Chapter 1 Introduction

Place names are often difficult to decipher on the Geological Survey one-inch-to the-mile map, Sheet 53. Accordingly all those that are used in this memoir are included in the Memoir index along with their *National Grid References,* the interpretation of which is explained at the bottom of the 3rd Edition map of 1948<ref>National Grid References with similar interpretation are also given in the index for several localities outside sheet 53.</ref>. Contours have suffered even more than place names in the preparation of Sheet 53; while two very important, comparatively recent roads, one along the south shore of Loch Leven to Kinlochleven, the other through Glen Coe, have not been inserted. The Seventh Series edition of the Ordnance Survey one-inch map remedies these failings. Sheet 46 of this Seventh Series covers the western part of Sheet 53 (Geological), as far as a N.-S. line about a mile east of Fort William, and Sheet 47 covers the remainder. Together these Seventh Series sheets extend well beyond the boundaries of Geological Sheet 53. There is also an Ordnance Survey one-inch Tourist Map of Lorn and Lochaber, compiled from these and adjacent Seventh Series Sheets, which covers the whole area of Sheet 53 (Geological). Attention may also be directed to (Figure 22), a contoured locality map of the Glen Coe district (p. 136).

Another difficulty arises in regard to the name Ballachulish, employed repeatedly in the sequel. The Gaelic means "distributed township of the narrows". Thus Sheet 53 (Geological) and Ordnance Survey 7th Series Sheet 46 show North Ballachulish [NN 052 603] (north of Loch Leven) as close to the ferry, and South Ballachulish (south of Loch Leven) as extending eastwards from the ferry for a couple of miles to the River Laroch [NN 080 560]. Here a bridge separates a village into West and East Laroch [NN 080 580]. In common speech these together are known as Ballachulish village served by Ballachulish railway station. Whenever Ballachulish village is mentioned in this memoir it is in the sense of West and East Laroch [NN 080 580]; but Ballachulish House and Ballachulish Hotel are situated just south of the ferry and are served by Ballachulish Ferry [NN 053 598] railway station; and what is known as the Ballachulish Pluton is a granodiorite complex that reaches southwards for five miles from where they stand.

Sheet 53 (Geol.) is divided into two parts by Loch Linnhe running north-east and south-west. The portion of the district lying south-east of Loch Linnhe, and north of Loch Leven, and of the River Leven which drains into the latter, belongs to Inverness-shire. All the rest falls to Argyllshire.

The main centres of population are Fort William, East and West Laroch [NN 080 580] (or Ballachulish), Onich, Kinlochleven, Clovulin [NN 000 630], and Portnacroish [NM 926 474] ("Appin" on the railway). Cultivation is restricted to the immediate vicinity of the coast-line and, even there, is extremely local. A considerable strip of sheep ground, half a dozen miles wide, flanks Loch Linnhe on the south-east, and cattle have been locally re-introduced as in Cona Glen [NM 955 720]; but most of the country is given over to deer. Glen Coe is owned by the National Trust for Scotland.

The slate quarries of Ballachulish have been worked for generations, and have a great name in Scotland. Other mineral products include granite, quartzite and dolomite. The rise of Kinlochleven is a notable development of the last fifty years. An important aluminium factory has been established here at the head of Loch Leven in the heart of the wild, romantic scenery of the district "twixt Ben Nevis and Glen Coe". It derives its water-power from the great Blackwater Reservoir [NN 250 605] which has been constructed in the valley of the River Leven, for the most part to the east of the border of the present map.

Physiography

The following account substantially reproduces what was published in the first edition of this memoir, which itself expanded a preliminary statement in the Proceedings of the Geologists' Association (Bailey 1911). The stock of interpretative ideas from which selection was made, coming fifty years ago, was very much the same as it is today. Some of the conclusions reached were debatable then and are so still. On p. 13 attention will be directed to contributions that have appeared in the interval.

The district is a much dissected portion of the main Highland plateau (*cf.* Geikie 1901, chap. 7), with a summit-level east of Loch Linnhe of about 3000 ft. Ben Nevis, 4406 ft high, and several other massifs, such as Bidean nam Bian [NN 140 543], 3766 ft high, south of Glen Coe, overlook the neighbouring ridges and appear to be features inherited from an earlier geographical cycle. West of Loch Linnhe the general level for the dissected plateau is some 500 ft lower than on the east. It is very commonly supposed that the main 3000-ft summit surface corresponds approximately with the land surface upon which the present drainage system was initiated, or else with the upper limit of hard Highland rocks beneath such a land surface. Both hypotheses may be very far from true.

In the vicinity of Loch Linnhe the eastern segment of the main high-level plateau merges southwards into the much lower plateau of Lorne, to which the island of Shuna [NM 920 490] and neighbouring portions of the mainland may reasonably be referred. There is no sharp boundary here between the two plateau regions such as is encountered along the Pass of Brander [NN 060 275] at the foot of Ben Cruachan (Sheet 45, Geol.).

Archibald Geikie has repeatedly drawn attention to the fact that the drainage system traversing the high-level plateau is of later date than the Tertiary volcanic outbursts of the Hebrides. The present district furnishes a good illustration of this, for many of its valleys, such as Glen Tarbert [NM 910 600], have been cut across Tertiary basalt dykes. On the other hand, Bremner, as we shall presently see, argues that since the Hebridean volcanoes were terrestrial there must have been contemporaneous and presumably even earlier rivers.

Structure-guided through-valleys

Through-valleys and hanging valleys are strikingly represented in the drainage system. Some of the through-valleys have clearly been determined by the structure or grain of the country; while others, so far as one can judge, are essentially independent of it. Of the first type the best illustration is the valley of Loch Linnhe, which lies along the shatter-belt'<ref>The term, shatter-belt, is adopted from J. E. Marr, whose Presidential Address, dealing with ' The influence of the geological structure of English Lakeland upon its present features ' (1906, pp. cii — cxxiii), materially assisted in the development of the conceptions set forth in this chapter. Marr, in later years, came to regard glacial erosion as of more importance than when he delivered this address, but many of his conclusions remain unaffected by this change of opinion.</ref> of the Great Glen, a continuous feature traversing Scotland from side to side; another shatter-belt valley is that of Loch Leven and Loch-Eilde Mòr; and yet another holds the upper part of Loch Etive [NN 000 330] (Sheet 45, Geol.), and the lower part of Glen Etive, as well as Lairig Gartain [NN 200 544], and, north of Glen Coe, Allt Lagan na Fèithe [NN 235 580].

It must not be imagined, of course, that structurally determined valleys are necessarily through-valleys maintaining their individuality for long distances at a time. In some cases the influence of structure can only be recognised for a comparatively short interval. Thus the river Nevis, above the entrance of Allt Coire na Gabhalach [NN 202 680], has been deflected for about a mile along a shatter-belt; while farther downstream, east of Meall Cumhann [NN 178 697], it follows for a rather longer distance a fold which was originally in large part occupied by easily eroded calc-silicate-hornfels. Then again, Glen Etive, in its upper reaches, and several tributary streams of Glen Coe (see Meeting of Three. Waters, (Plate 7), p. 139), have been guided by north-east dykes of porphyrite (and porphyry); and, in like manner, Glen Stockdale [NM 950 490], Gleann na h-Iola, and Glen Creran have been locally compelled to accept the direction of the strike of the schists.

It is impossible to pass without reference an important book by J. W. Gregory, published (1913) since the present chapter, as first written, was almost complete. Gregory's theme is the origin of fiords, and he includes Loch Linnhe and Loch Leven as characteristic examples of the class. His discussion is wide, and embraces the main topics dealt with in this chapter. In many instances his arguments and conclusions agree with those set forth below, and they are illustrated with a wealth of detail drawn from other lands, which gives them an additional value. In one important particular, however, Gregory's treatment differs from that adopted here, for he attributes a more direct share to earth-movement in the shaping of Scotland, especially the West Highland coast-line. A similar interpretation has been advocated for years in connection with the Norwegian fiords by de Geer and other Scandinavian geologists.

