PETROLOGICAL INVESTIGATION

of the

PRIESTLAW "GRANITE"

(East Lothian)

AND ITS METAMORPHIC AUREOLE.

By

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I. INTRODUCTION

The Priestlaw "granite" is one of a series of small Caledonian complexes emplaced within the Lower Palaeozoic rocks of the Southern Uplands (Fig. 1). It lies some 28° east-south-east of Edinburgh, on the main road from Gifford to Duns, and is easy of access.

The complex is exposed in the heart of the Lammermuirs - famous alike in Scottish geology and literature - of which Geikie (1866, p. 6-7) wrote: "The Lammermuir hills, rising to an average height of 1500-1600 ft. above sea level, are an undulating tableland with an inclination towards the south-east ..........

The surface of the Lammermuir uplands is singularly smooth. It is coated with short heath or coarse grass, save where a mantle of peat covers the hollows, or where the streams keep open their channels through the bare drift or hard rocks. Except along the sides of the watercourses, such a thing as a crag is unknown throughout the district. Even a knoll where the rock comes to the surface is rarely seen. It is only along the beds of the brooks and rivulets that the geologist meets with sections of the Silurian strata of which the hills are composed ........"

The general drainage of the area is to the south-east through a number of small valleys. The greater part of the Priestlaw /
Priestlaw complex occupies the erosional hollow at the junction of the Whiteadder and Faseny Waters, and covers an area of about one square mile. The metamorphic aureole is about half a mile wide, except on the west, where it is only about 200 yards. Cultivated fields and grazing lands occupy most of the area, but the main mass is fairly well exposed along the river sections. Owing to the cover of heather, peat and drift on the surrounding hill-sides, exposures of the contact and aureole rocks at higher levels are unfortunately poor and scanty.

The mass is chiefly built of medium- and fine-grained granodiorites which grade into dioritic types, while marginally granulites and hornfelses are developed. Very hard granular Silurian greywackes with bands of fine-grained shales, having a typical Caledonian strike, form the country rock. Several porphyrite dikes occur in the aureole on the south and north-west and a few within the complex; two or three of the dikes on the south are continuous from within the complex to the aureole.

Well-known in geological literature as the "Priestlaw Granite", the complex has attracted the attention of many famous geologists. But hitherto there has been no detailed modern petrological description of the plutonic and metamorphic rocks of the area comparable with those already available for many of the other Caledonian plutonic masses of the Southern Uplands. This thesis /
thesis, the result of a detailed investigation, is intended to supply a description of the Priestlaw complex with an interpretation of its mode of origin.
II. PREVIOUS WORK

The earliest reference to the "Priestlaw Granite" occurs in the "Illustrations" of Playfair (1802) where he wrote (Collected Works, 1822, p. 328) "Another instance of a real granite disposed in regular beds, but without any character of gneiss, is one which I saw in Berwickshire, in Lammermuir, near the village of Priestlaw. The little river of Fassnet cuts these beds across, and renders it easy to observe their structure.

A few years later Jameson (1805, Introduction, p. xix) remarked: "Granite is said to have been found at Fassnet burn, which is in the tract I consider to be transition. I suppose syenitic greenstone has been confounded with granite". But in a footnote on the next page he observed: "Since writing the above I have examined a suite of specimens brought from the Fassnet burn and the neighbourhood by Dr. Hope, and find my conjecture respecting the extent of the transition rocks, and the nature of the supposed granite of Fassnet, confirmed". Jameson called this 'granite' "sienitic greenstone", apparently as a compromise between his definitions of 'greenstone' and 'sienite' which are respectively as follows:

"Greenstone" (1821, p. 402): "A granular aggregate rock, generally of a green colour, of which there are two principal kinds, one composed of hornblende and feldspar, and another of augite /
augite and feldspar .......... Of these ingredients the hornblende and augite are the most abundant, the feldspar the least frequent, hence the general dark green colour of greenstone; it varies from rather coarse to compact ........ "

'Sienite' (1821, p. 403): "A granular aggregate rock of a grey, white or reddish colour, composed of feldspar and hornblende, with occasional intermixture of quartz, mica, epidote, and chlorite. In this rock the feldspar is the predominating ingredient, while in greenstone, as already mentioned, the hornblende or augite are the most abundant constituent minerals".

The Silurian country rocks were referred by Jameson to the "transition series" of Werner.

Describing the field occurrence of this "sienitic greenstone of the Fassmat burn", Ogilby (1808, pp. 126-130) wrote "The rocks are decomposable, favourable to vegetation and nowhere visible in the beds of rivulets". Approaching the mass from the south he encountered a felsite dyke of which he said it was "difficult to say whether it is Felspar Porphyry, a variety of compact felspar or of claystone"; he continued "this bed is 6 or 8 feet thick, and conformable with the strata of greywacke, and must therefore be regarded as of the same formation". Reaching the complex itself, he "met with a thin bed of sienitic greenstone resting immediately upon a greywacke, and covered by a bed of great /
great thickness, of a distinct granular aggregate rock, composed of reddish-white or flesh-red felspar, greenish black hornblende, and brownish black mica". Ogilby continues: "This bed is made up of strata from one to three feet in thickness, corresponding in direction, dip, and inclination, with those of the greywacke above and below it ....; this rock might be supposed, by those who only attend in a superficial manner to cryptognosy, to be essentially different from either sienite or greenstone. But a number of reasons here lead us to conclude that the mica is an accidental or adventitious ingredient, similar to crystals of felspar in basalt, or garnet in mica slate, by which the general characters of these rocks, or their names, are not affected .... The name Sienitic Greenstone, as used by Prof. Jameson for this rock, appears to me happily chosen, and quite unobjectionable".

Criticising Playfair for calling this rock granite Ogilby asked "Where was granite ever seen without quartz, and united with hornblende, and in such a situation?" Since these earlier geologists had to rely on their unaided eyes for their classification, this difference of opinion is understandable.

Ami Boué (1820, p. 94) briefly mentioned the Priestlaw mass as "granite sienitique", but the next detailed reference to the mass was by Cunningham (1835, pp. 101-103) who continued to call it a "sienitic greenstone", but recognised the unstratified nature /
nature of the "Priestlaw Granite" and also referred to it as a plutonic rock. But he described the structure of this "sienitic greenstone" as tabular, though it is far from clear what he meant to convey by this term (1835, p. 38).

Much more interesting from our point of view are the observations of Stevenson (1849, pp. 33-46) who, writing about the "Granite of Cockburnlaw and Stoneshiel" (a similar small complex situated about 12 miles south-east of Priestlaw) described the rock as "a regular granite, composed of distinct crystals of white quartz, red felspars, and black mica; but identical both in regard to geological age and lithological aspect with a granite (the Priestlaw mass) ... associated with greywacke mass near Fassney Bridge and ... intruded among the strata of the latter ....". It will be shown later that the "Priestlaw Granite" is exactly similar to that of Cockburnlaw, concerning which Stevenson wrote (p. 40): "the granite ..... in many places passes into a syenite. By "Syenite" Stevenson meant the fine-grained transition rock "near the outskirts of the mass".
(Cockburnlaw) it seems not improbable that the syenite of Cockburnlaw and Stoneshiel is nothing more than greywacke fused by the agency of the mother granite, and the mineral characters of the two rocks thereby blended together. The granite invariably assumes the aspect of syenite, as it approaches the greywacke..... hardness (of the greywacke) increases, the planes of stratification become less distinct .......

All these symptoms of metamorphism increase as we approach the igneous rock, the texture of the greywacke being changed to crystalline, the sizes of the crystals increasing ..... until we arrive at a point when it is impossible to decide from the appearance presented, whether the rock should be considered greywacke or syenite ....... As we proceed further into the mass the syenite ..... passes by a regular and gradual transition into the well characterised granite ....."

This recognition of the gradual transformation of the greywackes into the granitic rocks is very significant; and it may be noted here that in the present study the same conclusion has been reached from the additional evidence provided by microscopic examination of the rocks.

Sir A. Geikie (1866, pp. 14-17) gave the first detailed description of the "great felspathic mass of Priestlaw" and its relation to the surrounding rocks. He described "the true granite /
granite of Priestlaw" as "a granular mixture of pinkish felspar, grey quartz and black mica, with perhaps a little disseminated hornblende". Further, "the Priestlaw mass varies considerably in texture and composition throughout its extent. Most of it is a well-marked granite, sometimes coarser and sometimes finer in grain, and sometimes, where the hornblende increases, partaking of the character of a syenite ....... Except in the section .... in the Fassney, the junction of the granite with the stratified rocks is not well shown". Geikie had also observed (1864, p. 33) that "it is sometimes hardly possible to decide where the stratified rock ends and the unstratified rock begins". Here he was referring to the progressive metamorphism and not merely to the difficulty of finding contacts. Regarding the origin of the "Intrusive Rocks in the Silurian and the associated metamorphism, Geikie (1864, pp. 32-33) noticed that "the metamorphism appears to have been developed, not equally throughout the district, but in points of greater or less extent, that it is most intense where it can be traced into granite as into its ultimate stage, and that it is not dependent upon an abundance of dislocations and intrusive dykes. It was perhaps closely connected with the effects of great vertical and lateral pressure, whereby the strata were compressed without actual fracture. Wherever, owing to a failure of this pressure in one direction, the beds have been much broken,
dykes of felsstones have ascended through the rents, but the extent of the metamorphism is not thereby increased, if it be not in some cases really lessened". Geikie regarded the age of these 'intrusives' as "older than the Upper Old Red Sandstone of the district..... perhaps older than even the Lower Old Red Sandstone of Berwickshire" (cf. p. 18).

Later J.J.H. Teall (1899, p. 625) described three thin sections from the Priestlaw mass:-

1. a hornblende-biotite-granite from the centre of the mass;

2. a more basic rock "from near the edge of the mass" which he named hornblende-biotite-porphyrite but with a groundmass coarser and more granitic than that appropriate to a porphyrite; and

3. a quartz-augite-biotite-diorite "also from the edge of the mass" in the Faseny river.

Teall regarded the "hornblende-biotite-porphyrite" as a marginal modification, showing that "the physical conditions under which the margin of the Priestlaw rock consolidated approximated to those under which the porphyrite dykes were formed".

No further progress was made until F. Walker (1925, pp. 357-365) read a short paper before the Edinburgh Geological Society, dealing with "four granitic intrusions in South-east Scotland" including the Priestlaw mass. He recognised for the first time that the "Priestlaw granite" was not a true granite in/
in the sense of modern terminology but a granodiorite with a
dioritic margin. The porphyritic nature of most of the rock was
made clear, but Walker stated that the porphyritic granodiorite
occupied the centre of the mass and that it showed a gradual
transition outwards to true granitic types. Thus disagreeing
with Teall, he stated his own view (pp. 363-364): "Marginal
chilling is not therefore the cause of this porphyritic modifica-
tion. Possibly the rock encountered one of the last phases of
the Caledonian movements while some of the quartz and orthoclase
was still liquid. This would lead to a great increase of
pressure. Equilibrium would be thereby upset and new crystal
nuclei rapidly formed, leading ultimately to the production of a
fine-grained groundmass. The marginal portion of the mass, being
already solid through more rapid cooling, would be unaffected
... support is lent to this hypothesis by the fact that some
of the carlsbad twin-planes of the orthoclase show slight flexi-
tures which would seem to indicate movement during consolida-
tion ... ."

Walker gave two chemical analyses of the Priestlaw
rocks, and recognised their similarity to two analyses of por-
phyrite from the Fault Intrusion of Glencoe. He also showed
that the Priestlaw granodiorites are petrographically closely
allied to those of Galloway and Argyllshire.
The above views of Teall and Walker were obviously based on the orthodox assumption of a purely magmatic origin for the complex. More recently, A.G. MacGregor, writing particularly of the Distinkhorn complex (1930, pp. 51-52), has gone so far as to make the following sweeping generalization: "There is no evidence against the assumption that the various members of the plutonic complex are differentiation products of one magma-basin. In fact the close association of similar rock types elsewhere in the South of Scotland makes the truth of such an assumption quite certain". MacGregor included the Priestlaw complex in this generalization. In the course of the present thesis evidence will be presented which is completely inconsistent with the assumption of an alleged magma-basin and its subsequent differentiation.
III. PRESENT INVESTIGATION

The previous mapping of the area was accomplished by Ramsay, Howell and Geikie about the years 1858-59. The Geological Survey one-inch map (Sheet 33) including the area was first published in 1860; and, after revision by Clough, Burrow, Bailey, Anderson and others, republished in 1910. In the present investigation mapping has been carried out on the six-inch scale. Little modification of the survey outline of 1910 has been found necessary (Fig. 2) except for a slight westward extension of the western margin of the complex necessitated by the occurrence of certain exposures on the slopes of Penshiel Hill.

