CONTRIBUTIONS TO THE CALEDONIAN IGNEOUS GEOLOGY OF THE SOUTH-WEST HIGHLANDS

J.G.C. Anderson, M.A., B.Sc., Carnegie Research Scholar, University of Glasgow.

THE MARGINAL INTRUSIONS OF BEN NEVIS; THE COILLE LIANACHAIN COMPLEX; AND THE BEN NEVIS DYKE SWARM

THE SOUTH-EAST MARGIN OF THE ETIVE GRANITE COMPLEX

THE ARROCHAR INTRUSIVE COMPLEX

Contents.

Page

GENERAL INTRODUCTION

The South-west Highlands, lying mainly in Argyll and the neighbouring part of Inverness-shire, provide a magnificent opportunity for the study of geological problems. The district has been deeply dissected by erosion, which in places gives natural sections of a vertical extent of 3000 feet. In Lower Old Red Sandstone times the area was the scene of widespread igneous activity. Good use has been made of the natural advantages of the region for the study of all aspects of this phase of the geological history both by individual workers and by the officers of H.M.Geological Survey. Their results, though going far to unravel the problems afforded by the subject, at the same time have opened up many new grounds for research. It was to this district that the attention of the present author was directed at the beginning of a three years' tenure of a Carnegie Research Scholarship.

Work in the field to date has been confined to three areas, Ben Nevis, Ben Cruachan and Arrochar. In all three cases a preliminary study of relevant literature was made, and field-maps were copied at the offices of H.M.Geological Survey in Edinburgh. These maps were simply used as a guide, and in all three instances complete remapping was undertaken on the ground.

The field-work in the Ben Nevis region was undertaken in the summers of 1932 and 1933. During this period the remapping of the Outer Granite of Ben Nevis and of a small intrusion to the east, which may be referred to as the Coille Lianachain Complex, was completed (Fig. 1). Numerous measurements were also made of members of the Ben Nevis Dyke Swarm. The western part of the Ben Nevis area was studied/

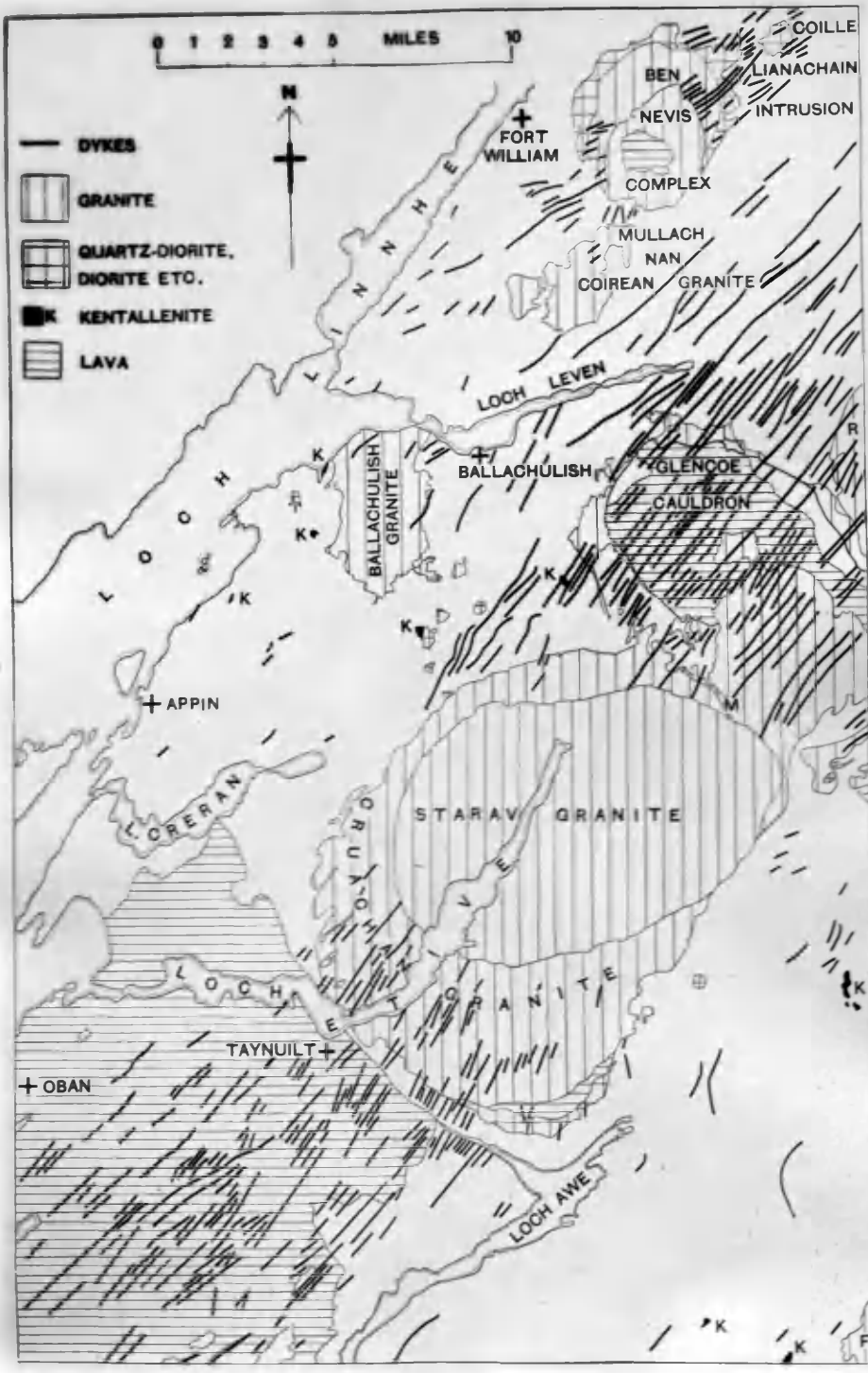

Fig.I :- Caledonian Igneous Rocks of Northern Argyll.

studied from a camp near Achintee, at the foot of the Ben Nevis path; and the eastern part, along with the Coille Lianachain Complex, from a camp at Lianachain, three miles south of Spean Bridge. The examination of the rocks in thin section and the preparation of the material for publication was undertaken during the winters of 1932-33 and 1933-34 in the Geology Department of the University of Glasgow.

In the Ben Cruachan area (Fig.1) field-work occupied parts of the summers of 1933 and 1934. A camp in the vicinity of Loch Awe station was used as a centre. Attention was at first directed to an arcuate mass of rock, consisting partly of andesite and partly of schist, within the south-east margin of the Cruachan Granite Complex. Mapping of this mass and of neighbouring facies of the Granite Complex has now been completed. It has become evident, however, that further research could be carried out with advantage in other parts of the massif, work which it is intended should be undertaken during the summer of 1935. During the investigation of the igneous rocks of the area, current and graded bedding, which throw light on the original order of succession, were observed in the neighbouring metamorphosed sediments. The results of these observations, although outwith the precise subject of research are included in a supporting paper. Laboratory work on the rocks of the Cruachan district was carried out in the Geology Department during the winters of 1933-34 and 1934-35.

In the Arrochar district a number of dioritic masses occur north-west of the head of Loch Long, and related intrusions are seen to the south-west and north-east (Fig.2). Mapping of these was undertaken on various visits during 1932 and 1933, and was completed during the early summer of 1934. The Youth Hostel in Glen Loin was used as a centre/

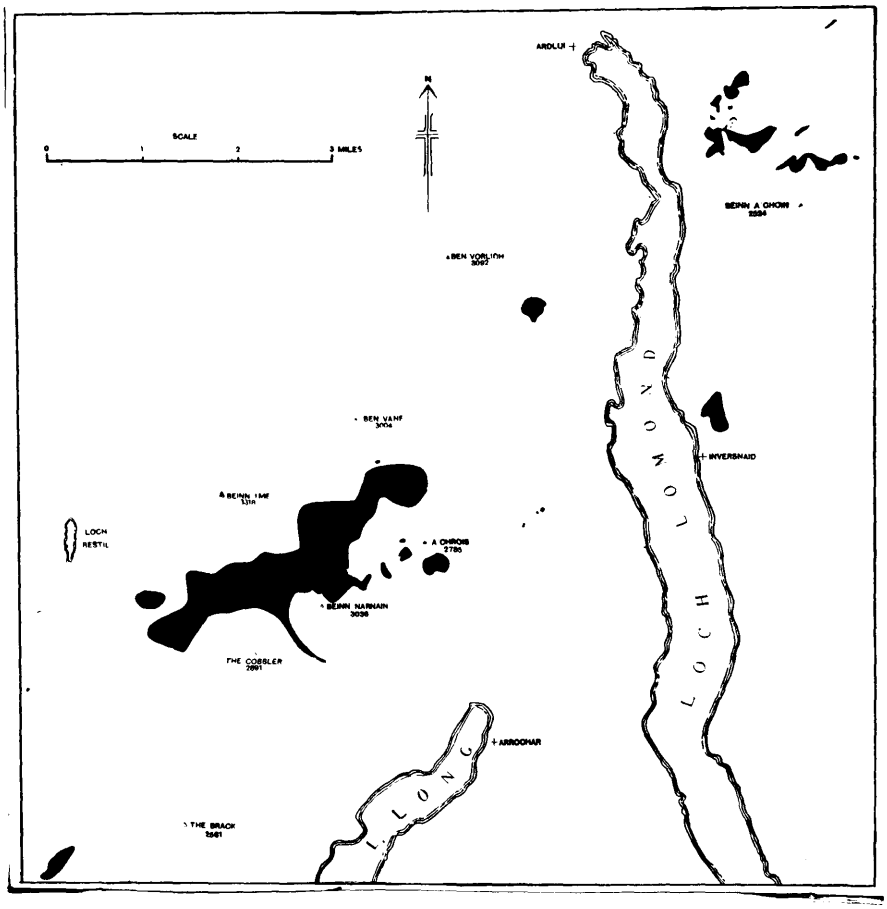

Fig. 2:- The Arrochar Intrusive Complex.

centre for most of the time, but camping was resorted to in the case of intrusions lying east of the head of Loch Lomond. In the laboratory the rocks were studied during the winters of 1933-34 and 1934-35.

The results obtained in the Ben Nevis district have been published in the Transactions of the Geological Society of Glasgow (vol.xix,pp.225-269). A preliminary account also appeared in the Quarry Managers' Journal for March 1934. As already stated, work on the igneous rocks of the Ben Cruachan district has not yet been completed. A short account of the position to date is included in the present thesis. The results obtained from the study of current and graded bedding have been published in a paper in the Geological Magazine (~~January~~ February,1935). A paper on the Arrochar district is in course of preparation for publication. Summaries of the findings obtained in both the Cruachan and Arrochar districts were given in a Presidential address to the G.U.Geological Society, which was later published in the Quarry Managers' Journal (January,1935).

THE MARGINAL INTRUSIONS OF BEN NEVIS; THE COILLE LIANACHAIN COMPLEX; AND THE BEN NEVIS DYKE SWARM.

1. INTRODUCTION

Subject of Paper. The igneous complex of Ben Nevis consists of a central core of volcanic rocks resting upon schist which has subsided into, and is now completely surrounded by, the Inner Granite. This in its turn is two-thirds encircled by a slightly more basic, and earlier, intrusion known as the Outer Granite (Figs.3 and 4).

The two main schist formations into which the Ben Nevis complex is exteriorly intruded are the Leven Schists and the Ballachulish Limestone. On the north-west side, however, the igneous rocks also comes in contact with the Eilde Flags and on the north side with black schist grouped with the Ballachulish Slates.

The Outer Granite is in the main a strikingly porphyritic pink rock, but around seven-eights of its periphery there is a non-porphyritic margin of varying breadth (Fig.5).

Very similar rock types to those found in this non-porphyritic margin also occur in the small plutonic mass (with an outcrop of a little under one square mile) lying half a mile to the east of the extreme north-east corner of the Ben Nevis complex and about three miles south of Spean Bridge (Fig.15). No detailed account of this intrusion has yet been published, and from the wood which covers part of its outcrop it is proposed to refer to it as the Coille Lianachain mass. It is with the latter, and with the non-porphyritic margin of the Outer Granite of Ben Nevis, that the present paper is chiefly concerned, but some account will also be given of the Ben Nevis dyke-swarm.

Historical. The early writers on Ben Nevis regarded the mountains composed of a mass of granite, Overlying schist, and in its turn overlain/

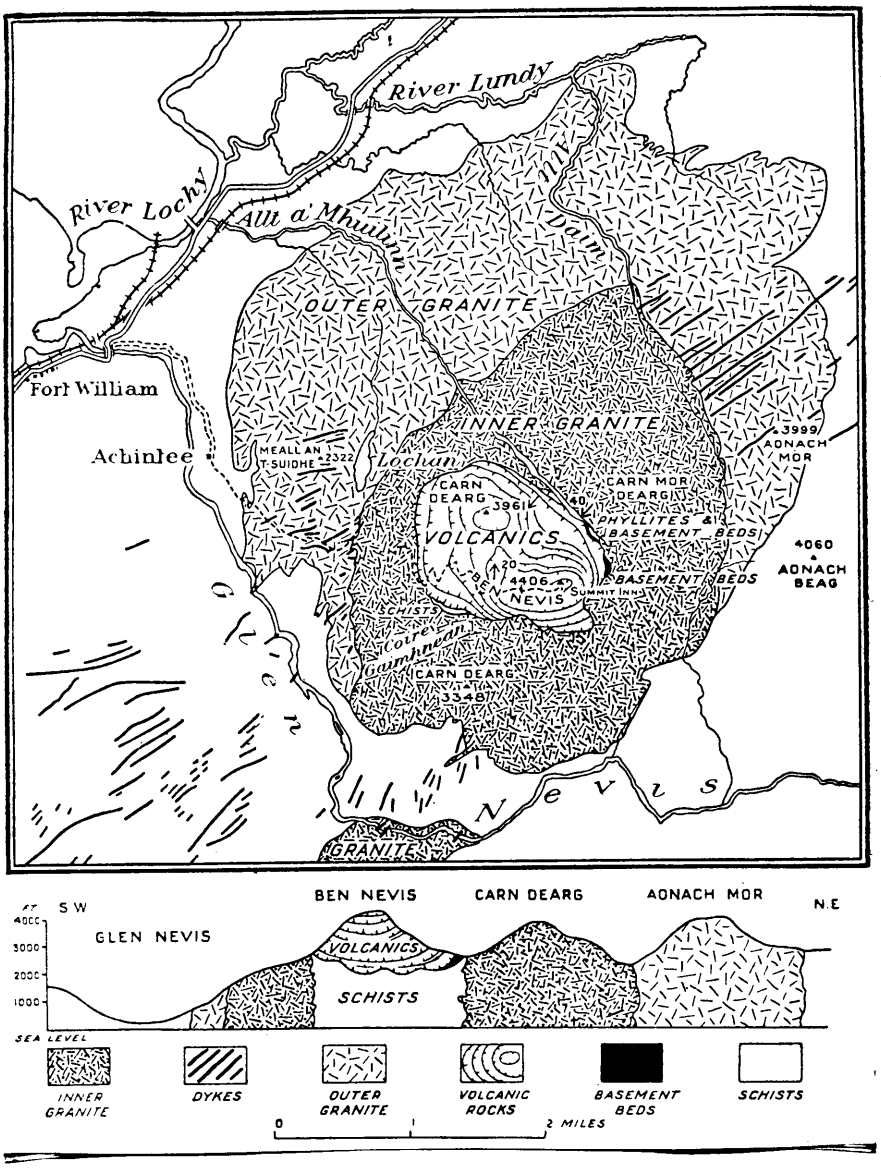

Fig.3:- Map and section of Ben Nevis (after Maufe).

overlain by porphyry (i.e.andesite lava).

Von Oeynhausen and von Decken (1830) recognised the intrusive nature of the granite and the vertical character of the junction between the granite and the porphyry. The latter, the considered, was injected into the former.

This view was held for many years until Bryce (1864) and Judd (1874) demonstrated the volcanic origin of the porphyry. These writers, however, repeated the error of regarding the latter as overlying the granite.

Much of the Geological Survey mapping of the Ben Nevis mass was done by Grant Wilson, who also mapped the Coille Lianachain intrusion, till then unknown. The latter he described as a hornblende-biotite-granite or quartz-diorite (1901,p.29). It is to Maufe, however, that the present interpretation of the Ben Nevis complex is due. His views were first published in 1910 (Fig.3).

Most authors note the Non-porphyritic Margin of the Outer Granite of Ben Nevis. Maufe refers to it as the 'grey, non-porphyritic marginal facies' and remarks that its junction with porphyritic type is 'never abrupt'. The use of therterm grey is locally misleading. The Non-Porphyritic Margin is pink along much of the east side of the massif. There can be no doubt that Maufe regarded these rocks as forming part of his 'grey' non-porphyritic marginal facies, since he stated that it is 'only absent for a short distance on the south-west side of the hill'. The author of the present paper prefers the term Non-porphyritic Margin to 'non-porphyritic marginal facies'.

Most of the Ben Nevis complex lies within 1-inch Sheet 53 but/

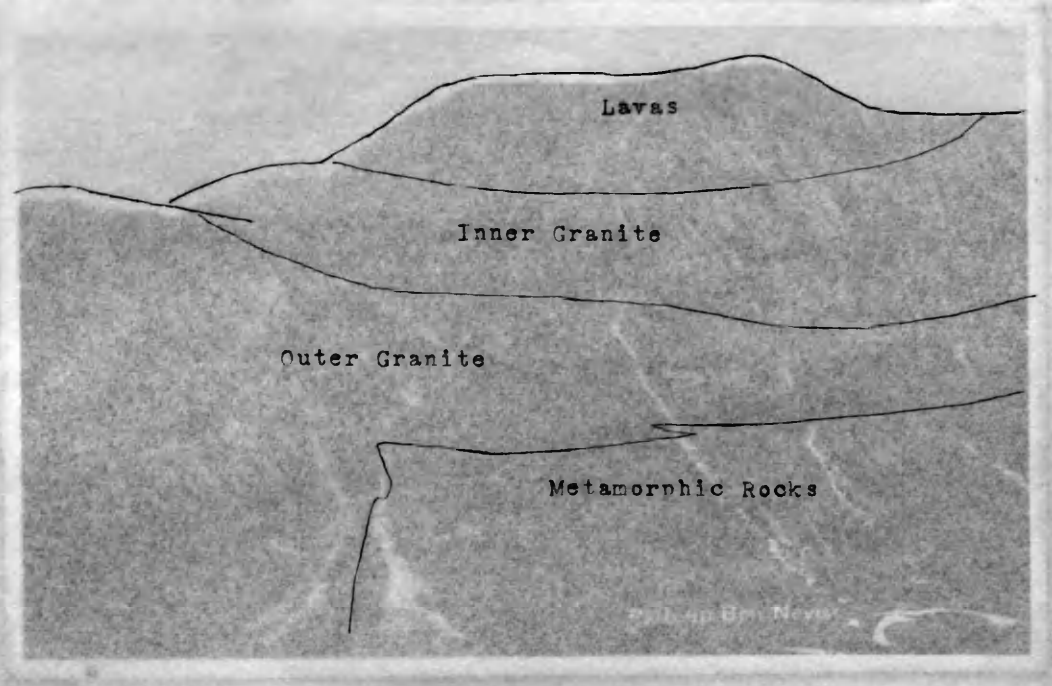

Fig.4:- Ben Nevis from west. Glen Nevis in foreground.

Fig.4:- Ben Nevis from west. Glen Nevis in foreground.

but a small part occurs in Sheet 62 to the north, which has not yet been published by the Geological Survey. The Coille Lianachain mass lies wholly within 1-inch Sheet 62 and is not mentioned in the Ben Nevis Memoir but it is shown on a map of the schists published by Bailey (1910,Pl.xlii).

From 1926 to 1929 occurred an event of considerable importance in the geological study of the district, namely the driving of the main tunnel of the Lochaber water-power scheme from Loch Trieg to near Fort William. This paases through both the Coille Lianachain mass (Fig.15) and the northern part of the Ben Nevis Complex (Figs.9 and 10). A geological section of the tunnel was prepared by Messrs.B.N.Peach (jun.) and R.D.Duncan with the assistance of Professor Bailey on behalf of the Geological Survey while a certain amount of mapping was done by the last-named around the Allt an t-Sneachda. The above information has not yet been published but has been made available for the present paper.

Peach has published a short account of the geology of the tunnel with a section and in this reference is made both to the Coille Lianachain mass and to the northern part of the Ben Nevis Complex (1930). In connection with the latter the following statement appears which admirably sums up the purpose of part of the present paper.

"The Ben Nevis Granite should be divided into three distinct masses, as the tunnel shows the 'outer' (porphyritic) granite clearly cutting the grey marginal granite, or rather diorite, which would now become an 'outermost diorite rim". (1930,p.223).

Statement/

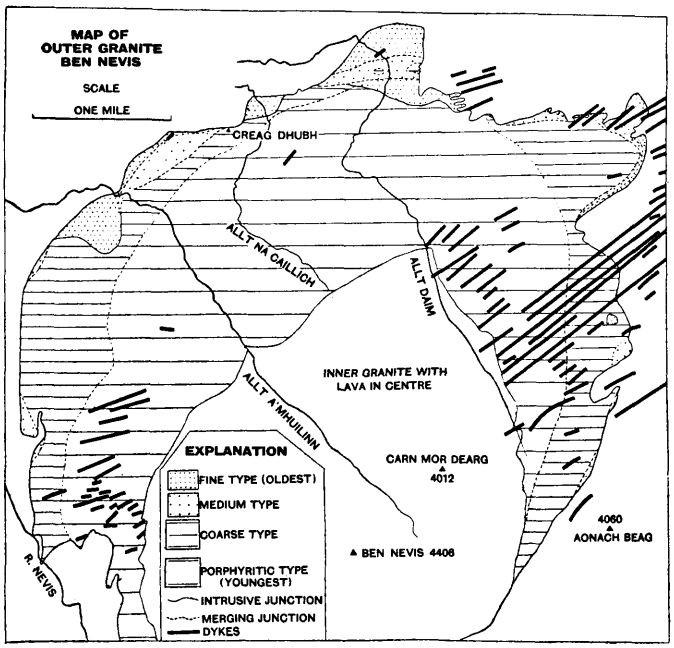

Fig.5 :- Outer Granite of Ben Nevis.

Statement of Problem. - From the paragraph quoted at the end of the previous section it is obvious that the Non-porphyritic Margin cannot be regarded as a mere marginal modification of the Outer Granite. On the other hand Maufe's statement that the passage between the porphyritic and the non-porphyritic facies is never abrupt is certainly justified in most sections. Further the Non-porphyritic Margin is itself complex in character. In some sections it consists of a fine-grained quartz-diorite veined by a coarse quartz-diorite; in others we find fine, medium and coarse types of quartz-diorite all present and merging into one another with the last merging into the normal porphyritic outer granite (Fig.5). The fine quartz-diorite frequently shows contact phenomena where cut by a later intrusion. It is necessary, therefore, to put forward an interpretation of the igneous history which will account both for the complex nature of the non-porphyritic margin and for the varying relationship which the latter bears to the porphyritic type.

Similarly a brief examination of the Coille Lianachain mass in the field shows that here too a considerable variety of types is present, with puzzling variation in their mutual relationships (Fig.15).

Preliminary Definition of Rock Types. - It has been mentioned that the Non-porphyritic Margin of the Outer Granite is of a complex nature. Before mapping the complex, therefore, it was essential to establish types which, while readily distinguishable in the field, should as closely as possible reflect the actual igneous history. It was found convenient to establish three types based upon differences of texture. This greatly simplified the mapping/

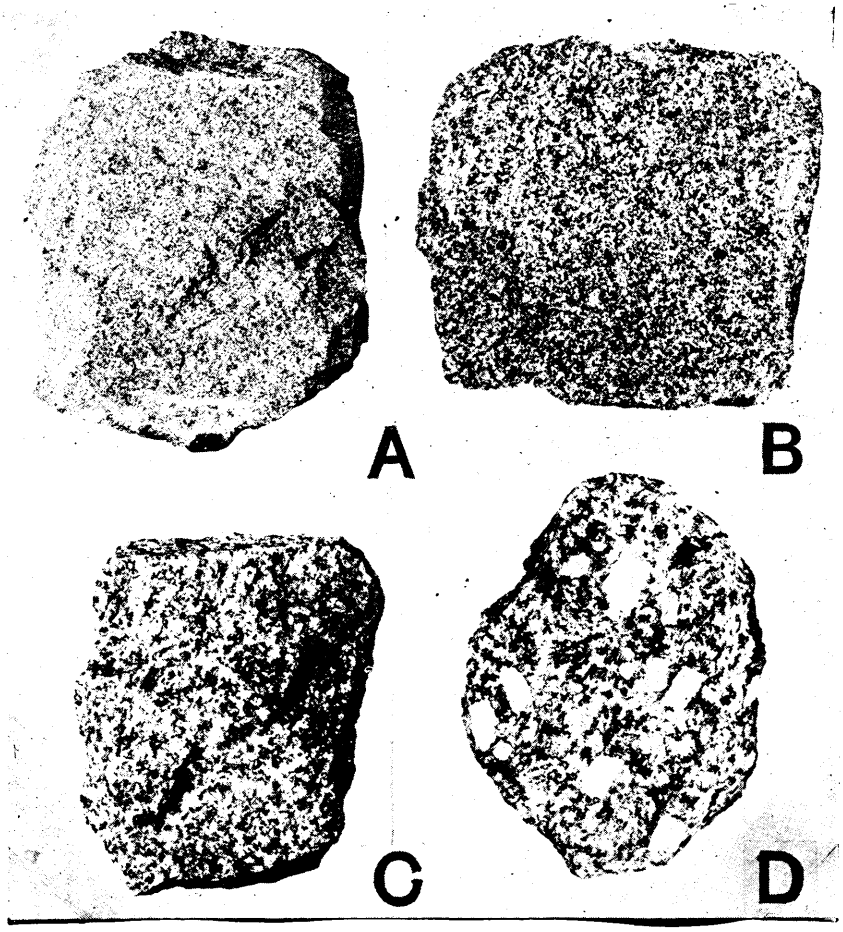

Fig. 6:- Rocks of the Marginal Intrusions of Ben Nevis.
A- Fine Type(oldest).
B- Medium Type.
C- Coarse Type.
D- Porphyritic Type(youngest).

mapping, for all the types within the Non-porphyritic Margin could then be referred in the field to the appropriate group without the necessity of awaiting microscopic examination. Although based upon texture, rather than upon composition, the three types were found to bear a close relationship to the actual igneous history (see pp.64-68).