The earth-movements to which Gregory appeals are supposed to have accompanied the foundering of the North Atlantic Ocean in late Miocene or early Pliocene times. Some few depressions as the Minch, inside of the Outer Hebrides, and the Midland Valley, south-east of the Highlands,<ref>Gregory, by mistake, ascribed this view to the writer (1913, p. 175).</ref> he attributes to trough-faulting. The fiords of the West Highlands he believes originated for the most part as gaping faults and joints, which have been worn into troughs by subaerial and glacial erosion. According to Gregory not only did new faults originate, but old faults moved again. In this connection it is worth quoting from J. Horne's description of the Inverness earthquake of 1901. "A long crack or fissure… formed in the middle of the towing-path (of the Caledonian Canal, near Dochgarroch Locks), and could be traced at intervals for a distance of 600 yds. In no place was the fissure more than half an inch wide. The position of the Great Glen fracture laid down on the six-inch field map coincides with the trend of this fissure" (*in Horne*, Hinxman and others 1914, p. 69). Gregory believes that the severance of the original drainage that crossed the line of Loch Linnhe ((Figure 1)) was accomplished by Tertiary subsidence on the north-west side of the Great Glen Fault; as stated above, the Highland Plateau north-west of Loch Linnhe is about 500 ft lower than to the south-east, though the correspondence seems scarcely definite enough to serve as basis for an argument.

While it is impossible to do justice to Gregory's position in a short notice, the following comments may be offered:

1. Gregory probably somewhat overrates the proportion of structure-guided valleys in the West Highlands.
2. The main features, apart from straightness, of the structure-guided valleys are reproduced in valleys independent of such guidance.
3. The shatter-belts which can be examined along the line of certain structure-guided valleys, as at the head of Loch Leven, seem quite sufficient in their nature to locate deep, straight valleys of erosion without assuming gaping fissures.
4. If such gaping fissures were very commonly developed during movements affecting the West Highlands in Middle Tertiary times, how is it that we never come upon any that have been, choked with the gravel and sand of the period ?
5. A similar conflict of opinion formerly existed concerning the origin of the Zambezi Gorge (Lamplugh 1907, p. 165). Some attributed its zig-zag course to a tectonic rent, but it is now admitted that the gorge is being excavated along intersecting joints which lie latent, so to speak, until the adequate conditions of erosion present themselves. This agrees with the long-accepted interpretation of structure-guided valleys in the West Highlands.

Independent through-valleys

Through-valleys of the second type, that is independent of structure, are well represented on both sides of Loch Linnhe: on the north-west lie Glen Scaddle, Glen Gour, and Glen Tarbert [NM 910 600]; on the southeast, Glen Nevis, the Lairigmòr and River Leven valley, and Glen Coe extended eastwards along the Moor of Rannoch (R. in (Figure 1); see also Bailey 1934b, fig. 3).

Two distinct interpretations have been adopted in regard to such through-valleys in the Scottish Highlands. H. M. Cadell (1886), H. J. Mackinder (1907, p. 126), and B. N. Peach and J. Horne (1910, p. 547) regard them as representative of a drainage system which once led continuously across Scotland, more or less from west to east, but is now in large measure broken up into segments owing to the development of subsequent valleys along special lines of weakness. R. S. Tarr (1908), on the other hand, regarded them as a result of glacial erosion. The last-named author summarised his position as follows:

"The through valley condition, a great aid to travel in glaciated lands, is found in the Alps, in Alaska, in Central New York, and in the Scottish Highlands. It is as characteristic of glaciated lands as are the hanging valley, the steepened slope, and the 'canal' valley, and, so far as I am aware, is all but unknown in regions which glaciers have never occupied".

This appeal from glaciated to unglaciated topography, to ascertain such features as have resulted from glacial erosion, is a most encouraging sign of the times. A like comparison was employed many years ago by A. C. Ramsay (1862, p. 201) in relation to rock basins; the extension of the principle, and its detailed application is, however, mainly due to American geographers such as W. M. Davis (1909) and Tarr. But when attention is paid to the through-valleys of Scotland as a

whole, their distribution seems too systematic to admit of a semi-accidental origin connected with glaciation. The evidence points strongly to the alternative conclusion, namely that the majority of them are remnants of a once continuous drainage system. In (Figure 1), expression is given to this alternative interpretation. It may be urged by some that the correspondence of the through valleys on the north-west with those on the south-east of Loch Linnhe, as shown in this figure, is fanciful. Perhaps, but at any rate the principle involved is vindicated in what appears to the writer to be self-evident fashion in two local instances: the first is afforded by the obvious former continuity of Lairigmòr River Leven drainage, now interrupted by the shatter-guided valley of Loch Leven and Loch-Eilde Mòr; the second, by the obvious former continuity of Glen Coe–Moor of Rannoch drainage, now interrupted by the dyke-guided valley of Upper Glen Etive.

Secondary watersheds

Once a river system has been broken up, following the development of subsequent streams along such lines of weakness as the Loch Linnhe and Loch Leven shatter-belts, secondary watersheds must originate as a matter of course in the isolated segments. According to the view adopted here, the low cols of the through-valleys of Scotland are, for the most part, such secondary watersheds in the process of development, rather than primary watersheds which have been all but obliterated by glacial erosion. That glacial erosion has, however, modified these cols is in some cases almost certain. Thus a powerful lateral stream which issues from the north directly upon the col of Glen Tarbert [NM 910 600] hangs distinctly above this col, while at the same time the main valley, where it crosses the col, is broad and open in its cross section. This combination of characters seems to necessitate a belief in powerful glacial erosion on the site of the col; in fact, vigorous erosion is exactly what one might expect in such a situation, and W. B. Wright has emphasised its importance in relation to certain flat-bottomed, high-level passes trenching spurs of the Binnean Mòr massif north of Kinlochleven (Sum. Prog. 1908, p. 63; see also p. 275 of this memoir).

The through-valleys near their cols have, as a rule, very low gradients. This is admirably illustrated in Glen Coe and in the long upper reaches of the River Leven. The latter are now occupied by the Blackwater Reservoir [NN 250 605] supplying power to the Kinlochleven Aluminium Works (Plate 2), p. 8; and incidentally we may note that this reservoir has drowned the pre-existing watershed, and that it continues well to the east of it. It would, therefore, appear that the rivers of the original drainage system of our district had arrived at maturity before they were beheaded. Such a condition clearly favours the formation of long obsequent streams in valleys that had been broken up into isolated segments. A well-graded trunk valley, once it has lost a considerable proportion of its water through beheading, cannot possibly keep its course clear. One deltaic cone after another, built by tributary streams, obstructs the channel, and serves in succession as its corrom or delta-watershed. Supposing the tributary streams all of equal importance, the first stream down from the breach, by which the main valley has been beheaded, builds the first corrom. During its periods of self-imposed diversion, it receives increased erosive power, through access to the beheading river system, and thus is able to keep in check the further growth of its deltaic cone. The second stream meanwhile, sheltered, as it were, behind the first-formed corrom, carries on its work of deposit with increased vigour until eventually it establishes a second corrom to supersede the first. And so the position of the corrom is shifted farther and farther along, in what was originally the downstream direction of the main valley, until a position of equilibrium is reached — that is, until the remnant of the consequent drainage is truly balanced by the successive additions made to the obsequent stream.

The word corrom, which has been used above to signify a delta-watershed, is based on the Gaelic *cothrom,* a balance. The stream already mentioned, which issues upon the col of Glen Tarbert [NM 910 600], is known as Allt a' Chothruim (the stream of the balance) since, at its point of entry, it has built up a great cone, upon which it is balanced, as it were, with the possibility of flowing either east or west. The name was borrowed from this Glen Tarbert [NM 910 600] example to describe delta-watersheds in general, once the physiographical importance of these structures was recognised by P. F. Kendall (Kendall and Bailey 1908, p. 8, foot-note).