Altogether 16 weeks were devoted to field-work; 12 weeks in May, June and August 1946, and a further 4 weeks in June-July and September 1947 during which some excavations were made to expose contacts of the mass with the country rocks. During August 1946 a few days were spent examining the plutonic mass of Cockburnlaw to facilitate its comparison with that of Priestlaw. Altogether 348 specimens were collected from the Priestlaw complex, its aureole and the adjacent country rocks, and a further suite of 37 specimens was collected from Cockburnlaw.

Before presenting the evidence, the main conclusions reached in the light of the results obtained during the present investigation /
investigation may be stated. It is inferred that the Priestlaw complex was formed by granitization (including biotitization and feldspathization) of the country rocks in situ, brought about by the introduction, exchange and driving out of the ingredients respectively necessary; that the aureole rocks show the preliminary stages of the transformations which eventually led to the formation of the granodioritic body; and that there is no need to postulate the existence of a liquid magma at any stage of the sequence of evolution, of which the successive products are now represented by the exposed rocks. It is possible, however, that a stage of magma formation may have been attained in depth, as an ultimate consequence of the transformations, and that such magma was eventually squeezed out to form the dykes.

The observations to be discussed in the light of the assembled evidence include the following:

1. The lack of evidence of any kind of structural displacement in the country rocks;

2. The absence of sharp contacts between the country-rocks and the plutonic mass;

3. The highly crystalloblastic nature of the rocks of the plutonic mass, and the essential similarity and serial relationships between the texture and composition of the granitic types of the complex and those of the granulitic and hornfelsic types of the aureole;

4. The patches of pyroxene-bearing types in the midst of mainly biotite- and hornblende-bearing varieties of diorite;

5. /
5. The mosaic, sieved, and skeletal structures of the plagioclase, biotite, hornblende and pyroxenes; and the clouding of the plagioclase; and

6. The remarkable assemblage of similarities between this mass and many other Caledonian plutonic masses occurring in the Lower Palaeozoic rocks of the Southern Uplands.

Most of these observations are inconsistent with genetic assumptions based on concepts of either multiple intrusions or of complex processes of magmatic differentiation. The "transformist" hypothesis for the genesis of the granitic rocks is found to correspond with the facts much more closely, and in particular it satisfactorily accounts for various textural and structural features that obviously could not be produced by any process of crystallization from a liquid magma.
IV. GEOLOGICAL SETTING

The Priestlaw complex is emplaced in formations consisting of hard siliceous greywackes with occasional shale partings. These sediments are unfossiliferous, which fact has long been known by the Survey Geologists (1899, pp. 56-59) who, utilising evidence from a larger area, have referred them to the Llandovery and Tarannon divisions of the Silurian. The general strike is north-east - south-west, thus conforming with the usual Caledonian trend. The strata lie vertically in most of the area immediately surrounding the plutonic mass, except towards the east where steep dips of 60° to 70° to the north-west have been measured. There is no change of direction of the strike towards the margin of the complex. In the vicinity of the plutonic mass the sediments have been altered to form a metamorphic aureole which surrounds the complex to a width of approximately half a mile, except on the west where it is much narrower. This metamorphic aureole consists of fine-grained hornfels and granulite, and is characterized by an abundant development of biotite, cordierite and feldspars; as the granitic rocks are approached, the development of pyroxene is noticed, and the granulites closely approach in mineral and textural characters the fine-grained marginal rocks of the complex itself.
Form of the Complex.

The plutonic complex has a roughly triangular outcrop with the apex of the "triangle" directed towards the east (Fig. 2). The western margin, forming the base of the "triangle" is nearly straight; the north-east side is outwardly convex, while the south-east side is outwardly concave. In the one-inch Survey map of 1910 the western margin from near the junction of the Fee Cleugh with the Faseny Water is shown as a curved line which joins the western margin as drawn in the present map roughly west of the ruins of Penshiel Tower. However, certain exposures of the granitic rocks found on the sides of the Fee Cleugh, and also near the woods at the head of the same stream, make it possible to extend the boundary of the mass further to the south-west, so bringing the western margin more directly north and south. Parts of the margin of the complex are covered by glacial drift (Fig. 2) and hence the position of the boundary line remains uncertain in these places.

The altitude of the walls of the complex could not be exactly determined, but the general form of the mass in relation to the contours suggests that if they are not vertical, they are certainly very steep. The mass is not notably elongated in any particular direction, nor is there any evidence of subsequent deformation.
deformation by earth movements. Roughly rectangular jointing is observed in the well-exposed central portions of the mass (Fig. 4). Apart from this normal jointing, no other fractures or foliation, banding or other lineation structures are seen within the boundaries of the complex.

Age of the Complex.

A lower limit to the age of the complex is easily fixed. Being unaffected by Caledonian movements the granitic complex is definitely post-Silurian. An upper limit to the age can be approximately ascertained by petrographic analogy, that is, by comparing this mass with similar Caledonian complexes in the neighbourhood, and in the Southern Uplands generally, some of which are demonstrably of Pre-Upper Old Red Sandstone Age. Walker (1925, p. 361) indicated the affinity of the rocks of Priestlaw to those of Cockburnlaw, and a few years later (1928, pp. 153-182) he established the petrological similarities of both masses to those of the other plutonic complexes in the Southern Uplands. Thus he felt justified in reaffirming the conclusion previously reached by Teall (1899, pp. 607 et seq.), namely, that all the plutonic bodies occurring in the Ordovician and Silurian tract of the Southern Uplands appear to be consanguineous and are therefore /
therefore likely to be of the same general age. Further, the Cockburnlaw mass is overlain by conglomerates of Upper Old Red Sandstone age which contain numerous pebbles of the rocks of both the Cockburnlaw mass and its metamorphic aureole (Walker 1925, p. 357; Midgley 1946, pp. 49-66). This relation reappears in the Lamberton Beach area (Walker, 1928, p. 156) where a plutonic mass, closely resembling the Priestlaw and Cockburnlaw complexes, is capped by an outlier of Upper Old Red Sandstone conglomerate containing pebbles of the Plutonic rock. The age of the Priestlaw complex is thus "restricted to Lower and Middle Old Red Sandstone, with a balance of probability in favour of the earlier division" (Walker, 1925, p. 363). Walker considers that the latter probability arises by virtue of the marked chemical and mineralogical similarities of the rock-types of Priestlaw with those of neighbouring complexes, the age of which has been established. Of these the Distinkhorn Plutonic Complex has been definitely proved to be of Lower Old Red Sandstone age (A.G. MacGregor, 1930, p. 25) from the following evidence:

(a) "..... red granodiorite belonging to the complex has baked sandstones immediately underlying the unaltered beds of the Penning Hill quarries from which the Lower Old Red Sandstone fish (cephalaspis) has been obtained"; and

(b) "..... they (the igneous rocks of Distinkhorn and other such masses) are never found cutting rocks belonging to formations younger than the Lower Old Red Sandstone".

Taken /
Taken together with the undoubted relationships between the Priestlaw complex and its neighbours of the Southern Uplands, as proved by Deer (1935 and 1937), Gardiner and Reynolds (1932 and 1936), Walker (1925 and 1938) and M. MacGregor (1937 and 1938), the analogies reviewed above make it reasonably certain that the Priestlaw complex was emplaced during Lower Old Red Sandstone time.
V. THE COUNTRY ROCKS

General Statement

Greywackes are the main country rocks of the area, and they are occasionally interbedded with siltstones and shales. A general description of these rocks has been given in the Geological Survey Memoir on the Silurian Rocks of Great Britain (1899, I, pp. 56-59) where they are assigned to the group classed together as Llandovery and Tarannon. As the rocks are completely unfossiliferous, no independent palaeontological evidence is available. 117 specimens were collected from the country rocks, including the aureole of metamorphism, and from them 84 thin sections have been made.

In thin section the following features of the country rocks are striking:

1. The constituents are of mixed sizes, ranging from as much as 1 mm. down to fine dust; large and small grains are intermingled, showing the deposits to be ungraded;

2. Most of the grains in the greywackes are angular, with fresh, sharp edges and points;

3. They are exceptionally poor in heavy minerals: hornblende, zircon and garnet are present, but are extremely rare;

4. Though composite grains derived from older rocks are present in all the coarser varieties, there are no pebbly bands as such; the composite grains present do not exceed the size of the larger grains of the rock, and are never very abundant; and
5. No calcareous beds have been encountered in the area.

For convenience the country rocks can be described under two heads:—

1. Greywackes

2. Siltstones and Shales.

The highly siliceous and coarser sediments are included with the greywackes; with increase in the content of muddy matrix the average grain size becomes conspicuously finer and the greywackes pass into siltstones and shales.

1. The Greywackes

Good exposures of the greywackes occur along the Faseny river up to the south margin of the Plutonic complex, and on the banks of the Whiteadder river on the east side. Elsewhere only isolated exposures are seen, including an abandoned quarry on the south-eastern slope of Kingside Hill. The greywackes form thick massive beds, very hard, compact, and resistant to weathering. The prevalent colour is various shades of grey; occasionally a brownish-grey or rusty-brown colour is seen, and seems to be due to ferruginous staining, since this colour is often deeper near the weathered surface and fades off to the usual grey towards the fresher underlying parts of the rock.
Petrography

Angular grains of quartz are the most prominent constituent of the greywacke; a few grains of altered lavas, granophyres, and what are probably altered cherts, are always present; detrital grains of biotite, chlorite, muscovite, altered feldspars, and iron ore are generally seen, though in small amount; still rarer are detrital grains of hornblende, zircon, apatite and garnet; a small part of every section is found to be made up of interstitial muddy matter that forms a cementing matrix (see Table III).

Specimen No. 356 from the Faseny Water, half a mile south of the plutonic mass, is a typical greywacke, and will be described in detail (Fig. 10).

The rock is grey in colour, and medium grained.

Quartz makes up more than 75% of the section; the grains are angular and unassorted, ranging in size from about 0.3 mm. down to less than 0.005 mm.; these unassorted grains of quartz give the rock its characteristic sedimentary texture.

Next in importance to the quartz in number and size of grains are those of various types of lava. Some of these grains are composed of a cryptocrystalline mass of felsic material, and seem to represent altered glassy or acid lavas. One or two of the larger fragments, about 0.3 to 0.4 mm. in size
size, contain minute feldspar phenocrysts in a glassy base; the feldspar is highly altered but seems to be orthoclase or acid plagioclase; these grains may have been derived from keratophyres. Others are entirely composed of an aggregate of biotitic matter, somewhat resembling altered basic lavas. Regarding the source of these grains of lavas, the Tweeddale Lavas (Eckford and Ritchie, 1931, pp. 46-47) provide a likely horizon, and some support is lent to this view by the same authors (1936, pp. 371-377) who, while discussing the "Haggis Rock" of the Southern Uplands, write: "The fragments are to all appearance keratophyres and bear a close resemblance to those found on Wrae Hill, which belong to the Tweeddale lava series" (p. 373).

A few of the composite grains consist of an aggregate of minute quartz grains, resembling altered cherty matter. Detrital biotite, chlorite and muscovite occur as small flakes, generally broken and frayed; often merely the altered shreds of the flakes remain. They show the usual optic characters; the biotite is pleochroic from X = brownish yellow to Z = dark brown; the chlorite is pale green and has faint pleochroism; the muscovite is colourless and shows its typically high birefringence. The main point to note is that the obviously detrital nature of these minerals is clearly recognisable.
Feldspars are sparsely present, and the few grains seen are highly sericitized; minute laths and roughly broken cleavage fragments are the usual forms; some appear to be orthoclase, while others retain faint traces of the original albite lamellae showing them to be plagioclase.

Grains of iron ore are sparsely scattered through the rock. Minute grains of hornblende, zircon and apatite are occasionally seen; they have been separated and are described below.

**Heavy Minerals**

The specimen described above and three other typical greywackes have been powdered, and the heavy minerals separated by bromoform (see Table I). Much of the quartz was also carried down with the heavy minerals since the quartz grains were intimately associated with iron-ore which could not be completely eliminated even by boiling in dilute hydrochloric acid. Among the heavy minerals identified in the residue were:

1. Iron ore, chiefly magnetite; 2. Green and colourless hornblende;
3. Biotite; 4. Zircon;
5. Apatite; 6. Garnet;

On the whole the results confirm the observations from thin sections that the greywackes are very poor in heavy minerals; only /
only the magnetite and hornblende are fairly common, all others being rare.

Magnetite

Magnetite occurs as irregular grains up to 0.3 or 0.4 mm. in size, with angular or sub-angular outlines. It is often in intimate association with quartz, the irregularities and re-entrant surfaces of which are lined with magnetite. By reflected light the magnetite shows its characteristic bright metallic lustre.

Hornblendes

Green hornblende is common in the residue, and is next in abundance to magnetite. It shows prismatic form, either stout and short, or slender and elongated; the prismatic ends have jagged and angular edges, while the sides, parallel to (110), are generally more regular. The size varies from less than 0.1 mm. to 0.4 x 0.3 mm., or occasionally 0.5 x 0.3 mm. The (110) cleavages are distinct; the pleochroism is X = pale green, or pale brownish green, and Z = grass green; the extinction angle $Z \wedge C$ is $16^\circ$ to $17^\circ$; optically it is positive, and hence is a variety of pargasite.

