DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

PROFESSIONAL PAPER 108—B

THE NEWINGTON MORAINE

MAINE, NEW HAMPSHIRE, AND MASSACHUSETTS

BY

FRANK J. KATZ AND ARTHUR KEITH

Published March 15, 1917

Shorter contributions to general geology, 1917
(Pages 11–29)

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THE NEWINGTON MORAINE, MAINE, NEW HAMPSHIRE, AND MASSACHUSETTS.

By FRANK J. KATZ and ARTHUR KEITH.

INTRODUCTION.

The present paper embodies the results of brief studies in 1915 and some earlier observations (1911–1914) on glacial and associated deposits in Maine and New Hampshire. It is preliminary in character, and the work was incidental to more extensive and detailed studies of the Pleistocene geology of southwestern Maine and vicinity, which will be the subject of later publications.

The fact that a belt of gravelly and sandy ridges in southwestern Maine and adjacent New Hampshire has the character of a terminal moraine was recognized by the authors while they were together engaged in geologic reconnaissance. The moraine was first noted in Biddeford and Wells, Maine, and in Newington and Portsmouth, N. H. Mr. Keith traced the course of the moraine from Rye, N. H., to Newbury Old Town, Mass.; the portion in Newbury and Newburyport, Mass., had been noted by Sears.[1] Mr. Katz subsequently studied the moraine from Saco, Maine, to Rye, N. H. The late Prof. C. A. Davis was for a time in the field with the authors and contributed to the results here announced. His familiarity with the geography and geology of the region about Portsmouth was of assistance in tracing the moraine.

Earlier geologic writings that are of interest as discussions of Pleistocene geology of the same region are limited to three—Warren Upham's chapter, "Modified drift," in Hitchcock's "Geology of New Hampshire," volume 3; J. H. Sears's "Geology of Essex County, Mass.," cited by full title below; and F. G. Clapp's "Complexity of the glacial period in northeastern New England."[2]

The name here adopted is taken from the town of Newington, N. H., in which the moraine is characteristically developed and forms a prominent topographic feature. The time of the Newington moraine will be designated the Newington substage.

GENERAL CHARACTER OF THE REGION.

The region in which the Newington moraine is situated is a coastal lowland from 12 to 20 miles wide, bounded on the landward side by an upland that rises inland by a series of thoroughly dissected rock platforms or terraces. The coastal lowland, which also includes several similar but lower terraces, is a hilly, heavily drift-mantled rock surface, rising from below sea level to about 300 feet above sea level. The rock floor of this terraced surface is thoroughly dissected into ridges separated by wide, open valleys, some of which are in part worn to depths below the present sea level. Some ridges, for example the Bauneg Beg Ridge, project from the upland terraces into the lowland area, and some monadnock-like rock hills or outliers of the higher terraces, notably Mount Agamenticus, rise above it.

The entire region has been rigorously glaciated and abundantly supplied with glacial deposits of many kinds. During part of the glacial epoch the coastal terraces were submerged beneath the sea, but since then they have emerged. During the period of subsidence marine clays and sands were deposited in the depressions, and these deposits are now to be seen as broad, flat areas only slightly dissected by a very young drainage system. Davis[3] has shown that "The present shore line is therefore not the direct result of submergence of a rugged land, but of the emergence of an uneven sea

[1] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., pp. 296, 301, map, Essex Institute, Salem, 1905.

[2] Geol. Soc. America Bull., vol. 18, pp. 505–556, 1907.

[3] Davis, W. M., Physiography, in Grabau, A. W., and Woodman, J. E., Guide to localities illustrating the geology * * * of the vicinity of Boston, p. 5, Am. Assoc. Adv. Sci., 1898.

bottom—uneven because the marine clays that were spread upon it had not been deposited in sufficient quantity to smooth over its previous inequality."

The glacial and marine deposits have modified and in general softened the relief of the region and have deflected many of the streams from the preglacial rock valleys. Nevertheless, the general trend of the principal drainage lines is now, as formerly, southerly to east-southeasterly. The marine deposits increase in breadth and thickness and indicate greater submergence toward the north and northeast. The surface of these deposits now slopes southeastward (toward the sea), and, furthermore, the broad plains of marine clay and sand lie at higher elevations in the northern part of the region than in the southern part. There appears, then, to have been some tilting. These relations, however, may be in part explained as due to differences in the degree of filling caused by differences in the quantity of material discharged into the sea at different localities and in the distance of the several localities from the shore line and the sources of the materials. The Pleistocene marine sediments of this region and the associated problems of coastal movements and delineation of shore lines are now being studied.

LOCATION AND DISPOSITION OF THE MORAINE.

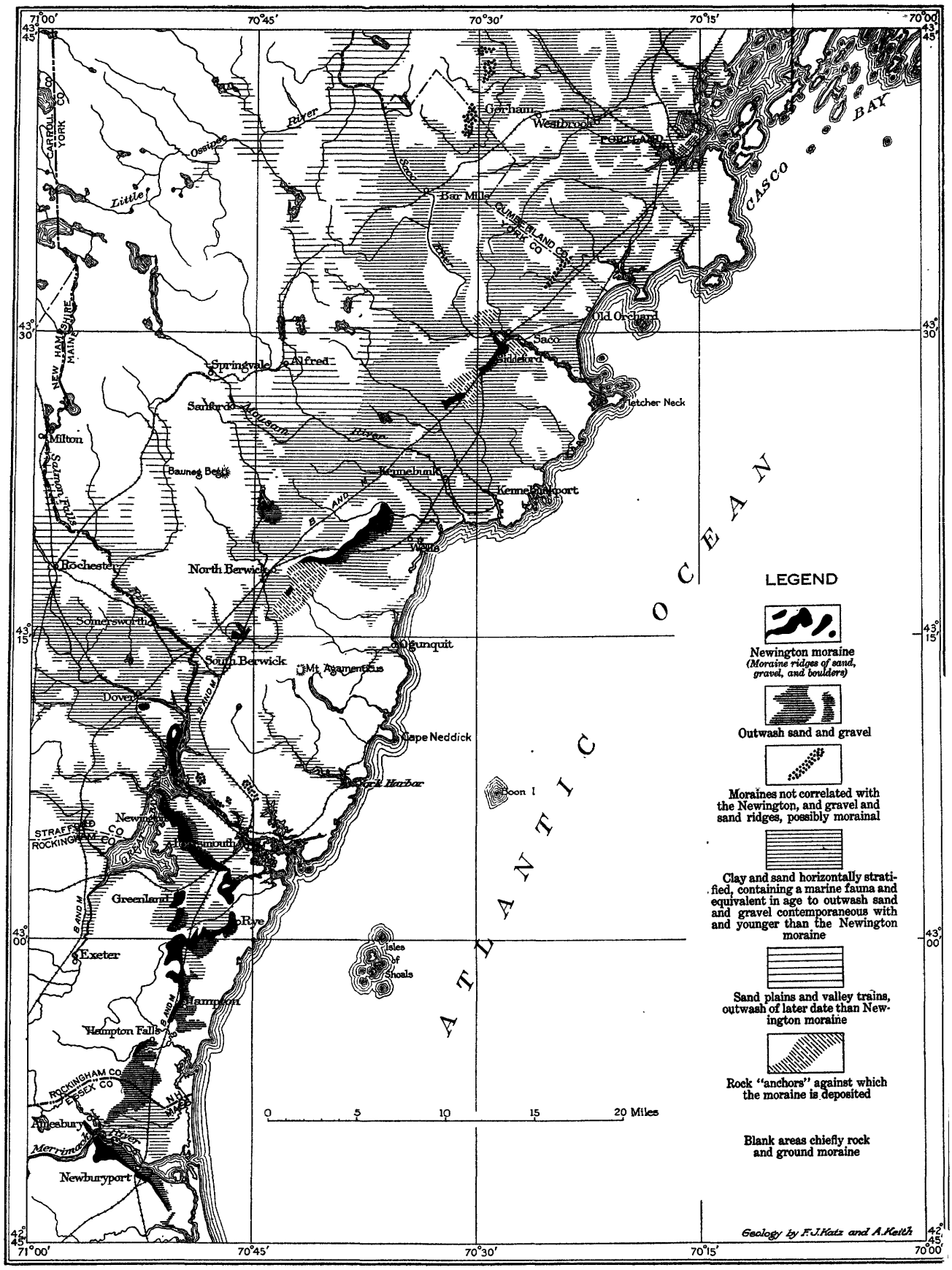
The drift formations here considered are distributed along a sinuous 60-mile course in York County, Maine, Strafford and Rockingham counties, N. H., and Essex County, Mass.[1] They lie nowhere more than 9 miles from the present Atlantic coast and in some places are adjacent to tidewater. Their distribution is shown on the accompanying map (Pl. IV).

The moraine does not form a continuous ridge but is made up of a number of segments, more or less widely separated by intervals in which no deposits belonging to a terminal moraine have been found. Nevertheless, there is a conspicuous alignment of the segments, as displayed on the map (Pl. IV), which supports the conclusion that all are parts of the same moraine. The arrangement and extent of the several segments and intervals are as follows:

Beginning at the north, the first is the Saco segment, in the western part of the city of Saco, Maine, on the north bank of Saco River just west of Deep Brook. It is a little less than a quarter of a mile long and trends southeast. Between the Saco segment and the next one, the Biddeford segment, is a short interval occupied by Saco River and its flood plain. The Biddeford segment has its north end south of the Saco segment, on the south side of Saco River, in Biddeford, and extends south-southeast for nearly a mile, and thence west of south along the west side of the post road for 1½ miles, finally turns southwestward and ends near the granite hills in the southern part of the town of Biddeford. Beyond an interval of 1¼ miles to the southwest, across granite hills, is the next segment, the Kennebunkport, which is a ridge 1½ miles long with southwest trend. About 7 miles to the southwest, across Kennebunk, Mousam, and Branch rivers and the flat lowlands adjoining them, is the Wells segment or Merriland Ridge. This ridge has a sinuous course about 7 miles long, trending south for a mile, then swinging westward and finally southwestward and terminating about 2 miles east of North Berwick village, against a massive hill of granite. About 2½ miles southwest of this point there is a small area of probably morainal sands and gravels. Two miles farther south is the Knights Pond segment, a crescentic ridge inclosing the southeast end of Knights Pond, in the northwest corner of the town of South Berwick. The succeeding interval, measured to either the Dover or the Dover Neck segment, is approximately 8 miles across areas of ground moraine (till), marine clay and sand, and rock ledges.

