge) marbles. Together they constitute the regionally important Sauk Sequence which is designated as Layer IIA(W) in Table 2. These metamorphic rocks and their correlatives constitute a shallow-water cover sequence that was formerly deposited on the uplifted and beveled continental basement rocks of the Grenville craton. These unconformably overlain cratonic rocks include the Proterozoic Y Fordham Gneiss and Proterozoic Z Yonkers and Poundridge gneisses (Y and PR, respectively in Figure 8), and coeval metamorphosed rift-facies strata (feldspathic quartzite and gneiss and volcaniclastic rocks), mapped in New York and Connecticut as the Ned Mountain Formation (Brock, 1989, 1993 ms.). The Sauk Sequence is unconformably overlain by the Middle Ordovician ("Good Old") Manhattan Schist (Unit Om in Figure 9) (= Annsville and Normanskill) formations which constitutes the Tippecanoe Sequence or Layer IIB.

Locally, these basement-cover rocks are structurally overlain by allochthonous rocks of the Taconic Sequence and their metamorphosed, dominantly massive southerly equivalents [the main body of the "Manhattan Schist" and related amphibolite in New York City (Unit Ꞓ-Om in Figures 8 and 9), the correlative Waramaug Formation, and locally, the structurally higher allochthons of the Hartland Formation (Unit Ꞓ-Oh in Figures 8 and 9)]. Farther north, beyond the Hudson-Reading Prong in New York State, less-metamorphosed lithostratigraphic equivalents of the Lower Paleozoic shallow-water Sauk cover rocks are found including the Poughquag Quartzite and the Wappinger carbonates. The Tippecanoe Sequence is represented by the Walloomsac slate and shale, the Normanskill graywackes and shale, and the structurally higher allochthonous rocks of the Taconic Sequence. Thus, the metamorphic rocks of the Manhattan Prong provide a rich source of metamorphosed, dominantly shallow-water rock types.

Western Connecticut Uplands

In this section, we begin by describing the contrasting metasedimentary rocks found adjacent to Cameron's Line and then summarize some of the distinctive mylonitic rocks and crosscutting igneous rocks. In westernmost Connecticut (north of the "panhandle"), rocks of the Manhattan Prong and the underlying Ned Mountain Formation crop out. As they were described above we need not mention them again here.

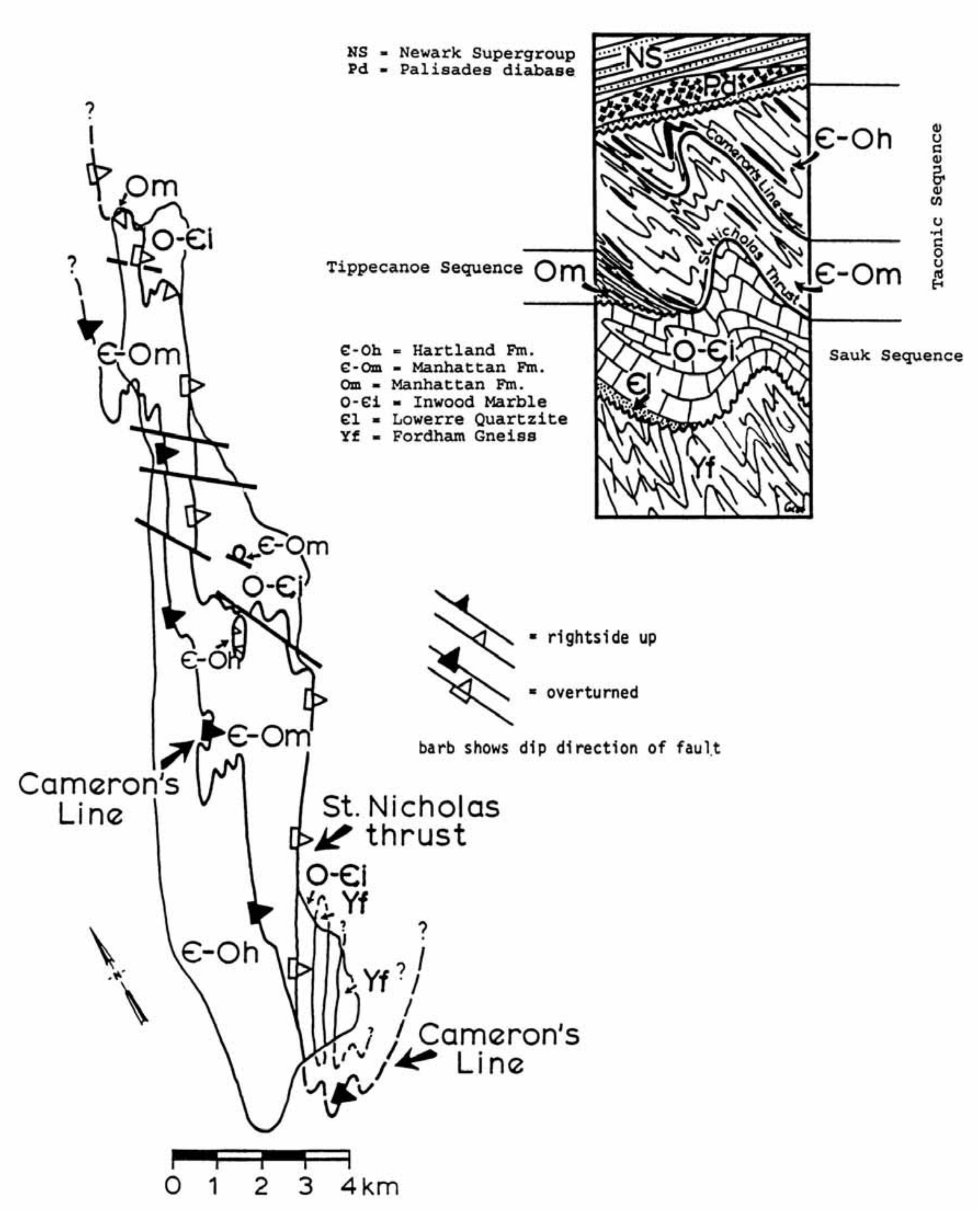


Figure 9. Geologic map of Manhattan Island showing a new interpretation of the stratigraphy- and structure of the "Manhattan Schist." (Drawn and mapped by Charles Merguerian.)

Geologic- and tectonic maps of western Connecticut (Figure 10; See also Figure 7) show that the western crystalline terrane consists of rocks that vary in metamorphic grade, lithology, and structure. Their metamorphic grade varies from greenschist facies in the SE (near New

Haven, Connecticut) sweeping to upper amphibolite facies in western Connecticut and adjacent areas of New York and Massachusetts. Rocks include the internally sheared Cambrian- to Ordovician Hartland Complex which consists of a thick sequence of dominantly well-layered muscovite-rich schist, micaceous gneiss and granofels, amphibolites (of various types) and intercalated mafic- to felsic metavolcanic- and metavolcaniclastic rocks. These stratified rocks are cut by felsic- through ultramafic plutons (typically metamorphosed to some degree), and include tectonically emplaced lenses of serpentinite (Merguerian, 1983, 1985). A unique lithology found throughout the Hartland Complex of western Connecticut, local bodies of ferruginous- and manganiferous garnet-quartz granofels (coticules) occur as highly laminated rocks within the metasedimentary- and metavolcanic sequences (Merguerian, 1980, 1981). Similar coticules have been mapped in the New York City tunnels and have been used as a tool for lithostratigraphic correlation (Merguerian, 1995). On the eastern half of the western Connecticut uplands, the Cambrian- to Ordovician Hartland Formation is overlain by Siluro-Devonian metamorphic rocks of the Straits Schist. Both Lower Paleozoic metamorphic sequences have been cut by local post-tectonic intrusives including Devonian lamprophyre and potash-feldspar-phyric Nonewaug Granite, as well as isolated bodies of Permian syenite, -adamellite, and -dacite porphyry.

To the east of the panhandle area of southwestern Connecticut, Silurian- to Devonian metamorphic rocks are included in the Straits Schist to the south and north of the Cambrian (?) gneisses of the Waterbury Dome. (See Figure 10.) 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 (and beneath the Hartford Basin) 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 crystalline terrane of Connecticut, the interpreted protoliths of Paleozoic metamorphic rocks of the western terrane of southeastern New York and western Connecticut become less "continental" and more "oceanic" in parentage. At Cameron's Line, an abrupt lithologic change is present. (See Figures 7 and 10.)

Cameron's Line, an important stratigraphic-structural contact that skirts the New York-Connecticut state boundaries, separates rocks of Layer II of the Manhattan Prong to the west from coeval Layer II rocks to the east that were deposited in a dramatically different paleogeographic setting. (See Table 2.) Metamorphic rocks representing former shallow-water facies (such as massive marble and quartzite) do not exist east of Cameron's Line. Merguerian (1983, 1985) interprets Cameron's Line as a thrust fault within a deep-seated subduction complex that formed during the mid-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 [Unit Om] and correlative) lithologies with transitional slope- and rise lithologies (the Manhattan [Units Ꞓ-Om and Ꞓ-Oh], the Waramaug-, and parts of the Hartland formations), from former deep-water (including volcanic) rocks found near New Haven. Thus, according to many workers, the juxtaposition of these largely coeval belts occurred during the arc-continent collision of the Taconic orogeny (Figure 11) and resulted in telescoping of the continental-margin sequence and overthrusting of the volcanic arc and its fringing oceanic-basin deposits which were underthrust to form a continent-facing accretionary complex (Robinson and Hall, 1980; Merguerian, 1983).

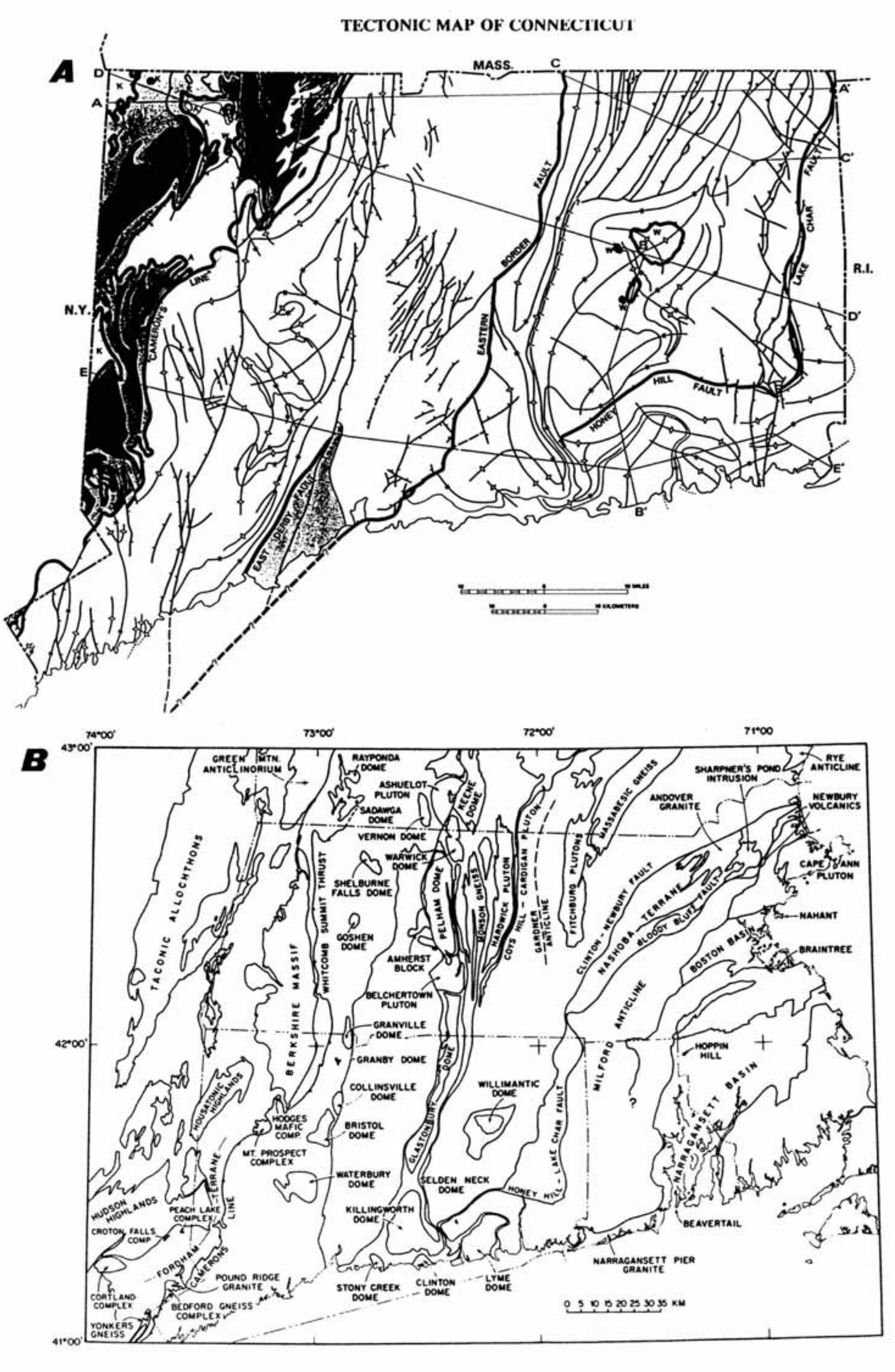


Figure 10. Maps of Connecticut and southern New England showing major tectonic features and rock bodies.
A. Tectonic map of Connecticut showing Cameron's Line and three major terranes. (John Rodgers, 1985.)
B. Tectonic sketch map of southern New England showing major domes, folds, and faults. (P. Robinson and L. Hall, 1980, fig. 3, p. 78.)

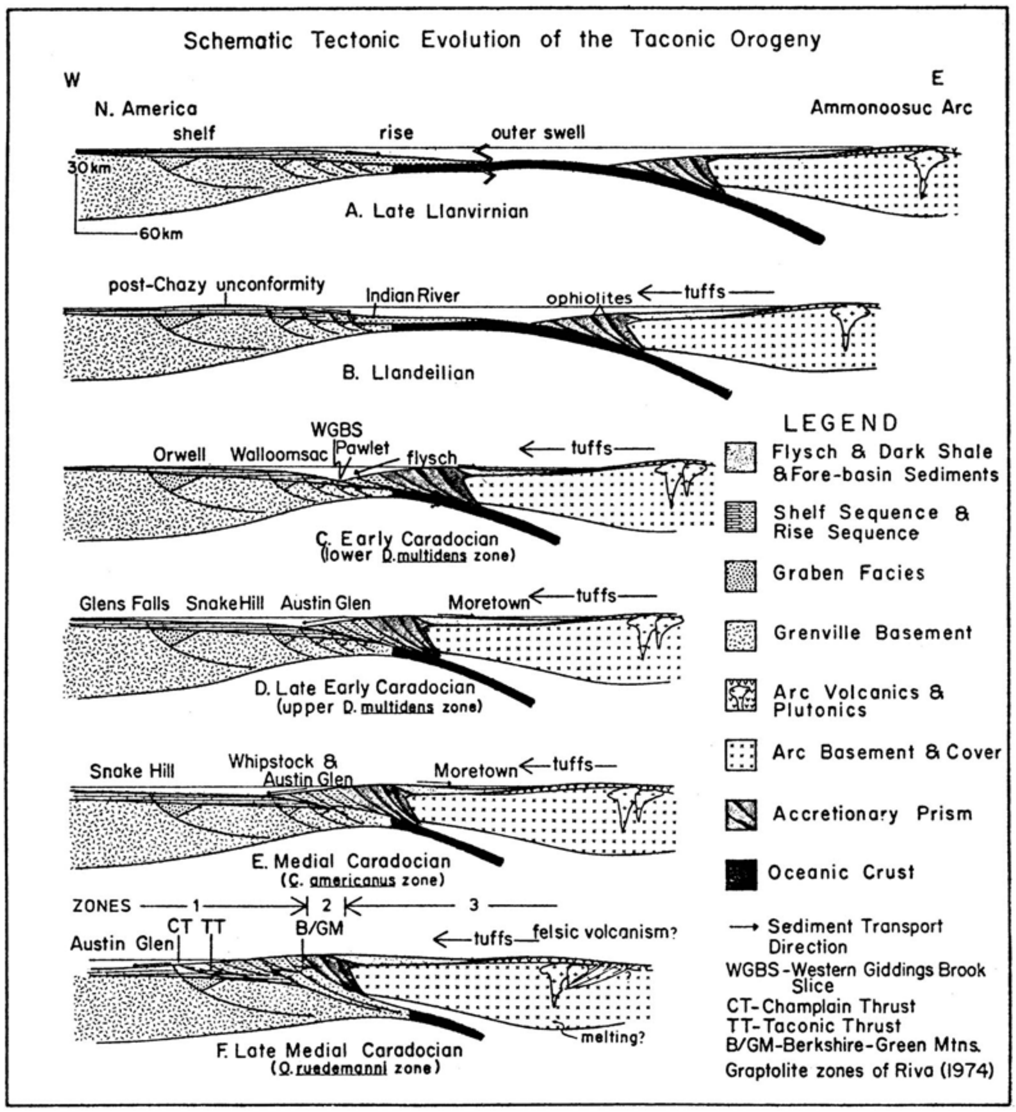


Figure 11. Sequential tectonic cross sections for the Taconic orogeny in New England. (D. B. Rowley and W. S. F. Kidd, 1981, fig. 4, p. 212.)

In this vein, lenticular, highly sheared bodies of serpentinite are found in association with ductile faults in the western terrane and are found scattered throughout the Hartland formation of western Connecticut and New York City (Merguerian 1981, 1985b, 1996). They are interpreted by many, including your heroes JES and CM, to mark the accreted remains of upper-mantle rocks, dismembered into slivers within the subduction complex that formed between the Taconian arc-continent collision zone. Indeed, along the Taconic suture (Cameron's Line) are displayed an impressive zone of mylonitic rocks that experienced abnormally high shear strain under conditions of deep burial during the Taconic arc-continent collision. Ductile-fault rocks bear unique metamorphic textures that can be easily identified: in the field, their highly laminated appearance can be seen megascopically; microscopic study of petrographic thin sections reveals unique, distinctive textures.

With respect to the Taconic orogeny, local plutons are both synorogenic and post-tectonic. The older group of synorogenic plutons cuts 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 (Merguerian and Sanders, 1990a, 1990e). 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 diorite, gabbro, norite, hornblendite, and pyroxenite occur farther north near Litchfield and Torrington, Connecticut and are known as the Mount Prospect and Hodges Complexes (Agar, 1930; Cameron, 1951; Merguerian, 1977 ms., 1985). Together, these orthogneisses represent late synorogenic 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 can serve as valuable indicator stones.

Unique small-scale economic mineral deposits occur throughout the crystalline rocks of western Connecticut. We are investigating the distribution of such 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. Many of the ore-bearing host rocks contain valuable trace- and rare-earth element geochemical signatures that may prove valuable in identifying glacial-flow directions. During an On-The-Rocks field trip in November, 1990, Oliver Wayne found one such erratic, containing pyrrhotite- and chalcopyrite ore minerals, eroding out of the Montauk "till".

In summary, the western terrane of Connecticut is chiefly underlain by metamorphic rocks that form part of the crystalline core of the Appalachians. (See Figures 10 and 12.) The age range of these rocks is from Proterozoic Y through Middle 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 ductile shear zone known as Cameron's Line. (See Figures 7 and 10.)

Central Terrane of Connecticut

Overall, the state of Connecticut can be conveniently subdivided into three geotectonic terranes (Figure 12) for the purpose of discussion: (1) The western terrane (which also includes the Manhattan Prong as discussed above) composed of Lower Paleozoic metamorphic rocks of the western Connecticut uplands. (See Figure 10.); (2) A central terrane that bounds the western crystalline block along fault-modified unconformable contact and consists of Mesozoic sedimentary- and igneous rocks of the Hartford Basin (to be discussed below); and, (3) An eastern terrane, against which the east side of the central terrane is in normal-fault contact in the vicinity of the Connecticut River. Proterozoic Z through Permian metamorphic- and metaigneous rocks compose this eastern crystalline terrane of Connecticut and Rhode Island.

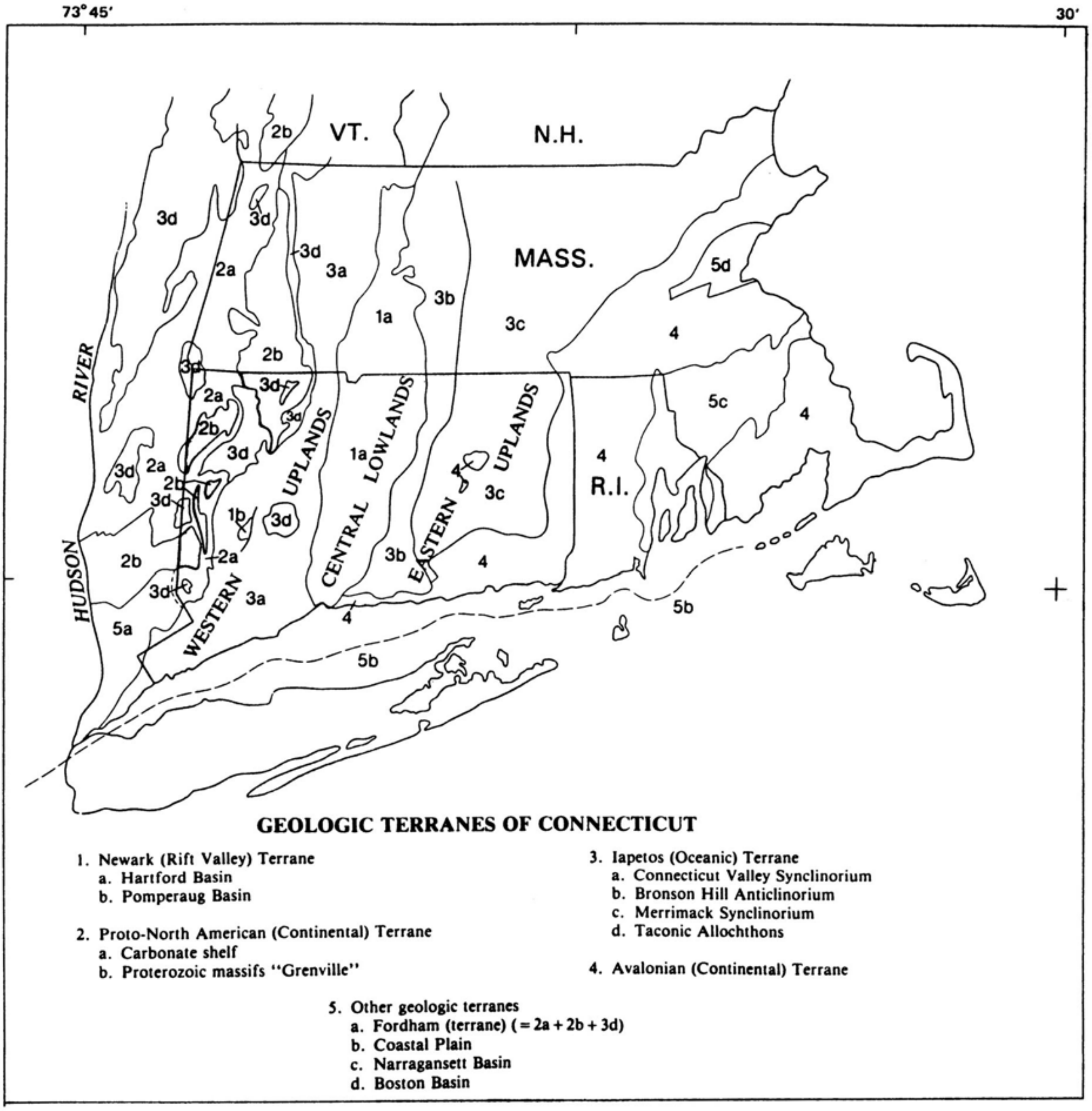


Figure 12. Geologic Terranes of Connecticut. (John Rodgers, 1985.)