Colourless hornblende is very rare; it has the same forms as the green hornblende, but is colourless and non-pleochroic;
non-pleochroic; extinction angle $Z \wedge C$ is $16^\circ$, and the optical character is negative.

**Biotite**

Biotite is seen as cleavage flakes with roughly broken outlines, less than 0.05 to about 0.3 mm. across; the colour is dark brown.

**Zircon**

Zircon occurs as minute colourless or very pale pink prisms, often with pyramidal terminations; the length is generally 0.05 mm. to about 0.2 mm. The pyramidal ends are sub-angular, and rarely rounded.

**Apatite**

Apatite was eliminated by the acid digestion of some of the specimens. In those not treated with acid, apatite is present sparsely, occurring as sub-angular grains, generally irregular and occasionally prismatic. It is colourless, has moderate relief, and is optically negative.

**Garnet**

Only two or three grains have been seen, occurring as sub-angular irregular isotropic grains with high relief and pale pink colour.
Augite

Augite is extremely rare, but one or two grains have been seen with prismatic form, pale green colour, extinction angle $Z \wedge C$ of $47^\circ$ and marked dispersion.

Pyrite

Pyrite is seen in specimens not treated in acid. It has no crystal form, and is seen adhering in minute patches to the quartz grains; by reflected light it shows brass-yellow colour with brilliant metallic lustre.

Very little is known regarding the heavy mineral assemblage of the Silurian greywackes of the Southern Uplands, the only report available being that of W. Mackie (1928, p. 556) whose examination of the greywackes around Peebles revealed an abundance of heavy minerals in the following order:

Augite, hornblende, enstatite, zircon, garnet, sphene, a mineral reported as melanite but later said to be unidentified, glaucophane, epidote, apatite, tourmaline, rutile, pyrite, chlorite, anatase, brookite, magnetite, dolomite, fluorite, and hypersthene.

The assemblage found in the present investigation is poor both in the number of minerals and in their relative amounts, but as only a few specimens have been studied no definite conclusion is warranted at this stage.
2. Siltstones and Shales

Occasional beds of siltstones and shale, about 1 to 3 feet in thickness, occur interbedded with the massive greywackes. Specimens have been collected from the Whiteadder river on the east, from the slopes of Hungry Snout on the north-east, from the abandoned quarry near Kingside Hill on the north-west, and from the Faseny Water on the south. These specimens are dark grey to bluish grey in colour, extremely fine-grained, generally show fine lamination, and are fissile, breaking with smooth surfaces along the bedding planes. The general features in thin section are:

1. Quartz is less abundant than in the greywacke, and is rarely detectable except in the coarser siltstones;

2. A dark coloured matrix forms the larger part of the sections; most of the material is indeterminate under the microscope, but flakes of mica can be recognised, and also carbonaceous and ferruginous staining.

3. Thin elongated flakes of mica - both muscovite and biotite- are common in the matrix and arranged parallel to the bedding, so contributing to the lamination and fissility;

4. The matrix has often undergone slight reconstitution as a result of the beginning of metamorphism, giving rise to a felt of cryptocrystalline biotitic matter;

5. No heavy minerals have been seen, except one or two minute grains of zircon.
Three examples with increasing fineness of grain may now be described.

No. 384 from the slopes of Hungry Snout is a relatively coarse-grained siltstone. Quartz is plentiful—though much less so than in the greywacke. It occurs in angular to sub-angular grains up to 0.1 mm. in size. The matrix is micaceous and is extremely fine, the grain-size being 0.005 mm. or less. Biotite, muscovite and chlorite can be recognised in the matrix. Slight metamorphism has set in, as evidenced by the presence of minute sheafs of fresh-looking biotite which shows only faint brown colour with weak pleochroism. Minute rounded grains of zircon are occasionally seen.

No. 309 from the quarry near Kingside Hill is a siltstone of finer grain than the above. Quartz is less abundant than in No. 384, and reaches a grain-size of only 0.05 mm.; the grains are sub-angular. The granularity of the micaceous matrix is finer than 0.005 mm. A minute veinlet of quartz cuts this specimen, varying from about 2.5 mm. to 0.5 mm. across and sending off extremely minute branches on either side; the veinlet is composed of a quartz mosaic, the well sutured grains ranging in size from 0.5 mm. to less than 0.005 mm.

No. 381 (Fig. 11) is a shale, from Hungry Snout, a few yards from No. 384. It is mainly composed of abundant flakes /
flakes of micaceous minerals, thin long shreds with their long axes set parallel to the bedding, in a dark muddy matrix. The flakes and shreds are found to be muscovite, biotite, and chlorite in that order of abundance; these grains are all detrital, as shown by the worn and frayed outlines and alteration; they are of varying sizes, the longest reaching 0.05 mm., but the breadth is never more than about 0.01 mm. Quartz is found only as small, irregular, detrital grains. The dark, extremely fine matrix is indeterminable and may be carbonaceous or ferruginous or both.

Besides the specimens described above, No. 370, from a bed about 4 ft. thick about half a mile north of the plutonic mass, is indistinguishable from a greywacke in hand specimen, but in thin section is seen to consist of rough broken fragments of lavas, quartz and feldspars, of all sizes up to 0.4 mm., occurring haphazardly in a fine-grained matrix which has been slightly biotitized. Some of the lava fragments contain plagioclase phenocrysts in a fine-grained matrix, and others are feldspathic and quartzose mosaics. The fragments of feldspar are mostly plagioclase, the composition being about An_{40-45}, since they give an extinction angle X \wedge (010) of 25^\circ. The quartz grains are angular with broken edges. The fine-grained matrix has undergone slight reconstitution with the formation /
formation of minute flakes of fresh biotite. The nature of the fresh and angular fragments of this rock suggests that this bed might be a sediment formed almost entirely from the detritus of Arenig lavas.
VI. THE METAMORPHIC AUREOLE

General

As the plutonic mass is approached, the greywackes become indurated and hardened, and glisten with abundant flakes of biotite. The bedding is often retained in the altered rocks; and frequently the formation of fine-grained hornfels has proceeded along lenticles and patches which are arranged parallel to the strike of the country rocks, with unaltered greywackes separating them. Nearer the plutonic rocks the metamorphism has proceeded so far that the country rocks resemble the fine-grained dioritic rocks of the complex itself; in fact the hornfelses merge imperceptibly into the marginal rocks of the complex in texture and composition; and this greatly adds to the difficulty of distinguishing the boundary of the igneous complex. In the present investigation the boundary is regarded as separating (a) granodiorite which is continuous, and interrupted only by streaks and "xenolithic" inclusions of hornfelsic relics, from (b) a hornfelsic framework which is structurally continuous, though interrupted by leucocratic pods, veinlets &c.

The early stages of metamorphism

Although localised bands, lenticles and streaks of cordierite-biotite-hornfels are seen in the greywackes as far as
as half a mile from the plutonic mass, the beginnings of a general ubiquitous change in the country rocks can be traced only to about 450-500 yards from the plutonic margin. Beyond this distance the greywackes (apart from the above-mentioned bands and streaks) are free from signs of metamorphism, even close to the cordierite-biotite-hornfels patches themselves; but from about this distance a gradual change takes place. The greywackes are still barely distinguishable from the unaltered rock in hand specimen, but the microscope reveals the development of minute biotite flakes in the muddy matrix of the original rock. At this stage the biotite shows no clear outlines; the thin wisps and shreds of biotite are oriented parallel to the bedding planes, and for the most part is too minute to be clearly distinguished. The slightly larger flakes show intense pleochroism from $X = \text{brownish yellow}$ to $Z = \text{dark reddish brown}$. Such slightly altered greywackes are exposed on the slopes of Friars' nose near the Whiteadder water east of the plutonic complex (No. 357, 358), near Craigknowe on the Faseny Water (No. 361), and along the Faseny Water south of the complex (Nos. 120, 121, 131).

**Development of Biotite-hornfels**

Increase in the amount of biotite nearer the margins marks increasing intensity of the metamorphism. The biotite gradually /
gradually develops into slightly larger flakes; many minute flakes grow in crystallographic alignment, forming the framework of skeletal crystals; others form clusters wrapped around the clastic quartz grains; the larger flakes of biotite are often oriented parallel to the planes of bedding. Simultaneously there is a marked increase of iron ore which forms specks and small clots among the growing biotites; specimens No. 126 from the Faseny Water 100 yards south of the complex, and No. 91 from near the south margin of the complex, both illustrate this stage of metamorphism clearly. These two rocks are dull grey in colour, medium-grained, and essentially like the greywacke in the field, except for the glistening of the small flakes of biotite. In thin section the rocks are seen to retain the texture of the greywacke; the quartz grains vary in grain size from about 0.05 mm. to 0.3 mm., while the biotite crystals vary from mere specks to about 0.1 mm.; the biotite is similar in colour and pleochroism to that of the slightly altered greywackes (p. 34), and has refractive index \( \rho = 1.642 \) (see Table II and Fig. 5).

A. Biotite-hornfels

Still nearer the plutonic rocks biotite becomes extremely abundant, feldspars begin to appear, and the texture of the /
the rocks of the aureole becomes typically hornfelsic. Specimens Nos. 144, 145, 135, 137 and 312, all from 50 to 100 yards south of the granitic complex along the river Faseny, represent good developments of biotite-hornfels. These rocks are intermediate in appearance between typical greywacke and fine-grained igneous rocks; the granular appearance of the greywacke is still seen, but the abundant biotite shows their altered nature clearly.

In thin section the hornfelsic mosaic consists of abundant quartz and biotite (Figs. 12, 14); in No. 145 mafic minerals - almost entirely biotite - form 38% of the rock (Table III, 4), while the quartz and feldspars amount to 54% (Table IV) in contrast with the 75% of quartz found in the unaltered greywackes. Besides quartz and biotite, very small amounts of plagioclase and orthoclase have formed; among accessory minerals iron ore is common, and zircon is found rarely, often only as very minute inclusions in the biotite. Heavy mineral separation also revealed (Table I) the presence of green hornblende, as in the greywackes, and rare pyroxene.

\textbf{Biotite} varies in grain size from very minute crystals up to 0.2 mm.; often aggregates of minute flakes in decussate arrangement measure as much as 0.4 or 0.5 mm.; the biotite frequently /
frequently wraps round the quartz grains, and occasionally grows through the quartz, cutting across the margins of neighbouring quartz grains. The biotite tends to develop good basal planes and cleavages, but the flakes lack well-developed crystal boundaries; pleochroic haloes round minute included zircons are common. The pleochroism is $X = \text{light brownish yellow}, Y = \text{reddish brown}, Z = \text{dark reddish brown}$; refractive index $\gamma = 1.644$ (Table II).

Quartz begins to lose its elastic appearance; the smaller grains tend to coalesce, and the slightly rounded larger grains have formed from smaller grains which faintly retain their original angular appearance. Biotite, and to a less extent feldspar, not only grow around the quartz grains, but also partly replace the original edges of the quartz. The biotites wrapping round the quartz sometimes cut off the more angular edges; biotite flakes are also seen growing into the quartz from outside. Feldspar forms irregular patches within the margin of the quartz, and often grows as embayments into the quartz which thus acquires the crenulate outlines seen in thin section.

Plagioclase grows as isolated porphyroblasts (Fig. 13), of lath-like or tabular form, the margins being sometimes irregular /
irregular. Albite twinning is common, and zoning is occasionally seen. Inclusions of flakes of biotite and patches of indeterminable matrix commonly occur in the plagioclase. The refractive index of the plagioclase, determined on (001) plates, showed the value of \( \gamma \) ranging from 1.549 to 1.557 (giving a mean of 1.553); this corresponds to a range of composition from \( \text{An}_{25} \) to \( \text{An}_{40} \), with an average bulk composition of about \( \text{An}_{33} \).

**Orthoclase** is generally much less in amount, and less well-developed, than the plagioclase. It has very irregular outlines, and grows between or along the margins of the quartz grains and occasionally also as isolated crystals; inclusions of biotite flakes or minute portions of the muddy matrix showing incipient reconstitution are common within the newly formed crystals of orthoclase.

The occurrence of iron ore and other heavy minerals has already been mentioned. It will be noticed from Table I that iron ore has increased in amount as compared with the unaltered greywackes; the hornblende has the same characters as the green variety found in the greywackes, but the colourless variety has not been met with.
B. Fine-grained Biotite-hornfels

In the biotite-hornfels described above the grain-size averages about 0.1 mm., the texture is hornfelsic, and the biotite tends to develop a decussate structure. Though this is the characteristic type of hornfels in the aureole, a different variety is developed locally on the north side of the plutonic rocks along the Whiteadder river; on the north-west between Kingside Hill and Penshie Hill; on the south-west corner, on the slopes of Penshie Hill; and on the east side along the Whiteadder river. Specimens Nos. 172, 182, 243 and 346 from the north; 309 from the north-west; 18 from the south-west corner; and 377 from the east side are examples of this type. Their general appearance, and the association with shale bands along the same strike indicate that they are formed from the fine-grained shaly bands in the country rocks; further, some of them - Nos. 182 and 346 particularly - look like compact shale with bedding planes clearly visible. All these rocks are very similar under the microscope; their grain-size averages 0.05 mm. or less; conspicuous banding due to the special abundance of biotite along parallel layers is present in all cases, and in some can be identified as the original bedding planes, since their strike is parallel to that of the country rocks in the field. The grain is notably uniform, and
and the texture hornfelsic. Biotite and quartz make up most of the rock, with small amounts of feldspars, cordierite, iron ore and apatite; tourmaline is sparsely present in No. 377. A photomicrograph of No. 172 is given in Fig. 15.