The Dover segment, including Pine Hill Cemetery, in the city of Dover, is an irregular area from half to three-fourths of a mile wide. This is separated by an interval of clay plain and till-covered rock hills, 1 mile wide, in a southeast direction from the Dover Neck segment, which is a north-south ridge 2½ miles long between Little John Creek on the north, Dover Point on the south, and Piscataqua and Bellamy rivers on the east and west, respectively. Across Little Bay, 1 mile south of the end of the Dover Neck ridge, is the north end of the Newington and Portsmouth segment, which extends south about 2¼ miles along or near the eastern shore of Great Bay, thence east three-fourths of a mile to Newington Town

[1] This region is represented on the following maps of the United States Geological Survey's topographic atlas: Portland, Biddeford, and Kennebunk, Maine; Berwick and Dover, Maine and N. H.; and Newburyport, N. H. and Mass. All these maps, except that of the Portland quadrangle, are of reconnaissance grade, and therefore too much generalized to bring out features like those described.



MAP OF NEW ENGLAND COASTAL REGION FROM PLUM ISLAND, MASS., TO CASCO BAY, MAINE, SHOWING DISTRIBUTION OF MORAINE AND OUTWASH DEPOSITS.

Hall, southeast 3 miles to Portsmouth Plains, south 1 mile to Peverly Hill, and south into the swamp along Berrys Brook. The part of the moraine between Newington and Peverly Hill is shown on Plate IX (p. 18). The Rye, North Hampton, and Hampton segment, beginning south of Berrys Brook opposite the end of the Newington and Portsmouth segment, extends west-southwest through Rye Center and West Rye 2 miles to Breakfast Hill, south and west of which, in North Hampton, morainal deposits are irregularly distributed over a broad area of several square miles. North of this area, in the town of Greenland, is an outlying moraine ridge 1¾ miles long from north to south. From North Hampton the moraine continues southward through Hampton village into Hampton Marsh, north of Taylor River. The Hampton Falls, Seabrook, and Salisbury segment begins in Hampton Falls, 1½ miles southwest of the preceding segment, and extends south and south-southwest through Seabrook and Salisbury to Merrimack River. The Newburyport segment begins in Amesbury and runs southeast across Merrimack River and for 7 miles in a nearly straight course into Newbury village, whence it extends south-southwestward for a short distance to Parker River. The moraine has not been traced beyond this point.

The above-outlined disposition of moraine segments indicates that the ice front of the Newington substage from Saco, Maine, to Newbury, Mass., a distance of 59 miles, had a general south-southwest course, though it was not straight. From Saco through Wells the line indicated by the segments was nearly 15 miles straight southwest. Beyond Wells, through North Berwick and South Berwick, Maine, and Rollinsford and Dover, N. H., the front was bowed 2 miles westward through another stretch of 15 miles around the Mount Agamenticus mass, which was a barrier to eastward ice movement. From Dover it swung southeasterly for 8 miles through Newington and Portsmouth into Rye, being held south of Piscataqua River, probably by the influence of both the Agamenticus highland and the Piscataqua estuary. This southeasterly stretch and the succeeding west-southwesterly course of 4 miles in Rye and North Hampton outline a small lobe, caused by the Great Bay depression. From North Hampton the general course of the ice front was south-southwest for 11 miles to Merrimack River, with a slight easterly bowing. South of Merrimack River its course has been traced for about 8 miles in a southeasterly direction, determined by the river, from Amesbury to Newbury Old Town.

GENERAL CHARACTER OF THE MORAINE.

The Newington moraine is a ridge ranging in height from 40 to 100 feet above its base and in width from a few rods to a mile or more. It consists of a western inner or ice-contact slope, the summit or moraine crest, and in some places an outer slope with which is associated an outwash apron. These parts are not everywhere distinct. The inner side is generally steep, rising abruptly the full height of the moraine from ground moraine or marine clay plains. The crest, whether narrow or broad, is nearly everywhere flat and approximately level. It is hummocky in only a few places, nowhere markedly so. It does not exhibit the typical knob and kettle form of kame moraines, nor the rough surface of till and boulder moraines. Where kamelike forms have been developed, as in Newburyport, Kennebunkport, and Dover, and locally in Newington and Portsmouth, they are small and subdued in form and relief. As a rule, kettle holes are few, isolated, and small. In Newburyport and North Hampton, however, there are groups of good-sized ones. Where the moraine does not lie against rock hills the outer side is a moderate slope descending to clay plains or merging into an outwash apron or else a low scarp between the outwash and the moraine crest. Outwash plains were not formed everywhere, and some of them are not distinct from the moraine. They are smooth gentle slopes a few rods to 1½ miles wide and locally pass gradually in both slope and constitution into broad flats of marine clay and sand.

Within a moderate range the moraine ascends and descends with the relief of the floor upon which it stands. Thus it rises out of the valley of Saco River upon the small rock hills in Biddeford and descends again into the valley of Kennebunk and Mousam rivers. In Wells and South Berwick it attains its greatest elevation of about 200 feet on the flanks of a large obstruction of high ground. Southwest of this locality it descends to sea level in Pis-

cataqua River. However, the maximum difference in altitude of different parts of the moraine does not exceed 200 feet.

The materials of the moraine are boulders, gravel, and sand. With the exception of some of those at one place, all the boulders and pebbles observed are foreign to the locality of the moraine. A very small amount of stratified clay has also been noted in the moraine, but no till has been identified in morainal deposits of typical Newington form. Boulders are not abundant as a rule but have been found in considerable numbers in the north end of Merriland Ridge, Rye Center, and Greenland. Gravelly sand and gravel made up of large cobbles, small pebbles, and sand predominate in the moraine. These materials are all more or less washed and water-rounded. The outwash materials are gravel and sand, dominantly of small size, and are progressively finer toward the farther limit of the outwash.

The moraine has in many places a well-developed internal structure consisting of a sorting and stratification approximately parallel to the cross profile of the moraine. Beds that are nearly flat in the center dip outward into and constitute the proximal part of the outwash plain. In several places in Biddeford, Newington, and Portsmouth the inner side of the moraine is made up of beds dipping strongly and in part parallel to the surface slope. These "backset" beds are well developed in the broader parts of the moraine and were deposited during slow retreat of the ice. In places in Newington the moraine contains structureless, unsorted sand and gravel. Irregularly distributed patches of sand and gravel were noted in Saco and Portsmouth.

LOCAL DETAILS.

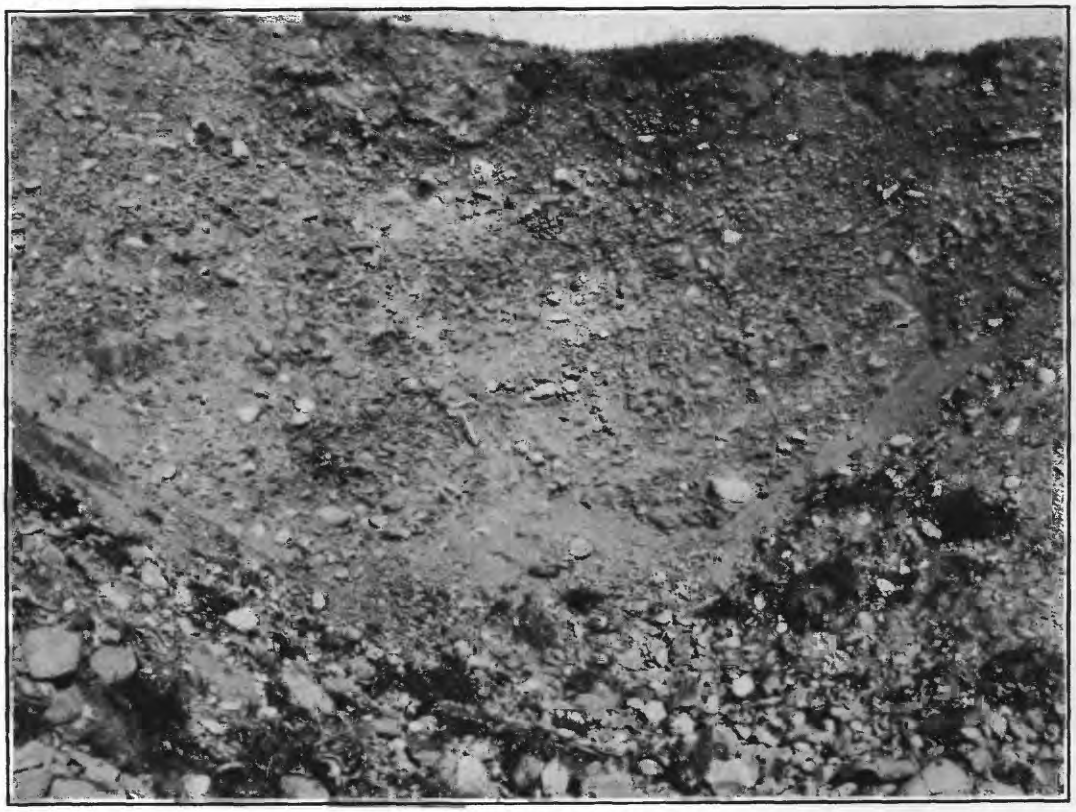
SACO SEGMENT.

The moraine in Saco is very narrow and inconspicuous; it consists of aligned sandy knolls almost covered by the surrounding clay and sand plain. The ridge extends northwest toward a till-covered rock hill, from which it is separated by nearly half a mile of horizontal sand plain. In two pits marine clay and overlying sand lie above the moraine material, which consists of waterworn sand, gravel, and boulders, not stratified but in pell-mell structure. Pebbles of moderate size predominate, although there are also numerous large boulders. The materials in these pits are not weathered.

BIDDEFORD SEGMENT.

Opposite the Saco segment is the north end of the Biddeford segment, also covered by clay. A broad mound of stratified sand overlain by marine clay on the north side of Main Street, Biddeford, is the northernmost recognizable part. Thence the moraine continues southeastward, rises above the clay as a gravel cover on the south-southwest slope of the rocky hill in the center of the city, and extends as far as Elm Street (the post road), where it forms a flat-topped sand plain that on the east in part abuts against higher granite hills and in part grades into a clay plain. From this plain the moraine narrows to an even-crested ridge which trends southwest on the west side of the post road for about a mile. This ridge is 160 to 180 feet above sea level, and from it the descent to the northwest is moderately steep for about 50 feet to a low area floored by rock ledges, ground moraine, and marine clay. On the southeast side, however, the ridge is only locally marked off by a low scarp and slight change in slope from the bordering sandy outwash plain, which slopes gently southeastward and merges into a clay plain. The difference in slope and altitude between the two sides is a most striking feature in a view from the top of the moraine. From the post road the moraine turns westward and decreases in height. It trends toward the granite hills on the edge of the town of Kennebunkport but ends at the low pass immediately east of those hills.

