The Structure and Petrology of the Eastern Part of the Central Igneous Complex of Arran

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The structure and petrology of the eastern part of the Central Igneous Complex of Arran. J.H.Ashford.

Summary of thesis.

The Central Igneous Complex of Arran is one of the Tertiary volcanic centres of the West coast of Scotland. The thesis describes the structure and petrology of the eastern part of the Complex, and includes a detailed account of the area of Glen Dubh.

Three main divisions of the Complex are recognised; the volcanic caldera of Ard Bheinn, in the West; the granite and agglomerate masses of the eastern part, on A'Chruach and the Tir Dubh; and the intrusions of diorite, dolerite and gabbro on the eastern margin of the Complex in Glen Dubh and Glen Ormidale.

The Complex is emplaced in rocks of Old Red Sandstone, Carboniferous and Permian age, and in the vents of Ard Bheinn, blocks of Rhaetic marls and chalk occur. The country rocks of the Glen Dubh area are Old Red Sandstone sediments, bleached and partly recrystallised by thermal metamorphism.

A sinuous fault divides the Glen Dubh area, and forms, to the North, the boundary of the Complex. In Glen Dubh, the Inner Area is mainly of dolerite and gabbro, the dolerite forming an irregular margin to the gabbro. A dyke of felsite occurs along the fault for a short distance and to the West in the Inner Area, there is a thick sill-like body of felsite breccia. Veins of breccia extend into the over-

overlying dolerite. In two places the brecciation of the dolerite above the felsite is so intense as to form small vents.

In the Outer area of Glen Dubh, there is a layered sequence Sediments of Old Red Sandstone age were intruded by a concordant gabbro and dolerite body (the base is not exposed) and subsequently, before cooling of the basic rocks, a thin sheet of microgranite was intruded along the contact. Reaction between the microgranite and the basic rocks resulted in the formation of a variable suite of diorites - finegrained diorites associated with the dolerite, and coarser varieties with the gabbro. In both cases a distinction may be made between diorites formed as a result of the alteration of solid gabbro or dolerite, mainly by diffusion of granitic material, and diorites formed by contamination of the microgranite, which intrude the other rocks in places.

Alteration of the gabbros is by the introduction of granitic material. No occurrence of assimilation of sedimentary material has been found, although small-scale assimilation of quartzite fragments in fine hornblende diorite occurs in one locality.

The igneous history determined for the Glen Dubh area is correlated with that of the rest of the Central Complex thus:

Glen Dubh	Ard Bheinn
1. Intrusion of gabbros and dolerites.	Gabbro found as small masses of uncertain relations.
2. Intrusion of microgranite sheet, and formation of diorites.	Creag Mhor granite. 2a Formation of Glen Loig Diorit
3. Intrusion of felsites and tuffs, and formation of breccias.	Development of volcanic complex of Ard Bheinn.
4. Emplacement of Central Granite with minor apophyses in Glen Dubh.	Emplacement of granite of Binnein na h'Uaimh and to the North of Glen Loig.

The isolated areas of diorite around the northern edge of the Complex are equivalent to the diorites of Glen Dubh.

The rocks of the Glen Dubh area are interpreted as being relics of the early stages of the igneous period which culminated in the formation of the vents and caldera of Ard Bheinn. The equivalent rocks in the Ard Bheinn area have been removed during the volcanic episode, or are present only as small isolated remnants.

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Note on the Maps.

All of the large scale mps, Figures 24, 25, 26 and 27 were made on the plane-table, using air-photographs to establish some of the principal reference points. The top of the map on these sheets lies WEST and the arrow in the margin also points West.

On Figs. 24 and 25, a grid has been shown at the margins of the maps for convenience of reference. The ordinate and abscissa read from left to right and bottom to top respectively, and are separated by an oblique stroke. (eg. 09/103). The subdivision of the squares are to the nearest tenth. The grid references of this form in the text refer to these Figures.

The contours shown on the maps are drawn accurately spaced but to an approximate datum, roughly equivalent to that of the O.S. 6 inch map. The errors in relative height do not exceed 5 feet per 1,000 feet, and the error in true height is least on the 400 feet and 1,000 feet contours.

Specimen Numbers.

Specimens collected in the course of this work are prefixed AA or AC. Specimen numbers prefixed H.M. refer to thin sections in the collection of the Hunterian Museum, The University, Glasgow.

I. INTRODUCTION

a) <u>Location and Physical Features.</u>

The Island of Arran, in the Firth of Clyde, is the site of one of the five known Tertiary volcanic complexes of western Scotland. The present study is concerned with the eastern part of the Central Complex of Arran, and in particular with the area about the head of Glen Dubh. (O.S.Nat. Grid. Ref. 9934). The area is part of a dissected plateau, with a uniform summit level in the peaks of A'Chruach (1679ft.), Bheinn Bhreac (1649ft.), and Ard Bheinn(1676ft.). Exposure is sparse over most of the area mapped, the ground consisting mainly of rolling grassy hills and shallow valleys filled with peat and heath.

In the northern part of the area, the plateau is cut sharply by the deep glacial valley of Gleann-ant-Suidhe, and on its slopes the streams of Allt na Calaman and the Glen Idig Burn cut down to bed-rock. To the west and south exposures are scarce except in the deep valley of Glen Craigag.

The only large areas of good exposure are on the eastern margin of the Complex, where the plateau is deeply dissected by the valleys of Glen Dubh and Glen Ormidale, the former providing an almost complete rock face, in a steep coire wall (See Figs.2a and 2b, 3a and 3b, 4b).

b) <u>History of research</u>

Early work in this part of Arran was carried out by Necker (1840), Ramsay (1840), Bryce (1855) and Zirkel (1871).

The first important contribution on the Central Complex, however, was that of Peach and Gunn (1901) who established the volcanic nature of the Complex. Gunn found remanié masses of fossiliferous Mesozoic rocks lying within the vent, and demonstrated the post-Cretaceous age of the igneous activity.

Tyrrell (1928) made a major contribution to the geology of the area. He showed that the Complex cuts through formations of Old Red Sandstone and New Red Sandstone age, superimposing a regional domed structure on an earlier southward tilt associated with the intrusion of the much more extensive Northern Granite of Arran. He developed the theories of Gregory (1924) on the origin of the pyroclastics and breccias of the Complex, and postulated a structure for the Complex analogous with that of the ring centres of Skye and Mull. Tyrrell regarded the western part as a complicated volcanic vent, surrounded by a wide ring of granite and granophyre. The marginal gabbro-diorite masses, particularly that of Glen Dubh, were regarded as the broken remnants of an early gabbro ring-dyke, now greatly intruded and "hybridised" by the granite.

The gabbro masses of Glen Dubh were regarded as a pair of ring-dykes, separated by an arcuate fault and a screen of quartzite. The granite was described as intruding the basic rocks from below and to the West, forming the complex suite of hybrids.

King (1955) studied the Ard Bheinn area of the Complex and showed that it represented a caldera of subsidence, within which there occurred a number of volcanoes, their foci coinciding roughly with the present peaks. The area was remapped in considerable detail, and a complex igneous history was demonstrated. King suggested that the arcuate forms of many of the igneous bodies were controlled by pre-existing or subsequent arcuate fractures, rather than, as had been previously held, that the intrusions and ring-fractures were simultaneous and interdependent. (cf.Richey, 1948p.51).

The Ard Bheinn area, which King mapped, adjoins the area of the present study to the West.

c) <u>The field of the present study.</u>

The results of the recent detailed work by King (op.cit.) on the western part of the Central Complex suggested that similar detailed work on the eastern part of the Complex might prove to be similarly rewarding. Further, Tyrrell noted (1928) that detailed petrological work was required on the rocks of the hybrid suite of Glen Dubh. It was considered, therefore, that it would be worth while undertaking detailed mapping of the eastern part of the Complex, with particular attention to the area of Glen Dubh.

The whole of the eastern part of the Complex was mapped at a scale of 6" to one mile, using air - photographs for control. In the limited areas of good exposure, especially around Glen Dubh where the geology is most complex, plane - table surveys were made. These occupied the major part of the time spent in the field, and provide the basis for most of this study. Approximately $1\frac{3}{4}$ sq.mls. at the head of Glen Dubh were mapped in this way, at a scale of 24" to one mile, and selected parts of this area were remapped at a scale of 96" to one mile to represent adequately the geological detail observed. About 450 specimens were collected, and 290 thin sections have been examined. On selected rocks, mineralogical determinations of the optical properties of the pyroxenes and plagioclases have been made, using universal stage techniques to determine optic axial angles in the pyroxenes and albite twin orientations in the felspars. For pyroxenes, N_y refractive indices were determined by immersion methods. Eight chemical analyses have been made, two of selected rocks by 'classical' methods, (Washington 1931), and a series of six on a contact specimen, by 'rapid' methods after the method of Shapiro and Brannock, (1952 and 1956) with minor modifications.

The work on which this thesis is based was done while the writer was a research student in the Department of Geology of the University of Glasgow. During this period, he was supported by grants from the Faculty of Science of that University, which are gratefully acknowledged. The writer wishes to acknowledge also the supervision and guidance of

Professor T. N. George and of Dr. D. R. Bowes, both of the Department of Geology of the University of Glasgow.

d) Summary of results

In the re-mapping of the eastern part of the Central Igneous Complex of Arran, the greater part of the time spent was on the area of good exposure and complex geology around the coire of Glen Dubh. The rest of the eastern part of the Complex was mapped on a scale of 6in. to one mile, and minor amendments were made to the map of Tyrrell (1928).

In the Glen Dubh area, the structure is simple, in spite of the apparent complexity of outcrops. The igneous formations are arranged in a layered sequence, the orientation of the layers being roughly parallel to the slope of the ground. The earliest intrusion, the gabbro and dolerite mass, was emplaced concordantly beneath the sedimentary country rocks and was followed, probably while still warm, though effectively solid, by a thin microgranite sheet, intruded more or less consistently along the gabbro or dolerite contact with the country rocks.

Between the microgranite and the basic rocks, a variable suite of diorites was developed by reaction between the two types. The diorites are grouped in four main varieties - those associated with the gabbro (coarse-grained diorites, mostly), and those associated with the dolerites (fine-grained varieties), and, within both groups, those which were mobile as a fluid of diorite composition, and those formed by alteration of the dolerite or gabbro in situ. The field relations of the four types are consistent over the area.

After the formation of the diorites, the Glen Dubh Fault was developed, and associated minor faults, which now, in part, define the margin of the complex.

Intrusions of felsite followed, the main body of felsite as a mass apparently of sill form. These intrusions were often brecciated on intrusion, and evolved considerable amounts of volatiles, leading to brecciation of the overlying dolerites and gabbros in irregular vents. Veins of felsitic material were intruded at this stage cutting the earlier veins associated with the microgranite.

The final phase in the igneous history of the area was the intrusion of the Central Granite of the Complex, cutting and metamorphosing the Inner gabbros of Glen Dubh, and the intrusion of a minor suite of small acid and basic dykes.

II. THE EASTERN PART OF THE COMPLEX

a) The regional setting.

The country rocks into which the Central Complex was intruded are those of the Old Red Sandstone and of the New Red Sandstone. In the East there is a thin development of Carboniferous strata, which is overstepped by the New Red Sandstone to the West, and only in one locality, near Windmill Hill, do Carboniferous rocks form the margin of the complex. (Tyrrell, 1928, p.55).

The intrusion of the Northern Granite, in early Tertiary times imposed a general southward tilt on the area now occupied by the Central Complex, and the doming associated with the early stages of central activity was subsequent to this tilting. This feature has been discussed, and the effect of the doming on the disposition and outcrop of the country rocks illustrated by Tyrrell (1928, p.167 - 169, and 1" Geological Survey Map).

In the area mapped in detail, the country rock of the intrusions is Old Red Sandstone; elsewhere, where the New Red Sandstone forms the contact, the lithology is so similar to that of the O.R.S. as to be difficult to separate in the field. Both of the red sandstones are bleached near the contact, and the rocks converted into grey or greenish impure quartzites. Tyrrell (1928, p.173) notes the considerable metamorphism of the sediments, with the development of biotite, pyroxene and epidote.

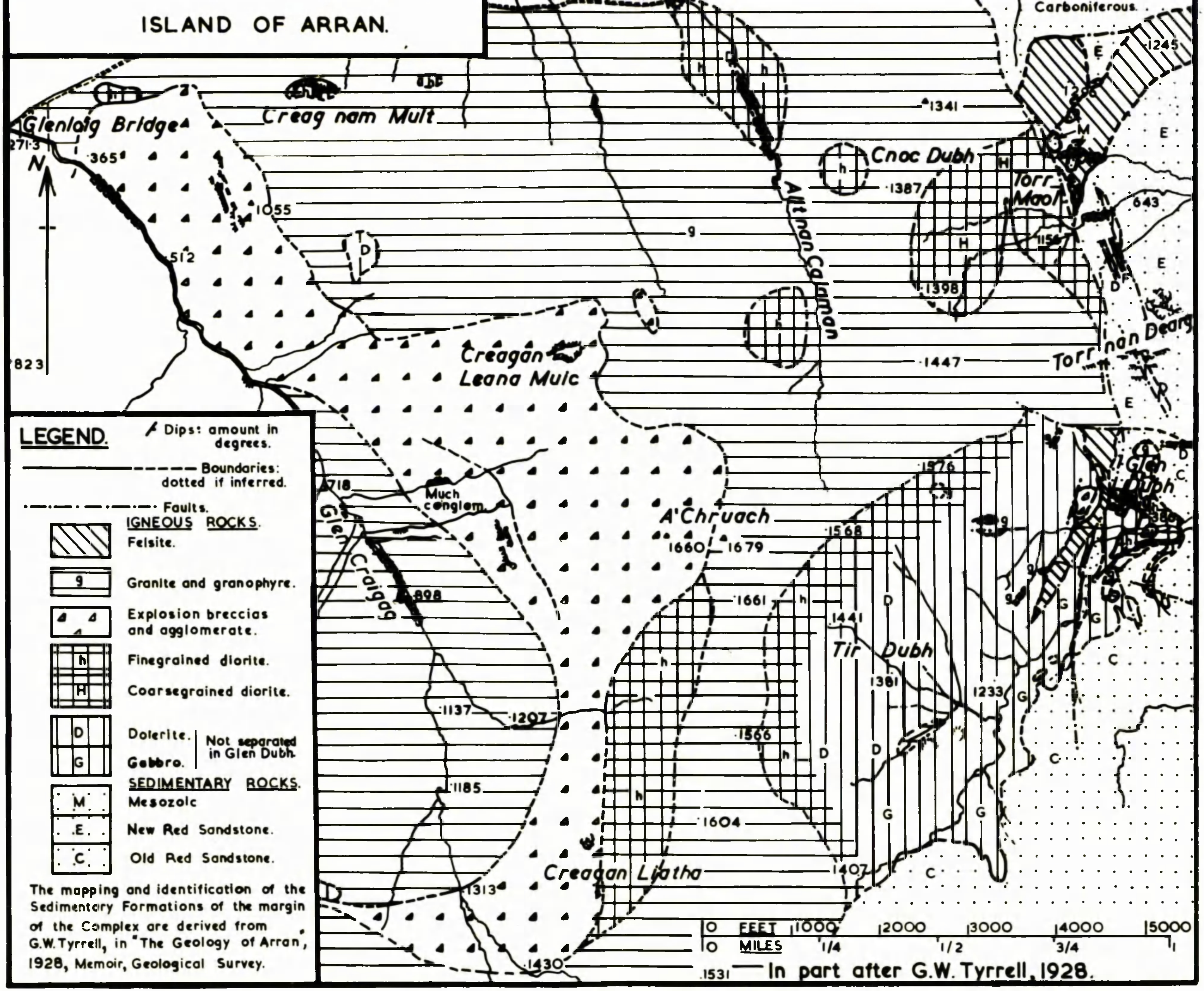
The Complex itself may be divided into three parts - the Ard Bheinn area, the area of arcuate granite and agglomerate intrusions of the central, upland part, and the areas of more or less disjointed gabbro-diorite intrusions of the eastern and northern margins.

The Ard Bheinn area, bounded roughly by Glen Craigag, the Ballymichael Glen, and the western margin, is a complex caldera, in which remanie masses of Mesozoic sediments are found among the deposits of several volcanic cones. (King, 1955). The granite and the agglomerate of the central part of the Complex are separated from the Ard Bheinn caldera by an arcuate fault. The ground is very poorly exposed, and little can be seen of these rocks.

The irregular areas of gabbro and diorite exposed in the eastern part of the Complex around Glen Dubh and Glen Ormidale, and in particular that of Glen Dubh are the main subject of Part 3 of this account.

b) The area mapped.

The ground described in this section is shown on the map Fig. 1. The area was mapped on a scale of 6 inches to one mile, using aerial photographs in conjunction with the 6 in. O.S. sheets. Minor amendments have been made to Tyrrell's map in the Arran Memoir, but little has been added to his account of the area. The ground is, as a whole, poorly exposed. Exposures in the bottom of peat hags are often bleached and may not be in situ.



ISLAND OF ARRAN.
Carboniferous.
Glenloig Bridge
Creag nam Mult
Cnoc Dubh
Torr Maol
Alltnan Calaman
Torr nan Dearg
Creagan Leana Muic
A'Chruach
Much conglem.
Glen Craigag
Tir Dubh
Glen Dubh
Creagan Liatha
LEGEND.
Dips: amount in degrees.
Boundaries: dotted if inferred.
Faults.
IGNEOUS ROCKS.
Felsite.
Granite and granophyre.
Explosion breccias and agglomerate.
Finegrained diorite.
Coarsegrained diorite.
Dolerite.
Gabbro.
Not separated in Glen Dubh.
SEDIMENTARY ROCKS.
Mesozoic
New Red Sandstone.
Old Red Sandstone.
The mapping and identification of the Sedimentary Formations of the margin of the Complex are derived from G.W.Tyrrell, in "The Geology of Arran", 1928, Memoir, Geological Survey.
0 FEET 1000 2000 3000 4000 5000
0 MILES 1/4 1/2 3/4 1
In part after G.W. Tyrrell, 1928.

<u>Figure 1</u>.

Geological map of the eastern part of the Central Complex of Arran.

The principal changes made to the map are to show areas of diorite found in the upper part of Glen Ormidale, (just east of Cnoc Dubh), and between A'Chruach and Creagan Liatha. The Glen Ormidale diorite is of the type associated in the Glen Dubh area with extensive veining of gabbro by granite within a few feet of the granite contact, suggesting that the Glen Ormidale outcrops represent a thin layer of altered gabbro lying on top of granite. Similar rocks are found all round the rim of the Tir Dubh. The area South of A'Chruach is of netveined dolerite and microdiorite, similar to the rocks exposed on Creag nam Mult, in the Allt na Calaman and North of the Cnoc Dubh.

All of the fine diorites appear to be of one type and origin. The more fine grained parts are virtually unaltered dolerite, and there is a progressive increase in diffuse veining and in alteration with increasing grain-size. Towards the contact with granite, net-veins of discrete fine granitic material are common, cutting the dioritic material. This suggests that the formation of at least some of the dioritic material preceded the intrusion of the main granite, and that the diorites may be related to the altered dolerites of Glen Dubh. Some of the boundaries of small microgranite bodies in the Tir Dubh have been redrawn. The exposures are so poor, that in places almost any interpretative boundary might be drawn. This applies also to the small exposure of agglomerate just East of Creagan Leana Muic.

On the West slopes of A'Chruach, considerable outcrops of conglomerate occur faulted on a small scale, and veined by granite, but not forming agglomerate. Blocks of this rock are common in the agglomerate further up the slope. The exposures are not sufficient to determine whether this outcrop of conglomerate might be a part of the original roof or wall of the complex, or possibly a mass of remanié material similar to those found around Ard Bheinn.

Elsewhere, the agglomerate on A'Chruach is very mixed, with a tendency for fragments of dolerite to predominate on Creagan Liatha. This occurrence supports the suggestion that the formation of the microdiorites preceded the intrusion of the main granite, since the latter clearly cuts the agglomerate, for instance in the burn in Glen Craigag.

There is an unusual dyke of a basic, or possibly ultrabasic, lamprophyre in the gorge of the Allt na Galaman (Marked D on the map). The dyke shows a platy jointing, spaced at 1 to 2 inches, parallel to the walls of the dyke.

The mapping of Windmill Hill (otherwise Mhuillin na Goaithe) which is 2000 yds. North-east of Cnoc Dubh is taken from Tyrrell (1928) and has not been revised outside the bounding fault of the Complex.

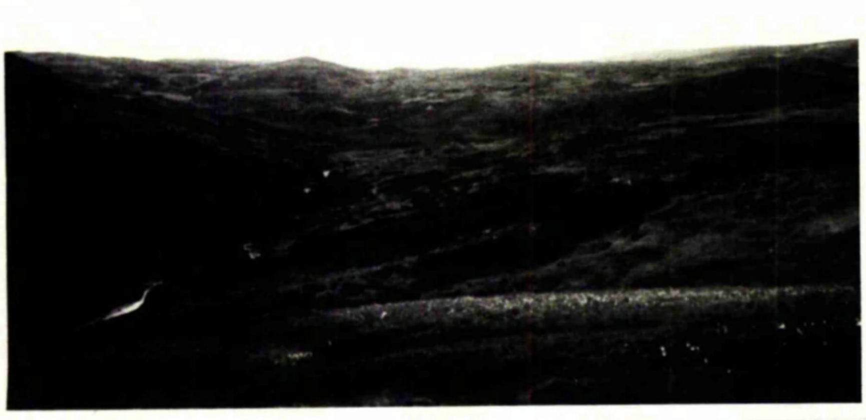


Figure 2a.

Lower Glen Dubh, from the East. The Glen Dubh Water is the prominent stream to the left of the photograph.

Figure 2b.

The Tir Dubh, from Gabbro Knoll, looking South. The stream is the Glen Dubh Water.

III. THE STRUCTURE OF THE GLEN DUBH AREA

a) <u>General.</u>

The major structures of the area fall into two groups separate by a sinuous fault, called here the Glen Dubh Fault. (See Figs. 24 and 25). The Glen Dubh fault is associated with a zone of intense crushing, shearing and alteration, which varies in width from 60 yards on the Knoll N. of burn A, to only a few yards on Torr nan Dearg. At the junction with the branching faults, by Gabbro Knoll, the shearing is particularly intense. A few yards to the North of where the fault crosses Burn A, the crush-rock is composed of material derived from both sides of the fault - gabbro and felspathic quartzite. A specimen (AA154) from this locality shows great shearing and brecciation with irregular minor folds and puckers in the felspathic material.

In thin section, the rock is seen to be mostly a mechanical mixture of fragments of dolerite and quartzite, mingled with fine rock dust, the whole cut by many planes of intense shearing. Epidote is common along these planes. In the interstices of the breccia, and replacing some of the felspar, granophyre growths are present. They range from severely folded to completely undeformed intergrowths, and are probably nearly contemporaneous with the crushing and shearing episode.

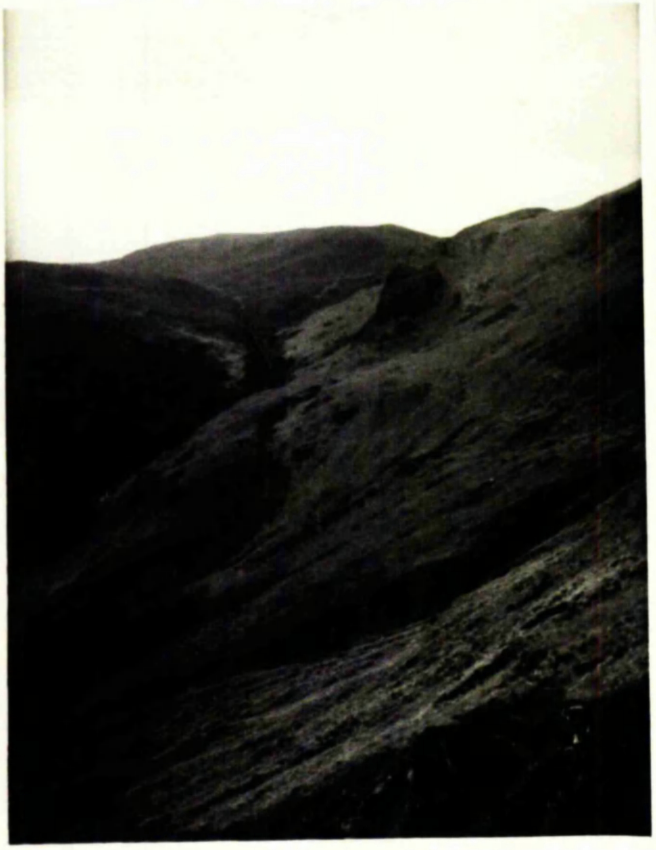


Figure 3a.

View from H3/093, looking South along the line of the Glen Dubh Fault towards Gabbro Knoll.

Figure 3b.

View from J4/090, looking Southwest, over the Inner Part of the Area.

Figure 4a.

The gully in the upper part of Burn A where the felsite is exposed. To the right of the gully, hornfelsed sediments lie concordantly above microgranite, diorite and gabbro.

Figure 4b.

Creag na h'Iolaire, showing the gully at DO/022.

