LOCAL PLEISTOCENE GLACIATION AND THE LEVEL OF THE SNOW LINE OF CROAGHAUN MOUNTAIN IN ACHILL ISLAND, CO. MAYO, IRELAND

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ABSTRACT. The group of corries on Croaghaun Mountain on Achill Island is described. The existence of these corries and the absence of any extraneous drift from the mountain is taken as evidence that the inland ice of Co. Mayo did not extend far beyond the present coast. The relation of the corries to the local topography is described, and the effect of the topography on the apparent snow line is discussed. The probable snow line of the main glaciation of the west of Ireland is shown to be in the neighbourhood of 1250 ft. O.D. (384 m.) but may have been as low as 1000 ft. O.D. (305 m.) and that of the Late-glacial period in the neighbourhood of 1750 ft. O.D. (533 m.).

RÉSUMÉ. L'auteur décrit un groupe de cirques glaciaires sur la montagne de Croaghaun, dans l'île d'Achill. L'existence de ces cirques, et l'absence de drift d'origine extérieure à la montagne, sont, croit-il, la preuve que la calotte glaciaire du comté de Mayo ne s'est pas étendue beaucoup plus loin que la côte actuelle. L'auteur décrit les rapports de ces cirques avec la topographie locale, et étudie l'effet de la topographie sur la limite apparente des neiges permanentes. Il montre que cette limite, lors de la glaciation principale de l'ouest de l'Irlande, était probablement aux environs de 384 m. mais a pu être plus basse, 305 m.; et que celle de la fin de l'époque glaciaire était aux environs de 533 m.

THE local glaciation on Achill Island is briefly mentioned by Charlesworth in a paper on the glacial geology of north Mayo and west Sligo.[2] Charlesworth considers that as most of north Mayo was "completely overwhelmed by the ice from extraneous sources" the local glaciations must have occurred after the maximum. It is not clear that this statement refers to the western part of Achill Island, indeed Charlesworth's map shows the outermost recognizable moraine of the mainland glaciation as lying at the base of the south-eastern slopes of Croaghaun and Slievemore in Achill. Recent investigations show that the local glaciation on Croaghuan was more extensive than indicated on Charlesworth's map, and they have confirmed his map in that no evidence has been found which would suggest that extraneous ice reached farther west than the eastern and southern foot of the mountain.*

