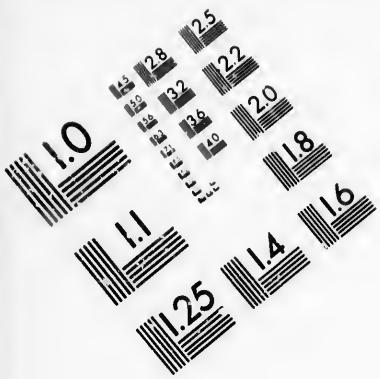

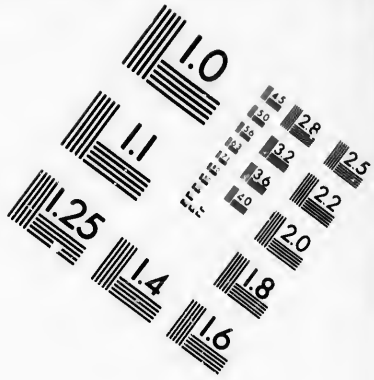

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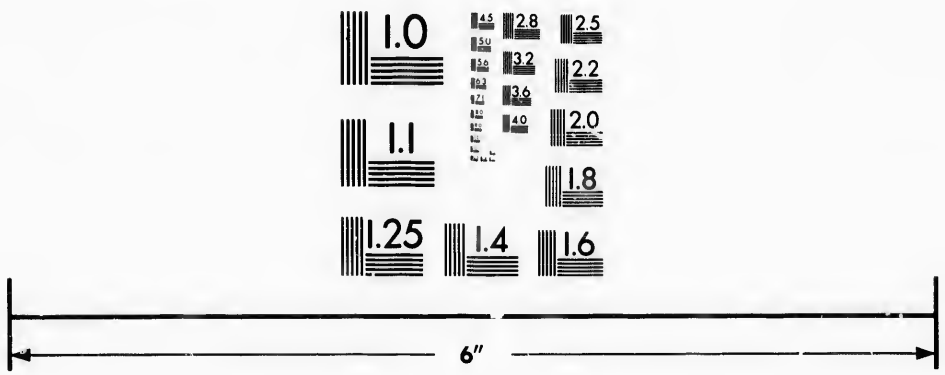

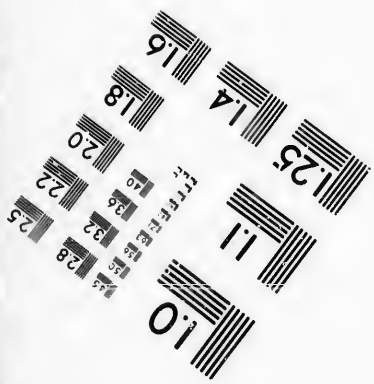

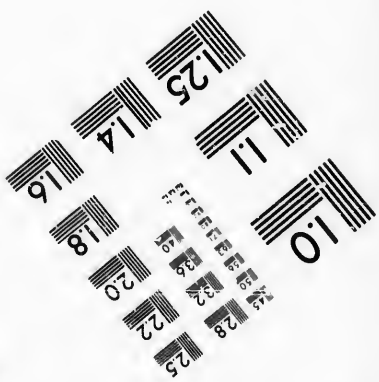

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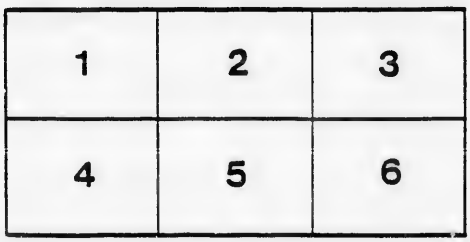

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[*Extracted from the Proceedings of the Rochester Academy of Science, Volume 2.*]

ESKERS NEAR ROCHESTER, N. Y.

By Warren Upham.

Rochester, N. Y.
Published by the Society,
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ESKERS NEAR ROCHESTER, N. Y.

A DISCUSSION OF THE STRUCTURE AND ORIGIN OF THE PINNACLE HILLS.*

By Warren Upham.

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The Area specially studied.

On the southeastern border of Rochester, N. Y., a remarkable esker series, named the Pinnacle hills, extends nearly four miles from east-northeast to west-southwest, rising from an approximately level country and forming the only conspicuous elevations of land close to that city. Under the guidance of Mr. G. K. Gilbert, this esker was examined by most of the geologists who attended the meetings of the Geological Society of America and of Section E of the American Association for the Advancement of Science in Rochester last August, and on the following morning about an hour was

*This paper was originally prepared for and read at the Ottawa meeting of the Geological Society of America, December 29, 1892.

given to discussion of the manner of its formation through the agency of the ice-sheet and the streams produced by its melting. Before stating some of the opinions brought out in that discussion, and attempting a full inquiry concerning the processes of accumulation of this and other eskers and kames, we will first go again, as I did on following days, over the Pinnacle hills and describe their contour and numerous sections exposed by excavations for road material and for the passage of streets. The other drift deposits and contour of their vicinity will be noted, and a second series of eskers lying several miles farther southeast in Pittsford, which I also examined, will be described, with their relationship to prominent drumlins near, and to terminal moraines more remote, on the south.

Description of the Pinnacle Hills.

