PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Irish Eskers

J. W. Gregory

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IV.—*The Irish Eskers.*

By J. W. Gregory, *D.Sc., F.R.S.*

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I. The Theories of Eskers.

The term esker is Irish and its definition should be settled by reference to the eskers of Ireland. They are hills of sand and gravel, which are typically ridges, but are sometimes mounds or groups of mounds. Excluding various suggestions only of historic interest, there are three chief theories of the formation of ridge-eskers. According to the first theory, due mainly to Hummel (1874, p. 3), eskers are accumulations of gravel along sub-glacial rivers. According to the second theory, due largely to Holst (1876–7, p. 97), eskers are deposited along rivers flowing either over, or perhaps partially within, glaciers. According to the third theory, which was advocated almost simultaneously by Hershey (1897, p. 241), Baron de Geer (1897, pp. 377–386), and Baron von Toll (1899, p. 22), eskers are the deltaic deposits of glacial rivers, and their ridged form is due to their continuous deposition at successive positions by the slow recession of the river mouth during the retreat of the ice sheet.* An esker so formed should show an annual banding due to the seasonal variations in the volume of the glacial river.† This banded structure is well developed in the Swedish osar (åsar), for many of which this receding delta theory may be regarded as established.

Prof. SOLLAS adopted HUMMEL'S theory for the Irish eskers. He described them (1896, p. 803) as the casts of systems of sub-glacial rivers. He justly objected to the supraglacial theory, since the eskers were clearly accumulated in their present positions (*ibid.*, p. 819) and had not been redeposited at a lower level on the melting of the ice. His map of the esker system of Central Ireland, compiled from the maps of the Geological Survey, shows some eskers arranged in convergent series like a river and its tributaries; and it was this arrangement which suggested the fluviatile origin of the osar of Sweden.‡ The Irish eskers have therefore been regarded as exactly equivalent to the Swedish osar.

The literature on the Irish eskers deals mainly with their distribution and general structure. It is therefore advisable, before considering their origin, to record some detailed evidence regarding their composition and intimate structure.§

II. IRISH ESKERS.

1. *The Eskers near Tullamore and Kilbeggan.*

One of the most important and instructive esker systems is that of Ballyduff and Newtownlow, to the north and north-east of Tullamore. It has been described by J. O'KELLY and illustrated by DU NOYER, in 'Mem. Geol. Surv., Ireland,' Explanation Sheets 98, 99, 108, 109, 1865, pp. 29–32. JUKES, in the introduction to that memoir (p. 8), refers to this group as including "the most remarkable eskers yet mapped in Ireland." The esker has the plan of a horseshoe, situated around the town of Clara. Its north-western arm appears to be an extension of the well known Streamstown Esker, and its southern arm to be a continuation of the long east-and-west trending esker through Seven Churches and Ballinasloe. The plan of this esker system, as shown on Prof. SOLLAS'S map (1896, Plate 69), appeared consistent with its formation by rivers which converged from the north-west, west, and south-west, and which continued eastward toward the Liffey through the two east and west

* VON TOLL clearly summarises his conclusions as follows:—"Die Bildung der Åsar am ehesten als das Product von Gletscherbächen anzusehen sind, die aus dem Thore eines Schritt für Schritt sich zurückziehenden Inlandeises hervorbrechen, oder mit anderen Worten als die Vereinigung einer Reihe auf einander folgender Schuttkegel" (1898, p. 22).

† I. C. RUSSELL (1893, p. 241) also adopted the view that the banding of eskers, or osar as he called them, was due to periodic variations in the streams.

‡ This arrangement is shown, *e.g.*, on the map by HUMMEL, 1874, Plate II, or in the figure by J. GEIKIE, 1894, p. 481.

§ The most detailed description is that in 'Mem. Geol. Surv.,' Sheet 112, of the Greenhills Esker, near Dublin, which is, however, especially in the part most fully described, not a typical example.

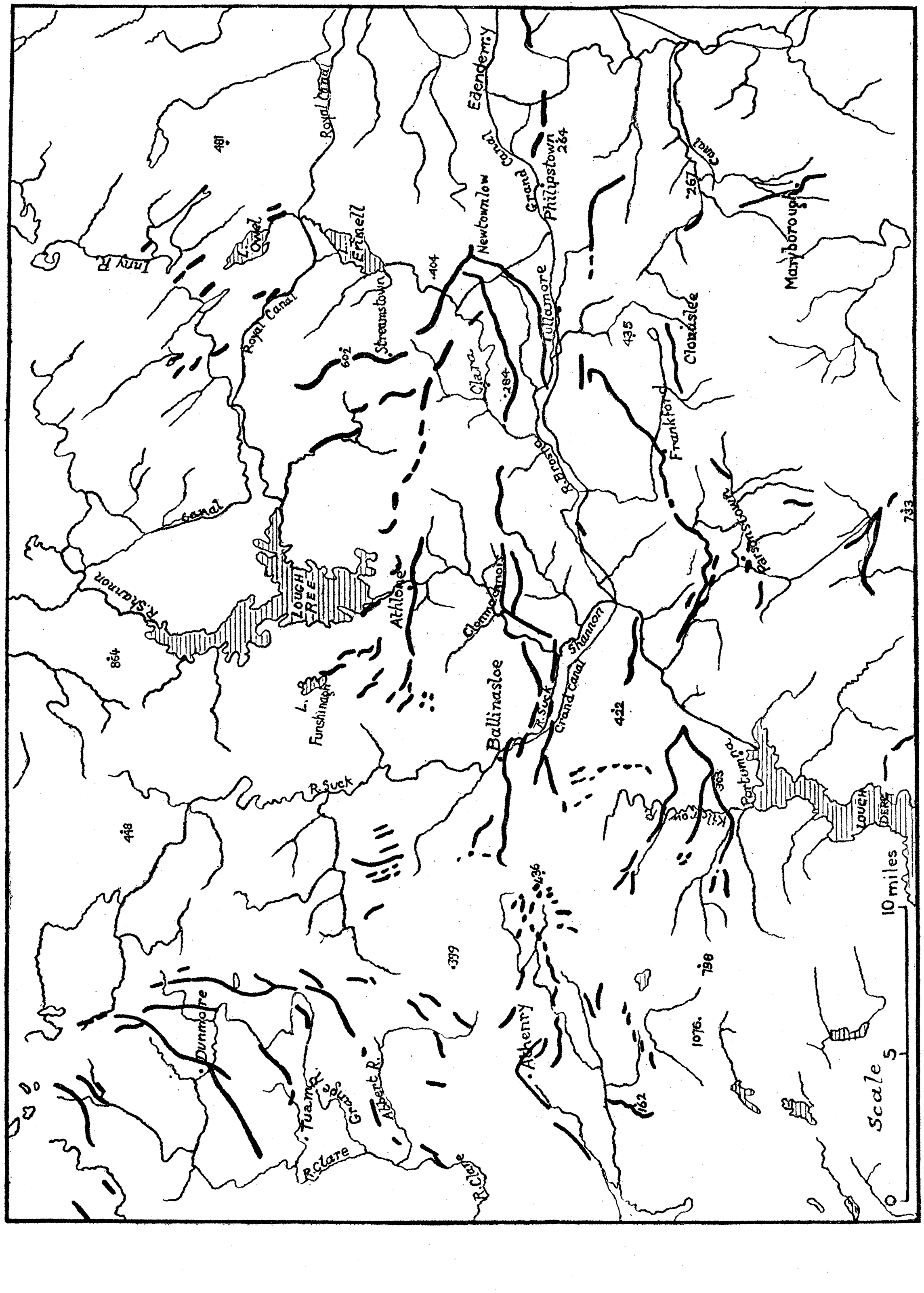

FIG. 1.—Sketch Map of the Irish Esker Systems (mainly after SOLLAS). The three chief convergent series are those of the Clare Basin, near Dunmore, of the Kilcrow River, near Lough Derg, and of the three esker lines which converge towards Newtownlow.

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eskers to the south and south-west of Edenderry. From them it is separated by a gap of about eight miles, which might be due to subsequent denudation.

The Ballyduff Esker is exposed in gravel pits beside the roads going north-west and north from Tullamore. The esker begins about $5\frac{1}{2}$ miles west-north-west of Tullamore, and good sections of it are exposed two miles north-west of the town by Ballyduff Bridge (fig. 2). The core of the esker there is a ridge of well bedded sands and fine gravel with a slight dip to the north. Four layers of clay are inter-bedded in the sands. These beds have been cut through by two faults with a downthrow to the north. These faults were contemporary with the formation of the esker, because the coarse gravel which forms the upper sheet of it passes unbroken across these faults. This fact is fatal, for this esker, to the supraglacial river theory. On the southern side the bedded sands have been denuded, and a coarse torrential gravel occupies the hollow thus formed, and passes upward into a fine-grained bedded gravel, which on each side dips away from the crest of the esker. The sands of the esker core were obviously once much wider, and are the remains of material deposited in quiet water. The faulting was probably produced by subsidences consequent on the melting of masses of ice included in the sands, as after the faults were formed powerful currents of water spread a sheet of coarse gravel over the ridge of sand.

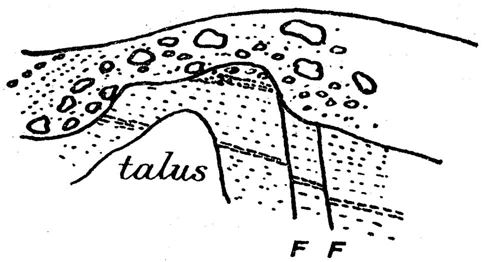

FIG. 2.—Section in an Esker, with contemporary faults. Ballyduff Bridge.

Sections on the southern slope of the esker beside the road to Kilbeggan, $1\frac{1}{2}$ miles north of Tullamore, expose at the base a coarse bouldery wash, which passes laterally to bedded sand and loam containing irregular masses of gravel and steeply inclined shoots of clay. The clay has a very steep dip and appears to have been dumped in its present position by slipping down a steep bank. The upper part of the esker consists of a regularly bedded loam.

The arched structure, which is often described as characteristic of eskers, is absent from this pit and from most of the sections in the Tullamore Eskers. Thus 2 miles north-east of this pit, to the south-east of Derrygolan Bridge (fig. 3), the base of the esker is a bed of stratified gravel with a flat upper surface which has a very slight inclination to the north. This bed is covered by a layer crowded with limestone and chert boulders, which are as much as 15 inches in diameter; they are all fully water worn, and lie horizontally. Some of the layers in this bouldery wash consist of closely packed cobbles and pebbles, and contain but little sand. The bedding planes are cut off abruptly by the slopes of the esker (fig. 3), which is therefore the remnant of a once wider ridge.

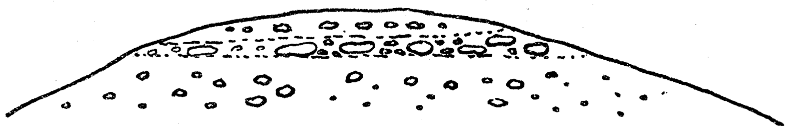

FIG. 3.—Section of an Esker, with horizontal bedding. Derrygolan Bridge.

Deeper sections in the same esker are exposed a mile further to the north-east at Murphy's Bridge. The base of the esker there is a bed of sharp sand containing some well rounded grains. The upper part is a bed of stratified dark to greenish sand and gravel, which contains a few small boulders and dips regularly to the north. This bed and its bedding planes are abruptly cut off above by from three to five feet of coarse bouldery gravel, which forms the surface of the esker (fig. 4).

