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The Formation of Eskers

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THE FORMATION OF ESKERS.

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Ever since work has been in progress in glaciated regions, long, narrow, winding, steep-sided, conspicuous ridges of gravel and sand have been recognized by geologists. They are best developed and were first recognized as distinct phases of drift in Sweden, where they are called Osar. The term Osar has the priority over other terms, but in this country, probably for phonic reasons, the Irish term Esker has come into use. With apologies to Sweden, Esker will be used in the present paper. Other terms which have been applied to these ridges in various parts of the world are serpent-kames, serpentine kames, horsebacks, whalebacks, hogbacks, ridges, windrows, turnpikes, back furrows, ridge furrows, morriners, and Indian roads.

Because of a similarity in distribution, in materials, and in general appearance, eskers have long been confused with kames. In the opinion of the writer, these points of similarity are more real than imaginary. In order to make this point clear, the origin of kames will be discussed briefly. A kame is a more or less circular hillock or knob of stratified material deposited in a crack or other re-entrant in the edge of an ice sheet, by a stream which flows from beneath the ice into that re-entrant. So long as the stream is beneath the ice, it is under pressure, has a high velocity, and carries a heavy load. At the point of issue the pressure is released, the velocity is checked, and deposition takes place against the walls of the re-entrant. When the edge of the ice has retreated, the material slumps down to its angle of rest on all sides. There has never been, and there is not today, any reasonable doubt of this mode of origin of kames. In some localities groups of kames are found, arranged in irregular fashion, and known as kame-areas.[1] They are considered to represent a much-broken ice edge where streams issue from the ice. Kames are more abundant than eskers.

There has always been speculation as to the origin of eskers and several theories have been advanced to explain them. The writer has had occasion to study several eskers in the field, and that study has led him to doubt the present accepted idea of their origin and to conceive another method by which they might be formed. A recent reading of the literature of the subject has confirmed his doubt of the existing

[1]Trowbridge, A. C., Ill. Geol. Surv., Bull. No. 19, pp. 50-56.

theory and his confidence in the new one. A partial bibliography of the subject of eskers is appended at the end of the paper.

Let us now bring together the characteristics which must be explained by any theory of the origin of eskers. For the sake of definiteness these characteristics are stated in separate paragraphs:

In shape, eskers are ridges, many times longer than wide.

Their dimensions vary greatly: In height, from 3 to 150 or even 200 feet, and in length from a fraction of a mile to 100 miles or more. Single esker ridges are measured through the base in dimensions of a few hundreds of feet rather than in figures of a higher order. Differences in height are generally the measure of differences in thickness.

The side slopes of the ridges range from 25° to 30° from the horizontal, and the slope in each case is the angle of rest for the material of which the esker is composed.

Eskers are found only in areas once covered by glacier ice, generally in ground moraine, which is near terminal moraine, or which has terminal morainic tendencies, less frequently in terminal moraine itself. No eskers occur beyond the maximum extent of the ice in the zone of outwash material.

No esker ridge can be traced for 100 miles, nor for 10 miles, without interruption. They are discontinuous without exception. The individual parts vary in length up to five or ten miles and the intervals between, up to two or three miles, or perhaps more.

The ends of the ridges, whether at the extreme ends or at the ends of the separate parts, are very abrupt, the degree of slope being as great as the side slopes. There is no apparent tendency to tail out and disappear gradually, except in a few cases.

Practically no esker ridges are straight; rather they have winding courses, somewhat similar to the meanders of a stream, although the symmetry of stream meanders is lacking. When eskers are plotted, with straight lines drawn from end to end across discontinuities, rather irregular courses are shown, with turns, bends, and breaks at all angles.

Combinations of several ridges, which have been termed "reticulated ridges,"[2] are common along the courses of eskers. A single main ridge may be joined by tributary ridges, or it may be broken up into distributary ridges, or there may be many ridges of about equal size braided with one another in such a way as to hold depressions or kettles between them. In some cases the total width of the compound esker, including the depressions, is more than three miles.

[2]Stone, G. H., Mono. XXXIV., U. S. Geol. Surv., p. 34.

Eskers have no particular relation to underlying topography. Although most of them lie in and parallel with valleys, many of them wind their way across valleys and divides and over surfaces of considerable relief, and not everywhere by the most direct routes or the lowest grades.

It is notable that eskers are more common in rough regions than in areas where the surface is smooth. For instance, they are most numerous in Sweden and in Maine. Hundreds of them are known in Maine, while in the flatter glaciated region of the Upper Mississippi valley they are so rare as to occasion special comment and detailed description when found.