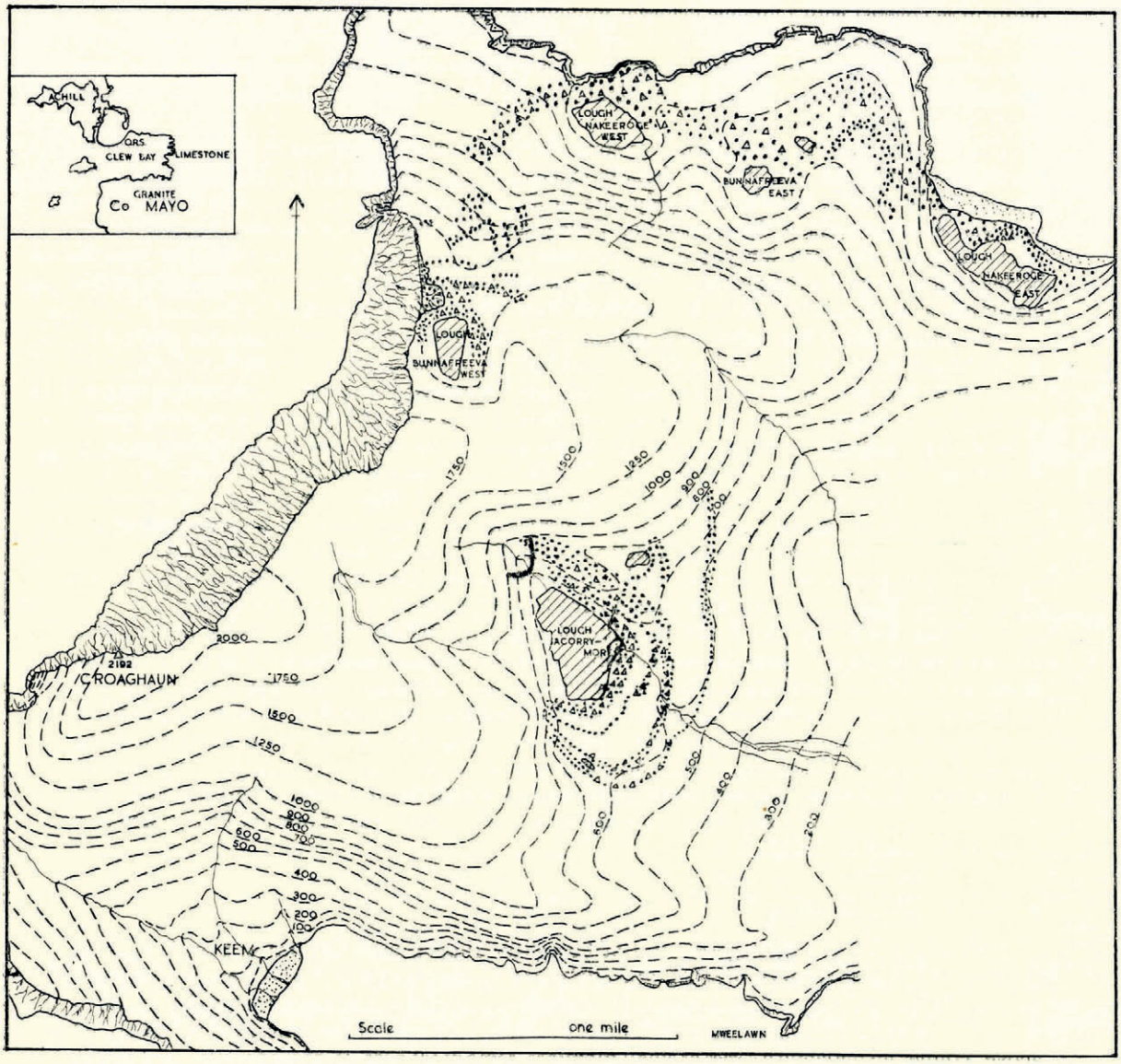
Achill Island lies at the extreme west of Co. Mayo, being separated from the mainland by a narrow channel. It is a large island some 57 square miles (148 sq. km.) in extent. Three-quarters of this area shows abundant evidence of invasion by ice from the south-east.

The general glaciation of this part of the west of Ireland emanated from a centre somewhere in south Mayo and Connemara. The general movement of the ice in north Mayo was from the south but this is a generalization to which many exceptions will be found when a detailed study is undertaken of the full history of the glaciation of the area. There must have been a strong westerly component in the movement of the ice, as is shown by the east and west orientation of the drumlins in Clew Bay and by the carriage of erratics. The best indicator rocks are (1) a distinctive granite with brown felspars, almost certainly from Corvockbrack in south Mayo, which has been found as far west as Keel in Achill, 25 miles (60 km.) north-west of the point of origin; (2) Carboniferous limestone from the head of Clew Bay, which has been found as far west as Dooagh, a west by north transport of a minimum of 20 miles (32 km.); (3) the Old Red Sandstone of Curraun Achill which has been found at Mweelaun about 15 miles (24 km.) west by north from its exposure. The last-mentioned erratic, which was found in a small patch of rubbly boulder-clay below scree, marks the farthest west of any recognized influence of the inland ice. All available sections to the west of this point were examined. None yielded any recognizable foreign stones. The next extensive sections on the coast lie at Keem Bay 1½ miles (2·4 km.) to the west. Here deep stream

* The published 6-inch maps of this area are not contoured. Col. N. MacNeill, Assistant Director, Ordnance Survey, whose kindness the author gratefully acknowledges, made the work possible by having contours put on the author's field maps.

sections down to rock, and the coastal cliff behind the beach, show nothing but local scree up to 20 ft. (6 m.) or more in thickness. In the streams coming down the southern slope of Croaghaun the same feature is evident.