The rocks of the central part of Connecticut represent an abrupt and refreshing change in geology compared to the western terrane. The strata filling the Hartford Basin underlie a N-S-trending lowland in the central part of Connecticut that continues northward into Massachusetts (Longwell, 1922, 1928, 1933, 1937). To the west, the basin is in fault-modified unconformable contact with Paleozoic metamorphic rocks of the western crystalline terrane and on the east is in sharp normal-fault contact with the eastern crystalline terrane of Connecticut and Rhode Island. Included in this discussion are similar rocks found nestled within the western terrane in an isolated half-graben known as the Pomeraug Basin. (See Figure 12.)

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 (the Buttress and West Rock dolerites). Correlative with the Upper Triassic to Lower Jurassic Newark Supergroup of New Jersey, 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 basin-filling strata have been 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. The distinctive colors- and lithologies 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.

The Newark and Hartford Basins

Extending southwestward from Stony Point, Rockland County, NY, on the Hudson River valley and into New Jersey, are Mesozoic igneous- and sedimentary rocks of the Newark basin. (See Figure 7.) 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. The west-dipping Palisades intrusive sheet, 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-textured diabase (dolerite) that was intruded into the Lockatong Formation to form an intrusive sheet. Farther westward at at higher stratigraphic positions, sheets of extrusive basaltic rock undelrying the Watchung mountains are intercalated within red-brown Jurassic sedimentary rocks. These constitute the fill of the Newark Basin, that extends SW from Rockland County, NY across central New Jersey and into Pennsylvania and beyond.

Near the Ramapo fault, the basin-marginal fault at the NW edge of the Newark Basin, distinctive clast-supported basin-marginal rudites are present that bear Paleozoic boulders eroded from above the Hudson-Reading Prong and from areas to the north- and northwest of the highlands, set in a red-brown matrix.

The Mesozoic sedimentary- and -igneous rocks rocks filling the Hartford Basin underlie a north-south-trending lowland in the central part of Connecticut. This central lowland is one of three major geologic terranes in Connecticut. The central terrane intervenes between the western terrane and the eastern terrane (to be discussed in a following section). The central-Connecticut lowland continues northward into Massachusetts (Longwell, 1922, 1928, 1933, 1937). To the west, the basin-filling rocks adjoin the Paleozoic metamorphic rocks of the western crystalline terrane. In at least two localities, the unconformable contact between the younger Mesozoic sedimentary rocks and older Paleozoic metamorphic is visible. In most places, however, the boundary between the Mesozoic rocks and the Paleozoic rocks is a normal fault of probable Mid-Jurassic (or younger) age that has dropped the Mesozoic rocks. On the east, the basin-filling rocks end abruptly at the basin-marginal fault (Merguerian and Sanders, 1991e, 1994d). 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 7.)]

Lithologically distinct, the strata filling the Mesozoic basins consist predominantly of east-dipping, red-colored sedimentary rocks and intercalated sheets of extrusive 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 (Merguerian and Sanders, 1989b, 1991g, 1993c, 1993e), 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 strata filling both basins have been 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 phyllites, -schist, and -metavolcanic rocks containing chlorite and epidote as erratics in concert with these distinctive Mesozoic lithologies would uniquely identify a Connecticut source. No such low-grade rocks of volcaniclastic parentage are present in the vicinity of the Newark Basin of New Jersey.

Eastern Crystalline Terrane of Connecticut and Rhode Island

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 (sic-sic-etc.) -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. Within this sequence, many unusual porphyritic gneisses are present 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. (See Foye, 1949; Dixon and Lundgren, 1968; Dixon, 1982; and Rodgers, 1985.)

From our brief summary, it should be obvious that chasing Pleistocene boulders 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.

Pleistocene Boulder Chasing

In our studies of the Pleistocene geology of SE New York and on Long Island we have relied heavily on the stratigraphy of superposed tills wherever we have been fortunate enough to find them. We have observed that tills and outwash produced by glaciers from directions (dominantly from the NW) that pass over the Newark-Hartford basins derive red-colored tills (Figure 13A). Glacial flow directions (from the NE) tend to have yellowish to grayish tills and associated outwash. Distinctive suites of boulders from the "crystalline corridor", from the Newark-Hartford Basin, and from the eastern Connecticut uplands also carry their distinctive lithologic calling cards. Although our work is still preliminary, we feel that our glacial-flow sequence fits the observed "boulder trail" (as opposed to our felonious paper trail) rather well. For example, only glacial flow from the NW (which is clearly possible given our views on the glaciation of the New York-Long Island area) would pluck rocks from these Newark Basin-filling- and "crystalline corridor" localities, generate erratics, and deposit them in certain spots on Long Island. A totally different distribution of erratics on Long Island results from a glacier flowing from NNE to SSW (Figure 13B).

Red-colored till would not uniquely identify the Newark- or Hartford Basins as source terrains. All is not lost however, as the presence of low-grade (chlorite- and epidote-bearing) schist and metavolcanic rocks as erratics in concert with red-colored till and 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.

Newark Strata Beneath Long Island?

A point of long-continued debate about the pre-Cretaceous geologic history of Long Island centers on the results of a deep hole drilled in search of water on Duck Island, Eaton's Neck, early in the twentieth century on the property of the Raymond V. Ingersoll family. W. O.

Crosby (1910 ms.), a very respected geology Professor from M.I.T., saw the samples from this well and inferred that the hole had penetrated the base of the Upper Cretaceous and drilled about 1400 feet into Newark-type strata. As has been the case with some of our On-The-Rocks guidebooks, Crosby's report stirred zero interest among his contemporaries. Many years later, Girard Wheeler (1938) discussed the regional significance of Crosby's report on the Duck Island well. The impact of Wheeler's paper matched that of Crosby's report: virtually zero.

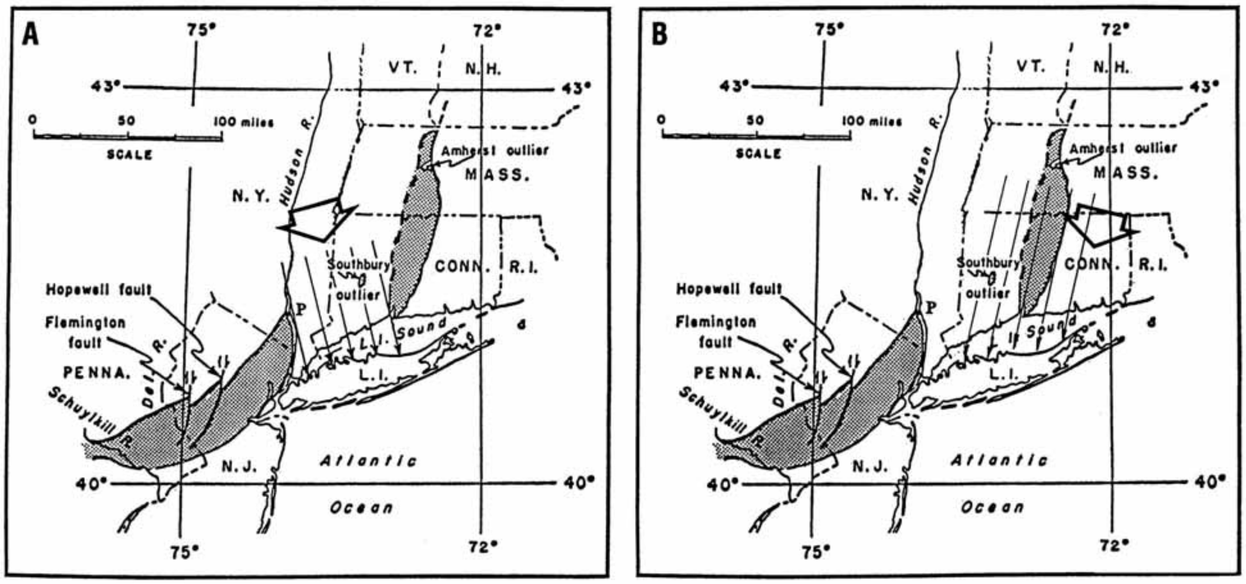


Figure 13. Regional map of part of northeastern United States showing locations of preserved filling strata of Newark Basin (NJ and PA) and of Hartford Basin (CT and MA) (light gray tone). Parallel line segments show how glacial ice flowing from each of the observed dominant directions distributes diagnostic erratics. (Base map from J. E. Sanders, 1963, fig. 7, p. 513.)

A. Flow from NNW to SSE, across the "crystalline corridor" between the fillings of these two basins, deposits reddish-brown erratics in extreme W and extreme E Long Island, but throughout a substantial stretch along the N shore of Long Island, did not deposit any reddish-brown Newark-type erratics. The distribution of erratics in the Harbor Hill Moraine and in the Ronkonkoma Moraine matches that associated with glacial flow from NNW to SSE.

B. Flow from NNE to SSW, as in the Woodfordian glacier, distributes reddish-brown erratics from the Hartford basin in CT and MA to the WSW. The absence of such erratics in the Woodfordian glacier's SSW downflow path along the N shore of Long Island suggests that the Woodfordian glacier did not reach much of Long Island and therefore did not deposit Long Island's two famous terminal-moraine ridges.

Most of the geologists in the U. S. Geological Survey's Long Island water-resources office are skeptical of the report about this ancient well; in the many wells to basement they have studied, they have not found anything resembling the Newark strata beneath the Cretaceous. Professor Lynn Savage of Brooklyn College, who prefers the interpretation that the well cut thick "residual deposits" related to the Cretaceous and not to any Newark basin-filling strata, wrote to the senior Raymond V. Ingersoll in the hope of obtaining a geologic description of the well cuttings (Lynn Savage and Raymond V. Ingersoll, Jr., oral communication to JES at dinner meeting of the Section of Geological Sciences of the NYAS on 04 March 1996). JES has discussed the point raised by Wheeler's 1938 paper (Sanders, 1960, 1963) and argued that the distribution of wells to basement does not preclude the possibility that Crosby and Wheeler were right about Newark beneath the Upper Cretaceous and that their conclusions should be taken seriously.

Additional evidence on the matter is available from geophysics. Seismic surveys in Long Island Sound (Oliver and Drake, 1951) made particularly to look for extensions of the Newark strata from the Connecticut Valley belt [now referred to as the Hartford basin (Cornet and Traverse, 1975; Froelich and Olsen, 1985; Froelich and Robinson, 1988)] failed to find any traces of Newark strata beneath the Cretaceous. The regional gravity map (Woollard, 1943; Hutchinson, Klitgord, and Detrick, 1986; Figure 14) clearly indicates a narrow belt of negative anomalies that suggest a depression in the basement rocks crosses west-central Long Island on a trend that could include the Duck Island well. Continuous seismic-reflection profiles from south of Long Island clearly show localized Newark-type basins underlying the coastal-plain Cretaceous (Hutchinson and Klitgord, 1988; Hutchinson, Klitgord, and Detrick, 1986; Klitgord and Hutchinson, 1985; Figure 15). The area shown with question marks north of the letters NYB (standing for New York Bight basin) is the southwestward extension of the gravity low. The geophysical data do not settle the matter conclusively, but they do suggest that beneath a few parts of Long Island, Newark-type strata may underlie the Cretaceous coastal-plain strata.

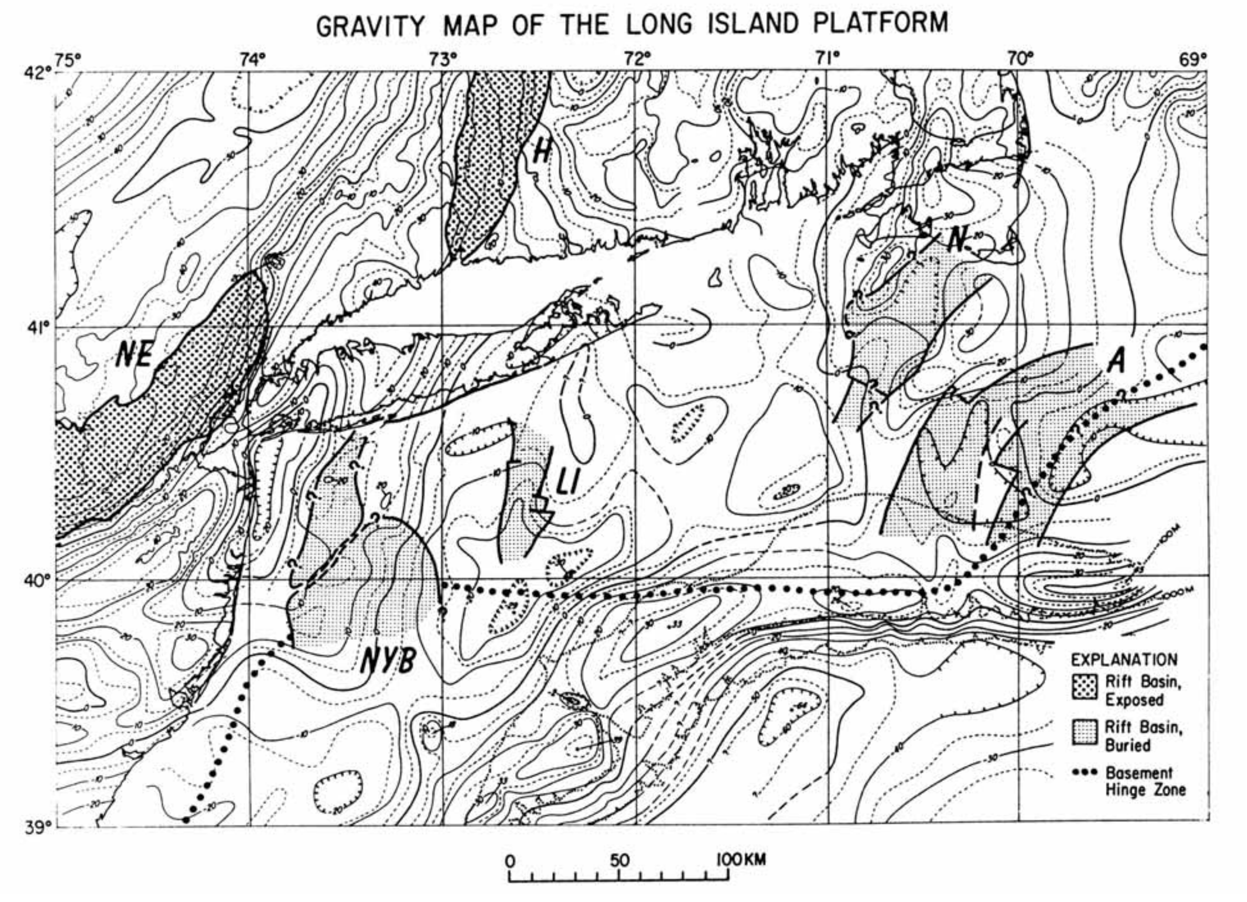


Figure 14. Regional gravity-anomaly map and locations of Newark type basins (2 exposed, NE for Newark basin; H, for Hartford basin; and 4 buried, NYB for New York Bight basin, LI for Long Island basin; N, for Nantucket basin; and A, for Atlantis basin. (D. R. Hutchinson, K. D. Klitgord, and R. S. Detrick, 1986, fig. 14, p. 697; gravity-anomaly map also in G. P. Woollard, 1943.)

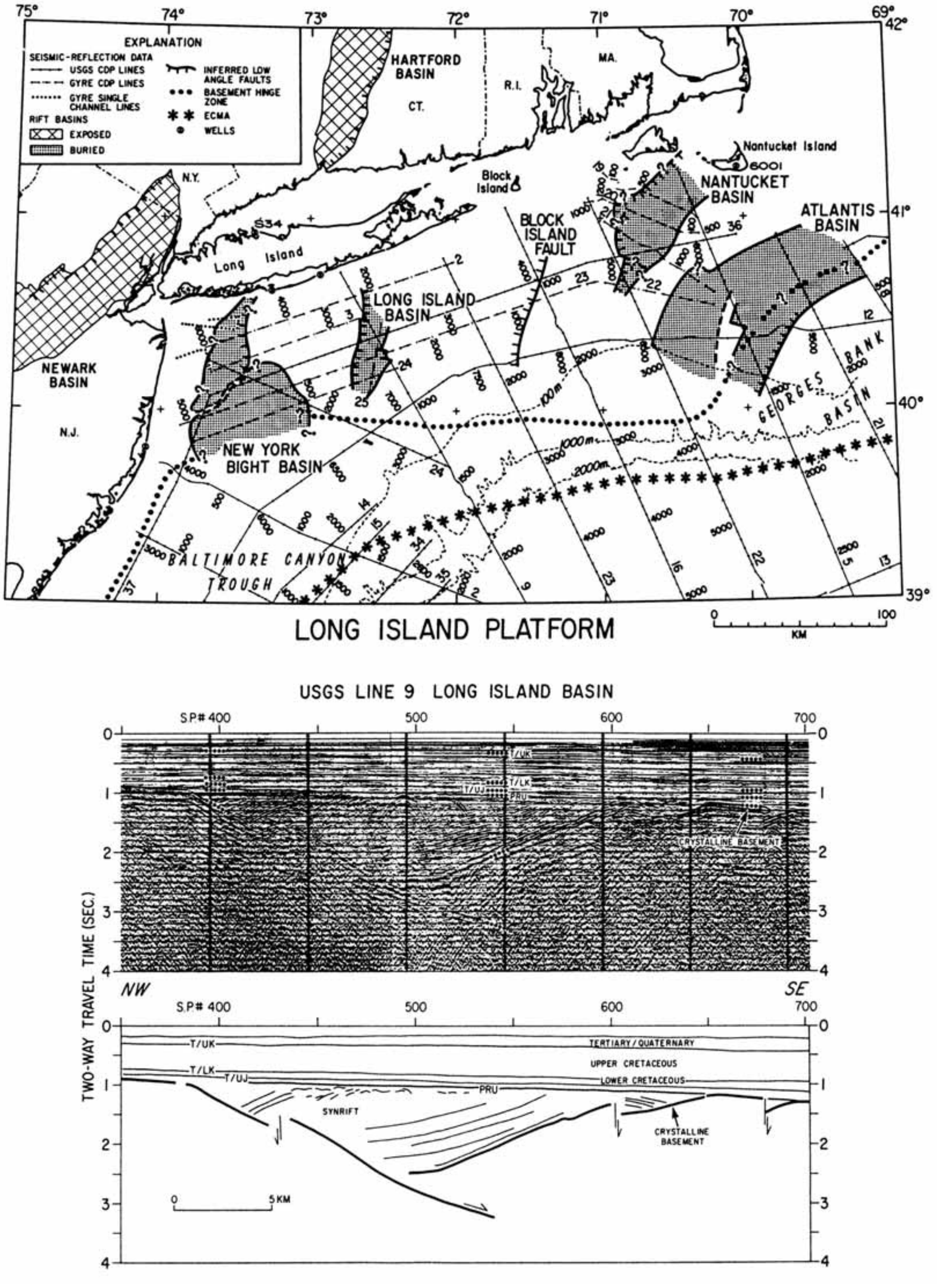


Figure 15. Seismic records of buried Newark-type basins on the Long Island Platform. (D. R. Hutchinson, K. D. Klitgord and R. S. Detrick, 1986, A, fig. 2 and B, fig. 3).

A. Map showing locations of multi-channel continuous seismic-reflection profile records across Long Island Platform and locations of buried Newark-type basins (stippled) and exposed Newark-type basins (squares in diagonal pattern).

B. Example of continuous seismic-reflection profile (Line 9 that crosses Long Island basin diagonally); in the buried Newark-type basin, the strata dip westward toward the basin-marginal fault, here located on the west side. Upper part shows photo of record; interpretative drawing to same scale shown below.

Coastal-Plain Strata; Mineralogic Maturity and the Lloyd Aquifer

After the Newark strata had been deformed and eroded, the tectonic setting of eastern North America changed profoundly. Unlike nearly all of our contemporaries, we think that this change, not the episode of the Newark-type basins, was associated with the opening of the Atlantic Ocean and the formation of a subsiding, passive continental margin, the setting which prevails today. By contrast, many geologists believe that the Newark episode coincides with the opening of the Atlantic Ocean. We think that this belief of an intimate Newark basin/opening Atlantic connection has resulted from repeated assertions in articles written by the "high priests" of plate tectonics and published in geologic journals that these two events were connected. We think that such assertions can be held seriously only by those whose knowledge of the Newark rocks has not progressed beyond what they learned in geologic "kindergarten." (We subscribe to many of the points made by the author of that delightful book: "We learned it all in kindergarten;" but as for geology of the Newark strata, "kindergarten" is not good enough.) [For a full discussion of this topic, see On-The-Rocks guidebook for Trip 34 (Merguerian and Sanders 1995) and also Merguerian and Sanders, 1994a, b.]

Whatever is your geologic "religion" about the Newark and the opening of the Atlantic Ocean, no argument surrounds the conclusion that the coastal-plain strata are products of a subsiding, passive continental margin on the trailing edge of the North American plate as it progressed away from the spreading center of the Atlantic Ocean, the mid-Atlantic ridge. The newest vogue is to analyze these strata in terms of the interaction between seaward subsidence of the basement and deposition of sediment in response to episodes of submergence and of emergence.

After all the post-Newark elevation and great erosion, an erosion surface having low relief (= a peneplain) formed. The surface that formed early in the Cretaceous Period is the Fall Zone surface (Sharp, 1929b). Evidence from borings indicates that this surface, formerly horizontal, now dips SE about 80 feet per mile (Figure 16). Many water wells deep enough to reach the basement rocks have been drilled since Fuller's time (DeLaguna and Brashears, 1948; Suter, DeLaguna, and Perlmutter, 1949). In general, the newer maps show that relief on this surface is small. A possible exception is a deep valley that extends SW from New Haven Harbor, Connecticut. The age of this valley has not been determined definitively; JES thinks that the most-likely possibility is pre-Cretaceous (Sanders, 1965, 1989 ms., 1994b). Flint (1963b) described upland remnants of the Fall Zone surface in Connecticut.

No sooner had the Fall Zone surface formed but another period of subsidence began. The newly formed eastern margin of the North American continent began its long-continued subsidence that enabled the coastal-plain strata to accumulate. The Upper Cretaceous coastal-plain strata are exposed in only a few places on Long Island (Figure 17). In some places, such as the Mannetto Hills (E of Hicksville, N of Farmingdale), the strata are in situ. In some of the coastal exposures, ice-thrust deformation has involved the Cretaceous sediments.

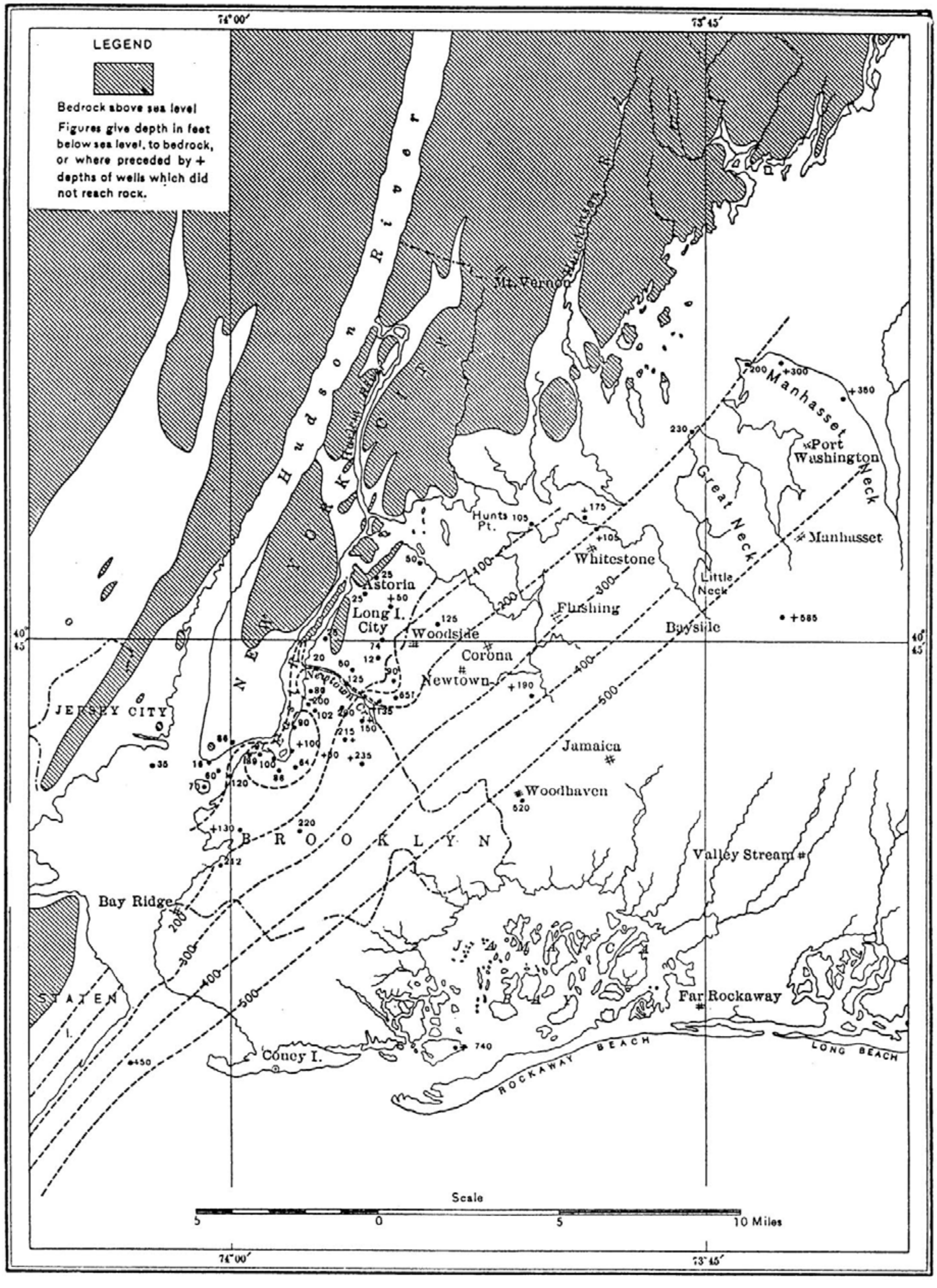


Figure 16. Map of NW Long Island showing contours on top of basement surface sloping 80 feet per mile to the SE. (A. C. Veatch, Pl. XV in M. L. Fuller, 1914, between p. 66 and 67.)