The three types established may be referred to as the Fine-grained Non-porphyritic Marginal Type, the Medium-grained Non-porphyritic Marginal Type and the Coarse-grained Non-porphyritic Marginal Type,[1] or, where confusion is unlikely to arise, simply as the Fine Type, the Medium Type and the Coarse Type (Fig.6). These types can be best examined in the Allt a' Mhuilinn where the complete succession is exposed.

The types were established in the northern part of the complex and are quartz-diorites. They are similar in the western and north-eastern Areas but in the high eastern Area they are more acid and are mainly granites. For the most part the rocks are grey, but the Coarse Type always becomes pink towards the Porphyritic Type and on the east side of the massif this pink coloration spreads right through the Coarse Type and even into the Medium and Fine Types. The variation in colour, therefore, is not sufficiently regular to be used as a basis for mapping.

In addition to the rocks described above there occur three small exposures of a hornblende-rich rock termed appinite (defined by Bailey, 1916, pp.167-168).

---

[1] The term Non-porphyritic is used in a general sense as a few of the rocks of this group carry sparse porphyritic crystals.

II. FIELD EVIDENCE.

A. Ben Nevis.

For the purposes of study the Non-porphyritic Margin may be conveniently divided into three parts roughly corresponding to the west, north and east sides of the Ben Nevis massif.

The northern limit of the Western Area may be taken as the Lochaber water-power pipe-line. South of this line the igneous margin runs roughly north and south, and generally coincides with the foot of a steep rise to 2000 ft. or more on the western flanks of the massif (Fig.8). Within this sector the relationship of the Non-porphyritic Margin to the Porphyritic Outer Granite is of the simplest.

The Northern Area lies between the pipe-line and the first burn east of the Allt an t-Sneachda. It is here that the Non-porphyritic Margin, both in its component parts and in its relationship to the Porphyritic Type, reaches its greatest degree of complexity. The igneous margin still roughly coincides with the beginning of the high ground, but instead of marking a sudden rise to 2000 ft. or more, we find it introducing a series of foothills along the northern flanks of the Ben Nevis range.

The Eastern Area lies east of the burn mentioned above and includes the north-east corner of the mass and the whole of its eastern margin to the point where the Outer Granite thins out 1¼ miles north of Steall in Glen Nevis. The igneous margin here bears but little relationship to the topography and the Non-porphyritic Margin once more resumes a comparatively simple character.

(i)/

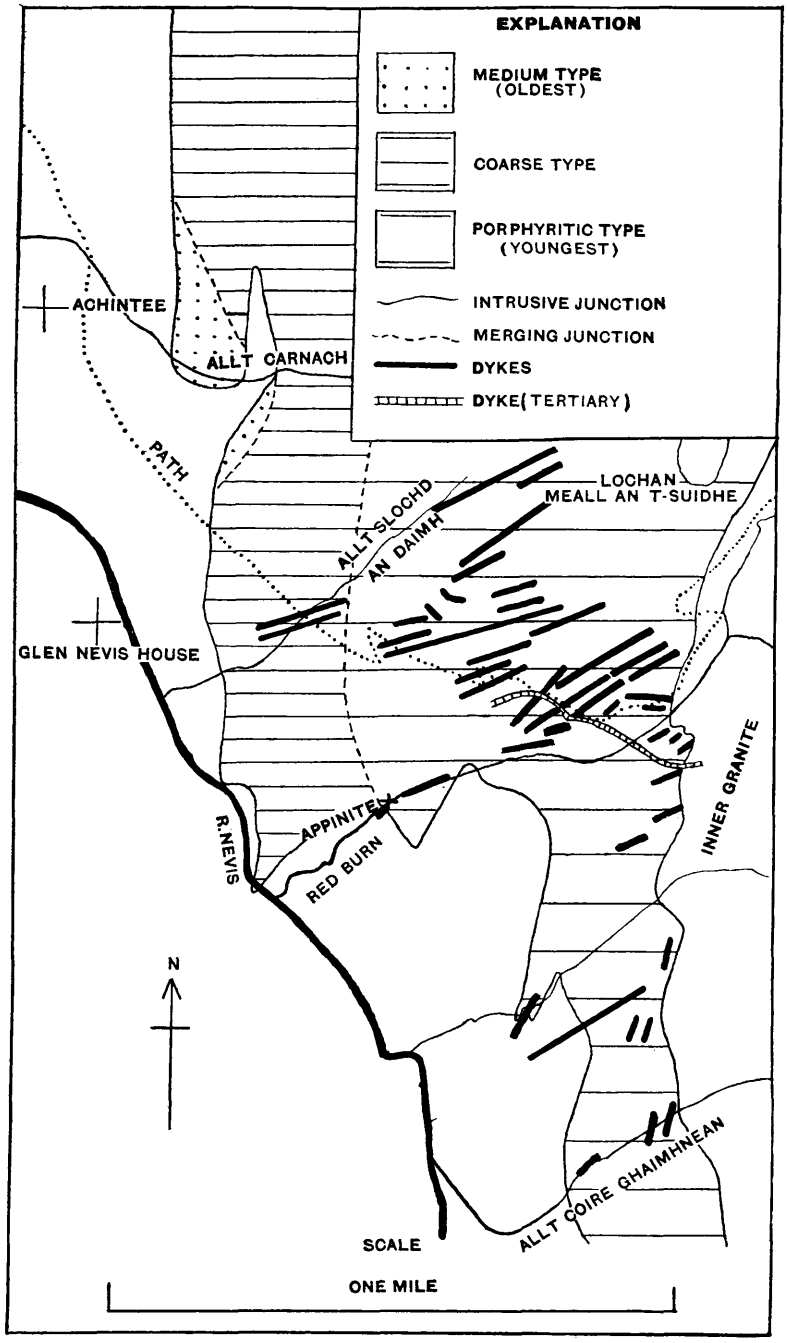

Fig. 7:- Western Margin of Outer Granite of Ben Nevis.

(i) Western Area (Fig.7)

South of the Red Burn (Allt na h-Urchaire). - The many streams flowing off the steep west face of Ben Nevis afford excellent sections in the Outer Granite, which here forms a narrow strip about a mile long and less than quarter of a mile wide between the Inner Granite and the schist. In the first stream south of the Red Burn the Ballachulish Limestone is altered to a calc-silicate hornfels and the Outer Granite retains its porphyritic character right up to the contact. In one or two sections further to the south, where the margin is not exposed, there is a tendency for the porphyritic character to disappear for the last few feet as the junction is approached. This is probably a mere modification along the contact and is not regarded as marking the presence of the Non-porphyritic Margin proper.

Section in the Red Burn.- At the foot of the conspicuous gorge in this stream pink porphyritic granite is seen against calc-silicate hornfels. This merely represents a bend in the margin, for the Porphyritic Type persists for 300 yds. below this point. At the lowest rock-exposure the contact is seen against a beautifully banded grey and white calc-silicate hornfels. The bedding planes of the latter are at right angles to the margin and have been injected by felspathic veins. For the last few inches the igneous rock is rich in euhedral hornblende. This is the exposure of appinite mentioned in the Geological Survey Memoir (Bailey,1916,p.168).

Section in the River Nevis.- At the Red Burn, partly owing to the incoming of the Non-Porphyritic Margin, the outcrop of the Outer Granite becomes very much wider. As a consequence, the igneous/

igneous margin runs west-south-west for some distance and crosses the River Nevis half a mile south of Glen Nevis House. At the end of the wall which runs from the road to the bank of the river an excellent contact is exposed in the stream showing coarse pink non-porphyritic rock, belonging to the Coarse Type, against calc-silicate hornfels along the bedding planes of which have been intruded pink felspathic veins. This is the lowest point reached by the Outer Margin of the Ben Nevis Complex. The junction almost immediately recrosses the river and 350 yds.downstream, on the east bank, a coarse grey non-porphyritic granite, rich in pyrite, is seen in contact with the hornfels.

Section between Red Burn and Allt Carnach (including path).- On the Ben Nevis path the first exposure of igneous rock is encountered half a mile south-east by south of Achintee. It is a Coarse-grained Non-porphyritic Type of a faint pink colour. As the path is followed upwards the proportion of pink felspar increases till in the Allt Slochd an Daimh a thoroughly pink Coarse Type is seen. By an increase in size of the felspar crystals this passes into the pink Porphyritic Type, which is typically exposed by the time the first zig-zag is reached. Similar features may be observed in various streams which cross the path. Upstream a passage may be traced into the Porphyritic Type while downstream the porportion of pink felspar decreases. Between the path and the Allt Carnach the Non-porphyritic Type becomes grey in colour away from the Porphyritic Type, while just south of the stream there is a small outcrop of the Medium

Type/

Fig.8:- Steep slopes of Medium Type and Coarse Type above Achintee, Glen Nevis. Allt Carnach in front of rounded crag.

Type which can be shown to merge into the Coarse Type. No evidence could be found for the embayment of schist shown on the Survey map (Fig.3), just north of the path and it is accordingly omitted on the author's figure.

Section in Allt Carnach (Fig.8). - Half a mile east by south of Achintee grey Medium Type is exposed. This persists to about the 700-ft.level, where it is seen in contact with calc-silicate hornfels. About 150 ft.further upstream igneous rock is again encountered, this time of the Coarse Grey Type, and still higher, pegmatites and aplites are common. On the sides of the deep gorge, out of which the burn flows, a passage into the Porphyritic Type can be traced. Here the change takes place more rapidly than on the path.

Between Allt Carnach and the pipe-line.- The Medium Type exposed in the lower part of the Allt Carnach also occurs in several streams immediately to the north. It appears unlikely, however, that it persists for any considerable distance along the margin, for in a small trial hole a little more than half a mile north-north-east of Achintee the Coarse Type is exposed in a position which must be near the margin. Exposures along the foot of the hill are scarce and nowhere is the contact seen. A bright red, somewhat shattered rock which outcrops a little over one mile north-north-east of Achintee is referred to the Medium Type.

Along the line of cliff forming the east wall of the mouth of Glen Nevis the Coarse Grey Type is continuously exposed, often honeycombed with thin pink merging veins. On the slopes overlooking the Allt Coire an Lochain from the west a gradual passage can everywhere be traced from the Coarse Grey Type through a Coarse/

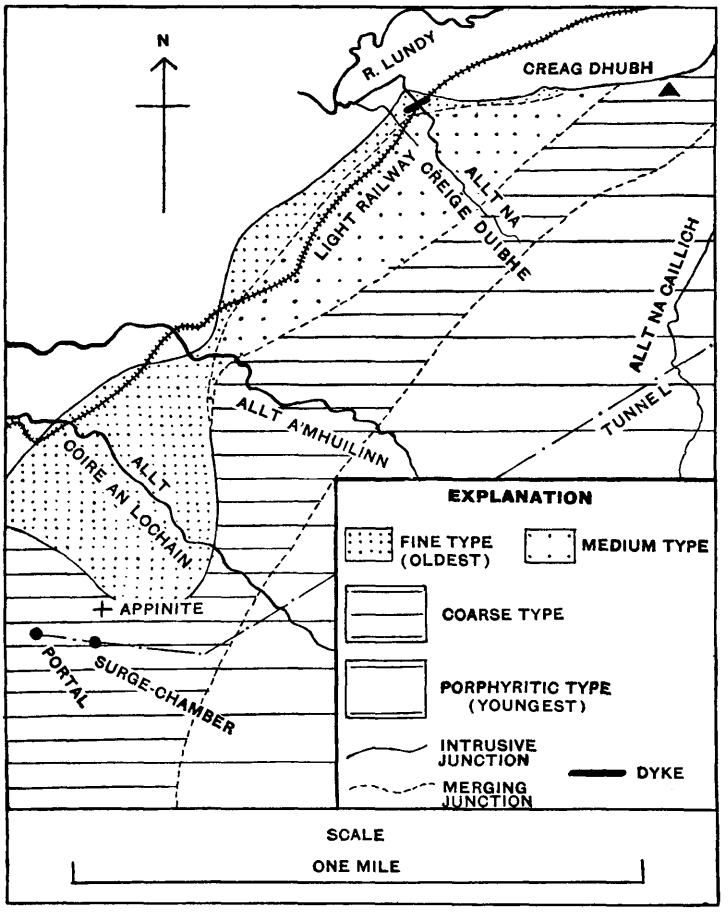

Fig. 9:- Northern Margin of Outer Granite of Ben Nevis between Tunnel Portal and Creag Dhubh.

Coarse Pink Type to the normal Porphyritic Outer Granite. It is here that the Non-porphyritic Margin attains its greatest width - about two-thirds of a mile (Fig.5).

Around the tunnel portal excellent sections have been opened in the grey facies of the Coarse Type (Fig.9).

(2) Northern Area (Figs.9 and 10).

Allt Coire an Lochain. For 150 yds.above the railway[1] bridge over this stream the Fine Type is exposed as a grey quartz-diorite. At the sharp bend in the stream a thick vein of the Coarse Type cuts the Fine, and for the next quarter of a mile such veins are abundant. Imperceptibly the area of Fine veined by Coarse passes into one of Coarse with Fine xenoliths. The latter gradually disappear, but the Coarse Type does not persist far; 800 yards above the Bridge it rapidly merges into the Porphyritic Type(Fig.9).

Area between Allt Coire an Lochain and surge-chamber.- On a conspicuous crag near the top of the cliff 100 yards north by east of the surge-chamber is exposed a tiny irregular boss of appinite which merges into the surrounding Coarse Grey Type. The dark green hornblende laths attain a length of $\frac{3}{4}$ inch. The rock shows considerable variation. There are veins in which the hornblende merely occurs as scattered laths in a coarse groundmass of quartz and felspar, while at the other extreme the latter minerals may entirely disppear and the rock is then composed of an aggregate of coarse hornblende crystals. On the east side of this boss the Coarse Grey Type contains a large inclusion of the/

&

1. The railway referred to in this and in succeeding paragraphs is the narrow-gauge light railway built in connection with the Lochaber Water-power scheme.

the Fine Type, which has a very altered aspect. Along a line eastwards towards the Allt Coire an Lochain many of the crags show similar inclusions in the Coarse Type; while in other cases the Fine Type appears as country rock and the Coarse Type as veins (Fig.9).

Allt a' Mhuilinn. - Sixty yards above the bridge which carries the light railway over this stream, the Fine Type is seen against dark hornfels. This only persists for about 50 yards and then merges into the Medium Type, which in turn passes into the Coarse Type some 50 yds. further upstream. The Coarse Type outcrops for about a quarter of a mile in the stream, and becomes pink before showing a merging junction with the Porphyritic Type (Fig.9).

Allt na Creige Duibhe.- The igneous contact is not exposed in the main stream. In the small stream a little to the west the Fine Grey Type is seen against dark hornfels in the waterfall below the railway bridge. In the main stream the Fine Type is also seen below the railway and it here contains a single vein of the Coarse Type as well as a screen or large inclusion of dark hornfels derived from the schists. Above the railway the Fine Type merges into the Medium, and the section is thereafter a repetition of that in the Allt a' Mhuilinn, with the exception that the outcrop of the Medium Type is broader and that of the Coarse Type correspondingly narrower (Fig.9).

Hillside exposures from Allt Coire an Lochain to Allt na Creige Duibhe. - Exposures are scanty within the Non-porphyritic Margin. On many of the crags, however, a merging junction can be traced between the Coarse Pink Type and the Porphyritic Type (Fig.9).

Creag/

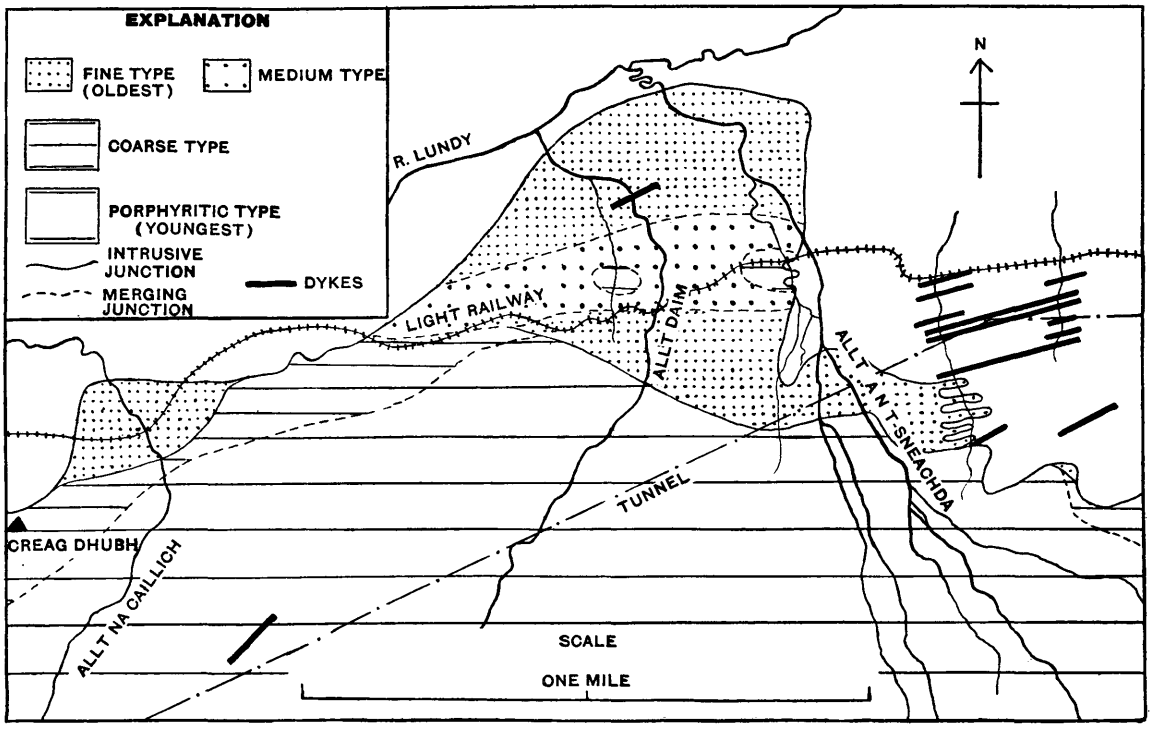

Fig. 10:- Northern Margin of Outer Granite of Ben Nevis between Creag Dhubh and Seond Burn east of Allt an t-Sneachda.

Creag Dhubh. - By the thinning out of the Fine and Medium Types the Coarse Type comes against schist hornfels on a conspicuous cliff north-west of Creag Dhubh. The igneous rock is full of xenoliths and sends veins into the hornfels. The junction, the vertical character of which is well demonstrated on the cliff face, runs east and then turns sharply north-north-east towards the lower part of the Allt na Caillich (Fig.9).

Allt na Caillich.- In this burn the relationships seen in the Allt Coire an Lochain are again encountered. The rock surfaces here are much cleaner and the Fine Type is beautifully veined by the Coarse Type and by aplites (Figs.11 and 12). The outcrop of the Coarse Type is very narrow, and the Porphyritic Type is almost in contact with the Fine. The phemonenon of the digestion of xenoliths may well be studied here, as the Coarse Type contains numerous inclusions of the Fine in various stages of assimilation. Rocks of a Medium Type are altogether absent (Fig.10).

Area between Allt na Caillich and Allt Daim.- That the Fine Type does not persist far along the margin is shown by an exposure of the Coarse Type close to the schist just above the railway ¼ mile east of the Allt na Caillich. Two-thirds of a mile east of the latter burn, in a small unmapped stream, the Medium Type is seen a little below the railway. On the crags above the railway, ¼ mile west of the Allt Daim, the Coarse Type, which can be seen to vein the Fine, thins out. The Porphyritic Type thus comes against the Fine Type (Fig.10).

Allt Daim.- Here the intrusive junction of the Porphyritic Type against the Fine Type is well exposed. The latter shows only a few aplite veins. There is a sharply defined junction between the two rocks, and the Porphyritic Type is coarse right up to the/

Fig. II:- Relationship of Marginal Intrusions; Coarse Type veining Fine Type, Allt na Caillich.

Fig. I2:- Relationship of Marginal Intrusions; Coarse Type cutting Fine Type, Allt na Caillich. Note xenolith of Fine Type in Coarse.

the margin. Below the railway, in the Allt Daim, there is an area of the Medium Type which merges on either side into the Fine. In a small unmapped stream to the west the interior of this area of Medium Type becomes Coarse. Apart from this outcrop the exposures in the stream below the Porphyritic Type are entirely in the Fine Type (Fig.10).

Allt an t-Sneachda.- Below the point where the stream is crossed by the light railway bridge conditions are the same as in the Allt Daim. The main stream actually runs out of the igneous rock for a short distance and a junction with banded calc-silicate hornfels is exposed. In a small stream to the west the area of Medium and Coarse Types is seen, the latter forming an interleaving junction with the hornfels just above the railway bridge. The Coarse merges into Medium, and the latter into Fine to the north and south. In places the Fine Type is honeycombed with pink merging veins. In the two branches of the stream above the fork the Fine Type is cut by numerous coarse granite and aplite veins. The junction with the Porphyritic Type is well exposed in the east branch at a dam which diverts the water into the tunnel. The Porphyritic Type retains its character right up to the margin although its phenocrysts do not enter into veins. It is full of xenoliths of the Fine Type (Fig. 16) in various stages of digestion (Fig.10).

Stream east of the Allt an t-Sneachda. - The igneous margin here is of a remarkable character. Beginning about 300 yards south of the railway no less than ten alternations of the schist hornfels and the Fine Grey Type are seen in the succeeding 200 yds. After the last exposure of hornfels the Porphyritic Type is encountered, cutting across a north-east dyke (Fig.10).

The/

The Tunnel Section.- The Loch Treig-Fort William tunnel enters the Ben Nevis igneous complex immediately to the west of the burn just mentioned. For 330 ft. 'grey monzonite, diorite and quartz-diorite' (cf.Fine Type) are recorded until the last is cut by the 'Porphyritic Granite'. Subsequently the tunnel runs entirely through the latter to 970 ft. east of the surge-chamber where it enters 'grey-granite' (cf.Coarse Type). Thus the surface geology is exactly repeated (Fig.10).

(3) Eastern Area.

North-east corner of complex.- In the area lying east of the unnamed burn east of the Allt an t-Sneachda (Fig.10) the Non-porphyritic Margin is absent for a short distance and in a small gully on the south side of a fence near the head of the former burn the Porphyritic Type is in contact with altered mica-schist.

The igneous margin then rapidly ascends the steep north-west slopes of Sgurr Finnisg-aig. Five hundred yards west by north of the summit of a small exposure of the Fine Type is cut by the Porphyritic and Coarse Types (Fig.10). The outcrop of the latter, which shows a merging junction with the Porphyritic Type, now rapidly widens as the outer margin of the Porphyritic Type continues south-east while that of the complex as a whole turns east along the foot of the cliffs forming the north face of Sgurr Finnisg-aig (Fig.13). Here the Medium Type makes its re-appearance and, in places, the Fine Type. The Coarse and Medium Types are pink. Just west of the high waterfall formed by the Allt na h-Aire the margin turns sharply south-east, cutting out the Fine and Medium Types and bringing the Coarse Type against schist, a little back from the edge of the cliff. The margin/

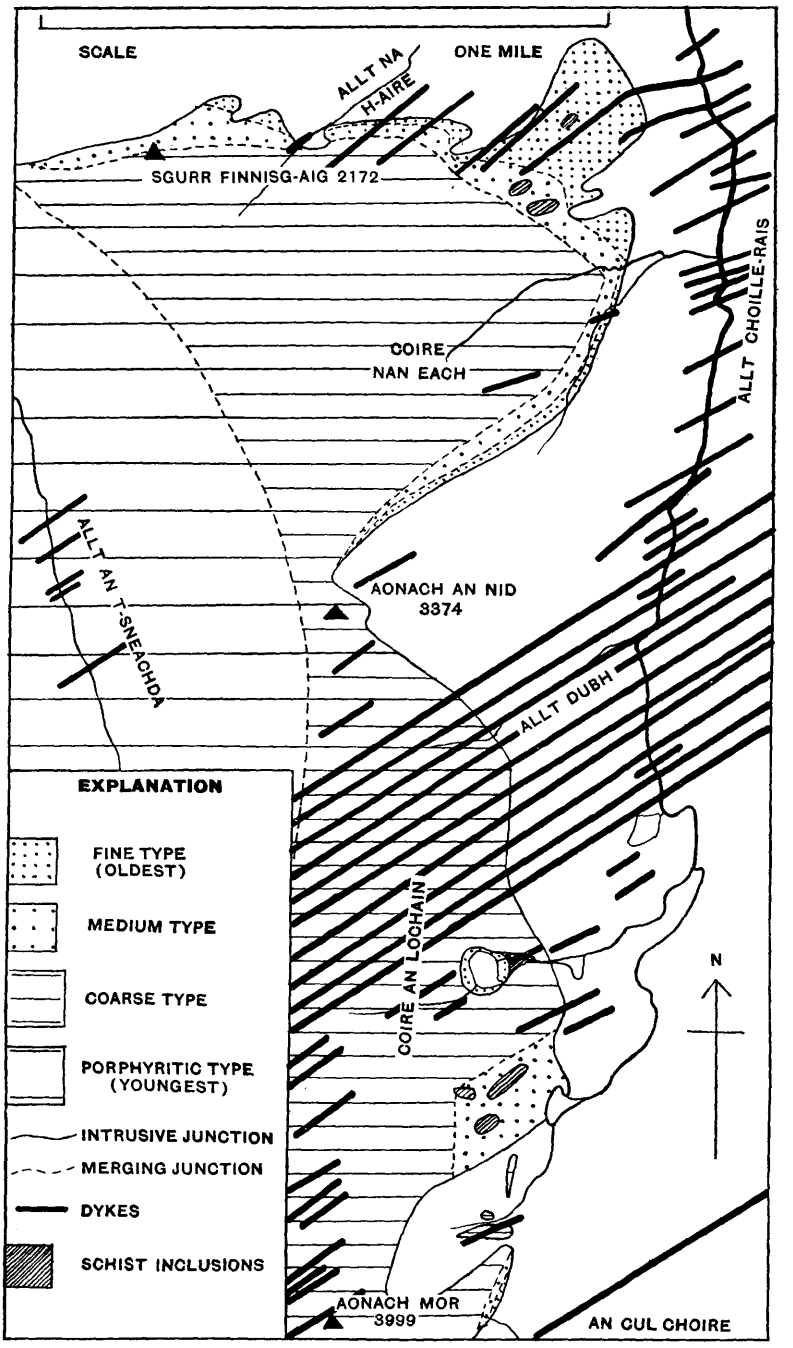

Fig. 13:- Eastern Margin of Outer Granite of Ben Nevis.

margin bends sharply back,however, and at the foot of the waterfall a Fine Pink Type is seen in contact with the schist. Along the foot of the cliff, east of the Allt na h-Aire, the Fine and Medium Types form a narrow margin to the Coarse Type outcropping at the top of the cliff. The extreme north-east corner of the complex corresponds to a swelling of the margin which brings the igneous rock far down the hill into the headwaters of the first stream west of the Allt Choille-rais. Within this swelling the Fine Type occurs, generally grey, but becoming pink where it merges into the Medium Type on the cliffs overlooking the Allt Choille-rais. Within this area occur three large inclusions of baked schist. The igneous margin is frequently well exposed and shows considerable complication before continuing in a south-west course uphill towards Aonach an Nid. Along this part of the margin the Fine and Medium Types form a narrow border to the pinkish Coarse Type. The Fine Type has not, however, exactly the same aspect as that seen in the Northern Area. It is darker and frequently carries porphyritic crystals of hornblende. The igneous contact, and the narrow margin of Fine and Medium Types, may be well studied in the headstreams of the tributary of the Allt Choille-rais flowing out of the Coire nan Each. On Aonach an Nid the Fine and Medium Types thin out, and the Coarse Pink Type comes against altered schist.