Near Newmill Bridge, a mile further north-east, are some excellent sections in the part of the esker sketched by DU NOYER (figs. 9 and 10, 'Mem. Geol. Surv., Ireland,' Explanation Sheet 98, etc., pp. 30–31). Three large adjacent pits show striking variations in the material. The south-western pit beside the old limekiln is characterised by its regular bedding. The base is a coarse wash with boulders a foot in diameter; above this is a layer of well bedded loam and clay, which is covered by a bed of sand containing large boulders. This is covered by a layer from 2 feet to 6 feet thick, which is crowded with boulders up to $2\frac{1}{2}$ feet in diameter. At the top of the esker is a bed of gravel 10 feet thick, with inconspicuous bedding and boulders up to a foot in diameter. The planes between the successive beds are cut off abruptly by the southern slope of the esker, showing that the beds were once more extensive.

Immediately to the north of this pit, on the opposite face of the esker, is a pit in sand with very confused false bedding. It offers a striking contrast to the regular bedding and coarse boulders and gravel of the southern pit.

The third pit, the north-eastern, is a confused mass of bouldery wash. The only evidence of stratification is afforded by occasional horizontal patches of large boulders. Some of the boulders are standing on end. The material in this pit, owing to the size and arrangement of the boulders, is very morainic in aspect; it resembles the redeposited moraine stuff of some of the larger Swiss moraines.

A little further to the north-east the esker turns abruptly north-west and is continued as the Newtownlow Esker and Long Hill. Good sections are exposed at Newtownlow. The base of the esker consists of coarse gravel, including patches of bouldery wash. Above this gravel is a thick bed crowded with large boulders, and against its steep western margin the bedding planes in the gravel have been inverted. This disturbance was contemporary (fig. 5); for this boulder bed and the gravels beside it have been planed off and a layer of sand is continuous across the junction. This sand is covered by bouldery wash which usually forms the surface of the esker.

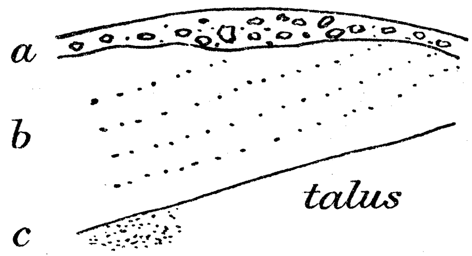

FIG. 4.

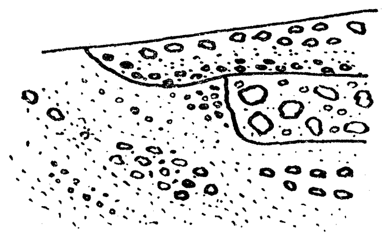

FIG. 5.

FIG. 4.—Section in an Esker at Murphy's Bridge, with fine sand near the core and coarse boulder drift on the top.

FIG. 5.—Section in an Esker, showing great contemporary erosion. Newtownlow.

Three miles west of Newtownlow, to the south and south-west of the village of Kilbeggan, is a long low esker parallel to the Long Hill Esker. It lies on the floor of the area included within the horse-shoe course of the Newtownlow, Ballyduff and Clara Eskers. Some shallow sections in the gravel pit near the fork of the road half-a-mile south of Kilbeggan show the general character of the material. The western end of the pit consists of beds of sharp sand separated by gravel, in which the pebbles and the few boulders present are all well rounded. The aspect of this material is like that of a river gravel. Eighty yards along the pit is a section of stratified sand and fine gravel passing up to gravel with some boulders. At the eastern end of the pit is the following section in descending order.

Soil: 5 feet of unsorted boulder drift; 2 inches of sand; 4 inches fine chert gravel; 18 inches stony loam, including 12-inch boulders; 1 inch to 10 inches irregular layer of sharp sand; 1 inch to 12 inches loam with very few pebbles; 2 feet stratified gravel, part of a lens which is 25 feet long and 3 feet at its thickest; 18 inches stratified sand with pebbles.

The general character of the Ballyduff-Newtownlow Esker is inconsistent with the glacial river theory. The extreme difference between adjacent parts of the esker, as shown at the three pits near Newmill Bridge, indicate that its material had been brought from the side and not carried along the esker. Its original formation can best be explained by the accumulation of material washed from the adjacent front of a melting ice sheet. The esker is not, however, a moraine, as its thoroughly water-worn character and bedding show that it was deposited by sheets of water. The material had obviously not been carried far by water, and its lateral variations are dependent on the nature of the drainage from the ice front. The material in the north-eastern pit at Newmill Bridge probably accumulated where the ice front was a steep wall, at the foot of which the boulders collected in heaps. The false bedded sand of the middle pit was deposited where a stream flowed from the ice. The widespread horizontal sheets of alternate sand and gravel in the south-western pit were doubtless due to variable floods of water.

The composition and structure of the Ballyduff-Newtownlow Esker, therefore, indicate that it was a marginal formation produced by the wash of material from a receding ice front; and this explanation agrees also with the general plan of that esker system.

The distribution and levels of the Parsonstown, Clara and Streamstown Eskers show that they are marginal formations beside an ice sheet which came from the north-west down the Suck and Shannon Valleys.

The Kilbeggan Esker, on the other hand, is like the Swedish osar, fluviatile in character and was probably deposited as a delta formation at the receding mouth of a glacial river.

2. *The Athlone Esker.*

South of the railway to the west of Athlone a large pit exposes a high section of a very coarse stratified gravel containing in one part closely crowded boulders up to $2\frac{1}{2}$ feet in diameter. Owing to the size and number of these boulders the material looks more morainic than fluvio-glacial. All the material has, however, been water washed, and the boulders were probably rolled from the ice down a steep bank of pebbles, so that they were easily moved a little distance from the actual edge of the ice.

This morainic type of esker continues west of Athlone and is well exposed near Mount William, about $1\frac{1}{2}$ miles west of Athlone, in the large ballast pit north of the railway. The pit illustrates the variable structure of this esker. The south-eastern part is strewn with big boulders, up to 6 feet in diameter; some of them show glacial striæ of the curved, blunt, short type, like those formed by the twisting movement when stranded ice is swung by the tide. The south-western corner of the pit is in a thick deposit of well bedded sands, which are in places false-bedded and contain some pebbly layers. At the north-western part is a projecting mass of coarse-grained angular faceted gravel, which has been cemented to a hard conglomerate, while the interbedded soft material has been worn into caves. The eastern part of the northern face of the pit exposes a variable series of boulder drifts, gravels, sands, and loam; the upper layer is usually a boulder drift overlying sand, with puckered and faulted seams of clay. In part of this face the beds have been violently disturbed. Towards the eastern end the beds have a dip of 25°, and there are three definite boulder beds inter-stratified with coarse bedded sands.

The beds in this pit include morainic drift along the southern side, sheets of sand which had been deposited in comparatively quiet water, and alternate beds of boulder bearing gravel and sand.

The Athlone Esker is of the marginal morainic type; but the smaller eskers which trend north-westward from it have a well developed banding. Thus about a mile to the west of the Mount William pit in a small pit a little east of Millbrook, the upper-most bed is a 3 foot layer of coarse drift containing boulders up to 18 inches in diameter; below is a layer of coarse sand, and then another 3 feet of bouldery drift containing boulders 20 inches by 30 inches. The stones in both gravels are water worn, and many of the pebbles are as rounded as in a river gravel. I saw in this pit no trace of glacial striæ. The banding shows variations in the rate of deposition, but there is no evidence to show whether it was due to seasonal changes.

Two miles further to the west-north-west, beside the junction of two roads, just south-east of Ballymullakill, is a large gravel pit, the face of which is partly overgrown, and the relations of the beds in places obscured by slipping. The pit, however, gives evidence of frequent alternate increase and decrease in the currents by which these deposits were laid down. In the length of 85 yards occur seven bands each composed of small boulders, cobbles, and coarse gravel; these bands are separated by layers of sand with small cobbles and pebbles. These bands dip to the north. At the southern end of the pit is a bed of gravel with a steep eastward dip; it has been cut across by a channel filled with boulder drift.

The banded structure of the esker is also shown a little further along it in a pit to the north of the road, half-a-mile west of Ballymullakill and a mile and a quarter south-east of Brideswell. Parts of this pit are overgrown; but the section shows, in a length of 100 yards, eight beds of bouldery drift which are separated by beds of sand and fine gravel (figs. 6 and 7). The beds dip to the north.

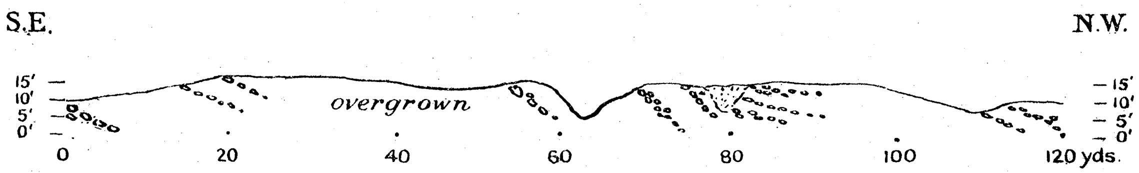

FIG. 6.—Longitudinal Section in the osar at Ballymullakill, north west of Athlone, showing the repeated beds of coarse bouldery gravel. Heights in feet; lengths in yards.

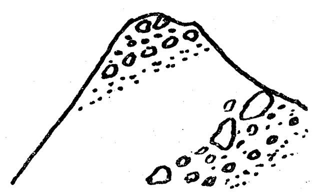

FIG. 7.—Section in the osar north-west of Athlone.

These and other pits between Athlone and Lough Funshinagh give clear evidence that this esker was formed by a stream flowing south-eastward, and that the banded structure was due to the varying strength of the current. It is tempting to regard the variation as seasonal, the succession of coarse to fine material representing the variation during one summer's melting. This banded structure is, however, so irregularly developed that it would be unsafe to conclude that the successive bands represent deposition in succeeding years.

The character of this banding could best be determined in the winter, when the coarse bands of material could be recognised beneath the turf. Detailed mapping of some of these longitudinal eskers would probably determine whether their banding is a seasonal stratification.

The Athlone Esker breaks up westward into a series of irregular mounds and short ridges, which are well developed around Castlesampson. Eastward it passes Moate, and probably continues as the ridge thence northward and north-westward along the valley of the Tang River, a tributary of the Inny, to the south-east of Ballymahon.

The Athlone Esker appears to have been formed by a glacier which came down the Shannon valley and through Lough Ree. It was bounded on both sides by driftless highland—to the west by that, over 500 feet high, south of Roscommon and east of the Suck valley; to the east by that south-east of Longford and that, over 400 feet high, east of Lough Sunderlin and Ballymore.

3. *The Ballinasloe-Clonmachnois-Clara-Streamstown Esker.*

To the south of the Athlone Esker is one of the longest, most regular, and best developed eskers in Ireland. It begins about eight miles west of Ballinasloe; its general course is from west to east, though it makes successive curves southward through Ballinasloe, New Town, and Cornaveagh. It is there breached by the Shannon, on the eastern bank of which, at Creevagh, it is joined by a branch which passes south of Ballinasloe through Glenlougham, Kellysgrove, and Shannon Bridge. The combined esker runs from Creevagh to Clonmachnois, where it again subdivides; the northern branch is the Pilgrims' Road Esker, and the southern branch continues due east through Clonfinlough and Togher, and, after a gap made by the valley of the Brosna, to Clara. It passes Durrow, south of Kilbeggan, unites with the Ballyduff-Newtownlow Esker, and bends sharply back and forms the narrow ridge known as the Long Hill; it crosses the Brosna valley, continues further north as the well known Streamstown Esker, and ends in the esker near Moyvore.

This esker is about 65 miles in length from its western end near Woodlawn, on the watershed between the Shannon and the Dooyertha (a stream entering Galway Bay), to its north-eastern end in the Inny valley; it is not, however, continuous for the whole distance. The esker receives a series of branches, and affords one of the best Irish examples of an esker with confluent tributaries, such as suggested the formation of eskers by rivers in glacial canyons. If that had been its origin, the combined river would have been formed by three main streams. The north-eastern stream would have deposited the Long Hill of Newtownlow, and would have been joined by tributaries from Streamstown, Ballymahon, and Athlone. The second main stream would have come from Ballinasloe, Clonmachnois, and Clara; and its chief tributary would have been that of the Shannon Bridge Esker. The most southern of the three main streams would have come from Tullamore and have carried the drainage from

Parsonstown, Eyrecourt, and Portumna. The outlet of the three combined rivers would have been past the fragmentary eskers south of Edenderry.

