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THE
GENERAL GLACIATION
OF
IAR-CONNAUGHT AND ITS NEIGHBOURHOOD,
IN THE
COUNTIES OF GALWAY AND MAYO.

BY
G. H. KINAHAN, M.R.I.A.,
Of the Irish Branch of the Geological Survey of the United Kingdom;

AND
M. H. CLOSE, M.R.I.A.

WITH A MAP.



DUBLIN:
HODGES, FOSTER, AND CO., GRAFTON STREET,
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With the authors' Comments -

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GENERAL GLACIATION OF IAR-CONNAUGHT,
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Introduction.—The mapping of both kinds of the glacial phenomena now to be considered was commenced, seven years ago, by Mr. G. H. Kinahan, and carried on during the course of his work on the Geological Survey. Afterwards further observation and record of the phenomena were made, under his superintendence, by Messrs. J. L. Warren, F.R.G.S.I., S. B. Wilkinson, F.R.G.S.I., J. Nolan, F.R.G.S.I., H. Leonard, M.R.I.A., and R. Cruise, M.R.I.A., Assistant Geologists; the phenomena being entered on the inch maps of the district, and leave to publish them being given by the late Professor J. Beete Jukes, F.R.S., then Director of the Irish Geological Survey. Afterwards Mr. R. G. Symes, F.G.S., Senior Geologist, supplied an account of both kinds of the glacial phenomena observed and mapped by him in the northern part of the district included in the accompanying map; permission for publication being obtained from Professor E. Hull, F.R.S., the present Director of the Survey. From these data, along with a few contributed by the Rev. M. H. Close, and some information derived from the Ordnance maps, and from W. Bald's excellent shaded map of Mayo, the accompanying map has been prepared by Mr. Close, who was, during its construction, in constant communication with Mr. Kinahan. To Colonel Wilkinson, R.E., Superintendent of the Ordnance Survey of Ireland, the thanks of the authors are due, for assistance kindly rendered by him.

The glaciation of the district under consideration has been already noticed and described, in part, by Professor King, D. Sc., Messrs. Birmingham, M. H. Ormsby, and Campbell, (*Frost and Fire*), and in the Memoirs of the Geological Survey; but no complete view of it has yet been given, without which it is impossible to understand fully its nature and significance.

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The authors are agreed, in the main, as to the general import of the phenomena; the only serious difference between them being as to the glaciation of the country on the N.E. side of Lough Corrib. This difference, however, need not be here stated, for, as far as the special subject of this paper is concerned, the disputed question amounts to no more than this—whether a certain limited extent of country, which is by both acknowledged to be near the boundary of the area belonging to the glacial system to be described, should be included in that area or not.

Description of the District.—The district, the glaciation of which forms the subject of this essay, is about equally divided between N.W. Galway and S.W. Mayo. The part lying west of Lough Corrib and south of Killary Harbour is named Iar (*i.e.*, West) Connaught, and includes the well-known Connemara. The elevations of the hills, lakes, &c., marked on the map, give a fair general idea of the conformation of the surface of the ground. The highlands situated west of Loughs Corrib and Mask extend northwards to Clew Bay. They form a distinct mountain group; being separated, on the one hand, from the Burren and Slieve Aughta hills, which lie southward of Galway Bay; and, on the other, from the mountains of Erris and Tyrawley, which are just north of Clew Bay, and some of whose lower summits come within the northern boundary of the map. The eastern part of the area under consideration is occupied by a low undulating plain, a portion of the central plain of Ireland, an arm of which extends to the head of Clew Bay.

Explanation of the Map.—The arrows (in blue) represent the parallel rock-scourings, which are so abundant in this district; the arrow-heads showing in which direction the scoring agent moved along the lines. In some cases, where the striated rock did not of itself afford evidence on this latter point, the arrow-heads have been omitted. Sometimes but one half of an arrow-head has been drawn; but this was only from want of room, and has no special meaning. Some, indeed, of the striations have been necessarily omitted altogether, for the same reason; but this is a matter of little consequence, as they agreed in direction with those by which they were crowded out. Two sets of striæ, crossing each other, are sometimes found on the same rock surface;

in a few instances even three sets ; in such cases the later ones are distinguished on the map by a dot, which is placed indifferently at either end of the stroke. The thick lines and spots, printed in the same colour as the map itself, mark the sites of the drumlins or ridges and mounds of boulder clay, to be described hereafter.