The absence of far-travelled erratics is negative evidence, but the sudden occurrence of thick local screes reaching down to sea level within a mile or two of the observed limit of the invading boulder-clay is more positive evidence. Furthermore, the great size and the low level of the corrie moraines to be described later are an argument in favour of the contention that the Croaghaun ridge was never overswept by extraneous ice.



Glaciation of Croaghaun, Achill Island, Co. Mayo, based on the Ordnance Survey by permission of the Minister for Finance of Ireland

https://doi.org/10.3189/S0022143000025442 Published online by Cambridge University Press

The Corries on Croaghaun

Croaghaun is a ridge, oriented north-east and south-west, with a length of 1½ miles (2·4 km.) above 1750 ft. O.D. (533 m.). It culminates at its southern end in a summit of 2192 ft. O.D. (668 m.) from which the ridge falls steeply to a col at 650 ft. O.D. (198 m.). To the north-west the slope from the top of the ridge is gradual until the 1000 foot (305 m.) contour is met where the ridge, having taken an easterly turn, falls sharply to 500 ft. O.D. (152 m.) at which level it continues for about half a mile before rising again to over 900 ft. O.D. (274 m.). To the north of that portion of the ridge which runs east and west, the slope steepens abruptly below 1000 ft. O.D. and in a series of cliffs and steeps falls to a platform at between 100 and 200 ft. O.D. (30–60 m.). This platform is covered with morainic material impounding three lakes against the cliff.

The most westerly of these lakes, Lough Nakeeroge West, lies at 162 ft. O.D. (50 m.) in front of an embayment in the cliff. A small stream valley comes down the eastern side of this embayment. There appear to be some slight signs of late corrie action in this valley at about 700 ft. O.D. (213 m.).

The lower part of this small valley has some debris of morainic type at a level of about 100 ft. (30 m.) above the lake, but it is not definite enough to map. The moraine which dams the lake appears fairly smooth, but this is largely due to the thick growth of peat; in fact it is a block moraine, as is every one of the moraines on Croaghaun. The moraine extends to the present coast where its material is seen forming the upper 8 or 10 ft. (2·4–3 m.) of the sea cliff. The moraine begins well to the west of the embayment before which the lake lies and may be associated with the maximum stage of another corrie, Bunnafreeva West, which will be described later.

The moraine continues to the east, fronting the cliff, until another embayment is reached in which Lough Bunnafreeva East is held up. This lake has a level of just over 300 ft. O.D. (91 m.). The cliff behind it is steep, as in the case of Lough Nakeeroge West; the embayment is deeper, but there is no stream valley. The moraine has its highest and biggest development at this place. A small lake, Lough Tinny, is completely surrounded by moraine, but its margins are gently sloping and it has not the appearance of a "kettle hole." Just east of Lough Tinny there is a secondary moraine which encloses against the cliff a lakeless hollow. This probably represents a last stand of the ice against a sheltered slope. There is no real corrie action to be seen on this part of the cliff. Near by, to the south-east, there is a similar but much smaller encirclement.

The main moraine continues and again reaches the coast. Here it forms the sea cliff, no rock being visible on the shore, and impounds a large lake at a level of 63 ft. O.D. (19 m.).

Half-way along this lake a new moraine of very large blocks begins and lies between the eastern part of the lake and the sea, curving round to meet the north-west facing wall of the escarpment. The cliff behind this lake is steep but does not reach higher than 500 ft. O.D. (152 m.).

The whole of this stretch of the north face of the ridge must be considered as having had one continuous glacier fronted by a moraine which now begins at about 700 ft. O.D. (213 m.), on the west of Lough Nakeeroge West, and falls, with some fluctuation in height, to sea level at Lough Nakeeroge East. The secondary moraines mentioned east of Lough Tinny and at Lough Nakeeroge East cannot be separated from the main moraine and must at present be regarded as a stage in the decay of the glacier.