From Brighton village and station on the New York Central railroad, three miles southeast from the station in Rochester, this prominent range of hills extends in an almost straight course about four and a half miles west-southwesterly to the Genesee river close south of the State dam. In passing the east end of this esker, the Erie canal turns from a due east to a due south course. Along its first mile from Brighton the esker rises 75 to 150 feet above the country on each side, and declines in height from 125 to 75 feet near the western end of this portion, where it is known as Cobb's hill. Immediately to the west, near the residence of Mrs. W. H. Cobb, a sag in the esker, as it was originally, before being cut down for the extension of Monroe avenue, had a height of only about 50 feet. Next westward the esker rises in the distance of a half mile to its highest point, called the Pinnacle, 200 feet above the nearly plain region on the north and south. Thence the continuation of the esker along its next two miles, varying in altitude mainly from 150 to 100 feet above the general level, is occupied, in order from east to west, by the St. Patrick Cemetery, the Highland Park, which includes the Mt. Hope reservoir in its western part, and the extensive Mt. Hope Cemetery In its next mile west to the river, the ridge is lower, having a height of only 80 to 50 feet above the State dam. The northeastern end of this hill range at Brighton is very definite, overlooking a wide expanse of the low land; but its western end is indefinite, for in the line of its continuation west of the Genesee it is represented along a distance of at least two miles (which is as far as my examination extended) by a low ridge, mostly 30 to 40 feet above the general level. Between

the Mount Hope Cemetery and the Genesee river and farther to the west, the material of the ridge is largely till, which shows that low portion to be a marginal or interlobate moraine; but the high range of the Pinnacle hills from Brighton to the Mt. Hope Cemetery is clearly an esker, 3½ miles long, consisting of interbedded gravel and sand, here and there enclosing boulders, sometimes in surprising abundance, but containing no till in the extensive sections nor on its surface.

The width of this hill range is mostly about a sixth of a mile, but varies from a tenth to a half of a mile. Along its whole extent it is a single range, nowhere presenting a combination of parallel series of hills; but, in some parts, especially in the Highland Park and near the reservoir, it is incised on each side by ravines between spurs and outlying hillocks of the main belt, and its top is occasionally very uneven in contour, with infrequent bowl-shaped hollows 10 to 50 feet below the surrounding surface. The profile of its crest line undulates in an irregular way, generally varying 50 to 100 feet in height upon each mile or half mile; and it nowhere maintains a level course for any considerable distance. In the vicinity of the Pinnacle and in many other places, the slopes on each side are very steep, ranging to a maximum of about 30 degrees; and the crest line has occasional slopes of half this steepness. More commonly, however, the slopes vary from 6 to 15 degrees, having from 10 to 25 feet of ascent in a distance of 100 feet.

When my first contribution to geology was published, sixteen years ago, "On the origin of Kames or Eskers in New Hampshire," (1) these classes of the modified drift, produced jointly by the ice-sheet and the water of its melting, had not been discriminated from each other. Every knoll, hillock or hill, short or long ridge, or series or network of ridges composed of irregularly and often anticlinally bedded gravel and sand, retaining nearly the original form in which it was accumulated, was then called interchangeably a *kame*, *esker*, or *as*, or a series of *kames*, *eskers*, or *asar*. The first of these terms is of Scottish, the second of Irish, and the third of Scandinavian origin, the last being Anglicized to *osar*, with *osars* as its plural form. It is found very desirable, however, to subdivide these gravel and sand accumulations into two classes, as proposed by McGee (2) and Chamberlin, (3) giving to the hillocks and short ridges the name

(1.) Proc. A. A. A. S., Vol. XXV, for 1876, pp. 216–225.
(2.) Report of the International Geological Congress, second session, Boulogne, 1881, p. 621.
(3.) U. S. Geological Survey, Third Annual Report for 1881–82, p. 299; Am. Jour. Sci., III, Vol. XXVII, 1884, p. 389.

kames, while the prolonged ridges are termed *eskers* or *osars*, excepting their peculiar development in northeastern Iowa, where they are composed chiefly of loess or fine silt and have received the name *paha*, alike whether singular or plural. (1) Kames, as thus defined, usually or often constitute an important part of the terminal moraines, and they are also frequent on many other portions of our drift sheet. Eskers are found likewise both in the vicinity of terminal moraines, sometimes being evidently of closely contemporaneous origin, and also remote from moraine belts. In length the eskers or osars vary from a mile or less to several miles, and in Maine and Sweden they extend in many continuous series, 20, 50, and even 100 miles or more. Their courses are commonly somewhat crooked, like those of rivers, but in general they run in parallelism with the glacial striæ and directions in which the ice-sheet moved and carried its boulders and other drift.

The structure of the Pinnacle hills esker is well exhibited near its northeast end, near Monroe avenue, and at various places separated only by short intervals, thence westward to Mt. Hope avenue and cemetery, by excavations for the use of its gravel and sand in road-making and masonry. Less than a quarter of a mile south of Brighton, a cut on the northern slope of the east end of the esker, just east of the north to south road (Arbutus avenue), has a depth of about 30 feet and length of some 12 rods. The upper 10 feet are fine gravel and sand, almost levelly bedded, beneath which the remainder of the section consists of very coarse but distinctly stratified gravel, with a nearly uniform dip of 15° W. S. W. This coarse gravel contains cobbles and rock fragments of all sizes, up to 1½ feet in length, packed closely together, their interstices being filled with finer gravel, sand, and very fine silt. About two thirds of all the stones are much water-worn, so as to have rounded forms; nearly all of the remaining third are somewhat worn, being subangular; and only about a twentieth part are rather sharply angular, with little or no evidence of attrition in their transportation by the glacial river. Fully half of the small gravel, up to six inches in diameter, are Medina sandstone; and about a third of the cobbles and masses from 6 to 18 inches in diameter are Archæan gneissoid rocks. Only four boulders of larger size, none of these exceeding four feet in diameter, were seen in this section.

