ORIGINAL ARTICLES.

The Pre-Glacial Valleys of Arran and Snowdon.

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Introduction.

THE history of the British Isles in the Pliocene has an important bearing on their glacial geology and on the origin of their existing geographical features. Physiographic evidence indicates that the Lower Pliocene was in Britain an epoch of depression, during which the sea covered parts of South-Eastern England, whereas the Middle and Upper Pliocene were marked by an uplift which excluded the sea from the British Isles, except in East Anglia and Western Cornwall. It is generally agreed that this uplift raised the low-lying plains that had been formed during the Lower Pliocene into plateaus from 500 to 1,400 feet above sea-level. The uplift lasted through a long period of time; and such a slowly rising land would naturally be greatly denuded by rivers. Plateaus and platforms due to the Pliocene uplift have been described by Dr. Mort for Arran and by Professor W. M. Davis for Snowdon; yet in their discussion of the present topography of those districts they attribute a very slight influence to stream erosion during the long pre-Glacial elevation.

The Island of Arran, amongst its many other attractions, offers much clear evidence on the history of this plateau and its bearing on the problem whether the Scottish valleys were made or merely moulded by glacial action. Dr. Mort has recently so attractively restated the case for the glacial origin of these valleys, that it may be advisable to summarize the evidence in favour of pre-Glacial rivers having been the more important agent in their formation. Though Dr. Mort's memoir appears to attribute to ice too large a share in the formation of the Arran valleys, it includes several such

[1] Since this paper was written, shortly after a revisit to Snowdon in September, 1915, the Pliocene plateau of Carnarvon has been described by Mr. Dewey, who demonstrates the pre-Glacial age of the Snowdon valleys: "On the Origin of some Land-forms in Caernarvonshire, North Wales": Geol. Mag., 1918, pp. 145–57, Pl. VII. The publication of the present paper has been delayed by pre-occupation with other matters and two years' absence abroad; it is issued as originally written except for a few verbal changes. I am greatly indebted to Dr. A. Scott, who during my absence kindly re-drew the sections for press.

important additions to the geographical history of Arran as to form a contribution of permanent value to the literature of Scottish physiography.

1. The Valley System of North Arran.

North Arran has a comparatively simple structure in spite of the great variety of its rocks. It consists of a nearly circular block of granite (Fig. 1) which varies from 7 to 8 miles in diameter

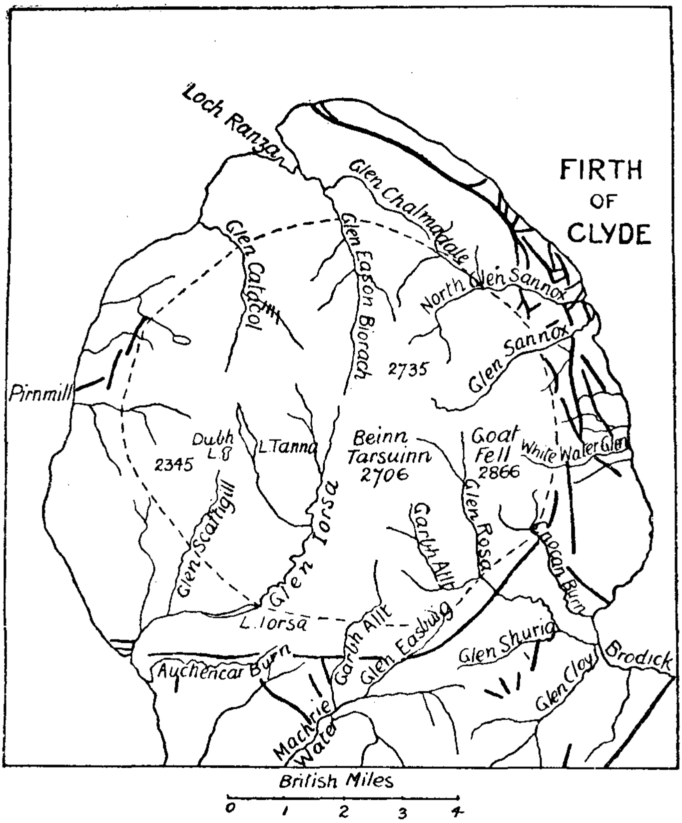

Fig. 1.—Sketch-map of North Arran, showing the faults (thick lines) and the granite (within the broken line).

and is surrounded by a girdle of metamorphic and sedimentary rocks. They formerly covered the granite as a dome from which rivers must have flowed radially in all directions. The highest mountain in Arran, Goatfell, is 2,866 feet, and three other summits rise over 2,600 feet; hence the area was apparently cut down to a plain at the height, in the granite district, of a little under 3,000 feet.[1] The date and mode of formation of that plain are uncertain; but it was probably cut when the country was lower than at present, and that plain may have been nearly at sea-level.

The history of the existing valleys begins with the elevation of this plain into a plateau. During the uplift radial streams must have flowed from the granite highlands. There are in North Arran about twenty-two radial streams in addition to the lower ends of the major valleys. These radial streams trend as follows:—

N.E. Two streams of North Glen Sannox.
E.N.E. Glen Sannox.
E. Four streams near Corrie, of which the longest is the White Water Glen.
S.E. Merkland Burn and Cnocan Burn from Goatfell.
S. The eastern Garbh Allt, from Ben Tarsuinn.
S.S.W. The western Garbh Allt from Beinn Nuis; and Auchenear Burn from S.S.W. of Beinn Tarsuinn.
S.W. Glen Scaftigill.
W. Eight burns, of which the longest is the Allt Gobhlach.
N.W. Abhainn Beag.