The divide at the head of Glen Nevis is a corrom. As a matter of fact the present-day corroms of Glen Tarbert [NM 910 600], Glen Nevis, and other valleys of this district have only a trifling importance in fixing the positions of the various watersheds which are fashioned essentially in rock; but they may not unreasonably be taken as symbolical of pre-glacial corroms responsible for obsequent diversion with corresponding rock erosion.

In many through-valleys of the Highlands the modern watershed is not a corrom. In some cases this may have resulted from the shifting of the position of the watershed by glacial erosion, but it is not unlikely that in other instances landslips helped, in pre-glacial times, to determine the divides between the consequent and obsequent drainage of the segmented rivers. The watershed of the Lairigmòr valley is situated at the foot of Stob Bàn, the bulging flanks of which are constituted of landslip material ((Plate 2), 2, p. 8). The slipped debris does not in this instance reach down to the valley floor, but it is easy to realise that a more extensive fall of rock in another instance might well turn the drainage of a beheaded river. A striking example of a landslip reaching right across a stream, and more or less blocking its course, is afforded in the valley of Allt Coire Gabhail [NN 162 550], on the south side of Glen Coe ((Plate 7), p. 139). A flat strath has been built up behind the landslip, but there has not been any chance of reversal of drainage in this case, since the valley here is steeply bounded and has not been beheaded.

Hanging valleys

Segmentation of a through-valley system, such as has been outlined above, may well rejuvenate a mature river system by a process of short-circuiting. This conception leads us to inquire into the origin of the hanging valleys of the district. First, it may be pointed out that the hanging-valley system shows evident trace of glacial action. A fine illustration of this is afforded by a hanging valley, or corrie, draining into Glen Nevis, 1½ miles east of Polldubh [NN 141 686] ((Plate 1), frontispiece). A powerful stream issues from this corrie and races to the bottom of Glen Nevis, 1000 ft below. From the road we see the tributary stream standing out as a long ribbon of foaming water, for it flows down the untrenched slope of the main valley. The latter at this point is of U-shaped cross section, unhampered by projecting spurs; it is the "canal" type of valley, as defined by Tarr. Aqueous and subaerial erosion could not have been so selective as to carve this gigantic hollow for the main river, without furnishing a gorge, however small, for the independent accommodation of the powerful tributary stream. A probable solution is that the present topography corresponds with a stage when a major glacier flowed down Glen Nevis, receiving an actively eroding tributary perched in the side corrie. Another somewhat similar example of a hanging valley is afforded farther up Glen Nevis by Allt Coire a' Mhail [NN 181 680], which is seen in the foreground of (Plate 5) before it cascades down an unnotched rock face at Steall [NN 177 685] ((Plate 13), 1, p. 275).

Turning to a side issue we may mention that this Steall [NN 177 685] waterfall affords an interesting illustration of how erosion is sometimes actually hindered by steepness of grade. At the foot of the fall one can pick up rounded pebbles smashed in two. They have been brought to the edge of the fall and hurled down without an opportunity of doing effective work. Above the waterfall the gradient is much less pronounced, and the pebbles, retained in pot-holes, have succeeded in lowering the bed of the stream, some 30 ft in places, since the glaciers retired.<ref>It must not be supposed that the gorge seen in the photograph above the fall is post-glacial. On the contrary, it is glaciated almost to the bottom, where pot-holes appear.</ref> The fall, it is true, is over quartzite, and the pot-holes above are cut in hard mica-schist, so that the comparison which has just been made must not be emphasised too strongly.

The important point, to return to the question of glacial erosion, is that the Steall [NN 177 685] waterfall, where it passes over the quartzite, has no bounding walls, although the rock on either side is a continuation of the same quartzite as is washed by the descending waters. It seems incredible that this condition could have been fully developed without glacial intervention.

But inquiry cannot cease here with the mere recognition of ice-work in the development of the present-day hanging-valley system. Scottish geologists are well-nigh unanimous in regarding glacial erosion as responsible for the majority of the rock basins of the Highlands.<ref>No more convincing example can be given than Loch Coruisk, described by A. Harker (1901a, p. 238). Many other authors might be cited, and the subject has been most completely dealt with by Peach and Horne in their report of 1910.</ref> It is unnecessary, therefore, to point out that on this assumption many tributary valleys in one part or another of the country must have been left hanging through glacial over-deepening of corresponding trunk valleys. It is well, however, to consider each case on its merits, and, accordingly, it is advisable to inquire whether glacial *over-deepening* can be called in to explain the hanging tributaries of Glen Nevis. This glen affords an imposing example of a U-shaped canal valley in the four miles of its course in which it drains north-westwards towards the open country near Fort William. Several minor hanging tributaries rush swiftly down its slopes from Ben Nevis. At Polldubh [NN 141 686] the glen turns so as to run east and west, and at the same time it is narrowed by a projecting spur of very hard contact-altered mica-schist. The valley thus constricted exhibits the V-shaped cross section of well-advanced

river and subaerial erosion; it is therefore very difficult to believe that ice can have had any effective part in the erosion of the glen at this point. This inference is much strengthened by the V-shaped cross section of two powerful tributary valleys, Allt a' Choire Dheirg [NN 139 676]and Allt Coire a' Mhusgain [NN 150 670], which enter Glen Nevis at Polldubh [NN 141 686] in normal adjustment with the level of the main river. Thus it appears that at Polldubh [NN 141 686] a pre-glacial section of Glen Nevis is preserved, and, as this does not hang above the canal portion of the valley farther downstream, it is a fair inference that the latter has not been over-deepened by glacial erosion, however much it may have been widened. Above Polldubh [NN 141 686], Glen Nevis is again for a couple of miles of the "canal" type, and receives from the north the waters of the particularly fine hanging valley to which special attention has been drawn already. Then beyond a right-angled bend as we ascend the glen, the river for half a mile flows hurriedly through a deep and narrow gorge cut in the base of a high-level gap which shows intense glacial erosion. This gorge is a very minor feature of the glen taken as a whole. Its position is marked in (Plate 1) by the downstream disappearance of the Water of Nevis. It cannot be of post-glacial origin, for it shows ice-moulding almost to the very bottom. It is at the same time far too narrow to be the direct work of glacial erosion. Thus here, as at Polldubh [NN 141 686], it would seem that a pre-glacial section of Glen Nevis has escaped with little modification.

Altogether Glen Nevis affords fairly satisfactory evidence of the existence in this district of a hanging-valley system, which has not been determined by glacial over-deepening. This inference is corroborated by an inquiry into the drainage system of the River Leven. The upper reaches of the Leven valley are thoroughly mature, and belong to a widespread high-level valley topography, which includes in the clearest possible manner the hanging portions of the downstream tributaries of the Leven itself. A little below the Blackwater Reservoir [NN 250 605], which now occupies the site of the string of lochans marking the river course in (Plate 2), 1, the river plunges from its high-level to its low-level valley in a series of waterfalls. The form of the entire low-level valley from the falls to the sea does not suggest glacial but aqueous and subaerial erosion. Allt a' Choire Odhair-bhig [NN 220 590] and Allt a' Choire Odhair-mhòir, tributary streams which join the Leven less than a mile below the falls, have done very little to adjust themselves to the low-level valley; Allt na h-Eilde [NN 210 620] and Allt Coire Mhorair [NN 195 600], which enter more than a mile farther downstream, have, however, eaten their way back, so that their hanging portions are well removed from the valley edge.

The case of Allt na h-Eilde [NN 210 620] draining Loch-Eilde Mòr is particularly important. The lip of the hanging valley in this instance is cut back for a mile from the Leven. The stream tumbles over the lip in the form of a waterfall and reaches a low-level valley. The latter is graded with the Leven, and yet, so far as one can speak with confidence in such matters, it is obviously not the work of glacial erosion — although, at the same time, it has suffered a certain amount of glacial modification. Since then we may take it that this lower adjusted portion of the Allt na h-Eilde [NN 210 620] is pre-glacial, it follows that the deepening of the Leven valley is pre-glacial too — an inference which many would regard as justified on a consideration of the form of this valley taken by itself.

