Chapter 12 Rocks of Lower Old Red Sandstone age: Boundary-Fault and Fault-Intrusion of Glen Coe

The volcanic series of Glen Coe occupies a cauldron-subsidence, circumscribed by a fault of some thousands of feet downthrow ((Figure 18), (Figure 19)). The cauldron, which measures 9 miles by 5, dates, in all probability, from the Lower Old Red Sandstone period, and does not, we need scarcely add, find expression as a hollow in the topography of to-day. At its initiation the boundary-fault was probably continuous, but its outcrop is now interrupted for about 4 miles by a northward extension of the Cruachan "Granite".

The sunken area is girdled by a discontinuous igneous complex in the form of an irregular ring-dyke (p. 35) of porphyrite merging into "granite". This is the Fault-Intrusion of Glen Coe — so named from its intimate connection with the Boundary-Fault of the Cauldron-Subsidence; some portions of it, generally more or less crushed, have been separated under the designation of Early Fault-Intrusion ((Figure 24), (Figure 25), (Figure 26)). The Fault-Intrusion rose up around the subsiding block as the latter settled down, but before we can substantiate this statement it is necessary to give a résumé of the evidence upon which it is based. A fuller account has already been published, to which the reader is referred (Clough, Maufe and Bailey 1909); and this has been elaborated in several respects in programmes for two road excursions in Glen Coe given on pp. 72, 137.

Subsidence of lavas

The existence of a cauldron-subsidence is suggested by the compact area occupied by the volcanic series in the heart of the schists, especially as, in many places, the lavas abut against the steep even plane of a bounding fault, and there stop abruptly. This last relation is especially well seen between An t-Sròn [NN 134 550] ((Figure 20), p. 133) and Dalness [NN 168 512]. The lavas also almost always show a marginal inward tilt, sometimes amounting to actual inversion ((Figure 20) (Figure 21), (Figure 23), (Figure 24), (Figure 25)).

Only very minor outcrops that can possibly be attributed to the Glen Coe volcanic series or its associated sediments occur outside the innermost branch of the Boundary-Fault. These have already been discussed under the heading "Fissure-Fillings or Outliers" (p. 150).

Subsidence of schists

The importance of the subsidence which has preserved the Glen Coe volcanic rocks from erosion is also strikingly illustrated by the distribution of the schists within the downthrown area. The effect of the Gleann Chàrnan [NN 135 500] branch of the Boundary-Fault is particularly obvious (Sections G and H, (Figure 7), p. 48). Here for a distance of two miles Leven Schists, in what we have called the "cover" position, are thrown down on the north-east against "basement" Glen Coe Quartzite and, for a short distance, against Ballachulish Limestone overlying the latter.

The same juxtapositions are found along the main fault where it crosses Glen Coe further north, though the evidence is somewhat blurred by the unconformable lavas inside the Cauldron, and by widespread invasion by Fault-Intrusion, outside the same. Under the lavas the Loch Achtriochtan phyllites belong to a rather high portion of the Leven Schist "cover", and are thrown down against external Ballachulish Limestone and "basement" Glen Coe Quartzite. The interest is heightened because the Loch Achtriochtan phyllites have suffered appreciably less regional metamorphism than the rocks against which they are thrown, which is taken to show that the grade of regional metamorphism in this district diminishes upwards (pp. 71, 78–9).

The Ballachulish Limestone of Glen Coe just outside the Cauldron has a continuous outcrop south of the river, where it passes south-eastwards under "cover" Leven Schists between Achnacon [NN 119 566] farm and the An t-Sròn mass of Fault-Intrusion. It also, north of the river, spreads out to give two extensive outlying patches, one of which reaches up to the watershed in Sgòr nam Fiannaidh [NN 137 584]. A further representative of these isolated external outcrops occurs immediately north of Meall Dearg [NN 163 585] ((Figure 23); Bailey 1934a, fig. 4, p. 487). Here the limestone is brought by an outer branch of the Boundary-Fault into contact, north-eastwards, with structurally underlying quartzites and mica-schists in "basement" position.

Within the circuit of the Main Boundary-Fault in this same northern district the Ballachulish Limestone, which one would expect to rise northwards from beneath the Loch Achtriochtan phyllites ("cover" Leven Schists) is seen in Coire Càm [NN 154 585] and Coire Mhorair ((Figure 23), (Figure 24)).The Coire Càm [NN 154 585] outcrop is minute, and rests on inverted basement conglomerate belonging to the Glen Coe volcanic series, as indicated by a note in (Figure 23). The Coire Mhorair outcrop is large and easily identified on Sheet 53 and (Figure 24). Closely associated volcanic rocks are in both cases steep, sometimes slightly overturned ((Figure 23), (Figure 24), (Figure 25)). Exposures to the north consist of structurally underlying quartzite, mica-schist and flags.

Moreover, contrast of strike is often seen in schists on the two sides of various branches of the Boundary-Fault as illustrated in (Figure 24), (Figure 26), (Figure 28); while the reappearance of Ballachulish Limestone from beneath the volcanic rocks in the Coire an Easain [NN 250 496] stream of (Figure 29), and of Glen Coe Quartzite in "cap" position in small inliers near Dalness (p. 89) fits in exactly with the general picture of subsidence.

Circumferential detail

The evidence so far advanced shows that the volcanic rocks and underlying schists occupy a region of subsidence. It is now necessary to give in outline the proof that the sunken region is bounded by a curving dislocation, and not by straight faults accidentally intersecting. The demonstration depends upon the possibility of actually tracing the Boundary-Fault, and this has been effected with great precision, thanks to excellent exposures. The task is made easier by the fact that the fault, or the main fault where there are branches, serves as the inner boundary of the ring-complex known as the Main Fault-Intrusion. Only three or four minute crops of this Fault-Intrusion are known within the circuit of the innermost branch of the Boundary-Fault, whereas outside, for a distance of about a mile, there are numberless masses of the intrusion; not only so, but wherever an individual mass is in contact with the fault it presents to it a smooth well-defined margin, though elsewhere its boundaries may be highly irregular. This feature is abundantly clear in the one-inch map, and in (Figure 19), (Figure 20), (Figure 21), (Figure 23), (Figure 24), (Figure 25), (Figure 26), (Figure 27), (Figure 28).

The contact-metamorphism induced by the Main Fault-Intrusion is similarly restricted, so that the lavas and schists within the Cauldron-Subsidence have escaped almost untouched, with the exception of the rocks in the neighbourhood of the large offshoot of the Cruachan "Granite". In correlation with this phenomenon the Main Fault-Intrusion invariably shows chilled margins to the corresponding branch of the Boundary-Fault wherever the two are seen in contact from Dalness [NN 168 512] in Glen Etive right round to Meall a' Bh&ugaveiridh [NN 250 504] (Figure 29). Along its external boundaries, on the other hand, while chilling is not uncommon, it is anything but universal.

A very brief statement of the phenomena encountered along the course of the fault is given below. C. T. C., H. B. M., E. B. B.

South of Dalness

The Boundary-Fault is in two branches south of Dalness [NN 168 512]. An inner fault is well seen on the hillside between 1100 and 1200 yards southeast of the house. It inclines steeply towards the region of subsidence, and separates quartzite on the south-west from rocks of the volcanic series on the northeast. A highly sheared band intervenes; and a thin streak of nearly vertical black flinty crush-rock traversing the rhyolite lavas close to the dividing plane shows incipient crystallisation due to hornfelsing (S11464) [NN 178 505]. A little farther up the hill a grey porphyrite, belonging to the Fault-Intrusion complex, extends along the Fault for a distance of about a third of a mile. Its north-eastern margin is chilled and nearly straight, while its south-western margin is distinctly less regular.

On the west flank of Beinn Ceitlein the outer branch of the fault can be recognised by evident discordance of.the schists on its two sides. It is inclined northwestwards or westwards often at comparatively low angles of about 50°. Like the inner branch it is locally accompanied by grey porphyrite acting the part of Fault-Intrusion. Further discussion is given on p. 88.

The two branches converge south-east of Dalness.

In chapter 18 it is shown that the Fault-Intrusion south of Dalness is contact-altered. There can be no doubt that the effect is due to the Cruachan "Granite". The two intrusions are seen together a third of a mile S.S.E. of Dalness, where abundant red "granite" strings project from the surface of the porphyrite. C. T. C.

Dalness [NN 168 512] to Glen Coe

The Boundary-Fault is again in two branches. The inner is clearly marked in this region as the limit of the volcanic rocks. It is further distinguished by the presence of a loose fault-breccia which weathers out, yielding a more or less decided hollow ((Figure 20), p. 133). The fault-plane inclines normally at about 70°. Almost along its whole course one finds Fault-Intrusionpink and grey "granite" and porphyrite — swelling to a large mass in An tSròn, and everywhere presenting a smooth chilled edge (S10309) [NN 134 549] to the fault. The loose fault-breccia involves this chilled edge, and is thus evidently due to a recurrence of movement along the old line of weakness. In keeping with this one finds the N.E. porphyrite dykes, of considerably later date than the Fault-Intrusion, thoroughly broken where they cross the line of the Boundary-Fault. Where the crush-rock in the fault is of a compact nature, as south of Dalness, at Stob Mhic Mhartuin [NN 207 575], and in the Càm Ghleann, the N.E. dykes cross without suffering brecciation. The crushing north-west of Dalness affects even a basalt dyke, presumably of Tertiary age.

The outer branch of the Boundary-Fault runs along Gleann Chàrnan [NN 135 500]. It is recognisable by its effect upon the schists, and its position is further marked by a line of loose crush-rock. A tongue of Fault-Intrusion extends along its outer side with the usual relationship. H. K., H. B. M.

