Chapter 13 The Cainozoic igneous rocks

The Northern Granite

General features

The great boss of granite which is the nucleus of the northern portion of the island, has been a subject of interest to geologists since the time of Hutton towards the close of the eighteenth century. Its form is nearly circular, being 8 miles by 7, and its circumference, viewed on the large scale, is very even and regular, with no large projections or detached bosses,<ref>There is, however, a marked bulge to the west of Corrie, showing a departure from the true circular outline of about a mile in a radial direction (*see* One-inch Geological Map, 1910, and (Plate 3)). The long, straight, northeastern boundary between Corrie and Glen Chalmadale is a fault (*see* p. 162), and may be connected with the above-mentioned bulge in some way. G.W.T</ref> and generally its boundary is sharply defined. There are two varieties of the granite; one, of coarse grain and earlier in age, forms the exterior of the mass, while a fine-grained and newer variety occupies the interior. The coarser kind is composed mainly of quartz and orthoclase felspar, with abundance of black or brown mica in certain places, but generally the mica is not conspicuous. Some plagioclase felspar also occurs in the granite. Here and there in the granite, dykes, sheets, and patches of a finer-grained rock occur, and these are not always later intrusions, but rather of the nature of segregations, for they may be seen sometimes to merge insensibly into the general mass. Patches of this kind are not uncommon near the junction of the granite with the surrounding rocks.

Many joints traverse the granite, and these in places are horizontal, or they dip at a comparatively gentle angle, so that the rock has a remarkably bedded appearance. The most marked joints in other localities are vertical, or dip at steep angles into the glens, their inclination not seldom coinciding with the slope of the ground, and forming surfaces which are very difficult to traverse. Occasionally we find more than one set of joints developed in the same rock, *e.g.* both horizontal and vertical joints, but the latter are generally most conspicuous near and parallel to the numerous intrusive dykes.

Some of the finest intrusive junctions of the granite with the older schists in North Glen Sannox were described by Hutton<ref>*See* his Theory of the Earth, vol. iii., p. 220.</ref> more than a century ago, and these and other junctions at Tor Nead an Eoin, and elsewhere on the eastern side of the mass, have since been often referred to, but others quite as striking occur on the east side of Glen Catacol at Madadh Lounie, and in several places north of Meall nan Damh. The granite maintains generally its ordinary coarse character near its junction with the schists, but there are several places where it is fine grained at the margin.

A good junction between granite and schist is seen near the 800-foot contour in the Allt a' Chapuill, west of Sannox. The contacts are sharp but very sinuous in outline. The general line of contact, however, when mapped, shows a lobe of granite projecting downstream. At the junction the granite becomes fine grained and porphyritic, and the schists are hornfelsed with the obliteration of their schistose structure. A marked line of crush intersects the granite near 1073 feet O.D., parallel to a system of vertical joints running in a direction a few degrees west of north. Another joint-system crosses the above at right-angles, and gives rise to straight-sided little gorges in the burn, whereas the former system causes waterfalls.

In Coire na Ciche, at the head of the Allt a' Chapuill, the main structural planes dip south-west, inwards towards the centre of the granite mass. On Cioch na h-Oighe, however, the bare rock surfaces show the usual outwardly-dipping slabs, which are probably exfoliation effects (*see* p. 160).

In the White Water, south-west of Corrie, the junction between granite and the Old Red Sandstone is a fault (*see* p. 162). The granite is well sheeted near the contact, and the sheets dip outwards in conformity with the dip of the adjacent sediments. There are many veins and irregular patches of aplite, which also forms bands dipping with the above-mentioned sheeting. At one place there is a thin vein (¼ inch) of a black compact substance (? pseudo-tachylyte), which on being followed, becomes at first thicker, and then frays out into threads. At the foot of the cascade the granite is dark and biotite-bearing, but the mass of the rock is coarse, miarolitic, and poor in dark minerals.

Along the Stacach arête north of Goatfell, especially near 2659 feet O.D., the granite becomes very coarse, and in places miarolitic. It is cut by thick, irregular masses of fine-grained granite, and by numerous aplite dykes and veins. The latter can also be well studied on the main path from Brodick to the summit of Goatfell. The principal dip of the granite slabs on Goatfell and the Stacach ridge (Plate 3) is to the east at angles varying from nothing to 20°. On the ridge connecting Stacach with The Saddle, separating Glen Rosa from Glen Sannox, there are numerous thick masses and dykes of aplite penetrating coarse granite.

In the Garbh Allt, a western tributary of Glen Rosa, the contact between granite and schist can be seen at about the 700-foot contour, half a mile W.S.W. of the Garbh Allt bridge in Glen Rosa. The granite becomes of appreciably finer grain only within a foot or two of the contact. In Glen Rosa itself the schist-granite contact can be located to within a yard in the bed of the river, a few yards below its confluence with the Garbh Allt. The granite closest to the junction appears to be somewhat more basic than the normal type, is intersected by fine granophyre veins, and shows large miarolitic cavities in which good crystals of smoky and amethystine quartz can he found. G.W.T.

Fine-grained granite

Several writers have described the finer-grained granite in the interior without, however, defining its exact boundaries. It is intrusive in the coarser variety which surrounds it, and is evidently of somewhat later date, but both belong to the same geological period and are probably parts of the same igneous magma, for they have generally the same sets of joints, and are alike pierced by similar dykes of pitchstone, felsite, quartz-porphyry, and basalt. The finer variety occupies nearly all the west side of Glen Iorsa, so that on this side of the island the coarser kind of granite is but a comparatively narrow strip varying from one mile in width to not more than a furlong at Iorsa Loch. On the east side of the Iorsa most of the granite is of the coarser variety, and the boundary between it and the fine is tortuous, some bays of the fine being almost detached and surrounded by the coarse. The fine granite occupies about 14 square miles, which is one-third of the whole granitic area.

All the peaky hills are formed of the coarse kind, the fine variety forming rounded or flat-topped hills, generally of lower elevation. Usually the fine variety breaks up into small slabs, which often so entirely cover the surface of the ground that no solid rock is observable. The debris of this rock is nearly white in colour, while the decomposition of the coarse granite produces a coarse, brown sand. Occasionally, however, the finer granite becomes coarse grained and massive; it then breaks up into larger blocks and forms crags. Good junctions of the two rocks are to be seen on the south side of Beinn Bharrain, on Sail Chalmadale, and in Glen Easan Biorach. South of Beinn Bharrain the junction of the two rocks is generally a vertical line which passes across the jointing, and both kinds of granite may be observed in one and the same slab. In Glen Easan Biorach also, the finest junction at the foot of the stream running north from Creag Dhubh is vertical; but often in this glen the boundary line is not well defined for some yards, owing to admixture of the two kinds. There seems no evidence anywhere that the fine overlies the coarse granite, and the appearances west of Cir Mhòr relied on for the support of this view are certainly deceptive.