The material of eskers ranges in texture from sand to bowlders several feet in diameter, the smallest glacial material, rock flour, and the largest, enormous bowlders, being absent. The material is only roughly stratified, though all of it is clearly water-laid. Stratification lines show evidences of disturbance, either by push of some sort or by slumping and settling. Where apparently undisturbed, cross-bedding planes dip parallel with the side slopes or toward the lee end of the esker; seldom, if ever, do they dip toward the stoss end. The pebbles of the gravel show effects of both ice and water wear. Most of them exhibit a partial roundness superimposed upon subangularity. Striated pebbles are rare.

Eskers differ from kames only in ground plan, the former being linear in shape, and the latter, where typically developed, being more or less circular. The material is the same, the slopes are the same, the general distribution is the same. The width of the average esker ridge is equal in amount to the diameter of the average kame. Perhaps the average esker is a little lower than the average kame, though the difference is not marked. Wherever eskers are discontinuous, kames occur commonly in the intervals. Moreover, all gradations can be found between kames and eskers, even in shape, from eskers of average length, through short eskers and slightly elongated kames, to typical kames.

Practically all the above-mentioned characteristics have long been known, but they have been interpreted in different ways by different investigators. Eskers were first thought to have been formed by ocean currents, but this theory was abandoned when it was discovered that they are associated with glacial drift, rather than with marine deposits. It was early agreed that they were deposited by water associated with the great continental ice sheets; that is, that they are fluvio-glacial in origin. This idea has stood, and will stand; the proof is too obvious to need demonstration. When the fluvio-glacial origin had been settled, it was first thought that the ridges were the result of deposition by streams flowing on the surface of the ice and the lowering of this deposit to the surface of the ground as the ice melted beneath it. But when the great Greenland glacier had been investigated and it was found that superglacial streams carried little sediment, and deposited none, and that the surface of the ice was relatively free from debris, this idea was abandoned by most people, and the theory of subglacial stream deposition came to take its place. It is agreed by all modern writers that most eskers, at least, were deposited under the continental ice sheets by streams flowing there in tunnels, the tops and sides of which were of ice, and the bottoms of which were the deposits of the stream itself. It is noteworthy that, although all modern text books state the subglacial origin of eskers, all of them do so with some apparent hesitancy or qualification, and some of them state that this theory might not explain all eskers.

In the opinion of the writer the subglacial theory is incompetent to explain all eskers, or even to explain most of them, especially the longer and more broken ones, although it is admitted at once that some eskers may have had such an origin. The writer has had occasion to teach this theory to a dozen or more university classes, both in the class room and in the field, and he has met with only mediocre success. The students who learn by rote accept the theory, learn it by heart and answer questions concerning it accordingly; almost invariably, students who think, either refuse the theory entirely or bring forward objections to it. The objections to the theory will be taken up point by point.

Subglacial streams must be under enormous pressure. All estimates go to show that the thickness of continental glaciers is to be measured in hundreds of feet, even a fraction of a mile from their edges, and the thickness 100 miles toward the center from the edge must be very great. And there is no escape from the conclusion that this weight must rest on the surface of subglacial streams, for present accepted theories of glacial motion are based on the principle that the ice at the bottom cannot maintain the weight of the ice above and that no competent arch could exist at the bottom. It is hardly conceivable that a body of moving ice, which fits into every irregularity of the surface and moves over hills and across valleys, and fits so tightly under overhanging ledges that it striates the under sides of the ledges, could by any possibility maintain open tunnels in its bottom. It seems doubtful that a stream flowing in a crowding ice tunnel under such great pressure would flow slowly enough to allow the deposition of sand. Neither do swiftly flowing streams have a habit of depositing sand and gravel and cobbles and bowlders all together.

Under this theory is it possible that there would be no differences between the materials of eskers deposited by streams under the ice and those of kames deposited by those same streams where they issue from beneath the ice? It is certain that the velocity is greatly checked at the point of issue and that it must be much greater before the stream issues. Should not the subglacial deposits have a coarser texture and a lower textural range?

It has been a source of wonder to all holders of the subglacial theory that esker ridges could avoid destruction by the ice constantly moving over them. That wonder is well founded. The explanation has been that eskers were made and preserved only in the last stages of an ice sheet and near its border, where the movement was slight and the weight of the ice not too great. But eskers which are 50 or 100 miles long could hardly be supposed to have existed under these conditions, at least toward their stoss ends, provided the whole esker was made at one time, as the theory postulates.