Close west of this road, nearly opposite to the foregoing and at a distance of 10 to 30 rods southwest from it, a larger excavation,

(1.) W J McGee, "The Pleistocene History of northeastern Iowa," in the Eleventh Annua Report of the U. S. Geol. Survey, for 1889-90.

also in the northern side of the esker, consists almost wholly of fine gravel and sand, with stratification mostly inclined 5° to 20° southward. This section, 30 to 40 feet deep, and the surface of the esker immediately adjoining it, have only very rare boulders; but within a short distance the southern slope of the ridge, where it is cut for the road, has many boulders on the surface and in the upper 10 feet of the gravel and sand. The rather broadly rounded top of the esker is here about 80 feet above the general level on the north, east and south. In its central part, 25 feet below the top and some 20 rods from its northern base, a small space of this section, 10 feet long and 6 feet in height, shows three sharp faults, each having 2 to 3 feet of displacement, with overthrust from south to north. The beds overlying the faulted portion, which was near the bottom of the excavation, and the continuations of the faulted layers away from this place on each side, were undisturbed, dipping 10° to 15° S. or S. S. W. Fifteen to 40 feet east from these faults, slightly higher beds show eight repetitions, within a thickness of 8 feet, of layers of gray gravel, 3 to 12 inches thick, separated by layers of fine yellow sand 1 to 3 inches thick. These alternations probably represent the rapid and strong currents of a glacial river during the fast melting of the ice surface by day and the slow currents at night, when ablation was at its minimum or ceased.

Another large excavation 300 to 500 feet west of the last, likewise in the northern side of the esker, has a vertical face of 40 to 50 feet, consisting of interbedded gravel and sand in its upper half, while its lower half is mostly sand. The largest cobbles in the gravel are about one foot in diameter, and no boulders were observed. Mainly the dip is 10° to 20° southward, but at the east end of this section its upper 10 to 15 feet are much contorted, with a prevailing northerly dip of 10° to 15°.

In the southeastern side of the esker, opposite to Mrs. W. H. Cobb's house, an excavation about 25 rods long and 50 to 60 feet high consists in its upper part, to a depth of 6 to 20 feet from the surface along its whole extent, of sand and very coarse gravel enclosing exceedingly abundant boulders of all sizes up to 6 or 8 feet in diameter, far more plentiful than in the ordinary till of this region. Below this portion, the remainder of the section, extending downward 30 to 40 feet, is irregularly interstratified gravel and sand, with only infrequent boulders. The whole section shows stratification by currents of water, and according to my estimate nineteen twentieths of

the gravel and small rock fragments are rounded or at least much worn on their edges and corners.

Other sections which were examined in our excursion on the northern slope of the esker near this place and about a quarter of a mile to the northeast, show the same astonishing profusion of boulders with the upper coarse gravel, underlain by beds having fewer boulders. The gravel and sand are characterized by irregular and often oblique bedding, variable thickness of individual layers, and occasional oblique or nearly vertical faults with small amount of displacement (1). Boulders are also strown in considerable numbers on the surface of this part of the esker, but elsewhere along most of its extent they are usually rare both on the surface and in excavations. Mr. Gilbert called attention to the origin of the boulders, and pointed out the very significant fact that many of them are of the Niagara limestone, which can have been transported no more than three or four miles from its parent ledges, since the northern limit of this formation lies within that distance. Some of these boulders were seen on or near the Pinnacle, at least 200 feet above the outcrops on the plain country northeastward from which they must have been derived.

Continuing over the Pinnacle and through the Highland Park, I examined numerous sections, all of which were interbedded gravel and sand with only very rare boulders or more commonly none. Occasionally, however, a boulder 5 or even 10 feet in diameter is found on the surface, or in a section, remarkably in contrast with the water-deposited sand and gravel, in which the largest pebbles and cobbles range from a few inches to a foot, or seldom one and a half feet in diameter. From the Pinnacle to the Mount Hope cemetery, most of the excavations are chiefly sand.

The cut made west of this cemetery by a branch of the New York, Lake Erie & Western railroad has a length of nearly a quarter of a mile from north to south and is from 15 to 25 feet deep. Large portions of this section are true till, or clay, sand, and small and large rock fragments, mingled in an unstratified deposit; but, like the till of the surrounding country, it contains only few large boulders. Among the half dozen boulders of greater size than two feet in length seen in the eastern face of this excavation, one of the largest, about five feet in diameter, was Niagara limestone. With the depos-

(1.) Numbers 323, 324 and 325 of the list of photographs of the Geological Society of America (Bulletin, G. S. A., Vol. III, p. 472) are views of sections of the Pinnacle hills esker at this locality, photographed and presented by Professor H. L. Fairchild.

its of till are many intercalated layers of stratified sand, from 1 to 5 feet in thickness, often continuous along a distance of 100 feet or more. These layers are mostly horizontal or only slightly inclined, and no contortion nor evidence of erosion or tumultuous pushing forward was observed.

Beyond its intersection by the Genesee river, this ridge is the site of the Rapids Cemetery, and thence it extends nearly due west two miles along or close to Brooks avenue. It rises by usually gentle slopes 30 to 40 feet above the land on its south and north sides, and has a width of 25 to 50 rods, being often quite irregular in contour, which with its clayey soil and occasional boulders, gives it a morainic aspect. Where it is cut by the Buffalo, Rochester & Pittsburgh railroad, nearly two miles west of the river and between an eighth and a third of a mile north of Brooks avenue, several recent excavations showed about half of its material to be till, and the remainder very compact stratified sand. These unlike deposits are irregularly accumulated together, but no interblending was seen. The till has no marks of water action, and the sand is free from boulders or gravel, and is horizontally bedded or nearly so, being sometimes 5 to 15 feet thick with an exposed extent of fully 100 feet.

Relationship to the surrounding Country.—Throughout the city of Rochester, excepting the Pinnacle hills and the gorge of the Genesee below its falls, the surface is nearly a plain, with slight descent toward Lake Ontario. The underlying Niagara and Clinton formations are covered generally with only 10 to 20 feet of drift, which is mainly till and in small tracts stratified clay or sand and fine gravel. Northward from Rochester, the surface in Irondequoit and Greece townships declines with a gradual slope 200 to 250 feet in the distance of 5 to 7 miles to Lake Ontario.