Lough Bunnafreeva West

Half a mile north of the highest point of Croaghaun ridge a small lake lies in a corrie right on the edge of the great western sea-cliff. The cliff is now eating into the wall of the corrie so that the bottom, far below lake level, is exposed. It is possible that at the maximum the glacier extended down the slope to the north and contributed to the western end of the long moraine described above. Higher up the slope a series of small moraines, some mere patches, some forming continuous ridges, give positions of the front of the glacier during its retreat. A very fine moraine, rising 40 or 50 ft. (12–15 m.) above the level of the lake, forms the final barrier. At one time the lake drained

out over the top of this moraine, at which height a continuous terrace runs right around the lake; but at present the drainage percolates through the moraine to issue about 250 ft. (76 m.) lower in the side of the sea-cliff at the bottom of the deep section of glacial debris which is exposed there. The depth of the lough is not known. Although the moraine which encloses the lake makes such a fine show on the surface it accounts for less than one-fifth of the total depth of the deposit and the other well-marked moraines are little more than small ridges on the surface of a great mass of drift.

If these morainic ridges on the surface represent retreat stages, and no other explanation seems likely, then the glacier in its advance may have overridden a great thickness of glacial detritus, that is, it may have continually advanced over its own moraine, or perhaps the surface topography may be due to a re-advance. If, on the other hand, all the material was deposited during the retreat, then a very large proportion of the total excavation and deposition of material must have taken place at the last stage of the corrie glacier. It would appear, however, from the topography that the last explanation is not likely, for the ridges, although definitely morainic, are too small to be the surface expression of large masses of detritus. In this connexion it should be noted that the material exposed in the deep section includes much fine matter, whereas the surface features are blocky. No evidence was found to decide whether there had been one or two advances of the glacier.

Lough Acorrymore

This lake lies on the east slope of Croaghaun in the largest of the corries. Its level is a little over 600 ft. O.D. (183 m.) and the cliff behind rises steeply in crags and ledges up to 1750 ft. O.D. (533 m.). In front of the lake a splendid series of moraines sweeps across the hillside in a belt some 600 yds. (548 m.) wide at its maximum. The lake is now bounded on its north-eastern side by a great bank of moraine which divides the corrie into two parts, the most southerly and larger part contains Lough Acorrymore and the other a small tarn, Lough Corynlawy. The outermost moraine encloses both parts of the corrie, and in front of this moraine lies an extensive peat-covered slope of outwash, smooth except for occasional large blocks of rock. The moraines stand up as remarkable banks, and several stages of retreat may be seen. As there is no evidence of extraneous ice on the mountain, and as the development of the moraines is so great, it is considered that the local glacier is contemporary with the glaciation of the mainland and is not a local glaciation which developed after the retreat of the main ice.

Four main stages are clearly seen. The maximum is marked by the outer moraine which spans the whole corrie, and the later stages by the three moraines which are confined to the southern part. Lough Corynlawy has two small moraines between it and the outer moraine. Two of the moraines in front of Lough Acorrymore are peat covered, but through the peat the blocky structure appears. The inner moraine still consists, to a great extent, of large rough blocks, many of great size, which even the vigorous growth of peat to be found in Achill has been unable to cover. All three of these moraines coalesce to form the great bank which divides the corrie. Exposures on this bank are bad and it is possible that it may have a rock core; no rock *in situ* is seen, however, and the form and position of the ridge make it almost sure that it is formed of morainic material.

An interesting feature is a small but very complete rampart of moraine which occurs at the head of the corrie. This lies partly on scree, which must have formed at a period when there was no ice in the corrie, and partly across the end of the dividing moraine. It is not possible to separate the main series of moraines into anything but retreat stages of one large corrie glacier, but the last-mentioned small moraine is something quite different and must represent a regrowth of the ice after a period of deglaciation. It corresponds closely in its association with the larger moraines to those found in the Leinster Mountains, particularly to the moraines of the Mount Leinster group.[3] It is therefore most probably Late-glacial in date.

