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THE GEOLOGY OF LONG ISLAND NEW YORK

BY

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THE GEOLOGY OF LONG ISLAND, NEW YORK.

By MYRON L. FULLER.

INTRODUCTION.

Location.—Long Island, New York, is the largest island adjoining the coast of the United States proper. It is 118 miles long, extending from the Narrows at the entrance of New York Harbor (longitude 74° 2′ W.) to a point nearly due south of the eastern boundary of Connecticut (about 71° 50′ W.). Its maximum width is about 20 miles. The island is included in the State of New York, but only a few miles of its shore line is adjacent to the mainland portion of that State, more than seven-eighths of its total length lying off the Connecticut shore (fig. 1).

Geologic relations.—In its general geologic relations Long Island belongs to the inner part of the Atlantic Coastal Plain (fig. 2), the line between the deposits of this plain and the metamorphic rocks upon and against which the sediments were laid down crossing the extreme west end of the island near Long Island City. The basal or fundamental deposits are of Cretaceous age and correspond to beds of similar age in New Jersey and the region farther south. They appear at a considerable number of points in the western half of the island but in the eastern part are nowhere seen at the surface. No equivalents of the Tertiary deposits of the mainland have been definitely recognized, although some loose sands possibly referable to the Tertiary period have been noted at one point.

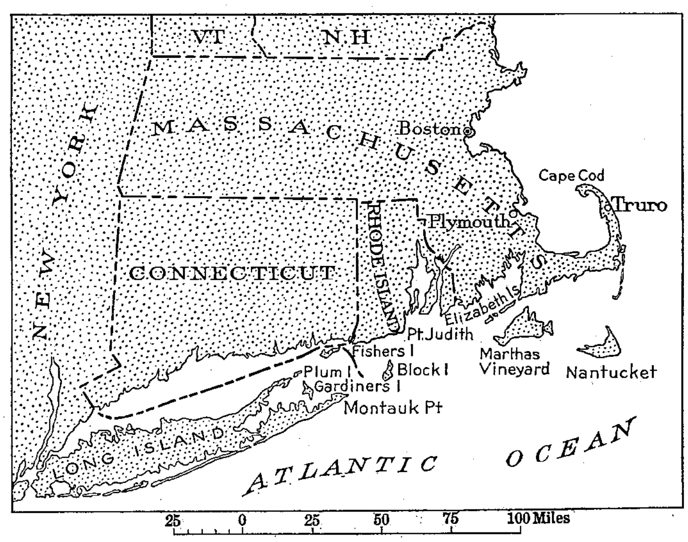

FIGURE 1.—Index map of Long Island and southern New England.

Only a part of the deposits of the island are true coastal-plain deposits, the greater portion of both the surface and the underlying materials throughout the island being of Pleistocene age and representing the morainal and outwash accumulations associated with the continental glaciers (fig. 2). The two morainal ridges, which are among the most conspicuous features of this area and which together form "the backbone of the island," are the direct continuation of the series of moraines of Wisconsin age which are traceable almost continuously from the Rocky Mountains to New Jersey and thence through Long Island and the islands on the east as far as Nantucket and Cape Cod. The various beds making up the considerable thickness of Pleistocene accumulations beneath the ridges mentioned and above the Cretaceous formations likewise represent older drift sheets of the central United States on the west and the Pleistocene formations of the New England coast on the northeast.

Purpose of this investigation.—The investigation of the geology of Long Island was undertaken in connection with a study of the underground waters of the island made by the United

States Geological Survey in cooperation with the Commission on Additional Water Supply of New York City. During the progress of the work many new geologic facts were developed, some of which demanded extensive modifications of the views previously held as to the structure and geologic history of the island. In fact, a complete revision of the geology became necessary in order that the observations on the underground waters might be thoroughly understood. This geologic work was conducted in connection with the water investigation during 1903, most of the roads on the island being traversed and a very large number of well records collected. Geologic work was continued during several weeks in 1904 and again for a few days in 1905, to complete a study of bluff sections along the north shore and to establish the correlation of the Long Island deposits with other Pleistocene deposits on the east and west.

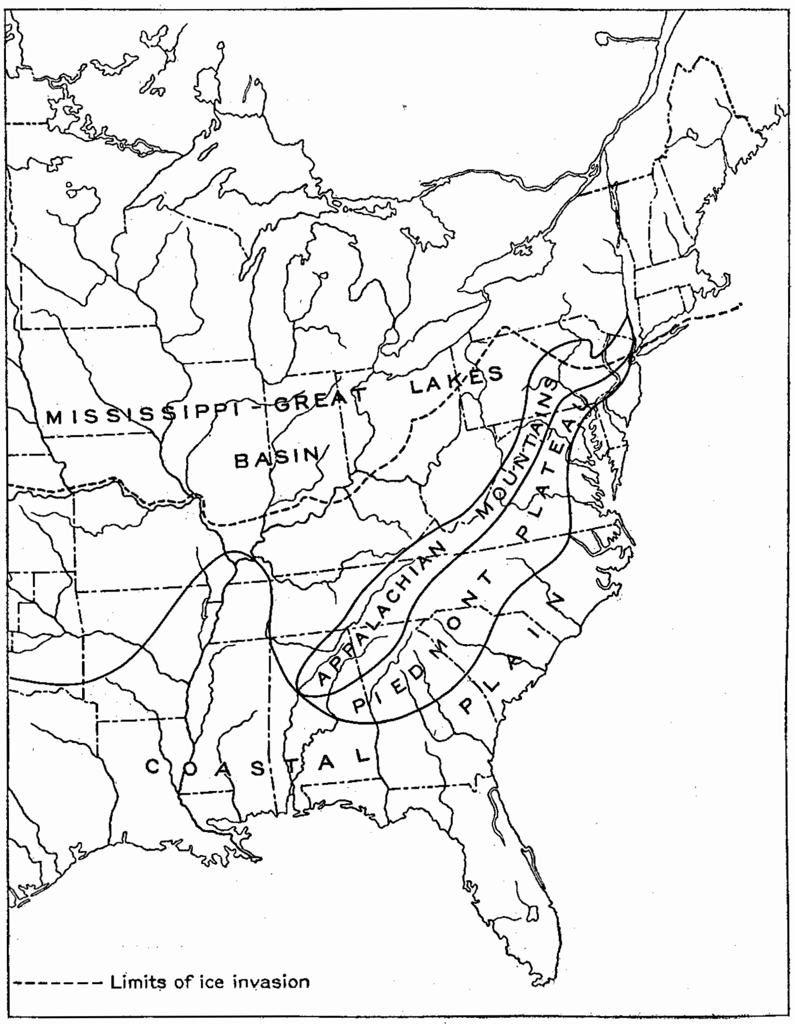

FIGURE 2.—Map of the eastern United States showing physiographic provinces.

Status of Pleistocene correlation.—From the able studies of Chamberlin, Calvin, Leverett, and other United States and Canadian geologists, the Pleistocene deposits of the interior of North America have been differentiated and their accumulation in a series of four or more successive glacial stages has been established. East of Ohio, however, because the last or Wisconsin invasion in many places advanced farther than the earlier ice sheets—removing, covering, or otherwise obscuring their deposits—little has been done toward the differentiation and correlation of the drifts. A fringe of old, deeply weathered drift stretching across Pennsylvania and New Jersey, it is true, has long been recognized outside of the Wisconsin moraine and because of the weathered state of its materials has been provisionally correlated with the Kansan or pre-Kansan. On Long Island Woodworth[1] recognized an earlier drift underlying the Wisconsin and separated from it by a distinct erosion unconformity, but beyond correlating it with the Columbia group of the Coastal Plain he made no attempt to assign it to a definite stage. On Block Island, Marthas Vineyard, Nantucket, and Cape Cod three glacial stages with intervening interglacial stages were recognized and a part of the Pleistocene history was deciphered.[2] The invasions were designated the first, second, and

[1] Woodworth, J. B., Pleistocene geology of portions of Nassau County and Borough of Queens: Bull. New York State Mus. No. 48, 1901, p. 624.

[2] Woodworth, J. B., Geology and geography of the clays, in Shaler, N. S., Woodworth, J. B., and Marbut, C. F., Glacial brick clays of Rhode Island and southeastern Massachusetts: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 975–988. Shaler, N. S., Geology of the Cape Cod district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 497–593.

third glacial stages, but no attempt was made to correlate them with the stages of the Mississippi and Ohio valleys, which in fact had not then been fully worked out. No further attempt at differentiation or correlation was made until the problem was taken up by the writer and his party in 1903, the question of equivalency of the eastern and central glacial deposits remaining one of the great unsolved problems of Pleistocene correlation in this country.

Results of the work.—The results of the work begun by the writer and assistants in 1903 and continued in 1904 and 1905 have been the apparent establishment for the eastern region of all but one (the Iowan) of the five principal glacial stages recognized in central United States, the recognition of one or more substages, the discovery of criteria for differentiating the deposits of each stage, and the unraveling to a large extent of the complicated history of the region. The evidences in regard to the conditions and history of the principal glacial and interglacial stages on Long Island appear to be fully as clear and conclusive as those in any single area of the earlier studied regions of the interior.

Scope of this report.—The investigations along the New York and New England coasts have brought out the facts that the formations of the Pleistocene epoch were nowhere so well developed and the sequence of events is nowhere so clearly set forth as on Long Island, which in fact may be considered as affording the type section of the earlier glacial deposits of the coastal zone. All stages except the Iowan are here represented. In the present report the Long Island section is discussed in considerable detail to supply a basis of comparison with similar deposits elsewhere. This systematic discussion is followed by a short tabular summary of the geographic distribution of exposures, for the benefit of teachers and others interested in the physiography and geology of special localities, and by a chapter on correlation, in which the equivalency of the deposits of Long Island to glacial deposits elsewhere, especially to those of the New England coast, is considered.

Field work and acknowledgments.—As already stated, the geologic work was undertaken in connection with a cooperative investigation of the water resources of Long Island by the United States Geological Survey and the New York Commission on Additional Water Supply in 1903 and was continued independently of the commission in 1904 and 1905. The ground-water investigation included a careful collection of well records, of which about 1,500—many of them accompanied by samples of the materials penetrated—were procured. Other geologic work in 1903 included traverses of practically every road outside of the portion of the island included in Greater New York and many visits to special localities, mainly in connection with the studies of ground water. In 1904 a traverse was made of the north shore from Port Jefferson to Orient Point and of the shores of Great and Little Peconic, Gardiners, and other smaller bays to Montauk Point, during which the bluff sections were examined in great detail and fossils were collected at a number of points. Gardiners, Plum, and Fishers islands, portions of the Elizabeth Islands, Marthas Vineyard, Nantucket, and Cape Cod were also visited. In 1905 the investigations covered the bluffs along the north shore of Long Island from Port Jefferson westward, the coast of Rhode Island from Watch Hill to Point Judith, and a number of previously unexamined points on the Massachusetts coast as far north as Boston.

Valuable assistance in the work was rendered by a number of geologists. A. C. Veatch, to whom the investigation of the underground waters was assigned, rendered especially valuable service in the collection of well records and samples, and D. W. Johnson contributed largely to the success of the areal investigations. Much paleontologic information in regard to the Cretaceous was furnished by Arthur Hollick, and Pleistocene fossils from several localities were identified by W. H. Dall. Aid in the geologic investigations on Long Island was also rendered by Isaiah Bowman and B. L. Johnson. In Rhode Island and Massachusetts F. G. Clapp assisted largely in establishing the Pleistocene correlations. For the interpretations and conclusions based on the bluff sections of Long Island and on the work done in the Elizabeth Islands and on Marthas Vineyard and Nantucket, as well as for most of those reached elsewhere in Massachusetts, the writer is alone responsible.

DEVELOPMENT OF THE GEOLOGIC LITERATURE ON LONG ISLAND.

GENERAL TREND.

The earliest publication relating to the geology of Long Island of which the writer has information appeared about 1750. From that date until 1800 little seems to have been written, but between 1800 and 1827 a number of contributions on the geology of the island were published. In 1837 the preliminary results of the examination by the New York Geological Survey appeared, marking a new epoch in its literature, and a few years later the classic report on the first district was published. From this time until 1878 a considerable number of papers, mainly descriptive, of Cretaceous and other fossils were issued, but little advance was made in the study of the younger deposits. Beginning with 1878 the drift received much attention, and many papers of importance appeared, in which, however, the glacial epoch was regarded either as a unit or as two or more stages of indefinite age. The work of differentiation and classification of the drifts, which began in 1901, opened the latest period in the literature of the island.

From the preceding outline it is apparent that there have been several phases or periods in the development of the study of the geology of the island as expressed by its literature, which for convenience may be described by terms indicating the characteristic trend of the papers published during the respective periods, as (1) alluvial phase, (2) diluvial phase, (3) early paleontologic phase, (4) early drift phase, and (5) later drift phase.

LITERATURE FROM 1750 TO 1837 (ALLUVIAL PHASE).

The period from 1750 to 1837 covers the beginning of the study of Long Island geology. In it the first geologic examinations of the island were made and the first classification and correlations of its deposits were attempted. It was not a period of detailed field examinations, most of the published observations being records of private travels, with occasional attempts at interpretation, but it was marked by the appearance of the first geologic map.

To Dupont de Nemours is credited the first statement on the geology of the island that has been found. In a publication[1] appearing about 1750 he said that Long Island, although not a delta in form is one in reality, being formed by marine currents depositing the fluviatile alluvium brought down by Hudson, Passaic, Hackensack, and Raritan rivers. This early reference is much more in harmony with present views than those referring the island to the "primitive formation," which immediately followed it. We now know that the southern two-thirds of the island, if not a delta as postulated by De Nemours, is at least made up largely of confluvial deltas from glacial streams.

The next writer of note dealing with Long Island appears to be Samuel L. Mitchill. Writing in 1800,[2] he referred the part of the island north of the "spine" (on the basis of the granitic bowlders which are abundant along the north coast) to the "primitive formation." His paper gave a summary of the topography of the island and the erosion that was going on, stating that the island has been separated from the mainland by the encroachment of the salt water during the lapse of ages. He also discussed the marshes and beaches, the character, distribution, and immense size of the bowlders, and the occurrence of marine fossils in wells. Mitchill gave a further description of the bowlders in a paper appearing in 1802[3] and expressed the belief that Plum, Gull, and Fisher islands on the north and Block Island on the south were once connected respectively with Orient and Montauk points. This is the first recognition of the essential continuity of the ridges later known as the inner and outer moraines.

In 1809 appeared the first geologic map of the United States, accompanied by an explanatory paper by William Maclure.[4] The map bears the note "By Samuel G. Lewis," but it appears to have been based on Maclure's observations, and is generally known as the Maclure map. On it the north half of the island is shown as "alluvial," a term then applied to all the unconsolidated beds of the Coastal Plain. This is also stated in the text.

[1] Quelques mémoirs sur différens sujets, quoted by W. W. Mather, Geology of New York, pt. 1, 1843, p. 150.

[2] A sketch of the mineralogical history of the State of New York: Med. Repository, vol. 1, 2d ed., 1800, pp. 279-303, 431-439; vol. 3, 1800, pp. 325-335.

[3] Mitchill, S. L., A sketch of the mineralogical history of the State of New York: Med. Repository, vol. 5, 1802, pp. 212-215.

[4] Observations on the geology of the United States: Trans. Am. Philos. Soc., vol. 6, 1809, pp. 411-428.

Mitchill, who a few years before had assigned the north side of the island to the "primitive formation," reversed his opinion in 1811 and stated that all of the material was alluvial except near "Hurlgate" (Hell Gate), citing the occurrence of shells in deep wells as evidence of such origin.[1] This appears to be the first reference to the fossiliferous silts now known as Gardiners clay. Seven years later Mitchill reiterated the conclusion as to the alluvial origin of the island and cited additional instances of buried shells.[2] In the same paper, in describing the northernmost ridge, he called attention to the superimposition of bowlders (Wisconsin) over the "marine deposits" (Manhasset formation). This may possibly be taken as the first subdivision of the deposits of the island.

In an account of his travels Timothy Dwight,[3] then president of Yale, noted the difference between the rounded character of the fragments over most of the island and their angularity west of Jamaica and at Montauk, this being the second distinction on Long Island of the deposits afterwards known as stratified drift and till. The hills at Shinnecock, which by many later writers have been regarded as moraines, were described by Dwight as being at that time bare hills of drifting sand. The island he regarded as having been formed as a bar by the Gulf Stream, which swept inward during the Deluge. Buried shells and logs of wood are described as occurring at several points.

Writing in 1824, John Finch said [4] that no rivers are competent to deposit such masses of alluvial material as are found on Long Island, which he considered as being the northern extension of the Tertiary, the ridges, however, being referred to as "diluvial." The whole island was considered to be underlain by sand, gravel, and clays containing fossil shells (Venus, Ostrea, Murex, etc.) and tree trunks, and these beds were correlated with the clays at Amboy, N. J.

In 1827 S. G. Morton arranged and published certain notes of Lardner Vanuxem,[5] who recognized the "Secondary" (the equivalent of the present Cretaceous of the island) in addition to the Tertiary already recognized.

LITERATURE FROM 1837 TO 1842 (DILUVIAL PHASE).

The period from 1837 to 1842, though the shortest of the five into which the geologic literature of Long Island has been divided, is nevertheless among the most important, being marked by the publication of the results of the first systematic field examination of the island—that by the first Geological Survey of New York. It is characterized by detailed observations rather than by inferences, and in it the complexity of the geologic history of the island was for the first time distinctly recognized. Little further progress in solving the problems of that history could be made as long as the hypothetical "diluvial process," the exact nature of which few pretended to comprehend fully, was appealed to as an explanation of the origin of the island.

A report on the preliminary reconnaissance of the island by W. W. Mather,[6] geologist of the first district of New York, appeared in 1837 and included discussions of the economic geology, erosion features, bars and spits, landslides, dunes, erratic bowlders, clays, and the occurrences of fossils and lignite in deposits penetrated by wells. A year later [7] further descriptions of the geologic features and processes were published. Mather's discussions of the extension of marshes, the occurrence of submerged tree stumps, the encroachments of the sea, the formation of beaches, spits, and bars, the occurrence of garnet and magnetite sands, and the distribution of bowlders are of special interest, as is also his prediction as to the ultimate value of the peat deposits of the island.

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[1] Mitchill, S. L., An amendment proposed to the geological chart of the United States: Am. Mineralog. Jour., vol. 1, 1814, pp. 129–133; Geology of Long Island: Idem, pp. 261–263.

[2] Mitchill, S. L., Observations on the geology of North America, appendix to Cuvier's Essay on the theory of the earth (tr. by Robt. Jameson), New York, 1818, pp. 379–382.

[3] Travels in New England and New York, vol. 3, 1822, pp. 283–336.

[4] Geological essay on the Tertiary formations in America: Am. Jour. Sci., 1st ser., vol. 7, 1824, pp. 31–43.

[5] Geological observations on the Secondary, Tertiary, and Alluvial formations of the Atlantic coast of the United States of America: Jour. Acad. Nat. Sci. Philadelphia, vol. 4, pt. 1, 1827, pp. 59–71.

[6] First Ann. Rept. New York Geol. Survey, 1837, pp. 61–95.

[7] Mather, W. W., Second Ann. Rept. New York Geol. Survey, 1838, pp. 121–184.

Four years afterward appeared the classic report on the First district,[1] which contained a detailed discussion of Long Island. In this report, in addition to more complete discussions of the processes and phenomena treated in the earlier reports, a classification of the deposits of the island was attempted and its origin was considered. The materials were divided into two systems—the Long Island system, called "Upper Secondary" and made to include the Cretaceous and Tertiary formations, and the Quaternary system, comprising the Alluvial, Quaternary, and Drift divisions. The principal mass of the island, including the white clays, was held to be older than Tertiary, the lower beds being regarded as equivalents of the Cretaceous deposits of New Jersey, Delaware, and Maryland. The colored clays above the white clay, which were believed to underlie the whole island, were recognized as older than the surface drift and were referred to the Tertiary. This was the earliest recognition of a clay floor such as that described by later geologists, although it is now known that two clays of widely different age and stratigraphic position were considered by Mather as one. After the deposition of the later clays (Gardiners clay) they were folded, as if by the lateral pressure of slides, after which they were denuded (Montauk ice erosion) before the deposition of the drift (Wisconsin) unconformably on their surfaces.[2] In the "Drift division" overlying the folded clays was included a thick deposit of what is now known as till (Montauk till member of Manhasset formation), and above this came the "Quaternary division," embracing the more recent clay and sand deposits of Long, Staten, and New York islands (Hempstead gravel member of Manhasset formation and later deposits). "Some bowlder and drift deposits (Wisconsin) overlie this formation, but the main drift deposit, which was usually called alluvium, erratic block group, bowlder system, etc. (Montauk till member), underlies this formation."[3] The "Quaternary division" had three members, the lower being a blue clay, the middle a gray to buff clay, and the upper a sand. The clays were correlated with those of the Hudson and Champlain valleys. There is little doubt, however, that the three members are really to be correlated, respectively, with what are now called the Gardiners clay, the Jacob sand, and the Herod gravel member of the Manhasset formation. Their assignment to a position above the main drift (Montauk till member of Manhasset formation) was doubtless due to the absence of this member of the Manhasset formation in Mather's type localities—an absence that is not at all uncommon.

Two drifts were also distinctly recognized elsewhere in Mather's report. In speaking of the "Drift division" he said: "It is believed there is abundance of evidence of two epochs of strong currents, with a period of considerable duration of comparative repose between them."[4] This statement, which was lost sight of by subsequent writers, deserves recognition as one of the earliest if not the first explicit assertion in America of the duality of the drift period. Mather's statement in regard to fossils is also full of significance. "Most of them without any doubt occur below the drift, a few in the drift, and none or very few in the Quaternary deposits."[5]

Mather's conception seems to have been that the "lower drift" (Montauk till member of Manhasset formation) and the drift of the ridges (moraines) were the same and were deposited simultaneously as irregular hills, over or about which the deposits of his "Quaternary division" were laid down in standing water. After this a layer of pebbles, gravel, and bowlders, "which was called the upper drift,"[4] was deposited over the whole. The deposits of his "Alluvial division," including fluviatile, lacustrine, marsh, and marine beds, all of which are still accumulating, completed the formations of the island. In explaining the origin of the drift Mather postulated diluvial processes requiring the action of strong currents laden with floating bergs and recognized two periods of great activity separated by a quieter period, in which the deposits of his "Quaternary division" were laid down.

LITERATURE FROM 1843 TO 1878 (EARLY PALEONTOLOGIC PHASE).

After the publication of the report on the First district the drift deposits received little further attention for a period of 35 years, Mather's work during this period being accepted as authoritative and extensively quoted.[6] Of the new scientific contributions during this period

[1] Mather, W. W., Geology of New York, pt. 1, 1843. [2] Idem, p. 272. [3] Idem, p. 123. [4] Idem, p. 158. [5] Idem, p. 264.

[6] Thompson, B. F., The history of Long Island from its discovery and settlement to the present time, 2 vols., New York, 1843.

by far the greater number related to paleontology, although several physiographic papers of importance appeared.

In Mather's report the older clays of Long Island had been assigned, on the basis of similarity to the New Jersey deposits, to the Cretaceous, but no fossils identifiable as Cretaceous had been found. In the year in which the report appeared, however, a notice of the finding by William C. Redfield of *Exogyra costata* in a well in the drift at Brooklyn Heights was published. This was asserted to be the first authentic discovery of a Cretaceous fossil on the island.[1]

Four years later notes on more recent fossils in the drift near Brooklyn were given in another paper by Redfield.[2] In commenting on this paper the editor said that the writer brought out the fact "that at least two periods of drift must be recognized, one of which was anterior to the deposit of clay in the valleys first referred to, the second that during which the shells on the summit of Montreal Island and Long Island were deposited." In 1848 E. Desor [3] reported shells in deposits of striated pebbles (Montauk member?) forming an anticline on the flanks of which were inclined sand and clays (Herod gravel member of Manhasset formation, etc.). Bouchepon [4] thought the structure might be due to a change of conditions caused by a shifting of the earth's axis.

The next contribution on the geology of the island was by C. H. Davis,[5] who described the action of currents on the configuration of the entrance of New York Harbor. In 1850 and 1851 appeared two papers by E. Desor,[6] who in the second of these papers explained certain phenomena of folding in the drifts about Boston as due to the settling of the deposits following the melting of buried ice masses, a conclusion of interest in view of the explanations later advanced in regard to the folding on Long Island. In 1854 a further note on the drift at Brooklyn was made by Redfield,[7] who reported the finding of additional fossils and advanced the view that the drift period was greatly protracted but was later than the time of the so-called post-Tertiary (fossiliferous) deposits, which he regarded as marking a distinct epoch. Desor [7] differed from Redfield on this point, arguing that the deposit at Brooklyn was simply an exception to the common rule of Quaternary formations.

The year 1857 was marked by the appearance of an important paper by George H. Cook,[8] who cited many instances of submerged timber and marshes, especially near Hempstead, Babylon, and Islip. Cook showed that undercutting by the waves does not explain the occurrences, which are more likely due to a subsidence that is still going on at the rate of 2 feet in a hundred years.

In an agricultural paper, published in 1859, Winston C. Watson [9] referred all of the island except the ledges near Hell Gate to alluvium, which he considered to have been formed by the sea in the same manner as the present beaches.

Four years later Dana,[10] in the first edition of his Geology, placed the northern limit of the Cretaceous at Staten Island. He seems inclined to refer the older deposits of Long Island to the Tertiary, although recognizing the glacial origin of the surface formations. He also illustrated the submarine valley off New York Harbor in connection with his discussion of Triassic rocks, saying: "The border, now submerged, has therefore in former times been dry land; it may have been partly so in the Triassic period." [11]

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[1] Am. Jour. Sci., 1st ser., vol. 45, 1843, p. 156.

[2] Redfield, W. C., On the remains of marine shells of existing species found interspersed in deep portions of the hills of drift and bowlders in the heights of Brooklyn, on Long Island, near New York City: Am. Jour. Agr. and Sci., vol. 6, 1847, pp. 213-219; Am. Jour. Sci., 2d ser., vol. 5, 1848, pp. 110-111.

[3] Proc. Boston Soc. Nat. Hist., vol. 2, 1848, p. 247.

[4] Idem, vol. 4, 1854, p. 180.

[5] Geological action of the tidal and other currents of the ocean: Mem. Am. Acad. Arts and Sci., new ser., vol. 4, 1849.

[6] Des alluvions marines et lacustres et du terrain erratique de l'Amérique du Nord: Bull. Soc. géol. France, 2d ser., vol. 7, 1850, pp. 623-631; [On the origin of contorted strata of sand and clay]: Proc. Am. Acad. Arts and Sci., vol. 2, 1851, pp. 282-283.

[7] Proc. Boston Soc. Nat. Hist., vol. 4, 1854, pp. 180-181.

[8] On a subsidence of the land on the sea coast of New Jersey and Long Island: Am. Jour. Sci., 2d ser., vol. 24, 1857, pp. 341-354.

[9] The plains of Long Island: Trans. New York State Agr. Soc., vol. 9, 1859, pp. 485-505.

[10] Dana, J. D., Manual of geology, 1863.

[11] Idem, pp. 441, 442.

In 1867 Sanderson Smith [1] published the first description of the clays of Gardiners Island, together with an account of the fossils, which, with one or two exceptions, were believed to be of species still inhabiting the waters of the region, although as a whole they were characteristic of a more northern locality.

Two years later Elias Lewis, jr.,[2] mentioned buried or submerged tree trunks and other evidences of subsidence, which he estimated had amounted to about 53 feet.

J. S. Newberry [3] in 1871 announced the finding in the drift of cemented sand fragments resembling Triassic material but containing angiospermous leaves not known to exist before the Cretaceous.

The geologic maps issued before 1873, including that of the New York State geologists in 1842, that of Edward Hitchcock and Jules Marcou in 1853, that of H. D. Rogers in 1858, and that of Sir W. E. Logan in 1868, but not that of William Maclure, had shown Long Island as Tertiary or alluvium. In 1873 C. H. Hitchcock and W. P. Blake, on a map of the United States prepared for the Ninth Census, showed the north shore of Long Island as Cretaceous. With this mapping Dana [4] took issue, stating that there were "no facts making the region Cretaceous." After receiving a letter of explanation from Hitchcock, Dana published another note, mentioning the source of the data supporting the map (Mather's observations) but expressing doubts of their value.[5] A reply by Hitchcock [6] the following year quoted Mather and Cook as to the equivalency of the Long Island beds with New Jersey deposits of known Cretaceous age. No mention was made by Hitchcock or Dana of the evidences advanced by Redfield or Newberry, but attention was called to them soon afterward by D. S. Martin,[7] and new evidences of angiospermous leaves were presented by Newberry [7] and of the occurrence of Gryphæa by J. J. Stevenson.[7] Dana,[8] however, in 1875 reaffirmed his belief that the Cretaceous does not extend under Long Island.

Before the discussion of the Cretaceous ceased, Elias Lewis, jr.,[9] had called attention to the occurrence of clay bowlders up to 8 feet in diameter in the stratified sands and gravels at Harbor Hill, "near Brooklyn." In 1875 Dana[10] published some very important observations showing complexities in the New England drift similar to those on Long Island. He noted striated bowlders under the clays and "stony beds" (apparently loose till) over the sands, the clays having been folded and eroded before the sands were deposited. Some of Dana's descriptions are suggestive of a still older gravel, possibly to be correlated with the Mannetto gravel of the present report. Unfortunately, he was content to refer most of the phenomena to unexplained variations in the diluvial processes accompanying and following the glacial invasion (which was regarded as a unit) and made little attempt to develop the history of the region. Submergence was advocated to explain the higher deposits. In another paper [11] Dana stated that the glacial ice probably passed over Long Island and out to the edge of deep water 80 miles farther south. The same statement appeared in the second edition of his "Manual of geology." The Sound, which was previously of less depth, was considered to have been occupied and partly eroded by large subglacial streams. Dana also believed that the land at that time stood at least 100 feet higher than at present and that the temperature was so low that marine life did not exist until after the retreat of the ice. The year 1875 was also marked by the appearance of a paper by Gabriel Furman,[12] who mentioned the occurrence of fossil shells and described the breaks in the South Beach, and of a bibliography of Long Island, by H. Onderdonk, jr.,[13] which, however, contained few references to scientific publications.

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[1] Notice of a post-Pliocene deposit on Gardiners Island, Suffolk County, N. Y.: Annals New York Lyceum Nat. Hist., vol. 8, 1867, pp. 149–151.

[2] Evidences of coast depression along the shores of Long Island: Am. Naturalist, vol. 2, 1869, pp. 334–336.

[3] Proc. New York Lyceum Nat. Hist., 1st ser., 1871, pp. 149–150.

[4] Dana, J. D., Geological map of the United States, compiled for the Ninth Census by C. H. Hitchcock and W. P. Blake: Am. Jour. Sci., 3d ser., vol. 6, 1873, pp. 64–66.

[5] [Cretaceous of Long Island]: Idem, p. 305.

[6] Hitchcock, C. H., Note upon the Cretaceous strata of Long Island: Proc. Am. Assoc. Adv. Sci., vol. 22, pt. 2, 1874, pp. 131–132.

[7] Proc. New York Lyceum Nat. Hist., 2d ser., No. 4, 1874, p. 127.

[8] Dana, J. D., Manual of geology, 2d ed., 1875, p. 455.

[9] Bowlder-like masses of clay in the Long Island drift: Pop. Sci. Monthly, vol. 2, 1873, p. 634.

[10] On southern New England during the melting of the great glacier: Am. Jour. Sci., 3d ser., vol. 10, 1875, pp. 168–183.

[11] Absence of marine life from Long Island Sound through the glacial and part of the Champlain periods: Am. Jour. Sci., 3d ser., vol. 10, 1875, pp. 280–282.

[12] Antiquities of Long Island, New York, 1875, pp. 1–434.

[13] Idem, pp. 435–469.

The next year, 1876, D. S. Martin [1] called attention to fossiliferous erratic bowlders of Silurian age, which he thought were drifted to the region by floating ice. In the same year a paper by Elias Lewis, jr.,[2] gave a detailed account of the drifting sands of the island, including the composition, weathering, structure, rate of advance, destructiveness, and methods of controlling the dunes.

In 1877 were published four more papers of interest by the same author. In the first [3] he described the large valleys of the south side of the island, noting the absence of streams competent to account for their formation, which he thought was more likely due to the action of subglacial streams. The lack of postglacial erosion was emphasized in this paper for the first time. Lewis regarded the land as having been submerged to a depth of 260 feet in glacial time, for stratified deposits are found up to that level. In the second paper [4] he pointed out the occurrence of thirty pronounced valleys between New York and Riverhead, some of which were said to extend across the Great South Bay to the ocean. Most of these valleys are characterized by a much steeper slope on the west or right-hand bank than on the east, and the general trend was said to be west of south. Deflection by the earth's rotation was suggested as the cause. In the third paper [5] the ridge or "backbone" appears for the first time to be definitely referred to the terminal moraine. A table of altitudes was given, and the suggestion was made that the amount of submergence during the formation can be determined from "the presence and position of modified drift upon these hills and along their slopes." This suggestion indicates that Lewis believed the moraine to be older than the drift plateau on the north or the sloping plains on the south. The fourth paper [6] was devoted to the supposed changes of level indicated by the deposits of stratified sands and gravel that are recognized at different levels by the submerged tree trunks and peat beds still to be seen, by the fossils and lignite encountered in wells, and by the submarine channels off New York. The absence of bowlders on the plains south of the moraine was supposed to be due to their destruction by the advancing and receding shore lines. The present Montauk till member of the Manhasset formation was recognized as a distinct bed of "coarse glacial rubble in deep beds without fossils, * * * chiefly on the north side of the island." Below this were placed the gravels (Herod gravel member of Manhasset formation) and below the gravels the fossiliferous clays (Gardiners clay).

The epoch was closed in 1878 by a paper by J. S. Newberry,[7] which, though a popular review of the geology, contained the statement that Cretaceous rocks underlie a large part of the island but that the finding of Tertiary beds is doubtful. In view of later developments this statement is of significance.

LITERATURE FROM 1878 TO 1900 (EARLY DRIFT PHASE).

The fourth period in the literature of the island began in 1878 with the first detailed discussion by Upham of the geology on the basis of the modern glacial theory, and continued until the work of differentiating the drifts was begun. Knowledge of the island in this period was advanced mainly through studies of the drift by Upham and Merrill, although, largely through the efforts of Hollick, there was a steady accumulation of paleontologic evidence as to the distribution of the Cretaceous along the north shore. The folding of the clays of the island and the formation of the submarine valley off New York also received a share of attention by Merrill and Lindenkohl, and the efficiency of subglacial streams as supplying many of the deposits and developing most of the existing topography of the island was advocated at short intervals throughout a large part of the period by Bryson.

Upham's first discussion [8] was devoted to a consideration of the moraines, which he described, giving their heights. He predicted that their continuation would be found crossing New Jersey,

[1] On the occurrence of Silurian fossils in the drift of Long Island: Am. Naturalist, vol. 10, 1876, p. 191.
[2] The formation of sand dunes: Pop. Sci. Monthly, vol. 8, 1876, pp. 357-363.
[3] On watercourses upon Long Island: Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 142-146.
[4] Certain features of the valleys or watercourses of southern Long Island: Idem, pp. 215-216.
[5] Heights of Long Island: Idem, pp. 235-236.
[6] Ups and downs of the Long Island coast: Pop. Sci. Monthly, vol. 10, 1877, pp. 434-446.
[7] The geological history of New York island and harbor: Pop. Sci. Monthly, vol. 13, 1878, pp. 641-660.
[8] Upham, Warren, Geology of New Hampshire, vol. 3, pt. 3, 1878, pp. 300-305.

Pennsylvania, and Ohio, and differentiated the inner and outer moraines. In a second paper,[1] appearing the following year, Upham carefully and in the main accurately described the moraines, gave elevations, and discussed their composition. He mentioned the prevalence of till west of Roslyn and its absence to the east, and described the Shinnecock Hills as composed of gravel.[2] He recognized two tills throughout Long Island and New England, the lower being composed of thick, clayey, compact bluish material and the upper of thin, loose, oxidized material. The stratified character of the drift now known as Montauk was noted. Upham regarded the Wheatley Hills as composed of till and thought the Mannetto and Half Hollow hills to have been deposited like kames or in ice-walled channels. Later there was a local advance of the ice sheet, accompanied by the deposition of drift over these elevations. In this paper the outwash character of the plains was recognized for the first time, the preglacial age of the clays near Bethpage was announced, and the folding and beveling of the clays on Gardiners Island were described. The change of the sands lying unconformably upon the clays to bowlder drift and vice versa was noted, and the deposits were correlated with those at Montauk, Bethpage, and Gay Head. Upham referred the Smithtown drainage system to erosion and described the numerous ponds that occupy old drainage channels.

In the following year, 1880, appeared still another paper by Upham, in which he described the extension of the "lower" (Montauk till member of Manhasset formation) and "upper" (Wisconsin) till over New England,[3] stating that the "lower" till is from 2 to 50 feet thick and forms the drumlins, and that the "upper" till usually occurs as a very uniform mantle 5 feet or so in thickness. In this paper Upham discussed the moraines of Long Island but made little addition to the data published in his preceding papers.

In 1883 N. L. Britton [4] gave an account of further discoveries of sandstone fragments containing Cretaceous fossils and predicted that correlation with the Cretaceous sandstones of New Jersey would be established. In the same year appeared the first of a long series of papers by John Bryson, a local geologist.[5] In this and the following papers Bryson recorded his conviction that there had been no change of level of the island since the ice age, and that the deposits are the work of subglacial streams which built up the island as a barrier across the courses of the Connecticut and other rivers that had previously flowed southward to the ocean. The fossils are assumed to have been washed up by the currents. The subglacial waters were thought to have been finally diverted toward the west, cutting the East River channel. The year 1883 was also marked by the publication of T. C. Chamberlin's paper on the terminal moraine [6] with which the moraines of Long Island are correlated. Chamberlin showed two moraines in the eastern part of the island, but made the northern one end abruptly not far from Port Jefferson instead of connecting with the other. His descriptions appear to be based entirely on the work of Upham, although in speaking of the southern plains he says: "These plains are undoubtedly due to glacial waters escaping over the moraine during its formation." [7]

In 1884 G. K. Gilbert [8] discussed quantitatively the effects of the earth's rotation on the deflection of streams, mentioning the steep right banks of the southward-flowing streams of Long Island. He pointed out that the conditions in rapidly deepening channels and in adjusted alluvial fans were not favorable to the action of this force. In 1885 A. Lindenkohl [9] described the deep submarine channel cut in blue clay for a distance of 100 miles from New York Bay, the presence of a bar of sand across it 75 miles from Sandy Hook, and the very deep ravine at the edge of the continental platform. He noted the fact that the channel is in line with the continuation of the moraine in New Jersey and suggested that the channel marks the position of the old ice front.

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1 Upham, Warren, Terminal moraines of the North American ice sheet: Am. Jour. Sci., 3d ser., vol. 18, 1879, pp. 81–92, 197–209.
2 Cf. Dwight, Timothy, Travels in New England and New York, vol. 3, 1822, pp. 283–336.
3 The succession of glacial deposits in New England: Proc. Am. Assoc. Adv. Sci., vol. 28, 1880, pp. 299–310.
4 Science, vol. 3, 1884, p. 25.
5 The glacial phenomena of North America as studied on Long Island, New York: Geol. Mag., new ser., vol. 10, 1883, pp. 169–171.
6 Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291–402.
7 Idem, p. 378.
8 The sufficiency of terrestrial rotation for the deflection of streams: Am. Jour. Sci., 3d ser., vol. 27, 1884, pp. 427–432.
9 Geology of the sea bottom in the approaches to New York Bay: Am. Jour. Sci., 3d ser., vol. 29, 1885, pp. 475–480.

The year 1886 was an active one in Long Island geology. N. L. Britton described the finding of fossil leaves, supposedly from the "Middle Cretaceous," in the clays at Glen Cove, and J. S. Newberry noted their occurrence at Glen Cove and Lloyd Neck.[1]

The principal contributions of the year were made by F. J. H. Merrill, who published a detailed paper on the geology of the island.[2] In this paper, which was based on a five weeks' study of the region, he divided the deposits into clays, gravels, and till. Of the greater part of the clays he said: "From their character and position we may surmise that the brown and red plastic clays of Huntington, Gardiners Island, and elsewhere belong to the age in question [Tertiary]," although he noted the impossibility, in the absence of any unconformity, of determining where the Tertiary stops and the Pleistocene begins. He recognized, however, the similarity of the clays at Glen Cove to the Cretaceous of New Jersey, although he said: "If the Cretaceous formation extends under the whole of Long Island it must occur at a very great depth, since deep sections at points east of Glen Cove do not record its presence." The gravels underlying the till were said to be "equivalent to and indeed identical with the yellow drift or preglacial drift of New Jersey." A belief in the superimposition of the moraine on the gravels is possibly indicated by Merrill's statements that till is not more than a few feet thick even where the land is high. In describing Montauk Point he mentioned a great thickness of "bowlder clay and hardpan of considerable depth covered by a shallow layer of till," apparently recognizing the existence of two till-like drifts. He regarded the shoving action of the ice as accounting for the elevation of the fossiliferous beds, for the lifting that formed the "backbone," and for the folding of the clays of the north shore and even of those south of the moraine, as at West Deer Park. The deep valleys of the north coast he explained as "plowed out by projecting spurs of ice." In regard to the amount of postglacial erosion Merrill differed from nearly every other writer on the subject, assuming it to be very extensive.

In a second paper[3] Merrill discussed at greater length the folding produced by the ice, reiterated many of the conclusions outlined above, and assigned an age much greater than that of the "Champlain" to the stratified fossiliferous deposits.

In 1888 W J McGee,[4] in discussing the Columbia group, noted the occurrence of "subestuarine terraces" up to 250 feet above the sea and in interfluvial regions up to 400 feet. He recognized the fact that their age is greater than that of the moraines and suggested their correlation with the extra morainal drift and the gravel deposits of Long Island. The erosion interval between their deposition and that of the later drift was regarded by McGee as of great length. The southward deflection of the rivers of the Coastal Plain he supposed to have taken place in Columbia time.

In the same year John Bryson[5] gave a partial record of a well at Woodhaven, near Jamaica Bay. Although noting the presence of lignite he referred all the materials to a glacial origin. This well was further discussed with full records in subsequent papers by Bryson[6] and Lewis.[7] Bryson considered the glacial materials to extend to 298 feet; Lewis to 213 feet. No greensand was found. The great depth assigned to the glacial deposits is of interest in connection with the assumption of W. O. Crosby and others as to the Tertiary age of the gravels.

In 1890 J. D. Dana[8] described the channels in Long Island Sound, ascribing them to the action of a Sound river, which passed through what is now the North Fluke, near Mattituck, into Peconic Bay, and thence eastward to the ocean. Other streams passed out of the Sound at its east end. The harbors of the north shore were ascribed to the action of subglacial streams. The presence of Cretaceous deposits had up to that time been disputed, but Dana admitted that they occurred in the foundations of the higher parts of the island and on the north shore. He

1 Fossil leaves in Staten Island and Long Island clay beds: Am. Jour. Sci., 3d ser., vol. 31, 1886, p. 403.

2 On the geology of Long Island: Annals New York Acad. Sci., vol. 3, 1886, pp. 341-364.

3 Some dynamic effects of the ice sheet: Proc. Am. Assoc. Adv. Sci., vol. 35, 1886, pp. 228-229.

4 Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, 1888, pp. 367-388, 448-466.

5 Am. Geologist, vol. 2, 1888, pp. 136-137.

6 Bryson, John, Artesian well, Woodhaven, Long Island, New York: Am. Geologist, vol. 3, 1889, pp. 214-215.

7 Lewis, Elias, jr., Woodham [Woodhaven] artesian well on Long Island: Am. Jour. Sci., 3d ser., vol. 37, 1889, p. 233.

8 Long Island Sound in the Quaternary era, with observations on the submarine Hudson River channel: Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 425-437.

referred to the "Champlain stage" the bed of bowlder clay (Montauk till member of Manhasset formation), 10 to 150 feet thick, beneath the gravel. The channel off New York Harbor was thought to have been cut in "Jura-Trias" time (the Cretaceous and Tertiary being, according to Dana, absent in its vicinity), possibly during an uplift accompanying a semiglacial epoch which he thought may have marked the close of the era. He quoted a letter from E. Lewis, jr., who presented evidences of well records showing that the Cretaceous clays, especially those at Deer Park and Bethpage, extend but short distances beyond their surface exposures.[1] David White [2] mentioned the occurrence at Glen Cove of plant remains similar to those of the Cretaceous of Marthas Vineyard and correlated them with the flora of the clays of Amboy, N. J. J. S. Newberry [3] agreed with White as to the correlations and stated that he had traced the clays from New Jersey to Glen Cove and believed them to extend the whole length of the island.

In 1891 A. Lindenkohl,[4] in a second contribution on the channel off New York, referred the erosion to glacial time and noted a subsequent subsidence of 210 feet. C. A. White,[5] in a review of published literature, recognized the presence of nonmarine Cretaceous deposits but was inclined to doubt the evidence of marine shells. F. J. H. Merrill,[6] in a paper on the Hudson Valley, ascribed the submarine channel to fluviatile rather than marine scour, suggested a "post-Champlain" submergence of 100 feet in New York, noted the occurrence of low terraces on Staten Island and the mainland, and correlated the plains of the south side of Long Island with the terrace of Hudson River, expressing his belief that a sloping plain could be cut on a rising or sinking coast without the formation of beaches.

In 1892 W. H. Dall and G. D. Harris [7] expressed the opinion, derived from a review of published literature, that Cretaceous and probably Tertiary formations are present on Long Island.

In 1893 McGee's geologic map of the United States [8] gave the northern half of the island as Cretaceous. Bryson [9] published three papers, all in favor of the subglacial theory. In the first he argued for the subglacial rather than submarine origin of the channels of the plains, as Shaler had postulated for Marthas Vineyard. In the second he placed the ice limit south of the island rather than at the moraines and correlated the Olympia mounds of Washington with the Easthampton dunes, referring both to subglacial action. In the third he considered the Shinnecock Hills to be of kame origin and Peconic Bay to be due to the action of subglacial streams. Heinrich Ries [10] followed Merrill in referring a large part of the clays of Long Island to the Tertiary period, but accepted the Cretaceous age of those at Elm Point, Glen Cove, Mosquito Inlet, Glenwood, and Northport. Ries pointed out the similarity of the clays of West Neck and Center Island to those of Fishers Island and recognized their folded condition and position beneath sand, which in turn is overlain by till. He recorded stems and leaves from the clays of East Williston.

The year 1893 was also marked by the appearance of the first contributions by Arthur Hollick on the Cretaceous formation of the island. In the first of these papers [11] he argues, from the evidence of the flora, for a former land connection with the New England islands and the mainland. Long Island Sound he ascribed to ice erosion, the moraines to ice shove, and East River and its channels to overflow from glacial streams behind the moraine, assisted by tidal scour. The moraine was believed to have been cut through in the "Champlain" period of submergence

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[1] Am. Jour. Sci., 3d ser., vol. 40, 1890, p. 430.

[2] On Cretaceous plants from Marthas Vineyard: Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 93–101.

[3] Bull. Geol. Soc. America, vol. 1, 1890, p. 555.

[4] Notes on the submarine channel of the Hudson River and other evidences of postglacial subsidence of the middle Atlantic coast region: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 489–499.

[5] Correlation papers, Cretaceous: Bull. U. S. Geol. Survey No. 82, 1891, pp. 84–86.

[6] On the postglacial history of the Hudson River valley: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 460–466.

[7] Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, 1892, pp. 38–39.

[8] Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, Pl. II.

[9] Bryson, John, The glacial geology of Marthas Vineyard compared with that of Long Island: Am. Geologist, vol. 11, 1893, pp. 210–212; The drift mounds of Olympia and Long Island: Idem, vol. 12, 1893, pp. 127–129; Origin of Peconic Bay and Shinnecock Hills, Long Island: Idem, vol. 12, 1893, pp. 402–403.

[10] Notes on the clays of New York State and their economic value: Trans. New York Acad. Sci., vol. 12, 1893, pp. 40–47.

[11] Plant distribution as a factor in the interpretation of geological phenomena, with special reference to Long Island and vicinity: Trans. New York Acad. Sci., vol. 12, 1893, pp. 189–202.

and the detached islands to have been thus formed. In the second paper [1] Hollick gave a summary of the previous writings on the island and a list of Cretaceous fossils. In the third and fourth papers [2] he recorded the finding of a palmlike fossil and described the plant. He quoted L. F. Ward as stating that the fragment is a Williamsonia and not a palm.

In 1894 four more papers by Hollick appeared. In the first [3] he described the distribution of fossiliferous ferruginous sandstone in the drift mainly west of Port Jefferson, and of the silicified Paleozoic fossils west of Lloyd Neck. These fossils occur mainly in the drift of the outer moraine, having been picked up by the ice at its first advance. The thick gravels were apparently considered by Hollick as the equivalent of the "yellow gravel" of New Jersey. In the second and third papers [4] he reported further discoveries of Cretaceous flora at Eaton, Lloyd, and Oak necks, Glen Cove, and Seacliff. In the fourth paper [5] he described the occurrence of pebbles containing Paleozoic fossils as far east as Eaton Neck, and on this evidence correlated the gravels (Manhasset formation) with the "yellow gravel" of New Jersey, notwithstanding their granitic character. He did not clearly indicate the age of the fossils but seems to have regarded them as pre-Pleistocene. In 1894 also the finding of Cretaceous leaves in water-worn sandstone fragments was recorded by C. L. Pollard,[6] and the occurrence of microscopic organisms of supposed Tertiary age in the clays at a large number of localities was reported by Heinrich Ries.[7] It is interesting to note that all these forms were found in beds which later work has shown to be Cretaceous, and none in what are now known to be Pleistocene clays, either on Long Island or on Fishers Island, although these clays were then thought by Ries to be Tertiary. A second paper by Ries [8] describes the discovery of Cretaceous fossils at Little Neck, in Northport, making it necessary to place the boundary farther south than had previously been done. In the meantime W J McGee,[9] who had investigated the unconformities of the Coastal Plain, reached the conclusion that although there had been erosion, amounting to 200 or 300 feet, since the Lafayette epoch, only about a foot had occurred since the Columbia. The Lafayette was regarded as marine and as separated from the overlying Columbia by the greatest unconformity of Neocene and Quaternary time. N. S. Shaler [10] gave considerable attention during the same year to the cause of the folding in the clays and associated beds of the New York and New England islands. He thought these folds to be similar to those of the Richmond Basin and to be due to downfolding and the production of a trough in the underlying crystalline rocks, with the resulting synclinorial structure in the softer beds—in fact as a part of the disturbance marked in the Coastal Plain farther south by faulting which has been going on since the movement in the Appalachians ceased. Shaler further stated that the folding can not be due to ice, for the folds were eroded before the Wisconsin ice advance. The earlier ice invasions were not then recognized by Shaler. Ries,[11] in discussing the same phenomena on Fishers Island, referred them to ice shove.

In 1895 A. M. Edwards [12] noted the finding of supposed fresh-water and marine Bacillariaceæ of Miocene age in clays near Rockaway. The deposits are now known to be Pleistocene or Recent, instead of Tertiary, as assumed by Edwards. Arthur Hollick,[13] in a paper on the folding

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[1] Preliminary contribution to our knowledge of the Cretaceous formation on Long Island and eastward: Trans. New York Acad. Sci., vol. 12, 1893, pp. 222–231.

[2] A new fossil palm from the Cretaceous formation at Glen Cove, Long Island: Bull. Torrey Bot. Club, vol. 20, 1893, pp. 168–169; Some further notes upon *Serenopsis kempii:* Idem, pp. 334–335.

[3] Some further notes on the geology of the north shore of Long Island: Trans. New York Acad. Sci., vol. 13, 1894, pp. 122–130.

[4] Additions to the paleobotany of the Cretaceous formation of Long Island: Bull. Torrey Bot. Club, vol. 21, 1894, pp. 49–65; Recent investigations in the Cretaceous formation on Long Island, New York: Proc. Am. Assoc. Adv. Sci., vol. 42, 1894, p. 175.

[5] Notes on the northward extension of the yellow gravel in New Jersey, Staten Island, Long Island, and eastward: Proc. Am. Assoc. Adv. Sci., vol. 42, 1894, pp. 175–176.

[6] Trans. New York Acad. Sci., vol. 13, 1894, pp. 180–181.

[7] Microscopic organisms in the clays of New York State: Idem, pp. 165–169.

[8] On the occurrence of Cretaceous clays at Northport, Long Island: School of Mines Quart., vol. 15, 1894, pp. 354–355.

[9] Graphic comparison of post-Columbia and post-Lafayette erosion: Am. Geologist, vol. 12, 1894, p. 180.

[10] Tertiary dislocations of the Atlantic coast of the United States: Am. Geologist, vol. 13, 1894, pp. 143–144; Notes on the Pleistocene distortions of the Atlantic coast of the United States: Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 138; Pleistocene distortions of the Atlantic seacoast: Bull. Geol. Soc. America, vol. 5, 1894, pp. 199–202.

[11] Trans. New York Acad. Sci., vol. 14, 1895, p. 20.

[12] The occurrence of Tertiary clay on Long Island, New York: Am. Jour. Sci., 3d ser., vol. 50, 1895, p. 270.

[13] Dislocations in certain portions of the Atlantic Coastal Plain strata and their probable causes: Trans. New York Acad. Sci., vol. 14, 1895, pp. 8–20.

of the clays and associated beds, noted that the disturbance is limited to the region covered by ice and is essentially superficial. He could see no evidence of preglacial topography. The "yellow gravel" (Manhasset formation) he regarded as the equivalent of the Lafayette. Heinrich Ries [1] referred a large number of the clay outcrops to the Tertiary, noting especially the similarity of the clays of Center Island, West Neck, and Fishers Island, which are "probably of the same age, possibly Tertiary." He recognized, however, the Cretaceous age of most of the clays of the north shore west of Northport. L. F. Ward,[2] in discussing the New Jersey equivalents of the Cretaceous of Long Island in the same year, referred them to the Lower Cretaceous. J. S. Newberry,[3] in writing on the clays of Amboy, N. J., correlated the clays of Long Island with the basal Cretaceous as developed in New Jersey.

In 1896 N. H. Darton [4] published a geologic section across the west end of the island and gave a number of well records. A. M. Edwards,[5] in a second paper on the Diatomaceæ, described the finding of 70 species near Far Rockaway in clays supposed then to be of Neocene age but shown by late work to be unquestionably Pleistocene or Recent. Arthur Hollick published two papers during the year. The first [6] contained an account of the finding of lithologic evidences of marl on the north shore near Oyster Bay, of Cretaceous mollusks in greensand fragments in the drift at East New York, and of ferruginous concretions with mollusks in the deposits at Montauk. The second paper [7] presents the additional suggestion that the clays of Little Neck near Northport have been pushed southward in a mass, as they should be north instead of south of the marl, fragments of which were found at Center Island. There seems to be some likelihood of error in such conclusions because of the assumption that fragments of ferruginous sandstone are weathered masses of marly deposits. W J McGee,[8] in another paper on the erosion epochs, placed the great erosion following the deposition of the Lafayette in the "Ozarkian" and assigned it to late Neocene time. He also recognized two interglacial periods of erosion. L. F. Ward [9] reintroduced the term "Island series," originally proposed by Mather, for the Cretaceous deposits of Long Island and correlated them on the evidence of the flora with the clays of Raritan and Amboy, N. J. O. C. Marsh [10] in the same year made the somewhat startling announcement, based on the Jurassic aspect of certain fossils found in Maryland, that all the deposits hitherto regarded as Cretaceous should be referred to the Jurassic.

In 1897 John Bryson [11] noted erratics on the "kame moraine" near East Williston, the first recognition of the outer moraine at this point. L. F. Ward [12] pointed out that the clays of Amboy, N. J., with which the clays of Long Island had been correlated, were distinctly younger than the Potomac of Maryland and Virginia. Lewis Woolman [13] published a number of records of wells near the west end of the island.

In 1898 John Bryson [14] described some contorted drift with interbedded till [Montauk?] in Brooklyn. Arthur Hollick [15] assigned the clays of Amboy, on the evidence of their flora, to the "Middle Cretaceous," though not denying that the older Potomac might be Jurassic. In another paper [16] Hollick gave additional notes on the occurrence of lumps of Cretaceous clay, some of them with fossils, in the drift, and on the finding of marl concretions on Montauk. Warren Upham [17] described the submarine channel off New York, postulating an uplift to 3,000 feet at the end of the Tertiary period. He regarded the fossils of Gardiners Island as preglacial.

[1] Clay industries of New York: Bull. New York State Mus. Nat. Hist. No. 12, 1895.
[2] The Potomac formation: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 345-346.
[3] The flora of the Amboy clays: Mon. U. S. Geol. Survey, vol. 26, 1895.
[4] Artesian-well prospects in the Atlantic Coastal Plain region: Bull. U. S. Geol. Survey No. 138, 1896.
[5] On the occurrence of Neocene marine Diatomaceæ near New York: Am. Naturalist, vol. 30, 1896, pp. 212-216.
[6] Geological notes, Long Island and Nantucket: Trans. New York Acad. Sci., vol. 15, 1896, pp. 3-10.
[7] Recent discovery of the occurrence of marine Cretaceous strata on Long Island: Proc. Am. Assoc. Adv. Sci., vol. 44, 1896, pp. 133-135.
[8] Two erosion epochs: Science, new ser., vol. 3, 1896, pp. 796-799.
[9] Age of the Island series: Science, new ser., vol. 4, 1896, pp. 757-760.
[10] The geology of Block Island: Am. Jour. Sci., 4th ser., vol. 2, 1896, pp. 295-298, 375-377.
[11] The Hempstead Plains, Long Island: Am. Geologist, vol. 20, 1897, pp. 61-65.
[12] Prof. Fontaine and Dr. Newberry on the age of the Potomac formation: Science, new ser., vol. 5, 1897, pp. 411-423.
[13] Artesian wells in Cretaceous strata on Long Island, New York: Rept. New Jersey Geol. Survey for 1896, 1897, pp. 155-165.
[14] Drift formations of Long Island: Am. Geologist, vol. 22, 1898, pp. 245-247.
[15] The age of the Amboy clay series, as indicated by its flora: Am. Geologist, vol. 22, 1898, pp. 255-256; Science, new ser., vol. 8, 1898, pp. 467-468.
[16] Geological notes, Long Island and Block Island: Trans. New York Acad. Sci., vol. 16, 1898, pp. 9-18.
[17] Glacial history of the New England islands, Cape Cod, and Long Island: Am. Geologist, vol. 24, 1899, pp. 79-92.

He recognized an early ice advance, producing the folding, as occurring before the advance that produced the moraines, and he suggested that the Kansan, Illinoian, Iowan, and early Wisconsin stages of glaciation in the Mississippi Valley may have taken place between the folding and the formation of moraines. The topography of the plateau and its deep valleys Upham thought to be due to the deposition of gravel around ice blocks. He pointed out the thinness of till near the limits of glaciation.

In 1900 W. O. Crosby [1] stated the principal formations of the island to be (1) crystalline, (2) Cretaceous, (3) Neocene Tertiary, and (4) terminal moraine. The surface gravels both north and south of the moraine, although granitic in character, he correlated with the "yellow gravels" of New Jersey and regarded as Lafayette. The "blue clay," which was supposed to form a uniform floor beneath the gravels, he referred to the Chesapeake. The gray gravels, notwithstanding their high percentage of granitic material, he likewise included in the Tertiary. These three formations are probably to be correlated with the Manhasset, Gardiners, and Jameco formations of the present report. Crosby supposed the Cretaceous to be confined to the northern part of each neck of the north shore and the Tertiary to be farther south on the same necks but going under the surface near the head of each bay or harbor. The exposures at East Williston, Bethpage, and West Deer Park he regarded as Tertiary and supposed to have been brought up by the pressure and thrust of the ice sheet. He considered the north-shore scarp to have been worn back by lateral tributaries of Connecticut and Housatonic rivers during an uplift of 3,000 feet preceding the ice advance.

In the same year F. J. H. Merrill [2] postulated an origin for the white Cretaceous clays of Long Island from the decomposition of the Lower Silurian [Ordovician] limestone and argued for the origin of Long Island Sound and East and North rivers through the solution of such rocks. Heinrich Ries [3] published an account of the clays, which, however, was essentially the same as an earlier paper.

LITERATURE FROM 1901 TO 1908 (LATER DRIFT PHASE).

Previous to 1901 no systematic studies of the island as a whole or of any considerable part of it had been attempted, with the exception of Mather's investigations from 1837 to 1843, although the detailed reconnaissances of Upham and Merrill approached such studies in character. In the period beginning with 1901, however, a number of reports have appeared that have been based on detailed and systematic field observations covering not only the surface deposits but also the underground geology as worked out from the records of many hundreds of wells and borings. The attempt has been made, moreover, to approach the problem from the standpoint of the student of geologic history and to apply knowledge of the drift succession in other parts of the country to the differentiation of the deposits of Long Island.

The first publication of the period was the geologic map of Long Island,[4] based on field work by J. B. Woodworth and J. E. Woodman and issued by the Geological Survey of New York. On this map the moraines were mapped in detail, and the fact that the later moraine crosses the older one near Lake Success was pointed out for the first time. The Westbury, West (Mannetto), and Half Hollow hills, which later work has shown to be much older, were shown as moraines, and the gravels of the ridge at Rockaway, now known to be Pleistocene, were referred to the Tertiary. In the same year J. B. Woodworth [5] published the results of a careful study of the Oyster Bay and Hempstead areas. He mapped the outcrops of Cretaceous rocks and clearly pointed out the Pleistocene nature of the thick gravels of the north shore (Manhasset formation) and the included bowlder bed (Montauk till member of Manhasset). In the region north of the moraine these gravels were also carefully mapped and their probable extension southward was indicated. Woodworth recorded the presence of underlying blackish or bluish clays, but considered that they are "not certainly of glacial origin and perhaps to be

[1] Outline of the geology of Long Island in its relation to the public water supplies: Tech. Quart., vol. 13, 1900, pp. 100–119.

[2] Origin of the white and variegated clays of the north shore of Long Island: Annals New York Acad. Sci., vol. 12, 1900, pp. 113–116.

[3] Clays of New York: Bull. New York State Mus. No. 35, 1900.

[4] Geologic map of New York, 1901, Long Island and Lower Hudson sheets.

[5] Pleistocene geology of portions of Nassau County and the Borough of Queens: Bull. New York State Mus. No. 48, 1901, pp. 617–670.

regarded as of Tertiary or older age." He admitted that the altitude of much of the Cretaceous material is due to ice shove but recognized a strong erosion unconformity between the Cretaceous and the Pleistocene. The bowlder bed in the Manhasset formation was recognized at many points and its change laterally from till-like to stratified materials noted. He described in detail the great erosion period following the early Pleistocene deposition but preceding the deposition of the last drift, which had not been recognized by Crosby and had been explicitly denied by Hollick. The deposition of the high gravels at Harbor Hill, Woodworth ascribed to subglacial streams. He discussed the straight face of the moraine west of Jamaica but reached no definite conclusion as to its origin. He suggested that the Jamaica Bay depression is an original constructional feature of deposition and that the Rockaway ridge is a remnant of the Tertiary. The moraine he distinctly recognized as superimposed on the Manhasset, representing simply a local thickening of the till sheet. The geologic history as outlined by Woodworth is as follows: (1) Erosion of the Cretaceous, (2) deposition of earlier Columbia deposits (Herod gravel member of Manhasset formation), (3) advance of the ice and deposition of the bowlder bed (Montauk till member of Manhasset), (4) completion of the deposition of the Columbia (Hempstead gravel member of Manhasset), (5) long period of erosion, (6) invasion by latest ice sheet (Wisconsin), and (7) retreatal deposition in glacial lakes. While many of the points brought out were not new, this paper was in many ways the most important that had yet appeared, as Woodworth did not stop with general statements but systematically described and discussed the various deposits and differentiated them for the first time on a map.

A paper by G. B. Shattuck [1] presented the following summary of the later Coastal Plain history: (1) Subsidence and deposition of the Lafayette, (2) elevation and erosion of the Lafayette, (3) subsidence and deposition of the Sunderland, (4) elevation and erosion of the Sunderland, (5) subsidence and deposition of the Wicomico, (6) elevation and erosion of the Wicomico, (7) subsidence and deposition of the Talbot, (8) elevation and erosion of the Talbot, and (9) subsidence and deposition of the Recent deposits. Shattuck stated that because of the difference in method of classification exact correlation with the New Jersey deposits could not be made, and he presented a table in which he suggested the correlation of the Sunderland with parts of Cape May, Pensauken, and Bridgeton; of the Wicomico also with parts of the Cape May, Pensauken, and Bridgeton; and of the Talbot with parts of the Cape May and Pensauken.

In the following year, 1902, appeared the New York folio,[2] in which that part of Long Island lying west of the area treated by Woodworth was fully described. In this folio an early Pleistocene elevation, during which the submarine channel was excavated and the channels of the East River were cut by a tributary stream, was assumed,[3] and the possibility of earlier glaciers similar to the last was suggested.[4] The possibility of old Pleistocene gravels correlatable with the Pensauken of New Jersey occurring beneath the late till of Staten Island was pointed out,[5] but no mention of their occurrence on Long Island was made. At least two ice advances were considered to have occurred in the region. The superimposition of the relatively thin moraine on older deposits was likewise recognized. The steepness of its face west of Jamaica was not attributed to marine erosion. The plains of the south side of the island were described, and the fact that their topography is not that of normal outwash plains was pointed out. The Rockaway ridge was attributed to marine action in late glacial or postglacial time, when the land was somewhat depressed. Although at least two glacial invasions in the region were admitted and the occurrence of stratified gravels below the Wisconsin till was noted, the existence of any extensive deposits of an earlier stage does not appear to have been recognized, the materials beneath the till apparently being referred to an earlier deposit of the same stage instead of to a distinct deposition separated from the last ice invasion by a long period of erosion, as postulated by Woodworth in the adjoining area on the east.

[1] The Pleistocene problem of the north Atlantic Coastal Plain: Circ. Johns Hopkins Univ. No. 152, 1901; Am. Geologist, vol. 28, 1901, pp. 87-107.
[2] Merrill, F. J. H., and others, New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.
[3] Willis, Bailey, and Dodge, R. E., Physiographic features of the district: Idem, pp. 17-18.
[4] Willis, Bailey, Outline of geologic history: Idem, pp. 2-3.
[5] Salisbury, R. D., Pleistocene formations: Idem, pp. 11-17.

G. B. Shattuck [1] published a second paper during the year reiterating the Coastal Plain subdivisions proposed in 1901.

In 1903 the present writer, assisted by A. C. Veatch and others, began a detailed study of the geology and water resources of the island. In a preliminary notice by Veatch,[2] who devoted himself largely to collecting well records and studying underground geology, the "uniform blue clay floor" of supposed Chesapeake age, which had been postulated by Crosby and others, was shown to be absent, and the presence of a deep buried valley across the island west of Jameco was pointed out. In this notice the present writer was credited with the discovery in the Wheatley Hills of hitherto unrecognized gravel deposits [Mannetto] older than the Manhasset formation and with the recognition of terraces of the Manhasset south of the moraine near Bethpage. A detailed section at the top of the hill west of Mellville was given, showing a considerable thickness of quartz gravels containing a few weathered granitic pebbles and underlain by sands, clays, "arkose," etc., of pre-Pleistocene age. The dip of the Cretaceous was determined for the first time, well borings showing it to be about 65 feet to the mile in the direction S. 23° E.

In another paper [3] Fuller and Veatch called attention to the extension of the Cretaceous to the Bethpage and Wyandance localities and to the discovery of greensand in the Millville section. The absence of Tertiary deposits was noted, the older gravels having been determined to be early Pleistocene. The supposed Chesapeake clays were separated into a number of formations, all of Pleistocene age. Gravels of glacial origin and of supposed Kansan age were noted beneath the early Pleistocene clay in the buried valley west of Jamaica. The occurrence of gravels of the Manhasset formation was recognized as far east as Montauk Point and their age was given as probably Iowan. The thinness of the outwash is emphasized for the first time. Later the present writer [4] discussed two of the pre-Wisconsin deposits in more detail. The older, deeply weathered gravels of the Westbury or Wheatley Hills and the West or Mannetto Hills were correlated with the Pensauken formation of New Jersey and assigned provisionally to water deposition during a pre-Kansan stage of glaciation, and their correlation with McGee's high-level Columbia of New Jersey and farther south and with the deposits of the Monongahela and Alleghany terraces was suggested. The discovery of a glacially derived gravel [Jameco] resting unconformably on the old weathered gravel [Mannetto] and of an extensive bed of Pleistocene clay [Gardiners] directly above it and the recognition of an epoch of folding by ice thrust were credited to Veatch, who assigned the glacial gravel to the Kansan, the clay to the Yarmouth, and the folding to the Illinoian stage. On the basis of these discoveries the unfolded Manhasset was referred to the Iowan. Veatch,[5] in a paper published a few weeks later, described the clays and old gravels of Gardiners Island, their contained fossils, and their folding and erosion. He gave the following succession for Long Island: (1) Pensauken gravel [Mannetto], glacial; (2) Jameco gravel, glacial; (3) Sankaty clay [Gardiners], interglacial; (4) Manhasset, glacial; (5) Wisconsin, glacial. The correlations with the various glacial stages are the same as in the preceding paper.

Four other papers relating to Long Island appeared during the year. E. P. Buffet [6] discussed the topography, bowlders, and beaches from the standpoint of the geographer. Arthur Hollick [7] gave a list of paleontologic accessions from Glen Cove. Heinrich Ries [8] referred the clays of Staten, Long, and Fishers islands to the Cretaceous, no Pleistocene clays on Long Island being mentioned. J. W. Spencer [9] described the submarine channel off New York, stating that its continuation may be inferred to a depth of 8,500 feet below the "cul-de-sac" of Lindenkohl.

[1] The Pleistocene problem in Maryland: Science, new ser., vol. 15, 1902, pp. 906-907.
[2] Notes on the geology of Long Island: Science, new ser., vol. 18, 1903, pp. 213-214.
[3] Results of the resurvey of Long Island: Science, new ser., vol. 18, 1903, pp. 729-731.
[4] Probable pre-Kansan and Iowan deposits of Long Island: Am. Geologist, vol. 32, 1903, pp. 308-312.
[5] The diversity of the glacial period on Long Island: Jour. Geology, vol. 11, 1903, pp. 762-776.
[6] Some glacial conditions and recent changes on Long Island: Jour. Geography, vol. 2, 1903, pp. 95-101.
[7] Field work during 1901 in the Cretaceous beds of Long Island: Fifty-fifth Ann. Rept. New York State Mus., 1903, pp. r 48-r 51.
[8] Clays of the United States east of the Mississippi River: Prof. Paper U. S. Geol. Survey No. 11, 1903, pp. 173-175.
[9] Submarine valleys off the American coast and in the North Atlantic: Bull. Geol. Soc. America, vol. 14, 1903, p. 214.

The cutting he thought to be mainly post-Miocene, although it may have begun earlier, being completed in post-Lafayette but pre-Columbia time. The Connecticut he regarded as flowing eastward, stating that there is no evidence of a channel across Long Island.

The year 1904 was characterized by a marked falling off in the literature dealing directly with Long Island. Arthur Hollick[1] described a number of new discoveries of fossil plants, including one from "Cretaceous shale" at Montauk Point. In a letter Dr. Hollick states that this was not found in place and that the Cretaceous does not at the present time show above sea level, hence his observations are really in accord with those of the present writer, who regards all the deposits as Pleistocene. C. E. Peet,[2] who studied the drift of the Hudson Valley, found masses of till both over and under the drift and clay bowlders within it, especially in the southern part of the area. Over the clay he noted also in many places a gravel with an undulating topography [Manhasset ?], the contact appearing as if the gravel had been pressed into the clay.

In 1905 W. H. Hobbs[3] published two papers in which he gave a number of sections across East River that showed the underlying rock to be mainly gneiss, with only two narrow local beds of limestone. He therefore regarded the channel as due to faulting and jointing rather than to solution of the limestone. In the same year the first presentation of the Pleistocene stages now recognized was made by the present writer[4] in a paper on Fishers Island. Although this paper did not deal primarily with the larger island, the Long Island succession was described in detail; all the divisions except the Hempstead and Vineyard were recognized and names were applied to the Gardiners, Jacob, Herod, and Montauk stages and substages. A further contribution to the literature on the submarine Hudson channel was made by J. W. Spencer,[5] who stated that he could trace it to a depth of about 9,000 feet below the surface of the sea.

Early in 1906 there appeared in Chamberlin and Salisbury's text book[6] a geologic map of the United States compiled by Bailey Willis, on which the north side of Long Island is shown as Cretaceous. The present writer[7] summarized the Pleistocene stages of the region and described the Long Island subdivisions and their equivalents on the mainland. An important contribution was made by A. C. Veatch[8] in a chapter of the report giving the results of the underground-water investigations by the United States Geological Survey. The Pleistocene formations recognized were identical with those discussed in the earlier paper by the same author in 1903, the new stages differentiated by the present writer, including the Jacob, Herod, Montauk, and Hempstead of this report, not being recognized. Veatch's report was prepared two years previous to its publication and before the subdivisions mentioned had been differentiated. Although no new stages were recognized, the paper was of importance as presenting a detailed statement of the subdivisions as they had been worked out in the first season's field work and fuller descriptions than had been given in the preliminary papers of 1903. Correlations were made with the deposits of Marthas Vineyard, but none were attempted with the drifts of the central part of the country nor with the Pleistocene formations of the Atlantic Coastal Plain. An important contribution to the knowledge of the Cretaceous deposits was made, these accumulations being regarded as the equivalents of the Raritan and Matawan formations of New Jersey and as being of Upper Cretaceous age. Veatch gave an extended discussion of the origin of Long Island Sound, which he ascribed to excavation by a westward-flowing stream crossing western Long Island and joining the submarine channel off Sandy Hook. In the same year Arthur Hollick[9] added to the information regarding the Cretaceous, and G. B. Shattuck's final report on the Pleistocene deposits of Maryland[10] was published, in which he still further elaborated his views.

1 Additions to the paleobotany of the Cretaceous formation on Long Island, No. II: Bull. New York Bot. Garden, vol. 3, 1904, pp. 403–418.

2 Glacial and post glacial history of the Hudson and Champlain valleys: Jour. Geology, vol. 12, 1904, pp. 415–469, 617–660.

3 Origin of the channels surrounding Manhattan Island, New York: Bull. Geol. Soc. America, vol. 16, 1905, pp. 151–182; The configuration of the rock floor of Greater New York: Bull. U. S. Geol. Survey No. 270, 1905, 93 pp.

4 Geology of Fishers Island, New York: Bull. Geol. Soc. America, vol. 16, 1905, pp. 367–390.

5 The submarine great canyon of the Hudson River: Am. Jour. Sci., 4th ser., vol. 19, 1905, pp. 1–15.

6 Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 2, 1906, colored plate.

7 Glacial stages in southeastern New England and vicinity: Science, new ser., vol. 24, 1906, pp. 467–469.

8 Outline of the geology of Long Island: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 15–52.

9 The Cretaceous flora of southern New York and New England: Mon. U. S. Geol. Survey, vol. 50, 1906.

10 Pliocene and Pleistocene, Maryland Geol. Survey, 1906.

No important papers bearing on the geology of Long Island were published in 1907, but in 1908 appeared a paper by F. G. Clapp [1] that was of unusual interest as showing the existence of the Long Island subdivisions or their equivalents in northern Massachusetts, in New Hampshire, and throughout Maine. The latest contribution to Long Island geology at the time of writing (1908) is an article by W. O. Crosby,[2] who reiterated his earlier belief in the unity of the glacial epoch and assumed only a single invasion, the Wisconsin. He referred the Gardiners clay to a Tertiary epoch (that of the Chesapeake group of the Miocene). The Pleistocene character of its fossils as determined by W. H. Dall and other competent paleontologists and the nonagreement of the deposits in character nor elevation with the adjacent Miocene deposits of New Jersey were disregarded. The large amount of granitic material, which is entirely at variance with the character of the Tertiary deposits elsewhere, especially with the clayey and marly deposits of this age in New Jersey, and the presence of large erratic bowlders in the Jameco and Mannetto were likewise regarded as without significance and these two formations were referred to the Oligocene. The heavy Montauk member of the Manhasset formation, several times as thick as the Wisconsin, was not recognized.

LITERATURE OF CONTEMPORARY PLEISTOCENE DEPOSITS IN NEW JERSEY.

In 1891 R. D. Salisbury published the first of a series of reports on the surface geology of New Jersey which has a direct bearing on the geologic history of Long Island. In this report [3] he compared the older extramorainic drift, which he regarded as the equivalent of the oldest drift of the interior, and the younger morainic drift. The weathering of the former he gives as at least 30 feet, but that of the latter as only 2 or 3 feet. In the second report [4] he gave considerable attention to the "yellow gravels," which were shown to be a complex series, in part of Tertiary and in part of Pleistocene age, containing some apparently berg-dropped bowlders. The essential completion of their present topography before the advent of the last ice sheet is recognized. The following tentative stages are postulated: (1) Submergence to 400-foot level and deposition of gravel; (2) elevation and long-continued erosion reducing the surface by 120 to 150 feet; (3) depression to 150 feet below the present level, with deposition of gravel and possibly the introduction of ice-rafted bowlders; (4) elevation and moderate erosion to the present level; (5) slight depression and formation of low terraces, and (6) elevation of about 40 feet. In the third report [5] he applied the name Beacon Hill to older gravels and Pensauken to the next younger. A new stage of submergence, marked by the deposition of loamy silts ("Jamesburg loam") with complex nonerosion topography, was postulated as occurring after the erosion of the Pensauken and before the deposition of the gravels of the low terraces. In his fourth report [6] Salisbury subdivided the Pensauken into a lower part, consisting of horizontally stratified loamy arkose sand, and an upper part, consisting largely of irregularly stratified lenticular beds of gravel which contain scattered ice-rafted bowlders and in which many of the granitic pebbles are deeply weathered. The upper part is clayey in many places in the northern part of New Jersey and presents vertical faces in artificial cuts, but this character does not prevail farther south. With few exceptions the gravel is heterogeneous both physically and lithologically, its constituents ranging from half an inch to 4 feet in diameter (compare with Montauk, p. 132). The "Jamesburg loam" was described as an imperfectly stratified surface mantle, in places much bent and contorted as if shoving or thrusting action had taken place. Its correlation with an older drift is suggested. Elsewhere Salisbury referred the Pensauken definitely to the Lafayette, stating: "There can no longer be any doubt that the Pensauken is the equivalent of the Lafayette formation of the south." The report for 1895 [1] was mainly descriptive of new localities, but the presence of clays in the Pensauken was noted, and the questionable character of the evidence for the separation of the "Jamesburg loam" pointed out. In the next report by Salisbury and G. N. Knapp,[2] the noticeable till-like char-

[1] Complexity of the glacial period in northeastern New England: Bull. Geol. Soc. America, vol. 18, 1908, pp. 505–556.
[2] Outline of the geology of Long Island: Science, new ser., vol. 28, 1908, p. 936.
[3] Preliminary paper on drift or Pleistocene formations of New Jersey: Rept. New Jersey Geol. Survey for 1891, pp. 35–108.
[4] Surface geology: Idem for 1892, pp. 33–166.
[5] Surface geology: Idem for 1893, pp. 33–328.
[6] Surface geology: Idem for 1894, pp. 1–150.

acter of certain parts of the Pensauken and the presence of striated bowlders were mentioned, and a new subdivision of the Pensauken with Beacon Hill affinities was suggested. The Pensauken was at this time regarded as glacial. In the report for 1897 [3] this subdivision was specifically defined as a gravel, sand, and loam formation, locally clayey, distinctly higher than the Pensauken, and intermediate in age between the Pensauken and the Beacon Hill. The name Bridgeton was applied to it and it was tentatively correlated with the Lafayette; the Pensauken was considered as "probably contemporaneous with an early glacial epoch (Kansan or Albertan)." The "Jamesburg loam" seems to be dropped from the list of formations, apparently for the reason that later work had shown it to be simply a surficial phase of the older deposits. The report for 1898 [4] dealt largely with the Cape May formation, or the terraces at 40 feet or thereabouts.

The physiographic history of the State was discussed in the report on physical geography,[5] but nothing new was adduced.

A report by R. D. Salisbury, H. B. Kümmel, C. E. Peet, and G. N. Knapp [6] gave an interesting summary of the Pleistocene history of New Jersey. The "only glacial formations which have been distinctly recognized in New Jersey are those of the Kansan (?) and Wisconsin formations." [7] The clays below sea level around Hackensack were regarded as equivalent to the "Champlain and Hudson River clays." A post-Wisconsin submergence of 40 feet in the southern part of the State was recognized and one of 100 feet in the northern part was suggested.

THE PRESENT REPORT.

Although dealing with the pre-Pleistocene as well as the Pleistocene geology of the island, the present report gives chief attention to the latter, largely because the new discoveries have related mainly to the Pleistocene formations. The report attempts, however, to arrange the Cretaceous beds for the first time in a number of groups, which are in general sufficiently distinctive lithologically to admit of the assignment of outcrops to their proper places with some degree of certainty. Until information that will permit a more precise definition is available, however, it does not appear desirable to apply new formation names to them. Their distribution is shown on Plate I (in pocket) and figure 56 (p. 69). The results of the Pleistocene work are best shown by the following table, in which the stages recognized, their origin, the deposits by which they are characterized, and their probable correlations with the deposits of central United States are given.

[1] Surface geology: Rept. New Jersey Geol. Survey for 1895, pp. 1-16.
[2] Surface geology: Idem for 1896, pp. 1-24.
[3] Surface geology: Idem for 1897, pp. 1-22.
[4] Report on surface geology: Idem for 1898, pp. 1-42.
[5] The physical geography of New Jersey: Final Rept. New Jersey Geol. Survey, vol. 4, 1895.
[6] The glacial geology of New Jersey: Final Rept. New Jersey Geol. Survey, vol. 5, 1902.
[7] Idem, p. 189.

Pleistocene events on Long Island.

<table>
<tr><th>Stage.</th><th>Substage.</th><th>Character.</th><th colspan="2">Represented by—</th><th>Thickness.</th><th>Probable time equivalents in Mississippi and Ohio valleys, etc.</th></tr>
<tr><td rowspan="2">Wisconsin.</td><td>Harbor Hill.</td><td>Glacial.</td><td colspan="2">Harbor Hill or inner moraine, and associated till and outwash.</td><td>Feet.</td><td rowspan="2">Early Wisconsin.</td></tr>
<tr><td>Ronkonkoma.</td><td>Glacial.</td><td colspan="2">Ronkonkoma or outer moraine, and associated till and outwash.</td><td></td></tr>
<tr><td>Vineyard.</td><td></td><td>Interglacial.</td><td colspan="2">Great erosion unconformity, and Vineyard formation, consisting of marine deposits and peat.</td><td></td><td>Sangamon (?), Iowan (?), and Peorian (?).</td></tr>
<tr><td rowspan="5">Manhasset.</td><td rowspan="2">Hempstead.</td><td rowspan="5">Glacial.</td><td rowspan="5">Manhasset formation.</td><td>Hempstead gravel member.</td><td>50–75</td><td rowspan="6">Illinoian.</td></tr>
<tr><td>Ice erosion unconformity.</td><td></td></tr>
<tr><td rowspan="2">Montauk.</td><td>Montauk till member:
1. Till.
2. Gravel.
3. Till.</td><td>0–60+</td></tr>
<tr><td>Ice erosion unconformity.</td><td></td></tr>
<tr><td>Herod.</td><td>Herod gravel member.</td><td>50–75</td></tr>
<tr><td>Jacob.</td><td></td><td>Transitional.</td><td colspan="2">Jacob sand.</td><td></td></tr>
<tr><td>Gardiners.</td><td></td><td>Interglacial.</td><td colspan="2">Gardiners clay.</td><td></td><td>Yarmouth.</td></tr>
<tr><td>Jameco.</td><td></td><td>Glacial.</td><td colspan="2">Jameco gravel.</td><td></td><td>Kansan.</td></tr>
<tr><td>Post-Mannetto.</td><td></td><td>Interglacial.</td><td colspan="2">Great erosion unconformity.</td><td></td><td>Aftonian.</td></tr>
<tr><td>Mannetto.</td><td></td><td>Glacial.</td><td colspan="2">Mannetto gravel.</td><td></td><td>Pre-Kansan.</td></tr>
</table>

In addition to the detailed descriptions of the various deposits, the older Pleistocene subdivisions, including all those antedating the Wisconsin, are for the first time shown on a map. The probable extension of the formations along the New England coast toward the northeast, their correlations with the New Jersey formations, the detailed geologic history of the island, the orogenic movements that have taken place upon it, and the relative length of its various geologic stages also receive attention. Special consideration is given to the topographic and physiographic features, including the various forms of Wisconsin drift, the submerged Sound valley, and the submarine valley and canyon of Hudson River. The conclusion is reached that the Sound is in no way related to the submarine channel heading off Sandy Hook but is the result of eastward-draining streams. The cutting of the Hudson channels is referred to Pleistocene rather than to Tertiary time. A table in which the points of interest are arranged geographically is provided to aid those who may have opportunities for field examinations in the region.

The Pleistocene deposits of Long Island are unusually complicated—their variations from point to point, the existence of great unconformities at several horizons, and the general similarity of many of the beds of different ages all combining to render the decipherment of their history a work of great difficulty. No complete section is found at any one point, and in order to establish the entire sequence it is necessary to patch together fragments of evidence from many scattered localities. The main events of the geologic history, however, seem to be clear, and inasmuch as they have been corroborated at many places in New England they may be regarded as established. Mistakes in details are inevitable in so complicated a region, and no doubt in the earlier parts of the investigation many things escaped observation which, if the work were to be done over with the main events of the history as now established in mind, could not fail to be noted. Furthermore, to obtain even a large share of the facts accessible would require, as on Gardiners Island, weeks of study where only a day or two was available. It is not improbable that on further investigation many new incidents will come to light, and the history of the island will prove to be more varied in detail than is here outlined.

PHYSIOGRAPHY.

SIGNIFICANCE OF TOPOGRAPHY.

There are few places in which so intimate a relation between topography and geology exists as on Long Island. The more conspicuous physiographic features, such as the plateaus of the north side of the island, the ridges constituting the so-called backbone, and the gently sloping plains of the south side, to say nothing of the form of the island itself, are all of constructional origin or the result of structure developed by geologic forces. In many parts of the island, especially in the southern half, the topography furnishes the clue for the recognition of many deposits whose composition, texture, or structure gives no help in differentiation. In fact, with the exception of the bluff studies and the collection of well records, the examination of the region was necessarily made mainly from the physiographer's standpoint, and a large part of the conclusions as to the deposits of the interior of the island are based on physiographic evidence. Thus one approaching the north shore from the water anywhere west of Port Jefferson sees before him a high plateau stretching back inland with an apparently level surface, upon which a number of miles from the shore a high ridge rises abruptly 100 to 150 feet or more above the plateau surface (fig. 3). A close inspection of the plateau shows it to be an accumulation of stratified materials, and a glance at the ridge shows its morainal character. We have, then, one great formation (the moraine), with another (the plateau gravels) underlying or backed up against it, but which of the two possible relations actually exists seems at first sight difficult to determine from the topography alone. After crossing the moraine one passes out upon a broad plain (fig. 4, *c*) everywhere gently sloping southward from its highest edge next to the morainal ridge and at once identified from its contour as an outwash formation contemporaneous with the moraine. A few miles south of the moraine, however, irregularities commonly begin to appear. Mounds, low ridges, and even broad, flat-topped plateau remnants emerge above the sloping surface and stand with their summits at elevations approaching more or less closely that of the plateau north of the moraine (fig. 4, *d*). A study of the erosion features of both the northern and southern parts of the plateau surface shows that it has an erosion topography far more advanced than that of the moraine or other Wisconsin deposits, the work done on it being 25 to 50 or more times that which has been accomplished since the deposition of the later drift. From topography alone, therefore, without the evidence of sections, it is obvious that the moraine is the later and rests upon an eroded plateau (Manhasset).

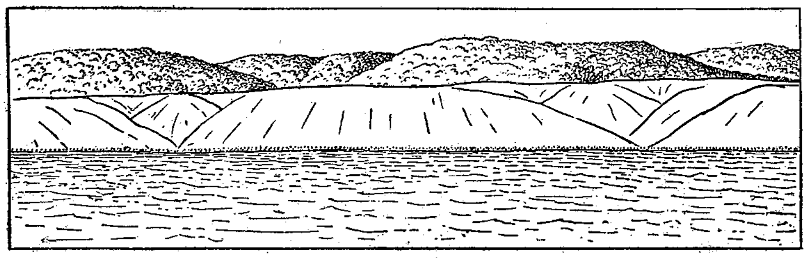

FIGURE 3.—Manhasset plateau and the superimposed moraine as seen from Long Island Sound.

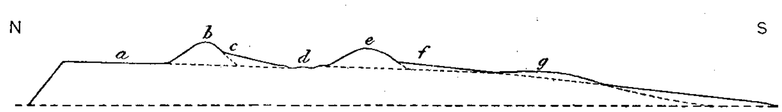

FIGURE 4.—North-south profile of Long Island. *a*, Manhasset plateau; *b*, Harbor Hill moraine; *c*, outwash from ice along Harbor Hill moraine; *d*, Manhasset surface; *e*, Ronkonkoma moraine; *f*, outwash from ice along Ronkonkoma moraine; *g*, Manhasset ridge projecting above outwash.

Farther south another ridge, likewise shown by its topography to be a moraine, rises above the older surface and is bordered by a second outwash, through which the plateau surface projects as it does through the northern outwash (fig. 4, *f*, *g*). The outer moraine also, together with the adjacent outwash, is therefore younger than and rests upon the eroded Manhasset formation. That the outer moraine is older than the inner is proved topographically by the fact that it is crossed by and buried beneath the inner moraine from the vicinity of Manhasset Bay westward.

The morainal ridges are not the only elevations rising above the Manhasset surface. The hills near Wheatley and the Mannetto Hills stand 100 feet above the Manhasset, and a glance at their contours as shown by the topographic map is sufficient to suggest that their origin is other than morainal. The general form of the hills near Wheatley, for instance, suggests erosion rather than accumulation. Because of this fact a careful search was made for exposures of older material beneath the surface mantle of drift, resulting in the discovery of a core of much older highly stained, deeply weathered Mannetto gravel. The topography of the Mannetto Hills similarly indicates a formation much older than the Manhasset, for although the Manhasset is deeply cut by erosion the plateau character of its surface is still apparent through practically its entire extent, but only an isolated and much-eroded remnant of the Mannetto plateau remains.

The topography alone, therefore, affords evidence of the existence of three great Pleistocene deposits separated by erosion intervals of great lengths—(1) the Mannetto gravel followed by the post-Mannetto erosion, (2) the Manhasset formation, after which came the Vineyard erosion, and (3) the Wisconsin drift. The well records and cliff sections fill in the gaps, showing the Jameco gravel, Gardiners clay, and Jacob sand between the Mannetto and Manhasset formations, and the Herod gravel, Montauk till, and Hempstead gravel members of the Manhasset. The topography is the key not only to the major incidents of the geologic history of the island but to many of the minor incidents as well, affording a clue to the origin of an almost infinite number of the subordinate features of the Mannetto, Manhasset, moraine, and outwash surfaces.

GENERAL FEATURES.

Long Island is long and narrow and in outline bears more or less resemblance to a fish or whale, a similarity early recognized by the maritime inhabitants, who, in carrying out the conceit, designated the ridge traversing the island lengthwise the backbone and the long points terminating the island at the east end the north and south flukes.

The broad end of the island, or the "head," is separated from Manhattan Island, the site of the oldest part of the city of New York, by East River, the narrow channel connecting New York Harbor with Long Island Sound. This channel is cut in rock, ledges of gneiss appearing on both banks, and is less than half a mile in width. On the northeast, however, it broadens rapidly, merging into Long Island Sound, from 5 to 20 miles wide, which lies between Long Island and the Connecticut shore.

Long Island presents a bold face toward the Sound, bluffs from 30 to 100 feet in height extending, with a few slight interruptions, through its entire length. West of Port Jefferson a well-marked though somewhat irregular plateau stretches southward from the tops of the bluffs for 1 to 7 miles at an altitude commonly from 100 to 200 feet. Along the southern limit of the plateau in the western half of the island and capping the bluffs along the north shore in the eastern half to Orient Point at the end of the North Fluke stretches the northern of the two morainal ridges that traverse the island (fig. 4), rising in places as high as 200 feet above the plateau, or 391 feet above the sea. A little south of Manhasset Bay a second ridge branches from the first. It is low and is interrupted at the west end but gradually rises eastward, reaching a height of about 410 feet at High Hill, south of Huntington. Thence it continues eastward as a strong ridge nearly paralleling the first but with some interruptions and terminates on the South Fluke at Montauk Point. Between the two ridges are extensive areas of sand and fine gravel, some being gently sloping outwash plains of sands, others plains pitted with deep, bowl-like depressions or valleys, and still others undulating hills of sand or gravel or flat-topped plateau remnants. South of the southern ridge the vast outwash plain of fine gravel and sand already mentioned stretches southward for 1 to 11 miles to the sea. This plain is characterized by many well-marked, though streamless, channels, and by low swells here and there, projecting slightly above the general surface. Besides the morainal ridges described there are near

Wheatley and south of Huntington massive hills of irregular outline, some extending well to the south of the northern ridge. These are the Westbury, Mannetto, Half Hollow, and Dix hills, which are, as is explained elsewhere, different in age and origin from the ridges.

Off the south shore of the island is a long, more or less disconnected barrier beach inclosing the broad but shallow Jamaica, Great South, Moriches, and Shinnecock bays and the great salt marshes between Coney Island and Babylon. Along the north shore lesser bars, beaches, and spits connect small islets with the main island or project into the numerous harbors and bays or into the Sound. In fact, these beaches have now joined with the main body (Long Island) what must originally have been about 15 distinct islands.

Although old channels abound on the island few have streams now flowing in them, and most of these are of small size. At Smithtown, on the north side, at Riverhead, between the two flukes, and near Yaphank and Great River stations on the south side are deeper channels that cut the water table farther from the coast than the others; hence the streams flowing in them are of greater volume.

FORM OF THE ISLAND.

AGENCIES INVOLVED.

Long Island is the resultant of opposed agencies of deposition and erosion. Marine currents, ice, and glacial streams have each played a part in both the upbuilding and the tearing down of the island. That the deposits now above sea level are small compared to those once existing in the region there is probably little doubt, indicating that since Cretaceous time erosion has on the whole predominated over deposition. Although erosion is not now going on very rapidly, the amount to be removed before the island is reduced to sea level is far less than that removed in the past, and if conditions remain unchanged the time may yet come when the island shall cease to exist. Notwithstanding the preponderance of erosion, however, the present form of the island is due to constructional rather than to destructional agencies.

EAST RIVER.

The northern part of the shore line of the west end of Long Island is determined by East River, a tidal channel connecting New York Harbor with Long Island Sound and separating Long Island from Manhattan Island. The southern part of East River occupies a channel cut in rock and the northern part meanders through deposits of drift. This channel has been discussed by a number of writers. S. L. Mitchill[1] urged that Long Island must have been recently separated from the mainland by the encroachment of salt water. John Bryson[2] referred its origin to the erosive action of the escaping waters of subglacial streams. F. J. H. Merrill[3] suggested that the rock channel was probably due to the solution of a belt of limestone. J. B. Woodworth[4] thought the escape of ponded glacial waters during the final ice retreat had something to do with the shaping of the channel in the drift. Bailey Willis and R. E. Dodge[5] regarded it as occupied by a tributary of the Hudson at the time of the excavation of the submarine channel. W. H. Hobbs[6] presented sections showing the general absence of limestone and proposed faulting and jointing as the explanation of the form of the rock channel. A. C. Veatch[7] made it the site of a tributary of the Hudson in the post-Miocene erosion interval.

The present writer regards the rock channel to be due to mechanical erosion by streams rather than to solution, as there seems to be too little limestone in the area to account for its size or its configuration. Its form was most likely controlled by joints (or possibly fault planes) or by the strike of the beds, with which the channel agrees closely in direction. It is not believed

[1] Med. Repository, vol. 3, 1800, p. 329.
[2] Geol. Mag., new ser., vol. 10, 1883, pp. 169–171.
[3] Annals New York Acad. Sci., vol. 12, 1900, pp. 113–116.
[4] Bull. New York State Mus. No. 48, 1901, p. 658.
[5] New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.
[6] Bull. Geol. Soc. America, vol. 16, 1905, pp. 151–182; The configuration of the rock floor of Greater New York: Bull. U. S. Geol. Survey No. 270, 1905.
[7] Underground water resources of Long Island: Prof. Paper U. S. Geol. Survey No. 44, 1906, Pl. VI.

that the present depression is due in any material degree to actual downfaulting. The northern part of the channel seems to have been cut subsequent to the period of the Manhasset accumulation, for the deposits of this formation, as shown by their remnants, undoubtedly overlapped upon the mainland. The channel was completed before the Wisconsin ice advance, but the escaping waters from this retreating ice sheet and the subsequent tidal scour probably did much to clear out the deposits left by the last glacier. The stream that excavated the rock channel seems to have been a short one, having no connection with the depression in which the Sound lies.

NORTH SHORE SCARP.

From a point near the west end of the island eastward to Orient Point, Long Island Sound is almost everywhere faced by a steep scarp, rising in places more than 100 feet above the water. Superficially it is plainly of erosional origin, having the form of more or less fresh bluffs and cliffs (p. 54). In reality, however, erosion has done little more than cut a narrow shelf into the land mass and wear away a few projecting points.

The history of the scarp is both long and complicated. The beginning of a scarp along the north side of Long Island dates back before the Pleistocene, to the time when the Tertiary streams were beginning to excavate the Sound Valley. The direction of the streams and the strike of the beds make it seem probable that even then a somewhat steep slope existed not far from the line of the present north coast—a slope which, though deeply buried, is still traceable in places by well borings. It seems likely that in the succeeding early Pleistocene stage (Mannetto) the ice margin rested along the erosional slope already formed, producing on its retreat a steep ice-contact slope that rose at least 350 feet above the present sea level. In the post-Mannetto stage, however, the active erosion, though deepening the Sound, everywhere attacked the scarp, with the result that it was nearly or completely obliterated in eastern Long Island, and toward the west end only a few remnants persisted at the terminations of projecting spurs of the old mass. Such appear to have been the conditions at the advent of the Jameco ice, which not only failed to add to the scarp but actually reduced its height by adding to the filling of the Sound Valley, a process that was continued through the Gardiners and Jacob stages. During the Manhasset invasion, on the other hand, the conditions seem to have been more like those of the Mannetto, and although the ice at times advanced much farther south the margin seems to have rested along the north side of the island for considerable periods, during which the thick Manhasset formation, rising in places to a height of 200 feet above the present sea level, was built up. At the same time the weight of the ice in the Sound region and its drag or shove on the land combined to produce a notable folding that helped to intensify the scarp, which was eventually left in the shape of an ice-contact slope on the retreat of the ice. The scarp was afterward notched by the streams of the Vineyard interval of erosion, subdued and rounded by the Wisconsin ice, and cut by the waves of the present Sound until finally it reached its present form. The amount of the late wave erosion is considered in the discussion of the bluffs (p. 54). The present conditions along the north shore in the western part of the island are represented in figure 5, which brings out the buried Cretaceous and Mannetto scarps beneath the Manhasset.

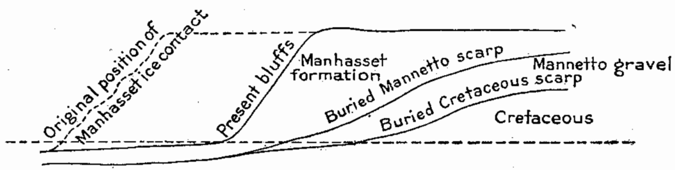

FIGURE 5.—Relations of Cretaceous, Mannetto, Manhasset, and present north-shore scarps.

HARBORS OF THE NORTH SHORE.

The north coast along the western half of the island from Port Jefferson to New York is indented by a series of harbors, including Flushing Bay, Little Neck Bay, Manhasset Bay, Hempstead Harbor, Oyster Bay Harbor, Cold Spring Harbor, Huntington Harbor, Centerport Harbor, Northport Harbor, Nissequogue Inlet, Stony Brook Harbor, and Port Jefferson Harbor. These harbors range in length from about 2 miles (Northport and Centerport harbors, etc.)

to about 5 miles (Hempstead Harbor, etc.), and their axes, with one or two exceptions, are straight or gently curving. Each one is bordered by slopes rising somewhat steeply to an altitude usually of 100 to 200 feet. Some of the indentations, as Port Jefferson, Stony Brook, Northport, and Huntington harbors, end rather abruptly in amphitheater-like terminations, but most of them extend inland for a number of miles beyond the limit reached by the sea, gradually closing in to V-shaped terminations. The valleys are generally free from conspicuous branching such as would be expected if they had been produced by the ordinary process of stream erosion. There are, however, on the borders of each main valley many small lateral valleys sloping toward the harbors, which, although more or less filled with late drift, are distinctly recognizable. At Smithtown, where little late drift is present, a typical dendritic drainage system is seen. (See topographic map, Pl. II, in pocket.) Like the others, it is of pre-Wisconsin origin, as shown by glacial deposits, including an esker in the bottom of the main valley.

The bluffs bordering the harbors consist as a rule of Manhasset materials, but well borings and outcrops along the shores indicate that the necks between the harbors have Cretaceous cores rising high above sea level. In other words, the present valleys, although generally cut in the glacial gravels of the Manhasset formation, are coincident in location with older Cretaceous valleys.

Much material bearing on the formation of the north shore harbors and valleys has been published. W. W. Mather[1] noted the action of springs in converting sand into quicksand so that large masses flowed from the bluffs. Elias Lewis, jr.,[2] also pointed out that many valleys are due to spring sapping, but he held that the harbors were formed by erosion by subglacial streams. Warren Upham[3] referred the Smithtown drainage system to stream erosion. John Bryson[4] followed Lewis in referring the excavation of the harbors to subglacial streams. F. J. H. Merrill[5] considered the harbors to have been "plowed out by projecting spurs of ice" and regarded the adjacent elevations as due to ice thrust. Arthur Hollick[6] and W. O. Crosby[7] agreed with Merrill.

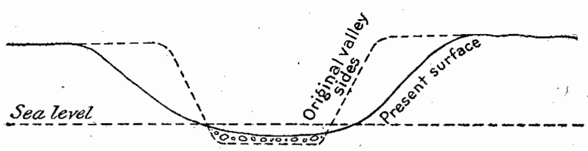

FIGURE 6.—Relation between the original and the present cross section of north-shore valleys.

J. B. Woodworth[8] distinctly recognized the stream origin of the valleys, although stating that they had been modified, enlarged, and deepened by the action of the Wisconsin ice. A. C. Veatch[9] brought out the fact that the present harbors, though not cut in Cretaceous formations, nevertheless coincide in location with buried Cretaceous valleys cut in pre-Jameco time. The coincidence of location he explained as due to the concentration of underground waters in the old depressions, giving rise to extensive spring sapping. Some modification by the Wisconsin ice was recognized. The present writer agrees with Veatch, but would lay more emphasis on "ice erosion," for the valleys, except the one at Smithtown, are much too broad in proportion to their length and terminate too bluntly to be characteristic of stream action. The trunk valleys are also larger in proportion to the lateral channels than is called for by normal stream erosion. Drift deposition (Wisconsin) has also obscured and obliterated many of the old valleys, as at Lloyd Neck and in the region south of Huntington. The erosion is regarded as the work of the basal part of the main ice sheet rather than the projecting lobes, as was asserted by some of the earlier writers. The conditions are illustrated by figure 6.

[1] Geology of New York, pt. 1, 1843, p. 32.
[2] Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 142–146.
[3] Idem, vol. 18, 1879, p. 201.
[4] The geological formation of Long Island, New York, 1885.
[5] Annals New York Acad. Sci., vol. 3, 1886, pp. 341–364.
[6] Trans. New York Acad. Sci., vol. 14, 1895, pp. 8–20.
[7] Tech. Quart., vol. 13, 1900, p. 105.
[8] Bull. New York State Mus. No. 48, 1901, p. 636.
[9] Underground water resources of Long Island, New York: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 43–44.

SHORE LINE EAST OF PORT JEFFERSON.

West of Port Jefferson, as has been seen, the coast is highly irregular, being indented by many deep bays and harbors. East of this locality, however, the shore is very regular, being made up of long, gently curved reaches with here and there a headland barely projecting from the general line. Throughout this stretch the contour of the coast has manifestly resulted from the action of the waves and currents of the Sound, its regularity being the direct result of its fairly uniform composition. For most of the distance the bluffs bordering the shore are made up of sands and fine gravels, but in places there is a more resistant bed of till or of clay which gives rise to a slight projection in the coast line. An exceptionally high bluff may also give rise to such a projection, as at Woodhull Landing. The swell at Rocky Point Landing is probably due to the presence of the Gardiners clay in the bluff, the one at Herod Point to the Montauk till member of the Manhasset formation, that at Roanoke Point to both clay and drift, that at Jacobs Point to the clay, those at Ducks Pond, Horton, Rocky, and Terry points to thick beds of till (Montauk member?), and the one at Mulford Point to the clay.

West of Port Jefferson the general trend of the coast is somewhat north of east. Here, however, the coast makes a decided bend and for 20 miles runs due east, beyond which it trends somewhat more northerly than at the west end. In these stretches the elevation of the bluffs becomes less, decreasing from 150 feet near Port Jefferson to 100 feet north of Riverhead and to less than 50 feet near Orient Point. It would seem almost as if the coast had been cut back through the plateau portion of the Manhasset formation into the sloping part on the south. If so, the original coast, as indicated by the eastward prolongation of a line along the Manhasset crest, must have been 5 miles or more north of its present position. Of this, however, there is no very definite evidence. A chart of the Sound shows no notable shoals such as should exist if the land had been thus cut back. In fact, the only shallow places are off Woodhull Landing and Herod, Roanoke, and Horton points and between Rocky and Terry points. Those at the first three localities are spitlike projections; those at the last two have the form of offshore shoals. None is situated more than about 1½ miles offshore. Elsewhere the bottom of the Sound is almost perfectly flat and affords little evidence of extensive erosion.

On turning to the island, however, it is found that, notwithstanding there has been no greater deposition of the late drift in the eastern part than at points farther west and no more opportunity for obscuring the old topography, large northward-draining valleys similar to those west of Port Jefferson are entirely absent. If such valleys ever existed, and there seems to be no reason why they should not have been formed here as well as farther west, they must have been obliterated by subsequent erosion of the coast line.

It is an interesting fact in this connection that the deep Sound channel, described elsewhere (p. 56), follows the coast of this part of the island at a distance of about 4 miles. It is probable that the land, if it ever extended much farther northward, did not reach beyond the line of this channel. On the whole it seems likely that the coast in this region has been cut back for several miles, but if so most of the erosion occurred in pre-Wisconsin time, possibly in a period of relative submergence that followed the cutting of the Sound and Peconic Bay channels, such as is assumed in the discussion of the shaping of the shores and islands of Peconic Bay. The post-Wisconsin cutting is not believed to have exceeded half a mile.

PECONIC AND GARDINERS BAYS.

No single feature of the outline of the island is more conspicuous than the great connecting bays lying between the North and South flukes. (See topographic map, Pl. II, in pocket.) Together these bays form a water body increasing in width from a few yards at the mouth of Peconic River to 14 miles near Gardiners Island, 27 miles farther east. The water body does not increase uniformly in width throughout and is much broken by islands, the largest of which are Shelter and Robins islands, and by projecting necks mostly connected with the mainland by beaches, among which are Jessup and Hog necks, near Sag Harbor, on the south side, and Little and Great Hog necks, in Southold, on the north side. These islands and necks all stand from

50 to 100 feet or more above the present sea level and appear to be remnants of old land surfaces at these elevations. Their topography, as well as that of the part of the main island adjoining the bays, seems to be in part constructional and in part due to stream erosion, although greatly modified and obscured by the subsequent passage of ice sheets over its surface. The contours of the shores, however, are due almost wholly to the action of currents and waves.

J. D. Dana [1] advanced the view that the Connecticut and other Sound drainage passed southward across the North Fluke in the vicinity of Mattituck into Peconic Bay, but what course it then took he did not state. Three years later John Bryson [2] suggested that the further course of this stream (which he assumed to have been subglacial) was through the depression at Canoe Place, and stated his belief that Block Island Sound and Gardiners and Great and Little Peconic bays are the result of subglacial stream erosion.

The drainage immediately preceding the last ice invasion was toward the chain of bays from all directions. Peconic River entered from the west, as at present. Along the North Fluke traces of pre-Wisconsin valleys leading southward may be seen at a number of points. Mattituck Inlet, although now opening into the Sound, then took the drainage southward, as is indicated by the marked convergence of the lateral valleys in that direction; but that it was not the outlet of Connecticut River nor of any other stream of the mainland or Sound, as was stated by Dana, is shown conclusively by its shallowness, narrowness, and the character of the tributary channels mentioned, which indicate that it formed the headwater portion of a minor drainage system rather than the outlet of a large river. (See Pl. XI, *C*, p. 52.) On the South Fluke, Sebonac Creek near Shinnecock, the Long Pond and Northwest Creek valleys near Sag Harbor, and Threemile Harbor, are valleys produced by northward drainage.

The course of the trunk stream receiving this drainage can not be located with any certainty. The bottoms of the bays are irregular and do not appear to contain any submerged channels. The deepest water at the present time is along the south side of Great Peconic Bay, off the points of Robins Island and Little and Great Hog necks, and between Shelter Island and the North Fluke, and this line may mark the course of the old drainage. It could hardly have passed outward at Canoe Place, for the gap in the Manhasset at this point is only a few hundred feet wide, nor through the shallow and circuitous passage south of Shelter Island.

All that can be definitely stated is that in the stage immediately preceding the last ice advance Peconic River flowed essentially in its present course, that the drainage entered the Peconic trough both from the north and the south, and that the waters passed eastward into the ocean. The land at this time stood at least 150 feet higher than at present, as indicated by the submarine channel east of Montauk (p. 60), but a submergence took place and much marine erosion, marked by a shaping of the shores and a separation of the islands, occurred before the advance of the Wisconsin ice. The ice, although modifying the topography in many ways, probably did not materially alter the main features. Postglacial erosion has likewise done little except to modify the contours of the shores.

Although the Peconic region was the site of a drainage system just before the Wisconsin ice invasion, it is doubtful if the depression owes its origin to stream erosion at that time. More probably the basins are largely the result of nondeposition in Manhasset time because of their occupation by ice masses around which the materials of the various necks and islands accumulated. If such was the case, it is not unlikely that incipient depressions favorable to the retention of the ice masses were early formed through differential compacting of the underlying materials by the weight of the ice sheet, through ice scouring, or through the uplift of the North and South flukes by the dynamic action of the ice.

OUTLINE OF THE SOUTH SHORE.

If the extension of the land produced in postglacial time by the formation of marsh deposits along the old shore is left out of account, the south coast of Long Island in its broader aspects consists of a number of broad, gently curving, lobelike projections of sands or fine gravels.

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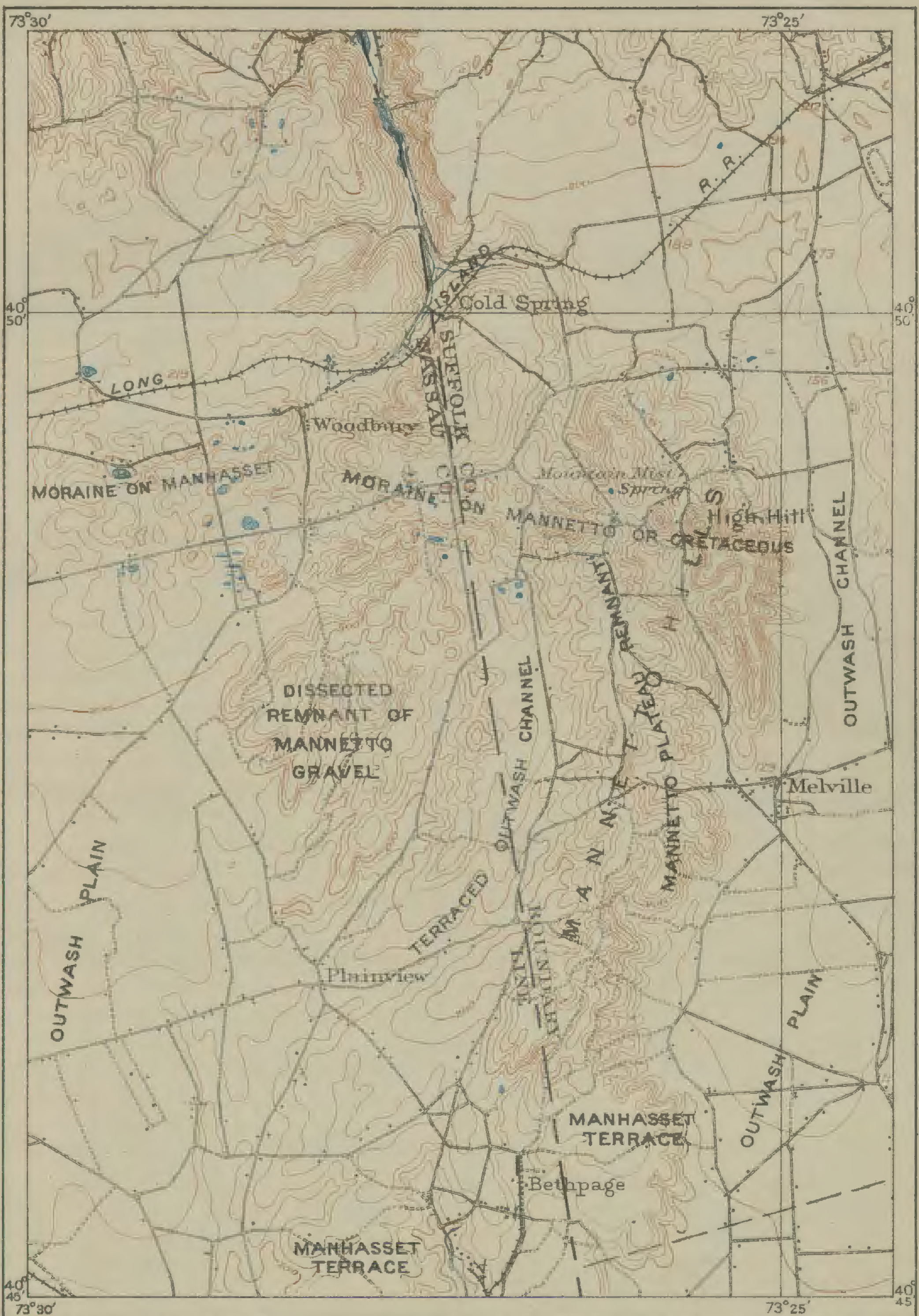
[1] Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 425–437.