The make-up of the Biddeford segment is disclosed in a number of gravel pits and sand banks from which material is taken for railroad, highway, and construction work in and around Biddeford. Two cuts on the summit and the large gravel bank worked by the railroad on the northwest side of the high ridge along the post road show that the material is made up of gravel and boulders packed in a sandy matrix without sorting or stratification and at least in part lying on granite ledges. The material is all more or less waterworn and rounded, and in the summit cuts it is iron stained and partly rotted. A sand pit near the junction of the post road and the Alfred pike, near the moraine border of the outwash plain, shows 20 feet of stratified and approximately horizontal sands. Pits in the northwest slope of the ridge and on the north side



A. UPPER PART OF PIT.

Shows 15 feet of rudely stratified moraine gravel.

B. LOWER PART OF PIT.

Well-stratified sand and gravel on inner slope of moraine. These sands are overlain by the gravel shown in *A*.

GRAVEL PIT IN BIDDEFORD, MAINE.

A.

B.

MORAINE FRONT AND OUTWASH, MERRILAND RIDGE, WELLS, MAINE.

In the upper view the moraine front is fairly smooth and not sharply separated from the outwash. In the lower view the moraine is scalloped and more sharply separated from the outwash.

of the Alfred pike expose 15 to 20 feet of sand and gravel. (See Pl. V.) This material is for the most part stratified and sorted, although but poorly so, and the beds dip strongly 35°–45° W.—that is, they are "backset" beds. The pebbles and boulders, the latter not uncommonly 2 feet and rarely 3 feet in diameter, are almost all rounded. Although some of them are somewhat polyhedral, like faceted pebbles or soled boulders, they have been so much rounded off that plane surfaces, other than joint or cleavage faces, are scarce. In these exposures beds of sand or small pebbles containing a few scattered larger pebbles are overlain by gravel beds containing 4 to 6 inch cobbles and many boulders. In all the gravel beds there is a closely packed matrix of sand and small pebbles.

The prominent part of the Biddeford segment is the ridge along the post road. The southwest end of this ridge, which is low and inconspicuous, trends toward and terminates near rock hills that are higher than any part of the moraine. The northeast end of this ridge lies against the higher rock ledges in the city, and the morainal gravels and sands continue to the north as a cover on the flank of these ledges. The northern part of the Biddeford segment and the Saco segment connect rock hills on both sides of Saco River. It is clear that these rock hills determined the form and position of the ice front and that the low ground between them was the site of the discharge of the glacial drainage of Saco Valley.

Between the Biddeford and Kennebunkport segments is an interval of 1¼ miles occupied by hills of granite that stand about 50 to 100 feet higher than surrounding areas. These hills for the most part are bare rocks, but in places they have a drift cover, no part of which has yet been recognized as belonging to a terminal moraine.

KENNEBUNKPORT SEGMENT.

The Kennebunkport segment is a narrow southwestward-trending ridge 1½ miles long and for the most part only 30 to 100 rods wide, though it widens to nearly three-quarters of a mile at its southwest end. It is made up of a number of coalescent sandy kamelike knolls and includes in its higher and broader southern part a few small rock ledges. This segment of the moraine springs from the south side of the granite hills, against which on the north the Biddeford segment terminates. On the east, north, and west the Kennebunkport segment is bordered by wide plains of marine clay and sand. These deposits fill the valleys of Kennebunk, Mousam, and Branch rivers, and except for detached protuberant hillocks of rock and ground moraine they bury all other formations. It is 7 miles south-southwest across these filled valleys, in which no terminal-moraine deposits have been found, from the Kennebunkport to the next segment.

MERRILAND RIDGE (WELLS SEGMENT).

The moraine of Merriland Ridge is terminated at both ends by granite hills. The north end springs from a small, low granite knob on Merriland River, in the town of Wells, about 2 miles above the mouth of the river. From this rock knob the moraine extends southward for a mile as a generally flat but in a small way hummocky area one-fifth mile to 1 mile broad. Over this area are scattered numerous large boulders, which, however, are more abundant on the western part of the broadest portion; the eastern part has fewer boulders and is more sandy. Southwestward from this broad, flat part the moraine is narrower, higher, and more sharply ridgelike, and from a point about 1½ miles north of west of Wells Beach station through a distance of 3½ miles west-southwest the moraine is a prominent sigmoid ridge which rises abruptly 40 to 50 feet above low and wide meadows on the northwest. (See Pls. VI and VII.) Through this distance it has a nearly level and generally smooth or gently undulating crest, at an altitude of about 200 feet above sea level. The crest is in some places only a few rods in width and in others several hundred yards. The southeast slope of this part of the ridge is short, 10 to 20 feet high, and steep. It is in places somewhat irregularly scalloped or ribbed and breaks sharply into a very gently sloping outwash apron of gravel and sand. In other places this southeast slope is smooth and merges gradually into the outwash apron. (See Pl. VI.)

The moraine is prolonged 1½ miles farther west, retaining its sharp ridge form. In this stretch it approaches the nearly parallel north slope of a large granite hill, against which it

ends at a point about 2 miles east of North Berwick village. Through this end of the moraine some ledges of granite protrude.

The material constituting the northern part of this moraine is largely bouldery gravel. Elsewhere, as seen on the surface, it is chiefly sand and gravel of moderate size. The only section found is the railroad cut through Merriland Ridge, the south bank of which is shown in Plate VII. The height of this section is about 35 feet. The material in it is stratified small gravel and sand, with a little clay and relatively few small and large boulders. The attitude of the beds, which is faintly indicated in the photograph, is in approximate parallelism with the front or east side of the moraine. The bedding has a low easterly dip under the outwash plain and rises to a greater inclination under the crest, and then with lessened dip the beds are cut off at the back slope. This attitude is shown in figure 1. The clay seam, visible as a dark streak at about the center of the section in the photograph, thickens very slightly eastward out to the limit of its exposure, and on the west it thins and is replaced by coarse sand. In appearance and composition this clay is very much like the marine clay of the region in general. The entire outwash apron along this part of the moraine slopes down to and grades into the low, flat sand and clay plains about the headwaters of Webhannet River.

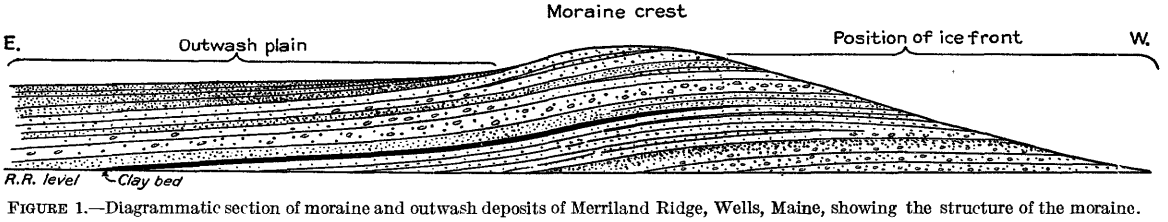


FIGURE 1.—Diagrammatic section of moraine and outwash deposits of Merriland Ridge, Wells, Maine, showing the structure of the moraine.

The continuation of the moraine was not sought in a southerly direction from the end of Merriland Ridge, because rock hills that are very much higher, culminating in Mount Agamenticus, 692 feet in altitude, extend for many miles southward and occupy a large area in the towns of Wells, South Berwick, and York. The westward swing of Merriland Ridge at nearly constant level against and around the north side of this high rock mass indicates that during the Newington substage the ice did not ascend these hills. A reconnaissance of the territory north and west disclosed no morainal deposits, but in South Berwick, at 2½ miles southwest of the end of the Merriland Ridge segment and on the west flank of the rock hills, was found the feature next described.

MORAINAL DEPOSITS IN SOUTH BERWICK.

In South Berwick, 1¾ miles southeast of North Berwick village, there is a small area of sand and gravel that fills a saddle between rock hills. No distinctly morainal features were noted here, but the position of this drift and its similarity in character to the drift of Merriland Ridge are suggestive of morainal origin. In 1890 Leonard H. Davis [1] regarded this drift as a moraine.

Three to four miles southwest of this area of sand and gravel is the ridge inclosing the south end of Knights Pond. This ridge is a crescentic belt, convex to the south, of small contiguous sand and gravel knolls which present a continuous smooth, even slope toward Knights Pond. There are no well-exposed sections in this ridge, and consequently its form and position with respect to the pond are the only evidence of its morainal character.

From Knights Pond to Dover, 8 miles southwest across the valley of Salmon Falls River, there are no known terminal moraine deposits.

MORAINAL DEPOSITS IN DOVER.

Pine Hill Cemetery, in Dover, N. H., is on a roundish kamelike hill 150 feet above sea level, or 60 to 70 feet above the adjoining plains of marine sediments. The hill extends east half a mile to a higher rock ridge and has a sloping southerly extension of 0.4 mile. A small rock ledge protrudes through gravels and sand 0.1 mile southeast of the summit of the hill. The higher central part of the hill is composed of unsorted gravels of moderate size in a sandy matrix. A gravel and sand pit in the cemetery, near the eastern limit of the kame area, ex-

[1] Unpublished notes filed in the U. S. Geological Survey.

SOUTH SIDE OF RAILROAD CUT ACROSS MERRILAND RIDGE, WELLS, MAINE.

Stratified gravels, sand, and clay constitute the moraine and outwash.

A. WEST SIDE OF INNER SLOPE OF NEWINGTON MORAINE ON BAY SIDE ROAD IN NEWINGTON, N. H.

The flat surface in the foreground is sandy marine clay.

B. SAND PIT IN PINE HILL CEMETERY, DOVER, N. H.

Shows irregularly bounded beds and pockets of sorted sands and fine gravel.

poses 15 feet of sandy material and has not cut through to the bottom. Plate VIII, *B*, shows a part of this section. Sand and fine gravel are very irregularly interspersed throughout the exposed section except at the top, which is clayey and more evenly layered; small gravel, in which the pebbles are less than half an inch in size, is more abundant toward the bottom. All the material is to some extent stratified, in general unevenly so, and as a rule the coarser material is the more uneven. The photograph brings out the irregular but sharp boundaries of the various kinds and grades of material. This is distinctly kame structure. Upham [1] refers to "the kamelike plain" of Pine Hill Cemetery and implies a connection between it and the sand and gravel plains north of Dover, which, however, are now believed to be outwash deposits of a later stage.

About 2 miles southeast of Pine Hill is the north end of the Dover Neck Ridge. This ridge is 2½ miles long, three-quarters of a mile wide, and 100 feet high near its north end, half a mile wide and 130 feet high 1 mile farther south, and about 100 yards wide and 40 feet high at its south end. The ridge is nearly symmetrical except in the broadest northern part, where the crest is nearer the west side and the eastward extension has the form of an outwash plain. The surface of the ridge is for the most part smooth, although in places it is very slightly hummocky. The material seen on the surface and also in small openings is gravel and sand. There are thin interstratified seams of sand and clay covered by small gravels in a cut near the summit, and near by is a small ledge of slate. On the sides are variously inclined sand beds which appear to grade toward and are not topographically distinct from the marine clay that fringes the ridge. The eastward expansion at the north end is a sandy plain that slopes toward and merges into a flat plain of marine clay.