Perhaps the greatest objection to the theory is that it does not adequately explain the discontinuities so common in eskers. It has been suggested that the breaks are due to irregular glacial erosion of an originally continuous ridge. But the ends of the individual parts are clearly depositional rather than erosional; at least they cannot be considered to be erosional if the sides of the ridges are not. Also the breaks are just as common where the ridges were parallel with ice motion and erosion was at a minimum, as where their crooked courses brought them at right angles with ice motion and erosion was at a maximum. It has been further explained[3] that the varying degree of confinement of the stream might account for the discontinuities, definite ridges being made only where the stream was confined to definite channels, and the material being spread in irregular areas where the streams were not so confined. The entire absence of stratified material in the intervals in many places, and the abruptness with which the ridges pick up on either side of a break seem evidence against this explanation. What sort of an opening would there be under the ice to contain a ridge 100 feet high and sloping upstream at an angle of 30°? Also, what would be the source of so great a supply of material all at once from a stream which had been so separated that it could not transport a load? Practically an opposite theory has been advanced by Stone,[4] who explains that the ratio of volume of water and size of tunnel varies in such a way that deposition takes place where the stream is small and the tunnel large and the velocity is therefore low, and that deposition fails

[3]Chamberlin and Salisbury, Geology, Vol. III, p. 373.
[4]Stone, G. H., Jour. Geol., Vol. I, pp. 246-254.

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when the ratio is reversed and the velocity is great. This presupposes that the stream goes from a small to a large tunnel *very suddenly,* and that open tunnels can exist 100 miles from the edge of an ice sheet where glacial motion is in progress. It is clear that if subglacial streams deposit eskers they do so where the stream is under hydrostatic pressure, for eskers exist on the stoss sides of steep hills, where there must have been pressure to force the water over the hill.

If eskers are subglacial in their origin, it must be concluded that kames, which occupy the discontinuities of eskers, are also subglacial. This necessity has been realized by some exponents of the subglacial theory,[5] and the conclusion has been accepted, but it is not made clear just how kames can be made beneath the ice. These kames in the intervals of eskers are identical in every particular with the normal type of kames known to be deposited at the ends of glaciers.

The writer believes that most eskers are simply kames drawn out into long lines by the slow retreat of the edge of the ice while kame deposition is in progress. If a kame is being formed at the edge of an ice sheet, and the edge retreats slowly, deposition will continue so long as the re-entrant remains and the stream continues to issue there, and the kame will be drawn out into a long ridge or esker. This theory seems to satisfy the points advanced as objections to the subglacial theory and to afford explanation for all of the observed characteristics of eskers as given above. The theory makes it unnecessary to conceive that swift subglacial streams deposit; it explains the close similarity between eskers and kames; it does away with the dim vision of a thick ice sheet moving over a steep, narrow, crooked ridge of non-resistant material without destroying it; it affords a reasonable explanation for discontinuities; and it allows for the presence of kames in the intervals. The discontinuities would result in this wise. During the recession of the edge of the ice, if the re-entrant ceased to exist, or if the stream ceased to issue there, kame deposition would cease; when a re-entrant and the mouth of a subglacial stream again coincided, deposition would begin again. This would make a break in the esker, whose length would be determined by the rate of recession of the ice and the length of time during which deposition was not in progress. Such changes as these would take place suddenly, and the beginnings and endings of the ridges would be abrupt like the ends and sides of kames. It is clear that kame-making conditions might be established at any time for only a brief period, resulting in typical kames in the intervals between the esker ridges. A slowly retreating ice edge, if conditions for kame deposition persisted, would

[5]Chamberlin and Salisbury, Geology, Vol. III, p. 376.

result in a considerable concentration of material and a high, thick esker ridge; rapid retreat would draw out a lower, thinner one; rapidly changing rates of recession would cause an esker of varying thickness and of considerable surface relief. Perhaps the higher knobs of eskers result from a temporary halt in recession. Crooked re-entrants or shifting stream mouths would result in crooked ridges. Where there was one re-entrant and one stream, there would be one ridge formed; where the ice edge was badly broken up and streams ran through all the cracks, the result would be a kame-area drawn out into an intricate series of ridges, rather than a single ridge. Converging cracks would result in converging ridges, diverging cracks in diverging ridges, and crossing and recrossing cracks in intricate reticulated ridges. Where the ice edge retreated uphill, the ridge would be extended uphill, where the ice receded across valleys and divides, the esker would be made to follow a course across a surface of high relief. The rougher the region, the more likely would cracks be in the edge of the ice, which explains the greater abundance of eskers in rough than in smooth regions.

To the writer this theory of the origin of eskers seems better than the subglacial theory, and he thinks that most eskers have been made in the way described, but he would not carry it so far as to say that *all* eskers are so made. It is entirely possible that streams might deposit for a short distance back from the edge under the ice, and that some short eskers and the parts of longer ones nearest their lee ends were made beneath the ice.

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