[2] Am. Geologist, vol. 12, 1893, pp. 402–403.



TOPOGRAPHIC MAP OF MANNETTO HILLS REGION, LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1913

A small but strongly curved lobe extends between New York Harbor and Jamaica Bay. East of this bay is the broad, flat lobate curve extending to South Oyster Bay, a distance of about 20 miles. The next lobe, which is of similar character, extends between Massapequa and Babylon; another still smaller lobe extends between Babylon and Bayshore. Beyond this point the shore is more broken and complex, but the general lobate character is visible as far east as Southampton. Between the lobes and also cutting their margins nearly every half mile are small estuaries a mile or so long and a quarter to half a mile wide or estuary-like valleys now occupied by marshes. Some of these depressions are traversed by streams and others are dry.

The lobes appear to have been formed by the deposition of materials carried out from glaciers by glacial streams during the melting of the ice. West of Bayshore the lobes are regular in outline and appear to owe their form largely to outwash from the last or Wisconsin ice sheet at a time when the land stood nearly at its present level. Farther east they are less regular, are cut by deep channels and bays, and lack to a considerable extent the even surface characteristic of the western lobes. It seems probable that the lobes are due primarily to deposition during an earlier ice advance, and that they were afterward subjected to erosion and finally to partial burial by the less copious outwash during the Wisconsin invasion.

The coast from Southampton nearly to Montauk Point follows a nearly straight line intersecting old headlands and crossing old bays. It is in part due to erosion and in part to deposition. In the vicinity of Southampton the land probably at one time extended half a mile to a mile or more farther seaward than at present. Southeast of Bridgehampton it possibly extended half a mile farther, at Apaquogue about the same, and between Easthampton and Amagansett a mile or more. That the shore at Montauk has retreated considerably is unquestionable. The Montauk shoals, which lie about 2 miles south of the present shore, indicate that the land probably once extended to that point. Much of the erosion may have occurred before the Wisconsin ice advance, and the amount of cutting back in post-Wisconsin time may be not over a mile and possibly less, although, as pointed out by W. W. Mather,[1] not less than 2 acres is lost annually by erosion in this region.

The same waves and shore currents that truncated the headlands formed beaches, connecting the projecting points and inclosing the so-called bays and ponds, most of which occupied old drainage channels in the gravels. Some of the bays are still connected with the ocean by narrow channels, but in most places the beaches are unbroken. The most important beach is Napeague Beach, lying between Amagansett and Montauk Point, which has a length of 4 miles and a width of 1½ miles. The sands of the beaches have for the most part come from the erosion of the land at the points mentioned, and the material not so used has been transported westward to the great barrier beach described under Recent deposits (pp. 177–178).

SURFACE LINEAMENTS.

INFLUENCE OF THE CRETACEOUS.

The Cretaceous of Long Island is extensively developed, as brought out in the bluffs of the north coast, where natural exposures are numerous, and in clay pits and wells in the interior. As it comes to the surface at few places in the island, it has little or no direct influence on the topography, the only possible exception that was noted being at High Hill, southwest of Huntington (Pl. III), where the character of the drift suggests that the core of this high knob may be Cretaceous, a supposition rendered not improbable by the finding of Cretaceous material in a near-by well (No. 586, p. 84) at an elevation of over 300 feet. Although not directly controlling the present topography, the Cretaceous core has nevertheless exerted a very extended indirect influence upon it through control of the Mannetto deposition, which took place over and around the Cretaceous remnants.

[1] Second Ann. Rept. New York Geol. Survey, 1838, p. 126.

MANNETTO REMNANTS.

Mannetto plateau.—At only one point on Long Island, so far as is known, is any trace of the original Mannetto surface left. Beginning a little south of the peak known as High Hill, near the north end of the Mannetto Hills, and continuing southward to a point about half a mile north of Bethpage, a distance of about 3 miles, is a narrow plateau, one-fourth to one-half a mile wide, constituting the flat crest of the hills (Pl. III). It ranges in altitude from about 330 feet at the north end to 270 feet at the south end and is believed to be a part of the original Mannetto surface. Whether the slope is original or is due to differential tilting is not known, but the writer is inclined to consider it original.

Hills of Mannetto gravel.—Outside of the Mannetto Hills the Mannetto gravel is commonly represented only by irregular hills, although traces of the plateau level are observable in the Dix Hills. In general, however, erosion has reduced this mass to a series of radiating spurs. Near Wheatley the erosion is even more advanced, and nothing but an irregular group of hills remains, as shown by Plate VI, *D* (p. 32) and the description on page 82. Similar but more isolated masses of the Mannetto gravel are believed, from the character of the overlying drift, to control largely the topography at Harbor Hill, at Roslyn, and in the knobs rising above the Manhasset surface on Manhasset Neck (p. 82 and Pl. IV).

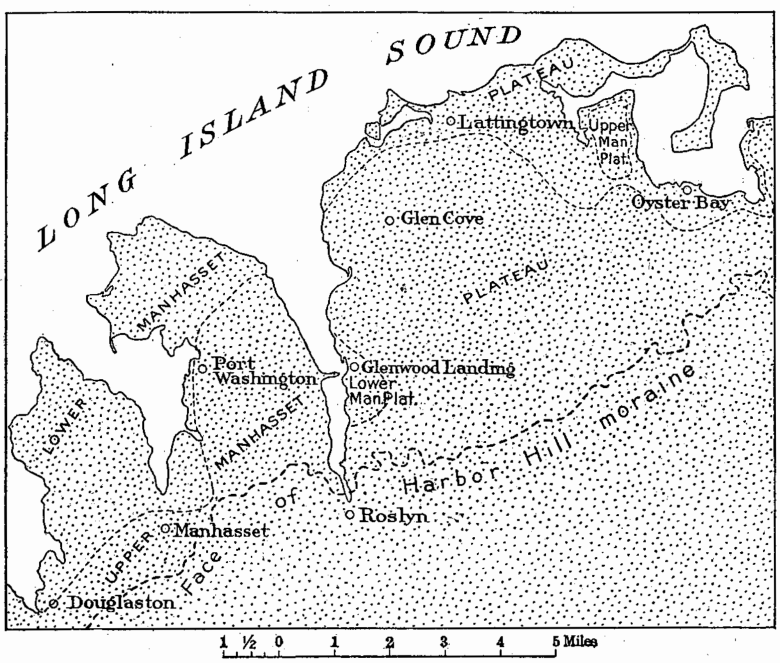


FIGURE 7.—Sketch showing location of the upper and lower Manhasset plateaus from Douglaston to Oyster Bay.

MANHASSET SURFACE.

Higher plateaus.—The Manhasset surface shows considerable diversity of contour, both original and subsequent forms being extensively represented in it, the former by the great plateaus and the latter by the deep valleys and sharp bluffs. The plateaus, although recognized by few of the earlier writers, principally because of the till coating and the semimorainal aspect of the surface, become, when the physiography of the island is studied in detail, one of the most conspicuous and important of its topographic features. Although they are spoken of as plateaus it must not be thought that the surface of the Manhasset formation is continuous or perfectly flat for any great distance. As a matter of fact, the plateau is deeply indented or even separated into detached parts by the deep bays and harbors, some of which extend back nearly or quite to the moraine, and is almost everywhere deeply trenched by stream valleys and characterized by superficial irregularities due to the deposition of a mantle of morainal outwash or other drift over its surface. The continuity of the plateau surface is also broken along the axis of Manhasset Neck by knobs of older material projecting to a height of 60 feet or more above the plateau level (Pl. IV).

The plateaus fall into three belts—the north-shore belt, extending from the vicinity of New York to Orient Point; the Middle Island belt, extending from Rockaway Ridge through Bethpage and Half Hollow hills, the highlands near Middle Island and south of Riverhead, and the islands and necks of the north side of Great and Little Peconic bays to Shelter and possibly to Gardiners Island; and the South Fluke belt, extending from its junction with the Middle Island belt south of Riverhead eastward along the South Fluke to Montauk. Each of the belts is

TOPOGRAPHIC MAP OF GREAT AND MANHASSET NECKS, LONG ISLAND, N.Y.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

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described at length on pages 119–121, and their characteristics are shown in detail by the topographic map (Pl. II, in pocket).

Lower plateau or terrace.—A peculiarity of the northern plateau belt in western Long Island is its double character or development at two distinct levels, as brought out by figures 7 and 8 and by Plate IV. The lower terrace, which lies along the coast, ranges from 1 to 6 miles in breadth and has a maximum elevation of a little over 100 feet; back of this surface and usually separated from it by a more or less distinct though gentle scarp lies a higher plateau at 180 to 200 feet, reaching back to the moraine and beyond. The significance of the lower plateau is somewhat obscure. The character of its surface and especially of the slope between it and the higher plateau is somewhat suggestive of wave work. The surroundings at certain points, however, as at Glenwood Landing on Hempstead Harbor, where the terrace is unusually well developed (Pl. VI, *A*, p. 32), would seem to preclude such action, it being hardly conceivable that the waves of a confined body of water hardly more than half a mile wide could have cut back a terrace nearly a mile in breadth in deposits rising a hundred feet above the water level. Aside from the fact that this theory would require a subsidence of at least 100 feet in post-Manhasset time, a movement of which there is elsewhere no record, examination shows that this plateau has a drainage topography fully as far advanced, considering its lower level, as that of the upper plateau and indicating equal antiquity.

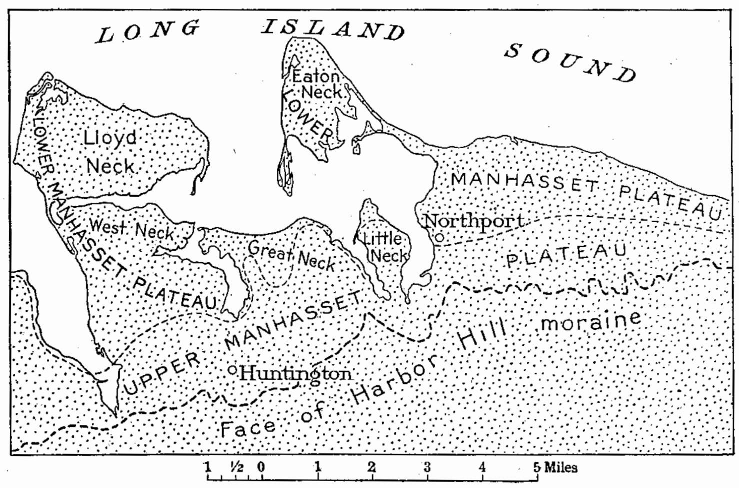

FIGURE 8.—Sketch showing location of the upper and lower Manhasset plateaus in the Lloyd and Eaton necks region.

The material of the lower plateau is clearly Manhasset and is, at least locally, the Montauk till member of the Manhasset, extending nearly or quite to sea level and therefore considerably below the level of the Montauk member in the gravel pits farther south on Hempstead Harbor, the conditions being similar to those shown in the generalized north-south section in figure 9. The explanation that the writer regards as most probable is that which assumes the lower plateau or terrace to be an original feature formed in connection with the Montauk ice invasion. On the first approach of the ice the margin probably lay in the Sound not far north of the present coast line (fig. 9, *a*), and in front of it the Herod gravel member of the Manhasset formation was laid down. On the actual invasion of the region the ice reached somewhat farther south, passing over the Herod gravel member at least to the head of Hempstead Harbor, as indicated by the bowlder bed capping the gravel. On its recession or on its subsequent readvance its margin rested along the line now marked by the scarp separating the low plateau from the high plateau (fig. 9, *b*), and in front of it were laid down the higher gravels (Hempstead member of Manhasset formation). This sequence of events explains the presence of the Montauk till member near the surface and the general absence of the Hempstead gravel member along the coast, the lobate form of the landward edge of the lower plateau, the similar erosion features of the two plateaus, the nature of the separating scarp (ice contact), the peculiar position of the terrace at Glenwood Landing (due to an ice tongue in Hempstead Harbor), and the greater disturbance exhibited by the material of the lower plateau (due to more prolonged shove and drag by the ice).

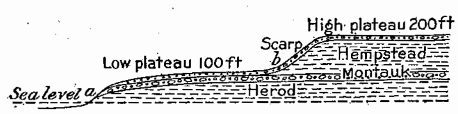

FIGURE 9.—Section showing relations of Manhasset plateaus and deposits along the north shore in western Long Island. *a*, Present bluff scarp at coast; *b*, modified ice-contact scarp between high and low Manhasset plateaus.

MORAINES.

MORAINES OF STRATIFIED DRIFT.

EXTENT AND GENERAL CHARACTER.

The moraines of Long Island have in the past been almost invariably regarded as the culminating physiographic members of the region, and although later work shows them to be subordinate to the Manhasset they are nevertheless striking features of the topography (Pl. V, *A*), rising in many places 100 to 150 feet above the surrounding level and reaching a maximum elevation of 410 feet above the sea. They are also of notable extent, stretching the entire length of the island without any considerable break. Topographically they may still be considered as constituting the "backbone" of the island, but it should be borne in mind that this is a superficial and not a structural relation, for the moraines are not a part of the foundation of the island but are only ridges resting on the Manhasset surface.

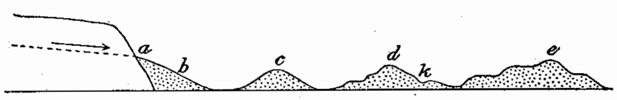

FIGURE 10.—Section showing mode of formation and profiles of morainal cones. *a*, Point of emergence of feeder; *b*, steep débris fan; *c*, isolated cone of regular contour; *d*, irregular cone; *e*, confluent cones; *k*, kettle.

The moraines show great diversity in form from point to point according to the nature of the material composing them and the conditions of its deposition, nearly all the common types of morainal accumulations being represented. They are described in detail in the section on stratigraphic geology (pp. 163, 168), and it is necessary to consider here only the special types and minor features of the morainal deposits.

MORAINAL CONES.

Isolated cones.—The isolated morainal cones represent one of the simplest forms of morainal accumulation, seemingly being the result of deposition by waters issuing from the ice front at a single point and at a considerable elevation above the base (fig. 10, *a*). The volume of the feeder must of necessity be very small and incapable of transporting material far beyond the limits of the confined ice channel, for a larger volume would soon cut down to the base of the ice and form a normal outwash channel. Both the character of the deposition and the elevated position of the feeding channels, therefore, point to small rivulets as the source of material of the morainal cones. When first formed the deposits had the form of a steep fan or semicone (fig. 10, *b*), but on the retreat of the glacier the part lying next to the ice was let down and a more or less irregular cone resulted. Some of the cones are rounded and have fairly regular slopes (fig. 10, *c*). Kettles may occur in any part of the cones but are most likely to be found near the margins (fig. 10, *k*). Considerable till is likely to be present on the ice-contact face.

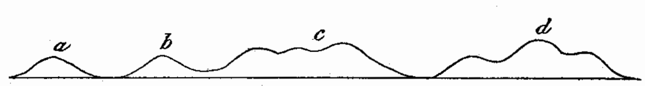

FIGURE 11.—Profiles of morainal cones. *a*, Isolated cone; *b*, semicone; *c*, confluent cones of similar magnitude; *d*, confluent cones of various sizes.

A cone completely isolated from the surrounding moraine (fig. 10, *c*) is not often seen. The best apparent examples are found at High Hill, at the north end of the Mannetto Hills, and in the unnamed hill immediately west of this point (Pl. III, p. 28). Both of these are sharp knobs resting directly upon the Mannetto or the Cretaceous plateau, above which they rise 100 feet, and they have practically no connection with adjacent morainal accumulations. It should be noted, however, that the knobs mentioned are possibly not entirely morainal and that they may contain cores of older material.

Confluent cones.—All gradations from the isolated cones that are described above (fig. 11, *a*) through semidetached cones (fig. 11, *b*) to completely confluent cones (fig. 11, *c*, *d*) are represented on the island. Their origin is essentially the same, each knob or cone representing the discharge either of a single rivulet or of a number of closely adjacent rivulets. Confluent cones result from the proximity of the contributory streams, which causes their deposits to impinge on one another and become united into a ridge in which the component parts are represented

A. OUTWASH PLAIN FROM ICE ALONG HARBOR HILL MORAINE.

B. BOWLDERY PART OF HARBOR HILL MORAINE NEAR CREEDMOOR.

A. UPPER AND LOWER MANHASSET PLATEAUS NEAR HEMPSTEAD HARBOR

B. TILL MORAINE NEAR JAMAICA

C. SAND AND GRAVEL MORAINE SOUTHWEST OF RIVERHEAD

D. MANNETTO, MANHASSET MORAINAL, AND OUTWASH TOPOGRAPHY NEAR WHEATLEY

JULIUS BIEN CO. N.Y.

TOPOGRAPHIC FEATURES OF LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

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by the several knobs. Where the feeders are of essentially the same capacity the result is to build up a ridge of fairly uniform height (fig. 11, *c*), but where they are of unequal transporting power the ridge is uneven, with one or more knobs representing the chief sources of sediment rising high above the others (fig. 11, *d*).

Examples of confluent cones are so numerous that a list of all those on the island would cover many pages; in fact considerable parts of the inner moraine and a large part of the outer moraine are made up of rows or groups of such deposits. One of the best examples of a confluent ridge of fairly uniform height is that southeast of Hauppauge or northeast of Central Islip (Pl. VII, *A*). Bald Hill, 4 miles southwest of Riverhead, affords an example of a cone rising prominently above its neighbors (Pl. VI, *C*). In fact, Bald Hill approaches the isolated cones in form.

MORAINAL RIDGES.

Simple ridges.—The simplest morainal ridge is that formed by confluent outwash cones along a stationary ice margin in the manner outlined in the preceding section. Such ridges have a simple cross section, as shown at *c*, figure 10. The best large-scale example is that mentioned as occurring southeast of Hauppauge.

Double ridges.—Inasmuch as the ice front is seldom entirely stationary during the upbuilding of a moraine, there is commonly a tendency to repetition of the ridges. The simplest form of moraine resulting from this tendency is a double ridge such as those shown in profile at *c* and *d* in figure 10, each ridge consisting of the confluent cones formed at a given position of the ice margin. The best example of a double ridge of this character separated by a flat outwash deposit was noted on the road crossing the moraine half a mile southwest of Woodbury or 1½ miles southwest of Cold Spring station.

Compound ridges.—Simple and double ridges are the exception among the moraines of Long Island, as elsewhere, the normal form being a compound ridge of considerable breadth, as shown in profile at *e* in figure 10. The formation of a ridge of this type differs in no essential way from that of the ridges described above, except that the cones composing it are confluent with those before and behind them as well as with those at their sides—a result following from changes in the position of the ice margin smaller than those giving rise to the double ridges. In general compound ridges are the result of deposition during a number of successive slight recessions of the glacial margin. The ice may also have temporarily advanced, overriding part of the earlier deposits and disturbing them more or less, thus giving rise to abnormal forms of relief. Under such conditions many ice blocks would become detached and buried beneath the drift, causing on melting the numerous kettles that almost everywhere characterize deposits of this type. The long-continued presence of the ice favored the incorporation of considerable till both within and on the ice-contact face and the scattering of bowlders over the surface. In fact, the conditions were such as to develop a most diversified morainal topography—high knobs, ridges, and gravel heaps of all shapes and sizes alternating confusedly with equally irregular basins, troughs, and deep, angular kettles. This complexity is brought out by the topographic sketch, Plate VI, *C*.

The greater part of the southern moraine is made up of compound ridges of the type described. Among the especially characteristic portions may be mentioned that lying south of Peconic River between Manorville and Riverhead, that north of East Quogue, and that between Hampton Park, north of Southampton, and Sag Harbor.

DEPRESSED MORAINES.

There is some doubt as to the propriety of applying the term "depressed" to moraines, as well as to that of considering the particular form of accumulation which it here denotes as a moraine at all. Yet this form occurs in so many places on the island that some term is needed for it, and the one given above was selected as best indicating its nature. In brief, the term is applied to irregular marginal accumulations developed along the ice front in line with the normal morainal ridges but failing to rise above the adjacent outwash. The "depression" is due rather to the nonaccumulation of morainal material than to an excess of outwash. The conditions of its formation are brought out in figure 12. Its mode of formation differs from that of the normal stratified moraine chiefly in the size and carrying capacity of the glacial streams that formed it, the water issuing in large volumes instead of rivulets and forming broad outwash aprons instead of the ordinary cones and ridges. The total accumulations, however, are not necessarily greater than those in front of the normal moraine. The topography of the depressed moraine is ordinarily similar to that of the compound ridges, exhibiting the same irregular kettle and knob aspect. In some places, where the morainal deposits are thin, the accumulations have little more than blocked the previously existing valleys of the underlying land surfaces, and many kettles of large size and great depth remain.

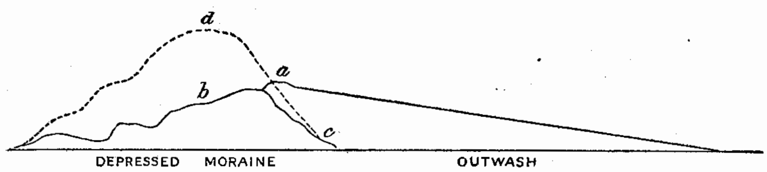


FIGURE 12.—Section showing relation between depressed moraine and outwash. *a*, Head of outwash plain; *b*, exposed part of depressed moraine; *c*, supposed buried part of depressed moraine; *d*, normal profile of moraine.

The most conspicuous depressed moraines along the northern ridge are in the region east of Port Jefferson station, where the kettle valleys above described are also best represented (Pl. VII, *B*). In the southern ridge the depressed moraines are best seen at the gaps in the hills between Yaphank and Shinnecock, although good examples are found near Ronkonkoma, farther west, and at several points between Sag Harbor and Easthampton, on the east. In some localities the morainal material is scanty and the north edge of the outwash approaches the simple ice-contact slope in form.

TILL MORAINES.

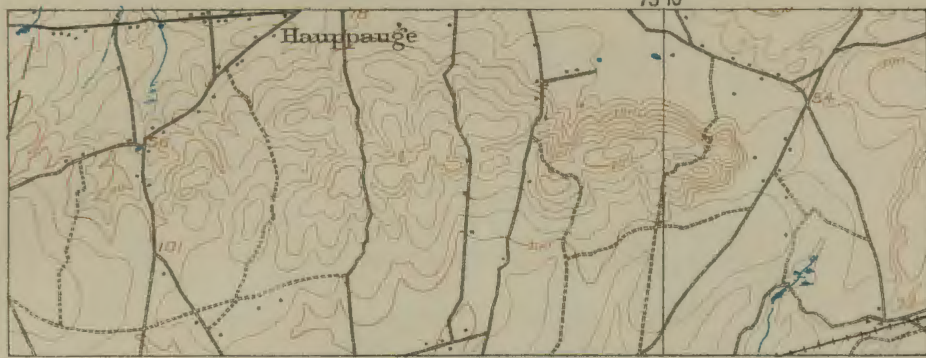
GENERAL FEATURES.

The topography of the moraines of Long Island varies widely according to the character of the materials of which the ridges are composed, those made up largely of till differing greatly from those composed mainly of stratified material. The presence of till in a moraine indicates deposition in direct contact with the ice, partly perhaps beneath its marginal portions, hence many such accumulations take on the subdued contours characteristic of formations overridden and rounded by glacial ice. Under such conditions the tendency is to form a more or less continuous belt made up of small masses exhibiting something of the ridge form and separated by intervening troughs or basins. The ridges are lower and more rounded and have gentler slopes than the stratified moraines, and the depressions are more regular and shallower and have less steep sides. Another feature of the till moraines is the essentially continuous character of the ridges, gaps such as those found in stratified moraines at many places (where they mark the emergence of glacial streams) being relatively rare. Cones and sharp ridges of drift are practically unknown. The till type of moraine is best developed in that part of Long Island included in Greater New York (Pl. VI, *B*, p. 32).

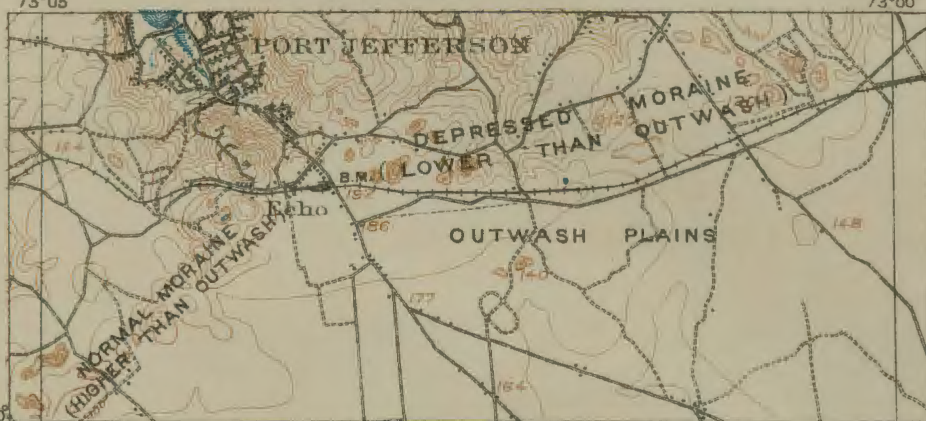
MORAINES DUE TO ICE SHOVE AND DRAG.

Little evidence of the competency of ice shove as a cause of morainal accumulation is afforded by existing glaciers, the tendency nearly everywhere being for the ice to override a mass of material in its path and drag it away little by little instead of pushing it along. At times, however, the ice evidently developed a tremendous power to push (pp. 201–207), the result of which was the formation of immense folds in the overridden material, some of them reaching an elevation of 100 or 150 feet, and the development of numerous faults, in both of which the positions of large masses of material were noticeably shifted.

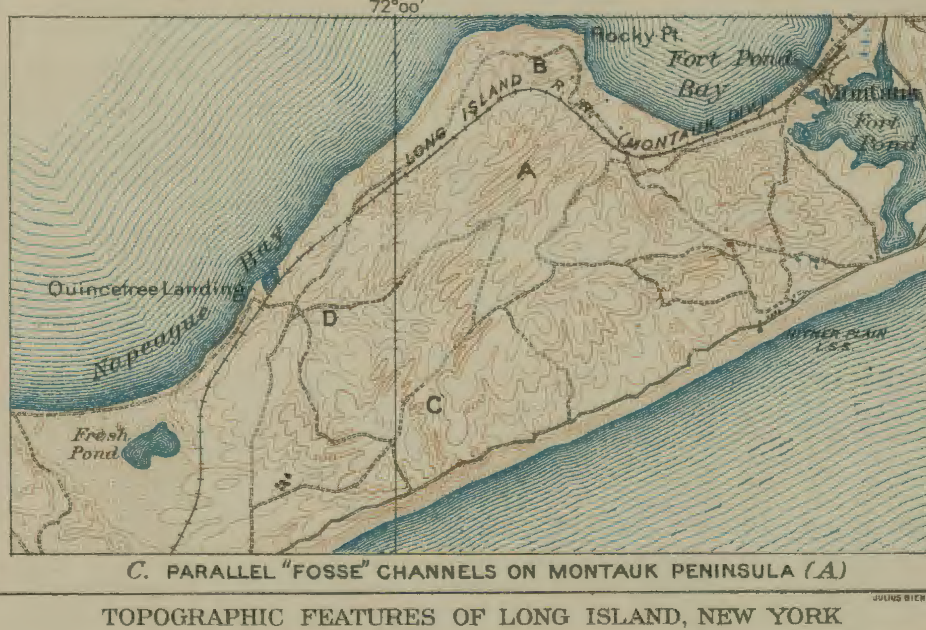
This shoving action was most conspicuous during the Montauk ice invasion, but was also developed to a considerable extent in the Wisconsin stage, during which the moraines under



A. SIMPLE MORAINAL RIDGE NEAR HAUPPAUGE



B. DEPRESSED MORAINE AND OUTWASH NEAR PORT JEFFERSON



C. PARALLEL "FOSSE" CHANNELS ON MONTAUK PENINSULA *(A)*

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TOPOGRAPHIC FEATURES OF LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level

1913

A.

B.

PSEUDOMORAINE (DUNES) NEAR FRIARS HEAD.

A. Distant view; *B*. Section.

discussion were formed. The action was most pronounced where the ice encountered scarps or other marked irregularities of surface, such as projections from hills or ridges between valleys, especially where the trend of the topographic features was at a considerable angle with the ice movement, as shown in figure 13. Under such conditions the previous topography was in many places greatly modified, partly by the shoving of the points, as near *A*, figure 13, partly by the pushing up of material in converging valleys, as at *B*, and partly by the breaking down of divides and the dragging of the material into the adjacent valley, as at *C*. Thus in the figure a ridge would cross the valley at *A*, both sides of the valley would be broken down, a small ridge and kettle would be formed at *B* and a larger one at *C*, the result being a topography such as is shown in figure 14. These figures show how the ice in passing over a region of diversified topography changes the surface to the morainal type, consisting of irregular hills and kettles.

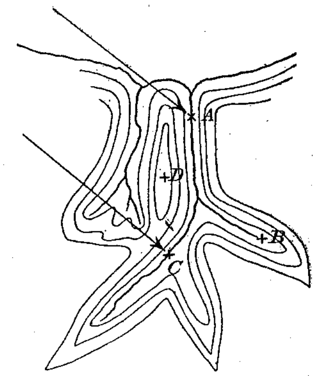


FIGURE 13.—Hypothetical drainage system in loose gravels before being covered by ice. *A*, *B*, *C*, and *D* are at the same points as in figure 14; arrows show the direction of movement of the approaching ice.

Examples of topography of this type, which is truly morainal, inasmuch as there has been an actual movement and redeposition of material, abound on Long Island, being observable at dozens of points scattered over the Manhasset plateau north of the main ridge of the Harbor Hill moraine and especially on Great Neck between Huntington and Centerport harbors, where there are several drift-obstructed valleys. Other good examples are afforded by the Shinnecock Hills and the hills between Napeague and Fort Pond bays, Montauk. In neither of these localities, however, are the surface irregularities due entirely to ice shove, a mantle of dune sand materially altering the surface relief of the Shinnecock if not of the Montauk hills. The former were covered with drifting sand hills when visited by Timothy Dwight as late as 1822.

A second type of ridges due to ice shove but not truly of morainal character, although the resulting topography has a decidedly morainal aspect, is produced by folding. The best development of this type is found on Gardiners Island, where the folds form several topographic ridges of considerable size. These ridges rise and fall, bend, separate, unite, cross, and merge into one another with an irregularity simulating that of a moraine, although generally preserving a marked alignment of features parallel with the ice margin. Considerable material has at the same time been transported or removed by the ice. Taken as a whole, the structure must be regarded as intermediate between a true fold and an ice-shoved moraine similar to that between the Shinnecock Hills and Montauk Point.

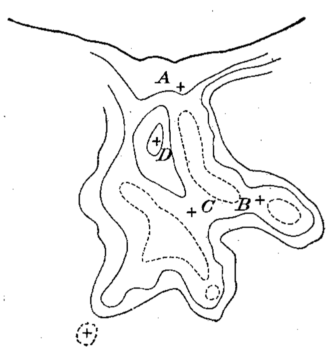


FIGURE 14.—Hypothetical condition of drainage system of figure 13 after being overridden by glacial ice. Points *A*, *B*, *C*, and *D* are the same as in figure 13. Dotted lines indicate kettles.

PSEUDOMORAINES.

In the class of pseudomoraines are included certain ridges of the north shore which, although not of glacial origin, are so intimately associated with the moraines and so closely resemble them that they demand consideration here.

From a point a little east of Port Jefferson to Orient Point the morainal ridge hugs the coast, capping the tops of the bluffs that line the shore. The ridge is practically continuous, and at first sight the moraine appears for the most part unbroken. At a number of places, however, sections along valleys cutting the ridge show that, although it possesses a kettle and knob topography indistinguishable from that of a moraine, it is in reality composed entirely of wind-blown sands (Pl. VIII), the true moraine being entirely absent. In fact, it is not unlikely that considerable areas of the ridges mapped as moraines are only pseudomoraines composed of dune sand, although they may contain a core of morainal drift.

OUTWASH DEPOSITS.

EXTENT.

The outwash is the most extensive of the Wisconsin deposits on Long Island. At first sight, in fact, it appears to cover fully two-thirds of the surface of the island, but closer examination shows that the great plains stretching southward from the morainal ridges are in reality composite surfaces made up of outwash and projecting swells of older materials (Manhasset). Notwithstanding its wide extent, the outwash as a whole is not normally developed, the Manhasset formation even where buried exerting through its kettle valleys and allied features (p. 42) a considerable influence on the topography. Locally, however, especially near the moraines, several typical forms of outwash plains are represented.

OUTWASH DEPOSITS ADJACENT TO MORAINES.

SIMPLE FANS.

The simplest form of outwash accumulation is the fan-shaped deposit made by water issuing from the ice front at a single point. These fans are closely related to the isolated cones described in the discussion of the moraines but differ from them in that the points of emergence of the feeding streams were usually lower down in the ice, and the volume of outflow and consequently the transporting power were materially greater. The amount of water in the streams forming the simple fans was, nevertheless, not very great, the streams deploying almost immediately on their emergence from the glacial sheet and depositing close to the margin the material brought in suspension from the ice. The fans thus formed are usually small, being from half a mile to a mile or two in diameter, and have a comparatively steep slope, not uncommonly reaching 40 to 60 feet in a mile. They lie at short intervals along the southern moraine, the individual fans, although confluent at their outer margins, still being distinctly recognizable. Along the northern moraine the plains are flatter, and the component fans are usually distinguishable only with difficulty. In general the fans head against the morainal ridges rather than at gaps in them, the streams that came through the gaps apparently being more powerful than those that produce the fans and carrying their load to a greater distance before depositing it. The normal outline of an outwash fan is semicircular, but very few fans have this simple form, the direction of currents, the variation in the supply of material, and the character of the underlying surface all tending to produce unsymmetrical outlines. The individual fans are not commonly of a magnitude to be brought out with any degree of clearness by 20-foot contours, but indications of them may, nevertheless, be seen at many points on the topographic map. They are especially noticeable along that part of the moraine lying south of Peconic River.

CONFLUENT FANS.

In the same way that the simple fan is related to the isolated morainal cone the group of confluent fans is related to the confluent cones and ridges of the moraines and like them represents the discharge of a number of adjacent contributory streams. The spacing of the confluent fans, however, is not necessarily so close as that of the confluent cones, the greater spread of the fans allowing them to unite at much greater distances from their heads. The spacing of many of the confluent fans is less than a mile, but the feeders of some were several miles apart. All gradations in the form of the confluent fans, from those in which the individual fans of the group barely touch at the edges to almost completely confluent forms, are observed on the island, but even in the groups of the latter type the heads of the component members can in places be distinguished. The confluent outwash groups range from 1 mile to 6 miles or more in diameter. The slope ranges from 40 feet in a mile near the moraines to 15 or 20 feet a few miles away.

The best example of such a group of fans on Long Island is probably the plain bordering the Ronkonkoma moraine from the Half Hollow Hills eastward to Central Islip station, which embraces eight or more separate fans, at least five heading along the south side of the Dix

Hills and three or more along the moraine east of the gap north of Edgewood, the principal centers of dispersion being north of Edgewood, Brentwood, and Central Islip stations, respectively. (See topographic map, Pl. II, in pocket.) Another fine group of confluent fans is found in the vicinity of Hicksville, the component parts heading at gaps in the moraine instead of against the moraine, as is more common. Other typical groups center in the vicinity of Prospect Park, Brooklyn, and near Richmond Hill, west of Jamaica. The great fan groups of eastern Long Island are so broken and modified by Manhasset remnants that their typical character is lost.

OUTWASH DEPOSITS DISTANT FROM MORAINES.

CONFLUENT PLAINS.

In the same manner in which the fans unite to form groups the groups eventually unite into broad confluent outwash plains. The union of the groups commonly takes place at a distance of 2 or 3 miles from the moraine, but the distance may be considerably greater where the groups are separated by older ridges, as at the Mannetto Hills, where the Hempstead and Huntington-Babylon groups do not unite until they reach a point 6 miles south of the moraine. The lobate character of the contours, which is strongly marked in the fan groups (see Pl. II, in pocket), becomes less distinct in the confluent plains, the contours taking on broader curves. Thus in the Hempstead, Westbury, East Williston, and New Hyde Park groups, which unite to form the Hempstead Plains, the lobate contours are very noticeable, but in the resulting plain the individual curves disappear and the contours, aside from the minor bends at the drainage creases, show only a single broad curve, best indicated by the coast line extending from Jamaica east to Massapequa, a distance of 16 miles. The slope of the plains decreases progressively from the heads of the fans near the moraine and is commonly reduced to less than 15 feet and in many places to hardly more than 10 feet in a mile along the shore. Where the outwash plain is well developed one may look over its flat floorlike surface for miles without observing any irregularities other than its channels.

The individual outwash plains, such as the Hempstead Plains, unite with other plains, such as those of Babylon and Islip, to form a broad outwash belt reaching for many miles along the south side of the island. The greatest stretch of pure outwash (free or nearly free from Manhasset projections) is formed by the union of the plains mentioned, the extent of the belt from west to east being over 30 miles.

If the composite plains (Manhasset and outwash) east of Connetquot River are combined with these more typical plains they form an almost uninterrupted outwash plain from Brooklyn to Promised Land, a distance of more than 100 miles.

COMPOUND FANS.

The term compound is applied to certain groups of fans differing from the normal confluent type. Among the more important of these compound forms are those termed successive fans, which are analogous to the double and compound ridges of the moraines, being formed by deposition at successive stages of retreat of the ice margin. The chief points of difference are the greater volume of water taking part in their formation and the greater distance between the stages of halt. The relations of successive fans to one another is shown in cross section in figure 15.

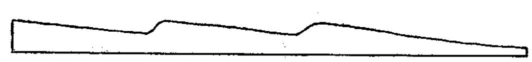


FIGURE 15.—Profile of a compound outwash fan of successive-plain type.

Suggestions of fans of this type were observed at a number of points, but few show a development as strongly marked as that indicated by the figure. One of the most accessible examples is found on the road south of Selden, where two or more southward-sloping fans with relations similar to those shown in the figure are seen.

SECONDARY OUTWASH FEATURES.

Besides the broader outwash features described in the foregoing sections there are many minor features that modify the general topography. Chief among these are the channels and valleys that cross the plains at short intervals. Many of these are sharply defined and of considerable width, several being a mile or more across. The various types, representing several distinct modes of formation, are described on pages 45–48.

Next to the valleys, the most important of the modifying features of the outwash area are those portions of the Manhasset surface which project above the outwash at many points. The continuity of the outwash surface is also broken by many kettles representing buried ice masses, which are considered at length in the next section. Still another source of irregularity is the extramorainal fosse described in connection with the other types of valleys (p. 47).

KETTLES.

To its glacial kettles Long Island owes many of its most pleasing features, including the hollows and basins which help to make the north shore an attractive residence district, the lakelets among its hills, the broad fresh-water ponds, such as Lake Ronkonkoma, and apparently even certain of its bays. In few regions is more diversity of type exhibited by kettles; in fact, it is difficult to imagine a greater range of form than is found on Long Island. This diversity is due to the differences in the conditions of their origin.

KETTLES OF THE TILL MORAINES.

As pointed out in the discussion of the topography of the till moraines (p. 34), the basins in deposits of this type are relatively shallow and have gently sloping sides and comparatively regular outlines, their flowing contours being strongly contrasted with the highly irregular outlines of the stratified moraines. This characteristic is brought out by the cross section shown in figure 16, a comparison of which with that of figure 17 will show the difference in profiles between the two types of kettles. So marked are the differences that they are even brought out by the 20-foot contours of the topographic map. Plate VI, *B* (p. 32), is a reproduction on an enlarged scale of a portion of the topographic map showing the till moraine north of Jamaica, and Plate VI, *C*, represents a typical portion of the stratified moraine south of Riverhead.

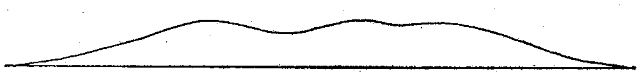


FIGURE 16.—Normal profile of till moraine.

The kettles of the till moraines usually mark the depressions between two accumulations of different stages rather than the sites of buried or projecting ice blocks, and have much less range in size than those of the stratified ridges. In fact, a kettle less than 100 feet or more than a quarter of a mile in diameter is exceptional in a till moraine. The tendency is toward elongated forms with the major axes parallel with the ice margin. Depths of more than 30 feet are rare, and the kettles are relatively isolated.

KETTLES OF THE STRATIFIED MORAINES.

As can be inferred from the conditions of formation of the stratified ridges (p. 33), their kettles are both more diverse and more numerous than those in the till moraines. Although shallow basins similar to those of the till ridges occasionally occur, the great majority of the kettles are relatively deep and steep-sided, the normal contour being similar to that shown in cross section in figure 17, which is in marked contrast to that of the till moraine, figure 16. The kettles of the stratified moraines represent in part the depressions left by melting ice blocks, in part the hollows between successive ridges or other forms of stratified accumulation, and in part depressions between heaps of ice-shoved materials. They have, therefore, a very great range, both in size and in form. Basins hardly 15 feet in diameter are observed here and there; and, on the other hand, some of the kettles have a diameter of one-fourth of a mile or more. In outline the kettles are equally varied, all forms from rounded depressions of the Lake Ronkonkoma type to elongated and branching kettles such as Great Pond, south of Riverhead,

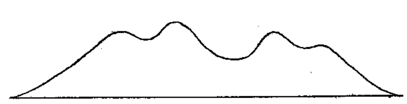


FIGURE 17.—Normal profile of stratified moraine.

being observed. The elongation, however, does not usually bear any close relation to the trend of the ice margin, and few linear groupings are noticeable, the common tendency being to an arrangement in crowded groups, as in the hills south of Riverhead. (See Pl. VI, *C*.)

KETTLES OF THE OUTWASH DEPOSITS.

KETTLES FROM BURIED ICE BLOCKS.

The simplest and least conspicuous of the kettles are those resulting from buried blocks of ice. The manner of their formation is brought out by figure 18, in which *a* represents an ice mass buried beneath the stratified outwash, *b*. On the melting of the ice the overlying sands or gravels are let down upon the underlying surface, as at *c*. The lower layers of the outwash are broken down into a confused mass, but the higher beds show only moderate sagging, and the surface is marked by a shallow basin with gently sloping sides, *d*. This is the typical form of buried-block kettles, but where the ice masses are larger and the covering of outwash relatively thin the kettles are of greater depth and their sides much steeper. In fact, all gradations between kettles from small buried blocks and those from large projecting masses are found. The kettles originating from completely buried blocks have as a class one distinctive characteristic, namely, the universal absence of bowlders from their surfaces; but as bowlders are likewise lacking in many projecting-block kettles (where the ice was free from englacial rock masses), this characteristic does not afford a criterion for the recognition of individual buried-block basins. Other negative characteristics of kettles of this class are the absence of rims, either of till or outwash, the absence of terrace or shore features, and the absence of drainage channels leading outward from the depressions.

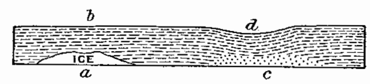


FIGURE 18.—Section illustrating the formation of a kettle from a buried ice mass. *a*, Buried ice mass; *b*, original outwash surface; *c*, structureless sands occupying space of melted ice mass; *d*, resulting kettle.

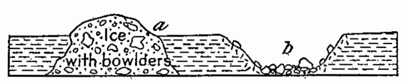


FIGURE 19.—Section illustrating the formation of a kettle from a projecting ice mass. *a*, Projecting ice mass; *b*, kettle resulting from the melting of similar ice mass.

KETTLES FROM PROJECTING ICE MASSES.

Formation.—The most characteristic and conspicuous of the outwash depressions are the kettles that result from the melting of large ice masses rising above the level of the surrounding outwash, as shown at *a*, figure 19. During the melting of masses of this type the materials banked against the ice are let down and the débris contained within the ice is set free and is left strewn over the bottom and sides of the kettle, as at *b*, figure 19. Few kettles of this type are entirely free from bowlders.

Steepness of sides.—The material let down as a broken mass around the perimeter of the depression rests with its surface at an angle which depends to a large extent on the profile of the ice border. Where the ice presented a vertical face the material on slumping took the steepest angle possible, its "angle of repose" giving slopes as high as 30° to 35° in some kettles (fig. 20, *a–a*); but where the ice presented a sloping face the material when let down lay at a much lower angle (fig. 20, *b–b*). Where the ice faces were regular the kettle sides are likewise regular (fig. 21, *a–a*); but where the mass of ice was irregular the slopes that resulted from its melting are correspondingly irregular (fig. 21, *b–b*).

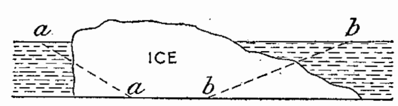


FIGURE 20.—Section illustrating the relation between the slopes of kettle sides and the shape of melted ice mass. *a–a*, Steep kettle side resulting from steep ice face; *b–b*, gentle kettle side resulting from sloping ice face.

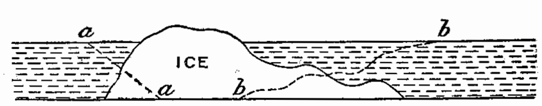


FIGURE 21.—Section illustrating the relation between the slopes of kettle sides and the shape of melted ice mass. *a–a*, Even slope resulting from melting of regular ice margin; *b–b*, irregular slope resulting from the melting of irregular ice margin.

Form.—The shape of the outwash kettles is of great irregularity, every form from simple circular or oval to highly branching (Pl. XX, p. 116) or long linear channels being noted. Some of the more conspicuous kettles are listed on the next page.

Typical kettles of Long Island.

Circular or oval:
- Lake Ronkonkoma, 1½ miles north of Ronkonkoma station.

Irregular oval:
- Lake Success, 2 miles south of Manhasset.
- Artist Lake, 1 mile east of Middle Island.
- Swan Pond, 2 miles northeast of Manorville.
- Great Pond, 2 miles southwest of Riverhead.
- Watermill Pond, near Watermill.
- Poxabogue Pond, 1 mile east of Bridgehampton.

Branching:
- Kettles, southeast of Huntington station.
- Kettles, southwest of Huntington station.
- Kettles, 2 miles southwest of Rocky Point.
- Dix Pond kettle, 1 mile southeast of Wading River.
- Long Pond kettle, 2 miles southwest of Wading River.
- Mattituck Inlet, near Mattituck.

Linear:
- Kettle, 2 miles west of Middle Island.
- Kettle, 1 mile south of Fresh Pond.
- Scuttle Hole, 2 miles northwest of Bridgehampton.

Size.—The normal outwash kettles range in diameter from a few rods to about a mile. In many of the linear kettles, however, as seen in the table on page 43, the longer axes are from 2 to 4 miles in length. Although the great bays between the North and South flukes are not typical kettles, there is reason to believe that they owe their existence to nondeposition of outwash drift resulting to a certain extent from the presence of large ice masses in these basins. In a way, therefore, Great and Little Peconic bays may possibly be regarded as kettles, in which case the maximum diameter of such depressions would be increased to nearly 6 miles.

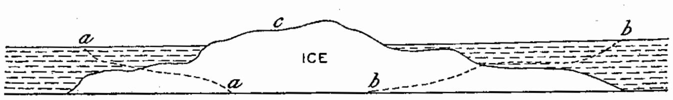


FIGURE 22.—Section illustrating the formation of kettle terraces by the melting of ice masses of especial shapes. *a–a*, Imperfect terrace; *b–b*, regular terrace; *c*, ice mass.

Depth.—Many kettles of the outwash deposits are of considerable depth, their bottoms standing from 20 to 60 feet or more below the surrounding region. Examples of the deeper kettles are given in the following list:

Deeper kettles of Long Island.

	Elevation of surrounding surface.	Depth.
	Feet.	*Feet.*
Lake Ronkonkoma, 1 mile north of Ronkonkoma station	107	50
Kettle, 1 mile south of New Village	160	85
Kettle, 1 mile southwest of Rocky Point station	130	80
Kettle, 1 mile southeast of Wading River station	105	82
Kettle, ½ mile northeast of Baiting Hollow	110	80
Scuttle Hole, 2 miles northwest of Bridgehampton	70	40

Terraced kettles.—By terraced kettles are meant those showing flat benches on their sides at levels intermediate between the bottom and the rim. They appear to have at least three possible modes of formation. Probably the most common mode is by the melting of basal projections of the ice masses, as shown in figure 22. Few such terraces are perfect, most of them showing some irregularity that betrays their origin.

A second type is due to the shrinkage of the ice mass (*a*, fig. 23) and the deposition of materials set free from the melting of the remaining block (*b*, fig. 23) in the space (*c*, fig. 23) between it and the inclosing outwash. It is difficult in the absence of sections to verify the existence of the conditions indicated, but that the ice may carry sufficient detritus to form such a terrace is proved by the presence of local outwash rims in a number of places. The amount of drift in the lower part of glacial ice is almost invariably greater than in the higher parts, hence sufficient material to form a terrace within a kettle might be set free, even where no outwash rim was formed by the melting of the upper portion of the ice.

A third type of terrace seems to have resulted from erosion in the free space between the shrinking ice mass and the kettle walls, due either to the action of waves upon the gravel or sandy sides or to the sweeping of currents around the perimeter of the ice block toward the drainage channel which leads away from the kettle. Terracing of this sort is of minor importance except where combined with deposition, as in the type last described.

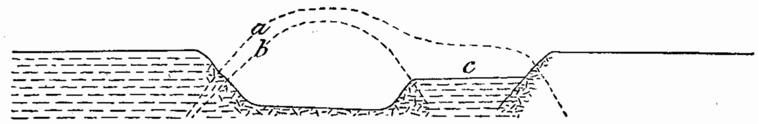


FIGURE 23.—Section illustrating the formation of depositional terraces between ice mass and kettle wall. *a*, Original profile of ice mass; *b*, later form of melting ice mass; *c*, sands and gravels deposited between ice and kettle wall.

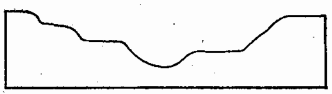


FIGURE 24.—Profile of terraced kettle near Lake Grove.

Terraces were observed in a considerable number of kettles, especially in the eastern part of the island. As this region was examined without a map (before the topographic survey by the United States Geological Survey), it is generally impossible to give locations with sufficient accuracy to make them of value.

Some very distinct terraces may be seen where the road crosses the deep kettle valley three-fourths of a mile northwest of Lake Grove and about 3 miles east of Smithtown Branch (fig. 24). Kettle terraces, however, are not usually persistent, and these die out within a few hundred feet.

Kettle rims.—Elevated rims are formed around the edge of certain kettles by materials set free by the melting of the ice masses to which the kettles are due. Three forms have been recognized. The most common form is probably the outwash fan (*a*, fig. 25) formed by the spreading out of fine materials over the surrounding outwash by rills from the melting ice. These fans are generally so flat as to be recognized with difficulty, but the slopes of some are steep and the fans are easily recognized when seen in profile.

FIGURE 25.—Profile of kettle with outwash rim (*a*).

A second form, much less common than the preceding, is represented by more or less conical heaps (*a*, fig. 26), analogous to the cones of a moraine (p. 32) and formed by small rills issuing from the ice several feet above the surface of the outwash plain.

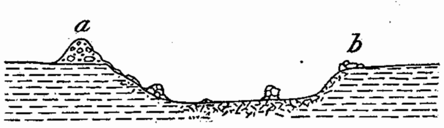


FIGURE 26.—Kettle rims. *a*, Till rim; *b*, bowlder rim.

The third form is similar to the second and consists of irregular heaps of till or lines of bowlders (*b*, fig. 26) that have slid from the ice face as it melted, without the intervention of water.

In the absence of sections it is difficult to distinguish rims of the second and third types, but the first type is more readily recognized. The best example was reported by D. W. Johnson at a point near the gap in the moraine about 2 miles northwest of Southampton. The drawing representing this kettle rim in Mr. Johnson's notes is reproduced in figure 27, in which the view is northwest, the direction of movement of the outwash being toward the northeast. The notes of Mr. Johnson also record "delta-like scallops, probably the discharge of melting ice blocks" near the north end of the Scuttle Hole kettle valley northwest of Bridgehampton. An example of what appears to be a till knoll is found bordering a kettle about a mile southwest of Cutchogue on the road to Mattituck, at an elevation of about 15 feet above the surrounding plain. Knolls of drift of intermediate or indeterminate types border the kettle valleys between Riverhead and Baiting Hollow and the kettles at the fairground southeast of Huntington station.

FIGURE 27.—Outwash rim adjoining kettle 2 miles northwest of Southampton. (From sketch by D. W. Johnson.)

DOUBLE KETTLES AND KETTLE CHAINS.

Double kettles are exceedingly numerous on Long Island; in fact they probably outnumber the simple isolated kettles. Examples are shown at many points on the topographic map. Twin lakes are present in many such kettles. Not only are double kettles common, but triple kettles are not unusual and in some places, as in the area northwest of Riverhead (Pl. IX, *C*) and in the Scuttle Hole locality northwest of Bridgehampton (Pl. IX, *A*), a considerable number of more or less connected kettles, which may be here appropriately called kettle chains, are found.

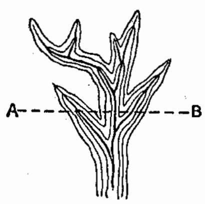


FIGURE 28.—Pre-Wisconsin drainage system in Manhasset formation. A–B, Line of section of figure 30.

In the double kettles and kettle chains the barriers separating the component members are nowhere as high as the surrounding plains, as a rule being not more than 15 or 20 feet above the kettle bottoms. Generally these separating ridges retain their original irregular or rounded contour, but well-defined notches cut by flowing waters connect some adjacent kettles. The channel mentioned in the description of the Scuttle Hole kettle, below, is typical of the class.

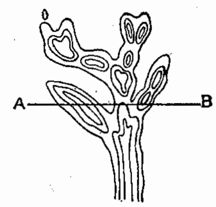


FIGURE 29.—Kettle valley system remaining after the melting of Wisconsin ice masses. A–B, Line of section of figure 31.

KETTLE VALLEYS.

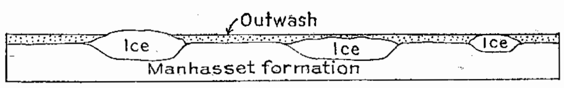


FIGURE 30.—Cross section along the line A–B of figure 28, showing residual ice masses partly buried by outwash.

In no other part of the glaciated area of America which has come under the writer's observation are kettle valleys so well developed. They are, in fact, among the most distinctive topographic features of Long Island. Briefly, they may be defined as long linear or branching kettles marking the positions of snow or ice masses that lay in the valleys of a previous surface and were covered with outwash. The conditions of their formation are brought out by figures 28 to 32. Figure 28 shows in plan a normal drainage topography, such as characterized the Manhasset surface at many points before the advent of the Wisconsin ice sheet. Figure 30 is a cross section along the line A–B of figure 28, showing the valleys occupied by snow ice or by residual ice masses left by the glacier during a recession, together with a covering of outwash spread over valleys and ridges alike. Figure 31 shows a profile along the same line after the melting of the ice masses of the valleys. Where the ice filling a valley was of uniform thickness and melted at a uniform rate, an open valley resulted, but where the ice was of irregular thickness and melted at differing rates in different parts the overlying outwash was let down more or less irregularly, being thin or lacking in some places and of considerable thickness in others. Where it was thick the old valleys have been almost invariably more or less obstructed and have been converted into a series of elongated kettles, as shown in profile in figure 32 and by the contours in figure 29. The kettle valleys of Long Island are not only numerous but large. Some of the more prominent are listed in the table on page 43.

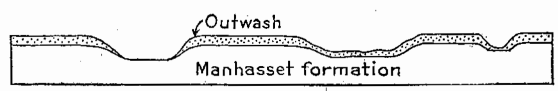


FIGURE 31.—Cross section along the line A–B of figure 29 after melting of ice masses.

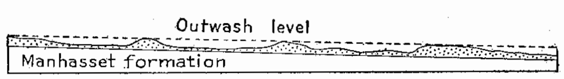


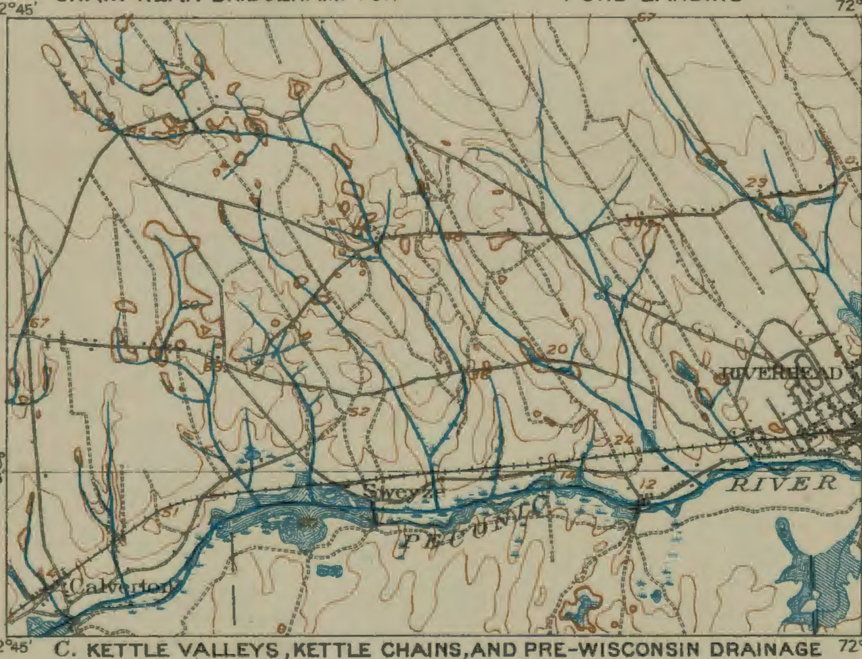
FIGURE 32.—Profile along the course of the kettle valleys of figure 29.

The Scuttle Hole kettle channel is described in the field notes of D. W. Johnson, as follows:

> It leads directly southeast [from its head near the moraine] with slight meanders to the big kettle and pond [near the railroad]. The gorge is from 20 to 25 feet wide at the bottom, which is flat except where cut by a little trench of recent erosion. The sides are abrupt. The gorge ranges in depth from 6 to 8 feet at its [upper] end to 20 or 25 feet where it opens into the big kettle. It has two [or more] insignificant lateral branches, both from the north and only a few rods long. The channel is cut sharply into the outwash plain, there being no slope toward it [other than the sides of the valley]. At the east end is a broad shallow kettle. This latter served as a receptacle into which the waters accumulated [coming from the northwest portion and cutting the minor trench mentioned].

A. KETTLE VALLEY AND KETTLE CHAIN NEAR BRIDGEHAMPTON

B. KETTLE VALLEY NEAR FRESH POND LANDING



C. KETTLE VALLEYS, KETTLE CHAINS, AND PRE-WISCONSIN DRAINAGE LINES NORTHWEST OF RIVERHEAD

TOPOGRAPHIC FEATURES OF LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1913

Large kettle valleys of Long Island.

Location.	Character.	Length in miles.
One mile southeast of Huntington station (Fairground)	Irregular, completely closed	1
One mile west of Middle Island	Long, narrow, branching, partly closed (Pl. XX, p. 116)	4
Two miles north of Middle Island	Irregular branching, partly closed (Pl. XX)	2
One-half mile east of Middle Island	Irregular, partly closed, containing Artist Lake (Pl. XX)	1
Vicinity and north of Lake Ronkonkoma	Highly irregular, practically closed kettle-valley system (Pl. X)	3
Two miles southwest of Rocky Point	Irregular, completely closed (Pl. XX)	2
Two miles southwest of Wading River station	Irregular kettle-valley system, partly closed, containing Long Lake	2
One mile southeast of Wading River	Branching, contains Deep Pond, completely closed	2
One mile south of Fresh Pond Landing	Valley, partly open, and kettle chain (Pl. IX, *B*)	3
Three miles northwest of Riverhead	Kettle chain (Pl. IX, *C*)	4
Near Mattituck (Inlet)	Branching, reversed drainage (Pl. XI, *C*)	2
Two miles northwest of Bridgehampton (Scuttle Hole)	Kettle chain and valley, mainly closed (Pl. IX, *A*)	3

PITTED OR KETTLE PLAINS.

The term kettle plains is here applied to those plains in which kettles are so numerous as to be the controlling factor in the topography. All gradations between isolated kettles (*a*, fig. 33) and kettles so closely crowded that only the higher rims reach to the level of the surrounding plain (*b*, fig. 33) are found on the island. In fact, not a few of the pitted or kettle plains grade off into irregular surfaces on which no trace of the original plain is left (*c*, fig. 33). Where the kettles are more or less isolated and are separated by flat outwash areas, as in the plains west of Cold Spring station and southwest of Huntington station (Fairground), the kettle-plain character is very apparent, but where they are more crowded the significance of the topography is less easily recognized. In such places the sky line affords the most reliable clue. If on looking from one of the higher points, such as *b* in figure 33, it is found that, notwithstanding the absence of flat remnants, the rounded knobs rise to a nearly uniform elevation (as they do in the direction of *a*) it is usually safe to assume that the surface is a pitted plain. An occasional flat-topped remnant makes the recognition much easier. The region northwest and west of Riverhead, the district about Bridgehampton, and the country between Riverhead and Mattituck are among the best examples of kettle plains.

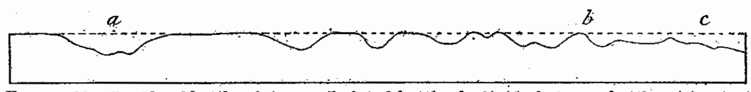


FIGURE 33.—Profile of kettle plain. *a*, Isolated kettle; *b*, divide between kettles rising just to level of plain; *c*, kettle surface with no remnants rising to surface of plain.

KETTLES OF DOUBTFUL ORIGIN.

About 2½ miles northwest of Babylon, east of the road leading toward the Half Hollow Hills, is a shallow kettle large enough to be shown on the topographic map, and a number of smaller basins are hidden by the underbrush of the vicinity. Other distinct kettles were noted in the vicinity of Farmingdale. The former are more than 10 miles and the latter 8 miles from the moraine from which the outwash issued and 5 to 7 miles south of the outer moraine. There are no evidences that the glacial ice ever extended to this region, and even if it did there would seem to be no possibility that ice blocks would have persisted from a period antedating the oldest moraine until near the close of the building of the youngest. Moreover, in the older outwash of this part of the island there are no kettles. Therefore, as there are no evidences of an extramorainal ice invasion or of snow-ice masses during the upbuilding of the earlier outwash, it would seem that the kettles, whatever may be their cause, were developed during the formation of the later outwash deposits themselves. The accumulation of snow or snow ice in channels temporarily dry and the freezing of the smaller deploying rivulets of the broad outwash fan and the burial of the ice thus formed by subsequent deposits suggest themselves as possible causes. It is to be noted, however, that the basins are all small and that they lack the sharp and irregular slopes that characterize most of the kettles of Long Island, and it may be that they have resulted from some unknown peculiarity of deposition. Similar depressions have, in fact, been noted by the writer in the flood-plain deposits of Mississippi, Ohio, and Wabash rivers, in whose formation ice has played no part.

KETTLES OF THE MANHASSET SURFACE.

Kettles on the Manhasset surface are exceedingly numerous and may be divided into those due to ice shove and drag, including obstructed and modified valleys, and those due to deposition. In the obstructed or modified valleys resulting from ice shove or drag there has been invariably a reworking or readjustment of materials, the accumulations being essentially morainal. The formation of kettles in this manner has been discussed in connection with moraines (p. 35, figs. 13 and 14). The kettles due to deposition are represented by the kettle valleys and kettle chains described in the preceding section.

PSEUDOKETTLES.

Besides the true kettles, comprising hollows between glacial ridges and basins left by melting ice masses, there are on the island several other forms of undrained depressions. Among these may be mentioned the unfilled areas between the moraines and the confluent outwash fans (p. 47), the sharp-angled, kettle-like basins and troughs of the sand-dune areas, and the irregular depressions in landslide surfaces. In wet seasons small pools form in the landslide depressions and small shallow temporary ponds gather among the dunes.

VALLEYS.

The valleys of Long Island exhibit a wide range of form according to the conditions under which they were produced. The types include those formed by glacial waters as well as those made by ordinary streams; all ages from early Pleistocene to Recent are represented, and both original and modified forms are found.

PRE-MANNETTO VALLEYS

The oldest valleys on Long Island of which a record exists are those eroded in the Cretaceous formations before the deposition of the Mannetto gravel, but as these were completely filled by the gravel deposits they have no direct topographic expression at the present time. Nevertheless, as is pointed out elsewhere (p. 29), they exerted an important indirect influence on the subsequent topography by their control of Mannetto deposition. The deposits of the Mannetto reached lesser elevations in the broad, low Cretaceous lowlands than over the higher surfaces, as a result of which the post-Mannetto erosion tended to follow the lines of the earlier drainage.

VALLEYS IN MANNETTO GRAVEL.

The valleys of the Mannetto gravel differ greatly in extent, all sizes, from the small notches around the borders of the plateau remnants, as in the Mannetto Hills (Pl. III, p. 28), to broad lowlands many miles across, being represented. Of the latter, the so-called Jameco Valley, crossing the island from north to south in the region between Hempstead and Brooklyn and occupied by the Jameco gravel, is the best example, but inasmuch as it is a buried valley rather than a feature of the present topography it need not be considered further.

Intermediate between the larger and smaller valleys mentioned are the valleys of the hills. In the Wheatley Hills, the most westerly considerable remnant of the Mannetto gravel, the valleys radiate to the southwest, south, and southeast from the crest near Wheatley village (Pl. VI, *D*, p. 32). Originally the valleys were probably deep and V-shaped and were separated by fairly straight, flat-topped interstream ridges, probably not unlike those in the younger deposits on the south side of the Half Hollow Hills (north and northwest of Wyandanch), valley depths of 100 and 150 feet being not improbable. Owing to the passage of the various ice sheets over them, however, the valley walls have been broken down, the minor ravines largely obliterated, and the main valleys obstructed and more or less filled with both till and stratified drift, giving the whole area a decidedly morainal superficial aspect, although the major contours, as brought out by the topographic map, are plainly due to erosion. The hills apparently represent a Mannetto surface dissected to the extent that the valleys met from all directions about a central crest and were separated by sharp ridges. The crest and ridges probably stood not far from the level of the original Mannetto surface, but little or nothing in the shape of flats at this altitude appears to exist. It is to be noted that the valleys on the north side of the hills have been completely obliterated by the ice sheets and their deposits.

The Dix Hills and the small mass of hills northwest of them are very similar in their topography to those near Wheatley, showing the same obscured or obliterated valleys on the north side, the same modified and partly filled valleys on the south, and the same superficial morainal topographic features. The dissection appears, however, to have been less advanced than in the Wheatley Hills, and it is probable that in the central part of the Dix Hills there were several remnants of the original Mannetto surface standing at an elevation of about 300 feet and having a considerable extent, although less than in the Mannetto Hills.

The Mannetto Hills afford the best-preserved examples of unmodified valleys in the Mannetto gravel, as only the north end of the hills was overridden by ice. The rough parallelism of the valleys and the lack of conspicuous branching, features which are so noticeable in the Wheatley Hills (Pl. VI, *D*, p. 32) and on the southeast side of the Dix Hills, are even more conspicuous on the Mannetto Hills, especially on their west flanks (Pl. III, p. 28). All the valleys have served as channels to conduct glacial drainage southward from the ice front as it laid along the moraine, hence they are considerably modified from the pre-Wisconsin forms. Several fine terraces may be seen in the valleys north and northeast of Plainview. It is noticeable that many of the longitudinal divides separating the valleys are reduced considerably below the 280 to 300 foot level (that of the Mannetto surface), although a few remnants, usually flat topped, occur well out on the spurs, as is shown by the topographic map. The chief remnant is found in the flat-topped ridge, in places of considerable width, stretching southward from the moraine to the vicinity of Bethpage.

The valleys of the Mannetto gravel above described were mainly developed in the post-Mannetto stage, immediately following the Mannetto deposition, for the distribution of the succeeding formations, including the Jameco, Gardiners, Jacob, and Manhasset, shows that relatively little further erosion took place after that stage, although trenching continued near the heads of the streams among the hills, as in the Wheatley, Mannetto, and Dix masses, until the covering of the hills by Wisconsin drift and to a less extent until the present time. The valleys of the east side of the Mannetto Hills extend considerably below the level of the Manhasset (as represented in the Bethpage and Half Hollow Hill remnants) and therefore belong to a post-Manhasset period of erosion.

OLDER VALLEYS IN THE MANHASSET FORMATION.

The valleys in the Manhasset formation are everywhere conspicuous features, cutting the formation from its surface at an elevation of 200 feet or less to a point considerably below sea level. As post-Wisconsin erosion has accomplished little more than a slight notching of the bluffs and steeper hillsides, practically all the valleys shown on the topographic map belong to the older or pre-Wisconsin group. Most of them do not, however, show the original forms, for, with the exception of the Nissequogue Valley near Smithtown (Pl. X, p. 46), there is nowhere in Long Island a Manhasset valley of notable size that has not been materially modified by ice action or the deposition of glacial débris. In many valleys, however, the modification was confined largely to the deposition of a superficial mantle of drift which, although giving rise to minor irregularities that in places simulate low morainal accumulations on the valley sides, does not obliterate the chief characteristics. The valley at Glencove, that of Mill Neck Creek, other valleys near Oyster Bay, the Cold Spring valley, and the valleys east of Northport are examples of this class.

When the action of the ice was more energetic or the deposition took place on a larger scale, many old valleys were obstructed and even partly obliterated, the remarkable kettle valleys described in detail on page 42 being produced.

The western half of the Nissequogue Valley at Smithtown is in an area practically free from Wisconsin drift and was protected from erosion by a filling of snow or ice. We have here, therefore, a practically unmodified remnant of the original Manhasset drainage system with its deep, sharp trenches and branching valleys. It is not unlikely that such systems existed at many other points on the island but have been materially modified by the passage of the ice over them or by more or less complete burial beneath Wisconsin drift. Remnants of such modified systems are found north of Lake Ronkonkoma (Pl. X), in the vicinity of Middle Island (Pl. XX, p. 116), near Wading River, and northwest of Riverhead (Pl. IX, *C*, p. 42).

South of the Ronkonkoma moraine the Manhasset valleys are represented by the short V-shaped valleys cutting the Mannetto and Half Hollow hills and by the broad, shallow, ill-defined valleys leading southward to the coast in regions where the Wisconsin outwash is thin. The valleys of the hills mentioned may be taken as representing a type of short valleys such as were probably developed also in the high bluffs at many places along the north shore; they are now represented by the valleys at the heads of Huntington, Centerport, Stony Brook, and other harbors.

It is difficult to describe with any degree of accuracy the broader Manhasset valleys south of the moraine, as it is generally impossible, even on the ground, to differentiate sharply between the Manhasset and the outwash gravels. The Manhasset topography was in general low, with broad, gently rounded divides and perhaps equally ill-defined valleys, the outlines of which were still more obscured by the deposition of the subsequent outwash. A somewhat sharply marked valley, however, appears to have led southwestward from the vicinity of Lake Ronkonkoma, uniting with another valley from the region east of Hauppauge at a point a little north of the railroad, whence it extended southward along the course of the present Connetquot River. (See Pl. II, in pocket.) Apparently its sides rose steeply to a height of 30 feet or more above its bottom, and it had many tributary valleys, especially from the east. A smaller valley probably entered the sea near Patchogue, and another large one, exceeding even the Connetquot channel in size, extended southward from Yaphank. This valley had a width of over 3 miles in places and was bordered by bluffs or steep slopes, probably rising originally in places to heights of not less than 80 feet above its bottom. Even after receiving the filling of outwash from ice along the Ronkonkoma moraine the bottom still stood, near the site of the railroad, at least 50 feet below the surrounding Manhasset surface.

VALLEYS ASSOCIATED WITH THE MORAINES.

Minor channels.—The simplest class of valleys of the moraines are the small wash channels extending down the sides of the morainal cones and ridges. The stratified morainal deposits were for the most part built up from small rivulets that were alternately overloaded and underloaded with glacial débris. When overloaded the water quickly deployed and ran down the surface of the deposits in many streamlets, effecting but little erosion. On the other hand, when underloaded the water, instead of spreading and depositing, tended to deepen some one of the many channels of the deploying rivulets and to concentrate itself in that single channel, which was soon enlarged into a valley of some magnitude. The tendency to form such channels was probably most pronounced in the closing stages of morainal building.

The water in its passage downward followed the natural hollows in the moraine, here entering a kettle and there passing around some knoll. At the start the channels were therefore of considerable irregularity, but as their development continued they tended to straighten, the minor bends being obliterated and only the long, swinging curves remaining. The channels are commonly from 15 to 50 feet wide, although some are wider, and are generally flat-bottomed, though some are slightly trenched by subsequent erosion. The sides are commonly steep and in places rise to a height of 30 feet or more. Remnants of terraces are seen locally, but few are

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TOPOGRAPHIC FEATURES NEAR SMITHTOWN AND LAKE RONKONKOMA, LONG ISLAND, NEW YORK

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

Contour interval 20 feet

Datum is mean sea level.

1913

well developed. The slope of the channels is commonly between 1 to 50 and 1 to 25, or 100 to 200 feet to the mile. Many groups of channels have a semiradial development from some central height, but as a rule the channels extending southward are much better developed than those running in other directions. The best areas for tracing such channels are in the great irregular hills of the Ronkonkoma moraine south of Peconic River (Pl. VI, *C*, p. 32), southeast of Riverhead, and between Hampton Park (Southampton) and Sag Harbor.

Kettle channels.—The small erosion channels that mark the pathways of waters escaping from an ice block into an adjoining kettle or from one kettle into another (fig. 34) are described and examples are given in connection with kettles (p. 42). They should not be confounded with the kettle valleys, which are of entirely different origin.

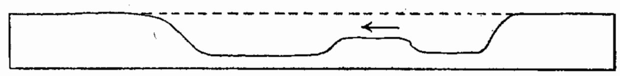


FIGURE 34.—Profile showing a channel between kettles.

Outflow channels.—The pronounced valleys leading through the morainal ridges and commonly cut to the level of the outwash plains bordering the moraines on the south are known as outflow channels. Through them flowed large glacial streams issuing from the ice margin or from the waters impounded between the ice front and the moraines; hence their origin differed in several essential particulars from that of the minor channels just described. They are relatively broad, few being less than 100 feet wide and some from one-fourth to three-fourths of a mile. The smaller channels commonly merge into outwash fans, of which they were the feeders, but the larger ones are generally prolonged as definite valleys across the outwash plains, being, in fact, the heads of the outwash channels described on page 48. The floors of the channels are mostly flat, with perhaps a small central furrow marking a late phase of outflow or with low terraces on one or both sides of the valleys. In general the higher points of the valley walls are constructional (morainal) rather than destructional, indicating that the gaps are mainly original features and are not due to erosion by waters forcing their way across the moraine. The locations of the most prominent of the outflow channels are indicated on the geologic map, Plate I (in pocket).

Outer morainal fosse.—On Long Island, as elsewhere, it is not unusual to find at the base of the outer border of the moraine a longitudinal depression or fosse lying between the ridge and the adjoining outwash plain (fig. 35). This feature is not especially well marked on the island, although some good local examples are seen. None are very deep, 5 to 10 feet being a common depth, although a few are deeper. Most of them appear to represent unfilled depressions behind the outwash fans, the tendency to deposit being least marked along the moraine at right angles to the direction of the emerging stream. Fosses due to this cause are without erosion features and commonly show by their topography their constructional origin. Other fosses, however, have the form of somewhat indefinite channels, as if occupied and modified by outflowing waters at some period subsequent to their formation. It is even possible that some are of the nature of true outwash channels and mark the positions of outwash streams that happened to occupy at the closing stages of outflow positions next the moraine.

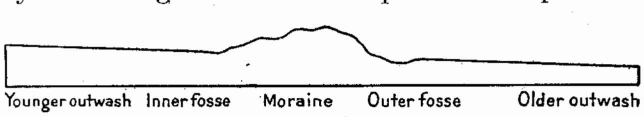


FIGURE 35.—Profile showing relation of inner and outer fosses to moraine.

Inner morainal fosse.—The inner fosse, although perhaps not so common as the outer on Long Island, is a much more striking feature. In its simplest form it is a channel running along the inner face of the moraine, apparently due to the lateral flow of water between the ice and the moraine (fig. 35). What is probably a channel of this type is shown at *a* in figure 36, from field notes of D. W. Johnson, who says: "This depression [near Duck Pond Point, Mattituck] is peculiarly constant for a considerable distance east and west," making a sharp trench in the inner face of the moraine.

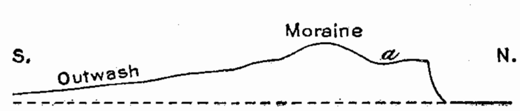


FIGURE 36.—Profile showing fosse (*a*) at inner base of moraine near Duck Pond Point. (After sketch by D. W. Johnson.)

The most remarkable fosses of this type occur on the north side of the Montauk Peninsula, between Fort Pond and Napeague bays, 1½ to 3½ miles west of Montauk station, where there is a succession of channels having a northeast-southwest direction parallel to the moraine. The channels, although too crowded for accurate delineation, are clearly indicated on Plate VII, *C* (p. 34). An examination of this map will show four main channels cutting the 100-foot terrace north of the moraine (dotted) and just southwest of Fort Pond Bay (A). These channels, which are the deepest and most conspicuous of the fosses, open to the southwest upon a bench of about 60 feet elevation and northeastward they extend to sea level. They are flat-bottomed, steep-sided erosion channels and appear to have been outlets for waters issuing from the ice margin at successive halts and escaping into Fort Pond Bay and thence through the pond depression into the ocean. Figure 37 shows a cross section of the moraine and terrace with the fosse channels. Indications of smaller channels on the lower slopes of the terrace are seen between the railroad and the shore south of Rocky Point (B, Pl. VII, *C*).

A second group of channels is found southwest of the first but draining in the opposite direction, to the southwest. The more southerly channels of this group appear to have carried the escaping waters to a gap leading southward across the moraine (C, Pl. VII, *C*) 2 miles west of Hither Plain life-saving station, whereas the more northerly drained into a channel (D, Pl. VII, *C*) leading westward to Napeague Bay near Quince Tree Landing, whence the water escaped to the ocean through the gap now closed by the long connecting beach.

As indicated by their form the main features of the fosse channels described are erosional, but there is some reason to believe that their position and to some extent their form and depth may be due to folding. Thus on Cape Cod, where the walls of similar channels are shown in cross section in the bluffs, they are seen to represent actual folds whose troughs were simply widened and otherwise shaped by outflowing waters. In the absence of sections, however, it is impossible to determine what part, if any, folding has played in the formation of the Montauk channels.

One of the largest of the closed inner-fosse depressions is that lying along the north face of the Ronkonkoma moraine from a point near Lake Grove, north of Lake Ronkonkoma, eastward through New Village, Selden, and Coram to Middle Island, a distance of nearly 10 miles. Its extent and outline are both well brought out by the 100-foot contour of the topographic map, although this contour does not quite close. The northern slopes of the fosse are gentle, being formed mainly by the Manhasset surface with its shallow drainage creases more or less modified by their outwash fillings. The south flanks are steeper, being formed by the inner face of the Ronkonkoma moraine. In the eastern part the bottom is marked by the great kettle valleys of the Middle Island region. The fosse has no surface drainage, the waters falling upon its sides and bottom escaping by underground percolation through the sands beneath the moraine.

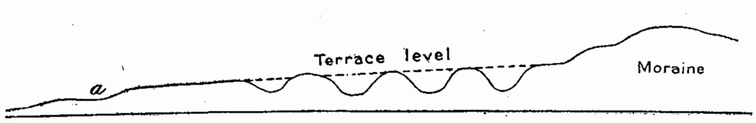


FIGURE 37.—Profile of inner-fosse channels west of Fort Pond Bay, Montauk peninsula (Pl. VII, *C*, A). *a*, Small channel on lower slope of terrace.

The fosse now occupied by Peconic River is fully as large as the one just described and is of the same general character, although it is an open instead of being a closed depression. Lying lower than the other, its bottom cuts the water table, giving rise to the river that enters Great Peconic Bay at Riverhead.

OUTWASH CHANNELS.

The outwash channels, which include all the drainage depressions of the outwash deposits, are among the most interesting of the topographic features of the island, presenting in their various types, forms, and relations many attractive problems.

RELATION TO MORAINES.

Most of the larger and more important of the outwash channels head in gaps in the moraine, being the continuations of the outflow channels described in connection with the morainal valleys. Among the most important of these may be mentioned the one leading southward from the Harbor Hill moraine at Roslyn and the Centerport-Babylon channel leading southward from the same moraine near Greenlawn; there are also many smaller unmapped channels heading in gaps in the moraine between Yaphank and Montauk. (See geologic map, Pl. I, in pocket.)

Besides the larger and better-defined channels there are a considerable number of smaller drainage lines heading either against the moraine or at one of the minor morainal channels. Some of these can be seen by tramping a mile or two almost anywhere along the south base of the Ronkonkoma moraine, but they are less common in front of the Harbor Hill ridge.

Channels of a third class start at points on the outwash plain some distance from the moraines and are apparently formed not by definite streams issuing from the moraine but by the gradual gathering together of waters from various sources, including those that had previously deployed and deposited their suspended material. The channels developing near Melville between the Mannetto and Half Hollow hills are good examples of this class.

A fourth class is due to the collection of the outwash waters through the agency of an older topography instead of by normal conditions pertaining to outwash accumulation. Such channels are exceedingly numerous on Long Island. Good examples are afforded by the channels uniting to form Carmans River between Middle Island and Yaphank, the streamless valleys leading to Peconic River west of Riverhead, and the many valleys leading to the estuaries of Moriches and Shinnecock bays.

Channels of still another class, represented by the great Connetquot channel leading southward from Smithtown Branch, originated in ice masses not resting against the moraine but are otherwise similar to those heading at the morainal gaps.

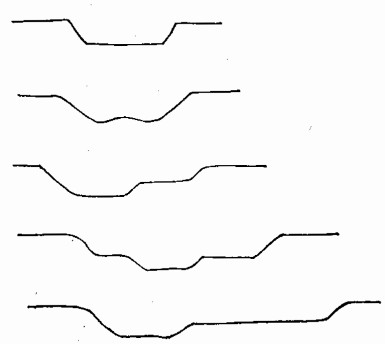


FIGURE 38.—Sections of terraced channel leading westward from Lake Ronkonkoma.

RELATION TO KETTLES.

A considerable number of minor outwash channels head in kettles, but as a rule the water from melting ice blocks was too small in amount to cut deeply into the gravels, and few such channels are large enough to be shown on the topographic map. They are probably most abundant in the kettle-valley region northwest of Riverhead, but similar channels lead from the lower kettles southeast of Scuttle Hole, near Bridgehampton (Pl. IX, *A*, p. 42). A larger and very sharp and definite channel leads westward from Lake Ronkonkoma and joins the main Connetquot channel (Pl. X, p. 46). As the Connetquot channel issued from a large ice mass occupying the Nissequogue Valley, it may itself be regarded as originating in a kettle, although the kettle was finally left open.

FORMS OF CHANNELS.

The valleys of the outwash are of two distinct types—true erosion valleys and interfan creases. The former are well-defined channels with flat bottoms, terraced borders, and steep banks (fig. 38); the latter are broad, shallow sags between two confluent outwash fans represented on the map by bends in the contours, but many of them hardly apparent to the eye. The two types occur in combination at many places, however, and at such places the faint interfan creases are accentuated by true channels, as in the region between Edgewood and Central Islip stations. Channels of this type are most conspicuous at a distance from the moraine.

Terraces are of widespread occurrence in connection with the outwash valleys, there being probably very few such channels that in the course of a mile do not show something in the shape of a terrace. A given terrace, however, is as a rule not persistent for any great distance, generally dying out in a few hundred yards and being replaced by another at a higher or lower level. So far as observed there is no uniformity in their number or elevation. They appear to be rather accidental remnants left at various altitudes during the practically uninterrupted period of downcutting. So numerous are the terraces that specific mention would be without value. The type is illustrated in figure 38, which shows cross sections at intervals of about one-eighth of a mile in the channel leading westward from Lake Ronkonkoma to the main Connetquot Channel (Pl. X, p. 46).

Although the bottoms of outwash channels are commonly flat there are numerous exceptions. The most common irregularity seems to be a low, rounded, barlike ridge along the center, such as that shown in figure 39, *a*, which represents the profile of a large channel along the road just south of Commack. The bars are commonly of no great extent, dying out gradually both up and down the channels. In places two or more overlap en échelon and others are more or less confluent and irregular. All gradations between normal bars and the ridges and terraces separating the double channels described in the next paragraph are found.

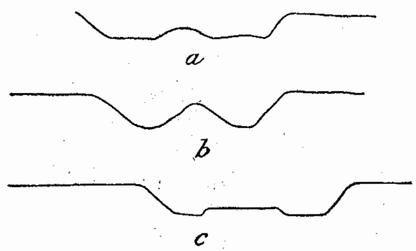


FIGURE 39.—Forms of outwash valleys. *a*, Channel with bar south of Commack; *b*, ridged channel 1½ miles north of Lake Ronkonkoma; *c*, double channel 1 mile west of Holtsville station.

It appears that in some places after the deposition of the bars above described the volume of water became lessened and was no longer able to fill the whole of the original channel but divided into two small streams, one flowing on each side of the bar. These streams gradually cut for themselves separate channels, the intervening bar eventually being left as a ridge, as shown in figure 39, *b*, which represents in cross section a southwestward-leading channel about 1½ miles north and a little west of Lake Ronkonkoma.

It seems to have happened not infrequently that during the closing stages of outflow the waters of the broader outwash channels were reduced to two small streams, one of which hugged one bank and one the other. These streams also cut subordinate channels, which were separated by a broad, flat terrace representing the uneroded part of the floor of the larger outwash valley, as shown in figure 39, *c*, which is a profile across a small channel 1 mile west of Holtsville station and a quarter of a mile south of the railroad. A similar and larger double channel is shown in the outwash valley between the Mannetto and Half Hollow hills, each side of which is marked by a broad, sharp channel that is well brought out by the geologic map (Pl. I, in pocket).

The slope of the bottoms of the valleys is usually gentle and uniform from the moraines to the sea, the rate being commonly from 10 to 15 feet to the mile but flattening in the lower mile or two, apparently owing to a slight sinking of the land, which has permitted the lower parts of the valleys to be occupied by estuaries of the sea and has caused a slackening of the drainage.

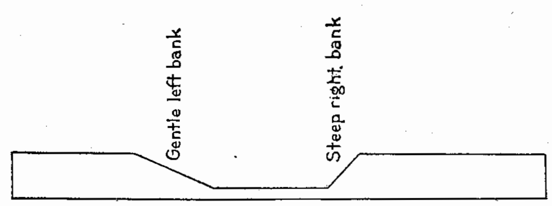


FIGURE 40.—Profile showing relative steepness of east (left) and west (right) banks of Long Island valleys.

As long ago as 1877 Elias Lewis, jr.,[1] called attention to the greater average steepness of the right-hand or westerly banks of the outwash channels as compared to the easterly or left-hand banks (fig. 40), stating that the difference had been long noted by travelers and referring it to the earth's rotation, as a consequence of which the streams are thrown against the westerly banks. Seven years later G. K. Gilbert[2] discussed the deflective force due to the earth's rotation, limiting it to streams of slight fall and citing the Long Island streams as good examples. The observations of the writer and his assistants seem to indicate that probably four-fifths of the ordinary shallow valleys of the outwash plains lying south of the outer moraine have steeper banks on the west than on the east side. In some valleys the difference is as marked as that shown in figure 40, but in others it is hardly appreciable. The development, however, must be recognized as remarkable when the weakness of the force is considered.

Local exceptions to the general rule of steep westerly banks were observed, but the only notable ones are in the relatively deep valleys formed where the outwash streams have cut

[1] Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 215-216.

[2] Am. Jour. Sci., 3d ser., vol. 27, 1884, pp. 427-432.

into the Manhasset formation. In such valleys the steepness of the bank depends on the curvature of the streams, being greatest on the outside of the bends. In straight reaches the banks are of nearly equal slope.

Although the cutting of the valleys of this type began in Wisconsin time, the erosion and shaping of the banks has extended to the present day, especially along the south shore, where the water table comes to the surface and supplies the short streams with water.

Many of the outwash valleys have been partly obstructed by the formation of deltas across the main valleys at the mouths of tributary streams. Usually the flow of water in the larger valleys has been sufficient to cut through the deltas, but here and there the obstructions have not yet been overcome, and wet weather ponds of considerable size accumulate behind the barriers. The best example of an obstructed valley with ponded water observed was on the northeast-southwest road three-fourths of a mile northwest of Lake Ronkonkoma, where a marshy pond over a quarter of a mile in length was seen in 1903.

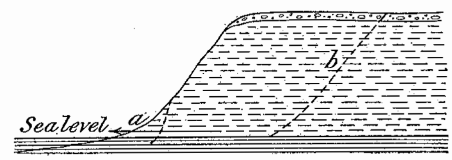


FIGURE 41.—Section illustrating formation of amphitheaters by spring sapping. *a*, Original point of emergence of the spring; *b*, profile of resulting hopper.

POST-WISCONSIN VALLEYS.

NATURE AND EXTENT OF EROSION.

Little work has been done in post-Wisconsin time by the larger streams of Long Island other than local widening of their valleys, for their channels had already been extended to or below the level of the sea when the Wisconsin ice sheet retreated before the opening of the present period. The principal recent changes have been accomplished by subordinate agencies, the chief of which are "spring sapping" and rivulet erosion, the former represented by numerous amphitheaters and the latter by short ravines and gullies in the bluffs and by small notches in the older valley floors.

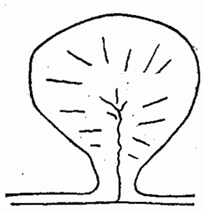


FIGURE 42.—Plan of hopper or amphitheater at an early stage.

FORMS OF THE VALLEYS.

Amphitheaters.—Wherever a body of clay or other impervious substance underlies a mass of porous material and comes to the surface at or near drainage level (*a*, fig. 41), there is formed a series of springs often perennial and copious in volume. At such places part of the overlying incoherent sand is almost always carried away, the action being limited at first to the immediate vicinity of the point of emergence of the spring (*a*, fig. 41) but extending later farther and farther back until finally a great hopper-shaped excavation or amphitheater results, as shown in profile in figure 41 and in plan in figure 42.

In the early stages the hoppers or amphitheaters are of nearly circular outline, but as the sapping progresses the erosion tends to become uneven through the influence either of inequalities in the underlying impervious stratum, or of variations in the character of the material in which the hopper is cut, or of other causes affecting the distribution of drainage lines. As a consequence of unequal sapping, erosion goes on faster at some points than at others, and an unsymmetrical amphitheater soon results (fig. 43). The irregularity continues to increase until a normal drainage system is produced. Few if any such systems, however, have been developed on Long Island in post-Wisconsin time. Hoppers 200 to 300 feet in diameter and 100 feet or more deep are seen at many points along the north shore, especially from Wading River eastward to Mattituck Inlet.

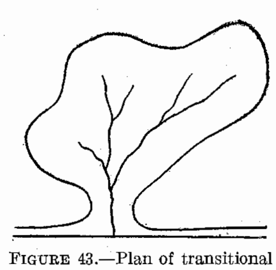


FIGURE 43.—Plan of transitional form between a hopper and a normal drainage system.

Notched cliffs.—The notched cliffs are produced by an agency working from above instead of from beneath, as in the hoppers, the underlying clay and its attendant springs being absent. The notching is greatly facilitated by the incoherent nature of the deposits of the Manhasset formation, in which most of the notches are cut, but is retarded by the porous character of this material, which causes it to absorb the waters before they can unite and form streams of much vigor. Many of the notches start at close intervals and develop into a succession of sharp, V-shaped parallel ravines separated by narrow rounded ridges giving a serrate plan and profile to the bluffs at many places, especially along the edges of the lower bluffs in the eastern half of the island (fig. 44).

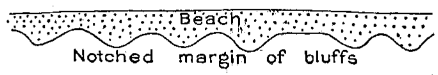


FIGURE 44.—Plan showing character of notching in bluffs of the northern coast in eastern Long Island.

Hanging valleys.—Where the shore line has remained unchanged for a series of years the ravines enter the sea at grade. As a whole, however, the coast is undergoing somewhat rapid erosion by the waves, a single storm not infrequently cutting several feet or even a rod or more into the base of the bluffs and leaving a large number of the ravines as hanging valleys with floors 5 to 10 feet above the beach (*a*, fig. 45). Where the stream erosion is slight the wave action may continue predominant for a long series of years or even permanently, in which case the action of the waves is cumulative and the valley enters at progressively higher points (*b*, *c*, and *d*, fig. 45) until perhaps only a slight notch at the upper edge of the cliff remains (*e*, fig. 45).

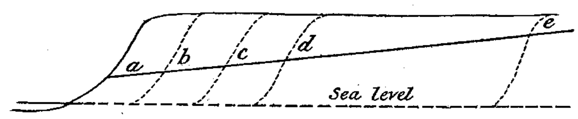


FIGURE 45.—Section illustrating the relation of height of hanging valleys to stage of erosion of bluffs. *a*, *b*, *c*, *d*, and *e*, Successive positions of bluffs; *a*–*e*, floor of valley.

As soon as the hanging valleys are formed by the cutting back of the cliffs their reexcavation by storm waters is begun, usually with a relatively narrow notch in their bottoms having a somewhat steeper grade than the older valley. (See fig. 46.) At the same time a steep fan is built up against the bluff at the point where the storm waters issue from it (*d*, fig. 46).

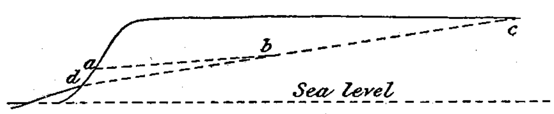


FIGURE 46.—Section illustrating the notching of hanging valleys. *a*, *b*, *c*, Original floor of valley; *b*, *d*, slope of channel of newly cut notch.

Examples of hanging valleys are usually very numerous, especially within the first year or two after a severe northerly storm, and all the types described may generally be seen in a walk of a few miles along the beach, especially in the region east of Port Jefferson. The citation of the examples noted during the progress of the field work would, because of the constant changes in the bluffs, be of little value.

Obstructed ravines.—Many of the ravines cut in the deposits of the north shore are more or less obstructed by materials brought in since their formation. Probably the most common cause of obstruction is the building of a delta or fan across a ravine from materials supplied by a tributary channel entering at a high angle. Such obstructions, however, are commonly due to local causes, such as a sudden increase of débris in a tributary, but are usually soon cut away. Another common cause of obstruction, especially in the sharper ravines, is the caving of the incoherent banks, letting down an irregular mass of sand, till, and other material (fig. 47). Several good examples were seen in 1903 in the region between Fresh Pond Landing and a point north of Riverhead.

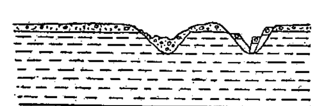


FIGURE 47.—Section illustrating the obstruction of valleys by landslides.

Refilled ravines.—Many ravines have been partly refilled with deposits having the relations shown in figure 48. This refilling appears to be due to the waters becoming overloaded in the later part of the ravine's history, a condition apparently caused by a decrease of rainfall and run-off. In brief, it is assumed that the original ravine was cut at a time of heavy run-off, perhaps during a storm or series of storms, and that the filling has taken place during a period of ordinary rains in which the run-off has been insufficient to sweep the material to the sea. The differences in run-off are doubtless due to irregular and accidental local variations in precipitation and other conditions, rather than to any real climatic change. A single heavy and continued downfall of rain may at any time sweep the valleys clear of their fillings and even cut them deeper than they were originally. Valleys of this type are constantly changing, but examples can probably be found along the coast near Fresh Pond Landing.

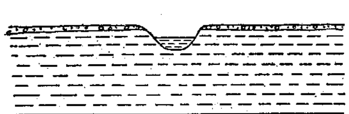


FIGURE 48.—Section of refilled ravine of the north coast.

A. PRE-WISCONSIN EROSION SCARP NEAR CREEDMOOR

B. RECENT EROSION SCARP OF NORTH COAST

C. BRANCHING KETTLE VALLEY WITH REVERSED DRAINAGE NEAR MATTITUCK

73°50′

D. SLIGHTLY MODIFIED AND OVERRIDDEN SCARPS NEAR BROOKLYN

JULIUS BIEN CO. N.Y.

TOPOGRAPHIC FEATURES OF LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1913

INLAND SCARPS.

PRINCIPAL EXAMPLES.

Inland scarps of considerable prominence occur at several places on the island, some being of glacial and others of subaerial origin. The most important are the scarp facing the Connetquot outwash channel south of Smithtown Branch, those facing the valley between the Mannetto and Half Hollow hills, and the one stretching along the south side of the Harbor Hill moraine west of its junction with the outer or Ronkonkoma moraine south of Manhasset Bay. (See Pl. II, in pocket.) The Connetquot scarp has been described and its origin has been discussed in detail on page 46. The scarps between the Mannetto and Half Hollow hills owe some of their features to stream erosion beginning as early as the close of Mannetto deposition, but the greater part of the valleys and ravines that now notch the edges of these scarps are clearly post-Manhasset, for they cut into and extend well below the surface of that formation. A further shaping, including the planing away of projecting spurs, resulted from the action of the waters of the broad Wisconsin outwash channel passing between the hills, and the final minor notching is the result of post-Wisconsin erosion.

THE GREAT INLAND SCARP OF WESTERN LONG ISLAND.

CHARACTER.

A well-marked scarp beginning at Lake Success, near the eastern boundary of the Borough of Queens, where the outer or Ronkonkoma moraine is crossed by the inner or Harbor Hill moraine, extends westward in almost a straight line to Fort Hamilton at the Narrows, a distance of about 20 miles, with a height of 60 to 100 feet above the outwash deposits bordering it on the south (Pl. XI, *A*). An examination of its face shows the surface material to be mainly till, some sections near the top of the bluff containing 20 to 30 feet or more of this material. Nevertheless records of wells put down a little back from the edge of the scarp generally show relatively little till, the drill soon passing into stratified sand or gravel, possibly a part of the moraine but more probably part of the Manhasset formation of which fine exposures north of the moraine are known to occur at this level. In Prospect Park, Brooklyn, more or less folded strata of sand and gravel, probably Manhasset, have been exposed from time to time. It is believed that a complete cross section would show the bluff to consist mainly of stratified gravel of the Manhasset formation, with a mantle of till varying in thickness from a few feet near Lake Success to 30 feet or more at points in Brooklyn, lying unconformably over its top and face. This till appears to be late Wisconsin, hence the scarp that it mantles must have been formed before that time.

Additional evidence as to the age of the original scarp is afforded by the notches in its face. From Lake Success to the vicinity of Hollis the notches are generally small and simple with little branching, and such notches are characteristic of most parts of the scarp. Northwest of Hollis, near Maple Grove, north of Woodhaven, and at several points west of East New York, especially near Prospect Park, Brooklyn, the notches are larger and resemble the dendritic systems characteristic of drainage development. In fact, it seems fairly clear that such was their origin. They are not postglacial features, however, for they have every appearance of being clogged and partly obliterated by the deposition of till.

In addition to the larger convexities, such as that north of Hollis, projecting swells of till and other material pushed forward by the ice occur here and there. J. B. Woodworth [1] in describing the scarp says:

> West of Prospect Park the morainal front maintains its lineal course toward New York Narrows, but with a rather bulging frontal slope composed of stratified gravels. As seen in pits open in the season of 1900 these stratified gravels rise up steeply from the northern margin of the frontal plain, then bend downward into a large kettle hole in the deposit. The attitude of the beds suggests frontal shoving on the part of the ice.

[1] Bull. New York State Mus. Nat. Hist., No. 48, 1901, p. 649.

ORIGIN.

That the original scarp was cut in deposits antedating the later Wisconsin drift (probably in the Manhasset formation), that it is the result of erosion, that it was subsequently buried by a mantle of late Wisconsin till, and that it has suffered little subsequent erosion, seem clear. The fact that its origin antedates the deposition of the latest drift explains why the scarp lacks the abruptness that would be expected if the cutting had been post-Wisconsin, and why no beaches or terraces have ever been found. The range in elevation of the base of the scarp from 240 feet near Lake Success to 60 feet near East New York, which has always been a stumblingblock in the way of accepting the theory of its recent marine origin, is due to the natural slope of the outwash plains built against it, the line of contact with these plains being in no sense a warped shore line.

The origin of this scarp appears to be clearly indicated by its topography, every feature of which is duplicated elsewhere on the island under conditions apparently admitting of the absolute determination of origin. The original scarp differed in no way from the bluffs at dozens of points on the north shore, and the drift-covered face and partly filled valleys have counterparts at many places. This is strikingly brought out by the maps given on Plate XI, *A* and *B*, which represent respectively a part of the morainal scarp near Creedmoor, and a part of the north shore near Miller Place, east of Port Jefferson. The same steep bluffs with minor indentations are seen in each locality, and the valleys cutting them are almost identical in character. The only difference in the topography, in fact, is the slightly steeper face at the Miller Place locality, due to the fact that there is no coating of till on the face of the bluff, which is being rapidly cut by the waves at the present time. There is little reason to doubt that the inland scarp under discussion is, in its main features, of marine origin but has been modified by late drift. (See Pl. XI, *D*.) There seems to be no ground for regarding it, as some have, as a morainal front, for it has few of the characteristics of a moraine except in its most superficial features.

How high the land stood when the scarp was formed can not be told. From the depth of channels in the vicinity of the island (see p. 59), it is known that the land stood considerably higher in relation to the sea in the Vineyard interval than at present. The fact that Cretaceous formations are found at a depth of about 100 feet, or about 25 feet below sea level in a well in front of the scarp at Hollis, shows, however, that unless the mass encountered represents an offshore island, the land could not have stood more than 25 feet higher than at present.

SHORE BLUFFS.

There is hardly a point on Long Island at which the highlands reach the coast where the shore is not bordered by bluffs, this being true of the bays and harbors as well as of the exposed coast line. The condition of the bluffs varies greatly from place to place, however, all gradations being observed from nearly vertical cliffs such as border the south coast west of Montauk light to relatively gentle slopes (25° to 35°) completely covered with trees. On the open coast probably four-fifths of the bluffs are free from vegetable growth, and perhaps a tenth are sufficiently free from talus to admit of the determination of their composition and structure from top to bottom. The remainder are clothed with grass or trees or artificially covered. In the harbors about half of the cliffs are covered with vegetation and half free from it. Harbor cliffs are, however, seldom free from talus, but even in the talus-covered cliffs the general structure can usually be made out by a little digging.

The condition of the bluffs often changes materially within a short time. The whole line along a coast may be modified by a single storm, which in some places eats into the bluffs and elsewhere throws up barriers of sand or gravel in front of them, according to the direction of the wind, the angle of impact of the waves, and the nature of the currents set up at the time. The barriers built up along the beaches in front of the bluffs persist until they are removed by storms or currents from other directions than those of the storms which formed them. Some of them last for many years—long enough for the cliffs behind them to become covered with grass or even forests—but sooner or later the cutting begins again and the cliffs are under-

GENERAL VIEW OF GREAT LANDSLIP AREA AT BROKEN GROUND, NORTHEAST OF NORTHPORT.

Photograph by G. N. Knapp.

A.

B.

BROKEN GROUND LANDSLIP AREA, NORTHEAST OF NORTHPORT.

A. Inner scarp and tilted block. *B.* Upturned Cretaceous clays at base of landslip mass.
Photographs by G. N. Knapp.

mined, landslides take place, and earth and tree trunks are mingled in confused heaps. (See "Landslides," below.)

The cliffs are best preserved where coherent materials, such as the Gardiners clay, Jacob sand, and Montauk till members of the Manhasset formation outcrop in the bluffs (Pls. XIX, *B*, p. 114; XXII, *A*, p. 136), and are least well preserved in the sands and gravels of the Manhasset (Pl. XX, p. 116). At the time of the examination of the shore line in 1904 the best exposures were on Gardiners Island, on Robins Island, and on the south coast of Montauk from Napeague Bay to the lighthouse. Fine exposures were also found on the south side of Great Peconic Bay, on the two large necks east of Sag Harbor, and especially along the north coast from Port Jefferson to Orient Point. Good exposures were seen northeast of Northport and on Eaton and Lloyd necks. West of Oyster Bay, although there were a few good exposures, as at Rocky Point and on the east side of Hempstead Harbor, the bluffs are prevailingly low and are in many places artificially covered. The south shore, except the Montauk Peninsula and the part of Shinnecock Bay south of the Shinnecock Hills, is essentially free from cliffs, although it has some bluffs 4 or 5 feet high.

LANDSLIDES.

Landslides may be ranked among the conspicuous features of Long Island, occurring, as would be expected, at many points on the steep bluffs of the north shore. Some of them represent a mere slipping of the surface of the bluffs, whereas in others the land is affected for many hundred feet back from the shore (Pl. XII). The slides are of a number of different types and are due to a variety of causes, the more important of which are noted below.

CAUSES.

Work of waves.—The action of waves is the direct cause of many of the landslides of the island and the indirect cause of most of the others. The whole north shore, the shores between the flukes, and the south shore between Montauk Point and Napeague Beach are exposed to the full action of the waves, which during storms, cut rapidly into the bluffs. When the cutting begins in the softer material, such as the Manhasset formation, the talus that has gradually accumulated since the last preceding storm commences to slide downward and is soon removed by the waves. The undisturbed drift itself is then attacked, and this, being generally loose and uncemented, crumbles as soon as a vertical face of a few feet is produced, often setting the entire face of the sandy bluff in motion, tilting or overturning the trees, shrubs, or plants that may have obtained a foothold upon it. A similar result often follows stream erosion on the sides of some of the small but sharp ravines of the north shore.

If the material is till, especially the partly cemented Montauk type, the erosion is somewhat different. The material does not crumble rapidly, and the waves often make progress only by tearing it away bit by bit until they produce a vertical or even overhanging face. Faces overhanging as much as 3 or 4 feet have been observed. When this stage is reached a new process, which may be called scaling, begins, the material peeling off in vertical layers or scales. Some of these layers are thin, but in places vertical slabs, the largest 20 feet or more high and 1 or 2 feet thick, become detached. The most typical examples of these slides, if they may be called slides, are seen at Montauk Point.

Work of springs.—The action of spring sapping on Long Island, which is a very prevalent cause of landslides, was described as long ago as 1843 by Mather. Springs act in two ways—by adding water to the finer sands and converting them to quicksands and by actual erosion by the streams proceeding from them. Commonly both processes go on together.

The gravels of the north shore are saturated by waters that ordinarily reach the sea between high and low tide by seepage without appearing at the surface elsewhere. Under these usual conditions few or no slides seem to be produced, for the water table is at some distance below the beach, and the quicksands, if any are formed, are prevented from escaping by the overlying material. But where an impervious layer holds the ground water in the bluff at a level higher than the beach, the sands may be changed to quicksands and flow seaward, allowing the overlying material to sink and producing landslides of considerable size. The action is generally localized and produces hopper-shaped instead of linear slides. At this stage the water of the spring begins its erosion, carrying the material brought down by the slide to the beach while new slides bring down additional masses to take the place of the first. The pronounced amphitheaters on the north coast and many of the short, sharp valleys are produced in this way.

Movements of clays.—The slides produced by the flowage and slipping of clays are by far the most conspicuous slides on the island, because of the considerable areas they cover and the confusion of the resulting topography. Many of the clays when wet are very plastic, and there is probably considerable flowage of those in the steeper bluffs under the weight of superincumbent deposits, although this is difficult to prove because of the absence of good cross sections. If not the cause of the landslides it is certainly an effect, for there are many places where the plastic clays have been pressed out upon the beach in contorted masses, as shown in Plate XIII, *B*.

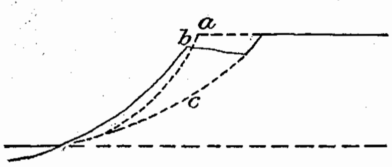


FIGURE 49.—Section showing the nature of displacement in the larger landslides and the origin of the scarps shown in Plates XII, XIII, *A*, and XIV, *A*. *a*, Original profile; *b*, profile after slipping; *c*, slipping surface.

The sliding of the layers of clay on their bedding planes is also doubtless an important cause of landslides, but here also no evidence has been found to show to what extent this movement actually takes place. Sliding may occur also along curved fractures, as shown in figure 49. Such a movement is suggested by the conditions shown in Plate XIII, *A*, although there is no reason why either of the other causes should not have produced the same effect. The sliding of sand beds over wet clays has been suggested as another cause of slides, but observation on Long Island seems to indicate that ordinarily no such slipping takes place. In every clay slide observed the clay beds themselves seem to have moved, as indicated by the contorted structure they have assumed.)

DETAILS OF LANDSLIDES.

The Broken Ground slide, the largest on the island (1904), is situated on the Sound shore, 3 miles northeast of Northport and 1 mile north of Fort Salonga.[1] The north face of the hill, which has an elevation of 100 feet, has been converted by the slides into a confused jumble of earth masses and prostrate trees. On passing northward over the crest one suddenly comes to a fault scarp varying in height from 5 feet at the ends to 30 or 40 feet at the center (Pl. XIV, *A*). At the base of the scarp is a broad shelf 50 yards across, representing the surface that was dropped by the fault (Pl. XIII, *A*). Beyond this is a succession of slip faults separating narrow tilted blocks, the whole grading off to the more confused earth heaps at the base (Pl. XIII, *B*). In 1904 many of the faults were still open to a depth of 5 to 10 feet. The whole disturbed area has a length of nearly half a mile and a width between an eighth and a quarter of a mile.

The other landslides on the island are relatively small, only the faces of the bluffs commonly being affected. It is obvious that any storm would be likely to remove old slides of this character and produce new ones, hence detailed descriptions would have little value. It may be said, however, that extensive slides may be looked for at any point where clays are cut by the sea. These localities are indicated on the geologic map (Pl. I, in pocket). Among the places where more or less definite slides were observed in 1904 may be mentioned the west shore of Eaton Neck (where Cretaceous clays outcrop); Woodhull Landing near Miller Place, west of Hulse Landing, Jacobs Point, Luce Landing, and Jacob Hill (Gardiners clay); Oregon Hills and Mulford Point (till).

SUBMARINE FEATURES.

LONG ISLAND SOUND.

The great Sound valley.—After the close of Cretaceous deposition in the Long Island region there was, as has been seen, an interval of nondeposition during most of Eocene time. The extent of the uplift in this interval, if any, and the amount of erosion are not known, but it does not appear to be represented by any great unconformity. During Miocene time the land, at least in the southern part of Long Island, was below sea level, and enough deposits were laid

[1] Incorrectly located by Veatch (Prof. Paper U. S. Geol. Survey No. 44, Pl. VII) as northeast of Huntington.

A. MAIN SCARP AT BROKEN GROUND LANDSLIP AREA, NORTHEAST OF NORTHPORT.
Photograph by G. N. Knapp.

B. CRETACEOUS DEPOSITS ON LLOYD NECK.
Showing composition and structure. Photograph by G. N. Knapp.

down to bury in large measure the erosion topography developed in the Eocene epoch. It is believed that up to this time the Cretaceous deposits existed as an essentially continuous sheet with its northern border overlapping upon the crystalline rocks of the Connecticut shore, and that the Miocene deposits rested on the Cretaceous with their shoreward margin somewhere in the southern third or half of Long Island.

In the Pliocene epoch the region was greatly reduced by erosion, in which both streams and the ocean took part. A. C. Veatch[1] believes that during the early part of this period (pre-Lafayette) Housatonic and Connecticut rivers continued to flow southward across the Coastal Plain but developed, through the agency of tributaries along the contact of the Cretaceous with the crystalline rocks, more or less marked lateral valleys with northward-facing scarps. These lateral valleys were partly filled but not obliterated by the Lafayette deposits, but the narrow valleys leading southward through the ridge are considered by Veatch to have been more nearly effaced. The post-Lafayette uplift he apparently regards as accompanied by a tilting toward the southwest, which caused Housatonic and Connecticut rivers to be deflected westward, passing across the site of Long Island in the vicinity of Jamaica Bay near the west end and, after uniting with the Hudson a few miles beyond, running southeastward in what is usually known as the submarine Hudson channel. Veatch's maps show that he supposes this course to have been maintained after the Mannetto deposition, amounting to 300 or 400 feet or more, and to have been deflected only after the deposition of the Manhasset formation (Tisbury of Veatch). To the erosion by the streams mentioned, acting through this long period, Veatch refers the development of Long Island Sound.