In addition to the main mass of finer granite, numerous small dykes and sheets of it have been intruded into the coarse in various places, but most of these are not large enough to be separately mapped. One of the largest detached masses occurs on the top of Beinn Nuis, between the Ordnance Station and the remarkable rock called Caisteal an Fhionn. It is apparently of an oval outline, and its greatest length from north to south about 300 yards. Another is found near the head of Glen Sannox on the south side of Caisteal Abhail, where the rock has a markedly jointed structure. In this is a closely laminated band of fine granite, about 9 feet in width, which may be traced for 100 yards or more. This is a peculiar rock, and differs from the fine granite which surrounds it in having an approach to a linear arrangement of the quartz in the rock, and it weathers into such thin plates or slabs that at first sight it reminds one rather of a schist than of a granite. Its laminae, however, dip steeply to the west, exactly in the same way as do the joints in the neighbouring fine granite. In some places it has the appearance of an injected vein.

Drusy cavities containing smoky quartz and orthoclase crystals are common in both granites.

A granitic or granophyric dyke occurs in Glen Chalmadale to the east of Lochranza, and appears to have an N.N.W. course. It crosses the main stream of the glen at a point nearly due north of the hill called the Clachan and 200 yards south-east of the foot of a branch burn called Allt na Meanie which comes in from the north. The rock is light-coloured, of rather fine grain, has many small drusy cavities, and altogether much resembles some varieties of the finer granite of the interior or the granophyre of the southern tract. The dyke is from 25 to 30 feet wide, but only the central portion appears to be granitic; the edges are finer in grain and of a darker colour, and are probably of intermediate or basic composition. The dyke appears again in Allt na Meanie, but cannot be traced continuously. Rock, however, of the same character appears at the head of a burn a mile distant to the north-west and a little to the south of the most westerly of the old slate-quarries. This is quite three-quarters of a mile distant in a straight line from the edge of the great granite mass.

The granite dykes which are found within the granite area are much finer in grain than even the fine-grained mass of the interior; they are, in fact, of the nature of elvans, and seem essentially composed of felspar and quartz. W.G.

Petrography

Dr. A. Harker's account of the petrography of the northern granite mass is as follows:<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, pp. 104–105.</ref> The first microscopical investigation of the Arran granites was made by Prof. Zirkel,<ref>*Zeits. deuts. geol. Ges*., vol. xxiii., 1871, pp. 6–9.</ref> whose account of the rocks was published in 1871. Mr. Teall<ref>British Petrography, 1888, p. 328. See also *Ann. Rep. Geol. Surv.* for 1896, pp. 75, 76.</ref> added to this some particulars, and, like Delesse, compared the Arran granites with those of the Mourne Mountains in Ireland, doubtless also of Tertiary age. Several writers have recorded the occurrence of special minerals in the druses of the granites.

Although the northern area of granite has been separated into coarser and finer varieties, the rocks do not differ in any important particular, excepting texture. They are biotite-granites, with some tendency to granophyric modifications. A specimen of the coarse type from the top of Goatfell (S9469) [NR 911 415] shows crystals of felspar up to 0.5-inch long and quartz-grains and mica-flakes up to 0.25-inch. The rock of the central part of the area is of considerably finer texture; and the same is true of apophyses, in which also there is sometimes a porphyritic tendency, indicated by the occurrence of a few relatively large crystals of felspar (S9476) [NR 97 47]. It can be seen in the hand-specimens that the quartz tends to form grains, which are sometimes enclosed in the felspar; also that the biotite, which occurs only sparingly, is often in very irregular shapes, having crystallized after part of the felspar. Another feature, very conspicuous in most of the rocks, is the occurrence of numerous, little drusy cavities of irregular form, on the walls of which the quartz and felspar assume good crystal-faces.

Thin slices reveal no other mineral, except an occasional grain of magnetite and some minute crystals of zircon enclosed in the biotite. The felspar is partly striated oligoclase, but chiefly what more resembles orthoclase. Much of the latter, however, has a fibrous appearance, becoming more evident with incipient alteration, and probably indicating a microperthitic intergrowth. The quartz contains many minute fluid-pores with bubbles, and in some of these cavities Zirkel detected minute cubes of salt. The mineral is generally idiomorphic towards the orthoclase and microperthite, but it also tends to be intergrown in an irregular fashion in those felspars. In the finer-grained type of rock the micrographic inter-growth is sometimes more regular, and one specimen from Glen Catacol, at the foot of Allt nan Calman, is a very beautiful granophyre (S9471) [NR 916 455]. It contains much micropegmatite of a very delicate kind, which is often grown round the felspar crystals, and, when it surrounds orthoclase, has its felspathic element in crystalline continuity with the crystal itself.

The granites of the northern and larger area, coarse and fine together, belong thus to a well-characterised type. The British rocks with which they compare most closely are undoubtedly those of the Mourne Mountains. The other British Tertiary granites — such as those of Skye and Mull — are usually hornblendic or augitic, and they run more frequently than these into granophyric varieties. An interesting point in common between the Arran and the Mourne rocks is the occurrence of special minerals in the druses. Albite, beryl, topaz, and garnet have been recorded in the druses of the Arran granite, besides stilbite (Macculloch).

'A specimen from an isolated area of coarse granite in North Glen Sannox is found to be identical with the rock of the main mass (S9475) [NR 973 481]. Some dykes traversing the mica-schists show a very different micro-structure. Two examples have been examined, one from Glen Chalmadale and the other from S.W. of the Cock slate-quarry (S9482)

[NR 96 48], (S9483) [NR 96 50]. They are fine-textured but still drusy rocks of pale colour. Both are found to be typical spherulitic granophyres. Crystals of quartz and felspar of small dimensions are enclosed in the spherulitic groundmass and have often served as nuclei for the spherulites. The inclusions in the quartz are here of glass, not of liquid.'

In some slices the plagioclase felspar is nearer albite than oligoclase. The analysed rock (S24380) [NR 981 394], from the Rosa Water, half a mile above its confluence with the Garbh Allt, is a coarse-grained variety which corresponds in all particulars with Dr. Harker's description. The aplite dykes and veins are white or light-grey rocks with a typical saccharoidal texture, and are composed of an allotriomorphic mixture of soda-orthoclase and quartz, with a little oligoclase-albite, and a few shreds of biotite. A specimen collected from the eastern face of Cir Mhòr (S25074) [NR 970 430] is comparatively rich in biotite.