Crossing Glen Coe

The reader is once more referred to the road excursions, pp. 72, 137.

North of Glen Coe

The evidence for the Boundary-Fault in its usually double, sinuous course north of Glen Coe is presented in (Figure 23), (Figure 24), (Figure 25), (Figure 26), (Figure 27), (Figure 28). The northern branch, north of Meall Dearg [NN 163 585] in (Figure 23), was recognised comparatively recently (Bailey 1934a, p. 486) as a result of reinvestigation of the schists (p. 80). All the rest was described in detail in 1909.

From its turning point in Coire Càm [NN 154 585] to Stob Beinn a' Chrùlaiste [NN 232 564] near the Glen Coe road, the main or southern branch is inclined outwards, that is towards the north, at angles varying between 70° and 50°. The northern, outer branch, at any rate from Coire Mhorair [NN 185 585] to Stob Mhic Mhartuin [NN 207 575], is similarly inclined, and is of earlier date.

From Loch Achtriochtan to Coire Odhar-mhòr [NN 196 583] the Fault-Intrusion is mainly represented by pink porphyrite. The "Granitite Fault-Intrusion" distinguished in (Figure 24) is easily separable from the main Fault-Intrusion. The junction of the two is exposed at the base of SrònGharbh and is not quite sharp, being marked by a foot or so of hybrid rock (S13342) [NN 186 593]. Probably the coarser rock is somewhat the later; its uprise may well have been contemporaneous with that of the main mass of the Cruachan "Granite".

Numberless intrusions of pink porphyrite belonging to the Fault-Intrusion occur between Garbh Bheinn and Glen Coe, and are particularly interesting for they frequently present unchilled margins. The district has probably been subjected to extensive explosive and pneumatolitic action. On the one hand, the porphyrite is often not only richly charged with xenoliths. of baked mica-schist and quartzite, but also loaded with quartz grains separated from the quartzite (p. 219); on the other hand, the quartzite, where it retains its individuality, is frequently saturated with pink felspar from the porphyrite. The irregularity of the geology prevents accurate mapping. W. G. Hardie has made a special study of the Garbh Bheinn district and thinks that some very considerable areas of quartzite belong to giant displaced xenoliths (1955).

It has already been pointed out that the alteration of the schists due to the intrusion of the Main Fault-Porphyrite is limited by the main branch of the Boundary-Fault. This is particularly well illustrated in Coire Mhorair [NN 185 585] and the ridge to the east ((Figure 24); and Bailey 1934a, fig. 4 and p. 505). Inside the inner, main branch of the Fault, well bedded, pure white quartzite (Glen Coe or older) dips steeply beneath thin black schists (Ballachulish Slates), and these under calcareous schists and limestones (Ballachulish Limestone), the whole showing no trace of contact-alteration. Outside, quartzite and Eilde Flags are encountered with obscure bedding and local well-marked reddening. An additional feature in these outer rocks is that they are pierced by many irregular intrusions of pink felsite, which are quite unknown on the downthrow side of the inner fault. One felsite is intruded by a vein of flinty crush-rock.

The most interesting single exposure of the Glen Coe Fault is exhibited in Stob Mhic Mhartuin [NN 207 575] ((Plate 9) and (Figure 27)). The map (Figure 26) shows how readily two branches of the Fault can be recognised by paying attention to the nature and strike of the schists which they traverse. What is not apparent on the map is the amount of disturbance and reddening characteristic of the schists between the two branches of the Fault and for about a third of a mile to the north-east.

The two branches of the Fault are accompanied outside by grey FaultPorphyrites, but the porphyrites in the two cases are not identical. The inner one can easily be recognised as the Main Fault-Intrusion of Glen Coe; the outer is Early Fault-Intrusion, a rather different rock, distinguished alike by original characters, and by its moved, broken, and baked condition. Traced westwards into Sròn a' Choire Odhair-bhig [NN 200 579] (Figure 24) the inner, Main Intrusion occupies the whole distance between the two branches of the Fault. To the north it exhibits a chilled undisturbed edge against a banded flinty crush-rock ((S12935) [NN 201 581]; see below), which on its other side passes imperceptibly into the strongly sheared margin (S12934) [NN 201 581] of the outer, Early Porphyrite (S12933) [NN 200 580]. No more convincing evidence could be desired: the outer Fault-Intrusion is of comparatively early date, and has suffered from a recrudescence of shearing posterior to its consolidation — shearing which has not affected its later neighbour. It may be added that the Main Fault-Intrusion hereabouts chills at all contacts, and not merely at the Main Boundary-Fault, thus departing from the rule followed when the Main Fault-Intrusion assumes either "granitic" or permeative crystallisation. E. B. B.

Before quitting the Stob Mhic Mhartuin [NN 207 575] section, special attention must be drawn to the shearing along the main fault, illustrated in (Plate 9) and (Figure 27). The rocks of the low frontal cliff of the Stob are well bedded quartzites lying on the downthrow side of the inner, south-west fault of (Figure 26). They are traversed by minor planes of movement crossing their bedding and occupied by a few inches of hard white rock composed of ground-up quartzite. Along the main line of movement the bedded quartzites are truncated by a zone of similar white crush-rock (S12329) [NN 2090 5735] two feet thick. Beyond this, long tongues of the white crush-rock begin to be isolated in a darker matrix with obvious flow-structure; then these tongues disintegrate, and the proportion of fluxional matrix rapidly increases. The fluxion-breccia which results is a foot wide, and next to it is a layer, an inch thick, of black flinty crush-rock (S12332) [NN 2090 5735]. C. T. C., E. B. B.

We may preface further detail regarding this type section by noting that much has been written on the subject of flinty crush-rocks; and the reader should consult the paper on the Cauldron-Subsidence (Clough, Maufe and Bailey 1909, pp. 629–31, etc.) to learn the part played by Clough and Holland in its early elucidation. Since then the most important publications have been by:

1. Termier and Boussac (1911), writing on mylonites in the Alps.
2. Quensel (1916), discussing mylonites in regard to Sweden.
3. Shand in his account (1917) of "pseudotachylite" at Parys Mountain, Orange Free State.
4. Bowen and Aurousseau in a discussion (1923) of artificial examples of flinty crush-rock accidentally produced in boring for oil.
5. Jehu and Craig in descriptions (1923–4) of a great flinty crush-belt in the Outer Hebrides discovered by Dougal (*cf.* 1928).
6. Waters and Campbell (1935) in relation to the San Andreas Fault, California.

Flinty crush-rock is an exceptional accompaniment of faulting. In fact, one of its peculiarities is narrow localisation in time and space. Thus flinty crush-rock is scarcely known in Britain away from Cheviot, Glen Coe, Ben Nevis and the North-West Highlands. In the three former it is of Devonian age; in the latter Pre-Cambrian. In all except Ben Nevis it was first recognised by Clough. So far as Cheviot, Glen Coe and Ben Nevis are concerned it might still be unheard of except for Clough; but in the North-West Highlands, especially the Outer Hebrides, it is conspicuous (one can sense its presence in Macculloch's descriptions); and it must certainly have been investigated ere now without Clough's initiative. As regards scarcity in other settings one must remember that Clough worked in many districts without discovering any trace. It is also worth noting that, whereas flinty crush-rock at Cheviot, Glen Coe and Ben Nevis is linked with volcanic activity, in the North-West Highlands it is not.

It is widely, but not universally, agreed by investigators in different regions of the world that flinty crush-rock has suffered partial fusion by frictional heat. The following common features can be illustrated by examples from Glen Coe:

1. Flinty crush-rock has definite association with faulting, *e.g.* it lines the early and main branches of the Boundary-Fault of Glen Coe, and also the Boundary-Fault at Ben Nevis.
2. Where found along faults it is apt to provide small irregular intrusive veins cutting neighbouring rocks, *e.g.* veins (S12333) [NN 1955 5802]; (S13929) [NN 199 581] cutting a crag of quartzite at locality (c) west of Sròn a' Choire Odhair-bhig [NN 200 579] in (Figure 24); see also (S13405a) [NN 207 575].
3. The flinty or subvitreous lustre immediately suggests glass, though abundance of debris makes it difficult to establish this interpretation under the microscope.
4. Almost all districts studied furnish occasional examples of micro-crystallisation of a type that seems to require previous melting, *e.g.* in (S12933) [NN 200 580], derived from crushing Early Fault-Porphyrite, there is detectable microtrachytic texture affecting microlites that have probably been hornblende and felspar.

With this background let us concentrate upon the one feature in which Glen Coe, with Ben Nevis, stands by itself, namely the frequent juxtaposition of contemporaneous flinty crush-rock and normal magmatic rock. No better place for its study could be selected than Stob Mhic Mhartuin [NN 207 575].

The two feet of "white crush-rock" of (Figure 27) cannot be distinguished in hand-specimen, and scarcely even under the microscope (S12329) [NN 2090 5735], from fine gritty sandstone. There are numberless angular quartz grains up to about half the size of those in the quartzite from which they have been derived; and this latter is represented by occasional small subangular bits resembling pebbles. Both in the isolated grains and in the compound fragments the quartz shows surprisingly little strain-shadowing. Also mica in the compound fragments is usually unaffected. Quartz in the matrix again abounds, occurring as easily recognisable, smaller and smaller grains; but mica, once it is freed from the protection of surrounding quartz, soon becomes unidentifiable. The nature of the ultimate base is irresolvable; but one may note an abundance of extremely fine dark powder. This is a common feature of flinty crush-rocks all over the world. Here the powder may be iron ore derived from destruction of biotite. One feature alone clearly distinguishes (S12329) [NN 2090 5735] from sandstone, namely, a drawn-out area of disintegrating quartzite in which separation of quartz grains, combined with marginal fragmentation of the same and with breaking down of mica crystals, is convincingly displayed. The conditions within this area explain the comparative absence of strain-shadowing in the liberated major quartz grains. The crushing is concentrated on intergranular material.

