GLACIAL GEOLOGY OF CENTRAL LONG ISLAND.[1]

This paper was submitted for publication in September, 1934, on the eve of the author's departure for the Antarctic with the British Graham Land Expedition. Accordingly it has been edited, and considerably reduced in length, without the author's having had an opportunity to revise it himself.—The Editors.

W. L. S. FLEMING.

INTRODUCTION.

In 1914 the U. S. Geological Survey published a Professional Paper by M. L. Fuller on the Geology of Long Island[2] in which the results of several years' work were embodied. Since that date no important contribution to Long Island geology has been made, and Fuller's thorough and comprehensive work has been widely accepted. Its more significant conclusions may be summarized thus:

Pre-Pleistocene Deposits.—The basement rocks consist of complex metamorphics. Their buried surface slopes southeast at an average rate of 100 feet per mile from sea level near Astoria. Cretaceous deposits rest unconformably on this metamorphic platform. From a number of well records Fuller found that the buried Cretaceous topography (Fig. 2) consists of a cuesta-like ridge extending a little north of east from a point about one mile southwest of Bayside, through the northern end of the Mannetto Hills,[3] where it reaches an elevation of over 250 feet, and thence east. The Cretaceous was not definitely recognized in the eastern half of the island.

With the possible exception of thin marls and "fluffy sands" exposed in one or two localities, Fuller found no deposits on the island definitely referable to the Tertiary.

[1] This paper is based on an essay which was submitted to the Faculty of the Graduate School of Yale University in candidacy for the Degree of Master of Science. The work was undertaken during the autumn, winter and spring of 1930-31 under the supervision of Professor R. F. Flint while the writer was the holder of a Commonwealth Fund fellowship. The writer wishes to express his indebtedness and gratitude for the generous help both of Professor Flint and the Directors of the Commonwealth Fund.

[2] Fuller, M. L.: The geology of Long Island. U. S. Geol. Survey, Prof. Paper 82, 1914. The reader is referred to this work for an excellent account of the previous literature.

[3] Excellent detailed descriptions of the hills, ridges, and plains mentioned here by name only, may be found in Fuller, *op. cit.*, to which the reader is referred.

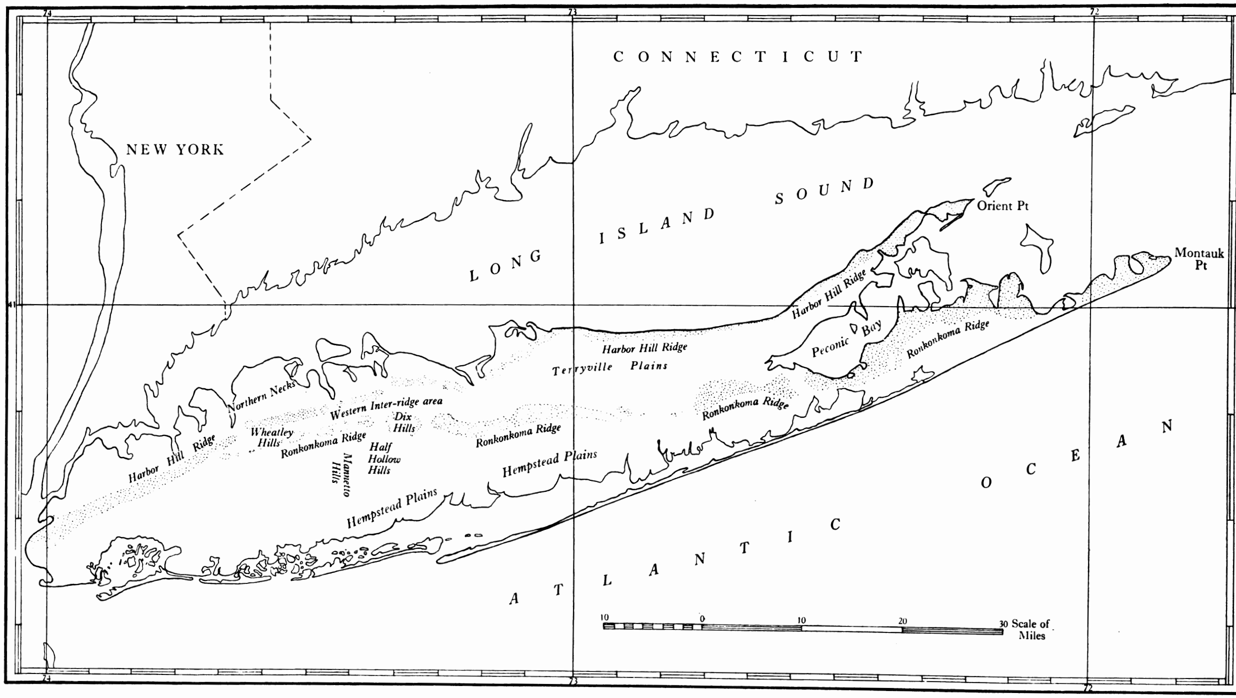

Fig. 1. Outline map of Long Island, showing the main topographic units.