The fjord-like Irondequoit bay, lying between Irondequoit township on the west and Webster and Penfield on the east, stretches about five miles southward from Lake Ontario, with a width varying from one mile to a half mile, bordered by cliffs 100 to 200 feet high, which rise to the general plain on each side. The maximum depth of Irondequoit bay is 80 feet, which must be added to the height of the bluffs to give the total depth of the eroded valley; and its southern end, where the Irondequoit river flows into it, is about five miles east from the center of Rochester. Before the Ice age the Genesee doubtless entered the lake through this valley, probably leaving its present course near the mouth of the Honeoye creek, flowing eastward, through Bush township and the southern part of Mendon, and thence northward along the Irondequoit river and bay. In the southeast

edge of Pittsford the Irondequoit, where it is crossed by the Erie canal and for three miles southward, is about 100 feet lower than the Genesee near the south line of the city of Rochester, above the State dam. Especially thick accumulations of the glacial drift in Mendon caused the Genesee after the Ice age to take its new course through Rochester; and its rock gorge, extending from the center of this city to its mouth at Charlotte, has been eroded during the Postglacial or Recent epoch, of which, like the gorges below the falls of Niagara and of St. Anthony, it affords a means of measurement, if the extent of recession of the Genesee falls during the present century can be determined.

Southward and eastward, elevations of equal height with the Pinnacle hills are first found at the distance of 7 to 10 miles, being prominent drift accumulations later to be described in this paper, lying in the southwest part of Pittsford and northwestern Mendon, and between Victor and Fairport.

The relation of the Pinnacle hills to the adjoining region will be further exhibited by the following list of altitudes, which are mostly derived from maps in the office of Mr. J. Y. McClintock, city engineer of Rochester, others being from the United States Lake Survey. They all are referred to mean tide sea level.

Altitudes in Rochester and its Vicinity.

	Feet above the sea.
Lake Ontario, low and high water, 245–249; ordinary stage	247
Iroquois beach, between Irondequoit bay and the Genesee river (Gilbert)	436
Erie canal, coping and tow-path of viaduct crossing the Genesee river in Rochester, 510; water	508
New York Central railroad track at Rochester station	516
Wide Waters of the Erie canal on southeastern line of Rochester	500
Railroad at Brighton station	460
Canal at Brighton	480
Summit of Arbutus avenue one-fourth mile south of Brighton, crossing the east end of the Pinnacle hills esker	536
Top of esker about 50 rods west of last	570
Top of esker one-third mile farther west	652
Depression close southwest of last	590
Highest point of Cobb's hill, one-third mile farther W. S. W.	663
Top of esker about 40 rods westward	608

	Feet above the sea.
Intersection of Monroe and Highland avenues, at Mrs. W. H. Cobb's residence, immediately south of last	544
The Pinnacle, one-half mile farther west	749
Summit of Pinnacle avenue, crossing the esker one-third mile farther west	583
Top of esker in Highland park, at the Memorial Pavilion	650
Mt. Hope reservoir, water surface	634
Summit of South avenue	617
Summit of Mt. Hope avenue	622
Highest portions of the esker in Mt. Hope cemetery, about	675
Crest of morainic ridge extending westward as a continuation of the Pinnacle hills, where it is cut by the Genesee Valley branch of the New York, Lake Erie & Western railroad	583
Same, on east bank of the Genesee river	559
Same, west of the river, at the Rapids cemetery and onward	555–560
Genesee river above the State dam, near the foregoing	508
At foot of this dam	504
At the Clarissa street bridge	502
At the Court street bridge	493
At the Andrews street bridge	484
Upper falls, top of rock, 476; water in ordinary stage at brink and foot of the fall	473–387
Above and below the Middle falls	374–348
At mouth of Deep Hollow creek and brink of Lower falls	345
At foot of Lower falls	251
At the steamboat landing, about one mile north of the last, on the level of lake Ontario	247
Seneca Park bridge, spanning the gorge close below the Lower falls	460
Highest ground at the Rochester University	520
Canal and railroad at Pittsford, about	460
Irondequoit river under the viaduct of the Erie canal, about	400
Turk's hill, a station of the U. S. Lake Survey triangulation, near the south line of Perinton township, about 12 miles southeast from the Pinnacle hills	928
Rush reservoir of the Rochester Water Works, 9 miles south of the Mt. Hope reservoir	753
Hemlock lake (maximum depth, 87 feet), source of the Rochester water supply, 19 miles from the Rush reservoir	898

Eskers in Pittsford.

From 2½ to 3 miles southeast of Brighton, the New York Central railroad makes a long cut through the northern end of a second esker series, which takes a course approximately at right angles with that of the Pinnacle hills. Beginning close south of Allen's creek, in the southwest corner of Penfield township, this belt of kames and eskers runs south-southeasterly through the east half of Pittsford and about a mile into the southwestern corner of Perinton, terminating in a sand plateau, which abuts upon the western base of the prominent Turk's hill range of drumloid drift. The length of this Pittsford esker series is about seven miles.

In its northern third, extending from Allen's creek southward to about a mile east of Pittsford village, the width of this belt varies mainly from a half mile to fully one mile, and it consists of a principal broad north to south esker ridge, becoming narrower and interrupted southward, with a considerable lateral expansion, especially on the east, in kames, or short ridges, mounds and hillocks, all being composed of sand and gravel, with infrequent enclosed boulders. The cut for the railroad is about a half mile long and 50 feet deep. Its greater part is yellow sand, nearly horizontal in stratification, excepting at the margins, where the bedding is more irregular, prevailingly dipping downward like the surface slopes. In this sand are occasional thin gravelly layers, but these are nowhere conspicuous. Very rare embedded boulders were seen. Only two, which were respectively about 3 and 5 feet in diameter, were exposed in the section at the time of my visit, and scarcely a half dozen in total lie at the foot of the banks on both sides of the railroad. The basal part of this section, however, for about an eighth of a mile west from its center, consists of coarse gray gravel, containing very closely packed gravel stones and cobbles up to 6 or 8 inches in diameter, but no larger boulders. On the north side of the excavation the gravel reaches to a height of about 20 feet above the track, and displays a very distinct anticlinal stratification.