Industrial development has emphasised this beautiful example of hanging scenery. Since the photograph of (Plate 2) was taken, conduits have been built approximately along the 1000-ft contour on both sides of the River Leven — on the north side leading from Loch-Eilde Mòr to the Blackwater Reservoir [NN 250 605] and on the south from the reservoir to intake pipes that descend in switch-back fashion to Kinlochleven. Once one reaches the southern conduit one is provided with a concrete path on old scenery belonging to what Peach and Horne have called the "intermediate plateau of the Highlands", while immediately below lies new scenery incised with reference to present-day sea-level at Kinlochleven.

Peach and Horne's "intermediate plateau of the Highlands", figured with its lochans in (Plate 2), 1, reappears to the south as the Moor of Rannoch (R. in (Figure 1)), where it is the eastward continuation of the through-valley of the Coe. The contrast between the Moor of Rannoch and Glen Coe is particularly striking. The Moor is cut in Moor of Rannoch "granite" which has proved itself to be easily erodable. The Glen is cut in more resistant volcanic rocks. The Moor and Upper Glen Coe have approximately the same bottom level, so that it seems certain that Glen Coe must have been opened up to some extent by the processes of erosion which, in pre-glacial times, fashioned the Moor. Also much of the pre-glacial opening up must have continued long after the westward reversal of the Coe, since this reversal was followed by the opening up of a long stretch of Lower Glen Coe and its concordant tributary, Fionn Ghleann [NN 124 550]. Upper Glen Coe hangs to Lower Glen Coe where rhyolite lava crosses the glen two miles upstream from Loch Achtriochtan. Further details are included in accounts of two Glen Coe excursions, pp. 72, 137.

If we take the Leven and Coe together we reach the conclusion that the original drainage system of the district, having reached a stage of maturity, became in part rejuvenated as a result of widespread beheading and resultant short-circuiting: the main valleys were cut back by waterfall and cataract action; the tribuary valleys made use of their opportunities as soon as presented; a hanging-valley system was thus developed, such as occurs in the Zambezi district at the present time (*cf.* Lamplugh 1907); then followed intense glaciation; in many cases trunk valleys were opened out, side spurs were truncated, and the walls of certain minor hanging tributaries totally obliterated.

It appears, then, that the glaciation of this district has accentuated a hanging-valley system previously in existence. Concurrently it has often produced very obvious results in the modelling of the walls and bottoms of the various glens in addition to the removal of lateral spurs. Allt Coire an Eòin [NN 223 740], flowing north-east from Aonach Beag of the Ben Nevis group, and Amhainn Coir ' an Iubhair, entering Glen Tarbert [NM 910 600] near Loch Linnhe, occupy valleys which are particularly well worthy of a visit in this connection. Their *moutonné* surfaces convey to even a casual observer a more vivid impression of the immense grinding power of ice than would reams of description. In such cases grinding has sometimes been associated to a quite obvious extent with plucking, the importance of which has been emphasised by American geologists. (Plate 13), 2 (p. 275), shows a *roche moutonnée* by the roadside in Glen Nevis partially destroyed by plucking, which has removed a great block thus interrupting the beautiful curving outline imparted to the surface by previous grinding. Morainic drift is banked some little way up against the broken surface.

Corries and landslips

At the head of Allt Coire an Eòin [NN 223 740] and Amhainn Coir' an Iubhair [NM 920 623], one enters upon truly magnificent corries, as fine as any in Scotland. Corries, indeed, are a characteristic feature of the physiography of this district in general, and accordingly we shall now pass on to consider how such great cliff-bound amphitheatres can have originated.

There is a general consensus of opinion that corries are restricted in their typical development to glaciated lands, and are therefore of glacial origin. From the preceding discussion of through-valleys and hanging valleys, for which, as we have seen, a similar claim is also advanced, it will be evident that this line of argument must be followed with great caution; still it seems to the writer that the case for the glacial origin of corries has been established. The only agency at present at work in the district which might be regarded as responsible for the production of corries is landslipping. Reference has already been made to big landslips on Stob Bàn above the watershed of the Lairigmòr valley ((Plate 2), 2, p. 8). There are many other important landslips, especially in the Coire na Bà [NN 188 650] glen, in the valley east of Binnean Mòr, in the Allt Coire Rath [NN 250 713] glen, and on the two sides of the long ridge which separates Allt Coire Rath [NN 250 713] from Allt Coire an Eòin [NN 223 740]. Behind the slipped material a hollow is left, which is often of semi-circular form and backed by steep crags. C. T. Clough, in his description of the Cowal district of Argyllshire (1897, p.276), has pointed out that hollows thus left by landslips often resemble corries; in fact, some of the larger landslip-hollows are actually small corries. He has further suggested that many of the crag features of Highland valleys may be due to pre-glacial landslipping followed by glacial removal of the fallen material. Such may well be the case.

Where slipping occurs along the two sides of a straight ridge, the cracks limiting the slips are sometimes straight themselves, and determine the production of a more or less continuous "knife-edge" *arete.* The best locality to convince any observer of this peculiarity, and of the considerable importance of landslips generally in shaping the physiography of some parts of this district, is the ridge summit separating Allt Coire Rath [NN 250 713] from Allt Coire an Eòin [NN 223 740]. Here one may examine not only innumerable slips but also vertical cracks which extend deep down into the solid rock in preparation for the fall of other great masses. In almost every instance the knife-edge character of the ridge has been maintained, but a little south of Stob Coire Easain the divide has been breached; in this case a high-level col has been formed, and the slipped material, which has travelled to the west, has built a prominent little hill ("Meall Tionail [NN 228 724]"), easily recognised even from a distance of several miles.

Many of the landslips referred to above have probably resulted from the instability of valley sides over-steepened by glacial erosion. Slipping in such cases is a step towards the re-establishment of gentler gradients, although its immediate result is often to produce cliffs and crags. Special conditions, tending to repeated landslipping, and the rapid transport of slipped material, are required for really successful corrie formation. Such conditions are apparently afforded at the

bergschrund of a glacier — the crevasse, that is, which forms every summer between a glacier-head and the containing valley. The bergschrund is in many respects analogous to the landslip cracks which occur so abundantly in some parts of the present district. The tug of the glacier before the bergschrund forms will be a powerful incentive to landslipping on a large and small scale, while the glacier itself is admittedly an efficient carrier of slipped material.

The importance of the bergschrund in connection with corrie formation was first suggested by Johnson (1904). In 1883 he descended a bergschrund at the back of a miniature glacier of the Sierra Nevada. The crevasse was about 150 ft deep and for the most part was' walled on both sides by ice. About 20 or 30 ft from the bottom, the fissure reached the valley side, and from this point down the parting had taken place, not between ice and ice, but between ice and rock. Johnson found that the zone of bare rock thus exposed bore evidence of intense and repeated frost action. In fact, he regards this localised frost action as the main element in the problem of corrie formation, although he states that plucking likely supplements the initial rupturing due to the frost. We are, however, inclined to lay greater stress on the plucking, but this is a point which can only be settled by further investigation of present-day glaciers. According to another view elaborated by Harker (1899, p.487), the bergschrund is not taken into consideration, and corrie formation is attributed to direct glacial grinding. "Erosion", he points out, "near the sources of a river is very feeble; a glacier, on the other hand, springs into being, like Athene, fully armed". Maufe noticed that, while the bottom slope of the great Ben Nevis cliff overlooking the head of Allt a 'Mhuilinn is strikingly smoothed and striated, the cliff itself is rough as though it owed its form to plucking.