I have examined this esker at a good many localities and failed to find that its structure agrees with the glacial river hypothesis. The shape of the boulders is not that typical of river gravels. In most places glaciated stones can be found, whereas the striæ disappear after transport by water for a very short distance. Even when no striæ are observable the boulders and pebbles commonly have flattened surfaces, characteristic of those of boulder clay. In some bands of gravel the stones have all been washed and rounded; but these bands form a small proportion of the constituents of the esker, and the abrasion of their stones and removal of the striæ may have been by surf action or by small local streams. The deposits are often unbedded or show only very faint and obscure traces of bedding. In some pits the material appears to have been merely dumped where it lies. The boulders may be packed very closely and large boulders often stand upon their ends. The aspect of many pits is morainic, and they include layers of sand or clay deposited on the floors of depressions in the drifts.

This esker and its branches appear to have been formed on the margin of an ice sheet, which came from the high grounds to the north-west in Mayo and eastern Galway, and deposited ridges of drift at various stages in its retreat. The branching of the esker appears to be due to the ice margin having remained stationary at one place, while it receded in a neighbouring locality. Thus the glacier held its position near Newtownlow while the ice front in the Shannon valley receded about 15 miles.

The evidence for these conclusions may be summarised as follows:—

The Ballinasloe Eskers.—West of Ballinasloe the esker is well exposed in pits beside the railway near Kilmalaw Bridge, north of Aughrim. The esker there consists of a confused mass of closely packed boulders, which are especially numerous in the top layer. Rough bedding can be seen in some layers. The largest boulder observed in the pit at Kilmalaw Bridge was $2\frac{1}{2}$ feet long. The boulders are often ice-scratched. Half a mile to the east of the Kilmalaw pit is another gravel pit of the same type. The bedding is obscure and the material appears to have been dumped. The boulders are irregularly packed.

Between $1\frac{1}{2}$ and 3 miles west of Ballinasloe, to the north of the railway line, is the Kilcloony branch of this esker. It is well stratified and consists largely of alternations of boulder drift and gravel, with some layers of sand. A pit south of the road about halfway along this esker shows a 6-foot bed of closely packed boulders, some of which are vertical. Beneath the bouldery drift is a bedded, fine-grained gravel. The structure of the eastern end of the Kilcloony Esker is well shown in two pits to the west of the lane leading to the church. The southern pit includes two beds of bouldery drift, separated by 10 feet of gravel. The beds have a steep dip to the north. In the northern pit the gravels are covered by 3 feet of false-bedded sand with lenticles of well-washed gravel; but in a layer of coarse gravel immediately beneath the sand are many well ice-scratched stones. The gravels include pebbles of a fine-grained gray biotite-granite and foliated granites which doubtless came from western Galway. The chief deposits of sand in these pits occur, as usual, on the northern side of the esker, as if they had collected in water between the esker and the receding ice front.

Half a mile south-east of Ballinasloe, on the western side of the canal just north-west of Somers Villa, is a gravel pit in the main Ballinasloe Esker. The core of the esker consists of a coarse bouldery drift with some interstratified beds of subangular gravel. It is capped by bedded sand and fine angular gravel which, on both sides of the esker, have been faulted. After the formation of these faults a layer of coarse pebbly drift was deposited across the esker, so that the faulting was clearly contemporaneous with its deposition. A bed of sand occurs on the northern slope of the esker. Some of the boulders are striated, and after the striation were encrusted by calcareous layers, one of which Madame LEMOINE has identified as a Lithothamnium. This esker rests on boulder clay, which is exposed in a pit beside the towing path of the canal, and the upper part of this boulder clay contains boulders bearing marine encrustations showing algal structure.

The Shannon Bridge branch of the Ballinasloe Esker is well shown in a pit $2\frac{1}{2}$ miles south-south-west of Ballinasloe, near Kellysgrove, and in other pits near Sinclair's Village and by Glenlougham Church. A section across this esker at Kellysgrove was figured in the 'Geological Survey Memoir' (Sheets 96, 97, etc., 1867, p. 25), and shows that the stratification is not in the same direction as the outer slopes. The bedding is arranged as a trough and not as an arch.

A pit just north-west of Sinclair's Village shows the close packing of the boulders which sometimes occurs in this esker. The boulders lie at all angles; they are not striated. Their matrix consists of narrow partings of a coarse sand, which includes some cobbles and small boulders. The largest boulder in the area sketched was 4 feet long by $1\frac{1}{2}$ feet thick, and a 6-foot boulder lay on the floor of the pit. A few of the pebbles are of porphyritic granite. The aspect of this pit (see fig. 8) is that of a moraine with closely crowded boulders.

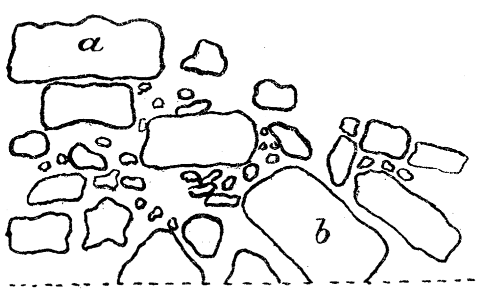

FIG. 8.—Part of Face in a Pit N.W. of Sinclair's Village, near Ballinasloe, showing crowded boulders. Scale, 1 inch = 5 feet. Boulder *a* is 4 feet × $1\frac{1}{2}$ feet; boulder *b* is 3 feet 8 ins. × 1 foot 10 ins.

Kellysgrove Esker.—At Glenlougham, to the west of Kellysgrove, the core of the esker consists of false-bedded gravel, with boulders and patches of sand. The sand patches consist of irregularly deposited lenticles. The upper part of the pit is in roughly bedded bouldery drift of morainic aspect. On the south side this bouldery drift is intercalated with wedges of gravel and coarse cobbly gravel. A short search yielded in the gravel six specimens of Galway granite.

Shannon Bridge Esker.—The Kellysgrove Esker is a continuation of the Shannon Bridge Esker, the structure of which is well exposed in pits south of the Ballinasloe road, west of Shannon Bridge. A long, shallow section on the northern face of the esker shows a crowded medley of boulders which are up to $2\frac{1}{2}$ feet in length; this bed overlies a black chert sand, with a steep dip to the north. The esker contains a few thin layers of clay. The deeper pits on the southern side show an unwashed, unsorted material, which is arranged as a confused dump. The structure of the esker agrees with its origin as a morainic deposit.

East of Shannon Bridge the esker bends to the north-east, and follows the eastern bank of the Shannon until it joins the Ballinasloe Esker near Clonmachnois. At Cloneff, south of the junction with the Ballinasloe Esker, the Shannon Bridge Esker consists mainly of sharp, angular, bedded sand, with lines of water-washed pebbles. This material would pass as fluvioglacial, but the sections are small and obscure. The nature of the esker must be judged by its characters where better exposed.

A little further north, to the west of Lough Nanag, the esker branches, and encloses a series of pits and hollows shown in the detailed map and sketches published in the 'Geological Survey Memoir' (Sheet 98, etc., pp. 24, 25, 26). A pit to the west of the road shows coarse bouldery drift overlying a bed of ill-sorted water-worn gravel; the boulders lie at all angles; some are vertical, and occur in a coarse pebbly sand.

Clonmachnois.—Just east of the Seven Churches at Clonmachnois, three-sixteenths of a mile east of the school, some shallow excavations show an irregularly dumped cobble gravel with faceted boulders, on which I did not see any striæ, and irregular patches of loam. There is no sign of deposition by streams of water. The material appears to have been dropped irregularly in water.

From Clonmachnois, two branches of the esker continue eastward; the northern branch is that of the Pilgrims' Road. The southern branch goes easterly, and extends, though with one gap of nearly four miles, to Clara, around which are many large and instructive sections.

Clara.—North of Clara Church are some deep pits in drift resting against a plateau. The lower part of the drift consists of false-bedded sand and gravel, with a prevalent dip to the east. The upper part is a bed of bouldery drift, 20 feet in thickness, which contains irregular patches of sand and fine gravel. The upper bed has in places been cemented to a conglomerate, which overhangs the underlying gravel. In the eastern part of this line of pits the gravels are covered by laminated false-bedded sand and pebbly gravels, with occasional boulders; these beds are in places faulted, and include large pockets of bouldery drift.

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The material in these pits is described in the 'Memoir of the Irish Geological Survey' (Sheet 98, etc., pp. 28 and 29) as an esker; but it is admittedly not an isolated ridge, for the beds flank a Carboniferous Limestone plateau, part of which is driftless. This material was apparently deposited where an ice sheet from the north-west melted against the side of the plateau. Some of the material was washed and sorted, and patches of sand collected in the depressions. The beds have been faulted and disturbed by slips during the settlement of the material.

East of Clara the Clonmachnois Esker subdivides. The southern branch is followed by the Tullamore road for a couple of miles, and then bends northward, reuniting with the northern branch near Durrow Abbey. The northern branch crosses the Brosna River, and then turns south-south-east, forming a ridge, which occasions the remarkable meander of the Brosna about a mile and a half east of Clara. Between the two branches of the esker the land is level and low.

The structure of the two branches of the Clara Esker may be illustrated by reference to the sections at the pit at Lehinch, and by the large gravel pits at Ashfield, $1\frac{7}{8}$ miles from Clara, on the road to Tullamore. The Lehinch pit is of interest, on account of the occurrence of a band crowded with fragments of minute calcareous tubes, some of which grow in tufts. The pit is on the eastern side of the road leading to the bridge over the Brosna, at the end of its horseshoe loop. The core of the esker at this point consists of sand and fine gravel, which are arranged in a shallow trough. At the west-south-west end the sands and gravel dip 50° to the south-west. This material is abruptly cut off above, and is covered by a bed of gravel composed of rounded and angular cobbles. Similar material covers the middle of the esker, and, on the other side, slopes down to the east-north-east. It is there covered by a bed of laminated sand and fine gravel, which dips 20° to the east-north-east. This material has the characteristics of an angular beach gravel. It is 10 feet thick. Below it is a layer, 1 foot in thickness, of coarse, loosely packed boulders, the largest of which are about 10 inches in diameter. In the sand between these boulders are many joints, and occasional tufts of calcareous tubuli. Many of the stones in this layer are encrusted by calcareous tubuli. Beneath this bed is a 9-inch layer of fine-grained gravel, also containing encrusted stones. Below are 18 inches of an angular beach gravel; it rests on a 6-inch boulder bed, in which the boulders are encrusted by tubes.

The Ashfield pit, on the southern branch of the Clara Esker, is better known, as it is larger, and is situated beside the high road to Tullamore. The core of the esker consists of a bedded gravel with an arched dip. The ridge is not symmetrical in section. The beds dipping south, on the southern side of the esker, are much thicker than those on the northern side, which dip north. The stratification on the northern side is more confused and irregular. The bedded gravels, which form the main mass of the esker, are covered by a bed crowded with boulders.

After the reunion of the two arms of the Clara Esker, it passes Durrow Abbey to

Newtonlow, where it bends sharply back to form the Long Hill, which is cut through by the Brosna River south of Ballynagore, and is continued, though with two gaps, through the eskers of Streamstown and Moyvore to the Inny Valley.

4. *The Athenry Esker.*

West of Ballinasloe the eskers are represented by irregular patches and mounds of drift.* Near Athenry the esker is again developed in continuous ridges, one of which is well seen from the railway to the north of Athenry Station. The structure of this esker is well exposed where it is cut through by the Tuam Railway, and in pits and road sections thence westward past Athenry toward Castle Lambert.