Specimens (S12330) [NN 2090 5735]; (S2331) taken from the one foot of "banded breccia with matrix of flinty crush-rock" of (Figure 27) have much in common with (S12329) [NN 2090 5735]; but it would be impossible to mistake them for sandstone. They have evidently been broken up at various stages of their development. Their small pebble-like lumps of quartzite frequently show intergranular disintegration accompanied by strain-shadowing of fine-grained shattered material. Much of their matrix is dark; and dark and pale streaks have frequently been brought by movement into conspicuously transgressive relationships. Some of the dark matrix of (S12331) [NN 2090 5735] has partially cleared in a reticulate pattern with what looks like cryptocrystalline devitrification.

The one-inch "flinty crush-rock" shown in black in (Figure 27) is represented by (S12332) [NN 2090 5735]; (S13402) [NN 207 575]; (S13403) [NN 207 575]; (S13403a) [NN 207 575] — about a quarter of its total thickness is included in Plate 11) 3 (p. 211). All these slices reveal virtually complete disappearance of quartzite fragments and continued abundance of unstrained isolated quartz grains, which are set in an evenly banded matrix of paler and darker material. In the paler streaks there is an appearance of microfelsitic devitrification. The three last slices listed above are particularly interesting since they show actual junction of Fault-Porphyrite and flinty crush-rock. Here we see, what can also be recognised in the field, that small, broken felspar xenocrysts are sparsely scattered through much of the flinty crush-rock. They are most numerous close to the porphyrite margin, but some few lie a full centimetre in from the contact. The biggest noted measures only 2 mm whereas the phenocrysts within the adjacent chilled margin of the porphyrite sometimes attain to 3.5 mm. The difference can safely be attributed to fracture. There cannot be any doubt that the crystals have been derived mechanically from the porphyrite, and have not developed *in situ* as porphyroblasts. Every stage of their separation can be studied. They are clearly somewhat broken xenocrysts, though they show no distortion or strain shadows. Where a felspar phenocryst projects from porphyrite into crush-rock we find its exposed side stripped clear of igneous matrix. Well inside the flinty crush-matrix, xenocrysts of iron ore survive along with the felspars, though of course they are rare but biotite xenocrysts seem to be limited to the, immediate neighbourhood of the junction.

It is noteworthy that, in so far as these slices are concerned, and also at Ben Nevis (S14044) [NN 1661 7067], it is the flinty crush-rock (in molten condition) that has eroded the porphyrite (also molten), and not *vice versa.* Thus while the more resistant solids of the porphyrite are to be found in the crush-rock, even for a centimetre in from the edge, the quartz grains of the crush-rock stop practically abruptly where the felsitic crystallisation of the porphyrite's chilled margin starts. There is, however, a very rapid merge of matrix crystallisation, since subdued felsitic texture extends for a fraction of a millimetre among the quartz grains adjoining the porphyrite. The presence of xenocrysts derived from the porphyrite demonstrates, of course, that a corresponding small amount of porphyrite matrix must have been digested, reaching well into the crush-rock; and yet the microscope scarcely hints at its presence.

The broken felspar xenocrysts of the flinty crush-rock are too equidimensional to show significant orientation. The felspar and biotite phenocrysts of the porphyrite are in (S13402) [NN 207 575] orientated parallel to the flinty crush-margin for at least one centimetre in from the same; but in (S13403) [NN 207 575]; (S13403a) [NN 207 575] such orientation is restricted to the immediate neighbourhood of the mutual junction. It is practically certain that the flinty crush-liquid only caught up porphyrite material so long as this latter was a mere film along the fault. Once the porphyrite magma arrived in bulk, the flinty crush-material functioned as a part of its composite chilling margin. (At one point in the exposure chilled porphyrite surrounds a small angular fragment of flinty crush-rock, but such a complication is commonly met with at chilled edges of intrusions.) That the porphyrite should be able to chill in contact with the flinty crush-rock, may at first sight seem anomalous, as the latter almost certainly started considerably the hotter of the two. The explanation is that the very small thickness of the flinty crush-material allowed it to carry only a negligible supply of heat, which was lost rapidly by conduction into the cold down-faulted mass within the cauldron-subsidence.

It is fortunate that we can contrast the margin just described, between contemporaneous Fault-Intrusion and flinty crush-rock, with another margin close at hand where Fault-Intrusion came in contact with flinty crush-rock older than itself. The locality has already been mentioned on the west slope of Sròn a' Choire Odhair-bhig [NN 200 579] (Figure 24), where Main Fault-Intrusion chills against flinty crush-rock that affects Early Fault-Intrusion immediately to the north. (The Main Fault-Intrusion is the same as in (Figure 27), but the flinty crush-rock is entirely different). The microscope shows in (S12935) [NN 201 581] an absolutely abrupt contact. The first crystallisation of the Main Porphyrite takes the form of a quartzofelspathic comb-fringe, a small fraction of a millimetre thick, with the teeth of the comb pointing back into the igneous rock except where they fill, crosswise, narrow cracks reaching into the flinty crush-rock.

The flinty crush-rock thus treated lies along the outer, older branch of the Glen Coe Boundary-Fault as traced in (Figure 24), (Figure 26). While at the locality just described in (Figure 24) it affects the Early Fault-Porphyrite in contact to the north, further east, north of the 2300-ft summit of Stob Mhic Mhartuin [NN 207 575] (Figure 26), it is unaccompanied by any shearing of this intrusion. In fact north of Stob Mhic Mhartuin [NN 207 575] one finds the same type of contemporaneous association between Early Fault-Porphyrite and early flinty crush-rock as has been described for the Main Fault-Porphyrite and main flinty crush-rock making the cliff of (Plate 9). The crushing of the Early Fault-Intrusion at Sròn a' Choire Odhair-bhig [NN 200 579] must be due to a local recurrence of movement.

An excursion to Stob Mhic Mhartuin [NN 207 575] is the most rewarding that can be taken in regard to the boundary-faults of the Glen Coe cauldron; and it is hoped that visitors will not damage the best exposures. The most convenient approach is from the Cnoc nam Bocan signpost on the Glen Coe road (Figure 22), where cars or buses may be parked in an extensive rhyolite quarry (p. 142). From here it is easy and interesting to traverse the hillside north-westwards, following the base of the volcanic series, until on a level with Stob Mhic Mhartuin [NN 207 575] which stands out a prominent, unmistakable little crag. From Stob Mhic Mhartuin [NN 207 575] it is a simple matter to continue along the crest of the summit ridge to visit Coire Odhar-mhòr [NN 196 583] and Coire Mhorair [NN 185 585] of (Figure 24).

The Stob Beinn a' Chrillaiste evidence further east is sufficiently set out in (Figure 28). In this sketch-map only the old road is shown, but the new road lies a few yards to the south-west. The patches of rhyolite and breccia between the Boundary-Fault and the road have already been discussed (p. 151). E. B. B.

Càm Ghleann and Coire an Easain [NN 250 496]

Afterleaving Stob Beinn a' Chrùlaiste [NN 232 564], the Boundary-Fault is obscured by moraine until Càm Ghleann is reached (Figure 29). It is easy, however, to trace a continuous broad band of Fault-Intrusion between the two localities. In Stob Beinn a' Chrùlaiste [NN 232 564] the intrusion is a coarse grey porphyrite, but it rapidly merges into grey "granite" when followed south-eastwards. It may be mentioned here that the Fault-Intrusion cuts, and encloses fragments of, the Moor of Rannoch "Granite". At the same time the junction may be much obscured by interaction. Thus a narrow hybrid zone (S12752) [NN 2379 5521]; (S12753) [NN 2379 5521] in the River Coupall, (S12747) [NN 2493 5459]; (S12748) [NN 2493 5459] in the Etive) may intervene between acid Moor of Rannoch "Granite" (S12749) [NN 2493 5459]; (S12750) [NN 2499 5466] and intermediate Fault-Intrusion (S9129) [NN 2492 5459]; (S12502) [NN 2445 5430]; (S12503) [NN 2408 5503].

In Càm Ghleann, the fault plane, inclining outwards, is very clearly exposed in the river bed, where it is marked by a zone of flinty crush-rock, against which the Fault-Intrusion chills. In Meall a' Bhùiridh the Fault can once more be accurately located, and again the Fault-Intrusion is found to be chilled at its contact.

The Fault-Intrusion continues southward from Meall a' Bhùiridh, but before long loses its main distinguishing characteristic, and ceases to show a chilled interior margin, although probably still bounded on its inner side by the fault plane. Beyond this it joins the Cruachan "Granite" at the point where the latter sweeps across the fault into the sunken mass within. A rather sudden change from grey to pink "granite" occurs in the crags north of the stream from Coire an Easain [NN 250 496].

The Early Fault-Intrusion shown in (Figure 29) is a grey diorite. It presents a chilled edge against an inner branch of the Fault. The interesting feature of this chilled edge is that it shows evidence of what may be contemporaneous shearing — but see p. 174. The phenocrysts are strongly deformed, especially the ferromagnesian elements, which are drawn out into filmy aggregates of biotite. The intrusion shows no evidence of crushing following its consolidation, but its early date is indicated by its truncation by the main Fault-Intrusion.

Turning back we may note that a small mass of diorite, of similar type to the Early Fault-Intrusion just described, is found a little distance within the Boundary-Fault in Càm Ghleann, where (Figure 29) shows it without ornament at the bend of the stream. It rests with an even base upon a gently inclined plane marked by intense shearing of the underlying schists. E. B. B., G. W. G.