The Level of the Snow Line

It might be thought that with an isolated mountain ridge like Croaghaun with well-marked corries upon it reasonably exact determination of the snow line might be made. This is not the case. Even if we consider the three corries with moraines on the north shelf as being a unit, we still have three levels at which corrie glaciers lay: (1) the northern group with the moraine skirting the sea-cliff at 100–200 ft. O.D. (30–60 m.) and even reaching sea level at the eastern end; (2) Lough Acorrymore with the moraines lying between 700 ft. O.D. (213 m.) and 600 ft. O.D. (183 m.); (3) Lough Bunnafreeva West with moraines between 1100 ft. O.D. (335 m.) and 700 ft. O.D. but the main mass at 1100 ft. O.D. to 1000 ft. O.D. (305 m.). Clearly the level of the moraines gives us little help, and for this reason the application of the usual method of determining a glacial snow line from a combination of the moraine level with the height of the upper limit of glacial sapping is of no service here, particularly when there is striking evidence at Lough Bunnafreeva West of how little indication the moraines give of the true depth of the corrie bed. If we approach the problem by the cautious method advocated by Blache [1] and use only the heights of the nearest summits to give a maximum level for the snow line there is still no immediate answer. Acorrymore lies below the summit of Croaghaun, 2192 ft. O.D. (668 m.); Bunnafreeva West lies below a portion of the ridge that does not rise much above 1750 ft. (533 m.). It should here be pointed out that, although much of the ridge must have been eroded by the sea since the corrie was formed, what remains of the western side of the ridge directly below the summit and the run of the contours at the northern end of the ridge, suggest that there never was higher land nearby.

At the lower level, the western end, and indeed two-thirds of the length of the escarpment below which the three northern lakes lie, has a summit at a little over 1000 ft. O.D. (305 m.), but at the eastern end the top of the ridge hardly exceeds 500 ft. O.D. (152 m.). Obviously once the condition exists that some portion of a *massif* is high enough to retain snow throughout the year the pre-existing topography is of prime importance in deciding where a glacier will form.

In the present case it is possible that the northern glacier was formed well below the snow line for the area. The main ridge of Croaghaun was well above the snow line and some of the snow which was precipitated accumulated in the lee of the steep north face of the island on the broad ledge which at present lies at 100–200 ft. O.D. (30–60 m.). It may be suggested that the snow which formed the glacier in this position was wind-blown from an accumulation area on the gentler slopes which are found above 1250 ft. O.D. (380 m.) on the mountain. At the western end some snow might have been added by sliding down from this accumulation area, but this could not apply to the eastern end at Lough Nakeeroge East where the narrow ridge behind is only 500 ft. O.D. The glacier at this point was fed by wind-blown snow or else the snow line was below 500 ft. O.D. The latter explanation is unlikely, for if the snow line had been so low one would certainly expect a completely different disposition both of local and inland ice. It may be noted here that the small valley which comes down the east slope of the ridge north of Lough Acorrymore was not glaciated. For these reasons the phenomena connected with the glacier cannot safely be used to determine the snow line; nevertheless the occurrence of the very considerable moraines seems to indicate a prolonged existence for the glacier, and it may well be argued that the snow line must have come below 1000 ft. O.D. The manner in which what are apparently the latest moraines on the shelf are found below the lowest part of the ridge strengthens this opinion.

Acorrymore lies almost due west of the highest part of Croaghaun and so, without some other indication, really gives no more information than that the snow line must have been below 2000 ft. O.D. (610 m.). Bunnafreeva West is therefore the place where a reasonably accurate determination of the snow line may be attempted. Here we may say that it must have been below 1750 ft. (533 m.). This is not inconsistent with the formation of the large corrie at Acorrymore or with the suggestion that the glacier of the northern shore might have been fed in part from snow lodged on the gentle slopes at about 1250 ft. O.D., and it is suggested that the probable snow line during the last glacial phase in Ireland must have been at least as low as 1250 ft. O.D.

With regard to the small recent moraine lying at the back of Acorrymore which is considered to be Late-glacial in date, it is not possible to say more than that the snow line must have been below the summit of Croaghaun (2192 ft.) and was probably below 1750 ft. O.D. The fact that the moraine lies as low as 750 ft. O.D. (228 m.) has little meaning, for the deep sheltered hollow with a very steep slope left by the previous glacier was an ideal place for the accumulation and preservation of a small glacier at a level somewhat below the natural snow line. The level of the Late-glacial snow line on Mount Leinster in Co. Carlow was formerly estimated at 1650 ft. (503 m.),[3] but with the more cautious approach employed above it would not be possible to say more than that the level must have been below 2000 ft. (610 m.).