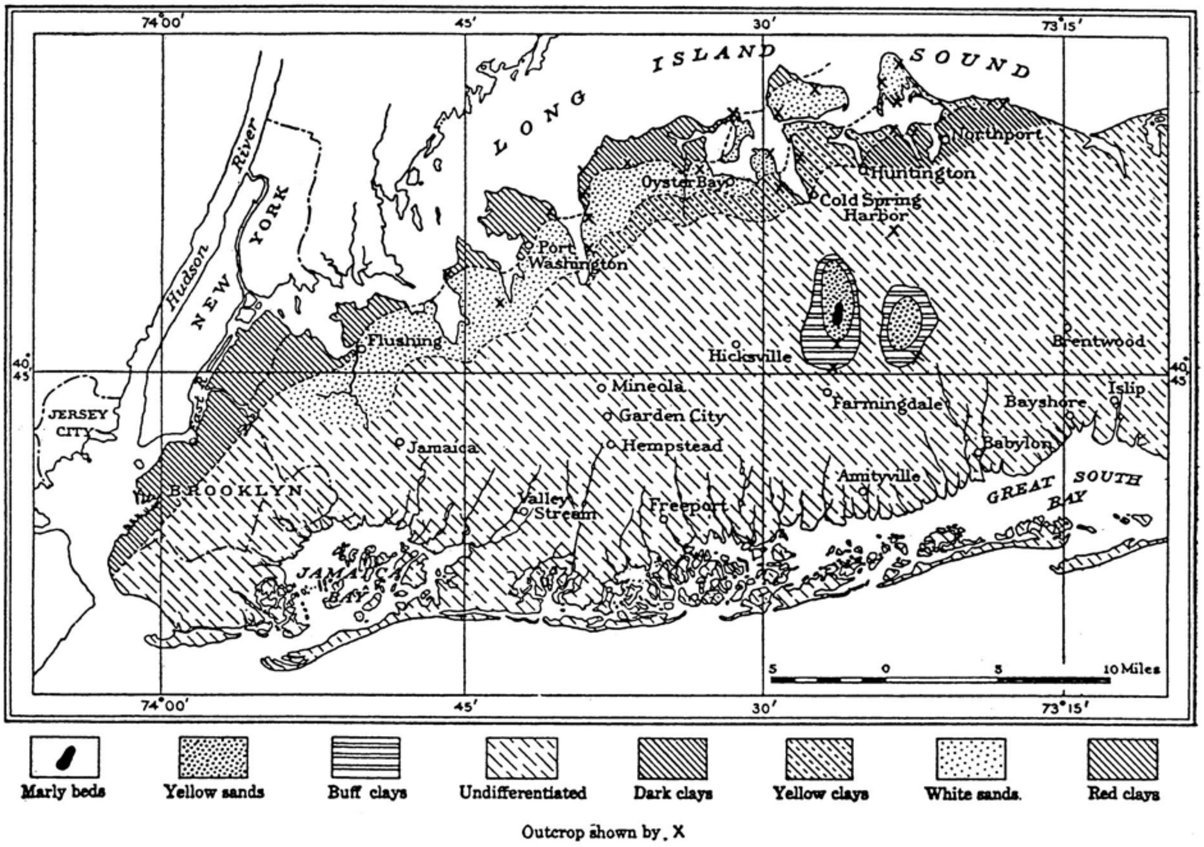


Figure 17. Map of western Long Island showing distribution of lithologic units in the Upper Cretaceous and locations of outcrops. (M. L. Fuller, 1914, fig. 56, p. 69.)

The coastal-plain strata beneath Long Island consist of a lower nonmarine part and an upper, marine part. The names of New Jersey formations have been applied on Long Island. Initially, only two New Jersey names were used: the Raritan, with basal Lloyd sand and overlying clay member, and Magothy(?) for the nonmarine units (Fuller, 1914; Suter, deLaguna, and Perlmutter, 1949; Perlmutter, Geraghty, and Upson, 1959). Later, the marine strata of the Monmouth Group were found in samples from a deep boring on Fire Island (Perlmutter and Todd, 1965). Based on a reexamination of the strata and a study of the pollen, Sirkin (1974) identified four New Jersey units, from base upward: Raritan, Magothy, Matawan, and Monmouth. Sirkin's correlation chart shows no sand in the Raritan Formation (in contrast to the basal sand earlier workers had assigned to the Lloyd). Sirkin identified with query a Lloyd Sand Member of the Magothy Formation (1974, p. 433; but see also Sirkin and Mills, 1975, p. 300, which includes the statement that: "The main water bearing (sic) stratum, the Lloyd Sand, may include thick sands deposited during both Raritan and Magothy time and separated occasionally by thin clay lenses").

The recharge area for supplies of potable water (=ground water) within the Lloyd Sand (whatever is its correct formational assignment) is Long Island itself. No long-distance subsurface route exists, as it does, for example, at Atlantic City. The deep wells at Atlantic City tap ground water from a formation that is exposed at the land surface in the New Jersey pine barrens. As shown in Figure 18, the Cretaceous strata generally stop along the south side of Long Island Sound. A few remnants are known out in the Sound (example: Stratford Shoal; see continuous seismic-reflection profiles of Tagg and Uchupi, 1967; Grim, Drake, and Heirtzler, 1970), and some Cretaceous strata may be preserved as the fillings of deep valleys (as in the West Haven valley described by JES in 1965; see also Haeni and Sanders, 1974; and Sanders, 1989 ms., 1994b; and for eastern Long Island Sound, Lewis and Needell, 1987).

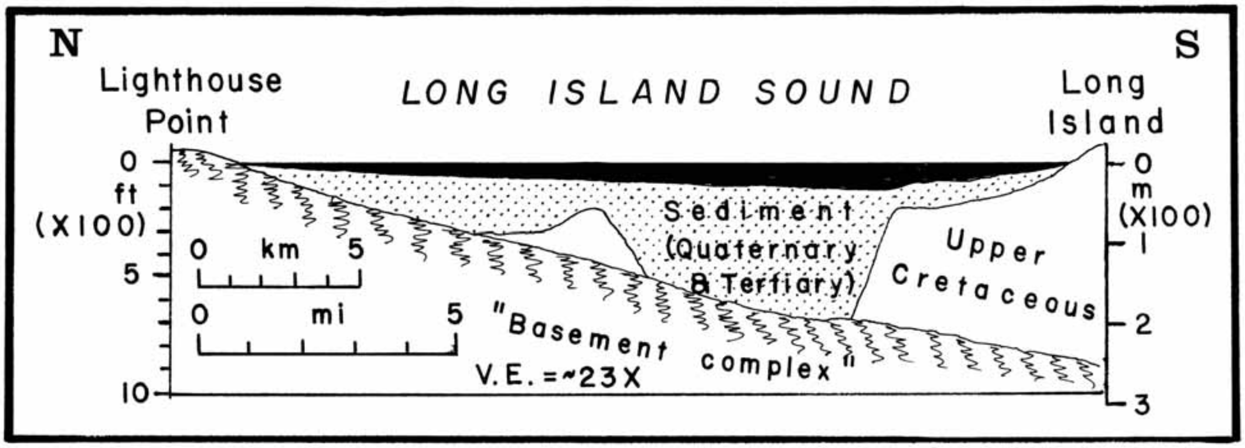


Figure 18. North-south profile-section from Connecticut, across Long Island Sound, to Long Island, along longitude 72° 53' W. Water depths from NOS chart. Subbottom relationships from M. S. Grim, C. R. Drake, and J. R. Heirtzler, 1970, fig. 12, p. 661. Water of Long Island Sound shown in black. (J. E. Sanders.)

The geologic relationships shown by the continuous seismic-reflection profiles absolutely preclude the possibility that any of Long Island's ground water from the Lloyd aquifer comes from a distant source to the north (say, from Vermont, as JES has heard some students in his geology classes, residents of Long Island, assert). As was first pointed out by a French geologist, Jacques Avias, the fact that the ground water in the Lloyd aquifer comes from rain which falls on Long Island means that the overlying Upper Cretaceous clays are not as impermeable as many geologists suppose. Although these clays may be impermeable on the scale of laboratory specimens, on the much-larger scale prevailing in nature, they must be cut by cracks that enable the water to penetrate from the surface to the base of the Cretaceous formations.

The deep wells that supply water to Jones Beach and Robert Moses State Parks (stored in the tall towers in the traffic circles at each park) tap the Lloyd Sand. Immediately beneath the Pleistocene formations in the park wells are Upper Cretaceous marine formations (Perlmutter and Todd, 1965). No Tertiary formations are present (as was incorrectly shown on the original version of the Raisz block diagram, Figure 3, but we have changed the label to show the correct relationships).

The Cretaceous of the north-shore cliffs has been described as consisting of:

> "...tan (sic) and orange colored (sic) sand, red (sic)
> and gray clay, white sand and gravel with a clay binder,

> and occasional lenses of lignite. There are also abundant concretions, ranging from iron-oxide nodules surrounding lignite or plant debris, pipes and paint pots of probable ground water (sic) origin, and marcasite (sic) and pyrite nodules" (Sirkin and Mills, 1975, p. 300).

A mineralogic characteristic of the local coastal-plain strata is the presence of sand-size minerals such as quartz and zircon that resist chemical decomposition during weathering and a general absence of feldspars and other minerals that are easily decomposed during weathering. Such accumulations of the resistant survival products of weathering are said to be mineralogically mature. In its simplest form, mineralogic maturity or immaturity is judged on the presence of feldspar in the sand fraction. Mineralogic maturity means a lack of feldspar (assuming that feldspar is present in the bedrock being eroded). The presence of feldspar indicates immaturity. In addition, the clay minerals of the coastal-plain strata are typified by kaolinite, a product of intense weathering that is found today mostly in the tropical-climatic zones.

Other points about the Cretaceous strata include the brick-red shales containing fossil leaves that closely resemble the Newark shales (Mills, 1969, Garvies Point educational leaflet) and the hematite-cemented conglomerates and -sandstones that somewhat resemble the Lower Silurian Green Pond Conglomerate and Middle Devonian Schunemunk Conglomerate. The predominant kind of clasts in the Cretaceous hematite-cemented conglomerates are rounded quartz pebbles; the rock breaks around the pebbles. Because of the silica cement and effects of deep burial and of deformation, the Green Pond Conglomerate breaks across the particles (and thus is technically a metaconglomerate).

In most of Long Island, the Cretaceous has been buried by Pleistocene sediments. In a few localities, however, the Cretaceous is exposed. We expect to visit three of these (Stops 2, 3, and 4). The geologic relationships of some of these localities clearly indicate that the Cretaceous has been thrust upward by Pleistocene glacial action (Mills and Wells, 1974).

The episode of coastal-plain sediment accumulation that began late in the Cretaceous Period (about 95 million years ago) continued until the Miocene Epoch (about 25 million years ago). From the record in New Jersey, we can infer that a series of fans built southeastward from the rising Appalachians. These fans pushed the shoreline southeastward and ended the episode of accumulation of marine sediments in what is now New Jersey. (However, marine sediments continued to accumulate in areas now submerged.) In the Pliocene Epoch (starting about 6 Ma), regional uplift, possibly combined with the first of many episodes of eustatic lowering of sea level, enabled deep valleys to be eroded. One such valley, named a strike valley because it is parallel to the strike of the gently tilted coastal-plain strata, formed along the eroded updip edge of the preserved Cretaceous strata. (This feature has also been named the inner-cuesta lowland.) The depression that has been filled with sea water and forms Long Island Sound began its career as such a stream-eroded strike-valley lowland.

Other deep valleys that trend across the strike of the gently dipping coastal-plain strata have been incised into the top of the Cretaceous. Some of these have been completely filled with sediments so that they lack topographic expression on the modern land surface (Figure 19).

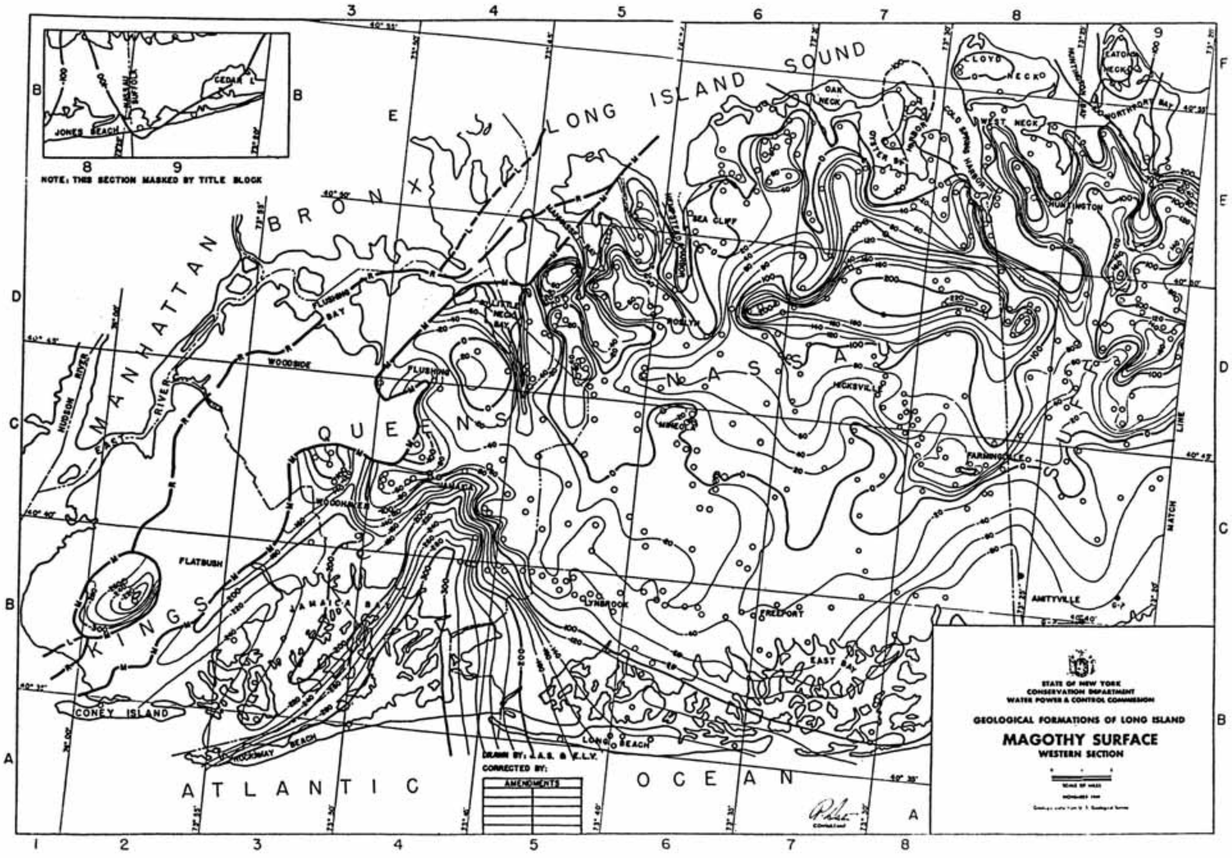


Figure 19. Contour map showing relief on top of Upper Cretaceous Magothy Formation. (R. Suter, W. deLaguna, and N. M. Perlmutter, 1949, fig. , p. .)

Components of Long Island's Quaternary Record

In this section, we summarize the following four major components of the Quaternary record on Long Island: (1) the terminal-moraine ridges, (2) deposits of Proglacial Lake Long Island, (3) north-draining coastal embayments between the "necks"; and (4) bodies of till. In following sections, we mention the facies changes in Quaternary sediments and discuss some nonstratigraphic age considerations.

Terminal-moraine Ridges

Each of Long Island's two terminal-moraine ridges forms the central spine of the two eastern forks of the Island, the Ronkonkoma on the south and Harbor Hill on the north. (See Figures 1 and 2.) Ever since their glacial origin was published, Long Island's two terminal-moraine ridges, the most-prominent features of the Pleistocene deposits of the New York City metropolitan area, have become world famous.

We review their first description, discuss the number of glaciers involved in their origin, and debate their age assignment(s).

First Description

Mather (1843) mentioned the two prominent curvilinear ridges now known to be terminal moraines, but he did not realize they were of glacial origin. Warren Upham (1879), a specialist in glacial deposits, recognized them as terminal moraines of a continental glacier and traced their course from Cape Cod to eastern Pennsylvania. Upham recognized two tills throughout southern New England and on Long Island. He noted that on Long Island, till is abundant W of Roslyn and generally absent to the E.

Near Lake Success, NY, the Harbor Hill Moraine truncates the Ronkonkoma Moraine, and continues on to the west. (See Figure 2.) The Harbor Hill Moraine crosses Queens and Brooklyn, forms The Narrows that separates Upper New York Bay from Lower New York Bay, and extends southwestward across Staten Island. According to Fuller (1914, p. 15), this relationship between the two moraines was first pointed out by J. B. Woodworth and J. E. Woodman in their contribution to the (1901) Geologic Map of New York State, Long Island and Lower Hudson sheets.

Product of Two Glaciers or of One Glacier?

Upham (1879) thought that each of these ridges had been deposited by two different glaciers (one moraine from the "First" and the other from the "Second" glacial epoch). As mentioned, the map pattern demonstrates that the Harbor Hill Moraine is the younger, but the map-view truncation does not prove whether these two ridges were deposited by the fluctuating margin of a single glacier or by the margins of two different glaciers. And the map relationships do not indicate the age or ages of the responsible glacier or glaciers.

Based on the general uniformity of the state of stream dissection of the outwash plains lying south of each moraine, T. C. Chamberlin (1883) made a persuasive case for concluding that these two moraines had been deposited by a single glacier. Chamberlin argued that if each moraine and adjacent outwash plain had been deposited by a different glacier, then during the interglacial interval prior to the advance of the second glacier, streams would have notably dissected the older, southern deposits left by the first glacier. Most geologists have accepted Chamberlin's same-glacier interpretation.

M. L. Fuller (1914) adopted the T. C. Chamberlin same-glacier view of the origin of these ridges; but, as is explained in the following section, Fuller did not agree that the ridge-making glacier had been of Late Wisconsinan age.

Age Assignment

M. L. Fuller's (1914) monographic study of Long Island's glacial deposits formed the basis for his conclusion that these two ridges had been deposited by the fluctuating margin of a single, but Early Wisconsinan glacier (Fuller, 1914, table of Pleistocene events, p. 21). (In the column marked Fuller 1914 in Muller's 1964 correlation table, his table 2, p. 104, the ages of these moraines is erroneously shown as Late Wisconsinan; this is the view of later workers, not that of Fuller. Our Table 3 show's Fuller's Early Wisconsinan position for these moraines not Muller's gratuitous Late Wisconsinan.

Since the mid-1930's (Fleming, 1935; MacClintock and Richards, 1936, 1937; and despite Fuller's 1937 little-cited but convincing rebuttal to the MacClintock and Richards position), the overwhelming consensus view is that these ridges were deposited at the fluctuating margin of the latest Wisconsinan glacier to visit this region (Figure 20), the Woodfordian (Cadwell 1986, 1989). (See Table 3.)

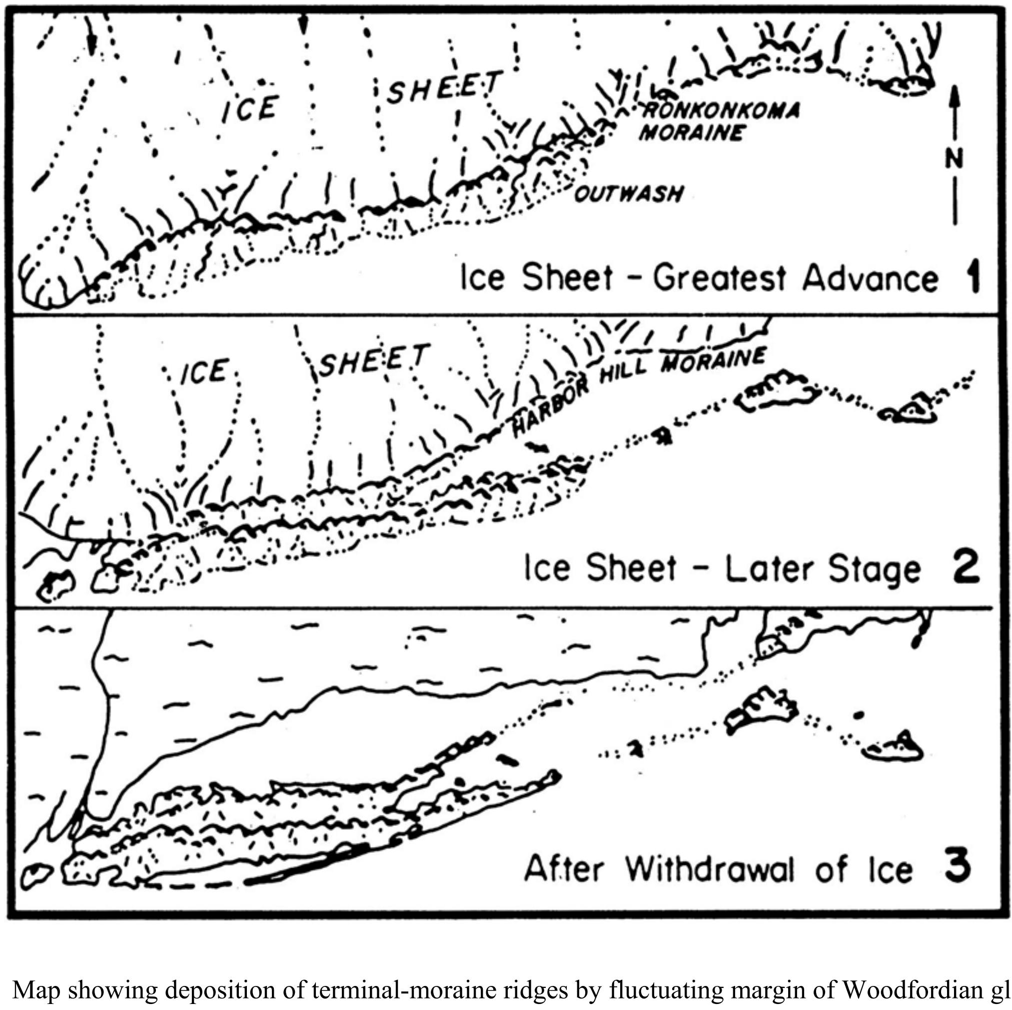


Figure 20. Map showing deposition of terminal-moraine ridges by fluctuating margin of Woodfordian glacier. Not accurately rendered is the relationship near Lake Success, where the Harbor Hill Moraine truncates the Ronkonkoma Moraine. (Y. W. Isachsen; Ed Landing; J. M. Lauber; L. V. Rickard; and W. B. Rogers, eds., 1991, fig. 12.21A, p. 177.)