Conclusions

In dealing with the relations of. the crush-rock and the Fault-Intrusion as exposed in Stob Mhic Mhartuin [NN 207 575], it was pointed out that the intrusion must have risen along the fault while subsidence was still proceeding. The same conclusion can be established on quite other grounds. As the Fault-Intrusion is constantly chilled against the fault plane, its introduction did not antedate the movement of subsidence. Equally certainly it cannot have been later, or else there would have been no cause to prevent the intrusion entering the schists inside the fault, for outside it has pierced these same schists with the greatest possible freedom. The faulting and intrusion were therefore contemporaneous; wherever the magma rising up the fault fissure trespassed into the subsiding mass it was carried down. Moreover, cold rocks were descending from above, against which the Fault-Intrusion chilled. It did not penetrate them freely. It did not even heat them sufficiently to produce appreciable contact-alteration.

The perfection of the adjustment is surprising. One would scarcely have expected to find the fault surface smooth and unbroken in contact with the Fault-Intrusion, and yet this is a phenomenon repeated in numberless exposures. An explanation has been offered based upon Daly's (1908) conception of stoping. The Fault-Intrusion may have worked its way upward largely by stoping, for it is extraordinarily full of xenoliths. The solid schists, at any rate, must have broken along numerous structural planes of weakness, with a tendency to sink as fragments into the intrusion. The fault plane, as the predominant plane of weakness, would in the process be preferentially stripped clean and bare.

C. T. C., H. B. M., E. B. B.

Even if we admit as probable important small-scale stoping, it is unnecessary to suppose that the abundant xenoliths in the Fault-Intrusion have everywhere suffered net depression. They may often have been carried upwards farther than they have sunk. It has been pointed out (p. 76) that, on the north side of Glen Coe, calc-silicate-hornfels (Ballachulish Limestone) has functioned as an impermeable layer, beneath which Glen Coe Quartzite, in "basement" position, has been riddled with Fault-Intrusion; while, on the south side of the glen, in An t-Sròn [NN 134 550], the same calc-silicate-hornfels has been disrupted by the Fault-Intrusion, which has risen on a large scale into "cover" Leven Schists. Now the Fault-Intrusion of An t-Sròn is strikingly rich in xenoliths of Glen Coe Quartzite. Maufe thought that these had sunk from the "cap" position seen to the south in Beinn Maol Chaluim [NN 140 520]; but it seems certain that "cap" quartzite had been largely eroded from the An t-Sròn area before the Fault-Intrusion rose into position, since just across the fault pre-intrusion lavas rest directly on Loch Achtriochtan phyllites (Leven Schists below the "cap" quartzite position). Accordingly the writer thinks that the An t-Sròn quartzite xenoliths, big and small, have been carried up from the "basement" position. The magma may well have had explosive tendencies, which may have helped it to acquire its wealth of inclusions.

E. B. B.

The occurrence of early branches of the Boundary-Fault, accompanied by Early Fault-Intrusions, distinct in material from the Main Fault-Intrusion, shows that the Cauldron-Subsidence was to some extent completed in stages. On the other hand the frequent development of flinty crush-rock indicates that movement, when movement occurred, was apt to be rapid. That considerable rapidity was sometimes maintained, through thousands of feet of subsidence, is demonstrated by the marked difference of temperature within and without the cauldron as registered in the behaviour of the Fault-Intrusion.

The merging of the Fault-Intrusion with the Cruachan "Granite" on the eastern side of the subsidence probably shows a very close connexion between the two. The Fault-Intrusion is best regarded as an advance guard of the Cruachan "Granite", though portions of it, as at Dalness, had undoubtedly consolidated before the main mass of the "granite" was intruded. The conditions under which the Cruachan "Granite" transgressed the Boundary-Fault and entered the Cauldron-Subsidence are considered in the following chapter. C. T. C., H. B. M., E. B. B.

The inclination of a ring-fault, such as the Boundary-Fault of the Glen Coe Cauldron-Subsidence, is always a matter of interest from the point of view of geomechanics. It is, however, important to realise that original inclination may sometimes have been modified.

Along the south-west margin of the Glen Coe Cauldron both Clough and Maufe have found the main branch of the Boundary-Fault to be inclined steeply and normally, that is inwards in the direction of downthrow. Maufe records the angle as about 70°.

In the southernmost part of this area, at Beinn Ceitlein [NN 176 490], Clough found an exterior branch-fault inclined towards the north-west or west at an angle of about 50°. It is uncertain at present whether this inclination is normal or reversed (p. 89).

No information seems to be available about the inclination of the Gleann Chàrnan [NN 135 500] branch.

Along the northern and north-eastern margin of the cauldron, many exposures north of the Glen Coe road, and isolated ones in Càm Ghleann and Coire an Easain [NN 250 496] show all branches of the Boundary-Fault with outward reversed inclinations at angles of from 70° to 50°.

In the southern summit of Bidean nam Bian [NN 140 543], seen behind An t-Sròn in (Figure 20), Maufe found the lavas of Groups 1 and 2 dragged up vertically close to the Boundary-Fault. This is what might be expected if, at the time of subsidence, the Boundary-Fault had normal inclination, for the descending mass would press on the inwardly directed slope of external country-rock. A problem, however, is presented when we meet similar marginal uptilting all the way along the northern stretch of the Boundary-Fault from Coire Càm [NN 154 585] to Coire Odhar- mhòr (Figure 23), (Figure 24), (Figure 25), in spite of the fact that the fault here has reversed, that is outward inclination.

Various hypotheses may be advanced, for instance:

1. The fault may have been normal to begin with, and may have been rotated by pressure on its original inward slope during the development of internal subsidence.
2. The fault may have been normal to begin with, and may have been rotated by subsequent earth-movement unconnected with the Cauldron-Subsidence.
3. The fault may have been reversed to begin with, and prior to arrival of Fault-Intrusion it may have been kept closed by bending forward of the extetnal country-rock, which, through making frictional contact with the descending internal mass, might lead to marginal deformation.

Attention may be directed to a dynamical interpretation of ring-fractures, advanced by E. M. Anderson (*in* Bailey and others 1924, p. 11; Anderson 1936). In this an outward inclination is expected. As shown above, outward inclination of the Glen Coe Boundary-Fault is not universal and, where it occurs, is open to more than one interpretation. At the same time outward inclination has been observed in a number of other ring-fractures elsewhere coupled with interior subsidence. E. B. B.

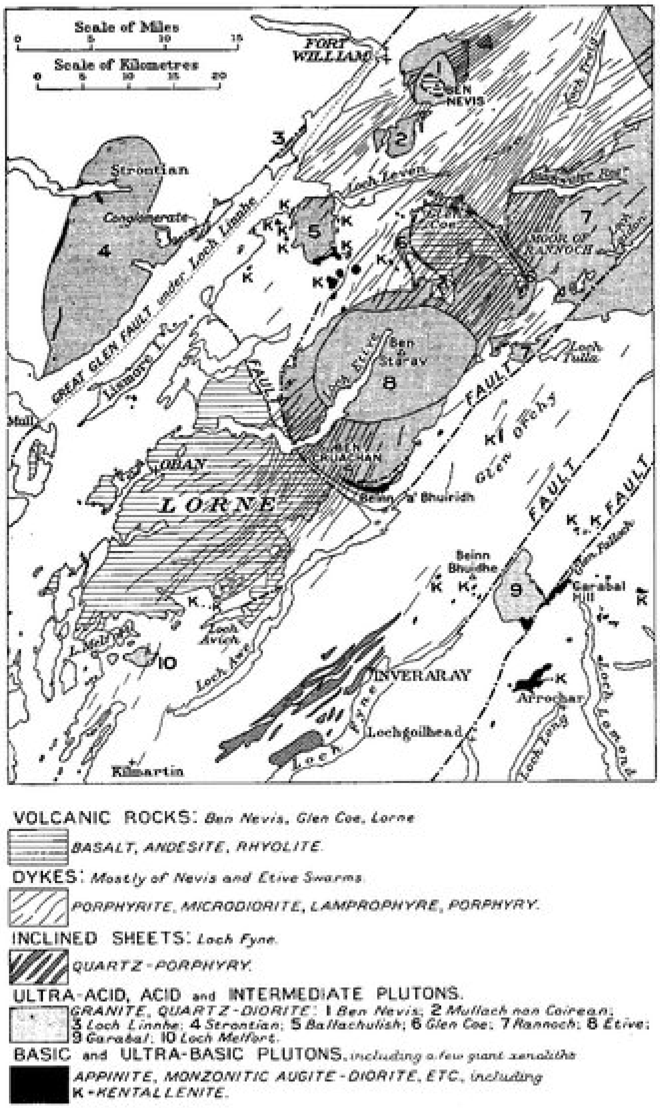


FIG. 18. Map of igneous rocks of South-West Highlands referred to Lower Old Red Sandstone Period

(Figure 18) Map of igneous rocks of South-West Highlands referred to Lower Old Red Sandstone Period.

