## On the Nature and Origin of the Eskers of Nova Scotia.—By Walter H. Prest, Halifax,. N. S.

*Introduction.*—My attention has been drawn to the lack of scientific work done on the eskers and other glacial deposits of Nova Scotia. Having given some time to the distribution and history of our glacial deposits, I should like to consider their origin and offer a few suggestions as to future and more critical examinations than I have had time to make. For years I have subscribed to the generally accepted opinion that eskers, as these ridges of sand and gravel are called, belong to the sub-glacial drainage system of the latest phase of the glacial age; but a more recent comparison of facts has convinced me that no such explanation could possibly account for conditions as they are now.

*A New Theory of Origin.*—I know that in advancing the theory of origin given below I am in complete opposition to some scientists of the highest reputation, but I trust the evidence I offer will carry weight enough to at least deserve consideration.

As some of the members of our Institute may not have bestowed much time on the glacial geology of Nova Scotia, I shall explain what an esker is. I will use the more familiar name of *esker*, rather than the Swedish name of *osar*, often used by American geologists.

*What an Esker Is.*—The esker is a narrow ridge of stratified sand and gravel with occasional boulders. These ridges with small interruptions often extend for many miles, resembling in some places a well-built highway or railway embankment. The *kame* is also composed of the same material as the esker but resembles a mound rather than an embankment. The kame properly belongs to a system of modified drift; but the esker has a system of kames altogether separate from the kames formed by other aqueous and erosive agencies. These are known locally as horse-backs, hogs-backs, turnpikes, Indian roads, etc. Kames are very common, while eskers are very rare.

*The Eskers of Nova Scotia.*—The number of eskers in western Nova Scotia is quite considerable, but may be lessened by exploration, when detached sections will probably be found to be only portions of longer eskers. Some of these attain a perfection of form not excelled elsewhere. The majority of these run across the drainage system of the province. The longest and most prominent eskers run across the highlands of the interior, crossing minor elevations and depressions on the way. The shorter ones are usually found where a plateau breaks off into a sloping surface, or where a valley bounded by high hills runs either across or parallel to the course of ice movement.

*The Great Central Esker.*—The longest esker in Nova Scotia is one that runs with few interruptions from south-west of Hectanooga in Digby County, north-easterly towards the source of Bear River. This is said by hunters to be the same one that runs from the source of Bear River easterly to the western side of Kejimkujik in south-western Annapolis County. It crosses the valleys and watersheds of all the streams running south into Yarmouth County and north into Digby County. It borders on or crosses lakes as broken gravel ridges instead of being spread out as deltas or flood plains, as we have been taught that they should be. On an elevated plateau south of Wentworth Lake it is broken up and meanders in a curious way completely independent of water-sheds, drainage slopes, and streams. Further west at the foot of a lake at Hectanooga it reaches its greatest development; sixty or seventy feet high it dams back a lake, and along its crest is built a highway. South west of this I did not trace it, but it is said to extend nearly to the sea-shore. Its eastern extension crosses some of the highest land in the western part of the province near the head-waters of the Liverpool, Tusket, Sissiboo, and Bear Rivers. where it is often 30 to 50 feet high. Its height and regularity makes it one of the most noteworthy natural features in the province. Its total length must be 60 or 70 miles. The eastern end of this esker is seen crossing the watershed and descending easterly to the Liverpool River at Kejimkujik. A more northern branch of it crosses the lake called the Frozen Ocean by a string of islands and gravel banks. Advancing up the next slope it crosses to Annapolis-Liverpool road north of Maitland. From thence it goes eastward, and 25 or 30 miles east of this a like ridge crosses the Nova Scotia Central Railway on or near the same latitude.

*West Brook Esker.*—A short ridge crosses the West Brook of the Liverpool River at the point where the higher level lands break off into the slope that descends to the river. Like may others, it marks a change in the angle of descent.

*Middlefield Esker.*—To the east of this and on the same course, a well developed ridge crosses the Annapolis-Liverpool road at Middlefield. This may possibly be the extension of the West Brook esker. It is a well defined ridge of gravel, rising and descending with the slope of the land on the watershed across which it runs. Like most of the others it crosses the general course of drainage as well as the direction of the glacial movement.