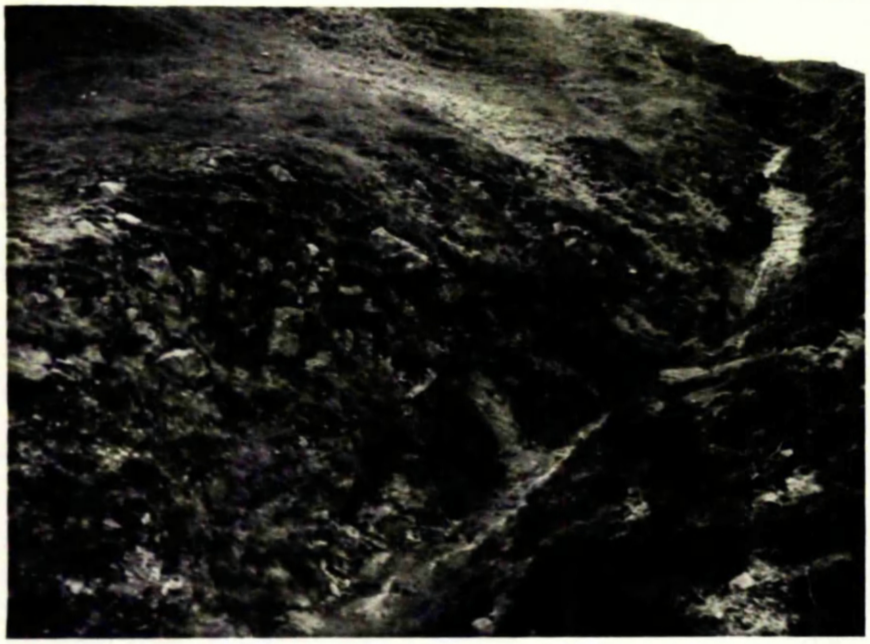
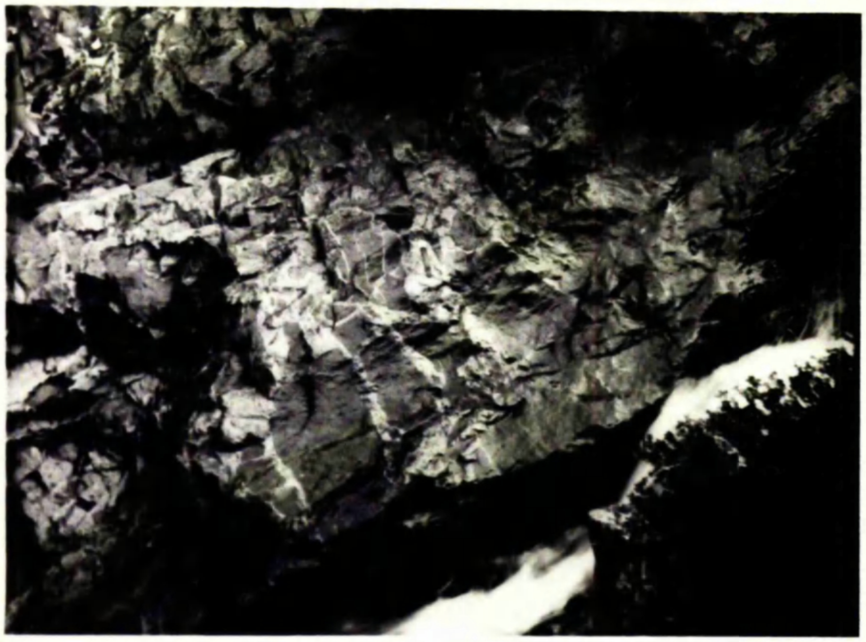


Figure 5a, b.

The upper part of Burn A.

Fig. 5a. is taken upstream from 5b, at the bend in the gully. Both show dolerite and dolerite breccia above felsite in the wall of the gully, and fresh felsite in the stream-bed.



Figures 6a and 6b.

Exposures showing net-veins of patchy hornblende diorite in dolerite in the Lower Glen Dubh Water at C2/054. Except in times of drought, the area shown in 6b is inaccessible.

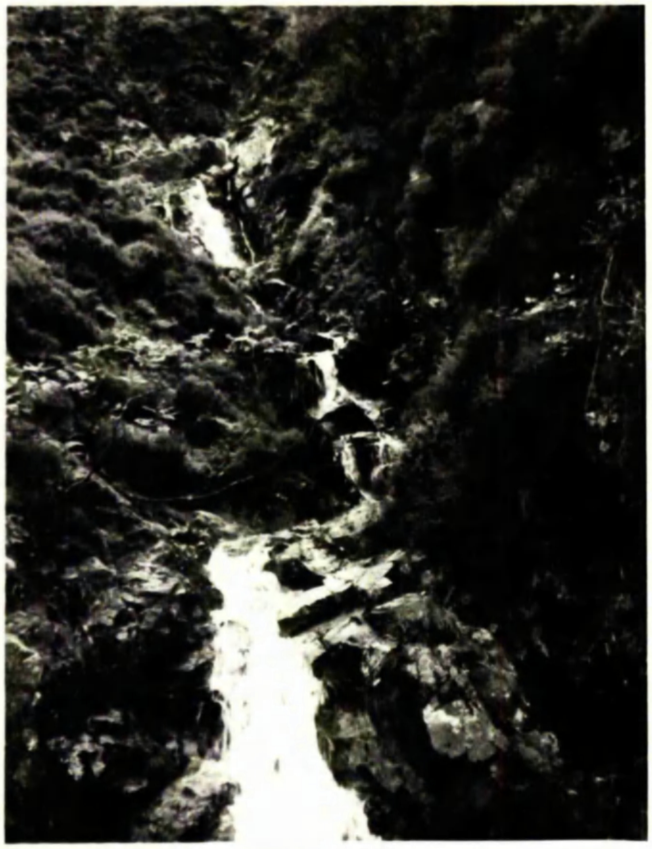


Figure 7a.

View from E3/047, looking up 'Slanting Gully'. The left wall is of hornblende microgranite, and the bed of the gully and the right wall are of diorite. In the background are the falls at F3/040.

Figure 7b.

Exposures in the Glen Dubh Water at G3/039. The cliff in the foreground is of hornfelsed sediments cut concordantly by microgranite and diorite, the contact about 18" above the stream, and dipping towards the camera. To the left is diorite, in the bed of the stream, and, further to the left, gabbro.

To the South, the Glen Dubh Fault dies out rapidly, in Old Red Sandstone and Trias Sandstones and grits. The margin of the Central Complex is here intrusive, but the branch faults, especially those along the line of the Glen Dubh Water, continue for a short distance to follow the arcuate trend of the Glen Dubh Fault, and probably take up most of the displacement on it, since the Glen Dubh Fault itself disappears in less than 200 yards along the line of the gully.

The evidence available in the area of Glen Dubh indicates that the displacement of the fault need not be greater than some 100 feet, downthrown to the South and East (outer) sides. Other faults in the area, mostly of minor importance, are shown on the map. In no case does the vertical displacement appear to exceed 50 feet, and rarely 20-30 feet. Such minor faults are irregularly distributed but show some tendency to run in a West to East direction (Fig.25). In general, the North or East side is the downthrow side of the fault, though in several cases this cannot be determined with any certainty.

It is convenient to divide the map, for structural purposes, into two parts: the area lying West and South of the Glen Dubh Fault, and that lying East and North of it. These will be referred to as the Inner Area and the Outer Area respectively.

The structure of the Outer Area is shown in its typical development in sections BB' and CC'. The country rocks in which the intrusion is emplaced are impure sandstones, breccias and silt stones of Old Red Sandstone age. They are steeply domed around the outcrop of the Central Granite, the dips ranging from 10°-65°. In the area over which the streams of Glen Dubh flow, i.e. between the Glen Dubh water and Burn A, the dip of the country rocks is very nearly parallel to the slope of the ground surface.

Along the Glen Dubh Water (Fig.27, BB'), these sediments are intruded concordantly by the nearly planar upper contact of a gabbro - dolerite body. This basic body shows a doleritic margin which locally passes into, and elsewhere is transgressed by, the main gabbro mass. Where gabbro - hornfelsed sediment, or dolerite - sediment contacts occur, the basic rock is chilled against the quartzite, and no assimilation of quartzose material is to be seen. Such contacts are, in fact, rare in this part of the area, for along the contact between quartzite and basic igneous rocks is intruded a thin but persistent sheet of microgranite or fine granophyre.

This microgranite cuts, and is chilled against, the sedimentary rocks. It is seen in a few places to absorb sedimentary material in small amounts, but this is difficult to detect especially in the field, due to the simulation of of granophyre by recrystallised quartzite (vide p. 75). Between the microgranite and the basic rocks, however, there is everywhere hornblende diorite - microdiorite where the contact is with dolerite, and a very coarse variety of diorite where the contact is with gabbro. Such diorite is seen to vein (locally to net - vein) the dolerites,(Fig.6a,b), and also to have partly absorbed xenoliths of dolerite, and, rarely, of the hornfelsed sediments. The diorites as a whole are patchy, variable rocks, more clearly defined by structural position than by composition or texture.

Thus the general structure outside the Glen Dubh Fault in the neighbourhood of Glen Dubh Water, is of a more or less evenly inclined concordant series of essentially sheet-like igneous bodies beneath the hornfelsed quartzite of the country rocks, the general dip being nearly parallel to the slope of the ground. This coincidence of structural and topographic surfaces is largely responsible for the exceptionally complex outcrop distribution in the area, and for great difficulty in drawing satisfactory boundaries to formations in poorly exposed tracts. This leads to the marked contrast between the apparently haphazard distribution of rock types shown on the outcrop map, and the comparative simplicity of the sections.

The layered structure is traceable to the North as far as Burn A. (Fig.27, CC'). Here there is a development of the coarse hornblende diorite, on the slabs North of the stream below the fault line. The cliff above shows the gabbro masses to pass concordantly beneath steeply dipping quartzite; the dip of the contact (55°) exceeds the slope of the ground at this point. (See p. 30).

To the South of the Glen Dubh Water, the junction between the top of the basic mass and the sedimentary cover is no longer concordant, (Fig.27, AA'), and the gabbro becomes markedly transgressive. This is associated with less regular dips in the quartzites and with most irregular behaviou of the micrograntite sheet. Outcrops of hornblende diorite are restricted to contacts between microgranite and gabbro - nowhere does it occur at a gabbro-quartzite contact in the absence of micro-granite.

The microgranite sheet is irregularly exposed West of section AA', but appears to thin rapidly in that direction. It is not closely connected with the microgranite sheets to the North.

The structure of the Inner Area of the complex is much less well defined. A large gabbro body appears to pass up into a dolerite margin, the passage between the two being irregular. The junction is normally indistinct, merging and difficult to define.

These basic rocks are cut by several intrusive igneous bodies, felsites and microgranites, and two small explosion-vents.

Felsite forms a dyke along the Glen Dubh Fault, and also a thick body to the West of the fault. Of the latter intrusion, no base is seen, but the top is nearly planar, and suggests that the general form is sill-like.

The microgranites cut felsites and vents, and are mostly thin sheets dipping Eastwards, which wedge out rapidly laterally. The contact between the Main Granite and the Glen Dubh Complex is nowhere exposed, but from the distribution of thermal metamorphism in the gabbros appears to dip fairly steeply outwards beneath the basic masses.

b) Details of structure.

The Outer Area.

1) Creag na h'Iolaire. (Fig.27, Section AA').

Creag na h'Iolaire is the prominent cliff forming the south-western rim of the coire of Glen Dubh. A deep gully divides the cliff face, providing good exposures, and from it, access is possible to most of the steeper part of the cliff face. (D/02). To the North and West, the cover of heather and peat is thick, and except along the foot of the cliff, exposures are not plentiful. On the cliff as everywhere in the Outer Area, the steeper ground is being rapidly eroded by streams and by small landslips, and the minor topography and the exposures vary considerably from year to year (Fig.4b).

Microgranite, microdiorite and quartzite outcrop together in the stream which flows from the foot of the gully to meet the Glen Dubh Water. Wherever a contact is observed between two of these rock types the same general relationship holds:

above;	Quartzite.
	Microgranite (if present).
	Diorite.
beneath;	Dolerite.

The quartzite found in the stream is in small exposures, sometimes visibly surrounded by diorite, and, where bedding can be seen, the dips are irregular and do not conform to the constant strike of the larger masses. It appears likely, then, that these quartzite masses are xenolithic fragments.

The little waterfall at the foot of the steep section of the gully, (D2/026), falls over microgranite, and this is exposed upstream as far as a narrow(3ft.) zone of crushing and shearing crossing the stream. (D1/023). This terminates the sheet-like form of the microgranite, and probably cuts off the basic dyke at this point. On the South bank of the gully the microgranite cuts across the junction of gabbro and quartzite, instead of passing along this junction, as it does elsewhere.

Above the small fault, the South wall of the gully is formed of gabbro, the North wall of quartzite (including a black siltstone variety), dipping SSE. or SE. at angles of 30 to 45 degrees, while two irregular microgranite dykes and an intervening screen of quartzite outcrop in the bed of bed of the stream.

The main cliff of Creag na h'Iolaire, Northwest of the gully, is of quartzite. This is cut, around E7/028, by an irregular body, (or possibly by irregular bodies), of micro-granite. These are bordered by a narrow zone of coarse hornblende diorite, (not represented in the sections), wherever there is a gabbro microgranite contact. Part of the micro-granite (the most accessible part, some 20 feet above the base of the cliff) seems to pass between gabbro and quartzite. Higher up the cliff, exposures are poor and less accessible, and it is difficult to determine the relationship satisfactorily. However, the microgranite on the cliff-face is certainly a tabular body parallel to the face. The origin of the small patch of microgranite on the highest point of Creag na h'Iolaire is obscure.

The fault which is shown cutting the gabbro and micro-granite on the cliff is most clearly seen at the foot of the cliff, where there is a zone of considerable brecciation, and of secondary alteration in the gabbro. No trace of the fault can be seen in the gorge of the Glen Dubh Water, and it is probably small. The small crag along the fault line exposes the junction between gabbro and another body of microgranite (F1/038). Here the gabbro passes beneath microgranite at a steep angle, but to the West the granite becomes an irregular dyke-like body. Unfortunately this ground is once more poorly exposed, and where the contact of the granite reaches the stream it is greatly distorted by a fault so that a satisfactory determination of the form of this part of the microgranite is not possible.

The steep slope from Creag na h'Iolaire to the Glen Dubh Water is heather covered and ill-exposed. The dip determinatio recorded on the map in this area have been made on exposures showing pebble bands.

2) <u>The upper part of the Glen Dubh Water.</u>

The critical exposures in this section, and indeed in the whole of the Glen Dubh Water section, can be seen satisfactoril <u>only</u> after a prolonged spell of dry weather. The same applies to many of the exposures in Burns A and B. The identification and discrimination of the various rock types is also very much more difficult in wet weather.

The bed of the Glen Dubh Water at GO/043 is covered by boulders, one of the few breaks in the almost continuous exposure along its course below the Glen Dubh Fault. In the North bank of the stream at this point, an irregular contact between hornblende microgranite and gabbro is exposed. Above the point GO/043, in the stream bed, hornblende microgranite is exposed, while the South bank is of massive green gabbro. On the North bank, the microgranite is seen to pass below the quartzites, (Fig.24 and Fig.7b), and this also takes place upstream, at the next series of falls.

At these falls, in the South bank, the quartzite is exposed above, but not in contact with, gabbro, while microgranite is similarly exposed in the bed of the stream below the level of the gabbro outcrop. This is interpreted as a "Stepping-down" of the microgranite to run in the gabbro rather than between it and the quartzite - a matter of some 8 to 10 ft. change in horizon.

To the South of the Glen Dubh Water, below the right angle bend in the stream, (H8/031), the quartzite forms the crest of a low ridge, and extends as far as the Fault to the West. No contact between gabbro and quartzite is seen, but the boundary can be mapped, and shows that the contact dips westwards, steeply in the South, more gently nearer the Glen Dubh Water.(Fig.27, AA'). North of the Glen Dubh Water, the quartzite continues as a low ridge. The northern flank is defined by a felsite dyke, and the Glen Dubh Fault, while on the Eastern flank, corresponding roughly to the outcrop of the gabbro, there is a terrace. Both of these topographic features die out to the North, towards Burn C. The quartzite outcrop, narrower to the North, crosses Burns C and B, without showing any indubitable contact with the gabbro to the East. Brecciation near the fault is very intense, and all of the quartzite exposed in Burn B is more or less broken.(G4/063).

3) Upper part of Burn A.

The upper part of the course of Burn A, outside the Glen Dubh Fault, flows down a steep area of rounded worn slabs, thinly grassed over in places, and elsewhere scraped clean by landslips or bared by minor streams. The shape of individual outcrops is liable to change rapidly and unexpectedly, due to landslips and to rapid erosion by flood-streams.

The coarse hornblende diorite, which is exposed over most of this area, lies above the green massive gabbro, and wherever a contact is found, it is nearly planar, and nearly parallel to the slope. Similarly, in the area around E4/079 the microgranite passes above the diorite. North of F/09 the quartzites can be seen to form a rugged, broken cliff, some 120 feet high, in which the dip of the sediments is parallel to the slope of the ground and of the igneous contacts and in which the diorite and gabbro pass concordantly beneath the quartzites.

Further to the North-east, at F0/099, there is a small cave, where microgranite is seen to cut quartzite. The contact is, in detail, irregular, but once more appears to pass beneath the sediments parallel to the general dip. This microgranite can be traced to the South some 250 feet in a line of small crags. North of the cave, the contact is obscured by scree, and only isolated exposures are found.

At F1/079 a cross-cutting tongue of microgranite runs in the gabbro some 10 feet below its top contact. Immediately to the East is a zone of severe shearing, which, while still active, was intruded by microgranite. It directs the course of the main branch of Burn A for some 30 feet.

The relationship of microgranite to coarse hornblende diorite is well exposed in small crags at E3/079, E2/080, and E0/080. To the South and East, the body of coarse hornblende diorite thins out, and hornblende microgranite comes into contact with dolerite and porphyritic dolerite. A gradual passage from gabbro to coarse dolerite is imperfectly exposed in Burn A.

4) <u>The Lower streams</u>.

The ground described in this section lies in a triangle bordered by the South bank of the Glen Dubh Water, the East bank of Burn A, and a line from G0/041 to E5/079. The rocks seen are almost entirely confined to the stream sections, those in the intervening areas being either very small or of doubtful provenance. (Fig. 2a).

The Glen Dubh Water, between the large boulder at D4/050 and the rapids at F2/040, shows very well the relationships of dolerite, diorite and microgranite. (Fig. 27, BB'). The South bank is, on the whole, of microgranite or microdiorite, and the various dioritic rocks exposed in the stream bed pass beneath the microgranite in the bank, the contacts dipping approximately 40 to 50 degrees to the South-east.

The two patches of quartzite shown just below the rapids (F2/040) are elongate blocks entirely surrounded by microgranite and almost certainly represent fragments of the quartzite roof of the microgranite. It is difficult to identify bedding in the blocks, and so the amount of their movement cannot be estimated. The course of the Glen Dubh Water from F2/041 to

E0/050 is largely determined by a marked plane of crushing. The crushing is most intense to the Southwest around F3/038, and the shear cannot be found to the East after it leaves the stream valley. (Fig. 7a).

Below the boulder at D4/050, the Glen Dubh Water flows over a broad, gentle slope of microgranite to the pool at the top of the lower falls. The stream is then constricted between a prominent block of quartzite and outcrops of patchy diorite. The microgranite has diverged here - a tongue 4 feet thick passing beneath the quartzite block, while the greater part passes over it. Beneath the microgranite there is a rapid transition through patchy diorite with many inclusions of basaltic fragments into a fairly homogeneous hornblende diorite with a few basalt fragments.

Below the quartzite block (C5/054) the stream-bed falls in a water-slide about 250 feet long and 120 feet high, ending downwards in a 15 feet waterfall. At the top of the slide, in the North bank, is a disoriented xenolith of quartzite, surrounded by patchy diorite. The contacts show no sign of significant corrosion or assimilation. Wherever there is a contact between diorite and quartzite fragments of basalt are common in the diorite. A very few partly corroded small xenoliths of quartzite may also be found.

A small sinuous fault divides the water-slide and forms a shallow groove in which the main stream-course lies. Two small, impersistent, basalt dykes along the fault in the lower part are later than the microgranite, and are unaffected by the earlier intrusives. In the upper part of the water-slide, are four large blocks of quartzite, all lying in attitudes markedly differing from the regional strike. These are interpreted as xenolithic blocks of the roof of the intrusion. About halfway up the slide, the diorite passes down into dolerite with numerous net-veins of microdiorite and hornblende microgranite. These veins are most common near the contact with the patchy diorite, and decrease away from the contact. A particularly good example is at B7/053, overlooking the pool. * (Fig.6a,b).

At B5/055, below the pool, is a small exposure showing dolerite with net-veins, in contact with diorite. The net-veins are continuous with the diorite, and form apophyses of it running into the dolerite. This exposure is the lowest of igneous rocks; the next exposures downstream are of hornfelsed sediments.

The other three stream sections (those of Burns C, B, and A, from South to North) do not yield the continuous exposure provided by the Glen Dubh Water. They provide however, several exposures important in interpreting the structure, as well as facilitating the drawing of boundaries.

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* The waterslide is readily negotiable in dry weather. In wet weather, it is slippery, and most of the exposures are under water. This applies also to the upper part of the Glen Dubh Water and to Burn A.

Throughout the sections exposed by these streams, the relations between microgranite, diorite and dolerite are constant, and are the same as those seen in the valley of the Glen Dubh Water.

Just below the junction of Burns B and C, the combined stream flows over a series of slabs of pale patchy diorite. In the diorite are abundant xenoliths of partly corroded dolerite and fine-grained dolerite, and a few xenoliths of quartzite. These quartzite xenoliths are recrystallised, but, except in two instances, (See p. 94 - 95), not at all assimilated by the diorite. In no case was assimilation of quartzite by dolerite seen.

There is an important exposure at the junction of Burns B and C. Here, in Burn B, fine dolerite shows a basalt (micro-dolerite) margin against quartzite. There is no sign of any reaction between the two. Away from the contact, the dolerite coarsens and passes into patchy fine diorite. This is a gradual transition. The dolerite is not intruded by the diorite as discrete material - it merely becomes paler and more patchy. In Burn C at this locality is a poorly exposed contact between quartzite and diorite.

The relationship between dolerite and gabbro in the Outer Part of the area, shown in the sections as a transition zone, has not been unequivocably established. There is no evidence of a fault along the contact, nor is there evidence that one cuts the other, and it seems reasonable that had either of these relationships been in fact present, evidence of it would have been found in at least one of the streams. On the other hand, a progressive coarsening of the dolerites towards the gabbro is observed, particularly in Burns A and B, and the gabbros first seen after the unexposed belt are finer-grained than those further into the gabbro outcrop, so that it seems reasonable to suppose a progressive coarsening of the dolerite to pass laterally into gabbro. A gradation is certainly observed in Burns A and B from the fine-grained microdiorite associated with the dolerites to that coarse-grained diorite constantly associated with the proximity of the micro-granite to gabbro.

c) <u>The Inner Area</u>.

1) <u>The Felsite Mass</u>.

The main felsite mass of the Inner Part of the area is exposed in an arcuate strip widening from South to North, except for a constriction near Burn A. It has two parts, a well defined dyke running along the Glen Dubh Fault, and a main sill-like mass, lying West of the Glen Dubh Fault.

The dyke is about 6 feet wide and lies in a zone of considerable crushing. The marginal country rocks are of hornfelsed gouge, and form a green, flinty rock. The intrusion can be traced for some 20 yards and may extend further. The felsite of the dyke is similar to that of the main body of felsite. (Fig.3a,4a).

The main mass of felsite is of indeterminate form. The top surface is planar, inclined East to Southeast at angles of 15-20 degrees. The base is not seen. The top is well exposed in the banks of Burn A, in Burn B, at J2/068 where it can be seen to pass beneath basic rocks, and at J7/085. The exposure at J7/085, where 4 ft.6 in. of felsite is visible passing beneath basic igneous rocks, fits well with the strike lines drawn for the top from the other exposures.

To the North of Burn A, the felsite steps up irregularly, as shown in Section CC' (Fig.27) and the outcrop widens to the North towards the Central Granite. To the East, the felsite is truncated by the line of the Glen Dubh Fault. From the state of the felsite dyke, it appears that the felsite has been intruded later than the fault movements, but the form of the mass is very much controlled by the shape of the Glen Dubh Fault.

The approximate position of the top of the felsite has been plotted on Sections AA' and BB' (Fig.27) to show that if its attitude where it is underground to the West is consistent with that where it is exposed, it would not outcrop again within the area of the map. The most northerly exposures in Burn A show the felsite becoming rapidly coarser and forming quartz-porphyry, and gradually changing towards fine granite. The relationship of felsite and Central Granite cannot be determined here due to lack of exposures.

The felsite intrusion is tentatively interpreted as a sill, and the dyke along the Glen Dubh Fault as a possible feeder dyke.

2) <u>The form of the gabbro-dolerite intrusion</u>

The general form of the gabbro-dolerite bodies of the Inner Area is not at all clear. To a certain extent, constant spatial relations have been observed between gabbro and dolerite, but the irregularity of exposure prevents any firm hypothesis of structure being advanced.

The contact between gabbro and the Central Granite proper, is not seen. As the Central Granite is approached, the gabbros and dolerites show the development of large flakes of red-brown biotite. The felspars in the gabbro also show clouding. These effects are found only in proximity to the granite contact, and are attributed to thermal metamorphism of the gabbros by the Central Granite. On this basis, the granite probably passes beneath the gabbros, the contact being a plane, inclined steeply (possibly at about 40 degrees) to the East. There is no evidence that the small intrusions of granite and microgranite shown on the map are directly connected with the Central Granite.

The relationship between gabbro and dolerite is less obscure, though complex. In different localities, the gabbro:

i) is fine-grained against, and apparently cuts, dolerite (M7/018),

ii) shows a gradual passage into dolerite, (M6/065),

iii) is apparently cut by dolerite (K7/082).

The second relationship is by far the most common. In the first and third cases, even though the boundary may appear quite sharp in the field, in thin section it is indeterminate, and the order of crystallisation obscure. The normal relationship is where there is a transition zone of some 4 to 10 feet width between dolerite and gabbro.

On the whole, the dolerite forms the crests and eastern faces of knolls and ridges, while the gabbro occurs more on the western faces and in the hollows. It is suggested therefore, that the form of the dolerite is that of an irregular sheet lying above the gabbro, and passing downwards into gabbro; i.e. that it represents a fine grained facies of the gabbro. The surface of contact between the gabbro and dolerite is fairly regular, and the general form corresponds to that established in the Outer Part.

The sections have been drawn to pass through the better exposed parts, especially Sections BB' and CC'. (Fig.27).

3) Microgranite intrusions.

Several minor bodies of microgranite outcrop in the area of the map.