The chemical composition of the dominant coarse-grained variety of the northern granite is given in (Table 3), (Table 7). In heavy residues from specimens collected at the same locality Dr. W. Mackie has found fluorspar; but fluorine, which was specially tested for by Mr. B. E. Dixon under the direction of Mr. R. Sutcliffe, of the Survey Laboratory, could not be detected in the analysed specimen. The composition of the northern granite is generally similar to that of the granophyric granite of the Allt nan Dris (Table 5), (Table 9), and the quartz-porphyry of Bennan Head ((Table 6), II) amongst Arran rocks. Both these rocks, however, are poorer in alkalies, especially potash, than the northern granite; the Bennan Head quartz-porphyry is also poorer in soda. None of the analysed granites or granophyres of Mull is strictly comparable with the Arran granite; and the only comparable Skye granite is that of the Beinn an Dubhaich boss, of which the silica percentage is 76.71. Dr. A. Harker includes this granite with those of Arran, St. Kilda, and the Mourne Mountains, as a subgroup of the British Cainozoic granites in which the silica percentage ranges from about 75 to 77, and the ferro-magnesian mineral is characteristically biotite.<ref>The Tertiary Igneous Rocks of Skye, *Mem. Geol. Surv.,* 1904, p. 153.</ref> In the second subgroup, to which some of the acid plutonic rocks of Skye, all those of Mull as yet analysed, and some of the other Cainozoic centres, belong, the silica percentage is from 70 to 72, and the ferro-magnesian minerals are hornblende and augite. This subgroup seems to be practically identical with the acid end-members of the craignurite series.

(Table 3)

	7	I	J	K
SiO_2	74.87	76.71	72.78	75.00
$A1_2O_3$	11.24	—	—	13.24
Fe_2O_3	0.34	—	—	2.52
FeO	1.22	—	—	—
MgO	0.22	—	—	—
CaO	1.30	0.47	—	0.69
Na_2O	3.31	—	4.08	3.07
K_2O	5.68	—	5.18	4.33
H_2O>105°	0.49	—	—	0.80
H_2O<105°	0.29	0.22	0.34	—
TiO_2	0.26	—	—	—
P_2O_5	0.09	—	—	—
MnO	0.05	—	—	—
CO_2	0.49	—	—	—
FeS_2	0.33	—	—	—
Cr_2O	0.02	—	—	—
BaO	0.04	—	—	—
Li_2O	0.00	—	—	—
F	100.24			99.65

7. ((S24380) [NR 981 394]. Lab. No. 820. Biotite-granite, northern granite mass, Glen Rosa, half a mile above confluence with Garbh Allt, Arran. *Anal.* B. E. Dixon.

(S8693) [NG 621 201]. Granite of Beinn an Dubhaich boss, Allt Cadha na Eglais, Skye. *Anal.* W. Pollard. Quoted from A. Harker, Tertiary Igneous Rocks of Skye, *Mem. Geol. Surv.,* 1904, p. 153.

(S8856) [NG 495 227]. Riebeckite-granophyre, between Meall Dearg and Druim an Eidhne, Skye. *Anal. W.* Pollard. Quoted from A. Harker, Tertiary Igneous Rocks of Skye, *Mem. Geol. Surv.,* 1904, p. 153.

Biotite-granite, Slieve Corragh, Mourne Mountains, Ireland. *Anal.* S. Haughton, *Quart. Journ. Geol. Soc.*, vol. *xii.,* 1856, p. 192.

A partial analysis of the Beinn an Dubhaich granite, and an old analysis of the Mourne Mountains granite, are tabulated for comparison with the analysis of the Glen Rosa rock. The calculation of the norm of the latter gives quartz, 32.6; orthoclase, 33.6; and albite, 26.2 per cent. There is no anorthite as the available alumina is fully satisfied by potash and soda, leaving an excess of soda which goes to form about i per cent. of aegirine. This peculiarity of composition is perhaps significant in view of the tendency for mgirine and riebeckite to occur in some acid members of the Cainozoic igneous suite of the Western Isles. In this connection it may be noted that a partial analysis of the riebeckite-granophyre of Skye ((Table 3), J) shows figures for silica, soda, and potash, which do not differ widely from those of the Arran rock. G.W.T.

Metamorphism around the Northern Granite

The alteration of the surrounding rocks by the intrusion of this great mass of granite is much less than might have been expected. Often the metamorphism seems to amount to little more than mere induration, and the adjoining rock is in some cases not more altered apparently than sandstone is near some of the dykes in the island. The fine-grained schistose rocks assume a bluer colour and break with a splintery fracture, while the Old Red Sandstone loses its purple or chocolate colour and becomes grey and very hard. Yet in. most cases the bedding still remains distinct, though in some the bedding or foliation is rendered very obscure and a set of joints produced parallel to those in the granite itself. The alteration is perhaps greatest in Glen Rosa, where it seems to extend 300 yards into the schists from the junction. Between Glen Catacol and Glen Easan Biorach the altered and hardened schist band is 200 yards wide or more, and it forms a marked ridge which is higher than the granite adjacent, and it also gives rise to gorges in the two streams.

Under favourable circumstances certain minerals appear to have been developed in adjacent rocks by the action of the granite, as andalusite in the schists of North Glen Sannox, and epidote in the altered rocks at the White Water junction, and at Allt a' Chapuill near Cioch na h-Oighe. Biotite has also been developed at the White Water by contact alteration. Perhaps the most marked instances of metamorphism are those which are found in certain basic dykes which -are of earlier date than the granite intrusion. One of these, penetrated by granite or granophyric veins, is visible in the Cnocan Burn below the old mill-dam.<ref>This dyke is described by Bryce (Geology of Arran, 4th edition, 1872, p. 79), but he does not notice the alteration of it due to the granite.</ref> It is an altered dolerite in which the plagioclase felspars and the patches of iron-ore have retained their original characters, while the augite has been converted into aggregates of pale-green hornblende, with which some brown mica is associated (S7442) [NR 99 39]. On the opposite side of the mass of granite another example of the same kind of alteration is found in a dyke nearly half a mile north-west of Lochan a' Mhill. This was described by Ramsay (Geology of the Isle of Arran, p. 49), who, however, thought that the dyke was intrusive into the granite. One of the most marked examples of alteration by the granite is found in Glen Iorsa, 400 yards W.N.W. of the boathouse, Loch Iorsa. A highly-altered argillaceous schist seems totally reconstituted, and contains abundant andalusite<ref>E. B. Bailey, Domes in Scotland and South Africa: Arran and Vredefort, *Geol. Mag.*, vol.lxiii., 1926, p. 486.</ref> in relatively large irregular crystals, and much finely-divided biotite (S9404) [NR 908 381]. This locality is nearly a quarter of a mile from the edge of the granite. In Glen Scaftigill, near the granite, a gritty schist is highly metamorphosed. There is new-formed biotite in large flakes, and there has been a recrystallization of much of the finer-grained portion of the rock, with doubtful andalusite formed in places. W. G.