The section at the Tuam Railway shows the following section in descending order :—Bouldery drift, inclined southward, 10 feet; fine-grained, black chert gravel containing numerous boulders; this gravel occurs in three layers, two of which unite in the middle of the section; the two bouldery beds there end off against a tumbled mass of boulders, which form the core of the esker. On both sides the beds dip away from the middle line of the esker. Some of the boulders are striated.

A small road section to the west of this pit shows a well-defined repetition of the coarser bands, to which my attention was called by Mr. R. DURDLE; and, as he remarked, this structure seems too indefinite to be a seasonal banding, though it is clearly due to variations in the strength of the currents which distributed the esker material.

On the southern slope of the esker, a little west of the last section, is a small pit, 10 feet deep, in a well-bedded coarse gravel interbedded with a much finer gravel. At the eastern end there are five layers of coarse gravel with cobbles; at the western end these have united to form only three layers. Some of the boulders in this pit are as distinctly glaciated as those in boulder clay.

At a pit further west, on the eastern side of the Tuam road, are numerous patches of sand in boulder drift. The arrangement of the material in this pit is very irregular, and the sheets of sand were probably deposited in water between the ice front and the esker.

At the quarry a little further north on the opposite side of the Tuam road the surface of the limestone is well glaciated. Upon this rests a sandy drift containing many striated and encrusted boulders. This material is identical with that sometimes described as boulder clay, though it is so sandy that the term clay for it is a misnomer. This drift does not at the quarry give rise to esker forms, though some of the sections are indistinguishable from esker drift; thus, in one place, a bed of false-bedded sand and gravel is cut off above, and is covered by a coarse morainic bouldery drift. The largest stones in this drift are striated.

The Athenry Esker in the sections from the Tuam road eastward to the Tuam

* 'Mem. Geol. Surv., Ireland,' Explanation Sheets 96–7, 106–7, p. 28 (1867).

railway is largely composed of sand and fine gravel. The sand is often as sharp as sea sand, and it is capped and interbedded with boulder drift.

5. *The Ballyhaunis and Dunmore System.*

One of the best cases of several eskers joining like the confluent tributaries of a river is supplied by the Ballyhaunis system. Thus in the Tuam district three eskers, which trend north-eastward, unite near Ballinlough (fig. 9).

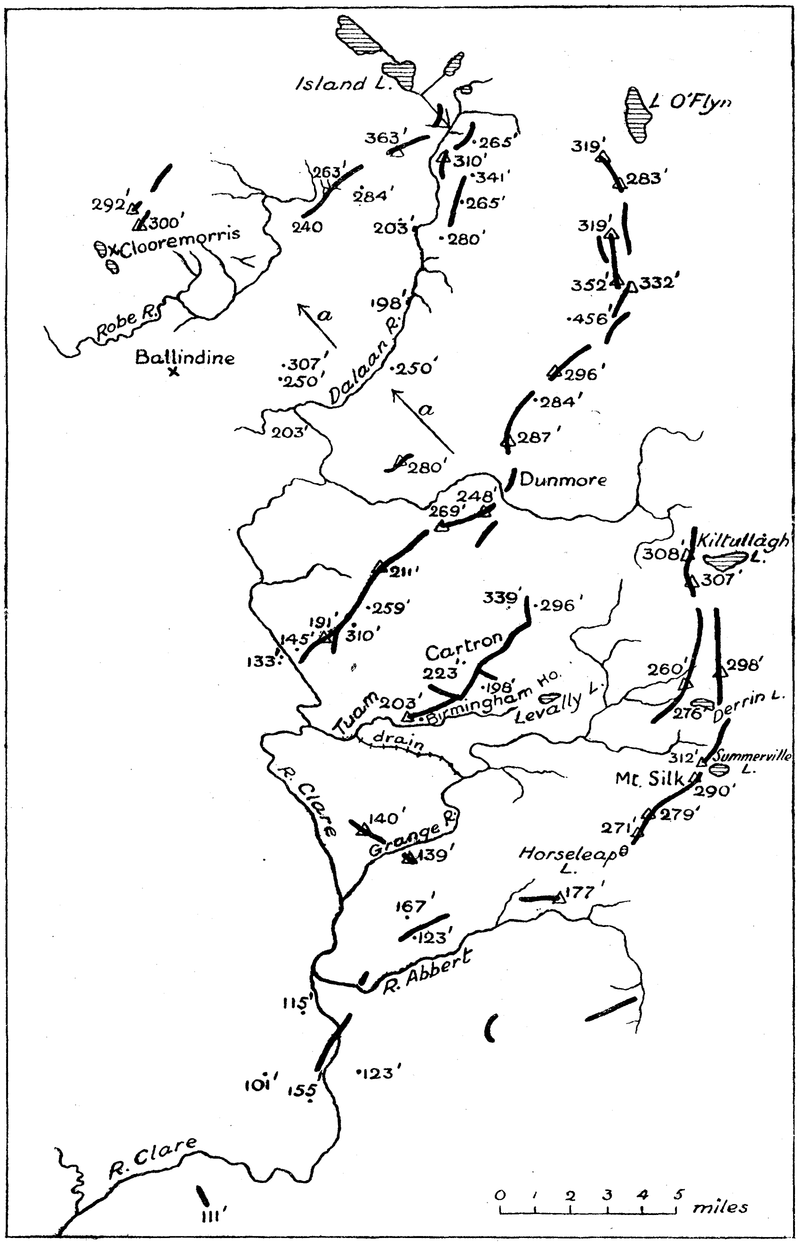

FIG. 9.—The Esker System, near Dunmore, Co. Galway. The arrows, *a*, *a*, show the course of the ice movement (after SOLLAS). Heights in feet from Ordnance and Geological Survey Maps. The eskers in this system are transverse to the course of the ice movement; they approach one another to the north, where the levels are higher than to the south. Eskers shown by thick lines. *For* Clooremorris *read* Claremorris.

Of these three eskers the southernmost follows at first the course of the Abbert River, and then crosses the divide between it and the Grange River, passing about six miles south and south-east of Tuam through Ballyglunin and Mt. Silk; it bends first northward through Raheen to the west of Kilnalag, and then north-westward to join the second member of this system.

The second esker begins a little east of Tuam, 2 miles east of which it passes Birmingham House; it is well developed 2 miles further east about Cartron; thence it trends north-eastward, and, after a long gap near Lake Makeeran, continues north through Stoneypark, and west of Cashel and Kilnalag, where it joins the two other eskers. The branching of this esker near Stoneypark is described and illustrated in the 'Mem. Geol. Surv., Ireland,' 1871, Explanation Sheets 86–88.

The third branch starts 2 miles north-west of Tuam, passes through Castletown and Dunmore, and joins the other two eskers, which continue northward towards Lough O'Flyn.

The easternmost of these three eskers lies along the watershed between the Clara and Suck Rivers. The general level of the adjacent country rises from south and south-west to north and north-east. As the ground is sloping southward if the eskers had been due to three rivers which had cut channels through a glacier down to the underlying rock, their flow should have been southward, and not in the opposite direction. On the fluviatile theory the rivers would have been divergent from the north and north-east, rather than confluent from the south-west. The three eskers, moreover, lie across the main direction of the ice flow. The distribution of the erratics, the directions of the striæ, and the trend of the drumlins, show that the main flow of the ice was from north-west to south-east.* These eskers were probably deposited along the edge of the ice sheet at stages in its retreat.

The morainic character of these eskers is shown in sections near Castletown House to the south-west of Dunmore, at Pollaphuca, at the old lime kilns beside the road junction to the south-east of Knockavenny House, and along the main road to Tuam near Birmingham House. The structure of the Dunmore Esker may be illustrated by reference to six gravel pits north-north-east of Castletown House and between it and the Dunmore road, near Grange. North of Castletown House the esker occurs in three branches, each of which has been cut through by the road. The eastern branch consists of beach material, with patches of fine gravel and scattered boulders, some of which are 2 feet long. It rests upon boulder clay, which is exposed in the low ground to the west. The westernmost division of the esker is very sandy, and is said to have yielded shells; but I did not find any.

The general character of the material in this part of the Dunmore Esker is an unstratified morainic drift. It may be described as a gravelly beach moraine. Most of the sections yielded ice-scratched stones and boulders up to 1 foot long; the

* Prof. SOLLAS recognised that the eskers near Ballyhaunis, Dunmore, and Tuam lie across the ice flow; he suggested that the position of the esker-forming rivers was determined by crevasses.

largest measured is 4 feet in diameter. The upper layer consists of a bedded sand. One of the best pits is that close by the roadside, south of Grange; in it the boulders range up to 3 feet in diameter, and are mixed with black chert, gravel, and sand; a faintly bedded character is given to the deposits by short lines of sand, but the material, as a whole, is unstratified. The irregular arrangement of the boulders and occasional bedding give this pit a morainic aspect.

The esker near Birmingham House and Pollaphuca shows more clearly the characteristics of a morainic drift, which is either unstratified or but occasionally stratified. It is therefore very different in character from ordinary fluvioglacial material. The pit in the esker just west of Birmingham House, 2 miles east of Tuam, contains boulders $2\frac{1}{2}$ feet in diameter, in coarse unstratified morainic drift.

One and a quarter miles further east, a branch road to the north-east towards Cartron cuts through this esker and shows clear sections, one of which is at an old kiln just by the junction of the two roads. This pit exposes unstratified bouldery drift, cut off above by a level layer of sand resting on a line of cobbles; above this old surface, which is the only definite stratification in the pit, is a layer of boulders and cobbles. The top of this esker must have been planed down and covered by a layer of sand, upon which fresh bouldery drift was deposited.

To the north of the bog, on the road to Cartron, the esker is exposed again on the western side of the road. The most interesting feature in this pit is the presence of large encrusted boulders, some of which are standing on end. Thus, in the upper part of the pit, a boulder, which is 2 feet 8 inches high and 2 feet 4 inches wide, is standing upon its lower edge, which is only 10 inches wide. None of the boulders seen are striated.

These two members of the Ballyhaunis system are therefore not composed of fluvioglacial, but of morainic material. The Ballyhaunis Eskers were probably deposited by ice, which came from the hills of Mayo, as a series of beach moraines at successive stages in its recession to the north-west.

6. *The Ross–Gortachalla Esker.*

The Ross–Gortachalla Esker, about ten miles north-west of Galway, extends from near Ross Station eastward to Loch Corrib. It was briefly described by KINAHAN,* and SOLLAS (1896, p. 809) has suggested, as a "bare possibility," that it may belong to the Ballyhaunis system. Its course is irregular, as denudation has in places broken it into isolated mounds. A pit, south of the esker and south-east of the Roman Catholic chapel at Ross, shows that it rests on a sandy boulder clay, which contains many boulders of limestone and some of porphyritic granite. The material in the adjacent esker is a stony gravel, with the pebbles strongly faceted and not very water-worn. Sections north of the road and north of the eastern end of Ross Lake show that the esker there consists mainly of closely packed pebbles,

* 'Mem. Geol. Surv., Ireland,' Explanation Sheet 105, p. 44 (1869).

while the lowest layer exposed is of sand, with but few pebbles. The cobbles are mainly of limestone and chert, with a few of gneiss and schist, but I saw none of the granite, which is so abundant in the boulder clay. The esker here consists of the remains of two ridges, and a third is represented further to the south, on the margin of Ross Lake. A pit in the esker knoll, situated just east of the road which goes south past the eastern end of Ross Lake, exposes a typical glacieluvial gravel, which is unstratified, and has abundant pebbles of schist and gneiss, but I saw none of granite. Many of the pebbles are faceted, but are not striated.

A gravel pit near Ower contains at its northern end many limestone boulders, from 3 to 4 feet in diameter, in a faintly bedded, fine-grained sand. At the southern end of this pit the sand is coarse, sharply angular, and unsorted; it is not a river sand, but resembles a bed of sand formed as rainwash. The arrangement of the materials here suggests the former existence of a lake between the ice and the esker. South of Ower the esker is a high, narrow, irregular ridge, which is steepest to the south. Some shallow gravel pits north-west of Gortachalla Lough work a stony, unsorted glacieluvial gravel, which consists of flat-sided, subangular pebbles. They are not striated; there are no boulders, and no specimens of the coarse porphyritic granite from the hills to the south-west. There are, however, abundant pebbles of gneiss and schist derived from the area to the west and north-west. In the southern slopes of the esker, toward the eastern end of Gortachalla Lough, the stones are in places packed as closely as in a shingle beach.