To the writer the history seems to be somewhat different. After the post-Miocene uplift the streams, as stated by Veatch, probably continued southward across the Coastal Plain to the ocean and very likely developed lateral valleys along the contact with the crystalline rocks. Any opinion as to what happened in the Long Island region in Lafayette and post-Lafayette time must be entirely speculative, for no Lafayette deposits have been identified, and there is no evidence yet available for distinguishing between the post-Miocene and post-Lafayette erosion periods.

The Mannetto deposition amounted to more than 300 feet and possibly more than 500 feet and in central Long Island appears to have buried all the older deposits, with the possible exception of those on High Hill, south of Huntington, where, though nothing but drift shows at the surface of the hill, the topographic features suggest that it may have a core of Cretaceous material. The Mannetto deposits would have completely obliterated any valley across Long Island that might have existed. If the drainage in post-Mannetto time took the course indicated by Veatch, it must have marked the beginning of a new cycle that was entirely independent of the earlier and did not inherit the courses of its streams.

The distribution and elevation of the Cretaceous deposits of western Long Island indicate that, in all probability, no conspicuous valley with its bottom much below the present sea level was ever formed across the island in the Jamaica-Jameco region. These deposits appear to be above sea level from a point east of Smithtown to a point north of Jamaica. At Whitestone they are less than 20 feet below sea level, and at College Point they appear to be less than 85 feet below sea level. The distance between the point of observation north of Jamaica and that at Whitestone is 2 miles, and that between Whitestone or College Point and the outcrops of crystalline rocks on the mainland is 1 mile. The intervening channel is only about 60 feet deep. There is, therefore, no room for any but a narrow and correspondingly shallow channel through the island at this point, there being no break comparable in size to the broad Sound supposedly due to erosion by the same streams. It would be strange if the stream that in its upper part eroded a valley from 10 to 20 miles wide should have a valley only 1 or 2 miles in width near its mouth.

The Sound is broadest at a point southeast of New Haven, where it has a width of over 20 miles. From this point it tapers gradually westward until only the narrow East River separates

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 28-32.

Long Island from the mainland. A more significant feature, however, is the similar form of the area inclosed between the mainland and the Cretaceous remnants lying above sea level on the island. At Eaton Neck the breadth of the strip between the Cretaceous boundary and the crystalline rocks is 8 miles, at Lloyd Neck 7, at Glen Cove 5, and at Elm Point 3 miles. At Whitestone the Cretaceous, which is here only 20 feet below sea level, is only about a mile from the crystalline rocks. If normally developed by subaerial erosion, such a valley could be produced only by a stream system draining eastward.

That the Sound is in the main the result of such erosion rather than of ice scour is probable, as the Pleistocene deposits of Long Island, although derived principally from the Sound, would not obliterate it if returned. Moreover most of the drift above sea level in the eastern part of the island appears to have been derived not from the Cretaceous deposits but rather from the mainland or from older glacial deposits lying in the Cretaceous trough. This trough is not the result of ice erosion, as is shown by the absence of corresponding glacial accumulations, and the great depth to the Cretaceous surface (555 feet below sea level in a well at Greenport) must therefore be referred to stream work. Other well records throw light on the eastward deepening of the buried Cretaceous valley—the Sound valley, as it may be called.

In a map based on such records Veatch [1] shows the Cretaceous to be at or within a few feet of sea level in the vicinity of the north coast from College Point eastward to the vicinity of Stony Brook. A well record, as stated above, shows it to be about 550 feet below sea level at Greenport, but at Fishers Island, still farther east, the top of the Cretaceous seems to be only 260 feet below sea level. None of these points, except perhaps the Greenport well, are in the present Sound valley, and there is no means of estimating the depth of the old valley except by prolonging northward the observed decline of the Cretaceous surface, as brought out by well records, and the present depth of the Sound, a method which is of course far from satisfactory. In the hills north of Old Westbury this surface has an elevation of about 230 feet. Thence it declines northward, being slightly below sea level at the coast. The same rate of fall would give it a depth of at least 100 feet in the center of the Sound. In the Mannetto Hills it is elevated about 300 feet, and it declines to sea level at Lloyd Neck, a rate which would carry it to 150 feet below sea level in the Sound. The water as a matter of fact is more than 100 feet deep at this point. At Westhampton the Cretaceous is about 150 feet below sea level, whereas at Riverhead, 8 miles to the north, it was not recognized in a well 300 feet deep. At Bridgehampton it seems to have been encountered about 75 feet below sea level, although 12 miles farther north, at Greenport, it was reported about 550 feet below sea level.

There seems, therefore, to be a broad buried valley in the Cretaceous surface in the Sound region, having a width of a mile or two near the west end of the island and opening out eastward to a width of about 20 miles near New Haven. The valley seems to deepen eastward from 100 feet or less near College Point to at least 550 feet in the vicinity of Greenport. Its southern rim is pretty uniformly from 300 to 400 feet higher than the lowest point of the valley. The shallowness of the Cretaceous on Fishers Island would seem to indicate that the axis of the valley passed south of this point.

The present valley of the Sound seems to be due principally to stream erosion, assisted, however, by a certain amount of ice scour. It appears to have been cut entirely in the unconsolidated Pleistocene and Cretaceous deposits, there being, so far as known, no corresponding depression in the underlying rock surface nor other evidence to support the theory of limestone solution advanced by F. J. H. Merrill[2] on the basis of the composition of the clay.

Later channels.—The bottom of Long Island Sound as a whole is remarkably even, in most places sloping gently southward from the Connecticut shore at the rate of 10 or 20 feet to the mile for about two-thirds of the way across the Sound, and rising somewhat more steeply to the Long Island coast. The level bottom is, however, as was long ago pointed out by Dana,[3] inter-

[1] Veatch, A. C., op. cit., Pl. III.
[2] Annals New York Acad. Sci., vol. 12, 1900, pp. 113–116.
[3] Trans. Connecticut Acad. Arts and Sci., vol. 2, 1870, pp. 65 et seq.; Am. Jour. Sci., 3d ser., vol. 10, 1875, pp. 280–282; vol. 40, 1890, pp. 425–437.

rupted by a number of more or less channel-like depressions. The most conspicuous of these extends eastward from a point about north of Oyster Bay and is from 25 to 50 feet deeper than the surrounding bottom (fig. 50). At a point north of the head of Great Peconic Bay it bends slightly southward and is lost in the shallow water of the Long Island coast. Dana considered that it passed across the site of the island near Mattituck, but of this there is little evidence, as the present valley at this point is of other origin. (See p. 28.) Another channel-like depression starts a few miles northwest of the point where the first ends and extends northeastward to a point beyond Little Gull Island, where it divides, one branch passing south and the other north of Valiant Reef. In this vicinity depths of 50 to 55 fathoms, or 300 to 330 feet, are recorded, although on each side of the channel the water is relatively shallow. East of Valiant Reef there are four branches; one passes north of Block Island and the others start in a southeasterly direction and are lost in the shoals north and northeast of Montauk Point. This digitate system of channels converges westward, and if it is the work of streams would indicate a westward drainage. The digitate portions occur only in what is known as the "Race," a locality of severe tidal scour, and their form may have resulted from tidal action. It is difficult, however, to account for the channels in the broader parts of the Sound in this way, for they do not follow lines of especially strong currents. Moreover, the general relations as brought out in figure 50 strongly suggest stream origin. If they were cut by streams they are, in all probability, to

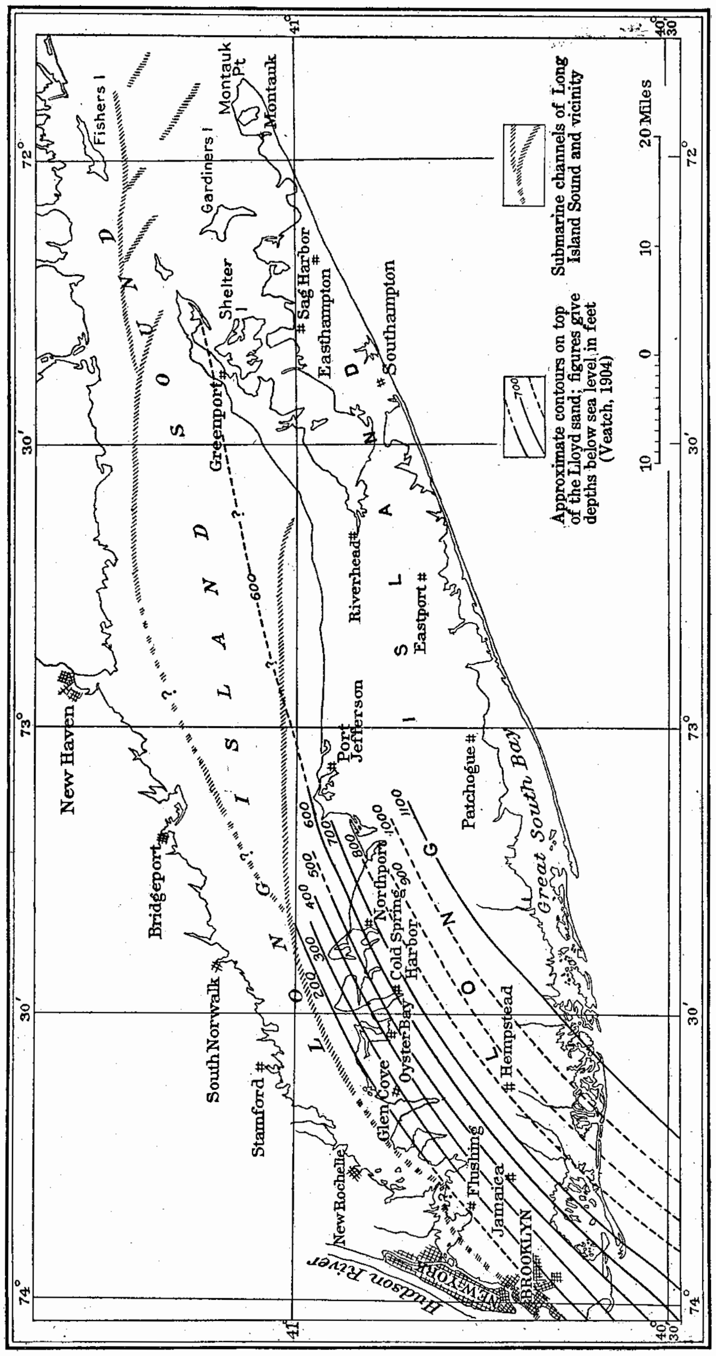


FIGURE 50.—Map showing Cretaceous structure and location of submarine channels of Long Island Sound.

be referred to the Vineyard erosion interval, as they are at a much higher level than the post-Mannetto land surface, which was developed at the last preceding stage of uplift, and there has been no post-Vineyard elevation sufficient to account for their depth. An earlier time than the Vineyard is also precluded by the tremendous ice scour and subsequent deposition characterizing the Montauk ice invasion. The point of outlet of the system, if one really existed, is unknown, but the absence of any break in the Manhasset deposition indicates that the outlet could have been only at the extreme west end of the island, probably beneath the present lowlands in the vicinity of Long Island City or even along East River.

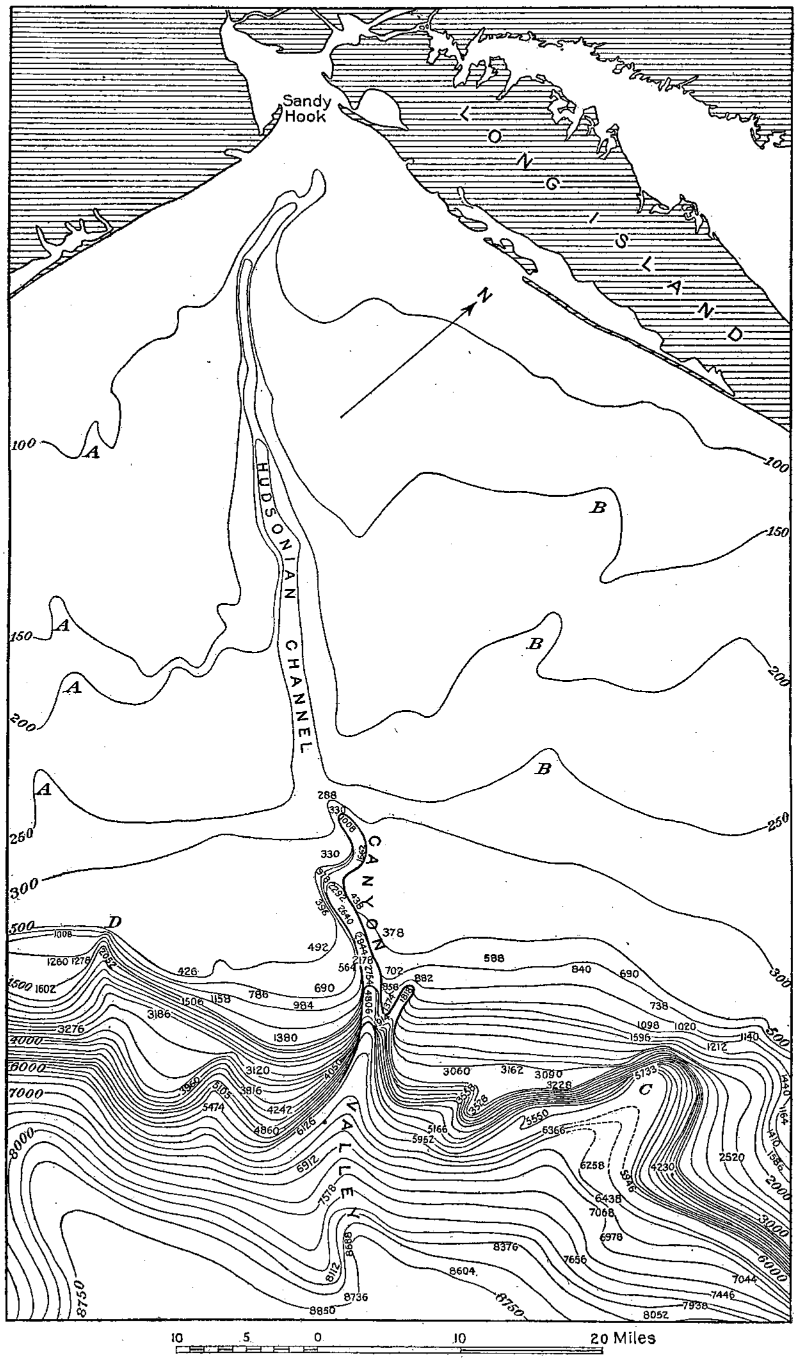


Figure 51.—Map of the submarine channel and canyon of Hudson River. By J. W. Spencer. Figures indicate depth in feet.

Starting at a point 7 miles east of Montauk Point, or a little over halfway to Block Island, a submerged channel, 50 feet deep in places, extends southeastward for nearly 10 miles. Its upper part is only about a quarter of a mile wide, and it is characterized by swings and other features of a true stream channel. It seems to be lost at a depth of 20 to 25 fathoms, hence at the time of its formation the land apparently stood 120 to 150 feet higher. A shallow depression connects this channel with one of the depressions southeast of the Race, but it seems to be nothing more than a tidal connection.

Conclusions.—The excavation of the Cretaceous deposits began in the post-Miocene period of erosion, but whether the valley then formed persisted through the Lafayette accumulation (if any took place in this region) and the Mannetto deposition is not known. The valley or its successor appears to have been completed, however, in the post-Mannetto stage of erosion. It was partly filled during the Jameco, Gardiners, Jacob, and Manhasset stages of deposition but was not obliterated, and at the close of the Manhasset stage it seems to have been occupied by a westward-draining river system, which excavated the submerged channels. At the same time a well-defined channel leading southward between Montauk and Block Island was formed. In the last ice advance the valleys were partly filled and otherwise modified by the action of the overriding ice and by the accompanying deposition, and in recent time tidal scour has done much to change the character of the channels.

SUBMARINE CHANNELS OF THE HUDSON.

GENERAL CONDITIONS.

Channel of the continental shelf.—Since the northern part of the continental shelf was first charted the so-called submarine channel of the Hudson has aroused much interest among both geologists and geographers, and many papers describing it and discussing its origin have been published. It may be described briefly as a submerged valley leading across the continental platform from a point a few miles east of Sandy Hook southeastward to the margin of the shelf, 55 miles from the beginning (fig. 51). Beyond this margin a sharp canyon-like notch extends down the escarpment to a depth of a mile or more below the surface of the sea.[1] The measurements of this channel given in the texts or shown on the maps by different writers do not entirely agree with one another, hence it is necessary to cite authority for the figures used. The depth of this channel at the start is about 15 fathoms, or 5 or 6 fathoms below the adjoining sea bottom; at 10 miles out the depth is 8 fathoms below the surrounding bottom, and at 20, 30, and 40 miles about 15 fathoms. Beyond the 40-mile point, owing to a steepening of the inclination of the platform, the slope of the channel being unchanged, the depth decreases and the bottom of the channel is only about 8 fathoms below the level of the adjacent bottom at the 50-fathom contour, 45 miles out. Immediately beyond this point, however, is the beginning of the narrow but deep outer canyon or notch, which is marked by an abrupt drop from 288 feet to 1,008 feet. This is followed by a gentle slope extending about 6 miles, at the end of which a second drop of about 400 feet takes place. A third drop of about 500 feet occurs about 12 miles from the head of the canyon, the total depth then reached being about 2,292 feet, or about 2,050 feet below the continental platform. The soundings at this point (fig. 52) seem to indicate the presence of shelves on the sides of the canyon, at a depth of about 1,250 feet, the origin of which is obscure. At 31 miles the depth of the canyon has increased to 4,800 feet, or 3,800 feet below the surrounding sea bottom. Spencer on his map (fig. 51) extends the canyon 43 miles farther, to a depth of 6,000 feet, and indicates a shallower valley-like depression extending to a distance of 71 miles from the head of the gorge, or to a depth of 9,000 feet,[2] but the evidence for the extension beyond the depth of 4,800 feet does not appear to be conclusive. A section showing the relations of the various channels is given in figure 53.

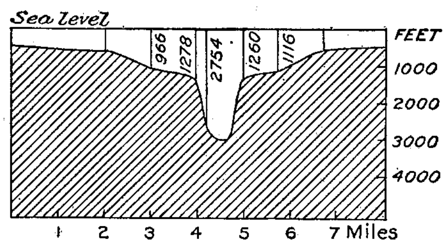


FIGURE 52.—Cross section showing relations of the broader valleys and sharp canyon of the submarine Hudson channels. By J. W. Spencer.

Hudson River rock channel.—Intimately related to the submarine channel just described is the rock channel of Hudson River. That this channel lies much deeper than the present river bottom and is covered with thick accumulations of drift is well known, but unfortunately information as to its exact depth is not available. The greatest depth yet recorded (1908) is near Storm King Mountain, where the bottom appears to be about 650 feet below sea level.[3] At New York City the greatest depth recorded is about 300 feet, but there is room for a narrow gorge of greater depth between the soundings. Local erosion by ice to a depth of several hundred feet in the unusually hard

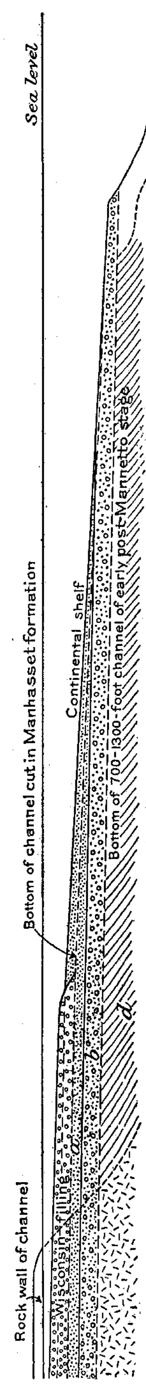


FIGURE 53.—Section showing relations of the submarine Hudson channels and their fillings. *a*, Manhasset formation, partly in channel; *b*, Jameco gravel, Gardiners clay, and Jacob sand; *c*, outer canyon of late post-Mannetto stage; *d*, Cretaceous and later deposits.

[1] Map by J. W. Spencer, Am. Jour. Sci., 4th ser., vol. 19, 1905, p. 2.
[2] Spencer, J. W., op. cit., pp. 6-7.
[3] Kemp, J. F., Am. Jour. Sci., 4th ser., vol. 26, 1908, p. 320.

rocks near Storm King (although the softer rocks of the vicinity were relatively little eroded) does not afford a satisfactory explanation of the depth at this point, and it is equally unsatisfactory to assume that a warping of 350 feet has taken place between this point and New York. As examinations have shown that there is no other possible outlet for the old Hudson waters, it seems probable, although not certain, that a buried canyon at least 700 feet in depth must exist somewhere beneath the Hudson at New York City.

HISTORY OF THE CHANNELS.

Agencies of formation.—In considering the history of the submarine channels it is necessary to start with an assumption as to the agencies to which their origin is due. The principal basis for this assumption must necessarily be the form and course of the channels themselves. From the soundings, which have been taken at unusually close intervals, probably closer than over any other submarine area of equal extent on our coasts, it is possible to contour the sea bottom with an accuracy comparable almost to that of topographic maps of the land surface. Not only are the broader features of the trough and the adjacent sea bottom brought out but many minor details, such as the accelerations of slope and the presence of shelves on the sides of the deeper canyons, are plainly shown.

The cross section of the submarine valley from Sandy Hook to the edge of the continental platform may be said to be practically identical in character with that of the normal streams which to-day cross the emerged portions of the Coastal Plain along the adjacent coasts. The sloping sides and nearly flat bottom of the submarine channel correspond with the similar gently sloping highlands that border the terrestrial streams and their alluvial bottoms. Likewise, the curves and bends of the submarine channel differ in no material way from the similar sinuosities of the present Coastal Plain streams.

The form and course of the trough, the presence of sand in the channel, although the surrounding sea bottom consists of clay, and the physical connection with the present Hudson River channel, except for the narrow bar of relatively recent deposits obscuring the channel between Sandy Hook and New York, all seem to point to a fluviatile origin. Inasmuch as such a channel could not be shaped by any process at work in the ocean, so far as known to science, and as it has none of the characteristics of a fault depression, the writer has been led to ascribe tentatively the origin of the shallower channel to subaerial stream action when the land stood from 300 to 350 feet above its present level with reference to the sea.

The origin of the deep canyon-like gorge extending seaward from the outer end of the shallower channel seems to be less certain. As shown by the map [1] (fig. 51) and section (fig. 52), the gorge exhibits, both as regards its course and the character of its cross section, the normal characteristics of an erosion notch cut back in the mesa-like edge of the continental platform, and the sharp drops or falls at intervals in its bottom are equally characteristic of young erosion. Furthermore, it seems to represent the continuation of the inner, shallower channel, which the writer considers to be due probably to stream erosion. Like the inner channel, it appears to have none of the characteristics of a fault fissure. It can not be considered a depression such as might be caused by the slumping of the materials along the steepened margin of the continental shelf, for such a depression would necessarily be approximately parallel with instead of at right angles to the margin of the platform. Submarine scour as a cause of canyon cutting appears to be entirely out of the question.

The theory that the gorge was excavated by stream erosion would involve an elevation of several thousand feet at the time of the erosion—not less than 4,806 feet being required by the depth of the floor of the lower part of the gorge, as shown in figure 51. The writer, in common with most other geologists, is loath to acknowledge the occurrence of any such elevation at this point in Pleistocene or late Tertiary time. It is not impossible, however, that in the reaction from the belief in great and rapid oscillations of level, held by many geologists a few

[1] It should be stated that the character of the channels was not determined from the few soundings shown on the map, but from a very large number of soundings, which could not be indicated readily because of the small scale of the drawing.

years ago, the pendulum has swung too far, and the present tendency may be to minimize the evidences for such oscillations. Notwithstanding the violent assumption of elevation involved, the form and character of the gorge itself appear to be more nearly those which normally result from stream erosion than from any other known agency. The writer does not wish to be considered as advocating the assumption of excessive elevation in general, and especially he does not wish to advocate it as an explanation of the broad troughlike submarine depressions of this and other localities that have been cited by some writers as erosion features, and even in the present instance he would go no further than to point out the apparent significance of the channel features.

The principal features to be accounted for in a consideration of the history of the channel and canyon are (1) the rock gorge of the present Hudson River, presumably cut to a depth of about 700 feet below sea level; (2) a broad outer depression, in the bottom of which the canyon notch is found; (3) the cutting of the deep outer canyon; (4) the filling of the first deep channel of the Hudson; (5) the cutting of the present shallow, upper submarine channel; and (6) the partial filling of the inner end of the upper channel.

Cutting of the 700-foot channel.—The rock gorge of Hudson River proper, which is assumed to be about 700 feet deep in the vicinity of New York, appears to be filled solely with Pleistocene materials, as indicated by the Storm King and other borings; hence, unless earlier beds had been deposited and subsequently removed by glacial ice, its cutting is to be referred to a date later than that of the deposition of the latest Tertiary beds in this region. It was probably cut at a much later date, for the Mannetto gravel (pre-Kansan?), which accumulated to a height of 300 feet above the present sea level in western Long Island, seems to have been originally continuous with the Bridgeton formation of New Jersey, which is built up to at least 200 feet above sea level in the northern part of that State. After the deposition of the gravel, however, there was a period of uplift and erosion in which the Mannetto was cut to a depth of at least 300 feet below sea level, as shown by the depth of the buried Jameco channel of Long Island. The great length of this period of erosion, indicated by the almost complete removal of the thick Mannetto gravel from the Long Island region, is in harmony with the time required for the cutting of the Hudson River rock gorge. Inasmuch as there are in the later deposits no unconformities that would indicate prolonged elevation of similar degree, it seems that the date of the cutting of the rock channel may be referred with a considerable degree of certainty to the long post-Mannetto (Aftonian?) interval.

It is not beyond the limits of possibility, however, that the 700-foot channel may be somewhat older than the post-Mannetto and pre-Jameco. Although the Mannetto gravel and Bridgeton formation were presumably continuous and stood at a considerable elevation above the sea in the region of the upper part of the present channel, it is not impossible that they were in part glacial outwashes from localized centers of dispersion, and in that case a gap might have been left in the region of New York City in which a pre-Mannetto channel might have persisted.

The channel began at some point well above New York City, for soundings to a depth of 650 feet in its fillings have been made as far north as Storm King Mountain, 50 miles above the city.[1] It extended southward and southeastward probably to the edge of the continental shelf. Possibly the land along the northern part was more elevated than that near the coast, and the excavation was therefore less near the sea than farther up the valley. That the gorge was excavated to a depth of more than 300 feet in the vicinity of New York City, however, has been established by borings, and a channel of at least that depth, if not of 700 feet, apparently must be assumed as having been formed across the continental shelf.

The broad outer depression.—Well-marked shelves occur at intervals on both sides of the canyon portion of the submarine channel, from the inner to the outer end. (See fig. 52, p. 61.) They are not continuous, however, the total space occupied being only about half the length

[1] Kemp, J. F., Our knowledge of the filled channel in the Hudson of the Highlands and the submerged gorge on the continental shelf: Science, new ser., vol. 29, 1909, p. 279.

of the gorge, and some of those at up-channel points are lower than those at down-channel points. Inasmuch as their absence can not be accounted for by incompleteness of soundings, it does not seem likely that the shelves represent an old valley marking a separate epoch in the history of the channels, as their appearance at first suggests.

The outer canyon.—The narrow, steep-sided, and deep outer canyon, although it is the most marked feature of the submarine channel system, would appear to require, if due to stream erosion, but a relatively short period for its formation, as compared with that needed for the excavation of the long rock gorge of the Hudson. This fact is emphasized by the great drops or falls in its bed, which could not exist had the period of canyon cutting been as long as that of the rock gorge. Probably it extended but little north of its present head, for there appears to be little evidence, to judge from the contours of the bottom, of anything more than a slight filling by later deposits.

So far as its observed features indicate, the outer canyon might have been formed during either the post-Mannetto or the Vineyard interval of erosion. The soundings, however, seem to show that it was to some extent filled at its head by the great series of deposits that obliterated the continuation of the 700-foot channel; hence it must apparently be referred to the same general period of erosion as that channel. If due to stream erosion at all, it must be referred to an elevation of great magnitude, occurring at the close of the post-Mannetto erosion stage, but of so transient a character that the chief work of erosion consisted of a notching of the edge of the continental shelf, the land back of this point being but little affected.

Obliteration of the earlier channels.—The post-Mannetto erosion was followed by a long period of deposition, as shown by the thick conformable series of deposits, including the Jameco gravel, Gardiners clay, and Jacob sand. During this period, so far as known, the sea bottom in the vicinity of the channel remained constantly below sea level. The deposits, which have a thickness of 200 feet or more on Long Island, doubtless extended far to the south and largely buried the early channel. The obliteration was probably completed by the outwash of the several stages of Manhasset deposition, including the Herod gravel member, the Montauk till member, and the Hempstead gravel member, which, although not having anything like the maximum thickness of 300 feet observed on the island, doubtless formed a sheet of considerable thickness.

Cutting of the present upper channel.—The upper channel has a depth at its outer end of only about 350 feet, hence an elevation of the land of this amount will explain its formation. As no time break is indicated in the deposits of Long Island from the beginning of the Jameco to the close of the Hempstead deposition, and as there are nowhere on the island, even on the exposed coasts, any erosion channels referable to Wisconsin or post-Wisconsin elevation, the formation of the upper channel is most logically referred to the Vineyard interval of erosion, following the Manhasset deposition. The valleys in the Manhasset deposits, although somewhat modified and partly filled with Wisconsin accumulations, are known to extend some distance below sea level at many points along the north shore, indicating a higher position of the land than at present. These valleys, most of which mark small intermittent streams, naturally are not nearly so deep as the channel formed by the large Hudson stream, and in themselves indicate little as to the absolute elevation of the land, which is shown only by the submarine channels such as that of the Hudson.

Filling of the upper channel.—The upper channel has been largely obliterated north of Sandy Hook, in part by the Wisconsin outwash and in part through the shifting of the sands by the littoral currents that now sweep along the coast. Its termination is somewhat indefinite, but where last recognized seems to point toward Jamaica Bay. As the Manhasset deposits contain no gap or channel marking the position of any outflowing stream, the bend seems to be without significance, so far as Long Island is concerned, and is probably simply one of several bends between Sandy Hook and North River at New York.

STRATIGRAPHIC GEOLOGY.

METHOD OF MAPPING.

The geologic map accompanying this report (Pl. I, in pocket) sets forth the present state of knowledge of the geology of Long Island so far as it can be represented with the data at hand. It is to be noted, however, that here as elsewhere the glacial deposits of one type in places grade insensibly into those of another with no sharp line of demarcation. As boundaries are necessary they have been placed where they seem, all things considered, to bring out best the relations it is desired to show, even if no exact line can be recognized in the field. Other real inaccuracies in detail have doubtless resulted from the fact that a large part of the work in the interior of the island was done before the topographic survey was completed and without any accurate base, as a consequence of which many features could be located only with difficulty, if at all, on the new base. More or less generalization has also been unavoidable because of the small scale of the map.

This map shows the outcrops of the older Pleistocene beds as exposed in the bluffs in 1903 and 1904, but as the condition of the exposures is constantly changing many sections then observed will now be found to be destroyed and their places to be taken by exposures not then visible. There will also be much difficulty in distinguishing some of the beds in certain localities. For instance, the Wisconsin till and the Montauk till member of the Manhasset formation in some places so closely approach each other in character that it is difficult to separate them when in contact, and they may appear as a single unit. It is for this reason that the Montauk member is not shown as occurring on the North Fluke, although in all probability it is present in the greater part of the length of the bluffs. Again, where the Montauk member is composed of reworked Gardiners clay, it is almost impossible to distinguish it from the true clay except in the few places where granite pebbles have been incorporated in the reworked mass.

In mapping the outwash areas considerable generalization has been necessary, as all gradations between pure outwash and nearly pure Manhasset occur. From the relations of the two deposits it is to be expected that Manhasset remnants may be found here and there projecting above the areas shown as outwash, and in some of the compound areas it may be difficult to detect any outwash. In fact, in many such areas the outwash is confined to a few channels.

The geologic map is not strictly a lithologic map, the attempt being made to bring out the history and relations of the deposits by means of a system of solid underprints representing the fundamental formations with overprints showing the superficial deposits.

The dune areas are probably much more extensive than is indicated, although the mantle is thin in places and the underlying deposits may show through. Where the developments are weak the topography is not striking, and owing to the covering of forest and the absence of sections, the full extent of the old dune areas is very difficult to determine.

PRE-CRETACEOUS ROCKS.[1]

The basement deposits of Long Island, originally considered in large part "Primitive" or composed fundamentally of metamorphic rocks, have been successively classed or mapped as alluvium, diluvium, Tertiary and drift, and Cretaceous and drift. The early conception of simplicity of the drift has likewise been abandoned, and where one formation was originally known at least five are now differentiated and a complex series of events is recognized.

The pre-Cretaceous rocks of Long Island consist chiefly of pre-Cambrian gneiss with intruded dikes of granite and a little dolomitic limestone. The gneiss, which is known as the Fordham gneiss, is of a gray color and is made up of bands rarely exceeding 2 inches in thickness. The bands differ widely in composition, some being highly quartzose, others biotitic, and still others pegmatitic. The banding stands at a very high angle and strikes about N. 25° E., being parallel with the course of that part of East River near Blackwells Island. The gneiss forms the western shore of Long Island from Lawrence Point southward to Newtown Creek. The dikes occur as narrow intrusions of gray and reddish granite, usually parallel to the band-

[1] For a more detailed description see Merrill, F. J. H., New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

ing of the gneiss, and, being somewhat more resistant than the surrounding rock, have given rise to many of the islands of upper East River. Many small dikes occur in the vicinity of Ravenswood, and there are pegmatitic masses of considerable size at Hunters Point.

The dolomite, which is known as the Stockbridge dolomite, consists of alternating layers of coarsely crystalline dolomite and limestone. It is well bedded, the layers standing at high angles and striking parallel to the gneiss. It is mapped by Merrill as a narrow band crossing the neck west of Astoria and has been encountered in at least two borings in East River.

Whether the Fordham gneiss is of sedimentary or igneous origin is not known, for the metamorphism that it has undergone has been sufficient to destroy all its sedimentary features, if any ever existed. It is, as already stated, of pre-Cambrian age. The Stockbridge dolomite is clearly of sedimentary origin and is regarded as being of Cambrian and Ordovician age. The granitic and pegmatitic intrusions in the gneiss are younger than the dolomite, for they cut the Hudson schist (Ordovician), which overlies it, and are therefore of Ordovician or later age.

These rocks have been compressed into close folds in which the beds stand nearly vertical, as shown in figure 54. There is considerable evidence that faulting has frequently taken place in the region, that the structure of the rocks is more complex than is shown in the sections, and that it may even have had a considerable influence on the topographic expression of the East River region.

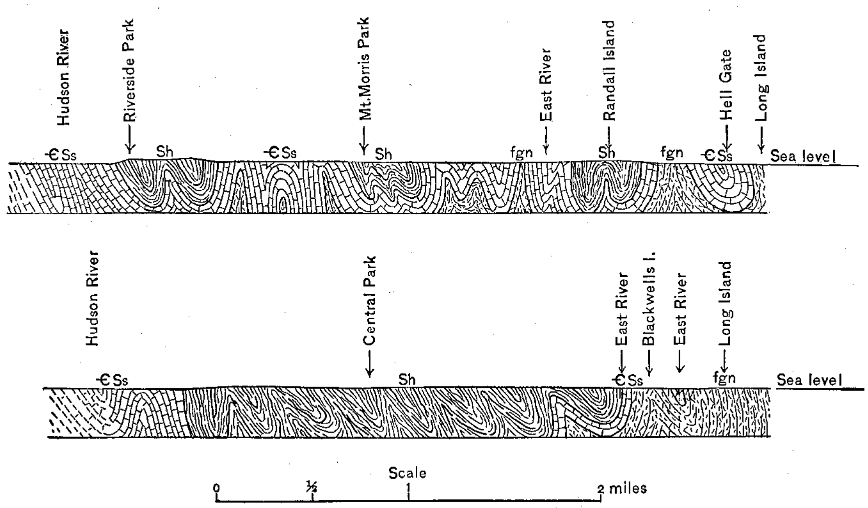


FIGURE 54.—Sections from Hudson River to Long Island, showing in a general way the folded and eroded character of the bedrock underlying Long Island. (After Merrill, 1902.) fgn, Fordham gneiss (pre-Cambrian); ꞒSs, Stockbridge dolomite (Cambrian and Ordovician); Sh, Hudson schist (Ordovician).

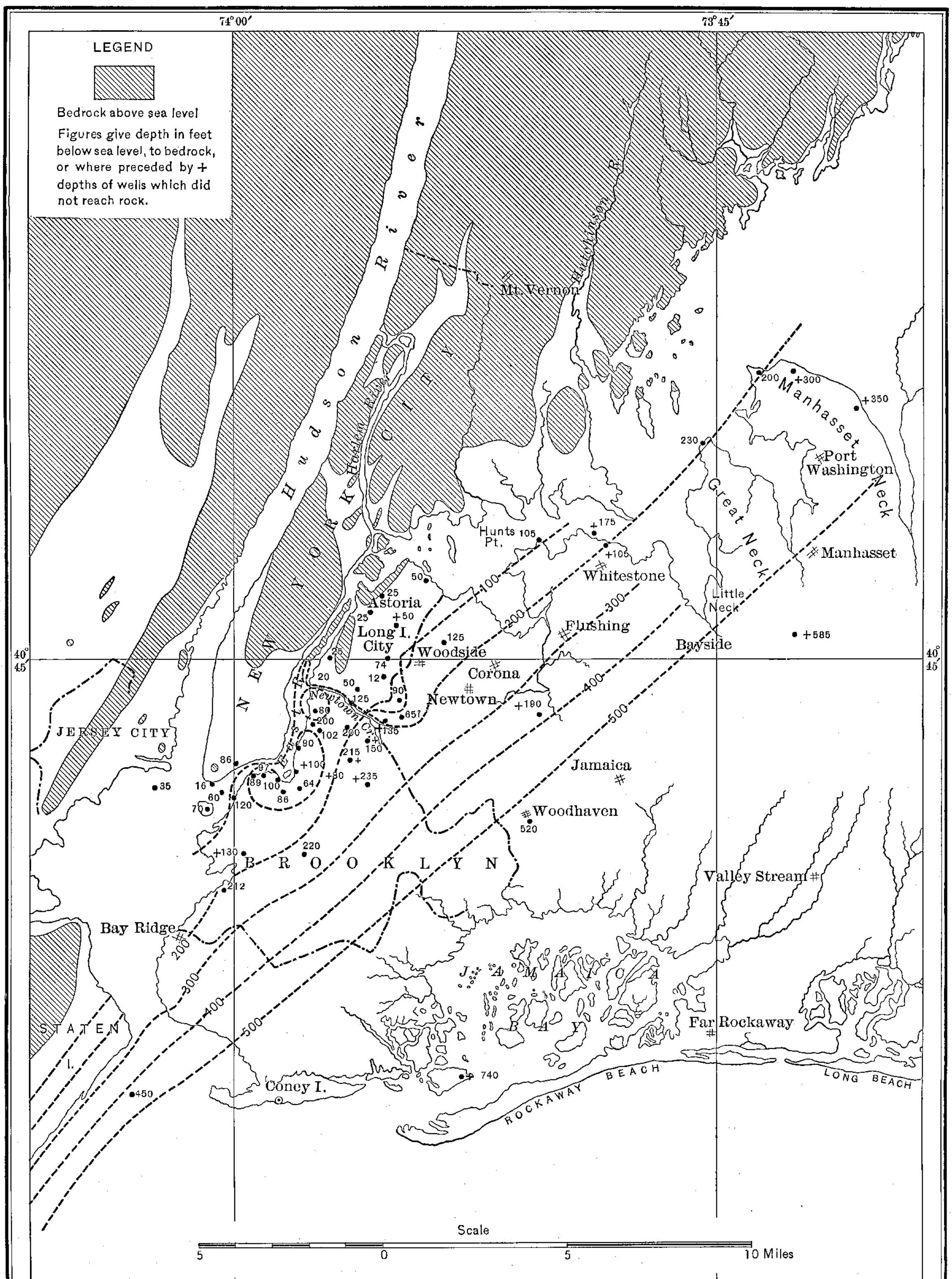
The metamorphic rocks are seen at the surface only in a narrow strip along East River, at the extreme west end of the island, but they have been encountered in a large number of wells in Brooklyn, in Long Island City, and at several points eastward to Woodhaven and northeastward to Manhasset Neck. From these occurrences it is possible to contour the rock surface roughly, as shown in Plate XV. The contours show that this surface slopes southeastward at an average rate of about 100 feet to the mile for a distance of 5 miles or more. Many minor irregularities are brought out by wells that are close together, but on the whole the slope seems to be very even in the western part of the island. At Greenport, near the east end, the slope is considerably less, rock being encountered at a depth of 670 feet at a point 11 miles from the outcrops on the mainland. The statements in regard to the well on Fishers Island are conflicting, the depth to rock being given as 150 feet, 204 feet, and 281 feet.[1]

CRETACEOUS SYSTEM.

The discoveries of fossils by which the existence of Cretaceous deposits was established have been described in the review of geologic literature (pp. 4–22). The well records collected in connection with the recent work and the discovery of evidences for separating the Pleistocene from the Cretaceous clays, with which they had often been included, have made it possible to determine the character and distribution of the Cretaceous beds within fairly close limits. The well records have already been published in Veatch's report.[2]

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 17, 167, 337.

[2] Idem, pp. 116 et seq.



MAP SHOWING POSITION OF BEDROCK IN WESTERN LONG ISLAND.

By A. C. Veatch.

CHARACTER OF THE DEPOSITS.

The Cretaceous deposits of Long Island differ extremely in composition within short distances. One well may show several hundred feet of clay and an adjoining well may show an equal amount of sand. Nevertheless there appears to be a certain general sequence, which is shown in the columnar section forming figure 55.

The term "basal clays" is applied to those at the base of the Long Island Cretaceous section as it has been disclosed by well borings, or in other words those lying beneath the Lloyd sand. Relatively few sections of these lower beds are available, but they seem to consist rather uniformly of dirty white, gray, and blue clays, with a few beds of gray sand and some grayish quicksands. Their total thickness probably ranges from 100 to 200 feet. The beds are nowhere exposed at the surface and are encountered in only a few of the wells near the west end of the island.

Veatch[1] has given the name "Lloyd sand" to the bed of yellow to white quartz gravel and sand with some clayey layers lying next above the basal clays. This is the main Cretaceous water bed and is usually about 80 or 90 feet thick. It does not outcrop anywhere at the surface but is probably not much more than 100 feet below sea level near College Point and in parts of Long Island City.

Above the Lloyd sand is a group called "red clays" but containing beds of yellow, salmon-colored, red, brown, chocolate-colored, and black clays, with a few relatively thin beds of sand, the total thickness ranging usually from 100 to 250 feet but in places exceeding 400 feet. The clays are found in the wells of the north shore, and are to be seen south of Mott Point, on Manhasset Neck, north of Glen Cove, and in the beach below high water at Rocky Point, Cold Spring Harbor.

Above the colored clays is a bed of "white sand" and clay reaching a thickness of at least 100 feet. This is the white arkose sand exposed on the east side of Hempstead Harbor, near Sea Cliff, at Lattingtown, at Center Island, and on Lloyd and Eaton necks.

The white sands are overlain by about 75 feet of "yellow clays," interbedded with red and brown layers. These lighter clays crop out along the shore of Cold Spring Harbor for more than a mile south of Lloyd Beach.

Next above these clays stratigraphically are the dark slate-colored clays of Little Neck and their chocolate-colored to black equivalents along the Sound 4 miles northeast of Northport. These beds are exposed in many clay pits and are seen to be well stratified and to carry, in the latter locality, numerous concretions. Several beds of light-colored sand are included among the clays. The thickness of this group, which is designated "dark clay" in figures 55 and 56, is estimated to be about 75 feet.

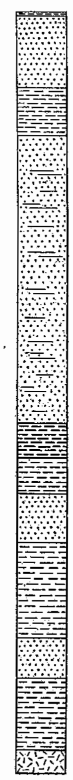


FIGURE 55.—Columnar section of the Cretaceous formations of Long Island.

Nothing is seen of the Cretaceous between the north coast and the Dix Hills, 4 miles south of the Little Neck outcrop, where undifferentiated beds of yellow, gray, and white clays of probable Cretaceous age were encountered in a cistern. Five miles farther south, near Wyandanch, there are considerable exposures; and at Bethpage and Farmingdale, a few miles west of Wyandanch, thick beds of clay are exposed in the clay pits. Allowing a dip of 65 feet to the mile, which is that observed at Oyster Bay, and allowing for a difference of 100 feet between the surface elevations, we find that a stratigraphic interval of nearly 600 feet must intervene between Little Neck and Bethpage. According to Veatch's well records this interval is occupied mainly by yellowish sand, with a clay bed here and there, as at the base of the Dix Hills.

[1] Op. cit., p. 21.

A group that may be called "buff clays" includes the gray, salmon, and buff clays at Bethpage and Farmingdale and the yellow, buff, and dirty-brown shaly clays near Wyandanch. The observed thickness and the distribution of these clays indicate that their aggregate thickness is, roughly, 100 feet.

Above the clays at Wyandanch and Bethpage is seen the "yellow sand." Talus slopes of this sand also appear at many points on the hillsides, and it was seen in a roadside section below the crest of the ridge west of Melville. A few clayey streaks occur in it, but the section, so far as known, is sandy throughout a thickness of 150 feet.

On the crest of the ridge west of Melville, beginning about 41 feet from the top of the hill, the following section was recorded by G. N. Knapp and the writer:

Section of marly beds near Melville.

	Ft.	In.
1. Sandy marly clay, greenish gray		6
2. Ferruginous, partly indurated, marly clay, yellowish brown		6
3. Marly clay; greenish marl, with chocolate-colored clay base	1	
4. Ferruginous (weathered) micaceous clay marl, yellowish brown		6
5. Clay marl; fine green sand mixed with chocolate-colored clay and some quartz sand; typical Merchantville of New Jersey (bed No. 1)	1	
6. Weathered, somewhat sandy, semi-indurated clay marl, yellowish brown	1	
7. Clay marl (same as No. 5, above)	1	
8. Iron plates alternating with marl, clayey sand, and gravel	2	6
9. Coarse green marly sand and clay, with abundant green sand; some quartz pebbles one-fourth to one-half inch in diameter; resembles arkose; weathered pits in lower half; like top of clay marls of New Jersey	3	
	11	

These beds and some greenish clays observed by Veatch at 156 feet in wells at Quogue and 155 feet in wells at Bridgehampton, at about the same stratigraphic horizon, are among the few representatives of the marl series that have been found on Long Island. The marly deposits of this section were first described by Veatch[1] as arkose, but in his final report[2] were referred to the marl series on the basis of the observations of G. N. Knapp and the writer.

DISTRIBUTION OF CRETACEOUS DEPOSITS.

SURFACE OUTCROPS.

Elm Point.—The westernmost important showing of Cretaceous beds on Long Island is situated at Elm Point, on the west side of Great Neck, between Manhasset and Little Neck bays, in North Hempstead Township. The Cretaceous deposits at this place consist of about 30 feet of dark-gray clay containing a few lignitic fragments, overlain by 15 to 20 feet of Pleistocene gravel and till.

Thomaston.—A small exposure of sand and other material may be seen in a railway cut between Thomaston and the head of Manhasset Bay, at the base of Great Neck.

West side of Hempstead Harbor.—The first indications of the Cretaceous in a journey north from Roslyn are found a short distance north of the sand spit known as Bar Beach, where white or yellowish Cretaceous clays are occasionally encountered in excavations at the bottoms of gravel pits. A little farther north white clayey arkose sands and bleached quartz pebbles appear amid the Pleistocene talus, and a considerable number of small exposures of the same material are seen in places. The sands are cross-bedded, although on a small scale, and contain many pinkish streaks. The Cretaceous also shows up to an elevation of 150 feet along the highway leading from Hempstead Harbor to Port Washington Harbor, about a mile north of Bar Beach. In a section at the highest point the Cretaceous was found in 1903 to be upturned at a high angle, the contact with the Pleistocene being absolutely vertical for the entire depth of the cut (about 25 feet). The materials here were mainly white, cream, and pink clays and sands. These belong to the "white sands" of figure 56.

[1] Veatch, A. C., Notes on the geology of Long Island: Science, new ser., vol. 18, 1903, pp. 213-214.

[2] Veatch, A. C., and others, Underground water resources of Long Island, New York: Prof. Paper U. S. Geol Survey No. 44, 1906, pp. 20-22.

Another good exposure is about half a mile south of Mott Point, where 15 feet of yellowish and reddish clay was seen in the bluff in 1905, and beds of cream, salmon, red, and black Cretaceous clays from 6 inches to several feet in thickness crop out on the beach between high and low tide limits. They are referred to the red-clay bed of figure 56.

Glen Cove.—A little north of Glen Cove Landing there is an outcrop of contorted yellow, pink, gray, and black plastic clays having crusts of hematitic sand and containing pyrite concretions. They have an entirely different aspect from the gray and yellow sandy clays (Pleistocene) between Weeks and Red Spring points and have yielded plant remains that establish their Cretaceous age. The clays are hidden near the landing, but are well exposed a quarter of a mile farther south and continue for many hundred feet. White, cream, yellow, red, purplish-red, gray, and black clays occur in strong contortions in which granitic gravels appear to be involved, for they clearly underlie the Cretaceous clay in overturned folds at one point. The beach is covered with a shingle of hematitic sandstone plates. The outcrops belong to the red-clay bed of figure 56 and are overlain by more or less of the succeeding white-sand bed.

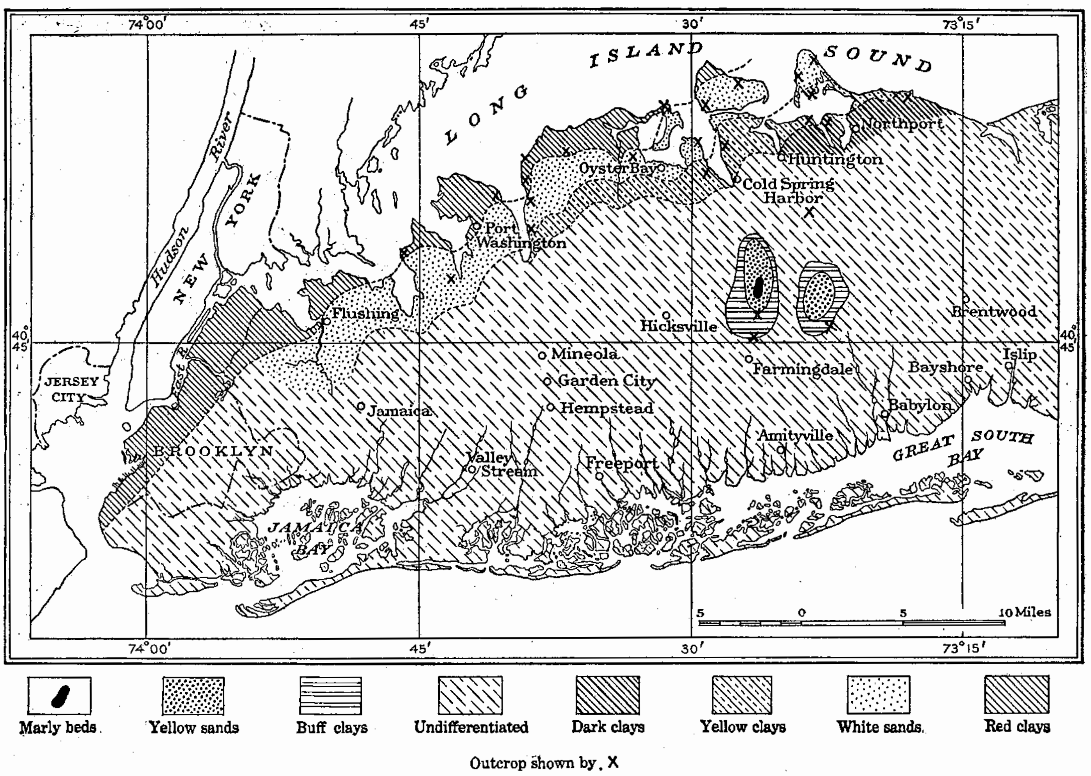


FIGURE 56.—Map showing known distribution of Cretaceous formations on western Long Island. By M. L. Fuller. Legend arranged in order of age—youngest formation at left, oldest at right.

Sea Cliff.—The first outcrop seen near Sea Cliff was in a sand pit on the south side of Mosquito Cove, opposite Glen Cove. Here 10 feet of white cross-bedded Cretaceous sand occurs unconformably below Mannetto gravel. At short intervals from this point to Sea Cliff there are exposures of Cretaceous deposits, mainly glaring white sand and sandy clay. Thick sections are to be seen in some of the big sand pits. Southward from Mosquito Cove there are traces of white sand and clay in the bluffs for a distance of half a mile, but no good exposures occur. A show of white clay occurs three-fourths of a mile south of Glenwood Landing. The materials are referred to the white-sand bed of figure 56.

Lattingtown.—The exposure of Cretaceous near Lattingtown is in a clay pit, 6 or 7 feet deep, situated just south of the highway, three-quarters of a mile southeast of the village, at an elevation of 130 feet. The materials are whitish clay locally tinged with pink and salmon. Little sand is present. They belong near the transition from the red clay to the white sand of the section shown in figure 55.

Mill Neck.—An outcrop in the railroad cut across the neck between Oyster Bay and Mill Neck station is mapped by Woodworth but is not described. Its stratigraphic position appears to be near the top of the white sand bed of figure 56.

Center Island.—The best exposure of clays on Center Island was seen at Rocky Point at the mouth of Cold Spring Harbor, where in the beach between high and low tide marks is a series of yellow and dark-gray to jet-black, very plastic clays, free from grit and similar to those near Glen Cove and Mott Point, with which they are correlated. The darker clays seen in the bluffs above tide level appear to be Pleistocene. On the west side of Center Island, just south of the point where it is nearly bisected by the marsh, an artificial pit showed in 1905 several feet of white clay streaked with white and pink sand belonging to the white sand of figure 56. White sand and grayish clay were also cut by the dredge in digging a basin a quarter of a mile south of the neck connecting with the main island.

Cold Spring Harbor.—There are two outcrops of Cretaceous materials on the west side of Cold Spring Harbor, one about half a mile south of Coopers Bluff and the other opposite the village of Cold Spring Harbor, half a mile northwest of the sand bar. The former shows only a few feet of white clayey sand, possibly talus, but the latter shows 10 feet or more of white sand and a considerable amount of yellow, white, and salmon-colored clays in the beach between high and low water marks. The sand belongs to the white-sand bed of figure 56, and the clays to the overlying yellow clays.

The best exposure on the east side of the harbor is in the large abandoned clay pits just south of Lloyd Beach, connecting Lloyd and West necks. In the bottoms of the pits the material seems to be light to dark gray clay, overlain by a considerable thickness of yellow and red clays. Many local variations of color and composition occur. The deposits belong to the yellow clay of figure 56. South of the pits red and white sands show in the beach at intervals for a quarter of a mile, and yellow and white sands with scattered traces of clay occur for the next three-quarters of a mile. These deposits are included with the Cretaceous on the map, although there is some reason for thinking that they may be reworked material.

The following is a section of the deposits exposed in this vicinity as given by Merrill[1] in 1886. The correlations are by the present writer.

Section on Cold Spring Harbor.

	Feet.
Wisconsin: Till and stratified gravel	10
Manhasset formation: Quartz gravel	45
Cretaceous:	
Red and blue "loam" or sandy clay	20
Diatomaceous earth	3
Yellow and red stratified sand	20
Red plastic clay	20
Brown plastic clay	25

Descriptions of the diatoms have been published by Ries. (See p. 78.)

Lloyd Neck.—The best exposure on Lloyd Neck is in a high bluff on the north side about three-quarters of a mile east of Lloyd Point. The following section was exposed in 1903:

Section on Lloyd Neck.

	Feet.
Dune sand	10
Brownish loamy till (Wisconsin)	10
Gravel and buff sandy clay, merging locally into lenses of till (Manhasset formation, with lenses of Montauk till member)	30
Bright-red clay mixed with overlying gravel (Montauk?)	2
White and pinkish clayey cross-bedded sand (Cretaceous)	48

The sand is somewhat arkose-like, and much of it is finely cross-bedded. Its character is shown in Plate XIV, *B* (p. 56). It belongs to the white-sand bed, figure 56.

Another exposure of clay is found in the bluff facing Cold Spring Harbor just north of the north end of Lloyd Beach. For some distance along the beach at this point there is here and

[1] Merrill, F. J. H., On the geology of Long Island: Annals New York Acad. Sci., vol. 3, 1886, p. 350.

there an outcrop of yellowish clay, more or less undulating or folded, dipping in places as much as 35°. It is underlain by a bed of gravel, which is mainly quartz but yields a few pebbles of decomposed granite, indicating that it is probably to be regarded as Pleistocene. The Cretaceous should be only a few feet lower, however, and it may be exposed from time to time as the waves cut into the beach or bluff.

Great Neck, Huntington.—At the end of Great Neck, northeast of Halesite, there are a number of exposures of Cretaceous deposits. Not far from the point where the highway reaches the beach a light-gray plastic clay, with a tinge of pink, is seen at beach level. A little farther along traces of chocolate-colored clays occur, followed in the next half mile by indications of salmon-colored and light-gray clay. White and pinkish clays appear at a number of points, the southernmost being just south of the little cove around which the road circles. The beds appear to belong near the top of the yellow clays of figure 56 and were formerly extensively worked.

Little Neck, Huntington.—Cretaceous beds are exposed on both sides of Little Neck for half a mile south of Little Neck Point. On the west side little but white cross-bedded sands is to be seen, although a dark-gray clay shows through the beach at one point. On the east side, however, the Cretaceous is well shown, both in the bluffs and in the big sand and clay pits. One pit contains 20 to 25 feet of coarse white Cretaceous sands, the materials being stratified on a broad scale instead of cross-bedded, as is usual. Another pit shows 30 to 40 feet of finely stratified and perfectly jointed black and gray clay containing large pyrite concretions and many leaves and even lignitized tree trunks (Pl. XVII, *A*, p. 82). White clay is said to underlie the dark clay but was not exposed in 1905. Twenty feet of gray and olive-colored clays were exposed in a bluff a quarter of a mile south of the wharf at the sand pit in 1905 and are referred to the dark clays of figure 56.

Eaton Neck.—The Cretaceous materials are best exposed on the west shore of Eaton Neck, from Winkle Point on the south to a point about half a mile north of the north end of West Beach. At Winkle Point the Cretaceous is represented by only a small show of pinkish sand, but in a large amphitheater a quarter of a mile farther north, on Price Bend, more than 30 feet of pink, yellow, and white sands with ferruginous concretions and hematitic sandstone plates are exposed. Half a mile farther north, and not far from the head of Price Bend, 20 feet of pink and white sand is exposed in the bluffs. In the high bluff just north of West Beach there is about 30 feet of similar material with a few clay streaks. Beginning a quarter of a mile north of the bluff, 10 feet of brown and black micaceous clay overlain by yellow sand is seen at intervals for half a mile. Three feet of white Cretaceous clays show on the east shore of Eaton Neck about half a mile southeast of Eaton Neck Light. These beds fall mainly in the white sands of figure 56.

Northeast of Northport.—The most easterly exposure of the Cretaceous on Long Island is on the Sound shore about 4 miles northeast of Northport or a mile north of Fort Salonga village. Here great masses of chocolate-colored and dark-gray to black clays have been upturned on the beach by landslides, and lighter-brown clays containing numerous calcareous concretions were to be seen in a clay pit opened in 1903. There seems to be at least 30 or 40 feet of the clays at this point. They are referred to the dark-clay bed of figure 56.

Dix Hills.—On the west base of the northern extension of the Dix Hills, 1½ miles south of Greenlawn, there is an exposure of yellow quartz gravel free from granite pebbles and underlain, as shown by a cistern, by at least 12 feet of white, gray, and yellowish clay. It is regarded as Cretaceous and is referred to the undifferentiated beds of the standard section.

Wyandanch.—Cretaceous exposures occur in some old clay pits in a deep valley in the Half Hollow Hills a little northwest of Wyandanch (West Deer Park). In the northernmost pit the clays are much disturbed, being in places upturned at an angle of 30°, apparently as the result of creep. The lowest deposits seen are nearly jet-black lignitiferous clay containing large concretions or disseminated crystals of pyrite. Above this there are locally red and white variegated clays. A deep, narrow pocket of yellow sand occurs in the surface of the clay, but whether as an infolded mass or in a small erosion channel could not be determined. On top is a bed of structureless sand and pebbles and granitic fragments resembling till. Elsewhere in the pit 10 to 15 feet of stratified yellow gravel was seen above the clay, and in an adjacent pit from 10 to 15 feet of brownish-gray shaly clay occurred. There were some small granitic fragments on the surface. A pit 800 feet south of the first exposed 5 feet of yellow gravel with granitic fragments on the surface. Below this was 10 feet of white and buff sand, and at the base 10 feet of salmon-colored and white clay. The sections in these pits differed greatly, even at points only a few feet apart, and no generalized section can be given. The beds are correlated with the buff clays of figure 56.

Farmingdale and Bethpage.—Clay is exposed in the pits of the brickyard just north of Farmingdale. At the time of the writer's visit from 20 to 35 feet of material was exposed. This comprised an upper layer of structureless gravel resembling till, from 1 to 8 feet thick, resting on a very irregular surface of gray, yellow, and pinkish clay having a maximum thickness of 10 feet. Below this layer the clay was darker, ranging from chocolate-colored to dark brown or nearly black. About 10 feet of this dark clay was exposed in 1903. The surface clays are somewhat disturbed, the structure being accounted for by creep. They belong to the buff clays of figure 56.

The conditions at the Bethpage pit are very similar to those at Farmingdale.

Melville.—At the top of the ridge near Melville the following section is exposed.

Section near Melville.

	Feet.
Yellowish gravel with rotten granitic pebbles	40
Fine orange-colored sands ("fluffy")	6
Marly sands	11
Gray, red, and yellow variegated clay with sand layers 6 inches to 2 feet thick	13
Coarse white or yellowish clayey sand	18
	88

The yellowish gravel at the top is referred to the Pleistocene; the orange-colored sands, which resemble the so-called "fluffy" sands of Miocene age near Kirkwood, N. J., may belong to the Tertiary; the remainder is Cretaceous. Details of the marly beds have already been given (p. 68). The clay series consists of about a foot of ferruginous platy sandstone at the top, followed by 9½ feet of irregularly bedded stiff, fatty, brittle gray clay blotched with red and yellow streaks alternating with laminæ or thin layers of sand, the sand layers being more numerous near the base. At the bottom is 2½ feet of orange-colored sand with some clay streaks and a few ferruginous plates and layers stained with manganese. The lower sandy member is horizontally but irregularly bedded, the bedding lines being darker and somewhat more clayey than the rest. These beds are the highest Cretaceous deposits encountered at the surface on the island and are to be referred to the marl stratum of figure 56.

CRETACEOUS DEPOSITS PENETRATED BY WELLS.

Evidence as to the character of the Cretaceous deposits below the surface must be derived from well records. Fortunately many deep wells have been sunk on Long Island and a large number of records were collected in connection with the studies of the water supply. Some of the more typical of these records are presented here. One of the striking features brought out by them is the large proportion of sand in the deposits, much more being shown than the surface outcrops would seem to indicate. The records are quoted from A. C. Veatch,[1] and the numbers are those used by him. The first record, which is that of a well in the northern part of Brooklyn (Williamsburg), near East River, gives a representative section of the deposits at the extreme west end of the island.

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 168–337.

66. Record of well at Meeker and Kingsland avenues, Brooklyn.

	Feet.
Filled ground	0–5
Wisconsin:	
Blue clay with bowlders	5–16
Sand and small bowlders with water	16–32
Blue clay	32–72
Light-gray clay	72–180
Cretaceous:	
Sand—not water bearing	180–180.5
Blue clay	180.5–205
Light-greenish clay, passing into dark-greenish clay containing small concretionary masses	205–215
Yellow and dark-colored sandy clay	215–225
Pre-Cretaceous:	
Rock, mica schist	225–

The deposits thicken rapidly southward and eastward and even the deepest wells are far from penetrating the full thickness of the Cretaceous. The following section shows the character of the beds penetrated at Long Beach, 18 miles southeast of Brooklyn.

373. Record of well of Long Beach Association at Long Beach.

	Feet.
Recent:	
White beach sand, with waterworn fragments of shells	0–36
Dirty-gray sand, with small quartz pebbles and particles of vegetable matter	36–40
Tisbury [Manhasset formation]:	
Fine to coarse gray sand, with a few small quartz pebbles (salt water)	40–50
Medium gray sand; no gravel	51–55
Grayish-yellow sand and small gravel, with a few greensand grains	55–65
Yellowish-gray sand	65–70
Orange-yellow sand and gravel, similar to Rockaway material	70–73
Sankaty [Jacob sand and Gardiners clay (?)]:	
Gray sand and gravel, similar to overlying bed in texture, but not iron stained	73–76
Large quartz gravel and pieces of blue clay containing sand and gravel	76–82
Jameco:	
Dark, multicolored coarse sand and gravel; considerable percentage of flattened shale pebbles; only 50 to 60 per cent of quartz; some biotite; looks as if it might be a sample taken from the Wisconsin moraine in the center of the island	82–90
Cretaceous:	
Black sand composed of fine gray quartz sand with a large percentage of lignite; some FeS and S; several large pieces of lignitized wood at 99 feet	90–99
Grayish sand with some free sulphur and a few particles of lignite	99–107
White sand with occasional patches tinged lemon-yellow, perhaps due to iron stains; a few particles of free sulphur	107–111
Dark-gray silty sand	111–119
White sand with small pieces of lignite; note on bottle says "120, petrified wood"	119–121
Very dark colored clay ("blue clay")	121–135
Coarse gray clayey sand, with particles of sulphur	135–143
Medium dark-gray sand (salt water)	143–145
Very coarse dark-gray sand	145–156
Olive-green sand and small quartz gravel; some sulphur salt water	156–158
Very dark lead-colored clay	158–174
White sand, containing at 190 feet a log of lignitized wood	174–192
White gravel and salt water	192–196
Clay	196–200
Fine sand	200–220
Solid blue clay; at 270 feet fresh water, sweet and chalybeate	220–270
White sand and wood	270–276
Clay	276–282
White sand and wood	282–297
Blue clay	297–305
White sand, wood, and water	305–308
Blue clay	308–317
White sand containing wood and artesian water	317–325

Cretaceous—Continued.	Feet.
Blue clay	325–340
White sand and mineral water; has considerable CO_2, sparkling and effervescent	340–356
Blue clay	356–360
White sand and pure water	364–378
Blue clay	378–380
White sand	380–381
White clay	381–383
Fine sand with artesian water	383–386

The next section is that of a well on the north side of the island between Hempstead Harbor and Oyster Bay, which cuts beds of a stratigraphically lower horizon.

470. Record of C. O. Gates's well near Peacock Point.

	Feet.
Pleistocene:	
Sand and gravel	0–40
Greenish-gray sandy clay, with a few quartz pebbles	45
Dark reddish brown sandy clay, with some biotite	60–80
Transition:	
Fine gray sand	90
Cretaceous (undifferentiated):	
Laminated reddish-brown sandy clay; no biotite	95
Very fine pinkish-white micaceous sand	100
Light-gray medium micaceous sand	105–130
Dark grayish brown sandy clay	135
Pebbles of ferruginous sandstone	140
Laminated red and white clay. In the fragments furnished the laminations show very great distortion; whether this is the natural condition of bed or is the result of the method of taking samples is not known. Sample 17 contains a few fragments of a lamellibranch, but the sample shows evidence of having been laid out on the ground before it was packed in the bottle, and the shell may have been picked up there	145–160
Brick-red, very plastic clay	165–190
Cretaceous (Lloyd sand):	
Fine reddish sand; the red color seems to be due in a great measure to the red clay from the overlying bed	195–210
Medium light-yellow sand	215–225
Fine to coarse light-yellow quartz gravel, with a few fragments of white, chalky-looking chert	230–

The following section shows the materials encountered in a well on Eaton Neck only a few miles from the point where the Cretaceous surface descends permanently below sea level:

670. Record of L. A. Bevin's well on Eaton Neck.

	Feet.
Pleistocene:	
White sand and gravel, with a percentage of erratics	15–30
Cretaceous:	
Medium-coarse white sand	40
Sand and small pebbles with a rather pinkish cast	50–75
Coarse pinkish-white sand	80
Medium white micaceous sand	90–100
Very fine gray micaceous sand	110
Medium to coarse white sand	120
Small angular quartz pebbles, evidently broken from larger ones	130
Medium to coarse white sand	130
Medium white sand	150
White clay ("kaolin")	159–160
Small white quartz pebbles	165
Fine gray micaceous sand	250–300
Medium-coarse white sand	215–240
Fine white micaceous sand	250–300
Medium yellowish-white sand	310–330
Fine sand and small quartz pebbles	335–350

The two following sections show the character of the Cretaceous deposits underlying the North and South flukes of Long Island:

892. Record of test well of Greenport waterworks, Greenport.

	Feet.
Wisconsin: Yellow gravelly material	0–20
Tisbury [Manhasset formation]: Alternate series of sands and gravel	20–100
Sankaty [Jacob sand and Gardiners clay (?)]: Brown clay similar to that in Sanford's brick-yard	100–150
Jameco: Fine sands	150–225
The well was then completed by Mr. E. K. Hutchinson, the only record kept being a few samples in a test tube preserved by Mr. Fred Klip. These show the following materials:	
Coarse yellow sand and gravel (probably glacial)	225–
Coarse quartz sand	
Coarse quartz pebbles (one granite pebble)	
Ferruginous quartz conglomerate	–555
Cretaceous:	
White, highly micaceous sand	555–605
Fine white sand	605–612
Bright-red sand and clay	612–619
Brick-red clay	619–635
Yellow sand and clay	635–640
Yellowish-white clay	640–645
Salmon-colored clay	645–
Fine, rather dark quartz sand	
Fine dark-colored sand	–650
Coarse quartz sand containing fresh water (Lloyd sand?)	650–670
Pre-Cretaceous:	
Schist	670–690

897. Record of Sanford & Son's well, Bridgehampton.

Tisbury [Manhasset formation]?: Gray micaceous clay, with a few small quartz pebbles	70
Sankaty [Jacob sand and Gardiners clay(?)]: Medium grayish-white sand and gravel, with pieces of greenish clay containing fragments of shells	100
Jameco:	
Fine to medium orange-yellow sand	105
Orange-yellow gravel, apparently identical with that of the old glacial bed on Gardiners Island	110
Very fine yellow silt, with orange gravel	112
Cretaceous:	
Fine gray sand, with muscovite and lignite	115
Medium yellow sand, with fragments of shells	140
Gray clayey sand, with fragments of shells	140
Greenish-gray sandy clay, with fragments of shells	155
Very fine dark-gray sand, with some coarse white quartz sand	165
Fine light-gray sand	190
Fine to coarse light-gray sand with partly lignitized wood	210
Medium white micaceous sand	215
Fine light-gray sand with lignite	222
Lignite and large flakes of muscovite	231
Medium white micaceous sand	235
White sand, muscovite, and lignitized wood	275–287
Fragments of iron pyrite	287–288
Fine to medium grayish-yellow sand	288–300

The Cretaceous deposits, although visible at the surface at only a few points, are shown by borings to extend under the whole island. In the eastern half of the island the borings are too few in number to indicate anything beyond the general depth of the deposits, but in the western part there are sufficient data to represent their position by rough contours, as in Plate XVI, which differs from the similar map by Veatch[1] in that the deep valley of the "Sound River" shown by him between Roslyn and Whitestone is omitted as not being indicated by the

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, Pl. III.

records and outcrops, the contours near the coast are modified, and the Cretaceous area is extended.

East of the area covered by the map the Cretaceous is encountered in wells at a number of points, as shown in the following table based on the records of Veatch:[1]

Wells encountering Cretaceous deposits east of Setauket, Ronkonkoma, and Sayville.

No.	Locality.	Owner.	Depth to Cretaceous.
			Feet.
771	Mount Misery Point		110?
778	Patchogue	City commission	99
781	....do	....do	39
795	Terryville	....do	40?
801	Port Jefferson	J. L. Darling	20?
811	....do	Port Jefferson Co	325
825	Wardenclyffe	Nikola Tesla	135?
858	Quogue	Hallock & Small	150?
859	....do	A. B. Hallock	156
860	....do	J. Wendell	200
892	Greenport	Waterworks	555
897	Bridgehampton	Sanford & Sons	115
919	Fishers Island	Ferguson	260?

STRUCTURE OF THE CRETACEOUS BEDS.

DIP.

In nearly every place where Cretaceous deposits are exposed at the surface they are much disturbed both by folding and faulting, it being not uncommon to find the beds standing nearly vertical. Overturned folds occur at several points. Well records, however, show this to be merely a surface condition, the beds at a slight depth having only a gentle and even slope to the southeast.

From observations in wells on the depth of the Lloyd sand, which is about 200 feet below the surface on the north shore, Veatch prepared a contoured structure map of the Cretaceous which shows that in the Oyster Bay and Huntington region, on the north shore, the dip averages 80 feet to the mile. This is between three and four times as great as the dip in New Jersey (22 feet) and is double that at Port Jefferson (40 feet). The dip probably decreases somewhat rapidly toward the east and south.

FOLDING AND FAULTING.

As indicated above, nearly every outcrop of the Cretaceous shows marked evidences of disturbance. In some places, as on the road across Manhasset Neck near Port Washington, the beds are vertical and dips of 20° to 30° are very common and may be expected at any locality. In general, folding is most conspicuous in the clays, which seem to have bent under the action of the forces producing the disturbance, while the sands in many places were crushed to a structureless mass. The effects of the disturbance are most conspicuous along the steep northward-facing bluffs of the Sound shore, less so on the sides of the north-south harbors, and least on the general upland surface, as in the sand pit on Little Neck. The surface disturbance is not confined to the north side of the island, but is well shown at West Deer Park (Wyandanch), south of the moraine.

The depth of the folding does not appear to be very great and probably there is little evidence of disturbance at 50 feet below sea level even on the north coast. There are few closed folds like those at Marthas Vineyard, where apparently a thickness of at least 500 feet is involved, although small closed folds and contortions are seen here and there, as south of Glen Cove Landing, where an overturned fold of Cretaceous clay is recumbent on Pleistocene gravels. Generally the disturbance is marked either by a mere surface crumpling or by broad, low arches and shallow troughs. In a few places detached masses of Cretaceous clay are found in the till. Faulting is observed here and there.

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 168-337.

MAP SHOWING THE ELEVATION OF THE CRETACEOUS SURFACE ON WESTERN LONG ISLAND, NEW YORK

By A. C. Veatch

modified by M. L. Fuller

0 5 10 Miles

1913

LEGEND

- Outcrops of Cretaceous rocks
- Area of Cretaceous rocks above sea level
- Approximate contours on upper surface of Cretaceous rocks, showing elevation above or depth below sea level
- Points at which the Cretaceous was encountered, with elevation in feet above or depth below sea level (●+30, ●−156)
- Points at which the Cretaceous was not encountered, with elevation of bottom of well in feet above or depth below sea level (●+60, ●−220)
- S — Cretaceous fossil shells, in place
- S — Cretaceous fossil shells, not in place
- L — Cretaceous fossil leaves, in place
- L — Cretaceous fossil leaves, not in place

FORM OF THE CRETACEOUS SURFACE.

The general form of the top of the Cretaceous deposits has been indicated in the discussion of the distribution of the deposits and is represented in Plate XVI. As shown by the map, the Cretaceous surface has a fairly close agreement with the present surface over much of the western part of the island, rising well above sea level in each of the necks and reaching almost to the highest points of the island in the Mannetto (West), Half Hollow, and Dix hills. Long Island Sound is a broad, partly filled Cretaceous valley. In fact, the Cretaceous depressions in general coincide with the Pleistocene valleys and the Cretaceous ridges with the high Pleistocene ridges, although it is known that there are many minor irregularities due to Cretaceous folds which have no surface counterpart and it is probable that there are many minor buried valleys not indicated on the surface. If the drift should be removed from the western half of the island, the remaining land mass, though smaller, would differ only moderately from the present in form.

AGE OF THE CRETACEOUS DEPOSITS.

STRATIGRAPHIC EVIDENCE.

The resemblance of the clays of Long Island to the similar beds of New Jersey led Mather as early as 1843 to correlate them with the Raritan formation of that State, a correlation which later work by Newberry, Hollick, and White tended to confirm. The stratigraphic evidence disclosed by well records and surface observations in connection with the present work confirms the conclusion of Ward that the flora of the deposits of Long Island is younger than that of the clays of Amboy, N. J., a local phase of the Raritan formation, and the beds are therefore stratigraphically higher.

A means of direct stratigraphic correlation is afforded by the Lloyd sand, which is found in the wells of both the north and south shores of Long Island and in New Jersey and is regarded by A. C. Veatch as "a horizon in the Raritan about 200 feet below the base of the Matawan." This would indicate that the outcrops at Glen Cove and Sea Cliff, including the red clays and white sands of the columnar section (fig. 55, p. 67), are uppermost Raritan, while the overlying yellow and dark clays are the supposed equivalents of the Magothy and Matawan formations of New Jersey. The leaf remains in the dark clays on Little Neck do not necessarily indicate the deposits to be Raritan, as collections made by E. W. Berry in the Matawan show essentially the same flora. Above the deposits which are believed to represent the Magothy and Matawan there is a great thickness of alternating sands and clays, with some lignite (undifferentiated bed of fig. 56), and, although correlation with specific formations is impossible, they show a general resemblance, especially as regards their sandy character, to the Matawan group (including the Englishtown and Wenonah sands), the Monmouth group (including the Mount Laurel and Redbank sands), and the Rancocas group (including the Vincentown sand) of New Jersey. Well borings are sufficiently numerous to make it perfectly clear, however, that there are on Long Island no thick greensand beds like those in New Jersey, their stratigraphic position being occupied by the sands mentioned. The observations of Newberry, Hollick, White, and Berry on the flora and the discovery of a probable Upper Cretaceous fauna in the Lloyd sand seem to indicate that the Raritan, with which the lower beds of the Cretaceous of the island are correlated, is basal Upper Cretaceous.

FOSSILS.

A large number of Cretaceous fossils have been found on Long Island and are described in papers by Newberry, Hollick, Ries, and others, but, except those of the outcrops at Glen Cove, Cold Spring Harbor, and Little Neck and those in the wells at Roslyn and Lloyd Point, the fossils have been obtained from materials transported by glacial ice rather than from undisturbed Cretaceous beds. The following list of fossils from the island includes species other than those first described from the island or those of questionable identification. The list of plants is furnished by Arthur Hollick and that of marine forms by Mr. Hollick and A. C. Veatch.

Cretaceous fossils from Long Island.

Locality.	Name.	Source.
Brooklyn, Clark St	Exogyra sp (?)	Drift.
Brooklyn, De Kalb Ave	Juglans crassipes Heer	Do.
East New York	Gryphæa vesicularis	Do.
Do	Ostrea larva	Do.
Do	Cucullæa sp (?)	Do.
Do	Serpula sp	Do.
Williamsburg	Dalbergia rinkiana	Do.
Elm Point	Liriodendropsis simplex Newberry	Do.
Do	Diospyros primæva Heer	Do.
Do	Magnolia alternans Heer	Do.
Do	Platanus newberryana Heer	Do.
Manhasset Neck	Nelumbo kempii Hollick	Cretaceous clays.
Roslyn	Terebratula filosa	Cretaceous in well.
Sea Cliff	Salix proteæfolia flexuosa Lesquereux	Cretaceous clays (?).
Do	Proteoides daphnogenoides Heer	Do.
Do	Andromeda parlatorii Heer	Do.
Do	Magnolia tenuifolia Lesquereux (?)	Do.
Glen Cove	Zizyphus elegans Hollick	Cretaceous clay.
Do	Aralia coriacea Velenovsky	Do.
Do	Andromeda flexuosa Newberry	Do.
Do	Premnophyllum trigonum Velenovsky	Do.
Do	Sassafras hastatum Newberry (?)	Do.
Do	Laurus plutonia Heer	Do.
Do	Sassafras acutilobum Lesquereux	Do.
Do	Podozamites angustifolius (Eichwald) Schimper	Do.
Do	Diospyros primæva Heer	Do.
Do	Dammara microlepis Heer	Do.
Do	Myrtophyllum (Eucalyptus) geinitzi Heer	Do.
Do	Sapindus morrisoni Lesquereux	Do.
Do	Nelumbo kempii Hollick	Do.
Do	Magnolia speciosa Heer	Do.
Do	Magnolia capellinii Heer	Do.
Do	Poacites sp	Do.
Do	Liriodendropsis simplex Newberry	Do.
Do	Sequoia sp	Do.
Dosoris Island	Liriodendropsis simplex Newberry	Drift.
	Magnolia longipes Newberry	Do.
Oak Neck Point	Andromeda latifolia Newberry	Do.
Center Island	Frenelopsis hoheneggeri (Ettingshausen) Schenk (?)	Do.
Do	Quercus morrisoniana Lesquereux	Do.
Do	Magnolia capellinii Heer (Glen Cove)	Do.
Cold Spring Harbor	Species doubtful	Cretaceous clays.
Lloyd Neck	Myrsine elongata Newberry	Drift.
Do	Dalbergia rinkiana Heer	Do.
Do	Tricalycites papyraceus Newberry	Do.
Do	Clausa americana	Cretaceous in well.
Eaton Neck	Colutea primordialis Heer	Drift.
Little Neck	Brachyphyllum macrocarpum Newberry	Cretaceous clays.
Do	Laurus augusta Heer	Do.
Do	Celastrus arctica Heer	Do.
Do	Paliurus integrifolius Hollick	Do.
Do	Eucalyptus (?) angustifolia Newberry	Do.
Montauk Point	Tricalycites papyraceus Newberry	Do.
Do	Gryphæa sp (?)	Do.
Do	Turritella lippincotti Whitfield	Do.
Do	Dosinia gabbi Whitfield	Do.
Do	Veniella inflata (Conrad)	Do.
Do	Ænona eufaulensis Conrad	Do.
Do	Corbula sp (?)	Do.

In addition to the macroscopic fossils in the above table, a large number of diatoms, etc., have been enumerated by Ries [1] (identified by C. H. Kain and others). These were all obtained at localities where Cretaceous deposits are known to occur, but none of the Pleistocene clays have so far afforded them. The species are all fresh-water forms.

Cretaceous diatoms.

Wyandanch	Melosira granulata [Ehr.] Ralfs.
Northport	Melosira granulata [Ehr.] Ralfs.
	Diatoma hyemale K. B.
	Cocconema parvum W. Smith.
Center Island	Stephanodiscus niagaræ Ehr.
Glen Cove	Melosira granulata [Ehr.] Ralfs.
	Stephanodiscus niagaræ Ehr.
	Diatoma hyemale.
	Melosira granulata [Ehr.] Ralfs.

[1] Ries, Heinrich, Microscopic organisms in the clays of New York State: Trans. New York Acad. Sci., vol. 13, 1894, pp. 165-169.

Cold Spring Harbor (diatom bed)	Stephanodiscus niagaræ Ehr.
	Epithemia turgida [Ehr.] Kutz.
	Encyonema ventricosum Kutz.
	Cymbella delicatula Kutz.
	Cymbella cuspidata Kutz.
	Navicula viridis Kutz.
	Navicula cocconeiformis Greg.
	Navicula major Kutz.
	Navicula varians Greg.
	Navicula lata Breb.
	Eunotia monodon Ehr.
	Gomphonema capitatum Ehr.
	Stauroneis phœnecenteron Ehr.
	Fragilaria construans Grun.
	Synedra affinis K. B.
	Campyloneis grevillei var. regalis.
	Triceratium trifoliatium.

TERTIARY (?) SYSTEM.

DISTRIBUTION.

Long Island has never yielded any fossils of Tertiary age, the diatoms from Rockaway and elsewhere described by A. M. Edwards [1] being from deposits that are clearly interglacial or postglacial. Lithology and stratigraphy must therefore serve as guides in determining the presence or absence of Tertiary deposits.

Eocene and Miocene deposits are definitely recognized in New Jersey and the Lafayette formation is doubtless present, although it has not been clearly differentiated. The Eocene (Shark River or upper marl) is a blue marl about 11 feet thick resting with a slightly discordant dip on the beveled edges of the Cretaceous. It occurs in eastern New Jersey as a narrow strip outcropping between the Miocene and Cretaceous beds and is intersected by the ocean at Deal Beach. Though covered farther south by later deposits, it seems to be continuous across the State in that direction. Its probable extension toward the northeast is suggested by fossils found in the drift on Cape Cod. The Miocene is well developed across New Jersey, where it includes the Kirkwood formation and the Cohansey sand, and it occurs on Marthas Vineyard and possibly at Marshfield, near Plymouth, Mass. It appears probable that originally both the Eocene and the Miocene extended across the Long Island area to the New England coast and that their presence or absence to-day depends solely on the amount of erosion to which the region has been subjected.

EOCENE (?) SERIES.

On Long Island a few feet of marl has been found at Melville and in the wells at Quogue and Bridgehampton (p. 68). The stratigraphic position of the bed at Melville, which is the only surface exposure, is very close to that at which the Eocene would occur if the Cretaceous maintains the same thickness as in New Jersey, and its strike is as indicated on Plate II (in pocket). The composition and the presence of the stony layers (see section, p. 68) agree closely with the character of the Eocene in New Jersey, as described by Cook,[2] who says "it is a mixture of greensand and light-colored earth; the upper 2 feet are quite hard and stony." On the other hand, it would be somewhat strange that one particular bed of the Eocene should be present where the great mass of Cretaceous greensands are unrepresented. Thus, although it is possible that the marls at Melville may be Eocene, it is at least equally probable that they are Cretaceous, and they have been so correlated in the present report.

[1] Am. Jour. Sci., 3d ser., vol. 50, 1895, p. 270; Am. Naturalist, vol. 30, 1896, pp. 212-216.
[2] Cook, G. H., Geology of New Jersey, 1868, p. 275.

MIOCENE (?) SERIES.

Resting on the marls just mentioned is a bed of loose yellowish quartz sand about 6 feet thick and similar in character to the "fluffy" Miocene sands (Kirkwood and Cohansey formations) of New Jersey. It occurs at almost the exact position where the Miocene would be expected and it may represent that series. On the other hand, sands of identically the same character were observed in the Dix Hills at a much lower stratigraphic horizon, unless there is an unconformity much greater than there is any reason to suppose, and very similar sands were noted in the Cretaceous area at many points. On the map this sand is included with the Cretaceous deposits.

PLIOCENE (?) SERIES.

LAFAYETTE (?) FORMATION.

At points farther south the Lafayette was deposited as a sheet overlapping on a slightly eroded Cretaceous surface. If the structure of the Cretaceous beds is regular in the Long Island region and if the topography is due solely to erosion, the Lafayette would be expected to occur at the top of the Mannetto Hills, if at all. The only bed at this point with which it could be correlated is the "fluffy" sand of the Melville section, which resembles the Kirkwood and Cohansey formations of New Jersey much more closely than it does the Lafayette farther south. The unconformity at the base of the overlying gravel of this section appears to be many hundred feet, and the gravel could not well be correlated with the Lafayette even if it did not carry erratic materials.

Overlying the Cretaceous clays at nearly every point, however, are more or less extensive deposits of white or yellow sands. In some places they are conformable to the clays and clearly a part of the Cretaceous, but elsewhere their relations are obscure and they may be of subsequent origin. They are not glacial, for they contain no erratic material. Some of them might be Lafayette if the early Pliocene erosion was strong enough to develop a topographic relief of 200 to 250 feet, which is the range of elevation of the clays on which the sands rest. This is much greater than the unconformity found farther south. There is, moreover, no conclusive evidence that the sands are a separate formation. Sandy beds are abundant throughout the Cretaceous of the island, and the materials may represent Cretaceous sands slightly disturbed and crushed by the ice. On the whole it appears that although the Lafayette may occur, no definite evidence has yet been obtained of its presence.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

MANNETTO GRAVEL.

NAME.

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

CHARACTER.

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

SOURCE OF MATERIAL.

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

RELATIONS TO OLDER DEPOSITS.

Although only a few sections showing the contact between the Mannetto gravel and the underlying beds have been discovered, there is no reasonable doubt as to their relations. In the roadside section west of Melville already mentioned (p. 68) the Mannetto gravel rests upon a thin bed of loose yellowish sand, probably of Cretaceous age, which in turn rests upon impure marls. The Cretaceous deposits, however, do not continue to outcrop farther down the hill, the surface consisting of horizontally stratified gravels of the Mannetto type. Their relation is brought out in figure 57.

The conditions indicated by the figure are substantiated by observations on the general relations of the older deposits in other parts of the island, especially at Sea Cliff, where an unconformity between the Mannetto and the underlying Cretaceous sands was well exposed in a large sand pit. Together with the Melville exposure and the numerous well records, this establishes the existence of a great erosion unconformity antedating the Mannetto deposition and representing an interval of sufficient length to admit of the complete removal of the Tertiary deposits, if such were present, and the reduction of the Cretaceous over the greater part of the island from a level at least as high as the crest of the Mannetto ridge to and below the present level of the sea.

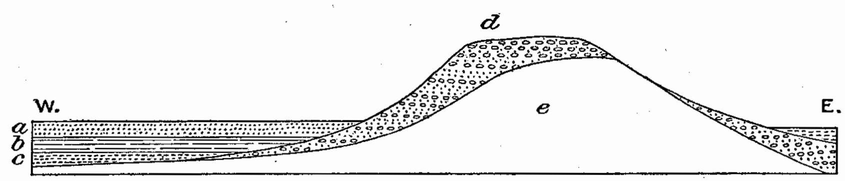


FIGURE 57.—Section showing general relations of deposits in the Mannetto Hills region. *a*, Manhasset formation with outwash mantle; *b*, Gardiners clay and Jacob sand; *c*, Jameco gravel; *d*, Mannetto gravel; *e*, Cretaceous deposits. The relations of the Jameco and Mannetto beneath the level of the Gardiners are hypothetical.

STRUCTURE.

The Mannetto gravel, so far as can be determined, lies horizontal wherever it is not disturbed by landslides or by the drag or shove of the ice sheets by which it was afterward overridden. This is shown by the horizontal bedding in the Melville section, in sections in Wheatley Hill near Old Westbury, and in the deeper and undisturbed parts of the Little Neck section, and by the extensive horizontal surface which it forms south of High Hill at the crest of the type locality, the Mannetto Hills. Great care has to be exercised in determining the dip because of irregularities of deposition due to the configuration of the underlying Cretaceous beds, as at Sea Cliff, and to the flow and plunge or larger cross-bedding features.

At points along the coast and to a less extent in the Dix Hills the Mannetto has been more or less disturbed and involved with other beds in the folding due to overriding ice. The flexures may be small, as shown in Plate XXIV, *B* (p. 162), or they may be many hundred feet across and correspondingly high, as at points on the north coast. The conditions under which the folding was produced are discussed on page 201.

DISTRIBUTION.

The Mannetto gravel was in part removed by stream and ice erosion in the subsequent interglacial and glacial stages and in part covered by thick deposits laid down upon it mainly during the latter stage, so that it is now exposed only at a few points in the erosion remnants of the Mannetto and other high hills or in bluff sections or artificial excavations on the north shore.

OUTCROPS IN THE INTERIOR OF THE ISLAND.

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

South end of Mannetto Hills.—Many sections of the Mannetto can be seen about the south end of the Mannetto Hills, especially in the vicinity of Bethpage, Plainview, and Farmingdale. In this region the old Mannetto topography was buried by subsequent deposits (Manhasset formation) and the whole was then complexly eroded. As a consequence of this superimposed topography the finding of the Mannetto can seldom be predicted from the altitude or form of the surface. In general, however, the Mannetto tends to form the ridges and the Manhasset tends to occur in terraces, as northeast of Bethpage.

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

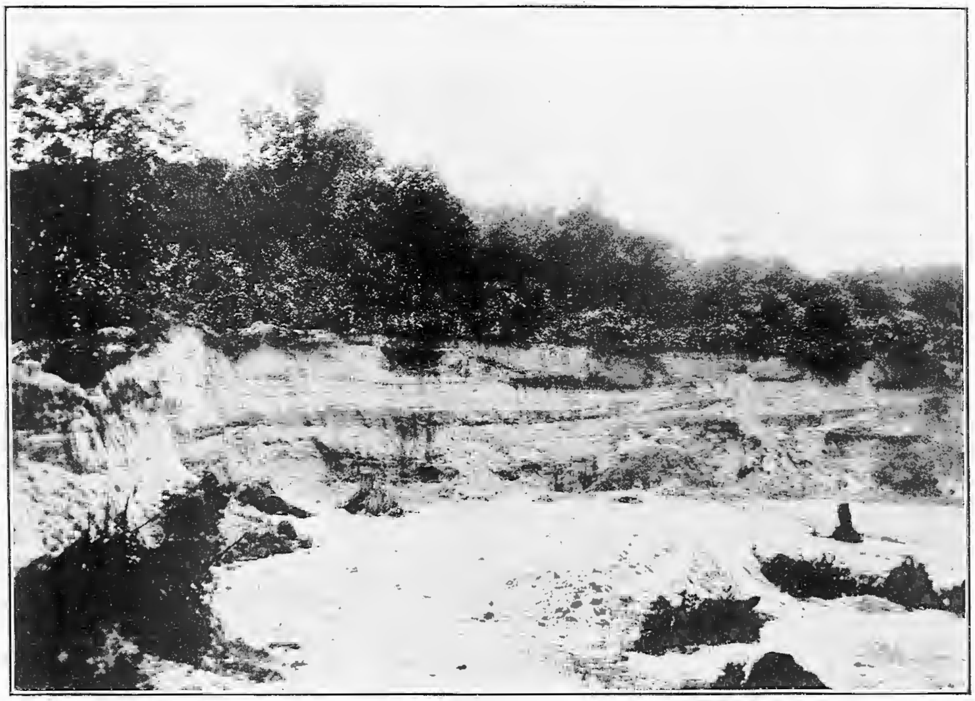
Half Hollow Hills.—From road sections it seems probable that a large part of the mass of the Half Hollow Hills also is made up of the Mannetto gravel, although no typical outcrops were discovered. Yellowish sands, however, such as occur in this formation at many places, were seen in several road cuts.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

Dix Hills.—The conditions in the Dix Hills are much the same as in the Half Hollow Hills, although, owing to the morainal belt across the southern portion of the Dix Hills, exposures of the Mannetto gravel are fewer. North of the moraine, especially in the hills southwest of Elwood, several shallow cuts along the roads show Mannetto beneath later drift deposits. Such an exposure is shown in Plate XXIV, *B* (p. 162).

Wheatley Hills.—Between Wheatley village and Old Westbury is a group of hills projecting southward from the moraine for 2 miles or more (Pl. VI, *D*, p. 32). Superficially these hills are covered with till of Wisconsin age, and they were classed by J. B. Woodworth[1] and earlier geologists with the moraine. On careful search, however, a number of excavations were found a quarter of a mile north of Westbury Pond and elsewhere, which showed beneath the mantle of drift typical orange-colored cross-bedded Mannetto gravel with its usual rotten granites. Well borings in other parts of the hills seem to indicate that these conditions are general.

Knobs of the north-shore necks.—On the plateau surface of Manhasset Neck (Pl. IV, p. 30) on the north shore, there are many well-defined knobs standing 20 to 60 feet above the general surface. No cuts deep enough to expose the material in them beneath the Wisconsin drift were discovered, but a study of the composition of the till, in which white quartz pebbles predominate, seems to indicate either a Cretaceous or a Mannetto core, probably the latter, as well records do not indicate that the Cretaceous rises to these elevations.

[1] Bull. New York State Mus. Nat. Hist. No. 48, 1901, map.



A. STRUCTURE OF CRETACEOUS CLAYS ON LITTLE NECK NEAR NORTHPORT.

B. LARGE DECOMPOSED ERRATIC BOWLDER IN MANNETTO GRAVEL.

OUTCROPS ON THE COAST.

Broken Ground.—Mannetto gravel of the usual quartzose type appears to occur in small quantities overlying the Cretaceous clay at Broken Ground, near Northport, and to be involved with the clay in the great landslides. This is the most easterly point at which the formation has been recognized.

Eaton Neck.—The Mannetto is well exposed on Price Bend, about one-eighth of a mile north of Winkle Point on Eaton Neck. The following section was measured:

Section near Winkle Point.

	Feet.
Wisconsin drift: Buff till with small bowlders	5
Mannetto gravel:	
Yellow mealy sand with a few pebbles	15
White and yellowish clay	1
Sand and gravel with weathered erratic bowlders	20
Cretaceous: Pink, yellow, and white sand with hematitic sandstone plates and concretions	30

The bowlders, one of which is shown in Plate XVII, *B*, were of acidic orthoclase granite and ranged from 1 to 2 feet or more in diameter. They are completely rotted and fall to pieces on pressure with the hand, so that none are seen in the talus, but a careful search reveals a considerable number in the gravels.

A little north of the head of Price Bend another good exposure was seen, the Mannetto here being overlain by 4 feet of a chocolate-colored clay. The contact is sharp and shows a strong unconformity. Mannetto gravel is also to be seen at a number of places farther north along the shore.

Little and Great necks, Huntington.—Gravel, probably Mannetto, shows in the talus at a considerable number of points on both the east and west sides of Little Neck near its north end but was not recognized in the clay and sand pits. On Great Neck quartz gravels containing weathered granite pebbles occur in outcrops and in the talus above the Cretaceous deposits at a number of points near the entrance of Northport Bay.

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

Section north of Lloyd Beach.

	Feet.
Montauk till member of Manhasset formation (?): Interstratified yellowish clay and sand with an occasional erratic up to 6 inches in diameter	2
Mannetto gravel:	
Dark-gray clay	1½
Bright-yellow clay	1
Yellow clay with ferruginous sand and pebble layers	2
Fine quartz gravel with iron and manganese stains; weathered granitic pebbles	5
	10½

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

Hempstead Harbor.—The Mannetto gravel was seen resting on the white Cretaceous sands in a number of the sand and gravel pits on the south side of Mosquito Inlet, at Hempstead Harbor. In one of these, just across the stream from Glen Cove, an unconformity was exposed in 1905. The old Cretaceous surface is marked by a dark band at the top of the steeply dipping sand. The first Mannetto layers are whitish, owing to their materials being derived from the Cretaceous sands immediately underlying them, but in the upper part of the exposure the admixture of foreign material gives them a darker color.

No other good exposure of the Mannetto was seen on Hempstead Harbor or at any point farther west, but the talus slopes afford indications that the bluffs at a number of points south of Sea Cliff are composed in part of Mannetto material. Indications of Mannetto material were noted in the drift on the knobs that rise above the general crest of Manhasset Neck and suggest Mannetto cones. Mannetto gravel was seen above upturned Cretaceous clays in the crest of the neck at a point due west of Sea Cliff.

DEPOSITS PENETRATED BY WELLS.

Owing to the small percentage of granitic material present in the Mannetto, it is distinguished from the Cretaceous quartz gravels in wells only with difficulty. There is, however, good evidence of its presence at a number of places, among which are those mentioned in the following paragraphs. The figures in parentheses indicate the number assigned to the well by A. C. Veatch in his report on the water resources of the island,[1] in which detailed records may be found.

The most westerly point at which probable Mannetto material was found was in a test well at Fresh Meadow pumping station, south of Flushing (No. 231), where 7 feet of coarse orange-colored sand and quartz gravel with a small amount of white chert was found 50 feet below the surface. A 20-foot bed of medium-grained reddish-yellow sand with some crystalline pebbles found at 125 feet in the well of W. K. Vanderbilt, jr., near Lake Success (No. 317), is probably in part Mannetto. A 12-foot bed of hard coarse gravel at 62 feet in the R. L. Cottnett well, near Old Westbury (No. 426), is also referred to this formation. The J. F. D. Lanier well, in the same region (No. 427), penetrated 10 feet of Mannetto at the surface. Material that is probably Mannetto occurs within 30 feet of the surface in the H. B. Duryea well, near Old Westbury (No. 430), and at 90 and 106 feet in the E. D. Morgan wells (No. 431), in the Wheatley Hills, which probably penetrate a buried valley.

In the S. Mortimer well, also in the Wheatley Hills (No. 434), the Mannetto appears to extend from a point near the surface to a depth of 150 feet. Other wells in this region contain probable Mannetto material as follows: Yellow quartz sand and gravel at 23 to 56 feet in the W. P. Thompson well, near Old Westbury (No. 511); yellow gravel in the first 70 feet of the J. H. Harriman well, in the Wheatley Hills; and fine sand to medium-sized yellowish quartz gravel at 51 to 81 feet in the Jules Kunz well, near Jericho. In Mrs. I. Vowman's well, near Roslyn (No. 436), the formation is probably present as a coarse reddish gravel at 90 to 115 feet.

The orange-colored sand found at 73 to 92 feet in the L. C. Wier well (No. 481), at 73 to 126 feet in the E. Latting well (No. 483), and at 83 to 108 feet in the W. D. Guthrie well (No. 484), all near Lattingtown, may be Mannetto, although orange-colored Cretaceous gravels also occur in that vicinity.

In the Mannetto Hills, according to Veatch, the following beds of the Mannetto gravel were penetrated by the well of H. L. Stimpson. The correlations, which are Veatch's, appear to be based on the occurrence of decayed cherts, which are locally present in the Mannetto but are rare in the Cretaceous.

586. Samples from H. L. Stimpson's well in the West Hills.

	Feet.
Wisconsin: Clayey sand and gravel with many compound pebbles	8– 20
Mannetto:	
Orange-yellow quartz pebbles, with a very few fragments of compound rocks, the latter probably derived from the overlying beds	28
Orange-yellow quartz pebbles, with considerable sand and yellow clay and many fragments of decayed white chert	40
White quartz sand, with much fine-grained red ironstone and decayed chert	52
Cretaceous?:	
White to light-yellow quartz sand and gravel containing fragments of decayed white chert.	60–120
Fine to coarse reddish-yellow sand	125
Fine to coarse white sand	130
Fine to coarse yellow sand	135
Medium yellow silty sand, with many small brown ferruginous nodules and a few pellets of clay	140–145
Medium to coarse light-yellow sand, with many fragments of dark-brown ferruginous sandstone	150–155

[1] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 168-337.

The Mannetto has not been definitely recognized in any of the wells on the eastern half of the island.

AGE.

No absolute proof of the age of the Mannetto gravel has yet been found, although all evidence seems to point to its post-Tertiary origin. The unconformity at its base is much greater than any of the Tertiary unconformities in adjacent areas in New Jersey, even the pre-Miocene unconformity or the pre-Lafayette unconformity farther south being small compared with it. Moreover, it differs in many ways from the sandy Kirkwood, Cohansey, and Beacon Hill formations of New Jersey. The Beacon Hill, for instance, carries many pebbles of rotten quartz and chert, whereas the quartz pebbles of the Mannetto are relatively fresh. Again, the Beacon Hill nowhere carries granitic pebbles, but they may be found in every exposure of the Mannetto.

The pre-Pleistocene formations, so far as observed at the surface, either on Long Island or in New Jersey or in the Coastal Plain States farther south, are, except for scattered pebbles of very acidic schist approaching quartzite in character, free from crystalline fragments. The only apparent exception in the region under discussion is a granite fragment measuring 2 by 3½ inches reported from the Cretaceous at a depth of 335 feet in the well of E. D. Morgan, in the Wheatley Hills.[1] Inasmuch as surface outcrops have yielded nothing of the kind, although well exposed at dozens of points, and especially in view of the well-known carelessness of drillers and the possibility of the fragment dropping from a higher level in the well, its evidence must be regarded as of doubtful value. The relative abundance of granites in the Mannetto suggests the correlation of the formation with the Pleistocene rather than with older deposits. The presence of erratic bowlders as much as 2 feet in diameter is also suggestive of glacial derivation, for although it is true that such bowlders can be transported by floating trees or other agencies besides ice, the fact that none are found in the hundreds of feet of Cretaceous and Tertiary strata exposed at the surface on Long Island and in New Jersey or, with the exception of the doubtful fragment mentioned above, in the thousand feet or more of such strata penetrated by the drill makes some other method of transportation than floating trees more likely. The coarse average texture of the Mannetto compared with that of the Cretaceous and Tertiary deposits indicates that a considerable change in the conditions of deposition had taken place since the latter were laid down. The structure of the Mannetto, especially the details of its cross-bedding, and the smooth, gently sloping upper surface of its remnants in the Mannetto Hills, is identical with that of parts of the outwash from Wisconsin ice, of late Pleistocene time, and suggests a similar origin. The degree of weathering is also suggestive, the decay of the granite pebbles being what would be expected of an early Pleistocene deposit rather than a Tertiary formation.

The available evidence as outlined above seems to warrant the inclusion of the Mannetto in an early glacial stage of the Pleistocene series, although a strictly fluvial origin of the deposits is not impossible. If the formation is glacial outwash, it was probably laid down early in the Pleistocene epoch, as indicated by its weathered character and stratigraphic position with reference to the associated deposits of the same epoch, most likely representing the pre-Kansan invasion.

JAMECO GRAVEL.

NAME.

The term Jameco gravel, which was used by A. C. Veatch in his report on the water resources of the island, was derived from the Jameco pumping station, near Jamaica South, 3 miles south of Jamaica, in western Long Island, where the deposits were first recognized in the deep wells.

CHARACTER.

The Jameco gravel, although it has not been definitely recognized at the surface at any point on Long Island, has been encountered in a considerable number of wells. In its type locality, in the area extending from Jamaica Bay northward toward Whitestone, it occupies a broad

[1] Veatch, A. C., op cit., p. 259.

depression in the underlying rocks (either Cretaceous or Mannetto). It is easily recognized in the wells in this locality because of its striking dissimilarity to all other Pleistocene beds (except the Montauk till member of the Manhasset formation) and to the Cretaceous formations. The difference between the Jameco gravel and the Mannetto gravel is especially marked. Although the older beds are prevailingly light-colored and composed principally of quartz, the Jameco is generally a very coarse dark-colored gravel containing a predominance of granitic pebbles with a few streaks of black or other dark sands or finer silts (wells Nos. 135, 195–206, 273, 290, and 291 of table, p. 90). The pebbles are well rounded and of different sizes, some being nearly as large as cobbles, but toward the east they become finer, being commonly from half an inch to 2 inches in diameter.

It should be noted that although on Long Island knowledge of the Jameco is derived mostly from samples obtained from well borings, the gravels beneath the Gardiners clay are well exposed at several points farther east, where folding has brought the beds to higher levels, especially in the Nashaquitsa Cliffs, on Marthas Vineyard; near Highland Light, Truro, on Cape Cod; and less perfectly between Balls Point and Clay Head, on Block Island. At most of these localities the relatively high granitic content, the absence of notable staining and cementation, the lack of marked weathering, and the strictly conformable contact with the overlying Gardiners clay effectually preclude any possibility of confusion with the Mannetto.

The darkest phase of the gravel is rather local, being confined mainly to the old Cretaceous valley mentioned. In Brooklyn and Williamsburg, which lie on the west of the valley, the Jameco is usually reported as consisting of yellow or reddish sands and gravels, with a little hardpan (in wells Nos. 5, 23, 37, 38, 62, and 65). On the shores of Long Island Sound the material, as shown by the north coast wells (Nos. 351, 469, 527, 529, 530, 532, 539, 543, 548, 549, 613, 633, and 652), is almost invariably a light-colored sand or gravel, although black sand (No. 545), brownish sands and gravel (Nos. 628, 629), and coarse granitic gravel (No. 654) are reported in a few records. Along the east side of the buried valley on the south side of the island, as at Valley Stream (No. 287), a sandy phase of the Jameco is developed locally, but the formation seems to be generally absent east of Rockaway Ridge, although a bed of dark clay and sand, probably the Jameco, is found beneath Muncie Island (No. 671). Near the east end of Long Island a yellow or white sand or gravel correlated with the same formation is found beneath supposed Gardiners clay (Nos. 897, 901).

Where lithologic characteristics are not determinative, the formation is recognized by its position below the fossiliferous Gardiners clay.

The following sections show the character of the Jameco gravel at a number of points. The numbers refer to records in Veatch's report, but the correlations are those of the writer. The first is a record of a well west of the Cretaceous valley.

38. Record of well at Bartlett Street and Flushing Avenue, Brooklyn.

	Feet.
Recent:	
Filled ground	0– 8
Black marsh mud	8– 9
Blue clay	9– 15
Hempstead gravel member of Manhasset formation:	
Light yellowish-brown sandy clay at	19
Bluish-gray, rather pure clay at	26
Montauk till member of Manhasset formation:	
Highly erratic glacial gravel	31– 36
Medium erratic sand	36– 62
Erratic gravel mixed with blue clay	62– 73
Herod gravel member of Manhasset formation: Coarse glacial sand	73– 81
Jacob sand and Gardiners clay:	
Impure bluish-gray sandy clay	87– 93
Yellowish-gray sand mixed with clay	93–108
Clean light-brown medium erratic sand	108–122
Bluish-gray sandy clay	122–124
Medium yellowish-brown clayey sand	124–127

	Feet.
Jameco gravel:	
Coarse yellowish-brown clayey sand	127–134
Very coarse dark-yellow clayey sand	134–145
Very coarse reddish-yellow erratic sand	145–174
Coarse, highly erratic sand	174–175

The following well section is typical of the region of the Cretaceous valley:

204. Record of Brooklyn test well No. 3, Brooklyn Aqueduct and New York Avenue.

	Feet.
Wisconsin: Reddish-yellow silty sand and gravel	0– 9
Manhasset formation:	
Fine to coarse reddish-yellow sand with granitic pebbles in lower portion	9– 45
Fine light-yellow sand	45– 86
Gardiners clay:	
Lead-colored clay	86–139
Fine dark-gray silty sand	139–158
Medium dark-gray silty sand	158–160
Gray clay	160–201
Jameco gravel: Fine to coarse dark granitic silty sand	201–277

The next record shows the characteristics of the deposits in the wells of the north shore.

652. Record of well of Huntington Light & Power Co. near Halesite.[1]

	Feet.
Recent:	
Filled ground	0– 6
Swamp deposit	6–10
Manhasset formation: Dark sand and gravel	10–70
Gardiners clay: Blue clay	70–71
Jameco (?) gravel: Light-yellowish gravel	71–75

On the south shore east of the Cretaceous valley the succession is as follows:

187. Record of James Caffery's well near Far Rockaway.[1]

	Feet.
Manhasset formation: Water-bearing strata, almost clear gravel	0– 42
Gardiners clay	42– 66
Jameco gravel:	
Black sand with water which looked and tasted good	66– 88
No record	88–112

The character of the Jameco in the eastern part of the island is shown in the record of the Bridgehampton well (No. 897) given on page 75.

In a number of wells at the Springfield pumping station wood is reported in the Jameco, as well as in the Gardiners clay. This is indicated in the abbreviated records in the following table, taken from the report of Veatch,[1] with the correlations of the writer.

Well sections at Springfield pumping station.

Well No.	Section.		
	Sand (Wisconsin and Manhasset).	Blue clay with wood and sand (Jacob and Gardiners).	Water-bearing sand and gravel; some wood and clay (Gardiners and Jameco).
	Feet.	*Feet.*	*Feet.*
15	0–74	74–182	182–207
3	0–50	50–117	117–177
2	0–50	50–124	124–178
6	....	....	160–177
7	....	....	160–177
8	....	....	139–179
9	....	76–135	....
10	....	....	132–156

[1] Op. cit., p. 201.

East of Long Island the Jameco occurs at a number of points. Veatch correlates the yellowish sands and the bowlder-bearing deposits beneath certain of the clays on Gardiners Island with the Jameco, but for the reasons given on page 90 the writer regards the presence of true Jameco on that island as doubtful.

The stratification of the Jameco where the beds are exposed at the surface farther east is fairly regular, cross-bedding being exceptional. An examination of the material at a number of points shows that the pebbles have not undergone any great amount of decomposition, although they are distinctly more weathered on the average than are the subsequent deposits. The thickness of the beds is ordinarily not very great, rarely exceeding 100 feet, and thicknesses of less than 50 feet are not uncommon.

SOURCE OF MATERIALS.

At the type locality in the buried Jameco channel the pebbles and even the smaller grains of the Jameco gravel are prevailingly granitic in character and therefore must have been derived from the crystalline area of the mainland on the north. The generally low percentage of quartz indicates that very little material was derived from the Cretaceous, from the later Coastal Plain formations, or from the Mannetto gravel, in all of which the pebbles are mainly quartz. Outside of the buried valley mentioned, however, much more quartz is present in the Jameco gravel, indicating that it must have received considerable contributions from the Cretaceous formations or the Mannetto gravel.

RELATIONS TO OLDER DEPOSITS.

The Jameco gravel rests unconformably upon the older Mannetto and Cretaceous deposits (fig. 57, p. 81), the principal portion on Long Island being laid down in the broad buried valley underlying Jamaica Bay and the region to the north, toward Jameco, Jamaica, and Flushing. Whether this old valley was cut wholly in Mannetto gravel or whether the erosion cut through the Mannetto into the underlying Cretaceous is not clearly shown by the well records. In either case the unconformity amounts to nearly or quite 600 feet, as there is that much difference between the altitude of the Mannetto plateau remnants and that of the bottom of the buried valley occupied by the Jameco gravel in the region mentioned. Taken as a whole it seems likely that the Jameco rests upon or abuts against both the Cretaceous and Mannetto (fig. 57), although to judge from the severity of the pre-Jameco erosion, which seems to have almost completely removed the Mannetto, the beds probably more commonly rest upon the Cretaceous. In western Long Island the accumulation of the Jameco took place almost entirely in the valley described. Farther east the deposits were banked against the north side of the Cretaceous and Mannetto land masses, such as those of the Mannetto and Half Hollow hill region, and in the extreme eastern part of the island they were spread out over the lower and flatter Cretaceous surface which existed there.