In mapping the surficial deposits of the 7.5-minute quadrangles in New Haven, CT and vicinity, Flint (1961) found a location where two tills are in superposition. He named the lower, older till the Lake Chamberlain Till, and the upper, youngest till, the Hamden Till. Flint used till-fabric analysis to work out the directions of flow of the relevant glaciers. Accordingly, he inferred that the glacier responsible for depositing the Lake Chamberlain Till had flowed from NNW to SSE. By contrast, a glacier that had flowed from NNE to SSW had deposited the Hamden Till.

Given that the Hamden Till is the youngest glacial deposit and that the direction of flow of its depositing glacier was from NNE to SSW, then one is able to predict where in the youngest glacial sediments on Long Island indicator stones from Connecticut would be distributed. Thus, if the Harbor Hill Moraine had been deposited by the youngest glacier and that glacier's direction of flow is correctly reconstructed as being along an azimuth trending NNE to SSW, then the glacial sediments along the north coast of central Long Island should be of reddish-brown color and composed of erratics from the Hartford basin-filling material and from the distinctive greenish metavolcanic rocks lying W of the Hartford basin and of the white-colored two-mica + garnet-bearing granitic rocks from near Branford and/or the pinkish granites and granite-gneisses from around Stony Creek, to the E of the Hartford basin. (See Figure 13B.)

Woodworth (1901) mapped the glacial deposits of NW Long Island. In Long Island City (Queens), he found the reddish-brown materials forming the Harbor Hill Moraine resting on a striated bedrock surface; the striae were oriented NNW to SSE. This relationship proves that at least part of the Harbor Hill Moraine was deposited by a glacier that flowed across the Newark basin and across the Hudson River on a path from the NNW to the SSE (Figure 21). Moreover, Woodworth found that these reddish-brown glacial sediments were not the youngest glacial deposits in the area, but were overlain by non-reddish till. [A till younger than that forming the Harbor Hill Moraine has been reported by Walter S. Newman (1973, 1977) and Newman and Pike (1975). We do not know what, if any, relationship exists between the post-Harbor-Hill till mentioned by Newman and Newman and Pike and Woodworth's non-reddish till.]

Our studies of the Pleistocene deposits and of glacially sculpted features on bedrock surfaces in New York City and vicinity (Merguerian and Sanders 1990, 1991a, d; 1992b; 1993a, b; 1994c; Sanders and Merguerian, 1991a, 1992, 1994b) re-affirm what J. B. Woodworth (1901) discovered in Queens, but that most subsequent workers have ignored. According to us, the distribution of stones in the Harbor Hill Moraine indicates that the flow pattern of the responsible glacier must have been from NNW to SSE. If this is correct, then the Harbor Hill Moraine was not deposited by the youngest (i. e., Woodfordian) glacier, whose flow direction was from NNE to SSW (Figure 22).

At South Twin Island, Orchard Beach, Pelham Bay Park, The Bronx, we have found other examples of reddish-brown till resting on a glaciated bedrock surface with striae oriented NNW-SSE (Merguerian and Sanders, 1991d, 1993a).

Striae oriented NNW-SSE are parallel to the predominant direction of "diluvial scratches and furrows" found by L. D. Gale (1828; in Mather, 1843) in Manhattan and by J. G. Percival (1842) in Connecticut.

We have found additional evidence on Staten Island that the glacier responsible for the Harbor Hill Moraine there flowed from NNW to SSE. This evidence consists of the orientation of a well-exposed glacial-tectonic recumbent fold in a displaced slab of Upper Cretaceous sediments exposed in the shore cliffs at Princes Bay, Staten Island (Sanders, Merguerian, and Okulewicz, 1995a, b). We regard this new evidence that the Harbor Hill Moraine was deposited by glacial ice flowing from NNW to SSE as a further compelling argument that this moraine was not deposited by the Woodfordian glacier, whose direction of flow was from NNE to SSW.

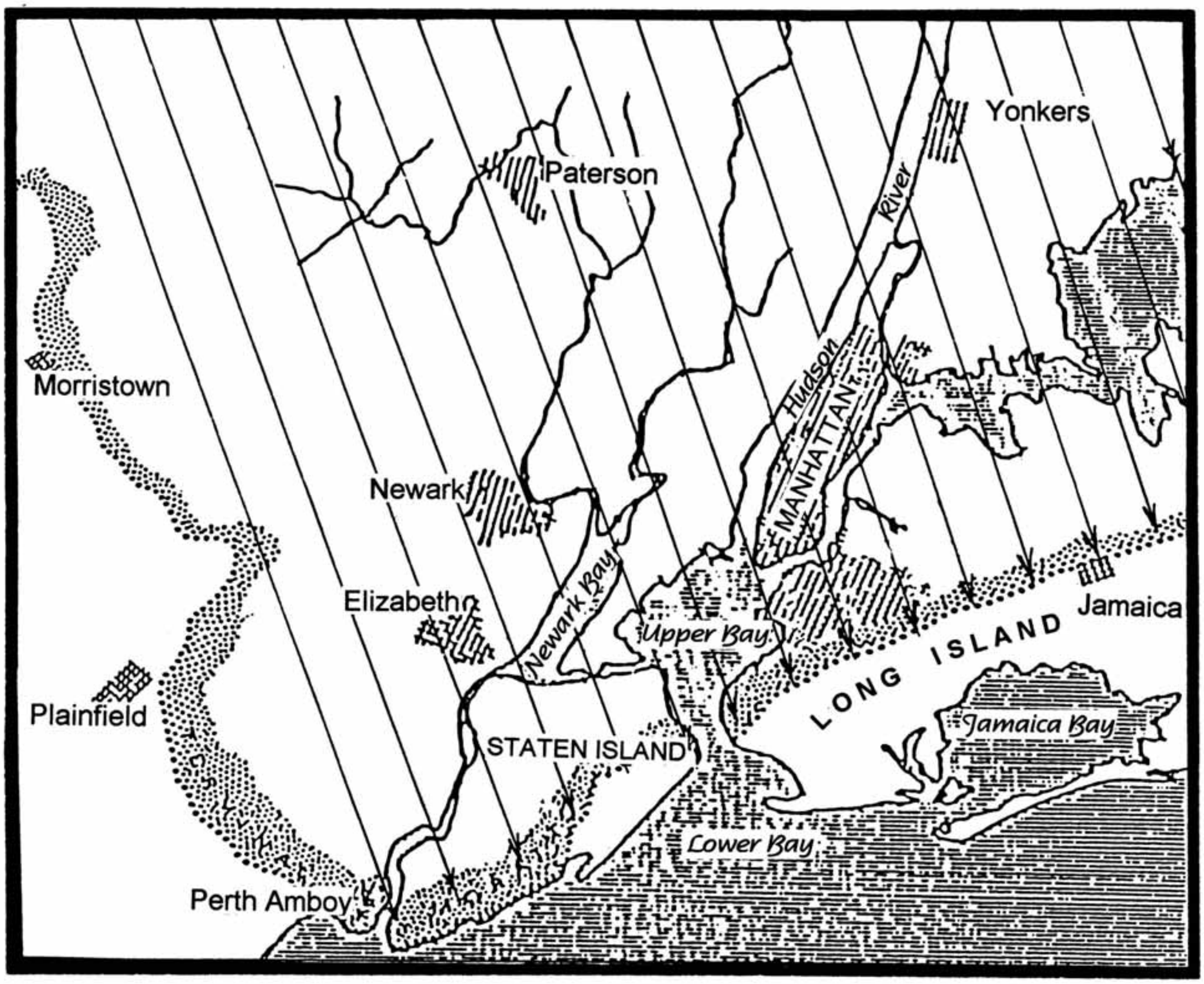


Figure 21. Rectilinear flow from NW to SE of glacier older than the latest Wisconsinan. This glacier flowed across the Hudson Valley and deposited red-brown till and -outwash on the east side of the Hudson River. (J. E. Sanders).

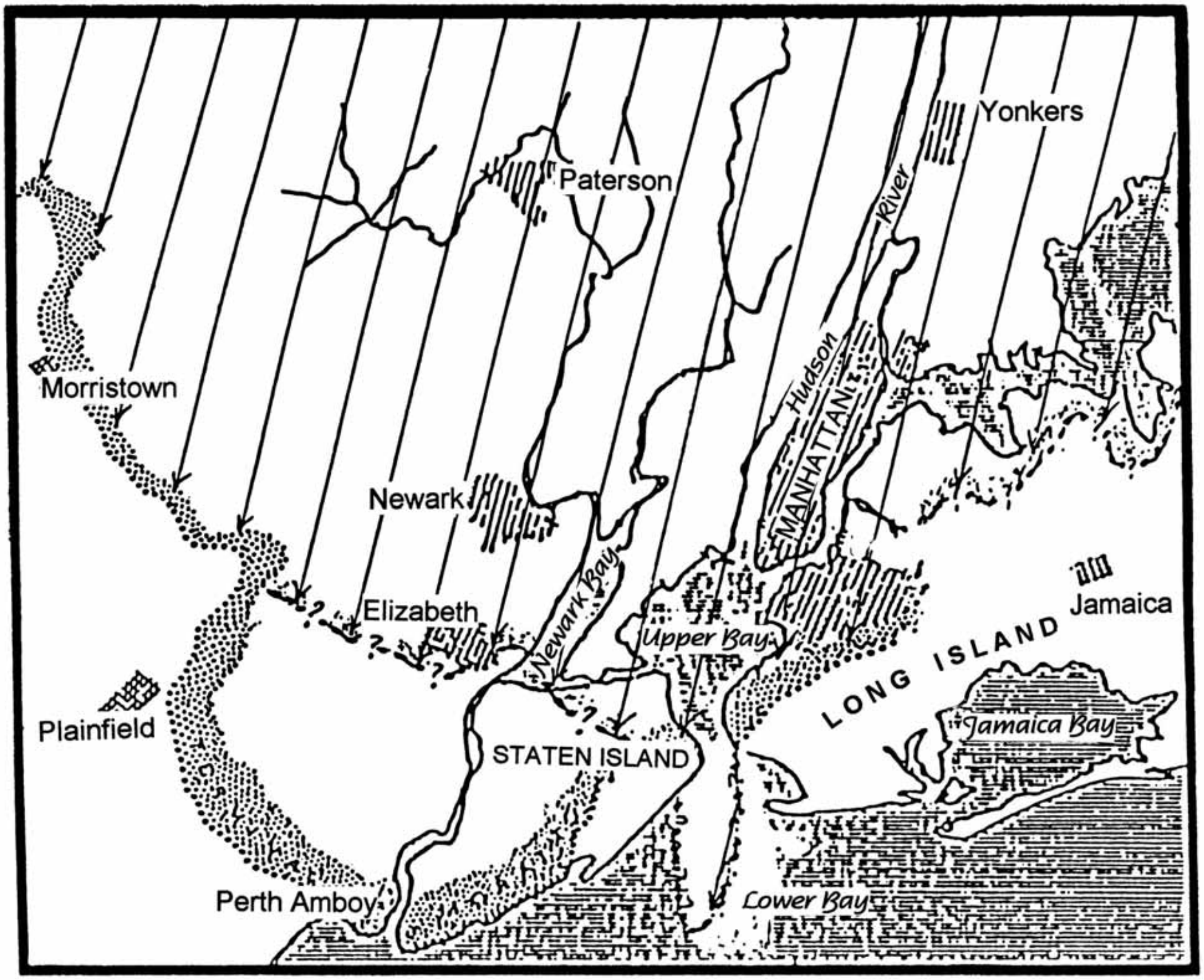


Figure 22. Inferred flow pattern of latest Wisconsinan glacier, down the Hudson and Hackensack lowlands from NNE to SSW. This glacier affected only westernmost parts of Long Island; elsewhere, its terminal moraine was along the south coast of Connecticut. (J. E. Sanders).

Based on the same distribution of erratics in both moraines, we think that the flow pattern of the glacier responsible for the Ronkonkoma Moraine matched that of the glacier responsible for the Harbor Hill Moraine. If the correlations that have been made between the inferred outwash sediments in the subsurface near Jones Beach (Rampino, 1978 ms.; Rampino and Sanders, 1981b) and the two Long Island moraines are correct, then these two moraines could not have been deposited by the fluctuating margin of the same glacier. This statement is based on the subsurface relationships whereby conditions between deposition of the lower inferred outwash (Merrick Formation; correlated with the Ronkonkama Moraine) and the upper inferred outwash (Bellemore Formation; correlated with the Harbor Hill Moraine) were sufficiently "interglacial" to enable the marginal-marine Wantagh Formation to be deposited between these two inferred outwash formations (Figure 23).

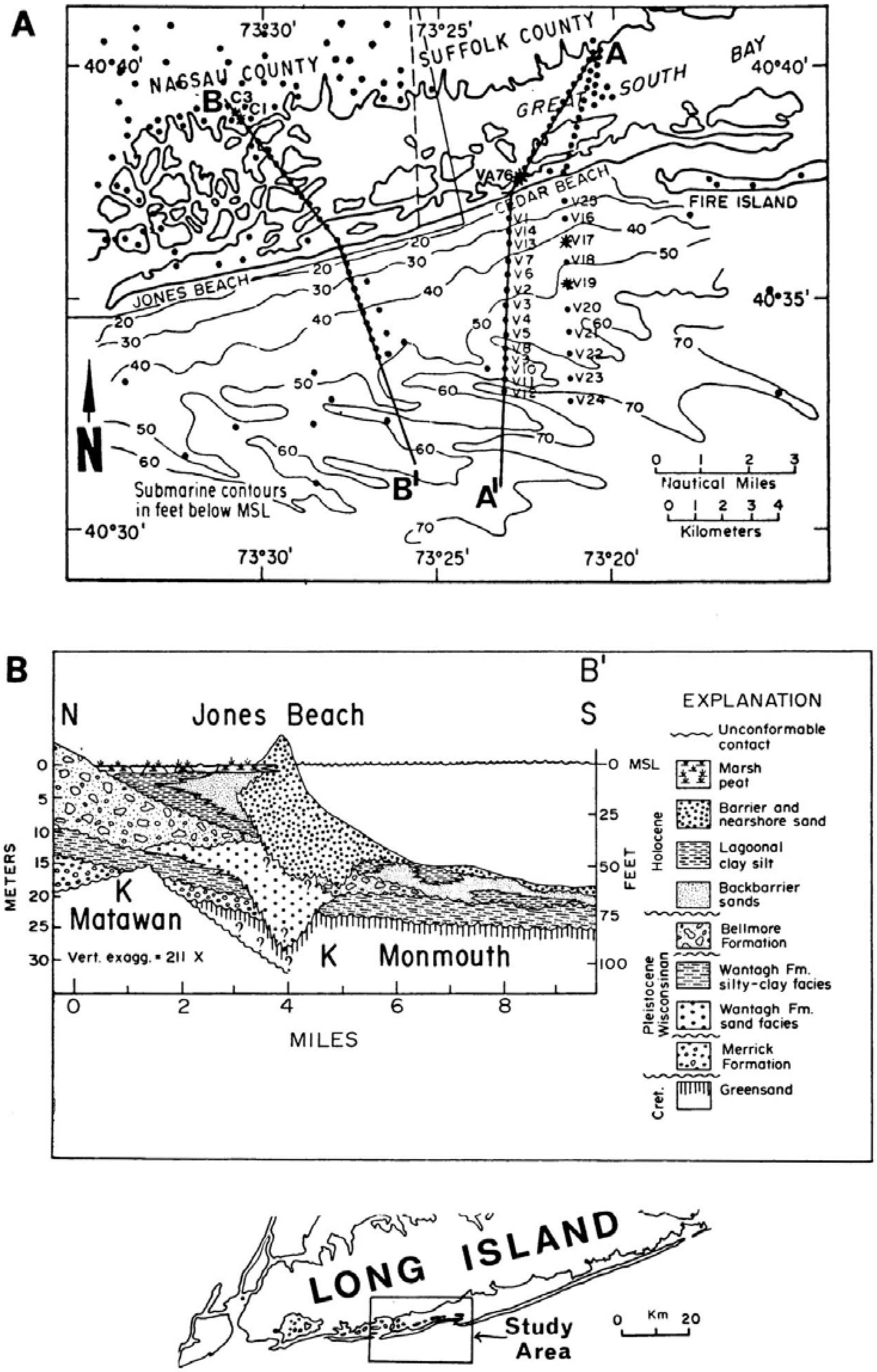


Figure 23. Shallow subsurface relationships, Jones Beach and vicinity. (M. R. Rampino and J. E. Sanders, 1981b; a, fig. 3, p. 118; b, fig. 4, p. 119.)

A. Location map of lines of borings used to prepare stratigraphic profile-sections. Line B-B' locates Jones Beach profile-section. Rectangle on map of part of Long Island locates the borings-index map.

B. Jones Beach profile-section showing tripartite Pleistocene succession consisting of Merrick Formation, Wantagh Formation, and Bellmore Formation. Further explanation in text.

According to us, these two moraine ridges were not built by the very latest Wisconsinan continental glacier (the Woodfordian), as is generally supposed, but by two older glaciers, each of which flowed regionally from NNW to SSE. The terminal moraine for the Woodfordian glacier, which flowed from the NNE to the SSW, is not present on much of Long Island, but is present along the south coast of Connecticut (Flint and Gebert, 1974, 1976).

We offer no additional chronostratigraphic evidence on the ages of Long Island's moraines, but from our general stratigraphic synthesis, we are inclined to apply to Long Island the age assignments of Illinoian and early Wisconsinan that Kaye (1964c) proposed for the two moraines on Martha's Vineyard, Massachusetts.

The "official" view of the New York State Geological Survey on this question is shown in Figure 20 and Table 3 (Cadwell, 1986, 1989). Because Cadwell believed (and continues to believe) in Sirkin's views, we review some of the writings from "the Book of Sirkin."

Initially, Sirkin (1968, Table 1, p. 234) assigned the two moraines to a pre-Cary Wisconsinan age. At Harbor Hill, Roslyn, "...the type locality of the Harbor Hill Moraine and the Harbor Hill Till..." the till/outwash contact is visible (p. 250). The long axes of pebbles from the Harbor Hill till at Alley Pond Borrow Pit "point generally NNW" (p. 248). [Note: this evidence supports J. B. Woodworth's interpretation; if we are correct, then it amounts to further proof that the age of the Harbor Hill Moraine is not and cannot be Woodfordian.]

At the intersection of Lakeville Road and the Northern State Parkway, Sirkin found "about 5 feet of Harbor Hill till overlying 20+ feet of stratified lacustrine sands with thin clay partings (Plate 1, figures 2, 3, and 4)" (p. 249).

At the intersection of Roslyn Road and the Northern State Parkway, Sirkin described what he saw as follows:

"Another cut into the Ronkonkama Moraine, on the northeast side of the road, has exposed the lower till (cf. the Montauk Till). Approximately 10 to 15 feet of till are overlain by 25 to 30 feet of coarse cobbly, outwash (or Kame) deposits (Plate 2, figures 1 and 2)" (p. 249).

Fuller (1914) placed the Montauk Till in the Manhasset Formation (with Herod Gravel below and Hempstead Gravel, above). We discuss the Montauk Till and Manhasset Formation in the following section.

Sirkin (Sirkin and Mills, 1975; Sirkin and Stuckenrath, 1980) claims that the Hempstead Gravel is Woodfordian outwash:

"It is proposed that the name, Flower Hill Sand, be adopted for the various outwash facies associated with the Altonian till (sic) in western Long Island (Figure 5)... It is proposed here that the Altonian till in western Long Island be named the West Shore Till."

Deposits of Proglacial Lake Long Island

After studying the strata exposed in eroding coastal bluffs on the north shore of Long Island, Mather (1843, Plate. I, fig. 1) used the term "Long Island Formation" informally for the tripartite sucession consisting of a basal "hardpan" with boulders, middle clay, and upper sand (fig. 1 of Mather's Plate I, our Figure 24). He assigned this formation to the Tertiary. We have been able to find some of the localities Mather sketched but not others. On 16 May 1996, we visited what we think is Mather's "Brown's Point" locality but found no strata exposed. We think that Mather's "Lloyd's Neck" locality is Caumsett State Park, our Stop 4.

At Lloyd's Neck, a storm exposed dipping strata that had been truncated and are overlain by horizontal strata (fig. 16 at bottom of Mather's Plate I, our Figure 24). Mather was not able to interpret these strata as any modern geologist would do. After all, Mather's date of publication preceded general acceptance of the concept of Pleistocene continental glaciation and was 42 years before G. K. Gilbert (1885) presented his analysis of the topographic features of lake shores in which he proposed the terms topset, foreset, and bottomset (Figure 25) as the three kinds of lacustrine deltaic strata formed along the shores of ancient Lake Bonneville, Utah (and 47 years before Gilbert's Lake Bonneville monograph appeared in 1890).

As mentioned, Fuller recognized the Manhasset Formation as the predominant unit in the Quaternary of Long Island. As shown in several of Fuller's figures, the north-shore bluffs in NW Long Island are cut into the lower part of the Manhasset Formation (Herod Gravel and Montauk Till). (See Figure 4B.) Fuller nowhere mentioned large-scale dipping beds as in Gilbert-type deltas, but such deltas were clearly illustrated by Woodworth (1901).

In exposures of the Manhasset Formation they examined, MacClintock and Richards (1936) could not find anything resembling the Montauk Till. They presumed that such a till would form a blanket-type unit that would be present everywhere on Long Island. Therefore, its absence caused them to be skeptical of Fuller's stratigraphic arrangement. That skepticism was a factor in their shifting the age of the Manhasset Formation upward in the Quaternary column. Sirkin accepted the MacClintock-Richards doubts about Fuller's Manhasset Formation.

Sandy strata of the Manhasset Formation that underlie the eroding cliffs at Sands Point and elsewhere on Long Island's north shore include diagnostic S-dipping Gilbert-type deltaic foreset sediments that we interpret as part of the areally extensive deposits of Proglacial Lake Long Island. At Caumsett State Park, these deltaic sediments contain abundant gravel including partly decomposed stones. At Montauk Point, we interpret the dipping layers of poorly sorted Manhasset rudites (Figure 26), considered by some to be ice-deformed tills, as being sublacustrine-deltaic debris-flow deposits. We have not seen enough exposures to be sure about this, but one possibility is that Montauk Till at its type locality does not belong in Manhasset Formation and that the middle member of the Manhasset Formation, the supposed Montauk Till, is not a till at all but rather a subaqueous debris-flow deposit. Before the U. S. Army Corps of Engineers installed erosion-protective structures near Montauk Lighthouse, we were able to confirm the existence there of dipping till-like diamictons as sketched by Fuller in his fig. 156, p. 143. These sublacustrine debris-flow deposits may be restricted to eastern Long Island. If so, then their absence in the deltaic sediments farther W can be logically explained as being controlled by facies changes (discussed further in a following section). Thus, the absence of a "Montauk Till" in the sandy, deltaic Manhasset Formation is irrelevant with respect to the age of a particular true till.