The corries of the district seem to favour a north-easterly aspect. One realises this on looking north from Bidean nam Bian [NN 140 543] across country towards Ben Nevis. The coincidence is not sufficiently striking, however, to need special explanation were it not that many observers in various northern lands have noticed a similar orientation. The effects have been very reasonably ascribed to the conjoint influence of sun and wind upon the course of glaciation, for even now the snow lies long in shady hollows whither it has been drifted before the prevailing westerly gales; thus, in the great corrie of Ben Nevis, there are patches of snow which are scarcely ever entirely dissipated by the summer's heat.

Rock-basins

We may now pass on to notice a few instances of glacial over-deepening recorded in rock basins within the limits of the present district, some of which are included in the Murray-Pullar survey (1910). Loch-Eilde Mòr and Loch-Eilde Beag are probably, both of them, rock basins. They are situated on the shatter-belt which has determined the position of Loch Leven. Loch-Eilde Mòr is 100 ft deep. The shallow lochans in the flat upper reaches of the River Leven almost certainly include rock basins. Loch Achtriochtan in Glen Coe is another example. Maufe has pointed out that this loch lies in soft phyllites behind a barrier of relatively harder rocks which here cross the glen on the down-stream side of a powerful fault; differential erosion of the softer material has given rise to the loch basin. Loch Coire na Creiche [NM 880 636] among the mountains on the other side of Loch Linnhe may also be cited as a clear example of a rock basin. Other rock basins might be mentioned, but the only ones of any size are those which probably exist submerged beneath the salt waters of Loch Linnhe and Loch Leven. Closed basins undoubtedly occur along the beds of these two lochs, as is clearly indicated by soundings; and, while some are due to accumulations of gravel, as at the narrows of Corran [NN 016 636], North Ballachulish [NN 052 603], and Caolasnacon, others, it is reasonably certain from analogy, are attributable to rock barriers (*cf.* J. Geikie 1894, chap. 19).

Various

Enough has now been said of glacial erosion. Glacial accumulation also deserves attention as a formative element in the topography. The main glacial accumulations are of the nature of morainic debris, more or less restricted to the valleys. Well-shaped moraine ridges are rare, but a few occur, including a fine terminal crescent on the lip of the Allt Coire Giùbhsachan valley, where the latter overhangs Glen Nevis. Most of the morainic drift has a hummocky surface. There is no more characteristic type of scenery than that afforded by hummocky drift where developed to perfection, as in the upper reaches of the River Leven valley and on the Moor of Rannoch at the head of Glen Coe.

A few words may now be added in regard to certain post-glacial and late glacial changes in the physiography of the district.

The summits of the high ridges were certainly exposed to frost action during late glacial times when the valley bottoms were still occupied by glaciers. This has contributed to render the results of frost conspicuous on many of the mountain tops. It is common, where the slope is gentle, to find the whole surface littered with slabs and fragments which have been prized loose by water freezing in joint fissures, but which have not travelled appreciably from their original source. The great domed surface of Ben Nevis affords a capital example of such an accumulation merging insensibly into genuine scree on the steeper slopes. On other mountain tops the debris covering, especially where it is composed of comparatively small fragments, has crept forward in a succession of steep-fronted, flat-topped waves or terraces. The movement appears to take place in times of storm, when rain is driving, and the whole surface is laden with water. In exposed situations the direction of movement, as indicated by the steep fronts of the terraces, is clearly determined rather by the direction of the prevalent gales than by that of the hill slope, so long as the inclination of the latter is not pronounced. In such cases any heather that manages to survive has assumed a prostrate habit and turned its head away from the blast. Patches of the surface are swept bare, and Lilliputian lochs are excavated with miniature storm-beaches to match. The turf in front of the advancing terraces of debris is turned up on end, broken and overwhelmed.

Frosts and torrents have been busy, too, among the cliffs and crags, picking out every little shatter-belt, and thus dissecting the relatively smooth surface left by glaciation. Great gullies have been cleared, and debris sent hurtling down to build widespreading cones of scree on the lower slopes. This type of frost action is illustrated very finely in Glen Coe, where precautions have been taken to prevent the scree from encroaching upon the road in times of flood. One can see that this scree formation, like the large-scale slipping so pronounced in the district north of the Leven valley, is busily undoing the work of the glaciers, and tending to produce a topography more in harmony with existing conditions.

While the ridges show signs of the severe treatment to which they have been exposed since they emerged from the glaciers, the stream-courses have also suffered to some slight extent. Many of the rivers have cut gorges a few feet deep, and it is interesting to see how their mode of attack varies with the nature of the rock. If, for instance, the stream is crossing quartzite, it quarries out fragment by fragment, making use of joint and bedding planes; if, on the other hand, mica-schist has to be removed, pot-holes are drilled, or a continuous channel is ground out with smooth flowing contours. Beautiful examples of breached pot-holes, forming arches through which the water plunges, may be seen from the road where Allt Nathrach [NN 160 631] runs down to join Loch Leven.

But of all post-glacial changes, the most important from the human point of view is one that is limited to the coast-line. A more or less continuous terrace, often backed by low, rocky cliffs, fringes the shores of Loch Linnhe and Loch Leven, and carries most of the roads of the district and the railway leading to Ballachulish. It is a record of the activities of the sea at a time when the land stood some 30 ft lower than at present. Fertile beach deposits, dating from this period, have determined the sites of the crofting villages of Onich, North Ballachulish [NN 052 603] and Clovulin [NN 000 630].

We may bring this discussion of the physiography of the district to a close by considering the influence of rock structure, which is responsible for many conspicuous minor features. Most of the country is composed of crystalline schists of various kinds, each with a more or less characteristic type of weathering. Thus white quartzite, interfolded among darker mica-schist, is strongly developed in the district between Ben Nevis and Glen Coe, and gives rise to remarkable scenic effects ((Plate 2), 2; (Plate 5); (Plate 13), 1). In Glen Coe itself, lavas of Old Red Sandstone age occur in striking contrast to the surrounding schists. Here the abrupt face of Aonach Dubh, built up of tiers of andesite flows, capped by rhyolite and agglomerate, at once attracts attention. The ridges that follow to the east, the two first of which, together with Aonach Dubh, constitute the Three Sisters of Glen Coe, are largely composed of rhyolite, with a peculiarly grand and massive type of scenery (Plate 6), reaching its culmination in Stob Dearg [NN 225 543] (Plate 8). There are also several plutonic intrusions in the district with a typical amorphous outline well illustrated in the hills formed of the Ballachulish quartz-diorite in Creag Ghorm and the Glen Scaddle "epidiorite" across Loch Linnhe. In the southern portion of the map a small part of the Etive "granitic" complex is included. This complex is divided into an outer rim and an inner core. Mountains constituted of the granite of the inner core, the Ben Starav [NN 125 427] Granite, are altogether remarkable for the extreme bareness of their slopes, which recalls the nakedness of the Norwegian Highlands.

Contributions to interpretation since the First Edition

The foregoing account of river development within Sheet 53 (Geol.) was composed under inspiration gained from the writings of Cadell, Mackinder, Peach and Horne, dealing mainly with other parts of Scotland. Since then a fairly extensive related literature has appeared, again chiefly concerned with outside districts. Some of the conclusions reached are in harmony with those set out above, while others are discordant. Among the former we find that both Bremner (1942, p. 54) and Linton (1951b, p.68) consider that east, rather than south-east (the latter favoured by Mackinder, Peach and Horne), is the characteristic direction of consequent streams in the Highlands. East is the direction indicated in (Figure 1).

Bremner's other general conclusions, right or wrong, introduce no special difficulty. For instance he thinks that the consequent streams suggested in (Figure 1) started on a tilted uplift carpeted with Upper Cretaceous sediments. He imagines that the site of the Hebridean volcanoes was "most strongly upheaved", so that consequent rivers radiated from it to begin, as he puts it, "the cycle of erosion that produced the Tertiary peneplain — the High Plateau". According to this conception, the volcanoes, situated on a high western land of hypothesis, did not, on their arrival, materially affect the eastward drainage across our district.