These radial streams are all of secondary importance. The major valleys, in which ground less than 1,000 feet in height reaches the centre of the granite mountains, run north and south. The granite dome is, in fact, dissected by three main valleys which cut across it north and south. The longest and most conspicuous of these valleys is that of Glen Iorsa and Glen Easan Biorach; it cuts across the middle of the granite mass. Further east is the valley of Glen Rosa, which is continued northward by Glen Sannox; this joint valley runs north and south for most of its length, but both its lower ends bend eastward to the sea. The third north and south valley, that of Glen Catacol and Glen Scaftigill, is on the western side of the island; its lower end bends westward to the sea, which the Scaftigill Burn reaches through the Iorsa Water. Each of these three valleys includes a large tract of ground below the level of 1,000 feet. On the floor of Glen Iorsa a band of alluvium, most of which is below the level of 250 feet, occurs in the very centre of North Arran; even the uppermost part of this alluvium is below 350 feet. Most of the floors of Glen Rosa and Glen Sannox are less than 500 feet above the sea.

In addition to the three north and south valleys there is another major valley in North Arran. It consists of Glen Chalmadale and North Glen Sannox; it crosses the island from Loch Ranza east-south-eastward to Sannox Bay and separates the plateau of Creag Ghlass Laggan (1,453 feet) from the rest of the highlands.

The valley system of North Arran may therefore be classified as follows:—

A. Minor Valleys.
  I. Radial valleys from the granite hills.
B. Major Valleys.
  II. The three north to south valleys across the granite hills.

[1] This feature was recognized and illustrated by Sir A. C. Ramsay (1841, sect. i, opposite p. 8).

III. The north-west to south-east valley across the north-east of the island between Loch Ranza and Sannox Bay.

IV. The valley which crosses from Brodick over a divide at 768 feet and separates the mountains of North Arran from the moorlands that form most of the southern part of the island.

2. Evolution of the Existing Topography.

The most striking feature of the major valleys of North Arran is their independence alike of the main slopes and geological structure. The major valleys are not radial from the mountains and they are independent of the geological structure. Thus the three north and south valleys cut right across the granite mass, and though their lower ends bend seaward this change of course appears independent of the structure of the schistose and sedimentary girdle.[1]

However greatly the valleys may have been enlarged by denudation, their plan was determined by some influence which affected the area as a whole and was independent of its structure.

In order to determine the origin of these valleys and the extent to which they are due to glacial erosion it is necessary to determine the general topography of the country at the beginning of its glaciation. That topography was the result of the geographical evolution of the island after the igneous activity of the middle Kainozoic. The next process was the planing of Arran to a gently undulating tableland, of which the surface in the Goatfell Mountains was, perhaps, 2,000 feet above sea-level. The land extended further on all sides, and the slopes were longer and gentler than they are now. During this stage Arran was part of the mainland ; and, as Dr. Mort suggests, the Chalmadale-North Sannox valley was probably initiated then by rivers that flowed south-eastward across North-Eastern Arran. The country was again uplifted, and Arran was isolated by tectonic valleys to east and west, and a series of north and south clefts parallel to these valleys cut across the granite mass of North Arran. The clefts were subsequently enlarged by denudation into the three major north and south valleys of the island.

After the second uplift the land must have remained stationary for a sufficient period, for the formation of a low plain, which was raised by a third movement into the thousand-foot platform (Fig. 2). This uplift doubtless reopened the north and south clefts,

[1] Among the valuable contributions in Dr. Mort's paper is his rejection of the view that the difference in form between the central and western mountains was due to the texture of the granite. His objections to that explanation seem convincing. The western hills were completely overridden by ice, of which the lower part would have been charged with rock debris from the smooth central peaks and would have worn down the western summits into rounded ridges. The lower part of the snow-cap over Cir Mhor and Goatfell may have been converted to ice ; but after the ice had removed the loose material it would have consisted of clean ice and have had but little abrasive power. By the time it had reached the western hills the lower layers were probably charged with rock fragments and were thus a more effective file.

and they were enlarged by denudation until their floors were but little above sea-level. During these movements the climate was becoming colder, as is shown by the disappearance from the British seas of those Lower Pliocene mollusca that are characteristic of warmer conditions. Frost action must have attacked the higher peaks and especially the slopes facing north and east; and the continual freezing and thawing of water in the joints of the granite led to the formation of corries along the margins of the snow-fields. Dr. Mort's memoir on Arran gives the first adequate description of its thousand-foot platform, which is also well developed in Ayrshire. Dr. Mort has advanced good reasons for the opinion that it was probably due in Arran to marine denudation.[1] If so, this platform is evidence of an uplift of at least 1,000 feet; and that it was several hundred feet greater than that amount is shown, as Dr. Mort remarks, by the buried valleys in South-Western Scotland. If this platform be a plain of marine denudation the uplift in Arran was not uniform. The platform varies in height from 800 to 1,200 feet around the Goatfell Mountains, and to the north-west of Brodick. It is from 700 to 1,000 feet beside the western coast from lower Glen Iorsa northwards to near Pirnmill; from 750 to 1,000 feet north of North Glen Sannox; from 500 to 750 feet in the south-western part of the island, between Blackwaterfoot and Glen Scorrodale; and between 500 or 600 feet and 900 feet in the south-eastern part of the island. That the uplift was differential agrees with the aspect of the land as seen from the steamer when approaching Brodick, as the platform slopes gently downward from the Goatfell Mountains both to south and north. That the greatest uplift occurred north of Brodick was recognized by Sir Andrew Ramsay (1841, section i, opposite p. 8), who represented the island as part of a great anticline with its axis ending on the eastern coast at North Sannox.