M.S. received 27 February 1953

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SOME NEW ASPECTS OF THE GRÍMSVÖTN PROBLEM

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Report of a lecture given to the British Glaciological Society at Cambridge on 6 March 1952

ABSTRACT. Grímsvötn (The Lakes of Grímur) is the name of a volcanic centre in Vatnajökull, the eruptions of which accompany the gigantic glacier bursts on Skeidarársandur which occur normally about every tenth year. Recent expeditions to Grímsvötn and reconnoitring flights have led to the view that between glacier bursts the Grímsvötn depression is gradually filled with water, forming a lake with a maximum area of about 35–40 sq. km. This accumulation of water is partly due to ablation and partly to continuous solfatara and fumarolic activity.

The close resemblance between the discharge graphs of glacier bursts from Grímsvötn and graphs of drainage of normal ice-dammed lakes such as Lake Graenalón is stressed. It is also pointed out that ten years' accumulation, about 7 cu. km., in the area drained into the Grímsvötn depression, corresponds roughly with the total discharge of a normal glacier burst from Grímsvötn. It is suggested that the glacier bursts determine the moment of eruption and not *vice versa*. This might explain the usually very regular intervals between these eruptions. The irregularities occurring since 1934 might be due to the present climatic amelioration.

ZUSAMMENFASSUNG. Grímsvötn (die Seen von Grímur) ist der Name eines vulkanischen Zentrums in Vatnajökull dessen Eruptionen die riesenhaften Gletscher-Ausbrüche am Skeidarársandur, die sich gewöhnlich ungefähr alle zehn Jahre ereignen, begleiten. Jüngst ausgeführte Expeditionen nach Grímsvötn und Auskundschaftsflüge haben zu der Ansicht geführt, dass die Grímsvötn Senkung sich zwischen den Gletscher-Ausbrüchen allmählich mit Wasser füllt und so einen See mit einer maximalen Fläche von ungefähr 35–40 km.^{2} bildet. Diese Wasseransammlung ist teilweise durch Ablation herbeigeführt, teilweise durch ununterbrochenes subglaziales Schmelzen, das auf der Aktivität von Solfataren usw. herrührt.

Die grosse Ähnlichkeit zwischen den Ausströmungs-Diagrammen von Gletscher-Ausbrüchen des Grímsvötn und Ablauf-Diagrammen normaler eisgedämmter Seen wie z.B. des Sees Graenalón wird betont. Es wird ferner darauf hingewiesen, dass das Anfüllen der Fläche des in die Grímsvötn Senkung abgelaufenen Wassers innerhalb zehn Jahren, *ca.* 7 km.^{3}, ungefähr der Total-Ausströmung eines normalen Gletscher-Ausbruches des Grímsvötn entspricht. Es wird angenommen, dass die Gletscher-Ausbrüche den Augenblick der Eruption bestimmen und nicht umgekehrt. Es könnte dies eine Erklärung für die gewöhnlich sehr regelmässigen Intervalle zwischen diesen Eruptionen sein. Die seit 1934 vorkommenden Unregelmässigkeiten mögen dem sich gegenwärtig verbessernden Klima zuzuschreiben sein.

THE lecture commenced with the early history of the eruptions in the centre of Vatnajökull, the situation of which was already known to the Icelanders before A.D. 1600. The probable routes used by fishermen crossing Vatnajökull in the fifteenth and sixteenth centuries are given in Fig. 1 (p. 269). In 1919 two young Swedish geologists, Erik Ygberg and Hakon Wadell,[13] rediscovered the volcanic centre of Vatnajökull, the eruptions of which are accompanied by great glacier bursts on Skeidarársandur. They named this volcanic centre Sviagígur, or Swede's Crater.