He regards the basin of the Irish Sea as due to depression in early post-uplift times. He does not, however, specifically refer to the Hebridean subsidences responsible for taking Tertiary lavas and underlying Cretaceous sediment in many places below present-day sea level; but he does remark that "the volcanics themselves fell a prey to the subaerial forces of denudation and now enter into the substance of the peneplain". Presumably this refers more especially to the Cuillin summits of Skye, composed of Tertiary gabbro and yet planed off at approximately 3000 ft.

Hans Cloos (1939) has given a closely similar picture. He thinks he can recognise a dome-shaped bulge, of which Great Britain constitutes the eastern portion and Ireland and the Outer Hebrides the western. In between he regards the Irish Sea and the Hebridean subsidences as a rift-valley, due to collapse of what had been for a time the most elevated belt of the upward bulge.

Linton (1951b) differs from Bremner and Cloos, for he speaks as though the Hebridean subsidences (or relative subsidences) dated from the beginning of the post-Cretaceous upheaval. "If our eastward slope", he says, "broke towards the west along the margins of the 'Hebridean Rift' there must from the outset have been two sets of rivers, the one set flowing eastward to the North Sea depression, the other westward into the Rift".

He thus pictures "from the outset" a watershed or watersheds on the Scottish mainland dividing eastward- from westward-draining rivers. Many of these oppositely directed rivers today occur in pairs, each of which occupies a through-valley; but he cannot accept the suggestion that many a pair originated as a single eastward-flowing stream. "If this is so", he asks, quoting J. Solch",where are the western mountains from which those rivers came ?" The answer of course is another question: Where are the thousands of feet of hard solid rock that presumably once covered the gabbro summits of the Cuillins ? All of us are merely groping our way towards a clearer understanding.

Linton, like Tarr, whose work is mentioned earlier in this chapter, is a firm believer in most of the through-valleys of the Highlands having originated as a result of glacial erosion. He has examined some with care, and has satisfied himself that he can reconstruct the approximate position and form of watersheds that have been almost obliterated by what A. Penck has termed glacial transfluence. He has rendered good service by directing attention to overseas publications on this subject. It is, however, surprising to read that "transfluence was first recognised in Scotland, though not called by that name, by Peach and Horne thirty years ago" (Linton 1951a, p. 11; the reference given is Peach and Horne 1910). Surely the phenomenon has been familiar to all Scottish geologists since Jamieson wrote of ice passing from upper Glen Roy [NN 300 880] into the Spey valley and from Loch Fyne [NN 100 070] into Crinan Loch (1862, pp. 176–7). Geologists, who have adopted a through-river interpretation of some of the through-valleys of the Highlands, have from the first been conscious that most of these through-valleys have been occupied at some stage of their history by through-glaciers eroding as they went. There is obvious room for difference of opinion in this matter. Tarr, Linton and others have dispensed with through-rivers and emphasised through-glaciers. Readers are recommended to study the glacial interpretation of through-valleys in the original publications. Linton in (1951b) and Dury in (1953) give long and useful lists of references.

Those who visit Sheet 53 (Geol.) will probably pass through Glen Coe. They should pause at Lochan na Fola [NN 210 560] to form their own judgment as to whether or no existing topography suggests that here an important watershed has been breached by glaciation. Also, even if they cannot visit them, they should note on the map the curious position of the watersheds of Glen Nevis, near Tom an Eite [NN 238 694], and of Glen Tarbert [NM 910 600], at Lochan a' Chothruim [NM 895 601]. In both cases the watershed corresponds with the advent of important tributary streams. This hardly looks like the location of a main pre-glacial watershed. unless the latter was built pre-glacially as a corrom across a beheaded through-valley — both sites, it will be remembered, are occupied by post-glacial corroms. Then too the pre-glacial hanging topography of Upper Glen Coe and the Moor of Rannoch, and of the Blackwater Reservoir [NN 250 605] should be taken into careful consideration. E. B. B.

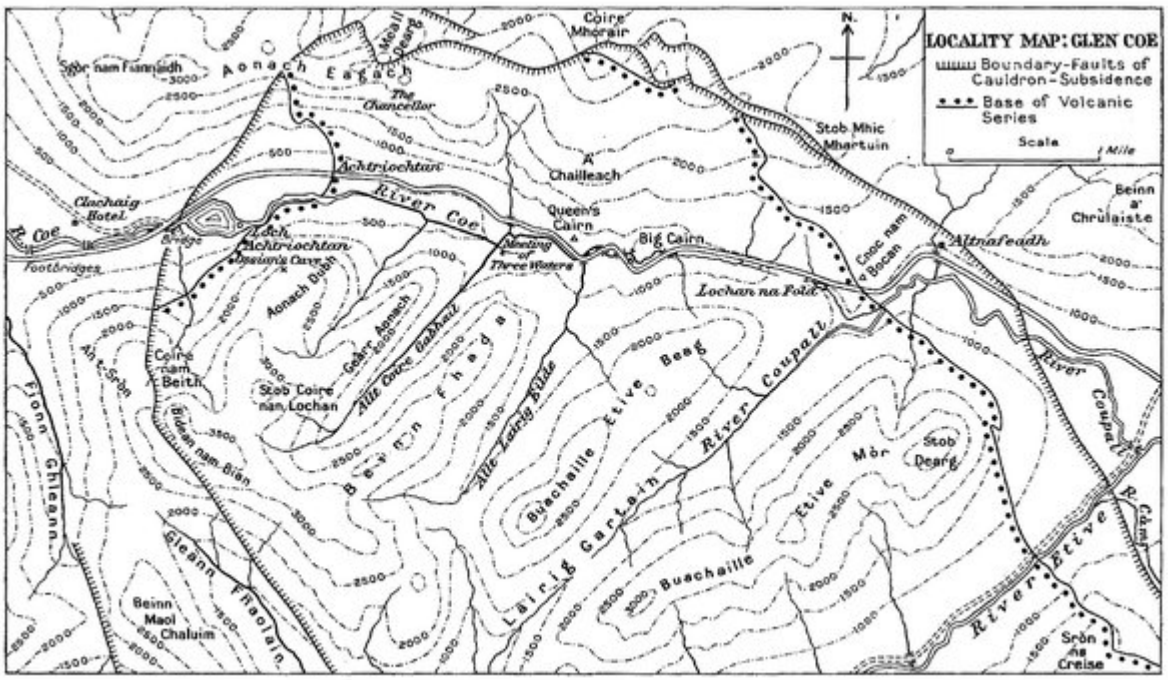


FIG. 22. Locality map : Glen Coe

(Figure 22) Locality map: Glen Coe.

(Plate 7) Melting of Three Waters, Glen Coe; and Rock-Fall, Allt Core Gabhail.