STRUCTURE.

The structure of the Jameco gravel of Long Island must, in the absence of known surface exposures, be inferred from the attitude of the overlying beds and from differences in the elevation of the buried surface. Such criteria are, of course, of value only where unconformities are absent. Although there is no direct evidence on Long Island that the overlying beds are conformable with the Jameco, observations on Block Island, Marthas Vineyard, and the Massachusetts coast, where the beds are perfectly conformable, indicate the probability of similar conditions on Long Island. If this is assumed as a fact and conclusions are based on the elevation of the Jameco surface or on the structure of the overlying Gardiners clay, it appears that the Jameco beds, although nowhere far from the horizontal, are yet more or less warped. In the region between Ridgeway, Brooklyn, and Valley Stream several undulations from 50 to 100 feet in elevation are brought out by the borings (fig. 58), and beneath Rockaway Ridge occurs a similar fold whose existence as a topographic feature is due to this arch in the underlying beds. This and similar irregularities on the north shore of the island are brought out by the depths in the table on page 90. Although the occurrence of the Jameco at the surface on Gardiners Island appears doubtful, it is probably present locally at no great distance below sea level and is doubtless involved in the strong folds which characterize all the older deposits of that island.

DISTRIBUTION.

POSSIBLE SURFACE EXPOSURES.

At a number of points on Long Island and in its vicinity beds of sand or gravel underlie the clays exposed in the bluffs. Sandy beds are in places intercalated with clayey strata in the Gardiners clay, but in the absence of well records it is not possible to determine whether the clay seen is the basal clay of the formation or one of the upper members. In the former case the sand or gravel would be referred to the Jameco; in the latter case it would be referred to the Gardiners. The exposures may, however, be described at this point.

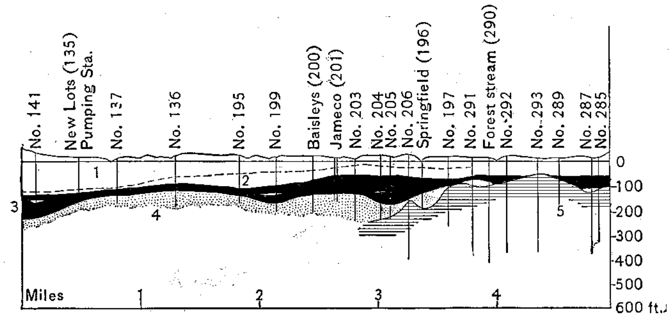


FIGURE 58.—Section from point near Ridgeway, Brooklyn, to Valley Stream. 1, Wisconsin drift; 2, Manhasset formation; 3, Gardiners clay; 4, Jameco gravel; 5, Cretaceous beds.

Jacob Hill.—In the bluffs of Jacob Hill, which is situated about 2 miles west of Mattituck, several conspicuous pinnacles of contorted reddish or chocolate-colored sandy clays were seen just back of the beach in 1904. The base was not well exposed, but the relations seem to be as indicated in figure 71 (p. 98). The gravel may be Jameco, but it seems more probable that the clay is involved in an overturned fold resting on the Herod gravel member of the Manhasset formation.

Mulford Point.—A short distance west of Mulford Point and about 3 miles west of the termination of the North Fluke at Orient Point a complexly folded exposure of Gardiners clay was noted. At the time of the writer's visit in 1904 nothing could be seen of the underlying beds, but Mather[1] in 1843 gave a section which seems to indicate that the clays are underlain by sands, possibly to be correlated with the Jameco.

Montauk Point.—At a point about 2½ miles west of Montauk Light a considerable thickness of gray to greenish sand and fine gravel with some yellow gravel was exposed in 1904 beneath 10 feet of interlaminated sand and chocolate-colored sandy clay, with the relations shown in figure 59. Most probably the material described belongs to the Jacob sand, but it is not impossible that the sandy clay belongs to the Gardiners clay, in which case the underlying material would be Jameco.

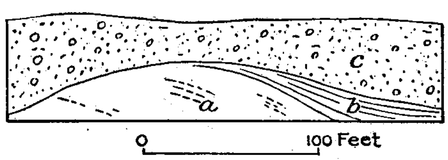


FIGURE 59.—Section 2½ miles southwest of Montauk Light. *a*, Gray to greenish sand with some yellow gravel; *b*, interlaminated sand and chocolate-colored clay; *c*, banded till (Montauk member of Manhasset formation).

Hog Neck.—On the west side of Hog Neck, 2 miles northwest of Sag Harbor, is exposed a section that seems to show beneath the Gardiners clay a considerable thickness of stratified gravels which would naturally be correlated with the Jameco gravel. The beds are strongly folded, however, and are probably overturned, so that the gravel may be stratigraphically above the clays though below them in the section. (See figs. 151 and 152, p. 142.)

Gardiners Island.—The stratigraphy of the Pleistocene deposits of Gardiners Island is complicated by the severe folding to which all the beds except the Wisconsin have been subjected, as well as by the somewhat unusual succession. Instead of the Gardiners clay being represented by a single stratum, as in many localities both east and west of this island, it occurs as a series of interbedded clays and sands; moreover, thin clays of very similar character

[1] Mather, W. W., Geology of New York, pt. 1, 1843, pl. 4, fig. 5.

occur in the Montauk till member of the Manhasset formation. Owing to the incompleteness of the exposures or to the complexity of the folding, it is in many places impossible to determine the horizon of a particular clay bed, and the identification of the underlying sand beds is still more difficult. For this reason the writer has found it impossible to identify positively the Jameco on Gardiners Island. Veatch[1] describes and figures a section near the middle of the northeast coast (diagram reproduced as fig. 60), in which a bed of gravel containing bowlders of granitic rocks is shown between a red clay and a bed of fine gray micaceous sand regarded as Cretaceous. To the writer, who examined the same exposure at a later date, it appeared that the bowlders referred by Veatch to the Jameco are a superficial deposit (Montauk) irregularly massed against an ancient bluff, and that the supposed Cretaceous sand is identical with beds intercalated with the Gardiners clay at other points and is to be correlated with that formation. The small unnumbered infolded bed between Nos. 4 and 5 has the appearance of belonging to the Herod gravel member of the Manhasset, and No. 4 resembles the Jacob sand. It would be strange if the Gardiners clay, which usually has a thickness of 30 to 100 feet and is represented by a number of alternating sands and clays, should at this particular point be represented by a single bed only a few feet thick. The Jameco is thought to occupy its normal position below sea level, possibly banked against the Cretaceous mass, the upper part of which is involved in the fold shown in the figure. It is very doubtful if any Jameco shows above sea level on Gardiners Island. The folded bowlder-bearing beds which underlie certain clays elsewhere on the island, and which are correlated with the Jameco by Veatch, belong almost wholly to the Montauk till member of the Manhasset formation.

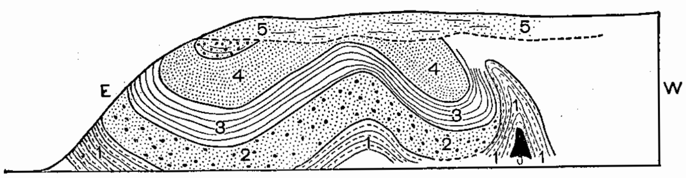


FIGURE 60.—Section near the middle of the northeast shore of Gardiners Island. 0, Black Cretaceous clay; 1, fine gray micaceous sand (Cretaceous); 2, Jameco gravel; 3, red clay (Sankaty); 4, silty sand (Sankaty); 5, Wisconsin till and outwash gravel. Height of section, 60 feet. Section and nomenclature by A. C. Veatch.

No beds that could be correlated with the Jameco gravel were noted on either Plum Island or Fishers Island, although they doubtless occur below sea level.

DEPOSITS PENETRATED BY WELLS.

Long Island.—The distribution of the Jameco gravel shown by the wells of Long Island is concisely presented in the following table, which emphasizes, first, the concentration of the coarse dark granitic gravel in the old Cretaceous depression north of Jamaica Bay; second, the finer, more quartzose, and lighter-colored deposits on either side of the depression and on the north shore; third, the general absence of the gravel from the south side of the old Cretaceous land mass; and, fourth, its occurrence as a light quartzose gravel in the extreme eastern part of the island.

Jameco gravel penetrated in wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of formation.	Character of the deposit.
			Feet.	
5	Brooklyn	Rapid Transit Co	139–212	"Hardpan" with black stones and coarse sand.
23	do	5th Avenue and 18th Street	[b] 55–135	Reddish-brown sand and gravel.
37	do	Bartlett Street and Harrison Avenue.	150–165	Coarse red sand.
38	do	Bartlett Street and Flushing Avenue.	139–176	Coarse yellow sand.
62	do	Ten Eyck Street	100	Beach sand.
65	do	Porter and Maspeth avenues.	190	Water-bearing gravel.
130	Barren Island	T. F. White Co	130–220	Reddish-brown sands with cobbles.
135	East New York	Dept. Water Supply	118–164	Coarse dark granitic gravel.
136	Aqueduct	Brooklyn waterworks	128–191	Dark reddish or yellowish sands and granitic gravels.
137	East New York	do	141–149	Coarse dark granitic gravels.
141	do	do	281–284	Gray silt and granitic pebbles.
176	North Beach	Bowery Bay Building Association.	36–82	Coarse sand and gravel.
187	Far Rockaway	Jas. Caffery	66–112	Black sand.
188	do	B. L. Carroll	65–190	Fine to coarse sand and gravel.

[a] Numbers refer to well records in report on underground water resources of Long Island, New York, by A. C. Veatch and others (Prof. Paper U. S. Geol. Survey No. 44, 1906).
[b] In part.

[1] Op. cit., p. 35.

Jameco gravel penetrated in wells of Long Island—Continued.

No.	Locality.	Owner or place.	Depth of formation.	Character of the deposit.
			Feet.	
191	Far Rockaway	Queens County Water Co	100	Beach sand.
195	Aqueduct	Shetucket pumping station	146-154	Coarse dark granitic gravels and clay.
197	Springfield	Springfield pumping station	106-109	Steel-gray sand with jasper pebbles.
199	Jamana South	Oconee pumping station	185-192	Coarse dark granitic gravel.
200	do	Baisleys pumping station	156-200	Black sand and gravel.
201	do	Jameco pumping station	135-161	Dark-brown granitic gravel and sand.
202	do	Connell Creek	142-156	Dark granitic gravel and sand.
203	do	Brooklyn test well No. 2	154-258	Dark granitic gravels and sands.
204	Springfield	Brooklyn test well No. 3	201-277	Do.
205	do	Brooklyn test well No. 8	212-260	Do.
206	do	Springfield pumping station	170-183	Reddish-yellow granitic gravel and sand.
212	Jamaica	Brooklyn test well No. 11	189-200	Dark granitic gravel and sand.
213	do	Pumping station, Jamaica Water Supply Co.	104-120	Coarse sand and reddish gravel.
239	Whitestone	Pumping station No. 1	45- 95	Glacial sand and gravel.
241	do	Railroad wells	85-120	Coarse granitic gravel.
243	do	W. W. Cole	70- 96	Medium coarse gravel.
261	Lawrence	D. D. Lord	70-100	Coarse sand, changing to gravel.
273	Hewlett	Queens County pumping station.	120-155	Coarse sand and gravel with granitic pebbles.
287	Valley Stream	Watt Pond pumping station.	118-130	Sand and fine gravel.
290	Springfield	Forest Stream pumping station.	105-115	Water-bearing iron formation.
291	do	Brooklyn test well No. 12	98-138	Dark dirty granitic sands.
292	Rosedale	Brooklyn test well No. 13	70-102	Reddish-yellow silty sand and gravel with granitic pebbles.
351	Plandome Mills	Robt. Seizer	100-113	Coarse sand.
469	Dosoris Pond	D. F. Bush	95- 97	Light-colored granitic gravel.
527	Oyster Bay	Charles Weeks	90-110	Micaceous sand.
529	do	Van Sise & Co	53- 57	Yellow sand and gravel.
530	do	D. W. Smith	50- 65	Fine yellow sand.
532	do	E. K. Hutchinson	50- 83	Sand.
539	do	W. J. and A. S. Hutchinson	185-190	Yellow sand and gravel.
543	do	O. L. Jones	135	Coarse sand.
545	do	T. Underhill	80-107	Fine gray and black sand.
548	do	Hamilton	80-130	Sand.
549	do	William Trotter	70- 90	Gravel.
613	Cold Spring Harbor	Eagle Dock	158-176	Fine sand and gravel.
628	West Neck	B. Ward	116-149	Dark-brown gravel mixed with clay.
629	do	Mrs. M. H. Oats	93- 97	Brown gravelly sand.
633	Lloyd Neck	O. L. Jones	105-122	Fine to coarse yellow gravel.
652	Halesite	Light & Power Co	71- 75	Light-yellowish gravel.
654	Centerport	R. S. McCrary	175-185	Granitic pebbles size of fist.
671	Muncie Island	E. H. Muncie	150	Dark clay and sand.
897	Bridgehampton	Sanford & Son	105-115	Yellow and orange sand and gravel.
901	Sag Harbor	J. K. Morris	143-145	Sharp white sand with biotite.

Plum, Gull, and Fishers islands.—On Plum Island the Jameco probably embraces the material from 2½ to 89 feet in the Army well. The Herod gravel member of the Manhasset formation, the Jacob sand, and the Gardiners clay were evidently here cut out by the Montauk ice.

Record of United States Army well on Plum Island, New York.

	Feet.
Montauk till member of Manhasset formation:	
Loam	0 - 2½
Sand and large bowlders	2½-20
Jameco gravel:	
Fine sand	20 -31
Fine sand and gravel	31 -49
Coarse sand and fine gravel	49 -89

Gull Island is only just awash and nothing but till, which may be either Montauk or Wisconsin, is exposed. The following record probably begins below the Gardiners clay, which, if present, would occur at about sea level.

Record of United States Army well on Gull Island, New York.

	Feet.
Jameco gravel (mainly):	
Loam and sand	0- 30
Coarse sand	30- 40
Very coarse sand	40- 46
Very coarse sand and gravel	46- 52
Sand	52- 57
Fine quicksand	57- 82
Sand and clay	82- 87
Gravel and sand	87- 91
Coarse gravel and sand	91- 98
Cretaceous:	
Fine sand	98-108
Light-colored clay	108-112
Dark-blue clay, rather oily; when exposed to the air became very hard	112-291

AGE.

The glacial or glaciofluviatile origin of the Jameco gravel is apparently shown by its highly granitic character, and if, as is believed, the Mannetto gravel is of similar origin, the Jameco was evidently deposited during a second glacial stage separated from the first by a long interval of deglaciation. The period of erosion between the two stages is somewhat comparable, so far as the effects on the island are concerned, with the long Pliocene epoch. It was in all probability at least as long as several of the later stages put together. This great length suggests that several stages of glaciation might have intervened, but nowhere on Long Island or on the New England coasts have evidences of glacial deposits that might be referred to such stages been found, notwithstanding the numerous localities where the older Pleistocene deposits have been brought up by folding and exposed in cliffs or have been penetrated by wells. A possible clue to the age of the Jameco is afforded by its place in the glacial sequence of the island, which is closely similar to the well-established succession of the Mississippi Valley. This evidence as well as the weathering of the Jameco materials suggests its possible equivalence with the Kansan stage of the interior of the country.

GARDINERS CLAY.

NAME.

The Gardiners clay derives its name from Gardiners Island, situated between the North and South flukes at the east end of Long Island, on which several clay beds with included sands are well exposed at a number of points. It is the exact equivalent of the Sankaty beds of Veatch [1] but is not the equivalent of the Sankaty beds of J. B. Woodworth,[2] with which Veatch mistakenly correlated it. The term Sankaty beds was proposed by Woodworth for a series of marine sands and gravels with a few minor clayey layers, locally carrying a Pleistocene fauna, which are involved in the folding that affected all the New England islands. The name is taken from Sankaty Head, Nantucket, where the fossils were first observed. No true clay was exposed at the type locality, except a fossiliferous bed only a few feet in thickness, although a series of brownish clayey sands incorrectly designated clay were exposed to a depth of 20 feet at the base of the cliff some 50 years ago.[3] The remaining parts of the bluff were made up mainly of sands, gravels, and semi-till.

Later Veatch,[4] on the ground of similarity of fauna, applied the same name to the blue, gray, or red Pleistocene clays of Long and Gardiners islands, which reach in the former island, according to the evidence of wells, a maximum thickness of about 100 feet. The present writer was originally inclined to the use of the term,[5] but subsequent field work, during which the greater part of the shores of Long, Gardiners, Plum, Fishers, and Block islands were traversed and the bluff sections of Marthas Vineyard, Nantucket, and Cape Cod were visited, brought out the fact that the true clays in each of the localities mentioned are stratigraphically below the lowest of the deposits at Sankaty Head and hence should not be included under the same name. Moreover, the Sankaty beds of Woodworth are separable into two distinct units, the Jacob sand and the Herod gravel member of the Manhasset formation (see pp. 106 and 121), each of which has been traced by the writer from western Long Island to Nantucket. The true clays, to which the term Gardiners clay is given, are interglacial deposits, but the Jacob sand and the Herod gravel member of the Manhasset formation are of glacial origin. The term Sankaty as used by Woodworth includes materials of unlike character but of glacial origin; as used by Veatch it applies to interglacial deposits.

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[1] Op. cit., p. 36.

[2] Glacial brick clays of Rhode Island and southeastern Massachusetts: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 977.

[3] Desor, E., and Cabot, E. C., On the Tertiary and more recent deposits in the island of Nantucket: Quart. Jour. Geol. Soc. London, vol. 5, 1849, pp. 340-344.

[4] Veatch, A. C., The diversity of the glacial period on Long Island: Jour. Geology, vol. 11, 1903, pp. 762-776.

[5] Fuller, M. L., Probable pre-Kansan and Iowan deposits of Long Island, New York: Am. Geologist, vol. 32, 1903, p. 311.

CHARACTER.

On western Long Island, where the formation reaches its maximum development, the Gardiners clay consists of irregular dark-colored beds alternating with layers or lenses of sand and fine gravel and attaining near Brooklyn an aggregate thickness of 150 feet. In this region the clays, unlike those in the localities farther east, grade downward through glauconitic and locally fossiliferous sand into the Jameco gravel, representing in fact transitional deposits. The clays themselves consist of a very fine silt, dark from the contained organic matter and carrying more or less lignitized wood. The included sandy layers are commonly from 5 to 10 feet thick and at some places have yielded fossil remains. Some of them are thought to represent the outwash from the adjacent land and others to be channel or shore-line deposits. The lignite fragments that they yield are rounded as if waterworn.

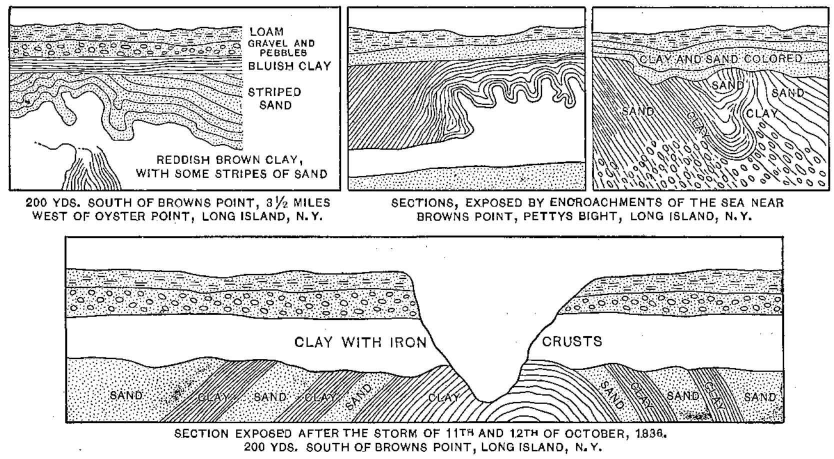


FIGURE 61.—Sections near Browns Point. By W. W. Mather.

Toward the east the clays gradually lose their dark lignitic color, bluish tints taking its place, but, if well records are to be relied upon, they are still fossiliferous. Near the east end of the island the bluish tint is replaced by reds and greens, although black clay is to be seen locally on Gardiners Island. The red color is commonly of a brownish tinge and appears to be due to the presence of material derived from the Triassic area of Connecticut, indicating the probable existence of Connecticut River in its present position. In some places a more intense red, similar to the color of the bright Mauch Chunk shale of eastern Pennsylvania, is to be seen. The amount of red material often appears to be in excess of what is actually present because of small quantities that have been washed down and form a coating over other deposits. In this region the formation is not a lithologic unit but consists of several alternating beds of clay and sand each from 5 to 10 feet or more in thickness. Probably the best illustration of this characteristic is afforded by the section figured by Mather in his report on the first geological district of New York.[1] Mather's illustration is reproduced here as figure 61. Similar complexity is shown by many Gardiners Island sections. One of the features of this phase of the Gardiners clay is the lack of persistence of the individual beds. A clay bed 10 feet in thickness may, for instance, disappear within a space of a few hundred feet, whereas in other sections, as in most of the exposures on the Massachusetts coast and islands, the formation is clayey throughout.

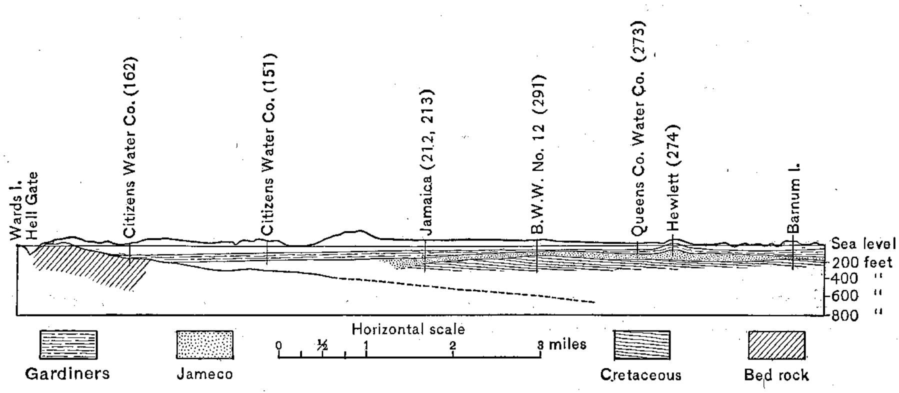


FIGURE 62.—Section from Wards Island to Barnum Island, showing fold at Rockaway Ridge (Hewlett) and the relations of Gardiners clay, Jameco gravel, Cretaceous deposits, and bedrock.

[1] Mather, W. W., Geology of New York, pt. 1, 1843, pl. 4, figs. 4–7.

On Montauk Point the clay maintains a reddish tinge, although the color is nearer to chocolate than to the bright red of Gardiners Island, and is more likely to be interlaminated with fine sand. In fact, the material is intermediate between the deposits of Gardiners Island and those of Port Washington. On Plum and Fishers islands the clay is similar to that at Montauk, but on Block Island and Marthas Vineyard and at Truro it is blue-gray to nearly black.

SOURCE OF MATERIAL.

Many difficulties are encountered in searching for an explanation of the derivation of the materials composing the Gardiners clay. The presence of fossils bearing evidence of a moderate climate and the occurrence of lignite point to accumulation in an interglacial stage, which, to judge from the thickness of the clays, was of long duration. In western Long Island, where they reach a thickness several times as great as near the east end, they may be conceived to have been derived from the erosion of Cretaceous deposits. The Mannetto gravel, which originally mantled the Cretaceous, had been almost entirely removed, and the Jameco gravel was below sea level. The streams and the sea were, therefore, free to act on the Cretaceous clays, and doubtless it was through their agency that a considerable part of the material for the Gardiners clay, especially the interbedded sands and gravels, was obtained. Probably not all of the material was thus derived, however, for farther east on the island there appears to have been little or no Cretaceous above sea level. A clue to the source of the clay in this part of the island may possibly be found in its color, which suggests its derivation from Triassic materials, probably brought into the ocean by Connecticut River, which, as previously pointed out, had apparently already taken its present course. The amount of clayey sediment now carried by the New England rivers is extremely slight, and the accumulation of 30 to 150 feet of clay over so wide an area would, under the present conditions, require a time interval of great length. It is not impossible that the land, although low in the vicinity of Long Island, may have been somewhat elevated farther north, in which case erosion would be facilitated and relatively large amounts of silt furnished. Of such an elevation at this time, however, the writer knows of no other evidence, unless the cool climate is to be taken as indicating the existence of elevated areas in the near vicinity—a not very reasonable supposition.

After the material was once brought to the sea its distribution would probably not be difficult, for the region is one of strong and shifting currents, as attested by the many moving shoals off Monomoy and Nantucket.

RELATION TO OLDER DEPOSITS.

The contact between the Gardiners clay and the top of the Jameco gravel is nowhere well exposed on Long Island, but so far as can be determined it is everywhere conformable. The line of demarcation, as brought out by well records on Long Island and especially by exposures on Block Island, Marthas Vineyard, and Cape Cod (see p. 220) is usually sharp, gravels of medium coarseness giving way abruptly to clay entirely free from sand or pebbles, as if the supply had been cut off by the sudden retreat of the ice sheet, which had previously furnished coarse materials in abundance. Sharp contacts such as occur in the New England islands are presumably present in eastern Long Island. The clay extends for several feet before coarser materials reappear as thin intercalated beds of sand or fine gravel, and no coarse gravels were laid down until after the deposition of 50 to 200 feet of clay and fine sand forming the Gardiners and Jacob formations. The only exception to the abruptness of contact seems to be in western Long Island, where there appears to be a transition through glauconitic or fossiliferous sand into the Jameco gravel, as brought out in the well records.

The great body of the Gardiners clay rests upon the Jameco gravel, but along the borders of the Jameco next to the Cretaceous land mass, especially along the edges of the great depression in the vicinity of Jamaica Bay, the clay laps up on the eroded surfaces of the Cretaceous and Mannetto (fig. 57) or even upon the metamorphic rocks (fig. 62), with sharp erosion and overlap unconformities.

CHARACTER OF THE UPPER CONTACT.

The Gardiners clay normally passes by gradual transition into the overlying Jacob sand, the clay first becoming slightly more sandy, then alternating with thin laminæ or layers of sand, and finally giving place to the characteristic clayey sand of the Jacob (fig. 61, p. 93). At many points, however, the normal conformable contact with the overlying beds is replaced by an unconformity resulting from erosion by the ice sheet that subsequently deposited the Montauk till member of the Manhasset formation. This powerful sheet not infrequently scoured through the Herod gravel member of the Manhasset and the Jacob sand into the Gardiners clay, so that the Montauk (fig. 63) or, in its absence, the still younger Hempstead gravel member of the Manhasset may rest upon the clay. The erosion has given rise to differences of level of many feet in the surface of the Gardiners clay, according to whether the ice removed only a few inches or took a considerable portion of its bed, and the greatest differences may be found within a space of a few yards. In many places the deposits were strongly folded by the ice before the Montauk till member was deposited over the upturned and eroded beds.

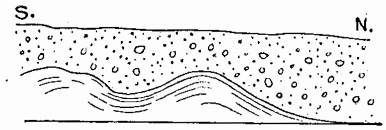


FIGURE 63.—Section near Eastern Plain Point, Gardiners Island, showing Montauk till member of Manhasset formation in contact with Gardiners clay.

The physical character of the contact with the Montauk till member differs with the nature of the till. Where a large amount of débris was carried by the ice, the clay in many places gives way rather abruptly to a bowlder-clay till, in which the only suggestion of transition is the unusual amount of clay and the strong red tinge imparted to the till by the material picked up from the underlying Gardiners clay. At other points, where less material was being carried by the basal part of the ice sheet, the demarcation between the two beds is less sharp, the Gardiners clay gradually becoming less regular in lamination toward the top and finally giving way to a structureless or irregularly laminated clay with a few foreign pebbles, indicating a reworking by the ice. This slightly reworked layer is a somewhat characteristic feature of the top of the Gardiners clay and is in places very difficult to distinguish from the undisturbed clay, especially in eastern Long Island and on the New England islands and Cape Cod.

STRUCTURE.

At no point where the Gardiners clay is exposed at the surface is it found in an undisturbed condition. At some places it is warped into broad, low undulations (fig. 193, p. 156) and at others it is compressed into sharp overturned folds (fig. 64), but it is nowhere horizontal for distances of more than a few yards. Its striking character and sharp contrast with the associated beds makes it an ideal key to the structure, and it is, in fact, upon this bed that most of the structural observations on the island have been based. In general the disturbance is most marked on the north side of Long Island and on the islands farther east, especially where the land presents a steep front to the north, becoming less conspicuous in the interior and on the south coast. In the former situations the clays are at many points thrown into closely compressed, locally overturned isoclinal folds. In practically all these folds the axes have approximately east-west directions. The anticlines have steeper slopes to the south than to the north, and the overturning is always toward the south.

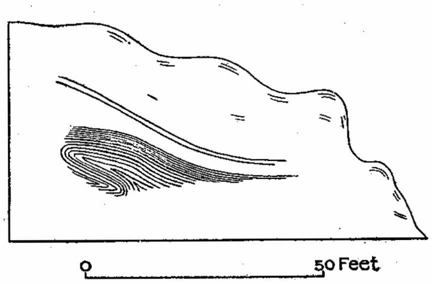


FIGURE 64.—Section near Jacob Hill, showing overturned fold of Gardiners clay beneath Jacob sand.

The folding is weakest at the west end of the island and becomes progressively greater toward the east, reaching a maximum on Orient Point, Gardiners Island, and Montauk Point. On the north coast of the western third of the island the Gardiners clay seems to have occupied baylike reentrants in the Cretaceous coast line and to have been protected both by the projecting Cretaceous headlands and by the thick overlying Herod gravel member of the Manhasset formation, which took up the greater part of the disturbance resulting from the overriding ice sheet. In the Jamaica region the ice seems to have overridden an even surface that presented few obstacles to its advance, and the disturbance appears to be limited to a few broad undulations apparently due to warping under the influence of the load of ice.

Farther east the Cretaceous land was lower, and the Gardiners clay was deposited as a fringe around its borders. The absence of protecting headlands of the older formation and the relative thinness of the overlying gravels left the Gardiners clay with less protection than at points farther west, and as a consequence the folding in it is much more pronounced. The details of the folding are brought out below, where the distribution of the clay is described.

Besides being eroded and folded by the Montauk ice sheet, the Gardiners clay has been more or less affected by a slight but somewhat widespread crustal warping. This warping seems to be represented by a slight uplift of the eastern part of the island, as compared with the western part, the clays being on the whole perhaps 25 feet nearer the surface at Montauk than at the Brooklyn end of the island. It is in part to this cause that their more frequent appearance at the surface in the eastern portion of the island is due, although the greater folding in this region and the absence of the protecting masses of Cretaceous deposits such as occurred farther west are perhaps the most important factors. It may be remarked that the uplift appears to have been still greater in the New England islands and on Cape Cod.

DISTRIBUTION.

SURFACE EXPOSURES.

The Gardiners clay has been recognized in surface outcrops at many localities on Long Island, from Manhasset Neck on the west to Orient and Montauk points on the east. It is also found on Robins, Plum, Fishers, and Gardiners islands.

Hempstead Harbor.—Although, as indicated by exposures of the Jacob sand, into which the Gardiners clay grades, the Gardiners is near the surface at Plum Point and vicinity and near Port Washington on Manhasset Bay, the most westerly exposures are those found on the east side of Hempstead Harbor. Just south of Red Spring Point about 5 feet of a gray sandy clay lying near beach level apparently represents the top of the Gardiners, and a little farther south, about halfway between Red Spring Point and Glen Cove Landing, another exposure showed a few feet of greenish clay with scattered quartz pebbles from an eighth to a fourth of an inch in diameter, likewise representing the top of the Gardiners clay. Still farther south, although the Jacob sand was exposed at several points, the Gardiners clay was not seen, even where the Cretaceous is above sea level, being covered, if it occurs at all, by talus of gravel from the higher parts of the bluff.

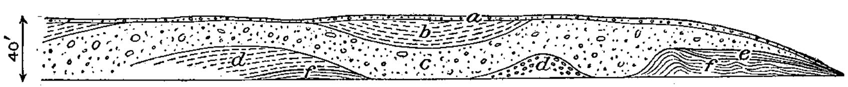


FIGURE 65.—Section at Rocky Point, west of Cold Spring Harbor. *a*, Wisconsin till; *b*, Hempstead gravel member of Manhasset formation; *c*, Montauk till member of Manhasset; *d*, Herod gravel member of Manhasset; *e*, Jacob sand; *f*, Gardiners clay.

Rocky Point, Cold Spring Harbor.—The next exposure of what appears to be Gardiners clay is found at Rocky Point, on the west side of the entrance to Cold Spring Harbor. A low arch at this point brings up about 5 feet of dark-gray clay containing the small scattered quartz pebbles characteristic of the Gardiners clay (fig. 65). The upper part of the clay shows the greenish-yellow tints due to weathering characteristic of the Gardiners clay. This clay should not be confused with the clay outcropping on the beach below high-tide level, which is referred to the Cretaceous (p. 70). Another exposure of the clay is reported west of Moses Point, at the south end of "the island."

Lloyd Neck.—At the foot of the bluff facing Cold Spring Harbor, for a quarter of a mile or more north of the base of the bar separating Cold Spring from Lloyd Harbor, there were to be seen in 1903 a series of yellowish Pleistocene clays which possibly represent the top of the Gardiners clay, although they may belong to the Mannetto. The following is a typical section:

Section of clays, etc., on Lloyd Neck.

	Feet.
Yellow clay interstratified with sand and containing cobbles up to 6 inches in diameter	2
Bright-yellow clay	1
Yellow clay with ferruginous sand and pebble layers	1
Yellow clay with clean quartz sand and pebbles	1
Fine quartz gravel with manganese and iron stains and an occasional decayed granitic pebble, extending to tide level	5

The outcrops show gentle warping with dips of 5° to 10°. In places there are indications of gray clay, probably Cretaceous, below tide level.

Eaton Neck.—In an amphitheater eroded back into the bluffs facing Huntington Bay, a little north of the base of West Beach sand pit, 4 feet of chocolate-colored clay of the Gardiners type lies unconformably upon a considerable thickness of Mannetto gravel (fig. 66). The clay dips toward the north and approaches the Cretaceous a little farther along the bluffs. Although resembling the Gardiners clay in character, this clay lies at an abnormal height above sea level and may be a phase of the Montauk till member of the Manhasset formation, such as is found near Montauk Point (p. 144). Half a mile north of this exposure 6 feet of black micaceous clay overlain by 3 feet of brownish clayey sand and 20 feet of yellowish sand is exposed in the bluffs. This may be Gardiners clay, but the freedom of the overlying sand from granitic or other northern material and its general similarity to the Cretaceous sands indicate that the clay should probably be referred to the Cretaceous.

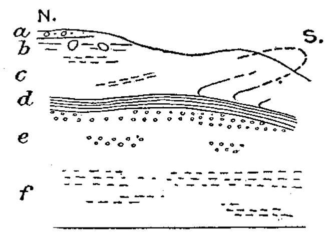


FIGURE 66.—Section north of West Beach, Eaton Neck. *a*, Wisconsin till; *b*, till (Montauk till member of Manhasset formation?); *c*, Herod gravel member of Manhasset formation and Jacob sand; *d*, Gardiners clay (?); *e*, Mannetto gravel with erratic bowlders; *f*, Cretaceous.

Woodhull Landing.—From Eaton Neck eastward for 20 miles no clays of the Gardiners type are exposed at the surface, but at Woodhull Landing, northeast of Miller Place, there was in 1904 a poor exposure of mottled buff to gray clay containing some sand and small scattered quartz pebbles. The clay appears to have a thickness of 10 to 15 feet or more and is traversed by joints with dendritic markings. Its characteristics are Gardiners rather than Cretaceous.

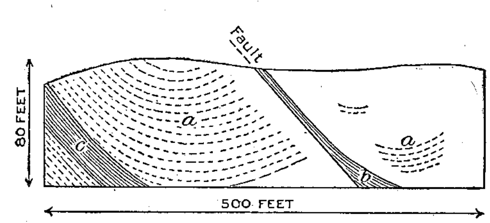


FIGURE 67.—Section half a mile west of Rocky Point Landing, northeast of Miller Place. *a*, Buff sand (Herod gravel member of Manhasset formation); *b*, light-brown clay free from pebbles (Gardiners clay?); *c*, sandy clay (Jacob sand).

Rocky Point Landing.—Half a mile west of Rocky Point Landing the section shown in figure 67 was observed in 1903. The material along the fault is a tough brown clay free from sand or pebbles, and as it resembles the unquestionable exposures of the Gardiners clay at other localities, it is referred to that formation. A quarter of a mile farther east is another exposure having the relations shown in figure 68. The material is a bright salmon-pink, finely laminated, very plastic clay with mica partings but without sand or pebbles; it seems to be 10 feet or more in thickness. The sand showing beneath the clay is probably thin and underlain by the main body of the Gardiners, as the thickness exposed is but a small part of that usually characterizing the formation.

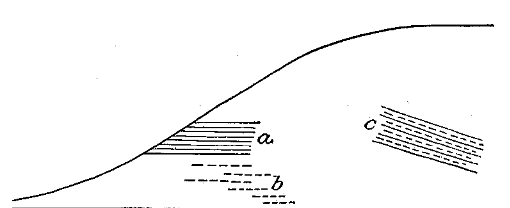


FIGURE 68.—Section near Rocky Point Landing northeast of Miller Place. *a*, Bright salmon-colored clays with micaceous sand partings (Gardiners clay?); *b*, white sand; *c*, buff sands and sandy clays (Jacob sand).

Hallock Landing.—Between Rocky Point and Hallock landings the beach is wet and springy, with occasional pools of fresh water, as if the clay were close beneath. The Jacob sand appears at several points, affording further evidence of the presence of the Gardiners clay at no great distance below the surface. A little clay, possibly Gardiners, was seen in a nearly vertical position (fig. 69) a little west of the landing, but its relations are somewhat obscure.

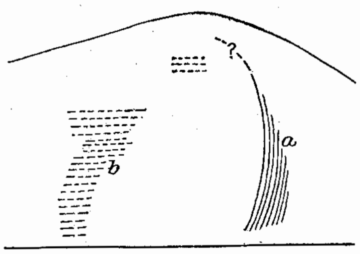


FIGURE 69.—Section west of Hallock Landing. *a*, Gardiners clay; *b*, granitic gravels (probably Herod gravel member of Manhasset formation).

Roanoke Point.—East of the last-named locality no Gardiners clay was seen for 10 to 12 miles, although the indications of the Jacob sand observed at a number of points suggest that the clay is close to the surface. The springs and pools of fresh water along the base of the bluff inside the beach and the numerous landslips also probably indicate the presence of clay beneath the surficial deposits. A clay was seen a quarter of a mile east of Roanoke Landing, where the section represented in figure 70 was exposed. This clay may be the Gardiners. Half a mile farther east another section, shown in figure 71, was seen. The clay was here strongly folded and overturned.

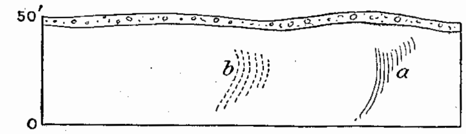


FIGURE 70.—Section a quarter of a mile east of Roanoke Landing. *a*, Gardiners clay (?); *b*, Herod gravel member of Manhasset formation (?).

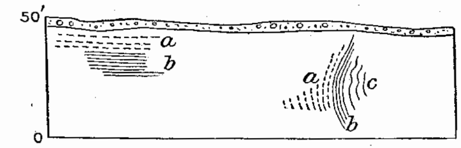


FIGURE 71.—Section three-quarters of a mile east of Roanoke Landing. *a*, Bluff sand (Heròd gravel member of Manhasset formation (?); *b*, clay (Gardiners?); *c*, Jacob sand (?).

Jacob Hill.—The first really good exposure of the Gardiners clay is at Jacob Hill, 2 miles northeast of Northville, where several pinnacles of contorted reddish or chocolate-colored sandy clays stand out prominently just back of the beach (fig. 72). The clay seems to be involved in an overturned fold.

Brown Hills.—No more exposures of undoubted Gardiners clay occur on the north shore for another 25 miles, the clays at the brickyards at Conkling Point, southwest of Greenport, belonging to the Montauk till member of the Manhasset formation, instead of to the Gardiners clay, representing, however, reworked and redeposited material derived from the Gardiners. At Brown Hills, northeast of Orient village, many indications of the presence of Gardiners clay were observed, although none of the exposures were fresh at the time of the writer's visit. Figure 73 shows one of the best exposures. The material is a tough, chocolate-colored clay dipping at angles as high as 80°. At the beach about 15 feet of the clay is exposed, but the base is not shown and probably the actual thickness is much greater, especially in the hills farther inland.

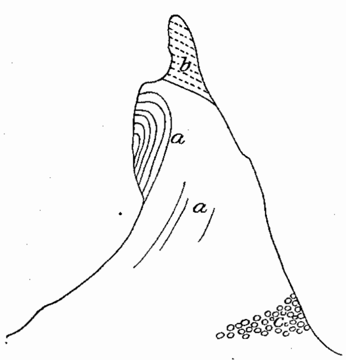


FIGURE 72.—Section near Jacob Hill. *a*, Reddish to chocolate-colored Gardiners clay; *b*, buff clayey Jacob sand; *c*, granitic gravels lying beneath overturned fold (Herod gravel member of Manhasset formation?).

The conditions for observations are best after severe storms. Mather, who examined the bluffs after such a storm on October 11 and 12, 1836, found some remarkably good exposures, the most striking of which, illustrated in figure 61 (p. 93), shows a broad anticline of Gardiners clay flanked with alternating sands and clays of the Jacob formation. The whole deposit is beveled off and is covered by a clayey stratified till ("clay with iron crusts"), here referred to the Montauk member of the Manhasset formation.

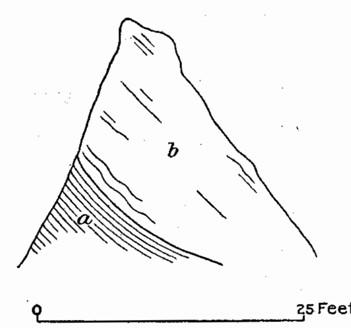


FIGURE 73.—Section at Brown Hills, near Orient. *a*, Chocolate-colored clay (Gardiners clay); *b*, gray sandy clay (Jacob sand).

Robins Island.—Several fine exposures of the Gardiners clay may be seen on Robins Island between Great and Little Peconic bays. The best of these are near the north end of the bluff on the west shore, where there is 10 feet or more of dark-gray, greenish, or purplish clay intermingled with a little sand and carrying a few small quartz pebbles and more rarely a granitic pebble. The beds are gently warped, in places rising 10 feet above the beach and in places sinking below sea level. Farther south blue and brown clays, with flat clay concretions, are seen at several places (figs. 74 and 193, p. 156). Half a mile south of these sections there was in 1904 a sharp nose showing buff and brown sandy clay, somewhat contorted and standing at an angle of 60° to 70°. The relations are shown in figure 75. Springs along the beach indicate the presence of clay near the surface at other points, but none was actually exposed.

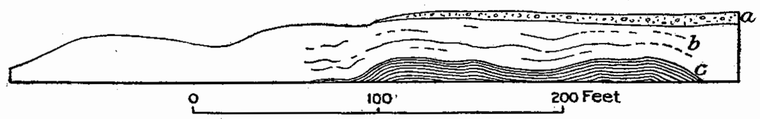


FIGURE 74.—Section on east side of Robins Island. *a*, Wisconsin till; *b*, buff contorted sand (Jacob sand and Herod gravel member of Manhasset formation); *c*, dark clay (Gardiners clay).

South shore of Great Peconic Bay.—One mile east of Red Cedar Point, near Southport, a nearly black clay carrying the characteristic quartz pebbles of the Gardiners clay occurs near beach level. It lies beneath the red banded Montauk till member of the Manhasset formation, with which it is involved in vertical or overturned isoclinal folds at two or more points. A third exposure was found in an abandoned clay pit a quarter of a mile east of Shinnecock Canal. The bottom of the pit appears to be a dark-gray to black plastic clay of the Gardiners type, grading upward at about the level of the floor of the excavation into a greenish-black clay full of pebbles representing reworked Gardiners material (Montauk till member).

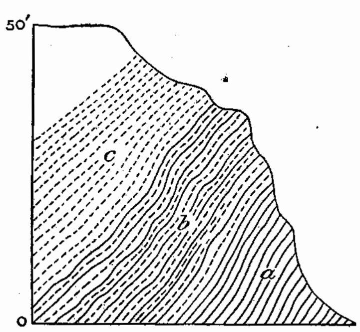


FIGURE 75.—Section on east side of Robins Island. *a*, Buff to brown contorted sandy clay (Gardiners clay); *b*, sand and clayey sand (Jacob sand); *c*, buff sand (Herod gravel member of Manhasset formation).

The next exposure is about 1½ miles to the northeast, in the bluff of Sebonac Neck, near the south end of which is seen about 6 feet of a bright blue-gray clay weathering greenish and carrying small quartz pebbles irregularly distributed through the mass. It is interlaminated with a few thin streaks of red sand or reddish-brown clay and seems to be true Gardiners clay.

Hog Neck.—Near the northwest point of Hog Neck several feet of folded greenish-blue fossiliferous clay was exposed in 1904. The fossil shells, however, were much broken and the clay carries granitic pebbles, indicating that it was reworked by the Montauk ice, although undisturbed Gardiners clay is probably not far below.

Sag Harbor.—Red clay, apparently representing the Gardiners clay, was noted in the moraine at several points southwest of Sag Harbor and has been worked on a small scale in times past. One exposure was seen in 1903 on a road through the moraine a mile west of the Sag Harbor and Bridgehampton road. Gray, red, and greenish clays were seen in an old pit on a private road between the two highways mentioned. The clay lies 100 feet or more above sea level and is everywhere disturbed. Its position is apparently due to folding or shove by one of the ice sheets—presumably the Montauk. Some pebbly clays represent the parts reworked by the ice.

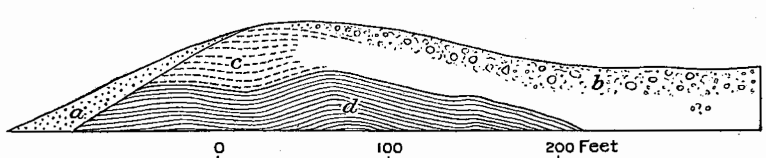


FIGURE 76.—Section half a mile west of False Point, Montauk.

Montauk.—Half a mile west of False Point, Montauk, a good exposure of the dark chocolate-colored type of the Gardiners clay was seen. Its relations are brought out in figure 76. Another exposure of clay, possibly Gardiners, having the relations shown in figure 87 (p. 107), was seen 1¼ miles southwest of Montauk Light, and a third exposure, showing upturned clay, was found about a mile farther west. The thickness exposed was nowhere more than 15 feet, but as the whole of the formation was not seen the entire thickness may be much greater.

Gardiners Island.—Gardiners Island, lying between the North and South flukes, is the type locality for the Gardiners clay. (See figs. 77 to 81.) On its western shore a few feet of contorted reddish clays interlaminated with grayish-buff sand representing the top of the Gardiners clay was seen in a low bluff about a mile north of Great Pond, but it was not observed again until a point half a mile east of Cherry Hill Point was reached. Here a succession of black, greenish (fossiliferous), and red clays, merging upward into Jacob sand and dipping 45° or 50° N., was exposed in gullies near the shore. The occurrence is illustrated in figure 77, which is a north-south section. Figure 81, representing a section near the south end of Bostwick Bay, shows the Gardiners clay banking against the Herod gravel member in an overturned fold. Near the northwest end of the bluffs on the northeast side of the island a broad anticline (fig. 100, p. 110) brings up 15 to 20 feet of red Gardiners clay, and a little south is an overturned anticline of red clay. The relations are shown in figure 78. Another exposure is shown in figure 129 (p. 129). Complicated exposures occur at short intervals as far as Eastern Plain Point. One of these, showing upturned Gardiners clay, is represented in figure 79 and Plate XVIII, *A*. A still more remarkable exposure is that illustrated in figure 80, which represents a bluff section about 1,350 feet long showing six distinct anticlines, several of them compressed and inverted, involving the Gardiners clay. The heights of several of these are from 100 to 150 feet. The section figured by Veatch and shown here in figure 60 has been discussed on page 90. Several instructive sections are afforded in the bluffs at the south end of Tobacco Lot Bay, in one of which fossils were found in a greenish-black phase of the Gardiners clay similar to that at Cherry Hill Point.

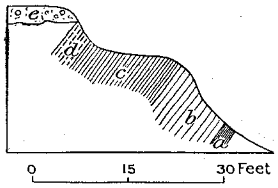


FIGURE 77.—Section near Cherry Hill Point, Gardiners Island. *a*, Black clay (Gardiners clay); *b*, greenish fossiliferous clays (Gardiners); *c*, red clay (Gardiners); *d*, buff sand and clay (Jacob sand); *e*, Wisconsin till.

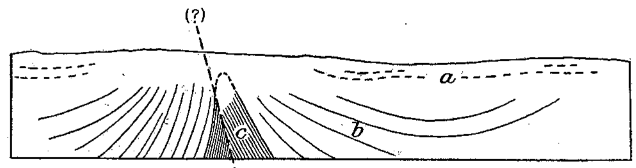


FIGURE 78.—Section a quarter of a mile east of northwest end of bluffs on northeast coast of Gardiners Island. *a*, Herod gravel member of Manhasset formation; *b*, fine gray Jacob sand; *c*, red Gardiners clay.

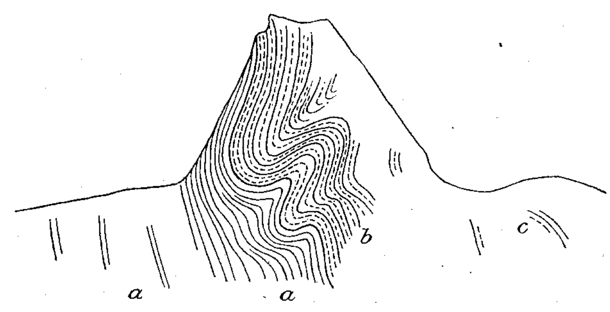


FIGURE 79.—Section three-quarters of a mile east of northwest end of bluffs on northeast coast of Gardiners Island. *a*, Red Gardiners clay; *b*, gray clay and sand (Jacob sand); *c*, buff sand (Herod gravel member of Manhasset formation).

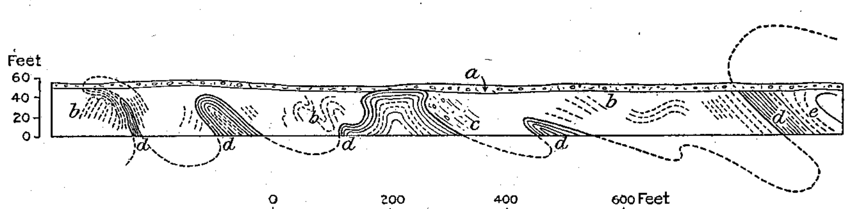


FIGURE 80.—Section near Whale Hill, Gardiners Island. *a*, Montauk till member of Manhasset formation; *b*, Gardiners clay.

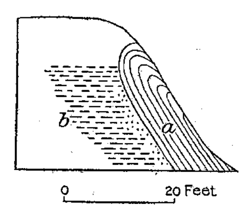


FIGURE 81.—Section near south end of Bostwick Bay, Gardiners Island. *a*, Red clay, greenish along contact (Gardiners clay); *b*, sand and gravel (Herod gravel member of Manhasset formation).

Plum Island.—On Plum Island, just northeast of Orient Point, the same general features are shown as on the neighboring parts of Long Island. On the north shore the Gardiners clay, although nowhere exposed above sea level, is everywhere near the surface, as is indicated by the numerous exposures of Jacob sand. On the south shore the clay is brought to the surface at one or more points by folds. One of the best of these exposures was that seen near the southwest end of the bluffs, where 15 feet of the clay with the relations indicated in figure 82 is brought up.

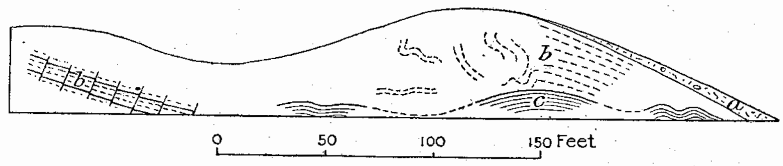


FIGURE 82.—Section on south side of Plum Island. *a*, Wisconsin till; *b*, folded and faulted beds of the Herod gravel member of Manhasset formation; *c*, brown to chocolate-colored clay with sand laminæ (Gardiners clay).

Fishers Island.—The best exposures of the Gardiners clay on Fishers Island (see fig. 83) are at the clay pit where the section shown in figure 84 was seen. The dip at the pit commonly averages 45° N., pointing to a fold of considerable magnitude, much greater than was supposed by Ries, who reported that the disturbance extended only to a depth of 20 to 30 feet. That the folding is essentially

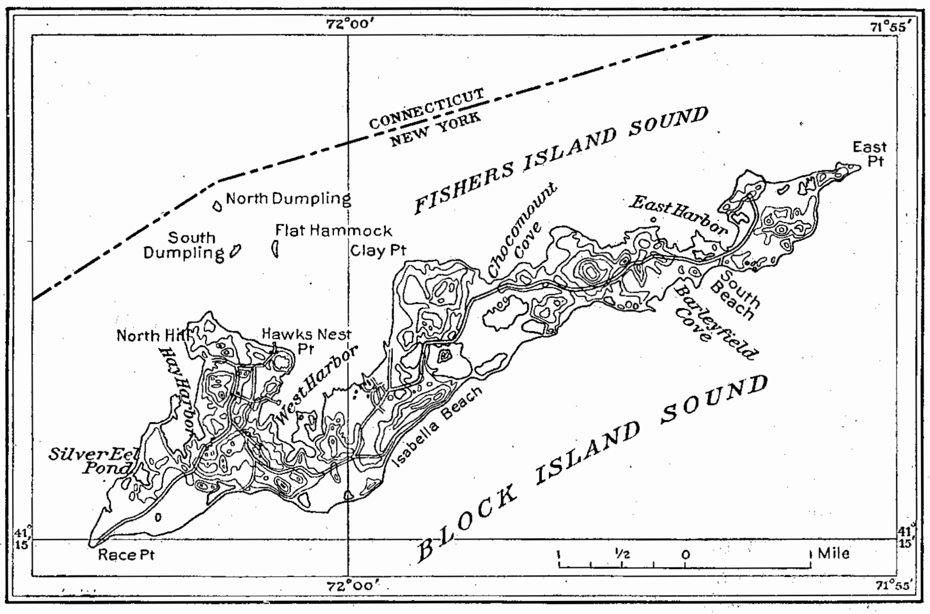


FIGURE 83.—Index map to localities on Fishers Island. Contour interval 20 feet.

superficial is likewise believed by the present writer (see fig. 85), but, as indicated by figures 84, 87 (p. 107), and 134 (p. 130), which are drawn to scale, it is certainly much greater than was stated by Ries. The clay pit was started in a valley where the clay showed at the surface, but it has been worked back until now 10 to 30 feet of till or gravel has to be stripped off. The outer or upper part of the material worked at the pit is a brownish sandy clay interlaminated with sand, perhaps 40 feet thick. The remainder is a dark grayish blue to nearly black plastic clay, with a slight brownish tinge. No pebbles could be found by the writer except in the lowest part of the clay exposed, where a lens of granitic gravel was seen, possibly due to the incorporation of some of the underlying Jameco materials. No fossil shells or leaves are reported. Some rounded clay concretions occur, and dendritic markings are found between some of the laminæ.

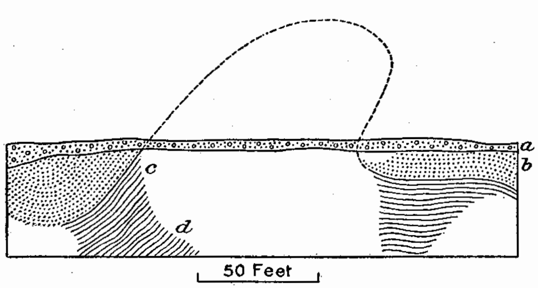


FIGURE 84.—North-south section at Clay Point, Fishers Island (June, 1904). *a*, Wisconsin till; *b*, Herod gravel member of Manhasset formation; *c*, interlaminated sand and clay (Jacob sand); *d*, dark-gray to brownish-black plastic Gardiners clay.

Besides the main folding there are many minor contortions which appear to be due to movements of the clay layers over one another. The only point besides the clay pit at which the Gardiners clay is well exposed is at Isabella Beach, where the sections represented in figures 86 and 106 (p. 112.) are to be seen. In the section shown in figure 106 the clay is 12 feet thick, and consists of alternating layers of gray and chocolate-colored silts, weathering to a somewhat darker color and dipping about 45° N. At the locality of figure 86 the clays are exposed to a thickness of more than 20 feet, and occur in a broad trough coincident with a surface valley. Clay is said to have once outcropped near Clay Point on the north shore of the island, but there is now nothing but Wisconsin till to be seen in the low bluffs in that vicinity. In the base of the bluff forming the headland three-quarters of a mile northeast of the north end of Isabella Beach there is a few feet of greenish-gray clay, free from pebbles and similar to parts of the Gardiners clay, but its relations could not be determined. (See fig. 135, p. 130.) At no other point was the clay seen, the hills apparently being composed mainly of sand and fine gravel. Any storm, however, is likely to alter the bluffs materially, and if the clay is above sea level it may be exposed at any time.

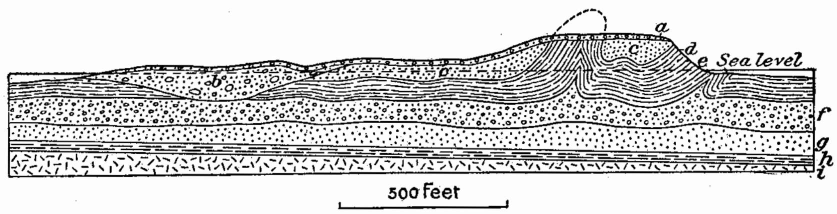


FIGURE 85.—Generalized section of Fishers Island. *a*, Wisconsin till; *b*, Montauk till member of Manhasset formation; *c*, Herod gravel member of Manhasset formation; *d*, Jacob sand; *e*, Gardiners clay; *f*, Jameco gravel; *g*, Mannetto gravel (?); *h*, Cretaceous clay; *i*, light-gray granite. The separation of Jameco and Mannetto is hypothetical.

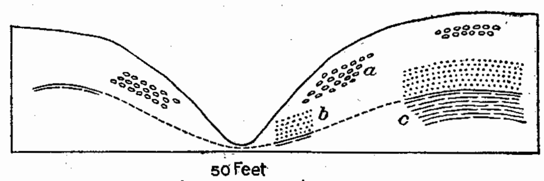


FIGURE 86.—Northeast-southwest section along Isabella Beach, Fishers Island. *a*, Herod gravel member of Manhasset formation; *b*, Jacob sand; *c*, Gardiners clay.

DEPOSITS PENETRATED BY WELLS.

The details of the distribution of the Gardiners clay as shown by wells are summarized in the following table, based on the records obtained in connection with the water investigations. The correlations in general are the same as in the report on the underground waters,[1] but in a few records, as in Nos. 71, 188, 258, 262, and 539, the writer from his study of the surface outcrops is inclined to make slightly different interpretations. Several exposures of clays that have been reported considerably above sea level on the necks of the north shore and correlated with the Gardiners (Sankaty of Veatch) have been omitted from the table as more likely belonging to the Cretaceous. In many of the records the material classed as clay probably includes the Jacob sand, which can be differentiated only with difficulty in wells.

Gardiners clay penetrated in wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of formation.	Character of the deposits.	Correlation, with name used in original record.
			Feet.		
5	Brooklyn	Rapid Transit Co	73–139	Clay	Sankaty.
35	do	Forest Street and Evergreen Avenue	105–	Blue clay	Sankaty or Cretaceous.
38	do	Bartlett Street and Flushing Avenue	87–127	Yellow or brownish sand and blue clay.	Sankaty.
62	do	Ten Eyck Street	75–100	Blue clay	Sankaty?
65	do	Porter and Maspeth Avenues	48–190	do	Do.
136	Aqueduct	Brooklyn test well No. 17	95–106	Dark-gray clay (swamp deposit).	Sankaty.
141	East New York	Brooklyn test well No. 5	216–281	Gray silty clay	Do.
176	North Beach	Bowery Bay Building Association	32– 36	Blue and gray clay	Do.
187	Far Rockaway	James Caffery	42– 66	Clay	Do.
188	do	B. L. Carroll	45– 65	Blue clay, without pebbles	Do.
188	do	do	20– 90	Blue clay and quicksand	Sankaty and Jameco.
191	do	Queens County Water Co	60–100	Blue clay	Sankaty.
193	Threemile Mill	T. R. Chapman	140–202	Dark clay, some very hard	Do.
195	Aqueduct	Shetucket pumping station	135–146	Gray clay	Do.
199	Jamaica South	Oconee pumping station	115–185	Fine gray clay	Do.
200	do	Baisley pumping station	106–156	Blue clay and quicksand	Do.

[a] Numbers refer to well records in report on underground water resources of Long Island, New York, by A. C. Veatch and others (Prof. Paper U. S. Geol. Survey No. 44, 1906).

[1] Veatch, A. C., Underground water resources of Long Island, New York: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 168–337.

Gardiners clay penetrated in wells of Long Island.—Continued.

No.	Locality.	Owner or place.	Depth of formation.	Character of the deposits.	Correlation, with name used in original record.
			Feet.		
201	Jamaica South	Jameco pumping station	78–144	Dark-gray clay, inclosing bed of yellowish sand.	Sankaty.
202	....do	Brooklyn test well No. 1	89–142	Gray clay	Do.
203	....do	Brooklyn test well No. 2	83–154	Dark-gray clay or silty sand	Do.
204	Springfield	Brooklyn test well No. 3	86–201	Fine gray silty sand and clay	Do.
205	....do	Brooklyn test well No. 4	72–212	Gray clay	Do.
206	....do	Springfield pumping station	65–170	Gray clay, with included bed of yellowish-gray sand.	Do.
212	Jamaica	Brooklyn test well No. 11	95–189	Gray clay	Do.
213	....do	Pumping station Jamaica Water Supply Co.	60–104	Blue clay	Do.
239	Whitestone	Pumping station No. 1	25– 45	....do	Do.
241	....do	Railroad wells	60– 85	Clay	Do.
243	....do	W. W. Cole	16– 70	Clay and quicksand	Sankaty?
258	Hewlett Point	G. B. Wilson	65–	Blue clay	Not correlated.
259	Lawrence Beach	Bathing Association	25– 55	Clay	Sankaty.
260	Isle of Wight	John Lawrence	40–100	Sand and clay	Do.
261	Lawrence	D. D. Lord	35– 70	Clay, fine gravel, and shells	Do.
262	....do	A. W. Hart	40– 76	Gray clay and white sand with shells.	Sankaty and Jameco.
273	Hewlett	Queens County pumping station	54–115	Blue clay, green sand, and quartz sand.	Do.
285	Valley Stream	Brooklyn test well No. 19	72– 95	Yellowish-gray clay	Sankaty?
295	Springland	Brooklyn test well No. 10	80– 94	Gray lignitic sand and blue clay.	Transition and Sankaty?
351	Plandome Mills	Robert Seizer	50–100	Mud and sand	Sankaty?
374	Barnum Island	Poorhouse	75–113	Dark clay and lignite	Sankaty.
469	Dosoris	D. F. Bush	85– 95	Reddish sand, gravel, and clay.	Do.
527	Oyster Bay	Chas. Weeks	15–	Clay	Sankaty?
528	....do	J. M. Sammis	30– 35	....do	Do.
529	....do	Van Sise & Co	30– 53	Clay and sand	Do.
530	....do	D. W. Smith	35– 50	Clay	Do.
532	....do	E. K. Hutchinson	35– 50	....do	Do.
539	....do	A. J. & A. S. Hutchinson	30–	Clay, etc	Wisconsin and Tisbury.
543	....do	O. L. Jones	60–	Clay	Sankaty?
545	....do	T. Underhill	25– 80	....do	Sankaty.
548	....do	Hamilton	30– 80	....do	Sankaty?
549	....do	William Trotler	10– 70	....do	Do.
613	Cold Spring Harbor	Eagle Dock	100–158	....do	Sankaty.
628	West Neck	B. Ward	88–116	Blue clay	Sankaty?
629	....do	Mrs. M. H. Clots	85– 93	....do	Sankaty.
671	Muncie Island	E. H. Muncie	45–	Clay	Sankaty?
691	Bayshore	Great South Bay Water Co	59–65(?)	....do	Do.
801	Port Jefferson	J. L. Darling	20– 40	Sticky brown to drab clay	Cretaceous?
877	New Suffolk	Reid well	4– 88	Clay	Sankaty?
880	Hampton Park	Mrs. S. F. McDonald	34– 80	Clay (part probably Montauk till member).	Do.
881	....do	E. G. Whittaker	2– 82	Very thin clay (part probably Montauk till member).	Do.
885	Shelter Island	J. N. Stearnes	27– 35	Red and blue clay and white and red sands.	Sankaty.
888	....do	A. O. Ryder	60–	Shells	Do.
889	....do	Shelter Island Heights Association	60–	Red clay	Do.
892	Greenport	Waterworks	100–150	Brown clay	Do.
901	Sag Harbor	J. K. Morris	100–132	Gray or yellow clay	Sankaty?
907	Shelter Island	Dr. Benjamin	45– 60	Sand, with fossil shells	Sankaty.

The table brings out the distribution of the Gardiners clay throughout Long Island, except over the higher Cretaceous areas, which were land masses during its accumulation. In fact, indications of the clay are found in nearly all the carefully kept records of the deeper wells outside the Cretaceous areas mentioned, except near Springfield (No. 197), where the overlying transitional Jacob sand is represented. It is not impossible that in some places, as at Port Jefferson, certain of the clays reported in the records may be Gardiners instead of Cretaceous.

At the west end of the island, in Brooklyn and vicinity, the formation, which there consists of bluish clay with a few layers of yellowish sand or quicksand, is persistent with a thickness usually of 25 to 50 feet, although in places, as at Porter and Maspeth avenues (No. 65), much greater thicknesses of clayey material are reported. It is not improbable that the thickness of 142 feet given in this well record includes the Jacob sand and a part of the Manhasset formation and possibly a part of the Jameco and the Cretaceous. The character of the Gardiners clay in this region is well brought out by the section of the well at Bartlett Street near Flushing Avenue, which has been given on page 86.

The formation in the region north of Jamaica Bay is described as a gray to almost black clay, in some places (No. 136) mixed with vegetable matter, suggesting salt-marsh deposits, and elsewhere (Nos. 295 and 374) carrying more or less lignite, much of it in the form of rounded fragments, as if derived from the reworking of the Cretaceous. Some greensand (glauconite) occurs mixed with the green clay near Hewlett and at Rockaway Ridge (No. 273) and fossils are found near Lawrence. A typical section of the ordinary nonlignitic type of the Gardiners clay in the Jamaica Bay region is afforded by the record of the Brooklyn test well No. 3, Brooklyn Aqueduct and New York Avenue (No. 204), given in the discussion of the Jameco gravel on page 87.

The tripartite arrangement of the formation—a sand included between two clays—which is characteristic of the Gardiners clay on the island, is well brought out by this record. Its thickness in the region under discussion ranges from 11 feet near Aqueduct (Nos. 136 and 195) to 140 feet near Springfield (No. 205). The changes in thickness are very abrupt, as shown by a well (No. 197) half a mile east of No. 205, which shows no clay whatever. The difference is due to a Cretaceous outlier at this point, which, though now buried by later glacial deposits, stood above the plane of deposition of the Gardiners clay. At Far Rockaway, one of two adjoining wells (No. 188) showed clay at 45 to 65 feet, and in the other it was reported at 20 to 90 feet. Similar differences occur elsewhere in the region, part being due to causes like the one above described, part to differences in the amount of deposition, and part possibly to erosion by the Montauk ice or to stream or wave erosion in later times.

On the north shore 14 feet of blue clay is reported at North Beach, west of Flushing Bay, 20 to 54 feet near Whitestone, 5 to 60 feet near Oyster Bay, and 8 to 58 feet on West Neck. In composition the clay is somewhat variable. Near Whitestone it is a blue clay associated with quicksand; at Dosoris a reddish-brown gravel and sand mixed with clay; at Oyster Bay a greenish clay with some sand; and at West Neck a blue clay. The Dosoris section, which is somewhat unusual as to materials shown but normal as to its tripartite arrangement, is given below from Veatch's report, with the writer's correlations.

469. Record of D. F. Bush's well near Dosoris Pond.

	Feet.
Recent:	
Yellowish-brown sand	0 – 4
Marsh deposit	4 – 7
Montauk till member of Manhasset formation: Blue clay with pebbles ("hardpan")	7 –15
Herod gravel member of Manhasset formation: Quicksand	15 –85
Gardiners clay:	
Reddish gravel and clay	85 –88
Very red sand	88 –88½
Reddish gravel and clay	88½–95
Jameco gravel: Light-colored gravel with a considerable percentage of glacial material; furnishes artesian water	95 –97

The wells of the north shore have in general yielded no fossils from the Gardiners clay. A "black marl" containing oyster shells identified by W. H. Dall as *Ostrea virginica* was reported at a depth of 18 feet, or about 80 feet above sea level, in a well on Manhasset Neck (No. 364), northeast of Port Washington, but from the information afforded by adjacent wells and exposures in the bluff along the harbor it seems altogether improbable that the Gardiners clay is present at this elevation. It is more likely that the fossils belong to an old drift, probably the Montauk till member of the Manhasset, and are of secondary rather than primary origin.

Toward the east end of the island the clays encountered in the wells are more reddish and are more commonly fossiliferous. Red clays are reported from Shelter Island (Nos. 885 and 889) and Greenport (No. 892). Pleistocene fossils are found at Quogue (No. 859), at Shelter Island (Nos. 888 and 907), and at Bridgehampton (No. 897). Clays are encountered at New Suffolk (No. 877), at Hampton Park (Nos. 880 and 881), and near Sag Harbor (No. 901). In thickness the clay ranges from a few feet on Shelter Island to 50 feet at Greenport, 84 feet at New Suffolk, and 80 feet at Hampton Park.

AGE.

Two lines of evidence bearing on the age of the Gardiners clay are available, the first being their fossil content and the second the character of the immediately overlying and underlying beds.

The fossils of glacial formations are either primary—those whose position and condition are such as to indicate growth in place; secondary—those that have been picked up and redeposited by the ice; or tertiary—those that were taken up first by the ice and later by water before being redeposited. All three kinds are represented on Long Island and great care is needed in discriminating them. Fortunately, those found in the Gardiners clay in most localities show features that indicate unquestionably their primary character.

Shells of "clams, oysters, razor fish," etc., have been repeatedly reported from wells on Rockaway Ridge and elsewhere on western Long Island in materials associated with the clay, generally in a sand stained black by organic matter found at the base of the clay. As they have been found in wells, their occurrence can not be actually observed, but their presence in a sand carrying lignite and greensand and thoroughly stained with organic matter, in short possessing the characteristics of sandy marine flats, points strongly to their occurrence in place.

At Fort Hamilton, facing the Narrows at the entrance of New York Bay, *Nassa obsoleta, Crepidula fornicata, Mytilus edulis, Anomia ephippium, Mya arenaria,* and *Solen ensis* were reported as being obtained from the Gardiners clay (Sankaty of Veatch) in a well sunk at this point.[1]

At Bedford, according to Redfield [2] and Desor,[3] were obtained Ostrea, *Venus mercenaria, Purpura lapillus,* and *Baccium obsoletum.*

A specimen of *Ostrea virginica* was obtained from a well on Manhasset Neck at an elevation of 80 to 100 feet above sea level, but it is evidently of secondary origin, unless the clay has been brought to an entirely abnormal and unusual height by the ice shove, which is regarded as improbable. The clam and oyster shells obtained near the bottom of a 40-foot layer of blue clay, at a depth of 60 feet below sea level, in a well near the end of the point (No. 368), were probably in place.

A "marl bed containing oyster shells" is reported as occurring in a well on Main Street, Oyster Bay, at a depth of 45 feet, or 35 feet below sea level.[4]

Many writers, including Samuel L. Mitchill in 1800, 1813, 1814, and 1818, Timothy Dwight in 1821, John Finch in 1824, W. W. Mather in 1837 to 1843, Gabriel Farnum in 1875, Elias Lewis in 1877, Warren Upham in 1879, and F. J. H. Merrill in 1886, have recorded fossil shells from wells and other sources mainly in the western part of the island at horizons corresponding to that of the Gardiners clay. (See bibliographic review, pp. 4–22.) Of these writers, Lewis alone notes the occurrence of shells in wells, the fossils observed by the other writers being in drift of shallow and possibly post-Wisconsin deposits. The wells noted by Lewis were at Flatbush, Prospect Park, Bath, East New York, Farmingdale, and Amagansett. In the field work for the present report shells of Pecten were reported in two wells at Hampton Park (Nos. 880 and 881).

The best exposures of fossiliferous strata are found on Gardiners Island, two localities yielding shells in place. One of these localities is just east of Cherry Hill Point, the western extremity of the island. A diagram of the beds at this place is shown in figure 77 (p. 100). The thickness of the strata from top downward are as follows:

Section of fossiliferous series near Cherry Hill Point.

	Feet.
Wisconsin: Till resting conformably across edge of following bed	2
Jacob sand: Sand and sandy clay in alternating layers	5
Gardiners clay:	
Red clay with a little lignite	15
Greenish clay with Pleistocene fauna in place	10
Black clay with organic matter, exposed	3

[1] Veatch, A. C., op. cit., p. 168.

[2] Am. Jour. Agr. and Sci., vol. 6, 1847, pp. 213–219; Am. Jour. Sci., 2d ser., vol. 5, 1848, pp. 110–111; Proc. Boston Soc. Nat. Hist., vol. 4, 1854, p. 181.

[3] Proc. Boston Soc. Nat. Hist., vol. 2, 1848, p. 247; vol. 4, 1854, pp. 180–181.

[4] Woodworth, J. B., Bull. New York State Mus. No. 48, 1901, p. 661.

The fossils collected by Veatch at this point were identified by Dall as *Arca crenella*, Modiola sp., and *Cyprina islandica* Gmelin. Considerable numbers of each of the forms occur.

On Shelter Island shells were reported in great variety at a depth of 60 feet in the well of A. O. Ryder. At Quogue, on the south side of Long Island, fragments of shells brought up from a depth of 135 feet in the well of A. B. Hallock (No. 859) were examined by Dall, who states that the material contained "fragments of Mulina, Astarte, an unidentifiable bivalve, a specimen of *Nassa trivittata* Say, and fragments of an echinoderm. This is probably Pleistocene." Pieces of shells embedded in greenish clay (the usual character of the fossiliferous part of the Gardiners clay) were brought up from a depth of 100 feet in the well of Sanford & Son at Bridgehampton (No. 897).

Broken shells of species now existing were found about one-fourth of a mile south of the north end of the bluffs on the west side of Hog Neck, 3 miles northwest of Sag Harbor. They occurred in a greenish-blue clay, which, however, contains a few erratic pebbles, indicating that it has been reworked by the Montauk ice. Although strictly speaking they are in till, there is practically no doubt that they were derived from the Gardiners clay of the immediate vicinity. Small fragments of broken shells were seen in the Hempstead gravel member of the Manhasset formation at one or more points but are apparently of secondary or tertiary origin.

From the distribution of the fossils it will be seen that they constitute a persistent feature of the Gardiners clay, occurring at all levels from the transitional basal sands, as at the Rockaway Ridge locality, to the middle, as at Gardiners Island. They also occur in the sands above the clays on Gardiners and Robins islands and Nantucket, a fact which would seem to indicate that the conditions were very similar throughout the period of accumulation, being in fact not very different from those existing on the southern coasts of New England to-day.

Besides the fossil shells, lignite and other forms of organic matter are of common occurrence in the Gardiners clay, especially near the west end of the island, and are found in small amounts as far east as Gardiners Island. In some places the black muck brought up from wells so closely resembles the muck of the present bays in color, texture, and odor that the two are practically indistinguishable. Some of the lignite is rounded as if rolled about by the waves, indicating an origin at sea level. It is thus seen that parts of the deposits have a close resemblance to salt-marsh or shallow-lagoon deposits.

Lignite and other woody materials were reported by many of the early investigators as occurring in the wells of western Long Island at horizons not far from that of the Gardiners clay. Probably some of these materials, especially the true lignites, are from the Gardiners clay, but it seems likely that many of the fresher fragments described as wood, tree trunks, branching trees, etc., are younger, probably representing soil zones of the Vineyard interglacial stage.

The Gardiners clay, as indicated by its fossils and its wood and lignitic content, muck, etc., must undoubtedly be regarded as an interglacial deposit. Below it lies the Jameco gravel, which, as has been stated, is probably of glacial origin, and above it is the great Manhasset formation (preceded by the transitional Jacob sand), consisting of unfossiliferous gravels with a thick intercalated till member (Montauk), all of which are likewise thought to be of glacial derivation. If the tentative correlation of these glacial formations with the Kansan and Illinoian glacial stages should prove correct, it would fix the time of the Gardiners clay as corresponding to the stage known in the interior of the country as the Yarmouth interglacial stage.

JACOB SAND.

NAME.

The Gardiners clay grades upward through interlaminated clays and sands into fine silty sands. When wet many of these sands are somewhat plastic and show a pinkish tinge due to their clay content, which gives them a certain resemblance to the Gardiners clay. Although their deposition followed without a break that of the Gardiners clay, they nevertheless show sufficient lithologic difference from that formation to permit their recognition throughout

Long Island and the islands farther east. Their lithologic characteristics, marking a distinct and persistent change in the conditions of deposition, entitle the beds to recognition as a separate formation.

To this formation the name Jacob sand has been applied, from Jacob Hill, a high point on the north shore of Long Island, 8 miles northeast of Riverhead, near which the formation is well exposed.

CHARACTER.

In its most characteristic form the Jacob sand consists of exceedingly fine sands, mainly quartz flour, but with many grains of white mica and some of dark-colored minerals. In color the sands commonly range from a very light gray to yellowish and buff tints, but where laminæ of true clay are present they may be stained reddish externally. They are everywhere clearly stratified, although individual beds several feet thick and appearing structureless to the eye are encountered. When wet most of them are somewhat plastic but lack the toughness of true clay; all are decidedly gritty to the teeth and most of them to the touch. Interbedded with the fine varieties of the Jacob deposits are some more distinctly sandy beds, usually buff or yellowish, and several feet thick, in which particles of fairly fresh granitic minerals can be recognized.

SOURCE OF MATERIAL.

Whether the gradual change from plastic clays to the exceedingly fine, claylike quartz sands of the Jacob formation was due to a change in level, to a change in direction and strength of the currents, to the advent in the region of the finer materials from the outwash of an advancing ice sheet, or to a combination of all these factors, can not be stated definitely.

Perhaps the best clue to the source of the material is afforded by the general sequence of the deposits. Following the fine plastic Gardiners clay, whose character indicates, in all probability, a very slow accumulation under conditions of scanty supply, the Jacob sand affords indications of increased supply and more rapid accumulation, and the succeeding Herod gravel member of the Manhasset formation affords evidence of still more rapid deposition and the near approach of the ice sheet associated with the Montauk till member of the Manhasset. In other words, the Jacob sand seems to mark the first influx of new material on the advance of the ice sheet, bringing to a close the interglacial stage characterized by the Gardiners clay.

RELATION TO OLDER DEPOSITS.

As previously noted, the Jacob sand in many places merges by insensible gradations into the Gardiners clay, although elsewhere the sand gives way to the clay more abruptly. It has not been seen in contact with beds older than the Gardiners, but it must overlap the Mannetto or Cretaceous at many points below sea level.

CHARACTER OF THE UPPER CONTACT.

Toward the top of the formation the beds grade upward into medium and then into coarse sands, which in turn give way to the Herod gravel member of the Manhasset. These upper sands are buff in color and in places reach a thickness of 15 to 30 feet. It is possibly in a sandy layer of this type that the fossils found in the bluffs on the shores of Great Peconic Bay, 2 miles west of the Shinnecock Canal, occurred. (See fig. 117, p. 126.)

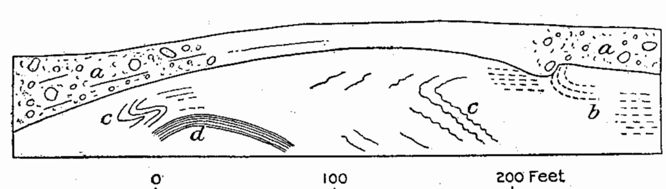


FIGURE 87.—Section 1½ miles southwest of Montauk Light. *a*, Banded Montauk till member of Manhasset formation; *b*, Herod gravel member of the Manhasset; *c*, contorted clayey Jacob sand; *d*, dark chocolate-colored clay interlaminated with white sand, possibly representing the Gardiners clay.

Owing to local nondeposition of the Herod gravel member, or more commonly to erosion by the Montauk ice, the Montauk till member of the Manhasset formation in places rests directly upon the Jacob sand. Generally the bedding of the sand and till is conformable, but in a few places the Montauk rests on upturned or folded Jacob beds, which have locally been more or less eroded. This is brought out in figure 59 (p. 89) and especially in figure 87, which shows the

Montauk member resting on the disturbed or eroded Jacob sand. Both the folding and the erosion, to judge from the contour of the resulting surface, seem to have been due to ice, presumably to the same sheet that later deposited the overlying Montauk till member. The unconformity due to erosion in many places amounts to many feet and differs from place to place. At some points the work of the Montauk ice sheet was wholly erosional, there being no deposition of drift, and at such places the overlying Hempstead gravel member of the Manhasset may rest directly upon the Jacob sand. Where the Montauk rests upon the sand considerable quantities of the sand have been incorporated in it, giving it a noticeably silty texture, which has been a potent cause of the characteristic cementation of the till. As in the Gardiners clay, there are all gradations between the undisturbed deposits through reworked Jacob sand into silty till.

STRUCTURE.

What has already been said as to the structure of the Gardiners clay applies with equal force to the Jacob sand. Though classed as sand, its texture was so fine and it contained so much silt that it behaved like clay under the action of the overriding ice, being bent, folded, crumpled, and overturned instead of crumbling and disintegrating as the coarser sands and gravels commonly did. Lying stratigraphically higher, and hence nearer the surface, it was more subject to disturbance than the Gardiners clay and has been exposed at more places along the coast. The Jacob sand, like the clay, is most disturbed along the north coast, especially near the east end of the island, exhibiting more gentle folds in the southern part. Most of the folds trend approximately east and west, although on the sides of the bays the lateral thrust has in places, as at Port Washington, produced folds with north-south axes. Details of the folding are given in the section on distribution below.

DISTRIBUTION.

SURFACE EXPOSURES.

The distribution of the Jacob sand on Long Island is in general the same as that of the Gardiners clay, although from its position above the clay it is more exposed.

College Point.—The most westerly outcrop noted was at the base of the bluff between College Point and Tallman Island, where several feet of fine light-gray micaceous sand was exposed in 1904 near tide level in a nearly horizontal position.

Port Washington.—The next locality toward the east at which the Jacob sand was seen is near Plum Point, on the east side of Manhasset Bay, 1½ miles northwest of the town of Port Washington. At many points near and at the bottom of the immense abandoned gravel pit at the base of Plum Point the Jacob sand was formerly to be seen, limiting the depth to which gravel and sand (Herod member) could be taken out. The exposures in this pit at the time of the writer's visits, in 1903 and 1904, did not admit of a determination of the structure of the formation, but in a similar pit near the shore about a quarter of a mile southeast a fine pinnacle of light-gray, highly contorted clayey sand was seen.

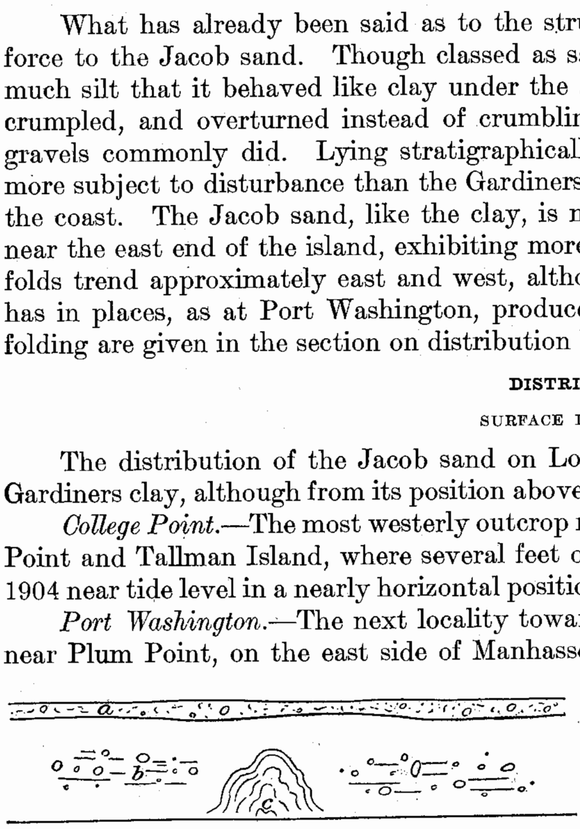


FIGURE 88.—Section north of Weeks Point, Hempstead Harbor. *a*, Wisconsin; *b*, Montauk till member of Manhasset formation; *c*, contorted Jacob sand.

Hempstead Harbor.—The Jacob sand is exposed at many points on the east side of Hempstead Harbor. A little north of Weeks Point, about 1½ miles northwest of Glen Cove, a sharp fold of Jacob sand rising 20 feet above the beach and having a breadth of about 40 feet was seen (fig. 88). Between Red Spring Point and Glen Cove Landing the sand was observed at several places, and still farther south, near Glenwood Landing, a pinnacle of light-gray Jacob sand rising about 10 feet above the floor of a large gravel pit (Herod gravel member) was seen.

Oyster Bay.—The Jacob sand was exposed in 1904 at the top of the bluff at Rocky Point, 2 miles north of the town of Oyster Bay. The bed was very thin and in places had been entirely removed by the Montauk ice (fig. 65, p. 96). An exposure of Jacob materials is also reported at the extreme southwest point of Center Island, and the sand of the same formation was again seen in the beach below high-tide level near the west end of Coopers Bluff, northeast of the town.

Lloyd and Eaton necks.—On Lloyd and Eaton necks the Jacob sand appears to be either below sea level or to have been removed by ice erosion (Montauk), the drift of this sheet generally resting directly upon the Cretaceous.

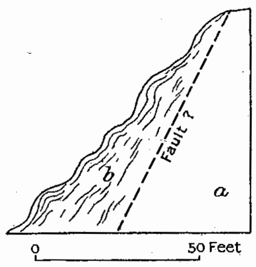


FIGURE 89.—Section a quarter of a mile west of Hallock Landing. *a*, Herod gravel member of Manhasset formation (structure not shown); *b*, contorted gray clayey sands (Jacob sand).

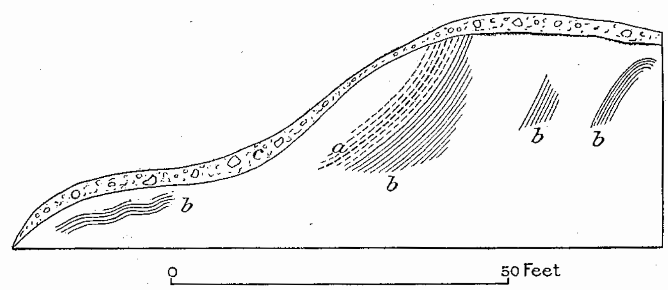


FIGURE 90.—Section near Woodville Landing. *a*, Upturned sand and gravel (Herod gravel member of Manhasset formation); *b*, contorted and folded Jacob sand; *c*, till.

Northport to Port Jefferson.—Throughout the stretch of nearly 15 miles east from Northport the Jacob sand appears to lie below sea level. At the only place where the lower beds are seen, which is on the coast 3 miles northeast of Northport and about a mile north of the village of Fort Salonga, the Jacob and associated beds appeared to be absent, the Montauk till member resting immediately upon the Cretaceous clays.

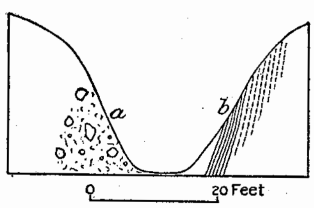


FIGURE 91.—Section at landing west of Jacob Point. *a*, Banded clayey till (Montauk till member of Manhasset formation); *b*, pink till, gray clay, and sand (Jacob sand).

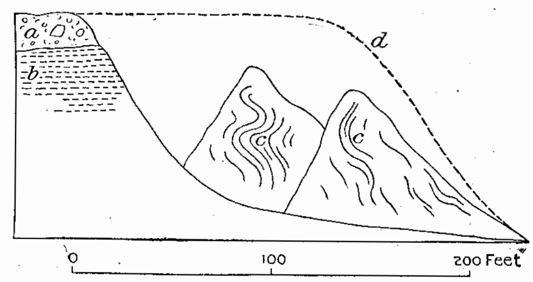


FIGURE 92.—Section near Jacob Hill. *a*, Till; *b*, Herod gravel member of Manhasset formation; *c*, upturned and contorted pinkish to buff clayey Jacob sand; *d*, former extension of bluff. Relations to sand not shown.

Port Jefferson to Wading River.—Beyond Miller Place exposures are fairly common. The first good outcrop seen was a quarter of a mile west of Hallock Landing (fig. 89), where the clayey sands are upturned at a high angle because of both folding and faulting. Two miles farther (about half a mile east of Woodville Landing) highly disturbed sands of the Jacob type are again seen (fig. 90).

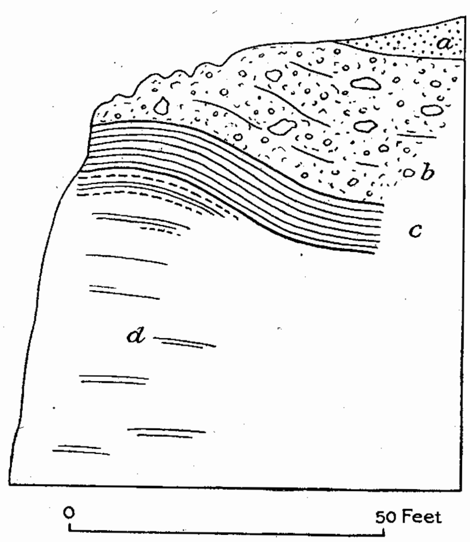


FIGURE 93.—Section at Jacob Hill. *a*, Dune sand; *b*, banded Montauk till member of Manhasset formation; *c*, brown clayey Jacob sand; *d*, buff clayey Jacob sand (poorly exposed).

Wading River to Orient Point.—For the next 10 miles the Jacob sand is not exposed, being below sea level along the bluffs. It first reappears in upturned and contorted masses a little east of Roanoke Landing, north of Centerville (fig. 71, p. 98). Two miles east, at the landing west of Jacob Point, the Jacob sand is nearly on end in a small ravine (fig. 91) and at several points along the beach for three-fourths of a mile or more, beyond which it again sinks below sea level. It was next seen $2\frac{1}{2}$ miles farther east, in the bluff at Jacob Hill, where great pinnacles composed of Gardiners clay and Jacob sand stand out from the bluff (fig. 92). Still better exposures, however, were found a quarter of a mile farther on, where some 60 feet or more of

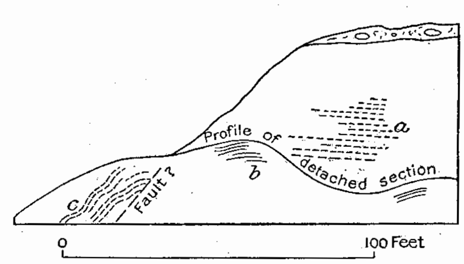


FIGURE 94.—Section at Brown Hills, near Orient. *a*, Gray to buff sands (relations to clay not clear, but probably the same as in fig. 97); *b*, dark clay (Jacob sand); *c*, yellowish upthrust sands (Herod gravel member of Manhasset formation).

brown and buff clayey sand or sandy clay of the Jacob type is exposed (fig. 93). In the 20 miles or more of coast between this locality and Orient Point the Jacob sand is exposed at only one place—in the bluffs of Brown Hills, northeast of Orient village. Here the exposures are much the same as at the point last described, the sands being highly disturbed, folded, and contorted. Something of the present character of the outcrops and the unconformable relation of the overlying sand is shown in figures 94, 95, 96, and 97.

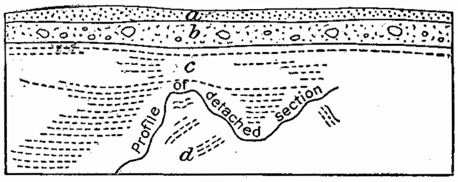


FIGURE 95.—Section at Brown Hills, near Orient. *a*, Dune sand; *b*, Wisconsin till; *c*, sand and gravel (Herod gravel member of Manhasset formation); *d*, very fine disturbed clayey sands (Jacob sand) standing out in detached masses. Relations probably the same as in figure 97.

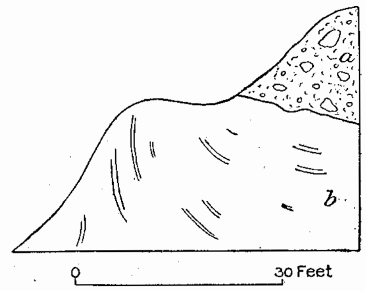


FIGURE 96.—Section at Brown Hills, near Orient. *a*, Till (Montauk till member of Manhasset formation); *b*, gray clayey sands.

Robins and Shelter islands.—South of the North Fluke the Jacob sand is well exposed on Robins Island, where it occurs on the west side, about 500 yards south of the north end of the cliffs, both in broad open folds and in highly upturned masses, like those shown in figure 74 (p. 99). Fossils occur in the bed shown in figure 98. The Jacob sand appears to be penetrated by wells on Shelter Island but is not clearly developed above sea level.

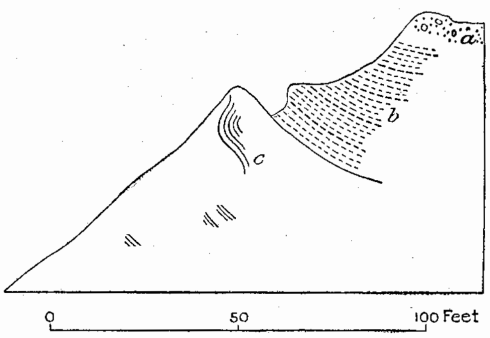


FIGURE 97.—Section at Brown Hills, near Orient. *a*, Till; *b*, Herod gravel member of Manhasset formation; *c*, disturbed clayey Jacob sand.

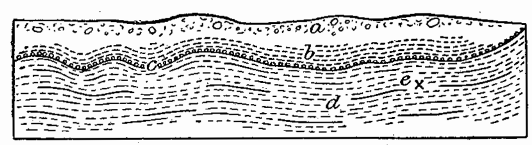


FIGURE 98.—Section on west side of Robins Island. *a*, Till; *b*, folded buff sand (Herod gravel member of Manhasset formation); *c*, thin layer of cemented gravel; *d*, gray clayey Jacob sand, with fossils at *e*.

Gardiners Island.—On Gardiners Island the Jacob sand is abundant, occurring in many places and reaching thicknesses of 20, 30, and perhaps 50 feet. Evidence of local and temporary returns to conditions favoring the deposition of clay is afforded by thin clays alternating with beds of Jacob sand.

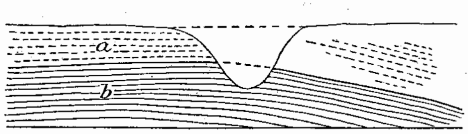


FIGURE 99.—Section half a mile north of Cherry Hill Point, Gardiners Island. *a*, Herod gravel member of Manhasset formation; *b*, fine gray ripple-marked Jacob sand.

The Jacob formation, consisting of alternating clay and fine sand, was seen above the red clay at the fossil locality east of Cherry Hill Point (fig. 77, p. 100). Half a mile north of the point the Jacob in the form of finely stratified gray sand with ripples (a common phase on Gardiners Island) was seen in nearly horizontal beds (fig. 99). Near the north end of the cliffs on the northeast shore it is involved in both open (fig. 100) and overturned folds (fig. 78, p. 100). A quarter of a mile southeast it is again seen in overturned folds (fig. 101 *a*, *b*), and 350 paces farther in the same direction it is involved in the highly contorted mass shown in figure 79 (p. 100) and Plate XVIII, *A*, the bedding being practically vertical. Other exposures are shown in figures 129 and 130 (p. ——). The Jacob sand continues in constant association with the

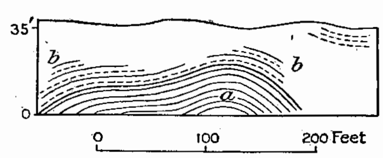


FIGURE 100.—Section near west end of bluffs on northeast shore of Gardiners Island. *a*, Red Gardiners clay; *b*, gray clayey Jacob sand.

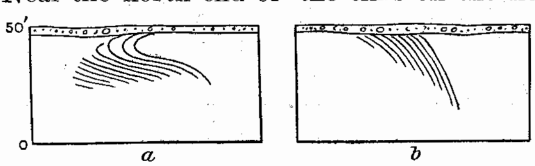
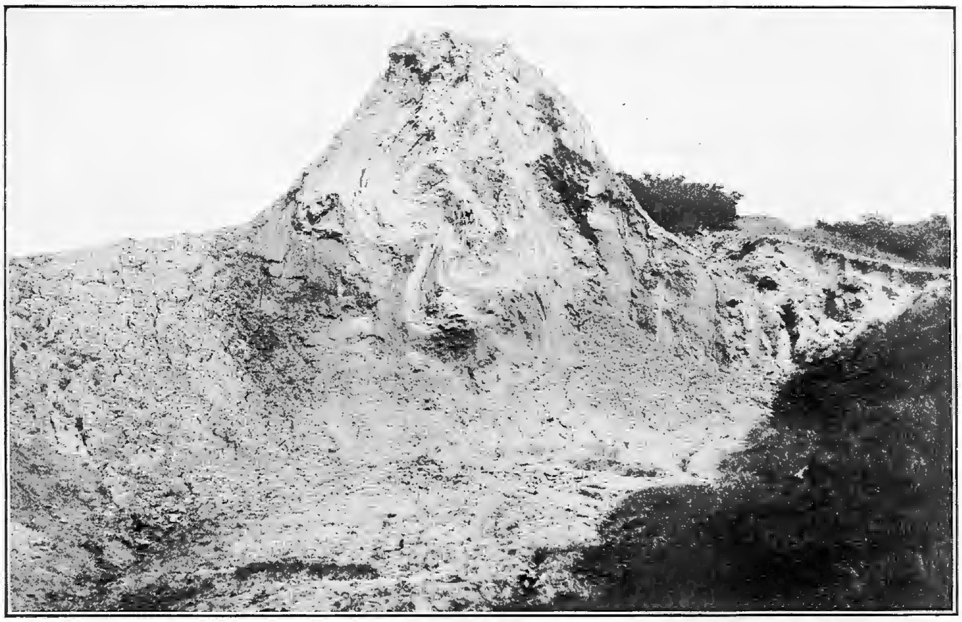


FIGURE 101.—Sections half a mile east of west end of bluffs on northeast coast of Gardiners Island, showing fine gray folded Jacob sand overlain by till.



A. UPTURNED GARDINERS CLAY AND JACOB SAND ON EAST COAST OF GARDINERS ISLAND.

B. OVERTURNED FOLD OF JACOB SAND LYING ON HEROD GRAVEL MEMBER OF MANHASSET FORMATION, EAST COAST OF GARDINERS ISLAND.

Gardiners clay in the 1,350-foot section represented in figure 80 (p. 100), near the end of the bluffs toward Eastern Plain Point. The details of one of the overturned and recumbent folds in this section are shown in Plate XVIII, *B*. The Jacob sand occurs here and there in the bluffs bordering Tobacco Lot Bay, but the beds are so contorted, faulted, and otherwise broken up that they form a confused jumble, the relations of which it would take weeks to work out in detail. Fossils occur in the Jacob at one point.

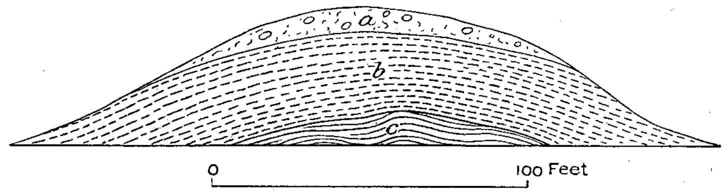


FIGURE 102.—Section half a mile west of landing, Plum Island. *a*, Till; *b*, Herod gravel member of Manhasset formation; *c*, fine micaceous contorted Jacob sand.

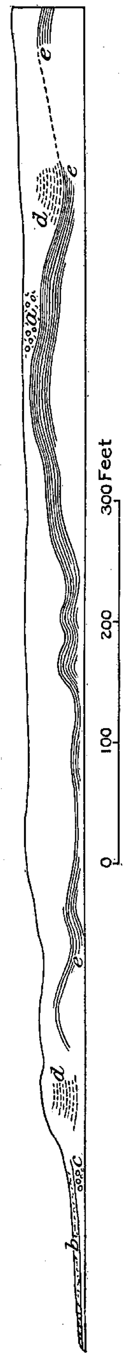


FIGURE 103.—Section along middle of south side of Plum Island. *a*, Till (Wisconsin?); *b*, greenish clayey sand (Montauk till member of Manhasset formation?); *c*, talus, Montauk type; *d*, Herod gravel member of Manhasset formation; *e*, gray clayey sand, in places brown or pinkish (Jacob sand).

South Fluke.—The Jacob sand is commonly absent on the South Fluke, owing to erosion by the Montauk ice. It occurs, however, at several points on Montauk peninsula. A mile west of Rocky Point, on Napeague Bay, contorted sand, possibly the Jacob, is present near the top of the bluff (fig. 126, p. 128). Half a mile west of False Point, northwest of Montauk Light, sands and gravels are seen between the Gardiners clay and the Montauk till member of the Manhasset formation, probably representing the combined Jacob sand and Herod gravel member of the Manhasset (fig. 76, p. 99). Two miles east of Ditch Plain life saving station beds of fine sand interlaminated with chocolate-colored clay are seen resting on a series of greenish-gray sands and fine yellowish gravels, the whole being much eroded and overlain in turn by the Montauk till member (fig. 59, p. 89). This might be either an overturned and recumbent fold of Jacob sand upon the Herod gravel member or a sandy phase of the Gardiners clay resting on Jameco gravel. The former is regarded as the more probable. A mile and a half southwest of Montauk Light there is some highly disturbed and folded Jacob sand having the relations shown in figure 87 (p. 107).

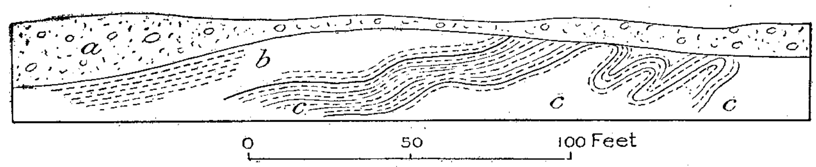


FIGURE 104.—Section east of Fort Terry, south side of Plum Island. *a*, Montauk till member of Manhasset formation; *b*, Herod gravel member of Manhasset formation; *c*, brown to reddish clay interlaminated with sand (Jacob sand).

Plum Island.—The Jacob sand is seen below the Herod gravel member in a broad, low anticline half a mile west of the Plum Island landing (fig. 102) and at intervals from this point to the lighthouse. It is everywhere disturbed, the bedding standing in places at an angle of 50°, and it probably occurs in a succession of folds similar to that illustrated. On the south of the island it is seen involved in broad, low folds from the west end of the bluffs to Fort Terry (fig. 103). About half a mile east of the fort it appears to be involved in several overturned and recumbent folds, having the relations shown in figures 104 and 105.

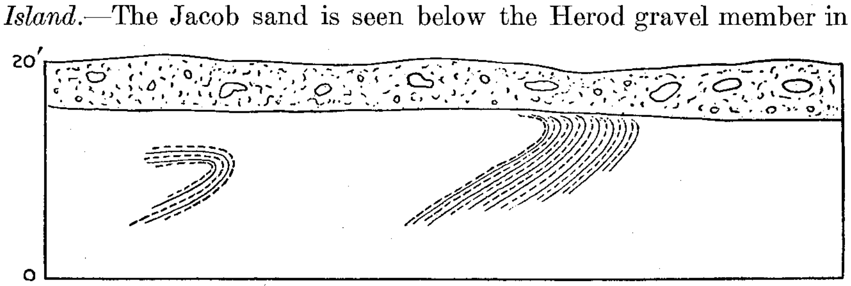


FIGURE 105.—Section east of Fort Terry, south side of Plum Island, showing part of overturned fold in clayey sands (Jacob sand ?).

Fishers Island.—The best exposures of the Jacob sand on Fishers Island are to be seen in the clay pit and in the sections at Isabella Beach. In the pit (fig. 84, p. 101) there is 40 feet of brownish sandy clay interlaminated with sands and overlying the darker and more plastic Gardiners clay into which it grades. At one of the Isabella Beach localities the Jacob sand is represented by 15 feet of fine gray clayey sand (fig. 86, p. 102). At the other about 35 feet of the Jacob appears with the top unexposed (fig. 106); the lower 15 feet is of the usual gray-green clayey-sand type, but the upper 20 feet approaches a gray sandy clay in character. In an artificial cut near the steamboat wharf on the west side of West Harbor a considerable amount of grayish clayey sand of the Jacob type is exposed, as shown in figure 173 (p. 147). The relations shown in the right-hand half of the figure, particularly the upturning and unconformity, are especially characteristic of the conditions at the Jacob stage in Long Island and farther east; but nowhere else, save at Sankaty Head, Nantucket, has a gravel been seen interbedded with the sands, as shown in the left-hand part of the figure. There is also somewhat less of the old look characteristic of most exposures of the drift of this stage, but this may be due to the freshness of the artificial exposure. The topography, moreover, has a distinctly pre-Wisconsin aspect, and the overlying till resembles the Montauk member rather than the Wisconsin. For these reasons it seems probable that the clayey sands are to be referred to the Jacob sand.

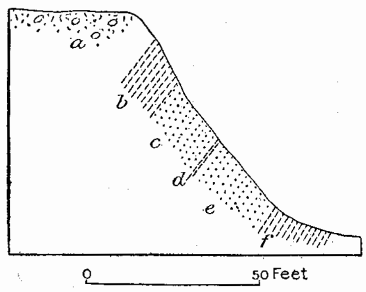


FIGURE 106.—Bluff section at Isabella Beach, Fishers Island. *a*, Wisconsin till; *b*, gray clay belonging to Jacob sand; *c*, gray sand belonging to Jacob sand; *d*, gray clay belonging to Jacob sand; *e*, gray sand belonging to Jacob sand; *f*, chocolate-colored and gray clay (Gardiners clay).

Along the base of the bluff on the south side of the high hill south of West Harbor a thickness of 10 feet of pinkish and brown sandy clay alternating with laminæ of sand is exposed in a low anticline about 100 feet across and a few feet high. This belongs without doubt to the Jacob sand.

DEPOSITS PENETRATED BY WELLS.

Because of the extreme fineness of the sand and the admixture of more or less clay it is very difficult to differentiate the Jacob sand from the Gardiners clay in drilled or driven wells, or those sunk by the jet process, and although surface exposures prove that the formation is fairly persistent throughout the whole of Long Island, it appears to have been recognized as a distinct bed in only a few wells. In most of the well records it is doubtless included in the Gardiners clay. Some of the records, with correlations of the writer, are given below.

Probably the best record is that of a well near Hewlett Point, at the west side of the entrance to Manhasset Bay.

258. Record of G. B. Wilson's well, near Hewlett Point.

	Feet.
Recent:	
Dug well (fresh water, slightly hard)	0–14
Beach sand	14–20
Montauk till member of Manhasset formation:	
Light-colored clay with stone	20–30
Quicksand	30–32
Stony clay	32–36
Herod gravel member of Manhasset formation: Coarse gray sand containing salt water at 46 feet and brackish water at 59 feet	36–59
Jacob sand:	
Alternate layers of sand and clay	59–63
Yellowish sand	63–65
Gardiners clay: Blue clay	65–
Jameco gravel:	
Fine yellow and grayish sand	–103
Hardpan	103–105
Yellow gravel with fresh water	105–108

The record of a well on the Dodge estate, near Port Washington, is of interest as showing the tendency to identify the Jacob as a clay. There is little reason to doubt that the dry yellow clay of the record represents the Jacob sand, for the Gardiners clay, so far as known, is nowhere yellow, whereas the Jacob sand is in many places buff or iron stained.

366. Record of well of Dodge estate, near Port Washington.

	Feet.
Wisconsin: Yellow stony loam	0–6
Hempstead gravel member of Manhasset formation: Fine dry sand	6–16
Montauk till member of Manhasset formation: Rough stratum of cobbles with scarcely any sand between	16–22
Herod gravel member of Manhasset formation:	
White building sand; very compact	22–40
White loose dry sand	40–50
Jacob sand: Yellow dry clay	50–71
Gardiners clay: Blue clay, containing some water	71–91

The record of a well on West Neck also suggests the Jacob:

629. Record of Mrs. M. H. Clots's well, West Neck.

	Feet.
Wisconsin: Surface loam	0–10
Montauk till member of Manhasset formation: Hardpan with gravel	10–25
Herod gravel member of Manhasset formation and Jacob sand: Fine brown sand; a little clay	25–85
Gardiners clay: Blue clay	85–93
Jameco(?) gravel: Brown gravelly sand; water bearing	93–97

AGE.

The Jacob sand is a transitional deposit between the Gardiners clay (here considered as representing the Yarmouth interglacial stage) and the Herod gravel member of the Manhasset formation (considered as representing a part of the Illinoian glacial stage), but is regarded as belonging to the Illinoian stage. There is reason to believe that the change in deposition, as was pointed out in the discussion of the source of material (p. 107), was caused by the advent of glacial silts brought down from the north during the advance of the Montauk ice, but long before it invaded the region under discussion. The character of its fossils seems to indicate that the climate at the time of its deposition did not materially differ from that existing during the accumulation of the Gardiners clay.

The best locality for fossils is near the south end of the cliffs on the east side of Gardiners Island and south of the point at the south end of Tobacco Lot Bay. Fossils from a 4-foot bed of sand and fine gravel (Jacob) at this point were described as early as 1867 by Sanderson Smith,[1] who gave a list of 25 species, all of which except one or two inhabit the waters south of Cape Cod at the present time. The shells, however, had a more northern aspect than those of the species now inhabiting these waters. The species are as follows:

Small coral.
Tornatella punctostriata Adams.
Bulla canaliculata Gould.
Fusus decemcostatus Say.
Purpura lapillus Lam.
Nassa trivittata Say.
Nassa vibex Say.
Columbella lunata Sowerby.
Chemnitzia interrupta Stimpson.
Crepidula unguiformis Lam.
Crepidula fornicata Lam.
Natica duplicata Say.
Natica heros or triseriata?
Arca transversa Say.
Arca pexata Say?
Ostrea borealis Lam.
Pecten islandicus Chemn.
Pecten magellanicus Lam.
Cardita borealis Conrad.
Astarte sulcata Fleming.
Lucina radula Gould?
Venus mercenaria Linn.
Mactra laterales Say.
Mya arenaria Linn.
Balanus fragment.

[1] Annals New York Lyceum Nat. Hist., vol. 8, 1867, pp. 149–151.

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A collection made by Veatch from sandy clays and sands at the same point and examined by Dall afforded the following species:

Chrypodomus pygmæus Gould.
Chrypodomus decemcostatus Say.
Natica (Lunatia) heros Say.
Pecten magellanicus Gmelin.
Astarte elliptica Brown.
Thracia conradi Couthuoy.
Cyprina islandica Gmelin.

Fossil fragments have also been found in the Jacob sand on Robins Island. (See fig. 98, p. 110.)

The views of Sanderson Smith as to the northern aspect of the forms were corroborated by Dall, who says: "The material appears to be practically identical from both localities [on Gardiners Island] and to represent the fauna now existing in the Gulf of Maine or on the coast north of Cape Cod, a little colder water being indicated than is now found south of the cape."

The extensive fauna from the same horizon at Sankaty Head, Nantucket, likewise points to temperatures no colder than those of northern New England.[1] As the accumulation of ice for the next invasion had begun, however, the beds must be classed with the Illinoian rather than with the Yarmouth stage.

MANHASSET FORMATION.

NAME.

Although the body of the deposits succeeding the Jacob sand may be subdivided into three distinct units, there are places, even in the best of cliff exposures, where the middle division is absent and the upper and lower beds, consisting of gravels of similar characteristics, unite to form a single unit. The combined beds give rise to the broad plateau stretching between the northern moraine and the north coast and projecting through the outwash plain here and there south of the outer moraine. Because the middle bed is locally absent, and because the deposits constitute a topographic unit and in the absence of cliff and other sections it is in places difficult to recognize the component members, it is necessary for their proper discussion to have a general term for the deposits as a whole. The term Manhasset is here used as a collective name for the beds referred to, being taken from Manhasset Neck, along the shores of which, in the immense gravel pits on the Hempstead Harbor side, are to be seen exposures of these beds more than 100 feet in height. The name was first applied by J. B. Woodworth,[2] who described and mapped in detail the deposits in a part of the west end of the island.