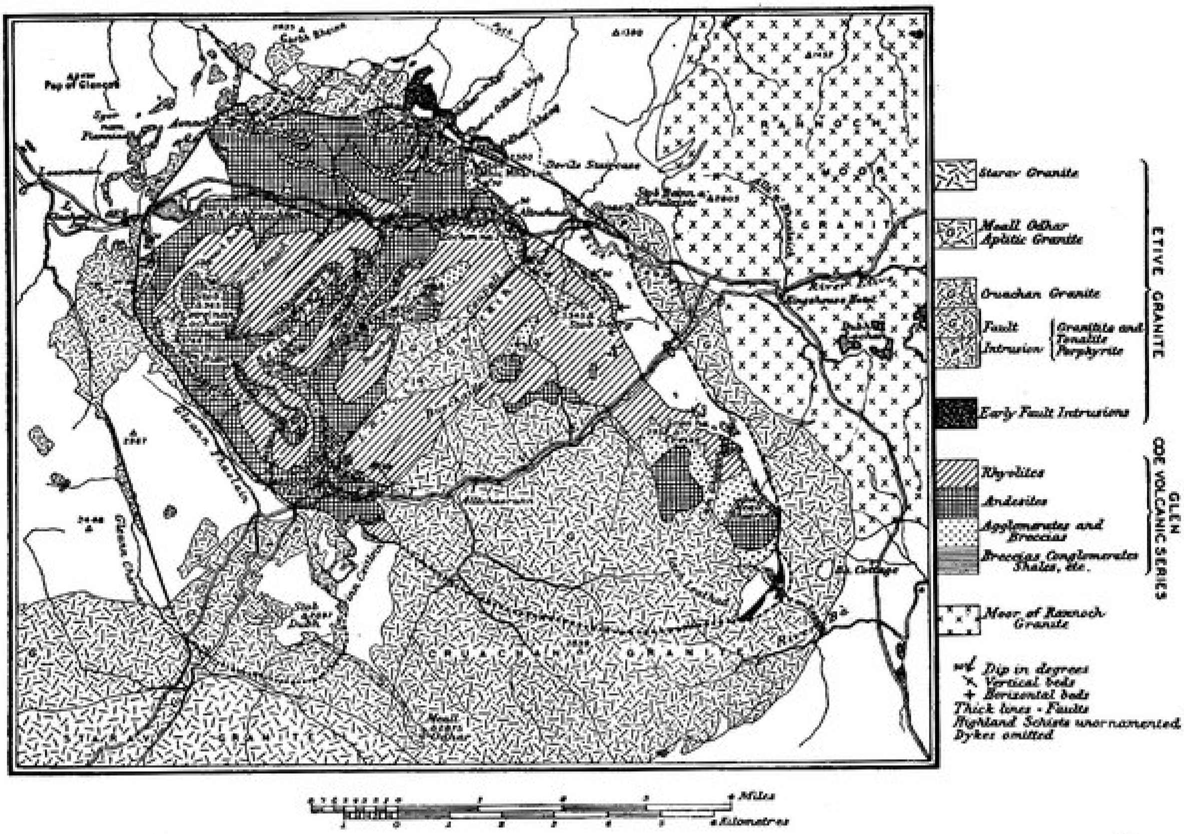


FIG. 19. Map of the Cauldron-Subsidence of Glen Coe and associated igneous phenomena
For new road see Fig. 22

(Figure 19) Map of the Couldron-Subsidence of Glen Coe and associated igneous phoenomena. For new road see (Figure 22).

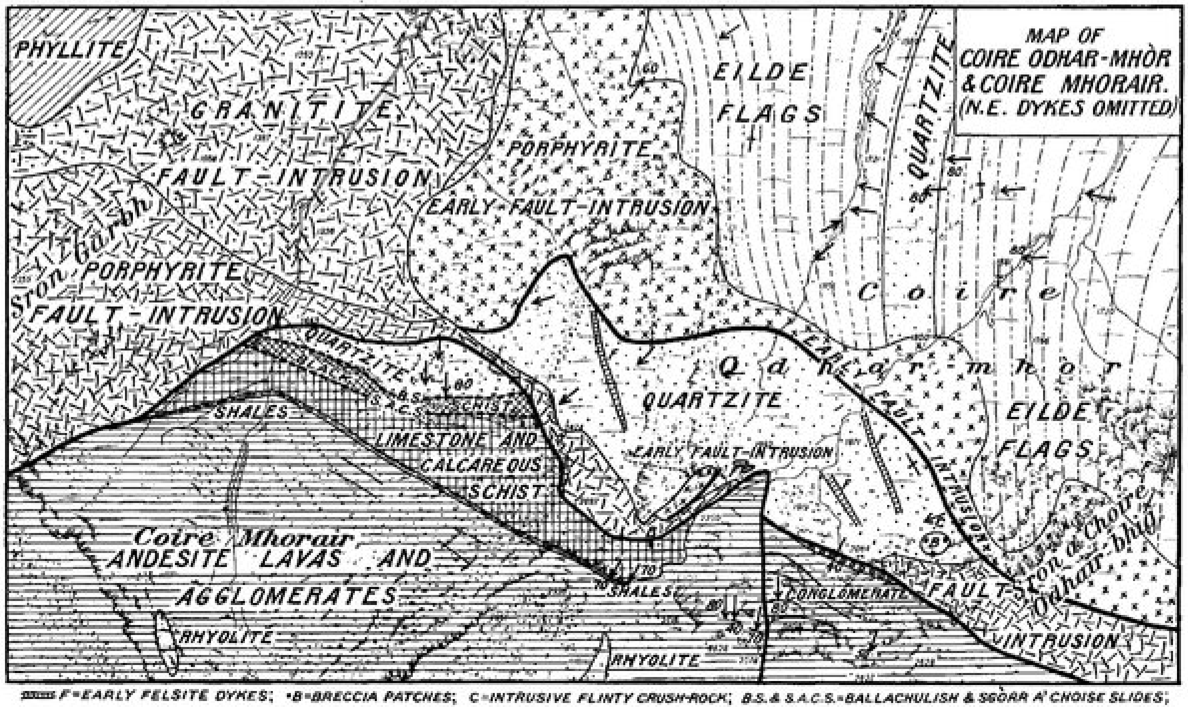


FIG. 24. Map of Coire Mhorair and Coire Odhar-mhòr

(Figure 24) Map of Coire Mhorair and Coire Odhar-mhòr [NN 196 583].

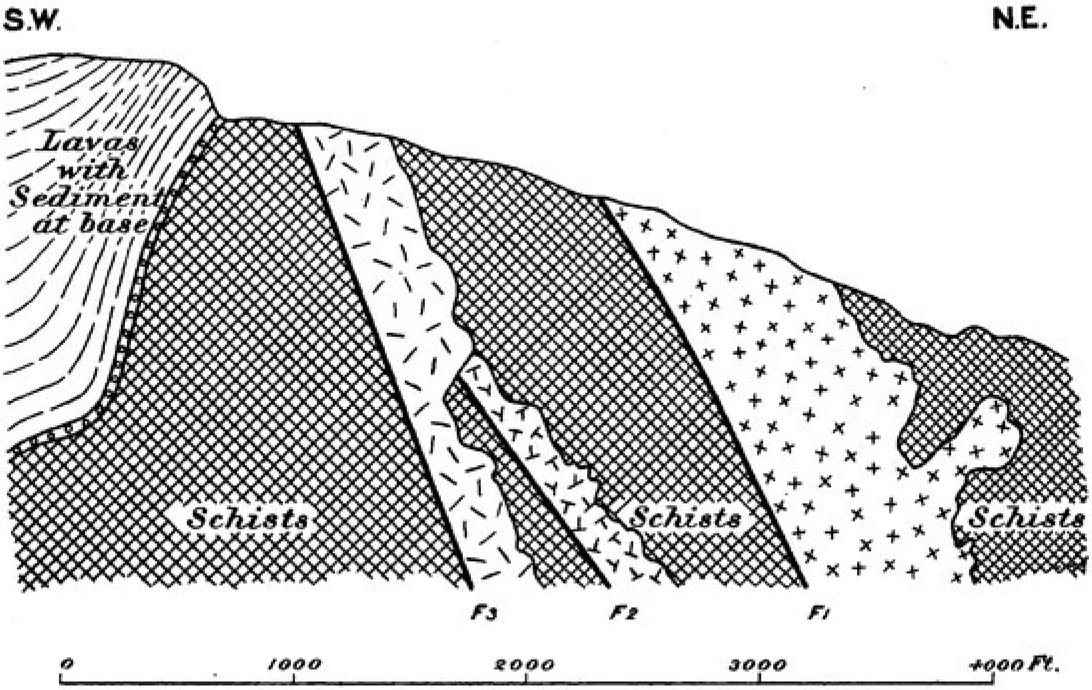


FIG. 25. Section through ridge W. of Coire Odhar-mhòr

F1 and F2 Early Boundary-Faults accompanied by Early Fault-Intrusions. F3 Main Boundary-Fault with Main Fault-Intrusion

(Figure 25) Section through ridge W. of Coire Odhar-mhòr [NN 196 583] F1 and F2 Early Boundary-Faults accompanied by Early Fault-Intrusions. F3 Main Boundary-Fault with Main Fault-Intrusion.