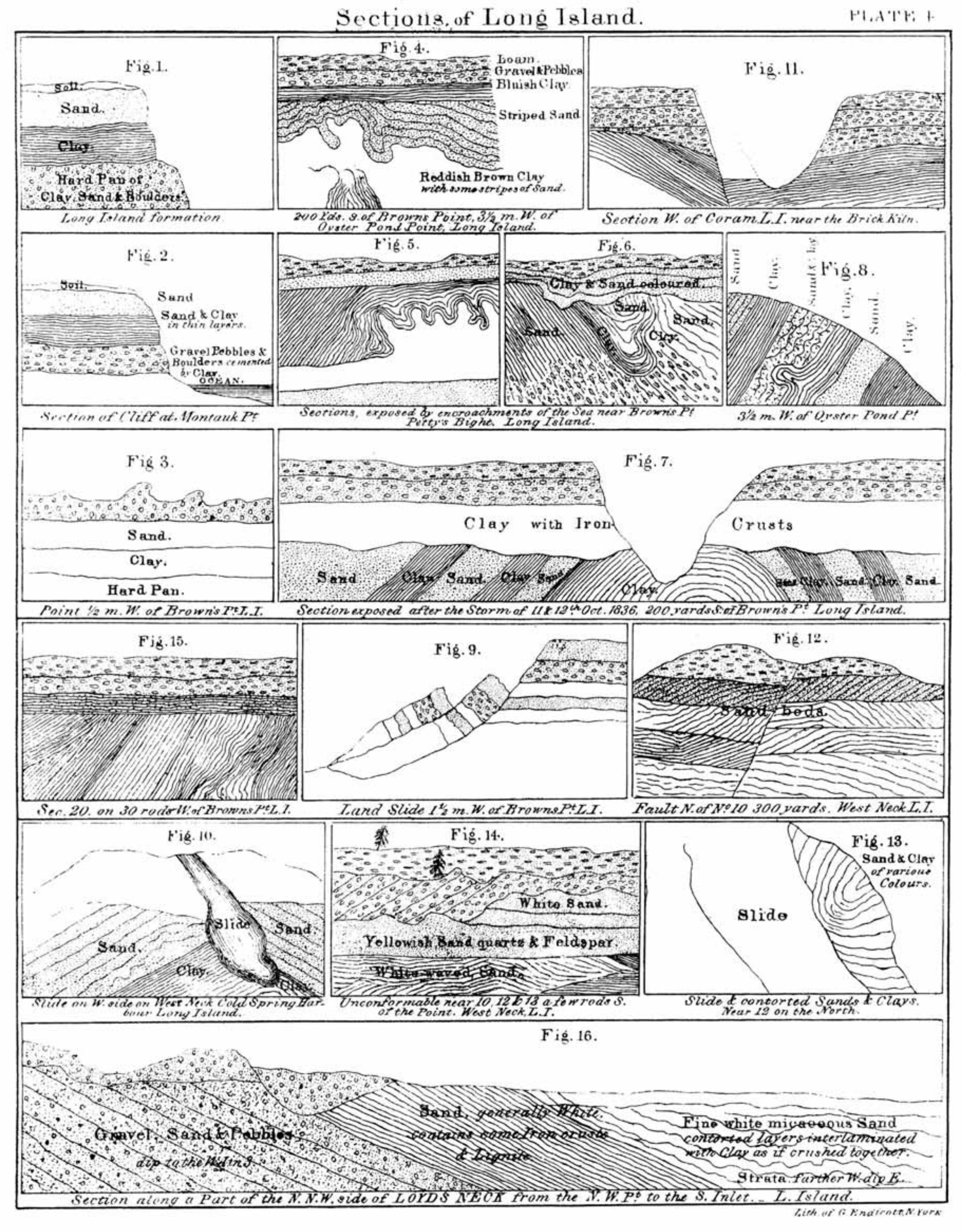


Figure 24. Copy of plate from Mather (1843). Further explanation in text.

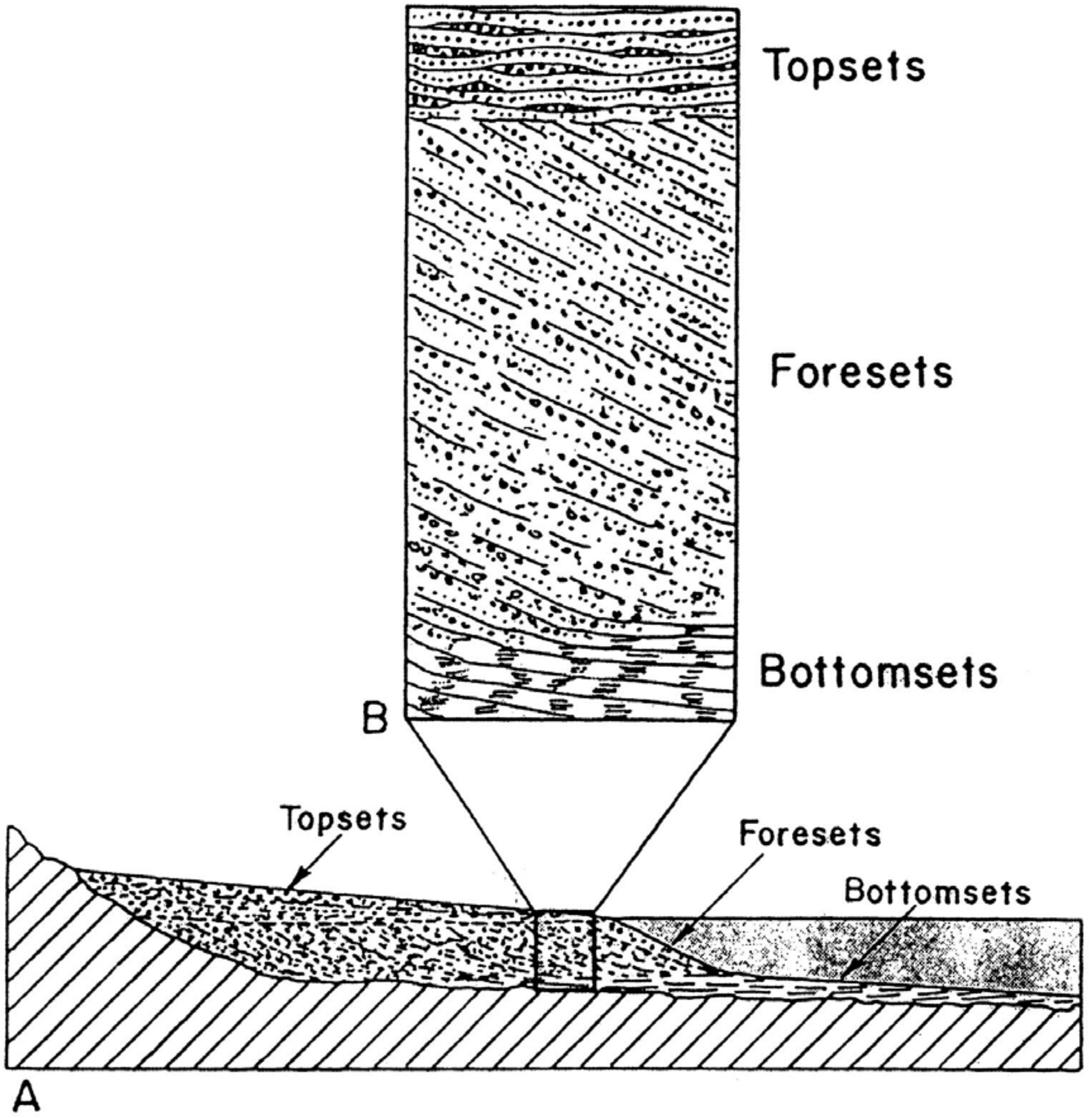


Figure 25. Three contrasting strata deposited on a Gilbert-type delta, where a shallow channel debouches into water that is much deeper than the channel. Note that horizontal topsets truncate dipping foresets. (G. M. Friedman and J. E. Sanders, 1978, fig. B-7,A, p. 502.)

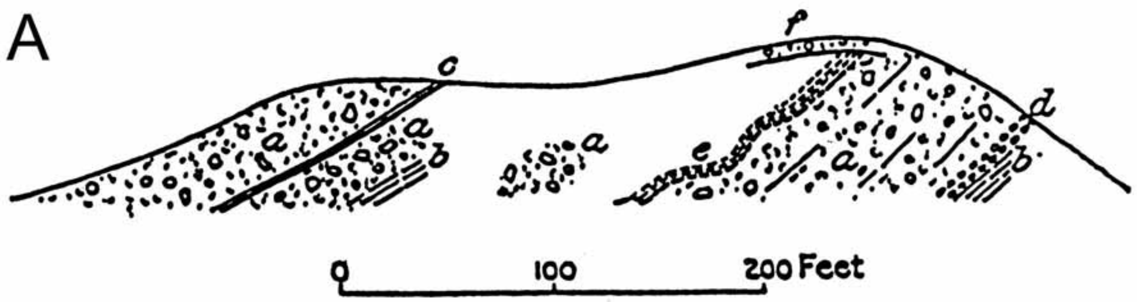


FIGURE 157.—Section half a mile south of Culloden Point, Montauk, showing intercalated sand and clays in Montauk till member. *a*, Montauk till member; *b*, clayey sand; *c*, clay; *d*, gravel; *e*, sand; *f*, Wisconsin till.

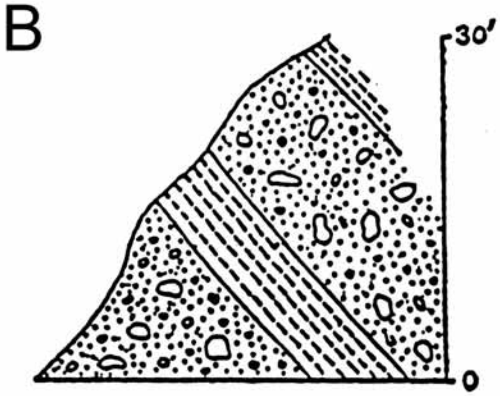


FIGURE 156.—Section 1 mile west of Rocky Point, Montauk, showing intercalated bed of gravel in Montauk till member.

Figure 26. Dipping interbedded strata composed of diamictites and clays, coastal cliffs near Mauntauk Point, NY. Fuller inferred that the coarse units were the Montauk Till, but we have reinterpreted these as subaqueous debris-flow deposits belonging to the deltaic Manhasset Formation. (M. L. Fuller, 1914, A, fig. 157; B, fig. 156, both on p. 143.)

Elsewhere, these lake-marginal coarse sediments grade into lake-bottom silts and -clays. The relationships at Montauk Point imply that Lake Long Island was there dammed on the S by a now-eroded pre-Ronkonkoma terminal-moraine ridge. At Sands Point, reddish-brown till (our No. II? or No. III?) occupies valleys eroded into these Manhasset sandy deltaic strata.

According to Fuller, the Manhasset Formation overlies the Gardiners Clay, which he assigned to the Kansan/Illinoian interval (Yarmouthian interglacial). If this is correct, then the age of these extensive proglacial-lake deposits is Illinoian. The only way they could be any older is if the age of the Gardiners Clay is not correct. MacClintock and Richards reclassified the Gardiners Clay as Sangamonian. This was part of their interpretation that Fuller's Manhasset Formation belonged in the Wisconsinan.

Very powerful support for Fuller's interpretation that the Gardiners Clay belongs to the Yarmouth, not the Sangamon interglacial was provided by H. C. Ricketts (1986). Ricketts collected shell material from two borings made near Kings Point (on Great Neck, west side of Manhasset Bay) and from the Port Washington sand pits (our Stop 2), on Manhasset Neck, W side of Hempstead Harbor. Ricketts 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 [225 ka]. (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.) Comparably ancient D/L leucene values were obtained from shells from the same Port Washington deposit where specimens collected by Sirkin have been radiocarbon dated at about 40 ka. So now, what to do? Whose dates do you believe? You pays your money and you takes your choice. We vote for Wehmiller, Ricketts, and Fuller.

On the basis of new stratigraphic evidence uncovered in the north-shore cliffs by the coastal storm of December 1992 (Sanders, Merguerian, and Mills 1993; Sanders and Merguerian 1994), on our investigations of flow-directional features eroded by glaciers on bedrock surfaces and of provenance of the tills (Sanders and Merguerian, 1991a, b; 1992; Merguerian and Sanders 1990a, f; 1991a, f, h; 1992c, e; 1993a, c; 1994a,), on the shallow subsurface relationships at Jones Beach and vicinity (Rampino 1978 ms.; Rampino and Sanders, 1980; 1981b) and of directional interpretation of ice-thrust features on Staten Island (Sanders, Merguerian, and Okulewicz 1995a, b), we challenge the two entrenched viewpoints about Long Island's two world-famous morainal ridges. We reject not only the Woodfordian age assignment that has appeared widely in the literature and has been adopted without question by most geologists but also the concept that these moraines were deposited by the fluctuating margin of a single glacier.

North-draining Coastal Embayments and Necks, NW Long Island

The NW coast of Long Island features deep embayments that are separated by peninsular "necks." From W to E, four prominent partner-characters in this "passion play" are: Little Neck Bay, Great Neck, Manhasset Bay, the "neck" that culminates in Sands Point, Hempstead Harbor, the Glencove-Oyster Bay peninsula (See Figure 3A), Cold Spring Harbor, and West Neck-Lloyd Neck (See Figure 3B). Because the interpretation of these features is one of the key points of difference between Fuller (1914) and the crowd, led by MacClintock and Richards (1936), that has cast aside Fuller's monumental work, we take some pains to present what these seemingly forgotten points of contention are.

Fuller interpreted these deep, north-opening coastal indentations as drowned stream valleys. He argued that they had been eroded during what he called the Vineyard erosion interval, which he assigned to the Sangamonian interglacial (See Table 3.) during which sea level dropped far enough to rejuvenate rivers to the point where they deepened their valleys creating local relief in the range of 300 feet. If these embayments are, indeed, drowned river valleys that were eroded during the Sangamonian interglacial epoch, then the sediments adjacent to them (and exposed all along Long Island's north-shore cliffs) are older than the valleys and therefore were deposited during the Illinoian- or an even-earlier glacial episode.

By contrast, MacClintock and Richards rejected the idea that the sediments underlying Long Island's north-shore cliffs are of pre-Wisconsinan age. So, how did they get around the problem of the coastal embayments? They proposed the novel idea that these embayments had not been eroded at all, but rather should be considered as giant, linear, north-widening kettles, which are depressions formed in glacial sediments that buried blocks of ice. When the ice melts away, the surface sinks down, and a low feature results. According to MacClintock and Richards, during the Wisconsinan glaciation, at each place that was later to become a coastal embayment, a tongue of ice protruded southward farther than the rest of the glacier's margin. Just why the glacier should stick "its tongues out," so to speak, in these localities is a point on which they remained conspicuously silent. According to their scheme of things, these tongues of ice were then buried by massive deposits of outwash on each side, building up the places that would later become the "necks." After deglaciation, the tongues of ice disappeared, leaving the embayments, not as products of erosion, but places where ice had prevented deposition. Under this arrangement, the sediments underlying the "necks" are younger than the embayments and no period of great erosion is involved at all.

The MacClintock-Richards hypothesis of origin of the embayments strikes us as being somewhat bizarre, but not totally impossible. Remarkably, no one other than Fuller seems to have challenged them to "put up or shut up" about their hypothesis. In our opinion, the proof, the burden of which should have been squarely on them, has never been demanded. Some critical tests would be: (1) the transverse profiles of the embayments as seen in borings made for highway bridges, for example, or even as recorded in continuous seismic-reflection profiles along traverses across the bays (Stumm and Lange 1994, 1996); (2) the provenance of the associated outwash sands (if the sands are of Woodfordian age, then they would have been associated with a glacier that flowed NNE to SSW); and (3) the sand eroded from the depression should not only display the appropriate provenance characteristics, but should also be present on the continental shelf south of the Block Island Channel.

If the embayments are drowned river valleys, then their transverse profiles should display typical V shapes. Bodies of till could be present, but they would be younger than the time of stream erosion. Beneath the till, the valley floor may be flat and its transverse profile U-shaped.

If the great body of outwash sand had deposited during the Wisconsinan, as MacClintock and Richards (and numerous others) believed, then, because it was deposited by a glacier that flowed from NNE to SSW, the parts of it deposited in the central areas of the north shore should be reddish-brown in color and full of erratics derived from the Hartford basin, CT and MA. The lack of such a body of reddish-brown Quaternary deposits in the territory of Long Island lying SSW of the Hartford basin is one of the strongest arguments we know of in support of our interpretation that the Wisconsinan glacier did not reach much of Long Island.

Bodies of Till (Real and "Virtual")

On most of Long Island, the proportion of till to outwash is very small. The most-continuous bodies of till are exposed in the coastal cliffs on the S shore of Long Island just W of the Montauk lighthouse. In at least two localities, (1) in the eroding coastal cliff at Montauk Point just S of the lighthouse (now covered by a layer of paving slabs intended to deter cliff erosion), and (2) at the E end of the Sands Point Reservation, a layer of boulder armor at the base of a stream-channel deposit implies the former existence of a now-vanished till (thus a "virtual till"). The stream reworked the till that formerly was present in these valleys, leaving behind a channel-floor lag consisting of a layer of boulders typically not thicker than the diameter of the average boulder.

Along the N coast, several isolated bodies of till are present, but no agreement has been reached about their stratigraphic assignments. One body of till was deposited by a glacier that plowed into the sandy lacustrine-deltaic outwash sands at Sands Point. Because of the distinctive red-brown color of this till, we infer that it can be no younger than the Harbor Hill Moraine, or Early Wisconsinan, according to Fuller, Kaye, and us.

Another body of till, characterized by large bouders, is exposed near the tops of the coastal cliffs of NE Long Island. We do not know the age of this till; by superposition it is younger than the main body of the deltaic outwash.

We have not yet seen the nonred, post-Harbor Hill till of J. B. Woodworth or W. S. Newman. And, we are not certain if Sirkin identified such a till as well. Clearly, a post-Harbor Hill till could well be present in western Long Island, having been deposited there by a glacier that did not reach much of Long Island. Possibly this is the result of the Woodfordian glacier, which probably also deposited the Hamden till in south-central Connecticut (Flint, 1961).

Facies Changes in Quaternary Sediments

Two kinds of facies changes can be observed in Long Island's Quaternary sediments: (1) compositional changes in the glacial sediments and (2) lateral changes in particle sizes and particle-size distributions in the lake deposits.

Composition of Glacial Sediments

If our interpretation of the flow patterns of the Quaternary glaciers is correct, then the compositional patterns in the mainland bedrock combine with a given ice-flow direction to determine the composition of the glacial sediments on Long Island. In this case, two aspects of composition are color and composition of indicator stones.

As an example, consider the relationships of the Harbor Hill Moraine in Queens, which J. B. Woodworth demonstrated was deposited by a glacier that crossed the region from NNW to SSE. (See Figures 13A and 21.) This glacier transported indicator stones from the Newark Basin and points to the NW into areas lying E of the Hudson River. The till deposited by this glacier, which includes that forming the Harbor Hill Moraine, undergoes a dramatic facies change controlled by the "crystalline corridor" in the bedrock that exists between NE end of the reddish-brown rocks filling the Newark Basin to the SW and the S end of the Hartford Basin to the E (Sanders and Merguerian, 1991b; 1994b). We have not found the exact line of separation along the north shore of Long Island where the color of the till deposited by this glacier changes from reddish brown (downflow from the Newark Basin) to gray or even yellowish brown (downflow from the "crystalline corridor"). We have so far determined only that this line of separation (which by its very nature will not be a sharp boundary) lies between Sands Point and Target Rock. At Sands Point, a reddish-brown till fills valleys cut into the deltaic sands underlying the coastal cliffs (Sanders, Merguerian and Mills, 1993). At Target Rock, the youngest till present is gray and contains erratics derived from the NNW, including Inwood Marble and ultramafic igneous rocks from the Cortlandt Complex near Peekskill, New York (Sanders and Merguerian, 1991b; 1994b).

The absence of reddish-brown till in the segment of Long Island lying SSW of the S end of the Hartford Basin strongly supports our interpretation that the Woodfordian glacier, which flowed from NNE to SSW, did not reach much of Long Island. (See Figures 13B and 22.)

Lateral Changes in Lake Deposits

Most lake deposits are products of two contrasting environmental settings: (a) lake margin, and (b) lake center. In the proglacial lakes that existed in the Long Island area, the marginal sediments were coarse and the lake-center deposits are clays and silts with some admixtures of fine sand.

Nonstratigraphic Age Considerations

By nonstratigraphic age considerations we mean features other than superposition of layers or various quantitative chronostratigraphic features such as radiometric measurements on minerals or racemization of amino acids in shells that give some indications of the passage of time. One such category is degree of weathering; another is relative extent of landscape dissection.

Degree of weathering

The principle underlying the use of degree of weathering is that chemical changes in the regolith progress with time. Assuming a comparable parent material, then the degree of development of a "soil profile" reflects the amount of time during which weathering has been going on. Weathering also affects the degree of decomposition of stones in a deposit.

Soil profiles; paleosols. The degree of development of a soil profile is easiest to recognize where carbonates are present in the regolith--a simple lab measurement suffices to indicate the relative extent to which the carbonate has been leached from the upper part of the regolith. Other obvious changes include degree of oxidation of iron-bearing minerals. Extent of iron migration can also be reflected in concretions and hematite cement among the quartz particles in sandy- or even gravelly layers. Examples include the "ironstone conglomerates" that are present in the Upper Cretaceous and are common as pebbles on the Long Island's north-shore beaches.

If shells are present, then the extent to which they have been leached of their carbonate is a rough indicator of age. For example, in the drumlins forming islands in Boston Harbor, MA (W. A. Newman, Berg, Rosen, and Glass, 1987) found an older till that contains shells eroded out of the subjacent interglacial marginal-marine deposit, thus substantiating Upham's results (1879, 1889a). During a later interval of interglacial subaerial weathering, the carbonate from the shells has been leached from the older till to depths of 8 m. Based on comparative studies of the weathering of the clay minerals, W. A. Newman and Mickelson (1994) assigned the older till to the Illinoian. If correct, then the marginal-marine formation from which the Illinoian glacier eroded the shells could be of Yarmouthian age, in which case it would be a correlative of Fuller's Gardiners Clay.

Given sufficient time, weathering will result in the formation of a paleosol, the technical term for an ancient soil. We have found a well-developed paleosol on one of the red-brown tills present in the Harbor Hill Moraine of southern Staten Island (Merguerian and Sanders, 1989a; 1991c; 1994e; Sanders and Merguerian, 1991a; 1994a, b; 1995a). We have not yet found a paleosol on Long Island.

Comparative Decomposition of Stones

Another effect of weathering is to cause individual stones to decay. Pieces of mafic rock are very useful in this regard. Changes with time include increasing thickness of the zone of oxidation and extend to total decomposition and development of concentric joints ("spheroidal jointing"; Figure 27). Among Long Island's Quaternary deposits we have seen varying examples along the sequence from thin oxidized zones to complete alteration and development of concentric joints.

Figure 27. Sketch of spheroidally jointed basalt caused by in-situ weathering. (A. K. Lobeck, 1939, sketch at lower R, p. 46.)

Displaced Products of Weathering

Because of the dynamic activities at the Earth's surface, products of weathering are prone to become sediments and thus to be moved. We shall refer to products of weathering that have been moved as "displaced" products of weathering. Obviously, one cannot use the results of weathering that took place elsewhere as a useful indicator of the extent of weathering of the formation where they are found.

Two major categories of displaced products of weathering ane known on Long Island: (1) supermature quartz gravel and (2) intensely decomposed granitic stones. Both kinds of displaced products of weathering need to be included in any attempt to use degree of weathering as a relative age indicator of the Quaternary units on Long Island. Both can be ascribed to the pre-Quaternary climatic conditions that prevailed in the New York City region, particularly during the Cretaceous, but extending into the Miocene.

Supermature Quartz Gravel

As mentioned in the section on the coastal-plain deposits, we think the geologic evidence supports the view that during the Tertiary, Upper Cretaceous supermature sands blanketed much of the mainland. Thus, before a glacier could erode the underlying bedrock, it would have to strip away this blanket (Figure 28). This situation would yield a weathering-type anomaly in the Quaternary deposits: The oldest Quaternary formation on Long Island might appear to be the "freshest." This could come about because being devoid a decomposable materials, such as typically display degrees of decomposition, the oldest Quaternary unit would lack any decomposed stones. Why? Because total decomposition during the Cretaceous left only the quartz (and resistant heavy minerals).