The (?) Arenig lavas come into contact with the granite on and near Cnocan Donna, at the north-eastern end of the Suidhe Fhearghas ridge, and half-way between North and South Glen Sannox. The rock here is tough and hard, and has its foliation and other structural planes obliterated. It is much shattered, and hard to identify. The slices (S9385) [NR 980 460]-(S9386) [NR 980 460] may have been cut from specimens of these altered rocks (*see* p. 27). Metamorphosed rocks are found to within 50 yards of the granite *in situ,* but the actual contact is not seen as the junction is marked by a line of swamp.

The altered schist at the Allt a' Chapuill contact (p. 150) is represented by the slice (S9409) [NS 00 44]. It shows numerous angular fragments of a recrystallized quartz mosaic in a fine-grained quartzo-felspathic matrix, in which new biotite has been developed.

At the White Water junction south-west of Corrie the granite is in contact with Old Red Sandstone, but the junction is undoubtedly a fault.' The induration of the Old Red Sandstone does not extend to more than 50 yards from the contact. It is altered to a hard, greenish quartzite, and contains shaly bands altered to a hard, green, flinty material. In general there is little or no new mineral formation save the introduction of epidote and perhaps chlorite; but a slice (S7441) labelled 'altered sandstone, White Water, near granite junction' does show a considerable development of newly-formed biotite in a coarse felspathic grit.

In the Uisge nam Fear, about half a mile south of the White Water junction, a band of schist again intervenes between the granite and the Old Red Sandstone ((Figure 2), p. 54). The latter, however, is distinctly indurated, and consists of dark, glistening quartzite, frequently of a greenish colour through the abundance of epidote. The schist shows foliated and wrinkled surfaces in places, but mostly it is hornfelsed, and hard to distinguish from the indurated Old Red Sandstone. Much of it must originally have been a quartz-schist, but is now metamorphosed to banded quartzite (S9406) [NS 010 410], with but little new mineral formation. Other more basic types have been baked to dark-green epidotic hornstones. This mineral appears to be cordierite with well-developed sector twinning. G.W.T.

Similar induration effects, epidotization, and discharge of the natural brown and red colours of the Old Red Sandstone in favour of greenish and greyish tints, may be noted in the Glen Rosa section, although a band of schist a quarter of a mile thick intervenes between the granite and the Old Red Sandstone. The schist becomes spotted with contact minerals at least 150 yards from the granite margin. Near the confluence of the Garbh Allt with the Rosa Burn there is coarse spotting in a dark hornfels, and half-inch prisms and needles of andalusite become visible on smooth waterworn surfaces. Cordierite is also occasionally developed here, as also in the schists at the contact exposed in the Garbh Allt.<ref>Dr. W. Mackie (personal communication) has recently found blue corundum in the hornfels on the margin of the granite.</ref>

Dr. A. Harker<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, p. 117.</ref> has described basaltic dykes metamorphosed by the northern granite near the contact exposed in the Cnocan Burn, north of Brodick. His account is as follows:

'A specimen taken in actual contact with the granite shows in a hand-specimen no noticeable peculiarity, but in a thin slice (S7442) [NR 99 39] it is seen that each ophitic plate of augite has been transformed into an aggregate of green hornblende. Occasionally a flake of brown mica is seen, usually clinging about a grain of magnetite. There is no indication that either the felspar or the iron-ore of the original rock has suffered any change, and the metamorphism is thus not of an extreme kind. Two dykes 60 or 70 yards from the granite in Glen Sannox Burn, one a dolerite, the other probably an augiteandesite, show a lower grade of metamorphism, the augite being replaced partly by little blades of green hornblende but partly by chlorite (S9416), (S9417)':

The most noteworthy feature in the contact metamorphism induced by the northern granite in the surrounding rocks is the differing grades of the alteration as it affects the Old Red Sandstone and the Dalradian schists respectively.<ref>G. W. Tyrrell, Excursion to Arran, *Proc. Geol. Assoc.,* vol. xxxv., part iv., 1924, pp. 407–408.</ref> The latter show a considerable degree of induration, hornfelsing, and new mineral formation. Within 100 yards of the granite margin new-formed biotite is common; closer in, andalusite and cordierite make their appearance. On the other hand the Old Red Sandstone (with one exception, *see* above, p. 157) has undergone little or no mineral change. It has been indurated and epidotized to short distances from the contacts.

One explanation of these facts is based on the different stratigraphical and structural positions of the Dalradian and the Old Red Sandstone with respect to the granite intrusion. The granite magma may have come into contact with the deep-seated Dalradian rocks when it was highly heated and gasified; but when it reached the more superficial Old Red Sandstone horizon it was at the final stage of intrusion, and was thermally moribund owing to degasification and loss of heat. <ref>G. W. Tyrrell*, Excursion to Arran, Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 408.</ref>

An alternative explanation is that the granite magma never came into actual contact with the Old Red Sandstone at all (at any rate, at the horizon of present-day exposures), and was always separated from it by a band of schists, with the result that the Old Red Sandstone was always at the remote periphery of the contact aureole. The actual contact of granite and Old Red Sandstone in the White Water, Corrie, is due to faulting. This explanation is supported by the fact that the Old Red Sandstone is altered in the same way, and to the same degree, whether it is in contact with the granite or separated from it by schist. G.W.T.

Tectonics and mode of intrusion

The intrusion of the northern granite and of the neighbouring Central Ring Complex, with the attendant disturbances of the adjacent strata, supply the clues to the tectonic structure of practically the whole of Arran. The late W. Gunn, with his usual perspicuity, noticed the connection between the intrusion of the granite and the general steep outward dip of the adjacent sediments, as is shown by the following quotation:

“On the southern side of the great granite mass, if we compare the dip and strike of the rocks near Brodick Castle and in Glen Shurig with those in the Shiskine district, we find that the Upper Old Red, the Carboniferous, and the Lower Triassic beds have all been nearly equally affected by upheaving or disturbing movements, so that these movements must have been very considerable since the Triassic period. And when we notice a general parallelism between the successive outcrops of these beds and the edge of the great granite mass we are driven to the conclusion that the intrusion of the latter has been the principal factor in causing the present arrangement of the strata in question.” <ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, p. 132.</ref>

The whole question has recently been thoroughly discussed by Mr. E. B. Bailey,<ref>Domes in Scotland and South Africa Arran and Vredefort, *Geol. Mag.*, vol. *lxiii.,* 1926, pp. 482–495.</ref> who has instituted an instructive comparison between the Arran granite uplift, and the similar but greater phenomena of the Vredefort Dome,<ref>A. L. Hall and G. A. F. Molengraaff, The Vredefort Mountain Land in the Southern Transvaal and Northern Orange Free State,' *Vali. d. Kon. Akad. v. Wetensch., Amsterdam* (2), Deel xxiv., No. 3, 1925.</ref> and has published a map and section illustrating the connection between the Arran intrusions and the tectonics of the island. This map has been freely drawn upon in preparing the tectonic map of North Arran (Plate 3).