Description of the Phenomena.—The rounding and scoring of the rocks need not be described in any detail. We may, however, note that the rounded and dressed rocks, or *roches moutonnées*, are often as remarkable and characteristic as can well be imagined. The naked sides of the Benna Beola, or Twelve Pins, and of the Maum Turk mountains, chiefly composed of quartz rock, also the flanks of Mweelrea along Killary Harbour, will be at once recognized from some distance, by any observer, as being greatly ground and crag-rounded. Some large masses of vein-quartz present most striking proof of the power of the abrading agent. The scorings vary from the finest etchings up to narrow or wide grooves, two or three yards long, and an inch deep ; some of them with jagged edges. The latter were evidently ploughed out by the point of a large block, and must have been produced immediately before the cessation of the glacial action ; otherwise the subsequent passage of the finer detritus would have smoothed away the rough edges. In some cases, the under side of an inclined bed of rock has been scored, as well as the rest of the crag from which it projects. In some places the striæ have been preserved only on masses of vein-quartz, or on quartz pebbles, in conglomerates. As to their elevations—some of the scorings marked on the Twelve Pins, and on the mountains in the neighbourhood of Maum Ean, are at the height of about 2,200 feet above the sea level ; these, however, are within the central area of dispersion ; which circumstance must, of course, be borne in mind in endeavouring to arrive at their significance. The lowest part of the saddle, or *col*, over the hollow which contains Lough Bellawaum, on Mweelrea, is 1,668 feet above the sea ; the striations there (not on the lowest part of the saddle) show that the scoring agent moved steadily across that place. The striæ on the S.E. side of the base of the final cone of Croagh Patrick are at the height of 1,600 feet, at the distance of about sixteen miles from the centre of dispersion. The table-land of the Formnamore mountains, all around the point

marked 2,239 feet, and at but a slightly lower elevation, has been scored by the abrading agent, which has flowed past that mountain mass on both sides. The striations are found at all lower elevations down to below the sea level.

The ridges marked on the map consist of stiff, unstratified boulder clay, containing well-blunted and scratched stones and blocks; they have been most unquestionably formed by the rock-scoring streams, since they are, with very rare accidental exceptions, always parallel to the striæ near them. They are similar to those found in other parts of Ireland, and quite distinct, both as to arrangement and composition, from eskers, which consist of washed and generally stratified gravels and sands. The name, "drumlin," which is applied to many of them in the north of Ireland, may be conveniently appropriated to these ridges, to distinguish them from those to which "esker" has been popularly allotted; although either name, as far as its original signification is concerned, might be applied to either kind of drift ridge. In those parts of the map where the visible rock striations are most numerous, the drumlins are fewest, and *vice versa*; the reason of which is obvious. These ridges always occur on comparatively low ground, either in the valleys among the hills or on the open plain, where they are much better developed. Some stand on ground below the level of the sea, and form islands and shoals; as in Clew Bay. (Some are islands in Loughs Corrib and Mask.) Some stand on ground 300 feet, and more, above the sea; as those from three to four miles north-westward of Ballyhaunis, beyond the eastern border of the map. There are some five miles N.E. of Westport, whose bases must be at the height of more than 250 feet. Several of them are about two miles long; their mean length is not less than half a mile. They are of all elevations, from 180 feet (the height of Inishturk and some others near it in Clew Bay) downwards. They have often an observable uniformity in size in the same neighbourhood; as, for example, those at the head of Clew Bay, and again, those around Castlebar. They have been unquestionably formed by some operation different from, and antecedent to, that which has produced the water-arranged gravels and the eskers. Deposits of water-formed gravel, &c., clearly of later date, often occur in the low ground between the