The uplift of the thousand-foot platform was unquestionably pre-Glacial, for deep valleys with glaciated floors, on which are well-preserved moraines, had been cut through it to the level of less than 100 feet above the sea. The effects of post-Glacial denudation on the island have been comparatively trivial; gorges, sometimes 30 feet deep, have been cut by streams through easily denuded rock. The post-Glacial period has been very short compared to that occupied by the formation of the major valleys.

In Glacial times Arran was a local glacial centre. Ice formed over the mountains of North Arran and flowed radially to the sea. Dr. Mort quotes with approval Gunn's remark that Arran had a "local icecap which shed material all round" (Gunn, 1903,

[1] Professor Davis (1909, p. 289) gives as a criterion for the distinction of marine from subaerial plains that in sea-cut plains "the border of the unreduced masses should have been a sea-cliff"; while in subaerial plains "there would presumably be a gradual transition from unreduced masses to the reduced plain". As Dr. Mort points out, the abrupt ending of the platform against the mountains favours the marine origin of this plain.

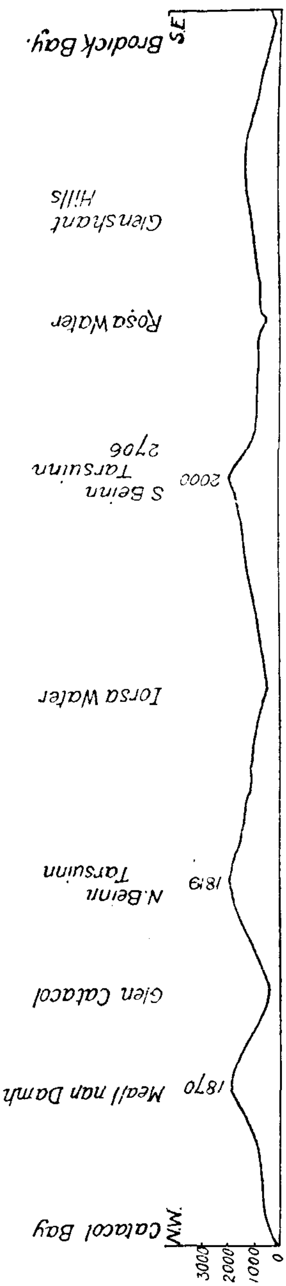

Fig 2. Horizontal scale 2/3" = 1 mile.

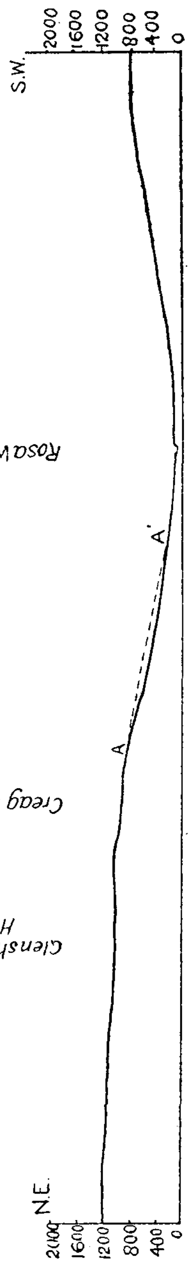

Fig. 3. Length of Section 1.5 Miles

FIG. 2.—Section from Catacol Bay, through Meall nan Damh, N. Beinn Tarsuinn, Glen Iorsa, S. Beinn Tarsuinn, to Glenshant Hills, showing the range of the 1,000 ft. platform in the S.E. part of the section. Horizontal scale, 1 inch = 1 mile.

FIG. 3.—Section across Glen Rosa through the 1,000–1,200 ft. platform on Glenshant Hill, and through the ice-worn slope of Creag Rosa to Glen Rosa.

On the view that Glen Rosa had its present depth in pre-Glacial times, the rock removed from Creag Rosa during the glaciation would be that between the broken line AA' and the present surface.

pp. 132–3). "From the high ground of the interior," says Dr. Mort, "glaciers diverged, which finally joined the main streams, and moved south down the Firth" (Mort, 1914, p. 25). The flow to the north was blocked by ice from the mainland, and the chief discharge was southward. As granite erratics from Arran are rarely found in Ayrshire its ice must have been deflected to the south immediately after leaving the island by ice from the north.

If the Arran valleys had been formed by the radially flowing ice they should have been radial from the granite centre, and it has been claimed that they "run approximately from the centre in radial fashion" (Mort, 1914, p. 7). This is true of the minor valleys; but the most conspicuous feature in the arrangement of the major valleys of Arran is that they are not radial.