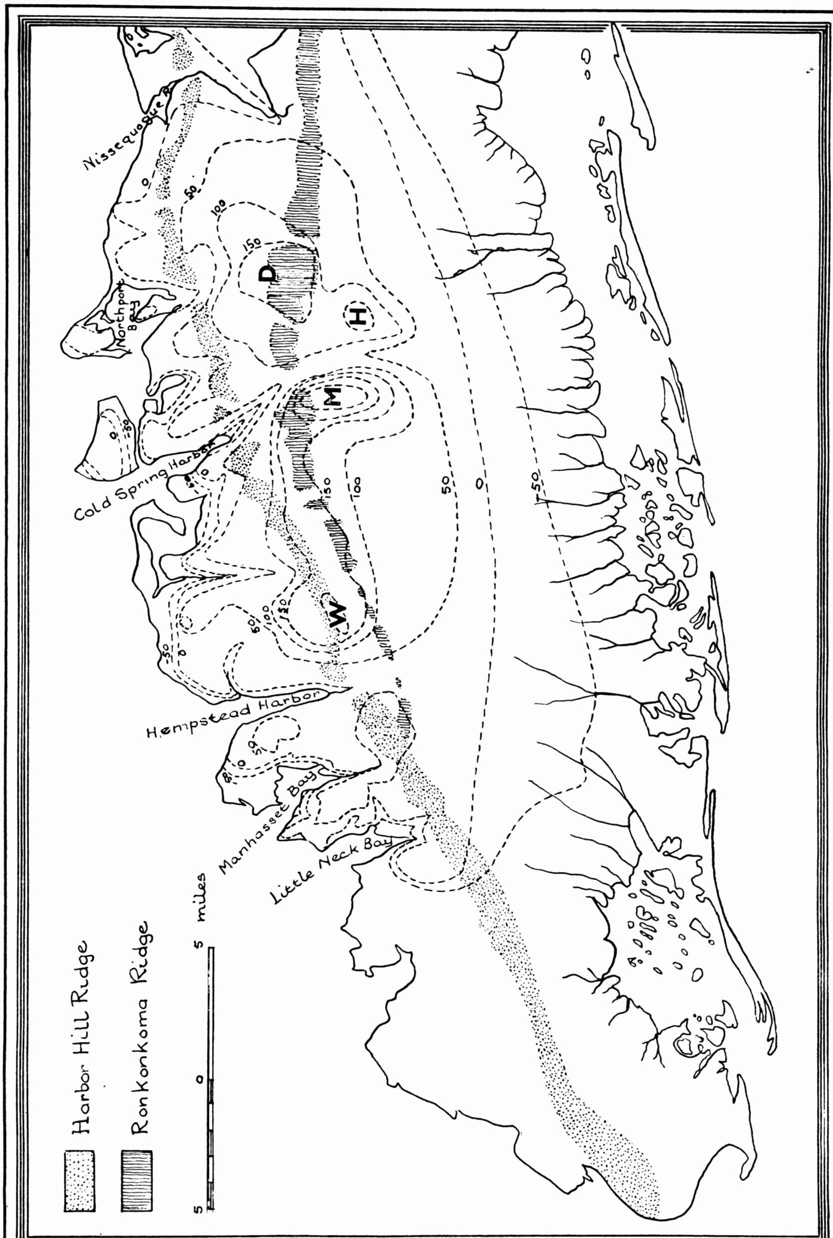

Fig. 2. Map showing the Cretaceous surface on western Long Island, after Fuller. The Harbor Hill and Ronkonkoma ridges are shown, to indicate that they are independent of the buried Cretaceous surface. On the other hand, the Wheatley Hills—W, the Mannetto Hills—M, the Half Hollow Hills—H, and the Dix Hills—D, correspond in location with regions of Cretaceous relief.

Pleistocene Deposits.—In the Pleistocene sands, gravels and clays of Long Island, Fuller found the equivalents of four of the glacial stages with intervening interglacial stages, known in the Mississippi Valley region. He regarded the Harbor Hill and Ronkonkoma ridges (Fig. 1), which extend practically the entire length of the island and form a striking feature of its topography, as end moraines, formed during the waning period of the last or Wisconsin stage, at a time when forward motion of the ice was counterbalanced by melting. Apart from these ridges only a thin covering of till or outwash was attributed to the last glaciation. The other Pleistocene gravels, sands, and tills were assigned to earlier stages, chiefly the Illinoian.

1. The Mannetto gravel belongs to the first of the glacial stages recognized by Fuller. It consists of quartz pebbles (many of them stained) with decayed pebbles and boulders, probably of glacial origin. He found these on the Mannetto, Wheatley, Half Hollow and Dix Hills up to nearly 300 feet above tide. He assumed that a continuous mantle of Mannetto gravel was laid down and in order to account for its removal from all but a few hill localities, an interglacial stage of erosion was inferred.

2. The gravel attributed to the second glacial stage was named Jameco gravel, and was distinguished from the Mannetto by a difference in lithology. The early-glacial dating of the Jameco deposits was based on the stratigraphic position of deposits outside the limits of Long Island, with which they were correlated. Glacial gravel attributed to the Jameco was found in a broad valley underlying Jamaica Bay, and the region to the north. Since these were found 600 feet lower than Mannetto gravel recorded in other parts of the island, Fuller supposed that the Mannetto was eroded during an interglacial stage prior to the deposition of the Jameco. In neither of the glaciations to which the Mannetto and Jameco gravel deposits were assigned, was the ice thought to have overridden Long Island itself.

3. Both Mannetto gravel and Jameco gravel were found underlying the Gardiners clay and Jacob sand. The two latter formations contain fossils indicating moderate climate and are overlain by glacial sand and gravel. They were, therefore, believed to indicate accumulation in an interglacial stage. Since the beds attain a thickness of 150 feet near Brooklyn, this stage must have been of considerable duration.

4. With the exception of the deposits constituting Harbor Hill and Ronkonkoma ridges, and a thin veneer of outwash and till throughout the rest of the island, all the Pleistocene post-Gardiners deposits (reaching a maximum thickness of 210 feet) were attributed to the Illinoian stage and were grouped together as the Manhasset formation. The deposits constituting this formation were found to form the great bulk of the beds above sea level on Long Island, and were divided by Fuller into three units: (a) The Herod gravel member, a series of current-bedded sands and gravels, taken to represent "water laid deposits marking the nearer approach of a great ice sheet, the first effect of which was the influx of sandy material of the Jacob formation.[4] (b) The overlying Montauk till member, interpreted as the ground moraine of the same sheet. (c) The upper or Hempstead gravel member, regarded as outwash deposited from the Montauk ice in the course of its retreat. During the deposition of the Hempstead gravel, the ice in the western part of the island was believed to have lain along the scarp separating that part of the northern necks at an elevation of about 100 feet which Fuller called the "Lower Manhasset Plateau" from the less regular terrace-like surface at higher elevations—called "the Upper Manhasset Plateau." In this way Fuller accounted for the fact that he could not recognize the Hempstead gravel member in the "Lower Manhasset Plateau." The Hempstead and Herod gravel members, being lithologically similar, could be differentiated only where the stratigraphic position of the beds with respect to the Montauk till was clear.

5. Fuller believed that by the close of deposition of the Manhasset, a great sheet of outwash had been built up to an elevation of more than 200 feet. After this he postulated an interval of strong subaerial erosion during which these deposits were trenched and extensive drainage systems were developed. "The erosion of this stage was at least fifty times and probably 100 times greater than that which has been effected in post-Wisconsin time."[5] Fuller believed that the bays and harbors of the north shore were excavated during this period, and that their peculiar shape was due to the erosional processes involved in spring sapping. To this interglacial erosion the name "Vineyard erosion interval" was assigned.