Another in the Blue Mountain region of Noithern Shelburne crosses the drainage system near Roseway Lake.

*Gold River Esker.*—A short esker flanked by well defined kames is seen on the West side of Gold River. It marks the junction of a slope with a tract of flat land above. It runs North and South parallel with Gold River, while the local drainage and ice movement in the last stage of the ice age was East toward the river.

*Stewiacke Esker.*—In the eastern part of the Province we find one of a moderate length and height on the north side of the Stewiacke River a few miles above Lower Stewiacke Station.

*Nine-Mile River Esker.*—The most conveniently situated esker for study is at Nine-Mile River in Hants County. It runs north-westerly, beginning nct far from Enfield Station, and crossing the river, runs with varying course and height for ten or fifteen miles. Another prominent, but short gravel ridge runs east and west in the valley of the Five Mile River on the Midland Railway in Hants County.

Two well defined eskers run down the valleys of the Hebert River in Cumberland County, and the Clyde River in Shelburne County. The first is about eight miles long and ten to fifteen feet high. The latter is also a large esker several miles long. The Hebert River esker begins at the foot of the Cobequid Mountains near Halfway Lake, and runs north along the west side of the river. While the south end is about fifteen or twenty feet above the river, the north end is forty to fifty feet above it, and the top is nearly level. The north end is about one hundred and ten feet above high tide in the Bay of Fundy. Branches become parallel to the main esker or sweep around hollows, enclosing bogs. The top is often only wide enough for a wagon. The ridge contains laige well worn boulders. Another esker near Thos. Leadbetter's, Upper Barney's River, is ten to eighteen feet high, with a narrow top. Near Round Lake, Guysboro County, is one about fifteen feet high and a half mile long; it is very narrow and runs north-east. An interesting esker is said to run North from the Northern boundary of Pictou Town, across Acadia Farm and into the woods beyond. A good section of it was made by the highway near its origin.

Other eskers exist in the Province, but quoting from memory, the above are all I can recall just now.

*Cross Drainage System.*—The most noticeable feature of these eskers is the fact that the most of them cross the present drainage system of the country. Few of them run parallel with the main streams.

*Eskers of Maine.*—Turning to the eskers of the United States, those of Maine are most worthy of notice. Mr. George Stone, in Monograph XXXIV of the U. S. Geological Survey, has reviewed the work of other geologists on this subject. Because of this review, his conclusions on the eskers of Maine are examined below.

*Cross Drainage System.*—These eskers, like our own, meander over hill, valley, and plain alike. They often pass from one valley to the valley of another stream, crossing a divide from 200 to 400 feet high. In level or swampy land they form natural roadways, and have been used as such. Quoting him, we read: "These great embankments reaching from 20 to 140 miles, cross rivers, valleys, plains and hills, skirting hill-sides far above the valleys, meandering across plains where no obstructions exist to cause it to meander." They are very variable in height and breadth, a narrow ridge a few feet wide being succeeded by a portion of the same ridge 100 to 200 feet wide. As in Nova Scotia, they often divide and re-unite, are interrupted, or spread out into lines of mounds.

*Gaps.*—There are many gaps in the Maine eskers; these are usually less than half a mile in width, but rarely two miles. The Nova Scotian eskers also have gaps, which as a rule are very short.

The Maine eskers, according to Stone, run south-west to south by east, coinciding in some places with the course of the drainage and ice movement, though not enough to suggest a controlling influence.

It will be noted that though these eskers do not always coincide with the local elevations and depressions, they agree in course with the central watershed and the general slope of the country toward the sea.

*Tributaries and Deltas.*—Stone also says that one esker has a tributary system at the north end and a delta system at the south end. I do not know how far this is self evident. I have never seen an instance of either in Nova Scotia. The nearest approach to it is on the top of a high open barren south of Wentworth Lake in southern Digby County, N. S., east of Hectanooga. This is certainly an unusual place for a delta, being nearly 20 miles from the end of the esker. In this province the eskers cross lowlands, swamps and lakes, as ridges, strings of islands, or gravel banks, without much evidence of the spread of their contents.