Dr. Mort remarks (op. cit., p. 71) that the Arran glens present features which cannot be explained by normal stream erosion; and this view is certainly correct as regards their plan, which would not have been adopted by streams flowing from the granite dome of Northern Arran unless the denudation had been guided by pre-existing lines of weakness. The same objection, however, would apply to ice erosion; for, unless guided by pre-Glacial valleys, glacial erosion should also have produced valleys radial from the high ground. The major valleys were probably determined by structural lines of weakness due to the uplift of the area. Glen Rosa and upper Glen Sannox occur along a basaltic dyke, which is the longest dyke in Arran. This dyke was forced into a north and south rift formed before the end of the igneous period. The uplift which formed the thousand-foot platform probably caused a series of north and south fractures which did not produce many faults, but rifts or bands of ruptured weakened rock (the shatter-belts of Marr). The streams naturally followed these rifts and weak bands, and thus the major valleys of North Arran were a series of three north and south valleys across the granite block. That these three valleys were tectonic in origin appears to be further indicated by their agreement with the general structural lines of the district. The general course of the eastern and western coasts has been determined by faults and fractures. Kilbrennan Sound to the west and the main Firth of Clyde to the east are probably both sunken blocks, which have been let down by north and south trough faults; and the block of North Arran was doubtless rent by north and south clefts formed by the same series of movements.

3. Tectonic Clefts and Shatter-belts.

The valleys, however, are not fault valleys, as no recognizable displacement has taken place among them. They may be simple clefts formed by the gaping of fractures in rocks undergoing tension during uplift. The necessary formation of such tension clefts has been repeatedly asserted, as e.g. by James Smith in 1862 (p. 24), by Ruskin (1856, vol. iv, p. 229, i.e. pt. v, ch. xv, p. 31), and Bailey

Willis (1893, pl. lxxv). Such tension clefts would be narrow, but would be enlarged by the streams that would flow along them.

Broader valleys would be formed where tension is relieved by a multiple instead of by a simple fracture. This multiple fracture might consist of parallel fractures connected by cross fractures, or of anastomosing branching fractures. Such multiple fractures would produce a belt of shattered rock and thus form one variety of the shatter-belts of Professor Marr. His definition (1906, p. 77; re-affirmed 1916, p. 71) attributed shatter-belts to oscillatory faults, which cause no final displacement as the rocks on both sides are restored to their original positions by the backward and forward movement. He describes these belts as many yards in width and as composed of rock "broken into a rubbly mass of angular fragments of varying size in a matrix of finer crushed material". Such belts of shattered material may also be formed by bands of rock being torn to pieces by tension cracks; and some shatter-belts of the Lake District would appear to be more easily explained as multiple anastomosing tension clefts than as faults; and the broader valleys of Arran and the major valleys of the rectilinear system around Snowdon may occur along shatter-belts due to tension during the Pliocene uplift. Shatter-belts probably often occur where they cannot be seen, for they would be seldom exposed on the floors of the valleys, and quickly obscured on the sides; and in the absence of clear exposures, shatter-belts formed as crush breccias are indistinguishable from those due to multiple tension fractures. The term shatter-belt may be conveniently used for both kinds.

4. Amount of Glacial Excavation in the Valleys.

With the increasing severity of the climate the country was occupied by glaciers, and they found an immature topography on which even limited glacial erosion would have produced conspicuous results. The ice flowing down the valleys must have pressed against the spurs, cut them back, and thus rendered the north and south valleys trough-shaped. There seems no convincing evidence that the ice materially deepened the valleys. Some of the alluvial plains may cover buried channels formed at the same time as those on the mainland; but none of the freshwater lochs of Arran have floors lower than sea-level. No known Arran valley has been excavated below the base-level of the pre-Glacial rivers. Accordingly there is no need to assume the glacial deepening of the valleys.

The amount of hard rock removed by ice in widening the valleys was not necessarily considerable. The ice doubtless wore away the spurs, some of which are now represented only by blunt gables on the hill-sides, such as Torr Breac at the bend of Glen Rosa. The smooth spurless slopes at first give the impression of extensive ice erosion. But if, as seems most probable, the three north and south valleys were formed along tension clefts made by the uplift, their original course would have been straight and the spurs on their sides would have been short and blunt. Their pre-Glacial walls probably stood quite close to the existing walls. One of the best-known ice-worn slopes in Arran is the southern face of Creag Rosa. But a section across this slope based on the Ordnance maps (Fig. 3), even with the vertical scale magnified twice, does not give the impression of any great overdeepening. If the floor of the valley had been at its present depth in pre-Glacial times, the dotted line on the figure would indicate the approximate position of the pre-Glacial slope, The greatest thickness of rock removed by the ice would only have been about 100 feet, and this layer would have been weakened by pre-Glacial disintegration. The thickness of hard fresh rock removed would have been insignificant.

5. Garbh Allt and the Glacial Deepening of Glen Rosa.

Dr. Mort, however, holds that Glen Rosa was glacially deepened to the extent of between 500 and 800 feet, a conclusion based mainly on the hanging valley of Garbh Allt. This stream rises on the south-eastern slopes of Beinn Tarsuinn, and at first flows south-south-east parallel to Glen Rosa; at 800 feet it bends suddenly eastward, and is joined by a tributary from the west; it follows the direction of this stream and discharges to the east-north-east by a series of cascades to Glen Rosa. It comes from a hanging valley which ends 500 feet above its confluence with the Rosa Water; and Dr. Mort holds that the difference in level between the hanging valley and the Rosa Water is due to glacial deepening of at least 500 feet and perhaps of 800 feet.