6. To the latest or Wisconsin glaciation Fuller assigned: (a)

[4] Fuller, M. L.: *Op. cit.*, p. 132.
[5] Fuller, M. L.: *Op. cit.*, p. 208.

very little erosion by the ice. (b) The formation of the Harbor Hill and Ronkonkoma ridges as end moraines resting on the subaerially eroded surface of the Manhasset formation. (c) The deposition of outwash south of these so-called moraines. (d) Elsewhere a thin superficial mantle of till, best exposed on the surface of the northern necks. (e) Following the formation of the Harbor Hill "moraine" only a small bulk of deposits was recognized.

It is to be noted that almost all the glacial deposits were regarded by Fuller as accumulations laid down in association with actively moving ice—either in front of the ice during its advance or retreat, or beneath it when it overrode the area.

The writer's conclusions differ from those of Fuller chiefly in that all the post-Gardiners deposits (which include the great bulk of the exposed glacial deposits in Long Island) are held to be of probable Wisconsin date, and some of the deposits are believed to have been formed in a manner differing from that envisaged by Fuller. A discussion of Fuller's interpretation of the Pleistocene deposits is outlined below, and a tentative hypothesis for the reconstruction of Pleistocene events is put forward, not as a definitive contribution, but in the hope that it may stimulate further work and interest in elucidating the complex history of this region.

COMMENTS ON FULLER'S INTERPRETATION.

Date of post-Gardiners Pleistocene Deposits.—Fuller relegated the "Manhasset formation" to a glacial stage earlier than the Wisconsin till and "moraine" for two reasons: (1) He found till overlying thick "Manhasset" stratified material north of the Harbor Hill ridge, and in some places he found the top of the "Manhasset" disturbed beneath this till. Also in some sections, as at Montauk Point and on the west side of Hempstead Harbor, he found deposits of till separated by stratified sand and gravel. This evidence suggested two distinct ice advances. (2) An interglacial interval of erosion between the "Manhasset" and the Wisconsin seemed necessary to explain the formation of the bays, harbors, and valleys of the northern necks region. Fuller also found certain deposits which he attributed to this interglacial interval.

The writer, however, believes the post-Gardiners Pleistocene deposits are referable to *one glacial stage* only, for these reasons:

1. Absence of weathering following the deposition of the "Manhasset" and prior to the deposition of Fuller's Wisconsin. In all those excavations which the writer has seen there is no post-Gardiners material which shows signs of weathering through a time longer than post-Wisconsin, nor is there any reference in the literature to such material. If the "Manhasset" had been subjected to much erosion before the later ice advance, a great part of the relatively deeply weathered loamy layer on the Manhasset surface would have been removed by the succeeding ice sheet. Remnants of the weathered material should, however, be preserved in depressions protected from ice scour, as in valleys transverse to the direction of ice flow. Fuller, finding that the post-Manhasset deposits are thin and only locally rest with unconformity on the "Manhasset," assumed that the glaciation responsible for their deposition was weak. It is thus all the more difficult to understand why, if the Vineyard erosion took place, no trace of the weathered pre-Wisconsin "Manhasset" surface is to be found.

2. Lack of topographic evidence for Vineyard erosion interval. The Vineyard erosion was regarded by Fuller as intense. In that part of the island north of the Harbor Hill ridge he thought it was followed by the deposition of a veneer of till rarely more than five feet thick. Here, therefore, the topography should be erosional, ineffectively disguised by later deposition and only slightly modified by the weak Wisconsin ice.

Field study has convinced the writer that here, as in the other parts of Long Island, the surface form is dominantly not erosional but constructional. With the possible exception of the Nissequogue drainage basin (the genesis of which is considered separately) the valleys of the north shore do not have the blunt heads demanded by Fuller's hypothesis that they were formed by spring-sapping during the "Vineyard erosion." The most conspicuous depressions of the northern necks trend north-south. Between these are minor depressions, varying in direction and showing in almost every case a 'hanging' discordant relationship with respect to the major ones. Their peculiar form is adequately accounted for by depositional causes to be described below.

3. Lack of lithologic evidence for Vineyard erosion interval. There is no lithologic evidence inimical to the hypothesis that all the post-Gardiners deposits belong to one glacial stage. The difficulty that Fuller found in distinguishing between the

lithology of his "Manhasset" and "Wisconsin" formations attests to the similarity of these formations.

4. Lack of deposits which can be attributed with certainty to the Vineyard Interglacial stage. Fuller found, at a depth of twenty to twenty-five feet beneath recent beaches, deposits of shells, wood peat, etc., which he tentatively assigned to the "Vineyard interglacial stage." There is no evidence, however, for correlating them with an interglacial rather than a postglacial stage. It seems at least equally likely that these deposits are to be correlated with those found at a similar depth along the Connecticut shoreline and that they owe their present position to postglacial submergence or to the compaction of marsh deposits under the weight of recent beach deposition.[6]

The record of a post-Gardiners interglacial stage should be found in erosion, weathering, or non-glacial deposition prior to the accumulation of the latest glacial deposits. Since none of these interglacial phenomena exists, it seems reasonable to conclude that all the post-Gardiners glacial deposits (the bulk of the material forming the island) should be assigned to one glacial stage. The relatively small amount of erosion and weathering they have suffered is evidence of their Wisconsin date.

Origin of the Harbor Hill and Ronkonkoma Ridges.—Fuller, like the previous geologists who had worked on Long Island, regarded the Harbor Hill and Ronkonkoma ridges as end moraines, formed by the Wisconsin ice sheet, and resting on the subaerially eroded surface of the "Manhasset formation" (Fig. 3 b). The writer, although regarding these ridges as ice-marginal features, does not regard them as typical end moraines for the following reasons:

1. Although the topography of the Harbor Hill and Ronkonkoma ridges resembles that of moraines, both these ridges are formed almost wholly of stratified material, except to the west of Lake Success. The only sections exposing the core of the Harbor Hill ridge are situated east of Woodville Landing. Here the ridge is cliffed along the shore, and freshly exposed excavations visible after storms, show that the cliffs are dominantly composed of stratified sand and gravel. Even where the cliffs have not been subjected to recent battering by a storm, till can generally be recognized by its clayey matrix, colour, greater resistance to 'creep,' and the way it impedes the

[6] Sharp, H. S.: Physical history of the Connecticut shoreline. Conn. Geol. and Nat. History Survey. Bull. 46, 1929.

downward percolation of subsurface water. On the basis of such criteria, it may be confidently asserted that till forms a relatively small part of the cliff sections. The greatest thickness of till that Fuller recorded in these sections is 80 feet at Roanoke Landing. A section just east of this locality was exposed in the winter of 1930, and here till reaches a maximum thickness of only fifteen feet. In any case this till was ascribed by Fuller to the Illinoian and not to the Wisconsin stage.