NEWINGTON AND PORTSMOUTH SEGMENT.

The moraine has been more carefully studied in Newington and Portsmouth than elsewhere. Its form and constitution in those towns are described below.

Beginning on the shore of Little Bay east of Fox Point, the moraine extends 1.1 miles across Fox Point and south along the shore, rising abruptly to a height of 40 to 60 feet to a narrow ridge at about 500 feet from the bay. A recent sea cliff 25 feet in height has been cut along part of this slope. The eastward descent is gradual and smooth through one-eighth to one-fourth mile to the level of the bay, or to flat plains of marine clay approximately 20 feet above sea level. The materials making up this ridge, as shown in cliffs on the shores and gravel pits on the crest, are sand and abundant well-rounded gravel, generally of moderate size but grading from small pebbles to large cobbles and containing also a few boulders. However, in the north end, where the moraine directly overlies slaty rock, many angular fragments of that rock are mixed with the gravels. South of the above-described section the moraine is very much broadened, owing to the east-southeasterly trend of its outer (easterly) border, whereas the inner margin continues southward for 1½ miles. The principal axis or crest of the moraine in this part curves from a southward to a nearly eastward trend toward Newington Town Hall. In the part where the greatest width is nearly a mile the height of the moraine is 60 to 80 feet and the surface is hummocky, being composed of small kame knobs and kettles. The material here is gravel and sand, dominantly sandy on the surface, and unsorted gravels and sand were seen in one pit. From Newington Town Hall the moraine trends east of south 1⅛ miles along the Greenland road to Gosling Road. Its width is half to three-quarters of a mile, and its top is broad and flat and stands at an elevation of about 100 feet. The descent to the west is fairly steep and about 20 to 30 feet high (Pl. VIII, *A*), but the eastward descent is less in amount and gentle. Near the town hall a rock ledge included in the moraine makes two small outcrops. Elsewhere the surface is sandy and bears a few boulders. Unassorted sands, rounded gravels, and small boulders are exposed in a bank west of the town hall.

Plate IX shows the position and outline of the moraine from Gosling Road in Newington to Peverly Hill in Portsmouth. The westerly boundary of the moraine in this length is sharp and marked by an abrupt change in slope. In places, particularly near New Road and at Peverly Hill, the morainal gravels present to the west steep walls and buttress-like forms

[1] Upham, Warren, in Hitchcock, C. H., The geology of New Hampshire, vol. 3, pt. 3, p. 153, 1878.

that could have been made only by accumulation of the gravels against a retaining mold—the ice front. In two places, however, at the inner margin of the moraine there are flat or nearly flat-lying sands and gravels, which are not distinctly separated from morainal materials on the one side and from low clay plains on the other. Although the exact nature and origin of these sandy flats has not been determined, it seems probable that they are the result either of deposition in small bodies of water ponded between the moraine and the ice after the ice had locally melted away from the moraine, or else of reworking and redeposition of the morainic materials by marine waters that flooded the region after the withdrawal of the ice.

The summit of the moraine is about half a mile wide along Gosling Road, is smoothly level, sloping inappreciably east, and grades into a narrow eastward-sloping outwash apron. South of Gosling Road the moraine is both narrower and lower and is not distinct from outwash on the east and a flat sandy plain on the west. Farther south, however, it rises to a flat gravelly top 90 feet in elevation and 0.4 mile wide on New Road. Here it has a steep west side, rising 50 feet out of a clay meadow, and a sinuous east border marked by a low scarp between the moraine and its outwash, near which it is pitted by a few small kettle holes. The flat top is continuous from New Road southeast to Middle Road, a distance of 1¼ miles, in which it ranges from 1,000 to 3,000 feet in width and descends from about 90 feet above sea level to 75 feet. The western slope is steep but is in part mantled at its foot by a belt of sand on very gentle slopes. The frontal scarp is pronounced and 10 to 20 feet high in this reach but vanishes east of Sherburne Road. The outwash plain is continuous for 4 miles from a point north of Gosling Road to a point a quarter of a mile northeast of the corner of Sherburne and Middle roads. It is an almost perfectly smooth surface, having a very gentle eastward slope, through which there is a gradual transition from gravel and coarse sand to clay. There is no natural boundary between this clay and the outwash, and there is no other basis for the line on the map than the limit of the wet, dead-level area of the clay plain.

Along Middle Road the moraine trends eastward and is rather lower than the parts already described. Here its surface is composed of irregular knolls of small size. Its limits are sharply defined against rock, till, and clay surfaces on the south and a clay meadow on the north. Portsmouth Plains is a flat expanse of sands and gravels making the crest of the moraine, which north and east of Portsmouth Plains abuts against rock hills.

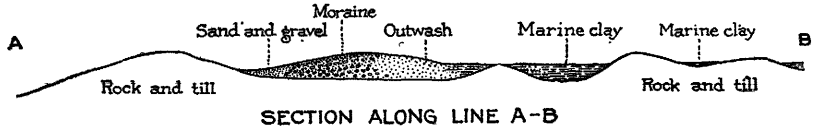
From Portsmouth Plains the moraine extends southward for about a mile to Peverly Hill. In that distance it is comparatively low and narrow, and north of Sagamore Creek is made up of small knobs of sandy gravel including a small, shallow, circular kettle. South of the creek the moraine is a flat-topped bench of gravel and sand about 40 feet in elevation, lying against the rock mass of Peverly Hill. In one place through a length of 100 feet or more the flat top of the plain does not quite reach the rock, there being a small and shallow depression or "foss" between them. The flat gravel bench extends along the northwest side of Peverly Hill and is continued eastward in a plain that surrounds the hill and descends by moderate slopes northward into the Sagamore Creek marshes and by gentle slopes eastward to rocky hills east of Lafayette Road. The moraine extends as a broad, smooth ridge of gravel southward from Peverly Hill across Lafayette Road to Bellyhack Swamp (Berrys Brook).

Gravel and sand pits and road cuts give the following data on the constitution of the moraine in Newington and Portsmouth:

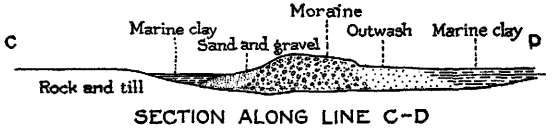
At the junction of Sherburne and Greenland roads, in Newington, in that part of the moraine which has a high, broad, flat top, the 10 to 15 feet of material immediately next below the summit is gravel, for the most part well rounded but containing also many boulders that have planed surfaces. The pebbles are not assorted as to size, yet there is a distinguishable succession of layers dipping about 15° W., and of these the upper layers are more abundantly composed of finer gravel and sand and the lower of coarser stuff.

In the same part of the moraine, at the junction of Gosling Road and the Greenland road, in Newington, an excavation of 3 to 4 feet in a flat sandy plain (1, Pl. IX) contains fine yellowish sand with relatively few rounded peb-

Base and geology by Frank J. Katz



SECTION ALONG LINE A-B



SECTION ALONG LINE C-D

MAP OF PARTS OF NEWINGTON, GREENLAND, AND PORTSMOUTH, N. H., AND DIAGRAMMATIC SECTIONS SHOWING RELATION OF THE NEWINGTON MORAINE TO ROCK AND TILL AND PLEISTOCENE MARINE SEDIMENTS.

bles or boulders and some rock fragments. No stratification is shown.

On the Sherburne road in Portsmouth, half a mile east of the excavation last noted, there are a pit (2, Pl. IX) and a road cut which show approximately 15 feet, measured down from the moraine surface, of large cobbles mixed with small pebbles and sand, which are like the material in excavation 1, but without apparent stratification. One-eighth mile to the south is a sand pit (3, Pl. IX), west of the Sherburne road, in the place where the moraine ridge is low and not distinct from the outwash plain. Here, the flat sandy top of the ridge shows 3 feet of yellow sand containing much dust and fine claylike rock flour, scattered pebbles 2 inches or less in diameter, and a few cobbles as large as 6 inches. This material is devoid of stratification and hence is not outwash but morainic dump.

In the cut on New Road (4, Pl. IX; see also Pl. X), at the west edge of the flat-topped moraine crest, there are exposed 10 to 12 feet of boulders and coarse gravel packed in fine gravel and sand, without clay or other cementing material. The material here, as in all but one other exposure, that near Little Bay, is dominantly of foreign origin, being composed chiefly of granite gneiss, pegmatites, basaltic porphyries, and much fine-grained micaceous graywacke gneiss, such as are not indigenous to the coastal towns of New Hampshire. Although there are many faceted boulders and pebbles, the dominant forms are round and subrounded, and none of them are striated. All the materials are surficially more or less iron-stained, giving to the bank as a whole a light rusty-brown color, and many of the pebbles and boulders are rotted. A small part of the west end of this exposure (Pl. X, *A*), through a thickness of 3 to 4 feet at the top, shows a faint trace of stratification parallel to the back slope of the moraine ("backset" beds).

In the Wiggins gravel pit, near Middle and Sherburne roads, in Portsmouth (5, Pl. IX; see also Pl. XI), there are undulating beds of interstratified clean sands and fine gravels which abut directly against unsorted coarse rusty gravels lightly packed with sandy material but not cemented. Weathering has produced a black rust varnish on pebbles and boulders and has rotted the gabbroid rocks.

The city gravel pit on Middle Road, Portsmouth (6, Pl. IX; see also Pl. XII, *A*, p. 24) shows stratified material consisting of gravel and sand beds and intercalated clay seams that have a southerly dip and are therefore "backset" beds. The gravel consists of pebbles, for the most part well rounded and under 6 inches in size, but the number of larger and only partly rounded and faceted cobbles is considerable, and they show prominently because of a lack of pebbles of intermediate sizes. The sand and gravel are loose and friable, but the clayey seams are stiff and project from the face of the bank.

On Peverly Hill Road low gravel banks (7 and 8, Pl. IX) show loose gravels and sands mostly unsorted and unstratified. A small cut on the north side of the road exposed in 1914 a vertical section of 8 to 10 feet of well-stratified small gravel, sand, and sandy clay, dipping 30° W. and about parallel to the surface of the moraine; the upper 3 to 4 feet was gravel and the lower part sand. A lens of finely laminated clayey sand lay between gravel beds near the top of the section, and these beds were in abrupt discordant contact with unsorted gravels that were all strongly iron-stained to the full depth of the exposure. Many of the pebbles had the form of faceted blocks whose edges and planes had been somewhat rounded. Immediately above this pit, in the flat summit of the moraine, where it lies against Peverly Hill, is another pit (10, Pl. IX) 8 to 10 feet deep, which shows evenly stratified, approximately horizontal sand and fine gravel lying on rounded glaciated ledges.