drumlins, and even banked up against them. It is interesting to observe, that where eskers happen to be strikingly developed within a district abounding in drumlins, there the last-mentioned ridges are either absent or obscure, the eskers being evidently composed of materials derived largely, or principally, from the destruction of the drumlins. Of this we have an instance on the north side of Claremorris, near the eastern margin of the map; and others near Ballyhaunis and Kilkelly, a little beyond that margin. The drumlins have frequently one end higher and blunter than the other; this end more usually points up stream, as is the case in other parts of Ireland also. Still we cannot always conclude, with certainty, as to the direction of the stream from the blunter ends of these ridges; since we know not what may have been the effect of the sea upon them during the submergence in which the just-mentioned gravels and eskers were produced. The sea is now escarping the outer exposed ends of the island drumlins in Clew Bay. The similar ones standing in Loughs Corrib and Mask have their south-western ends more strongly acted upon by the waters of those lakes, in consequence of the predominance of south-westerly winds. Now it so happens that the great majority of the blunt ends of the drumlins are directed southwards; their bluntness therefore may be sometimes due to that circumstance, as much as to their being generally the up-stream ends. This is confirmed by the fact that the ridges west of the town of Galway, whose up-stream ends are directed northwards, still have the blunt ends often pointing southwards. Some of the drumlins which have not been cleared for cultivation carry, on their *southward* ends, a number of large, loose blocks; these probably were more frequent formerly. This circumstance may perhaps be only accidental; yet it may be connected with what has just been stated; as the blocks may have been originally within the drumlin, and have been brought out by the removal of the finer material of that end of the ridge by marine action.

The parallel shaping of the surface of the ground in the drumlin district, is in reality even more strongly marked than it appears on the map. Many of the small lakes, bogs, and streams, which have no inserted drumlins on one or either side of them, are additional members of the system of parallel surface features.

It is a remarkable coincidence that the two quite different kinds of phenomena should be both so well exhibited in their respective parts of the same region ; since, although they are the work of the same agent, they are due to quite different operations of that agent, and, moreover, owe their preservation to entirely unconnected respective circumstances. The abundance of the now visible rock scoring arises from three favourable conditions :— (1.) The extensiveness of the exposure of rock, (2.) the general capability of resisting atmospheric erosion possessed by the various rocks, and (3.) the equability and temperateness of the climate, which affords comparatively little opportunity for the disintegrating effect of violent atmospheric changes and of severe frost.* As to the parallel drumlins, though we might have expected to find them, as they are, better developed on the plain than in the mountain district, yet it does not appear why they should be so numerous in one part and absent from another part of that plain. Where they are now well-exhibited they must have been both well-formed originally, and gently treated afterwards, by the sea in which they were submerged ; but why these conditions should have obtained in some places and not in others we cannot tell.

The rock-scorings and drumlins are equally useful in tracing the courses of the streams which have produced them both ; the latter, however, will often show more accurately the stream direction for some particular place than any single example of rock striation may do, because the direction of the scorings is liable to be influenced somewhat by the shape of the rock-surface across which they run.

The carriage of the Boulder Clay need not be dwelt upon at any length. In some places the direction of its movement is obscure, either from the absence of boulder clay, or from its quite local character, or from the unfavourable disposition of the areas of different kinds of rock, or from the confusion caused by the presence of stones which must have been deposited by floating ice. But

* The mean winter temperature of the town of Galway is the same as that of Rome, viz. 41° F. An interesting illustration of the character of the climate is afforded by the fact, that the following plants flourish here, although they range only up to much lower latitudes on the continent of Europe—*Saxifraga umbrosa*, *Erica Mediterranea*, *E. Mackaiana*, *E. ciliaris*, *Daboecia polifolia*, *Adiantum Capillus-Veneris*.

where the necessary combination of circumstances occurs to make it manifest, the translation of the boulder clay is in correspondence with the courses of the striations. For instance, in the country on the west side of the town of Galway as far as Barna, and on the east side of Cashla Bay, both on granite ground, where the pieces of limestone in the first case, and the blocks of non-local granite in the second, have come from the northward; on the north-east side of Lough Corrib, and south-east side of Lough Mask, where the boulder clay on limestone ground, contains blocks and stones of the Silurian and metamorphic rocks of the mountains westward; on the limestone ground near Westport, where the drumlins contain blocks of sandstone and metamorphic rock from the south-eastward; near Louisburgh, on metamorphic ground, where the stones of granite have^{***} come from the granite exposure on the south-east; and in the country northward of Castlebar, where the granite debris has moved northwards on to the limestone. (It is most probable that many of the large granite blocks which are found, some as much as twenty miles north of their native rock, were transported by floating ice.)