About 1½ miles southeast from this railroad cut, a small excavation for the passage of a north to south road through a kame deposit, chiefly of sand, near the east line of Pittsford and the east border of the esker and kame belt, reveals a boulder 3½ feet in diameter, embedded 10 feet below the surface. Beneath and above the boulder, the stratification of the sand and gravel is contorted and curved, in conformability with the outline of the rock mass.

After an interruption or gap about 40 rods in length, the more southern portion of the series, from a point about a mile east-southeast of Pittsford village to its termination about a mile southeast and south of the village of Bushnell's Basin in Perinton, is well described as follows, by Mr. Charles R. Dryer, in a paper which also treats of the Pinnacle hills, Irondequoit bay, and the massive hill ranges of till south of Pittsford and Fairport (1). Mr. Dryer, following the early usage of the term *kame*, applies it to the narrow esker ridge, with steep slopes and sharp crest, which he describes one to three miles southeast of Pittsford, succeeded in the next mile or more by a sand plain or plateau.

"The north end is a sharp ridge of very coarse gravel, fifty feet in height, one mile long, and in shape like a rude fish-hook. It is separated from the southern portion by the channel of Irondequoit river, which has cut the kame completely in two. In the southern portion the gravel is overlaid by fifty feet of fine sand which spreads out toward the southeast in a sheet a mile or more in width. This kame forms a dam across the valley, complete except for an interval of less than one-fourth of a mile on its western side. The Erie canal avails itself of this kame to cross the valley and by a fifty-foot embankment restores what probably once existed as a natural feature. South of the kame the valley is as level as a floor for three miles up the stream and was evidently once the site of a lake whose waters were held back by the kame as a dam."

Relationship to Drumlins and Terminal Moraines on the south.—To understand the history of the recession of the ice-sheet in this region and of the accumulation of its drift, it is needful for us to take for a moment a somewhat broad view southward. Beginning within a half mile south of Pittsford, drumlins are admirably developed upon an area extending six or seven miles to the south, into the northwest part of Mendon. They also form the crests of a massive drift ridge which stretches from Fairport south to Victor, culminating in Turk's hill; and beyond a depression, through which the railroad from Rochester to Canandaigua passes, similar massive, drumlin-crowned highlands extend from Victor several miles to the south and southwest. These highlands appear to me referable to the class of drumlins, rather than to that of terminal moraines marking the outlines of the ice-front at any stage of temporary halt in its general retreat. Eastward from this region, drumlins occur in extraordinary abundance for a distance of 60 miles, to the vicinity of Syracuse (2).

(1.) The Glacial Geology of the Irondequoit Region, Am. Geologist, Vol. V, pp. 202-207, with map, April, 1890.

(2.) L. Johnson, "The Parallel Hills of Western New York," Trans., N. Y. Acad. of Sci., Vol. I, 1882, pp. 78-80; Annals, do., Vol. II, pp. 249-266, with map.
D. F. Lincoln, "Glaciation in the Finger Lake Region of New York," Am. Jour., Sci., III, Vol. XLIV, pp. 290-301, Oct., 1892.
Warren Upham, "Conditions of Accumulation of Drumlins," Am. Geologist, Vol. X, pp. 339-362, Dec., 1892.

Between 35 and 60 miles south of Rochester, conspicuous terminal moraines run approximately from west to east, as described and mapped by Professor T. C. Chamberlin (1). On the meridian of Rochester these moraines are somewhat interblended, fragmentary, and irregular in their development upon a width of nearly 25 miles from the southern ends of Conesus and Hemlock lakes southward to the vicinity of Hornellsville. Farther to the east, for a distance of about 150 miles, to the Catskill mountains and the Mohawk river, they are more distinctly developed as two morainic belts, of which the southern one is traced in a slowly curving course, convex toward the south, along the valleys of the Canisteo, Tioga and upper Susquehanna rivers, while the northern one passes in a more sharply curved and lobate course by the south ends of the Finger lakes to Ilion and Herkimer on the Mohawk. In the valleys extending southward from the heads of the larger Finger lakes the thickness of the northern moraine appears to be several hundreds of feet, and in the case of Seneca lake perhaps more than 1,000 feet; but on the intervening plateaus the thickness of the morainic drift is comparatively insignificant, averaging probably no more than 25 to 50 feet upon widths varying from one to two or three miles.

A more distant moraine, however, lying on and near the boundary of the glacial drift, extends from the vicinity of Salamanca, N. Y., east-southeasterly to the Delaware river at Belvidere, N. J., and to Staten Island, the Narrows, and Long Island. This moraine, described in Pennsylvania by Professors Lewis and Wright, (2) passes about 100 miles south of Rochester.

Relationship to Glacial Movements.—The currents of the ice-sheet flowed perpendicularly toward its boundaries and marginal moraines, that is, to the south or somewhat west of south for the region about Rochester and Pittsford; but during the recession of the ice from that area, its currents were in some portions deflected much to the west, because of more rapid melting of the ice on that side and consequent indentations or embayments in its border. This faster melting on the west was probably at first due in large part to the laving action of the glacial Lake Warren, which extended from the western part of the basin of Lake Ontario over the upper Laurentian lakes, outflowing at Chicago to the Des Plaines, Illinois, and Mississippi rivers; and in the later stage of the glacial recession when the Roch-

(1.) Third Annual Report of the U. S. Geol. Survey, for 1881–82, pp. 351–360, with Plate XXXIII.
(2.) Report Z, Second Geol. Survey of Pennsylvania.

ester and Pittsford eskers were formed, the ice-melting was likewise promoted by the incipient Lake Iroquois, outflowing by Rome to the Mohawk and Hudson.