The well records in the Harbor Hill ridge published by Veatch[7] revealed stratified sand and gravel with a thickness greater than the relief of the ridge.

Unfortunately, the core of the Ronkonkoma ridge is nowhere well exposed, and is penetrated by few wells. But except at Montauk Point, the existing sections (e.g. in the cliffs between Culloden Point and Quince Tree Landing, and in the Shinnecock Hills) exhibit chiefly stratified drift.

2. Much of the surface of the Harbor Hill and Ronkonkoma ridges is strewn with large boulders, most of which lie directly on stratified sand and gravel free from boulders. This widespread occurrence of a great quantity of boulders lying on the ridges and restricted to the surface, is difficult to explain if each ridge is regarded as an end moraine formed during a single ice advance. The writer regards the boulders as the record of a readvance of the ice, after the sand and gravel of the ridges had been deposited.

Tentative Reconstruction of the Pleistocene History of Central Long Island.[8]

Influence of the Cretaceous Surface.

Two facts concerning the form of the Cretaceous topography already mentioned are of significance as regards its influence on the deposition of the Pleistocene: (1) The location of the Harbor Hill and Ronkonkoma ridges bears no relation to the position of the Cretaceous cuesta summit (Fig. 2). (2) The Wheatley, Mannetto, Half Hollow and Dix Hills, on the other hand, are situated in regions where the Cretaceous surface is high (Fig. 2). These hills so clearly reflect and exaggerate the broader features of the buried Cretaceous topography that their formation was evidently influenced by it.

[7] Veatch, A. C.: Outline of the geology of Long Island. U. S. Geol. Survey, Prof. Paper 44, 1906.

[8] A comparison between Fuller's interpretation of the relationship of the Pleistocene deposits on Long Island to the geomorphic units, and that of the writer, is illustrated in Fig. 3.

Pre-Wisconsin Glacial Deposits.

The writer has not seen any deposits which he can ascribe with certainty to the Mannetto gravel, Jameco gravel, Gardiners clay or Jacob sand and is thus not in a position critically to discuss the interpretations which Fuller ascribed to them. These four units are of small bulk and of no apparent topographic significance. If extensive early Pleistocene deposits were laid down over Long Island, they were stripped off, and on the advent of the post-Gardiners ice, the topography of the island can have differed little from that of the buried Cretaceous surface.

Wisconsin Deposits.

As there is no satisfactory evidence for a post-Gardiners interglacial stage, and as all the post-Gardiners deposits are equally fresh and little-weathered, the latter are held to be Wisconsin. They include two distinct tills, both of which are found in several exposures (e.g. sand pits on west side of Hempstead harbor) separated and underlain by thick stratified drift. On this stratigraphic evidence and on geomorphic grounds, the Wisconsin stage is divided into three ice advances —the Herod, during the waning stage of which the lowest stratified sand was laid down, the Montauk, represented by the lower till (which overlies the Herod sand and gravel) and succeeding stratified deposits, and the Latest advance, comprising the upper till and the overlying stratified drift and boulders. In each of these the ice overrode at least the northern part of Long Island, and between the successive advances all the ice was dissipated, except in the deep bays and harbors of the north shore and in the Nissequogue drainage basin where probably masses of dead ice lingered throughout the three Wisconsin oscillations.

Herod Advance.—The Herod sand and gravel, underlying the Montauk till, are best exposed in (1) the "core" of the Harbor Hill ridge visible in the cliffs east of Woodville Landing, and (2) the northern necks.

Harbor Hill Ridge.—Since the lower or Montauk till is nearly everywhere found near the summits of the cliffs exposed on the north shore east of Woodville Landing, and since stratified sand and gravel nearly everywhere compose the base of the cliffs, it seems probable that the greater part of the cliffs

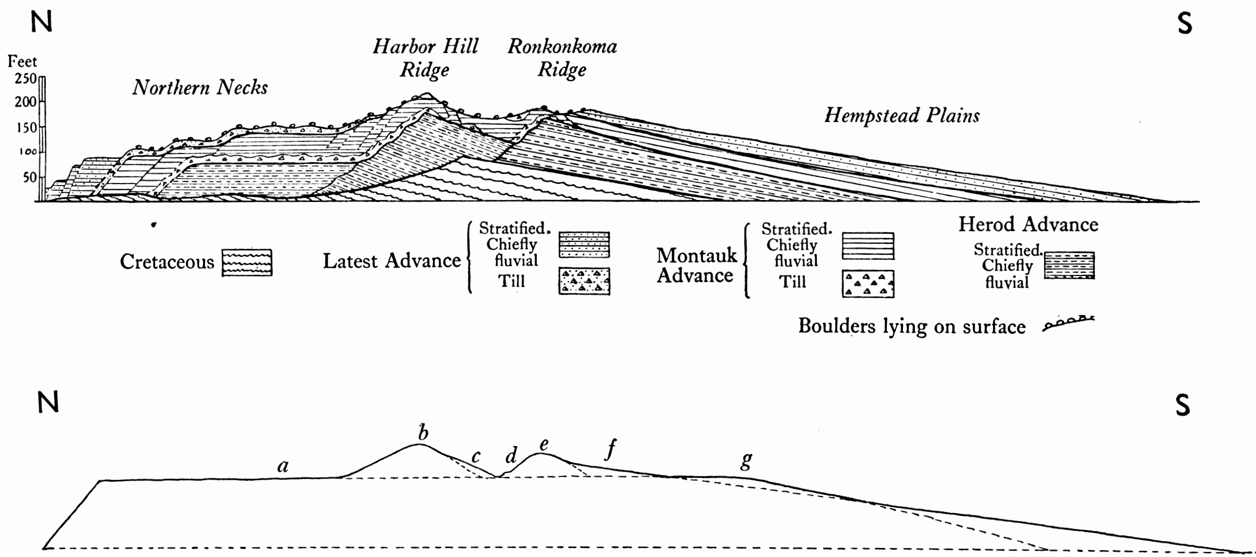

Fig. 3 a. Top—North-south section through Long Island, showing diagrammatically the relations of the Pleistocene deposits as inferred by the writer. The subsurface relations are shown in far greater detail than is warranted by existing information, and are included so as to make clear in a diagrammatic way the difference between the writer's view and that of Fuller.

b. Bottom—North-south section through Long Island after Fuller (*op. cit.*, p. 22, Fig. 4).—a, Manhasset Plateau; b, Harbor Hill moraine; c, outwash from ice along Harbor Hill moraine; d, Manhasset surface; e, Ronkonkoma moraine; f, outwash from ice along Ronkonkoma moraine; g, Manhasset surface projecting above outwash.