The material of this Ross–Gortachalla Esker is not fluvioglacial, because it is not a river deposit; most of it is unbedded, and, though its pebbles have been so washed as to have lost any glacial striæ, they are still angular and flat-faced. Bedding and layers of sand are exceptional, though they occur where small lakes or ponds had formed between the esker and the retreating ice. The abundance of pebbles of gneiss and schist show that the material came from the west or north-west, and, if the esker had been due to a glacial river, the pebbles should become smaller to the east. This esker seems to me a ridge of typical glacieluvial materials; its composition, course, and curvature show that it was due to a glacier which flowed south-eastward from the mountains of Connemara. The esker was probably deposited along the edge of the Loch Corrib glacier during one stage of its retreat.

7. *The Greenhills Esker, near Dublin.*

The Greenhills Esker, to the south-west of Dublin,* is one of the most accessible in Ireland, and is exposed in numerous extensive sand and gravel pits. I was kindly guided to it on my first visit by Prof. SEYMOUR. Its southern end is on the bank of the Dodder River at Balrothery. It rests in places on water-worn Carboniferous rocks, which are sometimes separated from the esker by a sheet of boulder clay.

* 'Mem. Geol. Surv., Ireland,' Explanation Sheet 112, Dublin, 1903, pp. 50–51, 97–100.

The existence of this clay has been used as an argument for the glacial-canyon theory of eskers. The esker in places shows the arched bedding, which is often claimed as characteristic of true eskers. The material is in places finer-grained on the western slope, while the bedding is steepest on the eastern front. Some of the large lenticles of gravel are coarsest to the south, but the included rocks indicate that the material came from the north or north-west—a fact previously recorded by CARVELL LEWIS (1894, p. 149). Glacial striæ are said to be not uncommon on the stones, and Prof. SEYMOUR and I noticed clear glacial grooves on the boulders in the lower part of the esker.

One of the most conspicuous features in the constitution of this esker is the abundance of laminated clay and loam, as in the deep pit at Airmont.* There the loam had been cut away in steps, and the hollows thus formed occupied by a coarse torrential gravel, which also forms the summit of the esker. The gravel often occurs in lenticular patches interstratified in the clays.

This esker is in some places a single narrow ridge, and in others a broad bank of confused interstratified sand, gravel, and clay. The material does not, as a whole, resemble the deposit in a glacial river, for the amount of clay is far greater than would be expected under such conditions.

The characteristics of this Greenhills Esker suggest that it was deposited as a wide bank of laminated sand and loam on the margin of a sheet of water; that the deposition of the finer materials was interrupted by occasional floods carrying coarse gravel; and that finally the bank was cut into by strong currents which deposited on its flanks and above it sheets of coarse torrential gravel.

The arrangement of the materials in this esker appears to indicate their deposition as a marginal bank along an ice sheet. The rise in level southward, although the material has come from the north, is incompatible with the fluviatile theory, unless the river had flowed over the glacier, and such a position appears irreconcilable with the regular bedding of the materials. If they had been first deposited on the bed of a supra-glacial river and then redeposited by the melting of the underlying ice, the bedding should have been more confused and irregular.

8. *The Eskers of Tyrone.*

A series of eskers different in several respects from those of the Central Plain occur on the moorlands of Tyrone on the divide between the Shrule, the upper part of the River Foyle, and Lough Neagh; and between the Sperrin Mountains (2,240 feet) to the north, and the hills to the north of Pomeroy. The eskers have been described in 'Mem. Geol. Surv., Ireland,' Explanation Sheets 26, 1884; 34, 1878; and 35, 1877. Some of these eskers are well exposed at Crockadoo (at the cross roads, 487 feet), at the north-western foot of Craigballyharky (771 feet), along the direct road from

* This locality is named Palatine House in the 1902 edition of Sheet 112.

Cookstown to Omagh, near Drumshambo, especially between Dunnamore Bridge (at 500 feet) and Teebane Bridge, and finally north of Creggan School (600 feet).

The eskers to the south of these hills in the valley between Pomeroy and Carrickmore appear to be much larger; they were referred to as kames by CARVILL LEWIS (1894, p. 115). He stated that the "kames" in this district, near Lough Cam, were the largest he had seen. I have chiefly examined those near the Cookstown-Omagh road, where they consist of coarse sand with many faceted but not striated pebbles. At Drumshambo they are mainly granite and greenstones, and the gravel has all the characteristics of glacieluvial deposits. The arrangement of the eskers is seen from the ridge (at 617 feet) west of Barony Bridge; and they are seen to lie along the northern foot of Evishanoran Mountain (886 feet), which is north by west of Pomeroy. The esker rises up the hill side on a sinuous course. It has obviously been formed as a marginal formation due to a glacier flowing northward and north-westward from the Evishanoran Hills. The esker near Dunnamore was probably similarly due to ice from Slievemore (842 feet). This series of eskers seems to have had a similar origin to the ridge at Polmont, in Linlithgow County, which has been described (GREGORY, 1912 (1), pp. 209–210) as a glacieluvial kame.

III. PALÆONTOLOGICAL EVIDENCE.

OLDHAM (1844, pp. 61–64, 130–132) has collected records showing that marine shells are widespread in the Irish drifts. KINAHAN found shell fragments in the esker at Maryboro*; their occurrence in the glacial drifts to the height of 1,300 feet at Three Rock Mountain near Carrickmines is well known, and the shells there were numerous and well preserved. OLDHAM records them from various localities near Dublin, including Howth, Bray, Swords (150 feet), and Finglass (200 feet), and ranging to the height of 600 feet above sea-level; in northern Ireland his records include Belfast (106 feet), Londonderry (300 feet), County Sligo (100 to 200 feet); in western Ireland, Tarmon Hill, County Mayo (250 feet); at Naas (380 feet); in an esker near Roscrea, County Tipperary, at 400 feet, "in the very centre of the island" (p. 66); also (*ibid*, p. 131) a *Buccinum undatum* in the gravels at Moate, a locality near Clara traversed by the eastern continuation of the Athlone esker.

According to OLDHAM and KINAHAN'S records marine shells have been found at three significant localities in the chief esker district of Central Ireland.

It has been suggested in conversation that these records are mostly based on shells which were carried inland for food and were dropped in the pits by man. The evidence cannot be so summarily dismissed. KINAHAN and MALLET (in OLDHAM, 1844, p. 131) were not likely to have mistaken modern shells for fossils; and as the shells at 1,300 feet above sea-level on Three Rock Mountain are undoubtedly fossil, there is no reason why marine shells should not occur at lower levels inland.

* 'Mem. Geol. Surv., Ireland,' Sheet 128, p. 30 (1859).

The shells in the esker drifts are, however, rare and fragmentary, as is only natural, since the drifts were no doubt deposited in conditions unfavourable either to the existence or preservation of mollusca. Shell fragments are friable and easily dissolved, and there would be little chance of finding them except in newly exposed material. They would probably occur only in pockets, found occasionally when the gravel pits were being worked more extensively than they are at present. The sections at Maryboro where KINAHAN found his shells are now overgrown, and the newer pits to the north are in material very unfavourable to the preservation of shells.

Although it seems necessary to accept the records it would be unwise to lay much stress on them since the shells may have been *remanié* from the underlying boulder clay. The "glacialoid boulder clay" or "semi-morainic drift" of KINAHAN is doubtless non-marine; but the lower compact boulder clay in which foraminifera are widespread, may be due, like the boulder clays in the Spitsbergen fiords, to glacier ice melting in the sea.

Looking for fossils in the eskers my attention was attracted by some calcareous encrustations in boulders near Clara and Ballinasloe, which were composed of confluent discs with lobed margins like Melobesia. Calcareous crusts are common in the eskers, and are no doubt usually tufaceous and inorganic. But some of them so strikingly resembled the nullipores which encrust the boulders on the Spitsbergen coast, that I had sections cut, and the first showed structures like those of calcareous algæ. I therefore submitted specimens to Prof. F. O. BOWER, who reported them to be "either Melobesia or some Melobesia-like organism." To obtain a more precise identification I submitted them to Dr. A. B. RENDLE and Mr. A. GEPP, of the Natural History Museum, who recommended, in order to secure the most authoritative available opinion on their nature, that they should be sent to Madame LEMOINE, of Paris. She kindly examined the material and identified the section from Ballinasloe as unquestionably a Lithothamnium.

Most of the calcareous encrustations in the eskers are no doubt inorganic, as shown by the fact that in some layers they occur only on the under surfaces; in others they have cemented grains of grit and small stones to the boulders. But Madame LEMOINE's identification shows that some of these encrustations are algal and marine in origin. Others may have had the same formation, but have been so altered by percolating water that any organic structure has been destroyed.* The encrustations which externally resemble calcareous algæ are restricted to special layers and to the low level eskers. I saw none, for example, in the high level eskers of Tyrone; and though their absence thence might be attributed to those eskers containing little limestone, this is not an adequate explanation, as some of the stones have

* The Melobesia-like aspect of these encrustations is soon destroyed on exposure to the weather. On returning to the pit at Ballinasloe, a few months after my first visit, to collect further specimens, I found the features which had led me to suspect their organic origin had almost entirely disappeared.

tufaceous calcareous encrustations. The algal-like encrustations are absent from the eskers to the north-west of Athlone, which seem to me due to glacial rivers; and also from layers of gravel in the main eskers which appear to have been deposited by streams of water.

The objection that if any of these encrustations were of marine origin, shell fragments would occur with them does not seem conclusive, for reasons stated on pp. 145–146.

The evidence of these encrustations is, however, open to the objection that the specimens may have been derived from the underlying boulder clay, the marine origin of which has been persistently maintained, in spite of the rejection of that view by, at one time, the great majority of British glacial geologists. The boulder clay has been shown by Mr. JOSEPH WRIGHT to contain widespread indigenous Foraminifera; and it seems very difficult to reject such evidence as to the marine origin of this material. If the boulder clay beneath the eskers be marine, it is possible that boulders encrusted by calcareous algæ were dropped into the eskers while embedded in frozen mud; and when the material thawed the clay would have been washed away, leaving the nullipores uninjured on the boulders. Owing to that possibility, the occurrence of Lithothamnium on the boulders is not conclusive of the marine origin of the eskers themselves.

In addition to the laminar encrustations, there are numerous tubular structures. The best preserved are small calcareous tubular branched tufts, resembling Bryozoa, which occur in hollows between the boulders in the pit east of Clara. The adjacent stones contain many encrusting tubuli, which I suspected to be the rooting fibres of Crisidia. On one of these occurred an expansion, which I sketched in the pit as the gonœcium of a Bryozoa, but this specimen was broken in transport. I showed some of these tubes to Sir SYDNEY HARMER, F.R.S., but he does not accept them as Bryozoa. I also showed some of them to Prof. J. S. GEMMILL, to know what else they might be. Owing to their resemblance to Bryozoa, he submitted them to Mr. ALEX. GRAY, the most experienced authority on the Bryozoa of the Clyde estuary; he stated that, in his opinion, they are the rooting fibres of Crisidia. In view, however, of Sir SYDNEY HARMER'S rejection of this conclusion, the nature of these tubes must be left uncertain.

Some tubular encrustations on the esker stones have been formed by the deposition of carbonate of lime around roots. Some of those near the surface may have been due to the action of grass roots in recent time, but many of the tubes were clearly contemporary with the formation of the esker, as they are found in the lower layers, which are separated from the surface by beds without these encrustations. Vertical calcareous cylindrical concretions, like those commonly found around grass roots and stems in calcareous dunes, occur occasionally, as, for example, in the Maryboro Esker.