The limited corrosion by the lower Garbh Allt is capable of another explanation. Dr. A. Scott suggested to me the possibility that the Garbh Allt was originally the head of the Easbuig Burn (Bishop's Glen), a tributary of the Machrie Water; and a visit to the locality showed the high probability of the suggestion. Figs. 4 and 5 show five sections across the hills to the west of Glen Rosa. Section 4A crosses the upper part of the Garbh Allt, which there flows through a valley clearly separated from the parallel valley of Glen Rosa. Section 4B crosses the middle part of the Garbh Allt, where the eastern side of the valley is inconspicuous. Section 4C is along the lower course of the Garbh Allt below the right-angled bend at 800 feet; the section is continued westward along the tributary which continues the course of the cascades of the Garbh Allt. Section 5D is along the low flat rise which separates Garbh Allt from Glen Easbuig to the south-west, and from the tributaries of Glen Shurig to the south-east. Section 5E crosses Glen Easbuig from north-west to south-east at the same distance from D as that is from Section C and as C is from B. These sections show a continuous valley which was probably the original course of the Garbh Allt when, instead of turning to the east at C, it descended from 1,114 feet in B, over the depression at a little over 1,000 feet in Section D to Glen Easbuig. The Garbh Allt has now been diverted eastward to

Glen Rosa, along the junction between the schists and the granites. The character of the falls and their rock steps show that the lower end of the Garbh Allt is along a modern channel. The fact that the stream has not cut down its bed there more deeply is due to its recent adoption of its present course, and is not evidence of the glacial deepening of Glen Rosa.

Dr. Mort also claims (pp. 57–8) that Glen Iorsa opposite Loch Nuis has been glacially deepened by from 500 to 800 feet, since the stream from that loch has made no notch in the bank of Glen Iorsa ; but the loch lies on a projecting spur of the thousand-foot platform and the drainage from it is insignificant. The larger streams which join Glen Iorsa, as from Loch Tanna and the streams from both the Bens Tarsuinn, have deeply incised the sides of the main glen.

The position of Glen Diomhan as a hanging valley 200 feet above Glen Catacol is advanced by Dr. Mort (pp. 54–5) as evidence that the latter has been deepened by ice ; but as Glen Catacol is one of the tectonic north and south valleys it was probably older than its tributary ; and their difference in level is the natural consequence of the small Diomhan Burn not having been able to deepen its valley as quickly as the larger stream, which was working along a line prepared by a tectonic fracture.

6. Arran compared with the Mainland of Scotland and Snowdon.

The amount of erosion in Arran attributable to glaciers depends then on the view adopted as to the geographical condition of the island at the beginning of the Glacial period. This principle is applicable to other parts of the British Isles. If the glaciers had found Scotland in the condition of a worn-down country with a mature topography many of the existing features would indicate great denudation during Glacial times by ice, frost, and rivers. If on the other hand Scotland had then an immature and rugged topography the present features could have been produced with insignificant erosion. But as Scotland was uplifted before Glacial times at least 1,000 feet, the glaciers had to work on a country with many rugged youthful features, upon which comparatively slight rock abrasion would have produced a very marked effect. The Pliocene uplift also affected England. The movement was smallest in the south ; in North Wales it was as great as in Scotland, for it raised Snowdonia about 1,400 feet.[1]

The Snowdon area has many interesting analogies to Arran. Its major valleys are rectilinear, and they resemble those of Arran by their independence alike of the geological structure and natural lines of drainage. The main valleys of Snowdonia trend from north-west to south-east or from south-west to north-east. Where the

[1] In conversation with Professor O. T. Jones I was glad to find that he was also of the opinion that the Snowdon valleys had been largely made by pre-Glacial rivers eroding the uplifted plateau.