The Glaciating Agent was Land Ice.—There is a great advantage in having two totally different kinds of stream marks; since this limits the number of hypotheses which might be plausibly advanced to account for them—no agent which cannot do *both* kinds of work, rock-scoring *and* drumlin-heaping can be proposed as having caused them.

The only explanations of the phenomena which, in these days, will be regarded as deserving of notice, are those which attribute them to—(1.) Floating ice carried on marine currents, (2.) “*Mud glaciers*” slipping off the land just as it was rising from submergence through the surface of the sea, and (3.) Land ice.

With respect to the first of these—there can, indeed, be no question but that floating ice was moving about during the period of post-Pliocene submergence, when the washed and stratified (or esker) gravels of this district were formed. To no other agency can we refer the transportation of the *far-travelled* blocks of Galway granite into the Queen’s County, Limerick, Cork, etc., which blocks are frequently found lying upon water-formed drift. But that floating ice has not produced the stream tracks, appears

to be absolutely certain from the following consideration, which is suggested with peculiar force by this district. A slight examination of the map is sufficient to show the radiating disposition of the flows in every direction from a quite small, though not well-defined, central area; which circumstance must be referred to again further on. But a system of steady marine currents, thus radiating from a circumscribed area of dispersion, would be, of course, an impossibility. It has been suggested that the tide, moving into and out of valleys, would carry up and down with it floating ice, which would produce striæ running along those valleys. But why should such floating ice scrape the rocks in one direction only, and not in the opposite also? Even if this insuperable difficulty could be got over, this theory would be only in a certain degree available in the central mountainous part of the district, and, as is evident, altogether inapplicable outside of that. In addition to this, we may observe that, by no reasonably conceivable process could floating ice form the drumlins, and also that it would be impossible for marine currents, (not in narrow sounds, etc.) continually affected by shifting tides and winds, to have the remarkably steady and unchanging courses which those streams must have had which shaped the drumlins.

It is really of but little importance, on the present occasion, to determine whether floating ice can extensively score rocks in steady parallel lines at all; because we are already compelled to have recourse to some other explanation of the phenomena; nevertheless we may advert to the following. The radiating disposition of the stream tracks shows that the rock-scoring was not effected by enormous masses of ice floating from arctic latitudes. If floating ice were the agent, it must have been in the form either of floes, which never have any great vertical thickness, or of small icebergs. Indeed, when the submergence was deep enough to account in this way for the higher striæ on Mweelrea and Croagh Patrick, any icebergs floating from the central area of dispersion must have been exceedingly small. Now, one of such floating masses could not produce clear, steady scorings, in the line of its translation, on a rock surface, unless the necessary combination of circumstances enabled it to grate heavily on the rock, and then to pass on without being turned round by the resistance.

But if, having scored the rock, it afterwards came to higher ground, it would either pass round this with a horizontal wheeling movement, or become lodged, when it would be lifted up and down, and shifted by changes of tide ; in either case it would leave behind a confusion of scratchings and dintings : and, on the other hand, if it afterwards came to lower ground, it would pass on without touching that ground at all ; yet we often find striations and drumlins on ground lower than that not far off in the up-stream direction. The scoring agent has left its traces running obliquely up the south-side of the eastern end of the ridge of Croagh Patrick, across the crest of that ridge, and obliquely down the north or lee side thereof—a feat impossible for such floating ice as has been moving about in this district.