*Stratification.*—Both eskers and kames are stratified in a very complex manner, the eskers often more complex than the kames. Both transverse and longitudinal sections show cross bedding. Sometimes the bedding has been twisted into almost vertical positions, the result of distortion since deposition. Some eskers consist of water worn pebbles and gravel out of which the fine stuff had been washed. In others the lines of stratification are said to have been obliterated, though I suspect that stratification has never taken place owing to scarcity of water. However, owing to lack of investigation, no definite opinion can be given on this point.

Crossing into the Province of New Brunswick we find a like system of eskers there. In the western and central parts of that province the glacial striæ runs from south to south 65 degrees east, inclining to the east and north-east as they approcah the gulf of St. Lawrence. Some of the eskers cross into the state of Maine, especially one on Eel River. Others are located at Canterbury and Queensbury, York County, and Wakefield, Carleton County; still others are seen along Deadwater Brook, Fish Creek, and the mouth of Nacawicac River. The courses are generally south-east. Whether these agree with the course of the local watersheds and valleys, I do not know. They also are among the points needing investigation.

In Nova Scotia, while the shorter eskers agree in course with the local elevations and depressions, the most important ones run lengthwise through the province on or parallel with the central watershed.

*Origin of Eskers.*—Regarding the origin of eskers, Mr. Stone says on page 40, "When one sees gravel systems going up the northern side of a hill 200 feet or more in height, it seems that a stream could flow southward over such barriers. That they actually flowed over such barriers is strong evidence of the existence of ice." Here I would ask why such inferences are assumed as facts in order to support theories so contrary to other evidence. The pressure and head of water needed to drive water with its load of gravel and rocks up and over such hills could only be secured in water-tight channels beneath or within the ice. Any leakage would lessen the power of the water to drive the debris forward.

*Subglacial Tunnels.*—Now this theory of subglacial tunnels is based on the assumption that the water and gravel actually ascended over 200 feet and in south-western Maine 400 feet. This would mean a pressure of 81 to 162 pounds per square inch—sufficient force to drive water through the interstices of any subglacial debris or to project a huge torrent with the force of a giant pump. But where the head and power for such a siphon tube is from fifty to one hundred and forty miles away from the watershed over which the debris is to be lifted, the chances for a perfectly tight tube of that length are exceedingly slender. Such phenomena have never been seen.

*Impossible Theories.*—I think the evidence justifies one in saying that siphon-like action by subglacial streams on such a large scale is absolutely impossible. I will consider further objections to this theory later on.

*Superglacial Streams.*—The theory of superglacial streams as a source of esker formation is also untenable because Nansen and other explorers say that glaciers or smooth or slightly undulating slopes carry no debris on their surface, as to those glaciers lying among projecting mountains According to Nansen, Peary, Nordenskjold, Shackleton, Amunsden and other explorers, neither Greenland nor the Antarctic continent show any support for the theory of the formation of eskers by either subglacial or superglacial streams.

*Confused Theories.*—To show the confusion and uncertainty attending past investigations into the origin of eskers, I will give several quotations showing the indefinite and contradictory theories so far advanced. On page 422 Stone says: "The conclusion is that the great length of the eskers of Maine favors the hypothesis that they were mainly formed in subglacial tunnels", yet on page 426 he says, "So far the probabilities favor the theory of superficial streams."

On page 363 both theories are reduced to impotence when we read this: "We naturally wonder whence the gravel-moving waters came and whither they went and what became of the finer material they carried with them". So the mystery deepens, and deeper mystery follows when we ask where these great streams emptied after ascending the 400 foot hills of south-western Maine, and after a flow of over 100 miles. No wide estuary is seen there. They simply disappear.

Further on Stone says: "Probably all the field phenomena may be accounted for by either hypothesis, but by such cumbrous complications that in the end must break down any hypothesis". Of extremely narrow eskers changing to wide, high eskers, he says: "That rivers capable of transporting so great a quantity of sediment should occupy such narrow channels is truly wonderful". To this we all agree.