The microgranite at M3/026 appears to be a narrow dyke. It is poorly exposed, and much broken. At M9/064 (Section BB') and at M1/078 (Fig.27 CC') microgranite forms thin sheets, the latter 8 feet thick, and the former more than 6 feet. These sheets show well defined chilled margins against gabbro and dolerite, and very little interaction with them.

At J7/053, a sill-like body of microgranite is seen to pass steeply beneath dolerite in a small gully (Fig.27 BB'). The exposure is good, and the shape of the microgranite can be well established. The form of the smaller body 50 feet to the Northwest is not clear.

Of the remaining microgranite outcrops, that at K1/038 appears to be a narrow(2') dyke, as are those at H4/090 and K7/117. Those bodies at N7/073, J5/073 and K6/082 are either poorly exposed or irregular in form.

4) Areas of tuff and breccia

Two small vents (See p. 105 below), are shown on the map in the Inner Area. They centre about J/09 and K8/035. The former is better exposed.

Both are emplaced in dolerite and gabbro, and are clearly cross-cutting. They show no internal structure except an unsystematic variation in the clastic rock types. The rocks within the vents are breccias and tuffs, (see p. 105), with small areas of virtually unchanged dolerite. The margins of the vents are not sharp, but are obscured by veins of tuff running out into the surrounding rocks.

Associated with the vents is particularly intense net-veining in the dolerites. This preceded the veining associated with the felsites (p. 106)(Figs. 8a,b,9a,b).

5) The Lower part of the Tir Dubh.

This part of the Inner Area of the Complex is shown on the small separate map (Fig.10).

Most of the area is of gabbro, with several minor bodies of microgranite, a few late basic dykes, and three small

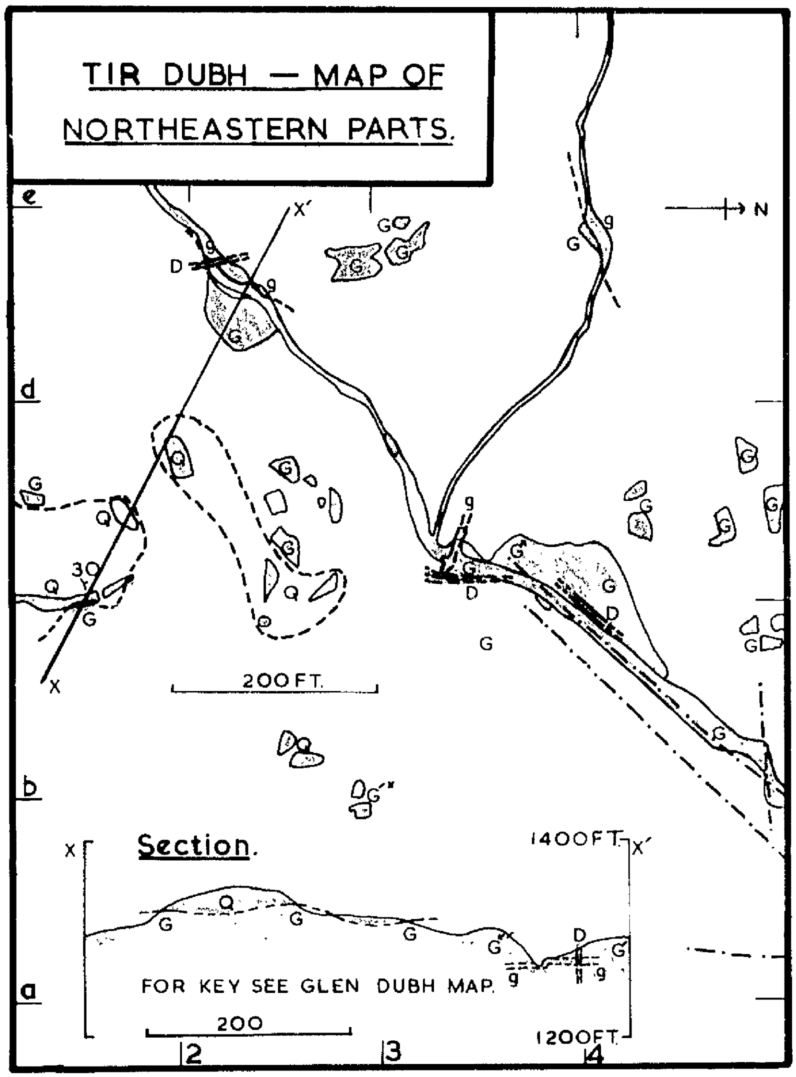
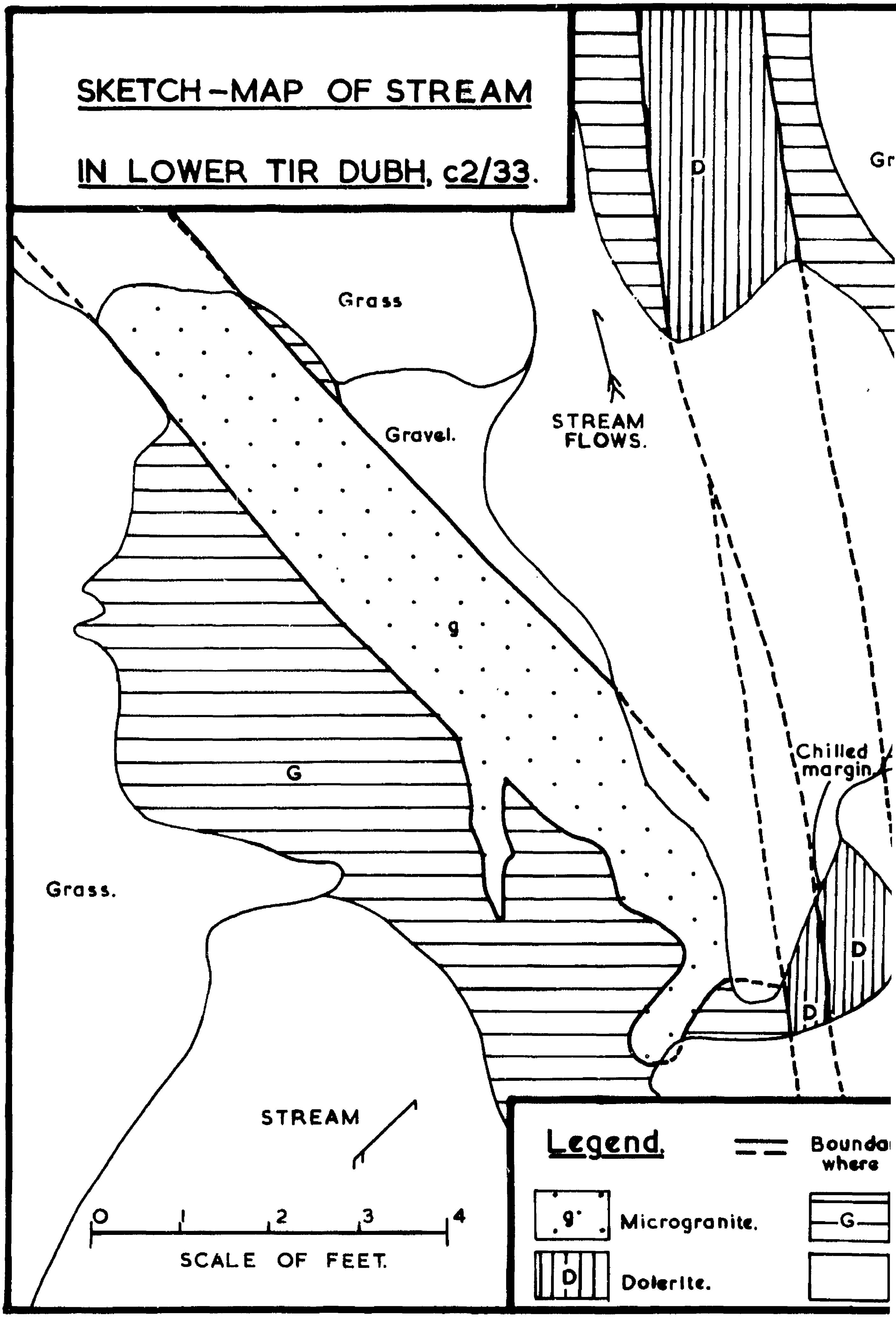


Figure 10.

Geological map of the northeastern parts of the Tir Dubh.

SKETCH-MAP OF STREAM IN LOWER TIR DUBH, c2/33.



areas of hornfelsed sandstones. The most westerly group of branch faults from the Glen Dubh Fault enter the area at the Northeast corner and die out rapidly to the Southwest. The course of the stream is largely determined by these faults.

At b0/49, a small irregular felsite dyke follows the line of the faults for about 20 ft. It is notably sheared and distorted. Further upstream, there are several blocks of quartzite in the South bank of the stream. On the North bank of the stream there is a 6 inch basalt dyke, running parallel to the fault system. The next small fall upstream (d3/33) is formed by a 3 feet dyke of microgranite, which crosses the stream and is itself cut by a pair of basic dykes running along the stream course. (Fig. 11).

The microgranite sheet exposed in the stream bed at d7/21 passes beneath gabbro in both banks of the stream. It is cut by a later dolerite dyke 18 inches wide, exposed only in the stream bed. Some 10 feet downstream, the microgranite sheet can be seen to "step-up" by about 4 feet in the Northwest bank of the stream. Here the sheet is 4 feet thick, and cuts gabbro. The microgranite exposed in the tributary stream at d8/41 can be seen to pass beneath gabbro in the South bank. The contact is nearly horizontal. The general form of the intrusion, and its extent, are not clear.

The outcrop of sandstone shown at c0/11 is continuous with the main outcrop of Old Red Sandstone. On the East face of the outcrop, in a small cliff, the hornfelsed sandstones rest upon gabbro, the contact being irregular but near-horizontal. The two other areas of hornfelsed sandstone shown, at c0/25 and b2/25, are probably outliers of the main sandstone body. The rock exposed in them is recrystallised to a siliceous hornfels, and is penetrated by numerous stringers of fine gabbro.

d) Summary of structure.

The Glen Dubh area is divided into two parts by a sinous fault. West of the fault, the structure is indeterminate, with a largely unsystematic distribution of dolerite and gabbro, which show a transitional relationship. The basic rocks are cut by a thick body, possibly a sill, of felsite, with which are associated two areas of breccias and tuffs, distinguished in mapping as vents.

The Outer part of the Area, East of the fault, shows a layered structure, with gabbro and dolerite intruded as a sill-like body concordantly into sandstones and breccias, and an interposed thin layer of microgranite intruded between the two.

The contact between microgranite and gabbro, or between microgranite and dolerite is characterised by the development of a variable suite of dioritic rocks. These diorites have been separated in the field into several types, although much of the finer diorite cannot be classified. The types recognised are; contaminated microgranite, (Glen Dubh Water South bank), altered dolerite, both intrusive and non-mobile, Burns A and the Glen Dubh Water); coarse contaminated microgranite found at the junction of microgranite and gabbro (for example at E6/085), and coarse hornblende diorite of gabbroic texture found adjoining the gabbro between the gabbro and microgranite.

The layered structure is essentially simple, (cf. sections, Fig. 27), but due to the coincidence of the slope of the ground and the dip of the layers, the exposure map appears unduly complex.

The position of the diorites in the structure is constant - they lie between microgranite and basic rocks, and are not found except in this context.

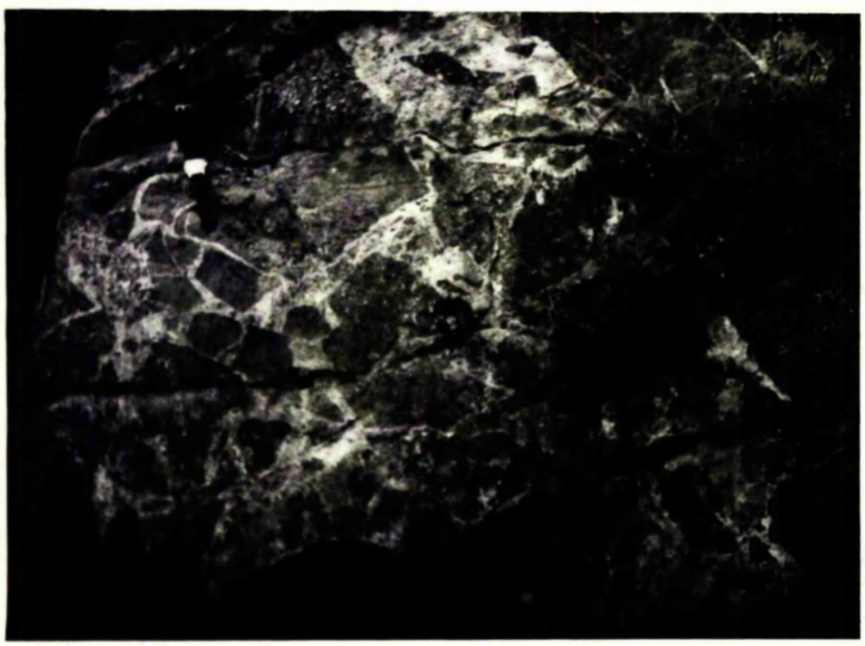


Figure 8a.

Coarse breccia of dolerite fragments in a tuff matrix, at JO/079.

Figure 8b.

Veins of felsite and felsite breccia, in dolerite, at H1/099.

Figure 9a.

Exposure showing two sets of veins in dolerite at L4/082.

Figure 9b.

Exposure showing two sets of veins in gabbro, at M8/061.

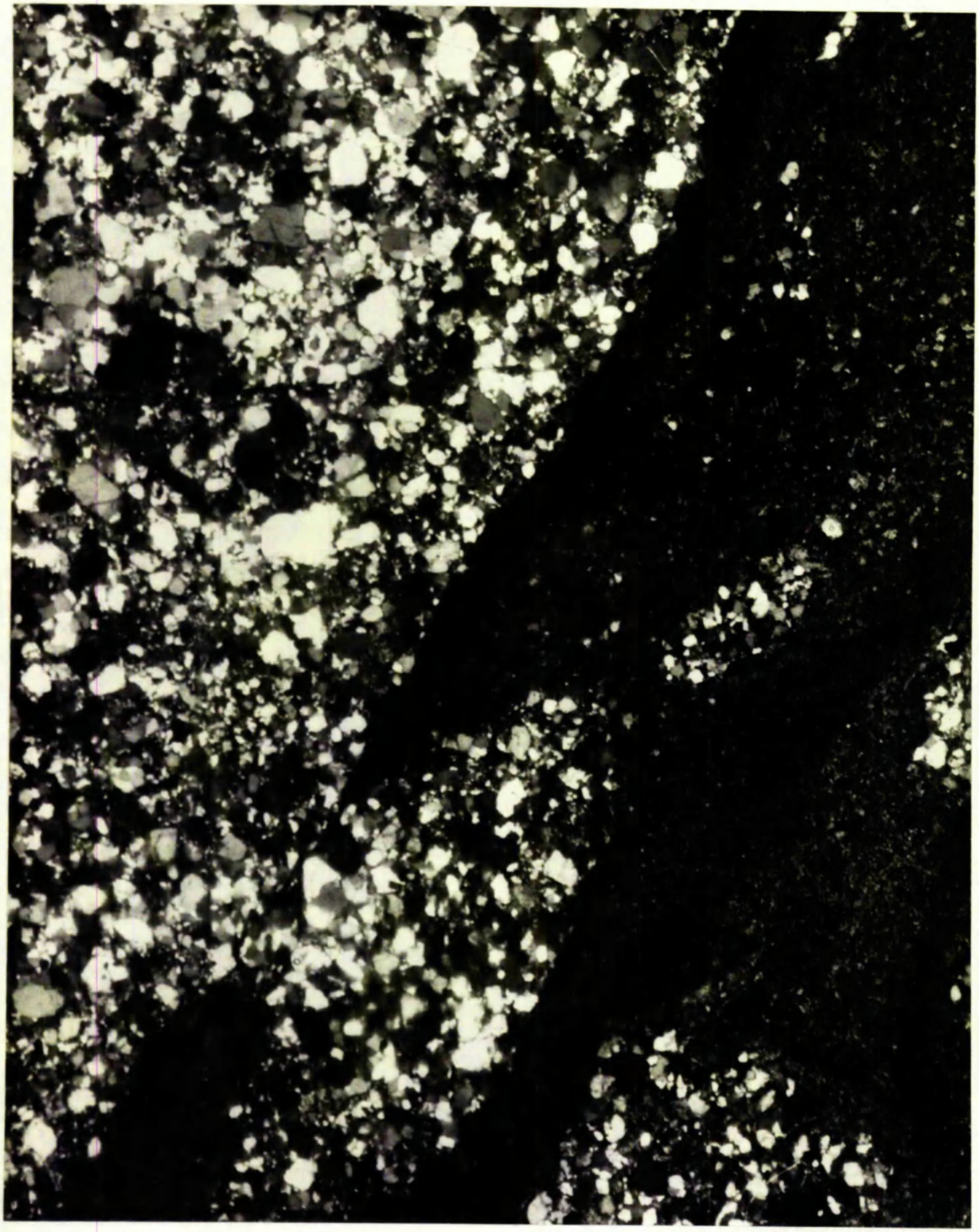


Figure 12.

Photomicrograph of hornfelsed breccia at D9/059.

Specimen AC 129. x30. Crossed nicols.

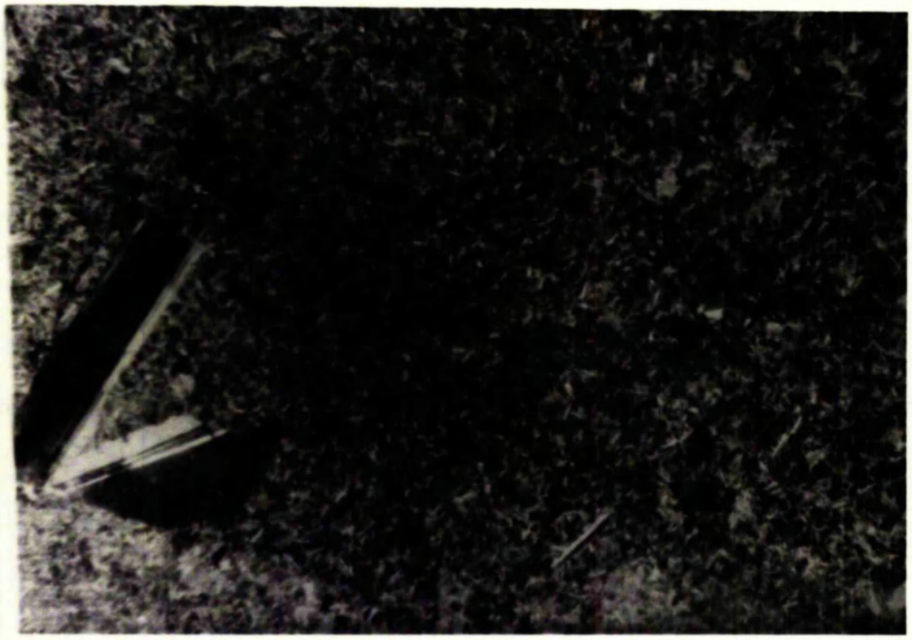
This photograph shows fragments of banded siltstone in a fine grit matrix. The rock is hornfelsed, and recrystallisation of the grit material is marked.

Figure 14.

Photomicrographs. x10. Crossed nicols.

Fig.14a. Specimen AA 173. Gabbro from J9/068. Analysed specimen.

Fig. 14b. Specimen AA 25. Gabbro from GO/070.



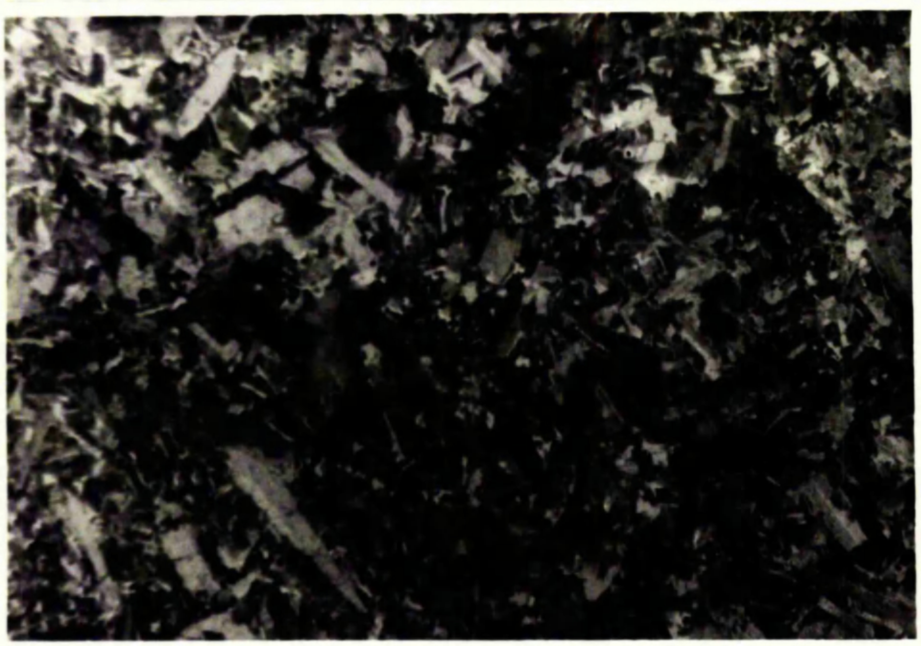
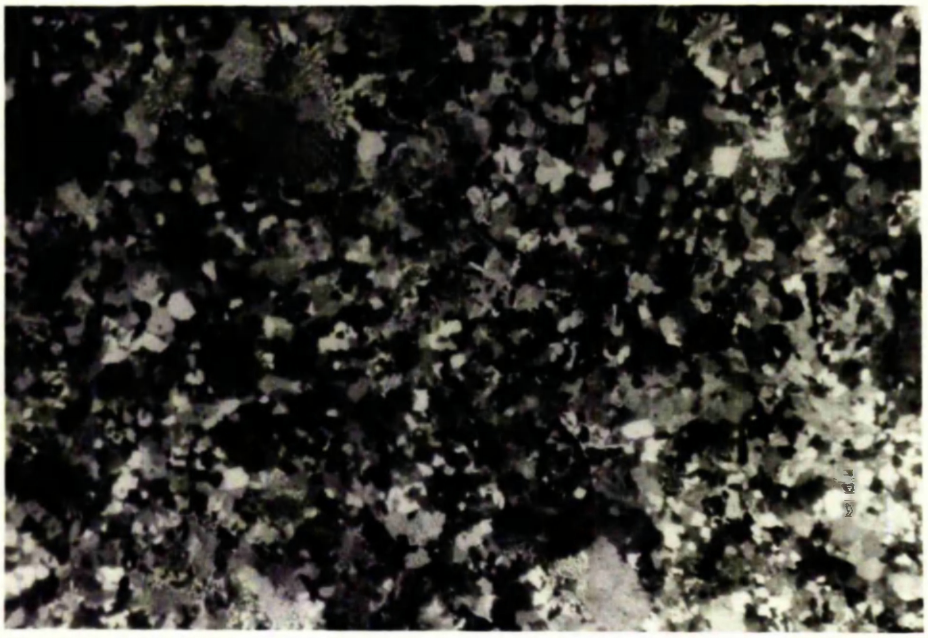


Figure 15.

Photomicrographs. x10. Crossed nicols.

Fig.15a. Specimen AC 201. Fine dolerite from C9/062.

Fig.15b. Specimen AA 100. Fine dolerite from E1/047.



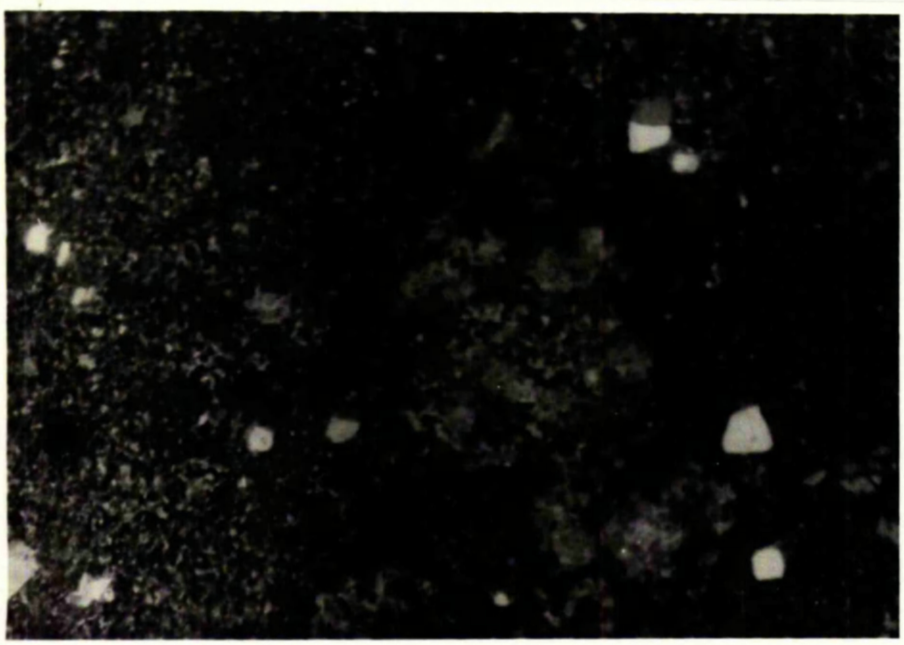


Figure 16.

Photomicrographs. x10. Crossed nicols.

Fig.16a. Specimen AC 217. Granophyre from KO/052.
Analysed specimen.

Fig.16b. Specimen AA 91. Felsite from dyke at H2/048.