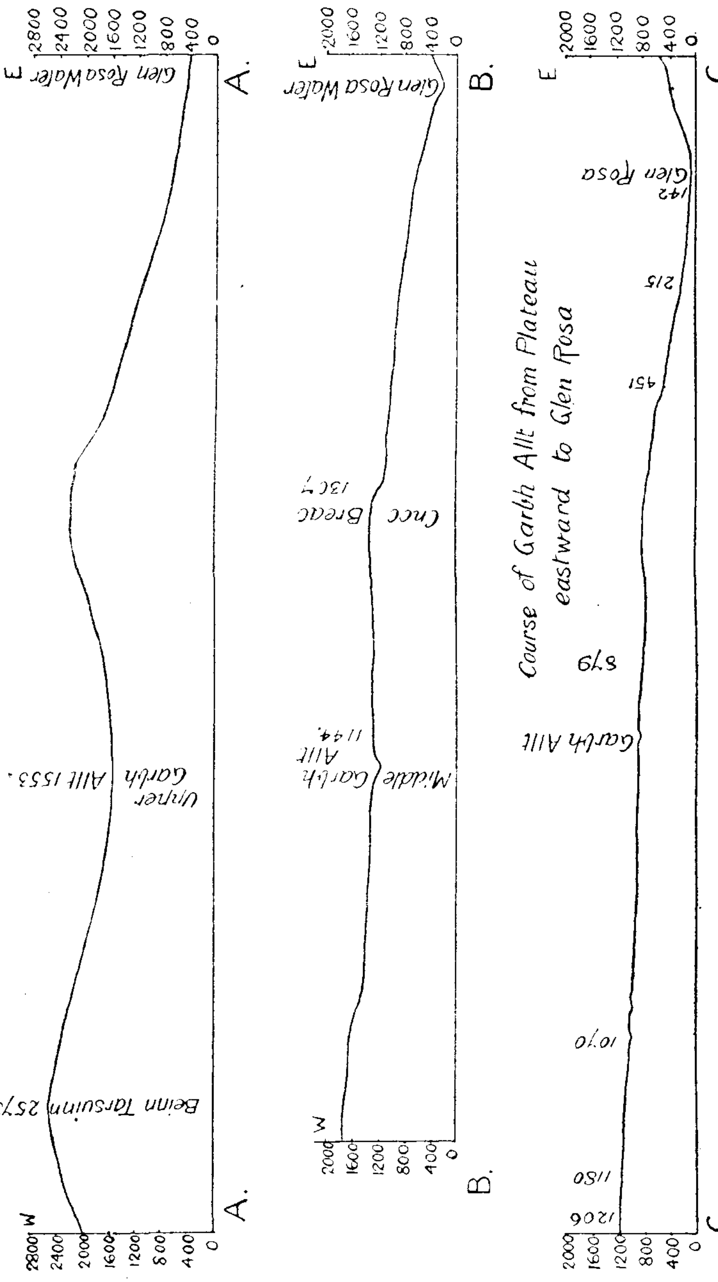

FIG. 4.—Sections across the valley of the Garbh Allt, west of Glen Rosa. A. Section across the upper part of the Garbh Allt on the plateau west of Glen Rosa. B. Section across the middle part of the Garbh Allt before its bend eastward. C. Section along the western tributary of the Garbh Allt, and its eastward course to Glen Rosa.

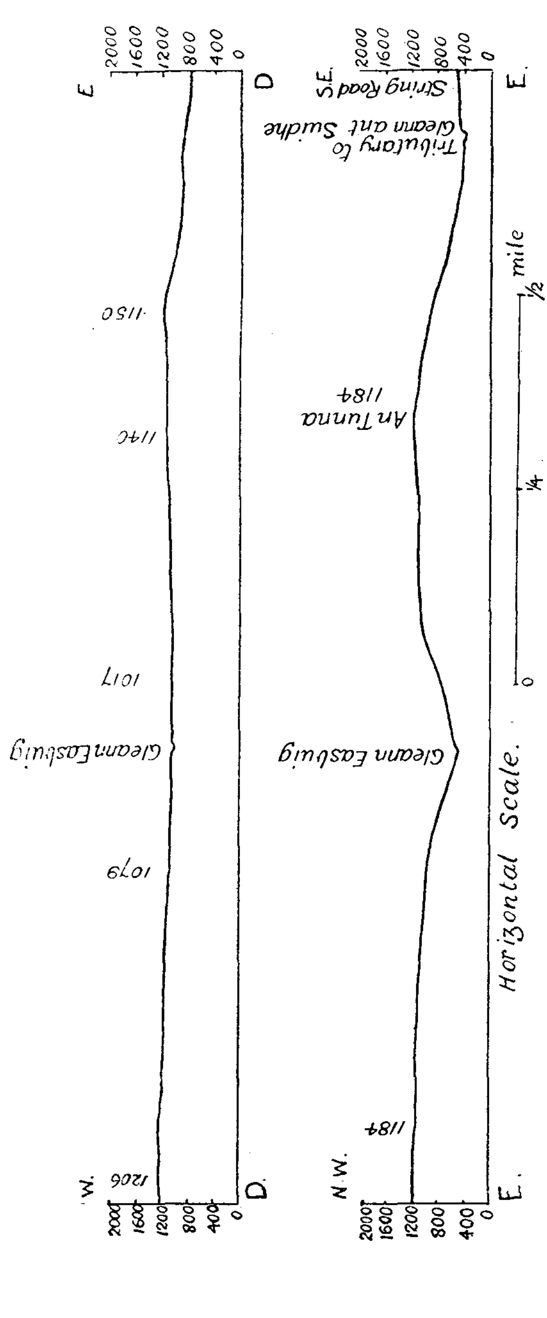

FIG. 5.—Sections across the valley of the Gleann Easbuig. D. Section along the divide between the Garbh Allt and the Gleann Easbuig. The main fall to Glen Rosa is further east. E. Section from N.W. to S.E. across upper Gleann Easbuig to the main valley traversed by the String Road.

valleys vary in direction they do so at sharp angles. Thus the Nant Gwynant runs north-eastward from Beddgelert to Penygwryd, where it bends east-north-east to Capel Curig; and on the continuation of its original direction occurs the valley of Llyn Cawlyd. The Nant Gwynant–Llyn Cawlyd valley is approximately parallel to the remarkably straight course of the 500 ft. contour along the north-western and western slopes of Snowdonia.

These rectilinear valleys have cut across some of the older valleys. Thus the formation of the Llyn Cwellyn valley beheaded the Afon Drws-y-coed (the upper part of the Nantlle valley) and captured its original head streams in the Cwm-y-Clogwyn, which, both from direction and gradient, appears the natural continuation of the Afon Drws-y-coed.

The course of this network of valleys is not what would be anticipated if they had been excavated by ice. If the valleys were glacial in origin they would have been expected to radiate from Snowdon, whereas the mountain is an oblong block enclosed in a rectilinear moat. The block would be almost an exact oblong but for the sharp bend in the south-western valley, which adds a triangular area to the southern corner.

A second resemblance to Arran is that Snowdon, as was clearly pointed out by Sir Andrew Ramsay (1881, pp. 271–3), was never completely overridden by extraneous ice. It was a centre of local glaciation; and as Ramsay remarked of its north-western glaciers (1881, p. 272), "on escaping from the high-bounding-walls of the upper parts of their valleys, they partly spread out in the shape of broad fans on the north-western slopes of the minor hills that now overlook the Straights." According to Ramsay, therefore, the valleys were pre-Glacial. The question is merely how far the glaciers enlarged and deepened these pre-existing valleys. The amount depends upon the condition of Snowdonia at the beginning of Glacial times; and, like the mountains of Arran, Snowdon was surrounded by a high platform trenched by pre-Glacial valleys.