IV. The Origin and Classification of the Irish Eskers.

The Irish eskers appear to include four different formations: (1) fluvioglacial ridges deposited along the course of glacial rivers; (2 and 3) ridges of fluvioglacial and of glacieluvial materials deposited beside the margin of melting ice sheets; and (4) banks of fluvioglacial material left by the denudation of larger sheets. The most important of the Irish eskers are the marginal formations, while the members of the first of the above four classes are comparatively few and small.

The first test whether the eskers were due to subglacial rivers or were deposited as marginal banks, is the source of the esker materials. These should have travelled along such eskers as were made, like Swedish osar, by subglacial rivers, whereas the materials of the chief Irish eskers were introduced from the side. "Drumlins," says Maxwell Close (1876, p. 211), "always seem to have been formed by something that acted along their length, whereas esker ridges seldom suggest such an idea." The available evidence as to the source of the Irish esker material is scanty, since there are few rocks in the esker district which show the direction of the ice movement. Granites and gneisses are strewn over the Carboniferous rocks near the western margin of the Central Plain and indicate a movement from west to east. But in these cases it may be argued that the rocks have been derived from the underlying boulder clay.

1. *The Trend of the Eskers and Direction of the Ice Flow.*

Prof. Sollas' map (1896, p. 805, fig. 2) represents the ice movement in the Dunmore district as from south-east to north-west. It is clear, however, that a little further south the predominant movement of the ice, which deposited the boulder clay and probably also the eskers, was from west to east, as granite from Iar-Connaught is found in the eskers near Athenry, and as Kinahan (Kinahan, 1878, p. 249; also Kinahan and Maxwell Close, 1872, p. 9) has recorded erratics of granite from western Galway scattered over the country and sometimes upon the eskers as far east as Woodlawn and Ballinasloe, and south-eastward at Eyrecourt, Portumna, Birr, and as far as Nenagh to the south-east of Loch Derg. The highlands of eastern Mayo rise to the north-west of Dunmore; hence the last ice movement in the Dunmore district would naturally have been from north-west to south-east.

Whether the ice in that district flowed from or toward the north-west, Maxwell Close and Sollas both represent it as having been at right angles to the trend of the Ballyhaunis, Dunmore, and Tuam Eskers. These ridges of loose drift could only have accumulated across the direction of the glacial movement after the ice had become stagnant. But as Tarr has remarked regarding the stagnant ice sheets of Alaska, the rivers have a very short course upon the ice; he states (Tarr, 1908, p. 97) that "no single case was found where an esker deposit was being made *on* the ice . . . the streams are short; they keep their bottoms fairly clear of *debris;* and in a short distance they disappear to the bottom of the glacier through moulins. Certainly, under Alaskan conditions, superglacial eskers are impossible."

Apart from the Alaskan analogy the local evidence is against the glacial-canyon theory, even if it be modified by assuming the stagnancy of the ice. For as soon as the water had worked its way to the base of the ice, it would have drained down the slope of the land; whereas the course of the confluent eskers is independent of the slope, and is often in the opposite direction. Thus the eskers between Ballyhaunis, Tuam, and Newton Bellew supply, according to Prof. SOLLAS' maps, one of the best instances of eskers joining like the tributaries of a river system. South of Ballinlough, eskers trending from the south-west at Dunmore, from the south at Curragh, and from the south and south-east past Raheen and Kilnalag, all unite into one main esker. The convergence of these eskers is, however, in the wrong direction, for as shown by the altitudes marked in fig. 9, the levels are lowest at the supposed heads of the glacial streams.

The Castletown Esker begins near the Clare River, 2½ miles north-west of Tuam at about 150 feet; it rises a mile north-eastward to 194 feet. The esker near the Grange River south of Tuam is at the level of 140 feet. The south-eastern member of this series begins north of the upper part of the Abbert River at the line of about 130 feet; the level is 271 feet at Horseleap Lough, 312 feet at Mt. Silk. The northern of these eskers near Kilnalag and Ballyhaunis occur a little above the 350 contour. Prof. SOLLAS remarked that these eskers run against the slope of the ground, and suggested that the apparent convergence to the north should perhaps be interpreted as a divergence southward, the water from the Ballyhaunis district discharging seaward through radial channels. This divergence is normal in deltas and where rivers emerge on to plains. The latter condition cannot be appealed to in this district, since the land slopes, as for example along the Dunmore Esker, about 12 feet in the mile; and the course of the eskers is independent of the relief of the land that had been established before the formation of the eskers. If the divergence be explained as a delta formation, it would imply that the eskers there were formed beside the sea or a large lake.

Hence the most striking apparent case of agreement between the plan of the eskers and that of a river system fails when examined more closely. The convergence of the three esker lines towards Ballinlough may be more probably explained as due to the ice front having retreated more slowly there than along the line from Newton Bellew to Dunmore.

2. *The Variability of the Esker Levels.*

The well known variability in the esker levels is illustrated in fig. 10 for the esker system from north of Portumna to the Clara district. The Kilcrow River, which enters the north-western corner of Loch Derg, cuts through three eskers, viz., those near Killimor, at Mootbridge, and Newbridge. These three eskers unite before reaching the Shannon. The northern or Killimor member of this esker series begins at the height of just below 300 feet, and descends to 174 feet where it is breached by the Kilcrow River. It then rises to 222 feet and 235 feet, and descends to 167 feet (with its base at about 150 feet) to the west of the Shannon. The Mootbridge Esker begins at 200 feet; it falls to 136 feet at Mootbridge, and rises to 198 feet at its junction with the third member of the series.

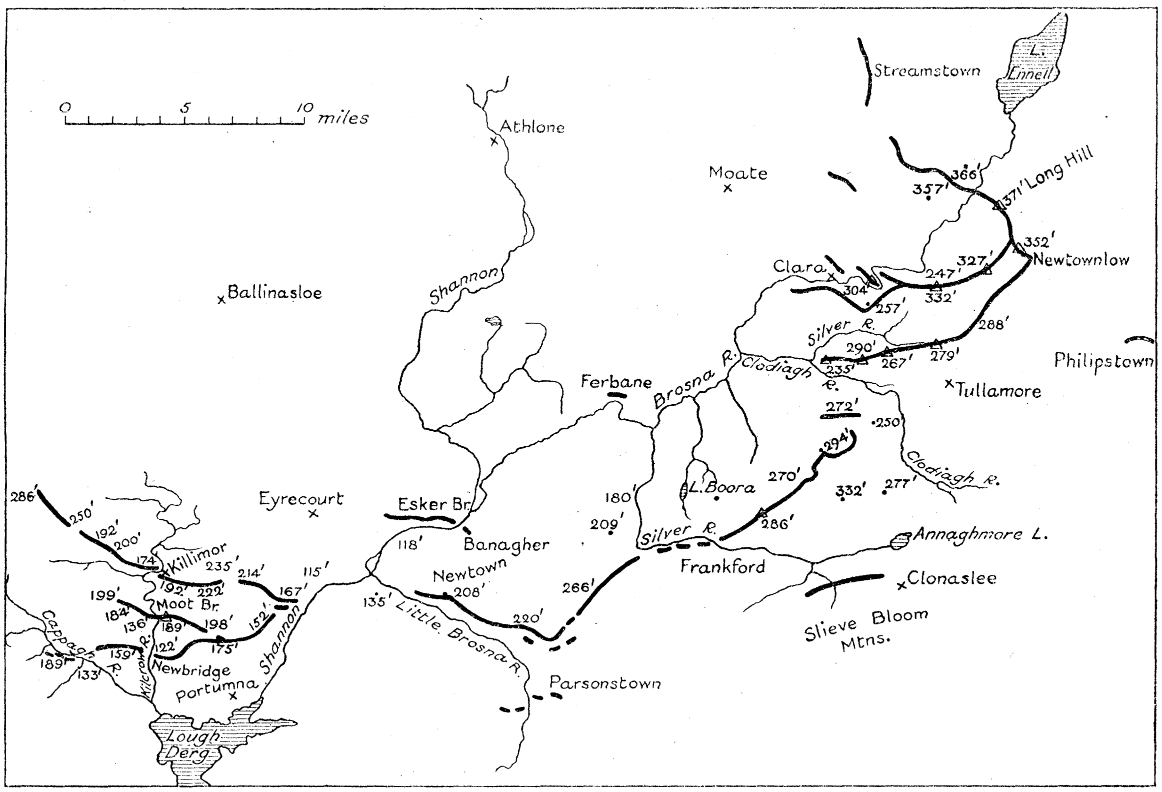

FIG. 10.—The Eskers from Portumna to Newtownlow, showing the rise and fall along their course. Heights in feet.

The Newbridge Esker also begins at about 200 feet, is at 159 feet just west of Newbridge, rises to 175 feet at its junction with the Mootbridge Esker, falls to 152 feet, and rises to 167 feet at its confluence with the Killimor Esker.

On the river theory these three eskers would have been formed by the head streams of the river which deposited the line of eskers from Parsonstown to Tullamore. That esker begins east of the Shannon, at Newtown, north of the Little Brosna River, at about 200 feet; it rises gradually eastward to 220 feet north of Parsonstown, to 266 feet at Fivealley; it is a little lower north of Frankford, and rises again at $2\frac{1}{2}$ miles to the north-east, to 286 feet; 4 miles further north-east it attains the level of 294 feet, and then descends the left bank of the Clodiagh River. It resumes its course at 235 feet in the angle between the Clodiagh and Silver rivers, rises eastward to 290 feet, varies from that level to 260 feet north of

Tullamore, and rises to 352 feet at its eastern bend near Newtownlow as it approaches the eskers from Clara and Streamstown.

Of the two branches of the Clara Esker one begins at 284 feet and the other at 259 feet; the esker rises eastward to 302 feet and 327 feet. The Streamstown Esker occurs at about 350 feet; its continuation south-eastward falls to 326 feet near the Brosna, after crossing which it rises to 371 feet and 368 feet as it approaches the eskers from Parsonstown and Tullamore. The supposed outlet of the esker river from the Portumna district is, therefore, about 200 feet above the level of its head streams. This argument would not be fatal to the theory of the eskers having been formed by superglacial rivers, but that view appears to have no supporters for Irish eskers. As Prof. SOLLAS (1896, p. 819) observed, the structure of the Irish eskers shows that they were deposited where they are now found, and that they were not precipitated in mass by the sinking of the floor of a glacial canyon. Mr. W. B. WRIGHT (1914, p. 39) remarks that the bedding is "frequently quite undisturbed." The levels are inconsistent with the river theory as advocated for Ireland, for if the canyons had been cut through the ice to the ground, the rivers could not have flowed in an opposite direction to the slope of the land.

It has been pointed out, as by NEWBERRY (1878, p. 41), that some of the American eskers occupy "a topographical position, which makes it impossible that they should ever have been the beds of rivers," as they cross or even lie along the divides. The fact that the Irish eskers are independent of the slope of the country is fatal to the view that they were deposited in rivers flowing through open glacial canyons.

Observed variations in level would, on the other hand, naturally occur in marginal deposits along the edge of an ice sheet resting on an undulating surface.

3. *Esker Structures not Fluviatile.*

That the river drift theory does not explain all, or even most, of the Irish eskers is shown by their structures. Glacial rivers, such as those assumed for the formation of eskers, are naturally shallow and rapid; and in them the coarsest material should collect in the centre of the channel, while fine silts would be deposited only in the quieter water beside the banks; but in many Irish eskers the reverse is the case. Thus the core of the Ballyduff Esker consists of fine silt and clay, which is flanked and capped by coarse gravel.

HERSHEY (1897, p. 242) remarked that in the Illinois eskers the "beds of coarse gravel, cobbles, and small boulders are almost invariably at the top of the deposit, contrary to what we usually find in the product of ordinary stream action"; and the same objection to the fluviatile theory is applicable to many parts of the Irish eskers.