The interior of this north-east swelling is not exposed, as the hollow south of Sgurr Finnisg-aig is deeply covered with peat (Fig.13).

Margin between Aonach an Nid and col at head of Allt Choille-rais.- On Aonach an Nid the margin turns through a right angle and runs downhill/

downhill in a south-east direction. The Fine and Medium Types are now completely absent. The junction is particularly well exposed in the Allt Dubh. The granite at the margin is of a Coarse Pink Type and retains this character even where veining the schist which in places assumes the character of a permeation breccia. A similar junction can be seen on the ridge to the south lying between the Allt Dubh and Coire an Lochain, and at the west end of the lower lochan in the latter corrie. Here, however, the Coarse Type at the margin is grey in colour. The shores of the upper lochan are formed of a pink Fine-grained Rock extensively veined by the Coarse Pink Type. In the stream below the lochan altered schist in contact with the Coarse Type is met with. The junction of the Fine Type and the schist is not exposed.

At the highest lochan there occurs a pink Medium-grained Type which has a considerable outcrop to the west before grading into the Coarse Type. The rock varies rather irregularly, however, and patches of the Coarse Type are found within the Medium. Three large masses of schist are also included in this outcrop, two determining the ridge running up from the north end of the lochan to the main ridge of Aonach Mor, and the third lying in the hollow to the south. The precipitous ridge running from the col between the Allt Choille-rais and An Cul Choire to the summit of Aonach Mor is formed in a large embayment of schist. Within the latter are several intrusions of Coarse Pink Granite and the igneous outcrop nearly meets round its eastern margin. On the actual col Coarse Pink Granite is seen at the tip of the toe on the south side of this embayment (Fig.13).

Ridge/

Ridgebetween Aonach Mor and Aonach an Nid.- There is a continuous exposure of a Coarse Pink Type on the line of cliff forming the east face of this ridge. This rock has a more acid aspect and is considerably closer in appearance to the Porphyritic Type than to the normal Non-porphyritic Marginal Facies. In fact the variety, which in the Western and Northern Areas merely occurs as a narrow zone in that part of the Coarse- Non-porphyritic Margin which is immediately adjacent to the Porphyritic Type, here forms a large part, or even the whole, of the Non-porphyritic Margin. The gradation into the Porphyritic Type is extremely gradual, as can be seen by following the western line of cliff running north by west from Aonach Mor (Fig.13).

Between Aonach Mor and the col joining Aonach Mor and Aonach Beag.-

The Coarse Pink Type described above forms the cliffs on either side of the broad ridge running south from Aonach Mor. The gradual passage from the Porphyritic Type may be well seen on descending the steep slope from the col to the head of the Allt Daim (Fig.5). After leaving the col between the Allt Choille-rais and An Cul Choire the igneous margin climbs south-south-west up the steep slope. In the furthest north headstream of the Allt Coire an Eoin, flowing out of An Cul Choire, there is a narrow development of the Medium and Fine Types, here pink in colour and rather acid in composition. The Fine merges into the Medium and the latter into the Coarse (Fig.13). Nearly $\frac{1}{4}$ mile south-east of Aonach Mor a crag about 30 ft.high rises out of the hillside. The nick between the crag and slope of the hill corresponds to the granite margin, the steep outward slope of which is well shown by the differential weathering of the baked schist/

Fig. I4:- Margin of Coarse Type near Aonach Mor. To the left is the rubbly igneous rock, to the right the precipitous baked schist. The nick in the hillside corresponds to the actual margin which can be seen to incline slightly outwards.

schist and the igneous rock (Fig.14). Where the margin crosses the ridge north of Aonach Beag there is a narrow outcrop of the Pink Medium Type (Fig.8). It is here that the igneous margin reaches its greatest height, over 3800 feet.

It is interesting to note that the difference in height between the highest exposure of the Coarse Type, that on Aonach Mor, and the lowest, that in the River Nevis, is over 3900 feet, the greatest exposed vertical thickness of any igneous intrusion in the British Isles.

Western slopes of Aonach Beag.- Three quarters of a mile north by west of the summit of Aonach Beag appinite veins occur in the schist near the igneous margin (not marked on Fig.5). The actual contact of the schist and Outer Granite is not seen at this point. There are many exposures, however, of the margin on the west slopes of Aonach Beag. All of these show the Coarse Type right up to the edge. As the hill is descended, the rock at the margin changes from the pink type to the grey type, and within the Non-porphyritic Margin the Coarse Type, while retaining its pink colour, is less acid than on Aonach Mor (Fig.5).

The Porphyritic Granite is exposed south of the head of the Allt Daim but rapidly thins out until the Non-porphyritic Margin comes against the Inner Granite. An actual contact between the two is, however, nowhere exposed (Fig.5).

B. Coille Lianachain (Fig.15).

As stated in the introduction the rock types exposed in the Coille Lianachain mass closely resemble types occurring in the Outer Granite of Ben Nevis. They seem to be referable to four units separately numbered in Fig.15.

The/

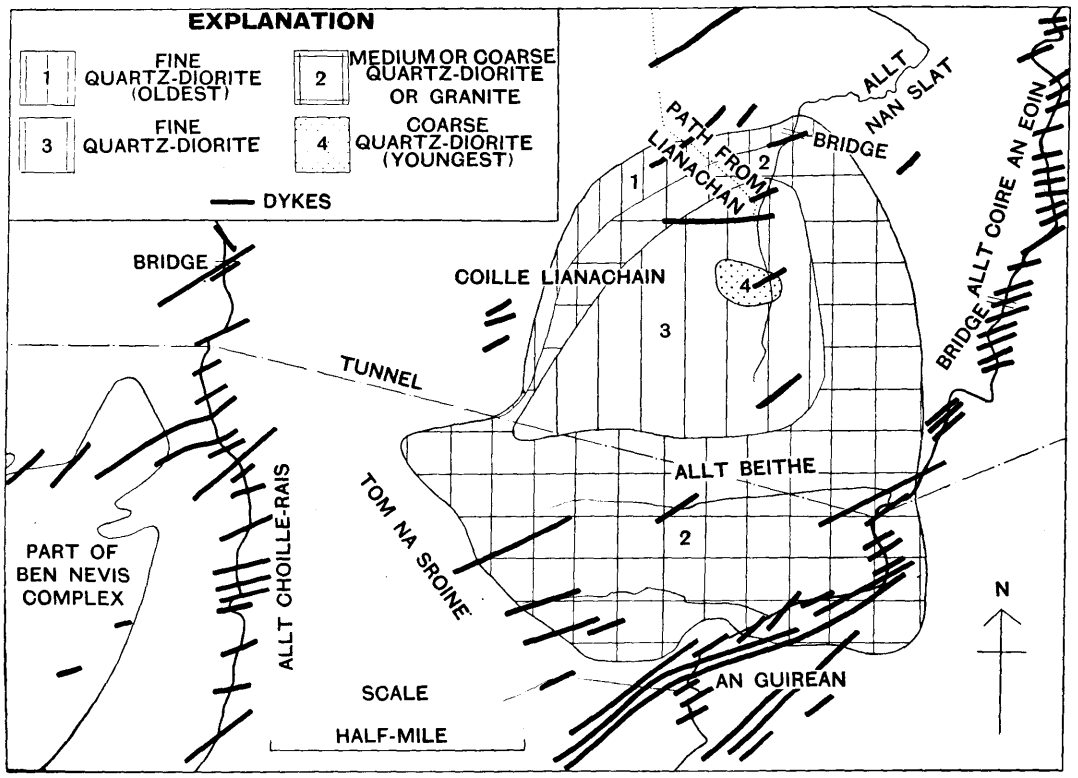

Fig.15:- The Coille Lianachain Complex.

The Allt nan Slat.- It is here that the most instructive section is exposed. The actual igneous margin is not seen but just above the point where the burn turns east at the foot of steep ground a very fine grey quartz-diorite (No.1) is encountered. This soon becomes coarser, being then closely comparable with the normal Fine Grey Type of Ben Nevis, and continues to the north side of the more southerly dyke exposed in a small waterfall (only one dyke shown in Fig.15). The total width of the outcrop is about 70 yards. On the south side of the dyke a coarse grey quartz-diorite (No.2) comes in and persists for about 100 yds. It closely resembles the corresponding type of Ben Nevis. At the next small waterfall it shows a sharp junction with a fine quartz-diorite (No.3). No veining is seen but No.3 is extremely fine at the contact although normal for its outcrop only three feet away.

Four hundred yards further upstream the fine intrusion (No.3) rather rapidly becomes somewhat coarser and then shows a fairly sharp junction with a coarse grey-diorite (No.4). The outcrop of the latter is narrow and is soon replaced upstream by the fine intrusion (No.3) once more, though this contact is not exposed. In the tributary to the west, just below this point, the coarse intrusion (No.4) makes a narrow outcrop and here appears to merge rapidly into the fine No.3 on either side. A single xenolith of fine grey rock was found in the coarse rock.

The remaining exposures in the Allt nan Slat are in the fine grey intrusion (No.3).

Allt/

Allt Beithe and burn south of Allt Beithe. - Exposures throughout are in a pink rock of granitic aspect and of varying, although always fairly coarse,texture (No.3).

Allt Coire an Eoin.- The eastern margin is not exposed. Near the mouth of the Allt Beithe occurs a fairly coarse pink granite or granodiorite with a slight tendency to carry porphyritic felspars and in the rock-cuttings around the tunnel-intake this becomes much coarser and the porphyritic felspars assume a large size (No.2). The rock is, however, dissimilar to the Porphyritic Type of Ben Nevis as the large porphyritic crystals are mainly plagioclase. Good exposures of the same coarse pink granite or granodiorite occur in the Allt Coire an Eoin as far as the mouth of the burn south of the Allt Beithe where the southern contact is exposed. The granite remains coarse right up to the schist, into which it sends felspathic veins.

Eastern Margin between the Allt nan Slat and the Allt Beithe.- The actual igneous margin is nowhere exposed but can be traced with a fair degree of accuracy owing to frequent juxtaposition of igneous rock (No.2) and schist. The fine quartz-diorite (No.1) does not appear to be present but intrusion No.2, generally coarse, sometimes assumes the character of the Medium Type of Ben Nevis. The variation is, however, irregular and does not admit of accurate mapping. In the northern part of the area under consideration the intrusion is generally grey but as it is followed southwards it gradually becomes pinker until it merges into the pink slightly porphyritic rock of the lower part of the Allt Coire an Eoin.

Southern Area.-/

Southern Area.- If the observer looks westwards from anywhere near the top of the waterfall in the Allt Coire an Eoin above the mouth of the Allt Beithe he can easily pick out the igneous margin on the hillside. To the south the north-easterly striking, steeply inclined schists produce well marked features running diagonally from south to north down the slope. To the north, within the area of igneous rock, the weathering is softer with small irregular outcrops exhibiting no directional features. From the south margin to the edge of the wood north of the Allt Beithe there are frequent exposures, all in a pink granite exhibiting some variation in texture but always remaining fairly coarse (No.2).

The contact of the igneous rock and the schist is well exposed in several localities on the east and north-east slopes of Tom na Sroine. At all except one exposure, close to the Allt Coire an Eoin, there is an inch or two of the fine grey intrusion (No.1) veined by the coarse (No.2) or else the latter carries abundant xenoliths of the former.

North-west Area.- Once it turns east after reaching its furthest west point the margin is nowhere exposed until it reaches the path from Lianachain. Here fine quartz-diorite (No.1) is seen against schist in the light railway cutting. Three hundred yards west of the head of the Allt Beithe, on a conspicuous crag, is an outcrop of fine quartz-diorite (No.3). The fine intrusion (No.1) is seen at the edge of the wood east of Tom na Iolaire and can be traced at intervals through Coille Lianachain to the outcrop in the Allt nan Slat. Inside of this area (i.e.to the south-east) medium and then coarse quartz-diorites are/

are seen (No.2) but exposures are poor and difficult to map within this thickly wooded tract.

A quarter of a mile south-east of the first bend in the path after it has come straight across the moor from Lianachain there is an exposure of the fine quartz-diorite of the inner intrusion (No.3).

The Tunnel Section.- For convenience the record will be quoted from west to east. First ten feet of 'diorite or fine granite' (No.1) occur veined by 'granite' (No.2) which has an outcrop of 15 feet. The latter is succeeded by 'fine diorite and grey granite' (No.3) but the relationship between the two rocks is not in this case stated. No.3 intrusion persists for 1187 feet with one intermission of 'granite with some pink felspar' (presumably No.2) the relationship of which to the rocks on either side is not indicated. Then, across an undescribed junction, No.3 intrusion is followed by 3200 feet of 'granite' (No.2 again) which shows a contact with the schist 1100 ft. east of the shaft leading down from the Allt Coire an Eoin.

C. The Dyke Swarm[1]

Maufe showed that, with few exceptions, the members of the Ben Nevis dyke swarm cut the Outer Granite and fail to penetrate the Inner (1910,p.89). For the most part the dykes are porphyrites and lamprophyres but a discussion on their exact nomenclature will be deferred to the section on Petrology.

Western/

---

1. In general, only a proportion of the dykes are shown on the maps in the present paper.

Western Area of Ben Nevis massif (Fig.7).- The dyke-swarm is exposed to the west and south of Lochan Meall an t-Suidhe and several examples may be seen on the Ben Nevis path.

Two interesting dykes are seen cutting the granite in the group of streams south of the Red Burn. The groundmass is somewhat similar to that of the fine grey plutonic type and the rock contains large rectangular porphyritic plagioclase crystals. In the Red Burn a few inches of appinite occur where the Outer Granite cuts across a south-west running spessartite dyke, which is only exposed for a few feet before being hidden by the bank of the stream. In places the appinite appears to merge into the dyke but in others to cut it.

Northern area of Ben Nevis massif (Figs.9 and 10).- Only four dykes have been observed within the igneous complex. This scarcity is not due to lack of exposure for in the tunnel section only two dykes are noted in the whole of the passage of the Ben Nevis complex.

In the first and second burns east of the Allt an t-Sneachda there is a small swarm which fails to penetrate the plutonic rocks. One is actually seen to be cut across by the Porphyritic Granite in the more westerly of the two streams. Several are cut by aplite veins which have emanated from the granite.

Eastern Area of Ben Nevis massif (Fig.13).- Several dykes cut the edge of the complex east of Sgurr Finnisg-aig. One of these a porphyrite with conspicuous felspars, can be traced into the Allt Choille-rais.

On the broad plateau running north from Aonach Mor and on the cliffs east of the Allt Daim and west of the Allt Choille-rais/

rais the dyke-swarm occurs in full force. It is also well developed in the Allt Choille-rais, between the lowest lochan and the point where the stream ceases to have a general northerly direction and turns north-north-east at the beginning of the flat ground. An interesting dyke is seen near the lower end of this section. In the centre it is sufficiently coarse to bear some resemblance to a granite, but near the margin passes into a fine grey porphyrite. It is cut by a fine-grained thin basic dyke (Fig.15).

A little downstream occurs a 15-ft. dyke of spessartite. This has a N.W.-S.E.direction. The rocks shows considerable variety in texture and in the coarsest parts contains beautiful needles of hornblende up to ½ inch in length (Fig.15).

Coille LIanachain Area (Fig.15).- The igneous rocks and the surrounding schists are freely cut by the Ben Nevis swarm. Very good sections occur on the crag known as An Guirean and in the Allt Coire an Eoin. At the mouth of the second stream south of the Allt Beithe another spessartite dyke is seen with bands containing hornblende needles up to ½ inch in length.

Tectonics of Intrusion.- The vast majority of the dykes conform to a N.E.,E.N.E. or intermediate direction. Most are vertical or nearly so and where they cut the schists are transgressive. But in the lower part of the Allt Choille-rais,on An Guirean, and in the lower part of the Allt Coire an Eoin several have taken advantage of the high angle and north-east strike of the schists.

Multiple intrusion is not common, but two examples are known from the Allt Choille-rais (Fig.13), one from the second burn/

burn south of the Allt Beithe, and four from the Allt Coire an Eoin (Fig.15).

III. PETROLOGY[1]

A. Plutonic Rocks.

(1) Classification.

The plutonic rocks of the Ben Nevis area and of Coille Lianachain closely resemble those of other Scottish centres of the same age. They are members of the granite-diorite suite and the diagnostic minerals are quartz,orthoclase,plagioclase,biotite,hornblende and occasionally pyroxene. For present purposes a classification has been adopted in which each term has a fairly wide application and which conforms with what appears to be general usage.

(a) Acid and Intermediate Divisions.- Here Teall's suggestion (1888, p.253)is followed, that acid rocks should have a silica-percentage of over 65 and intermediate rocks a silica-percentage of between 55 and 65. All the plutonic rocks described in the present paper (with the small exception of the more basic appinites)fall into one or other of these groups.

(b) Acid Division.- It is proposed to use the term granite for these rocks. When the orthoclase:plagioclase ratio falls below 1:2 we have an example of a granite,such as the Inner Granite,which is also a granodiorite,since the latter was defined by Lindgren(1900,p.269) as a rock belonging to the granite-diorite suite with an orthoclase: plagioclase ratio of between 1:2 and 1:6.5. For convenience we may add to his definition a silica-percentage of between 60 and 70. This last/

1.The numbers on brackets in this section of the paper refer to the catalogue numbers of slices in the collection of the Geology Department, University of Glasgow.

last condition appears justified because the apex of the silica-percentage curve for this rock published by Eyles and Simpson (1921,p.438) is at 65.9 and the average of 40 analyses given by Daly (1933,p.15) shows a silica-percentage of 65.01. The term granodiorite is thus clearly common to the acid and intermediate divisions.

When the orthoclase:plagioclase ratio is greater than 1:2 we have a granite which is not a granodiorite. The most important local example is the Porphyritic Outer Granite.

It should be mentioned that in the Geological Survey Memoir(Bailey,1916,p.159) the terms granitite and adamellite are used for the orthoclase-rich granites (Porphyritic Outer Granite) and aplodiorite for the orthoclase-poor Inner Granite. The two former terms, however, have since been discarded by the Committee on British Petrographic Nomenclature (1921,p.144), and aplodiorite is not referred to in their report.

(c) Intermediate Division.- Long ago it was advocated by Teall that all non-syenitic rocks of an intermediate composition should come under the head diorite (1888,p.254 and p.293). This is a term which has caused considerable trouble because a difference of usage exists among European and American authors as revealed by the silica-percentage curves published by Eyles and Simpson (1921,p.438). The average European diorite is a basic rock while the average American diorite, which probably always contains a fair amount of quartz, is an intermediate rock. In essence, American usage is in accordance with Teall's suggestion and has much to recommend it. Nevertheless if all rocks with a silica-percentage of less than 55 are banished from the diorites it/

it has the effect of excluding those rocks of the suite in which quartz is unimportant or absent. These are the plutonic equivalents of the non-alkaline lamprophyres, and, as revealed by the curves, are represented by the majority of the European rocks, as well as a considerable proportion of the American rocks, to which the name is given without the prefix quartz. It is not therefore proposed to follow Teall's suggestion since its adoption would necessitate the invention of a new term to connote the basic diorites (i.e. European diorites), a policy the present writer is unwilling to advocate.

It is probably a safe generalisation that all non-syenitic rocks with over 55 per cent.silica contain quartz and therefore in the present paper the term quartz-diorite will be used for the intermediate division. This finds support in general usage as the average of 55 analyses of quartz-diorite given by Daly (1933,p.15) shows a silica-percentage of 61.59, that of 10 analyses of its near synonym, tonalite, 61.32. Eyles and Simpson treat quartz-diorite and tonalite together and the apex of their silica-percentage curve is at 59.5.

The term tonalite is a little difficult to discuss. Usage would seem to define the rock as a hornblende-biotite-quartz-diorite but a widely quoted old analysis of the type-rock gives a silica-percentage of 66.91. The Committee on British Petrographic Nomenclature recommended that tonalite be replaced by quartz-diorite (Tonale type) and their advice will be followed here as well as the corresponding recommendation for the pyroxene-bearing quartz-diorite, banatite. In naming the latter the presence of an appreciable amount of pyroxene will be required. In/

In some of the quartz-diorites biotite is by far the dominant ferro-magnesian mineral and these will be designated mica-quartz diorites.

In the quartz-diorites the orthoclase:plagioclase ratio should be below 1:2. Those therefore which have a silica-percentage of over 60 are also granodiorites as defined above. The latter term is of use as avoiding an empirical assignation to the intermediate division in the absence of an analysis in the case of the most acid representatives of the group.

(d) Appinite.- This is the name of a suite rather than of a rock-type. The rocks are coarse-grained and characterised by the abundance of hornblende (Bailey,1916,p.167-168).

(2) Petrographic Description of Rock-Types: Ben Nevis.

(a) Inner Granite.- An analysis is included in the present paper in view of the incompleteness of that given in the Geological Survey Memoir. Only the analysed rock will be described here as the petrography of the mass is given in the Memoir (Bailey, 1916,p.166).

The essential minerals of the analysed rock (5806: column II,p.57) are biotite, plagioclase, orthoclase and quartz. Hornblende is very subordinate, and sphene, apatite and magnetite occur as accessories. The biotite is brown, atrongly pleochroic variety but is somewhat altered to chlorite. The area of the individual alkalifelspar and quartz crystals seldom exceeds .25 sq.mm. They never actually show graphic structure, but interlock considerably in the groundmass, which is crowded with small porphyritic crystals of plagioclase. The latter is more than twice/

twice as abundant as the orthoclase[1], and is strongly zoned with an average composition of oligoclase. The rock is a biotite-granite and also a biotite-granodiorite[2].

(b) Outer Granite (Porphyritic Type).- This rock appears to show little variation and only the analysed specimen need be described (5807:columnI,p.57). The large and abundant porphyritic crystals consist of anhedral perthitic orthoclase. Smaller porphyritic laths of oligoclase also occur. The groundmass is allotriomorphic and consists mainly of quartz with some orthoclase. The area of individual crystals seldom exceeds .25 sq.mm. The ratio of orthoclase:plagioclase is clearly greater than 1:2. The ferromagnesian minerals are biotite and hornblende with the former slightly in excess. The accessories are the same as in the Inner Granite, but sphene, a brown variety, is remarkably abundant. The rock is a hornblende-biotite-granite (perhaps microgranite).

(c) Non-porphyritic Margin (Coarse Type).- As a rule the representatives of this type occur at the basic end of the intermediate division (quartz-diorite) but in the high Eastern Area and in the passage zone into the Porphyritic Type they lie on the border-line between the intermediate group and the acid (granodiorite), or may even pass into the latter (granite).

In the typical examples the ferro-magnesian minerals are hypersthene, augite, hornblende and biotite (5808: column V,p.57). The hypersthene, which is fairly plentiful, often shows the characteristic/

---

1. As estimated by eye under the microscope.

2. Classification on the basis of grain-size is under consideration by a Committee of the British Association and it seems likely that this rock will ultimately be called a microgranite

characteristic pleochroism. The augite is a colourless variety. The hornblende frequently forms a rim to the pyroxene. The biotite is clearly the last mineral to have crystallised and is often in fact moulded on the plagioclase. The hypersthene may be absent (5745) and even the augite may practically disappear (5743). In the latter case the rock is a quartz-diorite of the Tonale rather than the Banat type. The plagioclase varies from andesine (5808, analysed specimen) to oligoclase (5754) and occurs as subhedral laths generally exceeding 1.5mm.in length and 0.5mm.in breadth. It is always more than twice as abundant as orthoclase. The latter, however, invariably occurs while quartz is fairly plentiful interstitially.

In the transition zone between the Coarse Type and the Porphyritic Type augite is practically absent while the two felspars appear to be about equal in amount. Quartz is abundant (5750). The rock is a hornblende-biotite-granite.

In the high Eastern Area also the Coarse Type is a hornblende -biotite-granite(5786), with biotite and hornblende in about equal amount and plagioclase (oligoclase) only slightly in excess of orthoclase. In other parts of this area the Coarse Type is slightly more basic, especially near its margin. It lies on the border-line of the acid and intermediate divisions and is best referred to as a biotite-granodiorite (5799).