Biotite is irregular in form, though a tendency is seen to develop into rectangular flakes with elongation parallel to the banding; it is generally the reddish brown variety with pleochroism \( X = \) brownish yellow \(< Z = \) dark reddish brown except in No. 18 where the greenish brown variety with \( X = \) pale yellow \(< Y = \) greenish brown \(< Z = \) dark greenish brown is common; the refractive index of the biotite in No. 18 is found to be \( Y = 1.645 \) (Table II). Inclusions of iron ore are frequent in the biotite; pleochroic haloes are common though not abundant.

Quartz forms an even-grained mosaic, generally with rounded or crenulate margins; it is relatively more abundant than biotite in the biotite-poor bands, and less abundant in the biotite-rich bands.

The feldspar is mostly orthoclase, growing as irregular blebs and patches; some plagioclase occurs, but this has not been accurately determined for want of clear crystal form and twinning.
Cordierite, colourless, and showing weak birefringence, is generally present. It forms vague patches, often crowded with innumerable flakes of biotite. Twinning is rare.

Tourmaline has been seen only in No. 377. It shows a grain size from 0.01 mm. to 0.05 mm.; the form is prismatic without proper crystal faces at the terminations, or irregular with no crystal faces at all. The pleochroism is $X = \text{very pale brown} < Z = \text{yellowish brown}$; the elongation is negative, and birefringence moderate.

Iron ore is well distributed, and becomes abundant in some sections.

Apatite is common as minute rounded grains, or rectangular laths, pale blue or colourless.

Zircon is seen occasionally as minute square or prismatic sections.

Heavy Mineral separation of No. 18 has been carried out, but only a very poor crop was obtained (Table I). Acid-digestion combined with the extremely fine grains probably destroyed all the iron ores and apatite. But tourmaline with the same characters as described in section No. 377 was found, and /
and also a few grains of green hornblende; as the heavy mineral separation of a shale was not successful, no comparison is possible.

G. Cordierite-biotite-hornfels

Development from fine-grained biotite-hornfels. The fine-grained biotite-hornfels is seen to grade into a variety rich in cordierite in specimen No. 346, from the exposures on the banks of the Whiteadder Water, a quarter of a mile north-north-west of Kingside School. This specimen is extremely fine-grained, and in thin section resembles the other fine-grained biotite-hornfels already described. But two bands of slightly coarser grain are present in the section; and also two bands which are rich in cordierite. The cordierite-rich bands grade laterally into the normal biotite-hornfels of the rest of the section (Fig. 16).

The biotite is the reddish-brown variety; it varies in grain size from indistinguishably minute flecks occurring in clots to more discrete forms about 0.03 mm. long. Except for the biotite, some of the quartz, and specks of iron ore, the rest of the section is a cryptocrystalline matrix in which individual minerals cannot be recognised. But in the coarser bands more of the quartz, some orthoclase, and spots of cordierite /
cordierite are visible. Towards the cordierite-rich bands, however, the cordierite rapidly increases in grain size to 0.08 mm. The cordierite has vague outlines, often forming irregular patches; it is littered with inclusions of biotite flakes, and minute patches of the matrix; the cordierite is colourless or is a very pale blue; no twinning is seen, and it gives a spotted appearance to the rock under low magnification. Rarely subhedral crystals of cordierite showing prismatic or basal sections occur sandwiched between biotite, quartz and iron ore. Accessory iron ore is dispersed through the rock; occasionally a light yellow stain is found spread over small areas of the slice; this is apparently the stain left when small quantities of limonite or other ferruginous matter in the original sediment are dehydrated by the metamorphism of the rocks.

**Occurrence in the greywackes.** Essentially similar to this band of cordierite-biotite-hornfels are the exposures of the aureole-rock found along the Faseny Water south of the granitic complex. These exposures are invariably found as intercalations between the beds of unaltered or slightly altered greywackes; they vary in thickness from a few inches to as much as 25 feet. While the thick beds, e.g. those of more than a few feet thick, are very persistent along the strike /
strike, the very thin intercalations are generally patchy, irregular and often are merely lenticles or lenses enclosed by the greywackes; even the larger masses of the cordierite-biotite-hornfels often enclose small stringy patches, or lenses elongated parallel to the strike, of coarser grained greywacke, unaltered or but slightly biotitized. It is worth noting that this patchy development of cordierite-biotite-hornfels does not seem to have been due to any patchiness or lithological variation in the sediments; where the patchiness occurs in abundance, the greywackes are found as massive beds on either side along the strike, and even shale partings are entirely lacking in that part of the area. The only explanation seems to be that the metamorphism is irregular and patchy in distribution, and the great significance of this point is discussed fully in a later section of the thesis (p. 148).

The outcrop of cordierite-biotite-hornfels farthest from the plutonic mass occurs about half a mile south of the complex; two specimens were collected from a 25 foot bed of the cordierite-biotite-hornfels which here strikes across the Faseny Water (Nos. 359, 360). About 300 yards farther northeast, down the same river, lenses of the rock were found in the greywackes (Nos. 342, 343, 344); three other specimens (Nos. 20, 250, 253) are from other scattered occurrences along the /
the banks of the same stream, all on the south side of the granitic complex.

**Petrography.** Cordierite-biotite-hornfels is extremely fine-grained, and has a bluish-black colour in hand specimen. Under low magnification it shows small spots of cordierite scattered through an extremely fine-grained biotite groundmass (see Figs. 18, 19). Under higher magnification the crystals of cordierite, crowded with inclusions, are seen to be set in a hornfelsic matrix largely formed of biotite. Besides cordierite and biotite, the only other determinable constituents of the rock are accessory quartz, iron ore and apatite.

Fresh, colourless cordierite, roughly hexagonal or oblong in form, comprises about a third of the section; the grains are rather uniform in size, each measuring up to 0.08 mm across. The mineral occurs as single individuals or as clusters of three or four with common margins; cleavage lines are rarely seen; twinning is commonly seen on sections parallel to (001) but is never sharp and clear-cut. All the crystal of cordierite are crowded with inclusions of biotite, iron ore and apatite. The biotite of the inclusions has the same characters as that of the rest of the rock, though often they are slightly smaller and less well-developed;
The apatite occurs as minute prisms and grains, has a faint pleochroism from \( Z = \) colourless to \( X = \) pale blue, and itself contains minute black specks, probably iron ore, as inclusions. Pleochroic haloes are rarely seen round the included apatites, and, when seen, are very faint. The iron ore included in the cordierite shows up prominently as opaque black grains and specks. There is a marked concentration of the iron ore content of the rock in the cordierite, since in comparison with that in the cordierite the iron ore dispersed through the matrix is in much smaller proportion.

The matrix surrounding the cordierite is predominantly composed of biotite, which is closely crowded, the grain size averaging about 0.01 mm.; the irregular and ill-defined flakes give the rock its characteristic hornfelsic texture. The biotite is the common brown type, pleochroism being \( X = \) pale yellow, \( Y = Z = \) dark brown. Inclusions are rare in the biotite.

Quartz is seen as very minute sub-angular or rounded grains and also as small irregular patches between the other minerals.

Thin prisms of apatite, similar to those included by the cordierite, are common in the matrix. Iron ore is seen in the matrix, but, as already stated, its concentration is much /
much less than in the cordierite.

A small percentage of the matrix is composed of indeterminable matter which may be a remnant of the finest muddy material of the original sediment.

The small lenses of greywacke enclosed by the cordierite-biotite-hornfels (Fig. 17) are similar to the slightly altered greywacke, very rich in angular grains of quartz, with biotite beginning to develop between the quartz grains.

D. Pyroxene-bearing Granulite

About 450 yards south-south-east of Priestlaw farm, just near the margin of the granitic rocks, a highly interesting rock is found in situ; it shows traces of bedding with the strike corresponding to that of the country rocks; but the brownish grey medium-grained rock that at first looks like a greywacke is seen on closer examination to have an "igneous" aspect, feldspar and biotite showing clearly through a hand lens. It is apparently a highly altered representative of the country rocks.

The thin section (No. 6; Figs. 20, 21) reveals a well-developed granulitic texture; more than 75% of the section consists of feldspars - mainly plagioclase with subsidiary orthoclase /
orthoclase - and the rest is made up of biotite, pyroxenes, iron ore, and accessory quartz and apatite. Occasionally grains of quartz with angular outlines are seen, and rarely a few grains of quartz retain the initial sedimentary texture; these relics, together with the bedding and the geological setting, obviously indicate a sedimentary origin for the whole rock. Now, however, almost all the original quartz of the parental rock has been used up in the formation of plagioclase, biotite and pyroxenes.

Plagioclase forms subhedral laths and tabular grains; cleavage lines are distinct; albite twinning is common, and pericline twinning rare; zoning is not very common, and where present is simple, the composition ranging from An$_{55}$ in the core to An$_{30}$ at the margins, as determined by the maximum extinction angle $\angle O10$ in zones perpendicular to O10. Some of the larger grains (about 0.5 mm. across) of plagioclase show mosaic structure, many differently oriented parts going to make up the whole crystal, and the different parts of the mosaic vary in composition - and hence in optical properties - through a range similar to that of the plagioclase of the section generally. Inclusions are abundant in the plagioclase, and commonly consist of minute scattered crystals of biotite, hypersthene, augite, apatite and iron ore. In some cases the inclusions are mere black specks, irresolvable microscopically, but possibly attributable to iron ore.
ore. There is no tendency for the inclusions to be arranged parallel to the margins or to the crystal-directions of the plagioclase.

Orthoclase is very small in amount. It is anhedral and occurs interstitially or on the margins of the plagioclase, which it invades and so appears partially to replace.

Biotite is better developed than in the hornfelses, most of the flakes having clear-cut basal planes; skeletal habit however, is very common, neighbouring isolated flakes often sharing the same optical orientation. Occasionally the biotite encloses, or has grown on the fringes of augite grains. Inclusions of iron ore are abundant in the biotite, and pleochroic haloes are common. The biotite is the common brown variety, with pleochroism $X = \text{straw yellow}; \ Y = \ Z = \text{dark brown}$, and $\gamma = 1.643$ (Table II). Many of the biotites contain streaks parallel to the cleavage, or small unoriented areas of dark reddish brown colour, which occasionally show pleochroism from $X = \text{dark reddish brown}$ to $Z = \text{very dark reddish brown}$.

Pyroxenes: Both rhombic and monoclinic pyroxenes are present. They occur as scattered grains of about 0.05 mm. average size, with a few crystals as large as 0.5 mm. across. While most of the grains are anhedral or show only rough crystal forms, a few have good prismatic form; sieve structure is prominent, inclusions of iron ore being common.
The monoclinic pyroxene is the more common; it is colourless or shows a pale green tint, is occasionally twinned, and has an extinction angle (Z \( \wedge C \)) of 45°. These properties suggest that it is a diopsidic augite.

The rhombic pyroxene has a very pale yellowish brown colour; pleochroism is very faint, being \( X = \) pale yellowish brown < \( Z = \) pale brown. It is optically negative, but sections parallel to the optic plane give a nearly straight isogyre. It is thus a hypersthene, with probably a low content of FeSiO₃.

Quartz occurs interstitially, without definite forms. The relics of sedimentary quartz have already been mentioned (p. 48).

Iron ore, as already noted, is scattered as inclusions in other minerals, or occurs amongst the different minerals as small or large grains.

Apatite as minute needles or prisms is fairly common.

Heavy Mineral separation yielded (Table I) in addition a few prisms of a green hornblende, similar to that of the greywacke, and rare grains of zircon.

Comparison with other areas:

Diopside- or augite-hornfels of the above type has been described from the metamorphic aureoles of many granitic complexes. Of these the high-grade hornfelses associated with the Griffel-Dalbeattie /
Dalbeattie mass (M. MacGregor, 1937, p. 470) and the augite-hornfels of the Newry area (D.L. Reynolds, 1934, p. 601; 19434 p. 235, 255) seem to resemble the Priestlaw occurrence. But while in the former areas calcareous sediments occur in the country rocks, no calcareous bands have been found in the greywackes of the Priestlaw area. Nevertheless, the evidence as to their formation from sediments is clear in all cases; and addition of alkalis and alumina has been suggested by both Reynolds (1934, p. 604) and MacGregor (1937, p. 470) to account for the difference in composition between the hornfelses and the original sediments. In the present instance the following points indicate that here, too, there have been definite changes in chemical as well as mineral composition:

1. The extreme abundance of feldspars, especially plagioclase;
2. The freshly developed biotite, augite and hypersthene;
3. The increase in iron ore and apatite;
4. The great reduction in the amount of free quartz.