Snowdon, at one part of the Pliocene, was apparently a mountain about 2,000 feet high surrounded by a low, widespread plain. The district was raised by a Pliocene uplift, and the plain formed the platform that now surrounds Snowdon at the height of from 1,250 to 1,400 feet. This platform occupies most of the area between the 1,250 and 1,500 ft. contours on the map (Fig. 6). It is shown in Ramsay's section through Yr Aran (1881, p. 158, fig. 23); the platform is at the level of from 1,200 to 1,400 feet to the north-west of Yr Aran, and somewhat lower to the south-east of it.

The uplift of Snowdonia led to the erosion of canyons along the floors of the old valleys, the width of which indicates that they had been worn down to base-level and their walls cut backward before the Glacial period. As the climate became more severe the gullies on the upper sides of these gorges were occupied by snow, and corries were excavated about them by the combined action of frost and streams.

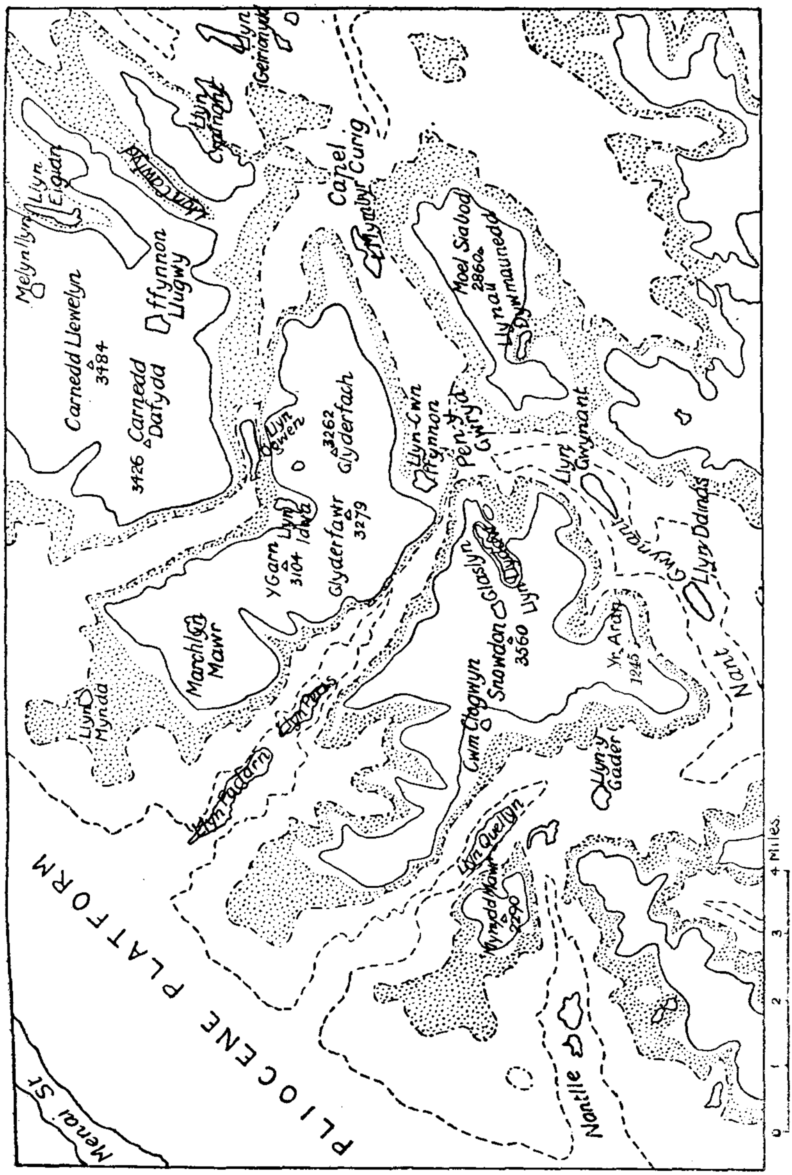

FIG. 6.—Sketch-map of the Snowdon district. The ground between the 1,000 ft. and 1,250 ft. contours is dotted to show the range of the upper platform.

When the glaciers flowed down the valleys they would have worn back the spurs, levelled the bars of rock on the floors, and thus the trough shape of the canyons, due originally to their formation along rectilinear fractures, was rendered more complete. The amount of solid rock removed by the ice according to this conception of the history of Snowdon was very small in comparison with that involved in the explanation adopted by Professor Davis. In his well-known paper both in the text and in an illuminating sketch (Davis, 1909, p. 307) he represents Snowdon at the beginning of the glaciation as a down-like upland, with gentle slopes and shallow valleys, cliffless, cragless, and without either corries or river gorges. In his paper (1909, p. 282) he describes pre-Glacial Snowdon as "a subdued