(d) Non-porphyritic Margin (Medium Type).- Some of the rocks of this type are very similar to the Coarse Type and are quartz-diorites of the Banat type with augite and hypersthene (5754). Other specimens, including the analysed rock (5809: Column III, p. 57), are quartz-diorites of the Tonale type with very little augite/

augite. Biotite and hornblende are about equal in amount. Plagioclase (oligoclase) is considerably in excess of orthoclase. The laths of the groundmass are generally about 1 mm. in length and 0.25 mm. in breadth. Quartz is fairly abundant interstitially.

As in the case of the Coarse Type the Medium Type is more acid in the high Eastern Area. Biotite is the only ferro-magnesian constituent while orthoclase may be nearly as abundant as plagioclase (5800) or even in excess (5802). Quartz is very abundant. The type in this area is thus a biotite-granite.

(e) Non-porphyritic Margin (Fine Type).- The texture of this type is more granular than that of the two types so far considered, although the plagioclase tends to assume a lath-like form, the laths being under 1 mm. in length and 0.25 mm. in breadth. Sparse larger porphyritic crystals of plagioclase also occur. The ferro-magnesian constituents are augite, biotite and hornblende. Plagioclase (oligoclase) is considerably in excess of orthoclase and quartz is abundant interstitially. The rock is a quartz-diorite or micro-quartz-diorite of Banat type (5810: column IV, p. 57). Hypersthene may occur and andesine-felspar (5755).

The Fine Type which forms the complicated margin east of the Allt an t-Sneachda is a biotite-granite of allotriomorphic texture with orthoclase and plagioclase about equal in amount (5759).

Round the north-east corner of the complex the Fine Type is slightly more acid than in the northern area and is generally a mica-quartz-diorite (5784). It often shows a strong porphyritic tendency (5785).

The mass of Fine Type enclosed in the Coarse in Coire an Lochain is a biotite-granite or biotite-granodiorite. Orthoclase, showing/

showing beautiful graphic intergrowth with quartz, may be the dominant felspar (5787) or plagioclase may be in excess of orthoclase (5788).

The Fine Type from the narrow outcrop at the margin a quarter of a mile east of Aonach Mor is an acid biotite-granite (5801).

(f) Appinite.- The best examples come from the exposure near the surge-chamber. The proportion of hornblende varies considerably. The mineral is usually green in colour (5770,5765) but may be brown in the more basic varieties and possess a core of augite (5769). Hypersthene and a colourless fibrous variety of hornblende also occur in the more basic varieties (5769). Plagioclase (oligoclase), orthoclase and quartz occur in about equal amounts in the average rock (5770,Fig.16) but in the more basic rock there is only a little andesine and quartz (5769).

The appinite seen at the margin in the Red Burn is a leucocratic variety (5789). Appinite also occurs ¼ mile west-north-west of Aonach Beag. It is composed of large euhedral crystals of hornblende, highly sericitised felspar, a little quartz and comparatively abundant apatite and sphene (5803).

(g) Intrusive Contacts.- A slice (5764) of the actual junction of the Fine Type and the Coarse Type in the Allt Coire an Lochain shows a fine quartz diorite (Banat type) cut by a coarse quartz-diorite (Tonale type). The junction is very clear cut but there is no sign of chilling of the younger rock. A large inclusion of the Fine Type in the Coarse near the surge-chamber is a highly altered rock, now in the state of a hypersthene-hornfels (5775). The ferro-magnesian constituents have been almost completely altered to hypersthene and to a lesser extent to augite. The hypersthene is often granular but/

Fig. 16:- Xenolith of Fine Type in Porphyritic Type; Allt an t-Sneachda (left).

Appinite from near Surge-chamber (right).

but may occur as large porphyrblastic crystals in which pleochroism from pale green to pale pink is well seen. Scraps of biotite still remain attached to or enclosed in the hypersthene crystals representing the original mineral. The plagioclase (oligoclase-andesine) has been completely recrystallised, and forms a clear granular mosaic with orthoclase and quartz. Magnetite and apatite occur as accessories.

A slice (5758) from the junction of the Fine Type and the Porphyritic Type in the Allt an t-Sneachda provides an example of fine quartz-diorite (Tonale Type) cut by porphyritic hornblende-biotite-granite. Near the porphyritic rock, which is unchilled, the Fine Type has developed secondary hornblende, which is bright green and euhedral, and also secondary sphene. Beautiful euhedral crystals of hornblende can be seen growing out at right angles from the recrystallised edge of the Fine Type into the large crystals of perthitic orthoclase of the Porphyritic Type (fig.16).

(h) Contact Alteration in Felspars.- The peculiar clouding of the plagioclase felspars, characteristic of thermal metamorphism (MacGregor,1931) has been observed in a number of the Ben Nevis plutonic rocks though, curiously enough, not in those of Coille Lianachain. The Fine Type (5751,5757,5762,5764,5784) shows it most frequently, but it has also been observed in the Medium Type (5754). It appears to affect the larger plagioclase crystals more readily and one crystal may show both clouding and sericitisation.

(i) Summary of Petrology.- In the lower part of the Ben Nevis complex, i.e. in the Western Area and in the Northern Area, the non-porphyritic rocks are quartz-diorites. They form a fairly close group in themselves and, as shown by the table of specific gravities, p. 59, the Coarse Type is the most basic/

basic with the Medium next and the Fine most acid. The Fine and Medium Types are very close to each other. It will be seen that the different Types overlap petrographically and there is little doubt that they form a closely associated group derived from the same magma. Where the Coarse Type merges into the Porphyritic Type with orthoclase phenocrysts it is more acid. In the north-eastern corner the Fine Type shows a different porphyritic tendency with phenocrysts of plagioclase, biotite and hornblende.

In the high Eastern margin all the marginal types are more acid. The Coarse Type either enters into the acid group and is a biotite-granite, or may occur just on the border of the acid and intermediate group and be a biotite-granodiorite. The Fine and the Medium Types change correspondingly and still remains more acid than the Coarse Type. They are biotite-granites.

(3) Petrographic Description of Rock-Types: Coille Lianachain.

(a) Intrusions 1 and 3.- The quartz-diorites of these intrusions are very similar to each other and to the Fine Type of Ben Nevis as exposed in the Northern Area. The only significant difference that can be detected between No.1 and No.3 is that the former tends rather to be a mica-quartz-diorite (though the Banat type does occur) while the latter is uniformly of the Banat type and may contain hypersthene in addition to augite. The description already given of the Fine Type of Ben Nevis (p.51) removes any necessity for a detailed description.

(b) Intrusions 2 and 4.- As exposed in the Allt nan Slat the coarse quartz-diorite (Banat type; 5816) is identical with the typical Coarse Type of Ben Nevis. Traced to the east and west of the the Allt nan Slat parts of Intrusion 2 are medium-grained and slightly less basic being quartz-diorites (Tonale type) with very little/

little pyroxene (5840). Traced southwards the intrusion becomes more acid. It varies from mica-quartz-diorite (5818) through biotite-granodiorite with porphyritic plagioclase (5845) to acid biotite-granite (5825).

The coarse rock (Intrusion 4) found in the centre of Intrusion 3 is a quartz-diorite (Banat type) without hypersthene (5832).

(c) Contact of Intrusions 2 and 3 in the Allt nan Slat. The coarse rock (No.2) is a quartz-diorite (Banat type) with a large proportion of hypersthene, some at least of which is secondary. The fine rock (No.3) is of similar composition but is very fine. Its small laths of plagioclase have a trachytic structure and are aligned parallel to the contact. They can be seen to cut across crystals in the coarse rock and in one case to stream around a hypersthene crystal contained therein. This slice, in conjunction with the chilling seen in the field, leaves no doubt that Intrusion 3 is the younger (5824).

(d) Summary of Petrology. - The inner (No.3) and outer (No.1) fine intrusions are very similar to each other and to the fine quartz-diorite of Ben Nevis. The coarse quartz-diorites (both Nos.2 and 4) of the Allt nan Slat are very similar to the Coarse Type of Ben Nevis but in the south-east and southern Areas Intrusion 2 changes from a quartz-diorite to a biotite-granite.

(4) TABLE OF ANALYSES.

	Granite.		Granodiorite.					Quartz-Diorite.							
	I	A	B	II	C	D	E	III	F	G	IV	H	J	V	
SiO_2	66.50	65.03	68.40	67.30	65.01	61.59	61.32	60.80	60.05	59.55	59.25	58.90	56.77	56.25	SiO_2
Al_2O_3	15.15	16.69	17.21	16.50	15.94	16.21	16.95	16.25	18.55	17.80	17.30	16.47	16.67	16.30	Al_2O_3
Fe_2O_3	1.34	1.19	tr.	1.20	1.74	2.54	2.39	1.70	.93	1.12	1.15	2.89	3.16	1.60	Fe_2O_3
Fe O	2.39	2.04	.92	1.98	2.65	3.77	4.29	3.38	3.41	4.14	4.07	4.04	4.40	5.05	Fe O
Mg O	1.88	2.25	1.03	1.27	1.91	2.80	2.84	3.72	3.46	2.86	3.60	3.57	4.17	5.12	Mg O
Ca O	3.15	3.61	3.05	2.85	4.42	5.38	5.56	4.75	5.44	4.10	4.95	6.14	6.74	6.55	Ca O
Na_2O	3.90	3.65	4.48	4.70	3.70	3.37	2.62	4.05	3.84	3.71	4.45	3.46	3.39	4.13	Na_2O
K_2O	3.68	3.40	2.88	2.75	2.75	2.10	2.20	3.05	2.72	3.22	2.50	2.11	2.12	2.02	K_2O
$H_2O+105°$	.90	1.58	.30	.50	1.04	1.22	1.22	.60	.35	1.90	.50	1.27	1.36	.95	$H_2O+105°$
$H_2O-105°$	.20		.12	.20				.30	.05	.45	1.00			.10	$H_2O-105°$
TiO_2	.55	.50	.28	.30	.57	.66	.23	.90	.42	1.00	.70	.76	.84	.90	TiO_2
P_2O_5	.18	.19	.14	.16	.20	.26	.33	.28	.29	.19	.21	.27	.25	.40	P_2O_5
Mn O	.10	—	—	Nil	.07	.10	.05	.10	.16	tr.	.15	.12	.13	.40	Mn O
CO_2	Nil	—	—	Nil	—	—	—	Nil	Nil	Nil	Nil	—	—	Nil	CO_2
Total	99.92	100.12	99.89 includes FeS_2 1.08	99.71	100.00	100.00	100.00	99.88	99.94 includes ZnO .27 FeS_2 tr.	100.04	99.83	100.00	100.00	99.77	Total
S. G.	2.68			2.67				2.76			2.71			2.81	

EXPLANATION OF TABLE OF ANALYSES

I. Porphyritic Outer Granite of Ben Nevis. Just above tunnel intake, Allt an t-Sneachda. Anal. W.H. Herdsman.

A. Porphyritic 'hornblende-biotite-granodiorite' centre of Priestlaw mass, Southern Uplands. Anal. F. Walker (Walker, 1928, p.161).

B. 'White Granite' from trial quarry, Rudh'a Bhaid Bheithe. Ballachulish Granite. Anal. W.H. Herdsman. (Walker, 1934, p.554)

II. Inner Granite or Granodiorite of Ben Nevis. Ben Nevis path, ¼ mile south of south end of Lochan Meall an t-Suidhe. Anal. W.H. Herdsman.

C. Average of 40 Granodiorites. (Daly, 1933, p.15).

D. Average of 55 quartz-diorites. (Daly, 1933, p.15).

E. Average of 10 tonalites. (Daly, 1933, p.15).

III. Medium Type of Non-porphyritic margin of Outer Granite of Ben Nevis. By side of light railway between Allt a'Mhuillinn and Allt na Creige Duibhe. Anal. W.H. Herdsman.

F. Hornblende-biotite-granodiorite, Kentallen Quarries, Ballachulish. Anal. W.H. Herdsman. (Walker, 1934, p.554).

G. 'Hornblende biotite-granodiorite' with accessory pyroxene, Shiel Hill, south margin of Spango mass. Southern Uplands. Anal. W.H. Herdsman. (Walker, 1928, p.161).

IV. Fine Type of Non-porphyritic Margin of Outer Granite of Ben Nevis. 150 yards below railway bridge, Allt na Caillich. Anal. W.H. Herdsman.

H. Average of 125 diorites, including 55 quartz-diorites. (Daly, 1933, p.16).

J. Average of 70 diorites, excluding quartz-diorite. (Daly, 1933, p.16).

V. Coarse Type of Non-porphyritic margin of Outer Granite of Ben Nevis. At mouth of tunnel leading from Surge-chamber. Anal. W.H. Herdsman.

TABLE OF SPECIFIC GRAVITIES

Ben Nevis.

	Lower Areas (West and north)			Higher Area (East)		
Type	No. of specimens determined.	Extreme S.G.'s	Average S.G.	No. of specimens determined.	Extreme S.G.'s	Average S.G.
Porphyritic	3	2.66-2.68	2.67	-	-	-
Coarse	5	2.75-2.82	2.79	3	2.68-2.70	2.69
Medium	8	2.72-2.80	2.75	2	2.63-2.67	2.65
Fine	12	2.67-2.77	2.73	1	-	2.64

Coille Lianachain.

Intrusion.	No. of specimens determined.	Extreme S.G.'s.	Average S.G.
1.	5	2.71-2.79	2.74
2.	6	2.67-2.78	2.74
3.	3	2.72-2.76	2.75
4.	1	-	2.70

B. THE DYKE SWARM.

The following divisions of the hypabyssal rocks are recognised in the Ben Nevis Memoir:-

(a) Felsite and Porphyry.

(b) Porphyrite.

(c) Malchite.

(d) Lamprophyre.

The term malchite, however, can no longer be employed. That the term is not valid is stated in the North Ayrshire Memoir (MacGregor,1930,p.32) where the rocks which come under that head fall into Group 2 of the classification there adopted, but are not named. The reason is given by A.G.MacGregor (1931,p.527) who states that Professor Bailey had found when comparing the North Ayrshire dykes with rocks from the Odenwald that the typical malchite was a contact-altered rock and that it was therefore undesirable to continue to apply the name to normal dyke-rocks. No name is advanced by Macgregor but in conversation with the author he has suggested the term microdiorite which is here adopted. For the definition of the different groups the reader is referred to the Ben Nevis Memoir (Bailey,1916,p.173), microdiorite being read for malchite.

Although types which occupy a rather acid position in the porphyrite group are fairly common, plagioclase is the dominant felspar in the vast majority of the hypabyssal rocks of the Ben Nevis district as is to be expected considering that they represent plutonic rocks with, to a great extent, the same characteristic. Accordingly rocks which can be classed in Group (a) are rare.

Of the remaining three groups the porphyrites are the commonest, but the microdiorites are a close second, while the lamprophyres are comparatively uncommon. The various types grade into one another.

Felsites.- Four dykes which fall into this category occur in the small swarm which fails to penetrate the Outer Granite (Fig.10) The rock (5779) shows a fine microcrystalline mosaic of quartz and alkali-felspar with patchy aggregates of more coarsely crystalline allotriomorphic quartz.

The only coloured constituent is scarce biotite. Muscovite also occurs sparingly. There are also very sparse large phenocrysts of perthitic orthoclase. Several of the dykes which fail to penetrate the Fault Intrusion of Glen Coe are of this type.(Bailey, 1916,p.173).

Rocks intermediate between Porphyry and Porphyrite.- As an example may be taken the broad dyke which has been traced from the Allt Choille-rais a considerable distance into the north-east corner of the Ben Nevis Complex (Fig.15). The most abundant phenocrysts are idiomorphic zoned plagioclases (oligoclase-andesine) with rounded angles. Less abundant are perthitic orthoclase and quartz, the latter with the angles greatly rounded. Biotite exceeds hornblende and both are somewhat altered to chlorite. The groundmass consists of a fine-grained mosaic of quartz and felspar (5793).

Porphyrites.- The phenocrysts are generally plagioclase, with biotite and hornblende, in a fine-grained groundmass of felspar and subordinate quartz with scraps of ferro-magnesian material. Sericitisation and albitisation of the felspars are very common and the ferro-magnesian constituents are generally altered to chlorite.

The/

The above description, for example, fits the later portion of the multiple dyke in the second burn south of the Allt Beithe (5828). Against the earlier portion, a microdiorite (5830), the porphyrite is strongly chilled and shows beautiful flow and spherulitic structures (5829).

Sometimes the sericitisation is very advanced and quite large flakes of muscovite and irregular patches of epidote may be formed within the plagioclase phenocrysts (5842).

The 75-ft.dyke of granitic aspect under the railway bridge in the Allt Choille-rais (Fig.15) is simply a porphyrite in which the phenocrysts are unsually large and crowded (5820). At the margin it grades into a normal fine-grained porphyrite with sparse phenocrysts (5821).

Pyroxene is not a common constituent, but a porphyrite dyke (5780) from the small swarm which fails to penetrate the Outer Granite (Fig.10) carries idiomorphic phenocrysts of augite along with biotite, showing slight marginal resorption, hornblende and abundant plagioclase (oligoclase-andesine). Considerable areas of the latter have escaped albitisation and these show the dusty clouding characteristic of plagioclase felspars in contact-altered rocks. There is curiously little indication of contact alteration in other respects.

Microdiorites- In the Allt Choille-rais, a little above 2000 ft. (Fig.13) is a multiple dyke both parts of which are typical examples of microdiorite. In fact, though the later portion (5798) is strongly chilled against the earlier (5797), they are indistinguishable under the microscope.

The/

The most abundant constituent is plagioclase (oligoclase), occurring as stumpy laths slightly zoned and albitised in the centre. The ferro-magnesian constituent is chiefly chlorite representing both biotite and hornblende. Quartz occurs interstitially in the groundmass but is very subsidiary. In addition very sparse larger felspar crystals are present as phenocrysts. They have rounded angles and are zoned with andesine centres.

Lamprophyres.- The most interesting representatives of this group are two hornblende-rich dykes from the eastern part of the area. One of these (5823) occurs in the Allt Choille-rais about 120 yds.below the railway bridge (Fig.15). It shows considerable variation in texture, coarser portions with conspicuous needles of hornblende occurring in irregular patches. Under the microscope the hornblende is dark olive-green and is often strikingly idiomorphic. Alteration has taken place to some extent to chlorite and epidote. The groundmass consists of felspar and subordinate quartz. The felspar is considerably albitised, but some appears to be orthoclase and it is possible that the rock may occupy an intermediate position between the vogesites and the spessartites.

The other example (5837) comes from the Allt Coire an Eoin at its junction with the second stream south of the Allt Beithe (Fig. 15). It too shows considerable variation in texture, but on the whole is coarser than the example described above, especially in the groundmass, and might almost be described as an appinite. The idiomorphism of the hornblende, which occasionally shows twinning, is very perfect. Quartz is practically absent. The rock is remarkable for the abundance of apatite which forms an interlocking mesh/

mesh of fine needles some of which are long enough to traverse several crystals.

The dyke (5772) connected with the appinite in the Red Burn (Fig.7 and p.20) is also of spessartite affinities, but the hornblende is irregular, and the rock contains a fair amount of biotite. Augite is present as globular aggregates but may be secondary.

The thin dark dyke (5822) cutting the 75 ft.porphyrite in the Allt Choille-rais (Fig.15) seems to be kersantite. In accordance with the custom of the time it had previously been called camptonite (Wilson,1901,p.28).

Very basic lamprophyre dykes are rare. An example (5746) occurs in the Allt na Creige Dhuibh under the railway bridge, and is one of the few dykes which cut the northern portion of the Outer Granite. Biotite, hornblende and augite all occur, but are not markedly idiomorphic. Biotite, a pale brown variety with but faint pleochroism, is the commonest. The hornblende has undergone considerable alteration. The augite is rather colourless variety, generally with a rim of hornblende. Parts of the rock are almost entirely composed of these constituents, but others are less basic and show a sparse groundmass of quartz and andesine.

IV. SUMMARY OF RESULTS AND CONCLUSIONS.

A.BEN NEVIS

Consideration of the field evidence along with the study of Fig.5 will show that the Non-porphyritic Margin of the Outer Granite of Ben Nevis may be regarded as composed of three interrupted arcuate intrusions corresponding to the Fine, Medium and Coarse Types; and that, with two exceptions, explained below, these are everywhere arranged/

arranged inwards from the margin in the above order. In the most fully developed section there is a complete series from the Fine Type through the Medium to the Coarse, and finally to the Porphyritic Type. These different intrusions are found to merge into one another and it is clear that they must have followed one another so rapidly that the earlier intrusion in no case had time to solidify completely before the next came in. In other sections, however, we find an intrusive junction between the Fine Type and the next intrusion of the particular locality; this is always the Coarse Type or Porphyritic Type. The Fine Type must have been solid when the next intrusion was injected and, as the Medium Type is always absent in such instances, it is reasonable to assume that, while the latter was being injected elsewhere, the Fine Type was allowed time to solidify. In other words, in some sections the Medium Type, or the Medium and Coarse Types, are replaced by an intrusive junction. It is only in connection with the Fine Type that this break has anywhere occurred. The Medium Type, where present, is always followed by the Coarse with a merging junction and the junction between the Coarse Type and the Porphyritic Type is invariably of a transitional nature.

The different parts of the Non-porphyritic Margin may now be examined in the light of the above conclusions.

On the west side of the mountain (at the present level of erosion is understood throughout) igneous activity began with the intrusion of the Medium Type (Fig.7). This took place only at certain parts of the margin. Before the complete solidification of the Medium Type the Coarse Type was injected over a much wider area and in turn was succeeded by the Porphyritic Type, also before

complete/

complete solidification.

Turning now to the Northern Area (Figs.9 and 10) we find the complete series of intrusions, with merging junctions throughout in the Allt a' Mhuillinn, the Allt na Creige Duibhe and the intervening ground, while to the west, around the Allt Coire an Lochain, and to the east, in the Allt na Caillich, the Medium Type is absent and the Fine Type is veined by the Coarse.

In the Eastern Area (Fig.13) the intrusion of the Coarse Type appears to have initiated igneous activity in most localities, but at certain places it was preceded by the intrusion of the Medium Type or of the Fine and the Medium Types. The Fine Type found nearly surrounded by and veined by the Coarse Type in the Coire an Lochain may be regarded either as a small isolated boss intruded at an early stage into the schist and later surrounded by the Coarse Type, or as a large block torn with the neighbouring schist from a Fine-grained Margin present at a lower level.

This still leaves the exceptional sections in the Allt Daim and the Allt an t-Sneachda to be explained. The following theory is advanced. First there was an intrusion of the Fine Type. Then into its still liquid centre was injected the Medium Type. When Coarse Type was injected some of its was intruded into the liquid centre of the Medium Type while some came against the now solid south margin of the Fine Type. Finally against most of this margin the Porphyritic Type was intruded with strong veining junctions. The injection of the Medium and Coarse Types into the centre of the Fine Type would account for the rather exceptional swelling of the igneous margin in this area. It is here too that the deflection of strike of the schists reaches its maximum.

The/

The Non-porphyritic Margin may therefore be regarded as representing the early stages of the injection of the magma which formed the Outer Granite of Ben Nevis into parts of an arcuate fissure. This injection was probably accompanied by the down-faulting of a central core, as postulated in Glen Coe by Clough, Maufe and Bailey (1909), but definite proof of this is lacking on Ben Nevis as far as the Outer Granite is concerned.

Generally speaking, the fissure appears to have opened round an increasing proportion of the periphery as the igneous history proceeded. But after the injection of the magma which gave rise to the Fine Type the fissure must have closed at certain localities, preventing the injection of the Medium Type, and not have re-opened until the period of injection of the Coarse Type, or even of the Porphyritic Type. With the incoming of the Porphyritic Type the fissure seems to have assumed comparative symmetry for, as can be seen by glancing at Fig.5 the outer margin of the Porphyritic Granite has a fairly regular circular outline, the irregularities of the igneous margin as a whole corresponding to the earlier types.

The following table may be inserted here as giving an idea of the relative importance of the different types which go to make up the Outer Granite.

Type.	Area of Outcrop	Angle subtended by outcrop at centre of Complex
Porphyritic Type	6 sq.m.	230 degrees
Coarse Type	2 "	190 "
Medium Type	.5 "	75 "
Fine Type	.4 "	65 "

As has been shown in the section on Petrology (p.45), in the high Eastern Area all the Marginal Types are more acid than the corresponding/

corresponding Types in the outcrops at lower levels elsewhere. This difference may be explained as due to gravitational differentiation, such as has been described from the Mull ring-dykes (Bailey, 1924,pp.320-330).

B. COILLE LIANACHAIN (Fig.15).

The existence of the outer arcuate intrusion of fine-grained quartz-diorite (No.1) is proved by the evidence seen in the Allt nan Slat, in the tunnel and the intervening ground. That this intrusion possibly extends underground for some distance round the south-west margin is shown by a slight occurrence of the fine quartz-diorite at the surface there. It appears to be absent from the eastern margin and is certainly absent where the latter is cut by the tunnel. Inside of this there is a complete ring-dyke of medium or coarse quartz-diorite, granodiorite or granite (No.2) narrow in its north east and west outcrops but broad to the south. In its narrow parts it is grey and more basic, but in the broad southern outcrop it is pink and more acid, with a tendency to become porphyritic in the south-east corner. That this ring is later than the outermost fine intrusion (No.1) is proved by the veining seen in the tunnel. In the Allt nan Slat the junction is obscured by a dyke but in the north-west corner the fine quartz-diorite (no.1) appears to merge through a medium-grained quartz-diorite into the coarse (No.2). This medium-grained quartz-diorite also appears in parts of the north-eastern sector near the margin. Within this continuous ring is a later intrusion of a fine grey quartz-diorite, seen both in the Allt nan Slat and in the tunnel and also in isolated outcrops west of the Allt nan Slat. That this is the latest intrusion so far considered is shown by the chilling observed in the Allt nan

Slat/

Slat and from the conclusive evidence afforded by a microscope slice of the actual junction.

Finally we have the small outcrop of coarse quartz-diorite (No.4) exposed in the upper part of the Allt nan Slat. The exact status of this outcrop is rather doubtful but it has been regarded here as a later intrusion of quartz-diorite (No.4) into the fine quartz-diorite (No.3), partly on the evidence of the xenolith of the fine rock seen in the coarse though this might have been derived from the earliest intrusion (No.1).