To effect these changes addition of Na$_2$O, K$_2$O, CaO, Al$_2$O$_3$, FeO, Fe$_2$O$_3$ and P$_2$O$_5$ and probably also F must have been necessary; these constituents would inevitably combine with most of the free silica. As discussed in the section on petrogenesis (p. 148) it is here assumed that these constituents were made available by chemical migrations from the neighbouring zone of granitization.
E. Marginal Dioritic Rocks

Near the margin of the plutonic complex there occur fine-grained, grey, "igneous"-looking rocks that are not easily placed on one side or the other of the boundary. Using the criterion mentioned on page 33 they are mapped as part of the aureole.

Microscopically these rocks resemble both the pyroxene-bearing granulite, which is undoubtedly formed in situ from the sediments, and the fine-grained quartz-diorite inside the complex itself, and probably represent an intermediate stage in the formation of "igneous" rocks from the granulitic and hornfelsic types of sedimentary derivation.

Three specimens of the marginal dioritic rocks have been sectioned:

No. 4 from near the extreme eastern margin of the complex;

Nos. 11 and 17 from the south-west corner.

These sections are somewhat similar to the pyroxene-bearing granulite in texture and mineral composition; the main differences noticed are:

1. The increase in size of the plagioclase which occurs as porphyroblasts measuring 2 - 3 mm. in the longer direction (well seen in Nos. 17 and 11, and less so in No. 4);

2. The occurrence of hornblende which has apparently grown largely at the expense of the pyroxenes; and
3. The increased abundance of orthoclase which occasionally forms poikiloblastic plates enclosing the other minerals, and is therefore interpreted as a replacement product.

Corresponding with these differences there is a coarsening of grains; the average grain-size of the groundmass is about 0.2 mm. in No. 4 and about 0.4 mm. in the other two.

In hand specimen these rocks are "igneous"-looking, and intermediate in colour and grain size between the granulite already described (p. 47) and the fine-grained quartz-diorite to be described later (p. 87). They are composed of abundant plagioclase with biotite and hornblende as the main mafic minerals, and orthoclase, occasional quartz, iron ore and apatite in no more than accessory amounts. The texture is markedly crystalloblastic and slightly porphyroblastic (Figs. 22, 23).

Plagioclase occurs as laths and tablets; the larger crystalloblasts show the usual square and oblong outlines; mosaic and sieve structures are very common in the larger crystals. Both albite and carlsbad twinning are general. Zoning is occasionally seen, and the composition ranges from about An₅₅ at the core to An₃₀ at the rims. The maximum extinction angle $X \angle 010$ in the zone perpendicular to 010 varies in different crystals of the plagioclase from 12° to 25° showing variation /
variation in composition from about An30 to An45. Some of the plagioclase also shows a later growth of slightly more sodic feldspar round the margins, which gives an extinction angle $X \wedge 010$ of about $4^\circ$ to $5^\circ$ indicating oligoclase, about An25. This oligoclase rim is clear and fresh, whereas most of the plagioclase has been partially altered to a brownish clayey material.

Biotite forms well-defined flakes and highly skeletal crystals; it is often intergrown with hornblende, commonly with one or other cleavage of the latter being coincident with that of the biotite. Chlorite is sometimes associated with the biotite as marginal growths or replacements, or as patches in the biotite. Sometimes the biotite has grown around feldspar grains, or has included small patches of the groundmass. The biotite has marked pleochroism with $X =$ brownish yellow $< Y =$ dark brown $< Z =$ very dark brown; refractive index is $\gamma = 1.641$ (Table II). Inclusions of iron ore are very common; pleochroic haloes are often seen, though the central inclusions are too minute to be determined.

Hornblende has the usual prismatic and terminal outlines; it is often associated with biotite; skeletal crystals, aggregates or clots of differently oriented individuals, and patchy crystals are quite common. Occasionally the hornblende encloses /
encloses relics of pyroxene, or is itself pseudomorphous after pyroxene. Colour and pleochroism are variable, and the extinction angle $Z \wedge C$ varies with the different types, as well as within each type:

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>$Z \wedge C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Green</td>
<td>Dark green</td>
<td>15 - 21°</td>
<td></td>
</tr>
<tr>
<td>Brownish green</td>
<td>Brownish green</td>
<td>Dark olive</td>
<td>22 - 25°</td>
<td></td>
</tr>
<tr>
<td>Colourless</td>
<td>Yellowish green</td>
<td>Dark green</td>
<td>26 - 28°</td>
<td></td>
</tr>
</tbody>
</table>

In No. 17 the hornblende is occasionally associated with epidote, which shows prismatic form, elongated parallel to the $b$-axis which is the $Z$-direction; the colour varies from $X$ = yellowish green, $Y$ = pale green, to $Z$ = bluish green or greenish blue; the extinction ($Z \wedge b$) is straight or about 4° to 5°, and the birefringence high.

**Orthoclase** is present only in small amount; it grows interstitially, and occasionally forms poikiloblastic plates enclosing laths of plagioclase, flakes of biotite and grains of amphibole.

**Iron ore** is concentrated mostly in the mafic minerals as inclusions in them, or occurring between the individual grains of clusters. But sometimes the ore is scattered as small or large grains amongst the feldspar, or even inside the feldspar, as seen in No. 4, and here the resemblance to the pyroxene-granulite /
granulite is remarkable.

Apatite is fairly common, and is often enclosed by the mafic minerals or by the plagioclase.

F. Variation of the biotite-hornfels towards granodiorite

General

Close to the margin of the complex the biotite-hornfels becomes further enriched in biotite, and begins to develop patches, pods and veinlets of quartzose or quartzo-feldspathic material; simultaneously the sedimentary mosaic of quartz is replaced by recrystallized granulitic aggregates of quartz. At and near the contacts of the granodiorites with the country rocks, this development of leucocratic material in the hornfels has reached such an extent that the aureole rocks have the appearance of mixed rocks, with granitic material occurring in very irregular veins, patches, enclosed pods, and minute lenticles, distributed all through the fine-grained dark hornfels. With the development of porphyroblasts of plagioclase in the pods and in the surrounding hornfels, the "mixed" rocks gradually become homogeneous, the volume of the biotite-rich hornfels is progressively reduced, and the aureole rocks grade into the normal biotite-granodiorite of the complex. In the isolated pods and veinlets still enclosed by the biotite-hornfels, the formation of plagioclase porphyroblasts leads to the development of /
of a rock-type exactly similar to the biotite-granodiorite. In the north-east margin of the complex, about 300 yards north-east of Kingside School, it can be seen that the biotite-hornfels, already highly enriched in biotite, develops granodioritic pods, which occupy an increasing volume of the hornfelsed country rocks as the contact is approached, where they merge into the normal granodiorites of the complex. Inside the complex, near the contact, inclusions of the hornfelsed country rocks are common, similar to the hornfels just outside the complex, even to the presence within the inclusions of felsic veins and pods. There is thus ample evidence in favour of the view that the granodiorites represent the final stage of the alteration of the country rocks in situ, the changes involving introduction and fixation of the alkalis and other bases necessary for the development of the rocks of the plutonic complex itself, together with concomitant driving out of materials destined to bring about within the aureole the mineralogical changes that have already been described.

Exposures of hornfelsic rocks containing such leucocratic pods, veins, lenticles &c. occur on Penshiel Hill on the west, near Kingside Hill on the north-west, on Summer Hill on the north, and at the base of Hungry Snout on the north-east. The series of dykes on the south, and the mantle of glacial drift /
drift on the south-east and south-west preclude any possibility of such contacts being seen in those localities. The best examples of these pods, showing the hornfels grading into true granodiorite, were obtained only after excavation (see Fig. 2) had been made near the contacts on the sides of Summer Hill.

The general characters of these interesting rock-types found in the pods &c. can be summarised as follows:

1. The coarsening of texture of the relics of the ancestral biotite-rich hornfels, accompanied by growth of quartz granules;

2. The decrease of biotite in the replacement pods &c., and its concentration along the rims of the newly-forming pods and veinlets;

3. The extreme abundance of pleochroic haloes in the biotites at this stage; such abundance of haloes is never seen in the biotite either of the hornfels or of the plutonic rocks away from the contact.

4. The mosaic-structure, small enclosures of hornfelsic or biotitic matter and occasional oscillatory and gradational zoning of the porphyroblasts of plagioclase;

5. The replacement of biotite by plagioclase as indicated by the crenulate margins of the biotite;

6. The development of potash feldspar, which often grows on the margins of the plagioclase, and the increase of quartz which forms embayments into the feldspars or builds poikiloblastic plates;

7. The general coarsening of texture leading to the development of the characteristic granitic texture which gives the resulting rock a typically granodioritic aspect.
The typical examples to be described fall into three groups:

1. **Exposures outside the west and north-west margins of the complex; e.g. on Penshiel Hill (Nos. 196, 301-306) and Kingside Hill (No. 308);**

2. **Exposures on the contact between the granodiorites and the country rocks; e.g. on Summer Hill (Nos. 315-320, 324, 325);**

3. **Exposure near the eastern margin of the complex; e.g. at the foot of Hungry Snout (Nos. 205, 210, 212).**

**1. Exposures on Penshiel Hill**

About 100 yards west of the western margin of the complex, and directly west of the ruins of Penshiel Tower, hornfelsed greywackes are exposed. Though most of the mass shows little sign of bedding, here and there dark banding is seen which is obviously a relic of the original bedding, as shown by its conformity with the general strike of the country-rocks and the roughly vertical position. The rocks appear fine-grained and dark grey in colour, like the high grade hornfels in other exposures, but they contain

(a) coarser-grained and slightly lighter-coloured patches and streaks, from about 1 mm. to 8 or 10 cm. across, occasionally appearing as parallel bands, but often quite irregular in distribution; and

(b) /
(b) disconnected leucocratic pods and lenticles from 1 cm. to about 5 cm. across, sometimes with sharp margins against the hornfels, and sometimes with more diffuse margins, and occasionally sending out minute veinlets into the hornfels.

Where bedding is visible, the rock often breaks parallel to the bedding plans and the broken surfaces are found to be coated with a thin layer of relatively coarse leucocratic quartzose and biotitic matter.

In thin section (Nos. 301-306, 196), it is seen that in the hornfelsic parts the abundance of reddish-brown biotite in decussate arrangement (Fig. 24), with abundant pleochroic haloes, is striking; quartz as a granulitic mosaic is plentiful; plagioclase and orthoclase are present; and apatite and iron ore are common accessories. The percentage of mafic minerals is 44, mostly biotite, showing further basification as compared with biotite-hornfels away from the margin (Table III; 8, 4).

The derivation of the hornfels from greywackes is very clearly shown by the preservation of relics of sedimentary quartz-mosaic, and the occasional presence of larger quartzose or feldspathic grains which resemble those noted in the greywackes.

The leucocratic pods are found to consist of the same minerals, but here quartz is the most abundant mineral and is responsible for the light colour of the pods, while the biotite, though growing into larger flakes, has decreased in amount. Feldspars have grown larger, but do not seem to have increased in /
in amount. The percentage of mafic minerals has come down to 25, indicating a change of composition towards granodiorite (Table III; 9). The grain-size is relatively larger than in the hornfels, and the texture tends to be granoblastic though the decussate structure of the biotite is often retained. The boundary between the hornfels and the pods is never very sharp; one grades rapidly into the other, with change in grain-size.

**Biotite**

(a) **Hornfels.** The biotite shows good 001 faces, and in its strong pleochroism from $X = $ brownish yellow to $Z = $ deep reddish brown resembles that of the biotite hornfels in other exposures. It differs, however, in its being crowded with pleochroic haloes surrounding inclusions of zircon; the refractive index is also different, being $\gamma = 1.650$ (Table II).

(b) **Pod.** The biotite forms larger flakes than in the hornfels; but the decussate structure is less prominent. The optical properties are similar to those of the biotite of the hornfels.

**Quartz**

(a) **Hornfels.** The quartz is generally of irregular outline, and rarely shows square or hexagonal outlines. Relics of sedimentary texture are occasionally seen, and angular grains like /
like those of the greywackes are sometimes met with.

(b) Pod. The quartz has grown into larger plates, sometimes poikiloblastically enclosing biotite and feldspars. Occasionally the quartz forms embayments into biotite flakes which then show crenulate margins towards the quartz. Quartz is more abundant in the pods than in the hornfels.

**Plagioclase**

(a) Hornfels. The plagioclase occurs as laths or tabular grains, some of which embay the biotite, while others are surrounded by minute flakes of biotite. Inclusions of biotite flakes are occasionally seen in the plagioclase. In different crystals the plagioclase varies in composition from about An₃₅ to An₄₅. Zoning has not been seen.