In an early paper which has been frequently overlooked Mr. John Smith<ref>A New View of the Arran Granite Mountains, *Trans. Geol. Soc. Glasgow*, vol.x., part ii., 1896, pp. 216–256.</ref> put forward a novel and ingenious view of the intrusion of the North Arran granite, based on extensive observations of the dip of the slabby jointing or sheeting. He showed that while the granite slabs dipped outwards towards the schists all around the margins of the mass, in the interior they were arranged in anticlines and synclines corresponding respectively with the mountain ridges and the intervening valleys (*see* map, (Plate 3)). He noticed that near the margins of the intrusion the igneous rock became fine grained, and the sheeting unrecognizable; but as he ascribed the jointing to pre-consolidation causes he was led to the hypothesis of the forcible upthrust of the solid granite to account for the observed phenomena, as is shown by the following quotation:

It is even possible, and indeed even probable, that the granite slabs, while still red-hot, were considerably increased in dip as the rock first began to be moved upwards; but a time would come when this ceased, and when the granite was quietly but forcibly squeezed up through the slate, turning it up on edge, or shearing up through it, as at the north side of the granite area. It was during this period of its history that the surrounding zone of fine-grained granite *i.e.* the contact zone] was formed by re melting from excessive friction, and the contained belt of confusedly-jointed rock was produced by the granite being crushed, and the individuality of the slabs destroyed.<ref>*Op. Cit., p. 254.* </ref>

Smith's main thesis is that the present surface of the granite is near its original surface, which, during the slow rise of the viscous magma, took the mould of the overlying schist roof, the synclines of schist occupying the glens, and the anticlines overarching the ridges.**</ref>***Op. cit.,* Fig. 22, p. 255.**</ref>** The slabby jointing or sheeting is then the expression of the cooling of the granite against the mould of schist. The fatal objection to this view is that the valleys and ridges should run northeast to south-west parallel to the original strike of the schists which then overlay the granite; whereas the only main glens which run in this direction are the upper parts of the Sannox Burns, and the lower part of the Iorsa. In these, however, the synclinal arrangement of the sheeting is poorly displayed or absent; whereas it is magnificently developed in valleys which, like Glen Rosa, run athwart the original strike direction of the schists.

As a matter of fact, the joint-system of the Arran granite was developed long after consolidation, and is mainly due to well-defined tensional stresses (p. 162). The slabby jointing or sheeting which is so apparent at the surface, but little displayed in deep section, is, in all probability, mainly an exfoliation effect, due to temperature variations operating from, and producing rifts parallel to, the present surface of the ground.<ref>*See* T. N. Dale, The Commercial Granites of New England, *Bull.* 738, *U.S. Geol. Surv.,* 1923, pp. 26–36.</ref>

On the western side of the granite mass Mr. Smith has mapped a zone of crushed granite extending in a general north to south direction from Glen Catacol to Glen Scaftigill, both of which run for some distances along this zone, and have evidently been guided by it. The belt of crushing bends to the north-east beyond Glen Catacol, and disappears near Glen Easan Biorach. At the south end of the belt there is a correlative twist towards the south-west (*see* map, (Plate 3)).

The structure of the rocks surrounding the granite is clearly dependent on the intrusion, for in general, as Gunn pointed out, the strikes of the adjacent rocks curve in conformity with the granite margin, and their dips are outward and steep for some distances from the margin. Mr. E. B. Bailey (*op. cit. supra*)has dealt with the structure in detail; and the map (Plate 3) summarizes the observations that have been made by Gunn and by him. A section across the south-eastern edge of the granite mass shows that the adjacent rocks, schists, Old Red Sandstone, Carboniferous, and New Red Sandstone alike, have been sharply uptilted to a distance of 1¾ miles from the margin. A section across the south-western margin shows similar features (Figure 21).

From analogy with the flat-lying Mesozoic rocks of the Hebridean and Antrim regions, and the absence of angular unconformities within them and the post-schist sediments of Arran, it is concluded that the latter were gently inclined until the intrusion of the granite, and that the steep dips are consequently of Cainozoic date.

The granite appears to have been intruded into an almost complete ring of Dalradian schists, the strike of which was originally north-east to south-west, congruous with the strike in the neighbouring parts of Cowal and Kintyre. The dip of the schists was predominantly south-easterly. Hence the intrusion of the granite merely steepened the dip on the south-east margin, where the schists were already dipping outwardly from the granite. In Glen Rosa there appears to have been actual overturning of the Old Red Sandstone, which in places dips towards the granite. On the north-west side the schists were dipping towards the granite, and the uplift produced by the granite, which was firmly welded to the schists, has resulted in the fine synclinal structures of the Catacol and Lochranza region<ref>E. B. Bailey, *op. cit.,* p. 490. *See* p. 21 of this Memoir. Mr. John. Smith also recognized the Lochranza syncline, *op. cit., Fig.* 9, p. 231.</ref> (Figure 21).

On the western and south-western sides of the granite the schists have been dragged round by the uplift, so that the strike swings into approximate parallelism with the margin. Only on the northeastern side of the granite does the schist preserve its original strike in some measure, so that it meets the granite contact at an angle approaching a right angle. Here apparently, the conditions were such that the granite failed to get a grip on the schists, so to speak, and the upward stresses were relieved by faulting, not by bending. In other words, the granite burst its cover on the north-eastern side. Mr. E. B. Bailey<ref>*Op. cit.,* pp. 486, 488.</ref> has shown that in this region the granite is bounded by a great fault, along which marked mylonization effects are to be noted in the White Water section (p. 157). He has continued this fault along the north-eastern edge of the granite, where its extension to the north-west coincides in a remarkable way with the straight eastern shore of Loch Ranza. Southward this fault is made to join up with the curved fracture separating the schists from the Old Red Sandstone on the southern side of the granite (Plate 3). Alternatively the faulting on the northeast and east sides may be explained by the hypothesis that part, at least, of the complicated fault-zone adjacent to the granite on this side (*infra*) pre-dated the granite, and that the latter thus found it easier to make room for itself by continuing the fracturing thus initiated.

It is further to be observed that only in this north-eastern region does the granite come into contact with the Old Red Sandstone. It is inferred that the uplift, taking place here by faulting instead of bending, ultimately brought the granite into contact with the Old Red Sandstone overlying the schists (Figure 21).