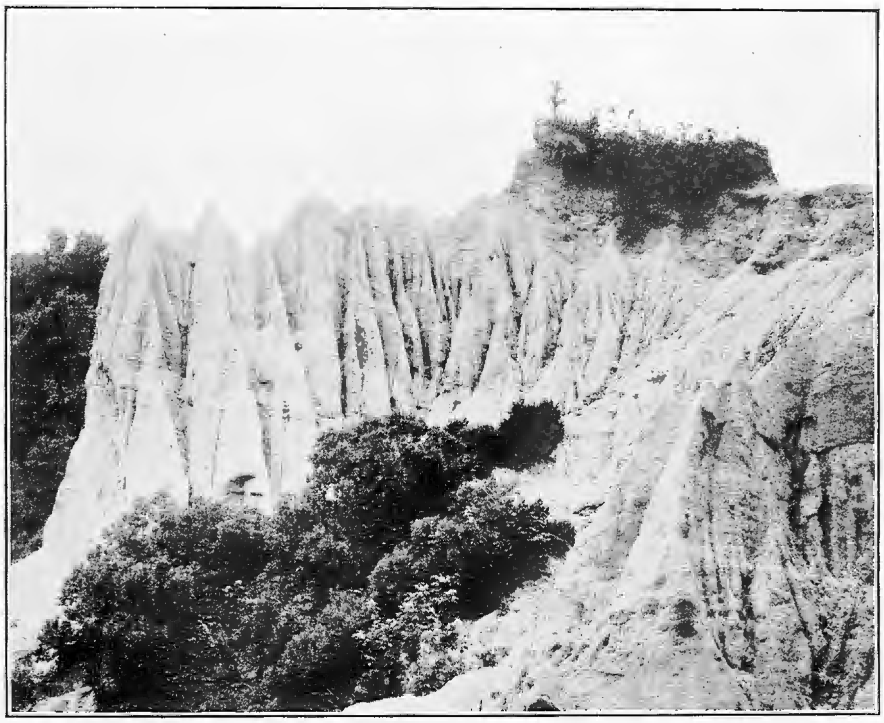
Veatch, in his report on water resources, substituted the term Tisbury for Manhasset, on the supposition that the beds were the equivalent of Woodworth's Tisbury beds of Marthas Vineyard,[3] which consist of stratified clays and clayey sands with some bowlders suggesting till outcropping along the north shore. The horizontality of these beds on Marthas Vineyard is emphasized by Woodworth, who says: "Their marked horizontality is strongly contrasted with the dislocated attitude of the beds in the outcrops of the older folded series which appear at intervals along the shore." Horizontality was in fact, according to information furnished to the writer by Prof. Woodworth, the principal criterion of recognition. Inasmuch as the beds of the lower part of the Manhasset formation on Long Island, as well as the corresponding beds on Marthas Vineyard (included by Woodworth in his Sankaty), are strongly folded (see Pl. XIX, *A*), it is evident that the term Tisbury as originally used was intended to cover only the undisturbed beds laid down subsequent to the epoch of folding due to the Montauk ice. In other words, it was probably used for the beds here described as the Hempstead gravel member of the Manhasset formation, although this correlation is only approximate. For these reasons it seems best to adopt the term (Manhasset) originally applied to the beds on Long Island rather than use the Marthas Vineyard term in a way apparently not intended by the geologist who proposed it. The relations of the Marthas Vineyard and Long Island terms are approximately as follows:

[1] Desor, E., and Cabot, E. C., Quart. Jour. Geol. Soc. London, vol. 5, 1849, pp. 340-344. Verrill, A. E., Am. Jour. Sci., 3d ser., vol. 10, 1875, pp. 364-375. Cushman, J. A., Am. Geologist, vol. 34, 1904, pp. 106-109.

[2] Bull. New York State Mus. Nat. Hist. No. 48, 1901, map.

[3] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 977.

A. FOLDED BEDS OF MANHASSET FORMATION NEAR TOM POINT, PORT WASHINGTON.



B. BANDED MONTAUK TILL MEMBER OF MANHASSET FORMATION NEAR FRIARS HEAD.

Long Island (this report).		Marthas Vineyard (Woodworth's section).
Manhasset formation.	Hempstead gravel member.	Tisbury beds.
	Montauk till member.	(?) Gay Head.
	Herod gravel member.	Sankaty beds.
Jacob sand.		
Gardiners clay.		Not exposed.

SUBDIVISIONS.

The Manhasset formation may be described as a series of glacial sands and gravels, 150 to 250 feet thick, having a middle member in which the sands and gravels are locally replaced by till. Where the middle member is well developed it is represented by a bed of till 40 to 60 feet or more thick, the overlying and underlying beds being reduced to thicknesses of 50 to 75 feet each. The central till is not everywhere well developed, however, being in places, as in the gravel pits on the west side of Hempstead Harbor, reduced to a bowlder bed only a few feet thick. In a few places it disappears entirely, grading laterally into coarse stratified gravels, and in such places the entire formation consists of sands and gravels, marked, however, by slightly coarser materials at the till horizon.

Although the till is locally absent, it is on the whole a persistent and easily recognized member throughout Long Island and in fact along the New England coast as far north as Maine, separating the two gravels into a lower bed here called Herod gravel member and an upper bed for which the name Hempstead gravel member is here introduced. The till itself is here called the Montauk till member.

GENERAL DISTRIBUTION.

The character, relations, and distribution of the three subdivisions of the Manhasset formation are considered in detail under their separate heads, only the distribution of the formation as a whole being here discussed.

The Manhasset formation constitutes by far the larger part of the beds found above sea level on Long Island, forming most of the drift hills at the west end of the island and the plateau that borders the north shore from East River to Port Jefferson and extends southward beneath the moraines toward the south shore, along which it rises above the outwash plains at numerous points. East of Port Jefferson the Manhasset forms the base on which the moraines rest, as well as the plateaus of Robins, Shelter, Plum, Fishers, and Gardiners islands and of the South Fluke.

OCCURRENCE NORTH OF THE HARBOR HILL MORAINE.

Western Long Island.—West of Little Neck Bay, which lies just east of Flushing, the Manhasset formation is not seen in any considerable amount, what there is of it being buried beneath the general till sheet, the Wisconsin moraines, and the later Wisconsin stratified gravels. These deposits have so obscured the Manhasset topography that the plateau character, which is very pronounced farther east, is not conspicuous.

Great and Manhasset necks, North Hempstead.—On Great Neck, east of Little Neck Bay, the plateau character is notably pronounced, large stretches of nearly level flats standing between 100 and 120 feet above sea level from the railroad northward (Pl. IV, p. 30). Manhasset Neck shows the plateau character still better, the upper surface being here about 180 feet above sea level from the moraine northward to a point beyond Port Washington village, where it slopes rather abruptly down to the 100-foot level, at which there is another extensive plateau stretching toward Prospect Point.

Hempstead Harbor to Oyster Bay.—The Manhasset formation is best developed in the region between Hempstead Harbor and Oyster Bay, where it forms a belt nearly 7 miles wide between Harbor Hill moraine and the coast. The surface seems to have a normal elevation of 180 to 200 feet, although rising somewhat higher near the moraine. South of Glenwood Landing, on Hempstead Harbor, is a local terrace of gravel at the 100-foot elevation, separated as usual by a fairly abrupt slope from the higher Manhasset level (Pl. IV). The equivalent of this terrace is traceable around the coast from the vicinity of Red Spring Point to Oyster Bay (figs. 7 and 8, pp. 30 and 31).

Oyster Bay to Miller Place.—From Oyster Bay to Northport the continuity of the Manhasset formation is broken by numerous bays and harbors and by deep pre-Wisconsin stream valleys, and the differentiation of the high and low deposits is more difficult, the one class grading almost insensibly into the other. Lloyd, West, and Eaton necks, however, belong in the main to the lower or 100-foot terrace, and Great and Little necks and the deposits stretching southward to the moraine belong to the 160 to 200 foot level. East of Northport to the point where the Manhasset disappears beneath the moraine near Miller Place, a strip a mile or two in width along the shore belongs to the 100-foot level, and the rest, extending back to the moraine, belongs to the higher Manhasset.

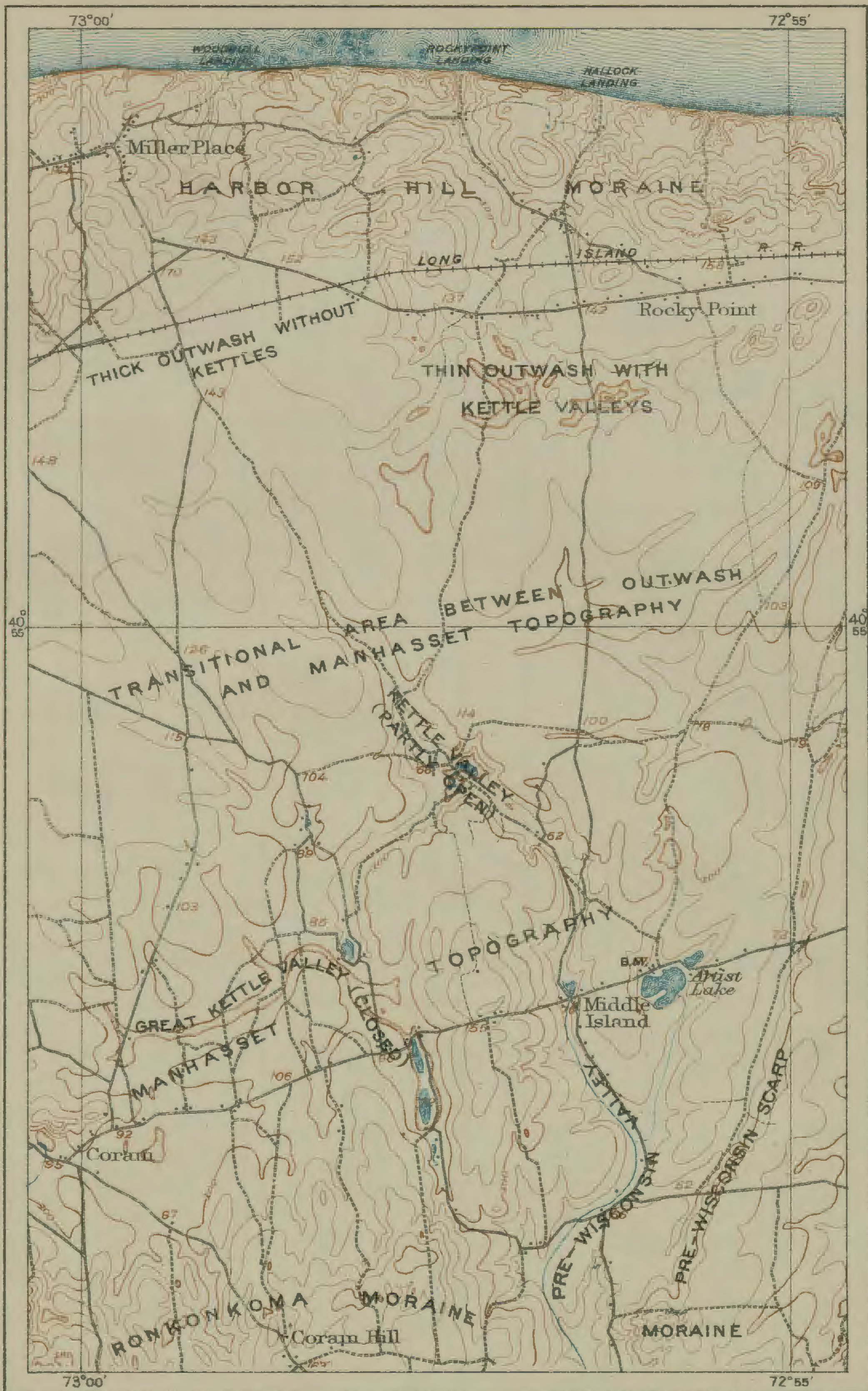
OCCURRENCE BETWEEN THE HARBOR HILL AND RONKONKOMA MORAINES.

Roslyn region.—Between the Harbor Hill moraine at Roslyn and the Ronkonkoma moraine south of Albertson station is a stretch of country of puzzling contour. On the map it appears as a fairly level plain suggesting an outwash accumulation, but on the ground there are many irregularities. Here and there over the plain hills and ridges rise 10 to 15 feet or more above the general level, their tops generally being flat and standing at accordant levels. Such a topography might arise from deposition around ice blocks or might represent projecting masses of the Manhasset formation, but in the absence of adequate sections it is impossible to determine which origin is more probable. In favor of the second suggestion, however, it may be said that the Manhasset undoubtedly extends beneath the moraines and is likely to come to the surface at almost any point. The altitude of the flat-topped elevations is accordant with that of the Manhasset level north of the moraine.

Huntington region.—In the region south of Huntington station (Fairground on the map) are many well-developed kettle valleys, the result of the melting of ice masses lying in the valleys of an older and now buried topography. The Manhasset formation, although not exposed, can not be far beneath the surface.

Smithtown region.—A glance at the topographic map (Pl. II, in pocket) shows the well-developed branching drainage system of Nissequogue River. An esker three-fourths of a mile northeast of Smithtown extending to the bottom of the present valley indicates the Vineyard age of the erosion features, and an examination of the materials exposed in the several valleys shows nothing but deposits of the Manhasset type. It seems clear that at this particular point practically all the deposits between the moraines are Manhasset.

Port Jefferson region.—In going southward from Port Jefferson station one passes over an exceedingly flat plain of outwash from Wisconsin ice, which continues with hardly a perceptible irregularity for 2 miles or more. At this distance, however, irregularities begin to appear. Kettle depressions pit the surface and low swells rise above it, as near Terryville. A little farther on the depressions take the form of broad, shallow, well-defined yet streamless valleys with branches on either side, the intervening ridges constituting the elevations. In fact, the topography has undergone a change from one due to deposition to one due largely to erosion. The valleys lead southward toward the sea but are cut off by the southern moraine, which rises above the plains, completely blocking the channels. The erosion is clearly assignable to the Vineyard interval and there is every reason to regard the deposits as Manhasset.



TOPOGRAPHIC FEATURES NEAR MIDDLE ISLAND, LONG ISLAND, N.Y.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1913

Rocky Point region.—In the region east of Port Jefferson conditions seem to be similar to those in the vicinity of Huntington. Just south of Rocky Point village are unusually good examples of branching kettles resulting from the melting of ice masses in the valleys of the underlying Manhasset surface. Plate XX shows one of these kettles as represented on the topographic map. A mile or two farther south the valleys, like those south of Port Jefferson, are evidently cut in the Manhasset formation.

Wading River region.—The conditions in the vicinity of Wading River are much the same as at Rocky Point village, except that the branching kettles and surface valleys in the Manhasset are still more conspicuous. Although the Manhasset controls the topography everywhere except within a short distance of the moraine, there is nevertheless here as elsewhere more or less Wisconsin drift, which locally complicates and even obliterates the Manhasset surface.

Middle Island region.—On the geologic map (Pl. I, in pocket) a considerable region, extending from Coram on the west to the headwaters of Peconic River on the east and from the vicinity of Long Pond on the north to the Ronkonkoma moraine on the south, is represented as till. Throughout this region the topography is characteristic of erosion. Several deep and fairly sharp valleys with branching and rebranching tributaries, all manifestly cut in a pre-Wisconsin surface, lead southward toward the sea. Plate XX shows what is probably the best example of a kettle valley on Long Island, the depression being nearly 4 miles in total length and having not less than five major branches (one of these rebranching) as well as many minor ones not shown on the map. Though mantled with a thin coating of later drift, the body of the deposit of this region belongs to the Manhasset formation.

Fresh Pond Landing region.—The moraine is very weakly developed near Fresh Pond Landing, the Manhasset capped by thin outwash stretching inward from the coast. It is cut by the northward-leading channel shown in Plate IX, *B* (p. 42), the continuation of which can be traced several miles toward the south by depression channels and kettles.

Riverhead region.—The region between Riverhead and the moraine on the north seems to consist mainly of the Manhasset formation, which was deeply dissected by stream erosion and later covered by a thin mantle of outwash along the moraine and by thinner and more irregular outwash deposits elsewhere. The old drainage topography is marked by the original channels, by kettle valleys, or by chains of isolated kettles. The region between Riverhead and Baiting Hollow probably affords the best illustration on the island of the last-named feature (Pl. IX, *C*). Some of the old valleys are almost as well and as definitely marked by the succession of kettles as if the channels were continuous.

Mattituck region.—The region about Mattituck presents another example of deeply dissected Manhasset deposits overlain by a superficial coating of late drift. This feature is best brought out by Mattituck Inlet (Pl. XI, *C*, p. 52), which represents an almost unaltered drainage system of the Manhasset. This channel originally led southward, but is now obstructed by Wisconsin drift and forced to empty northward into Long Island Sound through what was originally one of its headwater channels.

North shore from Mattituck Inlet to Orient Point.—Essentially the same conditions as at the localities farther west exist east of Mattituck Inlet. The Manhasset, here as elsewhere characterized by Vineyard erosion valleys, constitutes the main part of the deposits, the outwash from the Wisconsin ice being weakly developed and confined mainly to the vicinity of the moraine.

Peninsulas of the North Fluke and Shelter Island.—South of the line along which the Manhasset of the North Fluke proper and its mantle of outwash sinks beneath the sea lie a series of islands and peninsulas, the latter almost disconnected from the mainland, which rise abruptly from sea level to heights of 60 to 160 feet. From west to east these are Robins Island, Nassau Point, Great Hog Neck, and Shelter Island, the whole forming a belt exactly parallel with the North Fluke. Each of the peninsulas shows clear evidence of pre-Wisconsin erosion and equally clear evidence of, in the main, post-Gardiners deposition, and although the deposits are not a unit with those underlying the North Fluke proper, they must be considered as belonging to the same general series—the Manhasset formation.

Peninsulas of the South Fluke.—Stretching northward from the axis of the South Fluke, well north of the outer moraine, are a number of peninsulas similar to the peninsulas and islands associated with the North Fluke and likewise falling into a well-marked east-west alignment. Their exposures show them to be composed of Manhasset material, except for the Gardiners clay near sea level. Unlike the peninsulas of the North Fluke, however, they do not seem to belong to a series distinct from that of the fluke proper, but rather to represent remnants of a plateau or terrace similar to the north-shore plateau west of Port Jefferson.

OCCURRENCE SOUTH OF THE RONKONKOMA MORAINE.

Hempstead region.—East of Jamaica and continuing across the town of Hempstead to the Oyster Bay line, the broad plains that stretch southward from the Ronkonkoma moraine, although in their broader aspects having the appearance of outwash deposits from Wisconsin ice, present many minor features suggesting that an older topography may project here and there through the superficial mantle of outwash. Except at Rockaway Ridge, however, the topography is not sufficiently definite nor the exposures of the older beds sufficiently clear to identify them with certainty, but there is little doubt that the Manhasset constitutes the greater bulk of the deposits beneath the Wisconsin gravels that form the surface of the outwash plain. The development of the Manhasset deposits immediately north of the moraine and their observed occurrence beneath the northernmost of the morainal ridges would make it almost certain, even if there was no other evidence, that the Manhasset formation extends southward beyond the moraines in strongly developed form.

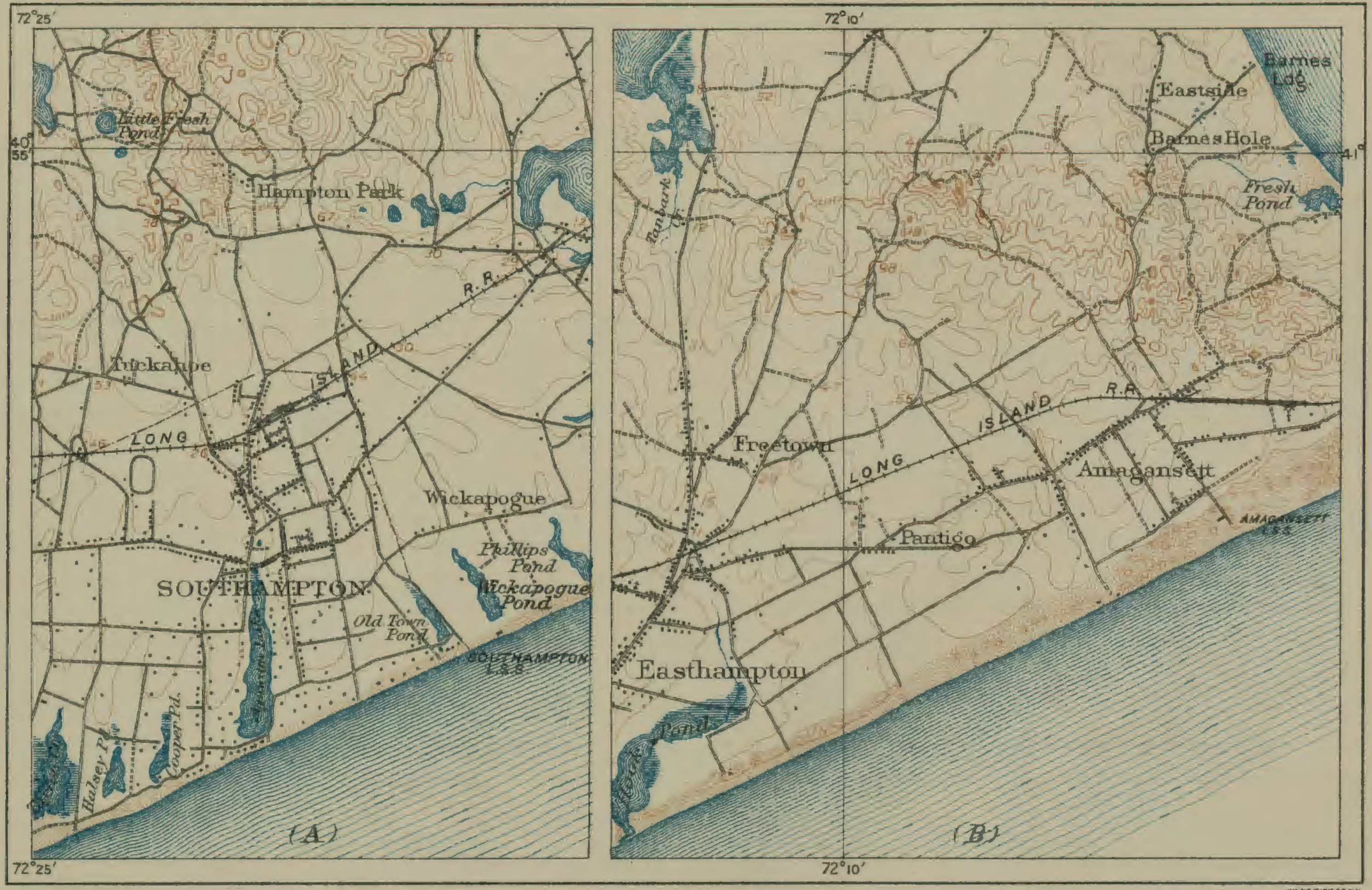
Rockaway Ridge (see Pl. II, in pocket) affords a good example of the extramorainal Manhasset material, standing many feet above the surrounding outwash plains from the Wisconsin ice and exhibiting an erosion surface evidently antedating the deposition of the surrounding gravels. The character and relations of these deposits are considered in more detail on page 127.

Bethpage region and Half Hollow Hills.—Two well-developed terraces of gravels of the Manhasset type occur just south of the West or Mannetto Hills (Pl. III, p. 28), and a single but higher and more extensive terrace is present in the Half Hollow Hills. These terraces are correlated with the Manhasset formation.

Wyandanch to Central Islip.—From Wyandanch, near the south end of the Half Hollow Hills, eastward along the railroad to Brentwood there is very little evidence by which to differentiate the Manhasset from the outwash, but from Brentwood to Central Islip station features suggesting an older surface are more numerous, making it clear that the Manhasset is at or near the surface and is beginning to exert a decided influence upon the topography.

Central Islip to Yaphank.—The Manhasset becomes an important factor in the topography immediately east of Central Islip but is soon interrupted by the broad outwash channel leading south from the Smithtown region north of the outer (Ronkonkoma) moraine. Near Ronkonkoma its control of the topography again becomes apparent, and similar conditions continue eastward to the second great valley at Yaphank. Along the base of the moraine and stretching southward to the railroad the Manhasset is recognized by irregularities in the shape of elevations rising above the outwash or by dendritic drainage channels, now streamless, quite different from the channels of the outwash proper. Throughout this stretch, also, the Manhasset is an important factor of the topography, especially near the coast, the outwash, except near the moraine, having only a subordinate influence. However, the relief of the old surface was so slight, the materials are so similar in composition, and the general slope is so near that of the Wisconsin deposits that, although it is possible to say that two surfaces of widely different ages are present, it is impracticable to differentiate between them with sufficient accuracy for mapping.

Yaphank to Shinnecock Canal.—Conditions similar to those just described exist in the region between Yaphank and Shinnecock Canal, the Manhasset apparently being even better represented. Along the coast, and especially on the peninsulas, much of the topography is



A. OUTWASH TOPOGRAPHY NEAR SOUTHAMPTON. *B*. MANHASSET AND OUTWASH TOPOGRAPHY NEAR AMAGANSETT LONG ISLAND, NEW YORK

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1913

clearly of a type characteristic of erosion rather than of deposition and belongs to the Manhasset rather than to the Wisconsin outwash. The necks southwest of the canal and southwest of Moriches are examples of accumulations that are apparently almost entirely of Manhasset age.

Bridgehampton region.—Eastward from Shinnecock Bay to Mecox Bay the Manhasset is not definitely recognized, although indications are not entirely lacking that the deposits are in places near the surface. Between Mecox Bay and Bridgehampton the Manhasset again controls the topography, although locally covered with a considerable thickness of outwash which has entirely obscured the older drainage. In several places, however, the older drainage lines are now indicated by kettle channels or chains similar to those occurring at many points between the moraines near Huntington, Rocky Point, Middle Island, Wading River, Riverhead, and elsewhere. One of these channels is shown in Plate IX, *A* (p. 42).

Amagansett region.—East of Bridgehampton the Manhasset is again absent from the surface as far as Easthampton, but from Easthampton eastward through Amagansett as far as Promised Land it shows at many points. The topography in this region is very irregular, almost no outwash being present. This is well brought out by Plate XXI, *B*, in which the extramorainal topography is in notable contrast to the more purely outwash topography shown in *A* of the same plate.

DEPOSITS PENETRATED BY WELLS.

The Manhasset is encountered in probably more than three-fourths of the wells on Long Island and is clearly represented in a large number of well records. In many records it is even possible to recognize the three subdivisions, as brought out in the tables and records given in the separate discussions of the Herod, Montauk, and Hempstead members. Data regarding a number of additional wells, in which the subdivisions have not been differentiated, are given in the following table:

Undifferentiated Manhasset formation in the wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of material.	Character of materials.	Correlation with name used in original records.
			Feet.		
35	Brooklyn	Forest Street and Evergreen Avenue.	23-105	Yellow gravel and sand	Wisconsin and Tisbury.
38	Do	Bartlett Street and Flushing Avenue.	[b] 6-45	Sand and gravel	Do.
135	East New York	New Lots Road and Fountain Avenue.	4-93	Yellowish sand, granitic gravel, and thin gray clays.	Do.
187	Far Rockaway	James Caffery	0-42	Yellowish gravel	Tisbury.
188	Do	B. L. Carroll	0-45	Fine to coarse sand and gravel	Do.
191	Do	Queens County Water Co.	0-60	Light-yellowish sand and gravel	Do.
193	Threemile Mill	T. R. Chapman	[b] 0-140	Sand, quicksand, and clay	Wisconsin and Tisbury.
195	Aqueduct	Shetucket pumping station	90-135	Fine to coarse gray to brownish sand	Tisbury.
199	Jamaica South	Oconee pumping station	[b] 9-56	Reddish-yellow sand	Wisconsin and Tisbury.
201	Do	Jameco pumping station	18-86	Yellow to gray sand with pebbles	Tisbury.
202	Do	Brooklyn test well No. 1	54-89	Gray to yellow sand and gravel	Do.
203	Do	Brooklyn test well No. 2	19-83	Yellowish to gray sand and gravel	Do.
204	Springfield	Brooklyn test well No. 3	45-86	Fine yellowish sand	Do.
205	Do	Brooklyn test well No. 4	27-72	Brownish-yellow and gray sand	Do.
206	Do	Springfield pumping station.	20-65	....do	Do.
212	Jamaica	Brooklyn test well No. 11	20-95	....do	Do.
241	Whitestone	Railroad wells	15-60	White sand	Do.
285	Valley Stream	Brooklyn test well No. 19	18-72	Gray to yellowish sands and gravel	Do.
287	Do	Brooklyn test well No. 25	15-62	Fine yellowish sand	Do.
291	Springfield	Brooklyn test well No. 12	30-98	Yellow, gray, and reddish sands	Do.
295	Do	Brooklyn test well No. 10	40-80	Yellow and gray sands	Do.
374	Long Beach	Poorhouse	0-75	Yellow to gray, sometimes clayey sands	Do.

[a] Numbers refer to well records in Prof. Paper U. S. Geol. Survey No. 44. [b] In part.

SPECIAL FEATURES OF THE DISTRIBUTION OF THE MANHASSET FORMATION.

The Manhasset formation as a whole displays three belts of more prominent development, which may be called the north-shore belt, the Middle Island belt, and the South Fluke belt.

North-shore belt.—Of the three belts the north-shore belt alone is continuous throughout the island, being represented by the broad Manhasset terraces from New York to Port Jefferson and by the bluff deposits from Port Jefferson east to Orient Point. The accumulations are thickest at the Sound shore and become rapidly thinner toward the south, being at a distinctly lower level south of the Harbor Hill moraine. The slope is well shown in the region east of

Wading River (fig. 107), where the outwash is relatively thin, the Manhasset surface declining from an altitude of about 120 feet along the coast nearly to sea level along Peconic River, which appears to occupy a fosse between the plain and the northern face of the Middle Island belt of the Manhasset. Just east of Riverhead the beds slope from an elevation of about 80 feet on the Sound to sea level on the shore of Peconic Bay, 4 miles to the south. Still farther east both the thickness of the Manhasset along the north coast and its extent toward the south decrease until near Orient Point the formation has a maximum elevation of only about 30 feet and a width of less than a mile.

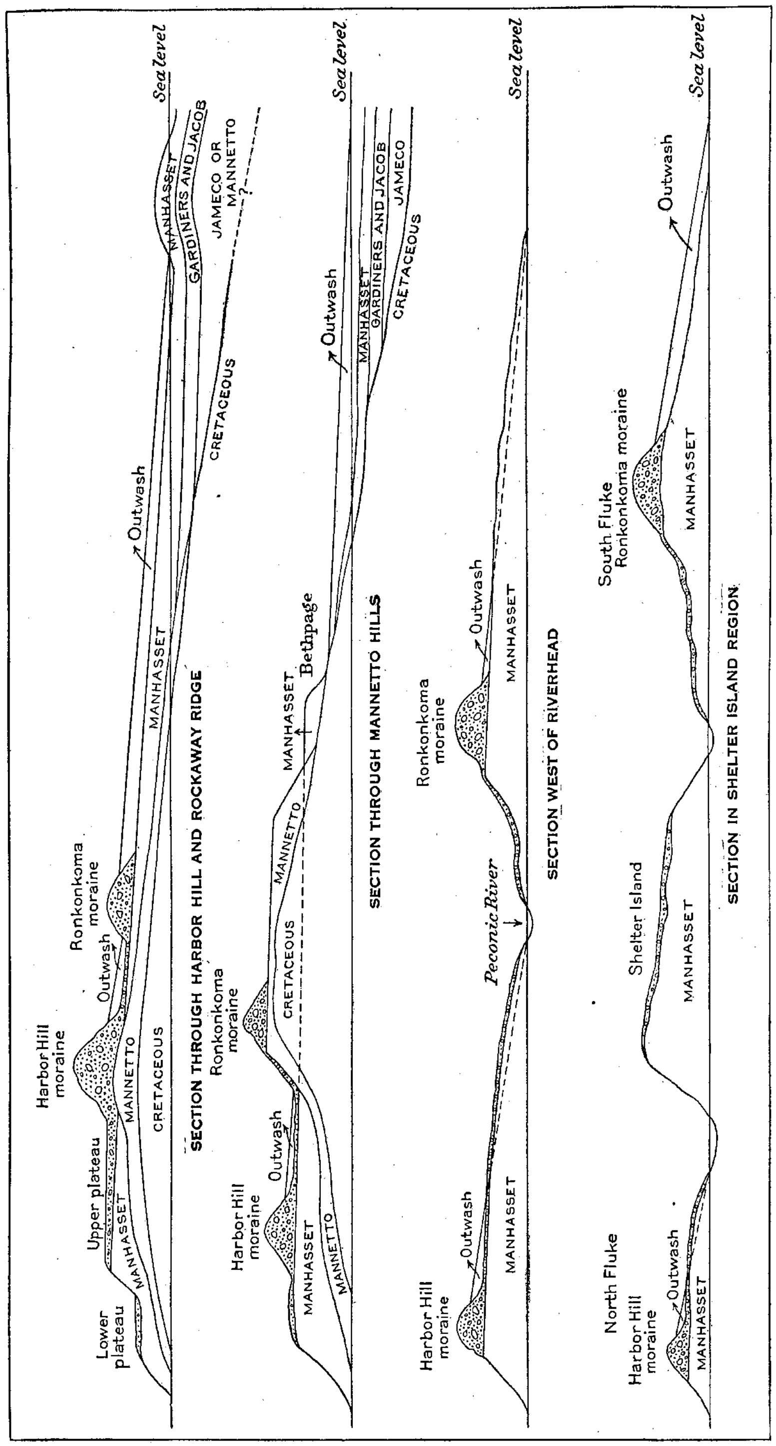


FIGURE 107.—Cross sections showing structure of Long Island.

Middle Island belt.—The Middle Island belt is most distinct at its east end, where it is represented on Shelter Island. To the west it is represented by Great Hog Neck, Nassau Point, and Robins Island, by the thick deposits bordering Peconic River on the south from Riverhead to South Manor, and by the high deposits between the moraines at and near Middle Island. West of this region the continuation of the Middle Island belt is obscured for many miles, but there are topographic indications pointing to a Manhasset scarp similar to that of the north-shore belt but mainly buried, extending westward along the line of the Ronkonkoma moraine to the Half Hollow Hills, which belong to this belt. The next representatives of the belt appear to be the Bethpage terraces, lying southwest of these hills and possibly indicating a swing of the belt in that direction. Rockaway Ridge, the last Manhasset remnant in this belt, agrees in trend with the southwesterly bearing assumed between the Half Hollow Hills and the Bethpage terraces. Possibly Gardiners Island, at the opposite end of Long Island, represents the easterly continuation of the same belt.

The Middle Island belt shows, where not obscured by later deposits, the same northward-facing scarp as the north-shore belt, but the southward slope is not so conspicuous. The drainage, however, seems to have commonly flowed toward the south, indicating a general slope in that direction. The formation maintains its thickness on the whole more persistently than in the north-shore belt, although showing great local variations. At Rockaway Ridge the upper surface stands about 30 feet above sea level; at Bethpage, 180 feet; in the Half Hollow Hills, 240 feet; at Middle Island, 140 feet; south of Peconic River, 100 feet; on Robins Island, 60 feet; on Nassau Point, 60 feet; on Great Hog Neck, 40 feet, and on Shelter Island, 100 feet or more. The subaerial erosion is fully as far advanced as in the north-shore belt, and the features due to marine erosion are even more conspicuous, although the erosive action was probably less.

South Fluke belt.—The South Fluke belt of the Manhasset formation is most readily traced by beginning at the east. The great mass of the deposits beneath the thin coating of late till on the Montauk Peninsula are Manhasset and constitute the east end of the belt. Interrupted by the connecting beach and dunes at Promised Land, the belt is continued toward the west by the broad Manhasset areas of the two great necks east of the town of Sag Harbor, by Hog Neck north of this town, and by the high hills between Noyack, Little Peconic, and Great Peconic bays and the moraine, as well as by the Manhasset remnants seen south of the moraine. The South Fluke belt seems to join the Middle Island belt in the vicinity of Riverhead. The maximum elevation of the Manhasset at Montauk is about 150 feet; in the region between Promised Land and Sag Harbor and on the shores of Little Peconic and Great Peconic bays it is 120 feet. From these altitudes the Manhasset appears to slope southward, passing beneath the moraine and a part of the outwash, and seems to have originally reached sea level a little south of the present coasts, which are now commonly lined with bluffs rising a few feet above tide level.

In figure 107 a number of profile sections bring out the relations of the Manhasset formation in the three belts described above.

HEROD GRAVEL MEMBER.

NAME.

The term Herod gravel member is applied to the sand and gravel beds constituting the lower third of the Manhasset formation, or that part lying below the middle or Montauk till member. The name is taken from Herod Point, near Wading River, on the north shore of Long Island, where the gravel is well exposed.

CHARACTER.

The Herod gravel member varies greatly from point to point, in some places being prevailingly sandy and in others consisting largely of gravel. The change in character is abrupt in many places, both vertically and horizontally, sand beds giving place to gravel or gravel to sand within a distance of a few yards. In general sand is more likely to prevail near the contact with the underlying Jacob sand, and gravel is more likely to become abundant as the horizon of the overlying Montauk till member is approached. In places beds of sand 10, 20, or even 30 feet thick, containing scarcely a pebble, are to be seen, but in its more normal phases the deposit consists of an alternation of thin layers of sand and gravel, the whole having a gravelly aspect. The pebbles are commonly small, those half an inch to 2 inches in size predominating, but in the upper part of the member they are considerably larger, 3 to 4 and even 6 inch pebbles being common. The character of the pebbles differs greatly in the different parts of the island.

Western Long Island.—Near the west end of the island a large percentage of quartz pebbles is present, this material in fact predominating over the granites. The greater part of the quartz pebbles are stained yellow by oxide of iron, giving rise to the term "yellow gravels," by which they were formerly known and on the basis of which they have been by some writers correlated with the "yellow gravels" of New Jersey. The "yellow gravels" of New Jersey are in reality a much older deposit, corresponding with the Mannetto or still older beds. In them the basic granite pebbles are gone, those of the acidic type are deeply rotted, and even the cherts and some of the quartz pebbles have been weathered and weakened. In the Herod gravel member, on the other hand, the granites are as a rule not deeply weathered and the quartz and chert pebbles are quite fresh.

Next to the quartz the granite or gneissic pebbles are most abundant, both basic and acidic types being represented. Many of the basic or biotitic pebbles are more or less weathered and rotten, although perfectly fresh specimens are not uncommon. It is believed that freshness is the normal condition, the alteration of the weathered pebbles having been well advanced before they were incorporated in the deposit. The acidic muscovite-orthoclase varieties seem to be but little weathered.

In addition to the quartz and granite pebbles there are numerous concretionary fragments consisting mainly of quartz grains cemented by reddish (hematitic) oxide of iron and ranging from a fraction of an inch to a foot in length. Limonite concretions occur here and there in place. Silicified fossils and cherts, although forming quantitatively a very unimportant part of the deposits, are nevertheless sufficiently common to be found by careful search in almost any exposure in this part of the island. It is interesting to note that on the whole the quartz pebbles are rounded as much as, if not more than, those of the granite.

The staining of the gravels is in part primary and in part secondary. Many of the stained quartzes, for instance, occur in beds in which the surrounding pebbles are entirely unstained, showing conclusively that their staining antedated their deposition in their present situation. On the other hand, the beds in many places have been discolored since their deposition. Locally the discoloration is limited to a small bunch of pebbles, perhaps not more than 6 inches in diameter in the aggregate, the staining material clearly coming from an iron-bearing pebble in the center. In some places the streaks extend directly downward from the source of the staining solutions, which may be either a pebble or a lamina of sand rich in iron-bearing minerals. An interesting feature is shown in figure 108, which illustrates what at first sight appeared to be a most puzzling case of vertical bedding. The vertical banding appeared to be as regular and perfect as in any normal bedding, and only close examination revealed it to be due simply to discoloration.

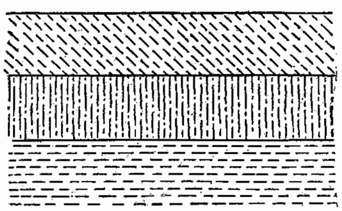


FIGURE 108.—Diagram of vertical pseudo-bedding in Herod gravel member.

The greatest amount of oxidation appears to have occurred where some finer sand or clay served to collect the downward-percolating waters, which have stained and even partly cemented the immediately overlying beds. In places, as in the gravel pits beneath the moraine on the east side of Roslyn, there appears to be a general staining of the section as a whole, the material being of the characteristic buff color.

The bedding of the gravelly phases of the Herod member is normally horizontal, as shown in the sections in the big gravel pits on Hempstead Harbor, but cross-bedding is not rare, especially in the upper part of the member. It is, however, generally of local occurrence and of no great magnitude. The bedding in the sandy phases of the member is nearly everywhere horizontal, except where disturbed by subsequent folding, and much of the lamination is distinct and delicate. Ripple marks are present here and there. Internal unconformities due to contemporaneous erosion and deposition are not uncommon, although in the member as a whole they can not be said to be numerous.

A noticeable feature of the member as exposed near Far Rockaway, on the south shore, is the presence of numerous pebbles showing faceting by the wind. A large part of these lie at some distance below the surface and beneath other gravels, but they appear from the absence of subsequent rounding to be substantially in place. No faceting was observed on the pebbles in the Herod member of the north shore.

Central and eastern Long Island.—East of Hempstead the character of the Herod member undergoes a gradual change. Quartz and concretionary fragments become less common and are seen at relatively few points beyond the Cretaceous and Mannetto remnants on Lloyd and Eaton necks, on the north coast, or east of the Mannetto and Half Hollow hills of Huntington Township, in the interior of the island. Cherts and silicified fossils appear to be absent. Structurally there seem to be more irregularities as one goes eastward, cross-bedding being much more common and bowlder pockets not rare. The stained appearance is largely lost, the beds in general having a very fresh aspect. Acidic granites become relatively common, but basic granites are comparatively rare, although some trap fragments occur. In the relative amounts of sand and gravel there is no marked change, although there appears to be a tendency toward greater fineness of material. Although it is difficult to make an accurate comparison of the Herod member with the outwash gravels of the Wisconsin stage, because of the absence of good exposures of the latter, it is probably safe to say that in general they resemble one another very closely both in composition and structure, and that in exposures where the relations are not shown it would be impossible to distinguish the two, a fact that adds much difficulty to the differentiation of the deposits south of the moraine.

SOURCE OF MATERIAL.

Western Long Island.—From the west end of Long Island eastward to the last exposure of Cretaceous and Mannetto at Eaton Neck and Northport there is, as has been pointed out, a predominance of quartz in the Herod member as a whole, but beyond the limits of the extensive older beds the quartzose character disappears. It seems clear, therefore, that it is to the beds of these older deposits, either on the island itself or in adjacent parts of Long Island Sound, that one must look for the source of the materials. If any considerable quantities were brought from the Sound itself, it would be expected that characteristic materials would be found east of the Cretaceous and Mannetto land masses. No notable quantities of such materials, however, have been found.

In the clayey parts of the Cretaceous the pebbles are usually white and entirely unstained, but in the sandy and gravelly phases staining is very common. The staining in the Mannetto appears to be universal. The stained pebbles of the Herod member may therefore be referred with some confidence either to the Cretaceous or to the Mannetto gravel, and the white pebbles would be referred either to the clayey Cretaceous deposits or to young drift brought in from the north. The only clue to indicate which source afforded the white quartzes is the extent to which they are rounded, the Cretaceous pebbles being in general considerably more rounded than those from the Pleistocene. From this indication the Cretaceous seems to have been the principal source. The so-called concretionary fragments appear to represent both actual concretions and thin cemented layers from the Cretaceous sands. Such layers are very numerous and in places highly irregular, simulating true concretions. Some may come from the Mannetto gravel, but none have been observed in place in this formation.

The granite pebbles appear to have been transported in the main from the Connecticut shore, the freshness of most of the material indicating derivation directly from the ledges. Some of the granites, however, seem to have been derived from ledges or from pebbles from older deposits in which weathering was already well advanced at the time of removal, although they were still sufficiently firm to permit their handling by ice or water. The relative scarcity of granite pebbles in the Herod member south of the moraine is attributed to the greater distance the materials were transported and the greater erosion they have undergone, whereby the smaller and more weathered pebbles were broken up and dissipated. The cherts and silicified fossils are evidently from the metamorphic limestones on the mainland to the northwest.

Central and eastern Long Island.—Although granitic pebbles are nearly everywhere abundant in the Herod member, it is on the whole more sandy than most glacial gravels. As has been shown, the Mannetto gravel was once a thick and extensive formation, stretching some distance into the region of the Sound, if not to the Connecticut shore. Notwithstanding the great erosion to which this formation has been subjected, it is not improbable that there were remnants of it beneath the Sound at the time of the Herod deposition, and these may have furnished some of the materials, although stained pebbles such as are found farther west are commonly lacking. Extensive areas of the Sound were also doubtless underlain by the Jameco gravel, which presumably furnished a large amount of material. To its derivation from these formations the Herod member probably owes its prevailing sandy character. The granite pebbles probably represent in part the reworked Jameco and in part fresh material brought in from the mainland.

RELATION TO OTHER DEPOSITS.

At the base, as elsewhere mentioned, the Herod gravel member merges by gradual transition into alternating layers of coarse and fine sands and finally into the clayey Jacob sand (figs. 67, p. 97; 75 and 76, p. 99; and 98, p. 110), the only unconformities being those of overlap where the gravel reaches beyond the Jacob sand and abuts upon the Mannetto gravel or the Cretaceous deposits.

In many small exposures the Herod member appears to be overlain conformably by the Montauk till member (figs. 109; and 167, p. 146), but in larger exposures, where several rods of the contact may be seen, an unconformity is almost invariably found. The unconformities range from shallow, almost unnoticeable depressions in the Herod surface to deep and perhaps sharp troughs, many of which cut entirely through the Herod into the underlying Jacob sand or Gardiners clay.

The nature of the contact between the Herod member and the Montauk member is far from uniform. Where the overlying deposit is a true till the contact is in many places sharp and distinct and it may be of the so-called knife-edge type, the transition from one member to the other taking place within less than a quarter of an inch. This is probably to be regarded as the characteristic contact. In places, however, there is a somewhat gradual transition from the gravel into the till, as if the former had been reworked and incorporated with the latter. Where the Montauk is represented by its gravelly phase there is no true contact, the finer gravel of the Herod member grading upward, although in places somewhat abruptly, into the coarser gravel of the Montauk member. Here and there the Montauk member is too poorly developed to be recognized and the Herod merges with the similar gravel of the Hempstead member to form a single thick gravel formation.

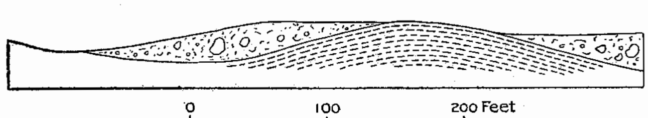


FIGURE 109.—Section near Quince Tree Landing, Montauk, showing till of Montauk type resting on arched Herod gravel member.

At a few places the Montauk ice seems to have planed and eroded the Herod member without leaving the usual deposit of till, and the Herod member is separated from the Hempstead member by an unconformity. One of these places is shown in figures 116 (p. 126) and 180 (p. 153). The ice in passing over broke up the stratification in the upper part of the lower sand and in connection with a subsequent oxidation or staining produced local phases strongly resembling soil zones.

STRUCTURE.

In common with the underlying beds the Herod gravel member was affected by the disturbance produced by the overriding Montauk ice. There are, however, certain points of difference. Because of its loose, friable character the Herod tended to crumble and disintegrate rather than to resist and become warped under the ice pressure. Folding is therefore less common in the gravel than in the more resistant Gardiners clay and Jacob sand, and where it has occurred the folds are generally broad and open, as if the material had been lifted by deformation of the underlying clay. This deformation may have been due to pressure transmitted laterally or to unequal settling under the weight of the ice sheet. In places, however, either because it contained a higher percentage of clay or because it was frozen at the time, the gravel appears to have afforded more resistance to the ice than usual and was folded in much the same way as the underlying beds, although never forming the sharp pinnacle-like folds nor showing the minute crumpling exhibited in many places by the clays. The character of the folding is brought out in more detail in the following discussion of the distribution of the gravel.

DISTRIBUTION.

East River to Little Neck Bay.—Along the north shore west of Little Neck Bay the Montauk till member reaches down nearly or quite to sea level, the Herod gravel member where present lying mostly below that level. It is possible that the Herod member is not as thick here as farther east, owing either to the earlier advance of the ice in the west and the consequent early replacement of the Herod by the Montauk, or possibly to greater reduction by erosion.

Great and Manhasset necks, North Hempstead.—The most western locality at which the Herod gravel member appears in considerable amounts is on Great Neck, where it forms the lower part of many of the bluff sections and extends below sea level. On Manhasset Neck the gravel is seen on the west and north shores (fig. 137, p. 135) but is best developed on the west side. A line of immense gravel pits cutting into the hills extends along the harbor, giving clear-cut sections of the Herod member from its contact with the Montauk till member at an altitude of 75 to 100 feet down to the Jacob sand or the Cretaceous clay near sea level. The material here consists of a fairly regular alternation of sand and fine gravel throughout the whole of the section.

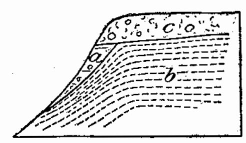


FIGURE 110.—Section on the coast north of Fort Salonga. Montauk till member (*a*) banked against Herod gravel member (*b*) and overlain by Wisconsin till (*c*).

Hempstead Harbor to Oyster Bay.—The Herod member is well exposed in the gravel pits near Glenwood Landing, on the east side of Hempstead Harbor, where 40 to 50 feet of rather fine cross-bedded gravel was seen. It seems to form a considerable part of the lower portion of the bluffs from Roslyn to the mouth of the harbor. From Hempstead Harbor to Oyster Bay the member is seen at few places along the shore, owing apparently to the extensive erosion by the Montauk ice, but it unquestionably occurs beneath the plateau stretching inland from the coast, probably embracing most of the materials from sea level to a height of 50 or 75 feet. At Rocky Point, 2 miles north of Oyster Bay, it is seen between the Gardiners clay and the Montauk till member but is here of slight thickness (fig. 65, p. 96). On both the west and east shores of Oyster Bay Harbor and at Coopers Bluff it appears to constitute the lower parts of the bluffs.

Lloyd Neck to Northport.—As is usual where the Cretaceous is present above sea level, very little of the Herod member is to be seen at Lloyd Neck, whatever Herod material may have been deposited around the Cretaceous masses having been removed by the Montauk ice or so disturbed as to be rendered unrecognizable. On West Neck, just south of Lloyd Neck, considerable Herod material is present and may be seen lying upon the Cretaceous clays (the Gardiners clay being absent) at one or more points along the shore of Cold Spring Harbor. From Halesite to Centerport on Great Neck the conditions are similar to those on Lloyd Neck, no good exposures of the Herod member being seen. On the west side of Little Neck a short distance south of Little Neck Point folded sands of the Herod type were seen underlying what appears to be the Montauk till member. On Eaton Neck, to the north, the conditions also resemble those on Lloyd Neck. In one section, however, folded beds of the Herod gravel member were observed between the Gardiners clay and the Montauk till member (fig. 66, p. 97). Fairly good exposures of the gravel, consisting of rather fine, even-bedded sand with wavy ripples, were found in the lower part of the bluffs on the east side of Northport Harbor, north of the town.

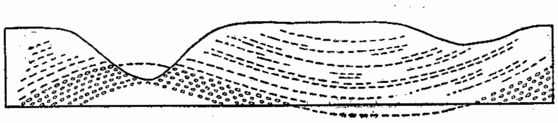


FIGURE 111.—Section half a mile east of Woodhull Landing, showing strongly arched beds of Herod gravel member.

Northport to Port Jefferson.—Gravels of the Herod member, 25 or 30 feet thick, were exposed in 1904 for some distance in the bluffs along the beach northeast of Fort Salonga, 3 or 4 miles northeast of Northport. Here the gravels are commonly horizontal, although some sections show a slight disturbance due to the Montauk ice, also unconformable contacts with the Montauk till member (fig. 110). Eastward from this point the Montauk member descends gradually to sea level, cutting out the Herod member. The Herod is seen again, however, on Nissequogue Neck between Nissequogue River and Stony Brook Harbor (figs. 139 and 140, p. 137) and in the vicinity of Stony Brook station (fig. 141, p. 137). Some of the contacts are unusually complicated (fig. 140), and much gravel is incorporated in the till.

Port Jefferson to Orient Point.—The first good exposure of the Herod gravel member east of Port Jefferson is found half a mile east of Woodhull Landing, where a great thickness of gently folded sand and gravel is seen (fig. 111). A quarter of a mile west of Hallock Landing the Herod member occurs in both horizontal and upturned and faulted masses, as shown in figure 112. The gravels underlying the upthrust Jacob sand near Hallock Landing doubtless represent the Herod member, as do also the horizontal gravels underlying the Montauk till member near Herod Point (fig. 113), Paine Landing (fig. 114), Hulse, Fresh Pond, and Jericho landings, and other points. The Herod member is exposed also as slightly warped beds beneath the Montauk till member near Friars Head (figs. 115; and 179, p. 153) and near Roanoke Landing and Point (fig. 144, p. 139), and it probably forms a considerable part of the material in the bluffs from Roanoke Point to the vicinity of Luce Landing and Jacob Hill, where it is again definitely recognized. In one section near Jacob Hill the Herod member is entirely cut out by the pre-Montauk unconformity (fig. 93, p. 109), although present in adjacent exposures (figs. 92, p. 109; 157, p. 143). The Herod member was seen between Luce Landing and Jacob Hill (figs. 145, 146, p. 140), also a mile southwest of Duck Pond Point (fig. 116), but at many points from this place eastward to the termination of the North Fluke at Orient Point the gravel is absent, the interval being represented by an erosion unconformity extending downward into the Jacob sand (fig. 96, p. 110). Figure 97 (p. 110), however, shows the Herod in its normal relations.

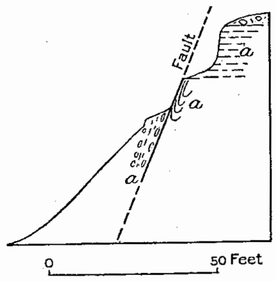


FIGURE 112.—Section a quarter of a mile west of Hallock Landing, showing faulted beds of Herod gravel member (*a*).

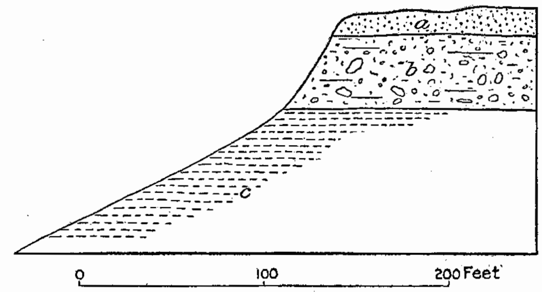


FIGURE 113.—Section west of Herod Point. *a*, Dune sand; *b*, banded till (Montauk till member); *c*, Herod gravel member.

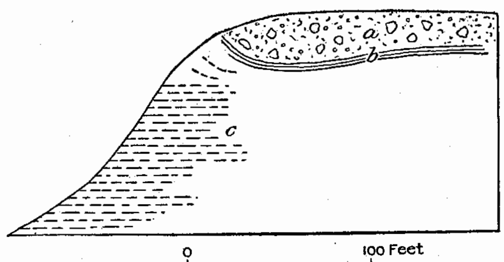


FIGURE 114.—Section near Paine Landing. *a*, Till (Montauk till member); *b*, thin clay layer belonging to Montauk member; *c*, Herod gravel member.

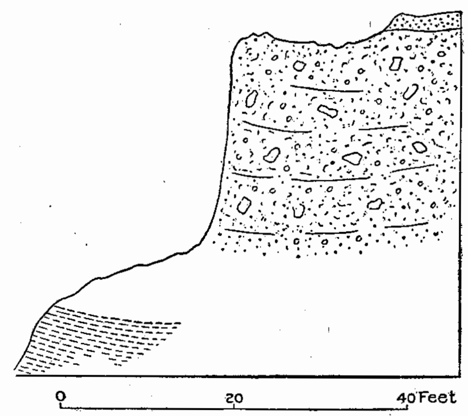


FIGURE 115.—Section near Friars Head, showing Herod gravel member beneath banded Montauk till member.

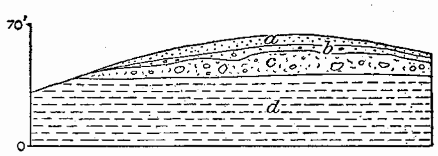


FIGURE 116.—Section 1 mile southwest of Duck Pond Point. *a*, Dune sand; *b*, Wisconsin till; *c*, Montauk till member; *d*, Herod gravel member.

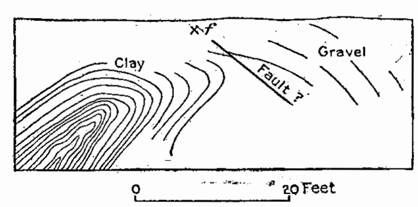


FIGURE 117.—Section northwest of Shinnecock Canal, showing folding and faulting in gray clay belonging to the Jacob sand and in the Herod gravel member of the Manhasset formation. Fossils (probably secondary) at *f*.

Bethpage terrace.—The altitude and thickness of the Herod member north of the moraine indicate strongly that it must be represented to a greater or less extent south of the moraine, but no exposures admitting of definite recognition are found between the moraine and the vicinity of the West or Mannetto Hills. Near the clay pits at Bethpage, at the south end of these hills, and immediately west of Farmingdale, a mile farther south (see Pl. III, p. 28) are two well-marked terraces nearly 2 miles long and half a mile to a mile or more wide, composed of granitic gravels. The fact that what appears to be the Montauk till member occurs at the top of the Half Hollow Hills, just east of this locality, at an elevation of 240 feet, seems to show that the terraces at Bethpage and Farmingdale are to be correlated with the Herod member. The deposits in general are rather coarse, especially at the Bethpage locality, where they contain a large number of pebbles and seem to represent the beginning of the transition into the Montauk till member.

Eastern Long Island.—As indicated on the geologic map (Pl. I, in pocket), the Manhasset formation occurs beneath thin coatings of outwash or in many places probably rises above the outwash material, south of the outer (Ronkonkoma) moraine from the Half Hollow Hills eastward to Great Peconic Bay, but the exposures do not permit the identification of the particular member of the Manhasset to which they belong. It seems probable, however, that the Herod member is mainly below sea level in this area.

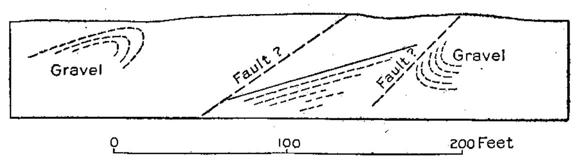


FIGURE 118.—Section northwest of Shinnecock Canal, showing folding and faulting in Herod gravel member.

Rockaway Ridge.—The ridge extending from Far Rockaway northeastward to Lynbrook rises distinctly above the Wisconsin outwash and has a much older topography. The gravel of the ridge differs from that of the normal Herod member in several particulars. The first of these is the unusual amount of quartz contained in it; in fact, at first sight quartz appears to be the only material present, a fact which led Woodworth [1] to place the deposits in the Tertiary. More careful search, however, has developed the presence of many granites, and wells sunk along the ridge penetrate the Gardiners clay after passing through the gravels. The latter are therefore younger than the former and older than the outwash; hence they must be placed in the Manhasset formation. Their position and the absence of any record of till or other deposits that could be correlated with the Montauk point to their being the southern representative of the Herod gravel member of the north shore.

The granite pebbles observed were all of the acidic type and were waterworn and rounded. Most of them were deeply weathered, thereby differing noticeably from the similar pebbles on the north shore—a feature resulting from their greater exposure to the weather. Many of the quartz pebbles were from 4 to 6 inches in diameter, and a large number of them exhibited a very marked and perfect faceting similar to that on the pebbles of Nantucket and Cape Cod, which the writer's work shows to have come from the same horizon.

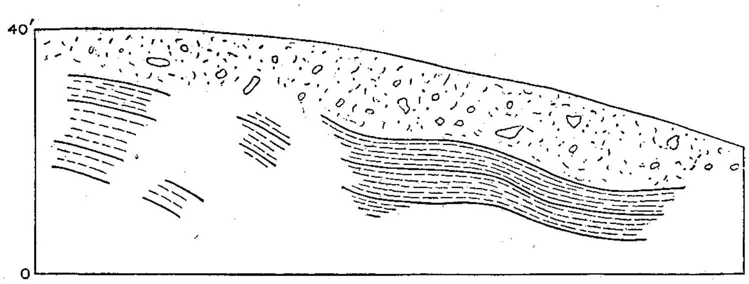


FIGURE 119.—Section east of Cedar Point, northeast of Sag Harbor, showing disturbed beds of Herod gravel member beneath Montauk till member. By D. W. Johnson.

South Fluke.—The Herod gravel member doubtless occurs at a large number of points on the South Fluke, but as the sections are covered with talus and as the key beds (Gardiners clay and Montauk till member of Manhasset) are absent at many places, it can be identified only with difficulty at those points. Good sections were observed in 1904, however, west of Shinnecock Canal, about midway between the canal and Red Cedar Point, where the beds were folded and faulted in a marked degree (figs. 117 and 118). Broken Pleistocene shells of secondary origin were found in the upper part of the member. On Jessup Neck, about 4 miles west of Sag Harbor, several exposures of disturbed gravels, possibly belonging to the Herod member, were seen, and on the west side of Hog Neck, about 3 miles northwest of Sag Harbor, there are several good exposures of the Herod, the relations being as shown in figures 151 and 152 (p. 142). Near Cedar Point the section shown in figure 119 was noted. Between Cedar Point and Sammys

[1] Bull. New York State Mus. No. 48, 1901, map.

Beach, 4 miles northeast of Sag Harbor, are many exposures of folded and faulted gravels, some of which appear to be overlain by the Montauk till member and hence are to be referred

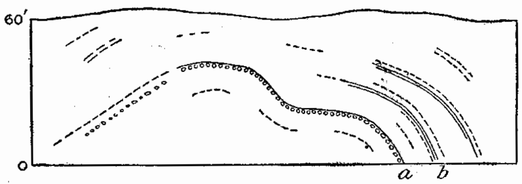


FIGURE 120.—Section between Cedar Point and Sammys Beach, northeast of Sag Harbor, showing folded gravels (Herod gravel member?) with cobble (*a*) and clayey (*b*) layers probably representing Montauk horizon.

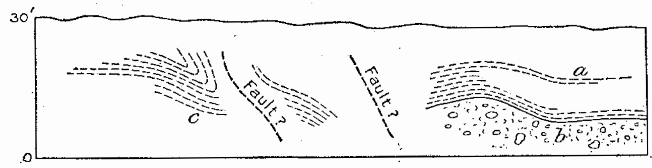


FIGURE 121.—Section east of Cedar Point, northeast of Sag Harbor. *a*, Hempstead gravel member; *b*, Montauk till member; *c*, folded and faulted gravels (Herod gravel member).

to the Herod member (fig. 120). The disturbed gravels shown in figures 121 and 122 are also probably Herod, as are the gravels and sands below the unconformity in figure 123. One of

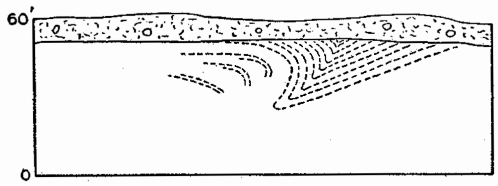


FIGURE 122.—Section east of Cedar Point, northeast of Sag Harbor, showing disturbed beds of Herod gravel member overlain by till (Wisconsin?).

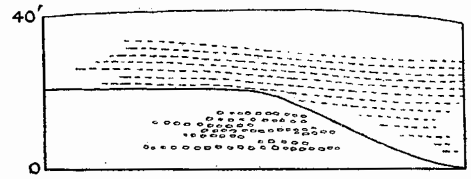


FIGURE 123.—Section west of Sammys Beach, showing probable unconformity separating Herod gravel member and Hempstead gravel member.

the exposures in the Montauk region is represented in figure 109 (p. 124), which shows a broad, low fold of the Herod member as it appears in a cliff section between the Napeague and Hither

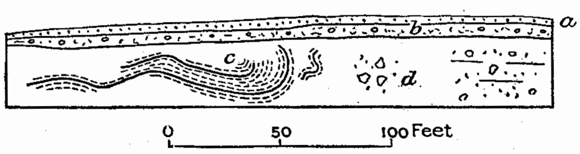


FIGURE 124.—Section near Culloden Point, Montauk. *a*, Dune sand; *b*, Wisconsin till; *c*, folded gravel (Herod gravel member?); *d*, banded Montauk till member.

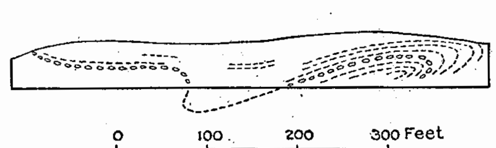


FIGURE 125.—Section 1 mile north of Quince Tree Landing, Montauk, showing folded beds of Herod gravel member.

Plain life-saving stations. On the north shore disturbed or overturned gravels, apparently belonging to the Herod member, are seen near Culloden Point (fig. 124). Other but more obscure exposures are found along the shore between the point and the landing near the railroad station. West of Rocky Point many exposures of folded gravels, possibly of the Herod member (fig. 125), were noted, but in general their relations were not disclosed. Near Quince Tree Landing, on Napeague Bay, however, the gravel is clearly seen to underlie the Montauk till member in one section, and in another it is banked against Jacob sand in an upturned mass (fig. 126).

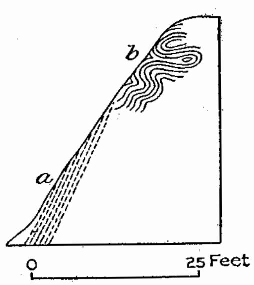


FIGURE 126.—Section 1½ miles north of Quince Tree Landing, Montauk, showing upturned beds of Herod gravel member (*a*) resting against clayey Jacob sand (*b*).

Robins Island.—The Herod gravel member is exposed in broad, open folds at many points in the bluffs on the west side of Robins Island (figs. 98, p. 110; 193, p. 156). At one point there appears to be a strong erosion unconformity due to the action of the Montauk ice, which, however, left no deposits (fig. 194, p. 157). A little farther along an important overthrust fault was seen, the upper part of the Herod member being shoved bodily over the lower part toward the south and the beds of the lower part being distinctly upturned and crumpled by the drag (fig. 127).

On the other side of the island the exposures are poorer, but there are long stretches of upturned and disturbed sands, overlain in places by the Montauk till member, which are apparently to be referred to the Herod member (fig. 128). At one point the gravel beds exhibited a distinct contortion in addition to the broader undulations (fig. 74, p. 99). An upturned mass is shown in figure 75 (p. 99).

Shelter Island.—Owing to the fact that wave cutting is relatively less active on Shelter Island than on the north shore of Long Island, more of the cliff sections here are covered with talus. Traces of folded sands and gravels, however, were noted at many points along the lower parts of the bluffs on the north side of the island. This material seems to belong to the Herod member, for it is stratigraphically below the heavy till correlated with the Montauk member, which is well developed on the island.

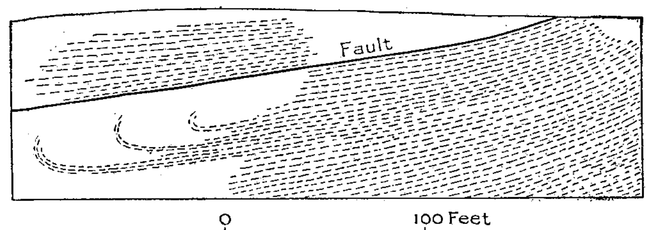


FIGURE 127.—Section on west side of Robins Island, showing thrust fault in Herod gravel member.

Gardiners Island.—The complexity of the folding and the covering of talus on most of the more gravelly bluffs of Gardiners Island make the tracing of the Herod gravel member very difficult. As no gravel beneath the Gardiners clay is here known, and as profound folding appears to be distinctive of the Montauk invasion, it is fair to presume that the great masses of the strongly folded glacial gravels of the island belong to the Herod member. The conditions can be best shown by the illustrations. Figure 167 (p. 146) shows the gravel in open folds beneath the Montauk till member at a point half a mile north of Cherry Hill Point, and figure 99 (p. 110) shows the Jacob sand and Herod member in thick and but slightly disturbed beds a little beyond. The contact is stained black and is more or less oxidized, suggesting a soil zone. A few hundred feet farther east horizontal Herod material was seen beneath an overturned fold of Gardiners clay (fig. 81, p. 100). On the northeast side of the island, near the west end of the bluffs and not far from the base of the sand spit, the relations illustrated in figure 78 (p. 100) were observed. At 980 paces from the end of the bluff the Herod member was again seen in a gentle fold (fig. 129), and beginning 1¼ miles from the end of the bluff an almost continuous section of folded beds of the Herod gravel member was to be seen in 1904 for a distance of 1,350 feet (fig. 80, p. 100), beyond which folded beds of the Herod were seen intermittently to Eastern Plain Point, a mile farther on. On the shores of Tobacco Lot Bay the Herod member appears to have suffered more from the Montauk ice erosion and is less seen. The accompanying section (fig. 130) shows the appearance of the best exposure near the point at the south end of the bay. South of the point there are fine exposures of buff horizontally stratified sands and gravels, which probably belong to the Herod member.

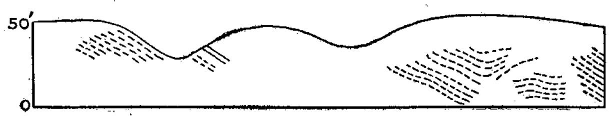


FIGURE 128.—Section on east side of Robins Island, showing disturbed beds of Herod gravel member.

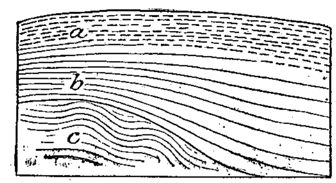


FIGURE 129.—Section half a mile south of west end of bluff on northeast coast of Gardiners Island. *a*, Herod gravel member of Manhasset formation; *b*, gray Jacob sand; *c*, dark-gray to black clay alternating with laminæ of fine sand (Gardiners clay).

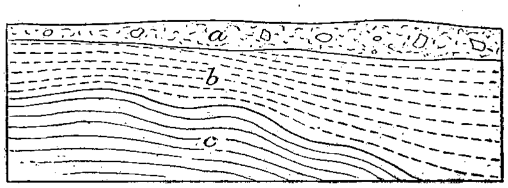


FIGURE 130.—Section near point at south end of Tobacco Lot Bay. *a*, Till (partly Montauk till member); *b*, Herod gravel member; *c*, block clay weathering green, with some pebbles.

Plum Island.—West of the steamboat landing on Plum Island the first good exposure of the Herod gravel member seen along the shore in 1904 was found about half a mile from the wharf in an open fold (fig. 102, p. 111). The next quarter of a mile showed a succession of similar folds, though not so well exposed at the time of the writer's visit. At the west end of the island, near the lighthouse, a thrust fault with the upper layers bent upward was seen. The fault plane makes an angle of about 45° with the horizon. The thrust is toward the south (fig. 131).

On the south side of the island the Herod member was seen in considerable thickness a quarter of a mile east of the west end of the bluffs, where it has the relations shown in figure 170 (p. 146). A hundred paces farther east it was again well exposed and showed a great number of parallel faults (figs. 82, p. 101, and 132), and a few hundred yards beyond it appeared in a highly folded mass. From this point to Fort Terry, although the exposures are not so good, the member is seen at short intervals (fig. 103, p. 111). About half a mile east of the fort several fine exposures show highly disturbed and eroded beds of the Herod member (fig. 104, p. 111), and a little farther on a good exposure of the Herod has till backed up against it. From this point to the east end of the island and westward along the north coast to the wharf the cliffs have been covered artificially and no exposures are now visible.

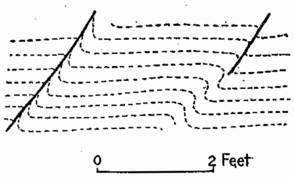


FIGURE 131.—Section near lighthouse at west end of Plum Island, showing folds passing into faults in Herod gravel member.

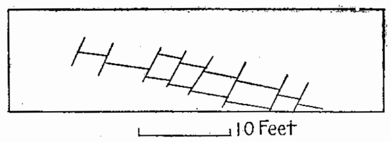


FIGURE 132.—Details of faulting in Herod gravel member near west end of bluffs on south side of Plum Island.

Fishers Island.—On Fishers Island the Herod member is best exposed in the clay pit, where the sandy phase is strongly developed in the big anticline. The relations and structure at this point are well shown in figure 84 (p. 101). Figure 133 shows additional details of the structure, although owing to the talus present the relations are not entirely revealed.

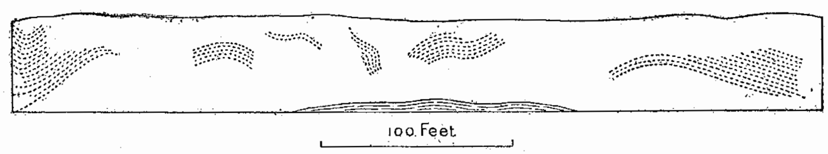


FIGURE 133.—East-west section in clay pit on Fishers Island, showing disturbed beds of Herod gravel member of Manhasset formation overlying Gardiners clay.

At Isabella Beach and at the bluff three-fourths of a mile northeast the Herod member is arched in broad open folds (figs. 86, p. 102; 134, 135). The conditions at the West Harbor locality (fig. 173, p. 147) are similar to those at Isabella Beach, except that the materials are moderately coarse gravels with pebbles the size of a hen's egg. The greater part of the high hill on the south shore south of West Harbor appears to be composed of the Herod member, which seems to be cross-bedded on an extensive scale, and which, to judge from the outcrop of the Jacob sand on which the beds rest, is folded into broad arches only a few feet high.

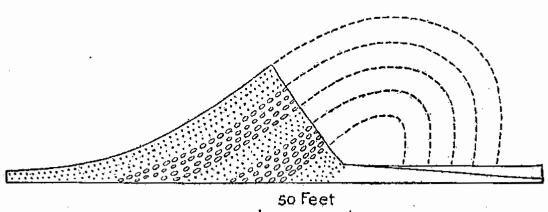


FIGURE 134.—Section through hill three-quarters of a mile northeast of east end of Isabella Beach, Fishers Island.

Except at the localities described, where the gravels rest on the Jacob sand, the Herod member can not be recognized with absolute certainty, although there is every reason to believe that the yellow and buff sands and gravels seen at a great number of points beneath the thin coating of Wisconsin till, forming, in fact, by far the greater part of the island, belong to this member. They probably reach their greatest development either in the high hills south of West Harbor, already mentioned, or in the similar hill southeast of Chocomount Cove, which rises more than 120 feet above sea level and is probably composed mainly of the Herod member.

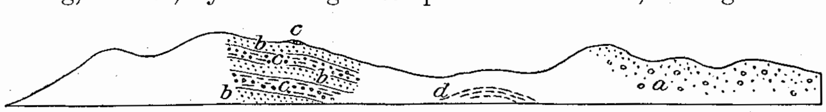


FIGURE 135.—Section parallel with beach at headland three-quarters of a mile northeast of east end of Isabella Beach, Fishers Island. *a*, Till; *b*, gray sand belonging to Herod gravel member; *c*, clayey gravel belonging to Herod member; *d*, greenish-gray clay (Gardiners clay).

Deposits penetrated by wells.—The tripartite division of the Manhasset formation (the Tisbury of Veatch) was not fully established in the first season's work and is not mentioned in the report on water resources. The subdivisions can be recognized, however, in many of the well records, and from these the accompanying table has been drawn up. The table includes only those wells in which the gravel is found below the Montauk till member. The Herod gravel member, however, is recognized in the beds overlying the Gardiners clay and the Jacob sand in many other wells, practically all of those listed under these two formations indicating also the presence of the Herod gravel member of the Manhasset formation.

Herod gravel member of Manhasset formation in wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of formation.	Character of materials.	Correlation with name used in original records.
			Feet.		
38	Brooklyn	Bartlett Street and Flushing Avenue.	73-81	Coarse glacial sand	Wisconsin and Tisbury.
62	....do	Ten Eyck Street	52-75	Coarse yellow sand and gravel	Tisbury.
186	Tallman Island	Railroad test boring	[b] 57-76	Sand (not quartz gravel)	Pleistocene.
200	Jamaica South	Baisley pumping station	97-106	Yellowish sand and gravel	Tisbury.
220	Hollis	Brooklyn test well No. 7	69-98	Grayish and yellow sand	Do.
246	Elm Point	H. B. Gilbert	56-114	Fine sand to coarse gravel	Do.
258	Hewlett Point	G. B. Wilson	36-59	Coarse gray sand	Not correlated.
357	Port Washington	T. Valentine	60-123	White and yellow sand	Tisbury.
366	....do	Dodge estate	22-50	White sand	Do.
421	Nuneola	Commission test well	30-55	Yellowish sand and gravel	Do.
422	Albertson	....do	23-37	....do	Not correlated.
436	Roslyn	Mrs. T. Vowman	53-90	Fine sand	Tisbury.
446	Glenhead	A. A. Knowles	75-136	Sand	Do.
457	Glen Cove	F. E. Willets	44-70	Light-colored sand	Do.
465	Dosoris	W. M. Valentine	70-125	Brownish sand and gravel	Do.
481	Lattingtown	L. C. Wier	63-92	White and orange-colored sand and gravel.	Tisbury and Mannetto.
483	....do	E. Latting	63-73	White sand and gravel	Tisbury.
484	....do	W. D. Gutherie	64-	White sand	Tisbury and Mannetto.
485	....do	....do	38-100	Sand and gravel	Tisbury.
629	West Neck	Mrs. M. H. Clots	[b] 25-85	Fine brown sand	Do.

[a] Numbers refer to well records in Prof. Paper U. S. Geol. Survey No. 44.

[b] In part.

The persistency of the Herod member is not only indicated by its outcrops but is also brought out and emphasized by the well records. Its character seems to be very uniform, the member being usually described as a white, light-gray, yellow, or brownish sand with gravel indicated in about half of the records. Although ranging from fine to coarse in texture, it appears in its most common phase to be medium grained. In development it shows the same differences in wells as it does in outcrops, the recorded thickness ranging from 10 to 60 feet. Some of the apparent differences are probably explained by imperfections in the records, but the greater part of them are doubtless due to erosion by the Montauk ice, as in the surface exposures.

Among the well records showing the character of the Herod member is that of the railroad test boring on Tallman Island, near College Point. The section as shown by a sketch by C. M. Jacobs, consulting engineer, in the museum of the Long Island Historical Society, with the correlation of the writer, is as follows:

Record of railroad test boring on Tallman Island, New York.

	Feet.
Recent: Sand and trap bowlders; old sea beach	0 - 7.3
Hempstead gravel member of Manhasset formation: Yellow quartz sand	7.3- 30
Montauk till member of Manhasset formation:	
Quartz gravel and bowlders	30 - 31.5
Yellow quartz sand, medium fine	31.5- 50
Trap bowlders, quartz sand, and gravel; regular glacial drift	50 - 57
Herod gravel member of Manhasset formation:	
Sand	57 - 63
Quartz gravel	63 - 66
Gravel and sand	66 - 73.3
Quartz gravel	73.3- 76.3
Cretaceous (?):	
Soft clay	76.3- 79.3
Lignite intermixed with clay bands	97.3- 91.7
Streaked red and white clay; hard, bored out as a solid core	91.7-110.4
Fordham gneiss: Soft white micaceous "sandstone"	110.4-159

The Herod member is also indicated in the record of a well (No. 366) on the Dodge estate near Port Washington, given in the discussion of the Jacob sand on page 113; in the well of the Commission on Additional Water Supply for New York City near East Williston (No. 421), given in the discussion of the Montauk till member on page 149; and in the Commission well near Albertson (No. 422). In the well of F. E. Willets, near Glen Cove (No. 457), the following section was recorded:

Record of F. E. Willets's well near Glen Cove.

	Feet.
Wisconsin drift and Hempstead gravel member of Manhasset formation:	
Brown loam	0– 9
Brownish gravel and sand	9– 29
Montauk till member of Manhasset formation: "Hardpan"; clay with bowlders	29– 44
Herod gravel member of Manhasset formation:	
Light-colored sand	44– 70
Brownish clay	70– 85
Sand, growing whiter as the depth increases	85–158
Cretaceous (?):	
Clay, with enough grit to make it hard ("hardpan")	158–164
White gravel (no water)	164–182
White coarse sand, with an abundant supply of water	182–186

AGE.

As already noted in the discussion of the age of the Gardiners clay and the Jacob sand, the Herod gravel member of the Manhasset seems 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, bringing the Gardiners stage of clay deposition to a close. This ice sheet eventually invaded the region, producing the erosion features which are everywhere pronounced and leaving the thick Montauk till member. The deposition of the gravel was merely an incident of the invasion and belongs to the same glacial stage, which is considered to have been the equivalent of the Illinoian stage of the central United States.

MONTAUK TILL MEMBER.

NAME.

The term Montauk till member is applied to the middle of the three subdivisions of the Manhasset formation. It is at the horizon of the deposits described by J. B. Woodworth[1] as the bowlder clay bed of the Columbia (Manhasset of his geologic map), occurring in the gravel pits of Hempstead Harbor and vicinity. More detailed study has shown it to be present throughout the island and to reach an especially strong development on the south side of Montauk Point, from which it takes its name. The Manhasset bowlder bed of A. C. Veatch is the thin western representative of this member,[2] but the name Manhasset can not be applied to it because that name is preoccupied for the formation as a whole.

CHARACTER.

General composition.—The Montauk member in the western third of the island appears at first sight to consist of coarse, roughly laminated sands, in which many pebbles and bowlders are irregularly embedded. A closer examination, however, shows that the spaces between the visible sand grains are practically everywhere filled by a clay or quartz flour. At the west end of the island, west of Hempstead Harbor, the member abounds in bowlders and is often spoken of as a bowlder bed. The pebbles and bowlders consist mainly of biotitic granite or gneiss and although many are much weathered they show signs of glaciation. Quartz pebbles, which are very common in the gravel beds above and below it, are scarce in the Montauk member.

Near the center of the island the bowlders form a less conspicuous part of the member, which here consists mainly of faintly laminated sands with an irregular sprinkling of pebbles and of bowlders 3 to 6 inches in diameter. The amount of clay present averages more than

[1] Bull. New York State Mus. No. 48, 1901, pp. 627-630. [2] Prof. Paper U. S. Geol. Survey No. 44, 1906, Pl. VII and elsewhere.

farther west, especially near the top of the member, where a pebbly clay is not uncommon. Bowlders, though not conspicuous in the exposed sections, are nevertheless present in considerable numbers, being thickly strewn along the beaches and over the floors of the erosion amphitheaters. Most of the pebbles and bowlders consist of acidic types of granites and gneisses.

In the Riverhead district and farther east the till is much more clayey, clay constituting in some sections, especially on the South Fluke, a large part of the member. Through it, however, are scattered many pebbles and bowlders, here largely of Triassic trap and sandstone. On the two flukes the till ranges from the faintly banded clay, sand, and bowlder type, like that noted as occurring in the center of the island, to the clay type of the Riverhead district, the latter phase being especially common at the top of the member. Cretaceous fossils are found in the till at Montauk.

Till and gravel phases.—Although in its typical development the Montauk member may be defined as a laminated till, it exhibits many variations in character. The lamination is likely to be found anywhere strongly marked, and the clay and sand to be assorted into laminæ and layers, giving the whole mass a definitely stratified character. The gravelly phase is generally coarser and more irregularly stratified and carries both more clay and more granitic material than either the underlying Herod gravel member or the overlying Hempstead gravel member. Transitional phases are commonly not difficult to recognize, but the pure gravel type, unless it carries berg-dropped bowlders or bowlder pockets, can seldom be identified with certainty. The gravelly phase is most common in the western part of the island, and the till phase is perhaps most persistent in the central part. Near the east end gravelly phases are also common, but here, instead of the whole bed giving way laterally to gravel, it is more common for only a part of the bed to undergo this change, gravels and sands being interbedded with till layers.

Lamination.—The lamination mentioned is very characteristic of the Montauk member, probably being visible in fully 95 per cent of the exposures, and from the fact that it is exceedingly rare in the Wisconsin drift it affords one of the best means of identifying the Montauk member. It might be called incipient stratification. It is usually inconspicuous when seen close at hand, especially in unweathered exposures, but it generally appears sharp when seen a few feet away. The appearance of lamination seems to be produced in some places by an alignment of scattered pebbles, but it is more commonly due to differences in texture, which although indistinct in fresh exposures are brought out clearly by differential weathering. The layers giving rise to the laminated aspect are more like bands than definite strata and are not distinctly separated from the adjoining mass.

Cementation.—The cementation of the Montauk materials is, next to the lamination, the most characteristic feature of the till phase, being observable in more than 75 per cent of the exposures of that phase. The material is cemented into a mass difficult to penetrate with a pick and impossible with a shovel. Such material may weather like soft rock, giving rise to the knife-edge ridges and needle-like pinnacles that are very characteristic of what is commonly known as "badland topography." The cementation, however, is not confined to the till but is present in the gravel phase of the Montauk member at many points. The best illustration of this feature is afforded by the gravels of Lloyd Neck, which, though not forming pinnacles like the till, nevertheless show a sharpness of noses and gullies not seen in any other gravel on the island.

Color.—The normal till of the Montauk member has a dull bluish or gray color, due in part to the high percentage of erratic fragments present and in part to the gray color of the quartz-flour matrix. Probably 75 per cent of the till exposures show this color. Of the remainder perhaps 5 per cent are of a dull gray-buff color, in part resulting from the smaller proportion of granites present and in part from a slight staining of the quartz.

In the Riverhead region some of the till is discolored by the fragments of Triassic sandstone that it contains, and some has a superficial staining due to wash. On the South Fluke and to a less extent elsewhere much of the body of the till is colored greenish, dark gray, or red by the Gardiners clay worked into it. At one or two points on the north shore quartz pebbles derived from the Cretaceous, the Mannetto gravel, or the Jameco gravel give the Montauk member an abnormally light color. Chalky grayish-white shades are also conspicuous beneath kettles containing peat, where the till is locally bleached.

Oxidation.—As indicated above, the Montauk is normally of a grayish color and, except where exposed at the surface, presents to the eye little evidence of oxidation. In some of the more sandy and porous phases, however, recognized by their buff color, incipient oxidation is observed. Where it rests in its normal position beneath the Hempstead gravel member there is no special weathering of its upper surface, hence its unconformable contact is doubtless the result of ice action rather than of subaerial erosion. Where the till was at the surface before the advance of the Wisconsin ice it appears to have been somewhat deeply weathered, but most of the weathered part was reworked and incorporated in the Wisconsin drift. Deep weathering is to be seen in some of the thick till of Montauk, Plum Island, and other localities.

SOURCE OF MATERIALS.

The materials of the Montauk till member are evidently of glacial origin, a large percentage of the fragments showing clear signs of glaciation, and the method of their accumulation indicating association with or at least close proximity to an ice sheet. The coarser materials, including the bowlders throughout the larger part of the member, are clearly derived from the area of crystalline rocks in Connecticut. The Triassic material so abundant in the district near Riverhead is likewise derived from Connecticut outcrops. Of the finer material, a part was probably derived from the deposits of Long Island Sound, but the greater portion seems more likely to have come from the Herod gravel member, the Jacob sand, and the Gardiners clay, which, as has been indicated, were all deeply eroded by the Montauk ice. The part that the Gardiners clay has contributed in places is clearly shown by the large quantities of colored clays reworked into the till on the South Fluke from Riverhead eastward.

RELATION TO OTHER DEPOSITS.

As is brought out in detail in the sections relating to the distribution of the Gardiners clay, the Jacob sand, and the Herod gravel member of the Manhasset formation, there is considerable variety in the relation of the Montauk till member to the underlying beds. The drift in some places rests conformably on the Herod gravel member (fig. 113, p. 126), but in others, where the erosion by the Montauk glacier was severe, it rests on the Jacob sand (fig. 93, p. 109) or even upon the Gardiners clay (fig. 62, p. 93). The underlying beds are almost invariably disturbed and in many places are highly folded and faulted.

In eastern Long Island, as stated in more detail on pages 201, 207, and 208, there were several advances of the Montauk ice, the last of which folded, crumpled, and faulted the underlying strata, including the earlier beds of the Montauk member, but deposited little or no till. As a result, the Montauk member in places has an unconformable upper contact (fig. 178, p. 153), even though the normal sequence was not interrupted, thus supplying an example of what may be called contemporaneous erosion.

In the greater part of eastern Long Island the ice seems to have lingered until the closing stages of the Manhasset accumulation, the Hempstead gravel member, which farther west marks the final stage, being commonly absent, and either the original or the ice-eroded Montauk surface being left practically uncovered until the mantle of Wisconsin till was spread over it. Owing to the reworking of the surface by the ice sheet that deposited the later drift, it has been impossible to determine the extent of the weathering.

STRUCTURE.

The Montauk till member is commonly less disturbed than the underlying deposits, mainly because the latter received the brunt of the first vigorous advance of the glaciers, before the ice became overloaded with drift and began to deposit. In fact, throughout the western two-thirds of the island the Montauk deposits are but little disturbed, for the ice apparently never regained sufficient vigor to produce either erosion or folding. In the eastern third of the island, however, and on the adjacent islands, the period of deposition appears to have been followed by a resumption of ice activity, bringing on a period of scouring, folding, and faulting even more vigorous than the first.

DISTRIBUTION.

West of Little Neck Bay.—An examination of the cliff sections west of Little Neck Bay seems to reveal the presence of two sheets of till separated in some places simply by an erosion unconformity and in others by the unconformity and a gravel bed. This region taken by itself affords few certain data for differentiating the deposits, all of which might belong to the Wisconsin. The lower till, however, shows the tendency to make abrupt transitions and to break up into irregularly stratified gravels which is characteristic of the Montauk member but which is rarely if ever seen in the Wisconsin of Long Island. Moreover, although the exposures are much interrupted, the till when followed step by step toward the east, appears to become more definite and to pass into the bowlder-bed phase of Hempstead Harbor. It therefore seems probable that the lower till of the region west of Little Neck Bay belongs to the Montauk member. The best section was that seen in the bluff one-third of a mile east of College Point, where the relations were as shown in figure 136.

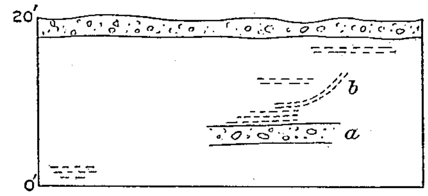


FIGURE 136.—Section one-third of a mile east of College Point, showing Montauk till member (*a*) beneath Hempstead gravel member (*b*).

Great and Manhasset necks, North Hempstead.—On Great Neck, North Hempstead, where the cliffs are not obscured by talus nor artificially covered, traces of the Montauk till member were observed here and there between the Herod and Hempstead gravel members, but only on Manhasset Neck were clear-cut exposures seen. Among the best of the cliff sections was that at Barker Point, on the east side of the entrance to Manhasset Bay. The section as observed by J. B. Woodworth[1] is shown in figure 137. The section as exposed when seen by the writer in 1904 showed the same succession but with more marked disturbance of the beds.

East of Barker Point, around the north end of Manhasset Neck, the exposures, although poor, show traces of the Montauk till member at many points. The till is best exposed, however, in the gravel pits facing Hempstead Harbor, south of Bar Beach. In these pits the Montauk member is represented by a relatively thin bed, usually ranging from 3 to 15 feet in thickness, which is remarkably persistent, being exposed in the same position in pit after pit. The bed here consists of a plastic or sandy bluish micaceous clay matrix in which are thickly embedded pebbles and glaciated bowlders of various sizes, some of them several feet in diameter. At this point there is no noticeable disturbance or erosion at the contact with the underlying beds. The large bowlders are here a characteristic feature of the formation, a feature which becomes still more marked in eastern Long Island and southeastern Massachusetts. So numerous are the bowlders along Hempstead Harbor that the bed may be traced, where not otherwise exposed, by the talus of large rocks trailing down the hillsides. Compared with those of the Montauk member, the Wisconsin bowlders are few and small. Heaps of Montauk bowlders in the gravel pits represent the unusable residue of the bed. Although in some respects among the best exposures on the island, the Manhasset Neck pits show the Montauk member in one of its weakest developments, the bed being not only thinner and less characteristic than at many other points but also lacking the usual accompaniment of folding and erosion.

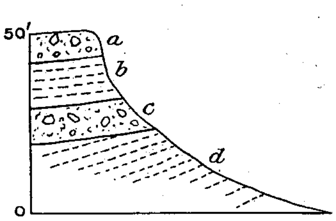


FIGURE 137.—Section at Barker Point, Manhasset Neck. *a*, Wisconsin till; *b*, Hempstead gravel member; *c*, Montauk till member; *d*, Herod gravel member. After J. B. Woodworth.

Hempstead Harbor to Oyster Bay.—Traces of the Montauk member were seen in some temporary exposures near Roslyn and at intervals to Glen Cove Landing. Just north of Weeks Point a very good exposure showing 20 feet or more of Montauk of the characteristic compact

[1] Bull. New York State Mus. No. 48, 1901, p. 629.

banded type was seen in 1904 (fig. 88, p. 108). A short distance to the north the till gives way to an equal thickness of the highly irregular gravelly phase of the Montauk. From this place to Rocky Point, 2 miles north of Oyster Bay, the bluffs are either obscured by talus or artificially covered. At Rocky Point, however, there are several fine exposures of the characteristic banded till of the Montauk member merging into semistratified gravels resting unconformably on the Gardiners clay and the Herod gravel member of the Manhasset formation (fig. 65, p. 96). At Coopers Bluff, on Cove Neck, the gravel phase seems to be strongly developed, although obscured at the time of the writer's visit.

Lloyd Neck.—Near the west end of the bluffs three-fourths of a mile southeast of Lloyd Point there is 50 feet or more of gravel of a very unusual type (Pl. XXII, *B*). It rests in apparent conformity on the Cretaceous, which is well exposed in the vicinity. It consists of irregularly bedded sand and gravel, the latter predominating. The pebbles are commonly from 1 to 3 inches in diameter, but there are many layers of coarse gravel in which not a few of the pebbles are from 4 to 6 inches in diameter. Quartz is, relatively speaking, sparsely represented. The great mass of the coarser material is granitic, giving the cliff a rather dark color compared with most of the cliffs of the island. At several points the pebbles were found to be much weathered, even the larger ones falling to pieces under the hammer and some of them crumbling in the fingers. Elsewhere the material appeared to be relatively fresh and firm. One of the most noticeable features of the gravel is its semi-induration, brought out in Plate XXII, *B*, which, although a face view, shows the noses and erosion channels very distinctly. These features appear still more sharp when seen in profile and afford a strong contrast to the outcrops of other gravels.

In its weathering the bed resembles to a certain extent the Mannetto gravel, but it differs from that formation in that the decay is not universal, that relatively little quartz is present though granites abound, that it averages much coarser in texture than any known Mannetto, and that its pebbles are unstained. The highly granitic character suggests some of the descriptions of the Jameco gravel as found in certain wells, but this gravel belongs below sea level, and in the absence of any evidence of folding on a scale to bring it up over a broad area there seems to be no possibility of correlating it with the Jameco. In its texture and in its cementation it differs widely from the Herod gravel member, but on comparing it with the gravelly phase of the Montauk till member we find more resemblances. As has been pointed out, this member, while normally a banded till, in some places grades into irregularly stratified gravels, which, though nowhere exposed on so large a scale as the gravels on Lloyd Neck, in small outcrops present the same appearance. In their cementation especially these gravels resemble those of the Montauk member, the only geologic division on the island above the Mannetto gravel that exhibits this feature. In fact their cementation, together with their peculiar stratification, affords an almost certain means of identification. The gravels at this point are therefore regarded as a local phase of the Montauk till member. The exceptional weathering of a part of the gravels is regarded as due to the incorporation of portions of ledges or of older deposits in which decay was already in progress but had not yet reached the stage of disintegration. The correlation is made more certain by the presence of the Montauk member in its normal phase resting against the opposite or east side of the Cretaceous knob, the relations at this point being as shown in figure 138. The Montauk member appears to sink below sea level where the beach curves toward the north half a mile farther east (fig. 175, p. 152), but it is seen again at several places for half a mile northwest from East Fort Point (fig. 176, p. 152). The Montauk member at this point is a fine-grained, clayey, compact, semi-indurated till, whereas the overlying Wisconsin is a loose, weathered, and not at all indurated till, with many large cobbles and small bowlders. The difference in color of the two deposits was striking and could be perceived readily by the eye at a distance of a mile. Actinically, however, the difference was not so great and the photograph reproduced as Plate XXII, *A*, does not show the contrast.

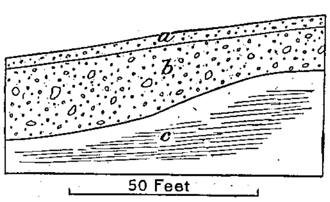
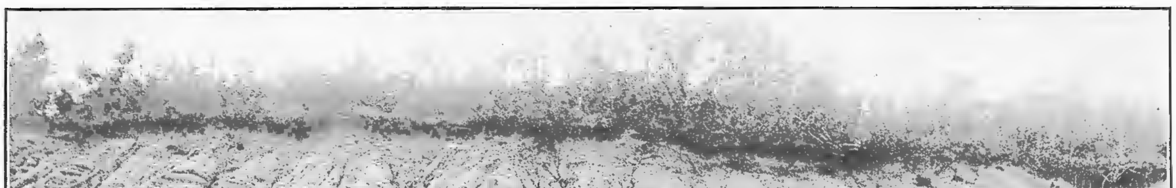


FIGURE 138.—Section east of Lloyd Point, Lloyd Neck. *a*, Wisconsin till; *b*, Montauk till member; *c*, Cretaceous.

A. CONTACT OF WISCONSIN TILL WITH MONTAUK TILL MEMBER AT LLOYD NECK.



B. GRAVELS (MONTAUK MEMBER OF MANHASSET FORMATION?) ON LLOYD NECK.

Showing composition and erosion. Photograph by G. N Knapp.

West Neck.—In the large abandoned clay pits near the south end of Lloyd Beach, on Cold Spring Harbor, a considerable thickness of semistratified till of the Montauk type is seen above the Cretaceous clay. The sections differ greatly but show a general resemblance to those on the north shore of Lloyd Neck. The thickness in the northerly pits is more than 30 feet, but in those farther south it ranges from 20 to 25 feet.

Little Neck, Huntington.—Half a mile south of Little Neck Point a bed of till about 20 feet thick containing many quartz pebbles was seen above the Cretaceous clay. Its relations were not shown, but from its thickness, which would be very abnormal for the Wisconsin at this point, it is believed to be Montauk. A little farther north a till resembling this bed was seen above highly folded and overturned glacial gravels (Herod member?). The same till still farther north grades into stratified beds of the type characteristic of the gravelly phase of the Montauk member.

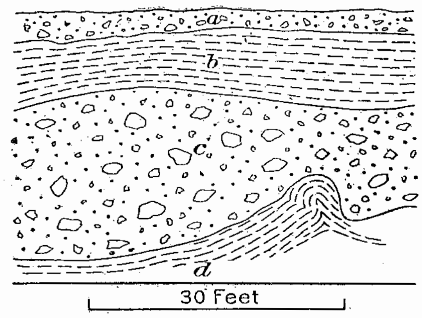


FIGURE 139.—Section midway between Nissequogue River and Stony Brook Harbor. *a*, Wisconsin till; *b*, Hempstead gravel member; *c*, Montauk till member; *d*, Herod gravel member. By D. W. Johnson.

Eaton Neck and vicinity.—Although evidences of Montauk erosion are pronounced on Eaton Neck, few exposures of the drift are seen. Figure 66 (p. 97) shows a few feet of the banded Montauk, as exposed near the base of the West Beach sand spit, on the west side of the neck. Other exposures were seen about four-fifths of a mile to the north, near Eaton Point and a quarter of a mile south of Eaton Neck light.

A quarter of a mile east of East Beach, which connects Eaton Neck with the mainland, the Montauk member was seen in the bluffs, and just west of the broad salt marsh the bluffs exhibited in 1904 a considerable thickness of the Montauk, separated by a sharp contact from the overlying brown loamy Wisconsin till.

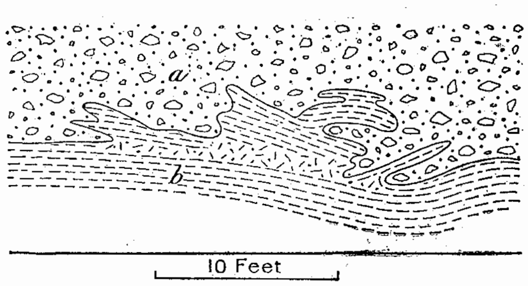


FIGURE 140.—Section showing details of the Montauk-Herod contact at the locality shown in figure 139. *a*, Montauk till member; *b*, Herod gravel member. By D. W. Johnson.

Fort Salonga.—In the bluffs east of the road leading to the beach from Fort Salonga, 3 miles northeast of Northport, are several fine exposures of the Montauk member. At the first of these, half a mile east of the road, 25 feet of gravel of the grayish semi-indurated and semistratified drift was seen beneath a few feet of structureless yellow Wisconsin till. A few hundred feet to the west the till graded laterally into gravel. The marked unconformity and disturbance between the Herod gravel member and the Montauk till member shown in figure 110 (p. 125) was near this point. A short distance farther east a fine section of indurated Montauk was noted. The Montauk was also seen above the Cretaceous clays west of the road to the beach.

Smithtown Bay region.—On the neck between Nissequogue Bay and Stony Brook Harbor the bluffs were commonly covered with talus, but a number of sections showing the Montauk till member resting upon disturbed beds of the Herod gravel member were noted, the contact being in places highly irregular (figs. 139 and 140). A similar exposure was seen in a roadside cut near the Stony Brook station (fig. 141).

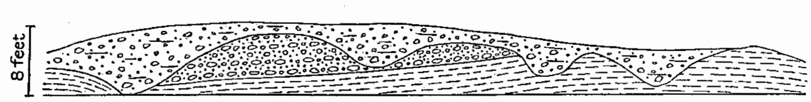


FIGURE 141.—Roadside section near Stony Brook station, showing contact of banded Montauk till member with Herod gravel member. By D. W. Johnson.

Crane Neck and Oldfield points.—The exposures of the Montauk south of Crane Neck Point rank among the best on the island, although its relations to the other beds are not well shown. From 30 to 40 feet of till is here shown, the lower 20 feet consisting of massive material with only feeble indications of banding. The upper part gradually becomes banded and then laminated and finally gives way at the top to gravel. One of the features of the exposure is an immense bowlder over 20 feet in diameter, occurring in the middle part of the till. On the north side of the point the bluffs are mainly talus-covered, but the Montauk till member appears to continue for half a mile. On Oldfield Point, 2 miles east, the exposures are poor, but the bluff appears to consist largely if not entirely of till, the greater part of which appears to be Montauk.

Port Jefferson to Wading River.—On the east side of Port Jefferson Harbor the exposures are poor, but the talus seems to indicate that the Montauk till member occurs low down, possibly extending below sea level. It probably rises inland, but it is not recognized in the big gravel pit south of Port Jefferson. East of Mount Misery Point, along West Beach, 20 feet of till was seen in places. This contains a bed of bowlders as much as 1 or 1½ feet in diameter, having an aggregate thickness of 4 or 5 feet. The till grades into gravel laterally and probably represents the Montauk member.

From this point eastward to Wading River nothing that could be definitely correlated with the Montauk member was noted. The bluffs in the interval show folded and in places faulted sands and gravels, the disturbance being of a magnitude comparable with that produced by the Montauk ice rather than by the Wisconsin. This feature would indicate that the Montauk, if present, occurs at a higher level than any exposures shown in the bluff, an assumption which is borne out by the fact that the next exposure of the Montauk—at Wading River—is at the top of the bluffs.

Wading River to Fresh Pond Landing.—Between East Landing and Herod Point, northeast of Wading River, the Montauk member reappears as a semi-indurated banded till at the top of the bluff, having a thickness of more than 20 feet (fig. 113, p. 126), but it soon disappears again. That its position is above the bluff sections is indicated by the disturbed character of the gravels. Near Paine Landing, three-fourths of a mile farther east, a thick bed of till of the Montauk type caps the bluffs and covers the slopes with its talus. The underlying layers are somewhat warped and eroded (fig. 114, p. 126). Just west of Hulse Landing the following section was measured in a gully:

Section west of Hulse Landing.

	Feet.
Recent: Dune sand	3
Montauk till member of Manhasset formation:	
Irregularly banded sands and gravels with bowlders	15
Pinkish sandy clay with pebbles	1
Gray banded till, semicemented	5
Herod gravel member of Manhasset formation: Horizontal sands and gravels	40

A similar section was seen in 1904 about 100 paces east of Hulse Landing at a point where the upper bowlder-bearing gravel was 20 feet thick and the lower till 10 feet thick, the intervening clay having disappeared. The till in this vicinity carries many large bowlders, hundreds of which lie upon the beach and extend out into the water, marking the former extent of the deposit. Some of them measure over 20 feet in diameter. A quarter of a mile to the east the Montauk member appears to reach a thickness of 50 to 60 feet but is of a grayish gravelly type rather than the usual compact partly cemented drift. From this point for half a mile eastward the till continues along the top of the bluff above 75 to 90 feet of the Herod gravel member.

Friars Head.—The most typical exposure of the Montauk till member on Long Island was seen in the vicinity of Friars Head, about a mile north of Baiting Hollow and 6 miles northwest of Riverhead. Nowhere else are the cementation, banding, and characteristic erosion so well shown. The drift is about 30 feet thick and consists of a mixture of sand, pebbles, and bowlders with some clay, which, with the help of percolating waters, has bound the whole mass into a firm, compact body that resists a hammer almost like a soft sandstone. The material seems, however, to loosen under the influence of water and has been eroded into sharp knife-edge ridges and needle-like pinnacles resembling the typical badland topography. This characteristic is well shown in Plate XIX, *B*, in which a thin layer of loose

Wisconsin till appears on top at the left. The view shows only small erratics, but bowlders 6 or 8 feet in diameter are seen at many places. Many of the fragments consist of trap and appear to have come from the Triassic areas of Connecticut. Some of them are weathered and rotten. So tenacious is the matrix that the bowlders stick to the almost vertical faces of the bluffs until it is almost entirely removed from around them (fig. 142).

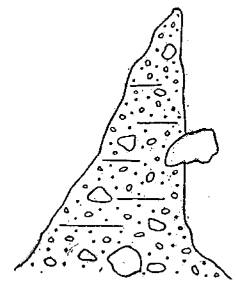


FIGURE 142.—Section of pinnacle of Montauk till member near Friars Head, illustrating tenacity of matrix as shown by projecting bowlder.

The banding of the Montauk member, which is faintly seen in a near view, is much more apparent from a distance, as brought out in Plate XIX, *B* (p. 114). The banding does not depart much from the horizontal, although it is here and there warped into broad undulations, as shown in figure 143. A near-by exposure shows the Herod gravel member beneath the till (fig. 115, p. 126), and a short distance to the east the Montauk is overlain by the Hempstead gravel member and Wisconsin till.

Roanoke Landing to Orient Point.—East of Friars Head the Montauk member is seen at short intervals for a distance of 2 miles, to a point nearly north of Riverhead, being in places represented by till and elsewhere by gravel phases (fig. 179, p. 153). A good exposure of the gravel was seen in a ravine a little west of Roanoke Landing, although near by the till phase was well developed. The following section shows the conditions near the landing:

Section near Roanoke Landing.

	Feet.
Recent: Dune sand	10
Hempstead gravel member of Manhasset formation: Buff, irregularly stratified sand and gravel	20
Montauk till member of Manhasset formation: Banded till with bowlders (possibly includes some Herod gravel member at base)	80

The Montauk member is reduced in thickness toward Roanoke Point, where it is represented by a 15 to 20 foot bed about two-thirds of the way up the bluff. It is in places clayey and here and there is tinged red by the wash from sandstone fragments, which with many trap bowlders have been brought from the Triassic area of Connecticut. Some of these bowlders reach 15 feet in diameter. The beds under the Montauk are in places strongly folded. Near Roanoke Point the Montauk is found at the top of the bluffs and merges with the Wisconsin till, but farther east it is seen in a lower position persisting as a reddish bed 15 feet thick at 80 to 100 feet above the beach (fig. 144). It has afforded large bowlders at several points.

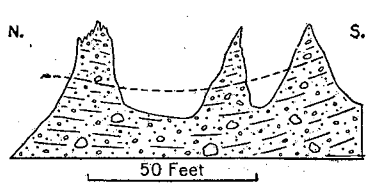


FIGURE 143.—Section near Friars Head, showing character of erosion and undulations of banding in Montauk till member.

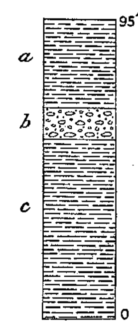


FIGURE 144.—Columnar section east of Roanoke Landing. *a*, Hempstead gravel member; *b*, Montauk till member; *c*, Herod gravel member.

A poor exposure of the Montauk member banked against upturned Jacob sand was seen at the landing west of Jacob Point (fig. 91, p. 109), but this member was not again observed between this landing and a point half a mile beyond Luce Landing, where the following section showing doubtful Montauk occurs:

Section east of Luce Landing.

	Feet.
Recent: Dune sand	5
Wisconsin: Buff till merging downward into gray till	15 (bracketed with next line)
Montauk till member of Manhasset formation (?): Gray till	
Herod gravel member of Manhasset formation: Irregularly bedded sand and gravel	60

A section just beyond is shown in figure 145, and another a quarter of a mile farther east in figure 146. In neither place is it absolutely certain that the till is Montauk. The till continues with similar relations for another quarter of a mile and then disappears from the bluff sections, although it is probably present higher up in the hills, as the lower beds are strongly folded. The sections shown in figures 93 (p. 109) and 182 (p. 154) were observed in 1904 near Jacob Hill. The till was of the normal banded, semicemented type.

The next exposure suggesting the Montauk member was seen about half a mile east of the west end of the Oregon Hills, where a bowlder bed of granites and Triassic traps and sandstones appears in the middle of the bluffs (fig. 147). The mass was stained reddish by wash from the sandstone fragments and in places graded into a sand. A quarter of a mile farther east a 10-foot bed of gray till overlain by cross-bedded ferruginous cemented sands and gravel (the gravelly phase of the Montauk ?) was exposed. A mile southwest of Duck Pond Point occurs the section shown in figure 116 (p. 126). Near this point several pockets of bowlders were observed at the horizon of the Montauk and probably represent that member (fig. 148). Farther east a persistent bed of cobbles was followed for several hundred feet.

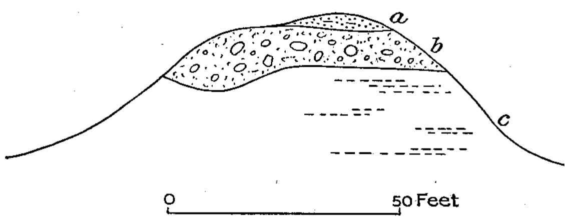


FIGURE 145.—Section half a mile east of Luce Landing. *a*, Dune sand; *b*, till (mainly Montauk till member); *c*, Herod gravel member.

A mile and a half east of Duck Pond Point the following section was measured:

Section 1½ miles east of Duck Pond Point.

	Feet.
Recent: Dune sand	3
Wisconsin: Bowlder till	5
Montauk till member of Manhasset formation: Banded, semicemented sands with pebbles irregularly distributed through the mass	10
Herod gravel member of Manhasset formation: Gravel and sand	12

Between the locality last mentioned and a point a quarter of a mile south of Inlet Point, northwest of Greenport, large quantities of till were seen, much of it crowded with bowlders. The washing away of the finer parts of the till has left a thick fringe of bowlders along the beach, in some places piled in great heaps. The exposures do not in general permit the differentiation of the Montauk member from the Wisconsin, but it is thought that a considerable part of the material may belong to the Montauk.

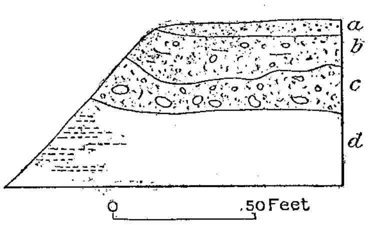


FIGURE 146.—Section three-quarters of a mile east of Luce Landing. *a*, Dune sand; *b*, fine banded till (Wisconsin or Montauk); *c*, Montauk till member; *d*, Herod gravel member.

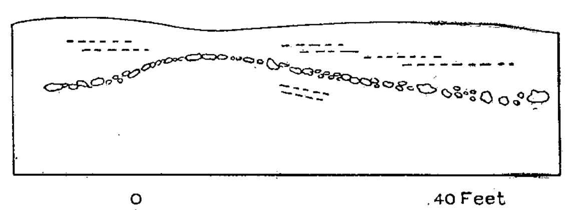


FIGURE 147.—Section at Oregon Hills, showing layer of cobbles and bowlders, presumably representing the Montauk till member.

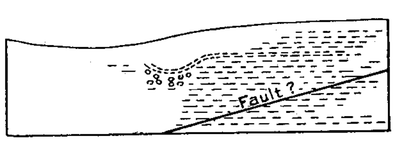


FIGURE 148.—Section near Duck Pond Point, showing fault and bowlder pocket (Montauk till member) in gravels of Manhasset formation.

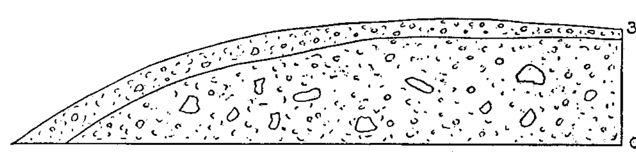


FIGURE 149.—Section a quarter of a mile south of Inlet Point, showing relation of Wisconsin till to Montauk till member.