(b) Pod. In the leucocratic patches plagioclase has grown into larger plates and tabular grains, often with well-developed crystal faces. Combined Albite and Carlsbad twinning is commonly seen. The composition of the plagioclase ranges from An₃₅ to An₄₅. Gradational zoning is occasionally seen, varying from An₅₅ at the core to about An₃₀ at the margins.

**Orthoclase**

(a) Hornfels. Orthoclase is seen in small amount, occurring as interstitial patches.

(b) Pod. Orthoclase has increased in amount, and occurs in interstitial patches and as rounded blebs or crenulate embayments on the margins of the plagioclase.

Apatite /
Apatite

(a) Hornfels. Apatite is more abundant than in the leucocratic areas. It occurs as minute prisms and grains; it has a very pale blue colour, but is not pleochroic. Minute black specks, probably iron ore, are sometimes seen as inclusions in the apatite.

(b) Pod. Apatite has decreased in amount, but has the same characters as in the hornfels.

Iron Ore

(a) Hornfels. Minute grains of iron ore are scattered through the rock, and sometimes included in the biotite.

(b) Pod. Iron ore is very much less plentiful than in hornfels, but shows the same characters.

Exposure on Kingside Hill

Outside the north-west margin of the complex, on the north side of the main road, biotite-hornfels showing similar pods and veinlets occur in a small exposure. One thin section (No. 308) resembles the type already described in having biotite-rich hornfelsic material enclosing relatively coarser-grained quartz- and feldspar-rich pods, lenticles and veinlets which show clear evidence of derivation from the hornfels.
2. Exposures on Summer Hill

General Statement

On the slopes of Summer Hill about 300 yards north-east of Kingside School, several boulders and much loose debris of biotite-hornfels, crowded with large and small pods, lenticles and veins of granitic material, were found. As the approximate margin of the complex had been found to run from north-west to south-east in the vicinity of this spot, an excavation of from two to three feet deep was made to remove the grass-covered soil and mantle debris. As the contact was reached, it was found to be very irregular; the granodiorite occurring as pods, veins and lenticles of all sizes from 1 cm. or less to about 50 cm., sometimes connected by veins to the main granodiorite, but more often isolated within the countryrocks, and surrounded on all sides by the hornfels. Within the granodiorite hornfels was found occurring as (a) thin streaks generally parallel to the regional strike, (b) inclusions of the "xenolith" type, often elongated parallel to the general strike direction, and (c) minute diffuse areas of hornfelsic matter, generally less than 0.5 cm., that seems to have been largely made over to granodiorite.

The various stages in the formation of typical granodiorite from hornfels can be clearly followed by studying a series /
series of leucocratic pods and patches representing intermediate steps in the progressive transformation:

1. The biotite-hornfels is enriched in biotite, and the grain-size may be increased;

2. Minute quartzose patches with subsidiary biotite and feldspars, coarser in grain than the hornfels, are formed in the biotite-enriched hornfels;

3. Plagioclase increases rapidly in the quartzose patches as well as in the surrounding hornfels; this leads to the development of leucocratic pods characterised by porphyroblasts of plagioclase of variable composition, with subsidiary biotite and quartz; such pods still contain relics of the hornfelsic mosaic.

4. Further increase in grain-size, development of orthoclase, and the more or less complete obliteration of the hornfelsic relics, lead to the formation of a biotite-granodiorite similar to that of the main part of the complex.

**Biotite-enrichment of the hornfels**

Where leucocratic pods and veinlets begin to form, the biotite-hornfels is first considerably enriched in biotite. Near the contacts in the exposures on Summer Hill a normal biotite-hornfels, No. 315, with about 37% mafic minerals (mostly biotite, dark brown variety with $\gamma = 1.642$) and similar to the biotite-hornfels previously described (No. 145, p. 36) passes within three inches into a biotite-rich type - No. 316 - with 46% biotite (mafic minerals 48%, see Table III).

In this basified hornfels, the biotite occurs as ragged flakes in hornfelsic arrangement with average grain-size of /
of about 0.1 mm.; pleochroic haloes are abundant; the pleochroism is strong being $X = \text{brownish yellow}$, $Z = \text{dark reddish brown}$; and refractive index $\gamma = 1.643$. The quartz is variable in form, occurring as sub-angular grains or irregular patches, and often granulitic in habit. Plagioclase lacks good crystal form, is generally unzoned, and different individuals have widely variable composition, the range being from about An$_{45}$ to An$_{30}$. Orthoclase is occasionally present as interstitial patches. Apatite is a common accessory, as minute prisms and grains, and is colourless and non-pleochroic. Granules of iron ore are scattered through the rock.

**Quartz- and Feldspar-enrichment of the basified hornfels**

The biotite-enriched and hence relatively basified hornfels described above contains numerous minute veinlets and thin streaks of leucocratic matter, often roughly parallel with the regional strike, but occasionally cutting across it. Most of these veinlets are less than 0.2 mm. broad, but they widen out in small areas or spots to 4 to 5 mm. across; the texture is relatively coarser than that of the hornfels, grain-size averaging about 0.2 to 0.3 mm. These leucocratic veinlets and streaks are richer in quartz than the enclosing hornfels; the biotite is less in amount; plagioclase and orthoclase have increased; and apatite and iron ore have decreased relative to the hornfels.
The quartz forms a granulitic mosaic with well-satured grains. The biotite is of essentially the same type as that in the enclosing hornfels, reddish brown in colour with marked pleochroism, and with abundant pleochroic haloes. The plagioclase tends to develop good crystal form, and the variation in composition from one individual to another, though the same range as in the hornfels, is still a notable feature. Orthoclase forms interstitial patches and sinuous grains.

A few inches nearer the main granodiorite of the complex the basified hornfels is more and more riddled with these leucocratic patches, spots, pods and veinlets. Nos. 317, 318 and 319 collected within a few inches of each other and serially approaching the granodiorite of the complex, show the gradual increase in the volume occupied by the leucocratic material until in No. 319 the hornfelsic relics are no longer continuous, but have been cut up into isolated portions. Porphyroblasts of plagioclase develop abundantly in these pods and the grain-size of the biotite, quartz and orthoclase also increases; simultaneously the hornfelsic mosaic is completely destroyed, giving place to granitic texture; the pod thus becomes a typical biotite-granodiorite (Figs. 25 - 29).

The plagioclase grown to a size of 1.5 mm. and occasionally 2 mm.; it shows good prismatic form; combined Albite and /
and Carlsbad twinning is very common; both quartz and biotite show crenulate margins against the plagioclase which embays these minerals. Biotite flakes, quartz grains, or minute areas of the hornfelsic matrix occur as inclusions. The plagioclase shows wide variation in composition from one individual to another, a number of determinations of the extinction angles \( X \wedge 010 \) and \( Z \wedge 001 \) giving a range of composition from \( \text{An}_{45} \) to \( \text{An}_{30} \); occasional zoning, gradational from \( \text{An}_{50} \) at the core to about \( \text{An}_{30} \) at the rim, is seen. Besides the porphyroblasts, minute laths of plagioclase are common in the matrix, and range in composition from \( \text{An}_{50} \) to \( \text{An}_{30} \); the results indicate that on average they are even more basic than the porphyroblasts.

The biotite forms larger flakes - 1 to 1.5 mm. - than in the basified hornfels. It has crenulate margins, is often skeletal in habit, and in its colour, pleochroism, and abundance in pleochroic haloes resembles the biotite of the hornfels. However, it forms only 10% to 15% of the leucocratic pods.

Granitization of the hornfels associated with the leucocratic pods.

In the specimens described above (Nos. 317, 318, 319), as the basified hornfels becomes riddled with numerous veinlets, streaks and pods of leucocratic material, the hornfels itself is gradually changed to a medium-grained grey "igneous"-looking rock composed of plagioclase, biotite, quartz and orthoclase, with /
with accessory iron ore and apatite.

Plagioclase porphyroblasts, similar in every respect to those developing in the pods, begin to develop in the hornfelsic matrix; the biotite forms larger flakes, but decreases in total amount; a slight coarsening of texture takes place; and microscopically the rock becomes equivalent to a quartz-diorite, but still retaining abundant relics of hornfelsic texture. This variety is obviously intermediate in character between the basified hornfels and the granodioritic pods; with further increase in the feldspars, and coarsening of grain, such granitized hornfels patches grade into the biotite-granodiorite of the leucocratic pods.

The biotite-granodiorite of the pods

Specimens Nos. 320 and 322 are parts of a pod of granodiorite about 25 cm. across, completely enclosed by the hornfelsic framework, a few inches from No. 319. In hand specimen the rock looks like a medium-grained grey granodiorite, with numerous inclusions and streaks of the hornfelsed sediment. These inclusions have a diffuse marginal zone of granodiorite which is slightly darker in colour than that of the rest of the pod. In thin section No. 322 (Fig. 30) is a typical biotite-granodiorite with about 50% plagioclase, occurring both as porphyroblasts and as smaller laths with variation in composition/
composition as in the pods; about 15% biotite having the same characters as that in the pods and hornfels already described; and the rest mostly quartz and orthoclase, both of which occur as interstitial patches and as occasional poikiloblastic plates.

These granodiorite pods rapidly increase in volume and abundance until they form one continuous mass merging with the granodiorite of the complex, but enclosing numerous hornfelsic relics as basic inclusions and streaks. Nos. 324 and 325 are specimens of this biotite-granodiorite of the margin, and are described later as part of the complex (p. 99).

**Hornfelsic Relics**

The granodiorites Nos. 324 and 325, and two others collected near these (Nos. 330 and 331) enclose a number of dark relics of the biotite-hornfels. Though some of these have the appearance of what are usually called "xenoliths", it should be noted that the term is inappropriate, since the inclusions are not "foreign" fragments picked up by a magma, but relics of the hornfelsed country rocks that were there before the formation of the granodiorite; here they are termed "hornfelsic relics" or "basic inclusions".

Most of the basic inclusions are described in detail in a later section (p. 105), where they are shown to have been highly basified relative to the normal biotite-hornfels, and sometimes /
sometimes basified even relative to the basified hornfels near the contacts (see Table III).

In some cases the hornfelsic relics are feldspathized relative to the basified hornfels, and the details correspond exactly with those relevant to the granitization of hornfels associated with the leucocratic pods, described earlier (p. 63).

Besides these, minute diffuse areas of the hornfels are often seen in the granodiorites mentioned above. These hornfelsic patches in the granodiorite have very diffuse margins, and are darker and finer-grained than the granodiorite. In thin section they occur as irregular streaks and patches, from very minute sizes up to about 0.5 cm. across, which retain the biotite-quartz hornfelsic mosaic, though partly disrupted by the formation of plagioclase porphyroblasts and occasional poikiloblastic orthoclase. They are apparently examples of relics left in places where the granitization of the hornfelsic inclusions just failed to reach completion.

3. Exposures on Hungry Snout

At the foot of Hungry Snout, by the side of the Tod Burn near the eastern margin of the complex, a single exposure shows the hornfelsed sediment gradually merging into a grey granodiorite which passes into a coarse-grained pink granodiorite.
The hornfelsed sediment is seen to have reached a higher grade of metamorphism than the biotite-hornfels previously met with; No. 210 is a fine grained grey rock with no visible sign of sedimentary structure. In thin section it consists mainly of a granulose mosaic of quartz with biotite in association with chlorite, completely sericitized feldspar, and accessory apatite, iron ore and occasional zircon; the sedimentary origin is revealed by the presence of occasional patches showing relict hornfelsic texture or retaining still recognisably sedimentary quartz grains.

The hornfelsic quartz averages 0.5 mm. in size, with rounded or crenulate margins. The biotite is irregular and skeletal; most of it is the reddish-brown type with pleochroism $X = \text{brownish yellow, } Z = \text{dark reddish-brown},$ but some has $X = \text{light greenish brown, } Y = \text{greenish brown} < Z = \text{dark greenish brown};$ pleochroic haloes are not abundant, but some are commonly seen. The biotite, especially the greenish brown type, is often associated with chlorite occurring as shreds or irregular patches adjacent to the biotite and in parallel growth with it; the chlorite is pale green in colour, shows weak pleochroism to a slightly darker green, and gives the typical bluish interference colours. Parts of the section are composed of aggregates of sericitic mica in very minute flakes in a muddy indeterminable/
indeterminable matrix; these aggregates probably represent feldspar so completely altered that no other trace now remains.
Pale blue apatite with faint pleochroism is a common accessory. Granules of iron ore are common, especially as inclusions in the biotites. Occasional rounded grains of zircon are present.

No. 205, a few inches from No. 210 is a medium-grained granodiorite, and properly belongs to the plutonic complex. It is composed of plagioclase porphyroblasts up to 4 mm. long in a matrix, of grain-size 1 - 2.5 mm., consisting of plagioclase, biotite, hornblende, orthoclase, accessory quartz, apatite and iron ore. This granodiorite will be described later as part of the complex (p. 99).