Another remarkable feature which is to be correlated with the foregoing is the occurrence of an extremely complicated zone of faulting on the north-eastern and eastern sides of the granite. The disturbed area includes all rocks from the schists to the New Red Sandstone, and is dominated by fractures running in a general north-west to south-east direction, with subordinate lines directed nearly north to south, and east to west. On the northern, western, and southern sides of the granite there are but few faults, and these are concentric with the granite margin (map, (Plate 3)). Beside the major fault separating the schists from the Old Red Sandstone on the south, W. Gunn mapped a fault running parallel to the granite margin about 2 miles east of Dougrie, and another two to the north-east of Pirnmill. Because of their strike at an angle to the granite margin, and their possible earlier fracturing in the Cainozoic directions (especially north-west to south-east), the rocks on the north-east side were structurally weak in relation to the stresses generated by the rising granite magma, and gave way by means of extensive faulting in both tangential and radial directions to the granite margin.

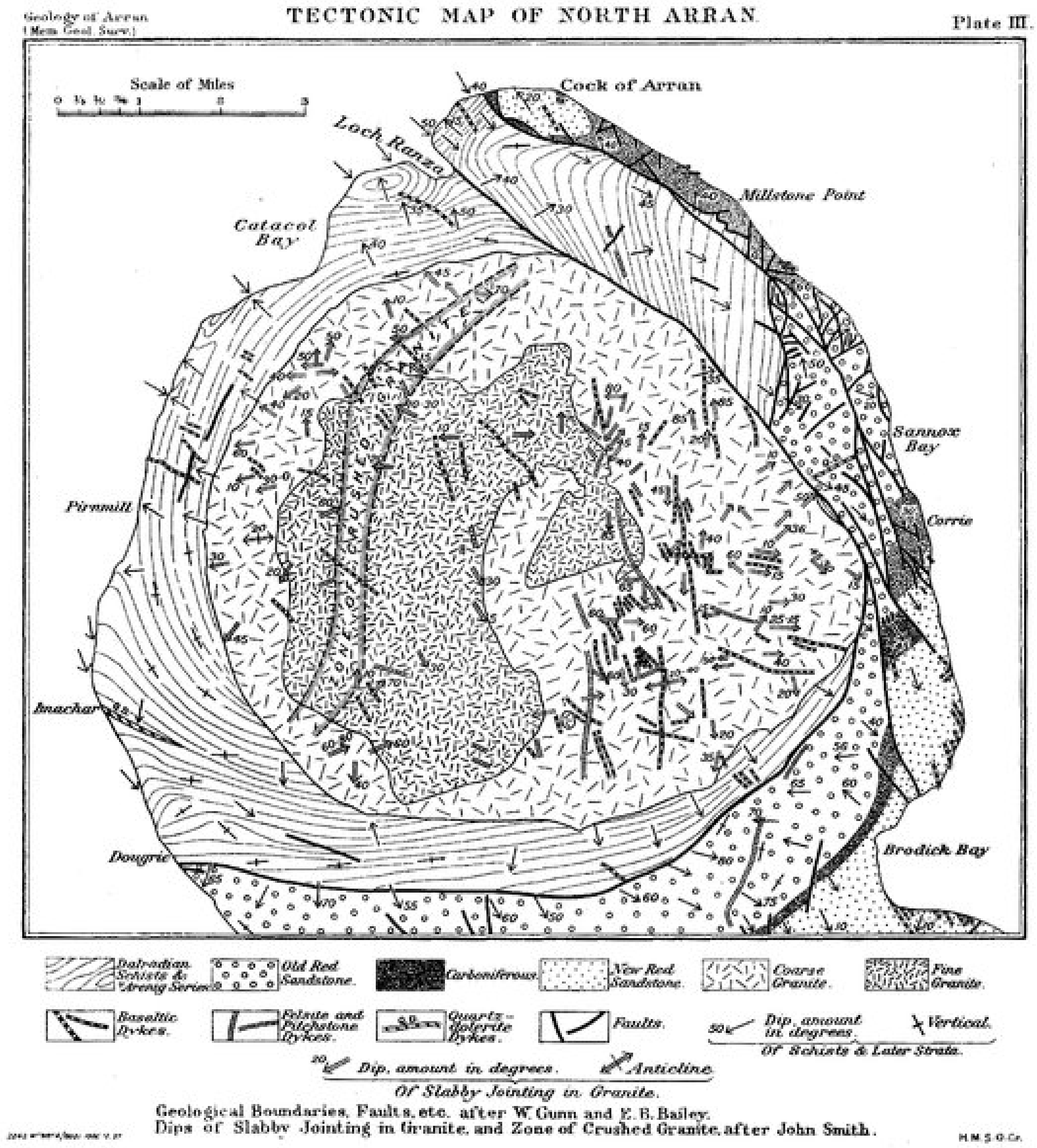
Attention may be here directed to the post-consolidation tensional stresses imposed upon the granite, as evidenced by the directions of the jointing features, and of the dykes intersecting the mass. Much work remains to be done in determining the directions of the joint-systems, as the only data available, those due to John Smith,**<ref>***op. cit. supra.***</ref>** refer solely to the slabby surface jointing or sheeting. It is probable that the vertical joint-systems will be found to conform to the dyke directions. On reference to the map (Plate 3) it will be observed that the dykes run in three main directions; approximately north-west to south-east, north to south, and east to west, directions which, as seen above, are represented in the faulting of the adjacent rocks, and in the zone of crushing on the western side of the granite. Felsitic and basaltic rocks fill rifts in each of these directions indifferently, although basalts are predominant in the north-west to south-east direction, and felsites in the north to south direction. The relative ages of these dyke directions and injections are as yet unknown, and further work is needed before the above observations can be turned to account in determining the tectonic conditions of Cainozoic times in the Clyde area according to the methods of Cloos and his school.<ref>H. Cloos, Tektonik and Magma, Bd. I, *Abh. d. Preuss. Geol. Landesanst.,* X.F., 89, Berlin, 1922, and Das Batholithenproblem, 1923. *See also* R. Balk, *Bull. Geol. Soc. America*, vol.36, 1925, pp. 679–696; G. W. Tyrrell, *Science Progress,* October 1925, pp. 211–213; The Principles of Petrology, 1926, p. 44.</ref> The subject is again discussed in a later chapter (p. 245).

A further question remains as to the mode of intrusion of the granite mass, and the relations of the fine-grained to the coarse-grained variety. The fine-grained variety is known to be intrusive into the coarse-grained, but its three-dimensional shape is unknown. In the Vredefort boss a later plutonic mass, represented only by small outcrops at the present surface, has uplifted a cover consisting of sediments and an even older granite.<ref>E. B. Bailey, *op. cit.,* pp. 491–494</ref> In the Arran example, however, the granite is intrusive into the sediments, and a somewhat younger mass has been injected into it. What were the parts played respectively by the older and coarser, and by the younger and finer granites in causing the peripheral disturbances ? In the absence of data regarding this question Mr. E. B. Bailey (*op. cit. supra*)rightly treats the northern boss as a single unit. He also shows that there has been very little lateral displacement of the adjacent rocks, as indicated by the absence of concentric folding such as there is around the Mull plutonic focus.<ref><*Mull Memoir,* 1924, Chapters XII., XIII.</ref> A great bulk of schist, however, has been displaced by the Arran granite, beside that constituting the lifted cover, now lost by erosion, and consequently the granite must have made room for itself either by stoping, by the subsidence of a cylindrical plug (as, for example, in the Glen Coe region), or perhaps by a combination of these two processes. It may be noted in this connection that the contact of the Arran granite with the adjacent rocks is sharp and clean-cut. Accidental inclusions of the country-rocks are rare even at the margins.