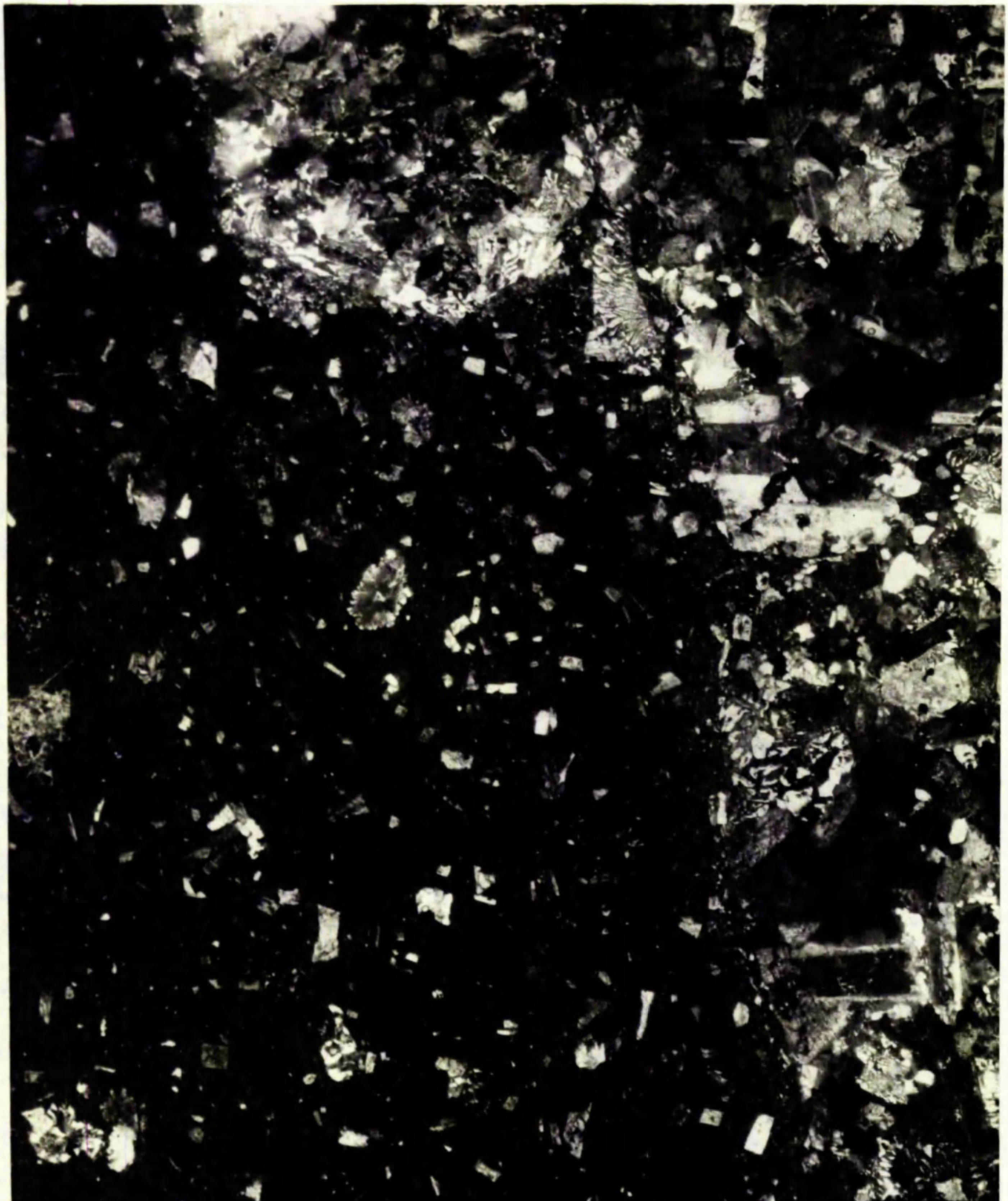
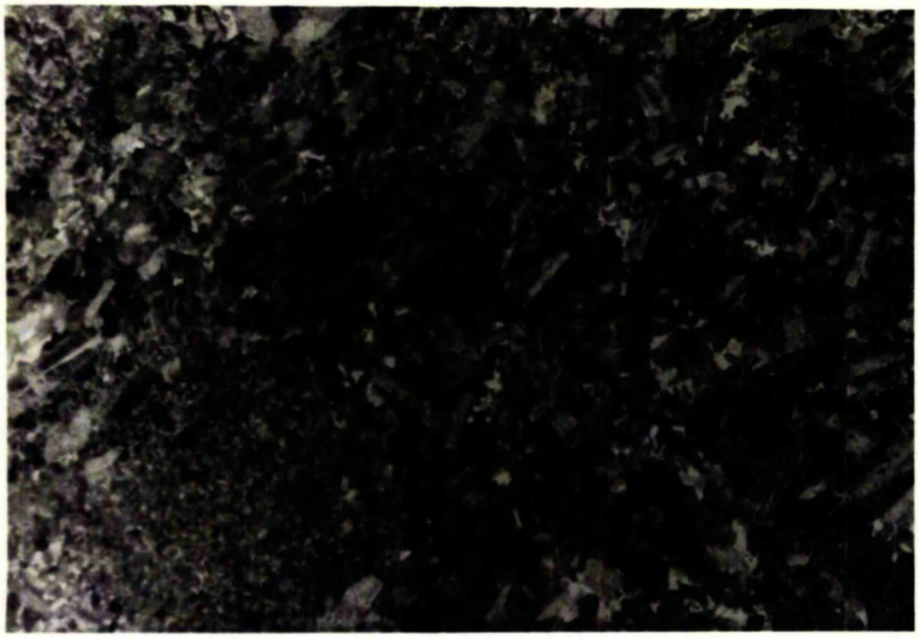


Figure 17.

Photomicrograph of contact between microgranite and hornfelsed sandstone at F1/098.

x20. Crossed nicols.



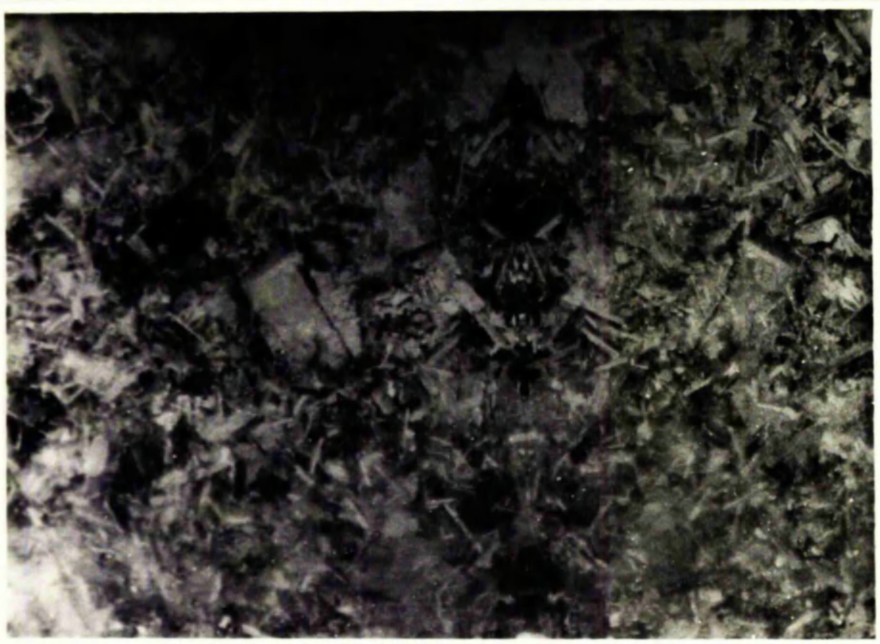
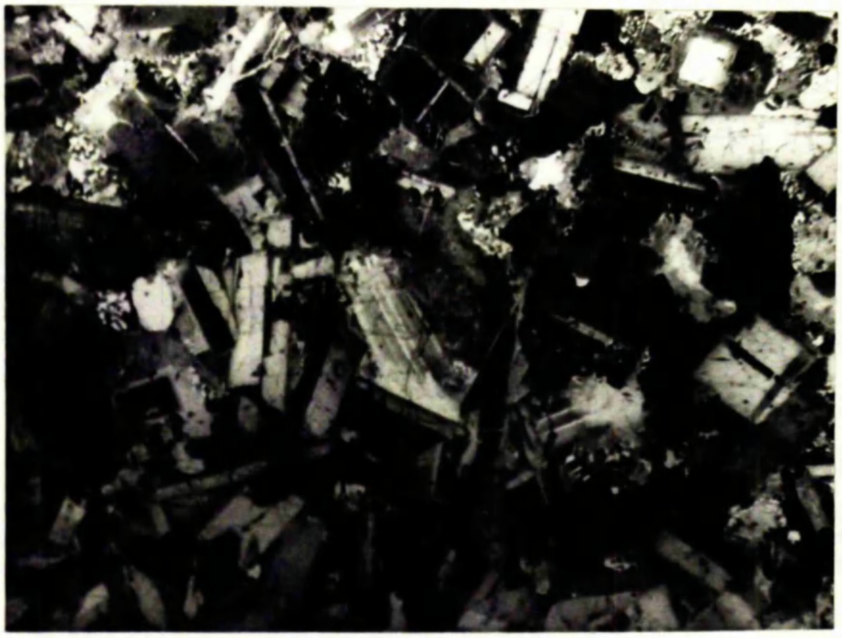


Figure 18.

Photomicrographs. x10. Crossed nicols.

Fig. 18a. Specimen AC 70. Fine Hornblende diorite.

Figure 18b. Specimen AC 103. Fine hornblende diorite.



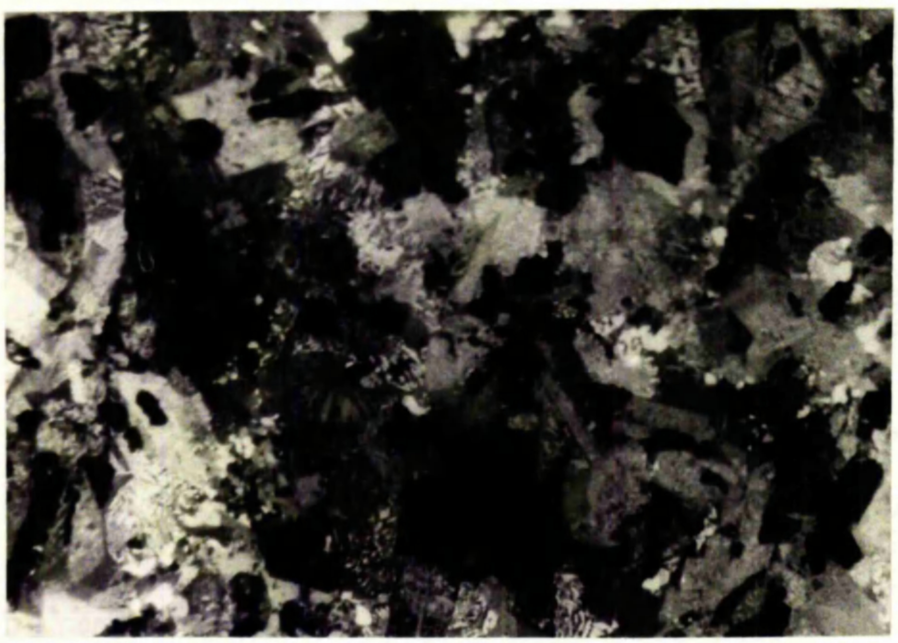


Figure 19.

Photomicrographs. x10. Crossed nicols.

Fig. 19a. Specimen AC117. Coarse patchy diorite, 2d, from F5/086.

Fig. 19b. Specimen AC122. Hornblende microgranite, of granophyric texture, 1c, from E4/087.

IV. THE PETROGRAPHY OF THE GLEN DUBH AREA.

a) Country Rocks.

The formations into which the Glen Dubh Complex is intruded are, a thick series of felspathic sandstones, breccias, conglomerates, and occasional silt stones, all well indurated, and hornfelsed close to the igneous bodies. The deep red colour associated with the Old Red Sandstone sediments elsewhere in Arran is here absent apparently due to thermal metamorphism causing reduction on the coloured ferric iron compounds in the matrix.(Tyrrell, 1928).

1) General.

There are four principal areas where sediments of Old Red Sandstone age outcrop in the area mapped in detail (Fig.25).

1) the foot of the falls of the Glen Dubh Water;

2) the cliffs of Creag na h'Iolaire;

3) the narrow strip along the Glen Dubh Fault;

4) the cliffs to the North of Burn A.

There are numerous other small exposures in the area enclosed by the lower parts of the Glen Dubh Water and Burn A, and three small areas of hornfelsed sandstone exposed in the Tir Dubh (Fig.10).

The rocks of the area at the foot of the Glen Dubh Water are massive, impure sandstones, well indurated, with occasional bands of breccia composed of fine-grained siltstone pebbles. Towards the contact with igneous rocks, the sediments are hornfelsed, to form, ingeneral, siliceous hornfelses, with subordinate felspar and diopside. All of the sedimentary rocks exposed in the streams of the lower part of Glen Dubh have been metamorphosed.

Bedding planes are difficult to determine - the rocks are massive and often homogeneous, and in the absence of breccia bands, the determination of dips is difficult. In some areas, a 'blocky' jointing is developed.

The succession in this part, and, with small variation, of the sediments of the whole area of the map, is made up of two principal rock groups - a dominant even-grained felspathic sandstone, and subordinate breccias, grits, and siltstones. There is no clear distinction between these groups; one grades into another vertically, and less often, laterally. Large pebbles of shale, siltstone or grit are found in otherwise even-grained sandstones.

2) Sandstones and fine grits.

The following table gives modes for a series of similar fine even-grained sandstones of increasing metamorphic grade, in a series collected towards the igneous contact. AC15 is probably most representative of the group in general.

Table 1. Modes of Sandstones and fine grits.

Mineral Rock No.	Quartz*	Felspar + Sericite	Amphibole + Pyroxene	Biotite	Chlorite	Opaque	Calcite
AC 12	36.1%	23.7	-	-	3.5	3.9	32.8**
AC 15	39.9	36.7	3.4	1.o	3.1	15.9	-
AC 21	45.1	40.0	12.6	-	1.2	0.8	-
AC 36	47.8	25.8	18.4	0.3	-	2.5	0.3

(Epidote of vein 5.3%

* The values for quartz are probably somewhat low, due to the difficulty of discriminating quartz in fine crystals in a felspar-sericite mass.

**The calcite is present as a vein. The small amount of calcite occurring as an alteration product of felspar is included with chlorite. The amount of such calcite is very small.

In hand specimen the rocks of this group are hard and compact, often with no trace of banding, and of a greenish-grey colour. The thin sections show numerous quartz crystals(about 30% of the rock) in a fine-grained matrix of felspar, sericite, and quartz. The large quartzes are angular, in general, although with increasing metamorphism they show progressive intergrowth with the matrix. Several examples of crystals showing undulous extinction have been noted, but these become less common with increasing metamorphic grade. Another feature apparently confined to the relatively unaltered sandstones is the presence of quartz fragments made up of several intergrown crystals - the typical fragment of the hornfelses is a single quartz individual. The size of the grains is variable, from 0.1 to 0.6mm. diam., but most are around 0.2mm.diam. The grainsize of the fragments does not noticeably change on metamorphism, but the margins are extensively embayed, apparently by corrosion by the matrix, and quartz in the matrix recrystallises in optical continuity with the larger fragments.

The unaltered matrix is mostly of fine felspar and sericite crystals, and is partly recrystallised to a fine granular mesh. Quartz is less in amount than felspar. Chlorite appears as small flakes in the matrix, in subordinate amount; it is stable in the low grades of thermal metamorphism. Opaque minerals, probably mostly magnetite, occur throughout the rock as small irregular flecks, both in the matrix and as inclusions in the larger quartzes. None of the quartzes examined show inclusions of matrix material. Calcite occurs in small amount as an alteration product of felspar, and occasionally as veins (AC 12).

A felspar crystal of exceptional size (0.2mm. long) and apparently stable, is of composition about An 30. Apart from this one crystal, the felspar is so fine-grained and sericitised as to be undeterminable by normal optical methods. Staining revealed no trace of potash felspar.

Six feet from the igneous contact, the rock is entirely recrystallised, and shows the larger quartzes much corroded, in a matrix of felspar, quartz and granular diopside which form a granular mosaic. Epidote occurs as occasional veins or detached flakes, and in AC 36, there is a single flake of white mica. Biotite appears at a late stage in the metamorphism (cf. the metamorphism of the siltstones.(p. 59) (AA34b). The opaque ore minerals occur in the highly metamorphosed rock as large, irregular blebs, up to 2 mm. diam., as well as in fine granules in the matrix.

3) Breccias and silt-stones.

The second main group of the sedimentary rocks is comprised of various grits and breccias, and dark grey silt-stones which occur both as layers in the sequence,(but not at th outcrops described above - only on Creag na h'Iolaire), and as fragments in the breccias.

A typical breccia (AC 1) contains numerous sub-angular fragments in a complex matrix. The matrix is essentially similar to the sandstones of the first group, with if anything a higher proportion of quartz ore material. The large fragments up to 9cm. long, include metamorphic quartzite, garnet schist, (in AC 1b), basalt and siltstone. The siltstone is the common coarse fragment in the breccias, and occurs also asisolated pieces in grits intermediate between the breccias and the fine sandstones. The siltstone fragments often show banding internally. The surrounding matrix is sometimes also banded parallel to the surfaces of the more tabloid fragments.

The following table gives modes of a typical breccia of the type with siltstone fragments only. (AC 8).

Table 2. Modes on AC 8.

	Quartz.	Felspar + Sericite.	Amphibole + Pyroxene.	Biotite	Chlorite	Opaque
Siltstone fragments	39.1%	31.3	2.6	11.7	8.3	7.0
Coarse part of matrix	76.2	17.6	0.2	0.9	0.2	5.0
Fine part of matrix	52.0	35.5	0.9	1.2	5.2	5.2
Totals for rock	57.2	25.4	1.4	5.8	4.3	4.3

With metamorphism in proximity to the igneous contact, the matrix behaves like the fine sandstones described above, and will not be further detailed except to note the development, in rocks of this group, of granophyric patches in the matrix at high grades. Whether this is due to fusion of the groundmass, or whether it is introduced from the igneous rocks is not clear.

The siltstone layers in the sediments are well exposed only on an inaccessable part of the cliff of Creag na h'Iolaire, but siltstone fragments are fairly common in the breccias. The fragments appear to be identical to the layered rocks, and th e breccias are interpreted as being due to penecontemporaneous brecciation of partly compacted siltstone beds, and partial reworking of the fragments.

On metamorphism, the siltstone develops biotite at an early stage, except in a zone 0.1 mm. wide around the margin of the fragment (AC129)(Fig. 12). At a higher grade, andalusite appears as diffuse intergranular blebs, and chlorite disappears. Fine opaque particles are ubiquitous. The integrity of the fragments is preserved, however, to an extreme stage of metamorphism, when the matrix has been largely replaced by granophyre, and the fragments rounded by corrosion and marginal recrystallisation. This is seen especially well in an exposure at E4/075, (AA 34b), and will be discussed more fully with the microgranites. (See Fig.12).

The sandstones of Creag na h'Iolaire are at least 250 ft. thick, and are mostly of the evengrained varieties, with subordinate siltstones. Bedding is apparent on a large scale, but difficult to find in detail. (Fig.3a,4a,b). Similar grey or greenish sandstones, often severely brecciated, form the strip along the Glen Dubh Fault, and the crags North and East of Burn A. In the latter outcrops, breccias are rare, and an even flaggy jointing is developed in the sandstones.

The outcrops in the Tir Dubh, (Fig.10), are of white quartzite, very hard and very pure. The contact with gabbro, except as rare veins, is not seen. Similar blocks of white siliceous hornfels occur at J3/007.

The xenolithic blocks of hornfelsed sediment exposed in the streams in the lower part of Glen Dubh include examples of all types, but are mostly of the finegrained sandstones, now metamorphosed to a diopside-bearing siliceous hornfels.

b) Gabbros and dolerites.

The dolerites and gabbros of the Glen Dubh area, both inside and outside the Glen Dubh Fault, appear all to be of the same suite, the differences between those of the Inner and Outer Parts of the Area being due to different histories of alteration and metamorphism.

1) General description.

In general, the gabbros of this region are pyroxene - plagioclase rocks, olivine and hypersthene bearing in the more basic and less altered variants, and of textures ranging from coarsely ophitic to hypidiomorphic and equigranular. Interstitial patches of quartz - felspar intergrowth are often present, associated with irregular diffuse veins, and with marked development of sodic rims on the plagioclases. The normal accessory minerals are magnetite, ilmenite and apatite, and alteration minerals amphibole, chlorite, sericite, serpentine, leucoxene, calcite and epidote. The dolerites are similar, but are distinguished from the gabbros principally on the grounds of finer grain size and dominantly ophitic structure.

Specimen AA173, (J9/068), is taken as a typical example of the gabbro of the Inner Part of the Area. In hand specimen, the rock is a medium-grained homogeneous gabbro, free from veins or mottling. Felspars and pyroxene are conspicuous, and occasional bronze-coloured flakes of biotite. The chemical analysis is given in Table 8, the mode in Table 4, and the norm in Table 10, and a photomicrograph, Fig.14a.

In thin section, the rock is seen to be composed principally of plagioclase and pyroxene, in a partly granular, partly ophitic, intergrowth. Opaque minerals, in skeletal or subhedral crystals are common. Accessory minerals include orthopyroxenes, biotite, epidote and chlorite. There are a few pseudomorphs of olivine, now replaced by serpentine, and a trace of fresh olivine. Alteration of pyroxene to chlorite, and, to a less extent, to amphibole, is common, and produces a fine dust of opaque minerals in the alteration products. (Fig.14a.).

Most of the felspar occurs as well-formed laths, ranging from 0.3 to 3 mm. in length. The crystals usually show compositional variation from core to margin, rarely in a series of discrete zones, more commonly as a graded change. No oscillatory zoning was found. Rims of felspar more sodic than the rest of the crystal occur on about half of those examined. The rim is separated from the rest of the crystal by a more or less clear change in composition, often so marked as to produce a sharp line under crossed nicols. The rims vary in width from 0.05 to 0.2 mm. wide. Within the zone, the crystal may show either a smooth gradation in composition to the centre, or a poorly defined outer zone around the core.

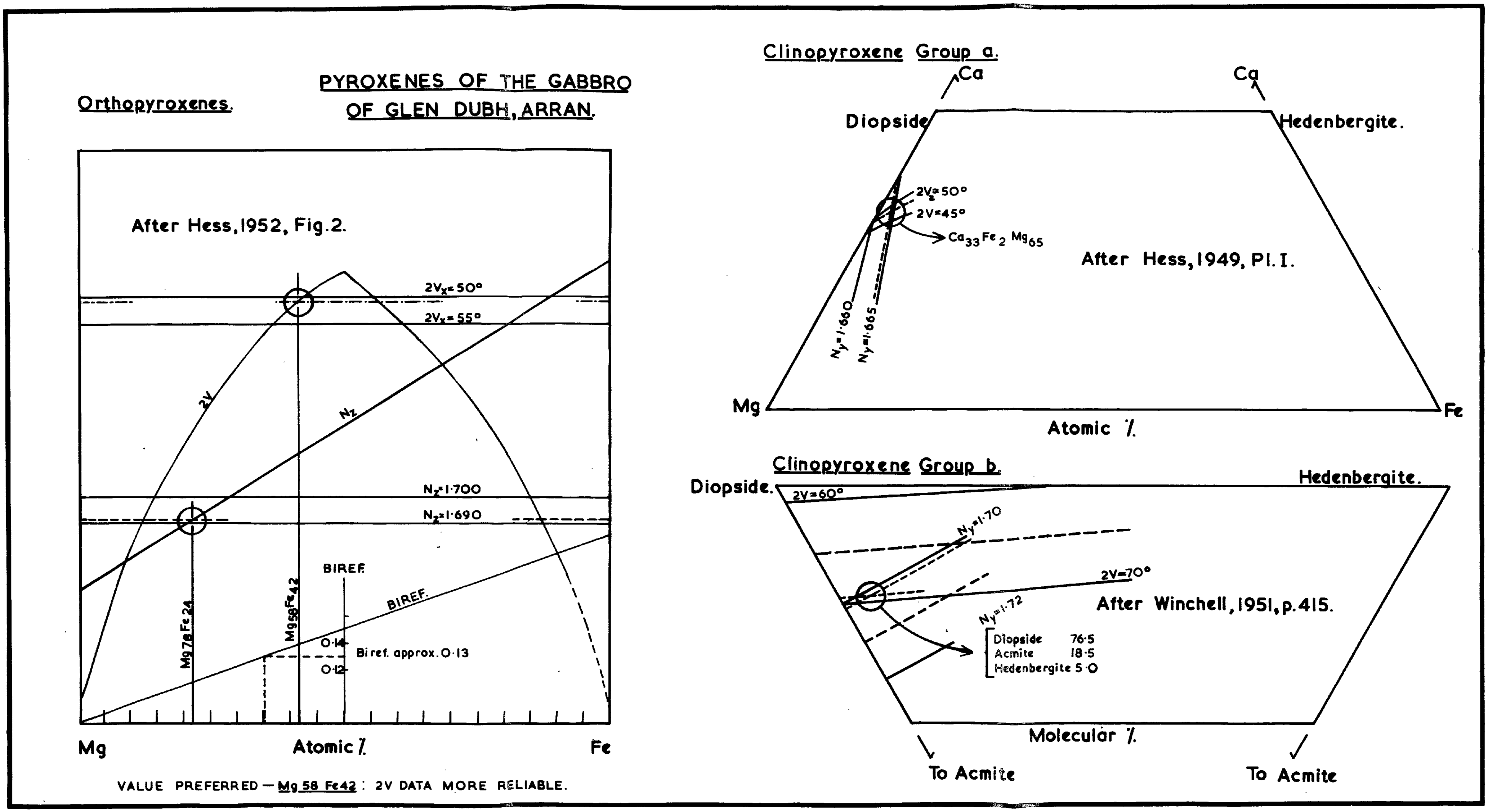

PYROXENES OF THE GABBRO
OF GLEN DUBH, ARRAN.
Orthopyroxenes.
After Hess, 1952, Fig. 2.
2V
$2V_x = 50°$
$2V_x = 55°$
N_z
$N_z = 1.700$
$N_z = 1.690$
BIREF.
BIREF.
0·14
0·12
Biref. approx. 0·13
$Mg_{78}Fe_{24}$
$Mg_{58}Fe_{42}$
Mg
Atomic %
Fe
VALUE PREFERRED — $Mg_{58}Fe_{42}$: 2V DATA MORE RELIABLE.
Clinopyroxene Group a.
Ca
Ca
Diopside
Hedenbergite.
$2V_z = 50°$
$2V = 45°$
$Ca_{33}Fe_2Mg_{65}$
$N_y = 1.660$
$N_y = 1.665$
After Hess, 1949, Pl. I.
Mg
Fe
Atomic %
Clinopyroxene Group b.
Diopside.
Hedenbergite.
$2V = 60°$
$N_y = 1.70$
$2V = 70°$
$N_y = 1.72$
After Winchell, 1951, p. 415.
Diopside 76·5
Acmite 18·5
Hedenbergite 5·0
Molecular %
To Acmite
To Acmite

Figure 13

Material of approximately the composition of the rims is also found as small interstitial crystals, anhedral, and often crowded with small inclusions. It has been included with the rims in the modes. The felspar in this rock is, on the whole, little altered, and, except the interstitial material, free from inclusions. Some crystals are strained, and a few broken, and thin epidote veins occupy the fractures.