The section exposed in the tunnel seems to suggest that some at least of the igneous margins within the Coille Lianachain complex hade outwards. Thus in the tunnel the eastern margin lies 600 feet north-east of its position on the surface. Then No.3 intrusion in the tunnel persists nearly to the Allt Beithe (with one small intermission of 'granite with some pink felspar' probably due to a bend inwards of the margin of Intrusion 2) under undoubted surface outcrops of pink granite (No.2). It appears probable also that the ring-dykes of the Coille Lianachain complex increase in diameter downwards. Their intrusion was probably accompanied by the downfaulting of central conical cores gradually diminishing in diameter. The rocks present bear a close resemblance to the Marginal Types of Ben Nevis and their injection was probably contemporaneous. In any case the intrusion of the Coille Lianachain mass cannot be later than that of the Inner Granite of Ben Nevis for it is freely cut by the Ben Nevis Swarm of dykes.

C. THE DYKE-SWARM.

The influence of the Inner Granite upon the position of the/

the dykes was noticed by Maufe (1909,p.84) who writes: "The vast majority lie between two lines . . . tangential to the boundary of the Inner Granite". The evidence derived from the tunnel section, and from the mapping carried out in connection with the present paper, supports this contention, which satisfactorily accounts for the absence of dykes in the Northern Area. The Coille Lianachain mass, however, also appears to have had some influence on the dykes. If parallel lines, running in a north-east-south-west direction, be drawn through points ¼ mile south-east of the extreme south-east corner of the intrusion and ¼ mile north-west of the extreme north-west corner, they will be found to enclose a very great proportion of the swarm. Thus south of Aonach Mor the number of dykes rapidly diminishes, though the area is well within the south-easterly north-east running tangent to the Inner Granite. The swarm continues in full force to the north-easterly tangent to the Inner Granite which is also the line parallel to the tangent to the Coille Lianachain mass.

Measurements were made of the thickness of the dykes in the Allt Choille-rais and in the Allt Coire an Eoin as well as of the breadth of the belt of country traversed by them. These measurements are tabulated below with corresponding figures from other areas for comparison.

Locality	Allt Choille-rais	Allt Coire an Eoin	Glen Coe	Mull	Arran
No.of dykes	80	70	31	375	525
Total thickness(ft)	758	789	1005	2504	6050
Average thickness(ft)	9.5	11.3	32	5.8	11.5
Total thickness (ft.)at right angles to/					

to general direction of dykes.	712	744	1005	2504	5410
Breadth of measured section(ft.) at right angles to general direction of dykes.	5965	4480	3399	66000	78100
Precentage of breadth of measured section occupied by dykes.	12%	17%	25%	4%	7%

Glencoe quoted from Clough,Maufe and Bailey (1909,pp.644-645).
Mull quoted from Bailey (1924,p.360).
Arran quoted from Tyrrell (1928,p.249).

Allowing for those dykes which are outside the sections measured the total thickness of the Ben Nevis Swarm on the east side of the mountain is a little over 1000 feet.

V. APPENDIX - SUGGESTED ROUTES.

In view of the rather uninhabited nature of much of the area dealt with in the paper the following suggestions as to methods of approach may be of some use:-

Western Area of Ben Nevis.- This can be well studied from Achintee, 2 miles from Fort William. The main Inverness road should be followed as far as Bridge of Nevis and from there a track(quite feasible for motor-traffic) leads to the foot of the Ben Nevis path. The exposure in the R.Nevis can be seen from the Glen Nevis road and is 3½ miles from Fort William.

Northern Area of Glen Nevis.- The western part of this area (i.e. around the tunnel-portal and surge-chamber and in the Allt Coire an Lochain) can best be approached by following the track leading to Achintee as far as the farmhouse of Claggan and then ascending the hillside parallel to the pipe-line. The eastern part is best approached by following the track which leaves the Invernass road just past the Bridge of Lundy on the south side. This track runs along/

along the south side of the River Lundy which can be crossed at most points unless exceptionally high. In this manner the various stream sections can be easily approached. The track is feasible for motor cars but care should be exercised.

Eastern Area of Ben Nevis and Coille Lianachain.- The southern part of the Eastern Area of Ben Nevis may be reached by ascending the Allt Coire Giubhsachan which flows into Glen Nevis at Steall. Most of the Eastern Area, however, and the whole of the Coille Lianachain Complex are best approached from Spean Bridge. From the main road a mile west of Spean Bridge a track (quite practicable for motors) leads southwards to Lianachain house, where it joins the road from the Bridge of Lundy. From Lianachain there is a path over to Coille Lianachain, the southern termination of which is shown on Fig. 15.

From this track the light railway may be followed to the Allt Choille-rais which is the best method of approach for most of the eastern area of Ben Nevis.

THE SOUTH-EAST MARGIN OF THE ETIVE GRANITE COMPLEX

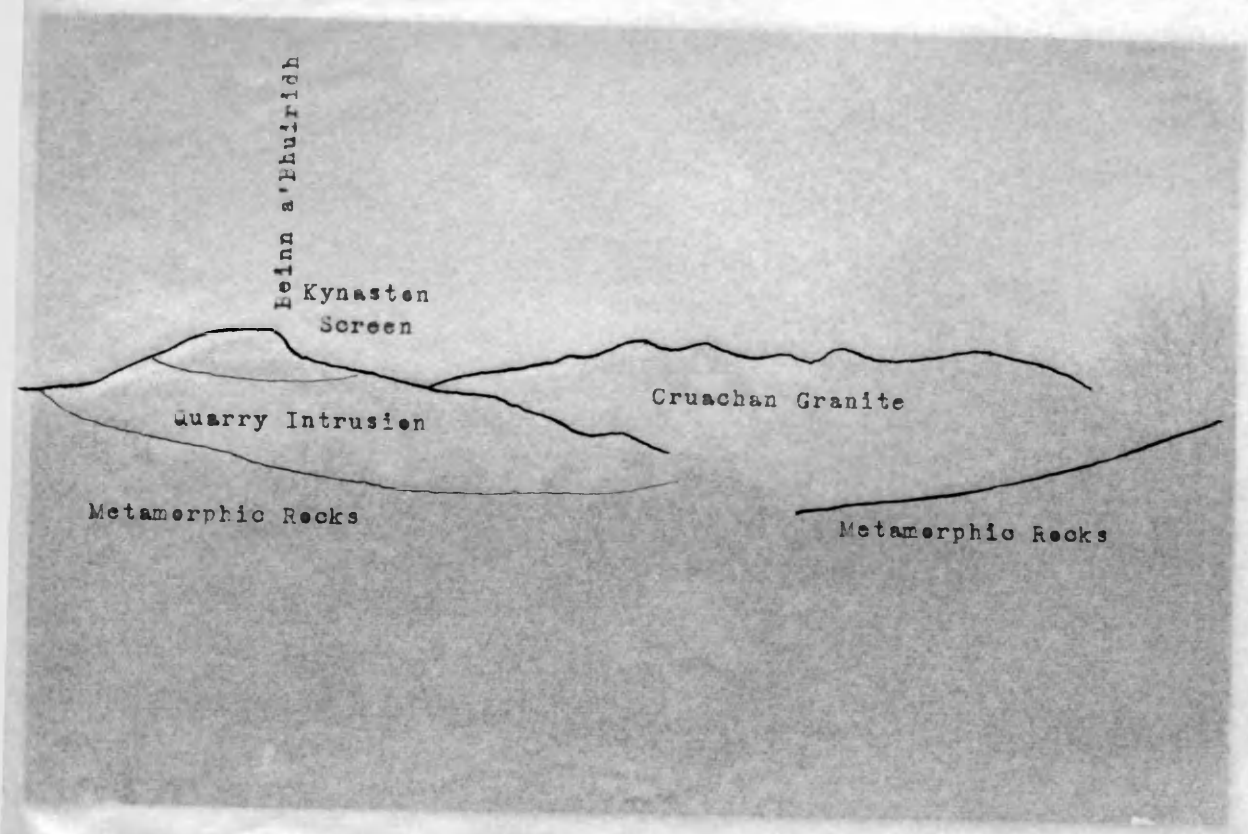

Fig.17:-South-East Margin of Etive Granite Complex.

Fig.17:-South-East Margin of Etive Granite Complex.

1. INTRODUCTION

Subject of Paper.

The Granite Complex of Etive is one of the largest in Britain. It occupies a considerable proportion of 1-inch Sheet 45 of the Geological Survey (Scot.) and extends into Sheet 53 to the north. It has already been divided into two major, and a small number of minor, divisions. The major divisions have been called the Cruachan Granite, occupying a discontinuous outer position, and the Starav (Glen Etive) Granite in the interior (Fig.1). The Cruachan is the earlier of the two. These names may be retained, though it is probable that further subdivision will be practicable. The author's research in the district to date has been concentrated on an arcuate complex that occurs to the south-east margin of the Cruachan Granite (Fig.18).

Historical.

The earliest geological account of Ben Cruachan was given by MacCulloch (1817). He describes the granite of which most of the mountain is composed, noting the pink acid type which forms the two main tops. He remarks on the veining of schist by granite and on the abundance of porphyry dykes cutting both. On Murchison and Geikie's map of Scotland (1862) the boundaries of the granite area are shown with a fair degree of accuracy which is improved upon on Geikie's map (1892). No attempt is made, however, to distinguish different intrusions. This deficiency was soon to be put right by the work of the Geological

Survey. In 1896 Kynaston described a coarse porphyritic rock, around the head of Loch Etive, which he called the Glen Etive Granite and considered to be slightly younger than the granite of Ben Cruachan. Further work proved this intrusion, which was found to have a non-porphyritic centre, occupied a large oval area almost completely surrounded by the Cruachan Granite. Around the periphery of the latter at various localities basic marginal facies were found to occur. Of particular interest in the present connection is the outcrop of quartz-diorite described by Kynaston (1898,p.86) from the southern slopes of Beinn a' Bhuiridh. From the upper slopes of the same mountain he described at the same date (1898,pp.90-91) a fine-grained horneblende rock which was traced into a schistose rock further to the north.

Kynaston's work for the Survey finally found expression in the publication of 1-inch Sheet 45 (Scot.) in 1907 (a colour-printed addition appeared in 1926 without revision) and in the District Memoir published in 1908. The northern part of the granite area extends into Sheet 53 and is described in the Memoir published in 1916 (Bailey, Clough, Grabham, Kynaston, Maufe, 1916, pp. 119-121). The whole mass is now referred to as the Etive Granite, including as its main members the Cruachan Granite and the Glen Etive Granite now renamed Starav Granite (Fig.1).

In 1934 Nockolds (pp.302-321) dealt with the contamination of the marginal quartz-diorite of Beinn

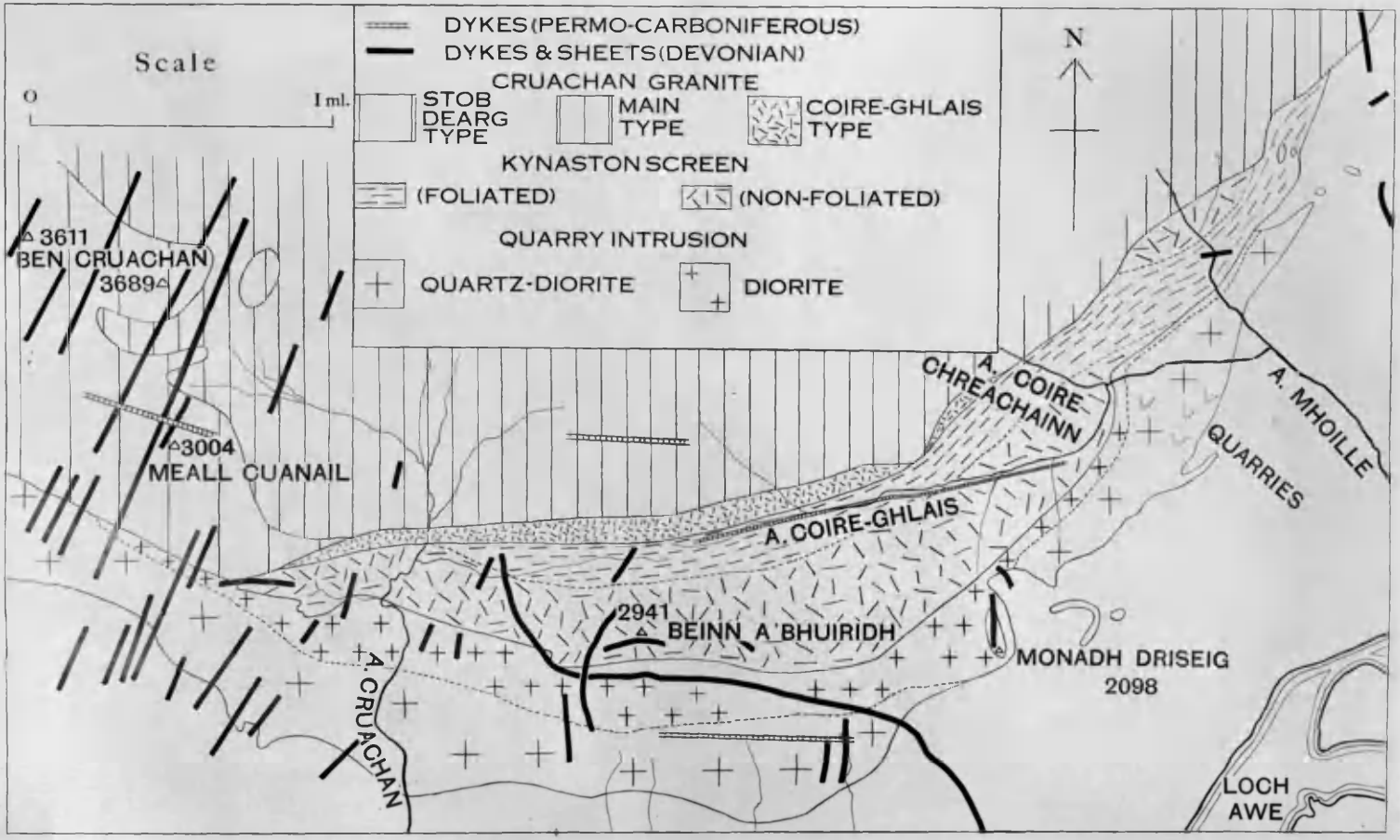

Fig.18:- South-East Margin of Etive Granite Complex.

——— Intrusive junction. - - - - Merging junction.

a'Bhuiridh and included a description and analysis of the normal rock.

Preliminary Definition of igneous units.

As can be seen from the historical survey three principal rock-groups may be distinguished on the south-east margin of the Cruachan Granite (Fig.17). To the outside there is an arcuate outcrop of quartz-diorite and diorite which it is proposed to refer to as the Quarry Intrusion as it is well exposed in the extensive, although now disused, Ben Cruachan Quarries, 3 miles west-north-west of Dalmally. To the north occurs the arcuate, partially foliated mass shown as Po and γPo on 1-inch Sheet 45. A happy suggestion of Prof. Bailey's is that this should be called the Kynaston Screen. Thirdly there is the Cruachan Granite proper, differentiated in Fig.18 into three types. These rock groups will now be dealt with in turn.

II FIELD EVIDENCE (Fig. 18).

The Quarry Intrusion:-

This forms an arcuate mass, five miles long and half-a-mile wide above the north-east and north-west arms of Loch Awe. The southern margin is everywhere against Dalradian rocks while the northern margin is almost entirely against the Kynaston Screen. To the north-east the intrusion leaves the screen and thins out in the Glencoe Quartzite. The limit of extension to the west has not yet been determined but in this direction the intrusion comes against the Cruachan Granite through failure of the Kynaston Screen.

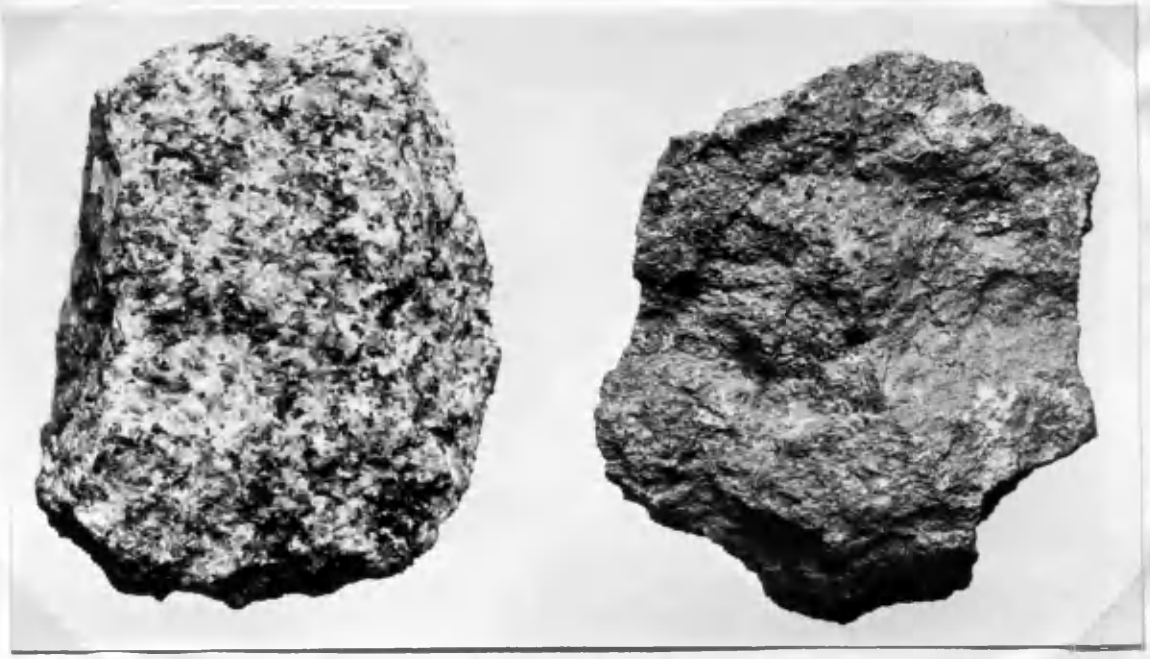

Fig. 19:- Quartz-diorite and diorite of Quarry Intrusion.

Fig. 20:- Non-foliated and foliated types of Kynaston Screen.

For the most part the Quarry Intrusion consists of coarse grey quartz-diorite. Against the Kynaston Screen, however, it is always more basic (Fig.19).

An interesting section occurs in the Allt Mhoille. At its outer (southern) margin the intrusion is a coarse grey quartz-diorite and extensively veins the adjacent Glen Coe quartzite without any sign of chilling. Traced upstream it gradually becomes darker and finer merging into a basic diorite parphyry against the kynaston Screen.

On the southern slopes of Beinn a'Bhuiridh the basic facies of the Quarry Intrusion is comparatively broad and, in fact, on Monadh Driseig makes up the whole breadth of the mass. In this broader outcrop the diorite facies is as coarse grained as the quartz-diorite. The one type always merges into the other. About a third of a mile east of the Allt Cruachan the contact of the Quarry Intrusion and the Kynaston Screen is well exposed. At the margin the diorite becomes a very fine porphyritic rock with a crypto-crystalline groundmass.

A good section across the intrusion is afforded by the exposures in the Allt Cruachan, but the contact with the Kynaston Screen is obscured.

To the west of the Allt Cruachan the diorite can be traced as a narrow strip for nearly a mile, first against the Kynaston Screen and then against the acid facies of the Cruachan Granite. Quartz-diorite is seen to the south and extends to the west, but just how far has not yet been determined.

The Kynaston Screen:-

Within this outcrop may be distinguished three main types of rock, firstly non-foliated contact-altered andesite, secondly rocks which in their extreme development are mica-schists (Fig. 20) and thirdly a type of dioritic aspect which may or may not be foliated. The first two types pass into one another. The third occurs as rare ramifying veins in the foliated rock and so far has only been observed in the Allt Mhoille and the Allt Coire Chreachainn.

In the Allt Mhoille a strongly foliated type appears against the Quarry Intrusion. The foliation is vertical and parallel to the margin. Traced upstream the Screen gradually loses its schistose structure until, against the Cruachan Granite, it possesses the aspect of a contact-altered rock without any well marked schistose structure.

Between the Allt Mhoille and the Allt Coire Creachainn a remarkable change takes place. Against the Cruachan Granite the screen-rock shows strong foliation, but downstream loses its schistose structure, and against the Quarry Intrusion closely resembles andesite. A similar passage from foliated to non-foliated may be observed in the Allt Coire-Ghlais. The strike of the screen within this area becomes east-west, and the direction of foliation alters correspondingly. The southern, and broader, part of the screen is not foliated and forms the north slopes of Beinn a'Bhuiridh, where precipitous crags at least 800 feet high afford a magnificent vertical section of the mass.

Fig.2I:- View eastwards from Allt Cruachan. Kynaston Screen to north craggy, Quarry Intrusion to south under grass.

Fig.22:- View westwards from Allt Cruachan. Kynaston Screen to north forms crag, Quarry Intrusion to south under grass.

Traced down the stream, which flows westwards into the Allt Cruachan, the screen gradually loses its foliated character. While no exposures occur in the Allt Cruachan itself, the view of the valley sides in either direction affords a striking illustration of the vertical nature of the screen, which stands out as rugged crags with the diorite to the south covered by grass(Figs. 21 and 22).

West of the Allt Cruachan the screen forms a conspicuous crag and then thins out on the southern ridge of Meall Cuanail. This portion consists of andesite, which shows contact-alteration, but only when examined microscopically.

The Cruachan Granite:-

Within the area so far mapped three principal types may be distinguished. The most abundant is coarse-grained hornblende-biotite-granite which may be referred to as the Main Type. Secondly there is a very acid pink type, varying somewhat in texture, which may be called the Stob Dearg Type, from one of the main peaks (3611 feet) of Ben Cruachan. The name is particularly suitable as Dearg (Gaelic) means red. Thirdly there is a fine grey biotite-rich type which may be referred to as the Coire-Ghlais Type from its exposure on the north side of that corrie.

North-east of the Allt Coire Chreachainn the Main Type comes against the Kynaston Screen and can be seen to vein it.

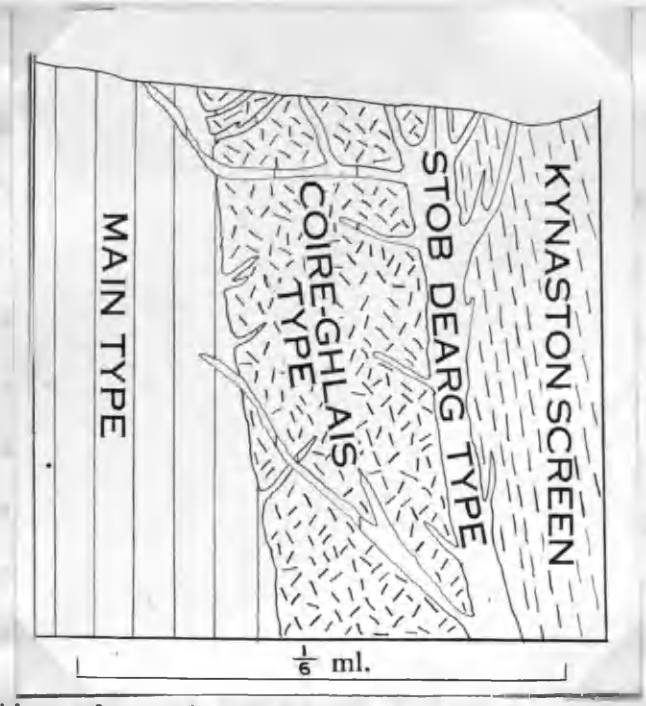

Fig.23:- Section of margin of Cruachan Granite north of Coire-Ghlais.

Fig.24:-Ben Cruachan. Highest top(3689) to left, Stob Dearg(3611) to right.
(With acknowledgements to S.M.C. Guide to Central Highlands).

Between the Allt Coire Creachainn, however, and the Allt Cruachan both the Coire-Ghlais and the Stop Dearg Types occur at the margin (for the sake of simplicity only the former is shown on Fig. 18 but both are shown in section on Fig. 23). The Stob Dearg Type extensively veins both the Coire-Ghlais and Main Types and in a large tributary draining the north wall of Coire-Ghlais and in the Allt Cruachan the Main Type can be seen to vein the Coire-Ghlais Type. The latter is sometimes foliated and a strip on the north side of Lairig Torran (the col north of Beinn a'Bhuiridh) shown by Kynaston (1-inch Sheet 45) as altered grit is now considered to be a schistose portion of this intrusion.

The floor of Coire Cruachan is cut out of the Main Type but the ridge running northwards to Meall Cuanail is entirely in the Stob Dearg Type. On the col north of the latter mountain, however, the Main Type occurs. A little way up the ridge leading to the highest top of Ben Cruachan a contact is seen between the Main Type and overlying Stob Dearg Type. The junction is a clean-cut one and the Stob Dearg Type presents a more felspathic margin to the Main Type and carries derived biotite crystals.

The Stob Dearg Type forms the two main tops of Ben Cruachan (Fig. 24). Although the junction between the two types is not a regular one (for example several alternations occur on the ridge east of Ben Cruachan) on the whole the Stob Dearg Type appears to overlie the Main Type. Kynaston has already noted the existence

of the two types through a wide area of the Cruachan Granite. He found the junction in places fairly well defined, but in others merging (this last relation has not been encountered in the author's field work). He also points out that the more acid (Stob Dearg) type tends to occupy the higher summits (1908,P.84). He does not discuss relative age, and it is in this direction that progress has been made, together with the actual mapping of the boundary.

III PETROLOGY.

Quarry Intrusion(Fig. 19):-

The more acid portion of this intrusion is a basic quartz-diorite (Tonale type). An analysis published by Nockolds (1934,P.315) shows that it has a silica percentage of 56.50. It consists of hornblende, often carrying a core of diopside, biotite, plagioclase (acid andesine), alkali-felspar and quartz. Detailed descriptions are given by Kynaston (1908,P.85) and Nockolds (1934,P.305) and need not be repeated here.