The outcrop of the granite is approximately circular, and it may be inferred from this that we are dealing with a deep-seated cross-section of a cylindrical subsidence filled with granitic magma. It may be conjectured that the process of uplift, with the consequent flexuring of the cover around the periphery of the mass, was initiated and continued to some extent by the coarse granite; and that the process was carried on to its ultimate end, with probably shattering of the cover, and of the adjacent rocks on the north-east side of the mass, by the intrusion of the fine-grained granite. On this view the present outcrop of the fine-grained granite represents the roots of a ring intrusion similar to that of the adjacent

Central Ring Complex with which it also presents great petrographical similarity. The latter, however is cross-sectioned at a considerably higher horizon than the northern boss, and remnants of its split, riven, and shattered cover are still preserved, as well as traces of the volcanic rocks which were erupted at the surface (*see* succeeding chapter). Profound erosion has bitten so deeply into the northern mass that all signs of its shattered cover, and of the probable superficial rhyolites and felsites, have long been removed; and the only fracture that is now visible is the long and deep-seated rent on its north-eastern border<ref>This view was foreshadowed by W. Gunn. *See* Geologv of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 903, p. 90.</ref>

If the North Arran granite has uptilted adjacent rocks as far up as the lower part of the New Red Sandstone, additional evidence is thereby supplied of its Cainozoic age, previously based on petrographic comparison with the post-Mesozoic granite of the Mourne Mountains, and with the granite of the Central Ring Complex, which cuts a breccia containing blocks of Cretaceous limestone. G.W.T.



(Plate 3) Tectonic map of North Arran.

TABLE III

	7	I	J	K
SiO_2 ..	74·87	76·71	72·78	75·00
Al_2O_3 ..	11·24	—	—	13·24
Fe_2O_3 ..	·34	—	—	2·52
FeO ..	1·22	—	—	—
MgO ..	·22	—	—	—
CaO ..	1·30	·47	—	·69
Na_2O ..	3·31	—	4·08	3·07
K_2O ..	5·68	—	5·18	4·33
$H_2O > 105°$	·49	—	—	·80
$H_2O < 105°$	·29	·22	·34	—
TiO_2 ..	·26	—	—	—
P_2O_5 ..	·09	—	—	—
MnO ..	·05	—	—	—
CO_2 ..	·49	—	—	—
FeS_2 ..	·33	—	—	—
Cr_2O_3 ..	·02	—	—	—
BaO ..	·04	—	—	—
Li_2O ..	·00	—	—	—
F	nt. fd.	—	—	—
	100·24	—	—	99·65

(Table 3) [no title].

TABLE VII

	14.	R.	15.	16.	S.	6.	17.
SiO_2	73·20	73·12	72·33	71·51	71·53	69·26	72·37
Al_2O_3.. ..	10·75	12·44	10·45	10·55	12·00	11·60	11·64
Fe_2O_3.. ..	·95	2·09	1·00	·79	2·90	1·31	1·42
FeO	1·02	1·65	2·14	2·22	2·02	2·57	1·08
MgO	·15	·14	·11	·52	·62	1·10	·52
CaO	·76	·88	1·44	1·52	2·33	2·61	1·30
Na_2O	3·78	3·90	4·09	4·12	4·27	2·08	4·15
K_2O	4·20	4·67	3·49	3·48	3·06	3·88	3·98
$H_2O>105^\circ$ ..	4·52	·24	4·02	4·07	·36	1·67	ign.
$H_2O<105^\circ$ ..	·18	·25	·16	·19	·13	1·61	4·86
TiO_2	·16	·39	·30	·33	·64	·45	—
P_2O_5	·19	·09	·16	·24	·17	·10	—
MnO	·37	·17	·50	·42	·36	·45	—
CO_2	—	·05	—	—	nt. fd.	1·76	—
FeS_2	—	nt. fd.	—	—	—	nt. fd.	—
(Ni, Co)O ..	nt. fd.	nt. fd.	nt. fd.	nt. fd.	·02	nt. fd.	—
BaO	·05	nt. fd.	·08	·08	·08	nt. fd.	—
Li_2O	nt. fd.	nt. fd.	tr.	nt. fd.	? tr.	nt. fd.	—
Cr_2O_3.. ..	—	—	—	—	nt. fd.	—	—
S	—	—	—	—	nt. fd.	—	—
V_2O_3	—	—	—	—	nt. fd.	—	—
	100·28	100·08	100·27	100·04	100·49	100·45	101·32

(Table 7) [no title].

TABLE V

	9.	N.	10.	8.
SiO_2 ..	75·65	73.12	53·67	52·43
Al_2O_3 ..	11·89	12·44	15·47	13·50
Fe_2O_3 ..	1·19	2·09	3·24	4·93
FeO ..	1·02	1·65	7·25	7·00
MgO ..	·15	·14	4·90	4·61
CaO ..	·91	·88	8·28	8·25
Na_2O ..	3·44	3·90	2·77	3·27
K_2O ..	4·26	4·67	·80	1·08
$H_2O>105^\circ$	·40	·24	·23	1·64
$H_2O<105^\circ$	·41	·25	1·73	·28
TiO_2 ..	·28	·39	1·28	1·91
P_2O_5 ..	·16	·09	·21	·21
MnO ..	·26	·17	·31	·20
CO_2 ..	·09	·05	·04	·08
FeS_2 ..	nt. fd.	nt. fd.	nt. fd.	·44
(Ni,Co)O ..	·02	nt. fd.	·04	n. d.
BaO ..	·03	nt. fd.	·04	·06
Li_2O ..	nt. fd.	nt. fd.	nt. fd.	·00
Cr_2O_3 ..	—	—	—	·02
	100·16	100·08	100·26	99·91

(Table 5) [no title].