The pyroxene of the rock is mostly monoclinic. The orthopyroxene is present in small amount as subhedral crystals, showing crystal outlines against felspar, and not entering the ophitic intergrowths typical of the clinopyroxene. The optical properties are shown in Table 7 and Fig.13. The ortho-pyroxene shows no reaction relationship to either olivine or clinopyroxene in the slide, and is fresh and little altered to chlorite.

The dominant pyroxene of the rock is monoclinic, and there are apparently two varieties, of different optical properties. These are listed in Table 7. The properties have been plotted on the diagrams of Fig.13, to show approximate compositions. The two varieties are not readily separable in thin section, and have similar relationships to the other minerals. The variety of high R.I. and larger $2V_z$ was found in the gabbros and not in dolerites.

Both clinopyroxenes are of a pale brown or brownish-yellow colour, with occasional pleochroism.(x:y:z:: pale brown: pale brown: greenish brown).

The crystals are well formed, enclosing or intergrown with felspar. Sometimes the pyroxene forms a granular aggregate of small crystals with small twinned felspars. In two crystals there are relict cores of olivine, now largely serpentine, and in several more, a core of pyroxene or amphibole of a different orientation to that of the rest of the crystal. These cores show more alteration to chlorite than the bulk of the pyroxene.

Schiller structure is common, parallel to c, and l^r to 010. The rods are not large enough to show reliable extinction angles, and have not been determined; in some cases the inclusions are wholly opaque, and have a brassy lustre in reflected light.

No zoning was seen in the pyroxenes.

Alteration of the clinopyroxene to amphibole is common, especially as rims around the margins of pyroxene crystals, and as interpenetrant growths along the planes of the prismatic cleavage. Both amphibole and pyroxene are often replaced later by a green chlorite, or, less commonly, by a colourless, fibrous amphibole.

Hornblende forms rims around and replacing pyroxene, and occurs as independent sub-hedral crystals, sometimes rimmed by a further discrete amphibole. The pleochroic formulae associated with the two types are:

1) Cores and euhedral crystals; x:y:z:straw:green:brown.
2) Rims and interstices; x:y:z:: Pale-green;green:brown.

A few patches of pale fibrous amphibole are to be found in places, usually associated with chlorite. The amphiboles are, on the whole, little altered, and appear to be stable with chlorite and sericite.

Opaque minerals - magnetite and ilmenite - are the common minor constituents, forming large skeletal crystals. Calcite and epidote are present as small veins and patches in insignificant amounts. No quartz was detected in this specimen, nor was any potash felspar.

The characteristic alteration products are sericite in the plagioclases, and chlorite. The chlorite is pale green and pleochroic, and shows very low birefringence with anomalous blue colours near extinction between crossed nicols. It is biaxial positive, with dispersion red violet. In replacing pyroxene, it forms a pseudomorph with an orientation generally unrelated to that of the original mineral. Pale fibrous amphibole occurs with chlorite at times, especially replacing pyroxene. Serpentine and fine granular magnetite are present as pseudomorphs after olivine. The serpentine is a yellowish, fibrous variety.

2) Crystallisation sequence in the gabbros.

The texture of the rock is hypidiomorphic, varying to sub-ophitic in places. The intergranular material is small in amount, and fairly coarse. The felspars form sub-hedral crystals, except against opaque minerals and some pyroxene. The pyroxene is partly euhedral, and partly intergrown with, and grown around, plagioclase. The probable order of crystallisation interpreted from the texture is:

Falling Temperature ————————————————

Olivine ——————————————————Alters to serpentine——

Ore minerals ——————

Early felspar———————————— late felspar ————

——Pyroxene ————Amphibole —————Chlorite ————

Secondary amphibole, chlorite ————

3) Normal variants of the gabbros.

The gabbro described above (AA173 Fig.14a) is fresh and is chosen as representative of the gabbros of the Inner Part of the Area. The main characteristics of these gabbros are, relicts of olivine, a dominantly pyroxene-plagioclase assemblage, abundant ilmenite, alteration of ferromagnesian minerals to chlorite of the type described above. Thermal metamorphism, towards the granite contact, leads to the appearance of biotite in more than accessory amounts.

This "type" gabbro is to be found, very much as it has been described here, over much of the gabbro outcrop of the Inner Part of the Area, and often in the Outer Part. The varietiesof gabbro found in the area are all close to this type and show individual distinguishing characteristics not associated with their spatial distribution. In any particular locality, it is usually possible to find examples of more than one variety of gabbro, although this is unlikely to be detectable except in thin section, and although from place to place, in the Outer Area especially, there is an uneven distribution of the different variants.

The most evident variation, seen in the gabbro both in hand specimen - as a flecked surface where it is weathered - and in thin section, is the development of interstitial patches of granophyric intergrowth of quartz and felspar. This is seen in specimens AA169 and 170, (Locality J3/077), AA163, (KO/119), AA221, (L8/030), and many others. It is usually found that the olivine in these rocks has been wholly replaced. No rock with interstitial quartz has been found to contain hypersthene. The interstitial granophyre is always associated with the development of rims of sodic felspar, of composition about An20, around the neighbouring plagioclases, often showing a sharp break in the normal compositional grading at the rim. These rims are present in gabbros showing no interstitial granophyre, (e.g. AA173), but are best developed where it is also present, and indeed at times the felspar of the rim grows on in optical continuity as one of the components of the granophyric material. (e.g.AA75).

The textural variation in the gabbros is from a mainly hypidiomorphic structure, to coarsely ophitic. This variation may be entirely at a coarse grain-size, from a gabbro such as AA163, (KO/119), which is coarsely ophitic, to one like AA173 , or the ophitic variant may be of finer grain-size. The latter variation leads to a gradual transition from gabbro into dolerite, as at MO/030, where specimen AA210 shows this change.

Mineralogical variation is rarely significant, except in the presence of the intergranular granophyric patches. The gabbros of the area around G5 often show, even in hand specimen, abundant magnetite and ilmenite (HM.8808, HM.8809). Biotite appears as the contact of the gabbros with the Central Granite of the Complex is approached (AA220, L8/079) but this is more apparent in the diorites.

All of these variations are independent, and any particular rock from any part of the gabbro outcrop may depart from the "type" in more than one way. On all forms of the gabbro, however, may be superimposed a further modification. This is due to the presence, particularly in the Inner Part of the Area, of diffuse veins, stringers and patches of dioritic or granodioritic material, which, locally numerous, have considerably altered some parts of the gabbro. (e.g. around N2/062). These veins are sometimes the diffuse equivalents in the gabbro of discrete felsitic or granophyric veins in the dolerite, their form controlled by the texture, and possibly the igneous history of the host rock, but in other localities, as at K6/084, are confined to the gabbro, and are cut by the discrete granophyre veins common in the adjacent dolerite. The diffuse veins in the gabbro are associated with, and are interpreted as being responsible for, the development of sharp sodic rims on the plaioclases, the conversion of most of the ferro-magnesian minerals to chlorite, and the alteration of the chemical constitution of the rock in such a way that it weathers to a dirty orange colour. (e.g.AA176).

There seems to be no essential difference, except in scale, between the rimming of plagioclases around the patches of interstitial granophyre, as in AA169, and the similar rimming effects found with the granophyre of the diffuse veins, especially in the constancy shown in both the composition of the rims, and to a less extent, in the possibility of the rims growing in optical continuity with the felspar of the granophyric material, apparently of the same composition. (AA75).

A minor feature of the gabbros is the large number of twin-laws exhibited by the glagioclases, all of the common laws being frequently represented except the Carlsbad Law. Albite and acline twins are particularly common. For no apparent reason, the gabbros showing the greatest number and variety of twins in the plagioclases, are those with most interstitial granophyric material.

Specimen AA25 (Fig.14b) has been collected from as near Tyrrell's locality as can be determined from the Arran Memoir account (Tyrrell 1924 p. 174). Tyrrell's analysis is included in Table 8 . The rock of AA25 is closely similar to that of the analysed specimen, (Hunterian Museum No. H.M.8802), except in being considerably fresher. The gabbro is of sub-ophitic texture, of the variety showing minor amounts of interstitial granophyric intergrowth, and with a relict and pseudomorph of olivine. This texture and composition is widespread in the Outer Part of the Area. The The mode and optical data for AA25, and the analysis of Tyrrell's specimen and a calculated norm are in tables 4, 5,8 and 10.

4) Description of the Dolerites.

The dolerites are separated from the gabbros arbitrarily, and probably not at all times consistently, on the basis of average grain-size, and to a certain extent, texture. That is, a "dolerite" as mapped here, is a rock of gabbroic composition and mineralogy, in which the larger crystals are just visible in hand specimen, and which shows an ophitic or sub-ophitic texture. In fact, all of the fine-grained basic rocks of this area, down to those of a very fine grain-size, show ophitic texture to some extent. (See Figs.15a and b).

In the part of Burn A around D2/073, rocks are exposed showing transition from fine-grained gabbro to dolerite. The gabbro, represented by specimens AC105, Ac106, is a medium grained, felsp athic gabbro, of a coarsely ophitic texture, and with sharply rimmed felspars.(Table 5). Closely adjacent, and grading into the above rocks, is a dolerite containing numerous large, clear plates of felspar, (AC1011), with a small patch of a variant composed mainly of these large felspars, with only interstitial ophitic material.(AC102).

(AC102 appears in Tables 4 and 5). All of these gabbros show a gradual transition to a fine-grained ophitic dolerite, (AC107,108), which is essentially similar in mineralogy. Olivine is never seen, a trace of quartz, usually less than 3%, is always found, and the opaque minerals are distributed throughout the rock as a fine dust, and the skeletal ilmenites typical of the coarse gabbros are uncommon.

All the dolerites of both the Inner and Outer areas are of this type, with little variation from place to place. Mod es and felspar data før dolerites from various localities are shown in Tables 4 and 5; the rocks are all similar, and similar, except in the absence of olivine, to the gabbros with little or no interstitial granophyric material. The secondary minerals and alteration products are the same as thos e in the gabbros.

The effect of the veins of microgranite and microdiorite which cut the dolerite of the Inner Part of the Area in many places, is slight. At the margin of the vein, felspars are much rimmed and the ferromagnesian minerals are largely altered to chlorite, but the effect rarely extends more than three inches in to the dolerite, and is usually much less. These discrete veins, when they pass from dolerite into gabbro, become rapidly more diffuse, and the amount of alteration of the gabbro is more marked.

5) Field relations of the dolerite and gabbro.

In places, dolerite appear in the field to be cut by gabbro, (e.g. at NO/064, $AC149_2$), where, near a contact with a microgranite sheet, the gabbro appears to have veined the dolerite. Elsewhere, for instance at MO/030, AA210, a contact which appears sharp in the field, is seen in thin section to be graded, from dolerite, to dolerite with coarse granular patches, to gabbro. There is no sign of metamorphism of the dolerite by the gabbro.

At contacts where late microgranite sheets cut the gabbro or dolerite, the amount of alteration of the basic rocks is less than at the margins of the veins. Over a short distance, the felspars and pyroxenes are affected, and chlorite is formed abundantly at the contact. Along the contact there is often a narrow zone in which derived crystals from the gabbro or dolerite float in granophyre to form a layer of microdiorite. (AC149) (Fig.20).

Where the gabbro or dolerite is intruded against the hornfelsed sandstones of the country rocks, the basic rock is usually chilled to a fine dolerite or basalt. A good exposure of a contact between dolerite and quartzite is exposed at C9/062. The dolerite is represented by AC201. (Fig.15a). This is a fine ophitic dolerite, with fresh pyroxene, and felspars. It contains a small inclusion, rounded, about 2.0mm. dia., of an aggregate of pale diopside epidote and biotite, with intergranular quartz and turbid felspar. Around the inclusion, the laths of the dolerite felspars have flowed. There is no sign of any reaction whatever between inclusion and dolerite. It may represent a xenolith of calcareous sediment.

6) Summary of Principal Features of Gabbros and Dolerites.

The gabbros and dolerites are not discrete types. The mineralogy is similar in both, with dominant pyroxene - plagioclase assemblages. In the least altered members, olivine and hypersthene are found. The usual accessory minerals are ilmenite, magnetite and apatite, and the secondary minerals amphibole, chlorite, sericite and serpentine. Part of the amphibole is probably primary.

The texture is hypidiomorphic or sub-ophitic in the gabbros, strongly ophitic in the dolerites. Near junctions with microgranite or diorite, small interstitial patches of granophyric intergrowth of quartz and alkali felspar are found which weather out on exposed surfaces as white flecks and patches.

The principal differences between the dolerites and the gabbros are found around such patches of granophyre. In the gabbro, zoning of the felspars is common - not as discrete zones, but as a gradual transition from a core of composition about An55 outwards to An 30 near the edge. Here there is a sharp break in the composition variation, and a discrete rim of material of composition An20. This is usual in the gabbros, and rare in the dolerites, where the zoning is often graded from core to margin. Similarly, a phenomenon found only in the gabbros is that around the granophyric patches, the pyroxenes are soda-rich varieties; this is not found in the dolerites.

Wherever the basic rocks come into contact with the sedimentary country rocks, the latter are hornfelsed, and the basic rock shows a fine-grained or chilled margin. No trace of assimilation of sedimentary material in gabbro or dolerite has been seen anywhere in the area.

The late microgranite apophyses of the Central Ring Granite, such as those at N5/064 have little effect on the gabbro apart from slight thermal metamorphism, and are not associated with a diorite suite. These late granite intrusions cut across the vein structures and dioritic patches in the gabbro and dolerites.

c) The Microgranite Intrusions.

1) The description.

The microgranite of the Glen Dubh Area forms a thin, extensive sheet, more or less regular, lying between gabbro and hornfelsed sandstones. (See p. 22-23). The extent of the outcrop is shown in Fig.24, and the structural relations are shown in Fig.27. The microgranite is often difficult to distinguish, in the field, from hornfelsed sandstones, except in the freshexposures of the stream sections.

A typical specimen, (AC217, from KO/052), comes from a sheet of microgranite intruded into dolerite, in the Inner Part of the Area. The chemical analysis and the norm are shown in

Tables 8 and 10, and a photomicrograph in Fig.16a. In hand specimen, the rock is a grey granular aggregate of barely distinguishable quartz and felspar grains, superficially similar to the hornfelsed sandstones. In this section, the rock is seen to contain some 3% of chlorite and opaque minerals, and the rest of the rock to be made up of a variable aggregate of quartz and felspar. From the analysis, Table 8, it is apparent that some of the felspar must be orthoclase, but it has not been identified in the thin section, either optically or by staining. (The staining method used gave excellent results in both microperthite and clear felspar of the Shap Granite.). Quartz forms approximately 35% of the rock.

The texture of the rock is complex. Some 20% shows a fine granophyric intergrowth of quartz and felspar, (Fig.16a), forming optically continuous patches up to 1.5mm. across. The intergrowth is sometimes in optical continuity with the rims of euhedral felspars. The rest of the rock is a granular aggregate of quartz and felspar, in anhedral equigranular crystals, with occasional euhedral or subhedral plagioclase crystals; the latter have compositions about An5-10. The chlorite forms occasional laths and flakes of small size, and, with the opaque material, is confined to the areas of granular texture.

Where the microgranite is in close proximity to diorite or to altered dolerite, the proportion of granophyric material increases, up to 70% of the rock. (e.g. AC 19). This is accompanied by an increase in the amount of chlorite - up to 8% - and is seen in the area around B5/055, in the numerous veins and apophyses of granite. Away from contacts with basic rocks, as at D4/047, AC 221, the texture is almost wholly granular, and in places shows poikilitic enclosure of euhedral plagioclase in quartz. At NO/064, a specimen collected as far from the granite-dolerite contact as possible, (AC208), has a texture almost entirely granular, except for intergrowths around a few rounded, clear, crystals of quartz.

A good contact between micrograntite and hornfelsed sandstone is exposed at F1/098. Fine grey microgranite cuts the dark grey sandstones along an irregular surface, and occasionally veins the hornfels. A slide cut of the contact, (AC 127 Fig.17), shows that the relations of the two are in places complex. In the hornfels, well-formed xenocrysts of felspar, and radial or globular aggregates of quartz and felspar have grown, and are most numerous near to the contact. At the contact, the hornfels is banded parallel to the contact with, on the side away from the microgranite, a dark band of partly glassy, partly micro-crystalline material; against the microgranite is a band of lighter, finely crystalline material with numerous small plagioclase laths similar to the xenocrysts in the hornfels. The material of the band in contact with the microgranite has been sufficiently mobile to 'back-vein' the micrognanite, cutting across and surrounding some of the patches of granophyric texture. This implies that the margin of the hornfels has been partly refused, and has been mobile at a time when the granophyre was sufficiently viscous or solid to be back-veined.

About 200 yards South of the top of Creag na h'Iolaire there is an unusual variant of the microgranites. A specimen (AC 219), shows, in the hand, clear blebs of quartz, in a fine matrix. In thin section, the quartz blebs are seen to be large ovoid crystals up to 5 mm. in diam., corroded and embayed along the margins. Most of the rock is of the poikilitic texture seen in AC 221, but around the quartz blebs, and occasionally elsewhere, there are fine botryoidal growths of fibres of quartz and felspar. While most of the blebs are of one crystal of quartz, some are of several grains.

A contact between microgranite and gabbro at F6/035 has been sectioned. (AA 149, Fig.20). This will be discussed fully later, (p. 85), but it is relevant to note here, that the microgranite shows, towards the contact with the gabbro, a marked increase in the proportion of granophyric material. It will also be noted from the analysis, (Table 2a,1), that the rock is unusually low in alumina. This will be more fully discussed below. (p. 90-91).

Inter-reaction of microgranite with the basic rocks of the area leads to the development of hornblende microgranites, and of a suite of dioritic rocks varying from contaminated microgranite through hornblende diorites to altered gabbro and dolerite. These are discussed in the next section. (pp. 77 - 101).

2) Summary.

The principal characteristics of the microgranites are the small amount of dark minerals, the variable texture - ranging from granular to granophyric, and the presence of potash minerals in a form difficult to detect under the microscope. Near contacts with basic rocks, the micrograniite develops a granophyric texture, and contains more ferromagnesian minerals. At contacts with sedimentary rocks in the Outer Part of the area at least, the micrograniite does not show a chilled margin, but is, in places, back-veined by the hornfelsed sedimentary material.

d) Diorites and Other Hybrid Rocks.

1) Introduction.

The diorites of the Glen Dubh area are confined almost entirely to the Outer area, although veins and patches of dioritic material do occur sporadically in the gabbros of the Inner area. In the following description, for convenience, the term diorite is used to include all the rocks of composition intermediate between the hornblende micrograniite, and the altered gabbros and dolerites.

In the field, it was found possible to separate several types of diorite characterised by their appearance in hand-specimen, and also by their relative positions between microgranite and gabbro. Since these groups have been found to be consistent with the features observed in thin sections of the diorites, the field classification has been used as the basis for the descriptions. In some cases, however, it was not possible in the field to draw boundaries between the types observed, either because of the tortuous outcrop of the junction, where it is nearly parallel to the slope, or because the rocks are often, except in the stream sections, deeply weathered.

2) <u>Field Classification of the Diorites</u>.

In the field it was found that there was a constant relationship to be seen in the rocks lying between the micro-granite and the dolerite, and a similar, but distinct relation-ship in the rocks between microgranite and gabbro. (See p. 23). Between the microgranite (1a) and dolerite there were discriminated the following;

Microgranite with abundant hornblende. (1b)

Fine hornblende diorite, seen to vein other rocks. (2a)

Fine hornblende diorite, with patches and veins, often with relics of ophitic texture. (2b)

Dolerite with net-veins, sometimes patchy, and most altered near veins. (3a)

Dolerite. (3b)

This series was always found in this order, although the relative amounts of the different members varied.

Similarly, between the microgranite and the gabbros, a consistent series was found;

Microgranite. (1a)

Hornblende microgranite, of coarse granophyric texture.(1c)

Coarse diorite, forming veins in other rocks. (2c)

Coarse diorite, patchy, with veins of lighter diorite, and relics of gabbro minerals and texture. (2d)

Altered Gabbro. (4a)

Gabbro. (4b)

The following diagram shows the parallel relationship.

Microgranite					Basic Rock
1a	1b	2a	2b	3a	3b
1a	1c	2c	2d	4a	4b

Since the gabbro in places passes into dolerite, (p.   ) there are, in a few places, exposures of diorite intermediate between those placed in the above series, and since the variation is virtually continuous from microgranite to basic rock, there are necessarily rocks which are not readily allocated to the groups chosen. These groups, however, form units which can be reasonably easily discriminated both in the field and in thin section.

3) <u>Description of the Diorites</u>.

Fine hornblende diorite, seen to form veins. (2a).

These diorites are found next to the junction with micro-granite and show all gradations from microgranite of dominantly granophyric texture with abundant hornblende laths and chlorite to a hornblende diorite with a colour index of 35. Granophyric intergrowths of alkali felspar and quartz form the bulk of the leucocratic portion - some 40% - 15% of the rock. The rest of the felspar is in subhedral laths, little zoned, and often much altered to sericite. In a few instances, albite twins were found in these felspars. The compositions were determined for plagioclases in two specimens, (AA 78 and AC 87) and are shown in Table 6. Some laths of plagioclase extend fringes into the granophyric intergrowth.

The ferromagnesian minerals are long subhedral laths of green hornblende, (much altered to chlorite), irregular patches of chlorite, and abundant patches of opaque dust and small crystals of magnetite, haamatite and ilmenite. The mode of a diorite of this group, (AA 197), is shown in the following Table.

Table 3.

Quartz	20.4%	Biotite	0.4%
Felspar	48.2%	Apatite	1.7%
Amphibole	Tr.	Opaque	2.1%
Chlorite	27.2%	Total	100.0%

(The granophyric part of this rock is sufficiently coarse to allow the quartz and felspar to be discriminated readily.) Fig.18a, is a photomicrograph of a diorite of this group (AC 70), a rock from the more basic end of the series, with only about 15% of granophyric material. The specimen was taken from an exposure where this diorite was seen to vein altered dolerite.

Similar diorites, all occurring in the same structural context have been collected at the following localities;

B6/055 - AC20 D6/067 - AC62 E2/057 - AC68, AC71

E2/080 - AC110x D8/049 - AC204.

Towards the junction with the patchy hornblende diorite with veins, the diorite becomes patchy and more basic. Xenoliths of altered dolerite are common, with rarely, some of sedimentary hornfels. Fig.18a shows a typical diorite of this group, AC70, from E2/057, with sub-ophitic texture and an inclusion of fine dolerite. The felspars are little zoned, but show a rim of sodic plagioclase. The approximate compositions are An30 and An17 for core and rim respectively. The rims of the plagioclases are enclosed by the poikilitic hornblendes.

The hornblende in AC70 shows, in a few cases, cores of pyroxene.

A similar rock, (AA17) provided two determinable felspars. In both cases there was a prominent rim, of composition An20, and little zoning within, the cores being about An46.

Fine hornblende diorite, cut by veins. (2b)

The diorites of this type are found adjacent to, above, and showing a passage to, the altered and net-veined dolerites. They are typically patchy, and are cut by veins of more acid diorite. A specimen is shown in Fig.18b. (AC103, from D0/070).

In hand specimen, this rock resembles a dolerite, except for a lighter colour, and a greenish appearance on broken surfaces. It has the typical ophitic texture of the dolerites of this area. There are, however, numerous patches of interstitial quartz-felspar intergrowth, amounting to about 8% of the rock. The felspars are occasionally strongly rimmed, (see Table 6), and the outer, most sodic parts of the rim are interrupted by adjacent pyroxene crystals. The sodic felspar is found only as rims or interstitially - it does not form lobes or embayments in the earlier felspar, nor is there any sign of perthitic structure.

The pyroxene of the rock is now largely altered to hornblende and chlorite, and hornblende encloses pyroxene cores. Opaque minerals and apatite are common accessories. The hornblendes do not show good crystal forms; this is in contrast to the subhedral forms seen in the more acid diorites.

The diorite exposed in the beds of the lower streams in Glen Dubh grades into dolerite, by gradual increase in colour index, and increase in the number of darker patches of less acidic material.

Dolerite with net-veins.

The dolerite near to the junction with the diorites is often cut by a reticulate set of veins of fine hornblende diorite of the type described above. (p.79)(Figs.6a,b). In the dolerite adjacent to the veins, there are small patches of intergrown quartz and alkali felspar, and the ferro-magnesian minerals are altered to chlorite. The veins are more discrete than those in the diorite, and have displaced the blocks of dolerite between the veins laterally, by small amounts.

These net-veins show no sign of the clastic structures seen in the veins associated with the felsite intrusions (See p. 105) and are all of hornblende diorite or of hornblende microgranite.

Hornblende microgranite, of coarse granophyric texture.(1c)

Wherethere are contacts between gabbro and microgranite, there is a series of diorites analogous to those described above. They are well exposed in the area of steep slabs around FO/084, and in the Glen Dubh Water.

The microgranite passes, towards the gabbro, into a hornblende microgranite of coarse granophyric texture. (The 'coarse' texture is relative to that seen in the fine diorites - it is just visible with the naked eye). The rock is readily recognised in hand specimen by the presence of numerous needles of green hornblende, from 3 mm. to 50 mm. in length. The needles are often grouped in clusters or sheaves, or may show a parallel orientation.