No. 212, a few inches further inside the complex is a pink biotite-granodiorite, porphyroblastic in texture, with plagioclase porphyroblasts, again up to 4 mm. long, set in a biotite-quartz-orthoclase mosaic resembling the hornfels. For detailed description see p. 99.

G. Nature of Metamorphism of the Aureole

The recrystallization and reconstitution of the country rocks around plutonic complexes have often been ascribed to the effects of thermal metamorphism. Teall (1899, pp. 632-647) described the alterations produced in the country rocks around /
around the Galloway granites as "contact-metamorphism"; no chemical change was recognized, though the development of abundant biotite of reddish-brown colour and intense pleochroism was clearly noted. Gardiner and Reynolds (1932, pp. 26-29; 1937, pp. 297-298) confirmed the observations of Teall, but the idea of thermal metamorphism by igneous "intrusions" appears to have been held so firmly that no chemical investigations were thought to be necessary. In spite of the large number of chemical analyses undertaken by W.A. Deer (1935, pp. 47-74; 1937, pp. 361-376) none of the country rocks or of the "contact-metamorphosed" sediments of the Carsphairn area were included; and the "basic-hybrids" of the margin were interpreted as products of contamination of an early intruded basic magma by sediments.

But during the present investigation conspicuous evidences of chemical changes have been noticed in the country rocks. The following facts are evident from the descriptions already given:

1. The development of new biotite, and its gradual increase, with simultaneous decrease of quartz, suggest chemical change involving gain of $K_2O$, total $FeO$, $MgO$ and $Al_2O_3$, and loss of $SiO_2$; the process is one of biotitization.

2. The small-scale and sudden patchiness of the metamorphism in rocks originally lithologically uniform (p. 44) can only mean that the chemical constituents that have been added migrated along irregular channels; this definitely precludes simple thermal-metamorphism.
thermal-metamorphism since the latter would be expected to produce uniform change in the same lithological type throughout a very considerable volume.

(3) The increase in feldspars - mainly plagioclase - in the close vicinity of the plutonic mass, and the formation of leucocratic pods and veins with plagioclase porphyroblasts indicate addition of Na₂O, CaO, K₂O, Al₂O₃ and decrease in mafic constituents; the process is mainly feldspathization.

(4) The biotite-hornfels, which is already desilated relative to the unaltered country rocks (cf. (1) above; also Table III, and pp. 23, 36) is further basified wherever it is in contact with either leucocratic pods and veins or with the granodiorite of the complex (pp. 60, 65, 70); this association indicates that the mafic constituents driven out during the feldspathization were fixed in the adjoining biotite-hornfels, these giving rise to a "basic front".

(5) The abundance of pleochroic haloes in the biotite of the basified hornfels is conclusive evidence of the incoming of radioactive constituents. The deep reddish-brown colour of the biotite at this stage possibly indicates a high content of TiO₂ (cf. Hall, Jean A., 1941, pp. 29-33).

Thus the metamorphism is conceived mainly as a metasomatic process whereby the country rocks were first enriched in K₂O, total FeO, MgO and Al₂O₃ leading to the formation of biotite-hornfels. Feldspathization of part of the biotite-hornfels then gave rise to the complementary development of still more basified hornfels; during this basification stage there was notable addition of radioactive constituents and TiO₂.

Metasomatic
Metasomatic metamorphism is a widely recognized process. Lindgren (1933, pp. 703-706) has given ample evidence that metasomatism is intimately associated with contact-metamorphism, and that in many cases it has been found impossible to separate the two processes. D.L. Reynolds (1936, p. 385) has made it clear that the biotitization and feldspathization of the sediments around the Newry complex, leading to the formation of mobilized sediments, were essentially processes of metasomatism, involving addition of alkalis and alumina. Potash and alumina enrichment has also been suggested by Malcolm MacGregor (1937, p. 470) to account for the biotite-rich rocks developed in the aureole of the Criffel-Dalbeattie igneous complex. Professor Holmes and D.L. Reynolds (1947, pp. 53-56) have demonstrated that the metasomatic metamorphism of quartzite to mica-schist involved increase of $\text{Al}_2\text{O}_3$, total $\text{FeO}$, $\text{MgO}$, $\text{K}_2\text{O}$, $\text{H}_2\text{O}$, $\text{TiO}_2$, $\text{P}_2\text{O}_5$ and $\text{MnO}$, and decrease of $\text{SiO}_2$, $\text{CaCO}_3$, $\text{CaO}$ and $\text{Na}_2\text{O}$.

D.B. McIntyre (1947, Ph.D. thesis submitted to Edinburgh University) has described similar biotitization and feldspathization of the greywackes in the aureole of metamorphism of the Loch Doon complex; the development of a "basic front" around the leucocratic pods and kernels, and the basification of the hornfelses where they came up against the plutonic rocks, are /
are characteristic of the general changes. S.N. Sarkar (work in progress on the Spango "Granite") has discovered similar metasomatic transformations of hornfelsed sediments which are again basified close to the granitic pods.

Thus it is clear that the metasomatic metamorphism of the aureole and country rock sediments, and the development of a "basic front" complementary to the formation of granitic rocks, are significant features of the petrogenetic processes that lead to the emplacement of granitic or granodioritic plutonic bodies. The further discussion of these processes is relegated to a later section (pp. 145 et seq).
VII. THE ROCKS OF THE COMPLEX

Field Observations

Like the other Caledonian granodiorite masses of the Southern Uplands, the Priestlaw complex is made up of various types of plutonic rocks ranging from very acid granodiorite, through intermediate types, to diorite. In the field it was found convenient to divide them into the following three groups:

1. Pink and greyish-pink granodiorites;
2. Fine-grained grey quartz-diorites; and

The internal contacts, if any, between these lithological types are not anywhere exposed; in Figure 2 the areas occupied by each are indicated within lines which have been drawn between the outcrops of the different varieties.

1. The pink and greyish-pink granodiorites together make up the greater part of the complex. They are exposed all along the bed and sides of the Faseny river from the south margin to a point directly north of Priestlaw farm (Figs. 3, 4); isolated exposures are found south and south-west of the farm, on the slopes of Penshiel Hill on the south-west, along the Fee Cleugh (which joins the Faseny Water near the south margin), and near the Kell Burn on the north-west corner of the complex.

These granodiorites are pink, light pink or greyish-
pink /
pink in colour, medium grained and rather variable in texture with frequent clotting of the mafic minerals; they are not seen to be porphyritic to the naked eye. Basic inclusions are not very common, and the few collected are all very small.

2. The fine-grained quartz-diorites are exposed in three small patches:—

(a) Between the Whiteadder river and Kingside School on the north of the complex;

(b) A quarter of a mile south-east of Priestlaw farm, on the west side of the Whiteadder river; and

(c) On the east side of the Faseny Water towards the south of the complex.

Although some variation can be recognized in the field, these diorites are generally fine-grained - grain-size generally less than 1 mm. - and of a uniform grey colour. Occasionally they contain small basic inclusions which often have diffuse margins.

3. The bluish-grey diorite forms a small patch on the Whiteadder river near the north margin of the complex. It is distinguished from the fine-grained types by its medium grain (2 - 3 mm.) and colour; moreover it looks bright and lustrous as compared with the other types. Basic inclusions have not been observed in the diorite.

Aplitic veins are occasionally found cutting all three types.

General /
General Microscopic Features

The field-division of the plutonic rocks of the complex into three types has been confirmed by the microscopic characters; but petrographically it is found that each division contains minor varieties within itself; thus the texture varies from porphyroblastic to granitic, while pyroxene, hornblende and biotite occur in different proportions in different varieties of each type. The percentages of mafic minerals in a number of slices have been determined (Table III, 10-40), and the results justify retention of the three general groups for descriptive purposes.

The percentages of mafic minerals of various rocks from the complex and its aureole (data in Table III) are plotted in Fig. 6; the most basic rocks are found to occur around the margin of the complex; this is a remarkable fact and its significance will be discussed later (pp. 158-159). In Fig. 7 the different types of plutonic rocks in the area are demarcated with their respective average proportions of mafic minerals; again the occurrence of the more basic members towards the margin is noteworthy (p. 158).

A. Petrography of the Diorites

1. The Bluish-grey Diorite

The occurrence and field characters of this mass of diorite /
diorite have already been given (p. 79).

Four representative specimens were micrometrically measured and the percentages of mafic minerals (Table III, 19-22) were found to be 38, 39, 43 and 36, giving an average of 39%.

Microscopically the texture is seriate; all the chief constituents occurring in all sizes from 0.2 or 0.3 mm. up to about 3 mm.; occasionally there is a slight porphyroblastic appearance owing to the development of large plates of plagioclase. Plagioclase is the dominant constituent; pyroxenes, hornblende and biotite are the usual mafic minerals; accessory iron ore, apatite and quartz are present; and one specimen (No. 174) contains zoisite.

According to the abundance of one or other of the mafic minerals, the medium-grained diorite can be divided into three varieties:

1. Very rich in pyroxenes; orthorhombic and monoclinic pyroxenes being the chief mafic minerals, with hornblende and biotite in only small amounts; Sp. No. 171 (Table III, 19) is typical.

2. Pyroxenes, hornblende and biotite are all present in amounts of the same order; No. 193 is representative.

3. Hornblende and biotite (always hornblende > biotite) are altogether more abundant than pyroxene which occurs sparsely or is represented only as relict cores of the former minerals; Nos. 187, 195 (Table III, 20-22), 188, 190, 195, all fall into this variety.
The constituents of the diorite can now be described individually.

**Plagioclase** occurs in all sizes from minute laths 0.2 or 0.3 mm. long to large ragged plates and tablets 2 to 3 mm. and occasionally as much as 4 to 5 mm., in the longer dimension. When the larger crystals are fairly abundant the rock has a slightly porphyroblastic appearance. The crystal form of the plagioclase, especially of the porphyroblasts, is very imperfect; the crystals have crenulate margins and embayments against the hornblende and biotite, and also against quartz where this is present. Blebs of pyroxenes, hornblende and biotite are often enclosed by the plagioclase, and some of the crystals are crowded with minute black specks and rods; occasionally the plagioclase shows a patchy cloudiness similar to that occurring in the plagioclase of the fine-grained quartz-diorite (p. 89). Mosaic structure is very common, and deformed-looking crystals are occasionally seen. Combined Carlsbad- and Albite-twinning is general, sometimes with diffuse margins between the different parts or laminae. Zoning is often seen, especially in the larger tablets; it is usually gradational from An$_{45-50}$ at the core to An$_{20-30}$ at the rims. But quite frequently the zoning is very irregular and in patches (Figs. 31, 32), the whole plate of plagioclase being made up of two varieties, intimately intergrown with highly irregular mutual boundaries, with the respective /
respective compositions \( \text{An}_{45-50} \) and \( \text{An}_{25-30} \). Amongst the smaller plagioclase laths, which are not appreciably zoned, the composition is also very variable, different individuals in the same slice varying from \( \text{An}_{45} \) to \( \text{An}_{35} \); some of the smaller laths in No. 171 are as basic as \( \text{An}_{55-60} \). The plagioclase is partly sericitized, the larger crystals, particularly their middle portions, being more affected than the smaller ones.

It is clear from this assemblage of characters that the plagioclase closely resembles the porphyroblasts that have been described (p. 67) from the leucocratic pods occurring in the hornfelsed sediments of the aureole. Moreover, in its structure and relations to the other minerals, it is similar to the plagioclase developed in the trondhjemite replacement body in the cordierite-biotite-hornfels of Goraghwood Quarry, Newry Complex (D.L. Reynolds, 1943, pp. 237-238).

Hornblende occurs in groups together with the other mafic minerals. It forms irregular prismatic plates and grains of all sizes up to 1 or 1.5 mm. long; parallel growth with biotite is common, and occasionally the cores of parts of the hornblende are pseudomorphous after pyroxene; sieved and skeletal structures are frequent. Lamellar twinning is sometimes present. The pleochroism is not very strong, and is \( X = \) pale greenish yellow or colourless \( < Y = \) pale green \( < Z = \) dull grass green.
green. The extinction angle in the vertical zone is $Z \wedge C 24 - 25^\circ$; refractiv index $\gamma = 1.655$ (Table II). In most of the sections the hornblende is partly altered to shreds of chloritic matter.

In No. 171, from the right bank of the Whiteadder where it approaches the road near the north margin of the complex, the hornblende, rather fresh in appearance, is mostly present as rims bordering the pyroxene, and is often associated with biotite in parallel growth; in other characters it is similar to the hornblende described above.

Biotite, as already indicated, is often associated with hornblende in parallel growth, and also occurs as aggregates with the other mafic minerals. It forms ragged flakes and cleavage fragments, frequently skeletal in structure and often with several isolated parts in perfect optical continuity. Pleochroic haloes are present though not abundant. Pleochroism is strong from $X = $ pale brownish yellow to $Z = $ dark reddish brown; refractive index $\gamma = 1.644$ (Table II). Inclusions of iron ore are common. Much of the biotite has undergone alteration to irregular shreds of chlorite.