According to notations of glacial striæ by Chamberlin, Gilbert, and Dryer, their courses are as follows: near the northeast corner of the city of Rochester, S. S. W. to S. W.; near the southwestern boundary of this city, S. W. to W. S. W.; and in Greece, the next township northwest of Rochester, four courses, intersecting or on contiguous rock exposures, S. S. E., S. S. W., S. W., and W. The southward courses are doubtless somewhat earlier than those running to the southwest and west, which belong to the short time when the glacial currents were deflected during the departure of the ice. Upon all the region of the Finger lakes the glacial striation is approximately from north to south, in parallelism with these lakes and the intervening ridges and plateaus. On the north the grand ice currents over the Province of Ontario moved mainly southward, with convergence from the southern part of Georgian Bay southeasterly, and from Montreal and the upper St. Lawrence southwesterly, toward the basin of Lake Ontario and the great re-entrant angle of the glacial border at Salamanca in southwestern New York.

The trends of eskers and drumlins testify of the directions of the currents of the ice-sheet as trustworthily as the courses of glacial striation on the bed-rocks, with which the esker and drumlin ridges are parallel. Both these classes of drift accumulations, however, were formed near the border of the ice during its recession at the close of the Glacial period; and they consequently often record local deflections of the glacial currents caused by unequal rates of melting and the resultant sinuosities of the ice-front. The Pittsford esker series, trending south-southeast, is nearly parallel with the general movement of the ice-sheet, both during the time of its maximum extent and thickness and during the decadence; but the Pinnacle hills, trending west-southwest, show that a considerable local indentation or embayment in the waning ice-border there turned its currents much to the west from their former course.

Probable Origin of these Eskers.

Although these two esker series, lying only a few miles apart, differ about 90° in their trends, they were probably formed at the same time or one very soon after the other, as might happen by diver-

sion of a glacial river from one avenue into another near its point of discharge from the ice-sheet. Each series seems to be attributable to deposition in the ice-walled channel of a stream of water flowing down from the surface of the melting ice-sheet, where the gravel and sand had been gathered from the previously englacial drift that had been exposed by ablation as a superglacial stratum. Near their mouths, or places of discharge to the land surface, these rivers appear to have flowed in valleys or gorges inclosed by unmelted plateaus of the ice-margin, upon which much drift rested. In some sections of our drift formations, as of Third and Fourth Cliffs in Scituate, Mass., which are partially eroded drumlins on the shore of the ocean, thick beds of stratified gravel and sand are found which were undoubtedly laid down by subglacial streams (1). But such beds formed under the ice-sheet are rare in most parts of the country, and the eskers here described and all others which have come under my examination of extensive areas in New England, and in Minnesota, northern Iowa, the Dakotas, and Manitoba, I believe to have been deposited in ice-walled channels open above to the sky.

Before proceeding to consider more in detail the structure and materials of these eskers in their bearing on this view of their mode of accumulation, it will be desirable to notice former expressions of opinion as to the origin of the Pinnacle hills. The earliest reference to this esker is by James Hall, in his report on the Fourth Geological District of New York, published in 1843. In pages 323 and 324 he gives a figure and description of the section where the ridge is intersected by Monroe avenue. "The gravel," Professor Hall remarks, "consists principally of waterworn fragments of the Niagara limestone, on which the whole deposit rests, and of the sandstones and limestones on the north. There are some boulders of the limestone, from two to four feet in diameter, worn perfectly smooth, or often striated with shallow grooves; and from the fact that this is the subjacent rock, they have received their rounded forms and smooth surfaces from attrition near the spot where we now find them." When this was written, the glacial theory of Agassiz had been published only a few years, and was not apprehended by Hall with such clearness as to seem adequate to account for this and our other drift deposits. It was observed that in this section "nearly all the strata dip towards the west," whence it was concluded that "the accumulation doubtless took place from

(1.) Proceedings of the Boston Society of Natural History, Vol. XXIV, 1889, pp. 228–242; Vol. XXV, 1891, pp. 228–242.

this direction, from the heaping of the coarse gravel upon the fine sand."

Mr. Charles R. Dryer, in the article before cited, calls both the Pinnacle hills and the Pittsford series kames, implying their deposition in the channels of glacial rivers. He especially notices that on the area where, if prolonged to the northeast and north, they would intersect, the valley of Irondequoit bay has been apparently filled with stratified sand and gravel to a height of 150 feet or more above the lake, as indicated by narrow terraces at such height left on each side of the bay. The level of the glacial Lake Iroquois during a late stage of its history, according to Mr. Gilbert, sank here considerably below the shore of Lake Ontario, and the depth of the Irondequoit bay suggests that the depression of this southern part of the glacial lake, permitting erosion of the former plain of modified drift in the Irondequoit valley, reached at least 80 feet beneath the present water level.

The discussion concerning the origin of the Pinnacle hills after the excursion to them last summer by members of Section E of the American Association was opened by Mr. Gilbert, who drew on the blackboard a sketch map of the esker series and the region about it and called attention to the narrowness of the east and west belts of outcrop of the several geologic formations. The Niagara limestone, occupying a belt that ranges from 2 to 7 miles in width through this part of New York, underlies the Pinnacle hills and much of the city of Rochester. Next northward the Clinton formation has a similar width, and beyond this the Medina sandstone outcrops on a somewhat wider belt which adjoins Lake Ontario. Each of these formations and the Archæan rocks of Canada are represented in the gravel and boulders of this hill range, and it is especially notable that usually the Niagara limestone is very plentiful, both as gravel and as boulders, which vary in size up to ten feet in diameter. Evidently this limestone drift can have been transported only a few miles, and its occurrence in the highest portions of the Pinnacle hills must be taken into account in inquiring how they were accumulated, for which, however, Mr. Gilbert had not framed any complete and detailed explanation.