In the case of extensive masses of mud slipping off the land as it was in the act of emerging from the waters, the striations caused thereby would be more closely connected with the fall of the ground in their immediate vicinity than we find them to be in this district. They would not cross summits and watersheds at heights of 2,200 to 1,600 feet, nor run *along* mountain sides at considerable elevations ; to say nothing of ascending hill slopes. Besides this, that mud slides could be of sufficient continuance to grind the *roches moutonnées* of this district into their actual forms is incredible ; and again, that mud slides could form the drumlins would be impossible. We beg pardon for insisting upon this ; we do not suppose for a moment that the distinguished author of this hypothesis would himself apply it to the glaciation of Iar-Connaught, etc., however suitable it might have seemed to the district he had in view when he first proposed it.

Nothing remains, then, but to account for the phenomena in question by the movements of a general covering of land ice of considerable depth ; notwithstanding that there are some particulars of its behaviour, which cannot be easily explained. Such an agent, granting its existence and necessary great development, is clearly capable of producing all the phenomena of abrasion ; and it has formed the drumlins by an operation evidently similar to that by which a stream of water often makes longitudinal ridges of sand in its bed.

The Movements of the Ice.—With respect to the behaviour of

the ice there are several particulars of interest. The first thing that invites attention is the fact, already mentioned, that the ice-flows have moved outwards in every direction, from a small, though not well-defined central area of dispersion. This includes the mountains on each side of the pass of Maum Ean, with the Twelve Pins, on the west, and perhaps, though this is doubtful, the group containing Bunnacunneen, on the north-east. Although the Twelve Pins occupy part of this central area, yet we see, from the way in which the ice has flowed closely round each side of them, that they were not as near the middle of that area as the Maum Ean mountains.

It is deserving of remark, that the central area of dispersion should be where it is, rather than more northward, about the upper part and north side of Killary Harbour, where there is a greater bulk of high ground. The hill masses about there would seem, both from height and grouping, to have been better entitled to the distinction of marking the centre of the glacial system; but they have been swept across by ice from the direction of Lough Inagh. The ice-stream has passed on, and moved, not only against Croagh Patrick, as already stated, but farther northward against the range of the Erris and Tyrawley mountains, some of whose lower elevations appear within the northern edge of the map. Although it has been partly forced out of its way by them, it has, nevertheless, streamed across them, certainly through their passes; *e.g.*, that of Coolnabinnia, on the west side of Nephin (as shewn by the striations on the summit of Tristia, nearly 1,100 feet above the sea), that of Lough Feeagh (witness the striations on the side of Buckoogh, at 1,200 feet, see map), and that of Bellacragher Bay, near Molrany (as evidenced by the striations in Corraun Achill, on the north-west side of Clew Bay, see map): in all these cases the movement of the red sandstone blocks corroborates the evidence of the striations. The explanation seems to be this—both the latter mountain groups were doubtless deprived of their full share of snow fall, in consequence of the south-west wind, which must have prevailed in the glacial period, for the same reason as it does now, having to pass over the former before reaching them. To which we may add a further reason, with respect to the last mentioned, that although they are as high, they constitute a less compact mass than those occupying the central area of dispersion.

The action of the ice about Clew Bay is sufficiently intelligible, once a general knowledge of the glaciation of this district has been attained ; although beforehand it might appear inexplicable. In the first place, however, let us observe that the evident confluence of the stream track near Newport, at the head of Clew Bay, with that running up from the head of Lough Mask, proves that the respective ridges, which partly constitute those stream tracks, must be of the same nature with each other ; and that, therefore, if one set has been formed by land ice, as is unquestionably the case, so must the other have been also ; which is corroborated by the fact, that those of the ridges about the head of Clew Bay, which have striations near them, are parallel to those striations. It is, then, perfectly clear that the ice moved over the site of Westport into what is now Clew Bay ; but there can be hardly any doubt but that, as just implied, it was moving, at the north-east corner of the bay, in landward, over the site of Newport (notwithstanding a little difficulty about the Boulder-clay stones in that vicinity). These at first sight apparently inconsistent movements are only parts of a local deflection. The ice was proceeding to move about north by west, across Clew Bay : but it was hampered by the mountains on both sides of the bay. The lower mass of Croagh Patrick is a definitely-formed, straight ridge, with a mean height of 1,500 feet, and four miles long, which lay somewhat obliquely to the course of the glacial stream. Near Westport the stream was curving into the wake of that ridge, to hug its lee side ; as a stream always does in such a case ; but more northward, away from the influence of this barrier, the stream was approaching another on the other side of the bay, and by this the part of the stream near the north-east corner of the bay was compelled to flow north-eastward.