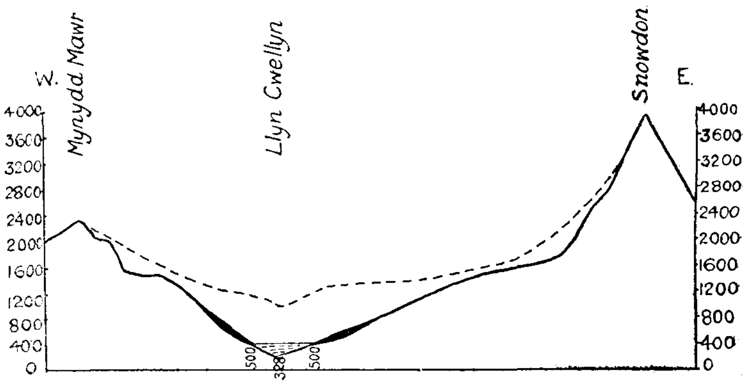

FIG. 7.—Section from Snowdon to Mynydd Mawr through Llyn Cwellyn. The broken line represents the approximate surface at the beginning of Glacial times, on the hypothesis that the down-like relief has been destroyed by glacial erosion. The areas in solid black represent the amount of solid rock removed on the alternative hypothesis that the valley had been excavated to approximately its present depth by pre-Glacial streams.

mountain form with dome-like central summit, large rounded spurs, and smooth waste-covered slopes, and with mature valleys drained by steady-flowing streams". He maintained (ibid., p. 281) that Snowdon was altered during the Glacial period and chiefly by glacial erosion from "a large featured, round-shouldered, full-bodied mountain of pre-glacial time" "into the sharp featured, hollow chested, narrow spurred mountain of to-day".

Professor Davis accepts the "late Tertiary" uplift of Snowdon, but considers that this would not have seriously changed its topography, as the only effect would have been the formation of a few minor gorges (p. 293). This conclusion is based on two arguments, first that Snowdon has no large trunk rivers, and the streams are not sufficiently different in volume to explain why some cut their valleys deeply and others were left as hanging valleys. These arguments would be conclusive if the valleys had been cut by normal consequent streams flowing down a uniform dome. But if the major valleys be regarded as a reticular system formed along fractures which gaped open at the uplift of the country, they could have been made without trunk rivers; and the depths of the main valleys as compared with some of their tributaries is a natural consequence of the more rapid denudation along the tectonic ruptures.

Professor Davis supports his case by reference to the rounded mountains, or "Moels". He holds (1909, p. 293) that they were not overridden by northern ice or "overwhelmed by the local ice", and that their rounded forms have been retained from pre-Glacial times; and he therefore claims that the adjacent valleys were also rounded then. But if the Moels on the north-west spurs of Snowdon have retained their pre-Glacial forms, they would tell against the view that the mountain has been greatly altered by glacial erosion, since some of them were in positions especially exposed to abrasion by the ice from central Snowdon.

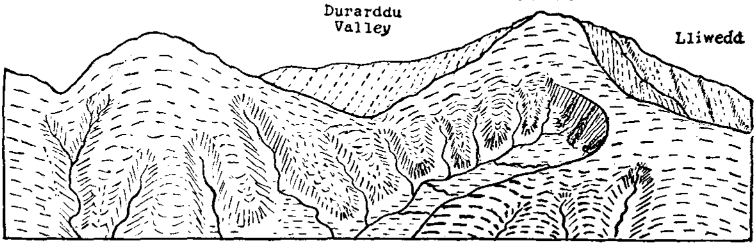

FIG. 8.—Hypothetical sketch of Snowdon from the north-west at the end of pre-Glacial times, illustrating the valleys formed in consequence of the Pliocene uplift.

As Snowdon stands in a position which rendered it subject to a heavy precipitation and is very varied in structure and composition, it appears improbable that it should have suffered so little from stream erosion during the long Pliocene uplift, as is admitted by Professor Davis' explanation. According to his view, on the section from Mynydd Mawr across Llyn Cwellyn to Snowdon, the pre-Glacial floor of the valley would have been at the present level of about 1,250 feet; Snowdon and Mynydd Mawr would have risen from the valley in gentle mature slopes along the upper boundary of the shaded area in Fig. 7. The valley below the broken line would have been excavated by glacial action.

According to the alternative view the pre-Glacial surface was along the lower line; the valley was a deep trench in the 1,200 to 1,400 ft. platform; the bed of the lake is 122 feet lower (Jehu, 1903, p. 436). The greatest removal of solid rock by the ice would have been along the edges of the Llyn Cwellyn Valley, and the amount removed would have been approximately that marked in solid black. According to this interpretation the topography of Snowdon at the beginning of the glaciation was essentially the same as it is now. Professor Davis's sketch probably shows the nature of the mountain slopes in the early Pliocene; but at the end of that period the increased power given to the streams by the uplift had enabled them to deepen their beds until they flowed through steep-walled gorges. The aspect of the mountain if seen from the north-west would probably have been approximately as represented in Fig. 8. The earlier down-like relief had been mostly destroyed owing to the excavation of the valleys of Snowdonia, like those of Arran, by streams during the Middle and Upper Pliocene uplift.

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Note on the Determination of the Limit between the Silurian and Devonian Systems.

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IN a recently published paper on the "Highest Silurian Rocks of the Clun Forest District, Shropshire",[1] the present writer gave an account of an area where the series of "passage-beds", marking a gradual transition from Silurian to Old Red Sandstone conditions, is well seen. The succession there is practically identical with that established by Miss Elles and Miss Slater in the Ludlow District.[2] From November, 1918, to October, 1919, whilst engaged in a study of Belgian Tertiary rocks, I have had an opportunity of visiting some of the more important sections of the Gedinnian in the Ardennes and also of examining the palæontological collections at Brussels, Lille, and elsewhere. This work has thrown very considerable

[1] Quart. Journ. Geol. Soc., vol. lxxiv, 1918, p. 221, 1919.
[2] Ibid., vol. lxii, 1906, p. 195.