(Length of sections about 15 miles.)

consists of the Herod formation, in some places more than 90 feet thick. As the Herod deposits constitute the foundation of the ridge, and form the greater part of it, it is probable that this part of the ridge was built during the Herod advance. As the Harbor Hill ridge is a geomorphic unit, it is thought probable that the whole of the ridge was initiated at this time. This belief cannot be confirmed at present because of the lack of suitable exposures in the western part of the ridge.

A satisfactory interpretation of the Herod formation in the Harbor Hill ridge should, therefore, satisfy the following conditions: (1) It initiated the ridge. (2) It was, therefore, disposed in a series of arcs, shown by the arcuate plan of the present ridge. (3) It was built of current-bedded sand and gravel, probably of fluvial origin. These conditions are fulfilled if we postulate that the Herod sand and gravel were laid down as a row of outwash fans at the margin of an active ice sheet of pre-Montauk Wisconsin date (Fig. 3 a). The conditions requisite for the production of these fans were probably much the same as those governing the formation of the Salpausselkä in Finland, except that the latter were deposited mainly as deltas.[9]

As the geomorphic characteristics of the Ronkonkoma ridge are analogous to those of the Harbor Hill ridge, and as from the meagre evidence available its composition appears to be similar, the initiation of the Ronkonkoma ridge is also tentatively attributed to the deposition of fans at the margin of the active Herod ice sheet, at a somewhat earlier time.

Northern Necks.—The Herod deposits are well exposed in the great sand and gravel pits on the west side of Hempstead harbor, where they consist of 80 feet of current-bedded sand and gravel extending from twenty feet above sea level up to the base of the Montauk till. Fuller assumed that the Herod formation was accumulated while the ice front was stationary and located somewhere off the north shore of the island. A series of outwash deposits would thus be built up with an essentially southward slope. This mode of deposition fails to explain why there is no trace of a southward slope initiated during the Montauk advance in the northern necks region which actually slopes north. Nor will Fuller's theory account for the non-deposition of Herod gravel in the bays and harbors

[9] The formation of the Herod fans was also probably analogous to the fans observed in process of construction at the margins of the Malaspina glacier. See: Tarr, R. S., Some phenomena of the glacier margins in the Yakutat Bay region, Alaska. Zeitschr. für Gletscherkunde, Vol. 3, p. 90, 1908.

of the north shore. These great depressions could not have been excavated by stream erosion as Fuller maintained, because of their peculiar form, nor were they formed by glacial excavation, for, apart from the improbability of differential ice thrust being able to produce such depressions even under the most favorable circumstances, the lack of folding or dragging in the deposits over which they moved indicates that the later glacial advances were weak.

After building the Harbor Hill fans, the Herod ice probably wasted back irregularly, persisting longest in depressions in the underlying floor. This latter hypothesis is the more probable, as it affords a reason, in place of chance coincidence, for the location of the bays and harbors at the sites of obsequent valleys in the Cretaceous cuesta (Fig. 2).

Montauk Advance.—Before the Herod deposits had been subjected to any discernible erosion, they were overriden by the ice and veneered with Montauk till. Fuller[10] gives a detailed account of the Montauk till. Its characteristic cementation and lamination seem to provide a reliable means of distinguishing it from the Latest till. The Montauk till varies considerably in thickness, rarely exceeding three feet where exposed in the pits on the west side of Hempstead harbor, but reaching 50 feet in the cliff sections southwest of Montauk Point. Its average thickness is about ten feet. Where it rests on the Herod deposits, there is rarely either strong unconformity or intense contortion of the underlying beds. On Montauk Point, however, this till rests with marked unconformity on greatly folded clay, correlated with the Gardiners clay. In the pits on the west side of Hempstead harbor, the Herod deposits are overlain by a boulder bed rarely more than three or four feet in thickness. The thinness of this bed, its well developed lamination suggestive of incipient stratification, its poor cementation, and the lack of folding or disturbance in the underlying sands led Woodworth,[11] Crosby[12] and Veatch[13] to contend that this bed was deposited by icebergs. It would be difficult, however, to attribute to such an origin the deposition of a layer only slightly variable in thickness and persistent in its character and relations over a wide area. Furthermore, in the south side of the Goodwin and Gallagher pit, half a mile south

[10] Fuller, M. L.: *Op. cit.*, pp. 132-147.
[11] Woodworth, J. B.: Pleistocene geology of portions of Nassau County and Borough of Queens. N. Y. State Mus. Bull. 48, pp. 627-628, 1901.
[12] Crosby, W. O.: Outline of the geology of Long Island. N. Y. Acad. Sci., Annals, Vol. 18, p. 428, 1908.
[13] Veatch, A. C.: *Op. cit.*, p. 41.

of Bar Beach, the boulder bed passes laterally into a till of Montauk character. This completely disposes of the iceberg hypothesis. The phenomena noted can be accounted for only if we assume that the condition of the ice in the area over which the boulder bed occurs was such that the material was washed by water during its deposition, thus differing from the till laid down contemporaneously in other parts of the island.

The Montauk till is stratigraphically but not topographically important. Presumably the Montauk advance caused some smoothing of the previous topography, but the till is rarely of sufficient thickness greatly to affect the relief.