The accompanying section (fig. 149) shows the relation of the Wisconsin and Montauk at a point a quarter of a mile south of Inlet Point. In general the Montauk appears to be a pebbly rather than a bowlder till.

From Inlet Point to Orient Point much the same conditions prevail. The Montauk member for the most part can not be separated from the Wisconsin till with certainty, although the thickness of the mass at many points and the extent to which the underlying beds have been folded seem to prove that the Montauk is represented (fig. 96, p. 110). A bowlder pocket similar to those formed at Oregon Hills and vicinity was noted three-fourths of a mile south of Rocky Point (north of Greenport), resting in a depression in the Montauk. This pocket deposit was of a type transitional between the till and ordinary gravel, consisting of interlaminated sand and clay with pebbles and small bowlders scattered through it.

East Williston.—Near the village of East Williston, about 3 miles south of the head of Hempstead Harbor and about a mile south of Ronkonkoma moraine, a clay pit in a shallow depression of the outwash surface exhibits the following section:

Section in clay pit at East Williston.[1]

	Feet.
Soil	1.5
Sand, gravelly, with quartz and granitic pebbles, locally reddened	8
Clay, sandy, with quartz pebbles	
Clay, sandy, in yellow band	
Clay, blue, finely laminated, rarely with quartz pebbles; exposed	3

In addition to the quartz pebbles the writer found in the pit many small pebbles of rotten granite and in a near-by well a greenish biotitic sand such as would be expected to result from a decomposed bowlder. Heinrich Ries[2] reports unidentifiable stems and leaves. The bed is of small extent, wells a mile away generally failing to encounter it.

The age and origin of this clay present a rather puzzling problem. Ries and Crosby seem to refer it to the Tertiary, but recent observations show that it not only contains glacial pebbles throughout but is also underlain by glacial gravels. In all probability it is to be referred to the Montauk member of the Manhasset or to the Wisconsin till, representing reworked Cretaceous materials, Gardiners clay, or deposits of the Vineyard interval. In favor of the Montauk origin may be mentioned the clayey character of the material and the advanced decay of the granites, although these might represent older deposits reworked into the Wisconsin. Against the Montauk origin is the altitude of the bed (150 feet), which is somewhat greater than the normal elevation of the Montauk member in this region. On the other hand, the altitude is what might be expected of an extramorainal deposit of Wisconsin till, but against the Wisconsin origin may be urged the thickness of the deposit, its extent (apparently half a mile or more), and its clayey character, all of which are abnormal for lenses of the later drift. On the whole the writer feels that the deposits will most likely prove to be Montauk.

Half Hollow Hills.—An examination of the materials forming the terrace-like top of the Half Hollow Hills discloses irregularly bedded gravels considerably coarser than the gravel members of the Manhasset and containing scattered bowlders, now seen on the terrace surface and on the slopes and at the foot of the hills. The largest bowlders were noted on the road leading into the hills 1½ miles northeast of Wyandanch. The materials of the hills most nearly resemble the Montauk member, with which they are provisionally correlated.

Middle Island region.—The surface of the region between Coram and the headwaters of Peconic River is characterized by many bowlders and some patches of material resembling till. Inasmuch as there is considerable Wisconsin drift in the region, as indicated by the superficial morainal topography and the obstruction of the Manhasset valleys, it is difficult to differentiate the surface material, but it is thought that a part of the bowlders and till may represent the Montauk member.

Red Cedar Point.—On the South Fluke, which is here assumed as starting at Riverhead, the first recognizable exposure of the Montauk member to the east appears about a mile east of Red Cedar Point and about 6 miles east of Riverhead. The till appears to begin almost at the west end of the bluffs but is not well exposed for some distance. About a quarter of a mile from the beginning of the cliffs, however, a fine exposure of highly folded and overturned

[1] Woodworth, J. B., Bull. New York State Mus. No. 48, 1901, p. 645.

[2] Trans. New York Acad. Sci., vol. 12, 1893, pp. 40-47.

Montauk and other beds was seen (fig. 150). The Montauk at this point is very clayey, consisting of alternating bands of gray and red clayey sand in which are embedded large numbers of bowlders of Triassic trap and red sandstones with some granite. The clayey character is believed to be due to the reworking of the underlying Gardiners clay and Jacob sand into the till. The mass is superficially stained a distinct red by wash from the weathered Triassic fragments, but internally it is of a buff or gray color. The beach in front of the exposure is paved with trap bowlders.

Shinnecock Hills and vicinity.—About half a mile east of Shinnecock Canal, in an old clay pit, on the shore of Great Peconic Bay, is an exposure of a pebbly clay type of Montauk till overlying and plainly derived from the Gardiners clay. In the hill north of Cold Spring Pond, 1½ miles farther northeast, the usual compact banded type of Montauk till was noted at several points. The full thickness was not exposed, but it is known to exceed 30 feet (fig. 183, p. 154). Bowlders of the Triassic formations continue to be conspicuous.

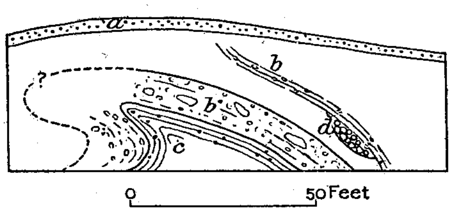


FIGURE 150.—Section 2 miles northwest of Shinnecock Canal. *a*, Wisconsin till; *b*, banded clay till with bowlders (belongs to Montauk till member); *c*, banded clay and pebble till (belongs to Montauk till member); *d*, bowlder pocket.

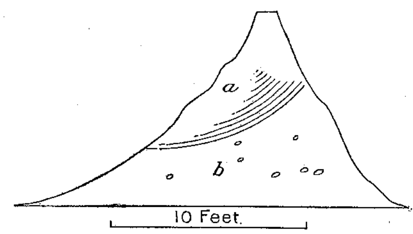


FIGURE 151.—Section on west side of Hog Neck, northwest of Sag Harbor. *a*, Overturned fold of sandy clays with erratic pebbles representing reworked Gardiners clay and belonging to the Montauk till member; *b*, Herod gravel member.

Jessup Neck.—On the west side of Jessup Neck, near the north end of the exposures, the section shown in figure 184 (p. 154) was seen. The material is a brownish till-like mass of bands of red and gray clay, in which pebbles and cobbles with some Triassic bowlders are irregularly embedded. The Montauk ice after depositing this mass seems to have become more vigorous and to have both folded and eroded the material it had laid down, so that the overlying Hempstead gravel member lies unconformably across the top. The surface of the exposure is stained red by the wash from the red clay and Triassic material.

Hog Neck.—A quarter of a mile south of the north end of the bluffs on the west side of Hog Neck, 3 miles northwest of Sag Harbor, several feet of greenish-blue clayey till containing both erratic pebbles and broken fossils was seen, the whole resulting from a reworking of the underlying Gardiners clay with a certain admixture of foreign material. The bed is much folded and contorted, standing out in the cliffs with the relations shown in figures 151 and 152. A quarter of a mile to the south a gray to bluish-gray till (Montauk?) is seen below an upper rusty yellowish to buff till representing the Wisconsin, the two being separated by a very sharp contact.

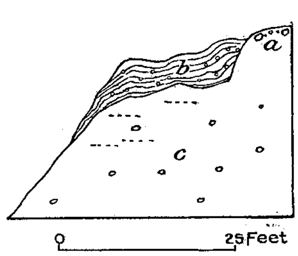


FIGURE 152.—Section on west side of Hog Neck, northwest of Sag Harbor. *a*, Till; *b*, overturned fold of contorted sandy clay with erratic pebbles representing reworked Gardiners clay and belonging to the Montauk till member; *c*, Herod gravel member.

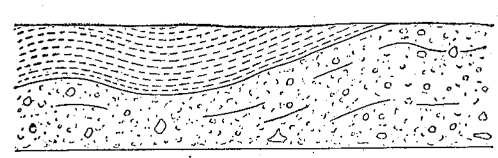


FIGURE 153.—Section near Hog Creek Point, on South Fluke, showing Hempstead gravel member resting on Montauk till member.

Cedar Point.—About two-thirds of the way between Cedar Point and Sammys Beach, some 5 miles northeast of Sag Harbor, typical banded till of the Montauk member was seen associated with highly folded and faulted gravels, the relations being as indicated in figures 119 (p. 127) and 121 (p. 128).

Hog Creek Point.—The bluffs between Sammys Beach and Hog Creek Point were generally covered with talus, but the greater part of the material appeared to be till, with some banded or even well-stratified layers, which, however, merge into true till. At the head of the point, near Lion Head Rock, till of the Montauk type was seen in broad low folds, the relations being as shown in figure 153. Similar relations appear to continue, though less satisfactorily exposed, at intervals to the end of the bluffs near Fire Place. Above the till at several points is a series of sands involved with the till in broad open folds (fig. 154). Their character and position are typical of the Hempstead gravel member, but the folds have been beveled off at the top in a manner exactly analogous to the erosion produced by the final readvance of the Montauk ice, and the gravels may be simply a phase of the Montauk member.

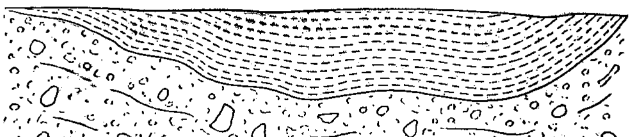


FIGURE 154.—Section near Hog Creek Point, on South Fluke, showing Hempstead gravel member resting on Montauk till member.

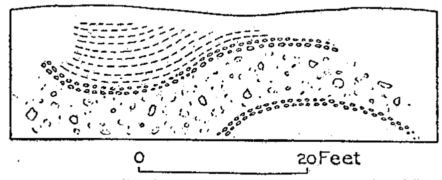


FIGURE 155.—Section 1 mile west of Rocky Point, Montauk, showing bed of banded Montauk till member beneath layer of granitic gravel and cobbles and granitic sand and gravel (Hempstead gravel member).

Montauk peninsula.—Between Fresh Pond and Quince Tree Landing, at the east end of the bluffs on Napeague Bay, the Montauk member was seen poorly exposed in the upper part of the bluffs. It is at least 15 feet thick and may be considerably thicker, as there are indications that it may in places extend down to the beach. Just south of the landing an exposure showing the Montauk member in a broad fold was seen (fig. 109, p. 124). Figure 155 shows folded beds of the Montauk member, as seen half a mile west of Rocky Point. A near-by section (fig. 156) showed a layer of gravel interbedded with till of the Montauk member. Strong talus slopes of till character are seen at Rocky Point and vicinity.

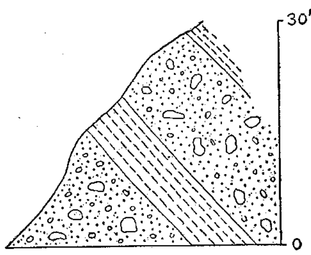


FIGURE 156.—Section 1 mile west of Rocky Point, Montauk, showing intercalated bed of gravel in Montauk till member.

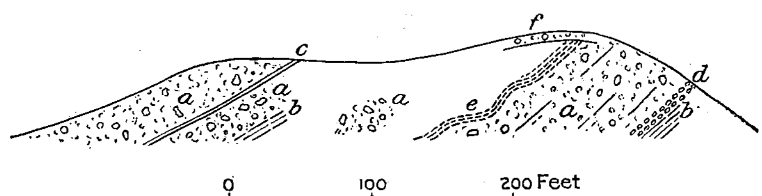


FIGURE 157.—Section half a mile south of Culloden Point, Montauk, showing intercalated sand and clays in Montauk till member. *a*, Montauk till member; *b*, clayey sand; *c*, clay; *d*, gravel; *e*, sand; *f*, Wisconsin till.

From Fort Pond to Culloden Point the bluffs are largely covered by talus, but till, presumably of the Montauk member, seems to be the predominating material. There are indications that thin strata of both clay and sand are interbedded with the till (fig. 157). Near Culloden Point the Montauk member is exposed for some distance at the base of the bluff. Its upper surface is very irregular, but whether the irregularity is due to erosion or to folding could not be determined (fig. 187, p. 155). An exposure showing what appears to be Montauk till member banked against folded beds of the Herod gravel member is shown in figure 124 (p. 128).

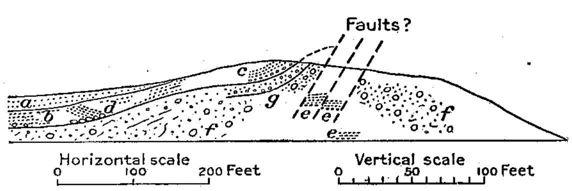


FIGURE 158.—Section east of Montauk Light, showing Hempstead gravel member resting on Montauk till member. *a*, Buff sand belonging to Hempstead member; *b*, sand, with greenish clayey laminæ, belonging to Hempstead member; *c*, sand and fine gravel belonging to Hempstead member; *d*, iron-stained bowlders and ferruginous conglomerate layer at top of Montauk till member; *e*, sands and gravels (downfaulted beds of Hempstead member?); *f*, faulted banded beds of Montauk till member; *g*, semistratified drift of Montauk member.

At Shagwong Point and at the headland just east of Oyster Pond 10 feet or more of indistinctly banded Montauk till member was seen in the lower part of the bluffs beneath reddish clay, apparently a local phase of the Montauk, from the wash of which it is stained red in places on its exposed surfaces. A quarter of a mile east of the second headland a considerable thickness of the Montauk was observed resting above a dark chocolate-colored clay assumed to be the Gardiners clay. The drift consists of an upper banded till of the type characteristic of the Montauk and a lower more gravelly phase grading laterally into gravel, as shown in figure 76 (p. 99).

The Montauk till member appears again a little southeast of False Point in folded masses with dips as high as 30° in places. Some of the exposures were very clear and sharp in 1904. Toward the southeast the till sinks below the beach, but it rises again near the lighthouse (fig. 174, p. 151). The till at this point contains many large fragments and is somewhat banded but is not much cemented. It grades upward into a banded clayey till with many erratics.

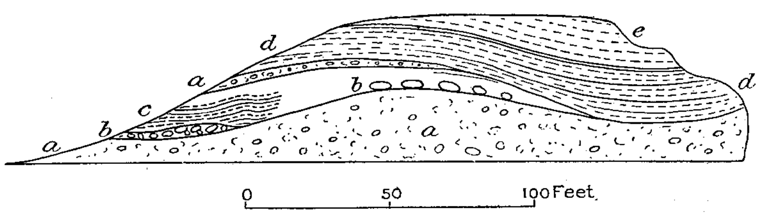


FIGURE 159.—Section southeast of Montauk Light. *a*, Till phase of Montauk till member; *b*, bowlder pocket; *c*, sand and clay phase of Montauk member; *d*, clayey sand phase of Hempstead gravel member; *e*, normal sandy phase of Hempstead gravel member.

In the immediate vicinity of the Montauk lighthouse the Montauk member is seen in a thick bed at the base of the bluff, where it has the characteristic banded development. The profile of the extreme point, looking east, was in 1904 as shown in figure 189 (p. 155). Figure 158 (p. 143) illustrates the complexity of the exposures just north and figure 159 shows the conditions immediately south of the lighthouse.

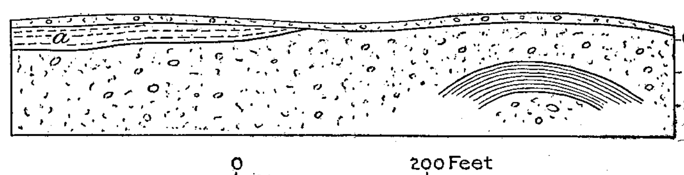


FIGURE 160.—Section 1½ miles southwest of Montauk Light, showing red clays intercalated in till of Montauk till member. *a*, Hempstead gravel member (?).

From Montauk Point southwestward to the point marking the abrupt change in the direction of the coast line to a more westerly bearing the exposures of the Montauk member are almost continuous. Among the features of interest in this stretch is a thick bed of dark-brown to red clay interbedded and folded with the till of the Montauk member at a point about 1¼ miles from the lighthouse and half a mile from the southerly point mentioned. Its relations are shown in figure 160.

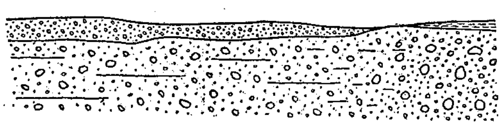


FIGURE 161.—Section 1¾ miles southwest of Montauk Light, showing gradation (from left to right) of banded and massive Montauk till member and its relations to the overlying Wisconsin.

West of the bend in the coast just mentioned the Montauk is almost continuously exposed for nearly a mile (fig. 192, p. 156). In places nothing but till is observed in the bluffs, although it is here divided into an upper loose buff to brown till, probably Wisconsin, and a much thicker banded mass belonging to the Montauk. The section is represented in figure 161, which shows the two tills and the gradation of banded into massive Montauk till. Half a mile farther east the Montauk shows a thick lens of sand and gravel, not unlike the Herod or Hempstead members, between two beds of drift (fig. 162). The lens is practically undisturbed, the stratification still retaining its horizontal position. A feature of the Montauk in this region is its whitish color beneath kettle holes containing peat. Though ordinarily of a buff color, it is here bleached to a chalky white, the difference in color

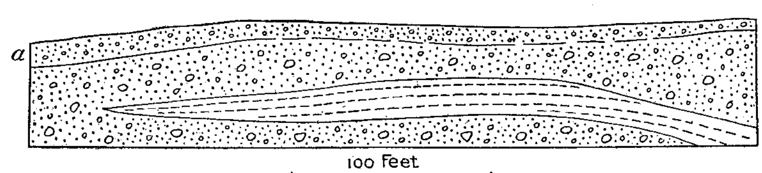


FIGURE 162.—Section 2 miles southwest of Montauk Light, showing lens of stratified gravel in Montauk till member. *a*, Wisconsin till.

between adjacent masses being noticeable even from a distance. Figure 59 (p. 89), shows the Montauk resting on upturned and eroded sands, gravels, and clays.

Between Ditch and Fort plains there appears to be another almost continuous exposure of the banded till of the Montauk member, but the outcrops are more obscured than farther east (fig. 191, p. 156). The upper part seems to be a thin coating of Wisconsin till, which at one place thickens to 25 feet, comprising nearly half of the bluff. Toward the west end of the bluffs the Montauk is seen in contact with the underlying gravel.

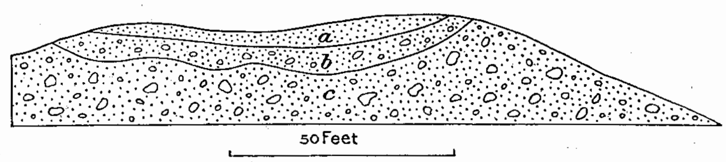


FIGURE 163.—Section on south side of Montauk peninsula between Napeague and Hither Plain life-saving stations. *a*, Dune sand; *b*, Wisconsin till; *c*, Montauk till member.

West of Fort Pond the bluffs of the south coast seem to be a duplication of those near Montauk Point, except that the gravelly phase of the Montauk is more commonly present. There is generally a sharp demarcation between the Montauk and the overlying Wisconsin (fig. 163). The Montauk till is not uncommonly interbedded with stratified clay, sand, and gravel (fig. 164), some of the beds of which reach in places a considerable thickness.

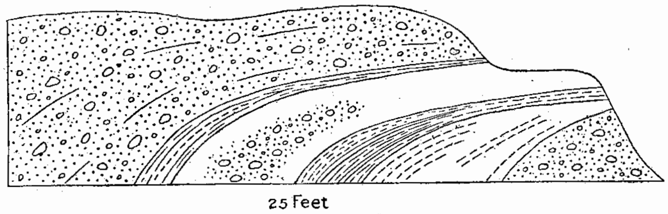


FIGURE 164.—Section on south side of Montauk peninsula between Napeague and Hither Plain life-saving stations, showing intercalated clays, sands, and gravels in Montauk till member.

The strong development of the Montauk member on Montauk Point, the profiles of the bluffs now cut in the south coast, and the offshore rocks and bars all point to a former extension of the Montauk member considerably farther south. It is not improbable that the Montauk ice sheet extended some distance into the sea, and in that case more or less Montauk till, if not eroded by the late Manhasset ice or in the Wisconsin stage, would naturally be found south of the moraine or even beneath the sea. The only known evidence of such extension is the uncovering of bowlders and other glacial material by the waves along the coast in the vicinity of Easthampton, noted by Mather.[1]

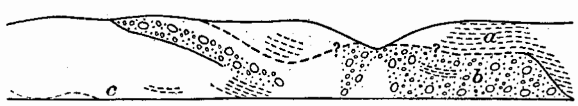


FIGURE 165.—Section on east side of Robins Island. *a*, Hempstead gravel member; *b*, Montauk till member; *c*, Herod gravel member (?).

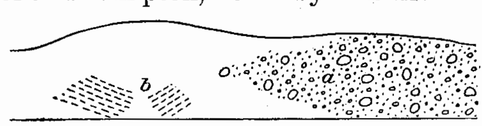


FIGURE 166.—Section on east side of Robins Island. *a*, Montauk till member; *b*, Herod gravel member.

Robins Island.—There does not seem to be any strong development of Montauk on the west side of Robins Island, for although the beds are folded and faulted as if by Montauk ice, only a thin layer of till, which might be either Montauk or Wisconsin, is seen at the top. Some of the gravels contain considerable quantities of clay intermingled with the grains in the sands and show more cementation than elsewhere occurs in the Herod gravel member. The same is true to an even greater extent of some of the gravels of the east shore and it is not unlikely that both may represent the gravelly phase of the Montauk. Near the north end of the bluffs on the east side the banded-till phase of the Montauk is locally well developed, although the complexity of the disturbance makes its relations uncertain. Figures 165 and 166 represent the conditions of the exposures in 1904.

Shelter Island.—Bluff exposures showing the Montauk in section are not known on Shelter Island, although it seems probable that the Montauk occurs under the talus in the lower part of some of the bluffs. If so, it is likely to be exposed in any storm. The surface till of the

[1] Mather, W. W., Geology of New York, pt. 1, 1843, p. 165.

southern half of the island, especially in the low till plains of the east and south coasts, is regarded as probably Montauk, as its thickness is much greater than it seems possible to ascribe to the Wisconsin, which is thin elsewhere.

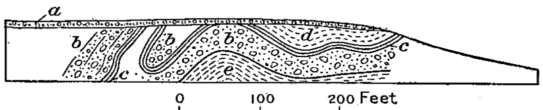


FIGURE 167.—Section at south end of Bostwick Bay, Gardiners Island. *a*, Wisconsin till; *b*, banded till of Montauk till member; *c*, thin layer of green to black clay (Montauk); *d*, sand and gravel (gravel phase of Montauk till member); *e*, Herod gravel member.

Gardiners Island.—Traces of banded till resembling the Montauk were visible at many points on the southwest coast of Gardiners Island, but no clear-cut exposures were observed. On the northwest coast between Cherry Hill Point and Bostwick Bay a very good exposure of the strongly folded and leveled Montauk member was seen, its relations being as indicated in figure 167. The contact between the till and the overlying gravel phase is marked by a layer of dark-green to black clay from 3 to 5 feet thick, resembling in occurrence that at Shagwong Point, on Montauk. In fact, the Montauk member of Gardiners Island presents many strong resemblances to that on Montauk peninsula.

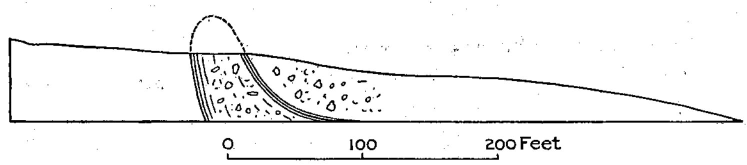


FIGURE 168.—Section near north end of bluffs on northeast shore of Gardiners Island, showing folding of bed of banded till of Montauk till member with the intercalated clay.

On the northeast coast the Montauk member is commonly absent, although its horizon is in places marked by erosion unconformities or by bowlder pockets or layers and near the north end a thick bed is involved in a large fold (fig. 168). Near Whale Hill it again attains a considerable thickness and is infolded with the other beds, as shown in figure 80 (p. 100). At one point a stratum of red clay several feet thick is interbedded with the till (fig. 169), again suggesting conditions similar to those shown in figure 160 (p. 144), at Montauk. Near Eastern Plain Point the Montauk forms in places the greater part of the exposures and contains two persistent beds of red clayey sand about two-thirds of the way up the bluff. These clayey beds tend to confuse the section because of their resemblance to the Gardiners clay. Folded Montauk material is again exposed near the south end of Tobacco Lot Bay.

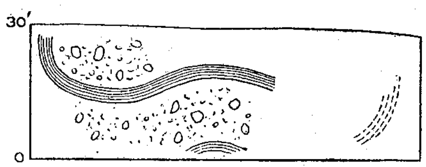


FIGURE 169.—Section east of Whale Hill, Gardiners Island, showing intercalated bed of red clay in till of Montauk till member.

Plum Island.—The north shore of Plum Island does not afford any good exposures of till, although there are indications that not less than 20 feet of this material is present in places, the greater part of it probably being Montauk. The southwest corner of the island consists of a broad bowlder-strewn plain, which rises toward the east, exhibiting till of the Montauk type in the bluff sections. It is overlain by a greenish clay containing pebbles similar to those in some of the exposures on Gardiners Island and on Montauk. The whole plain, except perhaps a thin superficial coating of Wisconsin material, is regarded as belonging to the Montauk member. On the east the drift abuts against an eroded surface of the Herod gravel member, as shown in figure 170. From this point east to Fort Terry no good exposures of the Montauk were seen, but a quarter of a mile east of the fort it reappears with the relations shown in figure 171. The bowlders on top of the section are probably Wisconsin. East of

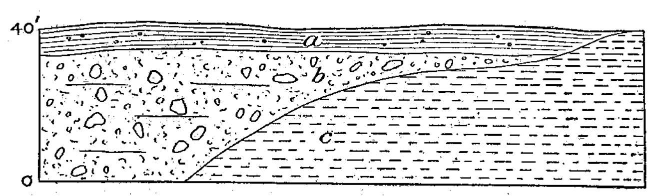


FIGURE 170.—Section near west end of bluffs on south side of Plum Island. *a*, Greenish clay with granitic pebbles (Montauk till member?); *b*, banded Montauk till member; *c*, Herod gravel member.

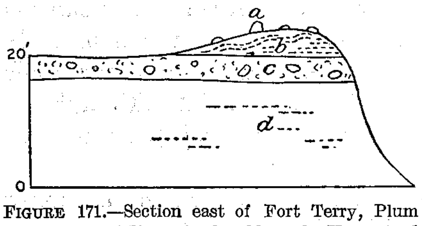


FIGURE 171.—Section east of Fort Terry, Plum Island. *a*, Wisconsin bowlders; *b*, Hempstead gravel member(?); *c*, Montauk till member(?); *d*, Herod gravel member.

this exposure the Montauk appears resting across the eroded edges of the Herod gravel member and the Jacob sand, as is shown in figure 104 (p. 111). One exposure showed a large Montauk bowlder stranded in process of plowing its way through the underlying gravel (fig. 172). The rest of the bluffs on the east end of the island are artificially covered.

Fishers Island.—On Fishers Island the Montauk member is of somewhat unusual character, although the exposures are typical of certain well-defined phases near the type locality. The member has been recognized above sea level at only two points—at the West Harbor exposures and in the bluff three-quarters of a mile northeast of the north end of Isabella Beach. The "bowlders" reported in the Ferguson well probably belong to this member.

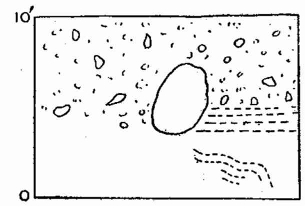


FIGURE 172.—Section east of Fort Terry, Plum Island, showing bowlder of Montauk till member arrested while plowing along the surface of Herod gravel member.

At the West Harbor exposure (fig. 173) the Montauk is probably represented by the heavy bed of till resting unconformably on the upturned and eroded edges of the Jacob sand and the Herod gravel member.

At the second locality mentioned the exposures show a series of beds of clayey sand alternating with beds of pebbles about the size of a hen's egg occurring in a matrix of clay or clayey sand. Both sand and gravel show the peculiar mixture of coarse grains or pebbles with fine silts that is characteristic of rapidly formed and only partly assorted deposits such as accumulate at the margin of glaciers. The deposit unquestionably belongs to the Montauk substage, representing certain of the more aqueous phases of deposition. A little farther north, although the contact is not seen, the semistratified deposits appear to be replaced by till.

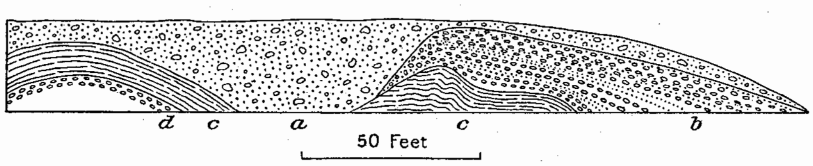


FIGURE 173.—Artificial section near the steamboat landing on west side of West Harbor, Fishers Island (1904). *a*, Till (Montauk till member?); *b*, gravel (Herod gravel member); *c*, gray clayey sand (Jacob sand?); *d*, gravel (probably lens in Jacob sand).

Deposits penetrated by wells.—Although the Montauk was not recognized as a distinct member during the first season's field work, it was well known that there was a bowlder bed in the middle of the Manhasset formation at many places, and it was looked for in the well records. The compactness of the member, the presence of bowlders in it, the large number of granitic pebbles that it contains, and its clayey constitution are all helpful in its recognition, and the writer feels that he can identify it in many records in which its presence was not originally suspected. Its occurrence in wells is summarized in the table on the next page, compiled from the records in Veatch's report on the water resources of the island.

Montauk till member of Manhasset formation in the wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of formation.	Character of materials.	Name used in original records.
			Feet.		
23	Brooklyn	Fifth Avenue and Eighteenth Street.	35- 45	Reddish-brown bowlder clay	Wisconsin and Tisbury.
29	do	Dean Street and Vanderbilt Avenue.	56- 81	Brown sand and bowlders	Do.
37	do	Bartlett Street and Harrison Avenue.	65-150	Red clay with large bowlders	Sankaty.
38	do	Bartlett Street and Flushing Avenue.	31- 73	Sand and granitic clayey gravel	Wisconsin and Tisbury (?).
62	do	Ten Eyck Street	[b] 0- 52	Clay, sand, and bowlders	Wisconsin.
71	do	99 North Eleventh Street	50-100	Blue clay, gravel, and bowlders	Sankaty (?) and Jameco (?).
99	Long Island City	Grove Street	33- 58	Hard, cemented hardpan and reddish-brown sand and gravel.	Wisconsin or Tisbury.
135	East New York	New Lots Road and Fountain Avenue.	93-118	Reddish-brown sand and gray gravelly clay.	Tisbury (?) and Sankaty.
137	do	Brooklyn test well No. 4	97-141	Dirty-gray sand and gravel and gray pebbly clay.	Tisbury and Sankaty.
141	do	Brooklyn test well No. 5	192-216	Gray clay and granitic silty sand	Sankaty.
151	Flushing	Citizens' Water Supply Co.	90-	Blue stony clay	Do. (?).
176	North Beach	Bowery Bay Building Association.	20- 32	Compact mixture of sand and gravel	Wisconsin to Tisbury (?).
186	Tallman Island	Railroad test boring	30- 57	Till, with interbedded sand	Pleistocene.
199	Jamaica South	Oconee pumping station	56-115	Grayish to dark-reddish brown sand	Tisbury.
200	do	Baisley pumping station	58- 97	Gray sand and gravel	Do.
220	Hollis	Brooklyn test well No. 7	15- 69	Granitic sands and gravel	Wisconsin and Tisbury.
223	Dunton	Montauk Water Co	8- 64	Blue clay and gray sand and gravel	Do.
236	Bayside	Commission test well	17- 55	Black clayey sand and reddish-brown sand and gravel.	Do.
237	do	do	0- 65	Light to dark sandy clays, sands, and granitic gravel.	Wisconsin.
246	Elm Point	H. B. Gilbert	0- 56	Yellow clay with bowlders, gray sand, and gravel.	Wisconsin and Tisbury.
258	Hewlett Point	G. B. Wilson	20- 36	Stony clay	Not correlated.
273	Hewlett	Queens County pumping station.	33- 54	Gravelly clay and dirty sand and gravel.	Sankaty (?)
357	Port Washington	T. Valentine	53- 60	Bowlder till	Manhasset bowlder bed.
364	do	C. H. Mason	18- 52	Black marl, loam, with pebbles and oyster shells (probably reworked Gardiners clay).	Not correlated.
366	do	Dodge estate	16- 22	Bowlder till	Manhasset bowlder bed.
373	Long Beach	Long Beach Association	76- 82	Quartz gravel, with pieces of blue clay containing sand and gravel.	Sankaty.
378	Rockville Center	Commission test well	48- 52	Sand and gravel, with bowlders	Wisconsin and Tisbury.
402	Greenwich Point	do	2- 3	Tough, sandy clay, with bowlders (?)	Do.
403	Hempstead	do	10- 11	Gray sand and glacial débris (?)	Wisconsin.
404	do	do	3-	Dark silt to cobbles (?)	Do.
421	Mineola	do	7- 26	Yellow clay, sand, and gravel, with bowlders.	Do.
422	Albertson	do	3- 21	do	Not correlated.
436	Roslyn	Mrs. I. Vowman	50- 53	Sand, with thin layer of bowlders	Manhasset bowlder bed.
446	Glen Head	A. A. Knowles	60- 75	Sand and clay	Do.
456	Locust Valley	Friends' Academy	80- 87	Brown clay	Do.
457	Glen Cove	F. E. Willets	29- 44	Hardpan, with bowlders	Do.
465	Dosoris	W. M. Valentine	76- 79	Hardpan	Do.
469	do	D. F. Bush	7- 15	Blue clay, with pebbles, hardpan	Wisconsin.
481	Lattingtown	L. C. Wier	60- 63	Red clay and gravel, hardpan	Manhasset bowlder bed.
483	do	E. Latting	60- 63	Red clay and gravel	Do.
484	do	W. D. Gutherie	60- 64	do	Do.
485	do	do	38-	Large bowlders	Do.
629	West Neck	Mrs. M. H. Clats	10- 25	Hardpan with gravel	Wisconsin and Tisbury.
707	Brentwood	Commission test well	45- 50	Coarse gravels, highly granitic	Do.
736	Lake Ronkonkoma	William Ralston	22- 25	Black hardpan with pebbles	Do.
737	do	J. Weber	38-	Clay without bowlders	Pleistocene.
744	Lake Grove	John Morrissey	17- 45	Coarse sand and large cobbles	Wisconsin and Tisbury.
745	do	Irving Overton	45- 52	Stony gravel	Do.
749	St. James	Commission test well	6- 45	Dirty gray sand and gravel	Not correlated.
750	do	Father Ducy	0- 60	Hardpan and bowlders	Wisconsin.
751	do	Jerome Saxe	0-160	Stony gravel and clay, hardpan	Pleistocene.
752	do	D. Emmett	0- 30	Coarse gravel	Not correlated.
756	do	Commission test well	5- 70	Gray sand and granitic gravel	Wisconsin and Tisbury.
760	Setauket	W. Rowland	0- 60	Hardpan and gravel	Do.
768	Crane Neck	John Thatcher	10- 50	Gravel with streaks of hardpan	Not correlated.
769	Old Field Point		0- 40	Hardpan	Do.
786	Farmingville	August Fuch	58- 62	Hard stony yellow hardpan	Tisbury.
797	Echo	Commission test well	50- 60	Dirty-gray granitic gravel	Not correlated.
848	Huke Landing	J. H. Darlington	35- 60	Dark-red clay and black sand	Sankaty.
854	Baiting Hollow	C. H. Wells	50- 51	Cemented clay and gravel	Wisconsin and Tisbury.
861	Quogue	Quantuck Water Co	3- 5	Sand, clays, and bowlders	Do.
875	North Sea	C. W. Payne	8- 10	Hardpan	Not correlated.
883	Shelter Island	Ulmer	14- 20	do	Wisconsin and Tisbury.
885	do	J. N. Stearns	15- 27	Hard mixture of clay, sand, and gravel.	Wisconsin.
890	do	Manhasset Hotel	8- 20	Hardpan, with sand bed	Wisconsin and Tisbury.
895	East Marion	W. F. Fursts	18- 22	Hard-packed sand and gravel	Wisconsin.

[a] Numbers refer to well records in Prof. Paper U. S. Geol. Survey No. 44.

[b] In part.

The differences between the correlations of Veatch and those of the writer, as brought out in the last column of the table, seem to be due to the fact that the existence of the member, further than the bowlder bed mentioned, was unrecognized at the time of the preparation of the report on the water resources, many of the beds being included by Veatch with his Sankaty (Gardiners clay) because of their clay content, no other clayey member then being known. The absence of any information as to the great unconformity and the consequent abrupt changes in level of the beds also tended to make the recognition of the member very difficult.

Among the well records in which the Montauk till member is recognized the following are of especial interest: Well at Bartlett Street and Flushing Avenue, Brooklyn (No. 38), given under Jameco gravel on page 86; railroad test boring at Tallman Island near College Point (No. 186), given under Herod gravel member, on page 131; the G. B. Wilson well, near Hewlett Point, at the west side of the entrance to Manhasset Bay (No. 258), given under Jacob sand on page 112; and a well on the Dodge estate near Port Washington (No. 366), given under Jacob sand on page 113.

The following is a record of a well near Bayside:

237. Record of commission's test well near Bayside.[1]

	Feet.
Wisconsin drift, or Hempstead gravel member of Manhasset formation:	
Yellow sandy clay	0– 2
Yellow clayey sand with some pebbles	3– 5.5
Montauk till member of Manhasset formation:	
Dark clayey sand	10–18
Mottled sand and gravel (pronouncedly glacial)	20–29.5
Multicolored sand and gravel similar to that found below the blue clay on the south shore.	35–36
Dark-yellowish clayey sand (glacial)	40–46
Dark, multicolored fine to coarse sand (glacial)	49–65
Herod gravel member of Manhasset formation:	
Fine to coarse yellow sand with very little glacial material	65–66
Yellow sand and small gravel with many fragments of ferruginous concretions	70–71

The records of the wells penetrating the somewhat doubtful materials at East Williston and vicinity may also be inserted at this point:

421. Record of commission's test well near East Williston.[1]

	Feet.
Wisconsin:	
Very dark brown surface loam	0 – 0.8
Reddish-brown loamy sand	2.7– 2.9
Montauk till member of Manhasset formation (?):	
Yellow clay and bowlders	7.5–13.2
Light yellowish-white sand and gravel	17.5–18.5
Reddish-yellow silty sand	22.5–23.5
Very black sand, full of mica, looks like ground-up bowlder	25 –26.5
Herod gravel member of Manhasset formation (?):	
Fine to medium yellowish-white sand	30 –36
Fine yellowish-white sand to medium gravel	40 –41
Small light-colored gravel (considerable percentage of glacial material)	41 –42
Fine to medium yellowish-white sand	45 –51
Small light-colored gravel with glacial material	54 –55

422. Record of commission's test well near Albertson.[1]

	Feet.
Recent black loamy clay	1.7– 2.3
Montauk till member of Manhasset formation (?):	
Brownish-yellow clay with a few pebbles very similar to the clay at East Williston.	3 – 3.5
Brown and yellow clay with reddish-brown sand and gravel (glacial)	8 – 9.5
Dark-grayish sand with much fresh biotite; evidently débris from a glacial bowlder	10.5–11.5
Yellow clay, sand, and gravel ("bowlder clay")	15 –21
Herod gravel member of Manhasset formation (?):	
Sand and coarse gravel (glacial)	23 –24
Fine yellow sand with a noticeable percentage of glacial material	27 –37

AGE.

The Montauk till member was clearly deposited, as its character indicates, either beneath or at the margin of an ice sheet. Although in certain parts of Long Island, especially near the east end, there are indications of several advances and recessions of the ice, there is no evidence

[1] Numbers refer to Veatch's report. Correlations by M. L. Fuller.

such as soil zones or features due to subaerial erosion to indicate any great lapse of time between them, and the period of deposition of the Montauk member is therefore to be regarded as a unit.

The Montauk is the third great drift deposit on the island, the two older sheets from their position, thickness, material, weathering, and erosion, being referred to the pre-Kansan and the Kansan. If the identification of these earlier drifts, especially the Kansan, is correct there is little doubt that the Montauk should be referred to the Illinoian, as the series of deposits is unbroken from the Kansan or Jameco through the Yarmouth or Gardiners to the Illinoian as represented by the Jacob sand and the Herod and Montauk members of the Manhasset formation.

Beyond Long Island the Montauk member continues through the New England islands into Massachusetts, where it is represented by a typical structureless till, being here a land rather than a glaciomarine deposit. The Montauk and the equivalent till of the mainland constitute the principal drift of New England, and in comparison with this body of till all other drift deposits are insignificant. In the interior of the United States a great drift sheet emerges from beneath the Wisconsin in western Pennsylvania and stretches westward to and beyond the Mississippi, reaching a thickness of hundreds of feet in places and, like its Montauk equivalent in New England, greatly surpasses in development the other drifts. In other words, in the Mississippi-Ohio valley, in New England, and on Long Island the third drift is by far the most important of the glacial deposits, and it is not unfair to assume that in each region it belongs to the same glacial stage, the Illinoian. The correlation of the Montauk with the Illinoian is rendered more probable by the recent investigations in Europe, which appear to show a close agreement of glacial stages with those of the Mississippi Valley and Long Island, as if the succession had been not only similar but simultaneous.

To attack the problem of age from another standpoint, it may be noted that the period of erosion between the Wisconsin and the Manhasset (the latter including the Montauk), was of great length, being many times greater than that reported between the Wisconsin and the Iowan drifts. If not of Illinoian age, the drift must be referred to another ice sheet unknown either in the Mississippi Valley or in Europe. That the most powerful sheet and the thickest drift in Long Island and New England should belong to an invasion not elsewhere represented is improbable if not impossible. If the grave doubts that have recently arisen as to the existence of the Iowan in the central portion of the country are justified the number of invasions in the eastern and central regions is the same and the correlation of one with the other is made more certain.

HEMPSTEAD GRAVEL MEMBER.

NAME.

After the Montauk invasion and its attendant erosion, deposition, and folding, the ice retreated from Long Island and a series of gravels were laid down, doubtless derived from the ice which appears to have lingered in the vicinity. For these gravels, which represent the uppermost of the three subdivisions of the Manhasset formation, the name Hempstead gravel member is here introduced, from Hempstead Harbor, along the west side of which the gravel is finely exposed in the upper parts of many large gravel pits.

CHARACTER.

The Hempstead gravel member is very similar to the Herod gravel member, showing the same variations in different parts of the island. In fact, there is nothing in its lithologic character by which it can be distinguished from the Herod member and the description of the Herod given on page 121 applies almost equally well to the Hempstead. If there is any difference it is in the more sandy character of the younger member. Because of their resemblance the beds can not be differentiated from one another except where they are associated with key beds, such as the Gardiners clay, the Jacob sand, or the Montauk till member of the Manhasset formation.

SOURCE OF MATERIAL.

What has been said of the source of material of the Herod gravel member is almost equally applicable to the Hempstead gravel member. The only difference to be expected is a smaller percentage of material derived from the Cretaceous and Mannetto deposits and a greater percentage from Connecticut sources. In general, however, the difference is not well marked, the Hempstead member of western Long Island showing practically as much of the Cretaceous and Mannetto material as the Herod member.

RELATIONS TO OLDER DEPOSITS.

The normal contact between the Hempstead member and the underlying Montauk member is conformable, but, as elsewhere indicated, the final event of the Montauk invasion in the eastern part of the island was a vigorous advance of the ice, as a result of which both the earlier Montauk and the underlying beds were folded, faulted, and eroded. As little or no deposition attended this last ice advance, the Hempstead, where occurring above the Montauk in this part of the island, is likely to rest on an eroded or folded surface (fig. 174).

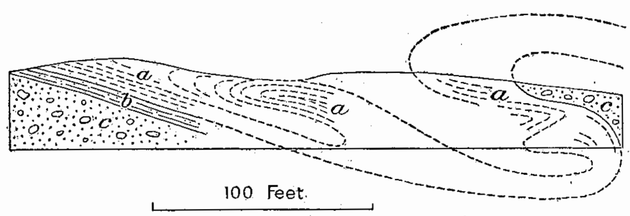


FIGURE 174.—Section east of Montauk Light. *a*, Hempstead gravel member; *b*, clay with glacial pebbles and bowlders belonging to the Montauk till member; *c*, banded till belonging to Montauk member.

The contact between the Hempstead and the Montauk, even where conformable, is usually sharp and abrupt, but in places a transitional phase from a few inches to a few feet thick is observed. Where the contact is unconformable it is almost universally abrupt.

STRUCTURE.

The Hempstead gravel member is much less disturbed than the underlying deposits, the overriding Wisconsin ice apparently having been either thinner, less active, or of shorter duration than the preceding ice sheets. The folding is in general rather superficial, affecting but a few feet of the gravel as brought out in figure 202 (p. 210) and Plate XIX, *A* (p. 114), although there are indications that it was of considerable magnitude in some places where the ice pressed against bluffs or other steep slopes.

DISTRIBUTION.

Relation of Hempstead gravel member and Montauk till member.—In western Long Island the Montauk member occurs as a thick zone showing abrupt lateral transitions from till to gravel or vice versa, so that not uncommonly one exposure shows a thick bed of till at a horizon at which an adjacent exposure shows nothing but coarser gravel. Between the extremes are many gradations, the till being thin or absent and the gravels relatively thick or the till thick and the gravel phase absent. The member, however, appears to be a unit and to represent a single event in geologic history. The overlying beds are in general undisturbed.

Farther east, in the middle portion of the island, the till phase becomes more common and persistent than in the west. It still retains its unity, however, and is still overlain by essentially undisturbed beds.

In the part of the island near Riverhead a marked change appears to have taken place. West of this point the period of Manhasset accumulation seems to have comprised, first a stage of aqueous deposition (Herod gravel member), next an ice invasion with the deposition of till (Montauk till member), and last a return to aqueous deposition (Hempstead gravel member). East of Riverhead the opening stage of aqueous deposition was much the same as at points farther west, but the epoch of ice invasion appears to have lasted much longer, continuing well toward the close of the Manhasset deposition. The invasion was not, however, confined to a single advance, as in the central and western parts of the island, and the deposits are not a unit. Instead the ice appears to have advanced and retreated several times, giving rise to the alternations of till with stratified clays, sands, and gravels noted on Gardiners Island, at Montauk, and elsewhere. Throughout the whole of the North and South flukes and on the adjacent islands exposures that can be certainly correlated with the Hempstead member are lacking, for although gravels and sands are found here and there above the Montauk member they appear, even where best developed, as on the Montauk peninsula, to have been overridden by a readvance of the ice and strongly folded or faulted. That this disturbance is very old, probably Montauk, is indicated by the deep subaerial erosion to which the beds were subjected between the time of disturbance and the advance of the Wisconsin ice. Unfortunately, however, the evidences of subaerial erosion are not everywhere conspicuous, and it is consequently impossible to say whether the folding is Montauk, the gravels being Montauk or younger, or Wisconsin, the gravels being perhaps as young as the Hempstead member. For this reason it has usually been impossible to differentiate the beds with certainty in eastern Long Island. When differentiation is impracticable the beds above the Montauk till member will be spoken of as the gravels of the upper Manhasset.

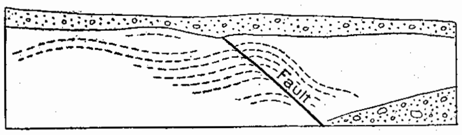


FIGURE 175.—Section 1 mile northwest of East Fort Point, Lloyd Neck, showing disturbed and faulted gravels apparently overlying the Montauk till member.

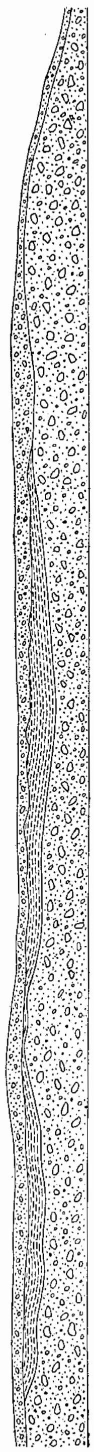


FIGURE 176.—Section northwest of East Fort Point, Lloyd Neck, showing Wisconsin till in unconformable contact with Hempstead gravel member and Montauk till member.

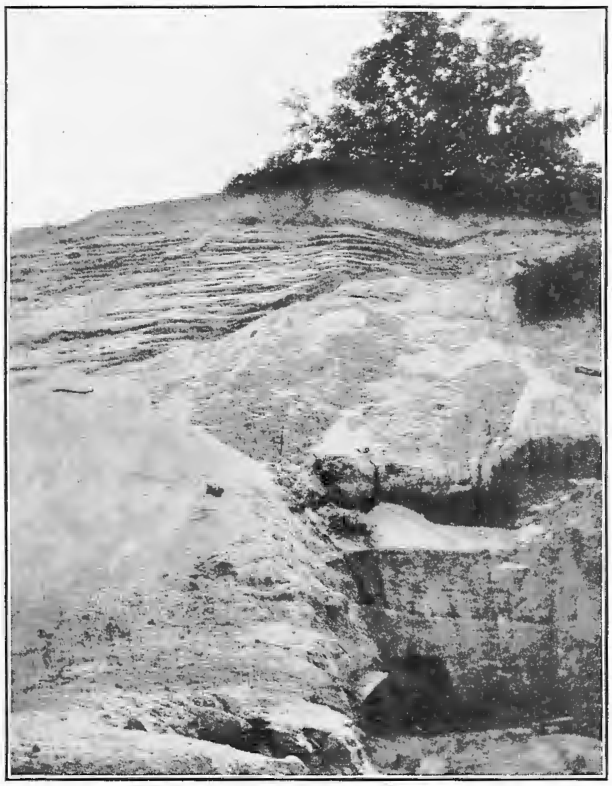
It is noted that the Hempstead gravel member, although generally absent from eastern Long Island, reappears on Block Island and at places farther east.

West of Little Neck Bay.—On the north shore near the west end of Long Island a bed of sand or gravel in places separates the Wisconsin till at the surface from the Montauk till member. This bed occupies the normal position of the Hempstead gravel member, with which it is probably to be correlated. Among the exposures best showing the relations of this gravel is that one-third of a mile east of College Point, represented in figure 136 (p. 135).

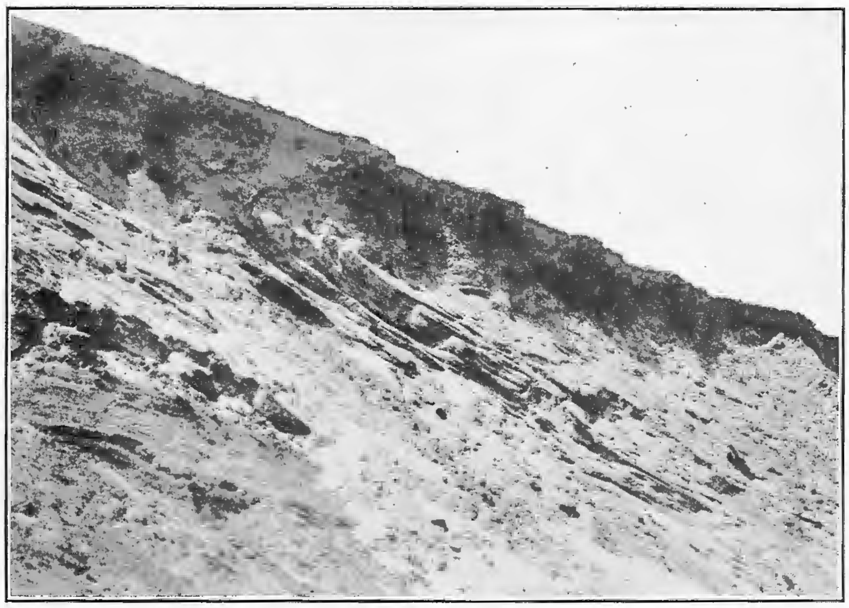
Great and Manhasset necks, North Hempstead.—Traces of the Hempstead gravel member between the Montauk member and the Wisconsin drift are seen here and there on Great Neck, North Hempstead, but the first clear-cut exposure showing the relations was seen at Barker Point, 2 miles northwest of Port Washington village, on Manhasset Neck, where the section shown in figure 137 (p. 135) was found. On the north and northeast shores of Manhasset Neck the exposures are poor, but south of Bar Beach on Hempstead Harbor the Hempstead member was observed in many gravel pits. Only the lower part, however, was seen, the upper part being eroded previous to the Wisconsin ice invasion and later covered with a thin coating of Wisconsin till.

Oyster Bay.—The Hempstead gravel member is nowhere well exposed along the coast between Hempstead Harbor and Oyster Bay, although unquestionably occurring beneath the relatively thin Wisconsin till in the highlands back from the shore. At Rocky Point, 2½ miles north of Oyster Bay village, an exposure about 15 feet thick was seen in a trough of the Montauk member (fig. 65, p. 96), and the Hempstead member appears to form the upper part of the bluff at Mill Neck, northwest of the village, and at Coopers Bluff, 2 miles northeast.

Lloyd Neck.—The Hempstead gravel member appears to form the upper part of the hills on Lloyd Neck beneath the mantle of Wisconsin outwash and till but is seen in few bluff sections. There is an exposure near the northward curve of the beach, half a mile east of the Cretaceous outcrop and 1¼ miles southeast of Lloyd Point, where folded and faulted gravel of the upper part of the Manhasset formation is exposed. The character of the exposure is brought out in figure 175 and Plate XXIII, *B*. A mile farther east and continuing to East Fort Point a fine to clayey sand,



A. UNCONFORMABLE CONTACT BETWEEN HEMPSTEAD (?) GRAVEL MEMBER OF MANHASSET FORMATION AND CRETACEOUS DEPOSITS ON LITTLE NECK, HUNTINGTON.



B. MANHASSET GRAVEL FOLDED BY OVERRIDING ICE.

probably the Hempstead member, was exposed above the Montauk member almost continuously, although here and there cut out by erosion during the Vineyard stage, especially near the east end of the section (fig. 176).

Little Neck, Huntington.—In the large clay pit on the east side of Little Neck, Huntington, a little south of Little Neck Point, finely stratified sands and gravel are seen resting against the Cretaceous clay with the relations shown in figure 177. The pebbles in the gravel are fresh and at the base there are a number of moderate-sized and perfectly fresh granite bowlders. The freshness of the granite seems to preclude its being Mannetto, and the large and fresh bowlders could, so far as is known, have been brought in only by the Montauk ice or floating bergs from its margin, hence the gravels are apparently to be correlated with the Hempstead member. The unconformity, which is one of the sharpest observed on the island, is shown in Plate XXIII, *A*.

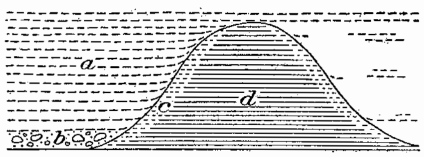


FIGURE 177.—Section in clay pit near end of Little Neck, opposite Northport. *a*, Slightly weathered gravel (Hempstead gravel member?); *b*, bowlder bed (Montauk till member?); *c*, greenish weathered surface of Cretaceous clays (*d*).

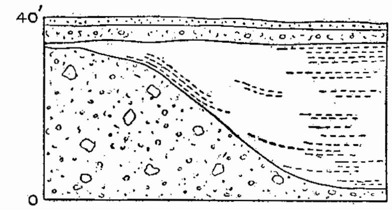


FIGURE 178.—Section near Friars Head, showing Hempstead gravel member resting unconformably against the Montauk till member.

Smithtown Bay region.—The Hempstead member is definitely recognized at few places around Smithtown Bay, but an outcrop on the coast between Nissequogue River and Stony Brook Harbor (fig. 139, p. 137) shows a somewhat well developed bed above the Montauk till member.

The gravel at the top of the bluffs on Crane Neck Point east of Smithtown Bay grades downward into the Montauk till member and may probably be regarded as the Hempstead gravel member, or at least as a transition between the Montauk and Hempstead members.

Port Jefferson to Wading River.—The gravels in the upper part of the bluffs bordering the east side of Port Jefferson Harbor are distinctly above the Montauk till member and are therefore apparently to be referred to the Hempstead member. In the big gravel pit south of the town of Port Jefferson the gravels are thought to be the Hempstead, at least in the upper part, although in the absence of information as to the position of the Montauk member, which is the key bed, it is impossible to determine the horizon of the gravel with absolute certainty. The Hempstead member appears to include the greater part of the deposits shown in the bluffs along West Beach north of the town. From this point to Wading River there appear to be no unquestionable exposures of the Hempstead member, the folded and faulted character of the gravel and the altitude of the Montauk member indicating that the gravels are perhaps to be referred to the Herod member, although the Hempstead member probably occurs in the higher lands back from the coast.

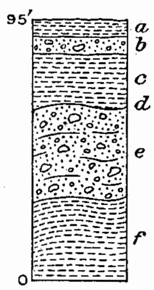


FIGURE 179.—Columnar section between Friars Head and Roanoke Landing. *a*, Dune sand; *b*, Wisconsin till; *c*, Hempstead gravel member; *d*, unconformity; *e*, Montauk till member; *f*, Herod gravel member.

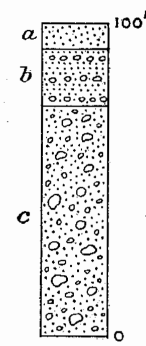


FIGURE 180.—Columnar section near Roanoke Landing. *a*, Dune sand; *b*, Hempstead gravel member; *c*, Montauk till member.

Friars Head.—From Wading River to Friars Head the Hempstead member is nowhere exposed, the Montauk being at the tops of the bluffs. A little east of Friars Head, however, the Hempstead lies lower, nearly 40 feet of buff sand and gravel having the relations indicated by figures 178 and 179 being exposed. The Hempstead rises a little farther on and is absent from the bluffs to a point near Roanoke Landing, where the gravels at the top of the bluff, above the gravelly phase of the Montauk member in the center of the section, represent the Hempstead member.

Roanoke Landing and Jacob Hill.—Near Roanoke Landing about 20 feet of the Hempstead member was seen above the Montauk till member, with the relations shown in figure 180 (p. 153), and a little east of the landing the section shown in figure 144 (p. 139) was measured. Near Jacob Hill a considerable thickness of gravel belonging to the upper part of the Manhasset formation was seen above the Montauk till member at several points (figs. 181 and 182).

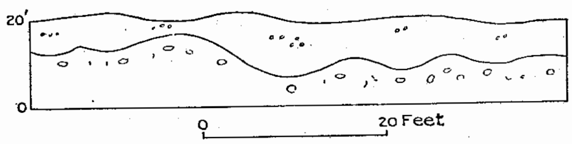


FIGURE 181.—Section west of Jacob Hill, showing irregular contact between Hempstead gravel member and Montauk till member (structure poorly exposed).

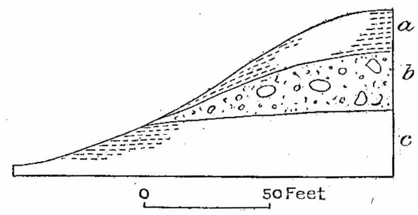


FIGURE 182.—Section west of Jacob Hill. *a*, Hempstead gravel member; *b*, Montauk till member; *c*, Herod gravel member.

Oregon Hills and vicinity.—If the bowlder beds and pockets noted near Oregon Hills and Duck Pond Point (fig. 147, p. 140) represent the Montauk member, as there is reason to believe, the gravels above them must be referred to the Hempstead member.

Rocky Point.—Because of the height at which the Hempstead member occurs, very little of the gravel is seen between the Oregon Hills and Orient Point. About three-fourths of a mile south of Rocky Point, north of Greenport, however, several sections show sand and gravel over the Montauk till member. The following is a section at this locality:

Section three-fourths of a mile south of Rocky Point.

	Feet.
Wisconsin: Till	10
Hempstead gravel member or Montauk till member:	
Sand and fine gravel	5
Coarse gravel	5
Montauk till member:	
Bowlder pocket	1–3
Semistratified till	20

Riverhead to Sag Harbor.—No good exposure of the Hempstead gravel member was seen between Riverhead and Shinnecock Canal, although traces were seen here and there (fig. 183). Half a mile or so east of the canal and in the bluffs north of Cold Spring Pond, 1½ miles to the northeast, gravel, perhaps the Hempstead member, was seen at several points above the Montauk till member.

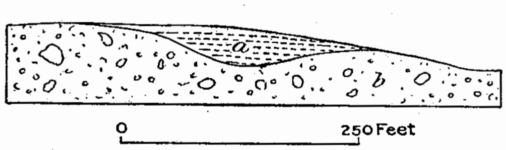


FIGURE 183.—Section northwest of Shinnecock Canal. *a*, Hempstead gravel member; *b*, Montauk till member (very clayey).

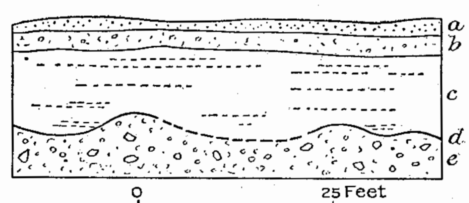


FIGURE 184.—Section on Jessup Neck, west of Sag Harbor. *a*, Dune sand; *b*, Wisconsin till; *c*, Hempstead gravel member; *d*, unconformity; *e*, Montauk till member.

On Jessup Neck there are many exposures of gravel, most of them only slightly disturbed. In only one place, however, near the north end of the bluffs on the west side, are the relations of the deposit clearly seen. At this point the gravel is a well-developed horizontal bed resting unconformably upon the Montauk member with the relations shown in figure 184. Another exposure near the same point was of interest in showing an early stage of a flexure such as has given rise to many faults on the island (fig. 185). From Jessup Neck to Sag Harbor there are no good exposures.

Hog Creek Point.—South of Lion Head Rock, near Hog Creek Point, gravels belonging to the upper part of the Manhasset formation were seen in strong development above the Montauk till member (figs. 153 and 154, pp. 142 and 143), and just north of Fireplace an exposure showed a marked unconformity in the gravels, seemingly the result of Montauk erosion. No drift of this stage is present, but it is probable that the gravels represent the Herod and Hempstead members (fig. 186). Gravels of the upper part of the Manhasset were also seen above the Montauk till member near Cedar Point, a few miles west (fig. 121, p. 128) and above the unconformity shown in figure 123 (p. 128).

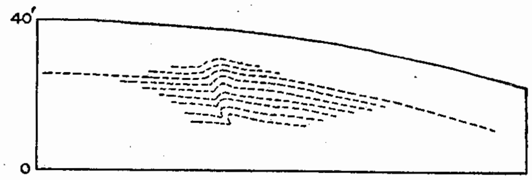


FIGURE 185.—Section on Jessup Neck, west of Sag Harbor, showing fold changing downward into fault.

Montauk peninsula.—Farther east the next point at which the gravels were seen was half a mile west of Rocky Point, on Fort Pond Bay, where the conditions shown in figure 155 (p. 143) were observed. The gravels here (upper part of Manhasset formation) are strongly folded. At Culloden Point, sands belonging to the upper part of the Manhasset formation, were seen resting upon and apparently infolded with the Montauk till member, as brought out in figure 187. Near Shagwong Point the section of gravels (belonging to the upper Manhasset), shown in figure 188, was exposed. A persistent bed of chocolate-brown clay (upper Manhasset?), 3 to 4 feet thick, was also seen near this locality above 10 feet of the Montauk till member and 1 to 3 feet of later drift.

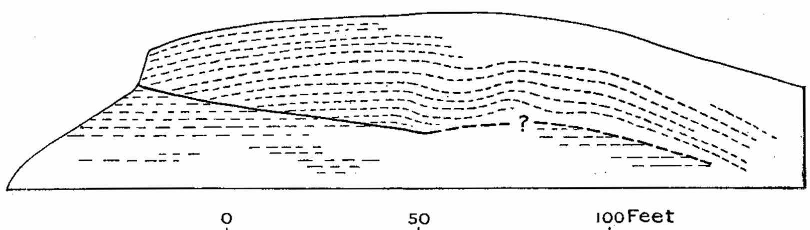


FIGURE 186.—Section near Fireplace, South Fluke, showing unconformity in gravels, presumably Hempstead and Herod gravel members.

Just north of Montauk Light occur several fine exposures of folded and overturned sands and gravels. They clearly lie above the Montauk till member, which rises from beneath them near the lighthouse, but it is possible that they represent the gravelly phase of the Montauk member. The conditions are illustrated in figure 174 (p. 151).

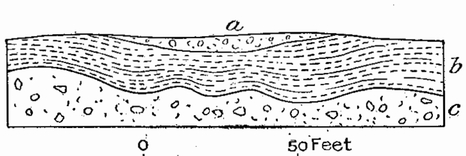


FIGURE 187.—Section near Culloden Point, Montauk. *a*, Wisconsin till; *b*, sand with reddish clay laminæ (either Hempstead gravel member or gravel phase of Montauk till member); *c*, Montauk till member.

Opposite the lighthouse and at the point a considerable thickness of sands and gravels which unquestionably belong to the Hempstead member lies above the Montauk member. Figure 158 (p. 143) shows the occurrence of possible Hempstead material in the bluffs and at the same time indicates the puzzling complexity of the exposures. The section between the small bay south of the lighthouse and the point is shown in figure 159 (p. 144). Figure 189 shows the profile at the extreme point.

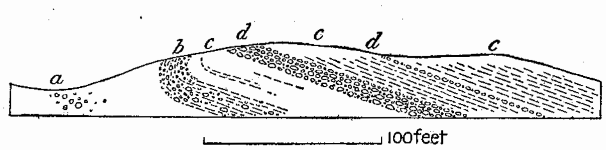


FIGURE 188.—Section 1 mile west of False Point, Montauk. *a*, Till (Montauk till member); *b*, cemented ferruginous sand and gravel with some bowlders (Montauk till member?); *c*, sand belonging to Hempstead gravel member; *d*, gravel belonging to Hempstead gravel member.

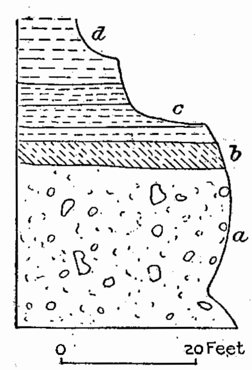


FIGURE 189.—Section south of Montauk Light. *a*, Montauk till member; *b*, cross-bedded sands belonging to Hempstead gravel member; *c*, alternating sand and clayey sands belonging to Hempstead gravel member; *d*, sand and gravel of normal Hempstead member.

In the 2-mile stretch of beach southwest of Montauk Point no good exposures of the gravel were observed. Just north of the bend of the shore from southwest to west, however, gravels belonging to the upper part of the Manhasset formation were seen above the Montauk till member for a distance of nearly a quarter of a mile. The general attitude of the beds is horizontal, but they are locally disturbed and folded (fig. 190). In the bluffs half a mile east of Ditch Plain gravels were noted resting on the Montauk member and apparently cut by an extensive thrust fault. The conditions are represented in figure 191. Near the beginning of the bluff west of Ditch Plain the somewhat complicated occurrence of gravel represented in figure 192 was observed.

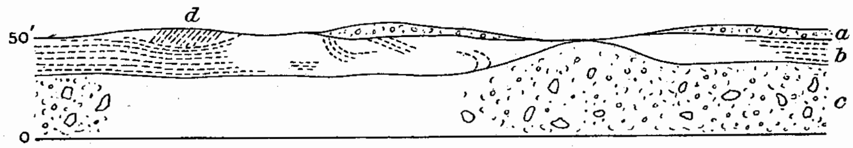


FIGURE 190.—Section 2½ miles east of Ditch Plain, Montauk, showing Hempstead gravel member overlying Montauk till member.

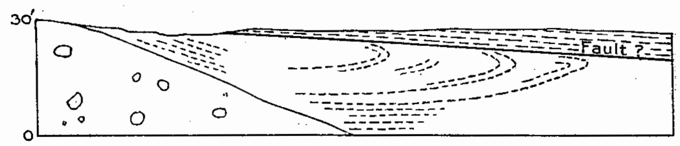


FIGURE 191.—Section half a mile east of Ditch Plain, Montauk, showing folded and faulted gravels overlying Montauk till member.

In the bluffs of the south shore west of Fort Pond traces of the Hempstead gravel member are seen here and there near the top. One of the best sections measured was at a point about a mile from the west end of the bluffs. It is as follows:

Bluff section near "First House," Montauk.

	Feet.
Recent: Dune sand	5
Wisconsin: Gray to buff bowlder till	3
Hempstead gravel member or Montauk till member: Buff sand and gravel with basal layers cemented by iron	25
Montauk till member:	
Sand phase (irregularly stratified sand alternating with thin clay laminæ)	20
Till phase (banded drift and talus)	30

Adjacent islands.—The conditions on the smaller islands adjacent to Long Island at the east end are very similar to those on the North and South flukes. Thin beds of sand or gravel are seen in places above the Montauk member on Plum Island (*b*, fig. 171, p. 146) and on Gardiners Island (*d*, fig. 167, p. 146), but except on Robins Island no noteworthy developments of the gravel were observed. On Robins Island, however, a considerable body of the Hempstead gravel member was noted above the till. Figure 165 (p. 145) shows disturbed Hempstead gravel resting upon an irregular surface of the Montauk member on the east side of the island; figure 193 shows a slight thickness of presumably Hempstead gravel member above an unconformity on the west side of the island; and figure 194 shows a greater thickness in unconformable contact with older gravels supposed to belong to the Herod gravel member.

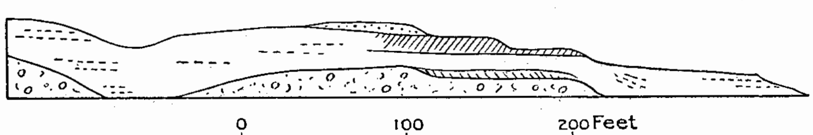


FIGURE 192.—Section west of Ditch Plain, Montauk, showing apparent unconformity between cross-bedded gravel (Hempstead gravel member) and underlying banded till (Montauk till member).

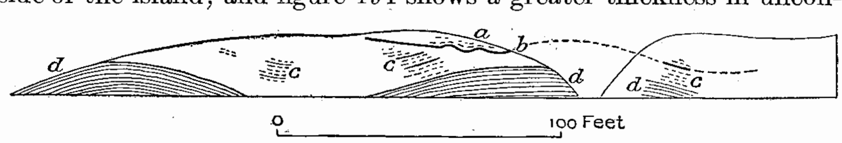


FIGURE 193.—Section on west side of Robins Island. *a*, Hempstead gravel member; *b*, unconformity marked by layer of ferruginous cemented gravel; *c*, sand, gravel, and clay (Jacob sand); *d*, dark-gray, green, and purplish clay (Gardiners clay).

Deposits penetrated by wells.—The Hempstead gravel member is penetrated by a large number of wells in the western and central parts of Long Island, practically every well that has entered the Montauk till member (see table, p. 148) having first passed through the Hempstead. In wells it is usually very difficult if not impossible to distinguish the member from the overlying Wisconsin drift, and this differentiation has not in general been attempted in the following table, which gives a few of the more definite occurrences:

Hempstead gravel member of Manhasset formation in wells of Long Island.

No.[a]	Locality.	Owner or place.	Depth of formation.	Character of materials.	Name used in original reports.
			Feet.		
23	Brooklyn	Eighth Avenue and Eighteenth Street.	15–35	Silty to clean sand and gravel	Wisconsin.
37	.....do	Bartlett Street and Harrison Avenue.	60–65	Coarse sand	Tisbury.
141	East New York	Brooklyn test well No. 5	[b] 16–192	Reddish-brown granitic gravel	Wisconsin.
200	Jamaica South	Baisley pumping station	21–58	Fine to coarse yellow sand	Wisconsin and Tisbury.
357	Port Washington	T. Valentine	15–53	Cobbles and yellow sand	Transition and Tisbury.
366	.....do	Dodge estate	6–16	Fine sand	Tisbury.
373	Long Beach	Long Beach Association	40–76	Gray to yellow sand and gravel	Tisbury and Sankaty.

[a] Numbers refer to well records in Prof. Paper U. S. Geol. Survey No. 44. [b] In part.

Of the wells included in the table complete records are given of No. 366 on page 113 and No. 373 on page 73.

AGE.

The Hempstead gravel member is a retreatal deposit of the ice sheet which at its farthest advance laid down the Montauk till member. As has been indicated elsewhere, the ice lingered in the eastern part of the island to the close of Manhasset deposition, the last important incident of its occupation being a vigorous readvance which scoured and disturbed the older beds at a time when it had withdrawn from the west end of the island, permitting the accumulation of the outwash deposits represented by the Hempstead member, which is thus contemporaneous with the last part of the Manhasset invasion and is to be placed in the Illinoian.

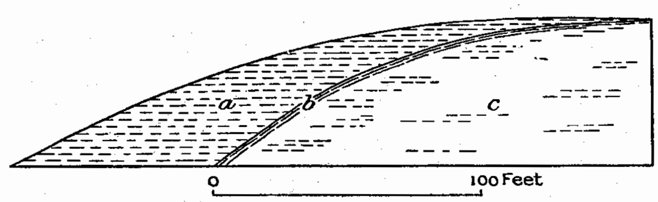


FIGURE 194.—Section on west side of Robins Island. *a*, Hempstead gravel member; *b*, brownish loamy zone along unconformity; *c*, Herod gravel member.

VINEYARD FORMATION.

Between the base of the Recent beach deposits, which probably do not extend more than 20 or 25 feet below sea level, and the horizon at which the Gardiners or the Jacob fauna is to be expected, peat, marsh muck, wood, stumps, and tree trunks, also quahog, clam, scallop, and oyster shells have been found. The finding of so many of these remains in deposits that seem to be above the Gardiners clay and the Jacob sand and below the Wisconsin and Recent accumulations seems to point to an intervening formation of intermediate age. As it is unlikely that they belong to the glacial Manhasset formation it seems probable that they should be referred to the Vineyard [1] interglacial stage, representing marsh, soil, and beach deposits formed at a time when the land stood considerably above its present position with reference to sea level.

In the following table is presented a list of occurrences of shells, wood, peat, etc., which seem likely to have come from this formation. The occurrences are largely taken from the reports of A. C. Veatch [2] and F. J. H. Merrill,[3] but the present writer alone is responsible for the interpretations.

[1] Woodworth, J. B., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 979.
[2] Prof. Paper U. S. Geol. Survey No. 44, 1906, well records.
[3] Annals New York Acad. Sci., vol. 3, 1886, p. 357.

Wells reporting possible occurrences of the Vineyard formation.

Location.	No. of well (Veatch).	Depth.	Material.
		Feet.	
Fort Greene (1814)	....	70	Clam shells.
Fort Lafayette	2	23-40	Gravel and sand with broken shells (possibly Wisconsin drift with secondary fossils).
	2	40-53	Compact silts with many shells including *Nassa obsoleta, Anomia ephippium, Mya arenaria, Crepidula fornicata, Mytilus edulis.*
Governors Island	10	70	Dark gravel with shells (under till).
Brooklyn, 556 Kent Avenue	55	129	Oyster shells (these occur below a thick clay and may belong to the Gardiners clay).
Long Island City, 408 Ninth Avenue.	118	50-57	Quicksand with marine shells (under till).
Brooklyn test well No. 3	204	72	Peat (in yellow sand above Gardiners clay).
Brooklyn test well No. 8	205	59-72	Water-rolled twigs (in gray sand above Gardiners clay).
New Utrecht	....	43-67	Pyrula, clam, oyster.
Flatbush Almshouse	....	40-50	Clams and oysters.
Between Brooklyn and Flatlands.	....	60	*Exogyra costata.*
Bushwick	....	40	Log of wood.
East New York	....	80	Clam shells.
Hicksville	502	15-22	Black silts, etc., resembling soil zone (beneath outwash).
Quogue	859	135	Mulinia, Astarte, *Nassa trivittata*, and fragments of echinoderms (horizon doubtful).
Bridgehampton	897	100	Shell fragments in sand and gravel.

WISCONSIN DRIFT.

The term Wisconsin is applied to the deposits laid down during the last glacial advance as a mantle over the older deposits of Long Island, the application of the term to this region being based on the tracing of the deposits by T. C. Chamberlin,[1] G. F. Wright,[2] and others across New Jersey, Pennsylvania, New York, Ohio, Indiana, and Illinois, into the type area in Wisconsin, from which the name was derived. As it is a surface formation, much more is known of its character, distribution, and manner of accumulation than of the features of the older drifts, and its deposits may with advantage be differentiated into a number of component parts, the most important of which on Long Island are (1) the till sheet or ground moraine, (2) the outer or Ronkonkoma moraine, (3) the outwash from ice along the Ronkonkoma moraine, (4) the later (inner) or Harbor Hill moraine, (5) the outwash from ice along the Harbor Hill moraine, and (6) the retreatal deposits.

THE TILL SHEET.

CHARACTER.

The till sheet or ground moraine includes the deposits laid down beneath the glacier when the débris contained in the base of the ice sheet or dragged along beneath it was set free, either through melting of the ice or by friction with the overridden surface. It is composed of unassorted mixtures of clay, sand, and bowlders, the nature of which differs greatly in different parts of the island. In western Long Island granitic material commonly constitutes 5 to 10 per cent of the pebbles, though in some localities nearly half of the pebbles are granitic. In other places, however, quartz pebbles predominate, it being in fact almost impossible to find granitic materials in some of the outcrops. Toward the central part of the island, beyond the Cretaceous and Mannetto remnants of Eaton Neck, the percentage of quartz rapidly decreases and that of granitic pebbles and bowlders increases. In the eastern portion of the island pebbles and bowlders of the granite type usually predominate in the till. In general it may be said that the till varies in composition with the character of the underlying materials over which the ice had recently passed. This explains the quartzose character of the till in the vicinity of the Cretaceous deposits and the Mannetto gravel, the gravelly or sandy character over the Herod gravel member of the Manhasset formation, and the more clayey character and local red coloration that it has where resting upon portions of the Montauk till member of the Manhasset formation containing Triassic material. At several points, especially on Jessup Neck west of Sag Harbor and on Montauk Point, the till appears to have been formed locally of reworked sand dunes, and it is not improbable that many of the sandy phases of the north shore are of similar origin.

[1] Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291-402.

[2] Bull. U. S. Geol. Survey No. 58, 1890, pp. 39-110.

The till has yielded fossils at a considerable number of points. The greater number evidently represent material reworked from the Gardiners clay, the Jacob sand, or the Vineyard formation, but many silicified fossils from the limestones of the mainland occur, and here and there a Triassic sandstone with leaf impressions is found.[1]

In color the till, where unoxidized, is usually a dull gray, with a slight tinge of buff or brown due to the oxidized materials incorporated in the mass. In western Long Island, however, it commonly exhibits a distinct reddish tinge, due to the presence of Triassic material. This coloration is noted in only a few places east of Little Neck Bay, Flushing, although traces are observed where the Wisconsin overlies the reddish phase of the Montauk till member of the Manhasset.

The thickness of the Wisconsin till is greatest in western Long Island, where it is commonly 10 to 15 feet thick, and in some places, where it is represented largely or entirely by slightly shoved or reworked portions of the underlying gravel, much thicker. It seems to become thinner toward the east, the bluff sections of the central part of the island commonly showing not more than 5 to 10 feet, and those of the extreme eastern parts usually less than 5 feet.

In structure the till is usually rather loose, its materials showing a general lack of coherency. For this reason exposures do not stand well as a rule and soon become covered with talus. Relatively little clay is present in the till. In this respect it differs very noticeably from the Montauk till member, which is not only associated with clayey beds in many places, but carries a sufficient amount of clay throughout its mass to act as a binder, thus making possible the cementation observed in it.

In texture the Wisconsin till is very diverse, all grades of coarseness from sand to bowlders being known. On the whole, however, it tends to be somewhat coarse, resembling the surface till of New England rather than the more compact till of the Montauk member. Bowlders are not very conspicuous in western Long Island, being in few places as large or as closely packed as in some areas of the Montauk till member, such as the bowlder bed of Hempstead Harbor. In fact large bowlders are of comparatively uncommon occurrence in the general till sheet mantling the Manhasset terrace, though they are abundant in the moraine to the south.

In general there are no indications of banding in the Wisconsin till, but a few exposures were seen in which a lamination similar to that of the Montauk member was noted. All such exposures were of very small extent and were clearly the result of local rather than of general conditions. They are confined mainly to the sandy phases of the till, being almost nowhere present in the coarser varieties (Pl. XXIV, *B*).

Where the Wisconsin till is less than 4 feet thick, it has commonly been oxidized from top to bottom and exhibits brownish or yellowish colors such as characterize the drifts of New York and New England. Where the till is thicker, the oxidation may fail to reach the bottom, the lower part being of a lighter and more grayish color. In most places where the till is 10 feet or more thick, however, it has a slight buff tinge throughout, due to the fact that a considerable portion of its material was oxidized before being incorporated into the glacier that later deposited it. Presumably if the invasion had been longer continued, the later till derived from less-weathered materials would have been as dark and unoxidized as that of the Montauk till member.

SOURCE OF MATERIAL.

The materials of the Wisconsin till are derived from the formations over which the ice passed, the larger portion of the deposits coming from the older unconsolidated gravels, sands, and clays of the immediate vicinity. This is especially true of the region from Flushing to Port Jefferson, where not only the great abundance of loose material but also the character of the topography favored the absorption of large amounts of material by the ice. Farther east the percentage of material derived from near-by deposits seems to have been less, the Sound affording unfavorable conditions for absorption. A considerable quantity of the coarser material, including the bowlders, is derived almost entirely from the mainland, as are the granite

[1] Newberry, J. S., Proc. New York Lyceum Nat. Hist., 1st ser., 1871, pp. 149–150.

pebbles except those derived from the Manhasset formation or older gravels. It is noticeable that Triassic fragments, which are common in the Montauk member, are relatively rare in the Wisconsin, except at the extreme west end of the island, apparently indicating that the Wisconsin invasion was weaker or less prolonged than the earlier Montauk invasion.

RELATIONS AND STRUCTURE.

The relation of the Wisconsin till to the older deposits is very simple. It is a superficial mantle resting upon the eroded surface of the older deposits and following closely the contour of the erosion surface, rising in the hills and sinking in the valleys. Where the surfaces on which it was laid down were even its thickness was commonly only a few feet, but in the valleys it was not infrequently deposited to a greater depth. Over one large area, including the greater part of the Nissequogue drainage system, the drift is so thin as to be unrecognizable.

The Wisconsin till in general does not itself show any indications of disturbance other than by landslides along the present bluffs. Folding and faulting, such as characterize the older formations, are generally absent, apparently indicating a very weak ice sheet compared to the Montauk.

The base is in many places sharply defined, especially where the Wisconsin till rests upon the Montauk till member, knife-edge contacts being common (Pl. XXII, *A*, p. 136). In other places, however, there is more or less transition between the underlying gravel and the till, as if parts of the gravel had been dragged along, reworked, and incorporated into the till. There are also many local examples of contortion and folding on a small scale (Pl. XIX, *A*, p. 114), although nothing comparable with the folding during the Montauk substage was observed.

DISTRIBUTION.

Greater New York.—West of the eastern limit of Greater New York, near Little Neck Bay, the Wisconsin till is relatively thick, covering the greater part of the surface with a mantle effectually hiding the underlying Manhasset formation. Exposures showing 15 or 20 feet of till are not uncommon, and even thicker sections are found at many points in the vicinity of Brooklyn and Long Island City. In fact, the general till sheet seems in this region to grade almost insensibly into the thick till of the moraine. The material is a rather tough bowlder clay apparently consisting largely of Triassic ingredients brought from the New Jersey side of the Hudson, 5 miles to the northwest. Both the composition and the unusual thickness are largely explained by the proximity to the outcrops at this point. The Ronkonkoma ridge, now crossed by the Harbor Hill moraine just south of the head of Manhasset Bay, originally extended across this region but was overridden and reworked at a later stage by the ice, and much of its material was incorporated in the Wisconsin till sheet.

A detailed investigation of the geology of this part of the island, which it did not appear desirable to duplicate in the field work for the present report, had been made by R. D. Salisbury and others [1] several years before, at a time when the Montauk till member had not been recognized as a separate division and all till was included in the Wisconsin. The writer had no opportunity for reexamining the region in detail, but from what he has seen he is inclined to regard the Wisconsin till, although undoubtedly of considerable thickness, as forming only a part of the till exposed, the lower and probably thicker portions seemingly belonging to the Montauk till member of the Manhasset, correlated with the Illinoian. The fact that the Illinoian is the principal till wherever found in New England and in the Ohio and Mississippi valleys, the Wisconsin being almost everywhere relatively thin, makes it seem improbable that the conditions at the point under discussion are exactly reversed, especially as the Wisconsin constitutes hardly more than a mantle in adjacent regions. The depth of oxidation, which is in not a few places 10 to 15 feet or more, is perhaps the most satisfactory of the direct evidences of the presence of older drift, being much in excess of the 5 feet commonly reached by the Wisconsin weathering.

[1] New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

In the vicinity of Astoria and between Little Neck and Flushing bays, according to R. D. Salisbury[1]—

The hillocks of ground moraine [till sheet of this report] occasionally assume an elliptical form, about twice as long as broad, the longer axes being parallel to the direction of ice movement. Such hills of ground moraine are called drumlins. One of the best examples of a drumlin in this region is the hill at Lawrence Point. Other examples of drumlins, or of drumloid hills, occur three-fourths of a mile farther south, half a mile northwest of Steinway, and north of College Point, where Tallman Island appears to be a drumlin. The elongate hill just southwest of Tallman Island also has something of the drumloid form.

Little Neck Bay to Oyster Bay.—Between Little Neck and Oyster bays, where the Wisconsin drift is seen in its most characteristic development, the till is gravelly, including large amounts of stained and white quartz pebbles from the underlying Cretaceous beds and the Mannetto gravel. It overlies the eroded Manhasset surface as a mantle or veneer, having a maximum thickness of about 15 feet but averaging considerably less. Even shallow roadside sections may cut entirely through the covering into the Manhasset below. Although the surface as a whole maintains the flatness characteristic of the Manhasset terrace, it shows in many places a subdued morainal aspect, due in part to the unequal deposition of the till and in part to a disturbance of the gravel of the Manhasset formation by ice drag or shove. As would naturally be expected, all gradations between slightly disturbed Manhasset material and thoroughly reworked gravels are found. Bowlders are not, as a rule, either numerous or large in the till sheet of this region, although blocks of considerable size are seen here and there. The till sheet follows the contour of the Manhasset surface rather closely, but its thickness is more variable in the valleys than on the terrace surface. In many of the smaller valleys the till filling is considerable, but in the large depressions now occupied by the harbors and bays of the north shore the amount of till is ordinarily rather slight, apparently because of a concentration of ice activity causing a tendency to erode rather than deposit at those localities.

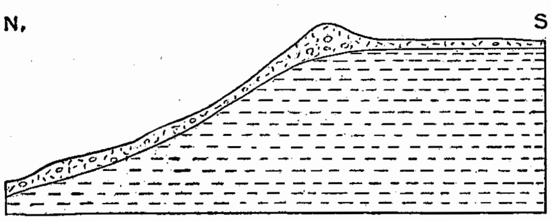


FIGURE 195.—Section showing till ridge at head of valleys opening to the north.

Oyster Bay to Port Jefferson.—The distribution and character of the Wisconsin till between Oyster Bay and Port Jefferson is very similar to that in the district immediately west. Its thickness, however, is somewhat less, and it is in general somewhat more gravelly and carries fewer bowlders. One very large bowlder, however, measuring nearly 40 feet on its longest diameter, was seen on the road between Port Jefferson village and the railroad depot. Because of the occurrence of the Montauk till member at the surface at many points it is difficult, at some places where the exposures are poor, to tell whether the till is Montauk or Wisconsin, but where the exposures are good there is usually little difficulty. The contact, where the older and younger tills come together, is usually very sharp.

A notable feature in this region is the thickening of the drift into a sort of miniature moraine at the head of a number of the north-south valleys, as indicated in figure 195, apparently caused by the shove or drag of the ice masses passing up the valleys.

Cold Spring Harbor region.—The Wisconsin till sheet undoubtedly extends beneath the Harbor Hill moraine and the outwash associated with it, reaching at least as far south as the Ronkonkoma moraine, but because of the thickness of the overlying deposits it is rarely seen. Here and there, however, where a pre-Wisconsin valley of considerable extent stretched back above the inner moraine, as south of Cold Spring Harbor, residual ice seems to have prevented the covering of the region by outwash, and a coating of Wisconsin till was left at the surface on the sides of the old valley. This is made manifest largely by bowlders, although outcrops of the till are not wanting. It is probable, however, that some of the bowlders came from the Montauk member of the Manhasset formation, which presumably outcrops around the border of the valley.

[1] Op. cit., p. 14.

Dix Hills.—The Wisconsin till is best seen where outliers of older formations rise above the outwash, as in the region north of the Dix Hills, where not only bowlders but also good exposures of till are seen overlying the older deposits. Plate XXIV, *B* (p. 162), shows an outcrop of banded Wisconsin till resting upon an older and somewhat disturbed gravel, apparently the Mannetto gravel.

Smithtown "driftless area."—The Smithtown "driftless area," which is driftless only in lacking conspicuous Wisconsin deposits, is one of the most remarkable regions of the island. A line extending along the south base of the Harbor Hill moraine from Nissequogue River westward to Kings Park, thence southward to the Ronkonkoma moraine, thence eastward within a mile or two of Hauppauge, and finally northward through Smithtown to the point of beginning, would inclose an area of nearly 15 square miles, comprising the western part of the drainage basin of Nissequogue River (Pl. X, p. 46), in which no recognizable Wisconsin till occurs. At first sight its absence might seem to be due to post-Wisconsin erosion, but that such a drainage system, the most advanced of all on the island, could have been developed here while practically nothing was being accomplished in post-Wisconsin time in other situations equally favorable to erosion is manifestly unlikely. The discovery of a Wisconsin esker three-fourths of a mile below Smithtown, extending to the very bottom of the present valley, fully established the pre-Wisconsin origin of the drainage system. That the ice passed over the region is conclusively shown by the presence of the well-developed moraine on the south rising from 40 to 100 feet or more above the Manhasset level. How, then, is the absence of drift to be explained? To the writer the most probable assumption seems to be that the district was covered with a thick mantle of snow or snow ice previous to the advance of the glacier, which on invading the region overrode the surface deposits without coming into contact with them. This would explain the absence of disturbance by shove, the lack of gravelly till accumulations such as are usually very conspicuous where the Manhasset formation has been overridden by the Wisconsin ice, and the almost perfect preservation of even the minor drainage features. Under this assumption the only drift to be looked for would be the englacial material set free on the final melting and retreat of the ice. The absence of bowlders in the region indicates that if present the englacial material must have been scanty and very fine grained. That such material may indeed have been set free is not improbable, but because of its similarity to the Manhasset deposits it has not been recognized. No coarse materials or in fact anything clearly identifiable as Wisconsin drift was seen anywhere in the western half of this drainage system.

Middle Island region.—Stretching from Coram northeastward to Long Pond, about 2 miles south of Wading River station, and thence southward to the Ronkonkoma moraine is a broad terrace-like tract of high land (apparently Manhasset formation), which stands above the outwash level and is more or less cut by pre-Wisconsin drainage lines (Pl. XX, p. 116), the whole clearly resembling the Manhasset terraces near Hempstead Harbor and elsewhere along the north shore. The surface is likewise characterized by a subdued morainal topography, apparently due to the drag or shove of the loose gravels by the Wisconsin ice, and is covered with more or less scattered bowlders, mostly small, and with patches of Wisconsin till. This is the largest single area of conspicuous intermorainal Wisconsin drift on the island.

Peconic River region.—The region along Peconic River between the two moraines (Pl. IX, *C*, p. 42) shows a fair number of bowlders and here and there a small mass of Wisconsin till, but the greater part of the region is made up of an undifferentiated mixture of Wisconsin outwash and gravel of the Manhasset formation. It is on the projecting Manhasset surfaces that the bowlders and patches of till are most likely to be found.

Riverhead to Orient Point.—The till south of the Harbor Hill moraine on the North Fluke is very thin, and through considerable stretches it is impossible to recognize the drift in sections. Its presence is made manifest, however, by a bowlder here and there and by irregularities of the surface due to ice shove.

Adjacent islands and the South Fluke.—The conditions on the adjacent islands—Robins, Shelter, and Gardiners—are not notably different from those on the North Fluke, although their

A. TYPICAL BOWLDER BEACH ON NORTH FLUKE.

B. BANDED WISCONSIN TILL ON OLD GRAVELS (MANNETTO?), DIX HILLS.

more rugged topography seems to have encouraged a more extensive reworking of the deposits by the Wisconsin ice and a greater deposition of till.

On the north side of the South Fluke essentially the same conditions prevail as on the islands. The till is mostly local and carries relatively few bowlders. On Jessup Neck and at places on Montauk the till seems to be composed largely of reworked pre-Wisconsin sand dunes.

South of the Ronkonkoma moraine.—There is no decisive evidence that the Wisconsin ice ever passed south of the line of the Ronkonkoma moraine in western Long Island. A number of granite fragments, the largest a foot in diameter, were noted over the surface of the Half Hollow Hills and a few still larger bowlders were seen in some of the hollows, but they are believed to belong to the Montauk till member of the Manhasset formation rather than to the Wisconsin. No unquestionable till was observed nor were any irregularities due to ice drag or shove, such as characterize the Manhasset surfaces north of the moraine, seen in this region, the disturbed condition of the Cretaceous beds of the clay pits being ascribed to creep. If the ice ever covered the region, its presence was but temporary, and it receded without leaving any lasting traces. The only clear evidence of till beneath the outwash on the South Fluke is in the vicinity of Easthampton, where in times past bowlders have been washed out from beneath the sands by the waves. This material is thought to be Montauk rather than Wisconsin, but it is not impossible that an extensive though very attenuated sheet of Wisconsin drift may exist beneath the outwash east of the Shinnecock Hills. The occurrence of numerous kettles in the outwash [1] (see p. 168) probably indicates the presence of ice south of the moraine, but whether these hollows represent ice blocks left after an invasion of the Wisconsin glacier or simply extra-glacial snow or snow-ice accumulations is not known.

RONKONKOMA MORAINE.

NAME.

To the outer moraine, which extends from the point where it emerges from beneath the later Harbor Hill moraine, near Lake Success, south of the head of Manhasset Bay, eastward to Montauk Point, the name Ronkonkoma is applied, from Lake Ronkonkoma, not far from the center of the island, and one of its best-known features.

CHARACTER OF MATERIAL.

The Ronkonkoma moraine exhibits marked variations in character in its different parts, ranging from almost pure till to fine sands. In a given area, however, its character is fairly uniform. The till phase is most largely developed in western Long Island, where certain sections reveal many feet of this material. Even here, however, the till is likely to alternate with gravels, indicating water action. In the western part of the island the gravels are commonly very coarse, with only faint traces of banding, and resemble the tumultuous esker deposits of New England and elsewhere. Finer sands and gravels, some of them distinctly stratified, are present in places.

Farther east, in the region of the West or Mannetto Hills, the gravelly phase becomes more pronounced. The greater part of the deposits observed are of coarse, almost structureless gravels, but till or similar impervious material appears to be present in considerable amounts, as indicated by the numerous springs, kettle lakes, and similar features. The stratified gravels occur in increased quantities.

East of the Dix Hills the material is finer, gravel and sand being here the predominant constituents of the moraine. Indeed, in places the moraine seems to consist almost entirely of sand, especially in the region near New Village and Selden, south of Port Jefferson, and at points between Manorville and Riverhead.

Bowlders are much less numerous and decidedly smaller in the Ronkonkoma moraine than in the inner moraine. Few are more than 5 feet in diameter and those exceeding 10 feet are exceptional. Notwithstanding this, one of the largest bowlders on the island, said to have measured originally 125 feet in circumference, was found in this moraine, at Rock Hill, 2 miles north of Eastport.[2]

[1] Mather, W. W., Geology of New York, pt. 1, 1843, p. 165.
[2] Bryson, John, Rock Hill, Long Island, N. Y.: Am. Geologist, vol. 16, 1895, pp. 228-233.

The weathering is mainly superficial, like that of the till sheet, and is rare, except on the included pebbles derived from older deposits. The only cementation occurs in the neighborhood of basic pebbles or similar sources of iron.

SOURCE OF MATERIAL.

In composition the moraine partakes less of the character of the local material over which the ice passed than the till sheet, owing apparently to the fact that much of the moraine was formed from material that lay high up in the ice, whereas the till sheet was built up from basal materials. During the time required for materials to work upward to a considerable height within the ice the glacier travels far, hence the morainal material was probably derived from a more remote point than that of the till sheet.

The granites, which abound in the moraines, are clearly derived from the New York or Connecticut mainland, although possibly in part reworked from the underlying drifts. The fact that the proportion of granitic pebbles and bowlders is greater in the moraine than in the drifts mentioned would seem to indicate that they were derived to a large extent directly from the mainland. There is, however, in the moraine of western Long Island a notable percentage of stained quartz pebbles which must have been derived largely from the Mannetto gravel of adjacent regions, and it is probable that in the sandy districts farther east a still larger part of the morainal material was obtained from adjacent beds of the Manhasset formation over which the ice passed. Very little Triassic material occurs in the Ronkonkoma moraine although, as previously seen, it is a large constituent of the older drifts.

RELATIONS TO OLDER DEPOSITS.

The base of the Ronkonkoma moraine rests upon the eroded surface of several older formations. In western Long Island it lies largely upon the Manhasset terrace, in the hills near Westbury upon the Mannetto gravel, in the Mannetto and Dix hills upon Cretaceous and Mannetto, and in the region east from these hills to Montauk Point upon the Manhasset. Inasmuch as the Manhasset rises to 200 or 240 feet above sea level and the Cretaceous in West Hill probably to 350 feet, it is clear that in western Long Island but a fraction of the total height of the moraine, whose maximum is about 410 feet, represents true morainal accumulations. Farther east, in the Riverhead region, the thickness of the morainal deposits is greater, only about 100 feet of a total of 400 feet being represented by the Manhasset. On Montauk the morainal deposits are again of subordinate importance, forming but a relatively small part of the 150 feet which measures their altitude.

DISTRIBUTION.

From Lake Success, south of Manhasset Bay, where the ridge emerges from beneath the Harbor Hill moraine, to Syosset, the moraine is composed mainly of kamelike accumulations of stratified drift and till. It is here relatively inconspicuous, being at many points cut by deep gaps and at others partly buried by the outwash deposits of streams issuing from the ice front during the accumulation of the later Harbor Hill moraine. From Syosset to High Hill the topography of the ridge is distinctly morainic, being marked by conspicuous and very irregular kettles and knolls. The high percentage of quartz in the deposits, topographic indications, and the evidence of well records all point to the moderate thickness of the morainal material, the Mannetto gravel reaching at some places within 20 feet of the surface.

At High Hill the moraine reaches its highest elevation east of the mountains of New Jersey and Pennsylvania, culminating in a sharp knob rising 410 feet above sea level, although the body of the moraine reaches only about 350 feet. The percentage of quartz pebbles in the knob strongly suggests Cretaceous or Mannetto material, but there is an admixture of granites to the very crest, indicating that the knob is a part of the moraine, at least superficially. In the lower part of the moraine at the same locality granites are very abundant, and quartz is present only in small amounts. The Cretaceous and Mannetto apparently rise to not less than 340 feet at this point, judging from the terrace on the south. Just east of High Hill, at distances of 1 and 1½ miles, there are two gaps occupied by outwash of the later stage, and another broad gap is found south of Commack. In the intervening areas the moraine is rather high, standing 100 to 200 feet above the outwash, or 250 to 350 feet above the sea.

From the Commack Channel to the big channel now occupied by Connetquot Brook, a distance of 7 miles, the moraine is, in the main, a well-developed and fairly continuous ridge, reaching an altitude of 220 feet, or 100 to 140 feet above the outwash. About 2 miles southwest of Hauppauge, however, at the headwaters of Nissequogue River, the moraine subsides locally to or below the level of the outwash plain, forming the most westerly example of what may be termed a "depressed moraine." Similar conditions exist in the vicinity of Lake Ronkonkoma, where great outwash plains take the place of the ordinary ridge of till or gravel. The moraine, however, is in most places represented by low till accumulations reaching slightly above the surrounding level, but more especially by the immense kettle plain formed by the deposition of an outwash sheet over great blocks and masses of ice, which, on melting, gave rise to the very pronounced kettle topography of the region. Lake Ronkonkoma itself represents a large kettle formed in this manner.

Southeast of Selden the morainal ridge becomes once more very pronounced, continuing with a height of 300 feet or so to Coram Hill. In this region very little but fine sand can be seen in crossing the moraine, and in places the vegetation is very thin and the sand still shifts slightly under the action of the wind. Superficially the material is largely dune sand, but whether this is simply a mantle over a moraine of the normal type or whether the moraine is unusually sandy and free from gravel at this point is not definitely known. The latter supposition, however, is thought to be probable.

Near Yaphank the moraine is interrupted by the deep channel now occupied by Carmans River, but from this channel to Shinnecock Canal the ridge is in general strongly developed, reaching a height of over 300 feet in places, as at Bald Hill, southwest of Riverhead. The moraine is not without breaks, however, there being several points in the region south of Manorville, southeast of Riverhead, and near Good Ground where gaps of considerable width occur.

Although some of the breaks in the moraine east of Coram Hill are due to erosion by the later outwash streams, more of them have resulted from the nondeposition of morainal materials, as in the vicinity of Lake Ronkonkoma. In such places the deposition by the outwash streams was usually much in excess of the morainal accumulation, with the consequence that the outwash deposits reach a much greater height than the morainal deposits, the moraine being of the depressed type.

At Rock, 2 miles north of Eastport, remnants of a bowlder said to have originally measured over 125 feet in circumference are to be found. The bowlder, which has been quarried intermittently by the people of the vicinity since the settlement of the island, and is now much reduced, is said to be still an imposing obelisk-like object 50 feet in circumference.[1]

At Shinnecock Canal there is a break in the moraine extending practically to sea level, but the Shinnecock Hills east of the canal, though largely composed, as shown by the bluff sections, of gravel of the Manhasset formation, nevertheless have a strong superficial morainal topography due largely to the disturbance and reworking of the underlying gravel by the Montauk ice and rendered especially conspicuous by the entire absence of trees such as elsewhere usually obscure the contours of the moraine. The irregular hills and steep intervening troughs, basins, and kettles are all well shown. It should be noted, however, that less than a century ago these hills were covered by drifting dunes, to which a part of the surface irregularities are due.

The moraine in this region, as in that south of Riverhead, is made up of confluent units and is not a simple ridge, the tendency being toward the accumulation of large, high hills, such as that north of Hampton Park, Southampton, or sharp knobs such as Bald Hill, southwest of Riverhead, and the high cone 3 miles southeast of Manorville, nearly 300 feet in altitude. A noticeable feature of these hills is that although the morainal topography is highly developed

[1] Bryson, John, Rock Hill, Long Island, N. Y.: Am. Geologist, vol. 16, 1895, pp. 228–233.

and is characterized by numerous knobs and kettles, there are in addition many radiating trenches apparently due in part to the action of running water. The forms are thought to be the result of the accumulation of steep detrital cones by overloaded waters issuing high up in the ice, 200 to 350 feet above sea level, if one may judge by the altitude of the deposits. The radiating channels mainly mark the position of the rivulets in the closing stages, although possibly they are to a subordinate extent due to subsequent erosion before the land became covered with vegetation. Many of the channels have flat bottoms, many have steep slopes on the outside of the swings, and in some the late erosion is distinguished from the older by a notching of the bottom.

From Shinnecock eastward to Promised Land the moraine is again strongly developed, being represented by a ridge rising to an altitude of more than 280 feet, or about 200 feet above the outwash plain. There are, however, a number of breaks similar in character and origin to those between Yaphank and Shinnecock farther west.

At Promised Land occurs the most important break in the moraine found on the island. The ridge is here interrupted for more than 4 miles, the intervening space being occupied by a sea beach covered with recent dunes. On Montauk the conditions are similar to those in the Shinnecock Hills, the morainal features being especially conspicuous because of the absence of trees. The morainal development, which seems to be more the result of disturbance and remodeling of the old Manhasset topography than of deposition or other accumulation, is on a larger scale than in the Shinnecock Hills. Probably not more than 50 of the 150 feet of the elevation, however, is to be referred to the moraines, and it is almost certain that on the outer point the thickness of Wisconsin deposits is very much less.

The Ronkonkoma moraine is supposed to be represented farther east by the morainal accumulations of Block Island, Marthas Vineyard, and Nantucket, but the correlation with these deposits is not absolutely certain, for the reason that the continuation of the Ronkonkoma moraine eastward is below sea level, and the evidence of connection afforded by the submarine bars is not conclusive.

OUTWASH FROM ICE ALONG RONKONKOMA MORAINE.

OCCURRENCE.

The outwash from the Ronkonkoma moraine includes the great sloping plains lying south of the moraine and extending continuously, except for the short breaks at the Shinnecock Hills, from the west end of the island to the vicinity of Amagansett. It is well developed around Lake Ronkonkoma, a large kettle lake surrounded by moraine and outwash in the central part of the island.

CHARACTER OF MATERIAL.

The material of the outwash plain ranges from the moderately coarse gravel with pebbles as much as 2 inches in diameter found along the margin of the moraine to find sand at the south shore. The relative percentage of quartz and granite pebbles varies greatly, all gradations being found from a pure quartz gravel not much different from portions of the Cretaceous and Mannetto, except that the staining is less conspicuous, to granitic gravels in which quartz pebbles form a very small part. In general, as in the older formations, the amount of quartz varies with the proximity to Cretaceous or Mannetto masses. West of the Dix Hills the percentage of quartz is especially high and in some places a granitic pebble can be found only with difficulty.

Because of the flatness of the deposits sections are extremely rare, but from the few shallow excavations it appears that all gradations from nearly horizontal stratification to a highly complicated flow and plunge structure exist. The materials are in few places weathered or stained and are not known to be cemented either by iron oxide or otherwise, even locally.

Certain parts of the outwash plain have a thin superficial coating of dark-brownish loam, consisting in some places largely of sand, but in others of pebbles intermixed with a certain amount of finer silt. It is this finer material, which is oxidized, that gives the color to the deposits. The depth is in some places only a few inches and was nowhere seen to exceed 1½ feet. No trace of lamination was noted in the deposits seen by the writer. The contact with the underlying material is usually sharp, and the material has the aspect of being a separate formation, apparently not greatly different from the so-called "Jamesburg loam" of New Jersey. The material is well developed in the Hempstead Plains and is seen near the moraine at points north of East Moriches and southeast of Sag Harbor.

SOURCE OF MATERIAL.

This outwash was, in general, fed by streams issuing at the base of the ice or at least at lower points than those forming the Ronkonkoma moraine. The materials, being derived from portions of the ice near the base, are of more local origin than the higher morainal deposits, a fact which would explain the greater percentage of quartz, etc., derived from the adjacent areas of Cretaceous and Mannetto. This is especially true of the outwash issuing through gaps in the moraine. The material from higher portions of the ice, as in the higher outwash fans along the base of the moraine, which were evidently supplied from the same sources as the moraine itself, is likely to have had a more remote origin, as was explained in the discussion of the source of the morainal materials. The diversity in the relative amounts of quartz and granite pebbles is very great and depends mainly on original differences in supply due to the character of the material over which the ice passed and possibly also to the presence of deposits of the Manhasset formation or other gravels in the path of the outflowing streams. Such deposits are known to have been present in the path of the streams that laid down the later outwash from the ice along the Harbor Hill moraine below the Mannetto and Half Hollow hills, where the gravels of the Manhasset formation approached the surface or projected through the outwash at many points.

RELATIONS TO OLDER DEPOSITS.

The outwash from the ice along the Ronkonkoma moraine rests upon an old and extensively eroded surface of gravels belonging to the Manhasset formation. This old surface had a southward slope similar to that of the present outwash, although somewhat more gradual. Under the action of long-continued stream work, however, it became trenched by many well-defined and fairly deep southward-leading valleys, its edges were indented by marine estuaries, and its borders were locally cut by low marine cliffs. Near the moraine, where the outwash deposits were most abundant, and especially where the deposition was effected by small rivulets rather than by large streams occupying well-defined channels, the older topography has been obscured, but farther south the outwash becomes attenuated and the Manhasset shows at the surface. In some places, where glacial streams of considerable size led through gaps in the moraine, the work was at first one of erosion rather than of deposition and channels were cut either in the earlier outwash or in the underlying Manhasset. Such channels may be seen extending southward across the Manhasset outwash at many points, although they are much smaller than those formed at the subsequent Harbor Hill substage. Some of the material brought down in these channels was deposited in the lower parts of their courses and in the estuaries of the Manhasset coast, but most of it was swept beyond the present coast line. In general, therefore, where the outwash is thick it overlies the Manhasset plain and valley alike, but where it is thin it rests largely in the valleys or other depressions of the Manhasset surface.

DISTRIBUTION.

West of Manhasset Bay, near the head of which the Ronkonkoma ridge disappears beneath the later Harbor Hill moraine, no outwash from ice along the Ronkonkoma moraine is recognizable, the deposits being entirely covered by the later drift.

From Jamaica to the vicinity of the Mannetto Hills stretches a great outwash deposit, constituting what has been called the Hempstead plains. The deposit is evidently made up of outwash material, part associated with the Ronkonkoma and part with the Harbor Hill moraine, but it has been impossible to differentiate these parts in the region as a whole, owing to the similarity of material and the absence of distinct topographic features. From the later Harbor Hill moraine several distinct channels pass through the Ronkonkoma moraine and lead southward across the outwash. The incision of these Harbor Hill channels shows that near the Ronkonkoma moraine at least the outwash from ice along the Ronkonkoma moraine is the principal surface deposit, reaching a height of 120 feet. Farther south many of the channels are less marked and indications of a spreading out of the later outwash in fans over the earlier outwash are observed.

In and around the west side of the Mannetto Hills is a local area of outwash from ice along the Ronkonkoma moraine without any apparent admixture of later drift, reaching a maximum elevation along the base of the moraine of about 200 feet. A similar area, now standing as a terrace 30 feet above the later outwash, or about 180 feet above sea level, is seen on the west side of the Dix and Half Hollow hills, and a smaller area is found on the southwest flanks of the group of hills between the Dix and Mannetto groups. The greater part of the area between the groups of hills and between the hills and the coast, however, seems to be outwash from ice along the Harbor Hill moraine.

From the Half Hollow Hills to Brentwood is a broad stretch of outwash from ice along the Ronkonkoma moraine rising to the height of 150 feet or more and having a typical contour. East of Brentwood, however, the outwash, though still present in considerable amounts, becomes thinner and the gravels of the Manhasset formation project through it at intervals. Its maximum elevation is about 160 feet. At Connetquot River the composite plain is interrupted by a broad outwash channel of the Harbor Hill substage, while south of Yaphank it is cut by a still broader channel of outwash from ice along the Ronkonkoma moraine unmixed with Manhasset material and apparently deposited in a broad valley or estuary in the Manhasset formation. The profile along the railroad near Yaphank station shows the relations of the outwash from ice along the Ronkonkoma moraine to the Manhasset formation and the notching due to Vineyard erosion (fig. 196).

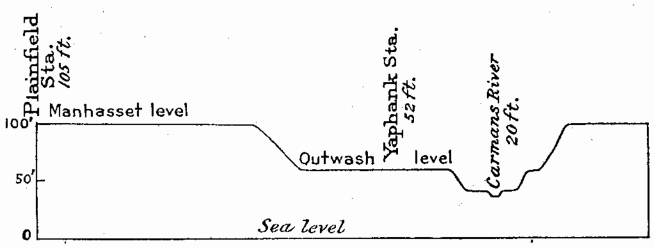


FIGURE 196.—Profile of Carmans River outwash channel near Yaphank.

From Yaphank to Shinnecock Canal the same intermixture of outwash and Manhasset forms that was noted west of Yaphank is observed (elevation along moraine 80 to 140 feet), but between Shinnecock and Mecox bays the outwash, although much lower, predominates. From Mecox Bay to and beyond Bridgehampton the topography is again composite, the Manhasset rising above the outwash at many points and even where below the outwash manifesting its presence by kettle channels and other similar features. The marked kettle channel at Scuttle Hole has been described (p. 43) and illustrated (Pl. IX, *A*, p. 42). Outwash deposits rise to 150 feet at this point. From Bridgehampton to Easthampton the outwash again controls the topography (Pl. XXI, *A*, p. 118), although considerable influence is exerted locally by the Manhasset and the surface is extensively modified by the formation of dunes west of Georgica Pond. From Easthampton to Promised Land the topography is of the mixed type (Pl. XXI, *B*). No outwash from ice along the Ronkonkoma moraine is found on Montauk.

HARBOR HILL MORAINE.

NAME.

After the upbuilding of the Ronkonkoma moraine and the associated outwash plains the ice retreated northward to or above the line marked by the northern or inner moraine and, perhaps after some fluctuation, finally halted on this line. The northern moraine, which extends from New York Harbor on the west to Orient Point and beyond on the east, has been designated the Harbor Hill moraine, from the hill of that name near Roslyn, at the head of Hempstead Harbor, this being the highest point of the moraine on Long Island (384 feet).

CHARACTER AND SOURCE OF MATERIAL.

Till is much more abundant in the Harbor Hill moraine as a whole than in the earlier Ronkonkoma moraine. This is especially true in the region west of the point where the Harbor Hill moraine crosses the Ronkonkoma moraine. From this point stratified materials rapidly decrease in amount, and till becomes more conspicuous, and from Jamaica westward nothing but till is seen in most of the exposures, even where these are 25 to 30 feet or more in depth. The moraine in this part of the island is, in fact, composed practically of till, consisting largely of Triassic material brought from the northwest across Hudson River. Bowlders abound in this region (Pl. V, *B*, p. 32).