A short distance southwest of Peverly Hill, near the inner edge of the moraine, there is a shallow cut (12, Pl. IX), showing small rounded gravel and sand, stratified and dipping southwest, resting against glaciated ledges. The city gravel pit on Lafayette Road (the Boston post road) near Sagamore Creek (11, Pl. IX) contains about 20 feet of stratified gravels and sand.

The continuation of the moraine southward from the part shown in Plate IX has not been closely studied. It is, however, known south of Berrys Brook in Portsmouth and Rye. In Rye Center the moraine is a prominent boulder and gravel ridge, which is narrow and has steep sides, but it broadens and rises to the southwest, where it abuts against a rock butte

east of West Rye. Thence the gravel ridge runs westward to Breakfast Hill, which is essentially a rock ledge but is partly mantled by the morainic materials. These materials are exposed in cuts along Lafayette Road, where they consist of stratified waterworn gravel and sand having a southerly dip. The moraine continues in a southerly direction from Breakfast Hill as a sandy gravel ridge with broad plainlike top extending to Hampton village.

RYE, NORTH HAMPTON, AND HAMPTON SEGMENT.

The portion of the moraine lying in Rye, North Hampton, and Hampton forms a flat-topped ridge running westward from Rye almost to Greenland depot and thence southward through North Hampton and Hampton, where it slopes southward and passes under Hampton Marsh. The morainal deposits of Greenland, described below, may be an outlying part of this segment. North and west of this segment lie low valleys along the heads of Berrys Brook and Taylor River, and the moraine stands above them with a well-defined scarp. These bounding valleys are floored in the main with rock covered with a thin coating of till and marine clay. Surfaces of this character practically surround the outlier near by in Greenland. The morainal ridge slopes gently eastward and merges very irregularly into the low till slopes with numerous rock ledges that extend to the sea.

Most of the ridge is more than 100 feet above the sea, as is also the Greenland section. The two highest points are a mile north of North Hampton village and in Hampton village. In outward form the morainal deposits of these towns are nearly everywhere outwash plains, made up of two distinct benches or terraces, from 15 to 20 feet apart, both of which are well seen in North Hampton and Hampton. In most places these terraces or plains have little visible slope, but locally they have a decided dip. This dip is best seen about a mile south of North Hampton village and also in the southerly part of Hampton village, where the plain slopes southward under the marsh. The westward scarp is usually to be seen and marks well the old position of the ice front. Along or near this are numerous kettle holes, a fine group of them appearing half a mile north of North Hampton village. The contrast between the flat-topped moraine and the valleys at the west is best seen in the village of North Hampton, where the moraine forms a westward-facing scarp of nearly 40 feet. Hummocky moraines, till ridges, or kames have not been found in this segment of the moraine. In the western corner of Rye, where the moraine turns southward, a rock hill projects 20 or 30 feet above the plain level and appears to have formed an anchor for the ice. Numerous other ledges project through the moraine, rising as high as any of its parts, as for instance in Hampton village.

The two terraces or benches mentioned above are formed by layers of hard gravel between the sandy portions of the morainal deposit. Although there are numerous minor exposures of these beds, there are no complete sections. A small pit at the west end of North Hampton shows about 20 feet of gravelly sand with waterworn pebbles. Usually the surfaces of the plains or terraces are sandy with scattered small pebbles, and as a rule even a small cutting below these surfaces exposes gravel. In general the amount of gravel appears to be somewhat greater in Hampton than it is farther south or east. The sections observed showed sorting and rough bedding of the materials.

MORAINAL DEPOSITS IN GREENLAND.

In Greenland, N. H., there are two areas of morainal deposits that extend south from the center of Greenland village along a course marked by the highway to North Hampton village. They are about 2 miles west of the Newington moraine in Portsmouth and, taken together, are in a general way parallel to it, but they also trend toward the broad area of morainal deposits in North Hampton, as if they formed a protrusion from that area. The deposit in Greenland village forms a broad, flat-topped ridge that descends to a narrow sag about half a mile south of the village which separates the northern from the southern part. The moraine rises southward rather steeply from this sag to a narrow, flat-topped ridge about 125 feet above sea level and 1½ miles long in a south-southwest direction. The west side of the moraine is a short and steep slope toward the low clay plain of Winnicut River, but the opposite side is a broad and gentle sandy wash slope which merges into the clay plains on the east.

Upham[1] describes the morainal deposits in Greenland as a "kame." He says:

> The academy in Greenland is built on a broadly rounded, kamelike ridge of gravel, which at a short distance to the southwest becomes a nearly level plain 40 or 50 rods wide [Greenland Parade] but still farther to the southwest is narrowed to a typical kame. The length of this deposit is a half mile. Its height is nearly 100 feet above the sea.
>
> At a schoolhouse half a mile south from the academy we rise to a plain about 125 feet above the sea, which extends a mile to the south and southeast, descending with a gentle slope 25 to 40 feet in that distance. This plain forms the highest land between Winnicut River and Berrys Brook. Its northwest portion is quite thickly strewn with boulders, the largest of which are 5 or 6 feet in diameter, and over nearly its whole extent these have been sufficiently abundant for walling the fields. Four wells, however, between the schoolhouse and the Eastern depot [Greenland depot, on the Eastern division of the Boston & Maine Railroad], varying from 20 to 30 feet in depth, passed all the way through stratified gravel, sand, and blue clay. In three of these wells the upper portion was fine gravel or sand. One of them, a half mile southeast, and a cistern a quarter of a mile south from the schoolhouse, showed at the top 10 feet of very coarse but waterworn gravel, which was underlain by clear sand.

The moraine in Greenland marks a halt of the ice at a short distance back from the small lobe of the Newington moraine in Rye and is seemingly very little younger.

HAMPTON FALLS, SEABROOK, AND SALISBURY SEGMENT.

Morainal deposits of the next segment consist almost wholly of outwash sand and gravel plains except in Hampton Falls, where a small ridge of till is exposed. This ridge starts in the center of the village and runs southwest for nearly a mile. Along its western border the sand plains of this segment pass very irregularly between a group of till-covered rock hills and drumlins in the town of Salisbury, Mass. In Seabrook, N. H., the moraine is bordered on the west by the low valley of Hampton Falls River, which is underlain mainly by till with scattered rock ledges. Eastward the sand-plain surfaces pass beneath the marshes of Salisbury and Hampton, except for a small area in South Seabrook, where till with scattered rock ledges rises a little above the general surface of the sand plain.

The sand-plain characteristics are very well marked, especially between Salisbury and East Salisbury, and there are also wide stretches of well-developed plain in Seabrook. Although these plains are in general nearly horizontal, there are locally strong dips—for instance, 1 mile southwest of South Seabrook, where there is a marked dip to the southeast. In Salisbury and East Salisbury there is a gentle though not obvious dip which results in the disappearance of the plain below the level of the salt marshes. Rock outcrops are comparatively common in these lower portions of the sand plains, but there seems to be no causal relation between the position of the rock surface and the plain.

The deposits of the sand and gravel plains of this segment lie in three benches or terraces, at the edges of which hard beds of gravel appear. Two of these benches are seen in most of Seabrook and in the northern part of Salisbury. The third bench is seen only in northern Salisbury about a mile west and southwest of South Seabrook. The lower two benches are about 20 feet apart; the upper two are about 15 feet apart and are separated by a heavy bed of fine white sand that is well exposed near the water tower a mile southwest of South Seabrook. The gravel is usually fine and makes a smaller proportion of the morainal deposits than the gravels of the Rye and Hampton segment. The gravels appear to rest upon marine clay along the edge of the marsh at East Salisbury and also along the small brook about a mile northwest of East Salisbury.

NEWBURYPORT SEGMENT.

The next segment of the moraine runs southeastward from Amesbury through Newburyport to Parker River in Newbury. Most of this segment is separated from the Salisbury segment by Merrimack River and the adjacent marshes. During the formation of this part of the moraine, however, the sand outwash plains probably extended northeastward into those of the south end of the Salisbury segment. The moraine in this segment in general takes the form of a distinct ridge bordered by gently sloping sand plains on the northeast. The Newburyport ridge is for most of its length flanked on the southwest by a low valley containing numerous rock outcrops or rocky hummocks

[1] Upham, Warren, op. cit., pp. 162–163.

thinly covered with till. In its northwestern part, however, the moraine abuts against a high rocky ridge through which the Merrimack has cut its course, thus separating about a mile of the moraine from the main part in Newburyport.

This segment of the moraine varies much in height. At its northwest end it forms a group of kames about 150 feet above the sea. These diminish in height within a short distance and pass southward and southeastward into a well-developed sand plain ("Grasshopper Plains") about 100 feet above sea level, which fills in the area between the rock ridge above mentioned and the morainic ridge.

"Grasshopper Plains" has a broad, nearly level surface of more than 1 square mile, which is markedly pitted near High Street in Newburyport by kettle holes ranging from a few yards to 200 and 300 yards across and reaching 40 or 50 feet in depth. The smaller kettle holes are round and regular in shape but some of the largest are less regular and have hummocky and ridged bottoms. From "Grasshopper Plains" southwestward through Newburyport the moraine is a narrow ridge with a definite southwestward-facing ice-contact scarp 30 to 50 feet in height. Part of this scarp, between 1 mile and $1\frac{3}{4}$ miles west of the railroad, is comparatively steep and is notably ribbed, with deep and sharp reentrants toward the north and northeast between the ribs, resembling the buttressed forms on the ice-contact side of parts of the moraine in Newington. Elsewhere this slope, although smoother and less steep, is well marked for a distance of over 4 miles, to the point where the ice front turned southwestward around the drumlins in the village of Newbury. In that distance its summit diminishes gradually in altitude from 80 feet above sea level at the northwest to 20 feet at the southeast. The crest of the moraine lies along and for the most part south of High Street in Newburyport. It is in general a smoothly shaped ridge decreasing gradually in height toward the southeast, but in it there are several large kettle holes. On the northeast side the morainic ridge is bordered by an outwash plain of sand which slopes eastward (in part northeastward to the tidal basin of Merrimack River). Through a distance of 2 miles between "Grasshopper Plains" and the freight railroad the moraine stands above the outwash plain and is set off from it by an abrupt frontal scarp, which in places is 15 to 20 feet in height and is slightly sinuous or scalloped in trend where best developed. To the northwest and the southeast there is less and in many places no topographic distinction between the moraine crest and the outwash. In the form of its slopes and in its relation to low meadows on the one side and higher, gently sloping sand plains on the other side, the Newburyport ridge presents features almost identical with those of Merriland Ridge and the moraine in Biddeford. The moraine in Newburyport extends, diminishing in width and height, to the drumlins in Newbury and appears also on the southeast side of these drumlins as a narrow gravel terrace from 10 to 20 feet above sea level.