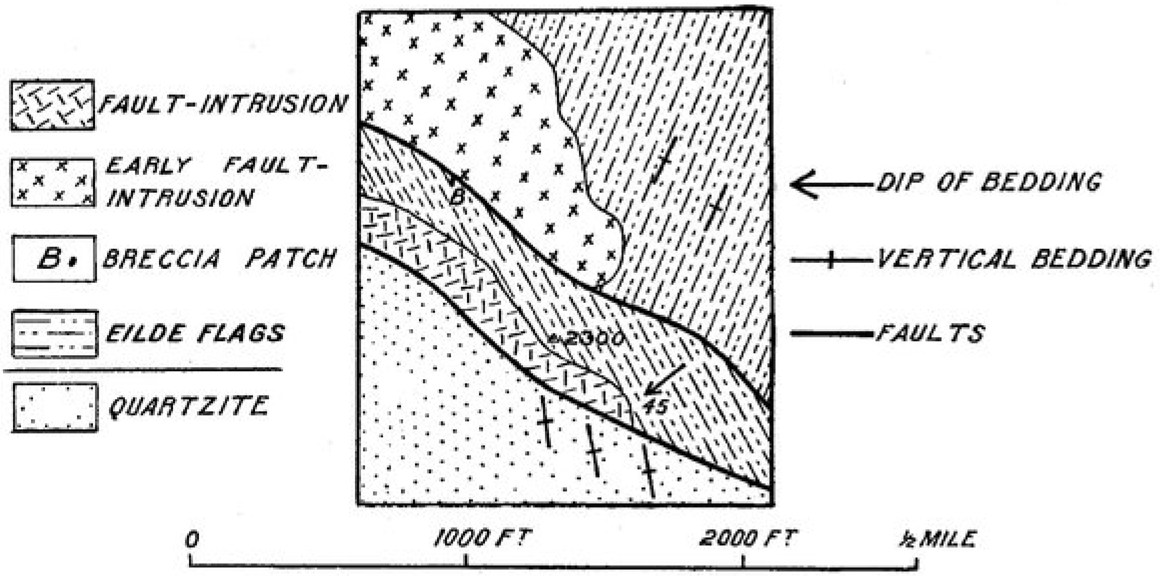


FIG. 26. Map of Stob Mhic Mhartuin. North-east dykes omitted

(Figure 26) Map of Stob Mhic Mhartuin [NN 207 575]. North-east dykes omitted.

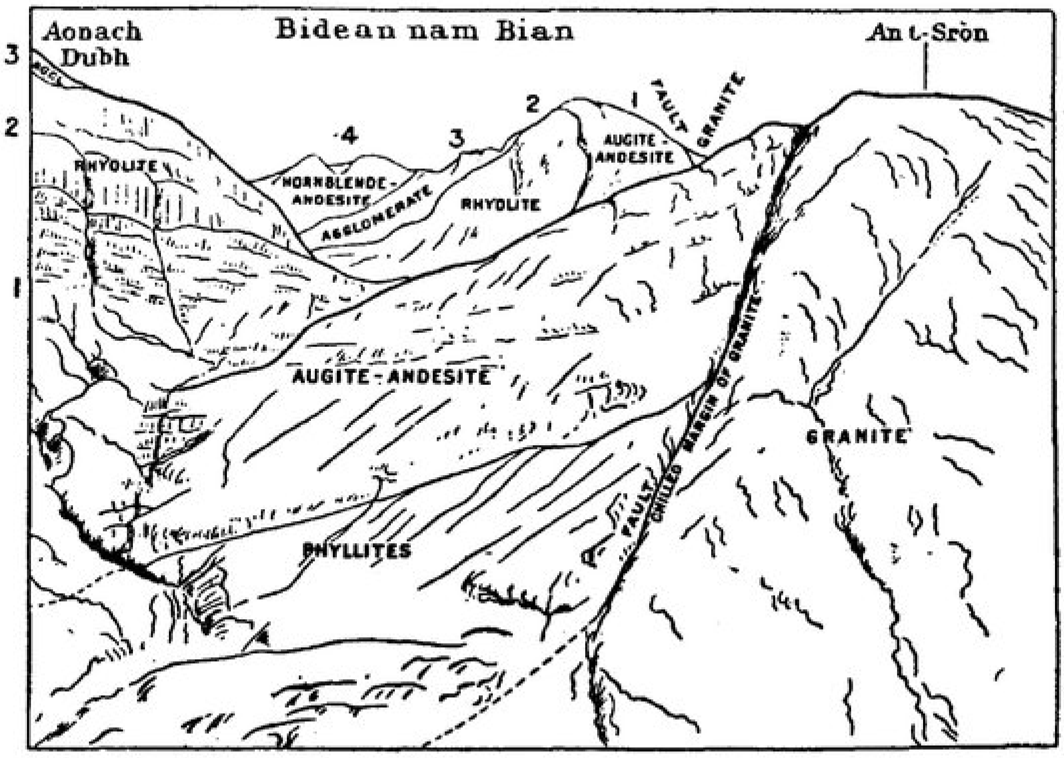


FIG. 20. View of Boundary-Fault of the Cauldron-Subsidence of Glen Coe as exposed in An t-Sròn

(Figure 20) View of Boundary-Fault of the Cauldron-Subsidence of Glen Coe as exposed in An t-Sròn.

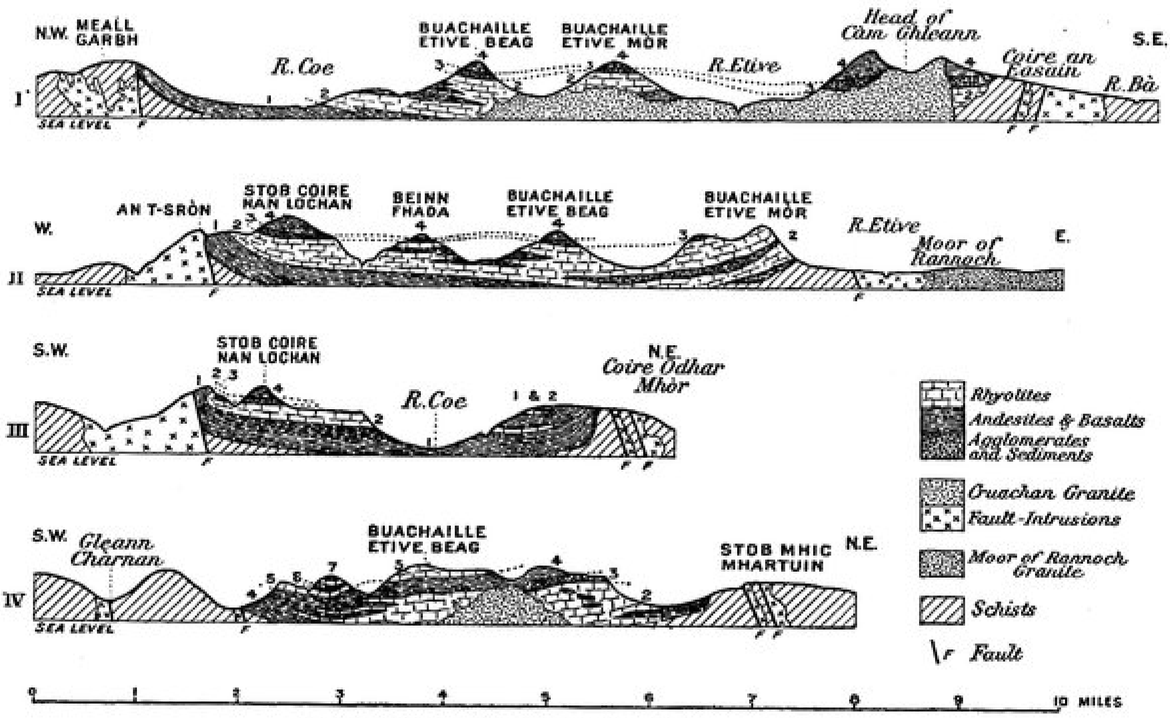


FIG. 21. Sections across the Cauldron-Subsidence of Glen Coe
The numbers 1-7 refer to groups discussed in the text

(At Coire an Easain the boundary-faults incline outwards to S. E., not inwards as shown above)

(Figure 21) Sections across the Cauldron-Subsidence of Glen Coe The numbers l-7 refer to groups discussed in the text (At Coire an Easain the boundary-faults incline outwards to S. E., not inwards as shown above).

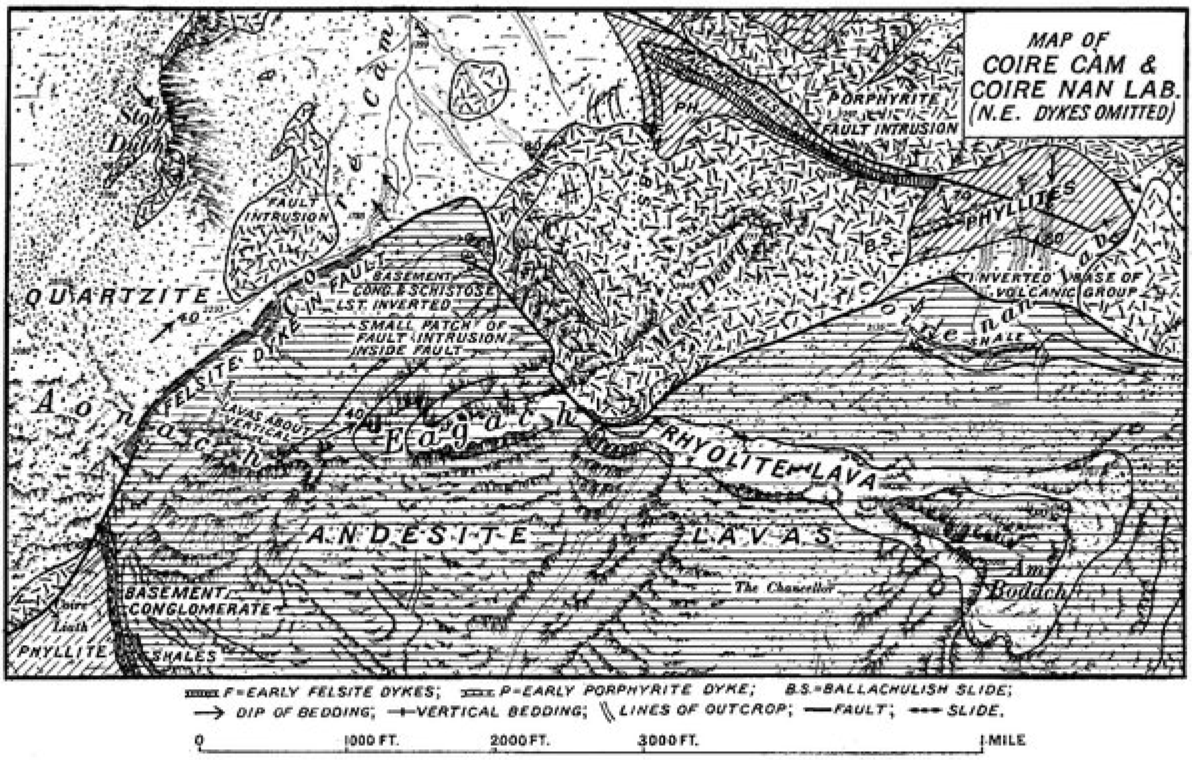


FIG. 23. Map of Coire Càm and Coire nan Lab. North-east dykes omitted. (The Fault-Intrusion is chilled at its contact with the early dykes north of Meall Dearg)

(Figure 23) Map of Coire Càm [NN 154 585] and Coire nan Lab [NN 167 584]. North-east dykes omitted. (The Fault-Intrusion is chilled at its contact with the early dykes north of Meall Dearg [NN 163 585]).