*Deflections.*—Regarding deflections in the course of eskers, many supporters of the subglacial theory cannot account for their leaving a valley to cross a watershed or to cross the course of the ice movement. Other deflections on level plains without any streams or obstacles to cause the deflection, are just as unaccountable when ascribed to the subglacial theory.

After considering a great many varied theories of origin, we read on page 426: "The long meanderings transverse to the ice-flow certainly add some difficulties to the hypothesis of subglacial streams". Under the subglacial or superglacial theory the following is unexplainable: At Leighton Brook, a few miles south-east of Aurora, Maine, is seen a ridge of boulders parallel with the ice flow. Across this at right angles is a well defined esker ridge—neither interferes with the other. Here we possibly have a subglacial stream crossing an esker without disturbance but the formation of the esker must have been due to some other cause.

*Confusion of Theories.*—The uncertainties attending these theories are well shown in page 430, where we read: "No positive inferences can as yet be drawn from the observed facts bearing on the question of subglacial versus superglacial streams, though probabilities favor superglacial streams." Page 323 gives us the following: "The general inference is that the courses of the great glacial rivers were determined to the passes before the eskers were deposited, or the hills bare of ice". Here Mr. Stone comes perilously near the true theory of esker formation, which he makes more probable on page 363. Here he says: "The fact that we find a gravel ridge without a delta in a place so favorable for the formation of a delta indicates that the ridge was deposited within ice walls before the ridge had retired as far north as the esker".

*Subglacial Streams.*—He presents evidence that calls for a totally different theory of origin and yet refuses to grasp it, for on page 426 he says: "For the subglacial waters to flow transversely to the motion of the ice must have been the exception rather than the rule".

*Indefinite Theories.*—This uncertainty is voiced by many authors, who, after considering the evidence for the different theories, have been unable to come to any decision. One investigator says: "It might happen that the same esker river was in different parts of its course, subglacial, englacial and superglacial". Another hopeless sentence is: "So complex is the problem that it cannot be claimed that all the elements have been set forth".

Thus there is little hope of a satisfactory solution to the mystery of the origin of eskers among such indefinite theories.

Such appears to be the general opinion of our foremost geologists, among whom are Chamberlain and Salisbury. Their Geology, Vol. VIII, is also a review, and indefinite conclusions abound in it.

*Tremendous Velocity of Subglacial Streams.*—Speaking of eskers they say: "Subglacial streams seem sometimes to have deposited gravel and sand in their channels". With commendable caution they say: "It is not to be inferred that eskers never originated in other ways, but it seems clear that this is one method and perhaps the principal one by which they came into existence". And again: "Long eskers sometimes wind up and down over low elevations and valleys, showing that the water which made them must have been under great head if they are of strictly subglacial origin". To prove the tremendous velocity of these subglacial streams some authors point to the so-called fact that the debris in these streams have been transported up and over high hills. Why this insistence on such facts, as they are called, when none have been proved? And how could water raise itself higher than its source? Some contest this with the theory that there has been an unequal elevation of land in this part of the state of Maine since the formation of these eskers. The known evidence, however, proves that there has been an equal amount of post glacial elevation all along the coast of Maine. It needs a very unequal amount of elevation to form new lines of drainage.

*Eskers Cross Drainage.*—The fact that these eskers do not coincide with the natural course of drainage shows that they were not formed by the sub-glacial drainage system. The gravel ridges in Nova Scotia also often run across both the course of drainage and glacial movement so that any motion in these ridges must have been at right angles to their course, that is down hill.

While most of the eskers of Nova Scotia and Maine cross the glacial striæ and the drainage system, the kames are nearly always parallel with the course of ice movement and the drumlins or hills of unstratified drift are always so; therefore we cannot possibly ascribe all to the same cause.

*Tributaries.*—Subglacial streams, naturally following the course of the drainage, would without doubt be joined by other subglacial streams; therefore the resulting esker would necessarily have tributary eskers. The facts are that the course of eskers is not governed by the slope of the land in Nova Scotia any more than in Maine; and as far as my explorations go the eskers of Nova Scotia are not joined by tributary eskers. The branch eskers of Nova Scotia with one exception, are parallel, re-uniting at a short distance. This exception divides going down a slope. The usually stratified condition of these eskers show the action of running water, but to what extent their formation is due to this remains to be investigated, but we know that the presence in the eskers of Nova Scotia of fine sand and sometimes clay shows usual deposition by a moderate current.