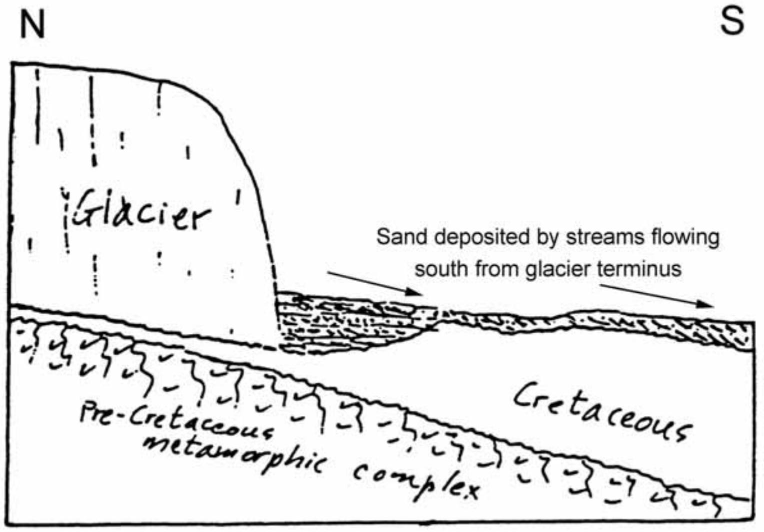


Figure 28. Restored profile-section from Connecticut to Long Island showing terminus of continental glacier standing in what is now Long Island Sound and spreading compositionally mature outwash sand and gravel southward to bury the Upper Cretaceous strata of Long Island. Extension of Cretaceous beneath 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.)

Intensely Decomposed Granitic Stones

Fuller (1914, p. 80) called attention to the presence of decomposed granitic pebbles in Long Island Quaternary formations. Indeed, he used such pebbles as the "index fossil," so to speak, of the Mannetto Gravel. Fuller considered that the Mannetto "is the earliest of the Pleistocene deposits" (Fuller, 1914, p. 80). We wonder if Fuller took the decayed stones as evidence of great age. Much of the Mannetto is confined to the subsurface, but in a few places, Fuller recognized it on the surface.

Sirkin (1971) suggested that decayed pebbles of granitic rock such as found in the Mannetto do not necessarily imply extensive in-situ decomposition within the enclosing formation, hence great age, but could have been derived from deeply weathered granite and granite gneiss in Connecticut. Sirkin held that such decomposed pebbles do not prove a pre-Wisconsinan age.

At first, we tended to ascribe the examples of decayed granitic rocks such as those we hope to show you at Garvies Point (Stop 3) as indications of in-situ weathering and thus of great age. Now, however, we have come around to the Sirkin view (what did we just say???) but with two significant amendments. We think a likely source of such decayed-feldspar granitic rocks is at the Garrison Water tunnel described by Berkey and Rice (1919 and by Berkey and Fluhr 1948). If correct, then pebbles of decayed granite become indicator stones.

For those who doubt that glacier could transport decomposed rock fragments we cite the example of fossiliferous bauxite that Kaye (1967b) found in the till on Martha's Vineyard, Massachusetts.

Degree of Landscape Dissection

The extent to which a region is dissected by stream erosion depends on length of time. Thus, a nondissection region is a young one compared with a maturely dissected area. In terms of its Quaternary history, Long Island has experienced several periods of deep dissection. One of these periods was post-Cretaceous and pre-Quaternary. (See deep N-S trending valley at lower L Figure 19.) Other deep valleys include the coastal embayments discussed previously. Since the last ice melted (whenever that was), only small-scale stream erosion has taken place on Long Island.

Geological Perspective on the "Greenhouse Effect" and "Global Warming"

Every time the summertime temperature along our eastern seaboard exceeds 95° F, we start hearing dire warnings about "global warming." We are told that because of our wanton ways with combustion of fossil fuels, we stand in dire peril of so changing the chemical composition of the Earth's atmosphere that global temperatures will rise, the remains of our two continental glaciers will melt, and the sea will rise, flooding our coastal cities. The numbers expressing these measured increases in carbon dioxide have been entered into various general-circulation computer models of the atmosphere and the output has been just what the chemists and modelers expect--increased carbon dioxide has put us on the road to "global warming." And, when the globe warms, the glaciers will melt and sea level will rise.

We offer the following geological perspective on this important matter. We start with Alfred G. Fischer's (1982) names for two of the Earth's contrasting climate modes: "ice-house" mode and "greenhouse" mode. By "ice-house" mode, Fischer meant intervals when continental glaciers expanded enormously and spread over much of the Earth's land areas, particularly in the Northern Hemisphere. During the Quaternary Period (See Table 3.), the Earth oscillated between these "ice-house" modes and the contrasting climates when the glaciers had melted back to something similar to their extents today, a Fischer "greenhouse" mode. Fischer's terms are vivid, descriptive, and easy to recall. They are useful even if it is not exactly known what climates were associated with each of these modes.

During the Quaternary, the back-and-forth oscillation from these two climatic modes was accompanied by systematic changes in sea level. During an "ice-house" mode, sea level dropped. During a "greenhouse mode," the sea stood near its present level. What seems to have been generally ignored in the climate debate is the significance of what happened to cause the shift from an "ice-house" mode to a "greenhouse" mode. W. S. Broecker refers to "terminations" as intervals that trigger the switch from "ice house" to "greenhouse." JES has been impressed with the widespread indications that before the sea rose from its "ice-house" low stands, tropical carbonates spread widely away from the equatorial belt, thus indicating very warm climate. JES has proposed the term "boiler-room" mode as a third category of the Earth's climate repertoire (in Friedamn, Sanders, and Kopaska-Merkel, 1992). During a "boiler-room" episode, climate warms, glaciers melt, and sea level rises. Sound familiar? It is exactly the situation the "global-warming" enthusiasts are telling us we are supposed to be headed for. According to them, we are going to go from the present "greenhouse" mode directly into a "boiler-room" mode (when glaciers melt and sea level rises, flooding all our coastal cities). Maybe we are, but consider the following. Throughout the Quaternary, the only times "boiler-room" episodes appeared have been at the ends of "ice-house" modes.

During the Quaternary, the climate shifted back and forth between whatever was the mode responsible for the growth- and spread of continental glaciers and whatever was the situation that prevailed after the ice had melted. Many students of Quaternary climates think it is intuitively obvious that when the glaciers were widespread (during "ice-house" modes), the climate was cold. Moreover, during the minimal-glacial times ("greenhouse" modes), the climate was warm.

Each time the great ice sheets have spread over the continents, they eventually have melted. Why? Because a "boiler-room" episode appeared to melt all that glacial ice. A distinctive- and unique feature about a "boiler-room" mode is that it always coincides with times of low sea level (Sanders and Friedman, 1969).

In a general way, climate and sea level are coupled. That is, during the "ice-house" modes, sea level was low; and during the "greenhouse" modes, was high. But, because "boiler-room" modes and sea level are decoupled, the general statement is not correct that the warmer the climate, the higher the sea level. If the "boiler-room" concept is correct, then the warmest climates will always coincide with lowest sea levels.

The Quaternary geologic record is unambiguous in enabling us to determine that the order of change has invariably been. This fixed order is: "ice-house" mode to "boiler-room" mode to "greenhouse mode." To JES, this invariable sequence prompts the following fundamental question that should top the scientific agenda: "Can the Earth's climate go from the "greenhouse" into the "boiler room" without first passing through the "ice house"? The only answer that the Quaternary geologic record supports to this matter is the same one-word comment Wayne Gretzky delivered about Bo Jackson's hockey prowess: "No!"

Holocene Sediments: Beaches, Barrier Islands, and Intertidal Salt Marshes Fringing the Shores of Bays

Long Island's varied coast displays many places where waves and tides of the transgressing sea are reworking the Upper Pleistocene sediments (cliffs composed of till near Montauk, but of outwash sand and -gravel in most other localities). No rivers deliver new sediment eroded from inland. The sediment present is that which happens to be available from past geologic activities.

The waves have built beaches and spits, and along the south coast, narrow, linear sandy islands known as barrier islands. Between this string of islands and the main part of Long Island is a "lagoon," the largest of which is Great South Bay. Over much of Great South Bay, tidal action brings in silt, which builds up mudflats that are soon colonized by salt-tolerant grasses to build intertidal salt marshes whose top surface approximates the level of mean high water. Once the marsh grasses have become established, they are able to survive further submergence at rates of up to 4 millimeters per year. They do this by trapping silt among their stalks and by growing upward. As they grow upward, they do two important things: (1) they spread landward, and hence can overlie any pre-existing material, including granitic bedrock; and (2) they build an ever-thickening layer of marsh peat beneath themselves. Initially, salt-tolerant grasses overlie intertidal mudflats and the thickness of the marsh peat equals half the mean tidal range. Thus, on a coast where the mean tidal range is 2 meters, the thickness of marsh peat is 1 meter. Marsh peat thicker than half the mean tidal range or marsh peat overlying non-tidal sediments indicates submergence (Sanders and Ellis, 1961). The intertidal salt marshes of Great South Bay are young; no older than 2,000 years (Rampino, 1978 ms.; Rampino and Sanders, 1981b). This age coincides with that determined for the adjacent barrier islands (Kumar, 1973; Sanders and Kumar, 1975a, b; Rampino, 1978 ms.; Rampino and Sanders, 1981a, c).

The tidal oscillations cause water to enter and to leave Great South Bay through narrow inlets within which swift currents flow. At the ends of the inlets are tidal deltas, composed of sand that has been transported back and forth in the deep parts of the inlets by the tidal currents but eventually is deposited where these currents spread out as thin sheets. An ebb-tidal delta is in a lagoon; a flood-tidal delta, in the open sea.

OBJECTIVES

1) To examine the Cretaceous strata of northern Long Island.

2) To study the relationships of the Quaternary sediments to the modern landscape.

3) To study the provenance of glacial erratics, especially of stones found on Long Island's north-shore beaches and facies changes in the Quaternary sediments.

4) To demonstrate the importance of lacustrine-deltaic strata in Fuller's Manhasset Formation.

5) To emphasize the general correctness of Fuller's interpretation of the stratigraphy compared with those who have cast Fuller aside, and,

6) To understand the general geologic relationships of the geologic units on Long Island and the occurrence of ground water in various geologic units.

DRIVING DIRECTIONS FOR LEAVING MANHATTAN

Turn L on 5th Avenue, drive S to 34th Street, turn L and use Midtown Tunnel and Long Island Expressway.

LIST OF LOCALITIES "STOPS"

STOP 1 - Sands Point Museum and Preserve, Sands Point.
STOP 2 - Sand Pits, Port Washington.
STOP 3 - Garvies Point Museum and Preserve, Glen Cove.
STOP 4 - Caumsett State Park, West Neck Road, Lloyd Neck.
STOP 5 - Target Rock Refuge, Lloyd Neck.
STOP 6 - Roanoke Landing Beach, Riverhead.
STOP 7 - Jacob's Hill, Southold, Mattituck.

ROAD LOG AND DESCRIPTION OF LOCALITIES ("STOPS")

Below we provide a detailed road log for Day 1 and a semi-detailed road log for Day 2. The log for Day 1 will begin at the road junction of the Long Island Expressway and Willis Avenue in Mineola. Mileages are approximate from the New York Academy of Sciences in Manhattan.

Road Log for Day 1

24.9 Road Junction of Long Island Expressway and Willis Avenue. Turn R to go north on Willis Avenue toward Roslyn. Presently in Sea Cliff quadrangle.
25.5 Boundary sign for Village of Roslyn.
26.1 Turn R onto Old Northern Boulevard and go downhill. Keep L for turn at bottom of hill.
26.5 Turn L at traffic light onto West Shore Road toward Port Washington. Follow sign to Bar Beach Park.
26.6 Sign for Village of Flower Hill. View of Hempstead Harbor to R. Continue straight.
28.8 Sea View Boulevard on L, then a big landfill.
29.0 Truck entrance to landfill.
29.3 Old entrance to sand pit (no entry).
29.5 Start divided highway.
29.8 Bar Beach Park on R.
30.2 Hempstead Harbor Park on R.
30.5 Pass Nassau County "Aerodrome" on L. Later we will visit here for Stop 2.
31.7 Road curves up hill and to the L.
32.2 Turn R at traffic light for Longview Road. West Shore Road becomes Beacon Hill Road at this light.
33.0 Road junction with Hampton Road on L. Continue on Longview Road.
33.1 Turn R onto N. Y. Route 101 (Middle Neck Road) Northbound.
33.2 Pass Saint Peters School on R.
33.3 Traffic light at Sandy Hollow Road. Harbor Road on R.
33.7 Traffic light. IBM Country Club on R.
34.5 Sign for Village of Sands Point.
34.9 Turn R into park entrance for Sands Point Preserve. Drive past Helen Keller National Center on L and over bridge past guard house.
35.3 Park in lot in front of former US Naval Reservation for a Rest Stop and Stop 1.

STOP 1 - Outwash, till, and loess in beach cliffs at Sands Point Museum and Preserve, Sands Point. [UTM Coordinates: 609.9E / 4524.3N, Sea Cliff quadrangle.]

We are indebted to Herb Mills, County Parks Naturalist, who will accompany us to Stops 1 and 2 and who has been helpful in arranging permissions for us to visit these localities. Take trail #3 (green markers) to beach past kettle lake. We shall examine the cliff to the W of the end of the trail (on L as we approach) first and then spend most of our time examining the cliffs to the E of the trail's end.

Cliff to W end of trail:

The cliff W of the end of the trail displays three contrasting materials: (1) Cretaceous(?) black- and deep reddish-brown sandstone (recently exposed at base of bluff just W of stairs); (2) Quaternary outwash (predominates to the W); and (3) Quaternary red-brown till (exposed close to the trail).

The newly exposed dark-colored sandstone, stained with probable manganese oxides and hematite, may be the Upper Cretaceous. Previously, we had noticed a similar manganese-oxide-stained sandstone E of the trail, but not enough of it was exposed to enable us to make any decision about it. The new exposures resemble the dark-stained Upper Cretaceous sands at the AKR exposure, SW Staten Island.

The horizontally stratified sand- and gravel in which quartz pebbles predominate is part of Fuller's Herod Gravel member of the Manhasset Formation. (See Figures 3A and 4B.) On our visits during the Spring of 1993, we dug into the upper part of this deposit and found its strata to be generally horizontal, but with small-scale cross laminae dipping toward the SW. We infer that these are fan deposits.

The red-brown till, which implies that the ice that deposited it flowed from NW to SE (requirement for obtaining the load of Newark debris responsible for the red-brown color), is probably not Fuller's Montauk Till. The outwash (which is not reddish-brown) clearly is older than the till, but the age of neither is definitely known. To our way of thinking, this red-brown till was deposited by a glacier of pre-Woodfordian age, possibly Early Wisconsinan, or even Illinoian. The outwash may be part of the same body that we shall study in the exposures E of the trail's end.

Cliff E of trail:

On the beach, note the abundant erratics including possible blueschist boulders. Also present here are the ubiquitous Cretaceous "ironstone" conglomerates with well-rounded white quartz pebbles, and small pieces of light-gray fossiliferous Devonian chert containing straight-hinged spiriferid brachiopods (probably from the Onondaga Limestone). Beneath the slope-wash cover (whose thickness is up to 0.5 m), the upper part of the cliff face consists of horizontally stratified outwash sand- and -gravel with mafic minerals, and rounded white quartz pebbles, as in the exposure W of the stairs. Toward the top of the cliff, the outwash is overlain by a thin till that probably qualifies as being the Montauk Till Member of the Manhasset Formation of Fuller (1914). Overlying this till is a layer of coarse reddish loess, 1 m thick, which undoubtedly was derived from a reddish-brown till.

The outwash forming the lower third of the bluff is usually obscured by slopewash, much of it from the till, the loess, and the pebbly outwash. The storms of December 1992 cut back the bluff and exposed what is usually hidden behind the slopewash: foreset layers of a Gilbert-type delta (Figure 25) that dip steeply to the S, away from Long Island Sound. By digging out the contact where the dipping layers are truncated by horizontal topsets, we proved that these were delta foresets (Sanders, Merguerian, and Mills, 1993).

Along the base of cliff above the modern beach, small fans are sometimes present. These are bodies of sediment that have accumulated at the mouths of each of the tiny watercourses or larger channels, where rainwater is concentrated into surface flows. When we visited this locality on Wednesday, 07 November 1990, fans of two generations, each truncated on their seaward sides by a steep scarp, were clearly visible.) Because of the storm on Saturday, 10 November 1990, all this changed. The distal parts of the fans had been washed away.

For many years, Herb Mills has watched some iron bars sticking out from near the top of the cliff several hundred yards E of the stairway. Aerial photos show that these first appeared about 1970. The rods, 50 ft long, were evidently laid horizontally on the ground perpendicular to the cliff face. By now, the last of them may have fallen down onto the beach. They show an average rate of cliff retreat of about 2 feet per year.

Farther E is a seawall in distress, with a road leadiing down from above. Here, near the top of the bluff, is a shallow, boulder-lined U-shaped trough. We infer that it marks a shallow till-filled depression that was reworked by outwash streams, leaving only the boulder pavement. (Compare with Mather's Fig. 16 in his Pl. I, our Figure 24.) We dug out the contact and discovered that any of the boulders containing biotite had decomposed considerably.

The beach sediment usually consists of alternating layers of sand and well-rounded quartz pebbles, and may be 0.5 to 1 meter thick. The storm of 10 November 1990 stripped away all the usual sand and gravel leaving only a thin veneer of dark-colored "heavy" minerals (specfic gravities larger than 2.8) resting a wave-eroded surface that dipped steeply toward Long Island Sound. We dug a trench perpendicular to shore through the heavy-mineral layer and and found beneath the heavy-mineral layer brownish sands that dipped steeply (30° to 40° to the S -- away from Long Island Sound). At least three reasonable hypotheses can explain these dipping layers. (1) The material is of Cretaceous age, and was deformed by a glacier; (2) the material is of Cretaceous-, or even Pleistocene age, and the layers were originally horizontal, but the S dip resulted from block rotation on a curving slump surface (Fig. 9 of Mather's Pl. I, our Figure 24), a common situation at the bases of steep clifff (Steve Englebright of Stony Brook drew our attention to this possibility); and (3) the material is Pleistocene outwash and the S dip resulted from deposition as steep foreset beds at the front of a Gilbert-type delta that grew southward into a proglacial lake.

Our first preference was for ice-deformed Cretaceous. We were inclined toward this view because of the known examples of ice-deformed strata found in the walls of the Port Washington gravel pits not far away that we shall study at Stop 02. However, in the spring of 1993, after the storms of December 1992, we came here and were amazed to see S-dipping sandy layers well exposed. From a distance, we thought Englebright's emphasis on slump-block rotation was correct. But, on close view, we found the contact between delta foresets and delta topsets. (See Figure 25.) We are now persuaded that the deltaic hypothesis is correct and that the S-dipping layers in the SST we dug on the beach are parts of the Gilbert-type delta in the Herod member of the Manhasset Formation.

Much of the present preserve was formerly part of the Sands Point US 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.

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

35.4 Drive out of lot by following exit signs.
36.0 Turn L on Middle Neck Road headed East.
40.7 Traffic light at Astors Lane on L and Harbor Road on R.

41.1 Traffic light at Harbor Road - Sandy Hollow Road on R.
41.3 Traffic light, Saint Peters School on L.
41.4 Turn L onto Longview Road.
41.5 Stop sign at Hampton Road.
41.6 Stop sign at Hillcrest Road.
42.1 Turn L at traffic light onto West Shore Road. Beacon Hill Road on R.
42.3 View ahead (east) to Hempstead Harbor.
42.9 Turn R into Nassau County Aerodrome for Stop 2.

STOP 2 - Glacial chaos in the Sand Pits, Port Washington. [UTM Coordinates: 612.0E / 4521.0N, Sea Cliff quadrangle.]

Till, Loess, ice-caused thrust sheets of Cretacous over Quaternary and within Quaternary tills, erratics, etc. On trip day, Herb Mills will accompany us.

We were not able to visit this site on our trip-check days, so we are that much more indebted to Herb Mills for his willingness to guide use through this complex area, about which he has written at least two articles (Mills and Wells, 1975; Sirkin and Mills, 1975). Figure 29 shows a profile-section of the west side of the northern end of this extensive exposure.

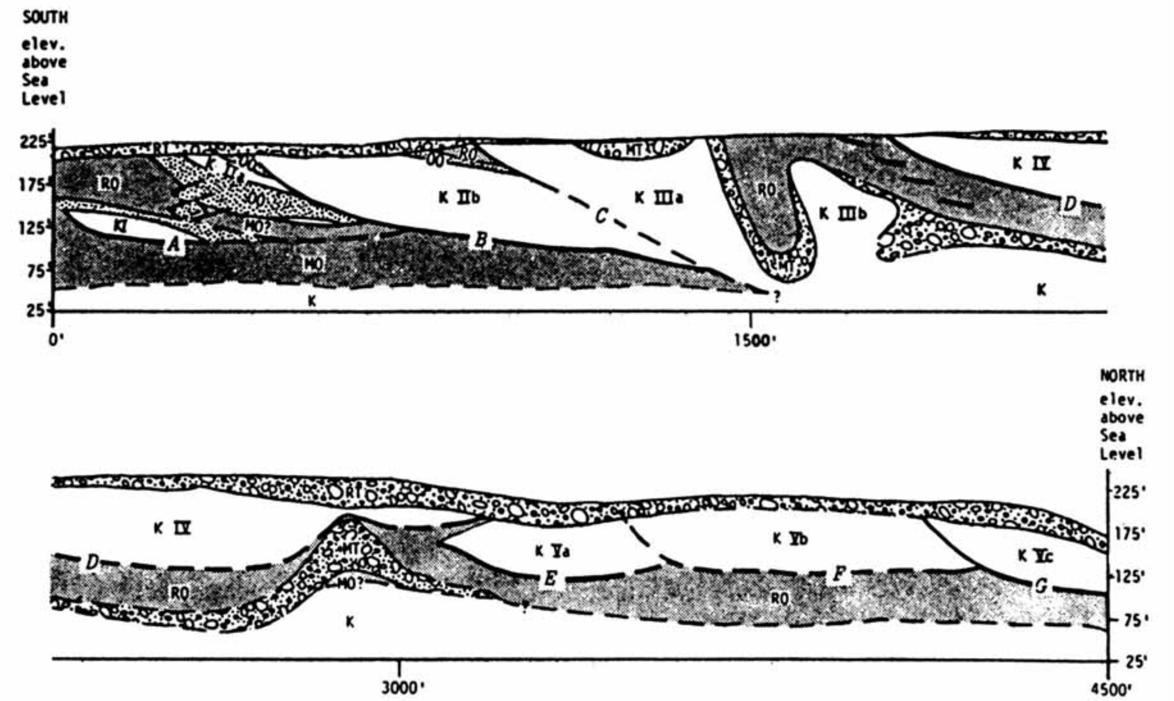


Figure 29. Profile-section of cliffs on W side, N end of Port Washington sand pits, showing results of ice-thrust deformation. Faults shown by letters (A, B, etc.). Cretaceous (K, KI, KII, KIII, KIV). Pleistocene units are: MT, Montauk (?) Till; MO, outwash, assigned to Early Wisconsinan; RO, outwash, associated with Roslyn Till (RT), both inferred to be of Late Wisconsinan age. (L. A. Sirkin, and H. Mills, 1975, fig. 4, p. 318; from H. Mills and P. D. Wells, 1974.)

The overall relationships here were determined by the ice-push deformation of the last glacier to invade Long Island, which Mills and Sirkin infer came from the NW and which they have classified as Woodfordian. We agree with the first two points about its being the "last glacier to invade Long Island" and that it came from the NW, but we reject their Woodfordian age assignment; we prefer Fuller's Early Wisconsinan. Be that as it may, this "last glacier" did a number on the Cretaceous, bringing it up from several hundred feet below sea level, carving it into slices, and placing them above the Quaternary sediments, as a series of ice-thrust "allochthons." These Cretaceous-over-Quaternary features are confined to the northern half of the former face that extended in a N-S direction for about 2.5 mi when the sand pits were still active. In the southern half of the face, the Quaternary strata are in normal order: from base upward, outwash, till, outwash, till. [We have not seen these, but surmise that the correct classification might be Fuller's Manhasset Formation (Illinoian) for the lower three, with the till between the outwash units being the Montauk, and the till at the top being our till No. IV (See Table 3.), associated with the Harbor Hill Moraine (Early Wisconsinan).]

The first major trail to the left leads to a small pit where black Cretaceous clay is exposed. Notable features of this clay are its concretions, pyrite, and "lignite" [all examples of which we think are not lignite but rather charcoal, which Hollick (1906) inferred are remnants of ancient forest fires].