East of the point where it crosses the older ridge the Harbor Hill moraine becomes more gravelly, stratified materials being observed practically to the top of Harbor Hill. In this region the moraine contains much stained quartz from the Mannetto gravel and some white quartz from the Cretaceous. Till is not at all uncommon and bowlders are fairly numerous, though generally small. From the vicinity of Oyster Bay eastward to Port Jefferson both till and gravel are largely represented in the moraine, but sandy phases, such as occur in the outer moraine, are not common.

East of Port Jefferson the moraine, although containing abundant stratified material, carries more unstratified drift, especially bowlders, which in places line the beach or even form bowlder pavements and heaps extending for considerable distances. The bowlders considerably exceed in number those in the outer moraine and their average size is much larger. Several from 30 to 50 feet in diameter have been seen.

In general the source of the material is similar to that of the material in the Wisconsin till sheet, for it likewise varies in character according to the nature of the material over which the ice passed. Granitic pebbles and bowlders are more common in the inner than in the outer moraine, indicating a greater percentage of materials, at least of the coarser sizes, from the mainland.

RELATIONS TO OLDER DEPOSITS.

The Harbor Hill moraine, like the Ronkonkoma, rests upon the eroded surfaces of several older formations. West of Hempstead Harbor it lies upon gravels of the Manhasset formation, the surface of which descends westward from about 180 feet above sea level near Roslyn to sea level or below at the Narrows of New York Harbor. For several miles east of Roslyn the moraine seems to be underlain by Mannetto remnants reaching a height of considerably more than 200 feet. To judge from the topography of the deposits of this character south of Wheatley, the buried Mannetto surface must be very irregular (Pl. VI, *D*, p. 32). From this point eastward to the end of the North Fluke the relations of the moraine to older deposits, though irregular, are very simple, the moraine resting almost solely upon the Manhasset surface, stretching across its flat terraces, descending its slopes, and crossing its deep valleys. The elevation of the base of the moraine ranges from a little below sea level to the level of the Manhasset Plateau. This plateau gradually declines from an altitude of 200 feet near Huntington to 160 feet in the vicinity of Port Jefferson, 80 feet north of Riverhead, and scarcely 20 feet at Orient Point.

DISTRIBUTION.

The Harbor Hill moraine shows a distinctly lobate form, the lobes being, however, on a smaller scale than those of the Ronkonkoma ridge and apparently being due to the influence of the bottom of the Sound or of the form of the north shore upon the movement of the ice. The lobes are not, however, marked by any distinctive characteristics of composition, structure, or form.

The part of the moraine west of Manhasset Bay differs from that in any other portion of the island both in composition and topography. The material is here practically all till, the moraine possessing a more subdued topography, the steep hills, small cones, irregular gravel heaps, and steep-sided kettles characteristic of the stratified moraine being replaced by larger, more regular hills with relatively gentle slopes and less irregular, shallower, and less abrupt depressions. The moraine in this region rises to a height ranging from 100 feet in the vicinity of the Narrows to nearly 260 feet southwest of Manhasset Bay, or from 80 to 100 feet above the Manhasset formation, upon which it rests. A feature of the ridge in this part of the island is the distinct erosion scarp along its south side from the vicinity of its junction with the older moraine south of Manhasset Bay westward to Brooklyn (Pl. XI, *D*, p. 52). This, however, is a subsequent feature and not a normal phase of morainal development.

East of Manhasset Bay there are no important gaps in the continuity of the moraine, the ridge being unusually persistent and uniform. At the heads of Manhasset Bay and Hempstead Harbor, however, the moraine is cut by sharp and deep channels leading southward across the outwash plain. Each of these gaps or passes has an altitude of about 180 feet, or very nearly that of the Manhasset surface. The moraine rises to a height of 384 feet in Harbor Hill, or 200 feet above the Manhasset level. Exposures in large gravel pits in the valley beneath the moraine near Roslyn show horizontal Manhasset deposits, establishing the superficial character of the morainal accumulations.

East of this point for about 7 miles the ridge is practically continuous, although gradually declining in elevation until near Cold Spring Harbor it hardly rises above the Manhasset outwash levels. The valley at this point, although the slopes are more or less covered with till, seems to have been occupied by residual ice during the upbuilding of the morainal and outwash deposits, and to this fact it owes its freedom from Wisconsin filling.

From Cold Spring Valley to a point near the bend of the railroad east of Greenlawn the moraine is again fairly continuous, although a break of some importance is found 2 miles southwest of Huntington. Near the bend of the railroad mentioned there is a still more important break marking the passage of an outwash channel, which can be distinctly traced to Babylon, on the south shore. Other breaks occur between Larkfield and Kings Park stations, at Nissequogue River, and at Port Jefferson. At the last-named point a large gravel pit gave (in 1903) an almost complete section of the Manhasset formation up to the base of the overlying moraine, conclusively showing the superior stratigraphic position of the morainal ridge.

The rolling topography of the Harbor Hill moraine is exhibited east of Port Jefferson, where, although the cliff is generally covered with talus, enough can be seen to show that the morainal till is a superficial deposit resting on horizontal gravels of the Manhasset formation, which make up three-fourths of the bluff. The moraine in this interval, although still having the nature of a ridge, in places rises less than 50 feet above the Manhasset terrace on which it rests. It is marked, however, by kettles that are more conspicuous than any found west of this point, some of them 40 to 60 feet in depth and having unusually steep slopes.

East of Port Jefferson station the moraine is essentially of the "depressed" type for 2½ miles (Pl. VII, *B*, p. 34), there being practically no ridge. Instead, the outwash plain breaks off sharply into a belt of immense kettles (fig. 12, p. 34), the bottoms of which lie as low as 100 to 120 feet above sea level, or 60 to 80 feet below the surrounding plain.

Near Miller Place the moraine again takes the form of a ridge, which persists without notable breaks for more than 10 miles. It reaches an elevation of 220 feet southeast of Miller Place, 260 feet near Rocky Point village, 246 feet northeast of Wardencliffe, and 230 feet northeast of Wading River. As the Manhasset rises but little over 100 feet above the sea in this region, the Harbor Hill moraine is thicker here than in most other places on the island. The bowlders in it rapidly increase in number and size east of Port Jefferson, although they are not so numerous on the beach as at points farther west, because the waves have not cut so far into the moraine. Among the largest of the inland bowlders is one found half a mile northwest of Wading River village near the marsh. It is a sharp pyramid of granite having a height of 20 feet, a base measuring 18 by 15 feet, and a cubic content of about 4,000 feet. About it lay several other large fragments, apparently originally parts of the same bowlder One of these was over 10 feet in diameter and contained 1,000 cubic feet or more. A still more massive bowlder was seen just north of the highway from Wading River as it turns to go up the valley toward Wardencliffe, a little over a mile west of Wading River. Although partly buried this block probably measures 20 by 20 by 16 feet and contains about 6,400 cubic feet.

Between Wading River and Fresh Pond Landing the morainal development rapidly weakens, the crest declining from a height of over 220 feet, or 120 feet above the Manhasset, at a point southwest of Paines Landing to 150 feet, or only 50 feet above the Manhasset, near Fresh Pond Landing. In fact, this point marks the end of the moraine as a prominent ridge, a considerable part and in places even the whole of the ridge farther east, although generally regarded as a moraine, consisting in reality of sand dunes. It is, however, very difficult to separate the two in the absence of sections, for a coating of sand a few feet thick may cover and obscure morainal accumulations of great importance and give the ridge the appearance of being composed of dunes when it is in reality largely morainal. For this reason it has been thought best, except where the dunes are known to predominate, to map the ridge as moraine.

In general, the moraine east of Fresh Pond Landing may be described as ranging from a low disconnected ridge to isolated patches of morainal drift, the whole covered in many places with a thick coating of dune sand. Here and there, as northwest of Centerville, the morainal deposits reach an altitude of 240 feet, or 140 feet above the Manhasset, but in general 170 feet is the maximum elevation and 80 feet the height above the Manhasset. The moraine is here usually a narrow ridge, which in places retains but a fraction of its original width, the remainder having been cut away by the sea, as shown by the bowlders upon the beach and in the water as well as by the topography. The seaward side of the moraine is generally a steep bluff more or less covered with talus, and the inner side is a more gentle depositional slope.

The pseudomorainal character of the ridge where it consists predominantly of sand has been mentioned. It is well brought out by Plate VIII, *B* (p. 34), which shows a ridge 20 feet or more in height and exhibiting a topography that would ordinarily be regarded as unquestionably morainal, but the section shows it to consist entirely of dune sand. The morainal accumulations are here represented only by the till less than 5 feet thick underlying the sand. Plate VIII, *A*, is a distant view of a much larger hill, probably not less than 50 feet high, which likewise appears to consist largely of dune sand.

The region east of Riverhead, more especially that east of Greenport, presents many opportunities for determining beyond all question the relations of the moraine to the Manhasset formation, many sections both in the bluffs and in the amphitheaters and ravines showing the thick till of the moraine resting upon horizontal Manhasset beds. In 1903 the best sections seen were half a mile northeast of Inlet Point, north of Greenport, and near Rocky Point, east of Marion. Any storm, however, is likely to change materially the character of the sections. Those seen in 1903 were no longer conspicuous in 1904, but probably others equally good have been exposed since. Care should be taken not to mistake the Montauk till member of the Manhasset formation, which occurs in considerable thickness at the top of the bluff at several points, for the Wisconsin morainal deposits.

The immense number and large size of the bowlders on the north coast from Greenport eastward constitute a striking feature. Not only is much of the beach covered with an unbroken pavement, but the bowlders are in places piled upon one another in great masses. Plate XXIV, *A*, shows the appearance of the beach where a moderate number of bowlders are present. A list of a number of the largest of those that have been measured or estimated is given below. It should be noted, however, that many of these bowlders lie in front of cliffs in which both Wisconsin and Montauk materials are exposed and that a portion unquestionably belong to the older deposit (Montauk).

Large bowlders on Long Island.

Location.	Situation or reference.	Size.
Near Whitestone Point	Reported by R. D. Salisbury [a]	20-foot bowlder.
Near Eden Point	Reported by R. D. Salisbury	Do.
Southeast of Manhasset	Reported by Warren Upham [b]	54 by 40 by 16 feet.
North Hempstead	Reported by Samuel L. Mitchill [c]	40 feet long, 20 to 40 feet wide, 10 to 17 feet high.
¾ mile southeast of Lloyd Point	On beach; probably from Wisconsin till	17 by 14 by 9 feet.
½ mile south of Halesite	In till in Manhasset Valley	Diameter 20 feet.
¼ mile south of Crane Neck Point	In Montauk till member of Manhasset formation	Diameter 30 feet.
½ mile south of Port Jefferson	In till in Manhasset Valley	35 by 20 by 5 feet.
½ mile west of Woodville Landing	On beach in front of moraine	25 by 10 feet.
1½ miles west of Wading River	Near highway through valley in moraine, etc	20 by 20 by 16 feet.
¾ mile northwest of Wading River	Slope of moraine near edge of marsh	Pyramid, base 20 by 18 feet, height 15 feet.
East Landing, Wading River	On beach in front of moraine	25 by 20 by 6 feet.
Near Hulse Landing	On beach and in water. Both Montauk till member of Manhasset formation and Wisconsin drift present in bluff.	Hundreds from 10 to 20 feet in diameter.
Near Friars Head	do	30 by 15 by 8 feet.
¼ mile west of Jacob Point	do	38 by 20 by 11 feet.
Middle of Oregon Hills	On beach in front of moraine	Diameter 15 feet.
¼ mile west of Duck Pond Point	do	Base 23 by 20 feet; height 10 to 18 feet.
1¼ miles east of Horton Point	In water in front of moraine	Diameter 25 feet.
½ mile east of Inlet Point	On beach in front of moraine	Do.
¼ mile east of Inlet Point	Bowlder pavement on beach in front of moraine	Many over 10 feet in diameter.
¼ mile southwest of Inlet Point	do	Do.
½ mile southwest of Rocky Point	In water in front of moraine	25 by 25 by 30 feet.
East of Rocky Point	On beach in front of moraine	Several bowlders 20 to 25 feet in diameter. Probably 30 to 40 feet before.
Jennings Point, Shelter Island	Reported by F. J. H. Merrill [d]	9,000 cubic feet.
2 miles north of Eastport	In moraine. Reported by John Bryson [e]	50 feet in circumference, 20 feet high (originally 125 feet in circumference).

[a] New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902, p. 14.
[b] Am. Jour. Sci., 3d ser., vol. 18, 1879, p. 201.
[c] Med. Repository, vol. 3, 1800, p. 330.
[d] Annals New York Acad. Sci., vol. 3, 1886, pp. 341-364.
[e] Am. Geologist, vol. 16, 1895, pp. 228-233.

Owing to the covering of dune sand, it is not always possible to recognize small breaks in the moraine. The first break in the region east of Fresh Pond Landing is northwest of Baiting Hollow, where the outwash, except for a thin coating of dunes, reaches the edges of the bluffs bordering the north shore. At Mattituck Inlet is a more important break, the gap here being more than a mile wide and extending to sea level. A small break with a southward-leading channel intersects the Oregon Hills. Other important breaks occur at Hashamomuck Pond and a mile northeast of that place, both the moraine and the Manhasset formation being cut to or below sea level. This shows that before their connection by sand bars and marshes what is now the North Fluke consisted of a number a detached semimorainal islands, such as Plum Island is to-day. The most easterly break is at Truman Beach, near Orient, this likewise marking a former channel between islands.

OUTWASH FROM ICE ALONG HARBOR HILL MORAINE.

GENERAL CHARACTERISTICS.

The deposition of the Harbor Hill ridge, like that of the earlier moraine, was accompanied by the formation of a more or less extensive outwash deposit. In composition this deposit shows no material difference from the outwash from the ice along the earlier (Ronkonkoma) moraine already described (p. 166), varying in the same manner from point to point according to the nature of the materials over which the ice passed. The sources of the materials of the two outwash deposits are practically identical, and so far as can be seen, the mode of deposition and character of the bedding (flow and plunge structure, etc.) are likewise the same. The brownish sandy or pebbly loam and clayey sand (comparable with the so-called Jamesburg loam of New Jersey), described as locally forming superficial coatings over the outwash from ice along the Ronkonkoma moraine, are likewise present in places on the outwash from ice along the Harbor Hill moraine, the most conspicuous developments being (1) in the easterly of two outwash channels northeast of High Hill, (2) in the region southeast of Elwood and northeast of the Dix Hills, (3) in the district north of Coram, (4) at points between Wardencliffe and Ridge, and (5) in the region south of Manorville. It is also found locally near Jamaica. Like the outwash from ice along the Ronkonkoma moraine, the outwash from ice along the Harbor Hill moraine rests upon the eroded surface of gravels of the Manhasset formation, and being, as a rule, relatively thin, in many places fails to hide the Manhasset topography, which is made apparent to the eye by the numerous kettle valleys or by elevations rising above the outwash level. The topography of the outwash differs in no essential way from that of outwash along the Ronkonkoma moraine.

DISTRIBUTION.

Narrows to Jamaica.—The plains in the stretch of more than 15 miles between the Narrows and Jamaica are low and flat, and exhibit a lobate fan-shaped outline with radiating drainage creases converging toward the base of the moraine at three distinct points—near Prospect Park, in Brooklyn, at East New York, and near Dunton, southwest of Jamaica. The surface is locally covered by a foot or more of brownish loam resembling the "Jamesburg loam" of New Jersey (p. 172).

Roslyn-Hempstead region.—The deposit in the area between the moraines south of Roslyn has been described under Manhasset formation (p. 116). It may be regarded either as a kettle plain over a Manhasset surface or as a thin outwash among higher Manhasset hills, but more probably it is a combination of the two. South of the outer moraine the kettles disappear and the later and earlier outwash deposits merge into the broad Hempstead plains, in which they could not be differentiated.

Wheatley-Cold Spring region.—From the Wheatley Hills to the valley at Cold Spring station the outwash from ice along the Harbor Hill moraine is represented by a narrow strip, in few places more than 2 miles wide, of what may be called a kettle plain, the ordinarily smooth outwash surface being broken at many points by kettles, some steep-sided and of considerable depth, which evidently mark the former positions of melting ice masses in the valleys of the Manhasset formation, which is here not far below the outwash surface.

Huntington-Babylon region.—Stretching southward from the Harbor Hill moraine between Cold Spring Valley and Greenlawn is one of the most strongly developed outwash deposits from ice along the Harbor Hill moraine. In detail it consists of two broad level outwash channels from half a mile to 1½ miles in breadth, one leading southeast from the morainal ridge near Cold Spring and passing between High Hill and the hills south of the Huntington fair ground, the other leading southwest from the base of the ridge near Greenlawn and passing between the Dix Hills and the hills before mentioned, the two uniting near Melville between the Mannetto and Half Hollow hills. Between the two channels, in the vicinity of the fair ground, is an extensive area of outwash of the kettle-plain type. Many of the kettles are more than a quarter of a mile long, two more than half a mile, and one more than a mile. Several kettles, especially the largest, have a branching form such as would characterize kettles resulting from the melting of ice masses in old Manhasset valleys, and this, in fact, is probably their origin. Some of the ice blocks evidently rose distinctly above the outwash surface, for ridges, apparently of materials set free from the melting of the ice masses, are found on the kettle rims along the fair-ground road and elsewhere.

The deposits of the united outwash channels pass southward as a belt more than 2 miles in breadth between the Mannetto and Half Hollow hills, beyond which they spread out in a broad fan stretching along the coast from Massapequa to Babylon.

The greater part of the outwash, including most of that south of the Mannetto and Half Hollow hills, appears to have been deposited during the earlier stages of the Harbor Hill ice halt and before the melting of the ice blocks in the intermorainic district. It is probable that at this time the entire area between the moraines was of the kettle-plain type. In the later stages of the ice halt less material was set free, the waters coming mainly from two points, one at each end of the area. By this time the ice blocks seem to have largely melted and the kettles along the two outwash streams became filled. No further materials, however, appear to have been deposited in the Fairground area between these streams. So slight was the amount of detritus carried by the streams that it appears to have been deposited before Melville was reached, the waters at this point gathering into definite channels, one on each side of the valley, leading southward toward the coast. Of these channels the one on the east side continues sharp and distinct to the point where it empties into Great South Bay, near Babylon, but the more westerly stream was apparently weaker and its channel is somewhat indefinite in the lower part of its course.

Smithtown region.—East of Greenlawn thick outwash is found only in a belt a mile or two in width along the base of the moraine, beyond which the Manhasset approaches the surface and exerts a decided influence on the topography. East of a line from Kings Park to Commack the outwash entirely disappears, leaving the broad drainage basin of Nissequogue River (Pl. X, p. 46) as destitute of outwash as it is of till. (See p. 162.) This is the so-called Smithtown "driftless" area.

Port Jefferson region.—At Smithtown Branch and St. James the outwash is again recognized along the moraine, but it decreases in thickness toward the south, Manhasset drainage lines being recognizable within 2 or 3 miles of the moraine. The southerly part of the belt is dotted by kettles, many of them occupied by ponds, the largest and most beautiful of which is the well-known Lake Ronkonkoma. Several of the depressions are of the kettle-valley type.

South of Port Jefferson the outwash plain is well developed for 2 miles or more south of the moraine, but irregularities in the form of kettles appear near Terryville, and a little farther south low but distinct ridges and valleys, such as everywhere characterize the Manhasset surface, are seen. It is evident that the outwash is very thin and probably is confined largely to the valleys. The surface of a considerable area near the outer moraine has been reworked by winds and a coating of dune sand spread over it, in places completely hiding the underlying materials.

Rocky Point and Riverhead area.—East of Port Jefferson the outwash becomes still thinner, and kettle valleys and even unfilled Manhasset drainage channels are seen close to the moraine at numerous points, as near Rocky Point, at Wading River, south of Fresh Pond Landing, and northwest of Riverhead. The kettle valleys in this region (see Pls. IX, *B*, p. 42; XX, p. 116) are among the most conspicuous on the island, individual kettles reaching a depth of 60 to 80 feet and having a length of several miles. Northwest of Riverhead chains of kettles, instead of single elongated hollows, mark the Manhasset valleys (Pl. IX, *C*). One of these is 4 or 5 miles long. Some of the kettles are marked by raised rims, apparently consisting of material set free from the ice blocks, which must therefore have risen above the surrounding surface.

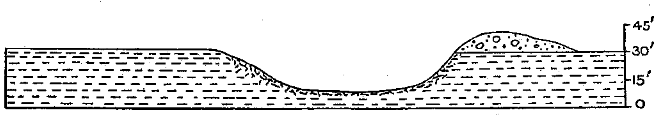


FIGURE 197.—Kettle rim of till near highway between Mattituck and Cutchogue.

The true outwash from ice along the Harbor Hill moraine does not extend south of Peconic River, the Wisconsin materials there consisting of kame and local outwash deposits resting on an irregular Manhasset surface, the whole having a distinct morainal aspect. The deposits are, nevertheless, in the main sharply separated from the Ronkonkoma morainal ridge and are better mapped as outwash than as moraine.

North Fluke.—On the North Fluke the outwash plain becomes narrower toward the east, being about 4 miles wide at Riverhead and absent at Orient Point. It becomes progressively thinner and the Manhasset controls more and more of the topography. There are, however, fewer kettles and kettle valleys, presumably because the Manhasset surface, on which the outwash rests, was more level than at points farther west owing to its slight elevation and consequently less-marked erosion. Kettles are nevertheless not uncommon, especially between Riverhead and Mattituck, and open Manhasset or kettle valleys nearly or quite cut through this fluke at Mattituck and at Hashamomuck and Truman beaches. Some of these kettles show, in addition to the usual bowlders, marginal ridges of drift set free by the melting of the ice blocks. One of the best examples of these, found about 1½ miles northeast of Mattituck on the road to Cutchogue, is shown in figure 197, the rims being raised about 20 feet above the surrounding plain. A pair of kettles near the second road leading northwest from the Cutchogue-Southold highway, about 1½ miles northeast of Cutchogue, showed a sharp connecting crease as if cut by water flowing from one into the other.

OUTWASH CHANNELS.

In the later part, or at the end of the Harbor Hill substage of outwash deposition, the outflowing glacial waters were no longer overloaded with débris, and hence ceased to deposit and began to erode. As a result numerous well-defined and some large channels leading southward toward the sea were cut in the surface of the outwash. The greater number of these channels start at or near the Harbor Hill moraine and cross the island to the south coast, but some start at the moraine and become indistinct before reaching the sea and others begin several miles south of the moraine.

Roslyn channel.—The most western channel of importance is that starting at the gap in the moraine at Roslyn. This is a sharp, well-defined channel several hundred feet wide, about 15 feet deep and in places, as at the road half a mile south of Roslyn station, characterized by a low terrace between the bottom and the outwash level. Its course is shown by the geologic map (Pl. I, in pocket).

Melville channels.—The next important channels are those leading southward from Melville between the Mannetto and Half Hollow hills. The character and significance of these channels have been discussed in another place (p. 49).

Centerport-Babylon channel.—One of the most persistent of the smaller channels is that east of the Dix Hills. Starting at the moraine near the head of Northport Harbor, it extends across the steep outwash fans to Elwood, across the combined outwash and Manhasset to Commack, through the Ronkonkoma moraine at the east end of the Dix Hills, and across the outwash from ice along the Ronkonkoma moraine to the south shore at Babylon, 16 miles from its point of beginning.

Connetquot channel.—The broad Connetquot channel, which measures from a mile to a mile and a half in width, starts near Smithtown and runs first eastward and then southward, emptying into Great South Bay between Islip and Sayville. In many respects it is unique among the Long Island channels. It neither heads in the moraine nor develops in an outwash plain. Instead, it starts high above drainage level on the east side of the Smithtown "driftless" area (Pl. X, p. 46) and makes a broad bend to the northwest and then another to the south before finally passing through the outer moraine. The northerly and easterly side of the channel is marked by a sharp and distinct scarp, 20 to 30 feet or more above the floor of the channel, and intersected at short intervals by drainage creases, now streamless. The same scarp is found at the gap in the moraine and on both sides of the channel for some distance to the south, but it gradually becomes less conspicuous and is bounded by gentler slopes. Many of the tributary drainage creases are well developed and branching, being far more advanced than any other post-Wisconsin channels on the island. A similar drainage system is found a short distance to the east, converging toward the gap in the moraine through which the main channel passes.

The advanced stage of development of the Nissequogue drainage system on the west side of the river suggests that a similar stage may have existed at some time on the east. This the writer believes to have been the case, the headwaters being represented by the larger branching channels entering the Connetquot channel between Smithtown Branch and the moraine. Another drainage system with its principal headwaters northwest of Lake Ronkonkoma, but with another branch heading somewhere east of Hauppauge, is thought to have led southward along the present course of Connetquot River. Before the advance of the main Wisconsin ice sheet the western half of the Nissequogue drainage basin appears to have been covered with snow or snow ice, so that the glacier passed over to the moraine beyond without either disturbing the surface or covering it with drift. In the eastern part of the basin, however, the conditions were different, at least in the later part of the invasion, and sufficient drift, mainly stratified, was deposited to cover and obliterate the drainage topography. The ice over the western half of the drainage system persisted after the retreat of the ice from the Ronkonkoma moraine, but in the eastern half only a few buried masses remained. Over this eastern area, it is thought, there swept large quantities of water, the current following the outside of the curve marking the easterly boundary of the Connetquot channel from Smithtown Branch to the moraine, cutting the sharp terrace which lies just east of the highway between the points mentioned, crossing the old divide east of Hauppauge, and flowing down a pre-Wisconsin channel of a tributary to the stream heading in the district northwest of Lake Ronkonkoma. After the cessation of the outflow the ice masses underlying the outwash deposits melted, leaving the rolling surface now seen, and the erosion of the minor notches in the cliffs began. The history outlined is somewhat complicated, but it seems to fit the facts better than any other explanation yet proposed.

Carmans River channel.—The only other channel of importance is that along Carmans River in the vicinity of Yaphank. Most of that part lying south of the moraine belongs to the Ronkonkoma substage, but a narrow channel along the present stream seems to belong to a later stage. The channel is believed to mark an intermediate outwash deposit laid down later than the Ronkonkoma moraine but earlier than the Harbor Hill moraine and the outwash from ice along it. (See fig. 196, p. 168.)

RETREATAL DEPOSITS.

The final retreat of the ice from its position upon the surface of the gravels of the Manhasset formation appears to have been accompanied by no considerable outwash, the deposits that were left on the surface during the retreat being composed of till rather than gravel. In some of the cliff sections a few feet of gravel rests on the till and it is believed to represent outwash deposits of the final retreat. Such deposits, however, are more commonly absent than present. Some of the swells breaking the regularity of the plateau-like Manhasset surfaces may represent low, flat outwash fans of this stage, but the number of bowlders lying upon most of the surface seems to indicate that the top deposits are mainly of till. Channels cut by streams issuing from the ice sheet during its retreat persist at several points.

R. D. Salisbury [1] and his associates mapped considerable areas on the north side of the island from East River to Flushing Bay as stratified drift of the last retreat, and as there was no opportunity for a reexamination of the area, this mapping has been followed in the present report. The fact that the surface gravel overlies the main drift of the region does not, however, necessarily indicate that it is Wisconsin. On the contrary it may be the Hempstead gravel member of the Manhasset formation resting upon the Montauk till member of the Manhasset, as was found to be true of the College Point "kames," the Wisconsin till in many places being almost unnoticeable.

The most satisfactory exposure of retreatal material is found on Manhasset Neck northwest of Port Washington (Pl. IV, p. 30), where a broad delta exhibiting characteristic foresets and topsets was formerly to be seen but has been now largely removed for the sand and gravel it contained. According to J. B. Woodworth,[2] who studied the delta in detail, it was formed in a local glacial lake during the ice retreat, the water standing about 80 feet above the present level of the sea.

A thin retreatal outwash deposit resembling that between the Harbor Hill and Ronkonkoma moraines south of Huntington mantles the surface of Lloyd Neck. At the time of its accumulation ice masses still rested in its valleys and on their subsequent melting gave rise to the numerous kettles and kettle valleys. These are well shown by the topographic map (Pl. II, in pocket).

RECENT SERIES.

EXTENT.

The Recent deposits, although not extensive compared to the glacial and older materials, are nevertheless of considerable importance. A stretch of nearly 100 miles of beach, probably averaging a quarter of a mile in width, has been constructed, making an addition of 25 square miles to the area of the island. The largest addition, however, has been made through the growth of the salt marshes, which have extended the area of the island by at least 100 square miles. The fresh-water marshes probably have an aggregate area of 15 square miles or more, and dune sands cover about 25 square miles of inland territory in addition to that along the

[1] New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

[2] Bull. New York State Mus. No. 48, 1901, p. 653.

beaches. In all probably more than 125 square miles of the present area of the island is due to accumulation in Recent time. This, however, is probably more than counterbalanced by the land lost by erosion and by subsidence.

STREAM DEPOSITS.

Deposits in stream channels.—Although Long Island abounds with stream-cut valleys and channels, there are few stream deposits that can be referred to postglacial accumulation. On the plateau of the north shore the valleys are older than the last ice invasion, with the deposits of which their sides are locally mantled. The action of streams in Recent time is usually limited to a shallow notching of the valley bottoms or to slight washes of sand and gravels from their sides.

Most of the channels in the plains of the southern half of the island are not occupied by streams at the present time, evidently having been cut under conditions quite different from those now existing. Some of these channels proceed from the outer or Ronkonkoma moraine, others rise back of it, and still others even start from notches in the inner ridge, indicating that the source of the water was in the ice. Many of the minor channels, however, are cut only a mile or two back from the sea, and these, it seems likely, were cut, in part at least, by postglacial stream action before the protecting mantle of vegetation obtained a foothold. In the latter channels, if not in some of the former, the surface materials have probably been more or less shifted in postglacial time and hence are to be included with the Recent deposits. The same is true of many of the notchlike channels at points on the flanks of the moraines.

Alluvial fans.—At the base of each moraine there are many more or less fanlike accumulations of sand and gravel brought down as local wash, largely before the surface was covered with vegetation, but in part by wash or creep in Recent time. These deposits are best seen where the moraine is high and the materials are sandy, as in the region between the Dix Hills and Coram and at a number of points farther east, but are commonly too small to be indicated by the contours of the topographic map. Many small but well-developed fans also occur at the mouths of the ravines of the Mannetto and Half Hollow hills south of the moraine, and typical talus cones and fans occur at the base of the bluffs and at mouths of ravines along the north shore of the island.

Deltas.—Because of the slight amount of postglacial erosion that has taken place, deltas are, as would naturally be expected, practically absent at the mouths of the valleys. Small deltas from 50 to 100 feet in diameter are often formed during heavy rains from materials washed from the ravines of the north shore, but these are usually destroyed by the currents or waves in a short time. The harbors of the north shore and the great bays of the south shore are more or less filled with sands shifted about under the action of the tide, but these deposits appear to bear no relation to the streams emptying into the sea in the vicinity. Here and there deltas are formed by tidal currents both inside and outside of the inlets through the beaches, but most of them are small. The shoal lying off the mouth of Nissequogue River is the only one of any consequence resembling a delta indicated by the charts.

MARINE DEPOSITS.

BEACHES AND SPITS.

A long stretch of beach extends with a few interruptions from Coney Island to Southampton, a distance of nearly 90 miles, and separates from the ocean several partly or completely inclosed bays, such as Jamaica, Great South, Moriches, and Shinnecock. The longest stretch of unbroken beach is that extending westward from Southampton to Fire Island Inlet—a distance of 45 miles. This beach, which is almost a straight line throughout its length, is rarely more than half a mile and generally less than a quarter of a mile wide. The part south of Shinnecock Bay is known as Hampton Beach, but most of the remainder is designated Fire Island Beach. Waves occasionally cut through it in time of storm, although the openings are commonly soon closed again.

Shinnecock Bay, just west of Southampton, 9 miles long and 3 miles wide, has at present no direct connection with the ocean, but a canal leads northward into Great Peconic Bay and another westward into Moriches Bay. An artificial cut made to the ocean was soon closed by the waves. Moriches Bay is connected through a narrow natural channel with Great South Bay, which in turn connects with the ocean through Fire Island Inlet.

The beach is composed mainly of quartz sand, although some garnetiferous and magnetic materials are seen. Pebbles are generally scarce, but some are seen where the beaches connect with the main island, as near Southampton and Westhampton. The surface above high-water mark is generally covered with dunes from 5 to 20 or even 30 feet in height, among which are scattered many small fresh marshes. The movement of materials by the waves is plainly westward, the chief source being between Southampton and Montauk, where the coast, as has been seen, has suffered considerable erosion. It is possible, also, that a part of the material has been thrown up from the shallow sea bottom of the vicinity by the action of waves. Practically no sand is contributed by the streams of the island at the present time.

West of Fire Island is the beach known as Oak Island Beach in the eastern part and Jones Beach in the western part. This beach begins about a mile north and a little more than a mile east of the west end of Fire Island Beach. It seems to have never been connected with the main island and appears to be older than Fire Island Beach, which is now being built outside and overlapping it. It is therefore a pure barrier beach, whereas Fire Island Beach partakes of the nature of a spit.

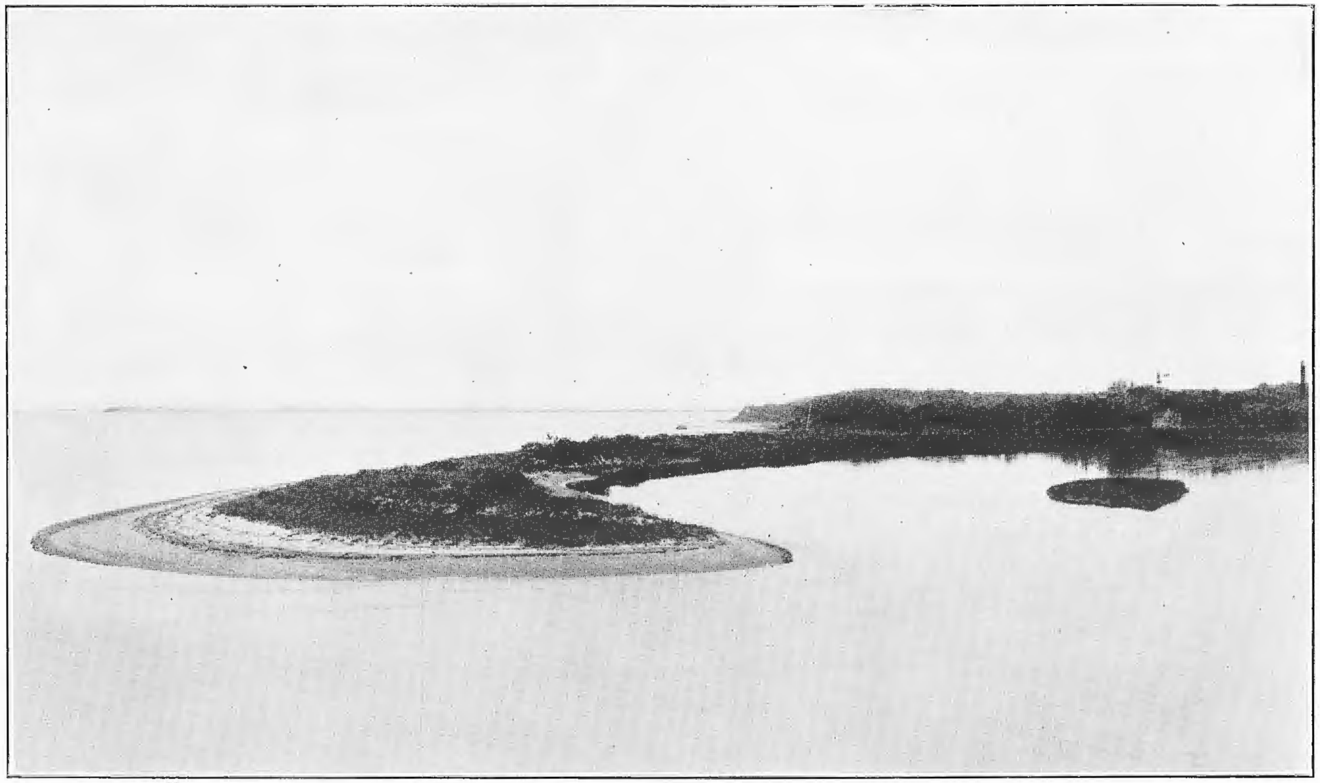
Just west of Jones Beach and separated from it by the narrow Zachs Inlet is Short Beach, about 2 miles in length. Beyond is Jones Inlet, followed by Long Beach, about 8 miles in length, and Far Rockaway and Rockaway beaches, which are continuous and together about 11 miles long. Manhattan and Brighton beaches, lying west of Rockaway Inlet on Coney Island, which are together about 5 miles in length, complete the list. All these beaches are without natural connection with the main island and have derived no material directly from it, being essentially barriers. They show some diversity in direction, with a tendency to overlap, seen where the Rockaway approaches the Manhattan Beach.

North of Long, Jones, and Oak Island beaches there are a number of small sandy islands in a line parallel to the beaches, with which their longer diameters are also parallel. These appear to represent the earliest bars formed by the waves and currents in the shallow waters off the south coast. Later the longer, higher, and more connected barriers, such as Oak Island, Jones, Long, and Rockaway beaches, were built up outside of the earlier bars from materials derived from the sea bottom. At the same time a spit was being projected westward from Southampton (Hampton Beach), composed of material derived from erosion of the shore farther east rather than directly from the sea bottom. Later, partly with material from the same source and partly with sands from the sea bottom, the spit was extended westward to Fire Island Inlet, slightly overlapping the earlier Oak Island Beach.

The process of formation of the beaches is not continuous. Many feet may be added in a single storm; again, the waters of the ocean may break through, leaving wide gaps in the previously continuous beach. There is also at many points a tendency to periodic changes from deposition to erosion. Thus for a long time Fire Island Beach has been building outward, but at the time of the present field work the waves were cutting it away, leaving everywhere at high-tide line a low scarp 4 or 5 feet high, giving a section through the original beach and its capping of dunes.

CONNECTING BEACHES.

When the ice of the last glacial advance retreated from the region there were many disconnected islets adjoining the main island. In most places the intervening waters were shallow, and waves and shore currents rapidly extended hooks and spits from the projecting points and later united many of them into connecting beaches, joining the previously independent islets and completing Long Island as it now appears. Marshes have also served as a connecting agency. Beginning at the west on the north shore, the first islet that has been joined to the main island is Hunters Point; next an unnamed island on the Sound in the northeastern part



HOOKED SAND SPIT AT ENTRANCE TO SMITHTOWN HARBOR.
Photograph by Edward P. Buffet.

of Long Island City; then Tallman Island near College Point; and Prospect Point on Manhasset Neck. All these are connected with the body of the island by marshes. East of Hempstead Harbor Dosoris and East islands are connected by beaches; farther along Oak Neck and Center Island by beaches and marshes; and Lloyd and Eaton necks, including Duck and one other small island, by beaches. There are no further indications of former islands between this point and Southold. Between Southold and Greenport breaks exist at Hashamomuck Pond and at Pipe Cove, and there was a channel at each end of Truman Beach, near Orient.

In the bays between the flukes Ram Island, Mashomuck Point, and another smaller island were connected with Shelter Island by beaches, and Little Hog Neck was in like manner joined to the North Fluke. On the South Fluke the Montauk peninsula was connected with the main island by Napeague Beach, nearly 5 miles in length. Near Sag Harbor, Hog and Jessup necks and two smaller islands were connected by beaches or marshes, as were Cow Neck and a small island on the south side of Great Peconic Bay. There does not, however, seem to have been any natural channel at Canoe Place, west of the Shinnecock Hills, although the land at this point is only a few feet above sea level and but a few hundred feet in width. The canal banks show glacial deposits rather than beach sands. A former connection of the waters of Peconic and Shinnecock bays would have necessitated a sinking of 10 or 15 feet below the present level of the land, a submergence of which there is no evidence.

SMALL SPITS AND HOOKS.

Among the minor shore features of Long Island are hundreds of small spits and hooks. Many of them are very typically developed. They are naturally most common along the irregular part of the north coast west of Port Jefferson and on the shores of the bays between the North and South flukes. Many smaller ones are found on the shores of Great South Bay and other bays of the south shore.

Currents sweeping along any stretch of coast tend to move in straight or gently curving lines just outside of the headlands, rather than on lines conforming to the minor irregularities and indentations of the shore. The material that they transport is deposited, owing to the slackening of their progress, when deeper water is reached, forming bars more or less completely connecting the headlands and at many points inclosing areas of relatively deep water. The beach between Horton and Duck Pond points, Southold, was formed in this way, and a second bar is in process of formation. In places, as near Peacock Point, between Oyster Bay and Hempstead Harbor, as much as 600 feet of beach may be built out in a few years.[1] Where the currents are feeble or conflicting, or the supply of material is not abundant, small straight or curved bars are formed rather than the longer ones described. In either case the bars generally continue to receive additions of material and are finally built up so that they come within the range of influence of the waves, which serve to pile up the materials still further, until they are brought above the level of the sea to form connecting beaches, spits, and hooks. Of the spits the more prominent are Lloyd Point and East Beach, on Lloyd Neck; Eaton Point and West Beach, on Eaton Neck; the spit at the entrance to Smithtown Harbor or Nissequogue River (Pl. XXV); West Meadow and the opposite beach at Stony Brook; Setauket and Mount Misery beaches on Port Jefferson Harbor; East beach, near Miller Place; Long Beach, near Orient Point; the spits at the north and south ends of Gardiners Island; Goff and Lazy points and Hicks Island, on the Montauk peninsula; and Cedar Point, Sammys and Acabonack beaches, between Sag Harbor and Napeague Beach. (See Pl. I, in pocket.) Of these, Lloyd Point, West Beach, and the beaches at Mount Misery, Lazy, and Goff points, Hicks Island, and Cedar Point are of interest as being curved, hooked, or otherwise complex spits. Many of the smaller unnamed beaches, such as those partly cutting Hempstead and Cold Spring harbors, are of equal interest.

MAGNETIC AND GARNETIFEROUS SANDS.

Among the most striking features of the material of the wave and current formed beaches of Long Island are the magnetic and garnetiferous sands, which are seen at many points along

[1] Mather, W. W., Geology of New York, pt. 1, 1843, p. 22.

the coast, especially on the north shore. These sands occur at some places in beds from half an inch to 4 inches thick, several feet wide, and 10 to 100 feet long. They are usually found well above the ordinary water level at points where the waves have beaten at unusually high tides or in times of storm. This is commonly at the very base of the bluffs. Farther down the beach the grains may be either mixed with the coarse sand or gravel, as along parts of the north shore, or they may occur as a surface film on the hard-packed sand, as on the more exposed beaches of the south shore.

The sands are derived from the breaking up of the crystalline pebbles or bowlders of the drift. The till contains much more of such material than the stratified drift, and the magnetic and garnetiferous sands on the beaches appear to be no more abundant in the vicinity of the till than elsewhere. This, however, may be due to the fact that most of the till bluffs stand in more exposed positions, where the wave action is so strong that the sands are washed away, leaving only the heavier cobbles and bowlders on the beach. Few beds of magnetic sands were observed on the south side of the island, owing to the general absence of crystalline materials except near Montauk, but they are reported on Fire Island Beach off Patchogue. The most conspicuous deposits seen in the course of the present field work were near Orient Point and between Wading River and Miller Place. The individual beds shift considerably in position during each storm, but the general distribution of the sands probably remains fairly constant, the present localities closely agreeing with those recorded by Mather in 1838 to 1843. In the early days the sands were collected for a forge in Connecticut.

In order that the magnetite and garnet may be separated from the quartz grains, a thorough stirring of the sand seems to be necessary. The advance and retreat of the ordinary small wave simply produces a surface film of the heavier magnetite and garnet grains without forming a bed. The sand must be churned up to a considerable depth by wave after wave before any considerable amount is separated, hence the beds are usually formed only in time of storm, a fact which also accounts for their high position on the beach.

WIND DEPOSITS.

CHARACTER AND GENERAL DISTRIBUTION.

Although not covering areas so extensive nor reaching heights so great as those of some other localities along the Atlantic coast, the dunes of Long Island are at many points a conspicuous local feature. They have received attention from a number of writers, beginning in 1822 with Timothy Dwight,[1] who in speaking of the Shinnecock Hills described them as bare dunes still drifting with the winds. Drifting sands near Brooklyn were mentioned by John Finch[2] in 1824. W. W. Mather[3] described the dunes of the island in detail in his three reports. Elias Lewis[4] published in 1876 a detailed discussion of their composition, manner of accumulation, distribution, and size. John Bryson[5] in 1891 referred the dunes of Easthampton to deposits of subglacial streams.

The dunes in process of formation at the present time, with few exceptions, are limited to the immediate vicinity of the beaches. At Easthampton, however, dune sands occur for a distance of 1½ miles from the shore, and there is also a considerable area in the interior of the island, between Patchogue and Port Jefferson, where wind action has been active in the past and is observed locally even at the present time.

The dune sands consist almost entirely of fine quartz grains, well rounded, and little stained by iron. Some garnet and magnetite and here and there grains of other minerals occur, and minute fragments of shells are not rare. The magnetite sands are sometimes rather conspicuous on the sand surfaces after a long-continued period of winds with velocities just sufficient to move the lighter quartz grains but not strong enough to transport the heavier magnetite.

[1] Travels in New England and New York, vol. 3, 1822, p. 317.
[2] Am. Jour. Sci., 1st ser., vol. 7, 1824, pp. 31–43.
[3] Rept. New York Geol. Survey, vol. 1, 1837, pp. 61–95; vol. 2, 1838, pp. 121–184; Geology of New York, pt. 1, 1843, pp. 30–33.
[4] Pop. Sci. Monthly, vol. 8, 1876, pp. 357–363.
[5] Am Geologist, vol. 8, 1891, pp. 188–190.

The dunes generally rest on a black loamy soil zone, if they are of recent formation, or on a brownish oxidized zone from which the organic matter has been leached, if they are among the older dunes.

DUNES AT NAPEAGUE BEACH.

Napeague Beach and vicinity constitute the most conspicuous dune area on the island. Five miles long and nearly 2 miles wide it comprises little but irregular sand heaps from 10 to 30 feet or more in height, between which are many small marshes fed by the fresh waters caught by the dunes. Leading westward from Napeague Harbor is a large fresh marsh, half a mile wide, lying between the dunes of Napeague Beach on the south and Promised Land on the north. The dunes reach their greatest development just east of the harbor, where they have an elevation of 100 feet. It is possible, however, that a part of this height is due to Manhasset materials, which may underlie them. The dunes of Napeague Beach have derived their materials mainly from shore wash from the east; those east of Napeague Harbor seem to have been supplied mainly from the same source with relatively little additions from the north side, their accumulation taking place mainly under the action of the southwest winds. It is believed that a part of the material of the dunes of Promised Land has had a similar source, being blown from the south coast by southwest winds, and that a part has come from the shore immediately to the west. The big marsh between the dune areas does not, however, convey the impression of having been crossed by a moving mass of dunes, and it is possible that very little of the material has come from the south.

DUNES AT EASTHAMPTON.

In the main the dunes of the south shore are confined to a narrow fringe along the beach, but at Easthampton the drifting sands have progressed a considerable distance from the seashore, typical dune topography west of the town being recognized as much as 1½ miles inland, or as far north as the railroad. The sandy character of the roads indicates that the area of drifting sand probably has extended considerably north of the railroad and westward to and beyond Georgica Pond, although this is not conspicuously shown by the topography. East of the town the dunes take the form of broad bare hills with wind-swept surfaces and hoppers. West of the town the dunes, though not so large, show an even more marked dune topography, the sharp ridges and knobs being especially conspicuous. This area is now being covered with summer residences, and the dunes are largely under control.

DUNES OF THE GREAT SOUTH BEACHES.

The barren beaches which extend along the south coast for nearly 90 miles are lined throughout their length by more or less strongly developed dunes, generally 15 or 20 feet in height. Along the inside of the outer beach the dunes form a rather uniform and continuous though somewhat notched ridge some 20 feet in height and extending for miles along the shore. On the inside of this barrier there is also very commonly a second ridge, which, however, is lower and less continuous than the outer one. Between the two there is generally an area of lower and flatter dunes among which are scattered knobs; many rise to a height of 20 or 30 feet. Between the ridges or among the low intermediate dunes many fresh-water marshes are found. Some of these merge with the salt marshes which line the inside of the barrier. The finest development of dunes seems to be on the Fire Island and Rockaway beaches, although the Rockaway dunes, as well as the once conspicuous dunes on Coney Island, have been much modified by human agency.

DUNES AT SHINNECOCK HILLS.

The Shinnecock Hills are composed of the Manhasset formation, in which, in this area, sand predominates. In the past this sand has often been taken up by the winds to form dunes, and to this action a part of the irregular surface topography of the hills is due. A hundred years ago much of the surface was composed of drifting sands,[1] but now the sands are mostly under control, although a little drifting still takes place.

[1] Dwight, Timothy, Travels in New England and New York, vol. 3, 1822, pp. 283–336.

DUNES OF THE NORTH COAST.

Practically every bluff section along Long Island Sound shows a layer of dune sand at the top, and some small valleys are filled with it, as near Woodhull Landing northeast of Miller Place. Usually this sand is only 2 to 5 feet deep, but some of the dunes are conspicuous hills from 50 to 100 feet high. They all rest on an old soil zone marking the horizon of the original surface (Pl. VIII, *B*, p. 34). Where the dunes are of relatively recent origin the zone is represented not only by the usual oxidized band but by bands of nearly black vegetable mold as well.

On this side of the island the dunes are best developed between Baiting Hollow and Northville, north of Riverhead, where they form a high and nearly continuous ridge more than 8 miles long. They rest in part on the edge of the Manhasset terrace or on the low moraine that traverses this locality. This coincidence of position with the drift ridge has led to the classification of the entire ridge as moraine, but as a matter of fact the moraine is rarely more than 10 or 20 feet thick and in many places is represented by only a few scattered bowlders. The great mass of the ridge in this vicinity is composed of sand. Plate VIII, *A*, shows the profile of the ridge usually classed as morainal, here over 50 feet in height, and Plate VIII, *B*, shows that in reality it is a ridge of dune sand resting on the Manhasset terrace.

Many parts of the dune ridge are very old, so that the humus of the underlying soil zones has been entirely leached out. Much of its surface is covered with forests. Elsewhere, however, the dune is still in process of formation. W. W. Mather[1] in 1843 recorded the local deposition of several feet of dune sand in a few hours during a storm in 1836. Jacob Hill, northwest of Mattituck, was once much higher than Coopers Hill (Mattituck Hills?) east of it, but the sand has blown off until it is now lower. Some arable land has been covered and a cedar tree has been buried. Elias Lewis, jr.,[2] in 1876, stated that a farm near Baiting Hollow had lost 30 acres by the encroachment of the dunes in 30 years and that 100 acres in all had been recently covered.

Another important dune area is at Horton Beach, near Southold, where the shore back of the beach is lined with dunes of moderate size. Though more or less covered with trees the sand is still blowing. There are several small fresh-water marshes among the dunes and a pond is inclosed between the drifting sand and the bluffs.

DUNES IN THE INTERIOR OF THE ISLAND.

In the western half of Long Island most of the surface deposits consist of fine gravels and coarse sand, both of which are in places somewhat loamy. No distinct evidences of dune formation have been observed in this region. Farther east, however, the surface deposits are finer and there are considerable stretches where nothing but fine white sand is seen in the roads. The fineness and looseness of the surface coating and its apparent lack of indications of aqueous stratification suggest that it is of dune origin, although there is little distinct topographic evidence of wind action. From Coram eastward sands perhaps of dune origin are common both on the plains and over the moraines. The part of the moraine south of Riverhead and southwest, south, and southeast of Sag Harbor is especially characterized by such sands. In most places they were formed before the region was forested.

Very large areas of similar sandy surfaces lie north and northwest of Patchogue and between Patchogue and the morainal ridge.

The moraine and the plains south of it are covered with forest or brush, and few evidences of wind action were seen. At the north base of the ridge near Selden, however, and at points eastward to Coram, westward to and beyond New Village, and northward halfway to Terryville not only does the surface consist of fine sand but there were in 1903 many spots free from trees and almost free from vegetation, showing a subdued dune topography. Some low sand hillocks and hoppers are being formed at the present time (Pl. XXVI, *B*). It is believed that this region was once forested and protected from the winds, as otherwise the dunes would

[1] Geology of New York, pt. 1, 1843, p. 31.

[2] Formation of sand dunes: Pop. Sci. Monthly, vol. 8, 1876, pp. 357-363.

A. UNDERMINED PEAT ON COAST NEAR PROSPECT POINT, MANHASSET NECK.

B. SEMIDUNE SURFACE IN INTERIOR OF ISLAND, NEAR SELDEN.

A.

B.

MUD CONES MARKING ORIFICES OF SPRINGS IN MUD FLATS NEAR DOUGLASTON.

be much more strongly developed. The opportunity for the present wind action to arise is thought to have been given by the destruction of the forests and the vegetable mold of the soil by the fires that repeatedly passed over the region. What the ultimate results will be can not now be foretold, for the conditions appear to be very nicely balanced. If the fires continue and the barren patches become larger so that they are no longer protected by the surrounding forests, the wind action may again become important and the dunes grow larger and more destructive. If, on the other hand, fires can be kept out, vegetation will soon cover the burns and restore the forest to its supposed former unbroken state.

MARSH DEPOSITS.

FRESH MARSHES.

Marshes of the south shore.—Along the entire south coast of Long Island, except near Montauk, the plains slope gently seaward at a rate of 10 to 20 feet to the mile. There are almost no streams on these plains, except near the coast, all the rainfall entering the porous sand and making its way seaward as ground water. Near the places where the plains reach sea level this water emerges at the surface, converting the edge of the plains into a marsh extending with hardly an interruption from Coney Island to Islip, a distance of nearly 50 miles. Farther east similar marshes, although not entirely continuous, occur at short intervals to Shinnecock Bay. The landward edge of the marsh is usually a luxurious meadow, which grades off with an intermingling of fresh and brackish water vegetation into a salt marsh, yielding great quantities of salt hay. The entire marsh may be a mile or more wide, although a width of a quarter of a mile is more common. The relative widths of the fresh and salt portions depend on the relative slopes of the land surface and the bottom of the bay, one or the other predominating according as one or the other slope is the gentler. The amount of ground water entering at a given level also has an important influence on the width of the fresh marsh.

Marshes in the valleys of the south side.—Where the plains of the south side of the island are not cut by valleys the water emerges from the lower edge of each plain, but where valleys are present the ground-water level is cut at some distance from the coast, and considerable volumes of water emerge along the valleys, forming extensive marshes and even streams of some size. Such a marsh is found in nearly every valley of the south shore, extending a mile or so back from the coast in the shorter valleys and several miles in the longer ones. The width is usually under a quarter of a mile. The principal streams bordered by marshes include Cornell Creek, south of Jamaica; Valley Stream; the stream east of Lynbrook; Meadow Brook, near Freeport; Jackson Creek, near Wantagh; Massatayun Creek, near Massapequa; Carlls River, near Babylon; Connetquot Brook, near Islip; Patchogue Creek and Swan River, near Patchogue; Carmans River, near Yaphank; Forge River, near Moriches; and a number of smaller streams farther east. The most extensive marshes are along Peconic River, stretching from a point west of Manorville to and beyond Riverhead, a distance of more than 10 miles. The only stream of notable size on the north side is the Nissequogue, near Smithtown. This is bordered by marshes for about 3 miles above its mouth.

Marshes near artificial ponds.—There are a number of artificial ponds and reservoirs along the south side of the island, as at Valley Stream, northeast of Lynbrook, and near Freeport, Wantagh, and Massapequa, and a few built for developing power or for other purposes at points in the interior of the island, as between Babylon and Wyandanch. There are two such ponds at Riverhead. The effect of damming the streams is to back the water up over the gently sloping valley floors and create marshes or swamps. This is notably the case at Riverhead, where the slack water extends upstream for some miles, forming considerable marshes.

Marshes in obstructed channels.—Some of the old channels, especially in the eastern half of the island, were obstructed by drift left by the ice in an advance after their formation, and surface waters have accumulated behind the obstructions, forming ponds or marshes. Grass Pond, northwest of Manorville, is a particularly good example of such an accumulation. Another is found in the valley 1 mile west of Middle Island, and still another in the valley north of this point, although these marshes are not so extensive as Grass Pond. Other examples may be seen at many points. About 1½ miles northwest of Lake Ronkonkoma is a series of marshes in a channel seemingly obstructed by wash from a tributary valley.

Marshes in kettles.—Besides the marshes in obstructed channels, or kettle channels, as some of them may be called, there are numerous irregular kettles occupied in whole or in part by marshes. These are too numerous to mention singly, practically every kettle that contains a pond also having a marsh around the whole or a part of its margin, and marshes are found also in many others in which there is no open water. Among the ponds bordered in part by marshes may be mentioned Lake Ronkonkoma; Artists Lake, near Middle Island; Long and Grass ponds, between Wading River and Manorville; Swan and other ponds near Manorville; the ponds south of Riverhead; and Poxabogue and other ponds near Bridgehampton. Many marshes unaccompanied by ponds occur in kettles in the vicinity of Manorville and Bridgehampton; these have never received names.

Marshes behind beaches.—Beaches have been thrown up across many of the reentrants of the north shore by the waves and currents, and behind some of these fresh waters have accumulated and replaced the salt marshes that originally existed there. The fresh marshes of this type appear to have been more extensive formerly than at present, for fresh-water peats containing stumps and prostrate tree trunks are found beneath the present salt marshes at many points, a condition apparently due to a relatively recent sinking of the land. (See pp. 212–216.) This probably explains why most of the marshes at the present time maintain communication with the salt water through narrow breaks in the barriers. In such places the fresh marshes are found only around the edges.

Interdune marshes.—At many places on the south coast, especially on the great beaches, the dunes occur in either scattered hillocks or more or less definite ridges, between which are level areas of moderate size. These areas usually lie a foot or two above high-tide mark but commonly have no surface-drainage connection with the sea, being, in fact, inclosed basins surrounded by dunes. Receiving not only the rain falling upon their surfaces, but also the seepage from the surrounding dunes, which absorb practically all the rainfall reaching them, these areas are naturally kept in a damp state very favorable to marsh growth. Marshes formed under such conditions, in fact, occur almost everywhere in the dune areas near sea level, such as those of the south coast. The largest single example is the marsh between Napeague Beach and Promised Land, on the South Fluke. Especially good examples can also be seen on Fire Island Beach, and minor marshes are to be found on nearly every spit and beach. They are absent from the dune areas of the interior, both at Easthampton and between Patchogue and Port Jefferson, where the depressions are well above the ground-water level.

SALT MARSHES.

Marshes of the south shore.—Inland from the edge of the fresh marshes, at a distance depending on the slope of the surface and the amount of seepage emerging, there is a change from fresh to salt water vegetation owing to contact with the waters of the ocean. Outward from this line to open water the marshes are for the most part salt meadows. Similar though less extensive marshes are built out from the inside of the great south beaches throughout their length of more than 75 miles. These marshes are almost entirely of the salt-water type, although some are bordered with fresh-water vegetation supported by seepage from the dunes.

An interesting feature of the distribution of the larger marginal marshes on the south coast is their limitation to the region west of Islip. This is due to a difference in the topographic character of the shores. West of Islip the average slope of the plains is much less than east of it. From Jamaica Bay to Islip the 20-foot contour line is from 1 to 2 miles back of the inner edge of the marsh—that is, the slope is from 10 to 20 feet to the mile and meets the water at a very low angle. East of Islip, however, the 20-foot contour is in many places only a few rods or a quarter of a mile from the shore, although locally retreating for a mile or more, and the surface meets the water at a higher angle or even as a low bluff—a condition that is unfavorable for marsh growth. The difference in topography is due to differences in the geologic history of the deposits, those west of Islip belonging to the gently sloping outwash from the Wisconsin glacier, whereas considerable portions of those east of Islip belong to the older, higher, and partly eroded Manhasset formation.

Marshes of the south-shore bays.—Besides the marginal marshes just described, large areas of marsh have been built up from the bottoms of the shallow bays of the south shore. None of these bays are more than 6 miles wide and most of them are much less. They are all very shallow, 11 feet being the greatest depth in Shinnecock Bay, 10 feet in Moriches Bay, and 25 feet in Great South Bay. The depth of 25 feet is found only in the tidal channel at the inlet, the ordinary depth being not more than 11 or 12 feet. Statements were made by Elias Lewis [1] in 1877 and by Warren Upham [2] in 1879 that channels connecting with the land valleys could be traced across the south side bays, but an examination of the charts seems to show that the few channels present are in no way connected with land valleys but are the direct result of tidal scour near the present or former inlets.

The marshes begin to form wherever the water is shallow enough for eel grass to obtain a foothold, usually a foot or two below low-water mark, and where no strong currents are flowing. The dead grass and the fine silt entangled with it gradually accumulate until the ground rises well above above low-water mark and marsh grass takes root upon it. The upbuilding continues until the marsh reaches a level covered only by occasional high tides. Part of the present salt marshes may have resulted from the advance of the sea over former fresh marshes or swamps, with the substitution of a salt-water for a fresh-water fauna. At the east end of Great South Bay, north of Long Beach, and in Jamaica Bay, where the water was originally very shallow, the marshes have taken possession of the greater part of the space inside the beaches, having a width in places of nearly 5 miles. They are not absolutely continuous, however, but are cut by many narrow and winding channels and here and there by more open spaces, such as Middle and East bays, near Jones Inlet.

W. W. Mather,[3] who gave considerable attention to these features, says:

> I have been credibly informed that the grass now grows on a marsh near Rockaway, where vessels have floated within the memory of my informant. On Coney Island also Mr. John Wyckoff informed me that many places which were ponds and pools within his recollection now produce good crops of grass. A very aged man also recollects having seen the surf roll in at the foot of the upland north of the marsh toward the east end of Coney Island. A broad marsh now intervenes between the upland and the beach.

In fact, the whole line of geologic evidence shows that with a few local exceptions the marshes are being rapidly extended along the south shore.

The marshes on the whole are rather stable when once formed and are seldom subjected to much erosion, except where the waves break through the beaches and obtain access to them.

Marshes of the north-shore reentrants.—The formation of salt marshes in reentrants on the north shore differs in no essential particular from the formation of marshes in the more extensive waters of the south shore already described except that more of them have probably resulted from the comparatively recent incursion of the sea over fresh-water accumulations. They may be seen at many points. On the side toward the Sound they are usually bordered by a barrier beach, but on the side toward the bay the beach is usually absent. Their transition to fresh marsh has already been described.

SUMMARY OF GEOLOGIC FEATURES, BY LOCALITIES.

Owing to the fact that many of the deposits are in the present report considered in detail for the first time, it has seemed desirable to bring together at one place the available facts pertaining to each formation, making the discussions stratigraphic rather than geographic. This has been done under "Stratigraphic geology." Unfortunately by this method the discussion of adjacent localities may be found on widely separated pages. Supplementary geographic discussions are desirable but would involve too much repetition. An attempt has been made, however, to meet the needs of geologists and others interested in particular regions by preparing the following tables, which summarize the chief points of geologic and physiographic interest.

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[1] Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 215-216. [2] Idem, vol. 18, 1879, pp. 81-92. [3] Geology of New York, pt. 1, 1843, p. 17.

To facilitate reference, the topographic and geologic maps are divided into rectangles by lines of latitude and longitude, these rectangles being designated from bottom to top by letters, and the columns of rectangles from left to right by numbers. The letters and numbers make it easy to determine quickly the points of interest in a particular locality or on a particular trip, and the page references make it practicable to look up details with the least possible loss of time.

It should be borne in mind, however, that inasmuch as 10 years have elapsed since the observations were made, few of the sections will be found exactly as described, especially those along the north shore. Here, although the outcropping edges of the formations seen in the bluffs often appear nearly horizontal, in reality many of the beds dip at high angles to the south, as may be seen by comparing *b*, figure 97 (p. 110), and *c*, figure 95 (p. 110), the former being a section at right angles to the face of a bluff and the latter section parallel to the bluff face. Under such conditions a bed that appears horizontal where the face of the bluff is parallel with the strike may appear notably inclined where the bluff makes an angle with the strike, or broadly arched where the coast line is curving. In many places it was impossible to determine the internal structure, and the greater part of the figures in the present report represent only the apparent structure as shown in the bluffs. Where the dips are high, the cutting back of a bluff as little as 5 feet will change the whole appearance of a section, and it is not to be expected that any particular feature will be recognizable after the lapse of a few years.

Principal points of geologic interest on Long Island.

Coordinates on Plates I and II.	Part of section.[a]	Locality.	Features.	Page of description.
1 A	NE	West of Coney Island	Sand spit and dunes	177–180
1 B	E	Near Fort Hamilton	Harbor Hill moraine, beginning of "inland scarp"	53, 168
2 A	N	Near Coney Island	Beach dunes and marshes	184
2 B	C, S.	Southeast of Brooklyn	Outwash from ice along Harbor Hill moraine	173
2 B	N	Near Prospect Park	Harbor Hill moraine "inland scarp"	53, 158
2 B	N	do	Confluent fans of outwash from ice along Harbor Hill moraine	36–37
2 D	SE	On shore of East River	Fordham gneiss outcrops	66
3 A	N	Rockaway Beach	Barrier beach, dunes, spits	178–180
3 A	NW	Barren Island	Outlier of Manhasset formation (?)	115
3 B	SE	Jamaica Bay	Extensive salt marshes in process of formation	185
3 B	W	Bergen Beach	Outwash outliers	169–170
3 B	NE	Near Remsen Landing	do	169–170
3 C	S	Near East New York	Outwash from ice along Harbor Hill moraine	172–173
3 C	C	Near Brooklyn Reservoir	Harbor Hill moraine (till type), "inland scarp"	34–35, 53
3 C	N		Wisconsin till; traces of Manhasset formation	115, 158–160
3 D	SW	½ mile northwest of Steinway.	Drumloidal hill	161
3 D	SW	Near Lawrence Point	do	161
3 D	E	½ mile east of College Point	Light-gray micaceous Jacob sand	108
3 D	E	Near Tallman Island	Drumloidal hill	161
3 D	S		Wisconsin till and retreatal outwash	Map.
3 D	S	Flushing Bay	Pre-Wisconsin valley enlarged by Wisconsin ice	44–45
4 B	SE	Far Rockaway	Rockaway ridge (Herod gravel member of Manhasset formation)	118, 127
4 B	N		Emergence of ground waters, fresh and salt marshes	183, 184
4 C	S	Near Jamaica South	Depression between outwash plains.	
4 C	C	North of Jamaica	Till of Harbor Hill moraine; "inland scarp"	34–35, 53
4 C	N		Thin till over modified surface of Manhasset formation	158–160
4 D	S		Thick till, including some Montauk till member of Manhasset formation, with occasional exposures of gravel of Manhasset formation.	158–160
4 D	W	Near Whitestone Point	20-foot bowlder reported	171–172
4 D	E	Elm Point	Thick bed of dark Cretaceous clay	69
4 D	SE	Little Neck Bay	Pre-Wisconsin valley, modified by Wisconsin ice	44–45
5 B	S		Double line of beaches (Far Rockaway and Hicks).	
5 B	C		Rockaway ridge (Herod gravel member of Manhasset formation). Faulted pebbles in pits.	127
5 C			Outwash plains from ice along Harbor Hill and Ronkonkoma moraines; outwash channels.	166–176
5 C	NW	Northwest of Creedmoor	Harbor Hill moraine; "inland scarp"	53, 158
5 D	S	Lake Success	Largest kettle in till or mixed moraine	40
5 D	S	½ mile northeast of Lake Success.	Outwash channel through moraine, crossing of Harbor Hill and Ronkonkoma moraines; eastern limit of unmodified "inland scarp."	164, 175
5 D	S	Southeast of Manhasset	Bowlder 54 by 40 by 16 feet reported	171–172
5 D	S	North Hempstead	Bowlder 40 feet long, 20 to 40 feet wide, and 10 to 17 feet high reported; possibly same as above.	171–172
5 D	C	½ mile east of Thomaston	Cretaceous sand in railroad cut	69
5 D	W	North of railroad, Great Neck.	Beginning of characteristic Manhasset plateau (100-foot level); exposures of Herod gravel, Montauk till, and Hempstead gravel members of Manhasset formation, in bluffs (rather poor).	31, 125, 135, 152
5 D	NE	Manhasset Neck	Manhasset plateau (180-foot level) projecting knobs of possible Mannetto gravel	30
5 E	SW	Base of Plum Point	Jacob sand in floor of abandoned pit	108
5 E	SW	½ mile east of Plum Point	Knob of contorted Jacob sand in old gravel pits	108
5 E	SW	Barker Point	Montauk till member of Manhasset formation between Herod gravel member and Hempstead gravel member.	135
5 E	S	Tom Point	Gravel of Manhasset formation, folded by Wisconsin ice	210
5 E	S	½ mile north of Tom Point	Large sand delta of Wisconsiu age, fine fore and top sets	177
5 E	S	North of Port Washington	Many pits of Herod gravel member of Manhasset formation	125

[a] Center is abbreviated C.

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
5 E	S	Northeast of Port Washington.	Scarp between high and low level Manhasset plateaus (from Port Washington Harbor to Mott Point).	31
5 E	C	Prospect Point	Montauk till member of Manhasset formation in bluff; undermined and submerged peat.	135, Plate XXVI.
5 E	SE	¾ mile south of Mott Point	Bright-colored Cretaceous clays; Mannetto gravel	69, 83–84
5 E	SE	1 mile south of Mott Point	Upturned Cretaceous and Mannetto gravel, 80 feet above sea level (on road crossing neck to Port Washington).	69
6 B	S	Near Long Beach	Double beach and dunes	180
6 B	SW	Barnum Island	Outliers of Manhasset formation (?)	30
6 B	C		Emergence of ground water; fresh and salt marshes	183–184
6 B	N		Lobate margin of outwash plains	36, 37
6 C	All		Outwash plains, outwash channels, loam patches resembling "Jamesburg loam" of New Jersey.	37, 48, 173
6 D	SW	Near East Williston	Clay pit in Montauk till member of Manhasset formation (?)	141
6 D	S		Mixed outwash from ice along Ronkonkoma and Harbor Hill moraines; outwash channels; morainic outliers; Ronkonkoma moraine (interrupted type).	37, 48, 30, 165
6 D	S, C		Kettle plain between moraines; remnants of Manhasset formation (?)	43, 114
6 D	W	East of Roslyn	Terraced outwash channel from gap in moraine	49
6 D	W	Southwest of Roslyn	Harbor Hill moraine; traces of modified "inland scarp" (2½ miles southwest)	53, 168
6 D	W	Harbor Hill	Highest point on Harbor Hill moraine; possible traces of Mannetto gravel	82, 170
6 D	W	West of Harbor Hill	Gravels of Manhasset formation beneath moraine	116
6 D	C	East of Harbor Hill	Outwash channel through moraine	175
6 D	NW	West side of Hempstead Harbor.	Montauk till member of Manhasset formation, between Herod and Hempstead gravel members, finely exposed in many gravel pits.	135
6 D	NW	Near Glenwood Landing	Traces of Cretaceous clays and sands near landing and southward; Jacob sand knob in floor of gravel pit near landing.	69, 108
6 D	NW	do	Local development of lower Manhasset plateau (100 foot)	31
6 D	E	Northeast of Old Westbury	Hills of Mannetto gravel (with Wisconsin mantle)	30
6 D	NE		High-level Manhasset plateau with semimorainal mantle of Wisconsin drift	30
6 D	NW	Bar Beach	Fine sand pit.	
6 D	NW	Hempstead Harbor	Pre-Wisconsin valley enlarged by Wisconsin ice	44–45
6 E	SW	West of Sea Cliff	Cretaceous white sands and Mannetto gravel in bluff	31, 69
6 E	SW	South side of Mosquito Cove	Cretaceous sand and Mannetto gravel in unconformable contact in gravel pit	81
6 E	S	East of railroad	Deep, sharp Vineyard erosion valley in Manhasset formation	208
6 E	C, SE		High-level Manhasset plateau (180–200 feet)	30
6 E	W	Near Glen Cove Landing	Montauk till member of Manhasset formation; yellow, pink, and black Cretaceous clays, both north and south of landing.	69, 135
6 E	W	Near Red Spring Point	Gray Gardiners clay with small quartz pebbles	96
6 E	W	Near Weeks Point	Gardiners clay, Montauk till member of Manhasset formation, etc	96, 135
6 E	N	Southeast of Lattington	White and pinkish Cretaceous clay in pit	69
6 E	N	Coast	Connecting beaches; low-level Manhasset plateau	31, 178–179
7 B	S		Beaches, spits, dunes	177–182
7 B	C		Salt marshes	184–185
7 B	N		Lobate outwash margin; emergence of ground water; fresh and salt marshes	36, 183–185
7 C	All		Outwash plains and channels; loam	37, 48, 173
7 D	S		Confluent outwash fans	36–37
7 D	C		Ronkonkoma moraine, partly on Mannetto gravel	163–166
7 D	W	South of Wheatley	Old erosion forms in Mannetto gravel, mantled by Wisconsin drift	82
7 D	N, NE	Near Syosset	Kettle plain between moraines	43
7 D	NW	Southeast of Brookville	Harbor Hill moraine	168
7 E	SW		Dissected Manhasset plateau (Vineyard erosion)	30
7 E	SE		Harbor Hill moraine	168
7 E	C	Near Oyster Bay	Numerous flowing wells.	
7 E	C	½ mile west of Moses Point	Gardiners clay, etc., reported	96
7 E	NW	Mill Neck	Remnant of high level Manhasset plateau. Cretaceous outcrop in railroad cut	30, 69
7 E	NE	West of Rocky Point	Connecting beach	178–179
7 E	NE	do	Cretaceous clays in beach. Gardiners clay and Montauk till member of Manhasset formation in bluffs.	70, 96, 136
7 E	NE	½ mile south of Rocky Point	Cretaceous thrown out in dredging harbor	70
7 E	E	Coopers Bluff	Jacob sand in beach; probably members of Manhasset formation (Herod gravel, Montauk till, and Hempstead gravel) in bluff (poor exposure).	108, 125, 136, 152
8 B	S	Near Jones Beach	Double beach, dunes, salt marshes	178, 180, 184
8 B	N	Coast	Lobate outwash margin, marshes, etc	36, 183
8 C	C	Massapequa River	Depression between Hempstead and Babylon outwash plains; outwash channel	173
8 C	N	Near Farmingdale	Cretaceous clays in large pits	72
8 C	N	½ mile west of Farmingdale	Terrace of gravel of Manhasset formation; outlying hills of Mannetto gravel	82, 118
8 C	NE	1½ miles east of Farmingdale	Westerly member of "Melville double channel"	49, 175
8 C	NE	Southeast of Farmingdale	Extramorainal kettles of doubtful origin	43–44
8 D	SW	1½ miles southwest of Plainview.	Depression between outwash from ice along Ronkonkoma moraine and compound outwash on the west.	49
8 D	S	Bethpage	Cretaceous clays overlain by pseudotill (?) in clay pits	72
8 D	SE	East of Bethpage	Bethpage terrace of gravel of Manhasset formation	118
8 D	C	Northeast of Plainview	Terraced outwash channel from Ronkonkoma moraine	49
8 D	C	North of Plainview	Hills of Mannetto gravel; pre-Wisconsin erosion topography	44–45, 82
8 D	E	Mannetto Hills	Mannetto plateau; sharp erosion gullies on margins	30
8 D	E	1 mile west of Melville	Roadside section of Cretaceous clays, marl, etc	72
8 D	E	Southwest of Melville	Western of Melville "double channels"	49, 175
8 D	NW	½ mile southwest of Woodbury.	Double moraine separated by flat outwash	33
8 D	N	High Hill	Highest point of Ronkonkoma moraine	32, 164
8 D	N	Near High Hill	Possible example of simple morainal cone; indications of Cretaceous or Mannetto core (?). Fine development of rough gravelly moraine.	32
8 E	SW	Northeast of Syosset	Kettle plain	43
8 E	S	Near Cold Spring Station	Deep Vineyard erosion valley in Manhasset formation; much Wisconsin drift on sides; some post-Wisconsin cutting.	208–212
8 E	SE	2 miles east of Cold Spring	Kettle plain, branching kettles	42–43
8 E	S	1½ miles east of Cold Spring	Harbor Hill moraine (interrupted)	170
8 E	W	¼ mile south of Coopers Bluff	White sandy Cretaceous clay	70
8 E	W	Coopers Bluff	See 7 E (E).	
8 E	W	West shore of Cold Spring Harbor.	Cretaceous sands and clays (opposite village of Cold Spring Harbor)	70
8 E	W	do	Pre-Wisconsin valley shaped by Wisconsin ice	44–45
8 E	NW	South of Lloyd Beach	Cretaceous clays, Montauk till member of Manhasset formation, etc., in old pits	70
8 E	NW	South base of Lloyd Beach	Mannetto gravel in hills	83
8 E	NW	North base of Lloyd Beach	Cretaceous, Mannetto gravel and Gardiners clay in bluffs (poor exposures)	70

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
8 E	N	West Neck	Kettle plain of retreatal outwash on Manhasset formation	43, 176
8 E	NE	Huntington Harbor	Pre-Wisconsin valley, reshaped by Wisconsin ice	44–45
8 E	NE	West side of Huntington Harbor.	Trace of Gardiners clay 1 mile north of head of harbor	97
8 F	SW	Lloyd Point	Fine spit	179
8 F	SW	1 mile south of Lloyd Point.	Traces of Mannetto gravel in bluffs	83
8 F	SW	½ mile southeast of Lloyd Point.	Evidences of subsidence (submerged bushes)	214
8 F	SW	1 mile southeast of Lloyd Point.	Cretaceous and Montauk till member of Manhasset formation in bluffs; big bowlder.	136, 170–172
8 F	SE	1½ miles northwest of East Fort Point.	Folded gravels of Manhasset formation (Hempstead gravel member)	152
8 F	SE	Northwest of East Fort Point.	Wisconsin till and Montauk till member of Manhasset formation in contact	136
8 F	SE	East Beach	Fine spit	179
8 F	S	Lloyd Neck	Kettle plain of retreatal outwash on Manhasset formation	43, 176
9 B			See 8 B.	
9 C			Outwash from ice along Harbor Hill moraine; outwash channels	173, 175
9 C	E	1½ miles southwest of Belmont Pond.	Kettles of doubtful origin	43–44
9 C	NE	Carlls River	Eastern of Melville "double channels"; depression between outwash from ice along Ronkonkoma and Harbor Hill moraines.	49, 175
9 D	SW		Broad Hill moraine, outwash channel in harbor.	
9 D	S	Northeast of Colonial Springs	Cretaceous and Mannetto gravel in abandoned pits	82
9 D	SE	Near Wyandanch	Outwash from ice along Ronkonkoma moraine	168
9 D	SE	1½ miles north of Wyandanch	Extramorainal bowlders near road ascending hills.	
9 D	C	Half Hollow Hills	Slopes of Mannetto gravel; level top with small bowlders and shallow basins (Montauk till member of Manhasset formation).	82, 141
9 D	W	¾ mile east of Melville	Eastern of Melville "double channels"	49, 175
9 D	W	1 mile northeast and 1 mile east of Melville.	Distinct terraces of outwash from ice along Ronkonkoma moraine, standing above the valley outwash from ice along Harbor Hill moraine.	
9 D	NE	Dix Hills	Ronkonkoma moraine on Mannetto gravel	168
9 E	SW	Southeast of Fairground	Kettle plain; branching kettles; kettle valley	42, 43
9 E	S, C	Northwest of Dix Hills	Late outwash from ice along Harbor Hill moraine	173
9 E	SE	North of Dix Hills	Hills of Mannetto gravel mantled with Wisconsin drift	82
9 E	E	1½ miles south of Greenlawn.	Cretaceous clays in wells, etc., on west edge of hills	71
9 E	E	1 mile northeast of Greenlawn.	Head of Northport-Babylon outwash channel	49
9 E	C	Northeast of Fairground	Harbor Hill moraine	168–170
9 E	NW	Great Neck	Obstructed valleys (pre-Wisconsin); retreatal outwash on Manhasset formation	52, 176
9 E	NW	½ mile south of Halesite	20-foot bowlder in Wisconsin filling of Manhasset valley	172
9 E	NW	1 mile northeast of Halesite	White, gray, and chocolate-colored Cretaceous clays and talus of Mannetto gravel shown in bluffs at mouth of Centerport Harbor.	71
9 E	N	Centerport and Northport harbors.	Pre-Wisconsin valleys modified by ice	44–45
9 E	N	Southwest of Little Neck Point.	Cretaceous dark clay and white sand in bluffs	71
9 E	N	Southeast of Little Neck Point.	Thick Cretaceous white sands and some dark clays in pits and bluff; Hempstead gravel member of Manhasset formation unconformably on Cretaceous.	71, 153
9 F	SW	West Beach	Fine spit	179
9 F	SW	Shores of Price Bend	Cretaceous clay, Mannetto gravel, Gardiners clay, and Montauk till member of Manhasset formation, shown in amphitheaters along shore of Price Bend and to north; Mannetto bowlders 2 feet or more in diameter.	71, 83
9 F	W	Eaton Point	Spit and dunes	179, 182
9 F	W	¼ mile east of Eaton Point	Montauk till member of Manhasset formation in bluff near lighthouse	137
9 F	W	¼ mile southeast of Eaton Neck Lighthouse.	Cretaceous, Mannetto gravel, and Montauk till member in bluff	137
9 F	S	East Beach	Fine connecting beach and low dunes	179, 182
9 F	SE	½ mile east of East Beach	Montauk till member in bluff	137
10 B	C	Oak Island Beach	Barrier beaches, dunes, and salt marshes	178, 181, 185
10 C	S	Coast	Lobate border of outwash	37
10 C	W	Near Babylon	Melville and Northport-Babylon channels (Harbor Hill)	49, 75
10 C	C, N		Outwash from ice along Ronkonkoma moraine (unusually flat)	166
10 D	C	Edgewood	Northport-Babylon outwash channel (Harbor Hill)	49
10 D	N, C	Base of moraine	Confluent outwash fans	36
10 D	N	Near Dix Hills	Ronkonkoma moraine, in part on Mannetto gravel	82
10 E	SW	North base of Dix Hills	Mannetto gravel beneath Wisconsin drift	82
10 E	SW		Outwash from ice along Harbor Hill moraine over Manhasset formation	172, 173
10 E	S	South of Commack	Bar in outwash channel	50
10 E	SE	East of Commack	Edge of Smithtown "driftless" area	162
10 E	W	South of Larkfield	Thick outwash from ice along Harbor Hill moraine	174
10 E	C	North of railroad	Harbor Hill moraine	168–170
10 E	N		Manhasset plateau, much dissected by Vineyard erosion	30
10 D	S	1 mile north of Fort Salonga.	Extensive exposures of chocolate-colored and dark-gray Cretaceous clays, traces of Mannetto gravel and Montauk till member of Manhasset formation; immense landslides affecting cliffs for ⅛ mile inland; landslide scarps. (This is the so-called "Broken Ground.")	56, 71, 83, 137
11 B	C	Fire Island Beach	Barrier beach, dunes, good examples of fresh marshes among dunes	178, 181, 183
11 B	N	Coast	Lobate outwash margin	37
11 C	N	North of railroad	Manhasset formation projecting above outwash	118
11 C	S		Compound topography (Manhasset formation and outwash)	118
11 C	N		Ronkonkoma moraine (confluent cone type); small outwash fans; south border of Smithtown "driftless" area.	32, 36, 162
11 D	SW		Smithtown "driftless" area; pre-Wisconsin topography	162, 208
11 D	SE	South of Smithtown	Head of Connetquot outwash channel	175–176
11 D	SE	Southeast of Smithtown Branch.	Erosion bluffs facing Connetquot channel; pre-Wisconsin valleys; post-Wisconsin notching.	175, 208, 212
11 D	C	Near Smithtown	Manhasset formation (Hempstead gravel member) exposed in railroad cuts	153
11 D	C	¾ mile northeast of Smithtown.	Esker (just north of road) extending from bottom of valley up hillside for ¼ mile, establishing pre-Wisconsin age of erosion.	116, 162
11 D	N	North of railroad	Harbor Hill moraine	168–170
11 D	N	Nissequogue River	Pre-Wisconsin valley, little modified by ice	44–45
11 D	N	Stony Brook Harbor	Pre-Wisconsin valley, much enlarged by ice	44–45
11 D	N	Coast	Montauk till member of Manhasset formation resting on disturbed beds belonging to Manhasset formation (between Nissequogue River and Stony Brook Harbor).	137

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
12 B	N	Fire Island Beach	Barrier beach and dunes	178, 181
12 C	N	Coast	This region is at end of extensive salt marshes (characteristic of outwash margins), and beginning of erosional coast line (distinction of Manhasset surfaces). Being transitional the forms are here indistinct.	
12 D	W	Along Connetquot River	Broad Connetquot outwash channel (Harbor Hill)	175–176
12 D	C, E		Thin outwash from ice along Ronkonkoma moraine; Manhasset formation controls the topography.	168
12 D	N		Ronkonkoma moraine (low and interrupted)	165
12 D	N	Lake Ronkonkoma	Largest kettle lake of island	40
12 D	N	Near Lake Ronkonkoma	Depressed moraine	165
12 D	N	West of Lake Ronkonkoma	Terraced outflow channel leading from lake to Connetquot channel (now dry)	47
12 E	S	¾ mile northwest of Lake Ronkonkoma.	Shallow pond and marsh behind recent delta in old channel in Manhasset formation	183–184
12 E	S	North of Lake Ronkonkoma	Kettle valley	42–43
12 E	S	1½ miles north and ¼ mile west of Lake Ronkonkoma.	Ridge in channel	50
12 E	SE	¾ mile northwest of Lake Grove.	Terraced kettle	40–41
12 E	SE	Near Lake Grove	West end of great intermorainal fosse depression (shown by 100-foot contour)	48
12 E	C		Thin outwash from ice along Harbor Hill moraine on Manhasset formation (Manhasset controls topography).	172
12 E	N		Harbor Hill moraine; dissected Manhasset plateau	30, 168
12 F	S, C		Dissected Manhasset plateau (Vineyard erosion)	30
12 F	W	South of Crane Neck Point	Heavy Montauk till member of Manhasset formation, grading upward into Hempstead gravel member; big bowlder.	137–138
12 F	N	Oldfield Point	Montauk till member shows in bluffs (exposures poor)	138
12 F	N	Setauket Beach	Fine spit on both sides of entrance to Port Jefferson Harbor	179
13 C	S	Fire Island Beach	Barrier beach and dunes	177–178, 181
13 C	N	Coast	Erosion outline of coast; mainly Manhasset border	212
13 D	All		Thin outwash from ice along Ronkonkoma moraine on Manhasset formation; Manhasset frequently controls topography; channels partly Manhasset, partly Wisconsin.	48–51, 172
13 D	N	1 mile west of Holtsville	Double channel (¼ mile south of railroad)	50
13 E	S	South of Selden	Ronkonkoma moraine, probably exceptionally sandy, covered with old dune sands at many points.	165
13 E	C	North of Selden	Great intermorainal fosse depression; surface largely covered with old dune sand, some local drifting at present time; Manhasset formation controls topography.	48
13 E	N	Near Terryville	Outwash topography gives way to Manhasset formation	168
13 F	SE	South of railroad	Outwash from ice along Harbor Hill moraine	172
13 F	SW	Southwest of Echo	Harbor Hill moraine (ridge type)	170
13 F	S, C	East of Echo	Harbor Hill moraine depressed type; many immense kettles north of railroad	40, 170
13 F	W	South of Port Jefferson	Large gravel pit in Manhasset formation with moraine above; large bowlder (both on road to station).	170, 172
13 F	W	North of Port Jefferson	Indications of Montauk till member of Manhasset in lower part of bluffs on east side of harbor; dissected Manhasset plateau (Vineyard erosion).	30, 138
13 F	W	West Beach	Cliffs of Manhasset formation overlain by one of the Wisconsin moraines; traces of Montauk till member of Manhasset formation.	137
13 F	C	East Beach	Old spit flanked with marsh	184
14 C	C	Fire Island Beach	Barrier beach; dunes	177–178, 181
14 C	N	Coast	Erosional coast line, mainly Manhasset formation	212
14 D	C, W		See 13 D.	
14 D	E		Carmans Valley outwash from ice along Ronkonkoma moraine	168
14 E	S		See 13 D.	
14 E	SE	Near Yaphank	Carmans Valley outwash with narrow channel of post-Ronkonkoma age	168
14 E	S, C	Near Coram Hill	Ronkonkoma moraine; morainal gap at Carmans River	165
14 E	C	Near Middle Island	Surface mantle of bowlders and some till-like patches (mainly Wisconsin till, possibly some Montauk till member of Manhasset formation).	162
14 E	C	2 miles southwest of Middle Island.	Kettle valley, kettle chain (branching and completely closed)	42, 43
14 E	E	½ mile east of Middle Island	Vineyard erosion valley in Manhasset formation (modified by ice and by recent erosion by Carmans River).	46
14 E	E	1 mile east of Middle Island	Kettle valley branching, partly open, occupied by Artists Lake	42, 43
14 E	N	2 miles north of Middle Island.	Branching kettle valleys	42
14 E	N		Thin outwash from ice along Harbor Hill moraine on Manhasset formation; Manhasset valleys and other pre-Wisconsin topographic features.	172
14 F	S		do	172
14 F	SE	1 mile southwest of Rocky Point.	Numerous deep branching kettles and kettle valleys	42
14 F	SE	1 mile southeast of Rocky Point.	Till-covered monadnock rising above outwash (morainal?).	
14 F	C	North of railroad	Harbor Hill moraine resting on Manhasset formation; Manhasset topography distinct on north side, many valleys being only partly obliterated by the moraine. Manhasset terrace well developed east of Hallock Landing.	116, 170
14 F	W	⅛ mile east of Woodhull Landing.	Poor exposure of mottled buff to gray Gardiners clay	97
14 F	W	½ mile east of Woodhull Landing.	Thick, gently folded beds of Herod gravel member of Manhasset formation	126
14 F	C	½ mile west of Rocky Point Landing.	Small exposure of tough brown Gardiners clay	97
14 F	C	¼ mile west of Rocky Point Landing.	Salmon-colored micaceous clay belonging to the Gardiners clay or the Jacob sand	97
14 F	C	⅛ mile west of Hallock Landing.	Upturned clays along fault plane (Gardiners clay or Jacob sand). Folded beds of Herod gravel member of Manhasset formation.	98, 126
14 F	E	1 mile east of Hallock Landing.	Bowlder 25 by 10 feet, embedded in beach	172
15 C	N	Fire Island Beach	Barrier beach, dunes, margin of Manhasset formation bordered by marsh (unusual).	177, 181
15 D	W		Carmans Valley outwash with narrow channel of post-Ronkonkoma age	168
15 D	E		Manhasset formation with thin outwash from ice along Ronkonkoma moraine (local).	172
15 E	S		Ronkonkoma moraine; morainal gaps and depressed moraine	165
15 E	C, N		Manhasset surface with thin till or mantle of bowlders; deep Vineyard erosion valleys.	162
15 E	NW	Northwest of Ridge	Kettle valley systems	42

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
15 F	S		See 15 E (C, N).	
15 F	SE	1 mile southeast of Wading River station.	Branching kettle-valley system (deep pond)	42–43
15 F	SE	2 miles southwest of Wading River station.	do	42–43
15 F	C	1½ miles west of Wading River station.	Bowlder (20 by 20 by 16 feet) near highway through moraine	171, 172
15 F	C	¾ mile northwest of Wading River station.	Bowlder (20 by 18 by 15 feet) near edge of marsh	170, 172
15 F	W	½ mile east of Woodville Landing.	Old brickyards and clay pit, probably in Gardiners clay and Jacob sand; upturned Jacob sand in ravines; Montauk till member of Manhasset formation overlies clay pits.	109
15 F	C	Coast	Landslips along bluffs and fresh-water pools along beach, both suggestive of Gardiners clay and Jacob sand beneath talus; many deep ravines and amphitheaters; magnetic and garnetiferous sands on beach.	56, 51, 180
15 F	E	Near Herod Point	Horizontal beds of Herod gravel member, overlain by Montauk till member of Manhasset formation.	126
16 D	S	Moriches Bay	Barrier beach; erosion coast line; estuaries of pre-Wisconsin age	177, 178
16 D	N		Manhasset plain and valleys; local outwash from ice along Ronkonkoma moraine (largely near moraine).	118–119, 168
16 D	N	North of East Moriches	Local patches of loam, resembling "Jamesburg loam" of New Jersey	172
16 E	S		Ronkonkoma moraine; depressed moraine at gaps (locally); compound type of morainal ridge.	165
16 E	C	South of Manorville	Morainal outliers	165
16 E	E	2 miles east of Manorville	Exceptionally heavy morainal development	165
16 E	N	Along Peconic River	Peconic River fosse	120
16 E	NW		Modified Manhasset surface with thin outwash; large kettles, kettle valleys, kettle chains, etc.	42–43, 120
16 F	S		Manhasset surface with original drainage but slightly obscured; thin outwash near moraine and elsewhere.	117
16 F	SW	Near Deep Pond	Branching kettle-valley system	42–43
16 F	E	South of Fresh Pond Landing.	Kettle valley and kettle chain	42–43
16 F	C	Along coast	Harbor Hill moraine rapidly diminishes; partly removed by sea; almost disappears at Jericho Landing; development of dunes at top of bluff and along north face of moraine becomes important.	171, 182
16 F	C	Coast	Fairly clean bluffs commonly showing from 50 to 90 feet of Herod gravel member of Manhasset formation; many amphitheaters; some landslips and springs suggesting Gardiners clay or Jacob sand near beach level.	51, 56, 126
16 F	W	Paine Landing	Montauk till member of Manhasset formation exposed in upper part of bluffs; many big bowlders on beach; thick Herod gravel member of Manhasset.	138
16 F	C	Hulse Landing	Same as preceding; Montauk till member continues to Fresh Pond Meadows, 50 feet thick in places; thick Herod gravel member of Manhasset formation.	138
16 F	E	East of Fresh Pond Landing.	Thick Herod gravel member; dunes at crest of bluffs	126, 182
17 D			See 16 D (S).	
17 E	S		See 16 D (N).	
17 E	W	2 miles north of "Rock Hill".	Bowlder 125 feet in diameter reported	165
17 E	C		Ronkonkoma moraine (strong development), morainal channels, cones, kettles, etc., of all types; Bald Hill cone.	32, 42, 48, 165
17 E	N	South of railroad	Peconic River fosse; Wisconsin outwash, etc., on Montauk formation; large kettles (Great Pond, etc.).	43, 120, 162
17 F	S		Vineyard erosion valleys in Manhasset formation; kettle valleys, kettle chains, etc.	42–43, 117
17 F	C		Outwash from ice along Harbor Hill moraine over Manhasset formation	174
17 F	W	Near Baiting Hollow	Numerous branching kettles (kettle-valley type)	174
17 F	N	Along coast	Harbor Hill moraine (weak development)	171
17 F	N	Coast	Steep bluffs cut by deep amphitheaters; dunes at crest of bluffs; many exposures of Herod gravel member of Manhasset formation.	51, 126, 182
17 F	N	Near Friars Head	Typical exposures of banded and cemented Montauk till member of Manhasset formation eroded into pinnacles and knife-edge ridges (in amphitheaters).	138–139
17 F	N	¼ mile east of Roanoke Landing.	Upturned clay (Gardiners)	98
17 F	N	Near Roanoke Point	Folded and overturned Gardiners clay and Jacob sand	98
18 D	N		See 16 D (S).	
18 E	S		See 16 D (N).	
18 E	C		Ronkonkoma moraine (see 17 E, C); depressed moraine at broad gap	165
18 E	N		Wisconsin outwash, etc., on Manhasset formation; many small kettles, pre-Wisconsin valleys.	43, 162
18 F	C, S		Outwash from ice along Harbor Hill moraine over Manhasset formation; numerous kettles and kettle valleys; some Vineyard erosion valleys.	174
18 F	N	Along coast	Harbor Hill moraine capping Manhasset terrace (weak development with many gaps); partly covered with dunes.	171, 182
18 F	N	½ mile west of Jacob Point	Bowlder 38 by 20 by 11 feet	172
18 F	N	Near Jacob Point	Tough dark Gardiners clay; Jacob sand; Herod gravel member of Manhasset formation; Montauk till member of Manhasset formation near top of bluffs.	98, 109, 126, 139
18 F	N	do	Pinnacles of Gardiners clay and Jacob sand; possible Jameco gravel; Herod gravel member of Manhasset formation; Montauk till member of Manhasset formation, near top of bluffs.	98, 109, 126, 139
18 F	N	Near Luce Landing	Submerged peat and stumps	213
19 D	N	Hampton Beach	Barrier beach; dunes, marshes	177, 181
19 E	S	Coast	Erosion coast line in Manhasset formation	118
19 E	S		Manhasset plains with thin outwash	121
19 E	C		Ronkonkoma moraine (depressed at gap)	165
19 E	C	Tiana Creek	Late narrow outwash channel in Ronkonkoma moraine	49
19 E	E	Shinnecock Canal	Outwash from ice along Ronkonkoma moraine	168
19 E	NW	North of moraine	Wisconsin outwash on Manhasset formation; kettles; Vineyard erosion topography.	43, 162, 208
19 E	NW	Red Cedar Point	Fine spit	179
19 E	N	1 mile east of Southport	Montauk till member of Manhasset formation and Gardiners clay in overturned folds in bluffs; Triassic bowlders in Montauk till member.	141–142
19 E	N	2 miles east of Southport	Herod gravel member of Manhasset formation in bluffs	127
19 F	NW		See 18 F (C, S).	
19 E	N	Mattituck Inlet	Submerged kettle valley in Manhasset surface	42, 117
19 G	SE		Outwash from ice along Harbor Hill moraine on Manhasset formation; outwash channels near Oregon Hills.	174
19 G	SE	Along coast	Moraine largely eroded, only low narrow ridge remaining; several important gaps.	171–172
19 G	SE	Near Oregon Hills	Montauk till member of Manhasset formation (with many Triassic bowlders) in bed in middle of bluff.	140

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
19 G	SE	Middle of Oregon Hills	Bowlder 15 feet in diameter	172
19 G	E	½ mile southwest of Duck Pond.	Bowlder 23 by 20 by 15 feet	172
20 E	SE	Hampton Beach	Barrier beach; dunes	177–178, 181
20 E	C	Shinnecock Hills	Hills of Manhasset formation shoved and dragged by ice; old dune sands	34–35, 181
20 E	W	¼ mile east of Shinnecock Canal.	Old clay pit showing Gardiners clay grading into Montauk till member of Manhasset formation; Herod gravel member of Manhasset formation.	99, 127
20 E	N	Northeast of Cold Spring Pond.	Gardiners clay and Montauk till member of Manhasset formation in bluffs	99
20 F	SE	Near Cow Neck	Irregular areas of Manhasset formation apparently laid down around ice blocks.	
20 F	C	West side of Robins Island	Gardiners clay, Jacob sand, Herod gravel member of Manhasset formation, and Montauk till member of Manhasset formation in bluffs (generally folded); fossils locally.	110, 128, 145
20 F	C	East side of Robins Island	Mainly Herod gravel member of Manhasset formation with some Montauk till member.	128
20 F	NW	New Suffolk	Outlier of Manhasset formation	117
20 G	C		Outwash from ice along Harbor Hill moraine on Manhasset formation	174
20 G	SW	1 mile southwest of Cutchogue.	Kettle with till rim near Mattituck highway	174
20 G	NW	Along coast	Narrow belt of Harbor Hill moraine (hardly forms a ridge)	171
20 G	W	West of Goldsmith Inlet	Much till, some apparently Montauk till member of Manhasset formation, shows in bluffs.	140
20 G	N	Horton Beach	Fine pocket beach backed by dunes inclosing large pond	179
20 H	SE	Near Horton Point	Bluffs, apparently till from top to bottom; many large bowlders on beach; one bowlder 25 feet in diameter in water 1½ miles east of point.	172
21 E	N		Outwash from ice along Ronkonkoma moraine with margin truncated by sea; estuaries converted into ponds.	168
21 E	NW		Ronkonkoma moraine	166
21 E	NE	Near Watermill	Watermill pond kettle	40
21 E	NW	2 miles northwest of Southampton.	Kettle with outwash rim	41
21 F	SE		Manhasset formation overlain by thin outwash	121
21 F	SW-NE.		Strongly developed Ronkonkoma moraine	166
21 F	NW		Deeply eroded Manhasset formation with thin mantle of Wisconsin till	119
21 G	S	West side of Jessup Neck	Herod gravel and Montauk till members of Manhasset formation in bluffs	127, 142
21 G	W	Great Hog Neck	Outlier of Manhasset formation with mantle of Wisconsin till	120–121
21 G	NW		Manhasset formation with thin mantle of outwash	120
21 G	NE	Shelter Island	Thick deposits of Manhasset formation with Vineyard erosion topography; mantle of Wisconsin till; fine spit at Shell Beach; bays of south side due to presence of Montauk ice blocks. Small show of Gardiners clay or Jacob sand opposite Conkling Point.	110, 121, 129, 162, 179
21 H	SW	Hashamomuck Pond	Submerged kettle valley	42
21 H	SW	½ mile northeast of Hashamomuck Pond.	Kettle valley filled with marsh deposits (this and the one next preceding bounding a remnant of Manhasset formation, formerly an island).	183–184
21 H	S	South side of fluke	Manhasset formation practically without outwash	120
21 H	S	West of Greenport	Big fresh marsh in depression in Manhasset formation	183–184
21 H	SE	Shelter Island	See 21 G (NE)	
21 H	C	Along coast	Narrow and interrupted morainal belt, little in shape of ridge	171
21 H	C	Coast bluffs	Bluffs mainly of till, probably largely Montauk till member of Manhasset formation; pavements and great heaps of bowlders on beach; some exposures of stratified gravels, probably Herod gravel member of Manhasset.	126, 140, 171
21 H	C	½ mile southwest of Rocky Point.	Bowlder 25 by 25 by 30 feet in water	172
22 E	NW		Barrier beach; Manhasset plains	121, 178
22 F	SW		Manhasset plains with thin outwash	121
22 F	SW	Scuttle Hole	Kettle valley, kettle chains, connected kettles; kettle channels, etc	42–43
22 F	S	Sagaponack Lake	Estuary cut off from sea by beach (depression between Manhasset formation and outwash).	
22 F	C	Poxabogue Pond	Part of kettle valley	40
22 F	SE		Outwash on Manhasset formation (outwash controls topography); loam in places	168, 172
22 F	NC		Strongly developed Ronkonkoma moraine	166
22 F	NC	Long Pond	Kettles in outwash channels through moraine	42
22 F	N	2 miles southwest of Sag Harbor.	Outcrops of Gardiners clay at considerable altitudes in moraine	99
22 F	N		See 21 F (NW).	
22 F	NW	Long Beach	Connecting beach	178
22 G	SW	Northwest point of Hog Neck.	Possible Jameco gravel beneath reworked fossiliferous Gardiners clay; Montauk till and Hempstead gravel member of Manhasset formation.	89, 142
22 G	NW	Shelter Island	See 21 G (NE).	
22 G	W	South of South Ferry	Flats of thick till (Montauk till member of Manhasset formation)	146
22 G	NW	Ram Island, etc	Islands united by connecting beaches	179
22 H	SW	Hay Beach Point	Low till bluffs (Montauk till member of Manhasset formation)	146
22 H	C	Long Beach	Spit, dunes, marshes	179, 182, 185
22 H	W	Truman Beach	Beach connecting island	179
22 H	N	South side of fluke	Manhasset formation with mantle of outwash	120
22 H	N	Coast	Moraine is a more pronounced ridge than for some distance west; bluffs largely Herod member of Manhasset formation, overlain by thick till (in part Montauk till member of Manhasset formation).	126, 140, 170
22 H	N	Bluff of Brown Hills	Many exposures of Gardiners clay and Jacob sand, highly folded and overlain by Montauk till member of Manhasset formation; possible Jameco gravel under the Gardiners clay.	89, 98
23 F	SW	Georgica Pond	Estuary closed by beach.	
23 F	C		Outwash from ice along Ronkonkoma moraine	168
23 F	SC	South and east of Easthampton.	Dunes over outwash, till and bowlders reported to have been washed out by waves on beach.	163, 181
23 F	NW		Heavy Ronkonkoma moraine	166
23 F	N	2 miles northeast of Hardscrabble.	Morainal gap; outwash valley; depressed moraine	168
23 F	E	Near Freetown	Outwash channel through Manhasset formation.	
23 F	NE	1 mile north of Freetown	Ronkonkoma moraine	166
23 G			Manhasset formation with thin mantle of Wisconsin drift; topography mainly Vineyard erosion, modified by Wisconsin ice; kettles.	121
23 G	C	West of Sammys Beach	Montauk till member of Manhasset formation overlying folded Herod gravel member.	127–128
23 G	C	Cedar Point, Sammys Beach.	Fine spits	179

Principal points of geologic interest on Long Island—Continued.

Coordinates on Plates I and II.	Part of section.	Locality.	Features.	Page of description.
23 G	E	Southwest of Hog Creek Point.	Low plain of till (Montauk till member of Manhasset formation)	142–143
23 H	NW	Near Orient Point	Mainly Manhasset formation; some outwash; magnetic sands on beach	126, 179–180
23 I	SE	North side of Plum Island	Gardiners clay; Jacob sand and Herod gravel member of Manhasset formation are involved in small folds; much till in bluffs (probably largely Montauk till member of Manhasset formation). Several faults in Herod member.	100–101, 111, 129, 146
23 I	SE	South side of Plum Island	Broad plain of Montauk till member of Manhasset formation on southwest end; faulted Herod gravel member of Manhasset; folded Gardiners clay, Jacob sand, and Herod member; Montauk till member, east of Fort Terry.	100–101, 111, 130, 146
24 F	C	Coast	Belt of dunes of considerable width	181
24 F	N	Along railroad	Hills of Manhasset formation with little outwash	121
24 F	N		Strong morainal ridge	170
24 G	SW		General upland of Manhasset formation, with Vineyard topography; broad lowlands of Montauk till member of Manhasset formation.	121
24 G	SW	Acabonack Harbor	Sand spit and marshes	179, 184
24 G	W	Near Hog Creek Point	Montauk till member of Manhasset formation in folded Herod gravel member.	
24 G	E	Ram Island, etc	Spit in process of formation, largely below sea level	179
24 G	E	Great Pond	Pond inclosed by V-shaped spit	179
24 G	E	West side of Gardiners Island.	Montauk till member of Manhasset formation north of Great Pond; Herod gravel member of Manhasset formation; reddish clays and clayey sands 1 mile north of Great Pond (Gardiners clay or Jacob sand).	100, 129, 146
24 G	NE	South of Tobacco Lot Pond	Jacob sand, Gardiners clay, and Montauk till member of Manhasset formation, (generally folded); fossils in Gardiners clay and Jacob sand.	100, 105, 110, 146
24 H	S	East of Cherry Hill Point	Fine section of red and black fossiliferous Gardiners clay overlain by Jacob sand	105
24 H	S	Southwest of Bostwick Bay	Jacob sand with ripples; Herod gravel and Montauk till member of Manhasset formation.	110, 129
24 H	C	do	Fine V-shaped spit inclosing pond	179
24 H	C	Gardiners Point	Sandy island making continuation of Gardiners Island spit.	
24 H	SE	Northeast coast of Gardiners Island.	Cretaceous possibly present; Jameco gravel under Gardiners clay (doubtful); Gardiners clay, Jacob sand, and Herod gravel member of Manhasset formation involved in complex folds. Montauk till member of Manhasset commonly poorly developed.	90, 100, 110, 129, 146
24 H	SE	Inland on Gardiners Island	Ridges due to folding	35
24 H	SE	Tobacco Lot Pond	Bay bar	177–178
25 F	NW	Napeague Beach	Big connecting beach; high dunes; fresh marsh among dunes	179, 181, 184
25 G	S	do	do	179, 181, 184
25 G	SE		Moraine (thin) on Manhasset formation; old dunes on surface; Manhasset erosion	166, 180–181
25 G	SE	Quince Tree Landing	Montauk till and Herod gravel members of Manhasset formation	128, 143
25 G	SW	Goff Point, Hicks Island	Hooked spits	179
25 H	SW	Eastern Plain Point	Herod gravel and Montauk till member of Manhasset formation	129, 146
26 G	SW	South coast	Thick Herod gravel member overlain by Montauk till member	128, 143
26 G	SW	Interior	Hills of Manhasset formation with superficial mantles of morainal drift (Wisconsin) and dune sand (local).	121
26 G	SW	¾ mile southwest of Rocky Point.	Intermorainal fosse channels	47
26 G	W	1 mile west of Rocky Point	Jacob sand under Herod gravel, member of Manhasset formation	111
26 G	W	do	Herod gravel and Montauk till members of Manhasset formation	128, 143
26 G	C	Montauk station	Bay bar	177–178
26 G	C	Fort Pond	Pond inclosed by bay bar	177–178
26 G	C	South of Fort Pond	Barrier of Montauk till member of Manhasset formation	145
26 G	C	Montauk station	Uplands of Manhasset formation. (See 26 G, SW.)	121
26 G	N	South of Culloden Point	Herod gravel member of Manhasset formation under heavy till, possibly Montauk till member.	128
26 G	E	Near Ditch Plain	Low plain of Montauk till member of Manhasset formation	145
26 G	NE	Great Pond	Pond inclosed by bay bar, the latter characterized by dunes, fresh marsh, and ponds.	177–178, 181, 183
27 G	NE	South coast	Mainly Montauk till member, often double or triple and including stratified sands; several outcrops of Gardiners clay and Jacob sand; Herod gravel member of Manhasset occasionally seen; possibly some Hempstead gravel member of Manhasset. Sands below clays may belong to Jameco gravel.	89, 99, 111, 144, 156
27 G	N	Montauk Point	Thick Montauk till member of Manhasset formation overlain by stratified gravel (Hempstead member of Manhasset).	144
27 G	N	North of Montauk Point	Folded gravels (Hempstead member or gravelly phase of Montauk till member)	156
27 G	N	Southeast of False Point	Montauk till member of Manhasset formation in bluffs	144
27 G	N	½ mile west of False Point	Dark chocolate-colored Gardiners clay; Jacob sand; Herod gravel member of Manhasset formation.	99, 111
27 G	N	1 mile west of False Point	Montauk till member of Manhasset formation exposed at point	143
27 G	NW	Oyster Pond	Pond behind bay bar	177–178
27 G	NW	Near Shagwong Point	Montauk till member of Manhasset formation	143
27 G	NW	Reed Pond	Pond behind bay bar	177–178

GEOLOGIC HISTORY.

PRE-CRETACEOUS EVENTS.[1]

Little evidence is afforded by the older rocks of the Long Island region as to the conditions existing on the island in Archean and Algonkian time. The Fordham gneiss, which occurs at the west end of the island, is of pre-Cambrian age, but as it may be either a metamorphosed sedimentary bed or an igneous rock, its exact relationship can not be told. Its quartzitic bands, which strongly suggest sedimentary origin, are parallel to the bedding of the Cambrian rocks, and in most places there is little evidence of any considerable unconformity between

[1] For a full discussion of the geologic history of the New York region, see New York City folio (No. 83), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

them. At a few points, however, important breaks exist. The region appears to have been under water through a part of the Cambrian at least, for a quartzite of this age is found at a number of points in the vicinity of New York. The quartzite is followed conformably, so far as is known, by the Stockbridge dolomite, indicating the presence of open water during late Cambrian and early Ordovician time. Similar conditions also continued without material break into late Ordovician time, as indicated by the conformable Hudson schist overlying the dolomite. There is no record of the Devonian and Carboniferous periods in the rocks of the region, and it is probable that during these periods the land was above water much of the time and was subjected to extensive erosion by streams. A little farther north considerable mountain masses were uplifted in Devonian time and were later reduced by erosion, and it is not impossible that some uplift occurred in the Long Island region, although not until near the close of the Carboniferous was the compression of the rocks into sharp folds (fig. 54, p. 66) finally completed. In the meantime there had been considerable igneous activity in the region, manifested in the intrusion of the granitic masses in the Fordham gneiss of Long Island. Some of these masses on Long Island are so sheared, presumably as a result of the folding, that they now have a decidedly gneissic structure.

After the period of mountain building there was a long period of erosion, during which the land was worn down to a low rolling surface. In the New Jersey region a shallow basin was gradually formed, and in late Triassic or early Jurassic time this basin was occupied by a body of brackish water, in which the red sandstones and shales of the Newark group were laid down. During the deposition of these beds there was a second period of igneous activity, producing both intrusions and surface sheets of diabase or "trap rock," among which is the great mass known as the Palisades.

Later, in Jurassic time, the entire eastern part of the United States became dry land and was worn down by streams until the whole surface was reduced to a gently undulating plain, with a few unreduced remnants or monadnocks. This plain, which was covered with the clayey products of decomposition, is known as the Schooley peneplain and extended from the Atlantic coast over what are now the Appalachian Mountains well into the interior of the country. Toward the close of the Jurassic period a tilting of the plain began, the part southeast of central New Jersey sinking below sea level and the part northwest of it rising.

CRETACEOUS EVENTS.