Extent of the Montauk Advance.—The small rounded hummocks of Ronkonkoma ridge are composed of stratified drift, capped by boulders. If we assume that the hummocks were formed during the Latest advance, no satisfactory explanation for their subdued character is apparent, nor is it clear why the boulders should be restricted to the surface. There seem to be only two possible ways in which these boulders could have been laid down upon fresh stratified sand and gravel. Either they must have been deposited from icebergs, or they represent the material laid down directly by ice during a readvance. If they were rafted by bergs, then their occurrence at varying elevations (including some of the highest parts of the island) would necessitate a body of water that completely submerged the island. No independent evidence of such submergence has been found. On the other hand, readvance of the ice sheet not only explains the boulders and the rounded forms of the ridges and hollows of the Ronkonkoma ridge, but is supported by definite evidence elsewhere. For this reason the stratified deposits on which these boulders are strewn are assigned to a time immediately antedating the Latest advance. The southern slopes of the Ronkonkoma ridge are not fan slopes, for there is an abrupt change of slope at the south base of the ridge. Nor does the ridge consist of morainic dump, much less of push-moraine. The deposits are stratified, and it seems clear that their topography before it was subdued by the Latest ice advance, consisted of terraces and knolls bounded by irregular slopes with intervening bluffs and sags. Evidently they were built as constructional forms banked against and upon stagnant or nearly stagnant ice. As the ice wasted, the sides of each terrace or ridge were left in the form of casts of the ice margin, or ice-contact slopes such as characterize the sides of deep kettles.

That the Montauk ice extended beyond the southern margin of the ridge is confirmed by the fact that on Montauk Point the clay on which the Montauk till rests has been contorted. Judging from the vigor of the Montauk ice at this point, it is probable that the Montauk ice extended some distance further south. Despite the fact that this ice was charged with débris, no Montauk outwash fan or morainic deposit is visible anywhere in the Hempstead plains. This may indicate that the physical conditions during the greatest deployment of the Montauk ice were inimical to the deposition of such terminal deposits; the simpler explanation is to suppose that the Montauk ice extended southward into the sea.

Hempstead Gravel.—The stratified deposits laid down during the disappearance of the Montauk ice constitute the Hempstead gravel, lithologically akin to the Herod deposits. It has been stated that the Ronkonkoma ridge owes the essential elements of its topographic expression (other than its initiation as a ridge) to the Hempstead deposition in contact with Montauk ice, and that its features have merely suffered minor modifications during the Latest advance. The kame-like hummocks of the Ronkonkoma ridge consist of what really amounts to a complex series of crevasse fillings of Hempstead date.

As the topography of the Harbor Hill ridge is analogous to that of the Ronkonkoma ridge, the outer shell of the former ridge is, therefore, believed also to consist of Hempstead deposits accumulated in ice-bound waterways during the wastage of the Montauk ice. Nowhere, however, is there more striking evidence for the deposition of the Hempstead gravel in contact with ice than in the region of the northern necks. Whilst, in those parts of this region that lie at altitudes below 85 or 90 feet, the topography consists of clean-cut terraces whose surfaces are free from till or boulders, above this altitude the surface is complicated by gentle but irregular undulations, and is found either to be composed of till or to be strewn with boulders. The sections exposed on the west side of Hempstead harbor and on the coast north of Glen Cove Landing clearly indicate that this till belongs to a post-Montauk ice advance and thus the sand and gravel which underlie it are of Hempstead date and rest on the Montauk till. The undulations and smoothed slopes of the higher parts of the northern necks are thus due to erosion and deposition by the Latest ice sheet. If we ignore these undulations, it becomes apparent that the topography of the overridden part of the northern necks consists of high terraces separated by irregular slopes. The flattened bluffs and smoothed reëntrants of the slopes which mark the junction between the terrace masses at various levels are interpreted as ice-contact slopes, which have been modified by the Latest ice advance.

This terrace complex is dissected by deep depressions which include the larger bays and harbors of the north shore. As a general rule the west slopes of these depressions and bays are steeper than the east, and whereas the west slope may lead up to some high level without intervening benches, some of the east sides are step-like (e.g. Hempstead harbor and the depression one and one-half miles northwest of Greenvale). For the reasons stated in the discussion of the Herod deposits, these depressions are interpreted as areas of non-deposition during the greater part of Hempstead time. Whilst sand and gravel were being accumulated on either side, these deep places were occupied by tongues of ice. The western borders of these ice masses were somewhat shaded from the rays of the afternoon sun, and the east, being more fully exposed, wasted more rapidly, permitting deposition in the places from which it had melted. This simple factor is believed to explain adequately the asymmetry of the cross profiles.

The cores of the Mannetto, Wheatley, Half Hollow and Dix hills are composed of Cretaceous sediments. With the exception of some flat-topped terraces on the south side of the Mannetto and Half Hollow hills, the topography of these hills consists of undulating smoothed terraces strewn with boulders. Like the higher parts of the northern necks, which they resemble in form, the writer believes that these modified terraces were built of Hempstead stratified drift, deposited by water and banked against decaying ice.

The western inter-ridge area and that part of the Terryville plains above an altitude of 85 feet is also ascribed to Hempstead deposition as the surface is undulating and strewn with boulders. In many places, however, a mantle of gravel and sand deposited by the Latest ice advance, with fresh kettles and unmodified ice-contact slopes, obscures the nature of the Montauk surface. No widely developed Hempstead terraces were recognized in these regions lying between the Harbor Hill and Ronkonkoma ridges.

The deposits of the Hempstead plains consist entirely of stratified drift. No till has been found in this region. Hence, it is impossible to determine what part of the great thickness of sand and gravel underlying these plains belongs to the Herod, to the Montauk, or to the Latest advances.

Latest Advance.—Deposits of the Latest ice advance were laid down on the Hempstead beds before the latter had suffered any noticeable erosion. Remnants of the Montauk ice were probably still left in the lowest parts of the island (e.g. bays and harbors of the north shore) when the ice once more readvanced over the island, modifying the earlier features in four respects:

(1) *Modification of the Montauk Surface.*—Although no profound erosion was effected, the readvance of the Wisconsin ice sheet modified the surface, subduing the Montauk ice-contact topography and scraping off the surface of the Hempstead gravel.

(2) *Deposition of Till.*—The Latest till is most extensively developed in the northern necks region, and in parts of the Harbor Hill and Ronkonkoma ridges. It was not found by the writer in any exposures of the Hempstead plains, the western inter-ridge area or Terryville plains, and even in a number of localities in the ridges it is not represented. In the northern necks region the relations of the till to the underlying beds are most clearly seen. The lack of deformation of the Hempstead gravel underlying the till is truly remarkable, and only in a few localities has the gravel immediately beneath the till been thrown into small folds.