In the "Death Valley"-like landscape visible at the end of the trail (trailbiker's "heaven"), several protruding parts of the Montauk Till are surrounded by light-colored Cretaceous kaolitic sands and -conglomerates. On 01 June 1996, we dug out the thrust contact at the top of this till and found, as Mills indicated, a thin zone of clay along the thrust surface. The S side of the main body of the Montauk Till (not visible from the vantage point at the end of the trail) displays several steep thrust zones of till against till. Near the top of the wall just west of the "till hill" is a layer, possibly 5 m thick, of white kaolitic conglomerate in which the pebbles are well-rounded white quartz. This unit is a major contributor to the pebbly wash that drapes over the lower part of the slope. (The aspect of the in-situ white conglomerate is very similar to that of the Silurian quartz-cemented Shawangunk Conglomerate of the western side of the Appalachians in NW New Jersey and SE New York.) In his lithologic map of the Upper Cretaceous on Long Island, Fuller shows the area of this pit as belonging simply to a unit entitled "white sands;" he did not mention such a conglomerate. (See Figure 17.) However, this Upper Cretaceous conglomerate must have been an important contributor to the pebbly supermature Quaternary outwashes erosion of which has provided pebbles for Long Island's north-shore beaches.

A key point of chronostratigraphic interest is the silt containing shells formerly exposed in the SW corner of the large excavation. (Before it was covered, JES saw it on 24 June 1977 during a visit to this site with M. R. Rampino.) Sirkin used the radiocarbon dates (about 25 to 40ka) on these shells as the basis for inferring a mid-Wisconsinan high stand of the sea [he named it the Portwashingtonian interglacial interval (Sirkin and Stuckenrath, 1980)] and for dating the Harbor Hill moraine as Woodfordian. By contrast, on shells that Ricketts (1986) collected from here, J. H. Wehmiller (Univ. of Delaware) obtained an amino-acid-racemization date of 225,000 yr. This contrast in numbers on specimens collected from the same locality lies the nub of the whole controversy between us and Sirkin. If the radiocarbon ages are accurate, then Sirkin's view is supported. If the amino-acid-racemization results are correct, then Fuller's chronology is established. As we have said before in other connections, both could be wrong, but only one can be correct. Jurors cast your votes!

44.0 Reboard vans and head south on West Shore Road.
44.4 Truck entrance for landfill on R. Mount Garbage and Decay on R.
45.5 Under viaduct.
45.55 Turn R onto Old Northern Boulevard.
45.8 Layton Street on R.
46.0 Turn R at traffic light.
46.05 Turn R at Exxon station to pick up Route 25A (Northern Boulevard). Nice view of Hempstead Harbor to L (North) as we pass over viaduct.
46.9 End of viaduct. Continue east on Route 25A uphill.
47.4 Drive under railroad tracks.
47.5 Sign for Village of East Hills.
47.6 Traffic light at road junction with Forest Drive. Continue ahead on Route 25A.
47.7 Traffic light at road junction with Chesnut Drive on R. Cemetery on L. Get on L for upcoming turn.
47.9 Turn L onto Glen Cove Road (Northbound).
48.4 Traffic light. Sign for Town of Oyster Bay, start divided highway.
48.5 Sign for Village of Roslyn Harbor.
49.2 Leave Sea Cliff quadrangle, enter Hicksville quadrangle.
50.1 Traffic light at Glen Head Road on R.
50.3 Road Junction with NY 107 North (= Swamp Road). Cemetery on R beyond Swamp Road.
50.7 Traffic light. Pound Hollow Road on R.
51.1 Traffic light. Cedar Swamp Road on R. Route 107 curves L. End divided highway. Note sign to Garvies Point Museum.
51.2 Sign for City of Glen Cove.
51.7 Pass under railroad bridge.
52.0 Leave Hicksville quadrangle, enter Sea Cliff quadrangle.
52.45 Traffic light (Route 107 is now Pratt Boulevard). Bridge Street on R.
52.6 Turn R onto Forest Avenue (Brewster Street).
52.75 Turn L onto Herb Hill Road. On trip day take high road to Mc Loughlin Street directly to Museum.
52.8 Turn R at stop sign for Charles Street.
54.6 Pass The Place on R. Charles Street is now Dickson Street.
54.7 Four-way stop sign. Turn L on McLoughlin Street.
54.9 The Landing School on L.
55.0 At stop sign, Carpenter Street on R. Go straight ahead.
55.2 At stop sign, junction with Germane Street, go straight.
55.3 Turn L onto Barry Drive to Garvies Point Museum.
55.5 Turn R into musuem parking lot entrance and bear L.
55.6 Park vans in lot and take trail 1 to beach for Stop 3.

STOP 3 - Outwash, till, and loess at Garvies Point Museum and Preserve, Glen Cove. [UTM Coordinates: 613.5E / 4523.7N, Sea Cliff quadrangle.]

We shall make a brief visit to the museum for a quick look at the exhibits and for any pitters needing the rest rooms. Afterward, assemble outside by the large erratic for a walk down to the beach.

At the bottom of the bluff, Cretaceous strata are exposed. Units visible are variegated clays and -sands with lignite seams. The stratigraphic succession as found in a slump block to the south of the wooden stairs (from the top down) is:

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

The slump block implies that these strata have been gravity displaced downslope from an original position higher up the slope. Given the normal relationship that the top of the Cretaceous lies below sea level, the pre-slump situation here probably involved upward displacement of the Cretaceous on glacio-tectonic thrusts, as in the northern end of the Port Washington pits at Stop 02. We have not seen any evidence at Garvies Point that Cretaceous has been thrust over Pleistocene, but it would not surprise us to find such a relationship.

About 150 m S of the stairs, whitish Cretaceous clay of the slump block, at beach level, is overlain by a reddish-brown till, about 1 m thick, consisting of deeply weathered granitic- and other stones, and Cretaceous ironstones; a manganiferous residue is present at the contact with underlying outwash. Other dark-reddish-brown outwash, ca 1.5 m thick, overlies the thin till. The till occupies channels in the white clay; the orientation of the long axes of the channels is NW-SE. The till also fills a crack that extends down into the white clay.

Unfortunately, the Quaternary sediments here, the reddish-brown till with deeply decayed stones and overlying outwash, are not associated with any other Quaternary formations. Therefore, with respect to the age assignment of the till and the outwash, we are forced back on the well-known geological principle of "guessing." One approach is to apply the Fuller principle, namely that the decayed granitic pebbles imply the Mannetto Formation and thus ancient age. However, as mentioned, decayed granitic clasts may be indicator stones from Garrison, New York, where a deep saprolite in granitic gneiss was found in the NY City water tunnel (Berkey and Rice, 1919; Berkey and Fluhr, 1948). If our ancient age assignment is correct, then in a normal stratigraphic relationship, Till I should underlie the Gardiners Clay and thus be found several hundred feet below sea level. Accordingly, the presence of this old till above sea level at Garvies Point is a further suggestion that the sediments here may have been displaced by glacio-tectonic activity.

This reddish-brown till and associated outwash closely resemble the till/outwash exposure at the AKR Company, SW Staten Island, which we think is the oldest Quaternary deposit in the New York City region. We have numbered the AKR exposure as Till No. I and assigned it to the Nebraskan. (See Table 3.)

The beach is littered with a great variety of distinctive kinds of erratics, some of bouder size, including plagioclase-phyric gabbro with xenoliths, pyroxene-phyric lamprophyre, potash-feldspar phyric granitic gneiss, mylonitic granitoid gneiss, augen gneiss, epidote amphibolite, potash-feldspar pegmatite, mica-rich red shale (Cretaceous), Cretaceous "ironstone" conglomerate, and many others.

END OF FIELD TRIP STOPS FOR DAY 1

TIME FOR A HASTY RETREAT TO OUR MOTEL (EconoLodge Motel in Hicksville.)

Road Log for Day 2

Drive toward the west a short ways and get on the Wantagh Parkway headed northbound. At the north end of the Wantagh, amid significant contruction (06/96), exit R for the Northern State Parkway (NSP) heading eastbound. The detailed road log will begin at Exit 35, the intersection point of the NSP and 107 at Exit 35 (Hicksville quadrangle).

88.7 Overpass for NY 107.
90.4 Pass ramp on R for Exit 36S.
90.8 Leave Hicksville quadrangle, enter Huntington quadrangle.
91.3 Pass ramp on R for Exit 36A to NY 135 (Seaford-Oyster Bay Expressway - locally known as the SOB).
92.0 Pass ramp on R for Exit 37.
92.6 Pass ramp on R for Exit 38.
93.3 Pass Manetto Hills, a famous place.
93.8 Enter Suffolk County.
94.0 Pass ramp on R for Exit 39.
95.7 Pass ramp on R for Exit 40S, prepare for next exit.
96.0 Turn off to R onto Exit 40N for Route 110 Northbound to Huntington.
96.2 After ramp merge with Route 110 North.
96.5 Traffic light, entrance for Times Square Stores Mall on R.
96.9 Traffic light for Amityville Road on R. This is northbound shortcut, via New York Avenue, in the event of traffic on the weekend. Here Route 110 is named Walt Whitman Road.
97.7 Traffic light with Clock Tower Plaza and Schwab Road on R.
98.0 Traffic light at entrance to Walt Whitman Mall to R. Note the ultra modern Burger King embedded in the Mall. This will be a rest stop if needed.
98.6 Traffic light at road junction with NY Route 25 (Jericho Turnpike).
98.9 Traffic light at New York Avenue which merges from R. This is the shortcut route, if taken.
99.4 Traffic light at East Hills Road on L.
100.1 Traffic light at road junction with County Road 11 (East Pulaski Road).

100.3 Pass under Long Island Rail Road tracks at Huntington Station.
100.6 Pass Whitman Village on L.
100.8 Traffic light at Nassau Road, diagonally on R, then start downhill.
102.1 Traffic light at Fairview Street on R and High Street on L. Continue straight on New York Avenue.
102.3 Turn L (west) at traffic light at road junction with NY 25A (Northern Boulevard).
102.4 Traffic light at Clinton Avenue.
102.5 Turn R on West Neck Road.
102.6 Traffic light at Gerard Street.
102.9 Leave Huntington quadrangle, enter Lloyd Harbor quadrangle.
103.6 Road forks R, road to L to St. Patrick's Cemetary.
103.9 Sign for Village of Lloyd Harbor. Start down long hill.
104.7 Lloyd Harbor Police Station on R [459-8800].
104.9 Kettle lakes on R.
105.4 Pass School Lane on R.
105.9 Pass entrance on R to Seminary of the Immaculate Conception. Then down hill again friom roughly 100' to sea level.
106.3 West Neck Beach on L.
107.4 Fort Hill Road on L (private drive).
107.6 Lloyd Lane on L.
107.8 Turn L into Caumsett State Park entrance.
108.1 Gate house at park entrance, then turn L, immediately after booth, between barns onto Fishing Lane. Bathroom signs here.
108.2 Turn L onto gravel road and follow around to the R.
110.1 End of road to 2FD on park map for Stop 4.

STOP 4 - Caumsett State Park, West Neck Road, Lloyd Neck. [UTM Coordinates: 628E / 4533N, Lloyd Harbor quadrangle.]

We have obtained permission to enter the Park and to drive our vehicle to the fishermen's landing at the beach.

The bluff is being eroding by gullying, slumping, and various debris flows. Root balls of trees from above are being undermined and the trees are in various stages of falling down. The same general situation applies to the boulders in the overlying till. Based on our reconnaissance to the shore cliffs on 08 Nov 90 and our previous trip, we saw the following: At the base of the section in draw at the E end are Cretaceous sands and -gravels characterized by a kaolinitic clay matrix and iron seams. Cross strata in sets of 10 cm to 15 cm dip to SSW with roughly 5 m aggrgate thickness.

The storms of December 1992 uncovered S-dipping Gilbert-delta-type foresets, as at Sands Point, but with several important differences. Here, gravel is very abundant in the dipping layers and many of the stones show evidence of decomposition, implying considerable antiquity. We infer that most of the bluff consists of deltaic foresets belonging to Fuller's Herod Gravel Member of the Manhasset Formation.

Higher up, the relationships are not too clear at a distance (we did not climb nor dig). Above the Cretaceous is a red-brown till that we sampled. Above it is outwash (yellowish) and clearly deformed judging by variation in dip as well as fault offset. Higher-still seems to be another brownish till, probably the Montauk, of Fuller, and at top, loess.

STOP 5 - Target Rock National Wildlife Refuge, West Neck Road, Lloyd Neck. [UTM Coordinates: 632.0E / 4531.8N, Lloyd Harbor quadrangle.]

En route, the trail crosses the loess, which forms the topmost layer of the cliff exposures (as seen at the N end of the Preserve).

The Target Rock exposures were described in Sirkin and Mills (1975, p. 319-323), who illustrated two tills and some laminated silts/clays in between. We have interpreted these laminated fine sediments as deposits of Lake Long Island (Sanders and Merguerian, 1994a; Sanders, Merguerian, and Mills, 1993).

The beach here contains abundant green pebbles featuring porphyritic volcanic rocks that we think came from W of New Haven, CT (Maltby volcanics). They are definitely not trap rocks from the Palisades, as suggested by Sirkin and Mills. They imply glacial flow from NNE to SSW, not NNW to SSE.

The lower half of the cliff exposed after the storms of December 1992 consists of till containing green porphyritic mafic erratics, so common on the beach. We correlate this till with the oldest till at Croton Point Park (the gray till containing decayed granite stones; Merguerian and Sanders, 1992b; Sanders and Merguerian, 1994b). Above this till is 1 cm or so of fine gray clay. Above the clay are silts-fine sands containing splendid examples of climbing ripples (as illustrated by Sirkin and Mills, 1975, in their description of Stop 3A). These rippled strata display lateral particle-size variations along the ripple profiles from coarser to finer, with superposition of theses yielding "pseudo-bedding." We infer that these rippled sediments and the clays are the bottomset beds of the delta foresets exposed at Stop 4. We assign them to the Herod Member of the Manhasset Formation. Another thin till at the top of the cliff (Montauk Till of Fuller?) must have been deposited by a glacier that flowed from NNW to SSE, to bring erratics from the Inwood Marble and Cortlandt Complex (Merguerian and Sanders, 1992b). If this bluff-top till is not the Montauk, then it may be the work of the glacier that deposited one of the two terminal-moraine ridges (Ronkonkama or Harbor Hill).

110.1 Back to vans and drive back to entrance of park.
112.0 Guard shack.
112.3 At entrance gate turn R back onto Lloyd Harbor Road.
113.8 West Neck Beach on R.
115.4 Lloyd Harbor Police Station on L.
117.2 Leave Lloyd Harbor quadrangle, enter Huntington quadrangle.
117.5 Traffic light at Nathan Hale Road.
117.6 Turn L onto NY Route 25A (Main Street) headed east.

117.7 Road junction with NY 110 (New York Avenue) South.

[NOTE: The road log continues headed east on 25A to Roanoke Landing Beach for STOP 6, to Jacob's Hill in the Mattituck quadrangle for STOP 7].

117.7 Drive east on NY 25A toward Centerport.
118.3 Leave Huntington quadrangle, enter Lloyd Harbor quadrangle.
120.6 Enter Centerport. Leave Lloyd Harbor quadrangle, enter Northport quadrangle. Continue east on 25A through Vernon Valley, and Kings Park. Pass road junction with the Sunken Meadow Parkway and continue past Smithtown, Brookhaven, and Stony Brook (Saint James quadrangle). Continue on 25A into Port Jefferson and Port Jefferson Station (Port Jefferson quadrangle) into Rocky Point (Middle Island quadrangle) and Wading River (Wading River quadrangle). Roughly one mile east of Wading River merge L onto Sound Avenue travelling east past Wildwood State Park. Continue east on Sound Avenue past Baiting Hollow (Riverhead quadrangle) and after roughly 2.1 miles turn L onto Roanoke Avenue northward to the end of the road for Stop 6.

STOP 6 - Roanoke Landing Beach, Riverhead. [UTM Coordinates: 692.8E / 4538.3N, Riverhead quadrangle.]

According to Sirkin (notes on June 1990 trip for Long Island Association of Geologists), the exposures here are a recessional moraine of the Connecticut lobe of the Woodfordian glacier (not much moraine left because of erosion). In the territory between the moraine ridges, vegetable farms are numerous. The moraine is capped by a diamictite that is overlain by loess (at top of cliff).

The results of our shovel action diclosed pebbly outwash in the lower bluffs, with mature composition (derived from the mature Upper Cretaceous). Higher up is a till; above it another outwash, then another till, and finally the loess at the top. We have not yet determined the proper age assignments for these units. However, after re-reading Fuller (1914, p. 139), we agree with his assignment of the beds here to the Manhasset Formation, including all three members, the basal Herod Gravel, the middle Montauk Till, and upper Hempstead Gravel. Fuller did not mention the loess at the top, but did mention "dune sand" 10 ft thick. The upper till may be his Early Wisconsinan Till (associated with the terminal-moraine ridges).

Turn around and head back on Roanoke Avenue to turn L onto Sound Avenue headed east. Pass Centerville (Riverhead quadrangle) and continue east past Northville (Mattituck quadrangle) to turn L onto Pier Avenue. Follow Pier Avenue north to the public beach for STOP 7.

STOP 7 - Jacobs Hill, Southold. [UTM Coordinates: 702.2E / 4540.5N, Mattituck quadrangle.]

We shall make a brief rest stop in the parking lot to enable needy pitters to do their things in the bathroom facilities. Assemble at the SE corner of the parking lot for a walk down the trail to the beach. Assemble by the van for a brief look at the topographic map of the Mattituck- and Mattituck Hills quadrangles. Notice that the houses shown on the Mattituck quadrangle map dated 1955? are no longer present. They probably disappeared during the big storms of December 1992, but we do not know this for certain.

Geologic descriptions of the locality referred to simply as "Jacob Hill" have been published by Fuller (1914) and by J. E. Upson (1970) of the US Geological Survey. Fuller made this the type locality of the Jacob Sand, which overlies the Gardiners Clay. (Both of these formations underlie the Manhasset Formation.)

Figure 30 shows three views sketched by Fuller, each indicating major ice-thrust deformation to yield the folds, and also block rotation along a curved slump surface (Fuller's fig. 92) of ice-thrust strata and also to bring up the Gardiners Clay and Jacob Sand from their normal positions below modern sea level. Figure 31 is Upson's sketch of the cliff section (his Fig. 2, p. B159).

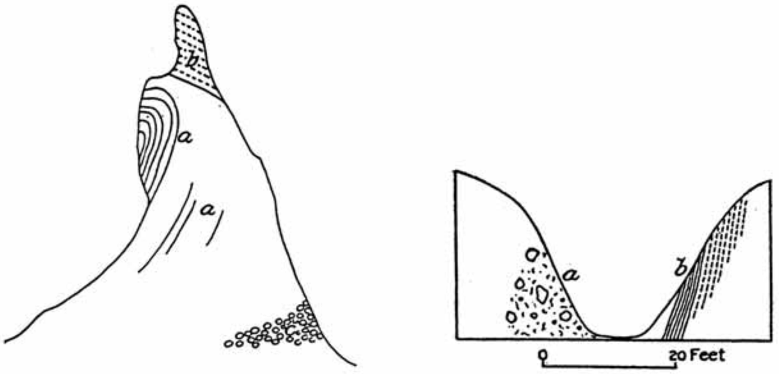


FIGURE 72.—Section near Jacob Hill. *a*, Reddish to chocolate-colored Gardiners clay; *b*, buff clayey Jacob sand; *c*, granitic gravels lying beneath overturned fold (Herod gravel member of Manhasset formation?).

FIGURE 91.—Section at landing west of Jacob Point. *a*, Banded clayey till (Montauk till member of Manhasset formation); *b*, pink till, gray clay and sand (Jacob sand).

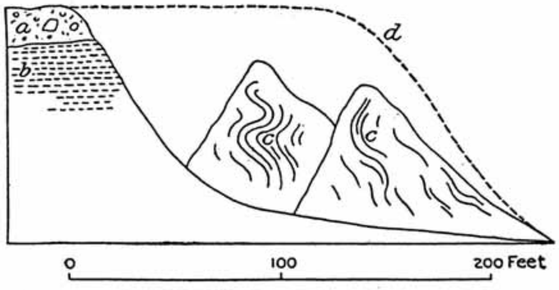


FIGURE 92.—Section near Jacob Hill. *a*, Till; *b*, Herod gravel member of Manhasset formation; *c*, upturned and contorted pinkish to buff clayey Jacob sand; *d*, former extension of bluff. Relations to sand not shown.

Figure 30. Sketches of ice-thrust-deformational features in Jacob Sand, Gardiners Clay, and Manhasset Formation visible in 1904 in bluff at Jacobs Hill. Fuller's Fig. 92 also shows additional steep dip caused by slumping along a curved surface. (M. L. Fuller, 1914, fig. 72 p. 98; and figs. 91 and 92, p. 109.)

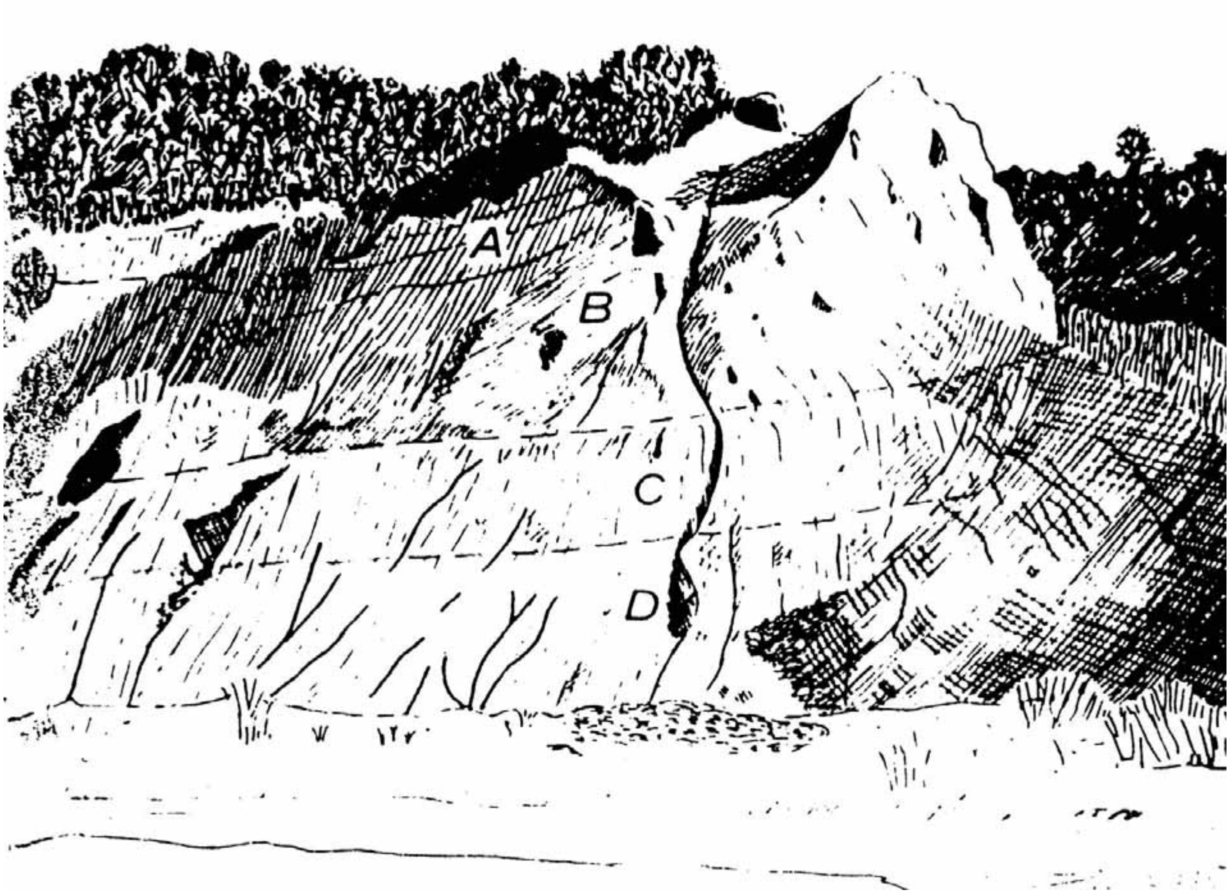


Figure 31. Sketch of strata exposed in north-shore cliffs below Jacobs Hill, Mattituck, Long Island. From base upward: D, sand, coarse, pebbly, white; mostly covered by wash (and not excavated); C, brown clay, becoming silty and sandy above (Gardiners Clay); B, very fine sand and silt (Jacob Sand); A, clay, chocolate brown. (J. E. Upson, 1970, fig. 2, p. B159.)