TABLE VI

	11.	O.	12.	P.	Q.	13.
SiO_2	75·22	71·98	54·83	53·97	54·11	55·79
Al_2O_3	12·22	13·13	14·10	14·65	11·65	15·97
Fe_2O_3	2·30	1·33	3·57	3·62	2·76	12·50
FeO	·22	1·64	5·87	6·32	7·02	—
MgO	·06	·56	4·88	4·49	5·30	2·22
CaO	·84	1·15	7·90	7·98	8·77	7·06
Na_2O	2·22	2·98	2·32	2·54	2·63	2·21
K_2O	4·94	4·93	1·73	1·52	1·75	1·86
$H_2O > 105°$ ..	·52	1·38	1·23	·94	·81	Ign.
$H_2O < 105°$ ..	·72	·39	·48	1·92	·68	2·43
TiO_2	·28	·37	·74	1·24	3·37	—
P_2O_5	·18	·19	·24	·27	·58	—
MnO	·25	·14	·37	·30	·21	—
CO_2	·03	—	1·90	·51	·05	—
FeS_2	nt. fd.	—	nt. fd.	·09	·22	—
(Ni, Co)O ..	nt. fd.	—	·03	nt. fd.	—	—
BaO	nt. fd.	tr.	nt. fd.	·04	·03	—
Li_2O	tr.	nt. fd.	tr.	tr.	nt. fd.	—
Cr_2O_3	—	—	—	—	·03	—
Cl	—	·01	—	—	—	—
S	—	—	—	—	—	·45
	100·00	100·18	100·19	100·40	99·97	100·49

(Table 6) [no title].

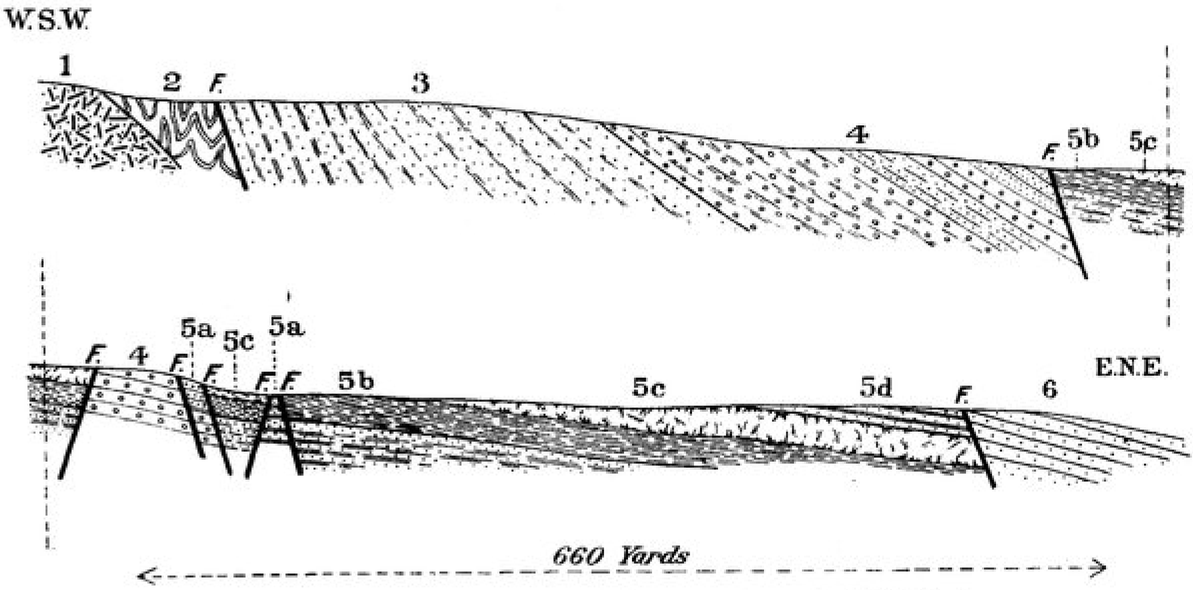


Fig. 2.—*Section along the Uisge nam Fear, half a mile south of High Corrie.*

1. *Granite*; 2. *Dalradian schists*; 3. *Lower Old Red Sandstone*; 4. *Upper Old Red Sandstone*; 5. *Calciferous Sandstone Series*; 5a. *Lower group of sandstones*; 5b. *Basaltic tuffs and red shales*; 5c. *Basalt lavas*; 5d. *Upper sandstones and marls*; 6. *New Red Sandstone* (*Corrie Sandstone*); F. *Fault.*

(Figure 2) Section along the Uisge nam Fear, half a mile south of High Corrie. 1. Granite 2. Dalradian schists 3. Lower Old Red Sandstone 4. Upper Old Red Sandstone 5. Calciferous Sandstone Series 5a. Lower group of sandstones 5b. Basaltic tufts and red shales 5c. Basalt lavas 5d. Upper sandstones and marls 6. New Red Sandstone (Corrie

Sandstone) F. Fault.

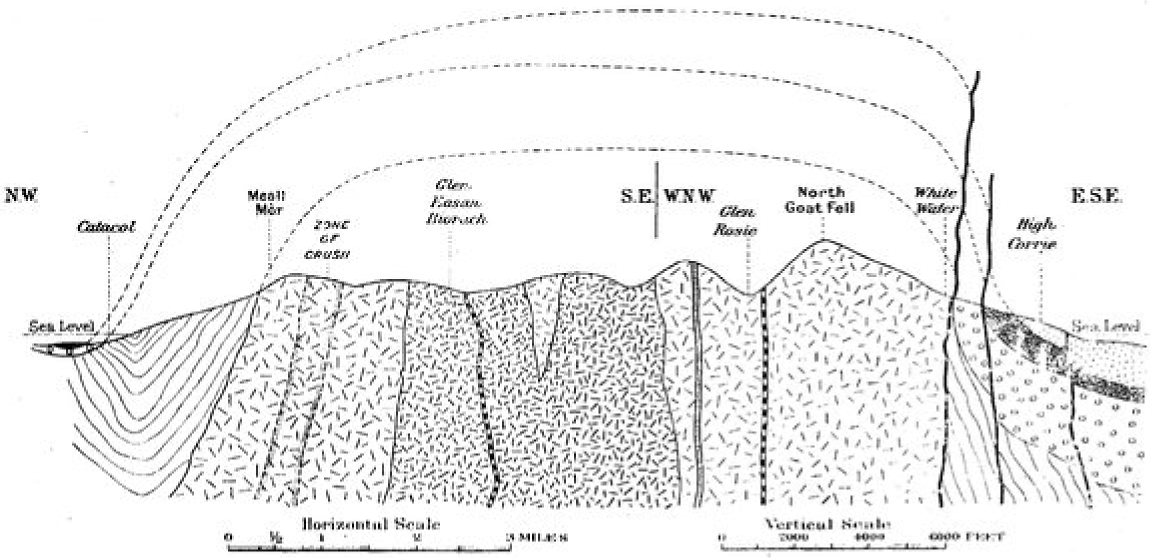


FIG. 21.—*Section across North Arran Granite. For explanation of ornaments see Plate III.*

(Figure 21) Section across North Arran Granite. For explanation of ornaments see Plate 3.