Professor G. F. Wright and Mr. C. W. Hayes spoke of their own observations and those of Prof. I. C. Russell on glaciers in Alaska, where much superglacial drift is exposed on the wasting borders of the ice-fields and portions of it are washed away by rains and streams, which in most cases carry it finally into crevasses and subglacial

water courses, like those of the Yahtse river and Fountain stream described by Russell as flowing out from beneath the Malaspina glacier. In these subglacial channels the streams must be building up eskers, while gently sloping gravel and sand plains are being deposited by the silt-laden waters in their course from the ice front to the sea (1).

Professor E. W. Claypole drew a section of the marginal portion of the ice-sheet, showing how, in his opinion, the Pinnacle hills were formed by a stream which gathered drift from the melting ice surface, and then fell through a crevasse and deposited the sand, gravel, and boulders in a tunnel under the ice.

Following these speakers, I remarked that the absence of any covering of till upon the top and slopes of this esker, such as must have fallen upon it from the englacial and superglacial drift of its roof of ice if it were formed in a subglacial tunnel, leads me to believe that its stream was wholly superglacial, and that the esker was deposited in a deep ice-walled gorge, open above to the sky, eroded in the border of the ice-sheet by the melting action of the running water.

The purpose of the present essay will be completed by more fully considering the probable manner of transportation of the many boulders found in some portions of the gravel and sand of the Pinnacle hills, the relationship of this esker to the lower morainic ridge continuous from it westward, the abrupt eastward ending of the Pinnacle hills range, and similar features of the Pittsford esker series, with the inquiry constantly in mind whether these features support the view that these eskers were derived from previously englacial drift and accumulated in superglacial channels. It will be needful at the same time to consider the drainage from the ice-border in its relations to the glacial Lake Warren and to the beginnings of Lake Iroquois. Beyond this we ought to learn, if possible, whether the same explanation is generally applicable to eskers in other regions.

The leading reason for our special interest in the Pinnacle hills is the demonstrably near sources of their Niagara limestone boulders, which have been transported only a few miles and yet were uplifted at least 100 to 200 feet into the ice-sheet from an approximately plain country. Here we have a demonstration of the competency of the glacial currents to gather drift into the lower part of the ice-sheet from a nearly flat area, and we may understand how this takes place by the differential movements of the upper, middle and lower portions of the ice. Upon a belt of the ice-sheet extending many miles

(1). For description of the present process of formation of eskers and sand plains by rivers of the Malaspina glacier, see Russell's paper on "Mt. St. Elias and its Glaciers," Am. Jour. Sci,. III, Vol. XLIII, pp. 169–182, with map, March, 1892

inward from the retreating margin, its surface had a considerable slope, so that the upper currents of the ice, unsupported on the outer side, would move much faster than its lower currents which were impeded by friction on the land. There would be accordingly within this belt a strong tendency of the ice to flow outward with somewhat curved currents, tending first to carry the onwardly moving drift gradually upward into the ice-sheet, and later to bear it downward and deposit it partly beneath the edge of the ice and partly along the ice boundary. The Niagara boulders, and others from the Clinton and Medina formations farther north, having been borne upward as englacial drift to a greater altitude than the Pinnacle hills, were exposed on the surface of the ice-sheet by its ablation and were swept by torrents bearing ice rafts, or probably sometimes by avalanches, into the river channel. Their great profusion in certain parts of this esker implies unusual abundance in and upon the contiguous portions of the ice-sheet, which may have resulted from convergent glacial currents and perhaps from a temporary re-advance of the thicker tract of the ice, massing its superglacial drift stratum in a way analogous with the accumulation of terminal morainic hills, which often are equally charged with boulders.

The morainic ridge continuing westward from the Mt. Hope cemetery seems probably to have been formed along the margin of the ice, on the northern side of a re-entrant angle or embayment into which the glacial river depositing the esker of the Pinnacle hills debouched. Close south of this ridge, a brick yard beside the Buffalo, Rochester & Pittsburgh railroad works the stratified clay which the river discharged into the shallow glacial lake of the embayment.

Finding so abrupt an end of this esker at Brighton, we are constrained to believe that the powerful river by which it was accumulated suddenly ceased to flow here. The neighboring Pittsford esker apparently shows the site of the new glacial channel, previously the course of some smaller stream, which then became the main avenue of drainage from the rapidly melting ice-fields of this region. But when the Pittsford esker had gradually grown in its length from the west flank of the Turk's hill range northward to the present site of Allen's creek, the glacial river which formed it was again diverted; or more probably thenceforward it emptied into a marginal lake so broad and deep that no distinct esker was made, the gravel and sand being then laid down in the valley which now holds Irondequoit bay.

If the eroded drift from the area north of the Pinnacle hills was carried upward by glacial currents having an average ascent of one

degree, it would rise within one mile 92 feet and within two or three miles would be higher than the tops of these hills. Currents ascending at this rate, or even two or three degrees or more, may very probably have existed in the lowest part of the ice sheet, on account of the acceleration of its upper currents, within distances from 20 to 50 miles or more back from its boundary. By these currents much drift eroded from the land surface would be gradually incorporated in the comparatively sluggish lower part of the ice, reaching altitudes 100 to 1,000 feet above the ground within a few miles from its sources.

It is also to be remarked that the rounded or at least subangular forms of the greater part of the pebbles and small rock fragments in the esker gravel do not necessarily imply wearing by the stream during a long transportation. Daubrée placed angular fragments of granite and quartz, ranging from the size of one's fist to that of a hazel nut, with water in slowly revolving cylinders and found that they became perfectly rounded when the revolutions amounted to 25 kilometers or about 15 miles. (1) Within a third of this distance probably some of the fragments had been well rounded, and in a less distance nearly all would be worn to subangular forms.