The moraine is composed entirely of sand and gravel in this segment. The materials are not now well exposed at any point, but a thickness of about 40 feet is shown in the railroad cuts in the city of Newburyport. Upham reports that wells in Newburyport show a maximum depth of 90 feet of sand and gravel. The materials are waterworn and appear from the poor exposures to be stratified, with gentle northeasterly dips. A gravel pit just northeast of the drumlins of Newbury shows about 20 feet of sand and gravel in which the pebbles are as much as 6 inches in diameter. The beds are roughly stratified and approximately horizontal, and they rest directly on large ledges of bedrock. No bedrock projects through the moraine except at the border of the high sand plain in the western part of Newburyport and also at the turn of the moraine next to the drumlins in Newbury. At these two localities the bedrock hills seem to have checked the advance of the ice.

OBSERVATIONS BY UPHAM.

Upham[1] made the following observations on the features herein described as the Newington moraine and on associated deposits in New Hampshire. It must be remembered in reading these extracts that the term "kame" as used by Upham in 1878 connoted deposits that were supposed to have been laid down by streams flowing between retaining walls of glacial ice—that is, in crevasses or between ice

[1] Op. cit., pp. 150, 155–156, 164, and 170–172.

lobes—or between an ice wall and a valley wall from which the ice had withdrawn.

In Newington and Portsmouth a kamelike plain of gravel and sand is the highest land between Great Bay and the Piscataqua River, but their shores, with the islands of this river below Portsmouth, are almost everywhere gently sloping hills of till or ledge.

Marine shells and other organic remains have been found in the lower portions of this valley [Piscataqua basin], showing that the ocean stood at a higher level when the modified drift in which they occur was deposited. * * *

Kames and kamelike plains about Dover and southward.—Near the coast from Dover to Newburyport are frequently found massive kamelike deposits, consisting of high plains or broadly rounded ridges of gravel and sand, which often form watersheds between wide valleys 100 to 200 feet below. The absence in these valleys of the terraces which mark erosion through modified drift shows that they were never filled with the same materials and that these remarkable plains and ridges were deposited in their present isolated position, with wide areas of lower land at each side. How this took place we can only explain by referring the formation of these deposits to the same causes which produced the kames. The ice sheet still remained unmelted upon each side at the time of their deposition, filling the valleys and wide areas of lowland, over which this gravel and sand must otherwise have been spread by the current of the floods on which they were brought.

The most extensive of these plains occur * * * in Newington and the northwest part of Portsmouth. Broadly rounded deposits of the same class occur frequently in this district, and southward, along the seacoast, they form the elevations on which the villages of Rye, North Hampton, and Hampton are built. A very interesting ridge of this kind extends from northwest to southeast through Newburyport. * * *

The last of these kamelike deposits which remains to be described within the limits of Piscataqua basin is the extensive plain of Newington and the northwest part of Portsmouth. This is 3 miles long from north to south, and for most of this distance averages a mile in width, forming a plateau 60 to 100 feet above Great Bay and Piscataqua River on each side. Outcropping ledges and scattered boulders are seen in many places upon its surface, but numerous wells show only modified drift to depths of 30 or 40 feet, being first coarse gravel, 3 to 10 feet in thickness, succeeded below by interstratified fine gravel and sand. The entire western edge of this deposit is a gently sloping escarpment, which descends 10 to 30 feet. On the north and east it rests mainly on ledges but at one place falls in an abrupt slope more than 50 feet. A section at its base in the north part of Newington showed sand overlain by gray clay, as at Dover. Southward, near the Concord & Portsmouth Railroad, its surface is sand, obliquely stratified. Between this and the Eastern Railroad it is changed to a broad ridge, 25 to 30 feet high, composed mostly of pebbles 6 inches to a foot in diameter, packed as compactly as possible, with no layers of sand. This gravel is finely exposed in an excavation, from which it is teamed 2 miles for repairing streets in Portsmouth. The deposit terminates southeast from the Eastern Railroad in a small plain of horizontally stratified sand. * * *

Modified drift along the seacoast.—The oldest and most prominent deposits of modified drift near our coast are kamelike hills, elevated plains, and broad ridges, composed of gravel, sand, and clay. * * * The gently sloping hill on which Rye village is situated, nearly 100 feet above the sea, is mainly stratified gravel from 25 to 40 feet in depth. It is coarse for the first 10 feet, with the largest pebbles a foot in diameter; below, it is fine but has little clear sand. The character of these deposits will be seen from the following sections of wells, 1 to 1½ miles southwest from Rye village, on the watershed south of Berrys Brook, and about 100 feet above the sea:

1. At J. Philbrick's (county map) [on the northwest side of Washington Road, 1.05 mile west of Rye Center], said to be the deepest well in Rye, coarse gravel, 25 feet; sandy, gray clay, very compact, free from pebbles, 28 feet; total depth, 53 feet. The only rock found in the clay was an angular block weighing about 200 pounds, 40 feet below the surface.

2. Near L. Brown's [on the northwest side of Washington Road, 1.15 miles west of Rye Center], coarse gravel, 8 feet; sand, 8 inches; coarse gravel, 6 feet; very coarse gravel, 10 feet, much of it composed of rounded rocks of nearly uniform size, about a foot in diameter, with scarcely any earth, so that "one could look down among the pebbles;" ordinary gravel, with layers of sand, 20 feet, resting on ledge; total depth, 45 feet.

3. At R. Shapley's [about 1.4 miles S. 65° W. of Rye Center], coarse gravel, 10 feet; fine white sand, 15 feet, resting on till or ledge.

Several other wells in this neighborhood, 30 to 40 feet in depth, encountered nothing but stratified gravel, sand, or clay.

Breakfast Hill, about 150 feet above the sea, and the plain about 50 feet lower, which extends southward to the first railroad crossing in North Hampton, are composed of coarse gravel and sand. Thence similar deposits, 100 to 125 feet above the sea, extend in nearly level plains southwest to North Hampton village, forming the watershed between Winnicut River and the ocean. They are bounded in many places by escarpments which descend steeply 25 to 50 feet, and a hollow, about an acre in extent and 50 feet deep, is half filled by Knowles Pond. This formation continues southward with nearly the same height to Hampton village, where it terminates, falling in gentle slopes toward the sea.

Nine miles farther south part of the city of Newburyport is built on a broadly rounded ridge of gravel and sand, which, like the foregoing deposits, probably had a similar origin with the narrow and steep ridges of the kames, having been bounded by portions of the melting ice sheet. The series of kames noticed by Rev. Mr. Wright in Newton and Amesbury may be continuous southeast to the Newburyport ridge. So far as traced, this deposit appears first in the south part of Amesbury. It has been cut through by Merrimack River and on its opposite side rises to a height of about 150 feet in Moultons Hill. A quarter of a mile farther to the southeast it is depressed to 75 feet and shows the sharp ridges and knolls of typical kames. From this point it extends, with a nearly uniform height of about 100 feet, along High Street to the middle of the

city and thence continues on the southwest side of this street to the Upper Green. Here it is interrupted for a little distance, beyond which it lies on the northeast side of this street, extending to within a half mile of Old Town Hill. It is thus at least 6 miles long. No other high deposits of modified drift are found in this vicinity, and wide areas of lowland lie on both sides. Excavations in the northwest part of the city show the ridge there to be composed mainly of waterworn gravel, with the largest pebbles about a foot in diameter. A railroad cut, known as Marchs Hill, 2 miles farther southeast, has only occasional layers of gravel, with the largest pebbles 6 inches in diameter, very irregularly stratified with sand, which is here four-fifths of the whole deposit. The depth of modified drift forming the ridge is shown by wells to be from 50 to 90 feet.

OBSERVATIONS BY SEARS.

Sears noted the ridge in Newbury and Newburyport and some sections in it that are not now exposed. He regarded it as partly moraine and partly barrier beach. The following quotation [1] shows that his interpretation of the position of the ice front with respect to the moraine differs from that of the present authors:

> The Merrimack River was probably a halting place of the glacial ice in its retreat northward, for its southern shore, from the mouth of the Parker River to Pipestave Hill, marks typical ice contacts of morainal till and overwash gravels capped by sand and silt. High Street, in Newbury and Newburyport, is laid out upon the top of the terrace formed by this ice contact, a section of which shows it to be composed of boulder till and clay beds resting upon the glacial bedrock * * * in varying depths. At Grasshopper Plain it is at least 50 feet in thickness and is covered by 20 feet of coarse gravel with 25 feet of fine sand at the surface. * * * A section of this terrace across High Street extending from the river through Green Street to the frog pond by "the Mall" gives boulder till on High Street at an elevation of 80 feet above tidewater. The frog pond is the site of a small detached iceberg that was buried in the morainal till. South of "the Mall" the overwash and outwash gravels have formed a series of cones and short ridges or kames of sand and gravel extending southeasterly into Newbury. The tracks of the Boston & Maine Railroad cut through these gravels on the west, and the track of the City Freight Railroad cuts through them on the east. In 1898 this cut exhibited a good section of the deposits some 300 yards in length. The gravels and sands dipped to the south at an angle of 35° and were capped by a deposit of clay having sand partings every few inches. The greatest depth of the gravel and sand was 40 feet. North of the center of the hill there was a dip 20 feet deep filled with clay having fine sand partings, and under the clay, at the bottom of the dip, there was a mass of peat, probably the site of an iceberg in the gravel before the clay was deposited.
>
> South of Oak Hill Cemetery there is a "kettle hole." * * * It is a typical small ice-block hole with southeastern outwash sand and gravel kames, probably deposited in cracks or gorges in the glacial ice which filled the whole valley of Little River.
>
> High Street, in Newbury, is built on sand and gravel that cap clay and till, a typical beach barrier sloping back to the lagoon at Four Rock Creek. The débris is washed away from the outcropping ledges that rise above the boulder till covering the surface. This beach barrier with the lagoon on the shore side occupied the whole of the Little River valley and was continuous on the southwest around Old Town and Little Old Town hills. A gorge between these hills, now filled with coarse waterworn gravels on top of boulder till, was the drainage outlet to the southeast. In front of the gravels the outwash sands spread out over Newbury Old Town, to the mouth of Parker River, where steep banks and fringing lobes extend into the salt marsh overlapping the boulder till.

[1] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., pp. 296, 301, and fig. 169, p. 352, Salem, Essex Institute, 1905.

OTHER ICE-FRONT DEPOSITS OF THE REGION.