Another note-worthy circumstance is the tendency shewn by the striations on the western, or coast, side of our district to take a north-westerly, rather than a westerly direction. This is, at once, intelligible in the neighbourhood of Clifden and Ballinakill, where the direction of the hill ridges might have caused it. But this north-westerly tendency of the glacial lines is perceptible all the way from that up to the neighbourhood of Louisburgh, and even on the islands which are several miles out to sea. This may be

partly (but, it would seem, only partly) due to the ground having, on the whole, a slope towards the north-west; as is indicated by the *general* direction of the coast there, and by the trend of the lines of equal soundings off that coast.

The flow which was moving south by west, down Bertraghboy Bay, began to send off a branch near Roundstone; this turned and flowed against, and over, Roundstone Hill, 987 feet, and then proceeded to move west by north, out of Mannin Bay. It seems impossible to account for this escapade.

The complexity of the movements in the neighbourhood of Lough Inagh is just what we might have expected, on finding that place to be contained within the area of dispersion.

The confusion of the ice marks, on the south side of the north-west arm of Lough Corrib, is easily explained by the fact that a branching of flows was about to take place near that, which would render the ice rather undecided in its movements; in addition to which came the obstruction of Seefin (which elsewhere would have been of very slight importance) to complicate matters. There being nothing to fix definitely the point of separation, slight alterations of pressure, due to variations in the growth or waste of the ice in different directions, would cause the situation of that point of separation to vary; and any particular spot near that place would be swept over by ice proceeding to join, sometimes one, sometimes the other, of the branch streams. The similar confusion on the south-west side of Oughterard seems explicable in a like manner.

The sharp turn northwards of the stream near the north end of Lough Corrib, and the sharp turn south-south-westward on the east of Oughterard, are evidently the result of the pressure of the ice on the eastward country—there is nothing in the shape of the ground to explain them.

Whatever difficulty may be presented by some of these particulars is no obstacle to the inevitable conclusion, that the glaciation of this district was effected by land ice; we are only reminded thereby that we are not in full possession of all the conditions of the question.

The *cross striations*, already referred to, come in fitly for consideration in this section. It is possible that some unconnected

instances of these may have been produced by floating ice acting under the favourable combination of circumstances above mentioned. But in some places the same set of cross, or secondary striæ, can be traced over a considerable area; as on the north side of the mouth of Killary Harbour, for a length of about a mile and a half, by a breadth of about a mile; and, especially, on the east side of Cashla Bay, over a space of about three by two miles (these instances are, of course, quite unconnected with each other). It is observable that in these cases the direction of the newer striæ differs from that of the older by not more than about 30° or 35° . The later scorings must have been caused by changes in the movements of the land ice in their respective localities; the new movements not continuing long enough to obliterate the older ice-marks. As to the reason of these changes;—we may conceive that, during some variation in the mass of the ice-covering of those places, new relations would arise among its different parts, and also between them and the shapes of the ground; which would give rise to altered directions of pressure. It is found that the scorings left by the Swiss glaciers, when at their former greater development, sometimes cross each other at considerable angles; even though the glacier was moving along a valley which might be expected to give, at all times, a very steady and definite direction to the moving ice;—which doubtless it did while the glacier remained pretty constant in size. There are indications, in other districts also, of similar local secondary movements of the ice; these, however, are much rarer than might have been expected; the explanation of this probably being that the movements of the general ice cap were somewhat quickly brought to an end by the subsequent submergence of the still ice-covered country in the sea. If we may judge from certain accounts cross striations seem to be more frequent in some parts of North America than in Ireland.