In its broad outcrop the diorite portion of the intrusion is a coarse grained rock. It consists of brown hornblende (with a core of augite), biotite, plagioclase and a very small quantity of orthoclase and quartz. The rock may be described as a mica-diorite. Next the Kynaston Screen it is much finer-grained and carries porphyritic crystals of hornblende and plagioclase.

Most slices from the Quarry Intrusion show contact-alteration, which increases to a noteworthy extent to the north. Hornblende crystals are replaced by biotite aggregates, while secondary hornblende, showing sieve structure, is developed. The plagioclase laths contain minute inclusions, which give the mineral a dusty appearance. This last feature has been described by MacGregor (1931) as indicative of contact-metamorphism. The inclusions are noted by both Kynaston and Nockolds, but are not ascribed to contact-alteration.

The Kynaston Screen(Fig. 20):-

Under the microscope the diorite type found as veins within the screen closely resembles the rock from the neighbouring portion of the Quarry Intrusion, though often in a somewhat foliated condition.

Kynaston (1908, pp.97-102) gives a detailed petrological description of the screen proper, and at the present stage little need be added. Briefly, the least altered portion of the screen is composed of contact-altered augite and hornblende-andesites. These may, or may not, carry plagioclase phenocrysts, but this feature so far has not lent itself to field mapping. Much of the mass, although not revealing schistose structure, has been completely reconstructed, and consists of a clear mosaic of quartz and felspar with secondary biotite. The more altered rocks are strongly foliated biotite schists. The transition from type to type is perfect. Even the most highly foliated varieties may retain large plagioclase phenocrysts. Contact-metamorphism may be observed throughout,

including clouding of the plagioclase felspars similar to that described from the Quarry Intrusion.

Cruachan Granite:-

Coire-Ghlais Type :- This consists of a mosaic of biotite, orthoclase and quartz with sparse porphyritic crystals of plagioclase. It may be called a biotite-micro-granite. At some localities the rock is slightly foliated, especially in the area north of Lairig Torran mapped by Kynaston as altered grits, but the porphyritic plagioclases persist. In fact most of the type appears to have under-gone crushing, and, in one instance, contact-clouding of the plagioclase felspars was observed.

Main Type:- This is a coarse hornblende-biotite-granite consisting of the two ferro-magnesian constituants mentioned in about equal proportions, oligoclase (in excess of orthoclase but probably not twice as abundant), orthoclase and quartz with apatite, magnetite and sphene as accessories.

Stob Dearg Type:- In places, especially in veins, this may be fine grained, but for the most part it is fairly coarse. Quartz and perthitic orthoclase make up practically the whole of the rock, the only other constituent being biotite occurring as sparse flakes.

IV CONCLUSIONS

The most difficult question to answer in connection with the area studied is that of the mode of origin of the Kynaston Screen. The shape is very clearly exposed (Figs.21 & 22). To quote Kynaston's account (1908,P96):- 'this rock mass traverses elevated ridges and deep corries

alike; it goes up one side of a ridge and down the other in a manner strongly suggesting the behaviour of a great vertical dyke-like mass.' The age relations are also demonstrable. The screen is the earliest of the three principal igneous units into which the south-east portion of the complex has been divided, for the Quarry Intrusion becomes fine-grained against it and the Cruachan Granite veins it.

At the present stage of research the author is unwilling to dogmatise upon the question whether the rocks forming the screen are intrusive or extrusive in origin. There can be no doubt that the rocks, in their least altered state, strongly resemble an assemblage of augite and hornblende-andesite lavas, though separate lava flows have not yet been differentiated, nor has any accompanying ash or sediment been detected. Still, quarter of a mile from any contact, it is much less mature in crystallisation than many a porphyrite dyke of 10 to 12 feet in thickness. As a working hypothesis the view will be taken that the mass is extrusive in origin, i.e. that it is the remnant of a lava pile. On this assumption the following theory of origin is offered.

First of all over the present Cruachan area there was the outpouring of a lava pile continuous with the Larne lavas still preserved south of the Pass of Brander Fault. Part of these Cruachan lavas sank within a great cauldron subsidence, in the same manner as in the classic example of Glen Coe (Clough, Maufe, and Bailey, 1909). At the same time the Quarry Intrusion rose along the boundary fault of

north

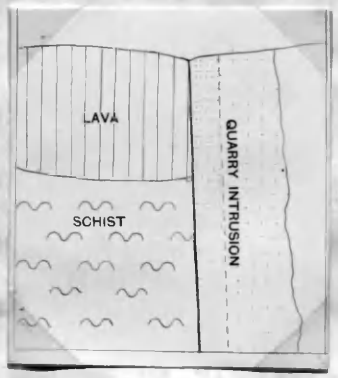

Fig.25:-Origin of Quarry Intrusion.

north

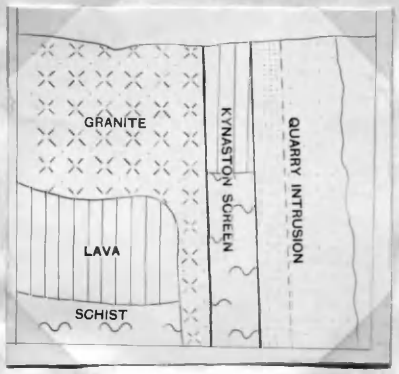

Fig.26:-Origin of Kynaston Screen.

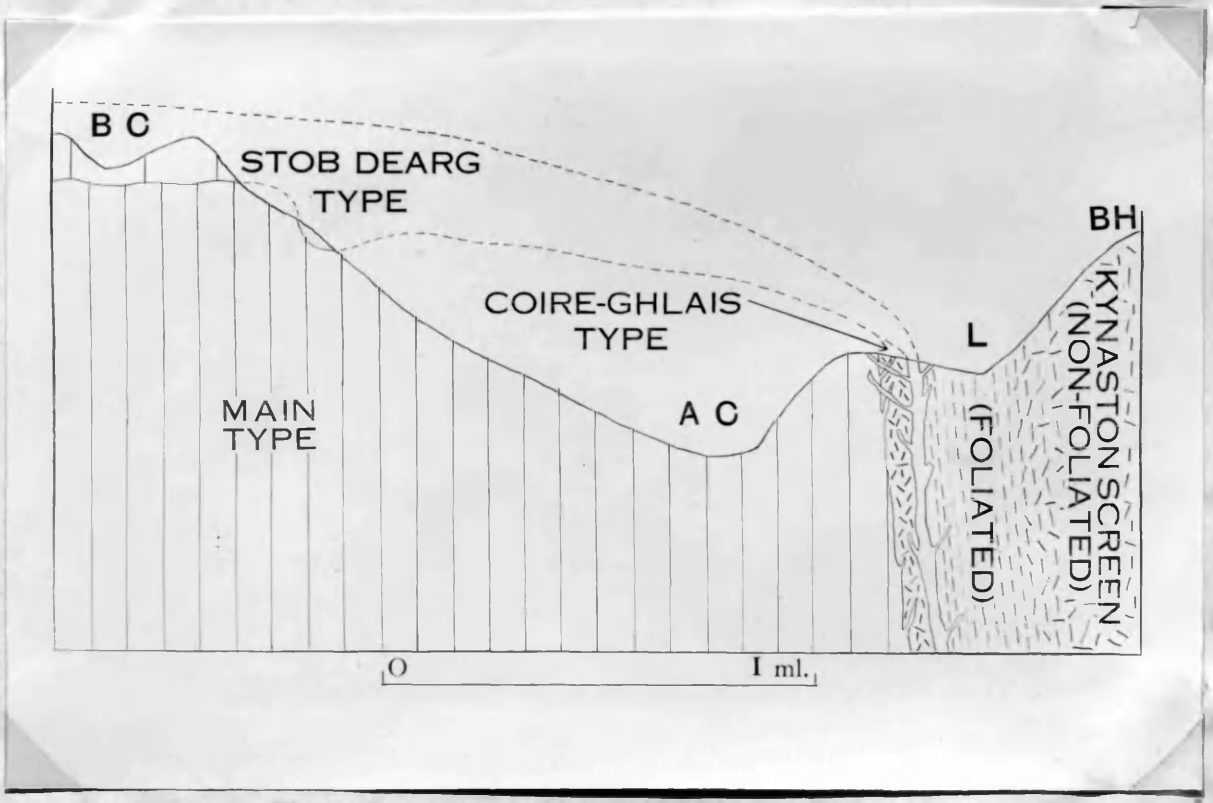

Fig.27. Section. B.C. Ben Cruachan. A.C. Allt Cruachan.
L. Stream flowing west from Lairig Torran.
BH. Beinn a'Bhuiridh.

the cauldron and was more or less chilled at its inner edge by the comparatively cold downfaulted mass of lava (Fig.25). The Quarry Intrusion thus corresponds to the Fault Intrusion of Glen Coe. The next stage at Cruachan, which also has an analogue at Glen Coe, though not on the same relative scale, was marked by the foundering of most of the central block of lava, under conditions which left a roof, since removed by erosion. The Cruachan Granite, at three stages, rose up to fill the subterranean cauldron as it formed. According to this interpretation the Kynaston Screen lies between two successive positions of the boundary fault of a cauldron subsidence (Fig.26) which in its early history was probably subaerial and later subterranean.

The foliation of the screen can be explained as due to shearing accompanying the downfaulting. The distribution of the foliation, however, requires come explanation. Most of the foliation occurs in a zone along the north margin and can readily be explained as due to the drag of the downwardly moving block, that made room for the Cruachan Granite, before the magma reached the level affected. Once the liquid rock intervened it would act as a lubricant preventing further foliation.

The change of the foliation from the north margin to the south margin in the Allt Mhoille is a puzzling feature. Initiation of the foliation along the south margin was here probably due to the faulting accompanying the injection of the Quarry Intrusion. Diorite veins, more or less foliated are common in this section of the screen, and it is possible

that for a time the latter acted as a conduit and that diorite came up through it instead of outside it. When the faulting moved northwards the already foliated part of the screen might act as a zone of weakness and localise shearing. According to this view the unsheared rock at present near the north margin in the Allt Mhoille came from a somewhat higher level than the unsheared rock of Beinn a'Bhuiridh.

The earliest phase of the Cruachan Granite was the Coire-Ghlais Type, which in places has suffered foliation similar to that affecting the Kynaston Screen. The intrusion of the Main Type probably accounts for the widespread contact-alteration observed in the Quarry Intrusion and the Kynaston Screen.

The Stob Dearg Type is later than the Main Type. Although further work is required there is evidence that it overlies the latter and also occurs irregularly at the margin (Fig. 27). It may have come in as a roof to the Main Type being intruded up the side in the manner described by Richey in his account of the Tertiary centre of the Mourne mountains (1927, p685.)

THE ARROCHAR INTRUSIVE COMPLEX

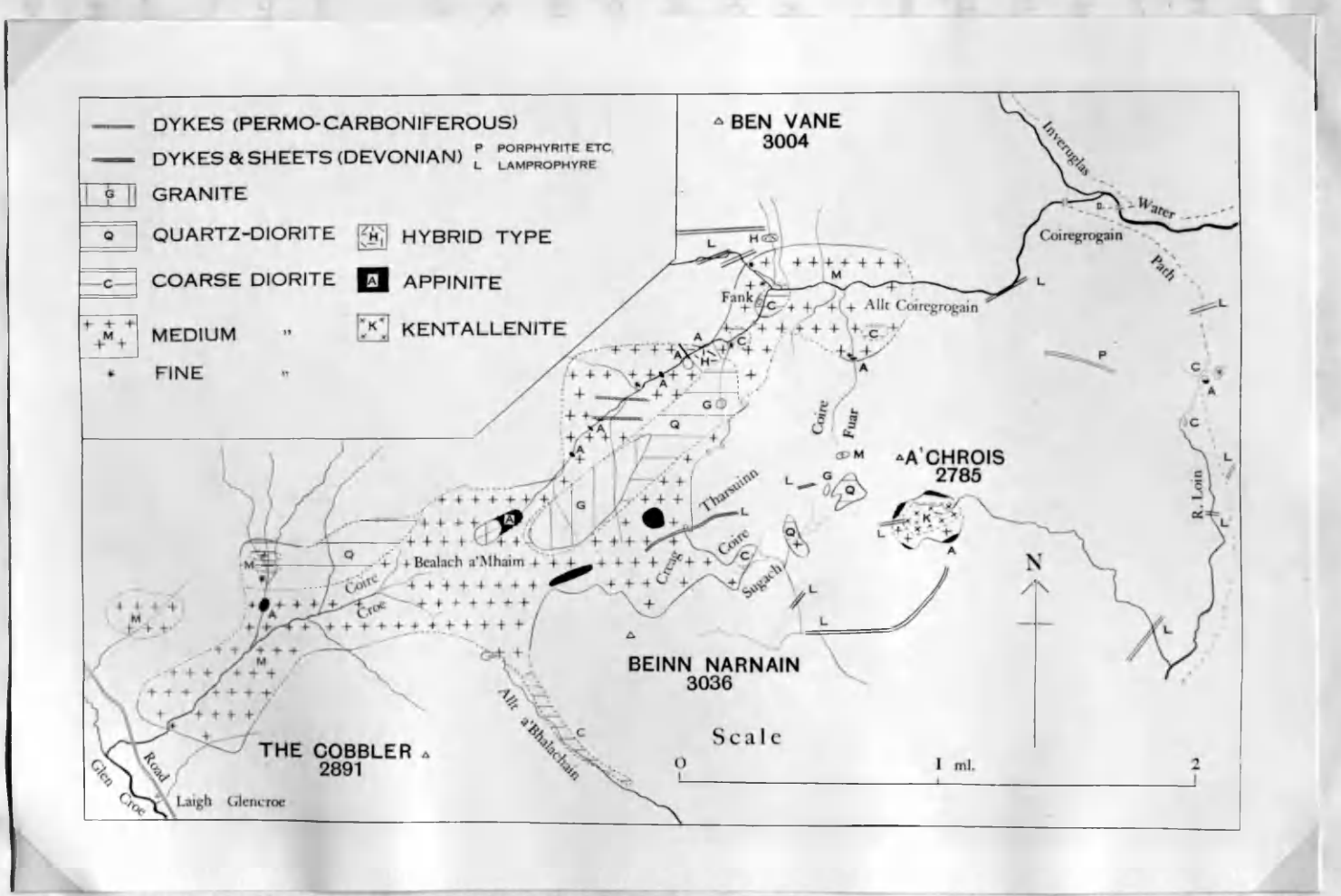

Fig. 28:- The Main Arrochar Intrusion and neighbouring smaller intrusions.

1. INTRODUCTION

The present paper deals with a number of intrusions lying within a north-easterly oriented belt of country, four miles wide and twelve miles long, running from a point 1½ miles west-south-west of the Brack, through the Arrochar mountains and across the head of Loch Lomond, to the upper reaches of Glen Gyle, 3 miles east of Ardlui (Fig. 28). Only one attains any considerable size. It lies north-west of the head of Loch Long and may be called the main Arrochar Intrusion.

The three most westerly intrusions, two of which are of extremely minute proportions, lie with 1-inch Sheet 37 (Inveraray) of the Geological Survey (Scotland) and are briefly described in the Mid-Argyll Memoir (Clough,1905,pp.93-94). The remainder occur within 1-inch Sheet 38 (Loch Lomond). No descriptive Memoir of the latter has been published. With two small exceptions all are shown on the above Geological Sheets under the general term diorite.

Excluding kentallenite, which partly makes up an intrusion quarter of a mile south-south-east of A'Chrois, all the rock-types found in the smaller masses occur in the main Arrochar Intrusion. The latter will therefore be dealt with first, and in some detail, and then a shorter description will be given of the smaller associated masses. A section will also be devoted to the dykes and sheets of the district.

II. THE MAIN ARROCHAR INTRUSION (Fig.28).

a) Shape of Intrusion.

The intrusion outcrops with an area of 1¾ square miles.

It/

Fig. 29:- Valley of Allt Coiregregain with Ben Vane in background.

Fig. 30:- Ceire Sugach. Igneous rock under grass to left. Schist forming cliffs to right.

It is a highly irregular mass, $3\frac{1}{2}$ miles long and on the average half-a-mile wide, and follows a north-east--south-west course through the mountain mass to the north-west of the head of Loch Long. It is mainly exposed in the valley of the Allt Coiregrogain (Fig.29), which runs in a north-east direction to the north-west of A'Chrois and Beinn Narnain, and in the valley of Coire Croe (Fig. 38), which drains in a south-west direction to the north-west of the well-known Cobbler (Ben Arthur). These two valleys are deeply-cut and lie between two schist ridges of considerable height the Ben Ime (3318 feet)--Ben Vane (3004 feet) ridge and the Cobbler (2891 feet) -- Beinn Narnain (3036 feet) -- A'Chrois (2785 feet) ridge. The impression thus inevitably arises that the cutting of the valleys accounts for the exposure of the igneous rock through removal of overlying schist. On examination however, of the contoured geological sheet 38, even without study of the intrusion in the field, this simple view is found to be untenable. The igneous margin frequently cuts sharply across the contours, and moreover, may be 1500 feet higher on one side of the valley than on the other, for example north of Beinn Narnain.

The field evidence is strongly against the flat-top hypothesis, especially as regards the north-eastern half of the intrusion. Exposures of the actual contact of igneous rock and schist are by no means abundant but where seen are invariably at a high angle. An excellent example occurs in a large tributary which flows into the Allt Coiregrogain just below a fank (sheepfold). The contact is seen at both sides of the stream at a small waterfall and is clearly vertical. Others showing the same relationship occur in the Allt Coiregrogain at two localities above the fank where the margin swings/

Fig.31:- Beinn Narnain. Mainly schist but igneous rock forms softer weathering ground in front of long ridge on skyline.

Fig.32:- North slopes of A'Chrois above Allt Coiregrogain. Craggy schist forms upper slopes, igneous rock under grass forms lower slopes and extends to col.

swings into the stream. Also, where the margin descends south-east into Coire Sugach (Fig.30) and where it runs south-west towards the summit of Beinn Narnain (Fig.31), it is obviously at a high angle.

The view is therefore put forward that, generally speaking, the intrusion has the form of a broad dyke. At the same time it should be borne in mind that it is likely that the mass widens underground, with outwardly sloping walls, and that in parts this slope may be at a comparatively low angle, for example near the western end of the intrusion, where exposures of the contact are very few.

On the dyke hypothesis the outcrop of the mass at a low level is explained on the supposition that the igneous rock has proved softer than the surrounding schist and has thus guided the erosion of the valleys. This view is supported by the observation that everywhere the igneous rock weathers in a soft fashion and is generally under grass while the schist weathers in a much more rugged manner (Figs.30,31,32,33). Thus the margin of the schist coincides on the hillside with the beginning of a line of cliff. This phenomenon may be particularly well observed from almost anywhere in the upper part of the valley of the Allt Coiregrogain or by looking north-west or south-west from a point well up on Sugach Corrie. There is nothing highly exceptional in the igneous rock giving rise to low ground compared with the country rock. Other Scottish examples of this phenomenon are afforded by the plutonic intrusions of Loch Doon and the Moor of Rannoch.

b) <u>Distribution and Relationship of rock types.</u>

Considering the evidence in a general way the sequence of rock-types/

types may be taken as follows, the youngest being printed at the top and roughly contemporaneous types side by side.

GRANITE (Fig.40).
QUARTZ-DIORITE
COARSE-GRAINED DIORITE (Fig.40) APPINITE
MEDIUM-GRAINED DIORITE (Fig.40).
FINE-GRAINED DIORITE (Fig.40).

The exact nomenclature of the dioritic types is discussed in the section of Petrography. For local purposes the three textural types will be referred to as fine diorite, medium diorite and coarse diorite. The use of these terms is purely relative and all three types are of fairly fine grain. The socalled fine diorite occurs in very small bulk and on Fig.28 is grouped with medium diorite, with merely an asterisk to indicate its principal outcrops.

The coarse diorite and appinite form small intrusions into the medium. Quartz-diorite occurs north of Coire Croe and in the centre of the mass. In the latter position the quartz-diorite is cut by an elongated intrusion of granite.

Fine diorite:- This type frequently forms a narrow merging marginal facies of the medium diorite. It is generally non-porphyritic, but a distinctive porphyritic variety also occurs with large composite phenocrysts of pyroxene. Thirty feet of this latter type, occur, for example, against the schist in the large tributary of Allt Coiregrogain which flows into the main stream at the fank, and similar rock is also seen near the margin in the stream which drains Coire Fuar (Fig.33).

The relation between fine and medium diorite is not always one of merging. At several localities fine diorite is seen included/

Fig. 33:- Coire Fuar. Igneous rock under grass in foreground. Schist forming craggy upper slopes. Small intrusion determines nick at lowest point of ridge.

included in, and veined by, the medium, for example in the fank tributary of the Allt Coiregrogain mentioned above, in the Allt Coiregrogain itself half a mile upstream from the fank and in the stream flowing from Coire Croe a short distance from the igneous margin. This included fine diorite is always non-porphyritic.

Medium diorite:- Abundant exposures may be seen in the valleys of the Allt Coiregrogain (Fig.29) and Coire Croe. The rock may carry sparse phenocrysts of pyroxene, but on the whole is non-porphyritic. It weathers a grey colour and gives rise to soft topography.

Microscopic evidence of contact alteration by later intrusions is rare, but it may be mentioned that medium diorite from the stream flowing out of Coire Croe, at its first tributary on the right bank above the road, shows intense clouding of the plagioclase felspars of the type described by Macgregor (1931) as indicative of contact metamorphism. Throughout its outcrop, moreover, the medium diorite is frequently traversed by a network of tiny ridges (Fig.34). Ridges of similar appearance characterise pneumatolytically altered lavas in Mull (Bailey,1924,p.95).

Coarse diorite:- This type is much more hornblendic than the medium. On the one hand, by an increase in hornblende it appears to pass into appinite and on the other, by an increase in quartz, into quartz-diorite. Evidence of age relationship to the medium diorite can be seen at only one locality. Twenty nine yards below a small foot-bridge over the Allt Coiregrogain coarse diorite appears to pass, within three feet, into fine diorite which very soon becomes medium diorite. It is suggested that the apparent

merge/

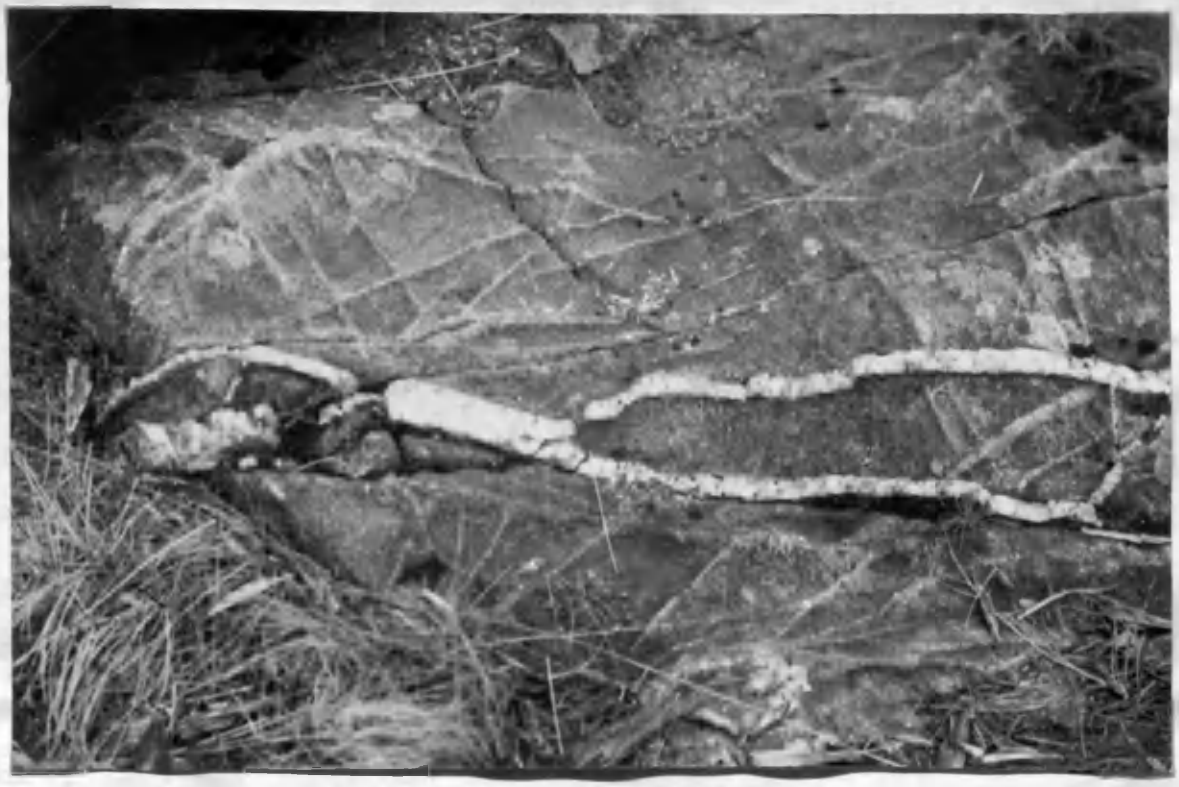

Fig. 34:- Medium diorite beside footbridge above fank, Allt Coiregrogain. Note network of small ridges due to pneumatolysis.

Fig. 35:- The Cobbler. Coarse diorite occurs in Allt a'Bhalachain in foreground.

merge is really the cooled edge of the coarse diorite passing into the remelted edge of the medium.

Part of the 'toe' projecting into Sugach Corrie is composed of coarse diorite which shows a sharp junction against the medium without affording any evidence of relative age. The south-easterly projection between the Cobbler and Beinn Narnain (Fig.35) consists of coarse diorite which is exposed in the Allt a'Bhalachain and also above the left bank of the latter stream further to the south-east.

Appinite (and pyroxenite):- Numerous exposures of appinite occur in the Allt Coiregrogain, although the relationship to the medium diorite is not always seen. The most interesting outcrop, 46 feet wide, lies 735 yards upstream from the fank. Here appinite presents relatively acid contact facies on both sides - downstream against a hybrid type (described later), and upstream against medium diorite. In both cases the suggestion is that the appinite is later than its neighbours. The contacts differ somewhat. Against the hybrid the appinite begins with two thin, sharply divided portions, much more acid than usual. Beyond these, at two feet from the contact and separated by another sharp junction, comes more normal, although still acid, appinite. This for the next 30 feet becomes gradually darker, passing into a thoroughly basic rock. The latter persists almost to the upstream contact with medium diorite, where a few inches of more acid type occur.