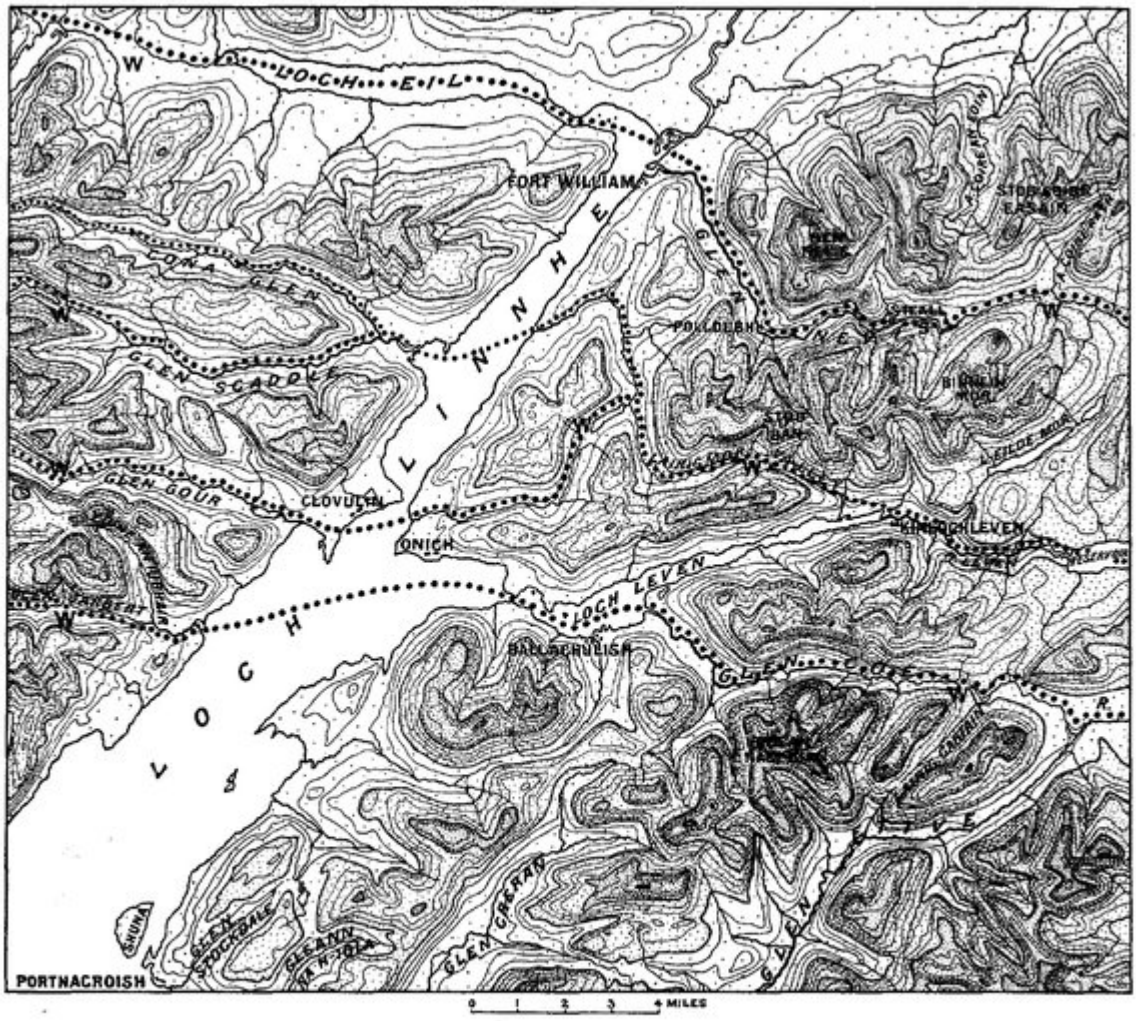


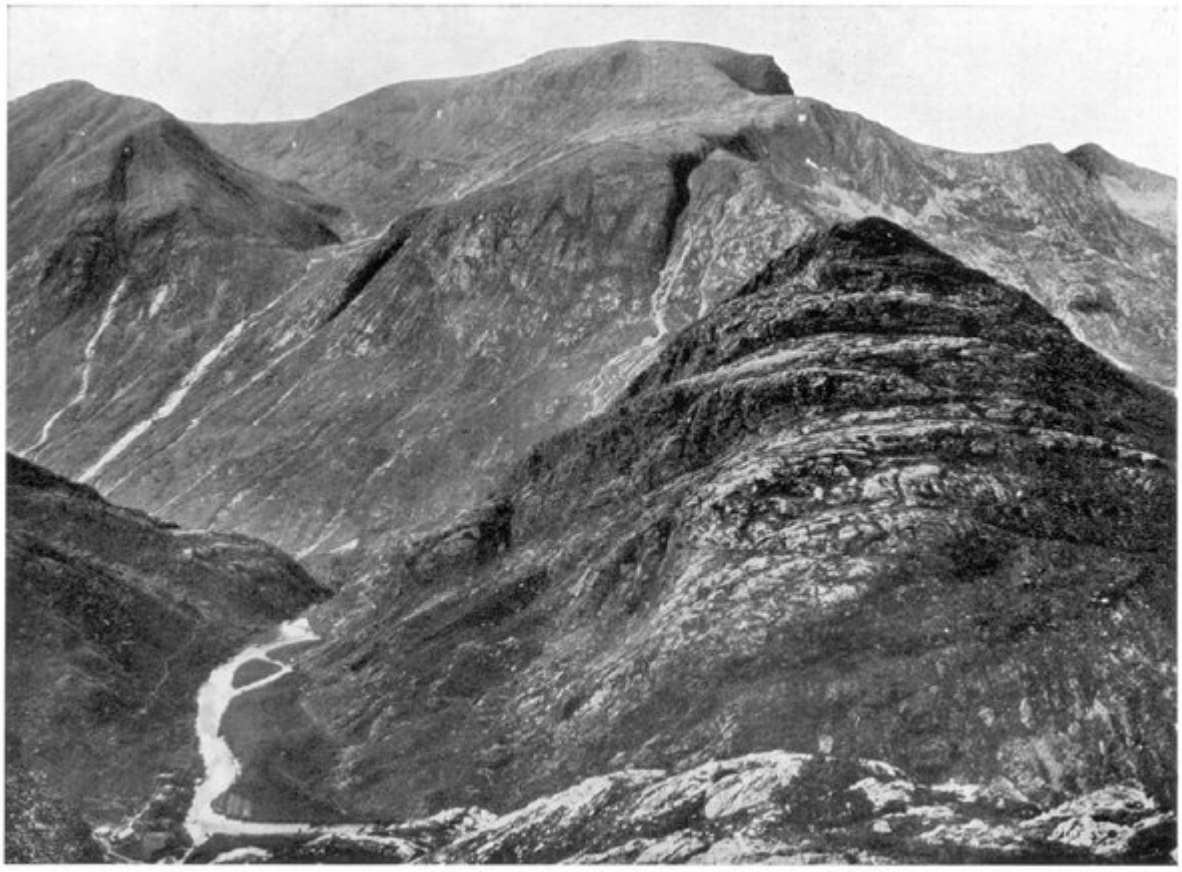
FIG. 1. Map of inferred original Tertiary drainage system (shown in heavy dots)

Shatter-belts guide Loch Linnhe, Loch Leven and Lairig Gartain.
Contour-interval 250 ft, with change of ornament every thousand feet.
W, Secondary Watersheds. R, west end of Rannoch Moor