In thin section, the needles are found to be of green chlorite replacing hornblende. The bulk of the rock - some 70% - is a complex aggregate of granophyric intergrowths of quartz and alkali felspar. This is shown in Fig.19b.(AC122, from E4/087). In this rock, there are a few very much altered laths of felspar from which fringes extend into the adjacent granophyre. Apart from the hornblende - chlorite needles, the only dark minerals are a few grains of magnetite, and a few flakes of biotite. Optical data for albite twins in specimen AA105 are given in Table 6.

Other similar diorites show occasional relics of pyroxene cores in hornblende. The hornblende shows its proper crystal outlines.

Coarse, patchy hornblende diorite, with veins. (2d)

This diorite is found in contact with gabbro at the junction of gabbro with diorite. Away from the gabbro, it grades into the hornblende microgranite described in the preceding section. The patchy diorite is variable in the field, but has a characteristic 'flecked' appearance due to the weathering out of large felspars. The dark minerals are usually notably green on a weathered surface.

In thin section, as in AC117, (from F5/086, Fig.19a), the texture is seen to be similar to that of the gabbros. The rock is made up of, dominantly, felspar, (60%), and pyroxene, (25%). Interstitially, there are numerous small patchesof granophyric intergrowth of quartz and felspar, the latter sometimes forming optically continuous fringes to the subhedral felspars. The granophyric material amounts to about 10% of the slide. The rest of the rock is made up of magnetite and ilmenite, in skeletal crystals, and as opaque dust, irregular flekes of chlorite, and rare traces of serpentinised olivine.

The pyroxenes are altered marginally to hornblende, especially near patchesof granophyre, and are pseudomorphed by the hornblende. Sodic rims on the plagioclases are interrupted by adjacent pyroxenes.

To the East, at F3/086, the diorite (AC116) shows interstitial granophyric material amounting to about 20% of the area of the slide. Both this rock and AC117 contain numerous zoned and twinned plagioclases, and compositions for several crystals are shown in Table 6. The plagioclases of this group of diorites show an unusual variety of twin laws, including pericline, acline, and possibly manebach laws.

4) Gabbro-Microgranite Contact at F6/035.

Description.

A specimen, AA 149, was collected showing the transition from microgranite to gabbro on a small scale. It is shown in Fig.20. The portion of the rock shown in the photograph was sectioned parallel to the flat surface shown, and chemical analyses were made of the areas indicated on the photograph. The analyses are shown in Tables 11 and 12, the calculated norms in Table 13, and two diagrams showing the compositional variation across the specimen in Fig.21. The parts chosen for analysis were intended to separate the areas of rock of visibly different texture.

The zones discriminated in the photograph (Fig.20) (photograph at actual size) are borne out in thin section, and from 1 to 4 show a gradually progressive change in texture and mineralogy. Zone 1, (Anal.AA149b 1), is a typical microgranite with about 70% of its area a complex aggregate of granophyric intergrowths of alkali felspar and quartz. Euhedral felspars aremuch altered to sericite, and are fringed by granophyre growths. Chlorite after hornblende needles, and as irregular flakes, amounts to above 4% of the area, and there are a few crystals of magnetite. Zone 2, (Anal. AA149b 2), is similar, with a change in proportion of the minerals present. Euhedral felspars form 40% of the area, and granophyre about 35%, while chlorite, (with now traces of hornblende cores in the laths), and opaque material have increased. The opaque minerals form a fine interstitial dust.

At the margin of Zone 3, a sharp change takes place in texture. The rock is now an open network of felspar laths, with hornblende as poikilitic crystals rather than as laths and needles, while the granophyric material, about 15% of the rock, is entirely interstitial. A few long laths of plagioclase appear to have grown out freely into the material of zone two, and form cores for granophyric intergrowths. All of the felspars of Zone three are markedly zoned, with an even gradation in composition for most of the change, then a break, and an abrupt change at the outer margin, to show a discrete rim of alkali felspar. This break does not occur in those


1
2
3
4.
5.
6.

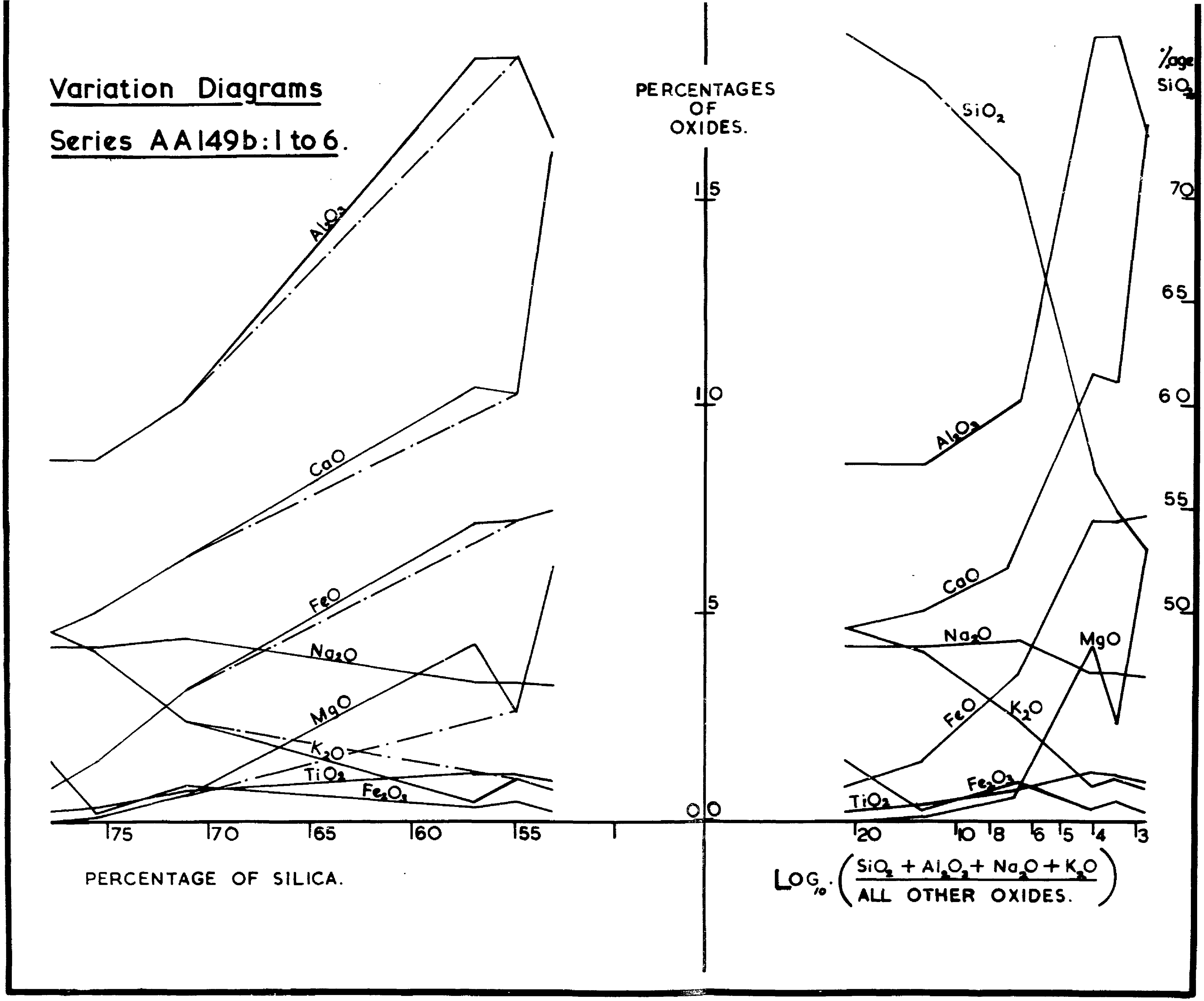
Figure 20.

Specimen AA 149b, actual size, showing the areas selected for chemical analysis. The numbers correspond to the numbersof the analyses.

Locality F6/035.

Variation Diagrams

Series AA149b: 1 to 6.



plagioclases which extend into Zone two. The ferromagnesian minerals of zone 3 are hornblende, much altered to chlorite, as laths and poikilitic plates, and subordinate magnetite, as skeletal and subhedral crystals. The texture of the plagioclase laths, and their parallel platy growth at the margin of Zones two and three, is interpreted as indicating that they have grown from a relatively solid base of Zone four, into relatively mobile material in zone two.

There is a sharp transition from Zone three to Zone four marked by a change to the sub-ophitic texture typical of the medium-grained gabbros. Intergranular granophyric material constitutes only some 3% of the area of the zone, and only close to the patches of intergrowth is there notable rimming of the plagioclases, although graded zoning is common. Hornblende (after pyroxene, with relict cores of fresh pyroxene), is the common ferromagnesian mineral, forming poikilitic plates and anhedral interstitial crystals. Ilmenite and magnetite occur as subhedral and skeletal crystals, and apatite is a subordinate accessory. In the slide, although this is not shown at the level of the photograph, Zone four grades into Zone six by increase in the amount of hornblende at the expense of felspar, and reduction of the amount of granophyric material to accessory proportions. Zone six is gabbro, though significantly more altered than, for example, AA 173, the analysed specimen. The pyroxene is largely altered to hornblende and chlorite, and the felspars are not wholly fresh, even in the least altered parts of the zone.

Zone five represents one of the diffuse pale patches common in the gabbro near the margin of the diorite. It is similar in mineral composition to Zone three, with a greater proportion of dark minerals, but lacks any sort of directional texture. The material of Zone five grades imperceptibly into that of the adjacent zones four and six.

Chemical Analyses of specimen AA149.

In Fig.21 the compositions of samples from these six zones have been plotted to show the way in which the relative proportions of the constituents vary. In the left-hand diagram, the percentages of the various oxides, recalculated water-free, have been plotted against the silica percentage. In the right hand diagram, the same oxide percentages and also that of silica, have been plotted against the logarithm to the base 10 of the ratio of felsic to mafic oxides. The log. base is used to plot the ordinates, since the two values whose ratio is plotted are already inversely related by the function $y = 100 - x$, and if plotted on a linear base, would be poorly separated on the horizontal axis. The diagram therefore shows, directly, only the way in which the proportion of silica varies relative to the other oxides.

Discussion of the analytical results.

On the left-hand diagram, the curves show a fairly even "straight-line" trend from No.1 to No.6, except where it is interrupted by either No.4 or No.5. For the reasons shown above, No.5 is regarded aslying outside the normal series of hybrids, forming a patch within the gabbro, and not occurring in the graded transition seen in the thin section. The dotted lines have therefore been drawn to show the variation trends when No.5 is omitted. Then the curves, except between No.4 and No.6 show the type of variation to be expected in a series of hybrids formed by addition of one end member of the series to the other with simple mixing, and no subsequent differentiation, or development of "fronts" of metasomatic origin. The disconformity between No.4 and 6, in the sharp increase in calcium and magnesium oxides and corresponding fall in alumina, is probably due to the effect of choosing No.6 as the 'apparently most basic part of the gabbro end', and so inadvertently selecting a part where there was a local segregation of pyroxenes. Such local variation in the proportions of felspar and pyroxene is common in the coarser gabbros, and the sample was necessarily so small that it could be, to some extent, non-representative. The high proportion of dippside appearing in the norm (Table 13) bears out this argument. No.5 then appears to be a local patch comparable to with Nos. 4 and 6, but with appreciably augmented quartz and correspondingly depleted diopside (normative); it is interpreted as being the result of the introduction of granophyric material at a late stage, when the gabbro was too cold to react readily, forming a "diffuse vein" in the gabbro.

Discussion of apparent anomaliesin the 'Norms' of the rocks analysed.

The "norms", (Table 13), recalculated from the analyses on the C.I.P.W. System, after Johanssen, (1931), demonstrate an unusual feature in the chemical composition of the acid members of the series. This is that both acmite and sodium metasilicate appear in the norms of Nos. 1 and 2, in small amounts. Acmite also appears in the norm of the Northern Granite. (Table 1c). However, both the granophyre AC217, and the gabbro, AA173, from the Glen Dubh area, which have been analysed, show fairly high alumina contents - 11.96 and 19.8 respectively - which are comparable with the analyses from other parts of Arran and with Daly's averages given in Table 8. The proposed explanation of this anomaly is that the granophyre of AA149 has absorbed a small amount of felspathic sandstone from the country rocks. The first minerals to be absorbed would be quartz, orthoclase and albite leading to enrichment of the microgranite in silica and soda potash and alumina. However, it is unlikely that the felspar in the sediment would be pure albite, and as soon as any anorthite was taken up, the crystallisation history of the melt would be affected. To provide the latent heat necessary to melt the xenolithic material, crystallisation of the phases in which the melt is saturated must take place, (Bowen, 1928, p.191), - in this case, an intermediate plagioclase, and hornblende.

While no phases which would not originally have crystallised from the melt will appear, (Bowen ibid. p.191), the amount of eutectic material will be markedly increased. This would explain the high proportion of granophyric material seen in the rock. At the same time, the abundant alkalis and silica present would facilitate the conversion of the pyroxene in the melt to amphibole - and, in a rock with much soda available, to a sodium bearing hornblende. In other words, the appearance of acmite and sodium metasilicate in the norm in small quantity does not necessitate any corresponding appearance of these minerals in the rock, since the calculation of the norm takes no account of the possibility of the entry of Na_2O molecules into ferro-magnesian silicate lattices.

While, however, absorption of a small amount of quartzo-felspathic sedimentary material is adequate to explain the rather high proportions of alkalis and silica in the analyses, and the abundant granophyric intergrowth of eutectic material noted in the sections, it cannot explain the small percentages of alumina molecule. No reasonably probable explanation can be offered for the low percentage of alumina in the analyses Nos.1 and 2, except that a minor addition of silica, for example, would disproportionately depress the relative proportion of alumina. This might be sufficient to explain the amount of some 3% by which the alumina percentage is below normal for the region.

5) Relation of Diorites to Sedimentary Rocks.

Contacts between diorite and sedimentary rocks are rarely exposed, and in only one locality has it been possible to demonstrate the junction of diorite with hornfelsed sandstones with any certainty. This is in Burn B, at C8/062, and is discussed below.

It has been consistently found, however, that near contacts between diorite and sandstone, there are numerous fragments of basalt or microdolerite as xenoliths in the diorite. The more fine-grained the xenolith, other things being equal, the less it is altered by the diorite. These basalt xenoliths are interpreted as being fragments of the chilled margin of the dolerite against the country rocks, left unaltered when the coarser doleritic material has been made over into diorite of 2b types. At C9/061, where is an exposure of dolerite chilled against hornfelsed sandstone. As the dolerite (AC201), is traced away from the contact, it becomes coarser and passes imperceptible with increasing grain-size, into diorite of Group 2b.

The structural position of the diorites, between micro-granite and gabbro ar dolerite necessarily implies a limited possibility of contact with the country rocks, and it is only where there are xenoliths of hornfels of a fair size that the relationship can be studied. Such conditions do in fact occur, as noted above, at C8/062, in the bed of Burn B.

Here diorite of Group 2b' enclosed blocks and fragments of hornfelsed felspathic sandstone, and of altered dolerite. Specimens AC 145, 146 and 147 were collected at this locality and have been sectioned to show the contacts between xenoliths and diorite. In all cases, the hornfels fragments show little effect of the magma; traces of granophyric material are common in the more gritty xenoliths, and all of the smaller xenoliths are recrystallised. At the margin of a few of the xenoliths, the diorite can be seen to have broken up the edge of the hornfels, and the crystals are disseminated in the adjacent diorite. In no case is the effect on more than a very minor scale. The xenoliths containing shaly fragments, when very small, may be almost completely assimilated, and then the siltstone fragments retain their integrity to the last stages, and are recognisable in the diorite after the rest of the xenolith has completely gone. Similar reactions in small xenoliths have been noted in small xenoliths at E5/076.(AA34b).

At the contact with the hornfelsed sediments at C9/062, the dolerite is chilled to a fine micro-ophitic basalt. No reaction with the sediment is seen, and there is no sign of assimilation of sedimentary material by the dolerite. This is generally true of the whole area, for both dolerite and gabbro. <u>In no case is either observed to assimilate sedimentary material</u>.

Tyrrell states, 1928, p.175; "Furthermore, on its eastern margin, the gabbro has been modified by the incorporation of Old Red Sandstone material, for the most part a fine-grained felspathic sandstone, producing results approximately similar in kind and degree to admixture with granite. The Survey material, however, is insufficient for the complete petrographic demonstration of these views, which are based on the study of the collection of the Geological Department of the University of Glasgow". The writer has examined the slides of this collection, now in the Hunterian Museum, including a slide of the analysed specimen of the Glen Dubh Gabbro, and has found no example of gabbro assimilating sediments, although there are several examples of a hybrid diorite doing so to a small extent. Wherever contacts between uncontaminated dolerite or gabbro and sediment have been found, there has been chilling of the basic rock against sediment, and in no case has an isolated fragment of quartzite been found in gabbro surrounded by an aureole of diorite or altered gabbro.

b) General discussion and interpretation of the diorites.

The principal features of the diorites, on which interpretation must be based, are the consistency of the arrangement and distribution of the diorite suite over the area of Glen Dubh, the constant association of particular types of diorite with dolerite and others with gabbro, and the systematic mineralogical and textural variations detailed in the foregoing sections. The previous hypothesis put forward by Tyrrell(1928) has been discarded on the grounds of new field evidence, and the assimilation of sedimentary material which he regarded as being of major significance is now regarded as a cause of minor variation in the fine diorites.

The diorites are a suite interposed between microgranite and dolerite and gabbro, and are not found except in this position. Microgranite does not cut gabbro in the Outer Part of the area except in the presence of a diorite group, and where micrognanite cuts country rocks (sediments) in the absence of basic rocks, there are no diorites. This means that the diorites are genetically related to the presence of a micro-granite/basic rock contact, and, since the diorites associated with gabbro are readily and consistently separable from those associated with dolerite, the formation of diorite must have taken place at or near the place where it is now found. This precludes the possibility that the diorites were intruded as a discrete intrusion, having been formed elsewhere, or even that they have been, on more than a small scale, mobile.

The differences between the diorites associated with the gabbro and those associated with the micrognanite are mainly textural. In the former case, the diorites and accompanying hornblende micrognanite are relatively coarse-grained, and the more basic diorites have the texture of the gabbros. In the latter, the diorites are fine-grained, and show, in part, ophitic texture. In both cases there is a marked division between those diorites which are seen to form cross-cutting veins in more basic rock, and those which are veined by more acid diorite. The former grade into micro-granite, and contain hornblende crystals showing their proper crystal form. These are interpreted as having crystallised from a magma, at least partially fluid, of dioritic composition. Then the hornblendes have grown freely in liquid conditions. This is seen in both hornblende and plagioclase in Zones 2 and 3 of specimen AA 149, p. 85. The plagioclase of these diorites is unzoned, or little zoned, and not often rimmed.

The other group of diorites, those showing textures comparable with the textures of the adjacent gabbro or dolerite, and which are cut in places by veins of more acid material, show, in contrast, hornblende replacing and pseudomorphing pyroxene , and zoned felspars with sharp rims. This means that pyroxene has been the primary precipitate, rather than hornblende, and that the formation of hornblende is subsequent. The group is also associated with proximity to the micro-granite junction. The preservation of the texture of the basic rock in contact with the diorite is interpreted as evidence that these diorites have been formed 'in situ' by the alteration of the dolerite of gabbro by a process essentially of diffusion of material over a range of up to 10 feet, from the microgranite into the earlier basic rock. The freedom of diffusion is attributed to the gabbros being still hot, though solid, at the time.

That the microgranite was intruded as a melt is clear from the occurrence of veins of microgranite in country rocks at numerous places. It is rarely chilled against the country rocks, (see Fig.17), and this is evidence that the country rocks were not, in fact, necessarily cold at the time of intrusion of the microgranite. The gabbro also shows the effect noted above, that the felspars show a consistent break in the gradation in composition and a discrete rim of more sodic felspar. Also, pyroxenes near to granophyre patches in the gabbro have soda-rich compositions. This is interpreted as evidence that the gabbro was not completely solid at the time of intrusion of the microgranite, and that the material diffusing from the microgranite into the still hot gabbro - it was precipitating plagioclase of composition An30 at the time - altered the crystallisation sequence by addition of more acid material, producing discrete rims on the felspars, and introducing soda molecules into the pyroxenes. The process must have been essentially one of diffusion, since the texture of the gabbro is undisturbed.

The dolerite, on the other hand, which is a marginal phase of the gabbro, was virtually solid at the time of intrusion of the microgranite, and the felspars had had time to complete their zoning down to An20; there are few sharp rims. Also, the solid dolerite was able to fracture in a brittle manner to allow penetration by angular net-veins, and to form sharp, coherent xenoliths. The range of diffusion in the dolerite rarely exceeds 3 feet.

The diorites therefore, fall into two main groups. Those of intrusive character have formed by contamination of the original melt of microgranite with material derived from dolerite or gabbro, have been able to assimilate limited amounts of sedimentary material, (p. 93), and differ only in the type of material, fine or coarse, derived from the gabbro. Those diorites which are cut by veins are formed by alteration of dolerite or gabbro essentially in situ, andhave inherited the textures of the rock from which they were formed.

At the time of intrusion of the microgranite, the gabbro was not completely solidified, although the dolerite had completed crystallisation. It seems likely that the development of the extensive suite of diorites seen in the Glen Dubh Area is due to the combination of several chance factors - the intrusion of microgranite shortly after that of gabbro and dolerite, the position of the microgranite along the contact between the basic rocks and the hornfelsed country rocks, and conditions of low mobility in the ensuing hybrid material preserving the original relations of the diorites.

There are a few minor points of supporting evidence for this explanation seen in the texture and mineralogy of some of the diorites, although the interpretation of this material is not wholly certain. In the fine diorites which show intrusive behaviour, the poikilitic amphiboles enclose the sodic margins of the plagioclases, (p. 81), whereas in the fine diorites showing veins of more acid material, the sodic rims are interrupted by the presence of amphibole crystals. This is taken to mean that the amphibole of the intrusive diorites completed its crystallisation after the formation of the sodic margins of the felspars, while in the other group, the amphibole (which is replacing pyroxene) preceded the sodic felspar. The poikilitic texture of some parts of the intrusive fine diorite is therefore not ophitic, since the amphibole is primary, not after pyroxene.

The texture seen at the margins of zones 2 and 3 in specimen AA 149, (Fig.20), is interpreted asbeing the consequence of relatively free growth of plagioclase crystals from the solid material of zone 4 into fluid material of zone 2. This provides a case in the coarse diorites parallel to that made out for the fine diorites above.

The diorite suite is thus interpreted as being formed by the interaction of an intrusive microgranite sheet on an earlier, but still warm, body of dolerite and gabbro. The suite of diorites is essentially of two parts - those diorite s resulting from contamination, from slight to extreme, of microgranite, and those formed by alteration 'in situ' of the dolerite and gabbro. Assimilation of sedimentary material, and separate intrusion of diorite are of very minor importance.

e) Felsites and tuffs

The felsites and tuffs of the Glen Dubh Area appear to be closely associated, and it is convenient to discuss them together. The first part of this account is concerned with the main body of felsite lying West of the Glen Dubh Fault, and the explosion-breccias of the same region. The minor intrusions of felsite are discussed on p. 112 .

1) The Main Felsite Body.

The general distribution and outcrop of this intrusion have been described above. (p. 35). It is not certain that the inference that the form of the body is a sill is correct, but this interpretation has been accepted in the following discussion.

Good exposures of the felsite are rare, except in the stream sections, and over most of the outcrop, the felsite is reduced to a gritty yellow clay at the surface. There are good exposures of the top of the mainfelsite body at G3/086, G8/098, J2/067, and J7/084, and in Burn A. When fresh, the felsite is pale blue in colour with visible crystals of clear quartz in a pale aphanitic ground mass. The yellow colour appears rapidly on weathering of a fresh specimen, one such exposure in the stream bed at G4/093 turning yellow, superficially, within a week. In thin section, the felsite (AA153, from H7/065, Fig.22) is seen to be much brecciated; this is the condition of the felsite all over the outcrop of the main body.

Unbrecciated felsite is to be found in the dyke near the main body, at H2/048. (AA91, Fig.16b). This dyke is of pale blue or grey felsite, with small phenocrysts of quartz visible in hand specimen. In thin section, phenocrysts are seen to make up about 5-10% of the rock, the proportion varying from place to place. The phenocrysts are dominantly quartz, crystals 0.2 to 0.8mm. in diam., clear and free from inclusions, but considerably rounded and embayed. Around the quartzes, in many cases is a narrow fringe of very fine-grained, felsite and

Figure 22.

Photomicrograph. x15. Crossed nicols.

Specimen AA 153. Brecciated felsite, from H7/065.

calcite crystals in the adjoining matrix. Greatly altered felspars form about one-fifth of the phenocrysts. The alteration is to sericite and calcite, and the calcite from the matrix appears to be growing in optical continuity with calcite replacing felspar. The composition of the plagioclas e felspars is between An5 and An10. There are a very few exampls of phenocrysts which are pseudomorphs in chlorite and calcite of small (less than 0.2mm.) pyroxenes, and also a few euhedral crystals of ilmenite, (now largely leucoxene), of about the same size.

The matrix is fine-grained, and interlocking granular in texture. The average grain-size is about 0.003mm. or less. The minerals appear to be dominantly quartz, felspar, calcite and sericite, with subordinate amounts of chlorite and opaque dust. In places, areas of the matrix 0.1mm. in diam. show simultaneous extinction of the intergranular material. Banding is seen in the matrix, both around phenocrysts and elsewhere, apparent mainly in the irregular distribution of the chlorite. It is possible that some of the chlorite may be extraneous, since the wall rocks of the dyke are of a finely comminuted gabbroic gouge, now largely composed of this mineral.

In so far as the felsite of the main body contains fresh unbroken material, it is ofthis type. Because of this, and because of the structural proximity of the two masses of felsite, the dyke is regarded as a feeder dyke to the main body.

The size and number of quartz phenocrysts are variable both tending to increase to the North-east along the outcrop, and the degree of alteration of felspars and matrix changes with the freshness of the specimen.