Immediately upstream from the more southerly of two east-west Permo-Carboniferous dolerite dykes a three foot dyke of appinite clearly cuts the medium diorite. The other exposures of appinite in the Allt Coiregrogain afford no evidence of age relationship.

An/

Fig. 36:- North slopes of Creag Tharsuinn to right. Note light weathering medium diorite and dark weathering appinite and pyroxenite. Ben Vane to left.

An 8-foot dyke of very coarse appinite cuts fine diorite near the margin in the stream flowing out of Coire Fuar.

On the north side of Creag Tharsuin occurs a roughly circular outcrop of ultra-basic pyroxenite with appinite margin. It can easily be picked out on the hillside by its black weathering. as opposed to the grey weathering of the surrounding medium diorite (Fig.36). The latter is veined by appinite. Another ultra-basic mass of similar composition, but with dyke-like shape, occurs to the south-west, quarter of a mile north-west of Beinn Narnain and runs up a broad conspicuous gully. The country rock is again diorite veined by appinite. The latter carries many xenoliths of its host, and the veining phenomena are spectacularly displayed on a cliff at the upper (south-west) end of the gully (Fig.37).

Quartz-diorite:- The principal outcrop of this type occurs around, and especially north-east of, the central area of granite. It is exposed in the various tributaries of the Allt Coiregrogain north of Creag Tharsuinn. Sometimes it appears to merge into the medium diorite and sometimes to cut it. The rock is of similar texture to the medium diorite.

Quartz-diorite also forms a considerable outcrop on the north side of Coire Croe. Some of the rock included within this area is fairly basic and may be better referred to coarse diorite. In three headstreams of a large tributary occur inclusions of medium and fine diorite. North of them, against the schists, the quartz diorite is particularly coarse.

Granite:- In the tributaries flowing into the upper part of the Allt Coiregrogain from the south-east is seen a mass of white or pink acid granite about half-a-mile long and one-sixth of a mile

wide/

Fig.37:- North-West slopes of Beinn Narnain. Appinite vein (running vertically past hammer, and weathering as crack) cutting medium diorite.

wide. The southern margin is exposed in a tributary which flows into the Allt Coiregrogain at the more northerly of the two Permo-Carboniferous east-west dykes. The granite, more acid than usual, comes in contact with quartz-diorite, and contains numerous xenoliths, not only of quartz-diorite, but also of appinite. Elsewhere the main contact is hidden but veins of granite are common in the neighbouring dioritic rocks.

A small intrusion of white granite is seen in a tributary of the Allt Coiregrogain, $\frac{3}{4}$ of a mile west-north-west of A'Chrois. Pink granite occurs at the head of the Allt Coiregrogain. At its north-east contact it veins appinite. The south-west contact is not exposed.

Throughout the Arrochar Intrusive Complex granite veins are abundant in all types.

Hybrid type:- Mention has already been made of a hybrid type occurring in the Allt Coiregrogain immediately downstream from an outcrop of apparently later appinite. One hundred and twenty yards farther east the hybrid type again comes in contact with appinite, but without affording evidence of relative age. The appinite persists for only three feet before giving place to schist. In the downstream side of this schist outcrop two feet of the hybrid type are seen. The section is then obscured for a short distance and the rest of the exposure is in medium diorite.

The hybrid type appears to be granite with xenocrysts of altered hornblende. The most likely source of the latter is appinite, although, as has been stated, the appinite seen in contact with the hybrid type is apparently later.

III. SMALLER INTRUSIONS OF DISTRICT

a) West of Loch Lomond/

a) West of Loch Lomond.

A'Chrois (Fig.28):- The most interesting of this group is the roughly circular mass, quarter of a mile south-south-east of A'Chrois, outcropping in the headwaters of a tributary of the River Loin. The exposures in the streams are almost entirely in kentallenite, which in the hand specimen bears a strong resemblance to the rock from the type locality. This is the furthest south exposure of the rock-type so far recorded in Britain. The relationship of the kentallenite to the medium diorite, of which most of the rest of the intrusion is composed, is difficult to determine; but to the north the two types appear to merge. Near the margin four small exposures of appinite occur. That near the north edge is the largest, and in places is extremely coarse. The time relationship of the appinite is not seen.

At the head of Coire Fuar there is a small outcrop of rather basic medium diorite (Fig.33). The rock is somewhat shattered and slickensiding in the schist suggests that faulting has taken place along its margin.

Quarter of a mile west-south-west of A'Chrois there is an irregular intrusion of fairly coarse quartz-diorite. The junction with the schist is exposed only at the south-west corner and the igneous rock is chilled at the margin. Where two tongues project south-west considerable shattering of the schist has taken place. This area shows up as a conspicuous brown scar on the hillside. Immediately to the north of this scar is a tiny oval mass of fine pink granite.

Quartz-diorite also makes up the northern portion of an intrusion/

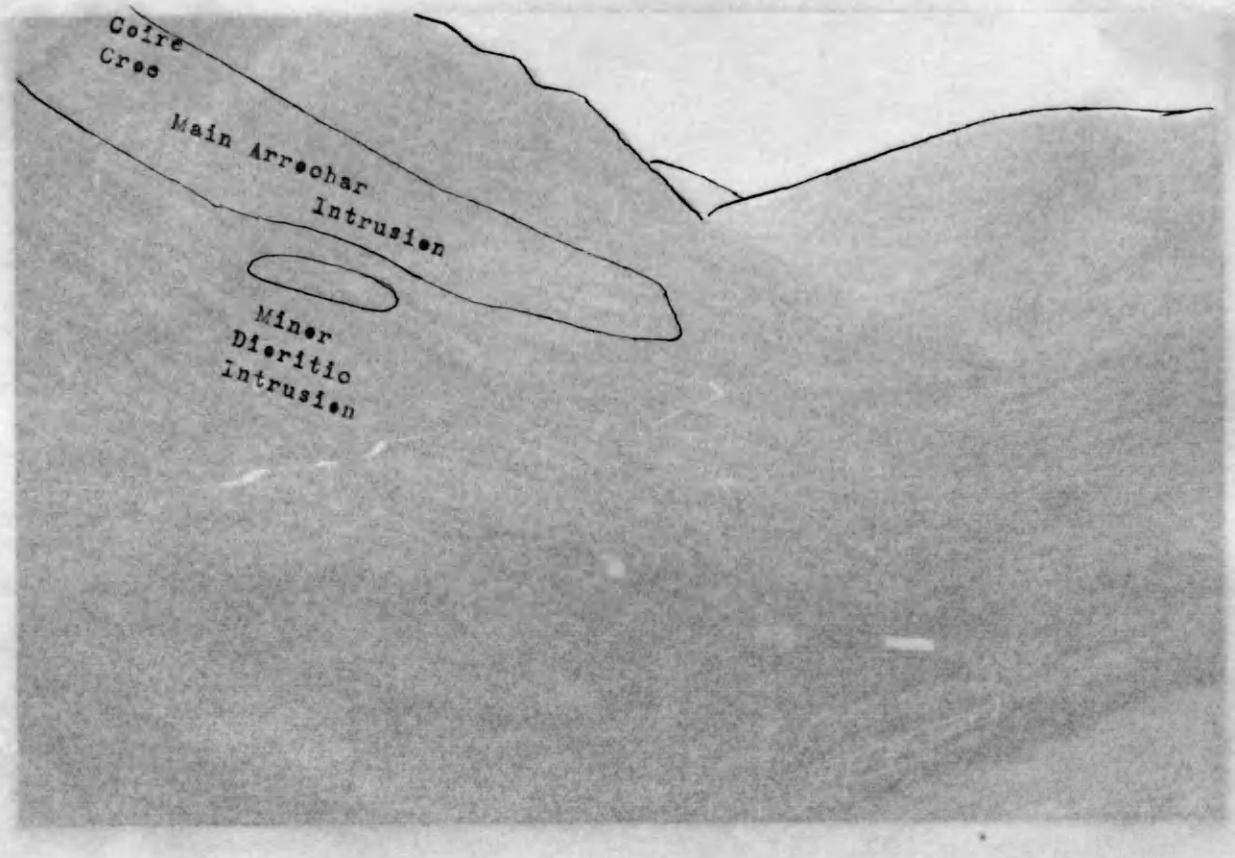

Fig. 38:- Glen Croe from head of Rest and be Thankful.

Fig. 38:- Glen Croe from head of Rest and be Thankful.

intrusion which outcrops across the stream draining the east wall of Coire Sugach. The exposures in the stream, however, and to the south-east, are of medium diorite. The relationship of the two types is not seen.

North of Arrochar Complex:- In a small stream which is crossed by the Glen Croe road (Fig. 38), a little below the milestone 'Tarbet $7\frac{3}{4}$ miles', a considerable outcrop of igneous rock occurs (Fig.28). It is the most westerly intrusion shown on Fig.28, and consists of medium diorite, cut in places by a peculiar coarse banded type (not separately mapped). On the Survey map (Sheet 38) this outcrop is shown connected to the main Arrochar Intrusion Complex. No evidence of the presence of a connecting link could be found on the ground, and so on Fig.28 the connection has been omitted. Here it may be added that on sheet 38 diorite is mapped one-third of a mile south by east of Ben Ime. The present author could not confirm this outcrop, for he only found a few large boulders of medium diorite and nothing in situ.

On the steep south face of Ben Vane (Fig.29) a small intrusion occurs in a tributary of the Allt Coiregrogain (Fig.28). The rock is a hybrid type with a close resemblance to that described from the Allt Coiregrogain.

Towards Loch Lomond, one mile east-south-east of Ben Vorlich (Fig.28), rather basic medium diorite is exposed above the 1600 foot level in the Allt Ardvorlich, a stream flowing into Loch Lomond $2\frac{1}{2}$ miles south of Ardlui. The rock tends rather to the coarse side for its type, but is chilled at the margin which is exposed both on the upstream and downstream side at a high angle. Isolated exposures show that the intrusion does not extend far to the north of/

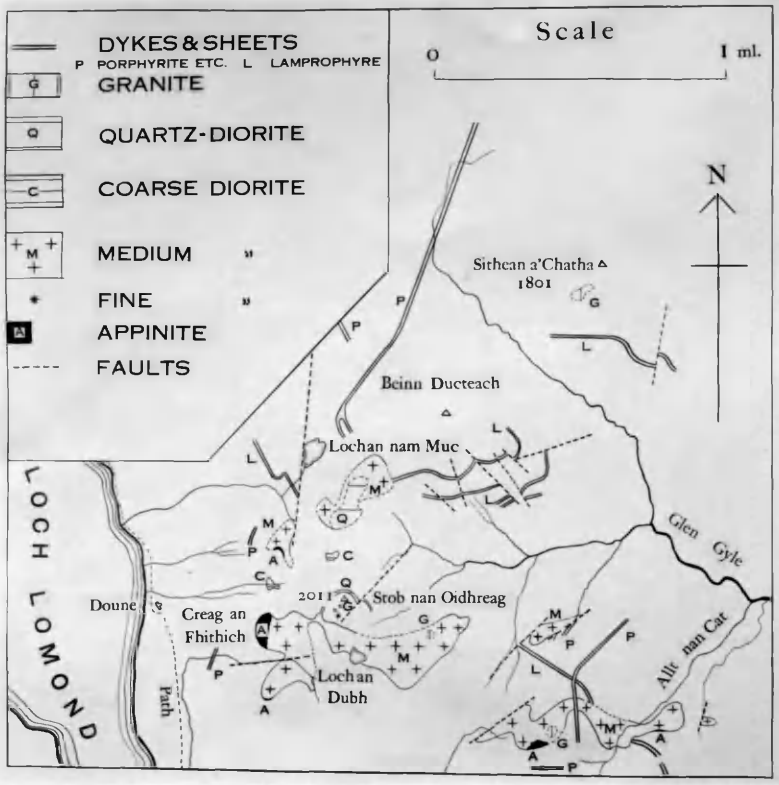

Fig. 39:- Intrusions east of head of Loch Lomond.

of the stream while continuing a considerable distance to the south.

Glen Loin (Fig.28):- Three small exposures of igneous rock occur near the Glen Loin path at the head of the River Loin. The most northerly, and largest, consists mainly of fine porphyritic diorite carrying phenocrysts of pyroxene. It is seen on top of a crag between the path and a neighbouring fence. Immediately to the east of the path comes another small intrusion, a coarse diorite, with vertical junction against schist, which passes south into appinite, full of vein-quartz xenoliths. The most southerly intrusion consists of decomposed coarse diorite.

West of Arrochar Complex (Fig.2[redacted]):- Three dioritic masses, two of which are extremely tiny, occur near the east margin of Sheet 37 and continue southwestwards the strike of the intrusions dealt with up to the present. They are described under the term hyperite by Clough (1905,pp.93-94). The rock of the two tiny intrusions to the north is referable to the fine diorite of the present paper and that of the largest intrusion to medium diorite.

b. East of Loch Lomond.

Sithean a'Chatha (Fig.39):- An intrusion lies 300 yards south-south-west of the summit of Sithean a' Chatha, a conspicuous craggy hill overlooking the head of Glen Gyle. The rock is shown on Sheet 38 as diorite, but consists mainly of granite with some quartz-diorite. Exposures are confined to a few scattered crags.

South-east and south of Lochan nam Muc (Fig.39):- South-east of Lochan nam Muc a fairly large intrusion is exposed on isolated crags. Medium diorite is the predominant rock but at the southern extremity/

extremity, and in the centre, fairly coarse quartz-diorite occurs, which sometimes becomes sufficiently acid to be regarded as a granite. At one locality on the north-west margin where the intrusion approaches closest to Lochan nam Muc the medium diorite can be seen to be veined by the more acid type which carries porphyritic crystals of augite veined with hornblende probably derived from the medium diorite.

Two small intrusions are seen on the hillside above the farmhouse of Doune on Loch Lomond. They occur a little below the crest of the ridge. The more northerly is exposed in isolated outcrops above the second burn which flows into Loch Lomond north of Doune. It consists for the most part of medium diorite. On the south-west side of the intrusion, appinite occurs and on the eastern margin there is a coarse acid type with very large derived phenocrysts of augite rimmed with hornblende. The smaller intrusion to the south consists of decomposed coarse diorite, exposed on either side of the extreme head of the burn flowing into Loch Lomond immediately north of Doune.

Stob nan Oidhreag (Fig.39):- A small intrusion is exposed on the ridge 300 yards north of Stob nan Oidhreag. The rock shows affinities to appinite, but is finer than the type and is shown on Fig.39 as coarse diorite. An arcuate outcrop of medium-grained quartz-diorite with pinkish felspar occurs immediately north of the summit. On Sheet 38 it is shown as connected to the large intrusion east of Creag an Fhithich, but no evidence for this could be found on the ground.

One hundred yards south-south-west of the peak there is a tiny isolated exposure of pink medium-grained granite, and fifty/

fifty yards further on in the same direction one of fine porphyritic diorite. The latter shows contact alteration, possibly caused by an underground mass of granite of which the previous intrusion is a small projection.

East of Creag an Fhithich (Fig.39):- The Creag itself, which can easily be picked out on the hillside as a high black cliff a little to the south of Doune, consists entirely of appinite. At the foot of the north-east end of the cliff a junction between chilled appinite and hornfels is well exposed and hades outwards at 80 degrees. At the south end of the cliff the junction can also be seen running steeply up the hillside. In and around the stream immediately to the south of the cliff medium diorite is exposed but the relationship of this to the appinite is not seen. At the extreme south-west corner of the intrusion, where a vertical junction between igneous rock and schist is well exposed, a few feet of appinite are seen between the latter and the medium diorite. No evidence of relative age can be deduced.

The medium diorite is cut by granite veins near the head of the stream. From the latter position a line of mica-schist cliffs run in a northward direction. For some distance no exposures of igneous rock are seen in the flattish ground in front of the cliffs, but near the northern corner of this part of the intrusion porphyritic diorite, with large phenocrysts of augite rimmed with hornblende, occurs and continues eastwards as a 6-foot dyke running up the cliff in a shallow gully. At the top of the cliff similar porphyritic diorite is again seen. This exposure is very close to rock of the same type a little further to the south-east, certainly belonging to the intrusion exposed around/

around Lochan Dubh, and there is little doubt that they are connected. At least there are no schist exposures separating them.

Most of the rock around Lochan Dubh and on the crags to the east is medium diorite. In places there is a thin acid marginal modification with large porphyritic crystals of augite rimmed with hornblende. Granite veins also occur and in the north-east corner there is a small exposure of this rock.

Allt nan Cat (Fig.39):- The largest intrusion in this neighbourhood is an irregular dyke-like mass, nearly a mile long but never more than 300 yards across, crossing Allt nan Cat. The contact exposed only at the north margin in the latter stream. In places, for instance along the straight north-west edge, the junction with the schists appears to coincide with a fault as the diorite is considerably shattered.

Most of the intrusion consists of medium diorite. At many marginal localities this shows a similar acid modification to that described from the neighbourhood of Lochan Dubh. West of a thick dyke, which cuts through the mass, pink fine-grained granite occurs and further to the west coarse appinite, with hornblende crystals up to two inches in length.

A small isolated intrusion occurs in a conspicuous cliff on the east of a small stream east of the Allt nan Cat. It consists of porphyritic medium diorite, rather more acid than the type and resembling the marginal modification mentioned above. The intrusion terminates abruptly on the cliff face, apparently along a line of fault.

A rather bigger intrusion of medium-grained porphyritic diorite/

diorite with phenocrysts of pyroxene is exposed in a line of crag midway between Allt nan Cat and Stob nan Oidhreag. The south-west margin where it crosses a small stream is faulted, and the diorite is considerably shattered.

Inversnaid Intrusion (Fig.2):- This is exposed round a low hill, Binnein, half a mile north by east of Inversnaid Hotel and about 500 feet above Loch Lomond. It has been briefly described under the name hyperite by Cunningham Craig (1901,p.27).

The junction of igneous and country rock is only seen along the southern margin and is vertical. Good exposures occur all over the outcrop and are in medium diorite which frequently carries phenocrysts of pyroxene. At some localities near the margin xenoliths of vein-quartz rock are abundant and have produced considerable acidification.

IV. DYKES AND SHEETS[1].

a) Of Lower Old Red Sandstone age.

Dykes and sheets associated with the present igneous area are comparatively rare. The commonest rock-type is spessartite, which occurs mainly as sheets, especially east of the head of Loch Lomond. The time relation of spessartite to diorite varies with locality. Although no actual contact has been observed, a spessartite sheet is cut by the intrusion crossed by the Allt nan Cat, while another finishes abruptly against the intrusion nearest Lochan nam Muc (Fig.39). On the other hand an inclined sheet of spessartite cuts the Arrochar Intrusive Complex on Creag Tharsuinn (Fig.28).

Under the microscope the spessartite is seen to consist of highly/

---

1. The numbers in brackets in this section refer to the catalogue numbers of slices in the collection of the Geology Department, University of Glasgow.

highly sericitised felspar with a little quartz and abundant euhedral needles of greenish-brown hornblende and occasional larger more equidemensional crystals of the same hornblende (5972). Large sparse crystals of augite may also occur with a fringe of brown hornblende (6096). All the slices examined were more or less decomposed. These spessartites, apart from the finer texture, correspond with the appinite already referred to.

Turning now to the rarer more acid dykes and sheets, we find little evidence of age relationships. In one case, however, a dyke of this type cuts a dioritic intrusion near the Allt nan Cat.(Fig.39).

These more acid minor intrusions are extremely decomposed and it is difficult to determine their exact affinities. The typical porphyrites of many Lower Old Red Sandstone igneous centres are absent. Most of the rocks appear to be intermediate between the porphyries and the porphyrites. For instance a slice (6103) from the dyke cutting the Allt nan Cat Intrusion has a groundmass of highly sericitised felspar and quartz with phenocrysts of chloritised ferromagnesian, sericitised felspar, some of which at least is referable to plagioclase, and quartz. The latter shows corrosion by the groundmass, a feature described in similar rocks from Glen Coe (Bailey,1916,p.174). Other examples from the present area are more acid, and are probably porphyries or felsites.
A few sheets and dykes in the extreme western part of the area included in Fig.2 have been described in the Mid-Argyll Memoir (Clough,1905,pp.102-106).

b) Dykes of Probable Permo-Carboniferous age. Several east-west dolerite dykes cut through the district and are shown on Sheet 38.

A/

A conspicuous example is one which crosses Loch Sloy and Loch Lomond and continues as far as the head of Loch Katrine. Similar dykes are described in the Sheet 37 Memoir (Clough and Hill, 1905, pp.115-117). Two dykes of this type may be specifically mentioned, however, as they are not shown on Sheet 38. They are seen cutting the Arrochar Complex in the Allt Coiregrogain north west of Creag Tharsuinn (Fig.28). Both are from 33-35 feet wide and within 5 degrees of true east-west. A rude columnar structure is developed at right angles to the edges which are strongly chilled. The rock is fresh and shows typical ophitic structure. It consists of labradorite and augite, with a very little quartz, orthoclase and serpentinous pseudomorphs after hypersthene or perhaps olivine (6013).

V. PETROLOGY[1]

Classification and Nomenclature:- The rocks of the present area are regarded as members of the granite-diorite suite. The acid (granite), intermediate (quartz-diorite) and basic (diorite) divisions are all represented, where 65 and 55 per cent SiO_2 are taken as marking the limits of the intermediate division. (For a discussion of the terms quartz-diorite and diorite see pp.46-48).

Medium diorite is the most important type within the present area. From the analysis (p.128,I) it is clearly a basic rock. In view of the importance of pyroxene in its composition, a case can be made out for regarding the rock as a member of the gabbro family. The/

1. The numbers in brackets in this section refer to the catalogue numbers of slices in the collection of the Geology Department, University of Glasgow.

The remainder of the mineral assemblage (p. 135), however, is against this view. Also the term gabbro appears to have been applied most frequently to rocks at the basic end of the basic division, and diorite to rocks at the acid end. This is seen from the silica percentage curves published by Eyles and Simpson (1921,pp.436-440). The apex of the silica percentage curve for gabbro is at 48%, while that for diorite (European) is at 51.5%. It would appear therefore that there are good grounds for regarding the present type as a member of the quartz-poor or quartz-free group of the diorite family of Rosenbusch.

It should be borne in mind, however, that many of the rocks of the medium diorite type are identical with the hyperites described by Teall (1899,pp.607-625) from the Southern Uplands, and in fact certain of the rocks which are the subject of the present paper have long been called hyperite. The latter term has fallen into disuse in modern terminology, but has sometimes been replaced by norite, for example in the case of the Loch Doon mass (Gardiner and Reynolds,1932). In the present area the name norite cannot be applied to the medium diorite type as a whole, as hypersthene is far from constant as an important constituent; but certainly many of the varieties rich in rhombic pyroxene may quite justifiably be called mica-norites.

Granite (Fig.40):- The average specific gravity of this type is 2.67. In a slice (6055) from the elongated mass of granite in the centre of the main Arrochar Intrusion biotite, frequently altered to chlorite and epidote, is the sole ferro-magnesian constituent. Plagioclase (oligoclase) occurs as large sericitised laths up to 2 mm. in length. Quartz and orthoclase form/

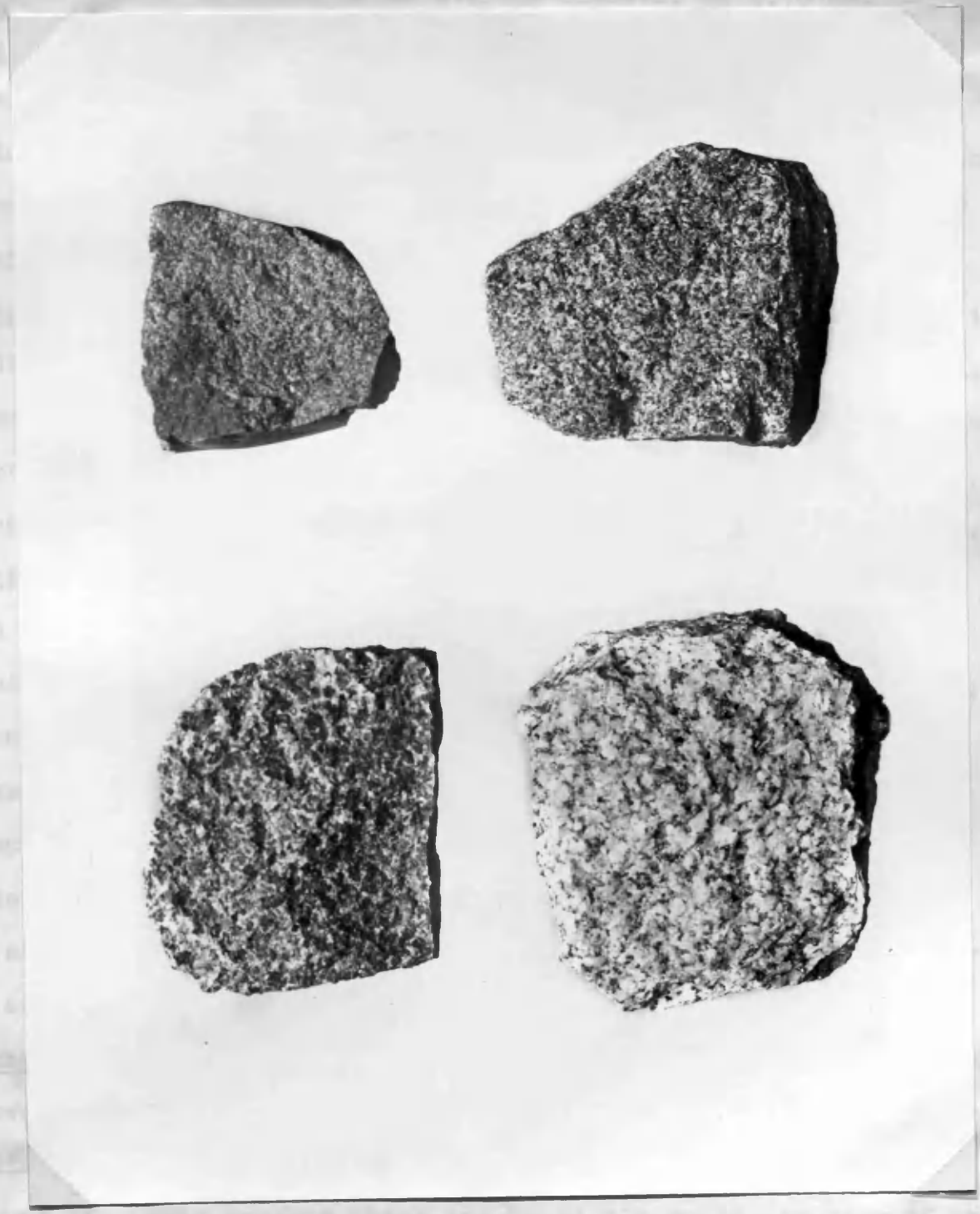

Fig. 40:- Rocks of Arrochar Intrusive Complex; fine diorite, medium diorite, coarse diorite and granite.

form irregular crystals of an average diameter of 0.75 mm. The accessories are apatite and magnetite. Other examples from the area are similar biotite-granites without microcline or primary muscovite, though the latter occurs, exceptionally, in the fine-grained granite which forms the tiny intrusion one-third of a mile west-south-west of A'Chrois (5955).