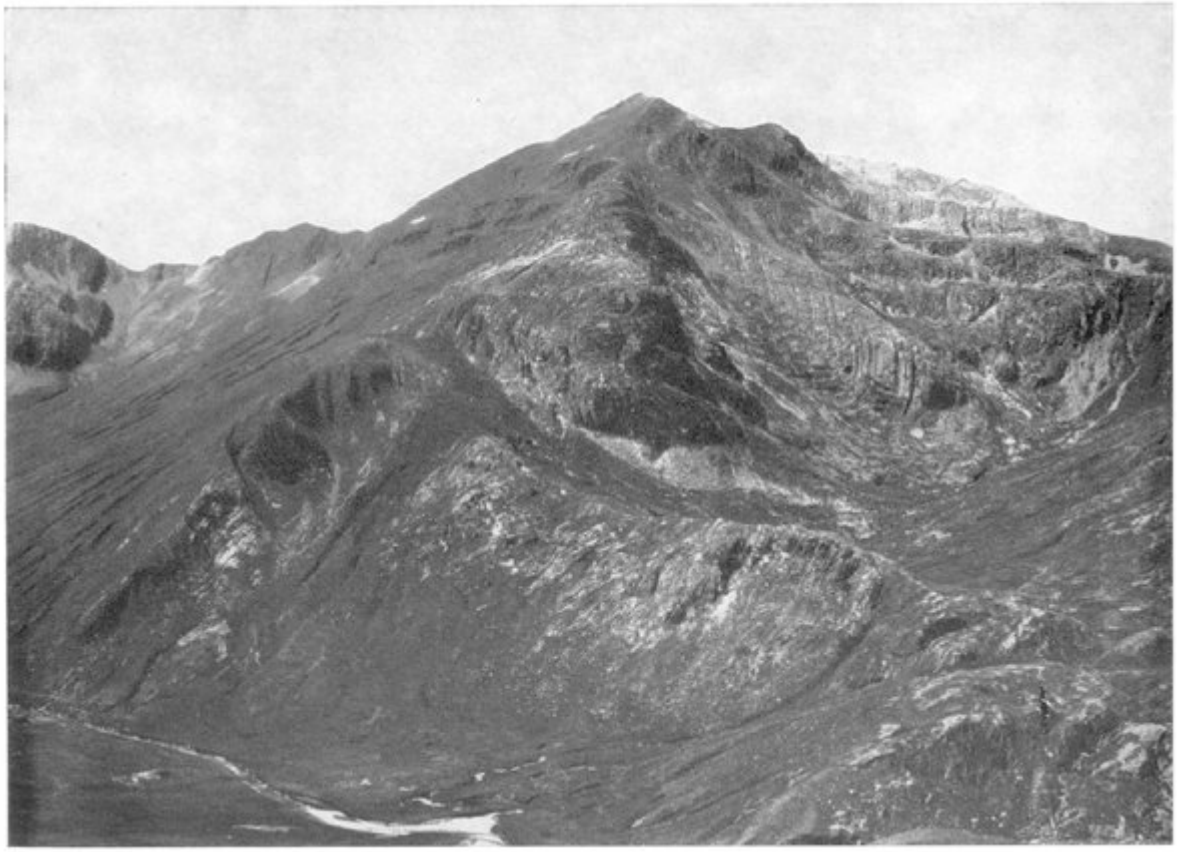
(Figure 1) Map of inferred original Tertiary drainage system (shown in heavy dots) Shatter-belts guide Loch Linnhe, Loch Leven and Lairig Gartain [NN 200 544]. Contour-interval 250 ft, with change of ornament every thousand feet. W, Secondary Watersheds. R, west end of Rannoch Moor.

1. Hanging portion of River Leven with dam site of Blackwater Reservoir

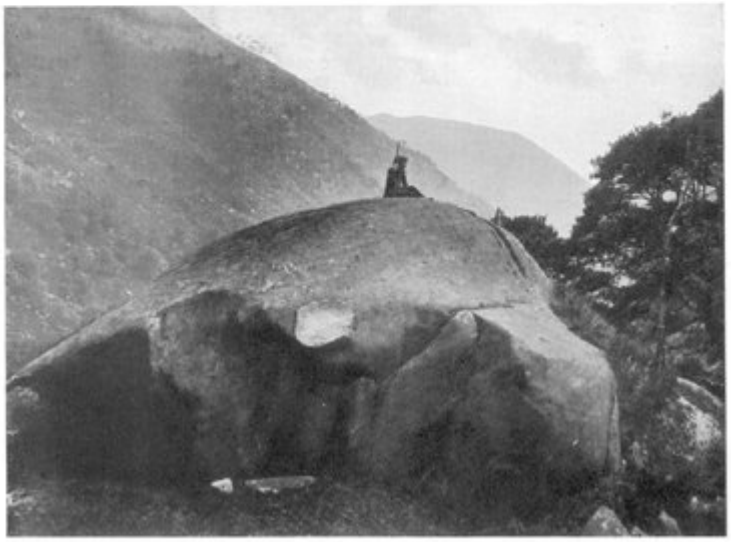
(Plate 2) 1. Hanging portion of River Leven with dam site of Blackwater Reservoir [NN 250 605]. 2. Stob Bàn, Near Watershed of Lairigmòr Valley, showing comparatively recent landslip.



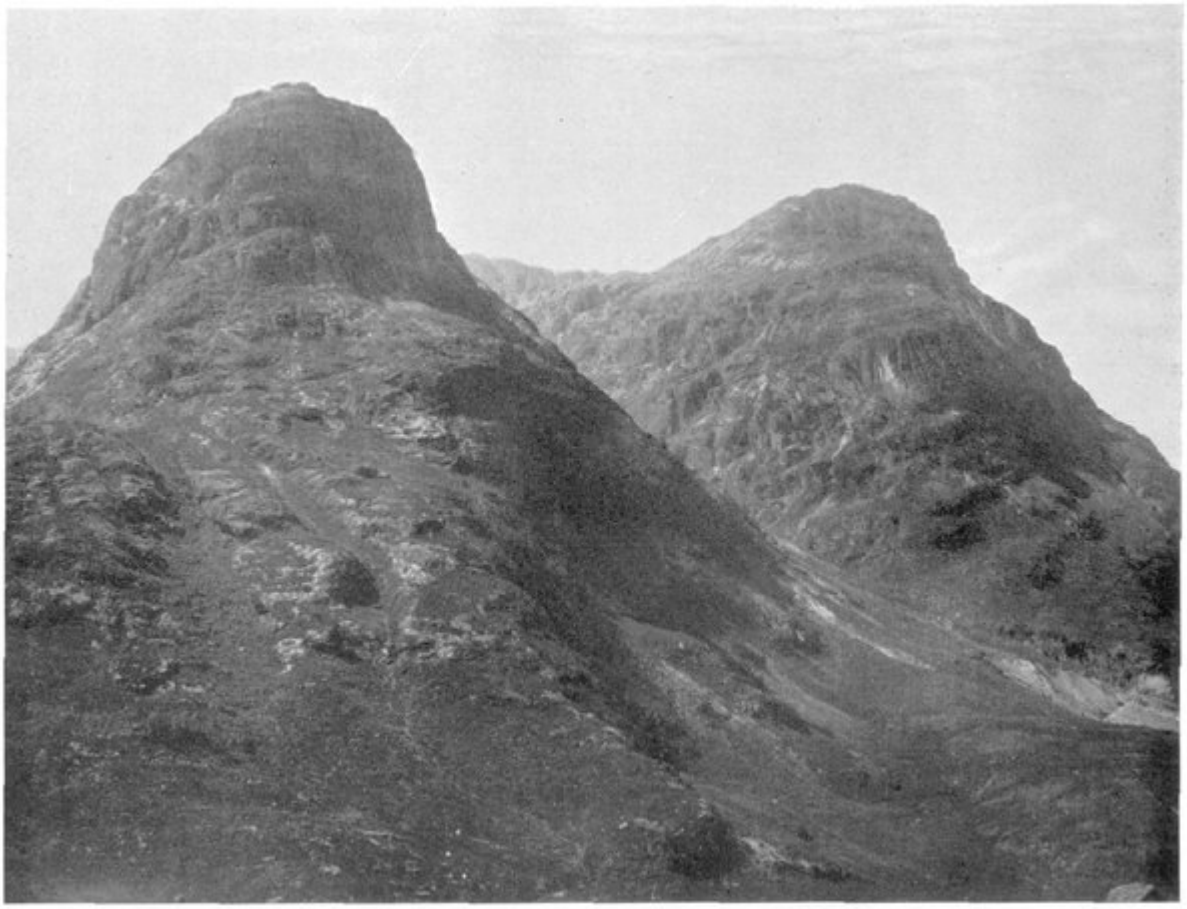
(Plate 1) Ben Nevis with hanging corrie and River Nevis [NN 200 680] disappearing into Nevis Gorge.



(Plate 5) Sgùrr A' Mhàim across Allt Coire A' Mhail Folded Glen Coe Quartzite.



(Plate 13) An Steall, The Waterfall of a valley hanging to Glen Nevis Water-worn crags on left due to stream cascading down marginal crevasse; Roche moutonnee, Glen Nevis, by roadside above Polldubh [NN 141 686] Note gap on "sloss" side due to plucking.



(Plate 6) Gearr Aonach [NN 160 555] And Aonach Dubh: Glen Coe "sisters" Largely rhyolite lavas.

(Plate 8) Stob Dearg Rhyolite lavas (crags) on schists (grass covered). Fossils at +.