*Course of Transportation.*—Tranverse eskers do not always contain the same constituents as the surrounding till or modified drift. This is an important point, as it gives us valuable information as to the source of the material of the eskers. However, like many other points, it needs investigation to decide whether this material came along the course of the so-called esker stream, down the drainage system, or directly along the course of ice movement.

Eskers, as a rule, contain little clay, indicating a leakage of the fine material, even on the lowlands.

Chamberlain and Salisbury say that esker stratification is often much distorted, probably on account of ice pressure. Ice pressure could not possibly exist in a subglacial stream which was continually eroding its channel with an extremely rapid current heavily loaded with coarse sediment. These varied opinions show the need of further investigation.

*Fatal Objections.*—Another and more fatal objection to the subglacial origin of eskers is the following: We have been considering the subglacial stream as fully formed, and in continual operations as a huge siphon, but there was a time when there was no subglacial channel and the whole eastern part of the continent to the latitude of New York was wrapped in a mantle of ice. When we think of the first few drops of water trickling through the first tiny crack, or leaking beneath the ice, by what vagary of natural law can we conceive it defying the force of gravity and forcing a passage up hills 400 feet high and down across well-marked lines of drainage as in Nova Scotia and Maine. To what natural phenomena can we turn to find a power that would drive a single drop of water over a watershed 200 to 440 feet high, and finally carry millions of tons of debris to the same height. What was the influence that guided the course of the first tiny crack directly across the line of drainage of Nova Scotia. If we admit the possibility of a transverse open crack we kill the siphon theory of subglacial action, as the crack must be filled 400 feet deep before running over a watershed of that height.

Another noteworthy fact is that on the plains or swamps or Maine many eskers are partly composed of sand. This indicates a moderate current. It needs a rapid current under tremendous pressure to drive large rocks over watersheds 200 to 400 feet high. This is also absolutely fatal to the subglacial theory of esker formation.

In view of these facts we are forced to admit the utter impossibility of accounting for the existence of eskers by any form of marine, fluvatile, or lacustrine agency.

*New Theory of Esker Formation.*—But there have been conditions under which the distorted stratification mentioned by Chamberlain and Salisbury was inevitable. In fact it could not be otherwise. This embodies a theory of formation of eskers different from any yet considered and will be detailed later.

*Other Objections.*—Eskers are irregular in size, height and character. Unlike rivers, eskers never increase regularly in size the further they go, except in river valleys. This fact furnishes one of the strongest clues to their origin. If eskers were formed in subglacial channels we would always find the smallest ridges near the surface of the streams and on high lands and the greatest spread of washed material on the plains. That this is not so is strong evidence that eskers were not formed in, or subject to, the outflow of any stream, either of the open or subglacial kind. We would also find a common system of tributary eskers, which we do not find.

A resume of the special characteristics of the eskers of Nova Scotia is as follows:

1. The principal eskers in this province run lengthwise over the highest lands of the watershed. Other shorter ones run lengthwise along the principal valleys. Thus there are two sets, one transverse to, and the other parallel to, the drainage system.

2. The majority cross the main lines of drainage.

3. They also cross lakes, rivers, and minor elevations and depressions.

4. They cross also the course of ice movement.

5. They were laid over hill and valley alike without leaving any sign of an accompanying watercourse eroded into the surrounding drift, even where the slope is suitable.

6. The most characteristic and well defined eskers are on level or slighly undulating land. The largest, but not the longest eskers are in the river valleys.

7. Well defined ridges often cross low or level land and lakes without showing a kame or delta formation.

8. Eskers are sometimes interrupted by gaps, small kames and pot-holes.

9. Transverse eskers, as a rule, contain more foreign material than the surrounding unmodified drift.

10. Eskers contain little clay compared with the surrounding drift.

11. Eskers often descend or ascend a slope, cross low land and continue up the opposite slope with undiminished height.

12. Since their formation as ridges, transverse eskers appear to have been subject to less modification than any other form of glacial deposit, though their exposed position would seem to make them more liable to erosion than others.