4. *The Ridge Form and the Esker Formation in Water.*

The glacial-canyon theory has the recommendation that it offers an explanation of the deposition of the esker material in long, narrow, sinuous ridges. It is true that these ridges were once wider, for where the grain of the esker is cut off abruptly by the slope (as in figs. 3 and 4), the esker has been reduced in width since its formation. Nevertheless the ridge form was clearly one of the original characteristics of the typical esker. Their composition and structure both show that they are not ordinary moraines. They have been described as "gravelly moraines" (*e.g.*, JAS. GEIKIE, 1905, p. 312); but it seems advisable to restrict the term moraine to direct deposits from ice, and to exclude those in which material derived from ice has been carried and deposited by water. Eskers consist sometimes of fluvioglacial deposits, due to the action of glacial rivers, and of glacieluvial deposits (GREGORY, 1912, p. 210), which are due to the irregular wash of water along the edge of a melting ice sheet. The eskers, according to this nomenclature, are mainly fluvioglacial; and they are usually laid down as long banks of water-worn gravel and sand. Eskers are unknown around Alpine glaciers, and the most similar structures around Arctic glaciers occur where the ice is melting in water. The late Prof. TARR (1908, p. 97), in his account of the deposits formed on the stagnant waning ice sheets of Alaska, states that eskers are commonly found where the ice ended in bodies of standing water. He adopted the term "kames" (*ibid.*, p. 98) as distinct from eskers, and described kames as forming along the margins of the glaciers, and as attaining their best development where the gravel is deposited in lakes or on sheets of buried ice, which melts unaccompanied by deposition.

The marginal Irish eskers, according to this interpretation, agree with the great marginal bank of drift in Finland, which marks one stage in the retreat of the Finnish ice sheet. This bank, known as the "Salpausselka" (see, *e.g.*, SEDERHOLM, 1899, p. 15), it is worthy of remark, was built up where the ice sheet ended on the margin of the Yoldia Sea. Mr. W. B. WRIGHT (1914, pp. 39, 41) has already adopted the view that the Irish eskers "are more or less marginal deposits, perhaps entirely marginal," and that "the essential condition for the formation of eskers is the presence of stagnant water in front of the ice sheet during its retreat." Mr. WRIGHT regards this water as a series of local sheets of "ponded water"; he was not disposed to regard it as the sea.

5. *The Eskers a Littoral Formation.*

The members of the Irish Geological Survey who originally surveyed the eskers, especially KINAHAN, adopted the view that they were marine; and some were called "shoal eskers," on the grounds that they were formed as shoals by strong currents in a shallow glacial sea. The marine formation of the esker has been generally dismissed, but it seems nearer the truth than the later theories, which ascribed them to glacial rivers. The marine theory agrees best with their distribution. If the eskers had been formed by rivers in glacial canyons or in local bodies of "ponded water," there seems no reason for their practical restriction to the zone between the contours of 150 feet and 350 feet, and why they should not, as in

Sweden, continue to the highlands (*e.g.*, GEIKIE, 1894, p. 482).* Patches of esker-like drift occur at higher levels; they have been recorded at 464 feet in Iar-Connaught, and up to 542 feet about eight miles south-west of Roscommon; but the eskers of the typical esker district are all found below the level of 400 feet and mostly below the level of 350 feet (Map, fig. 11). They are, says HULL (1891, p. 127), "confined to the plains." KINAHAN placed the submergence beneath the "Esker Sea" as reaching the 300-foot contour (1878, pp. 225, 259, etc.) and SOLLAS (1896, p. 818) says the ground on which the eskers stand seldom rises more than 350 feet above sea-level.

The eskers range from Dublin to Galway and from Ballyhaunis as far south as Portumna, but in that wide area they do not occur above the level of 400 feet. In Tyrone, on the other hand, the eskers between Cookstown and Omagh are at the levels of from a little under 500 feet to over 700 feet (see *ante*, pp. 133–134). But the Tyrone eskers are different in character from those of the central plain; they are very irregular in level; for example, the esker which crosses the Cookstown–Omagh road, near Barony Bridge, rises rapidly up the hill side and has the aspect of a terminal moraine, formed by a glacier that came down from the Pomeroy Hills. Its material, however, is sandy and its included stones are all washed and water worn; it is a glacieluvial marginal deposit.

In the typical esker district, on the other hand, the eskers disappear or occur as irregular mounds as they approach the contour of 350 feet. Thus the eskers of the Clara and Tullamore district are separated by a gap seven miles wide from their supposed continuation in the Philipstown–Edenderry Eskers. Their absence from the high ground west of Philipstown was probably due to non-deposition, as the land is above the esker level.

The Streamstown Esker is also significant as to the restriction of eskers by the 350-foot contour. From the heights marked on the maps and a view of the country from the railway I had regarded it as an exception to the rule; but a visit showed that it lies on the floor of a valley and that the higher ground on either side is free from eskers and esker-drift. This esker may have been formed of drifts deposited in a narrow gulf or in a strait connecting the arm of the sea that extended up the Inny Valley with that from Moate to Lough Ennell.

The relation of the eskers to the 300-foot contour is illustrated in fig. 11, which shows that across the middle zone of Ireland the eskers mostly occur below the 300-foot level, though they rise somewhat above it near Ballyhaunis. The main features in the distribution of the eskers in the area illustrated by that figure are:—

(1) Their restriction, with a few exceptions, to below the level of 300 feet.

(2) That when "esker drift" occurs above that level it is in scattered mounds, the "shoal-eskers" of Kinahan; as they are not ridges they are not eskers in the restricted sense of the term.

* The restriction also of the small river-formed eskers, as at Kilbeggan, to the low ground, is due to their formation where the river mouth emerged from the ice sheet to the plain or the sea.

(3) That the eskers have a more restricted distribution than the boulder clay, which is widespread and occurs at higher levels.

(4) That the eskers belong to four main groups :

(*a*) Those of the basin of the Clare River, east of Loughs Mask and Corrib, with occasional small eskers on the western edge of that basin ; its chief members are those of the Ballyhaunis–Dunmore district.

(*b*) The eskers of the Athenry district and of the streams discharging to the eastern end of Galway Bay.

(*c*) The eskers of the Shannon basin and its tributaries, the Inny, Brosna, Suck, and Kilcrow. This group includes the eskers of Ballinasloe, Athlone, Clonmachnois, Clara, Tullamore, Streamstown, Parsonstown, etc.

(*d*) The Roscrea, Clonaslee, Mountmellick and Maryboro Eskers, which lie around the northern foot of the Slieve Bloom Mountains and of other adjacent high ground.

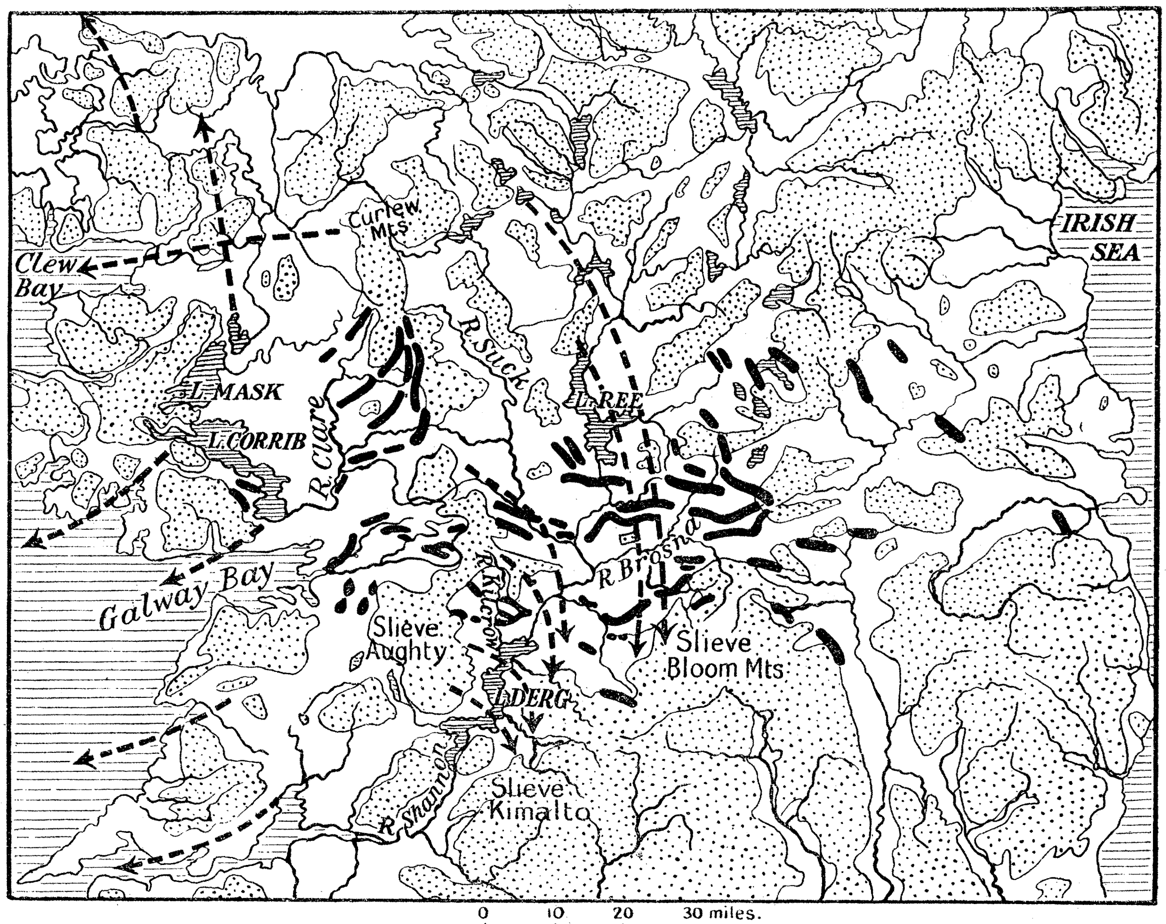

FIG. 11.—Sketch Map of the Irish Eskers in relation to the 300-foot contour; the areas above that contour are dotted; the eskers generally end at that level. The chief exception is the north-western group, which rise above 300 feet between the Clare and Suck Rivers. The broken arrows represent the course of the ice movement, after W. B. Wright; they show that the chief eskers lie transverse to the ice movement.

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Arrows indicating the ice flow are added from the map by Mr. WRIGHT (1914, p. 49), and they show that the chief eskers lie transversely to the movement of the ice. His map gives no definite directions for the Ballyhaunis district; but from the centre of ice accumulation to the east of Clew Bay and to the north-east of Lough Mask the ice flowed northward to the northern coast of Connaught, westward to Clew Bay, south-westward over Lough Corrib and western Galway. The position of the Ballyhaunis–Dunmore Eskers indicates their formation on the receding south-eastern edge of the Mayo ice sheet. Its recession left the Lough Corrib basin clear, and ice from southern Connemara was able to flow eastward past Galway to Athenry and Ballinasloe, carrying with it the boulders of granite from Iar-Connaught, which afford clear evidence of this movement. Some of this ice probably crossed the divide between Galway Bay and the Shannon, and reached Lough Derg through the valley of the Kilcrow River. This ice lobe then formed the eskers of the Killimor district, and later during its retreat those of the Athenry district.

Ice from the Curlew Mountains and other highlands of southern Sligo and Roscommon flowed south into the valleys of Suck and the Shannon, and reached the lowlands bounded to the south by Slieve Aughty, Slieve Kimalta and Slieve Bloom Mountains. Mr. WRIGHT'S arrows show that this Shannon glacier flowed transversely to the direction of the main eskers of Central Ireland; those of the eastern members of this series, such as the Long Hill near Ballygore, the Streamstown Esker, and those of the Inny were parallel to the main direction of this glacier, but they doubtless were the marginal formations along its eastern edge.