(3) *Deposition of Boulders.*—Apart from the patchy occurrence of till referred to above, in almost all these sections of the island that lie at an altitude of over 85 feet, the Latest ice deposited only boulders. These erratics are invariably present where the overridden Montauk topography forms the present surface, and it is significant that the boulders are more numerous on the north-facing than on the south-facing slopes.

The deposits of the last advance are represented over the higher regions by little more than large boulders strewn upon the preëxisting surface, whilst at lower levels the Latest stage is represented by stratified glacial deposits. This fact remains unexplained if deposition is assumed to have taken place along the receding front of an active ice sheet. On the other hand if the margin of the Latest sheet was stagnant, then the drift deposited by it over any area would reflect the character of the débris within the ice overlying that area when the ice became stagnant: thus regional variation in character of the material may be accounted for. It is likely that the ice was constantly in motion over Connecticut throughout Herod and Montauk time, or at all events the ice over the mainland had not been depleted beyond the point at which only the highest parts of the mainland were uncovered. Whilst the Herod and Montauk deposits may have been derived from the abundant englacial material carried in the basal Wisconsin ice, the latest ice to invade Long Island may well have consisted of the overthrust upper layers of the Wisconsin ice sheet, and in it one would expect to find only a small amount of rock débris consisting principally of fragments quarried from the higher regions on the mainland. Until it overrode the crest of the Harbor Hill ridge, the glacier was confronted by an adverse slope. This fact, coupled with the relative thinness of the sheet (inferred from the small amount of deformation it produced), would offer the glacier little opportunity for gathering much local material as it advanced. The lowest layers, instead of moving over the ground and gathering up débris as they advanced, were impounded against it. This would also hold true for the Ronkonkoma ridge, and the Mannetto, Half Hollow, Dix and Wheatley hills. Only as it passed over the favorable slopes of the relatively narrow western inter-ridge area, Terryville plains, and Hempstead plains, could it gather up material which on melting yielded sand and gravel deposits such as are found in these areas. This hypothesis also accounts for the greater proportion of boulders on north-facing slopes, due to the impounding of layer upon layer of the boulder-laden ice against such adverse slopes.

(4) *Deposition of stratified sands and gravels, chiefly fluvial.* —Most of the highest summits of the island, such as Harbor Hill, Bald Hill, and High Hill are capped by stratified sands and gravels on the surface of which no boulders are found. Unless the latest sheet was not thick enough to surmount these crests, the material of which they are composed must be attributed to the Latest glaciation, but even if they are of Montauk date their stratification provides a problem. Fuller could solve it only by supposing that these summits were formed as "the results of deposition by waters issuing from the ice front at a considerable distance above the base."[14] According to this theory, as indeed Fuller realized, the deposits when first formed should have the form of a "semifan or semicone" with an ice-contact face on the proximal side, and yet he noticed that some of the observed hilltops in question are "rounded and have

[14] Fuller, M. L.: *Op. cit.*, p. 32.

fairly even slopes," and he offered no explanation for this anomaly. Further, Woodworth observed[15] that the stratification on the north side of the hilltop at Harbor Hill was "dipping nearly flat," and this is not in keeping with the fan bedding demanded by Fuller's hypothesis.

An alternative hypothesis for the deposition of the stratified materials which form these high tops is that they were water-laid at the junctions of crevasses in stagnant ice. The cause of the formation and infilling of these crevasses on the ridge crests before the ice had wasted down to the level of the pre-existing summits presents a difficulty. The solution may possibly lie in the production of strains, and resultant crevasses in a thin ice mass immediately above points (such as a ridge top) where the subglacial surface abruptly changes slope.

The southern ends of the Mannetto Hills and possibly also of the Half Hollow Hills below the 190-foot contour consists of flat-topped terraces, separated from one another and from the Hempstead Plains by ice-contact faces. No boulders dot the surfaces of these terraces and there is no other evidence that they were overridden. It is believed that the Latest ice advanced further south than these hills, and, therefore, that these "fresh terraces" were formed during the Latest advance. Their surface form indicates that they were built of material accumulated against ice.

Hempstead Plains.—South of the Ronkonkoma ridge the Hempstead Plains slope to the south with a gentle gradient averaging twenty feet per mile. The surface is even, though locally characterized by low undulations. Underlying these plains are current-bedded sand and gravel which do not show any systematic horizontal or vertical variation in coarseness of texture, though there is a greater proportion of gravel near the head of the plains. The form of these plains, sloping fan-like from apices at gaps in the Harbor Hill ridge clearly indicates that they are built of outwash deposited by streams deploying from the gaps. This whole region must have been essentially free of ice before the streams heading north of the Harbor Hill and Ronkonkoma ridges built their fans at the head of the plains.

The inter-ridge area west of the Nissequogue drainage basin as far as Cold Spring did not receive more than a veneer of deposits from the Latest advance. East of this depression, however, the plains are lower and the topography has a much

[15] Woodworth, J. B.: *Op. cit.*, pp. 640-641.

fresher aspect. Between Smithtown Branch and Wading River, although the Montauk topography may determine the main features of the plains, yet the paucity of boulders and the freshness of the ice-contact faces of many of the kettles and kettle-valleys which form so prominent a feature of this region, indicate that the Latest deposits at least form a veneer over the Montauk sediments. To the east of a line drawn from Wading River to Middle Island the greater part of the Terryville plains lie below the 85-foot contour, and throughout most of the region the surface forms have that freshness that indicates deposition from the Latest ice.

The distribution of the kettles diversifying these plains is interesting. South and southwest of Centerville there is a smooth plain, broken neither by kettles nor by channels. A little further west, near Baiting Hollow, there is a great number of kettles, most of which are oriented in a zone extending southeast. Similar kettle-belts extend across the plains to east and west and their orientation clearly indicates that they are kettle valleys tributary to the Peconic River, which flows in a kettle valley itself. The drainage pattern revealed in the trend of the kettle valleys is attributed to the Herod stage. As the Herod ice stood along the line of the Harbor Hill ridge, the streams flowed south until they encountered the adverse slope of the Ronkonkoma ridge which the same ice sheet had previously built. The waters which had built the Harbor Hill fans could then flow either east or west: the fact that they chose the former route is explained, if, as seems probable, the underlying Cretaceous ridge becomes lower toward the east. The kettle valleys of the Terryville plains are thus interpreted as Herod stream valleys modified during the dissipation of stagnant ice derived from the Montauk and Latest advances.