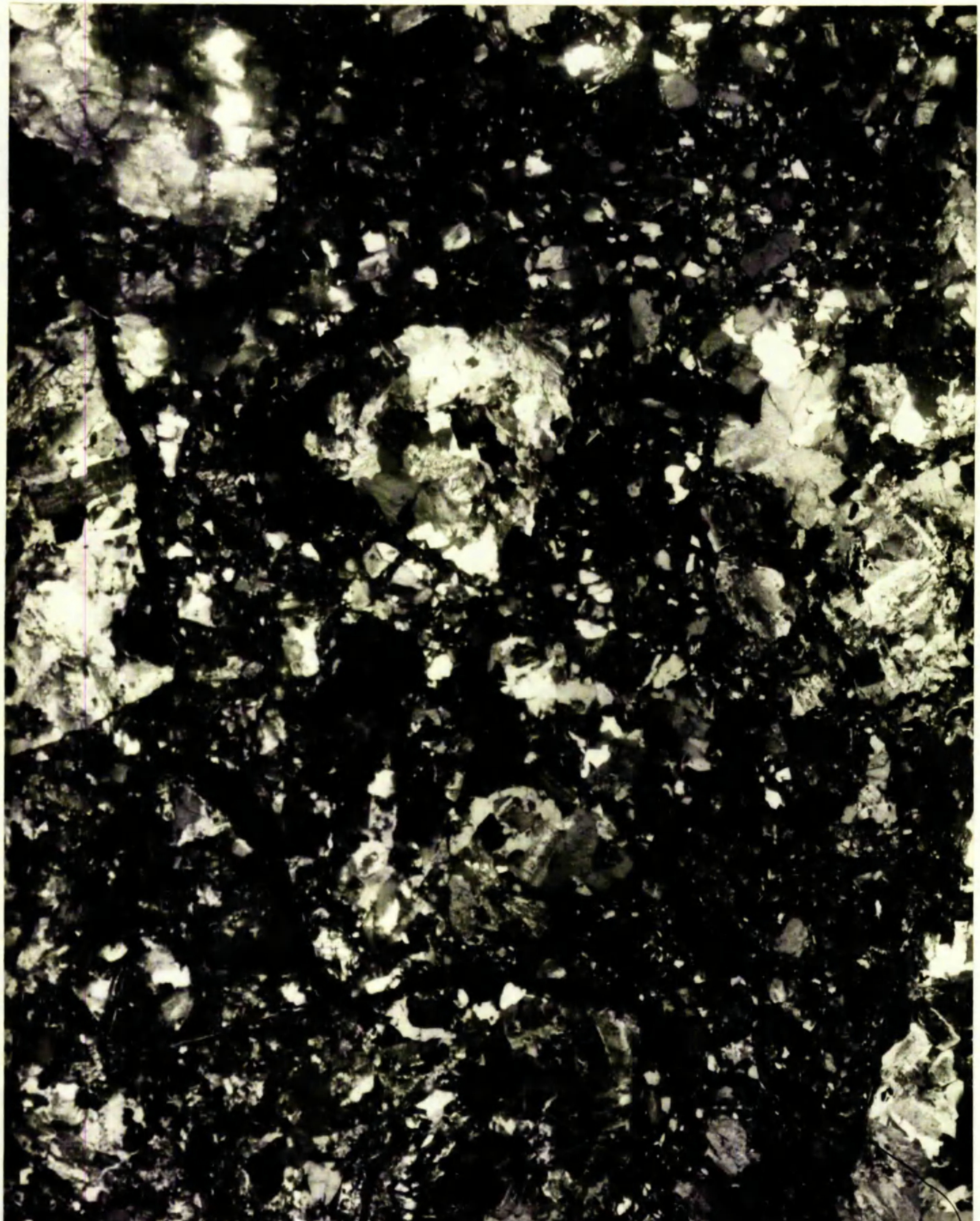
The specimen from H7/065, AA153 (Fig.22), is probably typical of the main body of felsite. About 60% of the rock is made up of material similar to that described above, in a disturbed, though recognisable condition. The quartz and felspar phenocrysts are much broken and strained, and the felspars altered. The matrix material is very similar, but now includes many fine fragmentsof quartz, and shows marked banding. A felspar showing recognisable albite twins was of composition about An8.

The rest of the rock is made up of granophyric growths. These occur both as independent pieces, showing fracturing and straining, and also as undisturbed growths, often in optical continuity with quartz and felspar in the groundmass. From place to place in the rock there are zones of particularly intense comminution, which form a network around the less severely brecciated parts.

So far as can be determined, the greater part of the main felsite body is of such material, a brecciated mass of felsite and subordinate granophyre in which crystallisation of the granophyric part has not ceased until after the episode of cataclasis.

2) Tuffs and breccias associated with the felsite.

At the contact with the overlying dolerites, the felsite



<u>Figure 23</u>.

Photomicrograph. x15. Crossed nicols.

Specimen AC 139. Breccia from H8/100. (Vent breccia).

The photograph shows fragments of dolerite in a finely comminuted breccia of dolerite and felsite.

veins the adjacent rock. However, these are not normal igneous veins, but are of breccia material similar to that found in the main part of the felsite. This is seen in specimen AC136 (H2/100) a dolerite of marked ophitic texture, with a sporadic development of radial aggregation of the felspars. This rock is cut by one of the veins - light coloured in hand specimen, and conspicuous against the dark compact dolerite(Fig.18b). The vein transgresses the internal structures of the dolerite. The material in the vein is about one half derived from the walls of the vein and the rest of material similar to the more comminuted portion of the felsite of AA153. The wall of the vein is sharp, and cuts across the ophitic growths along an almost straight line, and is lined, in places, with a fine growth of variolitic granophyre. This is exceptional. Usually the breccia material extends to the edge of the vein.

At the margin of the areas of breccia and tuff shown on the map, the amount of veining and brecciation has increased to such an extent that the greater part of the rock is of breccia the composition depending on the amount of dolerite incorporated. There is thus no sharp margin to the breccias; the boundary drawn is between a rock such as a dolerite, with occasional veins, and a rock where the veins are so numerous as to have reduced the bulk of it to fine breccia (Fig.8a). The areas of breccia shown on the map are regarded as small vents.

At H8/100, on the crest of the hill, the breccia is well developed in a fine-grained variety. (AC139). Here the rock is visibly an aggregate in hand specimen and in thin section the brecciation is marked. The specimen AC139(Fig23) shows an uneven breccia made up partly of sub-angular fragments 0.5 to 2.0 mm. diam. of coarse dolerite, (about half of the rock), and the rest a fine angular micro-breccia of quartz and felspar fragments in a matrix of chlorite, calcite and granophyric intergrowths of quartz and felspar. The granophyre has again, in part, crystallised after the deformation of the matrix, and encloses patches of the matrix. The calcite appears to have grown, to a large extent, as a primary mineral in the matrix, forming large, intergranular, but optically continuous crystals. The matrix stains yellow on treatment with sodium cobalti-nitrate after etching; this is taken to be due to the introduction of potassium minerals.

A few yards away to the South, the rock is wholly composed of micro-breccia, with no larger rock fragments, while at J2/085, a variety derived from gabbro shows a texture, with gabbro fragments analogous to that of AC139. A variety rich in magnetite grains in the fine breccia is to be found at H8/084 (AC143).

The rocks of the area of breccias to the South, K8/035, are in all respects similar except that the condition of complete reduction to breccia is not found. Away from this vent, the veins die out rapidly in the surrounding rocks, and the margins are less well defined than in the northern vent.

3) Interpretation of the relationship of the Felsites and Breccias.

A consistent interpretation of the phenomena recorded in the area of the felsites and breccias must take into account the following observations.

1) The felsiteis found in an unbrecciated condition, only in the dyke, or probably, feeder dyke.

2) The main body of felsite is made up of the same material as the dyke, in a stage of fine brecciation, and is observed to pass into the wall rocks of the felsite as veins of felsitebreccia.

3) Above the felsite body, veins composed of a mixture of wall rock and felsitic material run in, and break up, the dolerite and gabbro.

4) Areas of breccia and tuff, interpreted as vents of some form, lie above the felsite sheet, and the breccia is formed by the proliferation of veins such as those of 3.

5) The granophyric material in the veins and in the felsite of the main body has crystallised in part after the brecciation.

6) In the veins in the vents, calcite has formed growing as an intergranular mineral in the breccias as well as an alteration product and potassium, unusual in this area in basic rocks has been introduced in the matrix, and detected by staining.

7) The texture of the microbreccia in the veins is similar to that found on Ard Bheinn by King, 1955, and 1954,

p.7, (the slides Ka 145a, 144, 139, referred to in the text, have been examined, in the Hunterian Museum Collection). The microbreccia is also similar to the rocks described by Reynolds, 1954, p.577, and described as 'tuffisite'. Both King and Reynolds attribute the formation of these breccias to 'fluidisation'.

The proposed explanation of these phenomena is that they are the effectsof successive phases in the intrusion and crystallisation of a volatile-rich felsitic magma, and that the felsite bodies and intrusions and the vents are genetically related. In a recent paper, Hughes, (1958) argues that a series of felsites, explosion breccias, intrusive tuffs, and granophyre in Rhum, have been intruded in that order, marking increasing depths of formation. He concludes that the explosion breccias and intrusive tuffs have their origin in the escape of water vapour from acid magma, a sufficient pressure being reached to fracture the adjacent country rocks, with concomitant release of the pent gases.

In the ensuing discussion, p.108, King (1958) said;

"The impression conveyed by the idea of an explosion breccia was of a formation resulting from individual explosive acts; whereas tuffs classified as intrusive gave the impression of having originated as highly mobile solid-gas suspensions in which gas activity was much longer sustained. Evidence for this latter mechanism was very clear in relation to the felsites which invaded agglomerates and other earlier formations in the

Central Complex of Arran. The felsites, appeared to have undergone progressive fragmentation and comminution together with the invaded formations, the two giving rise to an intermediate zone of mechanically intermixed and graded tuffs, which often also showed elaborate interbanding of the constituent materials in varying proportions".

The main body of felsite of Glen Dubh is interpreted as having formed by crystallisation from a magma which gave rise to the dyke of felsite along the Glen Dubh Fault, and from which, on cooling expelled volatiles disrupted explosively the overlying dolerites and gabbros, particularly around two foci, brecciating the felsite, and carrying felsite fragments as "intrusive tuff" to mingle with comminuted country rock in the veins. The culmination of this brecciation was in the reduction in places of all of the basic rock at the level now exposed, to a tuff of rock fragments.

This explosive disruption of the felsite and adjacent rocks took place at a late stage in the cooling history of the melt, but there was sufficient of the eutectic fluid? left for the final crystallisation to take place of traces of granophyre, after the fracture. Similarly, the concentration of potassium in the late differentiate was introduced into the veins and carbon dioxide in the gases reacted to form intergranular calcite, either from gas phase, or in aqueous fluids.

The release of gas pressure would take place in the direction of least resistance, normally upwards, accounting for the restriction of the tuffs to areas laying above the felsite, and for the absence of veins adjacent to the dyke. The absence of brecciation in the dyke may be due to its having been less advanced in crystallisation at the time of the pressure release above, allowing it to crystallise normally with free loss of volatiles. Hughes,(ibid.), regards the porphyritic felsites as arising from crystallisation under shallow,volatile free conditions.

4) The Minor Felsite Intrusions.

The minor felsite intrusions lie in the Outer Part of the area, notably dykes at F1/091 and F8/062. The former is in irregular dyke, branching Westwards, of felsite similar to that of the dyke at H2/048, AA91. The dyke at F1/091 lies between gabbro and quartzite, Cutting the quartzite cleanly, but showing some reaction with the gabbro. (Specimens AA63 to 75.)

The fresh felsite near the contact with quartzite is of a type similar to AA91, but with irregular knots of green chlorite here and there. The groundmass is very fine grained. This rock is found across the outcrop to within 6 in. of the gabbro contact. Here there is a rapid increase in the amount of chlorite as large irregular flakes, and the rock grades rapidly into a severely altered gabbro. Fresh gabbro is found some 6in. away. Just at the point where chlorite becomes plentiful, long prismatic and acicular hornblende crystals, (subsequently replaced by chlorite), have grown freely in the felsite to lengths of up to 4 inches.

All of the other occurrences of felsite in the Outer Part of the Area are very small dykes and veins in the dolerites and diorites, and are of the unbrecciated fresh material, sometimes with patches and streaks of granophyre.

No connection was established between the felsites of the Outer Area and either the dyke along the Glen Gubh Fault, or the main body of felsite.

V. IGNEOUS HISTORY

a) <u>The igneous history of the Glen Dubh area.</u>

No extrusive igneous rocks have been found in the Glen Dubh area, nor are the tuffs and igneous breccias regarded as having been formed at the surface. The early doming of the area of the Central Complex, and the emission of the Plateau Basalts, (Tyrrell, 1928, p.151), appear to have preceded the first igneous events of which there are now exposed traces in Glen Dubh.

The earliest event in the history of the Glen Dubh Complex of which there is evidence at the present surface was the intrusion of the gabbro and dolerite masses, metamorphosing the country rocks. From the field relations of the dolerite and gabbro it appears probable that the dolerite was partly solidified when it was transgressed, in places, by the still mobile gabbroic part of the intrusion. The two are taken to be parts of the same body on the grounds of their petrographic similarity, and since they are seen to grade into one another in the field, and in thin section. However, the dolerite is taken to be the chilled margin, on a large scale, of the gabbro.

Before the final consolidation of the gabbro, a thin persistent sheet of microgranite was intruded along the contact between the basic rocks and the hornfelsed sediments, transgressing occasionally into one or the other. The microgranite reacted with the basic rocks to produce the complex suite of hybrid diorites. These diorites are divisible into a group associated with gabbro and a group associated with dolerite, and each group is sub-divided into two parts, diorite formed by alteration of basic rock in situ being discriminated from diorite formed by contamination of microgranite.

In the series of diorites, no evidence of inhomogeneity due to the immiscibilty of liquid phases has been found, and the marked local patchiness and variability of the diorite is to be attributed to the contrast in physical states of the several rock masses involved.

The next episodes in the history of the Complex are the formation of the Glen Dubh Fault, and the intrusion of the felsite dykes and sills, and the development of the vents.

It is not clear whether or not the initial faulting preceded felsite intrusion. In view of the undeformed nature of the felsite dyke in the fault plane, the apparent crushing of the felsite elsewhere has been disregarded, and attributed entirely to autobrecciation on intrusion. The faulting is then placed earlier than the felsite intrusion, and indubitably later than the gabbro intrusion and that of the microgranite, both of which are affected by the fault. The minor faults of the area are probably of the same period.

The relation of the felsite intrusion to the formation of the vents has been discussed above. The second set of net-veins in the Inner part of this area, many of which are partly clastic like those of the vent margins, is tentatively allocated to this period also. Certainly these veins cut some of the earlier veins, at M8/064, and are cut by granite at N7/073, and so belong to neither episode. Figs. 9a and 9b show the two sets of veins, the latter set discrete and cutting across the earlier, with little associated alteration of the dolerite or gabbro.

The later microgranite veins of the Outer Part of the Area cut the diorites, but it has not been possible to determine whether they belong to the same episode as the later veins of the Inner Area or not.

The last intrusive episode in the Glen Dubh Area was the emplacement of the Main Granite of the Central Complex, with the metamorphism of the gabbros towards the contact, and the intrusion of the late cross cutting apophyses of microgranite in the Inner Area.

Correlation of the Glen Dubh area with the Ard Bheinn area.

It is now possible to put forward a correlation between the igneous history deduced for the Glen Dubh area, for the rest of the eastern part of the Central Complex of Arran, and for the Ard Bheinn region.

King (1955, p.344) postulated that the granite of Creag Mhor and the area to the North (1955, Pl.XVI) was subsequent to the formation of the agglomerate and breccia masses of the Ard Bheinn area. However, subsequent re-examination has shown (Dr. D.R.Bowes - personal communication) that there is strong evidence at M23 to N24 on Plate XVI of King's paper that the granite is pre-agglomerate. The agglomerate at the junction with the granite is crowded with granite fragments of all sizes (from 6 inches across down to fragments of a single crystal). The larger blocks are angular or sub-angular, and much of the matrix is a powder of quartz, felspar and some mica, present not only as separate fragments, but as aggregates of small crystals - that is, as fine granite.

The diorites of Glen Loig Bridge (bl on Pl.XVI, King 1955) are related to the granite of the Creag Mhor mass, and similar diorites in the eastern part of the Complex are cut by the late Central Granite. This is essentially similar to the sequence of events seen in Glen Dubh, where the late granite cuts and metamorphoses the gabbros and dolerites, but does not produce diorites similar to those associated with the earlier micro-granite.

The following succession of events, and correlation between Glen Dubh and the Ard Bheinn area is postulated:

Glen Dubh	Ard Bheinn
1) Intrusion of gabbros and dolerites.	Gabbro found as small relict masses of uncertain relations.
2) Intrusion of microgranite sheet while the gabbro masses were still warm, and resultant formation of diorite hybrids.	Creag Mhor granite- pre-agglomerate relations not seen. 2a) Diorites of Glen Loig Br. Relations not seen.
3) Intrusion of felsites and tuffs, and formation of breccias.	Development of extensive volcanic complex of Ard Bheinn, with abundant pyroclastics, and acid intrusives.
4) Emplacement of Central Granite, with minor apophyses in the Glen Dubh area.	Granite to the North of Binnein na h'Uaimh and North of Glen Loig (in part).

The isolated areas of diorite found around the margin of the Complex are regarded as the result of hybridism between the early basic rocks, and the <u>earlier</u> granite, with the effect of the later Central Granite extending little beyond thermal metamorphism.

The Glen Dubh area is to be regarded, not as a separate section of the Central Complex, but as an integral part of the Eastern Part of the Central Complex, where, because the rocks lie outside the main caldera, the episodes of volcanic activity have not removed, as they have in Ard Bheinn, the evidences of the early history of the Complex. The rocks of the Glen Dubh area are interpreted as representing the early stages of the igneous period which culminated in the vents and calderas of the Ard Bheinn area, and the final intrusion of the cross-cutting Central Granite.

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VII. APPENDICES.

a) Tables.

Table 4. Modes of dolerites and gabbros.

Gabbro.	Felspar Rim;	Core	Pyroxene.	Amphibole.	Chlorite	Biotite	Opaque	Quartz	Others
AA 25	9.9	62.3	18.7	3.9	1.0	Tr.	2.8	0.8	0.8 (1
	72.2%								
AA 97	19.3	32.3	28.3	4.7	5.8	Tr.	9.4	0.0	-
	51.6								
AA 163	4.8	52.2	31.8	4.8	Tr.	0.0	3.5	2.4	-
	57.0								
AA 168	5	53	7	15	13	0	5	Tr.	Tr. (2
	58								
AA 169	4.4	54.8	21.4	0.7	14.6	0.0	4.1	0.0	Tr. (3
	59.2								
AA 170	16.7	53.5	4.0	9.9	14.2	0.0	0.4	0.0	1.3 (4
	70.0								
AA 173	53.8		20.7*	4.1	12.1	2.3	6.9	Tr.	-
AC 102	6.9	66.3	18.0	2.9	2.9	0.7	2.1	Tr.	-
	73.2								
Dolerites.									
AA 100	57.6**		16.2	4.4	7.1	Tr.	3.1	1.0	Tr. (5
AC 107	59.3		21.8	10.1	7.0	0.0	6.8	6.0	-

Notes.

1) Serpentine after olivine.

2) Olivine less than 0.2%

3) Prehnite.

4) Calcite 1.1%, apatite 0.2%

5) Olivine Trace. Calcite trace in vein.

*Clinopyroxene 18.0%
Orthopyroxene 2.7%

**1.5% as granophyric intergrowth.

Table 5. Compositions of felspars from gabbros and dolerites. (Determinations made on a universal stage, using the maximum extinction angles of albite twins in the zone perpendicular to (010), and using the determinative curves of Winchell, 1951, p.148).

No.	Crystal	Core	Outer part.	Rim	Notes.
Dolerites.					
AA 90	1	An52	-	-	Twin in ophitic matrix; no rim.
AA 100	1	53	51	-	Core and outer zone; no rim.
	2	46	-	-	No zoning; No rim.
AA 180	1	52	-	-	" " " "
	2	53	-	-	" " " "
	3	46	44	20	Sharp rim; graded inside.
AC 107	1	51	-	-	No zoning; no rim.
	2	46	24	-	Evenly graded.
Gabbros.					
AA 25	1	72	64	-	" "
	2	52	36	24	Rim fairly sharp; graded inside.
AA 163	1	45	-	26	Rim sharp; no gradation inside.
	2	46	-	27	" " " " "
AA 169	1	46	26	21	Rim sharp; graded inside.
	2	40	27	-	No rim.
AA 173	1	47	37	22	Sharp rim; graded inside.
	2	48	32	20	Sharp rim; uneven grading inside.
	3	61	28	20	" " " " "
AG 75	1	51	36	20	Sharp rim; discrete outer zone.
	2	67	40	20	" " " " "

Table 5. continued.

No.	Crystal	Core	Outer part	Rim	Notes.
Gabbros continued.					
AC 102	1	52	44	28	Sharp rim; discrete outer zone.
	2	59	38	-	No rim; outer zone grades into core.
AC 105	1	55	-	-	No rim; no zoning.
	2	51	37	20	Sharp rim; graded inside.
AC 106	1	38	-	22	Rim fairly sharp; no zoning.
	2	33	-	21	" " " " "

Table 6

Compositions of felspars from diorites.

No.	Crystal	Core	Outer Zone	Rim	Notes.
AA78	1	53	-	20	Sharp rim; no zones inside.
	2	45	-	21	" " " " "
AC87	1	33	28	20	Graded inside sharp rim.
AA17	1	46	-	20	Sharp rim; no zones inside.
	2	49	-	20	" " " " "
AA103a	1	45	33	20	Sharp rim; narrow outer zone grades inwards.
	2	41	23	20	" " " "
AA105	1	60	29	20	" " " "
	2	71	40	20	Graded inside sharp rim.
AC116	1	39	23	20	" " " "
	2	58	32	20	" " " "
AC117	1	50	graded to	19	Reversal at outer edge.
	2	49	36	17	Reversal at rim; Sharp rim, graded within rim.

Table 7

Optical properties of pyroxenes from gabbros and dolerites.

1) Orthopyroxenes.

Refractive Index N_y, average of two determinations:

$N_y = 1.692$ ($N_z = 1.708$, from Winchell, 1951, p.40(

Optical axial angles 2Vx, average of two determinations:

$2V_x = 51^o$ (Average of 50^o and 52^o)

All determinations on material from specimen A 173.

2) Clinopyroxenes. Group a.

Refractive index N_y, average of 16 determinations on four rocks: $N_y = 1.664$

Optical axial angles $2V_z$, average of 8 determinations

$2V_z = 48^o$

Details;	$2V_x$	$2V_z$	Notes.	Corrected for R.I.
AA173		46^o		47^o
		49		48
AC169		52		52
AA97	67		Obtuse Bx.	47
AA100		49		48
		48		48
		46		47
		49		48

Continued overleaf.

Table 7 continued.

Clinopyroxenes Group b.

Refractive Index N_y, average of three determinations on two rocks; $N_y = 1.706$ (Found only in AA173 and AA169).

Optic axial angles $2V_z$, average of five determinations;

$$2V_z = 67^{\circ}$$

Details:	V_x	$2V_z$	Notes	Corrected for R.I.
AA173	54.5°		Av. of 8	67°
AC75	53.5		Av. of 4	69°
		71		67°
AA169		65		62°
	52			72°

The association of the clinopyroxenes of higher refractive index with those of greater $2V_z$ is made on the evidence of a crystal removed from a slide of AA173, on which both N_y and $2V_z$ were determinable.

Table 8. Analyses 1a.

Analyses as reported, localities on next page.

Rock	A	B	1	2	C	D	E
SiO_2	74.87	75.65	75.13	47.14	52.43	46.49	48.24
Al_2O_3	11.24	11.87	11.91.	19.48	13.50	17.73	17.78
TiO_2	0.26	0.28	0.24	1.23	1.91	1.17	0.97
Fe_2O_3	0.34	1.19	1.39	3.72	4.93	3.66	3.16
FeO	1.22	1.02	0.73	7.81	7.00	6.17	5.95
MgO	0.22	0.15	Abs.	6.16	4.61	8.86	7.51
CaO	1.30	0.91	0.69	8.32	8.25	11.48	10.99
Na_2O	3.31	3.44	3.65	3.26	3.27	2.16	2.55
K_2O	5.68	4.26	5.08	1.07	1.08	0.78	0.89
H_2O_+	0.49	0.40	0.64	1.38	1.64	1.04	1.45
H_2O_-	0.29	0.41	0.19	0.29	0.28		
P_2O_5	0.09	0.16	Tr.	0.01	0.21	0.29	0.28
MnO2	0.05	0.26	0.04	0.10	0.20	0.17	0.13
CO_2	0.49	0.09			0.08		
FeS_2	0.33	Abs.			0.44		
S			0.03		0.03		
Cr_2O_3	0.02		Abs.	0.02	0.02		
BaO	0.04	0.03	Tr.	Abs.	0.96		
ZrO_2					0.01		
LiO_2	Abs.	Abs.			Abs.		
F	Abs.						
Totals.	100.24	100.16	99.72	100.02	99.91	-	-

Table 9. Analyses Ib.

Analyses recalculated water-free.

Rock	A	B	1	2	C	D	E
SiO_2	75.26	76.20	75.90	47.90	53.55	46.97	48.95
Al_2O_3	11.32	11.91	11.96	19.80	13.79	17.92	18.15
TiO_2	0.26	0.28	0.24	1.25	1.95	1.18	0.98
Fe_2O_3	0.34	1.20	1.40	3.78	5.03	3.70	3.21
FeO	1.23	1.03	0.73	7.96	7.16	6.24	6.04
MgO	0.22	0.15	Abs.	6.26	4.71	8.96	7.62
CaO	1.31	0.92	0.68	8.46	8.32	11.60	11.15
Na_2O	3.32	3.47	3.66	3.32	3.34	2.18	2.59
K_2O	5.72	4.30	5.09	1.09	1.12	0.79	0.90
P_2O_5	0.09	0.16	Tr.	0.01	0.21	0.29	0.28
MnO	0.05	0.26	0.04	0.11	0.20	0.17	0.13
Others	0.88	0.12	0.04	0.05	1.53	0.0	0.0

Localities.