Quartz-diorite:- Most of the quartz-diorite of the present area is medium-grained. There is considerable variation in composition. Hornblende may be as abundant as biotite (5997,6025), the rock then providing a typical example of the Tonale type, or the biotite, largely altered to chlorite and epidote, may be in excess (6024). Augite may occur in the core of the hornblende crystals (6060), and the rock is then comparable to the Banat type. Plagioclase (andesine) occurs as stumpy laths, generally about 0.5mm.x 0.2mm. Orthoclase, generally forming anhedral crystals about 0.5mm.in diameter, may be very much in the background (6060), or may be comparatively abundant and show a tendency to enclose the other constituents (6024). Quartz is plentiful as irregular crystals of an average diameter of 0.4mm., and apatite and magnetite occur as accessories.

Coarse diorite (Fig.40):- This type provides a link on the one hand between medium diorite and quartz-diorite and on the other between medium diorite and appinite. Although there is always a certain amount of quartz present there can be little doubt, in view of the average specific gravity, 2.88, that the rock is of basic composition. All the slices of this type examined were considerably decomposed. Hornblende, generally brown in colour, is the most abundant constituent (6002). Augite may/

may also occur and is generally surrounded by hornblende (5934). Biotite is always present and is generally altered to chlorite and epidote (6012). Plagioclase laths, of an average size of 1 mm. x 0.2mm. can be recognised but the felspar as a whole is very sericitised.

Appinite:- For the most part the Arrochar appinites are very coarse-grained. Thus the analysed rock has hornblende crystals up to 2 cm. in length, while the appinite dyke in the stream draining Coire Fuar shows crystals up to 8 cm. in length. Other rocks mapped as appinites in the present area are, however, finer. The hornblendes in the appinite forming Creag an Fhithich (Fig.39) do not exceed 0.5 cm. in length.

The analysed rock (p.128, III) with a silica percentage of 44.65 and a S.G. of 3.05 just falls into the ultra-basic category. In thin section (5993) it is seen to consist essentially of hornblende, felspar and quartz. Augite occurs very sparingly as a core to hornblende, while biotite is represented by a few scraps of chlorite. Apatite is a very scarce accessory, but iron-ore is comparatively abundant in large ragged crystals. The hornblende is a rich brown colour and is strongly pleochroic. The felspar is somewhat sericitised. Plagioclase exceeds orthoclase, but there is a fair proportion of the latter mineral, in graphic intergrowth with quartz.

Most of the other occurrences of appinite shown on Figs.28 & 39 closely resemble the analysed rock, and in all of them there is an abundante of brown hornblende. Relatively leococratic examples, are seen in the outcrop on the upstream margin of the hybrid type in the Allt Coiregrogain (Fig.28); while the intrusion/

intrusion 250 yards north by west of Stob nan Oidhreag (Fig.39) provides a link between appinite and coarse diorite; and the tiny intrusion by the path in Glen Loin (Fig.28) affords a passage from the one type to the other.

Very similar rocks occur at Garabal Hill, and have been named davainite (p.128, D) by Wyllie and Scott (1913). These authors divide the hornblende-rich rocks of their district into two groups, the davainites, in which the hornblende is secondary after diallage, and the hornblendites, in which it is primary. The present author considers the hornblende of the appinites as in the main original, and therefore does not feel justified in using the term davainite. The name appinite has been defined by Bailey (1916,pp.167,168) and employed by him (1916,index) and Walker (1927,p.154) in descriptions of the Loch Linnhe district. Very similar rock was earlier called hornblendite from Colonsay (Wright & Bailey,1911,p.29). Recently the appinite suite has been discussed by MacGregor and Kennedy in connection with the Morvern-Strontian granite complex (1932,p.107), and a comparison has been drawn between it and the so-called Ach' uaine type of hybrid of H.H.Read from the Lairg-Rogart complex of Sutherland.

Pyroxenite:- The central portions of the two masses shown as appinite on Fig.28 south of the head of the Allt Coiregrogain are very basic, S.G.3.26. The rock is best described as pyroxenite,but shows affinities with cortlandite. In thin section (6052,6054) it is seen that about 70 per cent of the rock consists of pyroxene. The latter is mainly colourless augite, but some hypersthene also occurs, and in one slice (6052) enstatite. The other/

other minerals present are olivine and brown hornblende. No biotite or felsic constituents were noted. All the crystals are ~~small~~ roughly equidimensional, the augite, hornblende and olivine having average diameters of 2.0, 0.75 and 0.5 mm.respectively.

Medium diorite (Fig.40):- The average specific gravity is 2.89. The groundmass is of the felspar-lath type. The coarsest rock mapped as medium diorite has laths of plagioclase of an average size of 0.7 mm. x 0.15 mm., while the finest has laths of 0.4 mm. x 0.07 mm. Considered as a whole the type could hardly be described as porphyritic. The pyroxenes, however, often show a porphyritic tendency, which may become conspicuous.

The analysed rock, S.G.2.89, contains olivine, hypersthene, augite, hornblende, biotite, plagioclase, orthoclase and quartz, with apatite and magnetite as accessories (6004). Olivine is by no means universal, but has been observed in several slices. It occurs as small anhedral crystals, largely altered to serpentine, and is completely surrounded by pyroxene. Hypersthene and augite build subhedral crystals with a slight porphyritic tendency, and the monoclinic pyroxene considerably exceeds the rhombic. Hornblende, green in colour, generally forms a rim to the augite crystals. Biotite is moderately plentiful and is moulded on the plagioclase (basic andesine). Quartz and orthoclase, which are very subordinate, occur interstitially.

In many of the slices (e.g.6006) from the main Arrochar intrusion hypersthene is as abundant as augite, while quartz and hornblende practically disappear. Biotite, however, remains a constant constituent, while orthoclase shows a tendency to increase/

increase, thus foreshadowing the differentiation of kentallenite. Examples very rich in hypersthene also occur in the intrusion in the south-west corner of Fig.2 , 1¼ miles west-south-west of the Brack (6042,S.G.2.93), and in others in Coire Fuar (5995, S.G. 2.95) and south-east of Ben Vorlich (5981,S.G.2.92).

A very basic modification occurs in Coire Croe. Augite (mostly diallage) is very abundant, and there is also some hypersthene; biotite occurs very sparingly; the rest of the rock is made up of laths of labradorite (6019). In the rocks mapped as medium diorite on the east side of Loch Lomond hypersthene is, as a rule, much less common than in those on the west. Examples showing a fair amount of hypersthene do, however, occur, for example in the Inversnaid Intrusion (6075) and from east of Creag an Fhithich (6080), the latter slide also showing olivine.

The predominant rock in this region has porphyritic augite as the chief ferro-magnesian constituent. Olivine may occur aparingly (6081).

Near the edge of several of the intrusions a more acid variety is found. It is almost certainly intermediate in composition, but is described under the present head as representative merely of a marginal modification. Large porphyritic crystals of augite persist and have a rim of brown hornblende, but the groundmass is much more acid and carries plentiful quartz in addition to highly sericitised felspar (6086). Richey has noted examples of relatively acid margins in some of the Tertiary plutonic intrusions of Ardnamurchan, and has explained them "by supposing that the intruding magma possessed

a/

a differentiated more acid upper position which was intruded first and formed a lining to the walls of the intrusion-cavity." (1930,p.210).

Taken as a whole the medium diorite may be referred to as a pyroxene-mica-diorite, but the varieties rich in hypersthene may be called mica-norites, and basic, diallage-rich varieties, such as that described above (6019) gabbro.

Kentallenite:-

The analysis of the rock from the present area (II, p.128) may be compared with analyses from the type locality(C) and from the Allt an t-Sithein in the Ben Buie region (B). The silica percentage of the Arrochar rock is close to that from the Allt an t-Sithein, but the magnesia is lower. As regards the other oxides, especially of sodium and potassium, the Arrochar rock greatly resembles the type.

The analysed specimen, S.G.2.95, shows in thin section (5989) abundant olivine, hypersthene, augite, plagioclase (andesine) and orthoclase, and also an appreciable amount of biotite. Apatite and magnetite occur as accessories, the former being comparatively abundant. The rock as a whole is very fresh. The olivine forms large subhedral crystals, altered to serpentine and magnetite along cracks. The pyroxene, especially the hypersthene, is often moulded on to the olivine. In the presence of hypersthene the rock resembles the Allt an t-Sithein occurrence, and differs from those in the type locality, the Loch Avich region, Glen Orchy (Hill and Kynaston,1900) and Colonsay (Wright and Bailey,1911). It resembles the three latter occurrences, however, in the predominance of plagioclase over orthoclase. The plagioclase occurs/

TABLE OF ANALYSES

	I	A	II	B	C	III	D	E	
SiO_2	53.75	53.40	52.90	52.09	48.00	44.65	43.53	40.26	SiO_2
Al_2O_3	16.20	18.83	13.02	11.93	12.52	12.40	7.24	15.74	Al_2O_3
Fe_2O_3	0.83	0.72	0.93	1.84	3.74	5.47	11.10	3.44	Fe_2O_3
FeO	7.42	6.86	7.01	7.11	-----	9.03	8.70	7.95	FeO
MgO	6.55	4.61	10.85	12.48	15.26	11.80	11.51	12.09	MgO
CaO	7.90	7.86	8.00	7.84	7.94	9.85	10.19	12.03	CaO
Na_2O	3.25	3.81	3.10	2.04	3.11	1.90	2.88	2.25	Na_2O
K_2O	1.46	0.93	2.35	3.01	2.68	0.89	1.39	1.36	K_2O
H_2O+	0.55	0.43	0.45	0.24	1.36	1.50	1.34	1.75	H_2O+
H_2O-	0.45	0.30	0.15	0.11		0.20	0.43	0.48	H_2O-
TiO_2	1.05	1.72	1.02	0.73	0.22	1.90	1.90	2.42	TiO_2
P_2O_5	0.15	0.18	1.20	1.34	-----	0.03	tr.	0.05	P_2O_5
MnO	0.25	0.44	0.15	0.15	-----	0.25	-----	0.03	MnO
CO_2	Nil	0.09	Nil	0.16	-----	Nil	Nil	0.03	CO_2
Total	99.81	100.26*	100.13	100.24†	99.83	99.87	100.21	99.87	Total
S.G.	2.89	-----	2.95	-----	-----	3.05	-----	3.19	S.G.

* Includes (Co, Ni)O=0.05, BaO=0.01, Li_2O=tr., F=0.02.
† Includes Cr_2O_3=0.10, (Co, Ni)O=0.07.

I. Pyroxene-mica-diorite; medium diorite of Arrochar Complex. Allt Coiregrogain, 1 mile south-east summit of Ben Vane. Anal. W.H. Herdsman.
A. Contact altered basic hypersthene-quartz-diorite. Avon Water, near Darvel, Ayrshire. Anal. E.G. Radley. (MacGregor, 1930, p.42, col. IV).
II. Kentallenite. Quarter of a mile south-south-east A'Chrois, Argyll. Anal. W.H. Herdsman.
B. Kentallenite. Allt an t-Sithein, Glen Shira, Argyll. Anal. W. Pollard. (Kynaston and Hill, 1900, p.537).
C. Kentallenite. (Originally called olivine-monzonite). Kentallen Quarry, Argyll. Anal. J.J.H. Teall. (Teall, 1897, p.22).
III. Appinite. Quarter of a mile south-south-east A'Chrois, Argyll. Anal. W.H. Herdsman.
D. 'Davainite.' Garabal Hill. (Wyllie and Scott, 1913, p.503).
E. Basic appinite. Ardsheal Hill summit N. Anal. W.H. Herdsman. (Walker, 1927, p.154, col.II).

occurs as well-formed laths, of an average size of 1.0 mm. x 0.2 mm., to which the biotite is moulded, while the orthoclase is interstitial.

Fine diorite(Fig.40):- Mineralogically the fine diorite does not differ from the medium, simply representing the same magma cooled more rapidly. In the porphyritic variety the composite pyroxene crystals may be up to 3 mm. in diameter. They consist of variously oriented segments of augite and hypersthene. Occasionally serpentinous pseudomorphs after olivine are included (6007), and there is generally a thin fringe of green hornblende. The groundmass consists of felspar (andesine) laths, about 0.3 mm. x 0.05 mm. with scrappy crystals of pyroxene, hornblende and biotite. Orthoclase and quartz occur very sparingly interstitially In addition to the plagioclase laths there may be larger, equidimensional crystals of plagioclase up to 0.75 mm. in diameter. They are strongly zoned and have rounded angles (5960).

In thin section the non-porphyritic fine diorite is generally similar in appearance to the groundmass of the porphyritic variety described above.

VI. CONCLUSIONS.

a) Summary of Igneous History:-

It is considered that in Lower Old Red Sandstone times there was a zone of weakness in the earth's crust in the present area, extending in a north-east--south-west direction, and that magma was thus enabled to rise to a comparatively high level. Upward projections from the elongated magma reservoir thus formed gave rise to the Arrochar Complex with roughly speaking the form of a dyke. The injection probably gave relief to tension, acting at/

at that time in a north-west--south-east direction as in northern Argyll (Bailey,1916,p.147).

Leaving out of account the detail of acid margins, it would appear that pyroxene-rich fine and medium diorites, with kentallenite, were injected first. These were followed by the amphibole-rich coarse diorite and quartz-diorite, the appinites representing a very hornblendic facies. Finally there was an intrusion of granite.

The age relationship of the appinites, however, requires special consideration. In the above summary the view is adopted that the type is later than the medium diorite. This is undoubtedly true as far as the main Arrochar Intrusion is concerned. Appinite however, is marginal to the kentallenite-bearing intrusion $\frac{1}{4}$ mile south-south-east of A'Chrois (Fig.28), and also to several of the intrusions on the east side of Loch Lomond (Fig.39). In none of these cases can any direct evidence of age relationship be adduced, but marginal facies are usually of earlier consolidation than the interior portions of intrusions. It is possible that in these cases we have a reversal of the sequence of rock types, but this need not occasion any great surprise in such a complicated series of intrusions as that under consideration.

b) Comparison with other areas:-

All the rock types of the present area are found in other Scottish aentres some of which are of proved or probable Lower Old Red Sandstone age. The nearest centre is that of the Glen Fyne-- Garabal Hill district, where the main intrusion is granite (Dakyns and Teall,1892; Wyllie and Scott,1913). On the east side this/

this granite merges into tonalite which in turn veins diorite. Some varieties of the latter resemble the 'medium diorite' of the Arrochar district, although hypersthene is not recorded. The same complex contains appinite and pyroxenite and also, beyond Glen Fyne, isolated intrusions of diorite and kentallenite (Hill and Kynaston,1900).

As indicated in some detail in the text appinite and kentallenite have a fairly wide distribution as small intrusions elsewhere in Argyll, and appinite seems to reappear in Sutherland.

The most closely comparable rocks to the 'medium diorite' of Arrochar are the 'hyperites' of the Southern Uplands (Teall, 1899,pp.607-625). Among other occurrences, these form considerable outcrops at parts of the margin of the Loch Doon mass and are described as norites and mica-norites (Gardiner and Reynolds,1932). Inside there is a large outcrop of Tonalite, with granite in the centre. The Loch Doon mass thus bears a considerable resemblance to the Arrochar Complex, differing chiefly in its much greater proportion of intermediate rocks. In fact it is the large proportion of basic rock which gives a fairly distinctive character to the present area.

VII. APPENDIX - SUGGESTED ROUTES.

For the study of the intrusions lying on the west side of Loch Lomond, Arrochar is the best centre, and for those on the east side Ardlui. Both can be very easily reached by the West Highland Railway or by road. The Brack Intrusion is, however better approached from Lochgoilhead, and the Inversnaid Intrusion from Inversnaid. Both of these places can be reached by road or by boat.

The/

The western part of the Arrochar Complex is the most easily studied as the igneous junction in the Coire Croe stream lies only a few hundred feet above the main Arrochar-Inverary road at the foot of the well-known Rest and Be Thankful Hill. The eastern part of the complex can be reached by following the path up the left bank of the River Loin from the bridge at its mouth and going over the low divide (about 500 feet above sea level) at its head to the Inveruglas water, and then up its tributary on the right bank, the Allt Coiregrogain. An excellent traverse can be made by following this stream to its head, going over the col, and then descending the Coire Croe stream to the main road and thence back to Arrochar (Fig.2).

Direct routes, taken from the map, are not always advisable in the Arrochar area as much of the area has undergone recent afforestation.

As regards the intrusions on the east side of Loch Lomond there is a bridge over the River Falloch two miles above Ardlui and from there a fairly good path as far as the farmhouse of Doune (Fig.3). Most of the intrusions can then be easily reached by following one or other of the various streams up the hillside. The most easterly intrusions, however, may also be approached by going up Glen Gyle from the head of Loch Katrine, there being a motor road as far as Stronachlachar and a good path to the head of the Loch.

ACKNOWLEDGEMENTS

In conclusion the author wishes to acknowledge the very great help and encouragement in both field and laboratory work so generously given by Professor E.B. Bailey and Dr. G.W. Tyrrell. He is also indebted to Mr. A.G. MacGregor for valuable petrological advice. Thanks are also due to the Geological Survey for affording every facility to examine maps, sections and other material.

The cost of five new analyses of Ben Nevis rocks and of three new analyses of Arrochar rocks was defrayed by means of a generous grant from the Carnegie Trustees for the Universities of Scotland.

For the original of Fig. 17 the author is indebted to Mr. W. Priest. Fig. 4 is a purchased post-card, while Fig. 24 is reproduced from the Scottish Mountain-eering Club Guide to the Central Highlands. The remainder of the figures illustrating rocks in the field are from photographs by the author.

Fig. 3 is from 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv., 1916, Fig. 25. The other diagrammatic figures are from drawings by the author, reduced for the most part by Mr. Filshill of the Photographic Department, University of Glasgow. The latter is also responsible for the careful photography of rock specimens for the purpose of illustration.

LIST OF WORKS TO WHICH REFERENCE IS MADE

BAILEY, E.B.	1910	'Recumbent Folds in the Schists of the Scottish Highlands,' Quart. Journ. Geol. Soc., vol. lxvi, pp.536-620.
	1916	In 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv.
	1924	In 'The Tertiary and Post-Tertiary Geology of Mull,' Mem. Geol. Surv.
BRYCE, J.	1864	'On the Geological Structure of Ben Nevis,' Proc. Phil. Soc. Glasgow, vol. v, pp.6,7, and 'On the Geological Structure of the Ben Nevis Group of Mountains,' Ibid., pp.104-105
CLOUGH, C.T.	1905	In 'The Geology of Mid-Argyll,' Mem. Geol. Surv.
	1916	In 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv.
CLOUGH, C.T., MAUFE, H.B. & BAILEY, E.B.	1909	'The Cauldron Subsidence of Glen Coe and the Associated Igneous Phenomena,' Quart. Journ. Geol. Soc., vol.lxv, pp.611-676.
COMMITTEE ON BRITISH PETROGRAPHIC NOMENCLATURE	1921	Report in Min. Mag., vol.xix, pp.137-147.
CRAIG, E.H.C.	1901	In 'Summary of Progress for 1900,' Mem. Geol. Surv.
DAKYNS, J.R. & TEALL, J.J.H.	1892	'The Plutonic Rocks of Garabal Hill and Meall Breac,' Quart. Journ. Geol. Soc., vol. xlviii, pp.104-131.
DALY, R.A.	1933	'Igneous Rocks and the Depths of the Earth,' McGraw-Hill Book Co.,New York.
EYLES, V.A. & SIMPSON, E.B.	1921	'Silica Percentages of Igneous Rocks,' Geol. Mag., vol.lviii, pp.436-440
GARDINER, C.I. & REYNOLDS, S.H.	1932	'The Loch Doon 'Granite' Area, Galloway,' Quart. Journ. Geol. Soc., vol. lxxxviii, pp.1-34.
GEIKIE, SIR A.	1892	'Geological Map of Scotland with Explanatory Notes,' Bartholemew & Co., Edinburgh.

GRABHAM, G.W.	1916	In 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv.
HILL, J.B.	1905	In 'The Geology of Mid-Argyll,' Mem. Geol. Surv.
HILL, J.B. & KYNASTON, H.	1900	'On Kentallenite and its Relations to other Igneous Rocks in Argyllshire,' Quart. Journ. Geol. Soc., vol.lvi, pp.531-558.
JUDD, J.W.	1874	'On the Secondary Rocks of Scotland. Second Paper, On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata,' ibid., vol.xxx. Ben Nevis, pp.391-394.
KYNASTON, H.	1896	In 'Annual Report for 1895,' Mem. Geol. Surv.
	1898	In 'Summary of Progress for 1897,' Mem. Geol. Surv.
	1908	In 'The Geology of the Country near Oban and Dalmally,' Mem. Geol. Surv.
	1916	In 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv.
LINDGREN, W.	1900	'Granodiorite and other Intermediate Rocks,' Amer. Journ. Science, vol. ix, pp.269-283.
MACCULLOCH, J.	1817	'Observations on the Mountain Cruachan in Argyleshire, with some Remarks on the Surrounding Country,' Trans. Geol. Soc., vol. iv, pp.117-138.
MACGREGOR, A.G.	1930	In 'The Geology of North Ayrshire,' Mem. Geol. Surv.
	1931	'Clouded Felspars and Thermal Metamorphism,' Min. Mag., vol.xxii, pp. 524-538.
MACGREGOR, A.G. & KENNEDY, W.Q.	1932	In 'Summary of Progress for 1931,' Mem. Geol. Surv.
MAUFE, H.B.	1910	In 'Summary of Progress for 1909,' Mem. Geol. Surv.
	1916	In 'The Geology of Ben Nevis and Glen Coe,' Mem. Geol. Surv.

MURCHISON, SIR R. & GEIKIE, A. 1862 'First Sketch of a New Geological Map of Scotland.'

NOCKOLDS, S.R. 1934 'The Contaminated Tonalites of Loch Awe, Argyll,' Quart. Journ. Geol. Soc., vol. xc, pp.303-332.

OEYNHAUSEN, C. VON & H. VON DECKEN. 1830 'Der Bein Nevis am Loch Eil,' Karsten' Archiv fur Mineralogie Geognosie, Bergbau und Huttenkunde: vol.ii, pp.38-54, plate i.

PEACH, B.N.(JUN.) 1930 'The Lochaber Water-power Scheme and its Geological Aspect,' Trans. Inst. Mining Engineers, vol.lxxviii,Pt.4, pp.213-233.

RICHEY, J.E. 1927 'The Structural Relations of the Mourne Granites,' Quart. Journ. Geol. Soc., vol. lxxxiii, pp.653-688.

1930 In 'The Geology of Ardnamurchan, North-West Mull and Coll,' Mem. Geol. Surv.

TEALL, J.J.H. 1888 'British Petrography with special Reference to Igneous Rocks.'

1897 In 'Annual Report for 1896,' Mem. Geol. Surv.

1899 In 'The Silurian Rocks of Britain, vol.i Scotland,' Mem. Geol. Surv.

TYRRELL, G.W.T. 1928 'The Geology of Arran,' Mem. Geol.Surv

WALKER, F. 1924 'A Marginal Modification of the Balla-chulish Granite,' Geol. Mag. vol. lxi, pp.550-554.

1927 'The Igneous Rocks of Ardsheal Hill, Argyllshire,' Trans. Roy. Soc. Edinb. vol.lv, pp.147-157.

1928 'The Plutonic Rocks of the Southern Uplands East of the Nith Valley,' Geol. Mag., vol.lxv, pp.153-162.

WILSON, J.G. 1901 In 'Summary of Progress for 1900,' Mem. Geol. Surv.

WRIGHT, W.B. & BAILEY, E.B. 1911 'The Geology of Colonsay and Oronsay,' Mem. Geol. Surv.

WYLLIE, B.K.N. & SCOTT, A. 1913 'The Plutonic Rocks of Garabal Hill,' Geol. Mag., vol. 1, pp.499-508 & 536-545.

PAPERS ON THE GEOLOGY OF THE SOUTH-WEST HIGHLANDS

By J. G. C. Anderson, M.A., B.Sc., Carnegie Research Scholar, University of Glasgow.

I THE DALRADIAN SUCCESSION IN THE PASS OF BRANDER DISTRICT, ARGYLL.

Supporting paper to main thesis. Describes current and graded bedding discovered in the neighbouring metamorphic rocks during work on the igneous rocks of the Cruachan district.

II THE MARGINAL INTRUSIONS OF BEN NEVIS; THE COILLE LIANACHAIN COMPLEX; AND THE BEN NEVIS DYKE SWARM.

Published account of portion of thesis under same title.

III THE OUTER GRANITE OF BEN NEVIS.

Short preliminary account of work on Ben Nevis.

IV CALEDONIAN IGNEOUS ACTIVITY IN THE SOUTH-WEST HIGHLANDS.

Contains short preliminary accounts of work described in thesis under 'The South-East Margin of the Etive Granite Complex' and 'The Arrochar Intrusive Complex.'