Few of the islands and necks between the two flukes have been studied by the writer. To judge by the topographic maps they seem to have more in common with the ridges than with the plains, and it is, therefore, probable that they should be grouped with the overridden Montauk topography. This is borne out by the subdued undulating topography on the large neck to the east of Noyack Bay, and the discovery of a section revealing till, most probably of Montauk age, at the surface on the southeast side of the same bay.

The Latest stratified gravels have a much narrower development on the south than on the north side of Peconic Bay and Peconic River. East of Southport there is not one place on the south fluke where any Latest stratified material could be recognized with certainty, and throughout most of that area the overridden Montauk topography characteristic of the Ronkonkoma ridge extends to the shores of the bays.

The Northern Necks.

The contrast between the surface overridden by the Montauk ice and the surface of the Latest stratified deposits is nowhere more strikingly seen than in the region of the northern necks. Everywhere above the 85-foot contour the topography is characterized by uneven sags and swells dotted with boulders; below are unmodified terraces with ice-contact faces and devoid of boulders.

Woodworth[16] had attributed these terraces to Wisconsin lacustrine deposition, but he imagined that the ice which dammed the lakes, and whose melt-water streams provided the débris, lay as an active unbroken sheet north of a line joining the northern ends of the necks, and that lobes of ice protruded south to cover the necks, the terraces being built out into ice-free bays by streams issuing from ice overlying the necks. If the 80-foot terrace northwest of Port Washington had been formed in this way, it should have a deltaic lobate front, and its surface should slope gently away from the ice. It does not, however, exhibit these characters. Unfortunately, the greater part of the terrace has been destroyed by artificial excavations, and it is impossible, therefore, to determine whether the slopes bounding the terrace were ice-contact or deltaic. It is very unlikely, however, that the ice lingered over the high ground as long as in the bays, as Woodworth postulated. The superposition of topsets on foresets so well seen in the sand pits northwest of Port Washington is to be expected in the sedimentation of an ice-bound lake just as much as in that of a delta, and cross-bedding is particularly favored in the former case. The data thus favor the hypothesis that these terraces were formed between the ice-free high ground on the necks and ice lying in the bays.

Origin of the Nissequogue Drainage Basin.—Near Smithtown, a basin several square miles in area and up to 100 feet deep, accents the Terryville plains. Bounded on the south by the Ronkonkoma ridge and on the north by the Harbor Hill ridge, it is drained by the north-flowing Nissequogue River. The slopes inclosing it appear to be chiefly constructional.

[16] *Op. cit.*, pp. 653-659.

Furthermore, the stratigraphy and surface features of the other parts of the island record no erosion interval of sufficient duration to have produced such a hollow by stream action since the Herod deposition. This basin received little deposition either in the Latest stage or in the Montauk, for it lies well below the surrounding Montauk surface. These facts suggest that during these two stages the basin was occupied by dead ice. The basin is believed to have been inherited from a low area in the underlying Cretaceous surface. The depression is thought to have been occupied by stagnant ice throughout all, or the greater part of the period of Montauk deposition and this enhanced the elevations of the regions surrounding it. If the center of the basin were still occupied with ice when the Latest ice advanced over Long Island, this area would have experienced essentially no deposition during Montauk time.

However, the bluffs and sags from which the ice had melted on the west side, and all the area on the east side of the hollow, were modified by the Latest advance. It is to this factor that the smoothed character of the ridges in the western part of the area are assigned, and it is this which gives them a superficial resemblance to the interfluves between erosion valleys. During the Latest advance a slight increase in the elevation of the region bordering the area on the east was accomplished by the deformation of a mantle of the Latest sands and gravels.

Within the Nissequogue basin itself the Latest ice left only an insignificant amount of sand and gravel in the form of swells and swales. The absence of boulders over the greater part of the area is remarkable, but since the lowest part of the ice may have existed as a residual from the Montauk advance, it is less surprising to find that the proportion of boulders is small. If the boulders do exist, they probably are mostly buried by the débris from the lowest portion of the ice (the last to melt away), namely that which had taken part in the Montauk advance. The latter was apparently not characterized by the same quantity of boulders as the Latest ice.

Boulders occur toward the southeast side of the floor of the hollow, one and three-quarter miles east of Hauppauge, near the gap in the Ronkonkoma ridge: They are also found actually on the floor of that gap. These facts are taken to indicate that when the Latest glaciers advanced, the gap was free of Montauk ice and had possibly received some Montauk deposition. By thus raising the altitude of the gap the Nissequogue River may have been assisted in capturing those tributary streams which in Herod time are thought to have flowed south to the sea by way of the Connetquot.

It is is only natural that this relatively depressed region should be the site of streams at the present day, and even though these have not accomplished much erosion, their very existence strongly suggests the erroneous impression that the topography is erosional, and that the hollow was scoured out by stream action.

Location of Gaps in the Harbor Hill Ridge.—The bays and harbors of the north shore not only form depressions north of the Harbor Hill ridge, but head in gaps in the ridge. During the initiation of these ridges, masses of ice were probably caught in the same Cretaceous obsequent valleys which determined the sites of the bays and harbors.

It is maintained that the marginal Herod ice was active up to the time of the building of the Harbor Hill fans, but that it then lost its motion. Thus the existence of lenses of ice underneath the fans over the sites of preëxisting valleys is not improbable. Quite possibly the ice wasted out after the fans had been deposited, and let down the superincumbent material before the Montauk advance. Once initiated, these gaps were increased, owing to their occupation by ice in Montauk times when the ridges were being enlarged by deposition. The gaps were enlarged during the Latest stage, due to similar causes, and some of the westerly ones functioned as outwash channels draining the ice to the north.

RÉSUMÉ.

The Mannetto gravel and Jameco gravel of Fuller may represent pre-Wisconsin glacial deposits, possibly Jerseyan. The Gardiners clay and Jacob sand formations may represent the Yarmouth interglacial stage. These four units are of small bulk and of no apparent topographic significance. All the remaining glacial deposits on Long Island, consisting principally of stratified sands and gravels, are believed to be Wisconsin.

On a basis of stratigraphic and geomorphic evidence, the Wisconsin stage is subdivided into three advances—the Herod, the Montauk, and the Latest. During the times between these advances the bulk of the ice that lay over the island was dissipated.

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