A. Northern Granite of Arran. Tyrrell 1928 p.155, no.7

B. Central Granite Arran. Ibid, p.192. From the Allt nan Dris.

C Gabbro of Glen Dubh, near F5/073, Outer Area. Ibid. p.174.

D Average Olivine Gabbro. Daly, 1951, p. , no.56.

E Average Gabbro. Daly, 1951, p. , no.57.

1 Granophyre specimen Ac 217, from KO/052. Analyst J.H. Ashford

2 Gabbro specimen AA 173 from J9/068. Analyst J.H. Ashford.

Table 10. Analyses 1c.

Analyses recalculated as "norms". (C.I.P.W. System).

Rock	A	B	1	2	C	D	E
Quartz	32.4	36.9	33.4	-	6.5	-	-
Orthoclase	33.9	25.6	30.0	6.7	6.7	5.0	5.6
Albite	25.7	28.8	30.9	27.8	27.8	18.3	21.5
Anorthite	-	4.5	1.1	35.5	18.6	31.4	33.9
Acmite	1.9						
$CaO.SiO_2$	1.4			2.6	9.4	7.3	8.5
Diopside $MgO.SiO_2$	0.4			1.5	5.6	5.1	5.6
$FeO.SiO_2$	1.1			0.9	3.3	1.6	2.2
Wollastonite			1.0				
Hypersthene $MgSiO_3$	0.2	0.4			5.9	1.6	
$FeSiO_3$	0.5	0.8			2.6	0.5	
Olivine $2MgO.SiO_2$				9.7		10.8	11.8
$2FeO.SiO_2$				6.2		3.7	3.7
Magnetite		0.3	1.6	5.3	7.2	5.3	4.6
Haematite			0.3				
Ilmenite	0.3	0.3	0.5	2.3	3.6	2.3	1.8
Pyrite	0.3		0.1	0.6	0.4	0.6	
Apatite						0.6	
Calcite	1.1	2.0					
Water	0.8	0.8	0.8	1.7	2.0	1.0	
Totals	100.0	100.5	99.7	99.3	99.6	100.7	100.8

Table 11. Analyses 2a.

Analyses of material from specimen AA 149b. (See Fig. 20).

Rock	1	2	3	4	5	6
SiO_2	77.5	75.1	70.5	53.4	55.4	51.4
Al_2O_3	8.6	8.6	10.0	18.0	18.6	16.0
TiO_2	0.20	0.33	0.71	1.05	1.13	0.95
Fe_2O_3	1.47	0.29	0.76	0.46	0.29	0.24
FeO	0.83	1.45	3.49	7.16	7.00	7.13
MgO	0.00	0.11	0.60	2.22	4.13	5.90
CaO	2.10	5.02	6.10	10.31	10.50	15.80
Na_2O	4.14	4.18	4.33	3.46	3.53	3.35
K_2O	4.47	4.14	2.39	0.98	0.78	0.75
H_2O_+	0.33	0.49	1.03	2.16	2.11	2.82
H_2O_-	0.35	0.36	0.39	0.39	0.36	0.27
P_2O_5	Tr.	0.02	0.18	0.18	0.16	0.13
MnO	0.01	0.01	0.04	0.09	0.09	0.09
Cr_2O_3	0.00	0.00	0.00	0.01	0.01	0.02
Totals.	100.1	100.1	100.3	100.1	99.9	99.9

Analyst - J.H.Ashford.

Method used after Shapiro and Brannock, 1952 and 1956.

Table 12. Analyses 2b. (AA 149b)

Analyses recalculated water-free.

Rock	1	2	3	4	5	6
SiO_2	77.8	75.6	71.1	54.8	56.9	53.1
Al_2O_3	8.7	8.7	10.1	18.9	18.8	16.5
TiO_2	0.21	0.33	0.72	1.08	1.16	0.79
Fe_2O_3	1.49	0.29	0.77	0.47	0.30	0.25
FeO	0.84	1.46	3.52	7.24	7.19	7.38
MgO	0.00	0.11	0.61	2.28	4.24	6.09
CaO	4.53	5.05	6.17	10.58	10.78	16.41
Na_2O	4.20	4.21	4.38	3.54	3.62	3.46
K_2O	4.53	4.17	2.42	1.00	0.60	0.77
P_2O_5	Tr.	0.02	0.18	0.18	0.16	0.13
MnO	0.01	0.01	0.04	0.09	0.09	0.09
Cr_2O_3	0.00	0.00	0.00	0.01	0.01	0.02

Table 13. Analyses 2c. (AA 149b).

Analyses recalculated as "norms". (C.I.P.W. System).

Rock		AA 149b1	2	3	4	5	6
Quartz		41.0	35.2	26.4	3.3	8.5	3.0
Orthoclase		26.6	24.4	13.9	6.1	4.5	4.5
Albite		18.9	20.9	36.2	29.3	29.3	28.3
Anorthite				2.2	30.3	32.8	26.4
$Na_2O.SiO_2$		2.7	2.3				
Acmite		4.2	3.6				
Diopside	$CaO.SiO_2$	0.9	2.2	5.9	8.7	8.1	11.8
	$MgO.SiO_2$	-	0.3	1.5	2.9	0.8	1.5
	$FeO.SiO_2$	1.1	2.0	4.8	6.1	8.2	11.5
Wollastonite		3.5	8.0	5.8			9.8
Hypersthene	$MgO.SiO_2$				2.6	0.2	
	$FeO.SiO_2$				5.2	2.6	
Olivine	$2MgO.SiO_2$						
	$2FeO.SiO_2$						
Magnetite				1.1	0.7	0.5	0.3
Ilmenite		0.5	0.6	1.4	2.0	2.1	0.2
Water		0.7	0.9	1.4	2.5	2.5	3.1
Totals		100.2	100.3	100.6	99.7	100.1	100.1

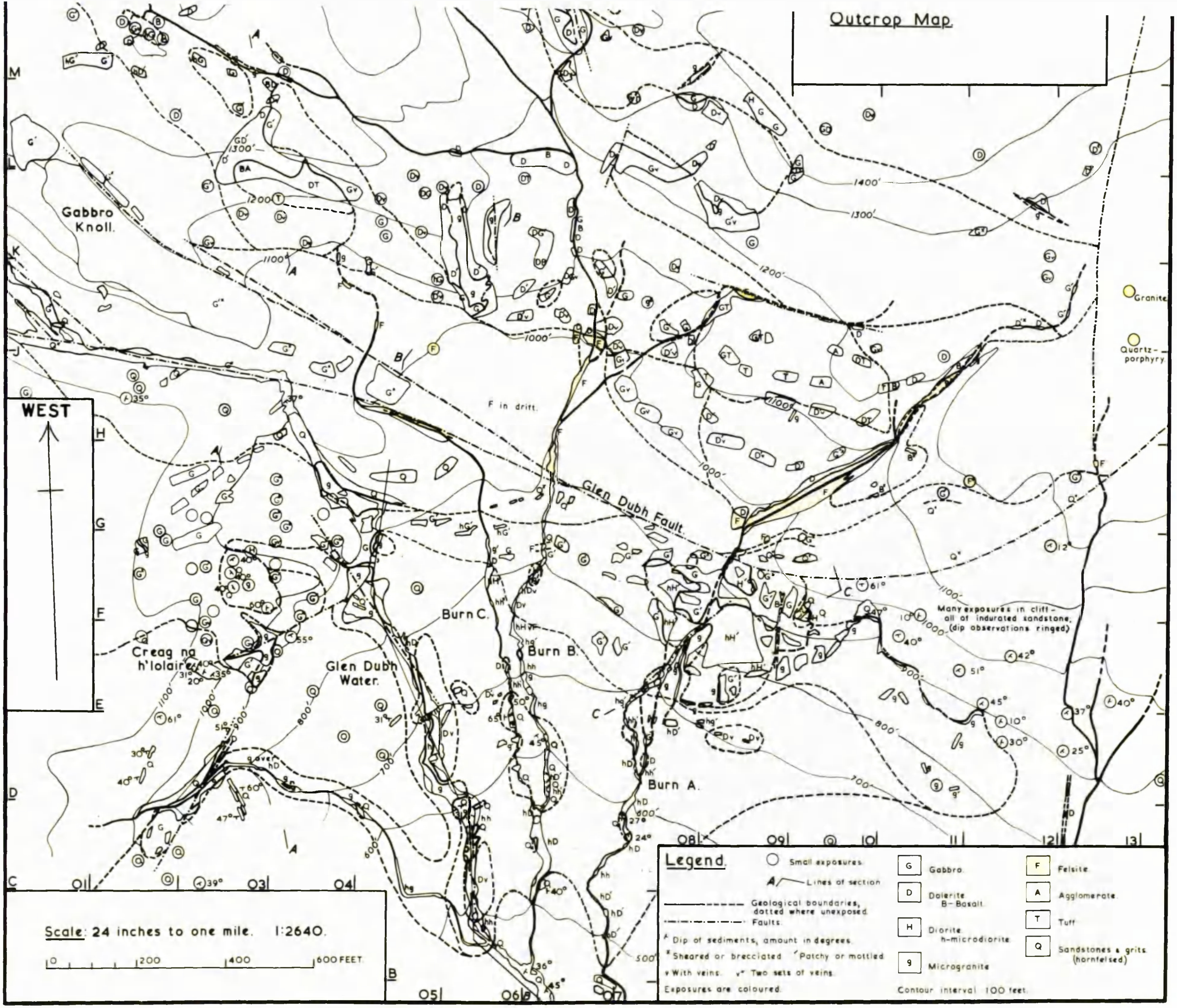
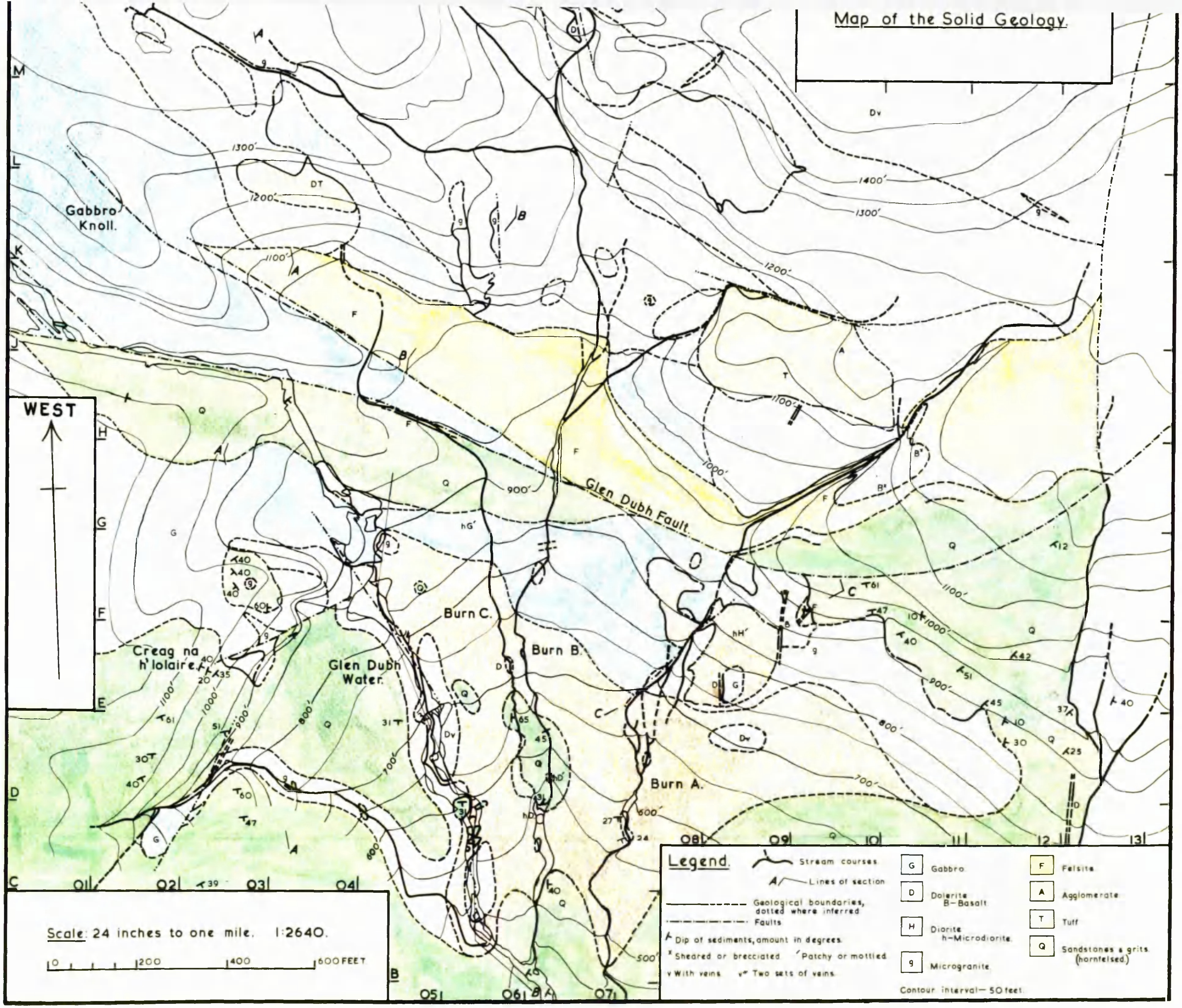
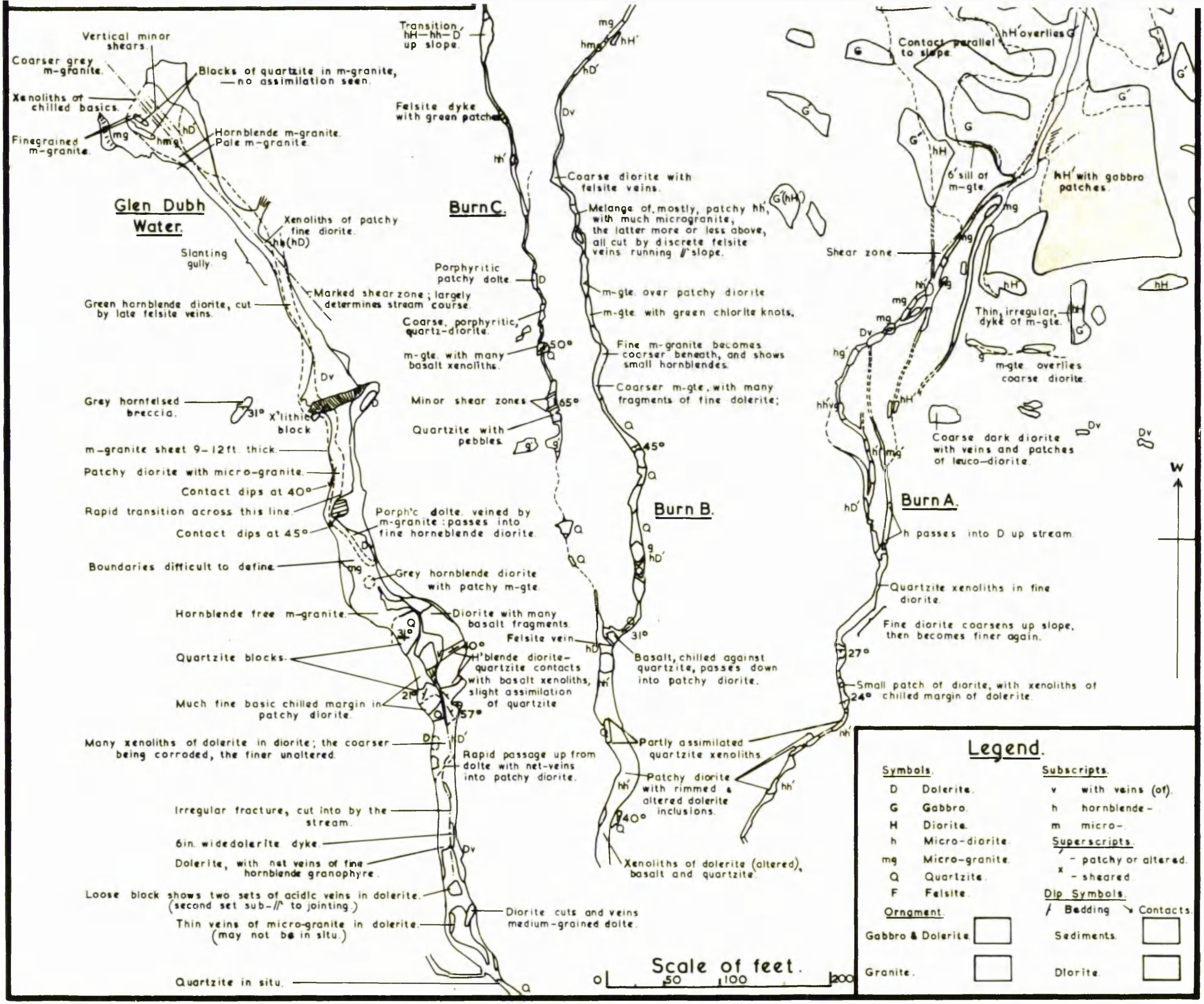

Outcrop Map.
WEST
Gabbro Knoll.
Creag na h'Iolaire.
Glen Dubh Water.
Burn C.
Burn B.
Burn A.
Glen Dubh Fault.
F in drift.
Many exposures in cliff - all of indurated sandstone, (dip observations ringed)
Granite
Quartz-porphyry.
Scale: 24 inches to one mile. 1:2640.
0 200 400 600 FEET.
Legend.
Small exposures.
Lines of section.
Geological boundaries, dotted where unexposed.
Faults.
Dip of sediments, amount in degrees.
Sheared or brecciated. Patchy or mottled.
With veins. Two sets of veins.
Exposures are coloured.
G Gabbro.
D Dolerite. B-Basalt.
H Diorite. h-microdiorite.
9 Microgranite.
F Felsite.
A Agglomerate.
T Tuff.
Q Sandstones & grits (hornfelsed).
Contour interval 100 feet.

Figure 24.



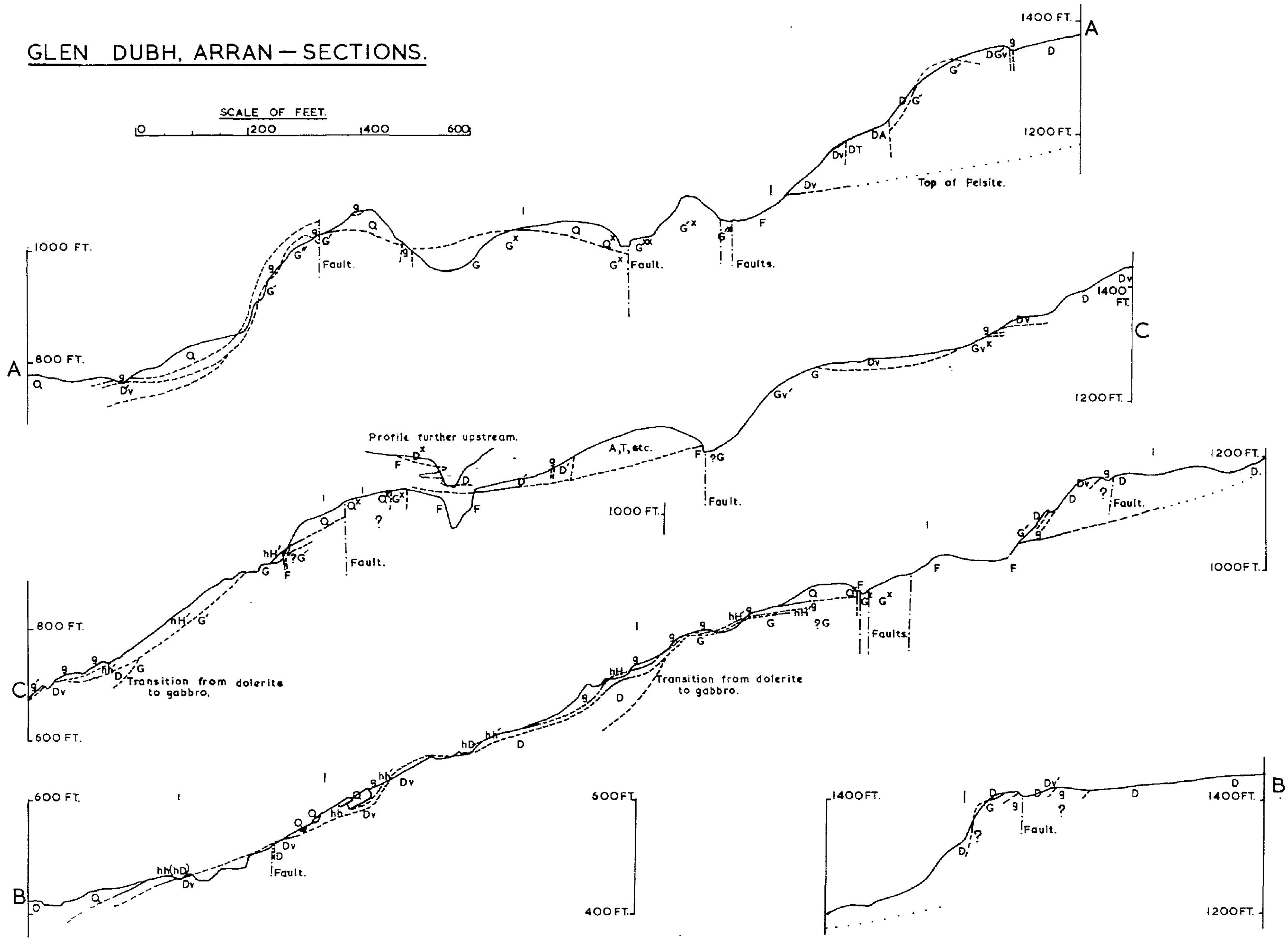
Map of the Solid Geology.
WEST
Gabbro Knoll.
Creag na h'Iolaire.
Glen Dubh Water.
Burn C.
Burn B.
Burn A.
Glen Dubh Fault.
Scale: 24 inches to one mile. 1:2640.
0 200 400 600 FEET
Legend.
Stream courses.
Lines of section
Geological boundaries, dotted where inferred
Faults
Dip of sediments, amount in degrees.
x Sheared or brecciated
' Patchy or mottled.
v With veins.
v" Two sets of veins.
G Gabbro.
D Dolerite B-Basalt
H Diorite h-Microdiorite.
g Microgranite.
F Felsite
A Agglomerate
T Tuff
Q Sandstones & grits. (hornfelsed.)
Contour interval— 50 feet.

Figure 25.



Glen Dubh Water.
Burn C.
Burn B.
Burn A.
Vertical minor shears.
Coarser grey m-granite.
Blocks of quartzite in m-granite, — no assimilation seen.
Xenoliths of chilled basics.
Finegrained m-granite.
Hornblende m-granite.
Pale m-granite.
Xenoliths of patchy fine diorite.
Slanting gully.
Marked shear zone; largely determines stream course.
Green hornblende diorite, cut by late felsite veins.
Grey hornfelsed breccia.
X'lithic block
m-granite sheet 9–12ft. thick.
Patchy diorite with micro-granite.
Contact dips at 40°
Rapid transition across this line.
Contact dips at 45°
Boundaries difficult to define.
Grey hornblende diorite with patchy m-gte.
Hornblende free m-granite.
Diorite with many basalt fragments.
Quartzite blocks.
H'blende diorite–quartzite contacts with basalt xenoliths, slight assimilation of quartzite
Much fine basic chilled margin in patchy diorite.
Many xenoliths of dolerite in diorite; the coarser being corroded, the finer unaltered.
Rapid passage up from dolte with net-veins into patchy diorite.
Irregular fracture, cut into by the stream.
6in. widedolerite dyke.
Dolerite, with net veins of fine hornblende granophyre.
Loose block shows two sets of acidic veins in dolerite. (second set sub-// to jointing.)
Thin veins of micro-granite in dolerite. (may not be in situ.)
Diorite cuts and veins medium-grained dolte.
Quartzite in situ.
Transition, hH—hh—D' up slope.
Felsite dyke with green patches
Porphyritic patchy dolte.
Coarse, porphyritic, quartz-diorite.
m-gte. with many basalt xenoliths.
Minor shear zones.
Quartzite with pebbles.
Porph'c dolte. veined by m-granite: passes into fine horneblende diorite.
Felsite vein.
Coarse diorite with felsite veins.
Melange of, mostly, patchy hh', with much microgranite, the latter more or less above, all cut by discrete felsite veins running //'slope.
m-gte. over patchy diorite.
m-gte. with green chlorite knots.
Fine m-granite becomes coarser beneath, and shows small hornblendes.
Coarser m-gte., with many fragments of fine dolerite;
Basalt, chilled against quartzite, passes down into patchy diorite.
Partly assimilated quartzite xenoliths.
Patchy diorite with rimmed & altered dolerite inclusions.
Xenoliths of dolerite (altered), basalt and quartzite.
hH' overlies G
Contact parallel to slope.
6' sill of m-gte.
hH' with gabbro patches.
Shear zone
Thin, irregular, dyke of m-gte.
m-gte. overlies coarse diorite.
Coarse dark diorite with veins and patches of leuco-diorite.
h passes into D up stream.
Quartzite xenoliths in fine diorite.
Fine diorite coarsens up slope, then becomes finer again.
Small patch of diorite, with xenoliths of chilled margin of dolerite.
W
Scale of feet.
0 50 100 200
Legend.
Symbols.
D Dolerite.
G Gabbro.
H Diorite.
h Micro-diorite.
mg Micro-granite.
Q Quartzite.
F Felsite.
Subscripts.
v with veins (of).
h hornblende-
m micro-
Superscripts.
' - patchy or altered.
x - sheared.
Dip Symbols.
Bedding
Contacts.
Ornament.
Gabbro & Dolerite.
Granite.
Sediments.
Diorite.

GLEN DUBH, ARRAN — SECTIONS.



THE HORIZONTAL AND VERTICAL SCALES ARE THE SAME.

FOR KEY TO SYMBOLS, SEE MAP.

Figure 27.
Sections drawn from the maps of the Glen Dubh Area, to show the interpretation of the structure.