13. Eskers in river valleys only show strong evidence of having become lines of drainage, until the total disappearance of the ice allowed the streams to follow their present course.

*A Rare Phenomenon.*—Most investigators have made the usual mistake of ascribing uncommon results such as eskers, to the most ordinary causes. They must necessarily be ascribed to uncommon causes, because of their striking difference from every other class of deposit.

*Glacial Crevasses.*—A perusal of the explorations of Peary and Nansen on the Greenland ice and Shackleton, Scott and Amundsen across the Antarctic continent shows that one of the most striking features of these ice-covered lands are the long deep transverse crevasses that obstructed their way. Nansen says that these crevasses were largest and most numerous in Greenland where the central plateau breaks off into slopes 7 or 8 miles from the east coast and 25 miles from the west coast. Nansen and Peary saw some crevasses 50 feet wide and on the Antarctic continent they were even wider. Nordenskjold also adds his testimony to this. So deep were some of these crevasses that they could not be sounded. So long were they that the ends were seldom seen. Shackleton mentions several from 10 to nearly 100 feet wide and mentions some down which he could see 300 feet. In others no bottom could be seen. Many of these great crevasses broke up into smaller ones which spread out and finally became untraceable. At least one of the long eskers of Maine exhibits this peculiarity. These deep snow-covered crevasses were veritable death traps. One black and apparently bottomless crevasse holds the last of Shackleton's ponies; others hold the bodies of many adventurous explorers, entombed in a sepulchre of ice. At another place was a belt of crevasses half a mile wide. This is probably a repetition of the tributary and delta systems among the eskers of Maine, as well as those of Sweden. At one point on the Antarctic glacier were two huge parallel crevasses probably thousands of feet deep.

*Valley Crevasses.*—One peculiar crevasse noted by Shackleton was formed lengthwise in a valley near Mt. Nansen; unlike those on ridges, this crevasse was closed at the top but was located because of a range of ice cliffs along the valley. As it was formed through the downward sag of the ice sheet, it would probably be open at the bottom and become a receptacle for eroded debris. These valley crevasses may account for many of the eskers lying parallel with the rivers. These only may be termed subglacial channels until the increasing temperature dissolved the ice and opened the crevasse to the light of day.

Valley crevasses have been seldom seen in Arctic and Anarctic regions for plainly obvious reasons. An ice sheet crossing a ridge would crack open at the top; an ice sheet crossing a valley would crack open at the bottom and therefore be invisible. The one mentioned by Shackleton became known only because the ice on one side of the crack sank below that on the other side and left a row of ice cliffs 20 feet high.

Crevasses formed on watersheds may be forced down the next slope, but the tension being relieved, no more crevasses may form for some time on the same ridge. In Maine some eskers are seen on hillsides far above a river valley. Having evidently been formed on the ridge to the rear it had only time to move slightly in its ice-walled channel when the ice sheet melted. Not being in or near the bed of a stream the esker remained undisturbed.

Eskers in valleys, such as those near Hebert and Clyde Rivers in Nova Scotia, must be placed in a different class, owing to a distinct difference in level and position. The original cracks, coinciding as they do with the course of drainage, and receiving the flow of water and sediment from above its level, the esker becomes in time an immense bank of water worn gravel, like those on the Ashuanippi and other rivers in Labrador. This condition would undoubtedly continue until the disappearance of the ice from the low lands allowed the sediment-charged waters to retire to their present beds. Thus all features of eskers are accounted for except those due to the most recent action of the present streams.

A. C. Lowe and others, in their explorations of Northern Canada, note the immense eskers of Labrador, especially one of 100 miles long, hundreds of feet wide and 40 to 60 feet high. The Hamilton, Ashuanippi and Dobuant Rivers are noted for their great valley eskers as well as other smaller but well developed ones on higher ground. Like all other valley eskers, they owe their birth and growth to a crevasse which formed when that part of Canada was still under the northern ice sheet.