Depth of the Ice, and its relation to the Mountain Group.—The radiation of the ice-flows from within the mountain district out to the low grounds on every side is, at first sight, calculated to confirm a misconception which is still entertained even by some glacialists who acknowledge the existence of the general ice-envelope of the British Islands. We beg leave to draw attention to this matter more pointedly than has been hitherto done, at

least as far as we know ; more especially as the present district affords peculiar advantages for the consideration of it.

Most persons, on perceiving the fact now mentioned, that the stream-tracks radiate in every direction from within the mountain group out to the surrounding low lands, would be ready to adopt the expression which has been used relatively to the flows of the general ice-covering of Great Britain, that the mountains had "given birth and movement" to the glacial streams represented on the map, and they would call those streams "glaciers." These expressions, though unobjectionable if used in a certain free sense, are often used in a literal and improper sense, and have thus caused confusion of thought ; they have also, what is worse, given opportunity for specious but fallacious argument against the land-ice hypothesis.

It is, indeed, evident that the mountain group in question has been, in some way or degree, concerned in the origination of the ice-flows ; since those flows have had their point of departure within that mountain group ; but in what way or in what degree ?

In order to answer this question, we must first consider what can be determined as to the depth of the ice. It is obvious, however, that the highest surviving striations can only indicate levels above which it must have risen. The striations passing across, and near to, summits of the Maum mountains and the Twelve Pins, up to 2,200 feet, show that the ice must have stretched over those groups with a somewhat level, doubtless dome-shaped, surface, whose elevation was greater still. Its depth in the open valley of Lough Inagh cannot have been less than 2,300 feet ; but it must have been much more, as the following considerations will show. The stream whose course we can follow for the greatest distance, viz., that which moved up what is now the basin of Lough Mask, and out of what is now Killala Bay (24 miles beyond the northern limit of the map), was at least 65 miles in length, how much more we know not, as the distal part of its track is now covered by the sea.* This stream flowed on the

* The continuous reach of this stream is clearly proved by the rock-scourings observed by Mr. Symes, in connection with the Drift-carriage, eastward thereof, long since described by Sir R. Griffith. The parallel drumlins run up to Ballina; beyond that, however, the mounds become irregular, although the rock-scourings continue their course to Downpatrick Head and the opposite side of the mouth of Killala Bay.

level plain for 60 miles of its course—which involves a greater depth of ice at its head than that just specified. It is quite impossible that the Maum mountains and the Twelve Pins could have given birth to the mass of ice to which that flow belonged, in the sense which would ordinarily be given to those words: we mean in the sense in which the Alps have given birth to their ice-mantle and their glaciers, the longest of which, the Aletsch, extends only about 15 miles. Or, to look at the matter from another point of view, the now dry-land part of the district occupied by the ice-system with which we are engaged, is, roughly speaking, about 2,500 square miles in extent, and the now submerged part must be a very large addition to this;* whereas the central area of dispersion is only about 50 square miles, or perhaps, if the neighbourhood of Bunnacunneen be included, 65 square miles. It is quite evident that, even supposing all the ice formed on this small central area to have reached the borders of the whole district, it must there have become greatly attenuated, and must have constituted a very insignificant proportion of the ice in those parts, which must have been of considerable depth to move as it has done. But, besides this, only a small portion of the ice formed on the central area can have reached the remoter borders of the district at all; perhaps none of it got as far as Killala Bay, being melted before it had time to travel such a distance; just as much of the water from the so-called “Source of the Shannon” must be evaporated before it can reach the sea. Consequently the ice of the farther parts of the district, although belonging to streams whose tracks can be followed back continuously to the middle of the mountain group, must have consisted chiefly of snow which fell outside that group, and, therefore, was but partly given birth to thereby. All that the mountains could do towards giving birth to such a collection of ice was to cause, at the commencement of the glacial period, a greater determination of snow-fall and consequent ice formation to their neighbourhood. This would continue after they were completely hidden beneath the ice; because a great

* The Aran islands, six or seven miles south of the southern limit of the map, if we may conclude from two well separated instances of rock-striation, are contained within the area of this system. The N.E. to S.W. striations on the south side of Galway Bay belong to a different system.

table-land of ice would have the same effect as a group of naked mountains in attracting to itself more than the mean snow-fall of the region.