The elevation of the land in the northwest led to a more active erosion, and the sand and clayey materials derived from the decomposition of the rocks were swept seaward and deposited along the coast, forming what is known as the Potomac group of New Jersey and regions farther south. The absence of marine shells and the presence of numerous leaves and other vegetable remains have led to the belief that the Potomac group is a fresh or brackish water formation deposited by meandering rivers or in estuaries or lagoons practically cut off from the sea by barrier beaches. Several hundred feet of the clayey deposits were laid down. The deposition of the Raritan formation seems to have been completed in the early part of the Upper Cretaceous epoch and in New Jersey was followed during the remainder of Cretaceous time by the deposition of more or less marly sediments characteristic of deeper water and indicating a continued tilting, which eventually carried the old crystalline surface well below sea level. When the tilting was completed the land in the vicinity of Schooley Mountain, in New Jersey, had been elevated 1,500 feet, and the surface along the Atlantic coast sloped off beneath the sea at the rate of 100 feet to a mile. In the Long Island region the late Cretaceous depression was less marked, clays and sands derived from the erosion of the uplifted peneplain continuing to be deposited while the marls were forming off the New Jersey coast. The fragments of fossil shells found here and there in wells or in the drift indicate that the clays and sands of Long Island were not all fresh or brackish water deposits, but were at least in part marine. The marl bed at the top of the hill near Melville (p. 68) suggests that fairly deep water covered this part of the island at the close of the period.

TERTIARY EVENTS.

EOCENE EPOCH.

Although there seem to have been slight interruptions in the deposition of the Cretaceous beds in certain parts of the New Jersey region,[1] the exposures on Long Island are too poor to admit of their recognition even if evidence of them is present. Between the Cretaceous and the Eocene deposits there was no strong break in New Jersey, for although a slight unconformity exists the deposits of the Eocene and the upper part of the Cretaceous are alike in character if not practically continuous in deposition. Where the Eocene deposits are seen they do not differ greatly in thickness but occur as a practically uniform bed across the State.[2] This uniformity would seem to indicate the absence of any strong unconformity, the thinness of the Cretaceous being due to nondeposition rather than to subsequent erosion. There is, however, evidence of a slight unconformity at the top of the Eocene, but no extensive erosion of either the Eocene or the underlying Cretaceous beds seems to have occurred. Physiographic evidence elsewhere seems to indicate that the Eocene may have been marked by the completion of a peneplanation begun in the Cretaceous, and that the surface stood at a low level, land erosion being nearly at a standstill.

MIOCENE EPOCH.

At the close of Eocene time there was a further differential tilting of the land, in the early stages of which the Eocene deposits may have been somewhat eroded. Later, however, the Coastal Plain was depressed and the sea advanced across the Eocene and over the Cretaceous deposits on the west. This depression probably completed the principal tilting of the early Tertiary peneplain. Over both the Eocene and the part of the Cretaceous covered by the ocean the sandy beds of the Miocene were deposited. These were thin near their western limit but somewhat thicker seaward, burying and obliterating the erosion surface cut in the Cretaceous and Eocene deposits.

EARLY PLIOCENE EPOCH.

After the deposition of the Miocene sediments there was a decided uplift, which raised the deposits above sea level and brought on a period of active erosion, which in the New Jersey region removed considerable portions of the Miocene beds and cut into the underlying Eocene and Cretaceous.

LATE PLIOCENE (?) EPOCH (LAFAYETTE FORMATION).

The early Pliocene was followed generally throughout the Atlantic Coastal Plain by a period of deposition during which the Lafayette formation, consisting of a mantle of sands and clays derived mainly from the underlying Cretaceous and other beds, was deposited over the Coastal Plain, even overlapping the metamorphic rocks in places and apparently obliterating the topography developed in the early Pliocene. It has usually been assumed that the deposition took place during the period of submergence that has been postulated by most geologists as occurring at this time, but Chamberlin and Salisbury [3] have recently argued that the Lafayette was laid down in eastward-transgressing zones of stream deposition, which filled the valleys and spread somewhat widely over the coastal peneplain that had been developed in the less resistant deposits in Eocene and Miocene time. The transgression they consider to be due to a moderate "bowing" of the peneplain rather than to submergence. They also supposed that the conditions affecting vegetation and precipitation had an important influence on the nature of the erosion and deposition.

It seems certain, however, whether the formation is marine or fluviatile, that the land could not have been far above sea level, for the widely spreading mantle of clays and sands could not well have been formed at its present elevation of 300 or 400 feet had the streams possessed the fall that this would require between the landward limit of the formation and the then existing coast, which could not have been far east of its present position.

[1] Clark, W. B., Science, new ser., vol. 4, 1896, p. 759.

[2] Clark, W. B., Correlation papers—Eocene: Bull. U. S. Geol. Survey No. 83, 1891.

[3] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, 1906, pp. 305-308. Compare views of Hill and Vaughan, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 246-247.

The general absence of glacial erratics in the Lafayette has led most authorities to refer the formation to the Pliocene, but Hilgard referred the similar deposits of the Mississippi Valley to the Pleistocene. The granitic materials at Natchez, on which his opinion was based, have since been shown by Chamberlin and Salisbury[1] to rest unconformably on the Lafayette, which they retain in the Pliocene. It has been suggested that the light sands overlying the known Cretaceous on Long Island (p. 80) might doubtfully be Lafayette, but they are destitute of crystalline pebbles, and this would seem to indicate a pre-Pleistocene origin.

POST-LAFAYETTE EROSION.

The deposition of the Lafayette formation was followed by a period of active erosion, during which the Tertiary and Cretaceous deposits were cut down in places in the Long Island region from an altitude of about 300 feet above the present sea level to one somewhat below it. The exact depth to which the erosion extended could not be determined with certainty, owing to the difficulty of recognizing the Mannetto-Cretaceous contact from well records and samples. The Mannetto gravel (the earliest Pleistocene deposit) is found resting on the Cretaceous down to sea level and the unconformity probably extends considerably lower.

The northward slope of the general Cretaceous surface and the buried pre-Pleistocene valleys in the Cretaceous show that a powerful drainage system existed north of the present island, and there is little doubt that extensive excavation took place in the Long Island Sound region at this time. The magnitude of the unconformity resulting from this erosion, which was many times greater than that producing the post-Miocene unconformity farther south, is the chief reason for placing it after the Lafayette. So far as the island is concerned, it is the only period of erosion between the Cretaceous and the Pleistocene of which a record has been left.

QUATERNARY EVENTS.

PLEISTOCENE EPOCH.

MANNETTO GLACIAL STAGE.

The earliest of the Long Island deposits that have been referred to the Pleistocene is the Mannetto gravel, which has been described elsewhere, and the reasons for its assignment to the glacial series have been there presented (p. 85). The term "Mannetto stage" is applied to the period of its deposition.

The large percentage of quartz and the sporadic yellowish clays in this formation are strongly suggestive of a derivation of the Mannetto material from the formations of the Coastal Plain like the Cretaceous and Miocene, or from glacial material forming a mantle of residual soil. Over 99 per cent of the material is probably from one or the other of these sources. The remaining fraction of 1 per cent consists of granitic pebbles and erratic bowlders, apparently, to judge from their absence in the Cretaceous and Tertiary deposits, derived directly or indirectly through some agent not acting in the earlier periods of deposition. Although it is possible that the deposits are strictly fluvial, it is thought more probable that glacial ice played a part in their accumulation, being the agent to which the peculiarities pointed out are due.

The deposits are now found up to a maximum altitude of about 330 feet, at or near which extensive remnants of an old flat surface of Mannetto gravel still exist. This fact may possibly indicate that the land stood 330 feet lower than at present and that a broad, flat sheet of gravel was built up to that level, at least in parts of the island. The slope of this surface from 330 feet at its north end to 270 feet at its south end, or at a rate of 15 to 20 feet to the mile, is very similar to that of the present outwash plain in the same region, and the flow and plunge structure of the two are identical so far as can be seen. On the other hand, the erratic bowlders of the Mannetto have no counterpart in the outwash on Long Island, although the Wisconsin ice is known to have abounded in such bowlders.

The slope of the old Mannetto surface and the internal structure of the deposit would favor an outwash origin. The evidence of the bowlders might seem to point to submergence, at

[1] Op. cit., p. 308.

least enough to admit of flotation by thin ice, but transportation by floating ice, such as might occur in the shallow deploying streams of an outwash plain, may readily be conceived, although nothing of the sort appears to have taken place in the Long Island region under what must be acknowledged as equally favorable conditions in Wisconsin time. It is possible that the lower part of the deposits in which the bowlders were found was formed below sea level, and that the upper part was a sloping subaerial outwash plain similar to those now existing on the island. The presence of the well-stratified clayey layers at low levels is also favorable to the hypothesis of partial submergence, for such clays have not been found in the later outwash deposits of the island and would be difficult to account for in those positions owing to the absence of any probable causes of ponding. (See Bridgeton formation, p. 223.)

The Sound depression already existed in pre-Mannetto time, as shown by the Cretaceous topography beneath the Mannetto, but it is possible that large Cretaceous deposits existed along the Connecticut coast and supplied much of the gravel making up the Mannetto formation.

The granite bowlders are found near the bottom of the Mannetto, as exposed on the island and granitic pebbles occur up to the very top, hence the ice invasion began early in the Mannetto stage and continued to its close. That the period of ice invasion was long seems to be indicated also by the great thickness of the deposit.

The small percentage of granite pebbles may be due to a long period of attrition beneath the ice or in waters near its margin, which effectively reduced most of the fragments. On the other hand, the fact that the first ice moved across an area of residual soils, where a large part of the materials picked up must have been disintegration products consisting largely of clay and quartz, with a few fresh granitic fragments, may be the chief reason for the small percentage of granitic pebbles in the Mannetto compared with the later Pleistocene gravels.

The exact place where the ice margin rested is largely a matter of speculation. It may have halted in the Sound trough a little north of the present edge of the island.

POST-MANNETTO INTERGLACIAL STAGE.

The deposition of the Mannetto gravel was followed by a period of extensive erosion during which the formation, originally 100 to 300 feet or more thick over western Long Island, was so completely reduced that only a few isolated knobs remained at the beginning of the Jameco deposition. The term post-Mannetto is applied to this apparently interglacial stage of erosion, which is well represented by the Wheatley Hills, near the village of the same name, the essential topographic expression of which, the superficial coating of till being disregarded, is due to erosion in this epoch.

The highest remnant of the Mannetto surface is found in the West or Mannetto Hills, in the northern part of which it has an elevation of 330 feet above sea level. In the Wheatley Hills remnants of the Mannetto probably occur as high as 300 feet. From this altitude, which appears to mark the upper limit of the formation in western Long Island, valleys were cut down to a point not less than 300 feet below the present sea level, the depth to which the succeeding Jameco gravel has been recognized in wells.

Whether the Mannetto gravel lay at a similar altitude over eastern Long Island is not known, but its development was probably somewhat less in this direction. Large masses, nevertheless, probably existed and the fact that the deposits as a whole were eroded until only scattered remnants were left points to a period either of very rapid or of long-continued erosion, or most likely both. The elevation as estimated from the Hudson submarine channels, which are assumed to have been formed at this time, appears to have varied from 1,300 feet in the earlier part of the stage to over a mile in the later part (p. 60).

The post-Mannetto erosion presumably followed, in its broader features, the lines of pre-Mannetto drainage, as the Mannetto gravel was probably somewhat lower over the deep Cretaceous valleys than over the Cretaceous knobs, in the same way that the Wisconsin outwash is lowest where the underlying Manhasset formation is low and highest where the Manhasset is high. That this is true in the Mannetto Hills region is shown by the section at this point (fig. 57, p. 81), the Mannetto and Cretaceous erosion surfaces being almost parallel. Where the Cretaceous relief was less marked, however, the erosion was independent of the old topography and cut indiscriminately into Mannetto and Cretaceous. This type of erosion was probably especially characteristic of the north-shore districts. In general, however, the land at the close of the post-Mannetto interglacial stage appears to have been not greatly different in extent and topography from that existing at the beginning of the Mannetto stage. The larger Cretaceous remnants appear to have been very nearly the same as before, the principa- differences apparently being the presence of a mantle of Mannetto gravel that covered and obscured the older deposits in places and the deeper trenching of those deposits elsewhere.

JAMECO GLACIAL STAGE.

The extensive erosion epoch just described was followed by an influx of material whose granitic character seems to indicate a glacial source. The position of the deposits below sea level and the necessity of depending on well records for a knowledge of them make the determination of their exact character and structure practically impossible, and it is not definitely known whether or not the ice actually invaded Long Island. The high percentage of granl itic pebbles present locally may mean the near proximity of the ice sheet, but the deposits as a whole do not differ greatly, so far as appears from well records, from the later Manhasset or from the Wisconsin outwash deposits, and they may have a similar origin, in which case the ice front presumably lay somewhere in the Sound. The distribution of the Jameco gravel on Long Island and the islands east of it would seem to indicate that the front extended along the Sound beyond Orient Point, passed north of Block Island, crossed southeastern Massachusetts (probably between Plymouth and Boston), and passed north of Truro, Cape Cod.

The deposits appear to have accumulated in part in the space between the ice front and the Cretaceous-Mannetto core of Long Island, and in part outside of and around the then existing land masses, the materials being swept westward and southward through the depression east of Jamaica and eastward and southward around the east end of the existing land beyond the Mannetto Hills. The depression of the land at this time seems to have been 150 feet or more (p. 218).

The erosion by the ice in the immediate vicinity of its margin appears, if we may judge by the relatively small amounts of quartz and other locally derived materials, much less pronounced than during the first invasion. In fact, the almost entire absence of recognizable material derived from the underlying Cretaceous or the Mannetto gravel would seem to indicate either a nearly stagnant condition of the ice near its margin or a sheet so overloaded with material that it could no longer erode.

GARDINERS INTERGLACIAL STAGE.

The Jameco gravel gives way abruptly to the Gardiners clay, as if the source of materials was suddenly removed, as it doubtless was by the retreat of the ice sheet from the vicinity of the island. So far as known there is no unconformity between the two formations, the lignitic, marshlike, and fossiliferous phase of the Gardiners following without any important time break upon the cessation of Jameco deposition.

The land masses during the deposition of the Gardiners clay remained essentially as during the Jameco deposition. No conspicuous change of level took place either at the beginning of or during the Gardiners deposition, although there was a slow subsidence, which kept pace with the accumulation, the top of the formation always remaining at or below sea level. The subsidence could have been little if any more rapid than the deposition, as there is apparently an entire absence of locally derived materials, such as would be present if the sea encroached upon the Cretaceous and Mannetto land masses to any extent. The actual position of the land, to judge from the general occurrence of the clays below sea level at the present time, appears to have been generally a little higher than the present level, the few occurrences of clays above sea level being apparently due to folding.

In western Long Island the clays appear to have accumulated in the form of marsh deposits bordering the preexisting land masses, but in eastern Long Island peat, muck, and other indications of marsh origin are less common, and the nonorganic character of the bulk of the deposits appears to indicate an offshore origin of the formation, except perhaps of the earliest phases.

The question whether the deposition took place during a true interglacial stage or simply during a temporary retreatal stage is somewhat puzzling. The presence of fossils in the clays at several places indicates a period of sufficient length to permit the reoccupation of the formerly glacial waters by animal life, and although this might, under favorable circumstances, take but a few years, the character of the remains indicates a climate no colder than that of the Maine coast at the present time, hence it is probable that the ice had drawn back to the northern portion of the continent, if it had not entirely disappeared. The lignite present in the clays on western Long Island and elsewhere and the general blackish color, presumably due to organic matter, of the same clays on the Massachusetts islands and on Cape Cod indicate that plant life had also extended itself over the region. The thickness of the clays themselves, taken in connection with their apparently slow accumulation, likewise points to a period whose length is more compatible with an interglacial stage than with temporary retreat.

JACOB TRANSITIONAL STAGE.

The fact that the transitional Jacob sand gives place to the glacial Herod gravel member of the Manhasset formation without any recognizable time break, and that the latter in turn gives way by transition to the great Montauk till member of the Manhasset, would make plausible the supposition that the advent of new materials from the advancing ice sheet brought about the change from the marine Gardiners clay to the more quartzose Jacob sand. It is not unreasonable to suppose that the change of material marking the beginning of Jacob deposition took place as soon as the advancing ice front reached the headwaters of the Connecticut and began to discharge its drainage down the valley of that river. Under such conditions only the finer material would be borne to the river's mouth and distributed in the surrounding region. The quantity of materials, if the supposition as to origin is correct, would indicate a very slow advance, as the Jacob sand reaches a thickness of at least 30 feet.

Although the materials seem to be of glacial derivation, the Jacob is essentially a marine formation. It extends from western Long Island to southeastern Massachusetts and its persistency points clearly to marine deposition rather than to accumulation in valleys or basins above sea level; moreover, its marine fossils fix its origin beyond dispute.

Evidence of any material change of level is lacking. That no considerable elevation took place is shown by the entire absence of any evidences of stream erosion in the deposits at this horizon, the only unconformities being those due to the scouring action of the overriding Montauk ice.

During the period of Gardiners deposition, as elsewhere pointed out, the land appears to have slowly subsided, the sinking just about keeping pace with the accumulation, as indicated by the fossils and salt-marsh deposits at the various horizons.

Such marsh deposits are absent, however, from the Jacob. This fact, taken in connection with the persistency of the beds, the regularity of the lamination, and the general absence of ripple marks, suggests a sinking of the crust and a deepening of the water. As noted on another page, however, faceted pebbles elsewhere in the immediately overlying Herod gravel member of the Manhasset point to a subaerial accumulation of the Herod; hence it is probable that the subsidence was slight, possibly only a few feet, or a little more than enough to keep pace with the accumulation. This slight depression probably resulted in a further contraction of the land masses of the island, so that, except in the Mannetto, Wheatley, and Half Hollow hills and certain other parts of western Long Island, marine currents had free sweep over the region.

MANHASSET GLACIAL STAGE.

HEROD GLACIAL SUBSTAGE.

The change from the fine sandy silts of the Jacob to the glacial gravels of the Herod member of the Manhasset formation indicates a nearer approach of the ice that supplied the materials. The sandy nature of the lower beds, the more gravelly character of the upper layers, and the final transition into the Montauk till member would seem to mark various stages of the advance of the ice, the front possibly just reaching the Sound at the time of the earlier deposition, advancing close to the north shore of Long Island in the later Herod accumulation, and eventually invading the island in the succeeding Montauk substage.

The Herod accumulation was marked by the development of strong currents, far more swift and powerful than those of the Gardiners and Jacob stages of deposition. In fact, no clay or fine silts could have been deposited if currents of like strength had existed during those stages. These currents may be regarded either as glacial streams, emerging from the near-by ice front and deploying over a subaerial outwash plain, or as tidal or other currents of the sea, according to the elevation of the region with reference to sea level.

The Jacob accumulation certainly took place below sea level, and in the absence of any evidences of stream erosion at its upper contact there is almost equal certainty that it was not lifted above sea level before the beginning of the conformable Herod deposition. The lower beds of the Herod must therefore have been deposited at or below sea level. Higher up in the Herod member, however, wind-faceted pebbles point to subaerial accumulation, making it seem probable that subsidence either was not going on at this time or did not keep pace with the upbuilding. This part of the Herod seems most likely to have been formed as an outwash plain similar to those of the Wisconsin stage, though on a larger scale. The accumulation appears to have been very slow, the surface being exposed for long periods before being covered by the succeeding layer. That the surface was probably nearly or quite devoid of vegetation and that it was subject to strong winds, transporting sharp sand as in a sand blast, and in fact possessed many of the characteristics of a desert, is shown by the faceted pebbles. That these conditions were widespread rather than local, furthermore, is shown by the presence of similar pebbles at the same horizon on Nantucket and Cape Cod.

It seems probable that different conditions prevailed toward the close of the Herod accumulation, the deposition of the overlying Montauk till member apparently taking place below sea level. It would seem, therefore, that the subsidence, which started at least as early as the beginning of the Gardiners deposition but which barely kept pace with the accumulation in the Gardiners and Jacob stages, went on more rapidly during the later part of the Herod substage; so that, notwithstanding the upbuilding of the earlier deposits to some height above sea level and the continued rapid deposition, the whole of the Herod was carried below sea level before the advance of the ice marking the close of its deposition.

The Herod member differs in thickness from point to point, as all deposits must whose materials are supplied by glacial streams, but on the whole the member displays remarkable persistency and uniformity for a glacial deposit. It seems to have had the form of a single broad southward-sloping cuesta-like outwash plain, partly subaerial and partly submarine, rather than that of a series of small outwash fans.

MONTAUK GLACIAL SUBSTAGE.

FIRST ADVANCE OF THE ICE.

Position of ice margin.—The ice, which was still remote at the beginning of the deposition of the Jacob sand, had approached nearer during the deposition of the Herod gravel member of the Manhasset, and it actually invaded the Long Island area at the beginning of the Montauk substage, as indicated by the change of the deposits from gravel to till. The ice is thought to have reached south in western Long Island in a lobe extending down the old Jameco valley between Jamaica and Brooklyn, depressing the Gardiners clay beneath its weight in that vicinity and giving rise to a doming at its edge, as recorded in the wells of the Rockaway Ridge.

Eastward from this region the ice front, for the most part, probably rested against the side of the Mannetto and Half Hollow hills, although bowlders in the Half Hollow Hills and a structureless mass resembling till resting upon the Cretaceous in the Bethpage pits suggest a temporary advance extending much farther south. Beyond the hills mentioned the margin bent to the southeast and passed off beyond the present coast line at a point somewhere west of the till exposures in the Easthampton beaches. Its invasion is marked in western Long Island by the bowlder bed of Hempstead Harbor and by the bowlders and till in the wells of the exterior of the island, and in central Long Island by a thick bed of till. On the North Fluke its work was mainly erosion, but it also laid down a certain amount of till, and on the South Fluke it accomplished both severe erosion and heavy deposition.

Erosion by the Montauk ice sheet.—The erosion unconformity at the base of the Montauk till member of the Manhasset formation has been described elsewhere (p. 134). It extends from Long Island through Block Island, Marthas Vineyard, and Cape Cod to the Maine coast or beyond and is nearly everywhere characterized by evidences of drag, by ice-shoved bowlders and till deposits, or by superficial thrust faults, folds, and contortions. In fact, the evidences are so clear-cut and decisive as to establish without question the eroding agency as the Montauk ice sheet.

The ice on its advent was strong and vigorous, as is characteristic of an underloaded glacier, and although it produced some folding, mainly of the open type, its work was largely erosion and consisted in scouring broad, shallow trenches and basins and in beveling the upturned beds of the arches and folds. Later its vigor appears to have decreased, probably through overloading by material picked up in its earlier stage, and deposition of the great beds of till which are characteristic of the Montauk member followed.

Accumulation of the earlier deposits of the Montauk till member.—The evidence bearing upon the conditions existing during the accumulation of the Montauk till member presents many puzzling features. The most characteristic phase of the Montauk is the till, and of this the most distinctive feature is its peculiar banding or lamination. This lamination, which is described in detail in another place (p. 133), is unquestionably the result of accumulation in the presence of water and may be conceived as due to deposition in local basins on a land surface, to purely aqueous deposition in the sea, to extremely rapid deposition in front of the ice margin by unconfined glacial waters above sea level, or to accumulation beneath the ice sheet overriding the water-saturated Herod gravel member and other deposits below sea level.

That the deposition did not take place in local land basins appears to be indicated by the extent of the Montauk member as well as by the absence of the necessary barriers; that it was not the result of unconfined glacial waters deploying upon the land is shown by the persistent character and horizontal position of the bedding, the member exhibiting neither the high angles of aqueous morainal accumulations nor the definite stratification that it would have if it were an outwash deposit; and that it does not represent marginal deposition below sea level is made apparent, likewise, by the absence of any well-marked assortment, such as would inevitably result from purely aqueous deposition of this nature. The member is filled with erratics irregularly distributed through its mass in far greater number than can be readily conceived as arising in any way other than by direct deposition as ground moraine beneath an ice sheet. The banding, however, is far more conspicuous than in any ordinary subaerial accumulation of till. Accumulation beneath the ice sheet in the presence of abundant water appears, therefore, to be the most probable origin of these deposits. It seems likely that the lamination results from dragging a loose body of drift, obtained by erosion or from the ice by basal melting, and its readjustment in the presence of water. The extent of the Montauk member seems to indicate that the water was a general rather than a local feature and suggests that the deposits were most probably laid down below sea level.

That the deposition of the gravel phase of the Montauk took place below sea level would of necessity follow if the interpretation of the origin of the till is correct, as the two have the same stratigraphic position, one grading laterally into the other. The angle of bedding, high in many places, the rapid change in direction of the dip, and the presence of delta and other flow and plunge structures and of contemporaneous unconformities of erosion and deposition are all in harmony with the assumed conditions of rapid submarine accumulation at the margin of the ice sheet. The bowlders, too, seem to point to an aqueous origin, for although ice-rafted bowlders are not uncommonly borne down the shallow streams of outwash plains and left in the gravels, such definite and continuous beds as characterize the Montauk horizon on Long Island are seldom formed in that way.

The absence of fossils, except those of secondary origin, in the reworked deposits of the Gardiners clay points to shallow water. In Inglefield Gulf, Greenland, overlooked on three sides by ice caps, abundant marine life was found by T. C. Chamberlin, who states[1] that 80 crinoids and numerous more common forms were obtained from a single haul of the dredge. If deep water had prevailed along the Montauk margin, similar evidence of life would be expected; but if the water was very shallow, the quantity of silt known to have been constantly discharged into it by glacial streams and the rapid upbuilding of the deposits by the coarser material would tend to prevent the occupation of the water by marine forms along the immediate border of the ice. The severity of the erosion by the Montauk ice indicates that the depth of the water was too slight to affect materially (through its powers of flotation) the scouring action of the glacier. On the whole it seems probable that the Montauk accumulation took place in very shallow water, possibly only a few feet in depth, with perhaps numerous islands, due to folding, rising above its surface. The actual depression of the land with reference to the present sea level appears to have been from 75 to 100 feet.

FOLDING DURING MONTAUK SUBSTAGE.

Extent.—The most marked feature of the Montauk till member, aside from the deposits themselves, is the great folding that the underlying beds exhibit. This folding is of widespread distribution, being found from Brooklyn on the west to Orient and Montauk points on the east, as well as on the adjoining islands. East of Long Island it is developed on a large scale on Fishers, Block, Marthas Vineyard, and Nantucket islands and on Cape Cod and the Maine coast. The magnitude of the disturbance is in places very great, at least for a surface feature, not a few of the folds reaching a height of 100 feet and some measuring 150 feet or more. The folds always present their steepest faces to the south or are overturned in that direction. Many of them pass into faults, almost always of the thrust type, the upthrow being on the north.

The disturbances affecting the beds are of at least five orders of magnitude—(1) tilting affecting the island as a whole; (2) low arches several miles in diameter and extending throughout the greater part of the length of the island, such as the North and South fluke ridges and their extensions; (3) low flat arches several hundred yards in diameter, representing irregularities in the broader arches of the second class; (4) steep, closed folds of considerable length but of slight breadth, many of them overturned and faulted; and (5) the minor crumplings of the individual layers of the sharp folds of class 4. These classes are not, of course, sharply differentiated from one another, all gradations between them being noted. Although the flexures differ in details of formation, all except those of the first class appear to have been the result of the same general agency, the nature of which is considered in the following paragraphs.

Anticlinal nature of the fluke ridges.—The anticlinal nature of the fluke ridges is brought out by the height of the Gardiners clay lying upon and near them. This formation on each fluke is commonly at or slightly above or below sea level, whereas between the flukes and, so far as can be determined from well records, both north and south of the flukes proper or of the Manhasset belts (p. 119) which mark their continuation to the west its height is about 50 feet lower. These ridges are therefore to be regarded as broad flexures having an altitude of about 50 feet and a length of not less than 50 miles on Long Island, to say nothing of their eastward continuations—the northern one through Fishers Island, Watch Hill, Point Judith, Elizabeth Islands, and Cape Cod, and the southern through Block Island, Marthas Vineyard, and Nantucket.

[1] Personal communication.

These broad flexures are not simple arches but compound folds or anticlinaria, being characterized by both minor local warpings and sharp, overturned folds and faults. The main warping affected all the Pleistocene formations and extended down into the underlying Cretaceous beds, as shown by the occurrence of the latter in many places along the axis of the arch farther east, as on Block Island and Marthas Vineyard. The minor warpings probably affected all but the lowest of the Pleistocene accumulations, but the sharper and smaller folds and the faults are still more superficial, the disturbance becoming rapidly less downward and in many places disappearing entirely, even in the cliff sections. It is doubtful if the beds lying 50 feet below the surface are much if any disturbed by even the more pronounced folds.

Possible causes of the flexures.—Reaching down into the Cretaceous, the disturbance could have been produced only by an agency of great power. Crustal warping at once suggests itself as this agency, but there are many reasons against accepting it as the real cause. If the two flukes and their prolongations were part of a single uplift, the arching would be of a magnitude that would make the theory of crustal warping seem somewhat reasonable, but as a matter of fact the arches, though long, are relatively narrow, their extent transverse to the axis being apparently far less than is to be looked for in true crustal warping. Their occurrence in two groups, separated by a broad undisturbed area, points to a repetition of local causes rather than a general cause such as crustal warping. It is believed, therefore, that such warping, if it played any part in the formation of the anticlinal ridges, was merely a subordinate agency. On the other hand, it seems equally certain that the ridges have resulted from causes differing also from those that produced the minor folds. They are too broad, low, and flat (some being several miles wide and only 50 to 100 feet high) to have resulted from tangential thrust, and furthermore the deposits consist of incoherent sands, clays, and other material entirely incapable of transmitting thrust.

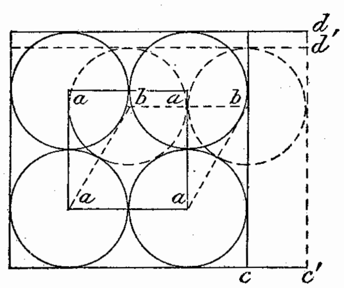

FIGURE 198.—Diagram illustrating compression of beds through rearrangement of grains.

That the anticlinoria are due to a warping of the surface in their vicinity seems clear, but that they were mainly the result of a general crustal warping is very doubtful. It is more likely that they are due chiefly to a warping of the unconsolidated deposits through agencies other than crustal movements.

Sediments vary greatly in bulk according to the arrangement or "packing" of the component grains or fragments. Being deposited without application of external pressure and exerting only about two-thirds of the pressure of their normal weight (owing to the buoyancy of the water) the particles of the sediments are at first very loosely arranged. As the deposits thicken they may undergo some readjustments leading to a decrease in bulk, but they remain far below their maximum density.

If the fragments were spherical they might be arranged (1) so that the lines connecting the centers of adjacent spheres would form rectangles, as shown by *a–a–a–a* in figure 198; (2) so that the connecting lines would form rhombs with an acute angle of 60°, as *a–a–b–b;* or (3) so that the lines would form rhombs intermediate between the rectangle and the 60° rhomb. The first arrangement gives the maximum and the second the minimum vertical thickness. If the grains of a sedimentary bed were originally deposited in the first manner and were subsequently forced by pressure to rearrange themselves into the second form, there would be a shortening of the vertical space taken up by the grains, represented by

$$2(r-r\cos 30°)=2\,r(1-\cos 30°)=0.268\,r.$$

The last factor is the equivalent of 13.4 per cent of the thickness of a given deposit (*d–d'*, fig. 198). If it is assumed that the original thickness of the Pleistocene deposits before the folding was 300 feet and that in the original deposition the fragments took an arrangement equivalent to the one first described, then if by the pressure of the ice their arrangement was later changed to the second form, there would have been a compacting of the deposits that reduced their thickness about 40 feet.

Of course, it is doubtless true that the grains never possessed as a whole the arrangement suggested, but observations on soils show that the grains may be far from uniformly in contact with one another, many vacant spaces occurring among them. The application of pressure would be even more likely to close such spaces than it would to rearrange the grains.

Actual tests on natural silts and sands, the properties of which may be taken as indicating the arrangement of the grains, show that although the average theoretical pore space is only about 30 per cent and the highest theoretical pore space only 47.64 per cent of the volume, the actual porosity,[1] as indicated by the water absorbed (which may amount to 50 per cent of the weight of the material [2]), is sometimes as high as 75 per cent. Pressure applied to such material could not fail to produce a very considerable compacting, probably fully equal to the theoretical amount due to the rearrangement of the grains. Experiments made on gravel under the writer's direction in 1912 showed that a pressure of 10 pounds to the square inch, corresponding roughly to the weight of 10 feet of material, resulted in a reduction of 5 per cent in the volume of the gravel tested. Higher pressures, up to and including 100 pounds, gave 1 per cent additional compacting.

In the rearrangement of grains just described the decrease in vertical thickness is not the only result. Figure 198 shows that this decrease in thickness is accompanied by an increase in lateral extent. This increase (c–c'), which is equal to the radius of the grain, is not cumulative, however, being the same in a horizontal distance of a mile as in a fraction of an inch, hence it can play no part in the warping.

It is well known, however, that clays flow readily under relatively slight pressure, as has been brought out many times by the movement of clays beneath even relatively low dams and railroad embankments. The long ridges of mud forced up on each side of the railroad fills recently built across a wide stretch of Great Salt Lake and the flow of the clays underlying the Gatun Dam at Panama are cases in point. The likelihood of such flow is now universally recognized by engineers, and in all important constructions great precautions are taken to avoid building upon clayey materials. If the flow is so pronounced in 15 to 20 foot embankments, it must have been much greater under the pressure of hundreds of feet of ice. The deposits over which the ice sheet passed were unquestionably saturated with water and the clays and fine sands, which when wet flow like quicksands, must have been very plastic. It is not improbable, therefore, that flowage toward the anticlinorial axes actually took place on a considerable scale, as it is known to have occurred in small degree in the case of some of the minor folds. The lateral flow of the clay may be conceived to have taken place either with or without an accompaniment of folding. Flows accompanying folding may be seen at many points on Long Island and the New England islands, being manifested by the squeezing of materials from the compressed parts of anticlines into the parts that were under less pressure.

Notwithstanding the competency of an ice sheet to materially compact the deposits which it overrides, the anticlinorial ridges of the north and south flukes can not be referred to such an agency acting upon a uniform series of deposits. Ice overriding such an accumulation might indeed compress the materials and reduce their thickness, but the result would be broad, even depressions stretching from the outer limit attained by the margin of the ice back to the hard rocks of the mainland, leaving the extramarginal deposits in their original horizontal position (fig. 199, p. 204). Such compression would, therefore, account only for the northward slope of the arches, as the compacting would take place only on that side of the belt, failing entirely to explain the equally conspicuous southward slope. In other words, the materials north of the flukes have not simply been depressed, but the deposits beneath the flukes appear to have been actually raised, as they stand materially higher than in the extraglacial region on the south.

It may be conceived, however, that the compacting was differential rather than uniform, the variation in amount being due either to differences in the character of the Pleistocene materials or to differences in the altitude of the underlying Cretaceous and consequently in the

[1] Slichter, C. S., Theoretical investigation of the motion of ground waters: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, p. 309.
[2] King, F. H., Principles and conditions of the movements of ground water: Idem, p. 70.

thickness of the Pleistocene deposits. There does not appear to be sufficient variation in the character of the Pleistocene deposits in the region to account for the abnormal difference between their altitude in the moraine and their level elsewhere; hence this aid to differential compacting need not be considered. An ice sheet moving over a region, such as that shown in figure 200, where porous glacial materials rest upon an irregular surface of more dense and resistant Cretaceous rocks, may be readily imagined to produce a considerable warping through compacting. It must be acknowledged, however, that though this may be a possible cause, the information at present available, either in the surface exposures or in well records, is insufficient to afford any absolute confirmation.

On the whole, squeezing and flowage of the clays appear to be an entirely competent cause of the arching, the materials being assumed to have been pressed outward, or to the south,

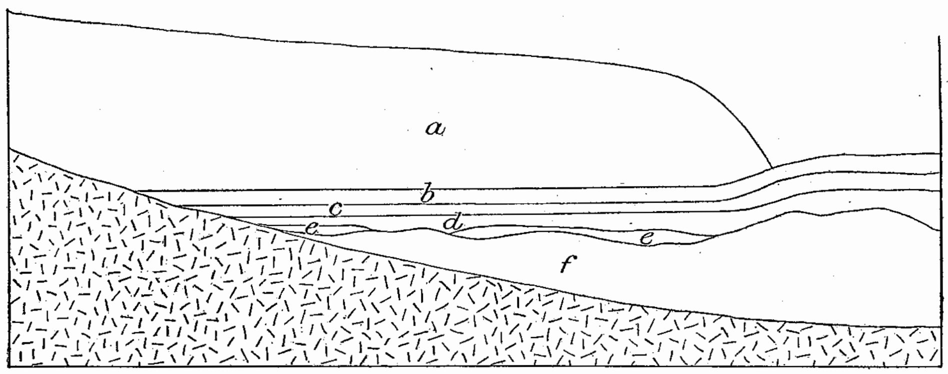

FIGURE 199.—Diagram showing supposed compression of beds under ice load in the Long Island region. *a*, Montauk ice sheet; *b*, Herod gravel member of Manhasset formation; *c*, Gardiners clay; *d*, Jameco gravel; *e*, Mannetto gravel; *f*, Cretaceous.

under the weight of the ice sheet, which, to judge from the presence of ice-deposited material at the top of the Mannetto Hills, could not have been less than 410 feet thick at its margin and may have been much more. Beyond the margin of the ice the pressure would be largely removed and the clay would tend to thicken and rise, lifting the overlying beds. Under this assumption the larger and more pronounced ridge would be formed at the outer limit reached by the ice, and a smaller ridge would be associated with a retreatal halt, for the clay would be less mobile and possibly thinner at the time of the halt, having already been subjected to the probably more severe pressure of the early advance. Although of the several causes suggested flowage of the underlying clays seems best to explain the features observed, the writer is loth to advocate the theory of a transfer of material on the necessary scale. At the same time warping and compacting seem, with the evidence now at hand, even more improbable explanations. Perhaps the least objectionable view is that which ascribes the origin of the arches to a number of agencies supplementing one another, of which crustal warping, compacting of deposits by pressure, and flow of plastic materials under pressure are the most important. Whatever the cause may be that raised the arches, it appears to have been assisted by the drag and folding due to the overriding ice. That the elevation of the anticlinoria has been considerably increased by such folding can not be questioned. In a section on Gardiners Island (fig. 80, p. 100) measuring about 1,350 feet, beds of a length of 2,500 feet have been compressed, giving rise to an increased elevation which, before the subsequent erosion of the folds, must have amounted to

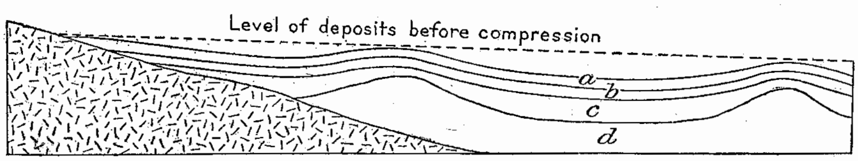

FIGURE 200.—Diagram showing supposed influence of Cretaceous masses in controlling the compression of the Pleistocene deposits under ice load. *a*, Herod gravel member of Manhasset formation; *b*, Gardiners clay; *c*, Mannetto and Jameco gravels; *d*, Cretaceous.

at least 100 feet. On Fishers Island (fig. 85, p. 102) the original elevation due to folding appears likewise to have been nearly double this amount, and on Marthas Vineyard the thickening is still greater.

Minor warpings.—Under the head of minor warpings are included the undulations (many of them isoclinal), usually reaching only a few feet in height and a few hundred yards in length, which are seen in many bluff sections and which give rise to a large part of the variations in the level of the beds. In some places warping of this particular type is more apparent than real, being due to the truncation of the sharper folds of the class described below along lines more or less parallel with their axes. There are, nevertheless, many warpings that are not associated with such folds, and it is the origin of these that is considered here.

Differential settling, which, as has been seen, is likely to take place in any thick formation, especially where there are, as in the Pleistocene deposits of the Long Island region, more or less minor variations in composition and texture, doubtless took place to a certain extent under the weight of the deposit itself, although the warpings so produced would be likely to be very slight. The principal readjustment, however, was probably due to the overriding ice sheet of the Montauk substage, which because of its great weight exerted a profound influence upon the overridden beds. Its action was especially pronounced in the later part of the invasion, when through differential erosion and deposition the surface had become more or less irregular and the weight of the ice was unequally applied at different points. Direct shove upon the irregularities of the surface under such conditions may have been an important factor in the production of the warpings. Ice pressure against the stiffer and more clayey beds at their outcrops may also have been transmitted beneath the overlying gravels, giving rise to warpings at some points of weakness.

Open and closed folds.—Although differing in magnitude, the open and closed folds are of the same general origin and may best be considered together. They include everything from an undulation barely well enough defined to be recognizable as a fold to the closely compressed and overturned and recumbent folds. In altitude they vary from perhaps 5 feet to 150 feet or more and in breadth from a few feet to an eighth of a mile or more. Their axes are generally parallel with the trend of the anticlinoria of the North and South flukes, of which they are a superficial feature, having a roughly east-west direction. Very few of the folds are symmetrical, almost all showing more gentle slopes on the north than on the south. Overturning, where present, is always toward the south.

Orogenic movements were postulated by many of the early workers as the cause of folding on Long Island, but the evidences against such movements are very definite. Arthur Hollick some years ago pointed out the superficial character of the folding and the undisturbed condition of the underlying beds. Very conclusive evidence was brought out by well records collected by A. C. Veatch during the present investigation, the logs showing the Cretaceous strata to dip uniformly at the rate of a few feet to the mile regardless of the disturbance of the superficial beds. Furthermore, the present field work brought to light many sections along the coast in which the folding could be seen dying out downward. (See figs. 98, p. 110, and 133, p. 130.)

The slipping in mass of a bed or series of beds down a dip or structural slope may cause the compression of the lower part of the mass into folds which are called slip folds. The movement takes place along bedding planes, which may have been more or less tilted. The most favorable localities for slip folding are in basins toward the center of which the beds dip steeply, but it may occur also on any monoclinal slope.

The origin of the Long Island folds and those of the New England islands farther east has sometimes been attributed to slip folding, the slipping movement being assumed to have proceeded from north to south because the beds were overturned in that direction. One of the chief difficulties in the way of accepting such an origin is the absence of any slope adequate to cause the slipping of the beds. The present normal attitude of the Pleistocene beds is almost horizontal, and the dip of the Cretaceous appears to be only a few feet to the mile, or a small fraction of 1°, and it is not probable that the original dips were any steeper.

Slip folding would seem to be more likely to characterize the clayey beds than the more sandy deposits. No such difference was observed, however, the clays being no more disturbed than the sands. In fact, the folding is in many places greater in the sandy material at the surface and much less in the underlying clays.

Slip folding would necessarily be accompanied by the production of a slip or fault plane, which in the present instance would have to be several miles broad and more than 100 miles long. That no such slip plane is present on the greater part of Long Island is unmistakably shown by the bluff sections, which, though reaching in places below the level of folding, nowhere afford indications of any but local breaks due to slipping. On the contrary the upper folded beds with a few minor exceptions grade downward into the lower undisturbed beds without breaks of any sort, showing beyond question that the beds are in place and that the folding is only a superficial disturbance. Where the folding is more profound and extends below sea level it is more difficult to prove the absence of the slip plane, although there is no evidence of its existence.

Among the phenomena associated with the folding and affording a clue to its origin may be mentioned (1) its maximum development along the borders of depressions, such as Long Island Sound and the bays between the flukes farther east, or along northward-facing escarpments; (2) its minimum development over flat surfaces such as the upper part of the Herod gravel member of the Manhasset formation; (3) its usual development at the Montauk horizon and at that horizon only; (4) the superficial character of the disturbance; (5) the rapid disappearance of the folding below the Montauk; (6) the absence of disturbance above the Montauk (except locally at the base of the Wisconsin till); (7) the constant association with the Montauk till member; (8) the evidences of drag in the incorporation of the underlying gravels into the till; (9) local evidences of the plowing of the underlying surfaces by bowlders; (10) the almost universal evidences of ice erosion at the Montauk horizon; (11) the massing of till against undisturbed beds; (12) the association of the folding with thrust faulting on planes at high angles; and (13) the overturning of the folds always toward the south.

It is to be emphasized that the folding is everywhere associated with the Montauk ice invasion; that it is practically absent at other horizons; that it was most marked where elevations rose above the surrounding level so as to present bold faces to the advancing ice sheet; that it was associated with notable ice drag and erosion; and that the faulting and folding were always in the direction of the ice movement.

Notwithstanding the general absence of folded beds beneath the glacial deposits of the country as a whole, the absence of any extended folding on Long Island by the Wisconsin ice, which reaches a thickness of more than 400 feet, and the general ease with which ice is known to override morainal and other unconsolidated deposits without material disturbance, there seems to be no question that it is to the ice sheet invading the region in Montauk time that the conspicuous folding is due. The theory accounts for all the associated phenomena, makes use of an agency that is known to have been at hand, and leaves nothing but its unusual vigor unexplained.

The cause of the unusual vigor of the ice in the Long Island region, as indicated by the extraordinary disturbance of the beds over which it passed, presents an interesting problem, the key to which is probably to be found partly in the thickness of the ice sheet, partly in topographic conditions, partly in the subaqueous nature of the deposition, and partly in the climatic conditions. The scarcity of folding in the glacial deposits of the American continent as a whole and its insignificant development as compared to that in the Long Island region are probably due largely to the general absence of scarps or other topographic forms adapted to receive the brunt of the attack of the advancing ice. In the Long Island region, on the contrary, the Montauk ice found opposed to its advance the thick series of gravels (Herod gravel member) previously deposited at its front. Against these it impinged with great force, bending, folding, shoving, and faulting them on a grand scale, the disturbance involving also the underlying clays, especially in the later stages of the advance, when considerable portions of the gravels had been eroded. Similar conditions likewise prevailed in the region between the flukes and along the South Fluke.

It is true that, notwithstanding the even more marked scarps opposed to the Wisconsin glacier, the folding it accomplished was much less than that due to the Montauk ice. Probably the greater effectiveness of the Montauk ice was due largely to the greater thickness of the glacier and to the greater vigor of its movement.

That the Montauk ice was thicker than the Wisconsin in the Long Island region seems to be indicated by the fact that it reached a more southerly limit, and that it was more vigorous is shown by the relatively great erosion that it accomplished as well as by the greater thickness of drift that it laid down, not only on Long Island but over a large section of the country. The fact that the beds over which the Montauk ice passed lay beneath the sea and were saturated with water, and hence possibly presented more favorable conditions for folding than the incoherent surface gravels over which the Wisconsin ice sheet moved may have had something to do with the more extensive folding by the older ice sheet. Again, the clay beds, which are most susceptible to folding, were more thinly covered in Montauk time than in Wisconsin time, and being thus much more accessible to the ice they consequently suffered greater disturbance. Still another factor favorable to greater erosion during the Montauk was the submergence, which was enough to prevent the accumulation of snow, though not enough to affect the erosion materially. The surface was therefore free from the mantle of snow or stagnant ice, which was present outside of the glacier in a part at least of Wisconsin time, and over which the glacier proper passed with little effect, as indicated by the Smithtown "driftless" area.

FIRST RECESSION OF MONTAUK ICE.

The fact that extensive deposition followed the active erosion of the first advance shows a decrease in the vigor of the invasion, doubtless due in part to the overloading of the ice by débris. There seems, however, to have been a decrease in ice movement, marked first by the several minor advances and retreats recorded in the alternating beds of till and gravel in the Montauk region, and finally by a more marked retreat during which the ice front was moved back at least as far as the north side of the Middle Island belt of the Manhasset formation (fig. 107, p. 120). It then rested about on a line reaching from the vicinity of Manorville along Peconic River, through Riverhead, north of New Suffolk through Cutchogue, northwest of Great Hog Neck, and along the north side of Shelter Island. The North Fluke proper was probably still covered by ice, as there is no record in the shape of deposits to indicate that the ice retreated beyond its southern border. In western Long Island the ice front lay somewhere north of the southern coast.

During the retreat of the ice there was more or less deposition by glacial streams, marked by the gravels found here and there between the erosion unconformities of the earlier and later Montauk ice invasions, but on the whole the deposition was on a very small scale until the ice came to a halt along the line just traced. On this line the margin probably remained stationary or nearly so for a period during which considerable accumulations of gravel were laid down. The greater part of the gravel deposits of Robins Island, Nassau Point, Great Hog Neck, and Shelter Island were apparently accumulated at this time, probably as sand and gravel deltas at the mouths of glacial streams. From the outline and topography of the various masses, due weight being allowed to subsequent wave erosion, it appears that the deposition took place not in an open body of water, but rather in irregular spaces among a number of detached residuary ice masses occupying the greater part of the interfluke area. It is not improbable that many small ice masses were buried beneath the gravel accumulations at this time and by their subsequent melting gave rise to some of the warpings now observed in the beds as well as to many of the numerous kettles.

As to the altitude of the land at this time very little is known. The heights of the deposits are not accordant and afford no indication of any common factor in the determination of their levels. Cuesta-like surfaces such as characterize both the late Manhasset and the Wisconsin outwash deposits are entirely absent, and traces of beaches, if any were ever formed, were removed by the later ice advances. The topography in a broad way resembles the kettle or broken plains of morainal aspect, such as are not uncommonly associated with subaerial outwash deposits laid down over and around ice blocks.

READVANCE OF THE MONTAUK ICE.

Evidence of the readvance is afforded by the strong scouring and folding of the beds laid down during the recession, which thus lie between two strong unconformities of ice erosion. The advance was least in western Long Island, where the ice appears to have reached little or not at all beyond the north coast, and was greatest in the vicinity of the South Fluke, where it extended beyond the south shore into the sea. It is to this readvance that the strong folding and faulting of the Middle Island Manhasset belt is referred. The advance was vigorous and the ice was even more active in erosion than during the earlier invasion, both scouring and folding occurring on a larger scale than at any previous time.

HEMPSTEAD GLACIAL SUBSTAGE.

FINAL RETREAT OF THE MONTAUK ICE.

The activity of the ice sheet on the second invasion seems to have terminated rather suddenly, the period of vigorous erosion giving place to one of extended aqueous deposition without the usual intervening period of till deposition, except in the Middle Island belt. To this period between the cessation of erosion and the beginning of the ice retreat is referred the formation of the older outwash deposits (Hempstead), which here and there project through the Wisconsin outwash on the south side of the island.

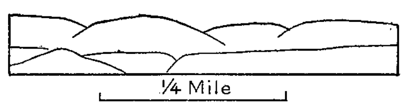

FIGURE 201.—Profile of imperfect 40-foot terrace east of Fort Pond, Montauk, as seen looking from Second House, with higher Manhasset and morainal hills in distance.

After the retreat of the ice from the region of the South Fluke no deposits of consequence were laid down until the ice reached a line close to the north shore of the island. Here the ice seems to have made a somewhat extended halt, and broad sloping outwash plains were laid down along its front. Traces of these old plains in the form of kettle valleys and other old drainage lines (many of them likewise partly filled with later drift) are found at many points, as elsewhere described (p. 174), from Miller Place, near Port Jefferson, to Orient Point.

Although these old gravel plains are everywhere obscured and many are completely buried by the later Wisconsin outwash, they appear to possess, in their upper parts at least, the typical fan shape and structure of subaerial deposits. Whether or not the lower parts were below sea level can not, owing to the general absence of beach lines or other marine phenomena, be determined with certainty, such features, if ever formed, now being hidden by the mantle of Wisconsin outwash. The terraces (fig. 201) at the 40-foot level on Montauk, which appear to have been formed soon after the completion of the Hempstead deposition, would appear, however, to point to a submergence at this time.

VINEYARD INTERGLACIAL STAGE.

EROSION.

The deposition of the Manhasset formation (including the Herod gravel member, Montauk till member, and Hempstead gravel member) was followed by an interval of strong subaerial erosion, known as the Vineyard stage, during which the deposits were trenched from an elevation of 200 feet or more above to at least 150 feet below the present sea level, and extensive drainage systems with many branches and dendritic headwaters, such as the Nissequogue system near Smithtown, were developed. The erosion of this stage was at least 50 and probably 100 times greater than that which has been effected in post-Wisconsin time. In fact the two are comparable in magnitude to a river valley and a small gully—the post-Wisconsin work consisting of hardly more than the formation of a few amphitheaters, a slight notching of the cliffs extending back only a fraction of a mile, or an insignificant trenching of the old valleys. It is probable that the Vineyard stage of erosion was of much longer duration than the post-Wisconsin, although from the fact that the land is known to have stood considerably higher in the earlier period it is difficult to make accurate comparisons. The climatic conditions were probably not materially different, and even if they were more favorable to erosion in the earlier than in the later stage, the difference could not, with any reasonable assumption as to rainfall and absence of vegetation, have been very great. In fact, with porous materials such as the sands and gravels of Long Island, the amount of precipitation has relatively little effect on erosion, except close to the sea, unless it comes in the heavy downfalls of so-called cloud-bursts.

In the later part of this period of erosion the land stood at least 150 feet higher than at present, as indicated by the depth of the submarine channels off Montauk, and the depth of the Hudson submarine channel suggests that it probably stood considerably higher than that. On Montauk there are evidences of a 40-foot terrace, which if due to erosion would indicate a submergence as well as an uplift during the Vineyard interval. In a view looking eastward from the hills on the west shore of Fort Pond Bay the terrace stands out distinctly, having the appearance shown in figure 201. It has a coating of Wisconsin drift, which would indicate that it was formed in the preceding or earlier stage of the Pleistocene.

On the New Jersey coast and farther south there is a persistent marine or terrestrial terrace known as the Cape May, formed practically at sea level, and now standing at an altitude of 40 feet or less, which has generally been regarded as of post-Wisconsin origin. This terrace is not developed on the Wisconsin outwash deposits in western Long Island, although on Raritan Bay, only 10 miles distant, where the supply of material was no greater and the exposure was much less, it has a typical development. These facts strongly suggest that the terrace, if formed on Long Island, antedates the Wisconsin outwash and lies buried beneath it. It is thought, therefore, that there was a rather widespread subsidence in the Long Island region, during which the land stood about 40 feet lower than at present. The date of this subsidence was probably the early part of the Vineyard interval, before the uplift which brought on the stream erosion.

DEPOSITION.

Owing to the elevation of the Long Island region in the Vineyard interglacial stage, no general mantle of deposits could be formed over its surface. The conditions were, however, not unfavorable to the development of soils over the surface, of peat and marsh deposits along the streams, and of fossiliferous beach deposits upon its borders. Such accumulations were, indeed, formed at many points and may still be recognized when penetrated by wells. The maximum elevation, as shown by the submarine Hudson valley, appears to have been at least 700 feet (see p. 63), but erosion had not attained any such depth on Long Island, most of the deposits of the Vineyard stage lying less than 100 feet below sea level. They would therefore appear to mark the closing stages of the interval, when the subsidence had progressed nearly to the present point.

WISCONSIN GLACIAL STAGE.

FIRST ADVANCE OF THE ICE.

The only evidence as to the nature of the climate during the long period of Vineyard erosion is that afforded by the shells obtained from wells. These seem to indicate that it was no colder than during the Gardiners deposition, when, as has been seen (p. 198), the climate was not far different from the present climate of northern New England. Toward the close of the stage, however, the climate became colder, or at least more favorable for the collection and retention of snow, and the region eventually became covered with ice.

Whether the ice invaded the region as an advancing glacier, like those pushing their way down the valleys in the Alps, or whether the region was first covered with snow which later thickened and changed to ice is not positively known. There are several indications pointing to the latter alternative. For instance, it seems impossible to account for the complete preservation of the drainage system west of Smithtown on the hypothesis of an advancing glacier plowing its way over the loose gravels, but the absence of erosion is easily accounted for if it is assumed that the valleys were previously filled with snow or snow ice, over which the ice moved without coming into direct contact with the surface itself. Again, the absence of till outside of the moraine in the Bridgehampton region is better accounted for on the theory that the masses giving rise to the kettles of the outwash plain at this point represented extramorainal accumulations of snow rather than residual ice blocks from a true glacial advance.

The climate along the borders of the glacier during the maximum known advance of the ice, when its front rested along the line of the Ronkonkoma moraine, was probably very severe, at least in regard to the amount of precipitation as snow, being in all probability even more rigorous than in the region of the semicontinental ice sheet of Greenland at the present time. In the Greenland region the scattered valley glaciers are able to take care of the excess of accumulation of the central ice cap, whereas in the Wisconsin stage on the continent a continuous front of thousands of miles was necessary to accomplish the same result.

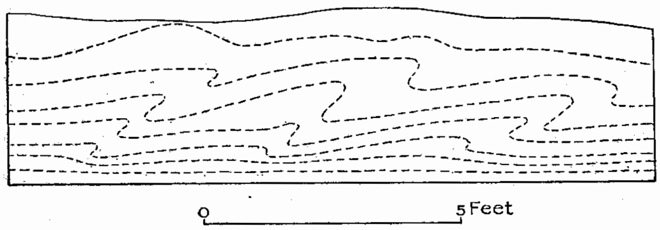

FIGURE 202.—Section at top of bluffs between Woodhull and Rocky Point landings, showing folding produced by the Wisconsin ice sheet. The figure illustrates the breaking up of the folds where in contact with the ice at the top and their disappearance at lower levels.

Stratified glacial deposits are found up to an elevation of 410 feet; hence the ice must have risen to at least that height above the sea level. In a living glacier the ice in the immediate vicinity of its front is commonly at least twice as high as the moraine. If this relation held in Long Island, the ice may have reached a height of 1,000 feet along the margin. Notwithstanding its considerable thickness, which could hardly be assumed as less than 500 feet, the Wisconsin ice sheet was not vigorous in its erosion, indicating either an overloaded condition or a very slow movement. Inasmuch as there is no evidence of any considerable amount of englacial material, it is probable that the sluggishness of movement accounts for the insignificance of its erosion and explains the relative scarcity of Wisconsin till.

The deficiency of vigor compared to that of the Montauk ice is well brought out by the smaller scale of the folding. In many places the Wisconsin ice overrode the Manhasset forma-

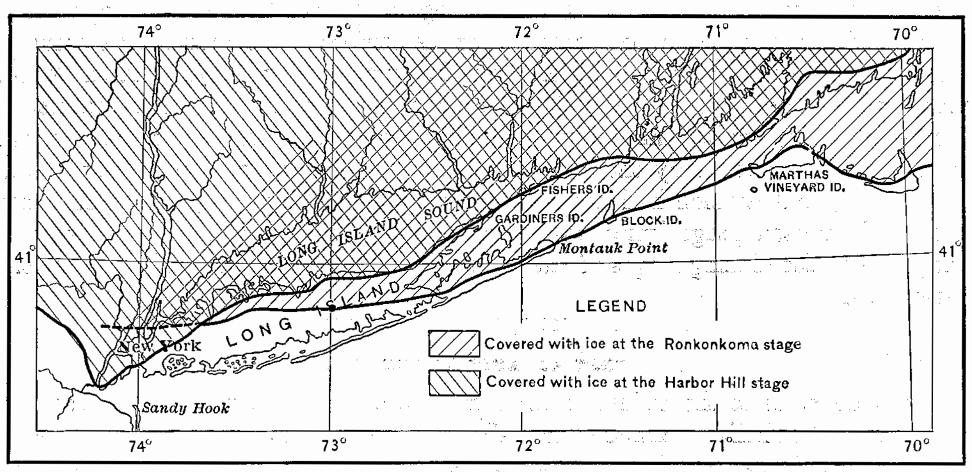

FIGURE 203.—Sketch map showing relative positions of ice during the Ronkonkoma and Harbor Hill substages of the Wisconsin stage.

tion without producing the slightest recognizable disturbance; elsewhere the folding was limited to a disturbance of the beds within a foot or two of the surface (fig. 202). Here and there, however, the disturbance was somewhat more extensive, reaching some distance below the surface, as shown in Plate XIX, *A* (p. 114). Nowhere were such profound folds observed as the larger of those produced by the older invasion, although there are indications that in many places where bluffs and other steep slopes opposed the ice movement the folding was considerable.

There was, however, more or less material, both beneath and within the glacier, that was either set free directly from the ice upon its melting or indirectly deposited by minor rivulets issuing from the margin and building up the great Ronkonkoma moraine (fig. 203) and the more or less detached gravel fans, which became joined into the nearly continuous plain of outwash from ice along the Ronkonkoma moraine. The sandy or pebbly loam present locally on the outwash presumably represents a "finishing deposit" laid down in the closing stages of deposition. Definite channels, representing the lines of outflow of the water just before the supply was cut off by the final retreat of the ice, lead from the moraine to the shore.

Estimates as to the duration of the ice invasion can not be made with accuracy in the absence of any definite criteria upon which to base calculations. According to F. J. H. Merrill, however, bowlders from as remote a source as the Adirondacks have been recognized in the moraines, and a journey of 200 miles is not improbable for many of the erratics. The rate of movement of a continental glacier is not known, but it must be many times slower than that of glaciers of the Alpine type, for these are fed by collecting areas several times as large as the distributing glaciers; whereas in continental ice sheets the opposite is true, the area of the sheet subjected to melting being larger than the area of collection. Probably the movement was not more than a few feet a year. Even at the rate of 100 feet a year, which is more than many valley glaciers average, it would take over 10,000 years to bring a single bowlder from the Adirondacks to Long Island. It is not unlikely that the duration even of the Ronkonkoma substage was several times as great.

FIRST RECESSION OF THE ICE.

The upbuilding of the Ronkonkoma moraine and the related outwash plain continued as long as the ice front remained stationary; or, in other words, as long as the melting of the ice margin was just counterbalanced by the advance of the glacier. This period was succeeded by one of the greater general warmth or lessened precipitation, which caused a retreat of the ice front from its position along the moraine throughout the region east of Lake Success, south of Manhasset Bay. The retreat began at the east end of the island and was taken up progressively westward. West of Lake Success the morainal deposits of the succeeding substage lie south of those of the Ronkonkoma substage, and it is doubtful if any retreat of the ice occurred in this region. If there was any it was more than counterbalanced by the later advance. It is likewise unknown whether in the region east of Lake Success the ice retreated any considerable distance to the north and then readvanced to the line of the moraine, or whether it halted on reaching the line now marked by the Harbor Hill moraine. The presence of kettles in the subsequent outwash from ice along the Harbor Hill moraine indicates, however, that the upbuilding of the late moraine followed very quickly after the recession of the ice and before the residual blocks had had time to melt. The retreat does not appear to have been uniform and continuous, but was rather marked by temporary halts, during which accumulations of considerable importance were laid down in the intermorainic area.

READVANCE OF THE GLACIER.

After the influence causing recession became exhausted the ice took on new activity, advancing with a regular front to the line now marked by the Harbor Hill moraine (fig. 203), and bringing on a new period of moraine and outwash accumulation. The conditions prevailing, however, differed somewhat from those of the earlier stage. A larger proportion of till was brought to the moraine, but the supply of sand and gravel, as indicated both by the smaller extent of the outwash deposits and by the smaller quantity of material in the moraine, was considerably less. In fact, the pronounced channels leading southward from the moraine of this stage show that the glacial waters, instead of being overloaded with gravel and sand, often possessed relatively little such material, and their work at such times became erosion rather than deposition. What deposition there was followed very quickly upon the retreat, for the numerous kettles of the outwash plains indicate the existence of residual ice blocks at many points.

As to the duration of the second stage of activity little definite evidence is at hand. The large quantity of till and bowlders suggests a prolonged ice movement, but the small quantity of outwash suggests the reverse. There is no basis for concluding that it differed greatly in length from the first advance.

FINAL RETREAT OF THE ICE.

The final retreat of the ice seems to have been rather abrupt and to have taken place without notable halt in the Long Island region, as is testified by the general absence of retreatal deposits. It is probable that as the climatic conditions ameliorated, the activity of the ice movement gradually lessened and finally ceased, and the margin of the ice sheet became broken up into detached masses as the ice melted. The masses occupying the valleys doubtless persisted longest, especially where covered with retreatal outwash and other débris. Under such conditions buried masses may have lingered for hundreds of years, possibly even after the region had become clothed with forests, as at the Malaspina Glacier in Alaska to-day. The porosity of the deposits and the free circulation of the ground waters would tend, however, to hasten the melting of such blocks.

In the earlier stages of the recession numerous lakelets probably existed between the ice front and the highlands of the north side of the island, but in general they seem to have been of short duration. No beach lines and only very small deposits have been recognized, the Port Washington delta and the outwash on Lloyd Neck being the only marked exceptions.

RECENT EPOCH.

WORK OF WIND AND WATER.

The final retreat of the Wisconsin ice sheet left the island standing a few feet higher than at the present time and probably nearly or quite destitute of vegetation, so that wind, streams, and waves were free to begin their work of reshaping the island. The work of the wind did not continue long, for except in the region south of Port Jefferson and along the coasts there is little evidence of dune formation, notwithstanding the favorable character of the materials, and none whatever of pebble faceting such as is found in parts of the Manhasset formation. It is probable that the small amount of wind work over the island as a whole is due to the fact that vegetation almost immediately covered the surface. Dunes have, however, continued to form on the coast to the present day, constituting high belts all along the south shore and capping the bluffs of the north shore at many points east of Port Jefferson.

Upon the retreat of the ice, waves and ocean currents began to sculpture the shore and to form numerous spits, bars, and connecting beaches. The result has been a straightening of the coast line by the formation of the great barrier beach on the south side and the truncation of the projections of the north shore. In fact, where the highlands come to the shore there is scarcely a point that is not marked by sea cliffs, most of them free from vegetation and not a few still undergoing active erosion.

Details of the work of the various agencies acting in post-Wisconsin times are given in the discussion of Recent deposits (p. 176).

SUBSIDENCE OF THE LAND.

EVIDENCE.

Submerged tree stumps and beds of peat on Long Island have been described by many writers. W. W. Mather,[1] in 1843, reported stumps and logs beneath the water near Peacock Point, between Oyster Bay and Hempstead Harbor. In 1857 George H. Cook[2] mentioned buried timber in the towns of Hempstead, Babylon, and Islip. At Hempstead an island covered with trees within the memory of Cook's informant was a salt marsh at the time he wrote, the highest part of the former island being lower than the meadow then existing. Elias Lewis, jr.,[3] in 1869 recorded a series of observations indicating that large areas which formerly had been swamp and woodland were then below the water level. Remains of fresh-water

[1] Geology of New York, pt. 1, 1843, p. 21.

[2] On a subsidence of the land on the seacoast of New Jersey and Long Island: Am. Jour. Sci., 2d ser., vol 24, 1857, pp. 341-355.

[3] Evidences of coast depression along the shores of Long Island: Am. Naturalist, vol. 2, 1869, pp. 334-336.

vegetation were abundant 4 to 91 feet below the surfaces of the marshes on the south side of the island (then about at sea level). Lewis described roots in place 10 feet below sea level. Near Fort Hamilton the tide overflowed marshes with trees still standing, and stumps were seen far out. It is said that 100 years earlier stumps abounded in Great South Bay, especially east of Islip. A line of fence posts put in a hundred years before were found in place beneath the sand at extremely low tide. Submerged meadows were seen at several places on the north shore, one a few miles east of Port Jefferson extending half a mile from the shore and to a depth of 16 feet in a compact mass. In a later paper [1] Lewis presents a number of additional observations. At Islip many stumps, the remainder of a forest still growing on the shore, were standing on meadows of William Nicol. The absence of kitchen middens is accounted for by the relatively recent submergence of the former marshes of Great South Bay. A large number of submerged pine stumps were seen in a bay a few miles east of Islip. Many stumps stood about the head of Great Peconic Bay and off the marsh north of the lighthouse at Montauk Point. Lewis also mentions many instances of lignite being brought up in wells, but these beds are now known to be pre-Wisconsin and hence do not bear on the question of recent subsidence. More recently Veatch has reported marsh muck to a depth of 23 feet at Fort Lafayette, peat at 25 feet at the Brooklyn Navy Yard, and tree trunks from the surface to a depth of 9 feet near Patchogue.

In addition to the evidence mentioned in the foregoing paragraphs most of the earlier writers cited the occurrence of oyster and other shells at considerable depths in wells. It is now known, however, that most if not all of these were from the Gardiners clay, the Jacob sand, or the Vineyard formation, and not being of postglacial origin they afford no evidence of recent subsidence. The same is true of the wood reported at considerable depths, this being found in the Vineyard formation, the Gardiners clay, and the Cretaceous beds, as well as in the Recent deposits.

Phenomena of the nature cited have been generally accepted as evidence of recent subsidence, but recently there has been a tendency on the part of some geologists to question such an interpretation. A number of occurrences noted in connection with the present field work threw doubt on certain of the supposed evidences and emphasized the necessity of caution in using submerged vegetable accumulations as criteria of subsidence.

Thus, in the vicinity of Luce Landing, north of Riverhead, the peat, with its included tree stumps, appears to have been largely let down to its present position on the beach below high-tide level by undermining. Near Prospect Point, north of Port Washington, the process of undermining could be seen in actual operation, the layers of peat projecting through the sand being bent and cracked as they are let down (Pl. XXVI, *A*, p. 182), although sufficiently connected to form a more or less continuous sheet at a level below their original position. In both places the beds have been exposed by the encroachment of the sea on marsh and swamp deposits behind barrier beaches.

In addition to the evidences cited there are important botanical indications of subsidence in comparatively recent time. These are afforded by the ranges of the common salt-marsh plants, which, according to C. A. Davis, are as follows:

Range of common salt-marsh plants.

Species.	Range.	Time covered by sea.
Juncus gerardi Loisal (black grass)	Between level of ordinary tide and upper limit of spring tides.	Covered by spring tides about twice a month.
"*Spartina patens* association" (salt-marsh grass): *Spartina patens* (Ail.) Muhl. and *Distichlis spicata* (L.) Greene.	Extends 9 to 12 inches above and below mean high tide.	Covered about 1 hour each tide.
Spartina glabra Muhl. (salt thatch)	Between mean high tide and half tide, or mean sea level.	Covered about half of time.
Zostera marina L. (eel grass)	Below low-tide limit	Permanently covered.

[1] Ups and downs of the Long Island coast: Pop. Sci. Monthly, vol. 10, 1877, pp. 434–446.

Mr. Davis, who made a special study of the peats of the island for the Geological Survey in 1911, making a large number of borings and taking samples at short intervals from the surface to a depth of 10 feet, is also the authority for most of the following descriptions.

At the salt marsh west of the head of Mount Sinai Harbor, about 1½ miles northeast of Port Jefferson, borings showed the "*Spartina patens* association," which is characteristic of the zone at high-tide level, to extend from the present surface to the underlying gravel at a depth of 5 feet, apparently indicating long-continued subsidence, with an upbuilding of peat at a corresponding rate.

A 9-foot test hole in a salt marsh 1¼ miles east of Riverhead showed a semifluid fresh-water peat for the entire depth below the thin surface mat of salt-water plants, indicating that the marsh has been covered by the tides only at a very recent date.

At the Mill Creek marsh, 5 miles east of Riverhead, the boggy wooded swamps above tide level give place downstream to a brush-covered area containing tree remains, followed by an open fresh marsh with scattered stumps and shrubs, and this in turn by a marsh with the "*Spartina patens* association," overlying nearly 9 feet of fresh-water peat with abundant stumps and roots, principally about 5 feet below the surface The incursion of the sea, as at the locality described above, is evidently very recent. The salt marsh along the east tributary of the main creek contains many stumps and logs at and below the surface and was clearly a forested swamp, also only recently invaded by the sea.

At the end of Pine Point, east of the marsh last described, pine roots show in the beach to or below low-tide level. A cliff about 2½ feet high, cut in the peat by the waves on the west side of the point, showed a gradation from a blackened sand soil at the base to *Spartina patens* turf at the top.

Another marsh a few miles east of Riverhead showed 8 feet of *Spartina patens* peat overlying a foot or more of brackish-water peat. Near the boat landing east of Meeting House Creek, 2½ miles east of Riverhead, 3½ feet of *Spartina patens* peat was found above a blackened sandy gravel soil bed.

Swan River Marsh, near East Patchogue, has the appearance of occupying a drowned valley. Toward the sea a wooded swamp gives way first to shrubs, next to fresh marsh, then to brackish marsh, and finally to salt marsh of the "*Spartina patens* association." Partly or completely buried stumps abound below the salt turf, here about a foot thick. An essentially similar sequence was noted along Mud Creek in the same locality.

The conditions along the north shore are less favorable for study, but examples of submerged peats and of progressive subsidence doubtless occur at a number of points. Near Lloyd Point, on Lloyd Neck, Huntington, the following succession was noted by the present writer at a point where the marsh laps up on the gently sloping surface of the upland: (1) Brush-covered upland; (2) marginal upland zone where bushes that had been recently killed by salt water reaching the roots through the porous sands still remained practically intact, even to the smaller twigs; (3) border of marsh with nearly intact bushes projecting through several inches of peat; (4) belt located a few feet outward from edge of marsh with only trunks of shrubs remaining; (5) a zone several rods from the edge with only low stumps visible; and (6) an outer area showing only the salt-marsh turf.

The occurrences noted appear to be too widely distributed and too variable in surroundings to admit of explanation by any other than a single general cause, seemingly a slow, long-continued, and apparently fairly uniform subsidence of the land with reference to sea level.

All authorities are probably agreed that such a subsidence has occurred in comparatively recent time, but there is a radical difference of opinion as to whether the sinking has continued down to the present day and is now going on.

The peat sections, as developed by borings made by Mr. Davis, show no variation in character that would indicate a halt in accumulation at the present time, and his observations on the rate of accumulation of *Spartina patens* peat near Lynn, Mass., based on cinders incorporated in the material since the building of the railroad more than 50 years ago (6 to 8 inches in a century), would seem to indicate that if there had been any halt in a movement of corresponding rapidity the upper limit of salt-marsh growth would soon be reached and it would be replaced by fresh-water turf. This is manifestly not the case.

On the other hand, it has been urged by D. W. Johnson that the belts of beach ridges of essentially the same height, formed progressively one after another at a number of points along the Atlantic shores, are evidences of present stability of the coast line. Johnson also considers that dead trees in conspicuous numbers, which he believes would inevitably be of general distribution under the hypothesis of present subsidence, are really of local occurrence and are rarely found except where a breach has been made through some protecting barrier, or where physiographic factors have produced changes in tidal levels.

CONCLUSIONS.

The fact seems to be established that a subsidence of many feet has taken place since the retreat of the latest or Wisconsin ice sheet, and that salt water now invades scores of marshes in which trees grew so recently that the stumps still project above the surface.

It is perfectly plausible to attribute, as Johnson has done, the invasion in individual places to variations in size, shape, or location of the openings through which the tidal waters obtain access to the marshes, or to changes in the character or position of the beach ridges or other protecting barriers themselves. Such changes would be expected, however, to favor the exclusion of salt water quite as frequently as they would its admission, and fresh-water peat should be found overlying salt-water peat as commonly as salt-water peat overlying fresh-water peat. Although the former succession may exist, the thousands of borings made by Mr. Davis show, except where the sea has been shut off by dikes or otherwise excluded, a practically entire absence of such succession, the nearly universal order being salt-water forms above fresh-water forms. According to Mr. Davis, in some of the places where there has been a recent incursion of salt water, as in certain of the inlets near Portsmouth, N. H., there are no evidences of either present or past barriers that could have influenced tidal levels. The writer also has noted a number of localities where there seems to be no probability of former barriers.

The apparent changes in the level of bench marks at several points along the coast appear to be inconclusive, as radical changes in tidal levels are likely to result from artificial causes, such as the building of docks or the dredging of channels, but the fact that these changes always point in the same direction, namely toward subsidence, seems to indicate that they should be given considerable weight.

Although there are no broad or extended belts of dead trees, except where changes of tidal levels of considerable magnitude have occurred suddenly through the breaking of barriers or changes in inlets, Mr. Davis states that dead trees are not only generally distributed along the whole coast but are fully as numerous as the conditions of subsidence would suggest.

The action of salt water upon vegetation is in a high degree selective, and while prolonged or repeated submergence would produce a general belt of dead vegetation, the incursion of single high tides, which, especially during periods of subsidence, always advance well beyond the normal tidal limits, would kill only the weaker species. More resistant species would survive but might appear sickly or partly dead. Still others might survive for many years. As oaks and other hard-wood stumps last an average of only 15 or 20 years, they may entirely disappear, while trees or shrubs not vitally injured by the tides that killed the oaks are still living.

This transitional or sickly belt is not conspicuous, but may usually be recognized without difficulty by careful observers. From what the writer has seen he believes the condition to be general in New England and on Long Island. It points strongly toward a present downward movement of the crust. It can hardly be otherwise if the limitations of the vertical range of salt-marsh flora are as stated by Mr. Davis.

The chief evidence against present subsidence is that afforded by the parallel beach ridges described by D. W. Johnson. At Cape Canaveral, Florida, for example, there is a broad belt, half a mile or more in width, of low parallel sand ridges having the appearance of beaches formed one after another and all of essentially the same height. These ridges are certainly very suggestive of stability of elevation with reference to sea level. Farther north, although similar ridges exist, the width of the belts and the number of ridges is less and their evidence is more open to question. It seems to the writer that so many factors of uncertain value enter into the computation of the time required to form such beaches as that at Nantasket, Mass., even on the assumption that there has been no material change of level during the period of their formation, as to outweigh the mass of evidence favoring continued subsidence.

On the whole, the view that the subsidence has continued down to the present time and is now going on is regarded by the present writer as the most probable. The rate suggested by Mr. Davis is perhaps higher than would be expected, but recent additional unpublished data collected by him seem to bear out the assumption of a rapid crustal movement.

The subsidence in the Long Island region since the retreat of the Wisconsin ice sheet is apparently not more than 25 feet, which at an average rate of 6 inches a century would require a period of 5,000 years. That the movement has been much more gradual in the past is possible, but the uniformity of material to the depth reached by borings (10 feet) seems to indicate that it has been uninterrupted for a considerable period of time. Earlier interruptions or reversed movements are entirely possible, but the evidences of them, if any exist, are presumably now some distance below sea level.

LENGTHS OF PLEISTOCENE AND RECENT STAGES AND SUBSTAGES.

The lengths of the several Pleistocene stages and substages are very difficult to determine because of the lack of knowledge of the many local conditions that always enter into problems of erosion and deposition. This difficulty is greatest in comparing stages of accumulations with those of degradation. It is possible, however, to recognize a progressive change in length from the earlier to the later stages, estimates of which are given in the following table, in which the unit A is taken as the length of the Recent epoch and B as the length of the Wisconsin stage of glaciation. The estimates are, of course, only approximate, especially as to the length of the stages or substages compared with the time units, but in general the relations are probably not far wrong. For example, it is almost certain that the Vineyard erosion interval was at least five times as long as the Recent epoch, that the period represented by the Gardiners and Jacob stages, as indicated by erosion in New Jersey, was even longer than that of the Vineyard degradation, and that the post-Mannetto stage was to all appearances longer than all subsequent Pleistocene time. The comparisons of the glacial stages are less reliable, but it is certain that there has been a variation similar to that indicated in the table.

Relative lengths of Pleistocene stages and substages on Long Island.

Epoch.	Stage.	Substage.	Nature.	Chief work.	Remarks.	Estimated length as compared to Recent or to Wisconsin.
Recent.			Postglacial.	Insignificant erosion and deposition.		A.
Pleistocene.	Wisconsin.		Glacial.	Deposition of 5 to 20 feet of till, thick outwash, and high moraine.	Short period as compared to preceding glacial stage.	B.
	Vineyard.		Interglacial.	Extensive erosion of older drift.	Erosion many times greater than Recent time.	5×A.
	Manhasset.	Hempstead.	Glacial.	Accumulation of 25 to 100 feet of gravel.	Thickness of deposits points to great length as compared to the Wisconsin stage.	5×B.
		Montauk.	Glacial.	Accumulation of 50 feet of till.		
		Herod.	Glacial.	Accumulation of 100 feet or more of gravel.		
	Jacob.		Transitional.	Accumulation of 25 feet of clayey sand.	Thickness of clay and extensive erosion in New Jersey show that these stages represent an exceedingly long interval.	10×A.
	Gardiners.		Interglacial.	Accumulation of 50 to 100 feet of clay.		
	Jameco.		Glacial.	Accumulation of Jameco gravel.	Exposures of contemporaneous deposits in New Jersey (Pensauken formation) show this to have been the most important period of deposition next to the Mannetto stage.	10×B.
	Post-Mannetto.		Interglacial.	Reduction and nearly complete removal of Mannetto gravel.	Longest interglacial stage.	20×A.
	Mannetto.		Glacial.	Accumulation of 600 feet of gravel.	Longest glacial stage.	20×B.

SUMMARY OF PLEISTOCENE AND RECENT OROGENIC MOVEMENTS.

In the earlier stages of the present investigation it was assumed that the principal Pleistocene deposits were of the nature of coastal-plain formation and that their upper surfaces indicated approximately the position of the sea level at the time of their formation. On these assumptions a depression of 300 feet was postulated as taking place during the deposition of the Mannetto gravel and 200 to 250 feet by the completion of the Manhasset accumulation. Further study, however, has shown that the Manhasset and, to a lesser extent, the Mannetto exhibit many features analogous to those of the Wisconsin outwash plains developed on the south side of the island, and it is now thought that they are in large measure of similar origin. It has been necessary, therefore, to turn to the adjacent coast of New Jersey for evidence as to submergence. Similarly it was ascertained in the course of the investigation that the data afforded by the erosion valleys were insufficient to determine the amount of uplift, and recourse to the submarine Hudson Valley was necessary. The movements are shown graphically in figure 204 (p. 218).

Mannetto depression.—As pointed out above, it is not improbable that the Mannetto gravel of Long Island is in part of the nature of an outwash plain and was formed above sea level. For this reason it is impossible to determine its position with reference to sea level from the elevation of its remnants on the island. The Bridgeton formation, however, which seems to be the New Jersey representative of the Mannetto, was not developed in the vicinity of the ice sheet but rather as a coastal-plain formation. Considerable areas of it face the open sea, and whether due to the action of the waves or to drainage at low gradient, their development could have taken place only near sea level. In no other way (in the absence of barriers) could the slack drainage necessary for the development of the flat terraces, under the hypothesis of deposition by streams of low gradient, be maintained. The present elevation of the Bridgeton formation on the New Jersey coast ranges from about 100 feet in the southern part to 200 feet in the central part, and indicates a submergence increasing from about 100 feet in southern New Jersey to 200 feet or more farther north. A continuation with the same grade would give a depression of 200 to 250 feet in the Long Island region at the time of the Mannetto deposition. Figure 204 gives 200 feet, the greatest depression actually known.

Post-Mannetto uplift.—As brought out in the discussion of the submarine Hudson channels, the deposition of the Mannetto gravel was followed by a long period of erosion, during which the rock gorge of the Hudson was probably cut to a depth of 700 feet. After the excavation of this gorge and its seaward prolongation, which probably occupied by far the greater part of the post-Mannetto interglacial stage, there was, if the submarine canyon is to be referred to stream erosion, an uplift of the land far surpassing in magnitude any known Pleistocene movement in the region before or since. The surface, to judge from the depth of the canyon,

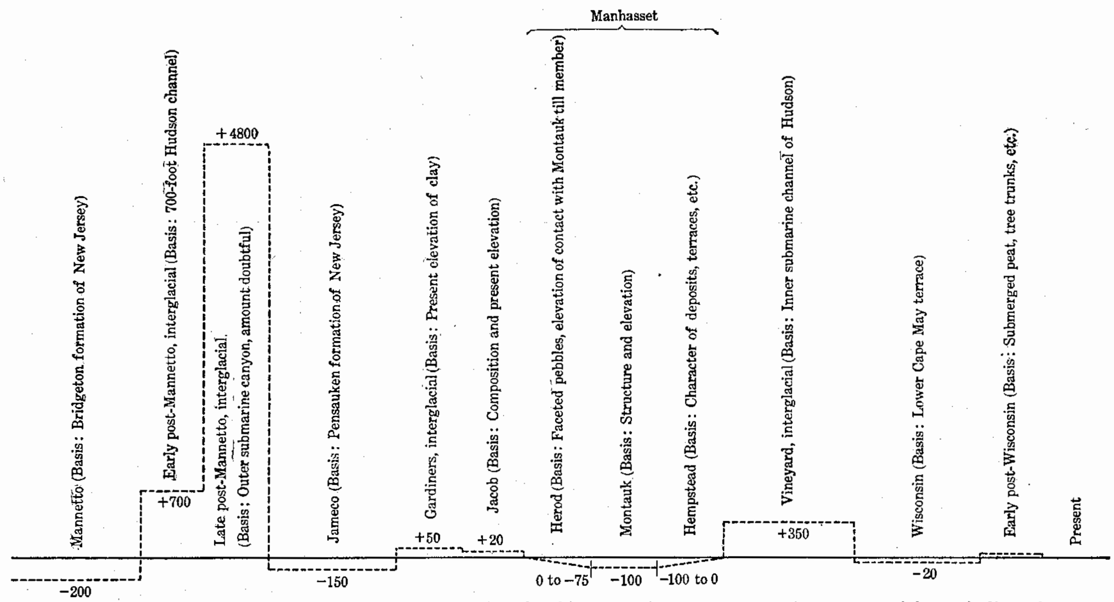

FIGURE 204.—Position of land with reference to present sea level in the Pleistocene stages and substages. Figures indicate feet.

must have stood 4,800 feet or more higher than at present. Although there is considerable doubt that an uplift of this magnitude really took place, its occurrence is tentatively accepted as best explaining the character and form of the canyon as described on page 61.

Jameco depression.—The Jameco gravel probably does not lie at the surface anywhere on Long Island, hence evidences of its origin that might be afforded by its structure are lacking. Moreover, as it is a glacial or glaciofluviatile formation, its position below sea level is of no significance. The only evidence, therefore, as to the elevation of the land in Jameco time is that afforded by its probable New Jersey equivalent, the Pensauken formation. The great body of the Pensauken formation was deposited in a trough, 10 to 15 miles wide, crossing the State from the vicinity of Raritan Bay to Trenton and thence extending down Delaware River. This accumulation seems to have been the result of deposition by streams of low gradient in a more or less closed basin, hence its elevation of 150 feet between Trenton and Raritan Bay is not necessarily an indication of submergence to that depth. Pensauken remnants are, however, found at similar elevations on the open coast, as northeast of Manchester and northwest of Asbury Park, hence there is every reason to believe that there was actually a submergence to a depth of about 150 feet. The fact that the submergence increased from 90 feet in south New Jersey to 150 feet in north New Jersey suggests that it may have been somewhat greater than 150 feet on Long Island.

Gardiners uplift.—The marsh deposits found at several horizons in the Gardiners clay show that this formation at times reached sea level, indicating an uplift of at least 200 feet after the Jameco deposition, as the contemporaneous Pensauken formation of New Jersey is now 150 feet above sea level, whereas the Gardiners clay is commonly 50 feet or more below sea level.

Jacob depression.—The Jacob sand is free from marsh deposits, but carries an extensive shallow-water fauna, indicating a depth of water not much greater than during the Gardiners deposition. It is probable that the depression was not more than 25 feet.

Herod and Montauk depression.—The subsidence, which during the Gardiners and Jacob stages about kept pace with accumulation, seems to have continued through the Herod substage of the Manhasset, so that on the advance of the Montauk ice the water stood 75 to 100 feet above the present sea level, as shown by the character of the Montauk till member (p. 200). The depression did not, however, keep pace with accumulation at all times, as is shown by the wind-faceted pebbles in parts of the Manhasset formation.

Hempstead uplift.—After the deposition of the Montauk till member of the Manhasset formation there seems to have been an uplift of 100 feet or more, as the later Hempstead gravel member of the Manhasset has the form of a normal outwash plain with contemporaneous drainage channels cut to the present sea level or below. A possible halt at about halfway up is suggested by the 40-foot terraces on the Montauk peninsula.

Vineyard uplift.—The valleys in the Manhasset formation were cut to a depth somewhat below the present sea level, hence a considerable uplift must have followed the previous period of deposition, but because of the modifications by the Wisconsin ice sheet and of more or less Wisconsin deposition it is impossible to determine with any degree of accuracy the actual amount of uplift, and it is necessary to turn again to the submarine valley of the Hudson for a definite measurement. As shown elsewhere (p. 64), the upper channel appears to have been cut in post-Manhasset time, and as it reaches a depth of 350 feet at its outer edge, an uplift of this amount seems to be established.

Wisconsin depression.—There appears to have been in Wisconsin time a depression which brought the land to a level about 20 feet lower than at present, as shown in New Jersey by the lower marine or low-gradient stream terrace of the Cape May formation, as developed along the New Jersey coast from Cape May to Raritan Bay. This depression is not recorded on Long Island, hence it is thought to antedate the completion of the outwash deposits.

Recent movements.—After the disappearance of the Wisconsin ice the land seems to have stood somewhat higher than at present, as indicated by the buried and submerged peats along the coast, the difference in level being perhaps 25 feet. This would indicate the elevation of 45 feet in late Wisconsin or post-Wisconsin time. In recent years there has been depression estimated at the rate of 6 inches to 2 feet in 100 years. A sinking of not more than 25 feet apparently has occurred since the beginning of this movement.

CORRELATIONS OF THE LONG ISLAND PLEISTOCENE FORMATIONS.

PROBABLE EXTENSION OF THE FORMATIONS ALONG THE NEW ENGLAND COAST.

MANNETTO GRAVEL.

The Mannetto gravel, which on Long Island is the oldest of the Pleistocene deposits, was originally the thickest glacial deposit on the island, but its deposition was followed by an erosion stage of such length that the formation was reduced in western Long Island to a few remnants, and in the eastern part it was nearly or entirely swept away. This formation, owing to either its slighter development or the greater erosion, was likewise largely removed from the coastal region of New England, if it existed there, so that the Cretaceous, where seen, is almost invariably overlain directly by deposits correlated with the Jameco gravel rather than by those of Mannetto age. This is notably true of the Cretaceous beds of Block Island and Marthas Vineyard, but in an exposure near Scituate, Mass., remnants of gravels which closely resemble the Mannetto have been seen, strongly suggesting that the formation originally extended at least to this point. Beyond this locality, however, the ice seems to have reached the coast, and the Mannetto materials, if any were deposited, were probably laid down in the region now covered by the sea.

JAMECO GRAVEL.

The Jameco gravel seems to be much more persistent in its present occurrence than the Mannetto. A gravel at the same horizon as the Jameco is, in fact, well developed beneath Cape Cod to Highland Light, Truro, and possibly locally along the west shore of Cape Cod Bay to the vicinity of Plymouth, its absence farther north being due to actual occupation of the region by ice. On Block Island the Jameco gravel appears to be represented by sands and fine gravels with granitic pebbles, having an aggregate thickness of 30 feet or more, occurring between the Cretaceous and the clay which is correlated with the Gardiners clay near Clay Head and Balls Point and beneath the dark-gray to black clay correlated with the Gardiners at several points west of Southeast Light. On Marthas Vineyard similar gravels having a thickness of at least 50 feet are seen beneath the great bed of dark-colored clay correlated with the Gardiners clay at the Nashaquitsa Cliffs. On Cape Cod similar gravels occur near Highland Light, with a thickness of 30 to 50 feet, below clays which occupy the position and are of the type of the Gardiners clay. On the main coast similar gravels are seen beneath clay at Indian Head, 8 miles southeast of Plymouth.

GARDINERS CLAY.

The Gardiners clay likewise appears to be a very persistent formation, a clay of the normal Gardiners type and position being found at short intervals all the way from New York Bay to Boston Harbor. Besides the development of the Gardiners clay on Long and Fishers islands, as described in this paper, a similar clay is found on Block Island, notably in the vicinity of Clay Head and Balls Point, near Black Rock Point, and locally west of Southeast Light. On the Rhode Island coast a clay of this type and horizon is seen in places between Watch Hill and Point Judith. A similar clay appears on the Elizabeth Islands of Massachusetts; on Marthas Vineyard it is strongly developed at the Nashaquitsa Cliffs, and on the Massachusetts mainland thick beds are found at Highland Light on Cape Cod; at many points on the coast between Orleans and Chatham; at Indian Head, southeast of Plymouth; at Third Cliff, Scituate; and beneath the drumlins in Boston Harbor. It reaches a maximum thickness of about 100 feet. Boston Harbor appears to mark the northern limit of the clay, although a stratigraphically higher clay with a different fauna extends north along the Maine coast and beyond. It is not known whether the absence of the clay north of Boston is due to nondeposition or to erosion by Montauk ice.

JACOB SAND.

The Jacob sand seems to have been originally rather widely distributed, but it was much more generally removed by the Montauk ice invasion than the underlying formations. A fine clayey sand of the Jacob type is found, however, on Block Island, overlying the supposed equivalent of the Gardiners clay in the vicinity of Clay Head and Balls Point. At Nashaquitsa Cliffs, Marthas Vineyard, the Jacob horizon is represented by alternating clays, sands, and gravels; on Nantucket it is represented by the gray clay and sands furnishing an extensive fauna at Sankaty Head; and at Highland Light, Cape Cod, it is represented by fine, mealy yellow sand.

MANHASSET FORMATION.

Herod gravel member.—The Herod gravel member of the Manhasset formation appears to be one of the most extensive of the Pleistocene deposits, a gravel resembling it apparently outcropping nearly everywhere from Long Island to the vicinity of Boston, including Block

Approximate correlations of the Pleistocene formations of Long Island with deposits of other areas.

Long Island.						
Stage.	Substage.	Origin.	Represented by—		Position of ice front.	Altitude of land.
Wisconsin.	Harbor Hill.	Glacial.	Harbor Hill moraine and associated till and outwash.		At Harbor Hill or inner moraine.	About 20 feet lower than at present.
	Ronkonkoma.		Ronkonkoma moraine and associated till and outwash.		At Ronkonkoma or outer moraine.	
Vineyard.		Interglacial.	Great erosion unconformity; 350-foot submarine Hudson channel; channels (later) of Long Island Sound and of sea bottom off Montauk; and Vineyard formation, consisting of fossiliferous sands and muck, peaty deposits, etc., in buried valleys; soil zones, etc.		No evidence of any approach of ice near enough to be marked by deposits.	About 350 feet higher than at present.
Manhasset.	Hempstead.	Glacial.	Hempstead gravel member.	40-foot terrace (?).	Probably north of Long Island Sound.	About 40 feet lower than at present.
				Upper Manhasset Plateau.	Near north coast of island in east; along scarp between upper and lower Manhasset plateaus in west.	About 100 feet lower than at present.
	Montauk.	Glacial.	Montauk till member.	Readvance and folding.	At south shore or beyond.	75 to 100 feet lower than at present.
				Temporary recession (local deposition of gravel).	North of Shelter Island and "Middle Island belt."	
				First advance (folding of older beds and deposition of thick till).	Near Bethpage in west; beyond south coast in east.	
	Herod.	Glacial.	Herod gravel member.		In Long Island Sound, probably near north coast of island.	About 75 feet below present level in early part of stage; above sea level at times.
Jacob.		Transitional.	Jacob sand.		Probably south of the headwaters of Connecticut River.	Probably about 20 feet above present level.
Gardiners.		Interglacial.	Gardiners clay.		No traces of ice within drainage areas of streams entering Long Island Sound.	About 50 feet above present level.
Jameco.		Glacial.	Jameco gravel.		Probably in Long Island Sound or vicinity.	150 feet or more below present level.
Post-Mannetto.		Interglacial.	Great erosion unconformity; nearly complete removal of thick Mannetto gravel; cutting of outer submarine valley and canyon and of rock gorge of Hudson River; excavation of Long Island Sound (principal stage).		No evidence of ice.	4,800± feet above present level(?). 700± feet above present level. Slightly lower than at present.
Mannetto.		Glacial.	Mannetto gravel.		Probably in Long Island Sound or vicinity.	Probably about 200 feet below present level.

Stage.	Substage.		Fishers Island, N. Y.	Block, R. I.	Marthas Vineyard, Mass.	Nantucket, Mass.	Elizabeth Island, Mass.	West Barnstable, Mass.	Buzzards Bay, Mass.
Wisconsin.	Harbor Hill.		Thin sheet of morainal drift.	Absent.	Absent.	Absent.	Relatively thin morainal drift; numerous bowlders.	Thin to fairly thick bowlder till, in places with morainal topography.	Thin sandy till with bowlders; in places represented solely by scattered bowlders.
	Ronkonkoma.		Undifferentiable from younger drift.	Relatively thin mantle of morainal drift.	Moraine and outwash plains.	Moraine and outwash plains.	Undifferentiable from younger drift.	Undifferentiable from younger drift.	Undifferentiable from younger drift.
Vineyard.			Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Erosion unconformity.
Manhasset.	Hempstead.	40-foot terrace (?).	Questionable terraces at about 40 feet.	Not recognized.	Possibly the 40-foot terrace near Vineyard Haven.	Not recognized.	Not recognized.	Not recognized.	Imperfect terrace remnants at about 40 feet.
		Upper Manhasset Plateau.	Possibly some local gravel patches.	Gravel on east and south coasts.	Plateau of north coast (Tisbury terrace of Woodworth).	Gravels in upper part of some of bluffs of northern part of island.	Uppermost of the pre-Wisconsin gravels.	Upper gravels beneath moraine.	Gravels of upper terrace or plateau (100 to 125 feet).
	Montauk.		Local deposits of banded till.	Heavy banded till near Clay Head, Balls Point, and west of Southeast Light.	Banded till in bluffs of north coast.	Banded till or poorly assorted gravels in bluffs near Sankaty Head and northward.	Banded pebbly-clay till (reworked material from older formations).	Banded pebbly-clay till (reworked material from older formations).	Probably the heavy tills, which in places form hills rising above the sands and gravels.
	Herod.		Folded gravels.	Folded gravels.	Folded gravels.	Disturbed gravels.	Folded gravels present locally; in some places cut out by ice erosion unconformity.	Cut out by ice erosion unconformity along coast; probably present in highlands of interior.	Probably below sea level.
Jacob.			Gray clayey sands.	Thin buff sands.	Thin yellowish sand alternating with clay laminæ.	Clayey sands and fossiliferous beds at Sankaty Head.	Not seen.	Not seen.	Possibly some of clays on Burgess Neck and in valley of Monument River.
Gardiners.			Chocolate, gray, and red clays.	Dark gray to black clays near Clay Head, Balls Point, Black Rock Point, and west of Southeast Light.	Dark gray to black clay at Nashaquitsa and locally on north coast.	Probably represented by the blue clay formerly exposed beneath the fossiliferous beds at Sankaty head and by the blue clays reported below sea level.	Probably occurs just below the reworked clays at or a little below sea level.	The clays below the reworked material at the clay pit are probably Gardiners clay.	Possibly some of clays in valley of Monument River, and below sea level elsewhere.
Jameco.			Below sea level if present.	30 feet of sand and fine gravel near Clay Head, Balls Point, and west of Southeast Light.	30 to 50 feet of granitic gravels at Nashaquitsa cliffs.	Below sea level.	Below sea level.	Below sea level.	Below sea level.
Post-Mannetto.			Unconformity below sea level.	Unconformity at top of Cretaceous.	Unconformity at top of Cretaceous.	Unconformity below sea level.	Unconformity below sea level.	Unconformity below sea level.	Unconformity below sea level.
Mannetto.			Probably cut out by post-Mannetto erosion.	Absent; probably cut out by post-Mannetto erosion.	Absent; probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.

Stage.	Substage.		Truro, Cape Cod, Mass.	Chatham, Mass.	Indian Hill, Plymouth, Mass.	Manomet Hill, Plymouth, Mass.	Boston Harbor and vicinity, Massachusetts.	Northeastern New England (Clapp).
Wisconsin.	Harbor Hill.		Thin sandy to clayey till; in places only scattered bowlders.	Thin sandy to clayey till; thickness locally; in places has morainal topography.	Thin sandy till with scattered bowlders.	Sandy till, with some bowlders; thickness unknown, but probably small.	Superficial mantle of postdrumlin till.	Older Wisconsin drift.
	Ronkonkoma.		Undifferentiable from younger drift.	Undifferentiable from younger drift.	Undifferentiable from younger drift.	Undifferentiable from younger drift.		
Vineyard.			Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Erosion unconformity.	Clays overlapping upon lower slopes of drumlins. Erosion unconformity.	"Leda clay." Erosion unconformity.
Manhasset.	Hempstead.	40-foot terrace (?).	Not definitely recognized; probably sparingly developed locally.	Local gravels.	Not recognized.	Low, imperfect terraces.	Possibly some of wash lines on drumlins.	100 feet of stratified and unstratified gravels.
		Upper Manhasset Plateau.			30 feet of gravel.	Gravels of plateau bordering shore.		
	Montauk.		Banded pebbly-clay till (reworked material from older formations).	Banded pebbly-clay till (reworked material from older formations).	Banded pebbly-clay layer.	Heavy bowlder till at beach level near Manomet; bowlder till forming bluffs west of Rocky Point.	Greater part of the drumlins.	Till sheet beneath "Leda clay"; most of drumlins.
	Herod.		Thick sands present locally.	Sands and gravels in bluffs.	Cut out locally by ice erosion unconformity but probably present in places along coast.	Below sea level along coast but may rise to a considerable height in hill.	Gravels beneath drumlins.	Thin gravels (10 feet).
Jacob.			Not separable from the underlying clay.	Not separable from the underlying clay.	Not separable from the underlying clay.	Below sea level along coast; probably occurs in hill.	Not seen; generally below sea level; possibly represented by fossiliferous beds encountered in wells.	Absent.
Gardiners.			Thick dark gray to black clays in bluffs at lighthouse.	Thick gray or greenish to black clays exposed in anticlinal folds along coast (east).	Gray clay, with small quartz pebbles constituting lower part of clay beds in bluff.	Below sea level along coast; probably occurs in hill.	Fossiliferous clays of outer harbor reworked into drumlins; fossiliferous blue clay beneath drumlins at Great Head, etc.	Absent.
Jameco.			30 to 50 feet of gravel beneath above-described clay at lighthouse.	Below sea level.	Gravels.	Below sea level along coast; probably occurs in hill.	Possibly some of gravels reported in harbor wells.	Probably represented by some of the predrumlin tills.
Post-Mannetto.			Unconformity below sea level.	Unconformity below sea level.	Unconformity below sea level.	Unconformity probably above sea level but not exposed.	Unconformity at top of Cretaceous (recognized in borings).	Unconformity (land 200 feet or more higher than at present).
Mannetto.			Probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.	Probably cut out by post-Mannetto erosion.	The thickness of Pleistocene stratified deposits in this hill exceeds combined post-Mannetto formations; Cretaceous either rises high above sea or Mannetto gravel is present.	Mannetto gravel probably present above Cretaceous at Scituate. Possibly represented by weathered and oxidized tills of interior.	Probably represented by greater part of predrumlin till.

Stage.	Substage.	New Jersey.				Supposed time equivalents in the Mississippi and Ohio valleys, etc.
		Nonglacial formations.		Glacial deposits.		
Wisconsin.	Harbor Hill.	Cape May formation.	"Trenton gravels."	Wisconsin drift.	Upper part of till sheet.	Early Wisconsin.
	Ronkonkoma.		Lower Cape May terrace of Delaware Valley.		Lower part of till sheet.	
Vineyard.			Erosion interval between higher and lower Cape May terraces of Delaware Valley.	Erosion interval.		Peorian (?) Iowan (?) Sangamon(?)
Manhasset.			Higher Cape May terrace of the Delaware Valley; higher (40 to 60 feet) terraces of Raritan Bay, etc.			Illinoian.
Jacob.		Erosion interval and stream deposits.		Erosion interval.		Yarmouth.
Gardiners.						
Jameco.		Pensauken formation.				Kansan.
Post-Mannetto.		Erosion interval and stream deposits.		Erosion interval.		Aftonian.
Mannetto.		Bridgeton formation.		Jerseyan drift.		Pre-Kansan.

Island, the Rhode Island coast, Elizabeth Islands, Marthas Vineyard, Nantucket, Cape Cod, and the Massachusetts coast as far as Marshfield and Scituate. The member appears to be represented by the stratified sands and gravels found beneath some of the drumlins on the shores and islands of Boston Harbor and by similar materials found here and there beneath the thick till along the coast of New Hampshire and Maine. These deposits reach a thickness of at least 100 feet in places, generally constituting a large part of the bluffs at the Rhode Island and Massachusetts localities mentioned. North of Boston their thickness is greatly reduced, 10 feet being a common maximum, and at many points the gravels are absent. As on Long Island, most of the deposits of the Herod horizon have been extensively folded, and many of them have been eroded, presumably by the Montauk ice.

Montauk till member.—The Montauk member of the Manhasset formation is the most persistent of the Long Island deposits. On Block Island what appears to be the till phase of the Montauk is even better developed than on Long Island, constituting a heavy folded bed in the cliffs near Clay Head and Balls Point and forming a large part of the bluffs west of Southeast Light. On Marthas Vineyard a similar till is seen at several points in the bluffs on the north shore. Similar conditions exist in Nantucket, although the till phase does not seem to be strongly represented. On Cape Cod it is found mainly in the form of reworked clay (probably Gardiners clay) from older formations, with a few pebbles and bowlders incorporated in it. The best localities for observing the deposit are at the West Barnstable clay pits in the Chatham region and on the west side of the cape near Wellfleet. On the main coast however, the development seems to be much stronger, the till being a thick sheet filled with bowlders, giving rise to the bowlder pavements near Manomet Hill, south of Plymouth, and, it is believed, to the till hills and big drumlins of the Boston region. In northeastern New England it apparently continues to be the principal till, ranging from 20 to 300 feet in thickness. The invasion in New England, as on Long Island, seems to have been dual, the first advance depositing the greater part of the material and the second advance accomplishing most of the folding. In fact, the later advance is in some places represented solely by its erosion unconformity. The folding is characteristic of the advance throughout, being found in northeastern New England as well as on Long Island.

Hempstead gravel member.—The Hempstead gravel member of the Manhasset formation is limited as a continuous deposit to the western half of Long Island but seems to be developed as an interrupted sheet along the coast throughout New England. Gravel of this horizon is seen above the supposed Montauk till member on both the east and south coasts of Block Island; it caps the bluffs at many points on the north coast of Marthas Vineyard; it occurs above the fossiliferous beds at Sankaty Head, Nantucket; and it is seen at numerous places on the Elizabeth Islands and Cape Cod and along the Massachusetts coast to Plymouth and beyond. It is also found in New Hampshire and Maine above drift correlated with the Montauk member, in places reaching a thickness of over 100 feet.

VINEYARD EROSION INVERVAL.

The extensive erosion unconformity developed in the stage following the deposition of the Hempstead gravel member of the Manhasset formation, is fully as well developed in southern New England as on Long Island, the terraces of Block Island, Marthas Vineyard, Nantucket, Elizabeth Islands, Cape Cod, and the Massachusetts coast showing substantially the same deep stream cutting previous to the deposition of the Wisconsin till as is found between Manhasset Bay and Port Jefferson on Long Island. North of Boston little erosion occurred in early Vineyard time largely because of the submergence which continued through a considerable part of the stage and during which the "Leda clay" of the Maine coast was deposited. In the later part of the stage, however, a considerable uplift accompanied by erosion appears to have occurred in northeastern New England.

WISCONSIN DRIFT.

The Wisconsin till sheet forms a mantle over the whole of New England essentially the same as on Long Island. On the whole it seems to be but little better developed than on the island, although in some places it reaches a somewhat greater thickness. F. G. Clapp [1] gives its maximum thickness in northeastern New England as 20 feet, which is about the same as the average in southern New England and Long Island.

CORRELATION WITH THE NEW JERSEY NONGLACIAL FORMATIONS.[2]

GENERAL CONDITIONS.

The conditions in New Jersey were so unlike those on Long Island and the nature of the deposits is so different that with the information at present available the correlations are of necessity doubtful, except perhaps in the vicinity of Staten Island. In the Long Island region the ice advanced with a long front facing the sea, into or along the borders of which it emptied its débris-laden waters. In New Jersey, on the other hand, the ice margin lay well back from the coast and its till and outwash accumulated on the surface of the land. The ice was not the only source of the material in the New Jersey region nor was the vicinity of the ice margin the only place of deposition. The Cretaceous and Tertiary highlands were everywhere being cut down and their materials were being deposited along the valleys, which in places were aggraded to elevations of 150 to 200 feet above the sea level.

CORRELATIONS.

The chief Pleistocene deposits of New Jersey and their correlation with the deposits of Long Island are shown in the table facing page 220.

Lower Cape May terrace.—The lower Cape May terrace is composed of a quartz or granitic gravel, locally somewhat sandy, occurring as a low terrace about 20 feet above Delaware River

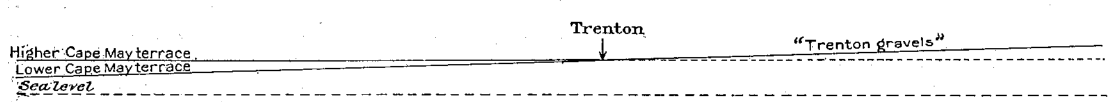

FIGURE 205.—Diagram showing the relations of the higher and lower Cape May terraces to the so-called "Trenton gravel" along Delaware River in New Jersey.

below Camden, as a broad, flat terrace bordering the sea at about the same elevation at Cape May, and as similar terraces in the reentrants of Raritan Bay and elsewhere. Along the Delaware it rises upstream, apparently rising above the higher Cape May terrace beyond Trenton and merging into the so-called "Trenton gravels," a local development of the Cape May formation. The relations appear to be as shown in figure 205 and would point to the completion of the valley phase of the Cape May in late Wisconsin time. The marine phase, however, seems to be somewhat older, apparently antedating the Wisconsin outwash, as no traces of it are found on Long Island, although the conditions were presumably as favorable for its formation as at the typical locality on the shores of Raritan Bay only a few miles away. The writer believes that the Delaware development of the Cape May corresponds with the great outwash streams of the Harbor Hill substage and regards the marine phase as having been developed at a somewhat earlier stage, supposedly contemporaneous with the cutting of the great inland scarp bordering the Harbor Hill moraine from Brooklyn to beyond Jamaica.

Higher Cape May terrace.—The deposits of the higher Cape May terrace are more quartzose than those of the lower terrace and carry a greater percentage of iron crusts from the Pensauken formation. Along the Delaware Valley they include a considerable admixture of northern material, including fresh subangular granites, but in the tributary streams and coastal phases

[1] Bull. Geol. Soc. America, vol. 18, 1908, table opp. p. 512.

[2] In studying the correlations the writer spent several days in going over the best New Jersey localities with Mr. G. N. Knapp, of the New Jersey Geological Survey, in 1903, and two weeks in company with Dr. H. B. Kümmel, State geologist, in 1907. Cordial thanks are due for the many courtesies and the valuable assistance received from the State Survey during these visits.

the materials are wholly of local derivation. The higher Cape May terrace has a maximum elevation of 40 to 60 feet on the borders of Raritan Bay, along the New Jersey coast, and in the open Delaware Valley, but may rise to considerably higher levels in the tributary valleys. Inasmuch as the granites of the deposits are fresh, whereas in the next older formation (the Pensauken) they are invariably weathered or rotten, it seems likely that the higher Cape May terrace of the Delaware Valley corresponds with the Manhasset formation of Long Island, in which the pebbles are likewise fresh. No deposit is known on Long Island with which the higher terraces of Raritan Bay and the coast can be correlated, unless it may be the 40-foot terraces (Hempstead gravel member) on the Montauk peninsula.

Intermediate stream deposits.—Deposits of locally derived gravels have been formed mainly in the valleys cut in the underlying Pensauken by tributary streams entering the Delaware trough. They are lower than the Pensauken and higher than the uppermost Cape May, and represent the deposits of the intervening stage, constituting a subaerial formation probably contemporaneous with the marine Gardiners clay of Long Island.

Pensauken formation.—The principal development of the Pensauken formation is in the great trough in the Cretaceous deposits extending across the State from Raritan Bay to Trenton and down the Delaware Valley to Salem County. In this region the formation is commonly an arkosic ferruginous sand or quartz gravel containing numerous pebbles of rotten red shale and deeply weathered granites but no fresh pebbles. The formation in the tributary valleys and along the coast is composed of local materials derived largely from the Bridgeton formation. In the trough mentioned the formation attains a maximum altitude of 150 to 200 feet, but along the coast it stands at about 90 feet. In general it lies in troughs or valleys eroded in the Bridgeton formation.

The presence of bowlders apparently ice rafted along the Delaware belt suggests that it was formed during an ice advance, but there are many difficulties in the way of definite correlation with the deposits of Long Island. Weathering is, on the whole, distinctly more advanced in this formation than in most of the Manhasset of Long Island, although not more than in certain phases such as those at Lloyd Neck (p. 136). According to the sequence of events it should be correlated with the Jameco gravel, but a grave difficulty is encountered in the fact that the upper surface of the Jameco is 50 feet or more below sea level, and that of the Pensauken formation along the coast is at least 90 feet above it, although the localities are only a few miles apart. The Jameco is a glacial formation and may have been deposited at some depth below the sea while the nonglacial Pensauken formation was accumulating at a considerable elevation above it. Such an origin of the Jameco demands a subsidence, as the land stood considerably higher both immediately before its formation (as shown by the post-Mannetto erosion valleys) and immediately after it (as indicated by the marsh deposits and the shallow-water fauna of the Gardiners clay). Unless another glacial stage is introduced, of which there is no other indication, there seems to be nothing besides the Jameco with which the Pensauken can be logically correlated. In being a valley formation in an erosional depression of an older surface, it agrees with the Jameco.

Bridgeton formation.—The Bridgeton formation is largely a cross-bedded quartzose gravel of the Mannetto type, with some rotten cherts and granites, and was developed over extensive upland areas in southern, central, and northern New Jersey. It was afterwards largely removed in the central part, where it is now found only as caps on the higher hills. In elevation it varies from 100 feet at the southern limits to 200 feet in Camden County. Its habit is the same as that of the Mannetto gravel of Long Island, the formation occurring as a broad, sloping terrace, which as a rule covers and obliterates the underlying Cretaceous uplands of New Jersey in the same manner as the Mannetto gravel covers the Cretaceous remnants in the Mannetto Hills of Long Island. The character of the Bridgeton formation and its position in the Pleistocene series are so similar to those of the Mannetto gravel that its correlation with the Mannetto seems reasonably certain. The two formations are probably contemporaneous with the extramorainal drift farther north in New Jersey.

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