*Transverse Crevasses.*—The larger visible crevasses of Arctic and Antarctic regions were formed across the course of ice movement, just as in Nova Scotia and most important eskers lie across the courses of both drainage and ice movement. What deposits these great crevasses actually contain will be unknown until a future interglacial age lays bare the earth probably 5,000 feet beneath the present surface. That they contain debris is both possible and probable, as we know that the edges of these crevasses have the same eroding power as the edge of the ice front. This, however, we cannot see.

*The Crevasse Theory of the Origin of Eskers.*—But this we know:

1. That the visible crevasses run across the course of ice movement as the majority of our eskers do.

2. That they cut across all minor undulations as our eskers do.

3. That the true drainage channels cut across and drain these crevasses, thus preventing them from becoming torrents as they would be if they were the *only* drainage channels. The same conditions probably prevailed in Nova Scotia where the streams cross the eskers.

4. Systems of diverging fissures, caused probably by the ice sheet passing over a hill or mountain spur, have been seen by Shackleton. Corresponding systems of diverging eskers have been seen in Maine and possibly in other countries.

5. Therefore we know that these crevasses are not a part of the permanent drainage system of Nova Scotia, Sweden or Eastern America.

6. That these transverse crevasses are being carried forward with all that is in them, with slow but invincible power, undoubtedly causing distorted stratification, and a mixed condition of the contents, such as we actually see in our own eskers, is evident.

7. If there is debris for the subglacial stream to gather up and transport there must be also debris for the transverse crevasse to gather and transport.

8. While the stream gathers debris only from its line of drainage, the crevasse would gather debris from the whole breadth of country behind it, hence the accumulations must be somewhat different in each. So too, is there a difference to some extent between the contents of the eskers and the valley kames of Nova Scotia.

9. As to the origin of the esker contents, Prof. Russell says that the lower 50 feet of the Malaspina glacier contains much earth, pebbles and other eroded material; the same is said of some of the Swiss glaciers.

10. Glaciers carrying debris at last come to a stand-still, and when melting the crevasses must leave their contents behind them in a comparatively undisturbed condition, altogether different from that of the stream gravels and other modified glacial deposits in the line of drainage, as is evident in Nova Scotia.

The evidence elsewhere is much the same as here. Nansen tells that in Norway eskers are rare, but that in Sweden they are both numerous and prominent, and this is in accordance with conditions as the slopes are steeper and more mountainous in Norway than in Sweden, and eskers if formed, would be more easily swept away.

The fact that most of the esker ridges of Nova Scotia and Eastern United States have been but slightly disturbed by eroding influences where they were supposed to have been most exposed to them, shows that neither marine nor fluviatile agencies were active.

*No Marine Action.*—On the coast of Maine, where a postglacial elevation took place, there is no evidence of marine action on the eskers; therefore they must have retained their protective covering of ice until after the sea had retired.

*A Natural Conclusion.*—The natural conclusion is that eskers could be formed in glacier crevasses, but could not by any possibility be formed in subglacial streams; and being confined between these walls of ice, the contents could not be eroded to any extent until the disappearance, or partial disappearance, of the ice in the next interglacial age exposed them to view. Thus protected, they have preserved their special characters. When an increasing temperature began to melt the ice, subglacial streams and leakage would carry off without doubt much of the excess of water from the crevasses, thus preventing erosion and transportation of the elevated portions of transverse eskers. The proof of this is that these uneroded ridges are still to be seen in their original positions; so when the last fragments of the ice shed disappeared it left the gravel ridges reposing in almost their present form, except where since denuded by brooks or rivers.

*Potholes and Gaps.* Potholes, gaps and small kames could be, and probably were, formed by surface streams pouring into the crevasses, but as this process is beyond the reach of observation, it can only be considered as a theory with the probabilities in its favor.

*Formation of Eskers.*—When in the latest stage of ice melting, local glaciers took the place of the continental ice sheet, those ice sheets on level ground naturally ceased to move while those on sloping ground continued their motion. The result could only be that these eskers on sloping ground continued to move and were eroded or modified, while those on level ground remained unaltered, except here and there by stream erosion.

How far the local and general slopes, or local and central watersheds of a country acted as a cause in the formation of crevasses, remains for future investigators to decide.