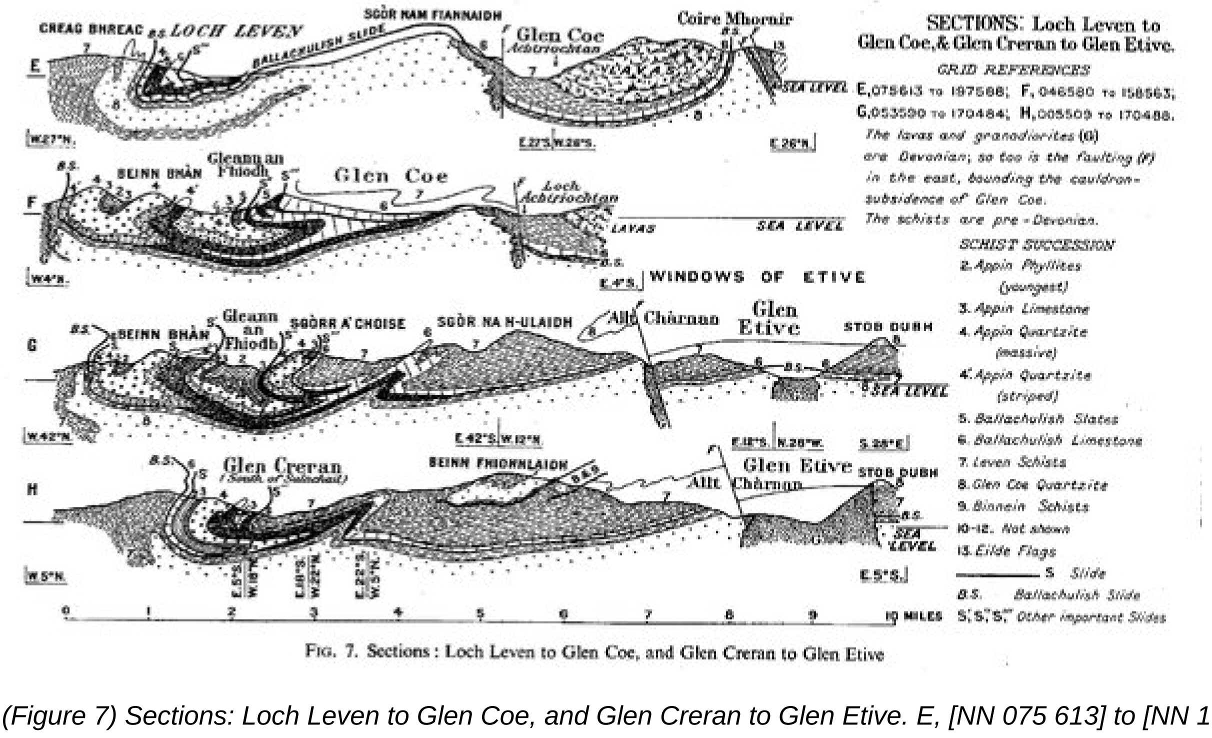


FIG. 7. Sections: Loch Leven to Glen Coe, and Glen Creran to Glen Etive

(Figure 7) Sections: Loch Leven to Glen Coe, and Glen Creran to Glen Etive. E, [NN 075 613] to [NN 197 588]; F, [NN 046 580] to [NN 158 563] G, [NN 053 590] to [NN 170 484] H, [NN 005 509] to [NN 170 488].

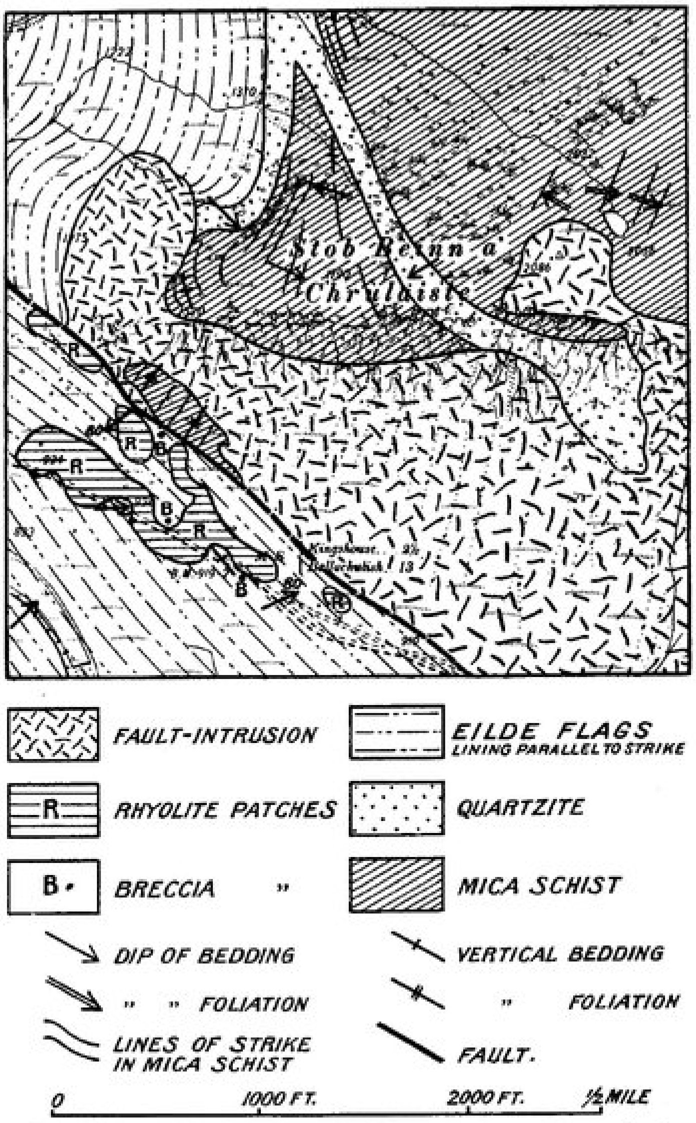


FIG. 28. Map of Stob Beinn a' Chrùlaiste. North-east dykes omitted

(Figure 28) Map of Stob Beinn a' Chrtilaiste. North-east dykes omitted.

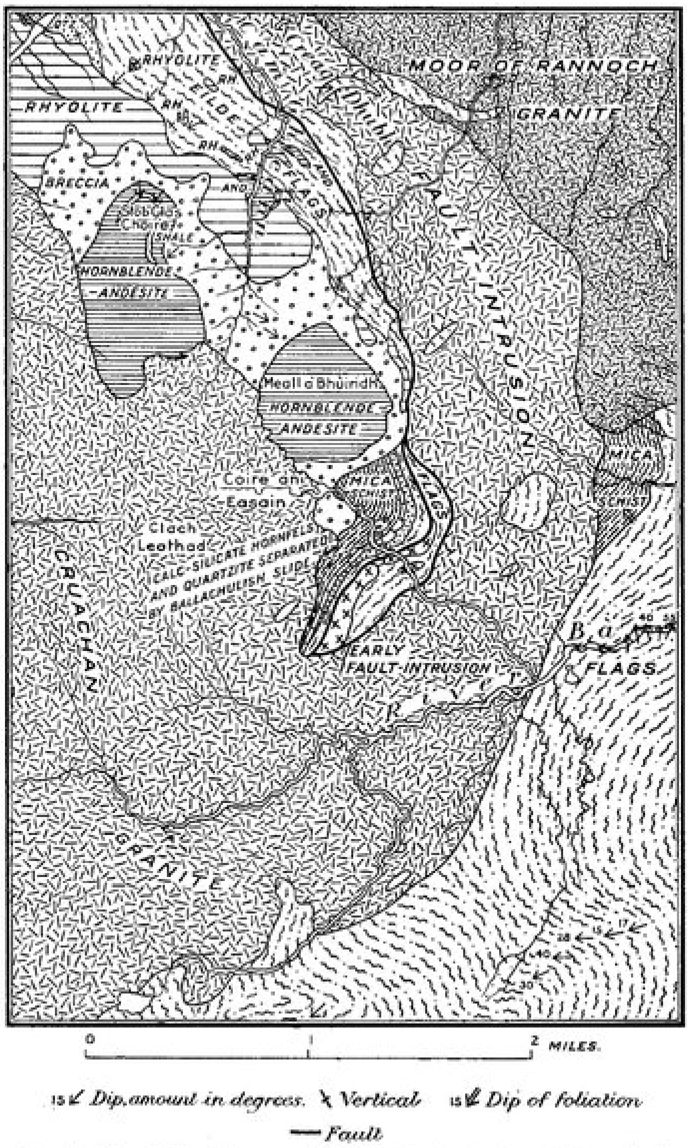


FIG. 29. Map of Càm Ghleann and Coire an Easain. North-east dykes omitted

(Figure 29) Map of Càrn Ghleann and Coire an Easain. North-east dykes omitted.