Many features of the modified drift, comprising glacial flood plains, eskers and kames, show that the melting of the ice-sheet at the close of the Glacial period was mostly very rapid. In the vicinity of Rochester it was hastened by the laving action of the glacial lakes on its southern border. Lake Warren had formed a beach which extends to the south side of the east end of Lake Erie, where its altitude is 860 feet above the sea. (2) At the time of formation of the Pinnacle hills and Pittsford esker series, the ice-border in New York appears to have receded so far that the water of the upper Laurentian lakes was no longer held up to the level of Lake Warren, which had outflowed at Chicago, and avenues of drainage seem already to have been opened eastward along the ice-border past the northern ends of the Finger lakes to the Mohawk valley. Undoubtedly the deposition of these esker gravel and sand beds took place above the level of such fringing lakes, which from the Genesee and Irondequoit basins could have no place of outflow eastward lower than by the way of Victor and Mud creek. The divide at Victor is somewhat higher than the general surface on which these eskers lie ; hence it seems probable that when the esker beds were laid down in their ice-walled channels a depth of some 100 feet, more or less, of ice still remained unmelted

(1.) Etudes Synthétiques de Géologie Expérimentale, 1879, pp. 248-250.
(2.) Bulletin, G. S. A., Vol. II, pp. 258-265 ; Vol. III, pp. 484-487.

beneath them. In like manner I have shown that certain eskers in New Hampshire and Manitoba were underlain by ice at the time of their accumulation and by its melting away were afterward allowed to sink to the land. (1)

Application of this Explanation to Eskers elsewhere.

If eskers were subglacial deposits, we should expect them to be often covered wholly or partly with the englacial drift, as boulders and loose deposits of till, which would be permitted to fall upon them when the ice-roof was melted away. Such a roof would be more or less overspread with the drift that had been contained in the higher portions of the ice-sheet and was exposed on its surface by ablation. Sections indeed are occasionally found where subglacial beds of modified drift have become covered by subglacial and englacial till; (2) but these usually differ widely in their character from the torrential esker and kame deposits, which very rarely contain or bear upon their surface any considerable abundance of boulders or other drift materials that have not evidently been transported, worn, and assorted by water. In nearly all the localities where I have observed boulders or masses of till imbedded within eskers or lying on their surface, the most probable explanation of their derivation has been by falling from the enclosing ice-walls of channels open to the sky, or by being brought while frozen in ice-floes. (3) At only one place, in Dover, N. H., I have found a portion of an esker covered with a deposit of boulders and till which may have fallen from a melting ice-roof, though another interpretation seems to me preferable. (4)

A different view is taken by Professor W. M. Davis, who regards certain eskers in the vicinity of Auburndale, Mass., which I have repeatedly examined with him and other glacialists, as probably of subglacial origin. (5) These eskers I think to have been formed in ice-walled channels, open above and underlain by a slight depth of ice Extending southward from them are associated sand plains or plateaus, deposited just outside the ice front by the streams which produced the esker ridges. Professor Davis describes a backwardly dipping strati-

(1.) Geology of New Hampshire, Vol. III, 1878, pp. 107,116. Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888-89, pp. 36-41 E.

(2.) Geology of N. H., Vol. III, pp. 108, 131-137, 259-291. Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for 1879, pp. 113-114; Final Report, Vols. I and II. Proceedings of the Boston Society of Natural History, Vol. XXIV, 1889, pp. 241-5, 237-9.

(3.) Geology of N. H., Vol. III, pp. 45, 46, 85, 88, 100-102, 127, 145, 148, 158, 199, 162. Geology of Minn., Final Report, Vol. II, p. 550. Geol. and Nat. Hist. Survey of Canada, Annual Report, Vol. IV, pp. 41-42 E.

(4.) Geology of N. H., Vol. III, p. 150.

(5.) Bulletin, G. S. A., Vol. I, pp. 195-202, with sections. Proceedings of the Boston Society of Natural History, vol. XXV, 1892, pp. 477-499.

fication of the beds forming the edge of the plains where they adjoined the ice-sheet, and attributes it to the upflow of subglacial waters bringing with them the sediments which make the plain and reach to a considerable distance, having in their lower portion, on the greater part of their area, the forwardly dipping stratification that is characteristic of deltas or of deposits swept by torrential currents into the slowly flowing broad expanse of flooded rivers. It seems to me, however, more probable that the back-set beds were formed by the downward and backward transfer of sand from the surface of the plain, to fill in succession the small spaces from which the ice-sheet was gradually withdrawn.

Because the summer melting of the North American ice-sheet in the Champlain epoch, or closing stage of the Glacial period, was far more rapid than that of the Alaskan glaciers at the present day, the previously existing small subglacial stream-courses were inadequate for the transportation of the large supplies of englacial drift then set free, by which, indeed, the subglacial tunnels appear to have been mostly obstructed and closed. The waters of the glacial melting and of accompanying rains therefore flowed, as I believe, in channels on the ice surface, often near their mouths more like cañons than like ordinary land valleys, there depositing the eskers and kames.

My studies of the Pinnacle hills and Pittsford esker series, of the very massive kame deposits forming the greater part of the outermost terminal moraine on Long Island eastward from Roslyn (1), of the large kame called the Devil's Heart, rising in a somewhat conical hill 175 feet above the adjoining country south of Devil's lake in North Dakota, and of the esker named Bird's hill, seven miles northeast of Winnipeg (2), seem to me to demonstrate, beyond all doubt, that their material, and probably likewise that of eskers and kames generally, was supplied by superglacial streams from the plentiful englacial drift, and could not have been brought from drift beneath the ice by subglacial drainage.

(1). Am. Jour. Sci., III, Vol. XVIII., pp. 84-88, Aug., 1879.
(2). Geol. and Nat. Hist. Survey of Canada, Annual report, new series, Vol. IV, for 1888-89, pp. 38-42 E, with section.