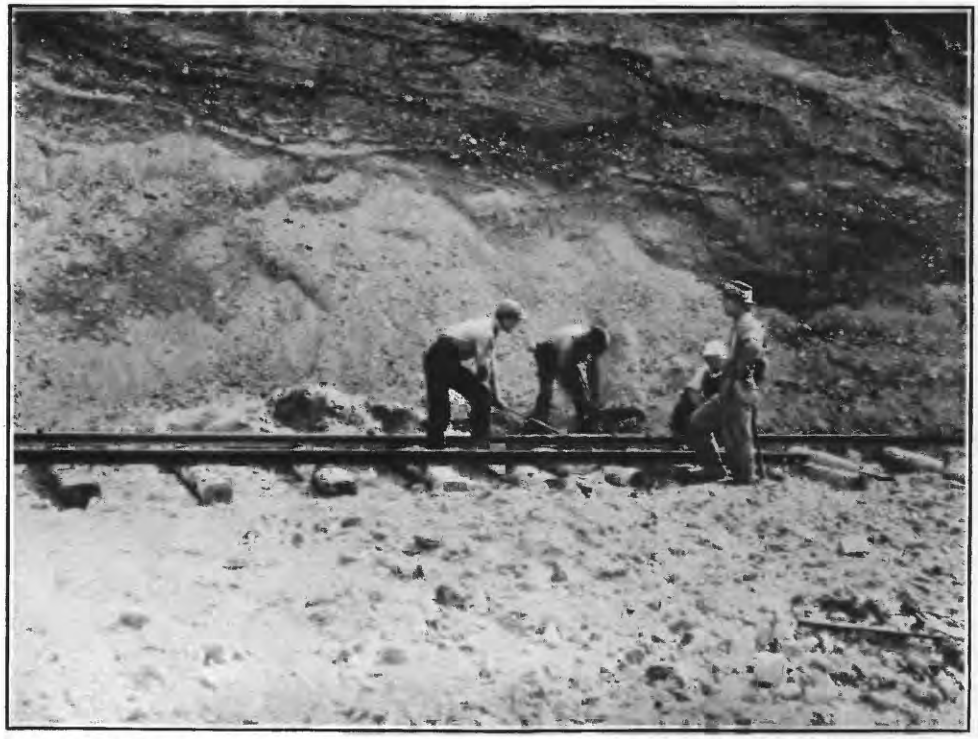
In this region there are a few other ice-front or morainic deposits which do not seem to be related to the Newington moraine and yet are of interest in connection with the subject of this paper by reason of their bearing on the interpretation of the glacial history of the region. The most distant of these is the moraine which lies across the south end of Lower Bay, Sebago Lake, Maine, 18 miles north of the Saco segment. This is a gravel ridge trending southwest to west-southwest, rising steeply 50 to 60 feet from the lake level, and presenting a very gentle southward slope of gravel and sand in which there are several deep pits occupied by ponds. At the lake the outwash slope has an altitude of 300 feet above the sea and is composed of coarse sand and gravel. About 1½ miles southwest, at an altitude of 200 feet, the outwash is very fine sand which grades imperceptibly into marine clay.

The moraine at Bauneg Beg Pond, 3½ miles north of North Berwick village (Pl. IV, p. 12), in the towns of North Berwick and Sanford, Maine, is several miles west of Merriland Ridge. It surrounds the south end of Bauneg Beg Pond as a hummocky, "knob and kettle" surface which grades eastward and southward into the broad sand plain that overlies marine clay in Wells and North Berwick.

The moraines at Bauneg Beg Pond and Sebago Lake lie several miles back from the Newington moraine, at the western edge of the coastal lowland. Besides these moraines and their outwash deposits, there are extensive sand

A. GRAVEL PIT ON MIDDLE ROAD, PORTSMOUTH, N. H.

Shows stratified gravel, sands, and clay in the inner side of the moraine, containing here and there larger but little-rounded cobbles.



B. GRAVELS AND SAND, PERHAPS OF KAME ORIGIN, IN SUNSET HILL, ELIOT, MAINE.

Poorly sorted, unevenly stratified gravel.

plains that front the highlands and valley trains in the valleys that debouch from the highlands upon the coastal lowlands, as, for example, in the valleys of Salmon Falls, Mousam, Little Ossipee, and Saco rivers, which seem to indicate other moraines or at least ice-front positions correlative with the moraine at Sebago Lake. The outwash from these later ice halts is larger in amount and more broadly and deeply spread over the region. In places the later outwash covers the Newington deposits and extends beyond them to the present shore line.

In Eliot and Kittery, Maine, there are a number of hills (indicated by moraine symbol on Pl. IV), wholly or in part composed of stratified drift, which lie a short distance east (outside) of the Newington moraine. The stratified gravels and sands of these hills are seemingly kame or other ice-front deposits which show no relation to one another nor to the Newington moraine. They do not appear to mark any definite or continued stand of the ice front. The following have been noted, and there are doubtless others in the region. In Kittery there is a broad, flat-topped ridge of gravels and sand in which the Boston & Maine Railroad Co.'s gravel pit exposes a thickness of about 40 feet of well-sorted and stratified materials. An area of stratified sands and gravels lies immediately east of Bolt Hill, a drumlin, in Eliot. At Greenacre, in Eliot, and including Frankfort Island, in Piscataqua River, is a narrow patch three-quarters of a mile long of low, hummocky knolls which are distinctly kamelike and are composed of waterworn gravel and sand. Sunset Hill, in Eliot, is probably composed largely of till but contains in its northern part thick deposits of stratified sands and gravel, perhaps of kame origin (Pl. XII, *B*).

These scattered kamelike or moraine-like deposits east of the moraine indicate no prolonged halt in the retreat of the ice before the front reached the Newington position.

NORTHWARD EXTENSION OF THE NEWINGTON MORAINE.

In the town of Saco (see Pl. IV and the map of the Portland quadrangle), from Goosefare Brook to Stuart Brook, for 1¾ miles along the Boston-Portland post road, is a line of smooth, flat-topped ridges about 100 feet in elevation, composed of sand and small gravel which is in part water-rounded, sorted, and stratified. These ridges rise only a few feet above the surrounding plains of marine clay and sand except where rock ledges having the same northeast trend protrude through the gravels. These ridges are 4 miles northeast of the Newington moraine at Saco River and are separated from it by a lowland consisting chiefly of clay. They may be an extension or an equivalent of the Newington moraine, but the observed facts indicate rather that these ridges are to be classed with other northeastward-elongated hills in the Portland quadrangle, such as part of Oak Hill, Pleasant Hill, and Sandy Hill, which are drift-covered ledges having superposed mantles of stratified gravels formed by the reworking of their till and other drift by the sea, which at the same time deposited clay in the low places around them. There are no other drift deposits farther northeast in the Portland quadrangle that can be regarded as morainal. If there were such a northeastward extension of the moraine it may have been destroyed after the Newington substage by strong streams that discharged from the Sebago Lake or younger ice fronts through the territory now largely covered by marine clays in Saco, Scarboro, South Portland, and Portland. It is more likely that any moraine deposited in this region, where the pre-Newington bedrock and till surface is generally low (being now in large part below or only slightly above sea level), would have been buried by the later marine deposits. Morainal material has not been observed where it might be expected on rock surfaces that protrude above the level of the marine clay and are in the line of general trend of the Newington moraine. It may be inferred, therefore, that the Newington ice front departed from this trend either seaward by the advance of a lobe through the Saco and Scarboro lowland or else northward. Southeastward lobation is not attested by any known deposits of morainic materials. To the north, on the other hand, in the northwest corner of the Portland and the northeast corner of the Buxton quadrangles, in Gorham and Buxton, there are gravel ridges and a kamelike gravel hill (Pl. IV) which may well be parts of the moraine. They are about 2 to 8 miles south of the moraine at Sebago Lake and

approximately on the line between that moraine and the Saco segment of the Newington moraine, which is 12 miles farther south. On this line also is the rock ridge north of the Saco segment, which may be a link between moraine segments like the rock hills between the Biddeford and Kennebunkport segments. The conditions thus afford a weak suggestion of connection between the Newington moraine and the moraine at Sebago Lake. The latter, however, may belong wholly or in part to a later substage, for its gravel and sand outwash in the main is continuous with and in part overlies the clay and sand plains, which can be traced without interruption or break in their nearly plane surface to and over the moraine in Saco.

SOUTHWARD EXTENSION OF THE NEWINGTON MORAINE.

The Newington moraine was not traced southward and southwestward beyond Newbury. Very probably correlative deposits will be found when that region is studied.

RELATION OF THE MORAINE TO OTHER PLEISTOCENE FORMATIONS.

ROCHES MOUTONNÉES AND TILL.

All the moraine segments noted lie in part on roche moutonnée surfaces and by inference also on ground moraine, or till. They have not been found to overlie stratified drift or such marine sediments as abound in the region. Glacially sculptured ledges lie both inside and outside of the moraine—in fact, all the ledges in the region have been glaciated. Till also is found on both sides of the moraine, and there are no perceptible differences between any of the exposures of till seen in the region. No till has been found in or on the typically developed moraines.

MARINE SEDIMENTS.[1]

Marine clay and associated sand beds, in the main horizontally stratified and in a few places fossiliferous, form extensive plains of sedimentation throughout the region, both east (outside), and also north and west (inside) of the moraine. In a few places the clay is sandy or contains sandy lenses and beds, and over a large part of this region, particularly at the north and west, the top beds are clean sand.

[1] These formations, the so-called "Leda clay" and overlying sands, as developed in southwestern Maine and southeastern New Hampshire, are the subject of another paper, to be published later.