*Emergence of Eskers.*—Until distinctly contrary evidence shall be brought to bear, I shall feel justified in claiming that the evidence so far adduced points to the theory that nearly all, if not all of our eskers, were formed in the crevasses of a continental ice sheet. This ice sheet moving toward the lower ground carries with it the contents of the crevasses, eroded and gathered up as it proceeds. Crevasses, usually formed on watersheds, in valleys, or on the edge of declivities, may have moved one or one hundred miles with their load of debris before the increasing temperature dissolved the enclosing ice walls and disclosed the material within. In short, the subglacial drainage system had nothing to do with the origin of eskers and only denuded them in the latest stage of the glacial age.

*Only Reasonable Theory.*—This is the only explanation that will solve the puzzle of the uneroded and unmoved eskers so often seen in positions exposed particularly to erosion.

In eskers we have an example of the rarest and oldest of glacial deposits, the first to be formed but the last to be laid bare to aerial erosion, hence their preservation and their peculiar characteristics.

*Crevasse Theory Supported by Facts.* Thousands of pages have been written on the origin of eskers without one theory accounting for all the facts. But in the crevasse theory we have a simple explanation which is supported by every known fact.

*Investigation Needed.*—In offering to the Institute this explanation of the origin of these curious gravel ridges, I may be calling for criticism, and rightly so, as there are many points needing investigation and comparison which my limited leisure prevents me from carrying through. I know that in advancing this theory of origin I am going counter to the opinions of many men of distinguished reputation including Nansen, Nordenskjold, Peary, Stone, Wright, Winchell, and a number of others. But these opinions conflict largely with the evidence as now understood, and which has been brought forward to support them. Their several varied theories show selections from the most plausible but still unsatisfactory opinions. While such doubt exists there is room for investigation.

*Former Estimates.*—I am encouraged in advancing this opinion by the fact that in 1894 in a paper read before the Institute I claimed 28,000 feet as the least thickness of the gold-bearing formation of Nova Scotia. That statement has been completely verified by the labors of Mr. Faribault of the Canadian Geological Survey. But another distinguished worker on that survey sent me a post-card criticism, with the remark that I would change my opinions with more years and experience.

*Is This Theory New?*—With this lesson to encourage me, I have ventured this theory of the origin of eskers; however, I cannot say positively that it has not already been given in detail in some of the voluminous literature relating to the Glacial Geology of Europe.

In the question of the nature and origin of eskers we have a large field for investigation which will take many years to exhaust. No excavations have been undertaken here to learn in detail the structure of an esker. Some structural secrets may have been revealed in road cuttings, but so far the disturbed and cross-bedded stratification seems only to have increased the mystery of their origin.

*Nature's Record.*—The history of these strange ridges lies hidden in their bosoms, and to the earnest investigator the record is plain. Every descent and ascent, every layer of gravel, sand or clay, every polished stone, irregularity, or sign of orderly arrangement, has a plainly written lesson that even an amateur may learn. It would give me much pleasure to pursue this and other investigations to a finish, but necessity compels me to leave the task to others.

Before closing, I should like to offer a few suggestions to students in this branch of Glacial Geology. Among the well defined eskers that can be investigated, that at Nine Mile River, Hants County, is probably the most conveniently situated for exploration, and I trust that when peace again gives the war weary world a little leisure, the suggestions following may be considered worthy of attention.

*Suggestions for Future Work.*—Some of the points requiring elucidation are the following:

1. The necessity of deciding by excavation, in which way the current which formed the esker, had run.

2. By examination of the debris to discover its source, its time of exposure to erosive action, and the power of the current depositing it.

3. By contour surveys and correct mapping, to discover the influence of surrounding slopes and drainage channels, and to find out how far watersheds and valleys determined the position and course of crevasses and their resulting eskers.

4. By comparison with other glacial deposits to discover whether the same agencies and influencies operated on both.

5. By examination of the junction of eskers with modified or unmodified drift to detect their relative ages.

6. By examination of the line of deposition to discover some trace on the surrounding drift of the great erosive power of a stream supposed to have flowed under a tremendous pressure as in a subglacial channel.

7. By examination of the gaps and kames interrupting eskers to find out if they are merely reformed eskers, or places in which there never was an esker.