A notable feature of the cliff here is the till at the top that contains large boulders, many of which now litter the beach. This is the Montauk Till of Fuller's Manhasset Formation. This till is overlain by the ubiquitous loess.

Our two digs that got through the thick slopewash layer, which is prone to continuous slumping, showed Gilbert-type delta foreset beds, some dipping E, in fine sands. In one of our excavations, the sediments from two adjoining delta lobes come together. The lobe on the W, with foresets dipping E, was deposited first. The S-dipping foresets of the lobe on the E onlap onto the steep W-lobe surface, which dipped toward the E lobe. As a result, the E-lobe foresets "climb" toward the W. We assign these foreset-bedded sands to the Herod Member of the Manhasset Formation. [No mention is made of delta foreset beds at this locality in either Fuller's (1914) or Upson's (1970) descriptions.]

After the digging, drag your weary bones back to the van. Turn around and return to Sound Avenue. Turn L and after 0.15 miles turn R onto Manor Lane. Continue southeasterly on Manor Lane and then turn R onto NY Route 25 in Jamesport. Follow Route 25 west into

Riverhead and pick up the LIE to head back to New York City. On the way back, read about what we did not try to see at Montauk Point.

The dramatic story at Montauk Point is the relationship between the Montauk Lighthouse and the eroding coastal cliffs composed of Pleistocene sediments (two tills, coarse, braided-stream outwash, and well-bedded fine-textured sediments, probable lake deposits). First, the lighthouse, then the geology.

According to legend, George Washington himself surveyed the site where the government was planning to build a lighthouse. He inquired of his superiors how long they wanted the lighthouse to last. "Two hundred years," they are alleged to have replied. George then conferred with the local residents concerning their knowledge about cliff erosion. He made a few calculations and did some measuring and finally picked the present position for building the lighthouse. Now, 200 years later, the waves, right on schedule, are practically washing away the base of the lighthouse. (Score one for George.)

Locality (A) in this discussion is at the base of the cliffs at the E end of the gabions, and Locality (B), at the W end of the gabions (Italian word for "basket;" the wire-mesh rectangles filled with angular blocks).

Locality A (east end of gabions). The beach here consists of a mixture of modern skeletal debris, boulders washed out of the Pleistocene deposits, and block of gray carbonate rocks of Cambro-Ordovician age that have been barged here from a quarry in the mid-Hudson valley near Poughkeepsie. They were emplaced as part of an earlier attempt by the US Army Corps of Engineers to control erosion. Smaller pieces of these carbonate rocks have been used to fill the gabions; some of these have leaked out where the wire mesh has been broken.

In the Pleistocene sediments, a great contrast exists between the fine-textured, well-bedded sands/silts on the right and the underlying gray diamictons, one of which displays a pronounced fissility (even stratification), in which the dip is no longer horizontal. We interpret these as two facies of the lacustrine Manhasset Formation. The fine-textured sediments are central-lake deposits, whereas the diamictons are deposits of sublacustrine debris flows on a delta lobe. What is surprising about these lake sediments is that they face the open ocean. In order for a lake to have existed here, some kind of dam must have been present to the south. Presumably the Montauk shoals just offshore are the remnants of a former terminal-moraine ridge older than the Ronkonkama Moraine, which forms the coastal bluff.

Locality B (west end of wall of gabions). Some of the large slabs of concrete on the shore here are remnants of bunkers that were dug into the cliffs during World War II to house coastal artillery to shoot at German submarines that were causing great losses to ships in the Transatlantic shipping lanes. In the subsequent 50 years, cliff erosion has undermined and exposed the bunkers and they have toppled down onto the beach. Notice that the beach here consists of sand, as contrasted with gravel at A. This is a consequence of the vast amount of sandy outwash in the cliff that is being eroded. Most of the slope-stabilization attempts have been built on the fine outwash, proglacial-lake deposits. This fine sand fills a channel that has been cut into the till. The floor of the channel has been lined with a boulder residue where the water washed away the fines from the till below (a "virtual" till). The same thing is happening today on the beach, where the waves have washed the till and left behind a boulder residue.

Above the outwash is another till. How these fit into our new scheme of things is not yet clear.

ACKNOWLEDGMENTS

We are indebted to Mr. Herb Mills, Sand's Point Preserve; Mr. Frank Merklin, Commissioner of Public Works, Mineola; Ms. Kathryne Natale, Garvies Point Museum and Preserve; Ms. Carolyn Casey, the New York State Department of Parks, Recreation and Historic Preservation; the guard at Caumsett State Park; and Mr. David Beall, Target Rock National Refuge for their combined efforts in gaining access to the first five stops of our trip. Thanks also to Matt Katz, and Marcie Brenner for their logistical help, and special kudos to the inventor of the GI trenching tool.

TABLES

Table 01 - GEOLOGIC TIME CHART

(with selected major geologic events from southeastern New York and vicinity)

ERA **Periods (Epochs)**	**Years (Ma)**	**Selected Major Events**
CENOZOIC		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley. Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley. Repeated continental glaciation with five? glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
MESOZOIC	66.5	
(Cretaceous)		
	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(**Begin Atlantic Passive-Margin Stage II**).
(Jurassic)		Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
		Atlantic Ocean starts to open. Newark basins deformed, arched, eroded.
(Triassic)	190	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive. Newark basins form and fill with non-marine sediments.

PALEOZOIC	245	
(Permian)		Pre-Newark erosion surface formed.
	260	**Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)		Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	**Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
(Silurian)		
	440	**Taconic orogeny.** Intense deformation and metamorphism.
	450	Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line and St. Nicholas Thrusr Zone). Arc-continent collision. Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata.
(Ordovician)		Ultramafic rocks (oceanic lithosphere) sliced off and transported structurally above deposits of continental shelf.
(Cambrian)		Shallow-water clastics and carbonates accumulate in west of basin. (= **Sauk Sequence**; protoliths of the Lowerre Quartzite, Inwood Marble, Walloomsac Schist). Transitional slope/rise sequence (Manhattan Schist) and deep-water terrigenous strata (Hartland Formation) form to east. (= **Taconic Sequence**).
PROTEROZOIC		
	570	Period of uplift, rifting,and erosion followed by subsidence of margin and development of **Iapetan Passive-Margin Stage I**.
(Z)	600	Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
(Y)	1100	**Grenville orogeny.** Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands and related rocks).
ARCHEOZOIC		
	2600	No record in New York.
	4600	Solar system (including Earth) forms.

Table 02

Generalized Descriptions of Major Geologic "Layers", SE New York State and Vicinity

This geologic table is a tangible result of the On-The-Rocks Field Trip Program conducted by Drs. John E. Sanders and Charles Merguerian between 1988 and 1998. In Stenoan and Huttonian delight, we here present the seven layer cake model that has proved so effective in simplifying the complex geology of the region. Under continual scrutiny and improvement, we provide this updated web-based information as a public service to all students and educators of geology. We encourage any comments, additions, or corrections. References cited can be sought by following this link.

LAYER VII - QUATERNARY SEDIMENTS

A blanket of irregular thickness [up to 50 m or more] overlying and more or less covering all older bedrock units. Includes four or five tills of several ages each of which was deposited by a continental glacier that flowed across the region from one of two contrasting directions: (1) from N10°E to S10°W (direction from Labrador center and down the Hudson Valley), or (2) from N20°W to S20°E (direction from Keewatin center in Hudson's Bay region of Canada and across the Hudson Valley). The inferred relationship of the five tills is as follows from youngest [I] to oldest [V]. [I] - Yellow-brown to gray till from NNE to SSW, [II] - red-brown till from NW to SE, [III] - red-brown till from NW to SE, and [IV] - yellow-brown to gray till from NNE to SSW, and [V] - red-brown till from NW to SE containing decayed stones (Sanders and Merguerian, 1991a,b, 1992, 1994a, b; Sanders, Merguerian, and Mills, 1993; Sanders and others, 1997; Merguerian and Sanders, 1996). Quaternary sediments consist chiefly of till and outwash. On Long Island, outwash (sand and gravel) and glacial lake sediment predominates and till is minor and local. By contrast, on Staten Island, tills and interstratified lake sediments predominate and sandy outwash appears only locally, near Great Kills beach.

[Pliocene episode of extensive and rapid epeirogenic uplift of New England and deep erosion of major river valleys, including the excavation of the prominent inner lowland alongside the coastal-plain cuesta; a part of the modern landscape in New Jersey, but submerged in part to form Long Island Sound].

~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~

LAYER VI - COASTAL-PLAIN STRATA (L. Cretaceous to U. Miocene; products of Passive Continental Margin II - Atlantic).

Marine- and nonmarine sands and clays, present beneath the Quaternary sediments on Long Island (but exposed locally in NW Long Island and on SW Staten Island) and forming a wide outcrop belt in NE New Jersey. These strata underlie the submerged continental terrace. The basal unit (L. Cretaceous from Maryland southward, but U. Cretaceous in vicinity of New York City) overlaps deformed- and eroded Newark strata and older formations. Also includes thick (2000 m) L. Cretaceous sands and shales filling the offshore Baltimore Canyon Trough. At the top are Miocene marine- and coastal units that are coarser than lower strata and in many localities SW of New Jersey, overstep farther inland than older coastal-plain strata. Capping unit is a thin (<50 m) sheet of yellow gravel (U. Miocene or L. Pliocene?) that was prograded as SE-directed fans from the Appalachians pushed back the sea. Eroded Newark debris is present in L. Cretaceous sands, but in U. Cretaceous through Miocene units, Newark-age redbed debris is conspicuously absent. This relationship is considered to be proof that the coastal-plain formations previously buried the Newark basins so that no Newark-age debris was available until after the Pliocene period of great regional uplift and erosion. The presence of resistant heavy minerals derived from the Proterozoic highlands part of the Appalachians within all coastal-plain sands indicates that the coastal-plain strata did not cover the central highlands of the Appalachians.

[Mid-Jurassic to Late Jurassic episode of regional arching of Newark basin-filling strata and end of sediment accumulation in Newark basin; multiple episodes of deformation including oroclinal "bending" of entire Appalachian chain in NE Pennsylvania (Carey, 1955), and one or more episodes of intrusion of mafic igneous rocks, of folding, of normal faulting, and of strike-slip faulting (Merguerian and Sanders, 1994b). Great uplift and erosion, ending with formation of Fall-Zone planation surface].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER V - NEWARK BASIN-FILLING STRATA (Upper Triassic and Lower Jurassic)

Newark-age strata unconformably overlie folded- and metamorphosed Paleozoic strata of Layer II and some of the Proterozoic formations of Layer I; are in fault contact with other Proterozoic formations of the Highlands complex. Cobbles and boulders in basin-marginal rudites near Ramapo Fault include mostly rocks from Layers III, IIB, and IIA(W), which formerly blanketed the Proterozoic now at the surface on the much-elevated Ramapo Mountains block. The thick (possibly 8 or 9 km) strata filling the Newark basin are nonmarine.

In addition to the basin-marginal rudites, the sediments include fluvial- and varied deposits of large lakes whose levels shifted cyclically in response to climate cycles evidently related to astronomic forcing. A notable lake deposit includes the Lockatong Formation, with its analcime-rich black argillites, which attains a maximum thickness of about 450 m in the Delaware River valley area. Interbedded with the Jurassic part of the Newark strata are three extrusive complexes, each 100 to 300 m thick, whose resistant tilted edges now underlie the curvilinear ridges of the Watchung Mountains in north-central New Jersey. Boulders of vesicular basalt in basin-marginal rudites prove that locally, the lava flows extended northwestward across one or more of the basin-marginal faults and onto a block that was later elevated and eroded. The thick (ca. 300 m) Palisades intrusive sheet is concordant in its central parts, where it intrudes the Lockatong at a level about 400 m above the base of the Newark strata. To the NE and SW, however, the sheet is discordant and cuts higher strata (Merguerian and Sanders, 1995a). Contact relationships and the discovery of clastic dikes at the base of the Palisades in Fort Lee, New Jersey, suggest that the mafic magma responsible for the Palisades was originally intruded at relatively shallow depths (roughly 3 to 4 km) according to Merguerian and Sanders (1995b).

Xenoliths and screens of both Stockton Arkose and Lockatong Argillite are present near the base of the sill. Locally, marginal zones of some xenoliths were melted to form granitic rocks (examples: the trondhjemite formed from the Lockatong Argillite at the Graniteville quarry, Staten Island, described by Benimoff and Sclar, 1984; and a "re-composed" augite granite associated with pieces of Stockton Arkose at Weehawken and Jersey City, described by J. V. Lewis, 1908, p. 135-137).

[**Appalachian terminal orogeny**; large-scale overthrusts of strata over strata (as in the bedding thrusts of the "Little Mountains east of the Catskills" and in the strata underlying the NW side of the Appalachian Great Valley), of basement over strata (in the outliers NW of the Hudson Highlands, and possibly also in many parts of the Highlands themselves), and presumably also of basement over basement (localities not yet identified). High-grade metamorphism of Coal Measures and intrusion of granites in Rhode Island dated at 270 Ma. Extensive uplift and erosion, ending with the formation of the pre-Newark peneplain].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)

Mostly nonmarine coarse strata, about 6 km thick, including thick coals altered to anthracite grade, now preserved only in tight synclines in the Anthracite district, near Scranton, NE Pennsylvania; inferred to have formerly extended NE far enough to have buried the Catskills and vicinity in eastern New York State (Friedman and Sanders, 1982, 1983).

[**Acadian orogeny**; great thermal activity and folding, including metamorphism on a regional scale, ductile deformation, and intrusion of granites; dated at ~360 Ma].

LAYER III - MOSTLY MARINE STRATA OF APPALACHIAN BASIN AND CATSKILLS (Carbonates and terrigenous strata of Devonian and Silurian age)

(Western Facies)	**(Eastern Facies)**
Catskill Plateau, Delaware Valley monocline, and "Little Mountains" NW of Hudson-Great Valley lowland.	SE of Hudson-Great Valley lowland in Schunnemunk-Bellvale graben.
Kaaterskill redbeds and cgls.	Schunnemunk Cgl.
Ashokan Flags (large cross strata)	Bellvale Fm., upper unit
Mount Marion Fm. (graded layers, marine)	Bellvale Fm., lower unit (graded layers, marine)
Bakoven Black Shale	Cornwall Black Shale
Onondaga Limestone	

Schoharie buff siltstone	Pine Hill Formation
Esopus Formation	Esopus Formation
Glenerie Chert	
Connelly Conglomerate	Connelly Conglomerate
Central Valley Sandstone	
Carbonates of Helderberg Group	Carbonates of Helderberg Group
Manlius Limestone	
Rondout Formation	Rondout Formation
Decker Formation	
Binnewater Sandstone	Poxono Island Formation
High Falls Shale	Longwood Red Shale
Shawangunk Formation	Green Pond Conglomerate

[**Taconic orogeny**; 480 Ma deep-seated folding, dynamothermal metamorphism and mafic- to ultramafic (alkalic) igneous intrusive activity (dated in the range of 470 to 430 Ma) across suture zone (Cameron's Line-St. Nicholas thrust zones). Underthrusting of shallow-water western carbonates of Sauk Sequence below supracrustal deep-water eastern Taconic strata and imbrication of former Sauk-Tippecanoe margin. Long-distance transport of strata over strata has been demonstrated; less certain locally is proof of basement thrust over strata and of basement shifted over basement. In Newfoundland, a full ophiolite sequence, 10 km thick, has been thrust over shelf-type sedimentary strata]. In NYC and throughout New England, dismembered ophiolite is common (Merguerian 1979; Merguerian and Moss 2005, 2007).

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER II - CAMBRO-ORDOVICIAN CONTINENTAL-MARGIN COVER (Products of Passive Continental Margin I - Iapetus). Subdivided into two sub layers, IIB and IIA. Layer IIA is further subdivided into western- and eastern facies.

LAYER IIB - TIPPECANOE SEQUENCE - Middle Ordovician flysch with basal limestone (Balmville, Jacksonburg limestones).

Not metamorphosed / Metamorphosed
Martinsburg Fm. / Walloomsac Schist
Normanskill Fm. / Annsville Phyllite

Subaerial exposure; karst features form on Sauk (Layer IIA[W]) platform.

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER IIA [W] - SAUK SEQUENCE	**LAYER IIA [E] - TACONIC SEQUENCE**
Western shallow-water platform	**Eastern deep-water zone**
(L. Cambrian - M. Ordovician)	(L. Cambrian-M. Ordovician)
Copake Limestone (Stockbridge,	
Rochdale Limestone (Inwood Marble)	
Halcyon Lake Fm.	
Briarcliff Dolostone	(Ꞓ-Oh) Hartland Fm.
Pine Plains Fm.	(Ꞓ-Om) Manhattan Fm.
Stissing Dolostone	
Poughquag Quartzite	
Lowerre Quartzite	
Ned Mtn Fm.	

[**Pre-Iapetus Rifting Event**; extensional tectonics, volcanism, rift-facies sedimentation, and plutonic igneous activity precedes development of Iapetus ocean basin. Extensional interval yields protoliths of Pound Ridge Gneiss, Yonkers granitoid gneisses, and the Ned Mountain Formation (Brock, 1989, 1993). In New Jersey, metamorphosed rift facies rocks are mapped as the Chestnut Hill Formation of A. A. Drake, Jr. (1984)].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER I - PROTEROZOIC BASEMENT ROCKS

Many individual lithologic units including Proterozoic Z and Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks identified, but only a few attempts have been made to decipher the stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure. Followed by a period of uplift and erosion.

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

[**Grenville orogeny**; deformation, metamorphism, and plutonism dated about 1,100 Ma. After the orogeny, an extensive period of uplift and erosion begins. Grenville-aged (Proterozoic Y) basement rocks include the Fordham Gneiss of Westchester County, the Bronx, and the subsurface of western Long Island (Queens and Brooklyn Sections, NYC Water Tunnel #3), the Hudson Highland-Reading Prong terrane, the Franklin Marble Belt and associated rocks, and the New Milford, Housatonic, Berkshire, and Green Mountain Massifs.]

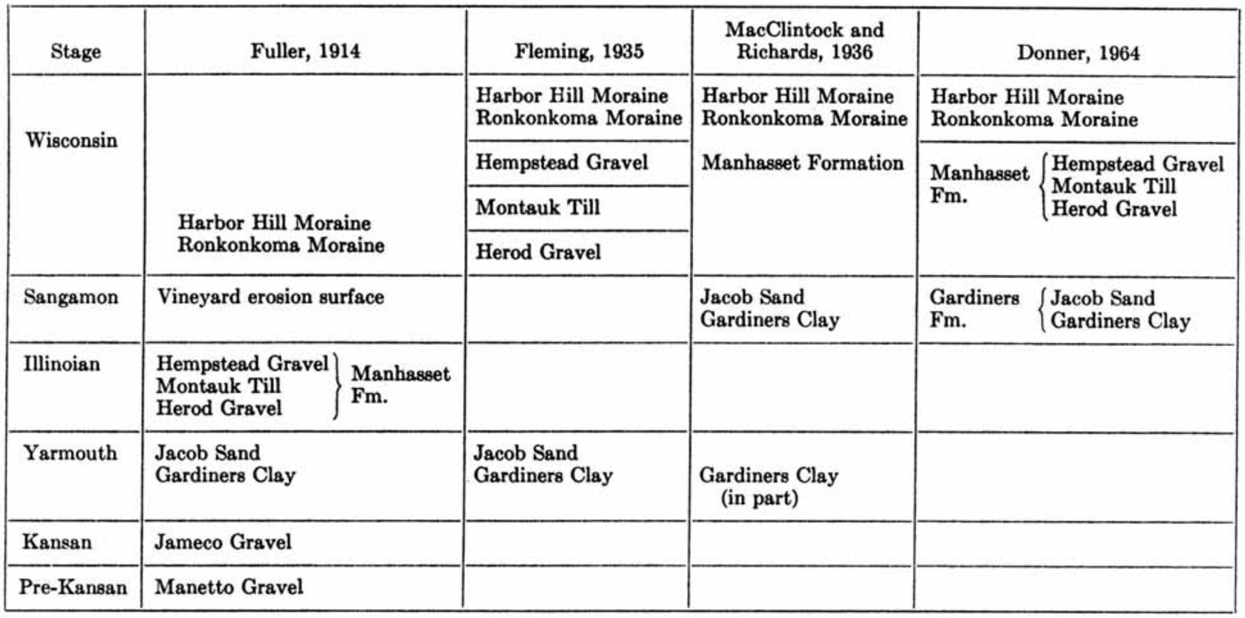
~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

In New Jersey and Pennsylvania rocks older than the Franklin Marble Belt and associated rocks include the Losee Metamorphic Suite. Unconformably beneath the Losee, in Pennsylvania, Proterozoic X rocks of the Hexenkopf Complex crop out.

Table 03 – Proposed new classification of the Pleistocene deposits of New York City and vicinity. (Sanders and Merguerian, 1998, Table 2).

Age	**Till No.**	**Ice-flow Direction**	**Description; remarks**
Late Wisconsinan ("Woodfordian"?)	**I**	**NNE to SSW**	**Gray-brown till in Westchester Co., Staten Is., Brooklyn, & Queens (but not present on rest of Long Island); Hamden Till in CT with terminal moraine lying along the S coast of CT; gray lake sediments at Croton Point Park, Westchester Co.**
Mid-Wisconsinan (?)			**Paleosol on Till II, SW Staten Island.**
Early Wisconsinan(?)	**II**	**NW to SE**	**Harbor Hill Terminal Moraine and associated outwash (Bellmore Fm. in Jones Beach subsurface); Lake Chamberlain Till in southern CT.**
Sangamonian(?)			**Wantagh Fm. (in Jones Beach subsurface).**
	IIIA	**NW to SE**	**Ronkonkoma Terminal Moraine and associated outwash (Merrick Fm. in Jones Beach subsurface).**
Illinoian(?)	**IIIB** **IIIC**		**Manhasset Fm. of Fuller (with middle Montauk Till Member; in lower member, coarse delta foresets (including debris flows) deposited in Proglacial Lake Long Island dammed in on S by pre-Ronkonkoma terminal moraine.**
Yarmouthian			**Jacob Sand, Gardiners Clay.**
Kansan(?)	**IV**	**NNE to SSW**	**Gray till with decayed stones at Teller's Point (Croton Point Park, Westchester Co.); gray till with green metavolcanic stones, Target Rock, LI.**
Aftonian(?)			**No deposits; deep chemical decay of Till V.**
Nebraskan (?)	**V**	**NW to SE**	**Reddish-brown decayed-stone till and -outwash at AKR Co., Staten Island, and at Garvies Point, Long Island; Jameco Gravel fills subsurface valley in SW Queens.**
			Pre-glacial (?) Mannetto Gravel fills subsurface valleys.

Table 04 – Formations of Pleistocene age in Long Island showing original arrangement by Fuller (1914) and changes proposed by three subsequent workers.
From Muller (1965).



Stage	Fuller, 1914	Fleming, 1935	MacClintock and Richards, 1936	Donner, 1964
Wisconsin	Harbor Hill Moraine Ronkonkoma Moraine	Harbor Hill Moraine Ronkonkoma Moraine	Harbor Hill Moraine Ronkonkoma Moraine	Harbor Hill Moraine Ronkonkoma Moraine
		Hempstead Gravel	Manhasset Formation	Manhasset Fm. {Hempstead Gravel Montauk Till Herod Gravel}
		Montauk Till		
		Herod Gravel		
Sangamon	Vineyard erosion surface		Jacob Sand Gardiners Clay	Gardiners Fm. {Jacob Sand Gardiners Clay}
Illinoian	Hempstead Gravel Montauk Till Herod Gravel} Manhasset Fm.			
Yarmouth	Jacob Sand Gardiners Clay	Jacob Sand Gardiners Clay	Gardiners Clay (in part)	
Kansan	Jameco Gravel			
Pre-Kansan	Manetto Gravel			

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