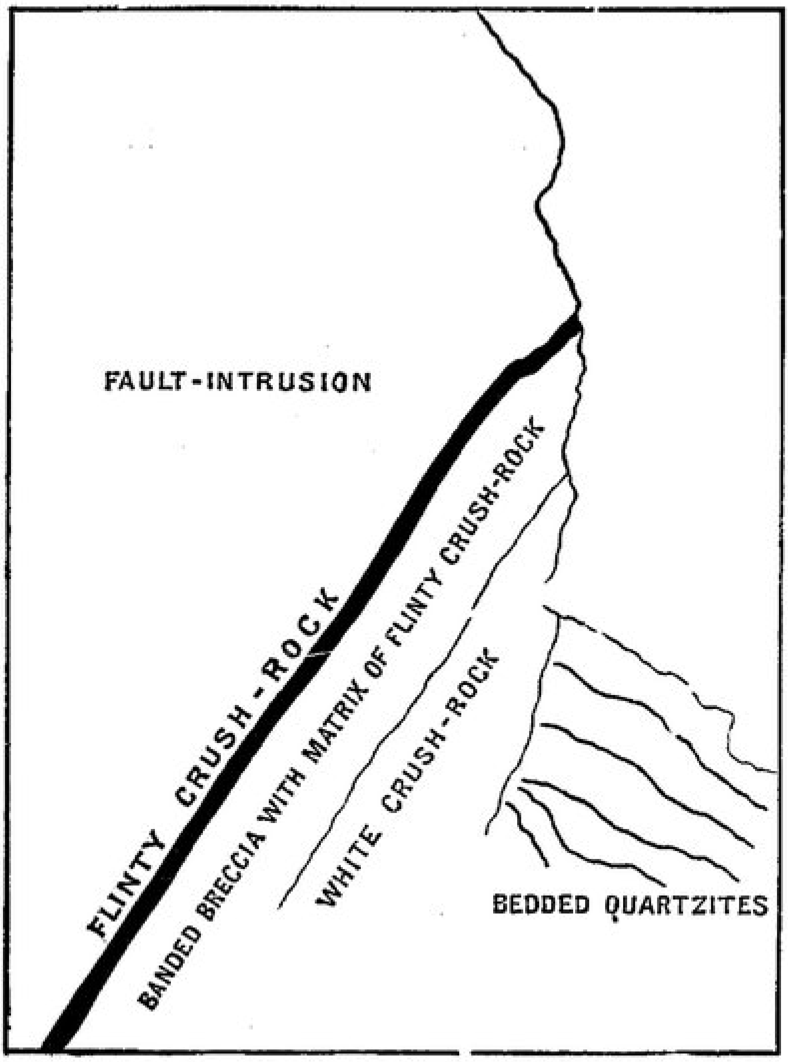
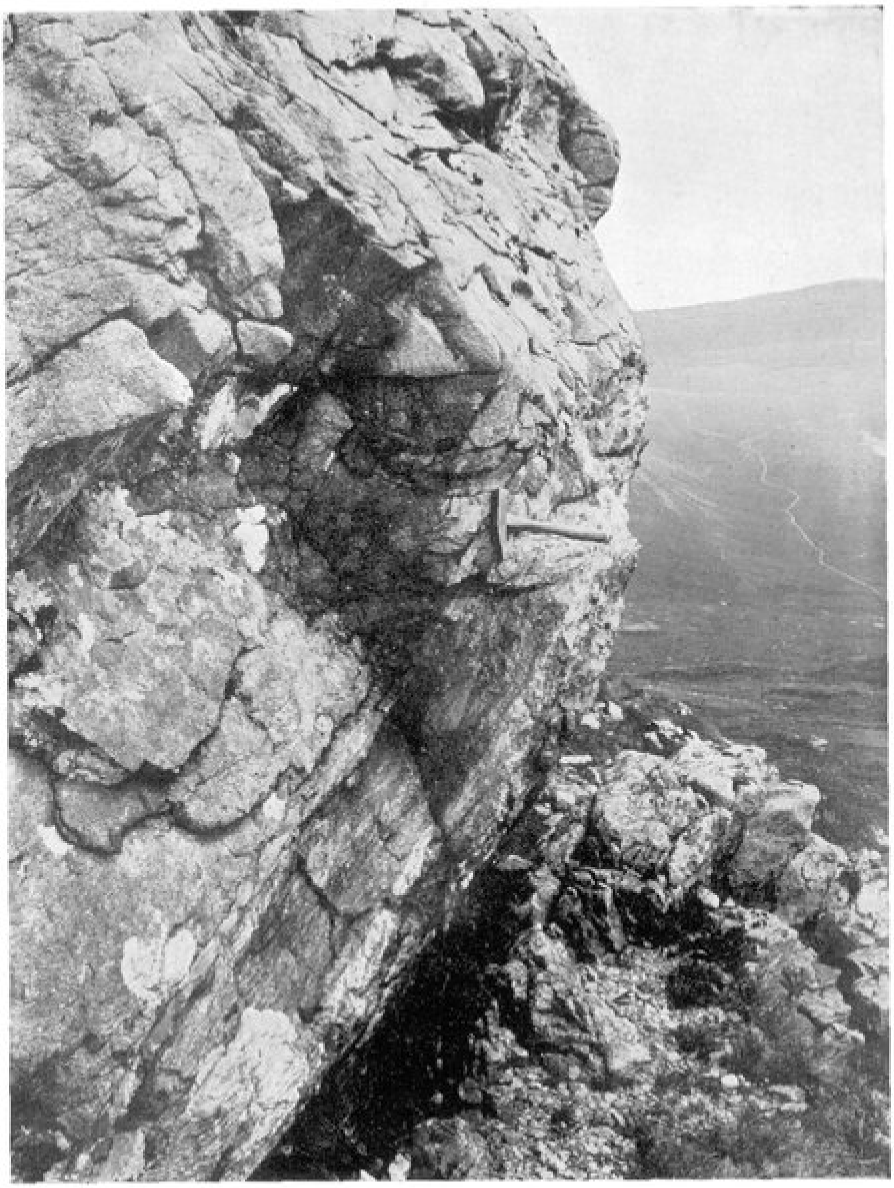


FIG. 27. Diagram explaining Pl. IX

(Figure 27) Diagram explaining (Plate 9). [Glen Coe Fault, Stob Mhic Mhartuin [NN 207 575].].



(Plate 9) Glen Coe Fault, Stob Mhic Mhartuin [NN 207 575].

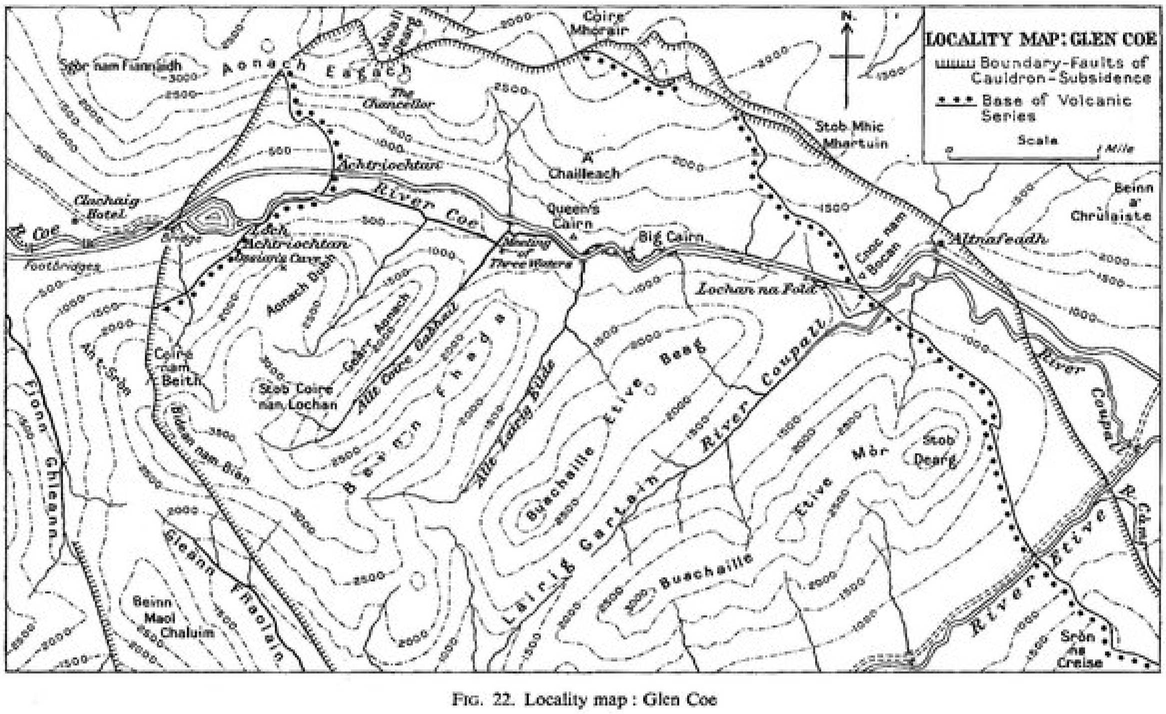


Fig. 22. Locality map : Glen Coe

(Figure 22) Locality map: Glen Coe.