Some of the clay lying outside of the moraine is contemporaneous with and stratigraphically equivalent to the moraine. This relation is best shown at Merriland Ridge, where, in the railroad cut (Pl. VII and fig. 1), a bed of clay identical with that in the broad plains of marine deposits is intercalated in the sand and gravel beds of the moraine and outwash. At that locality also the entire outwash plain slopes down to and grades into a low, swampy sand and clay plain about the headwaters of Webhannet River. It is clear that this clay bed records a period of quiet discharge of glacial waters during which they carried to and deposited on the moraine only the finest of glacial detritus—rock flour and mud. At other periods such materials were borne or drifted seaward and deposited in deeper or less disturbed waters than those at the ice front, and there formed the plains of which the flat in the valley of Webhannet River is one. This particular plain probably received no appreciable contributions of outwash during stages later than the Newington substage, because it is some distance away and cut off by rocky uplands from the Kennebunk and Mousam valleys on the north and the Great Works and Salmon Falls valleys on the southwest. It was from points farther up these valleys that the outwash of later stages came. On that account the marine clay deposits in the lower parts of these valleys are more extensive and at higher altitudes than in the coastal territory between the drainage basins of these streams. In other places the earlier clay deposits and some of the sandy outwash of the Newington substage are covered by more or less clay discharged into the sea from more northerly and later stands of the ice, during the time when clay was accumulating behind and upon the inner slope of the moraine. In Saco and Biddeford, along Saco River, excavations for gravel and sand show that the clay overlies the northwest side of the moraine and in places covers the crest. In most places where the marine clay borders the inner side of the moraine the surfaces of the two formations meet at an angle, and there is no significant mingling of their materials, as there is on the opposite side. Wells along the western base of the moraine in Portsmouth show that the clay does not pass under the moraine but lies against it. The inference to be drawn from this fact is that all the deposits of marine clay and sand lying inside the New-

ington moraine are younger than that moraine. Furthermore, these deposits are traceable inland into the broad sand plains and valley trains shown on the map (Pl. IV), which are evidently glacial outwash from ice that stood some miles back of the Newington moraine. However, all the clay in this region, from the lowest and oldest bed to the highest and youngest, must, for the following reasons, be regarded as a stratigraphic unit that was deposited uninterruptedly during a period perhaps beginning before the Newington substage but certainly continuing through and after it. First, the clay can be traced as a continuous deposit from points well inside of the moraine through such breaks as are made by Saco, Kennebunk, and Salmon Falls rivers in the moraine ridge to areas outside of the moraine. Second, careful scrutiny of the surface forms of the clay deposit,[1] of sections in the clay, and of the physical character of the clay itself fail to reveal any basis for subdivision of the clay into younger and older deposits.

EVIDENCE THAT THE MORAINE WAS LAID DOWN IN THE SEA.

The foregoing observations on the relation of the Newington moraine to marine sediments indicate that the ice front stood in the sea at the time and place of deposition of this moraine. This conclusion is established by the following evidence:

1. The surface of the moraine, as shown above, is in most places fairly smooth or is hummocky only in a small way by reason of knolls that are low and have gentle slopes, in contrast to the characteristically knobby kame forms, and in large part the crest of the moraine is broad and flat. Furthermore, although the material of the moraine is predominantly rounded, water-transported, and accumulated by glaciofluvial discharge, the form is not that of moraines accumulated subaerially but is like that of a delta or a line of many laterally confluent deltas, as for example in Biddeford, Wells, Newington, North Hampton, and Seabrook.

2. These very nearly level and broad, flat delta-like tops are all near the sea and are not separated from it by any present obstructions as high as the moraine. Therefore, unless it is postulated that an ice block, of which there is no evidence, or some high land not now remaining separated the moraine area from the ocean, there could have been no body of standing water not part of the sea at the required place and altitude to determine the form of the moraine.

3. In Merriland Ridge the interlamination of clay with moraine and outwash material, and the continuity there indicated of the sand and gravel beds in the moraine with marine clay beds in the plains to the east show that the débris from the glacier was discharged directly into the ocean.

4. Although the wide, level plains of marine clay were deposited in situations open to the disturbing influence of river, tidal, and storm currents, the clay is characteristically uniform in composition and texture and in the attitude of its bedding. Therefore the clay must have been deposited in quiet water—namely, in this instance, water whose surface was considerably above the levels up to which the clay plains were built and in consequence probably deep enough to submerge the moraine.

POSITION OF THE MORAINE WITH RESPECT TO DIRECTION OF ICE MOVEMENT.

The general direction of ice movement in this region was south-southeastward, as is indicated by numerous striae and also by a few drumlins. In the neighborhood of Biddeford, Maine, the striae trend S. 10°–15° E., and from Biddeford southwestward the easting increases with seeming regularity to S. $40° \pm 5°$ E. in the neighborhood of Portsmouth, although there are local exceptions. The ice flow was in accord with the general southeasterly land slope and approximately parallel to the trend of the major drainage lines. The moraine segments in Biddeford, Kennebunkport, Wells, South Berwick, Rye, the Hamptons, Seabrook, and Salisbury are then approximately athwart the general course of ice movement, and such departures of the moraines from that trend as are indicated by the map are accounted for by the influence of the local topography of the rock floor.

On the other hand, the Dover Neck, Newington and Portsmouth, and Newburyport segments are in part oblique to and in part even nearly parallel to the general direction of ice movement. The explanation of this seeming

[1] The writer's observations offer no support for subdivision of the clay on the basis of "distinct topographic types," as postulated by F. G. Clapp (Complexity of the glacial period in northeastern New England: Geol. Soc. America Bull., vol. 18, pp. 505–556, 1907).

discordance is found in the fact that the moraine is predominantly the product of accumulation of the load of effluent glacial waters and is not pushed material. It might therefore lie at any site on the margin of the ice which permitted the discharge of glacial streams, regardless of the normal form of the front with respect to the direction of ice advance. The factor that in all probability chiefly determined the form of the ice edge in the vicinities of Portsmouth and Newburyport was the destruction of the glacier by calving of bergs and melting in the deep waters of the Piscataqua and Merrimack estuaries. Thus reentrants were made in the ice front. Probably also subglacial drainage in large volumes was discharged at these low points and assisted in cutting back the front.

RECESSIONAL NATURE OF THE MORAINE.

A large number of exposures of drift deposits have been observed in the course of five seasons' field work on the general geology of southwestern Maine and the adjacent part of New Hampshire, particularly in the regions of Portland, Maine, and Portsmouth, N. H., which have been closely examined. In none of these exposures is there any evidence of more than one ice advance over that region. There is no superposition of later till on earlier till; there are no differences in the degree of weathering or extent of erosion of till which could safely be ascribed to any other cause than accident of situation or exposure; and there are no "interglacial" deposits. There is, therefore, no basis for assuming that the Newington moraine marks the termination of an epochal advance or readvance of the ice, nor even of a very short readvance. It can only be concluded that this is a recessional moraine that marks a stand of the ice front conditioned by a balance between the rates of ice movement and of ablation. In accord with this conclusion is the evident lack of angular till and of materials heaped up by glacial shove, a fact which suggests that the ice was not moving vigorously. The regular stratification of the washed material also indicates that the ice front made no advance during the deposition of the moraine. On the contrary, the great width of parts of the moraine and the thickness of the "backset" beds indicate slow retreat of the ice front during the accumulation of the moraine.

DISCONTINUITY OF THE MORAINE.

The major intervals between the segments of the Newington moraine which require explanation are of two kinds. Those in Biddeford and Kennebunkport and in Wells and South Berwick are occupied by rock hills of greater height than the moraine. These rock hills are, in fact, links rather than gaps between the moraine segments. They obstructed the advance of the ice and were the anchors that held the ice and in a measure determined the position of the Newington halt. No effort was made to find on these hills morainal deposits marking the position of the ice front; perhaps careful search will disclose them. However, the absence of push material and the preponderance of stream-borne materials along other parts of the ice border lead to the inference that little morainic drift was piled up against or on these hills, for they could not have been the sites of glaciofluvial discharge. Such materials as were dropped here from the melting ice were perhaps too small in amount to make a noticeable accumulation and would otherwise be indistinguishable from ground moraine.

On the other hand, the Kennebunk, Mousam, and Salmon Falls valleys make real breaks in the continuity of the moraine so wide (7 and 8 miles) as to demand special consideration. A brief search in these valleys for morainal deposits or for evidence of either absence or obliteration of the moraine was without conclusive result. On account of the deep filling by later marine sediments there seems to be little chance of establishing either the presence or the absence of the moraine across these valleys, but the manner in which the clay and sand plains surround exposed ends of moraine segments suggests strongly that the continuations of the segments lie buried under clay in the deeper parts of these valleys, just as the Biddeford and Saco segments are partly buried in the Saco Valley.

AGE OF THE MORAINE.

The age of the Newington moraine can not be decisively stated until the general problems of Pleistocene correlation in northern New England have been settled. It is established that

the Newington moraine is the youngest strictly glacial deposit in the immediate vicinity of the coast of New Hampshire and southwestern Maine. The only younger deposits are the later beds of marine clay ("Leda") and sand which overlie parts of the Newington moraine, and, as has been indicated, these are sea-laid outwash materials of a somewhat later stage during which the ice front stood not far back from the Newington moraine. Clapp's statement [1] that there is a till formation younger than and overlying marine ("Leda") clays finds no support in any exposed sections of the clay and its associated deposits which the authors have been able to find. But it is not merely for that reason that Clapp's conclusion is held to be inapplicable to the coastal region here considered. The critical fact is that the surface of the clay deposit is not glaciated but is a plain of deposition which, except for slight or moderate trenching by stream erosion, has been entirely unaltered since its formation. It is not denied that Pleistocene marine clays older than the Newington substage may have been covered by till, but if such clays are present in this region they are not to be seen because they are buried. It is also granted that elsewhere marine clays equivalent to the Newington or later substages may have been glaciated but not that such relations have yet been established.

It seems reasonable and safe to assume that when ice of the Wisconsin stage occupied Long Island, Marthas Vineyard, Nantucket, and the Cape Cod Peninsula [2] there must have been ice over the coastal counties of New Hampshire and southwestern Maine. Therefore, it must be concluded that the Newington moraine is of Wisconsin age, probably late Wisconsin, and, as a corollary, that so also is the marine ("Leda") clay of that region.

[1] Clapp, F. G., Complexity of the glacial period in northeastern New England: Geol. Soc. America Bull., vol. 18, pp. 505–556, 1907.

[2] The correlations of moraines in these regions with the early Wisconsin moraine of New Jersey is accepted. See Fuller, M. L., The geology of Long Island, N. Y.: U. S. Geol. Survey Prof. Paper 82, table opposite p. 220, 1914.

SUMMARY.

A recessional moraine consisting of several separate segments disposed along a sinuous course lies near the Atlantic coast and has been traced through 60 miles from Saco, Maine, to Newbury, Mass. It is for the most part about or less than 100 feet above sea level but rises to 180 feet in Biddeford, Maine, 150 feet in Dover, N. H., and Newburyport, Mass., and is between 200 and 250 feet above the sea in Wells and South Berwick, Maine. Although not more than 40 to 100 feet higher than surrounding Pleistocene formations, nevertheless it is topographically prominent because it is in a region of slight relief. The moraine rests upon and is surrounded by a floor of ice-smoothed rock and of till. The region was submerged during the building of the moraine, and the ice front stood in the sea. The moraine is the result of the accumulation of glaciofluvial detritus discharged directly into the sea; consequently in some places it is built up as broad, flat, delta-like plains of sand and gravel. Clay ("Leda clay") was continuously deposited in the sea, both while the moraine was accumulating and after the ice retreated from the moraine, so that the younger clay beds in some places overlie the moraine. This clay is the fine glacial outwash. The moraine and the marine clay probably belong to a late Wisconsin substage of the Pleistocene epoch.