One remarkable contrast between the eskers of the Clare River and of the Shannon is that those of the Shannon basin are further to the south, which suggests that the Shannon glacier lasted longer than that which flowed into the Clare basin from Mayo, so that the emergence of the country prevented the formation of eskers during the recession of the ice from Lough Ree northwards. The dilapidated fragmentary condition of the western ends of the Ballyhaunis and Dunmore Eskers is consistent with their formation somewhat earlier than those in the Shannon basin.

The Roscrea, Clonaslee,* Mountmellick, and Maryboro Eskers were probably formed by ice which flowed down the northern slopes of the Slieve Bloom Mountains.

This sharp vertical limitation of the eskers is in favour of their formation having been controlled by a sheet of water, and this must have been either the sea or a glacial lake.

The difficulty in the assumption of a glacial lake is to account for the containing barriers. There is no difficulty regarding its northern and north-western margin, for that would be formed by the ice sheet itself. Partial boundaries would have been provided to the south-west by the Slieve Aughty Mountains, to the south by the Silvermines Mountains, and to the south-east by the Slieve Bloom Mountains; but these hills would leave wide gaps below the level of 350 feet, and even below 250 feet

* The Clonaslee Esker ranges up to 390 feet.

at Loughrea, Scarriff (140 feet), and the Nenagh–Curraheen gap (247 feet), while to the east of Tullamore there were wide tracts below the level of 350 feet. Unless all these outlets had been blocked by ice, there could have been no glacial lakes adequate for the formation of the eskers.

The extension of the sea across the esker plain presents no such difficulties. Some submergence of the British area during glacial times is now generally accepted; and even if this submergence were inadequate for the deposition *in situ* of the shells at 1300 feet on Three Rock Mountains south of Dublin, it was sufficient for the sea to have covered the Irish plain. Even the late CARVELL LEWIS, a most resolute opponent of the view that the British Isles were submerged in glacial times to the contour of about 1300 feet, accepted a submergence of 400 feet to the west of Dublin; and that amount would give the sea the range in Ireland required to explain the deposition of the eskers in a glacial sea.

The Irish eskers do not appear to be ordinary beach deposits, though KINAHAN at one time ('Mem. Geol. Surv., Ireland,' Explanation Sheet 128, 1859, pp. 29–30) compared them to raised storm beaches, in which the material is piled up with an arched dip down both slopes. The rejection of this hypothesis is not dependent on the absence or rarity of marine shells; for though OLDHAM'S paper (1844) shows that marine shell fragments are widely distributed in Ireland, they are certainly rare in the eskers. The absence of shells from these gravels does not, however, disprove their marine origin; for, as was pointed out by BROWN (1870, pp. 638, 688), many parts of the Greenland fiords, owing to the disturbed and muddy condition of the water, are "bare of marine life" and "unfavourable for sea-animals"; hence the deposits in them would be unfossiliferous. From the character of the esker materials any shells that might have been present would have been destroyed during its formation or dissolved subsequently.

6. *The Rarity of Fossils.*

The poverty of the marine fauna in both the Boulder Clay and the eskers is not surprising on the assumption that they were deposited in an ice-covered sea. NANSEN (1902, pp. 422–3) has pointed out that where the Arctic Sea is ice covered, owing to the absorption of light very few plants live in it. "We found," he says, "extremely little plant-life in the interior of the North Polar Sea, and it is as a rule in vain that Mr. H. H. GRAN has searched our plankton samples for diatoms." The poverty in plant-life involves the rarity of animal life. NANSEN refers to the extreme poverty of the plankton life in the Arctic Ocean (*ibid.*, p. 423; also vol. 4, 1904, p. 221), and to the unusually small amount of matter originating from organisms in the oceanic deposits. He says that it was "in most cases extremely difficult to find traces of shells of Foraminifera or other organisms," and that "I hardly found any Foraminifera in the Plankton samples taken in the North Polar Basin." He therefore attributes the few Foraminifera that were found to deposition when "the biological conditions of the North Polar Basin were more favourable than they are now" (*ibid.*, vol. 4, p. 221).

As remarked by SCOULER (quoted OLDHAM, 1844, p. 64), the eskers were deposited "in shallow but turbulent waters, little favourable for the abode of molluscous animals." Even on open beaches in the Antarctic shells appear to be exceptional. According to Mr. JAMES MURRAY, the biologist with Sir ERNEST SHACKLETON'S first expedition, the action of the shore ice prevents the accumulation of shell beaches in the Antarctic. He states (1910, p. 2) that "on the shore there is no vestige of marine life, animal or vegetable, such as is found in the littoral zone of other coasts." "The presence of an ice-foot throughout the greater part of the year, and the grinding of ice along the coast where there is open sea, must destroy any living things which attempt to establish themselves. The zone thus kept devoid of life is of no great depth." HEDLEY (1916, p. 85) has remarked that the shell-bearing "raised beaches" of Macmurdo Sound are not shore beaches, but are probably upheaved from a deeper horizon.

If the eskers were deposited when the sea extended over Central Ireland to the contour of between 300 and 350 feet, the esker area would have been covered by a shallow bay, connected to the outer sea by narrow straits to the south-west and south, and with broader but still shallow channels to the east and south-east. This bay would have been occupied by ice-cold muddy water, swept by strong tides, and constantly churned up by waves from the calving ice front. The conditions would have been most unfavourable to animal life. Though the occurrence of shells would therefore be exceptional, they have been recorded in the eskers of Naas (380 feet) to the east, at Maryboro to the south-east, at Roscrea (400 feet) to the south, and at Moate (approximately 250 feet) in the centre of the esker area.

Madame LEMOINE'S determination of the nullipore from Ballinasloe is therefore consistent with the records of marine shells in the eskers of that part of Ireland.

7. *Definition of the Term Esker in Glacial Geology.*

When MAXWELL CLOSE (1867, pp. 211–212; see also KINAHAN and CLOSE, 1872, p. 6) separated drumlins from eskers, he accepted the latter term for fluvio-glacial ridges and mounds. In 1912 (No. 2), I summarised the history of the term kame and esker, quoted a series of authorities as to their usage, and followed Prof. T. C. CHAMBERLIN (1883, p. 300; renewed in 1899) in adopting the term kame for marginal fluvioglacial formations and osar or eskers for fluvioglacial ridges which are due to glacial streams, and occur on lines parallel to the flow of the ice. That definition, which has been often adopted in America, and Prof. SOLLAS'S interpretation of the Irish eskers, would restrict the term esker to fluvioglacial ridges deposited along glacial rivers. It would be synonymous with osar. The Irish eskers, however, include several varieties of fluvioglacial and glacieluvial ridges, and also mounds, and, if restricted to osar, the term would be limited to the least extensive and important variety of eskers. G. H. STONE has proposed (1899, pp. 359–360) to "employ the term esker as a general term applicable to any mass or ridge of gravel irrespective of genetic classification," and that proposal is consistent with the Irish use of the term. The term osar was adopted by JAS. GEIKIE (1894, p. 169; spelt åsar) in preference to esker, and STONE accepted it in the same restricted sense. It seems best to follow their example and use the term esker in its original meaning for Irish ridges and mounds composed of glacial sand and gravel, and adopt osar, as the approximately phonetic rendering of åsar, for fluvioglacial ridges formed along glacial rivers. The term kame is then applicable, in accordance with general usage, for the marginal formations. According to this terminology, however, the major Irish eskers are kames.

The following classification summarises the structure of these drift formations as thus defined :—

(I) Drumlins—mounds composed of boulder clay.

(II) Osar—fluvioglacial ridges formed of sand and gravel deposited along the course of a glacial river and typically showing a transverse seasonal banding. Irish examples are those at Kilbeggan, near Clara, and the north-west of Athlone.

(III) Kames—ridges or mounds of sand or gravel deposited by water on the margin of a melting ice sheet. They consist either of fluvioglacial material where deposited by well defined streams and rivers; or of glacieluvial material where deposited by the wash of water down the margin of an ice sheet or by water welling up along the margin of an ice sheet.

V. SUMMARY OF CONCLUSIONS.

The Irish eskers belong to four groups.

I. The typical eskers on the Central Plain are kames, or marginal formations, deposited on the receding edge of an ice sheet. They are not moraines, as their materials were laid down by water and not dumped directly from melting ice. They were not formed along river beds, as adjacent segments vary greatly and irregularly in composition, patches of false-bedded sands and gravels alternating with coarse washed morainic drift; the false-bedding and the variations in the composition of the eskers indicate that the material came from the side of the esker and was not carried along it. The predominant material in some eskers is a bouldery drift, which has been so washed that the ice-scratches have been destroyed; in such places the material is glacieluvial.

That the main eskers were marginal is also indicated by their relation to the drumlins, of which the longer axis is regarded as lying in the direction of the ice flow. The main eskers are transverse to the drumlins.

The main eskers are also transverse to the ice movement as indicated by the striated rock surfaces and the distribution of the erratics where the rocks give evidence as to the direction of the ice movement. The main eskers lie between the levels of 100 feet and 350 feet; they occasionally reach 400 feet. Their abrupt upward limit indicates that their range was controlled by some agent which was widespread over the plain of west central Ireland, but had a limited vertical range. These conditions are best provided by a sheet of water; and the melting of the ice as it entered a wide sheet of water best explains the heaping up of its material into a ridge instead of its deposition as a widespread sheet.

That this sheet of water was the sea is most probable for the following reasons :—

1. The underlying boulder clay and associated drifts contain foraminifera and marine shell fragments; these range up to 1,300 feet on Three Rock Mountain and appear to be widespread at lower levels.

2. Encrustations formed on boulders at Ballinasloe are identified by Madame Lemoine as Lithothamnium.

3. The poverty of organisms is explicable by the present distribution of life under analogous conditions in the Arctic and Antarctic seas.

4. It is now generally agreed that large parts of the British area were submerged in glacial times to a sufficient height to have flooded the typical esker district of Central Ireland.

5. The alternative that the water was a glacial lake is improbable, as the esker sea was probably in existence after the ice had receded from the southern part of the central plain; and there would be no available southern margin for the lake.

II. A second type of esker consists of banded eskers lying within and transverse to the main marginal eskers, parallel to the direction of movement of the ice. They were probably deposited as delta deposits at the mouths of glacial rivers, and are thus equivalent to the Swedish osar.

III. In Tyrone, on the hills to the north and north-west of Pomeroy, is a third group of eskers, formed as glacieluvial marginal deposits around glaciers flowing from the hills.

IV. A fourth type consists of irregularly distributed mounds of fluvioglacial drift, as west of Athlone, which are probably due to the denudation of sheets of glacial sand and gravel.

The restriction of the term esker to any one of these four groups would be inconsistent with its original meaning. The term has been often defined so as to include only eskers of the second group, which in Ireland are relatively unimportant. The most typical eskers are those of the first group; they are kames, according to the widely adopted definition which uses the term kame for marginal formations. To avoid the use of the term esker with different meanings in geology and geography, its use is recommended as a general term for Irish ridges and mounds of glacial gravels and sands, and that of osar for fluvioglacial ridges which have been formed along the courses of glacial rivers.

REFERENCES.

For general references see R. L. PRAEGER, 1896, "Bibliography of Irish Glacial and Post-glacial Geology," 'Proc. Belfast Nat. Field Club,' vol. 2, App., pp. 240–316; also 'Memoirs of the Geological Survey, Ireland.' The chief references to eskers are in the Explanations to the following sheets:—

1882. 19. Co. Londonderry; resorted eskers near Kilrea, pp. 18, 19.

1884. 26. Tyrone, pp. 21, 23. Creggan and Teebane Bridge.

1878. 34. Tyrone, pp. 21, 22. Esker section at Eskreagh, etc.

1877. 35. P. 78. Tyrone; esker at Broomhill.

1871. 36. Esker, near Lisburn, p. 37.

1871. 37, 38, 29. Co. Down, Dundonald Esker, p. 40.

1879. 41, 53, 64. P. 22. Esker between Foxford and Barrowford in Moy Valley.

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