We may now proceed to observe that, in such a state of things, the mountains could not *give movement* to the ice-flows, any more than a submarine mountain can send off sea currents in all directions down its slopes. It was the greater development of the general ice-covering of the country over the mountain group, and its consequent greater weight there, which caused an outwardly directed pressure, resulting in radiating ice-flows.* The mountains, indeed, determined the position of the great ice-dome; but the latter, when fairly established, spread abroad on its own account. If, when the ice-dome had been formed, the mountains could have been annihilated, and their vacant room filled with ice, so that the surface of the ice-dome might remain unchanged, the outward movement of the ice would have been facilitated and not the reverse. Although the valleys have, indeed, acted as channels which have conducted the flows outwards on every side, they have sometimes, as is evident, led the ice out of the direction which it would have taken if its movements had been quite unconstrained; and the friction and other resistance of the *sides* of the valleys offered an additional impediment; and neither of these would have been in existence but for the mountains.

The greater or less definition of the flows, as they appear on the map, is due to the shaping of the ground, which influenced, more or less, the movements of the underneath part of the universal ice-envelope. Those flows cannot have been really as distinct as they sometimes appear on the map. It is misleading to call them "glaciers," which term suggests the local and distinct ice-streams of the Alps, etc. They can be called glaciers only in the same loose and improper sense as that in which currents of the ocean and those in straits, etc., among islands, may be called rivers.

The ice-flow already mentioned, which moved out of what is now Killala Bay, was co-ordinate with that which joined it (after describing a considerable curve) from the hill district about

* Mr. T. F. Jamieson has already pointed this out in one of his papers on the glaciation of Scotland.

the source of the Shannon. (See eastern side of map.) These confluent streams have evidently affected each other by mutual pressure. The latter was also co-ordinate with that which extended from the same origin across the central plain of Ireland to Dublin Bay. The last two have left as clear evidence of their existence and continuous stretch as the first has done. Consequently the ice-system with which we are immediately concerned was a constituent part of the general envelope of Ireland. The mountains, indeed, helped in the formation of the material of which it was composed, and thus became the occasion of its radiating structure and its individuality as a system; but they were not an indispensable requisite for the existence of an ice-covering in this district.

The radiation of the ice-flows from a single central area of dispersion is the circumstance which makes the mountain group under consideration differ from that of Kerry, in one respect, and contrast strongly with that of the Cos. Wicklow and Wexford, in another. The glaciation of Kerry has not been as thoroughly examined as we hope it may yet be. It certainly would seem, however, that there, instead of a single centre of dispersion, there were, besides the principal predominant one, certain others, inferior but independent; the reason evidently being the greater extent of the mountain country and the greater height of the mountains. But, on the other hand, when we turn to the mountain groups of the east side of Ireland, we find no proof of their having supported radiating ice-systems at all. The glacial stream has flowed against and across the northern end of the Wicklow group, and it has been divided thereby. When M. Agassiz was in Dublin, in 1840, he very naturally supposed that the Wicklow mountains must have been a centre of land-ice dispersion; but of this there seems to be no existing evidence, though they had their later *local* ice action and a floating-ice dispersion of *surface* blocks.

There are other centres of dispersion in the western part of Ireland besides the two mentioned. It is an interesting fact that these were all on the west, and that there is no sign of any having been on the east. Still, it is reasonable to suppose that, while the general ice-mantle was being slowly formed, in the earlier part of the glacial period, the mountains of Wicklow and Wexford may

have been a centre of dispersion, although only a feeble one, which had but a short time for development before it was overborne by the superior vigour of the western centres. The explanation seems to be this : (1.) There is a greater extent of hill country on the west than on the east of Ireland, and (2.) the same well-known circumstances which now produce a much greater rain-fall in the west than in the east of Ireland, must have prevailed in the glacial period to cause a similar unequal distribution of snow-fall, and moreover (3.) there are reasons for believing that, during the period of the general glaciation, the west of Ireland was higher, relatively to the east, than it now is.

It is outside the purpose of the present paper to mention the later local glacial action, of which there is evidence in some of the corries, or mountain hollows, in this district.