The biotite is very similar to that occurring in the biotite-hornfels of the aureole, except for the decrease in the number of pleochroic haloes.

Pyroxene /
Pyroxene, both monoclinic and orthorhombic, are well-developed in No. 171 and less so in No. 193, while in the others they are represented only by relict cores and pseudomorphs. The better-formed crystals occur as prismatic plates up to 2 mm. by 1 mm., but small rounded grains and irregular fragments are also common. Rims or margins of hornblende, or of hornblende and biotite (Figs. 33a & b) are frequently seen. Good 110 cleavages, and occasional lamellar twinning, are present. Sometimes the pyroxenes contain schiller inclusions of dark lines arranged parallel and perpendicular to the cleavage. The pyroxenes are colourless, non-pleochroic, show high refringence and birefringence, and have strong dispersion.

The orthorhombic pyroxene is enstatite; it gives straight extinction in vertical sections, and is optically positive.

The monoclinic pyroxene is a diopsidic augite; it has an extinction angle in the vertical zone of $Z \wedge C = 36-39^\circ$.

Zoisite has been detected only in No. 174 from the Whiteadder river, a few yards south-east of 171. This specimen is the most highly altered of all the bluish-grey diorites examined, and scarcely any plagioclase, hornblende or biotite is left in the original condition; in fact zoisite is the only well-defined and fresh mineral in the section. It occurs as radiating /
radiating sheaf-like aggregates, with marked cleavage lines parallel to the negative elongation; it is colourless, shows moderate relief, has straight extinction, and gives interference colours (in sections of normal thickness) of bright red, yellow and blue in patches of the same crystal. It is surrounded by patches of sericitic and turbid material, suggesting that it has apparently been formed at the expense of plagioclase.

In this slice aggregates of very pale green, or colourless, chloritic matter, occurring as irregular shreds and fragments, are probably the only remnants now detectable of the original pyroxenes, hornblende or biotite.

Apatite is a common accessory, often enclosed by the plagioclase or biotite. It occurs as narrow prisms or minute hexagonal plates, pale blue or colourless.

Quartz is sparsely seen as interstitial infillings between the other minerals.

Iron ore occurs as irregular granules dispersed through the mafic minerals or associated with them in the mafic clusters.

Heavy mineral separation (Table I, 187) revealed the presence of minute prisms and rounded grains of zircon in addition to the mafic minerals and apatite.
2. The Fine-grained Quartz-diorites

The exposures of the quartz-diorites are indicated in Fig. 2 and briefly described on p. 79. The rocks are grey, and lighter in colour than the diorite already described. The grain size is less than 1 mm., except for occasional crystals of feldspar which reach a length of 2 mm. Feldspars, biotite, hornblende, pyroxene and quartz can be seen on a fresh surface with the aid of a lens. In general appearance these rocks very closely resemble the igneous-looking marginal types (p. 52).

The percentages of mafic minerals in seven specimens are given in Table III (12, 23-28); the average value is found to be 27%, the highest being 33%, and the lowest 23%.

These fine-grained diorites are composed of plagioclase, hornblende, biotite, monoclinic pyroxene, and accessory quartz, orthoclase, iron ore and apatite. The textures are notably crystalloblastic, resembling those of the biotite-hornfels and pyroxene-granulite of the margin (Fig. 35); decussate arrangement of plagioclase and biotite is often seen. The granularity is seriate, all the main minerals occurring in all sizes from 0.2 mm. to about 1 mm. The relative amounts of hornblende, pyroxene and biotite vary in different specimens even in the same exposure, but all three are present throughout Nos.
Nos. 159, 155, 156, 103, 215, 216, 89, 161, 252, 345, 354 and 369 represent the quartz-diorites from the different parts of the complex.

Plagioclase varies in size from about 0.2 mm. to 2 mm. in the longer dimension. It tends to develop crystal form, occurring in section as broad laths, or nearly square or rectangular plates. Often a number of laths are crowded together into groups with a crude decussate arrangement, emphasizing the crystallographic texture. Mosaic structure is very common. A single composite individual may be composed of different parts which are not optically continuous, each part often having Carlsbad and Albite twinning in its own right; occasionally the albite lamellae of the neighbouring parts of a mosaic are seen to be slightly inclined to one another, so giving a deformed or broken appearance to the crystal when viewed between crossed nicols. Combined Carlsbad and Albite twinning is universal, while pericline twinning is very rare. Zoning is developed in some crystals, but is not very general; it is usually gradational from $\text{An}_{45-50}$ at the core to $\text{An}_{25-30}$ at the rim. Occasionally oscillatory zoning is seen, with sometimes as many as 15-20 zones in a crystal 1 mm. across, the alternating bands being very narrow and averaging $\text{An}_{25-30}$ and $\text{An}_{45-50}$ respectively. Sometimes the plagioclase shows a very patchy growth /
growth, the patches being very irregularly distributed as in the patchy feldspars already described from the bluish-grey diorite (p. 81). The patches form intimate intergrowths of contrasted parts, the compositions of which are approximately An$_{45}$ and An$_{50}$. The average composition of the unzoned plagioclase laths and tablets also varies in different individuals in the same rock-slice; values determined on combined Carlsbad-Albite twins and on sections normal to Z range from about An$_{25}$ to An$_{50}$.

Abundant inclusions of mafic minerals occur in the plagioclase as small grains, rounded blebs or as minute strips elongated parallel to the cleavage of the feldspar. The inclusions are generally distributed haphazardly, but sometimes they occur in zones parallel to the margins of the plagioclase, or occupy only the central part of the crystal. Occasionally the margins of the plagioclase contain minute blebs or crenulate patches of quartz and orthoclase which have apparently grown after the formation of the plagioclase.

One of the most interesting features of the plagioclase of the quartz-diorites is the very frequent occurrence of clouding. The plagioclase appears to be covered, uniformly or in patches, with a brownish grey dust, which under high magnification is seen to be composed of minute specks and rods of a black mineral, possibly iron ore. This clouding is not characteristic /
characteristic of every crystal of plagioclase, but it is very common in these particular rocks; similar clouding is occasionally seen in the plagioclase of the diorite already described (p. 82).

Clouded plagioclase has been described from other granodioritic bodies of the Southern Uplands and Ireland (A.G. MacGregor, 1930, p. 40, 48; D.L. Reynolds, 1936, pp. 341-342). A.G. MacGregor (1931, pp. 524-538) has assembled a large number of cases of clouded feldspars and concluded that clouding was caused by thermal metamorphism which caused the iron, originally dissolved in the feldspar, to be concentrated as minute inclusions. But D.L. Reynolds (1946, p. 436) suggests that the clouding may represent a forward migration of iron from a region of granitized country rock, into the marginal basic varieties which characteristically show clouding. In the present case, the patchiness of the clouding, and its absence from certain crystals which are otherwise identical with the clouded ones, suggest that irregular migration of material is a more probable explanation in this case than thermal metamorphism, which would be expected to produce a uniform distribution of clouding.

Hornblende generally occurs grouped together with biotite and pyroxene (Figs. 34a & c), and often in parallel growth /
growth with them. Prismatic form is common, and the basal sections show well-developed prismatic edges. Skeletal structure and sieved appearance due to the presence of inclusions of laths and blebs of feldspar are often seen. The hornblende is occasionally twinned, prismatic sections showing parallel lamellae. Sometimes it is pseudomorphous after pyroxene, suggesting the possibility that much, if not all the hornblende may be a derivative from original pyroxene. The pleochroism is $X =$ colourless to pale yellowish green, $Y =$ pale green, $Z =$ dull or grass green. The extinction angle, $Z \wedge C$, ranges from $26^\circ$ to $32^\circ$ in different crystals of the same rock, and the refractive index $\gamma = 1.650$ (Table II).

Biotite is found grouped with pyroxene and hornblende with which it is often in parallel growth. It occurs as ragged flakes with irregular margins; skeletal structure is very common. Pleochroic haloes are fairly common. The biotite is strongly pleochroic, with $X =$ straw yellow and $Z =$ very dark brown. Refractive index $\gamma = 1.645$ (Table II).

Pyroxene is monoclinic throughout. It is typically associated with the mafic minerals already described, either of which may border the pyroxene, or form with it a polycrystalline individual (Figs. 34a & b). The pyroxene tends to be euhedral, though it is often skeletal and sometimes occurs as irregular grains /
grains. Twinning is seen occasionally. The pyroxene is usually colourless, but sometimes a very pale green colour is seen. Extinction angle $Z \wedge C$ varies from $29^\circ$ to $50^\circ$ in different crystals even in one slice. Some of the grains show such strong dispersion that there is no complete extinction. These properties suggest that the pyroxene is a colourless or light-coloured augite.

Apatite, as slender prisms or hexagonal grains, colourless to very pale blue, and grains of iron ore are usually associated with the clusters of mafic minerals and are often included by them.

Quartz and orthoclase occur interstitially, in formless patches or rounded blebs, the latter sometimes invading the margins of the plagioclase in myrmekitic fashion.

Zircon is rarely seen, as minute oblong or square crystals.

Heavy mineral separation (Table I) of one specimen, No. 159 from north-west of Kingside School, yielded only the minerals already described.

3. Basic Inclusions

Occasionally the quartz-diorites contain extremely fine-grained, dark grey to blackish inclusions which are never more /
more than 2 cm. across. They are usually rounded and have gradational margins. The inclusion contained in No. 216, from the right side of the Whiteadder near the south-east of the complex, is a very good example. It is made up of a horn-felsic mosaic about 0.2 mm. in grain-size, and consists of abundant biotite and plagioclase, associated with small amounts of hornblende and pyroxene, the latter mostly as relics in the hornblende; iron ore, apatite, and rare quartz are the accessories. The percentage of mafic minerals in the inclusion is 44, compared with 27 in the enclosing rock (Table III, 12, 13); the basification of the inclusion is seen to be comparable to that of the basified biotite-hornfels near the margins of the complex (p. 60, 65 and Table III, 6, 8).

The plagioclase occurs as twinned laths, varying in composition from An50 to An35; the biotite shows decussate arrangement, forms ragged and skeletal flakes, and is similar in its optical properties to that of the diorite; the hornblende is often sieved with frequent pyroxene relics, and is also similar to the hornblende of the enclosing diorite; quartz is seen as rounded grains and interstitial patches, but occasionally angular grains recalling those of the original sediments are observed. The inclusion is similar in texture and mineral composition to the plagioclase-biotite-hornfels of the /
the aureole (pp. 65-69 ) and there is no reason to doubt that it is a relic of the hornfelsed sediments, now considerably enriched in biotite and plagioclase.

4. Mode of Origin of the Diorites

The diorites occur along or near the margins of the complex. Though their large-scale structural relations with the aureole-rocks and the granodiorites cannot be exactly determined owing to the poor exposures, the small-scale features and the microscopic details clearly bring out their close similarity to the fine-grained marginal dioritic rocks already described (pp. 52-56 ). In general appearance both types of rock look nearly alike, and the following textural and mineralogical resemblances are remarkable:

1. The highly crystalloblastic and sometimes porphyroblastic textures of the rocks;

2. The essential similarity of the plagioclase and all its peculiar characteristics in the rocks compared (porphyroblasts as well as matrix crystals); the mosaic structure, inclusions of mafic minerals, complex twinning, gradational and oscillatory zoning, and above all, the irregular variations in composition and the occasional clouding, are all worthy of note;

3. The ragged skeletal flakes of biotite common to both, and showing the same properties throughout;

4. The sieved hornblende, often showing evidence of having been formed from pyroxene; and

5. The quartz and orthoclase (when present) growing on the margins of the plagioclase, and occasionally forming myrmekitic intergrowths.
It has been shown that the marginal dioritic rocks represent an intermediate stage between the biotite-hornfels and pyroxene-granulite, and the fine-grained quartz-diorite. From the textural and mineralogical resemblance of the quartz-diorites to the marginal dioritic rocks, it seems reasonable to conclude that the former have also formed from the hornfelsed country rocks in situ by enrichment in alkalis, lime and alumina with the simultaneous driving out of the excess of felsic constituents which have contributed to the basification of the hornfelses and the basic inclusions. Then the bluish-grey diorite would represent a more advanced stage of the same series of changes whereby the texture is coarsened and rendered more nearly granitic, with the complete obliteration of the granulitic matrix. If this mode of origin be accepted, the two most outstanding characteristics of the marginal basic varieties of the plutonic body are logically explained, viz:-

1. The highly crystallloblastic, and occasionally porphyroblastic texture; and

2. The variation in the size and composition of the plagioclase.

Such a mode of origin also makes it clear how it comes about that the more basic varieties of the plutonic complex occur near the margins, grading to granodiorite towards the interior of the mass and passing into hornfelsic types towards the aureole.
B. Petrography of the Granodiorites

General

Excluding the dioritic bodies described above, the rest of the complex consists of granodiorites which are distinguished by their normally light pink colour - becoming pale pink or greyish white in the more altered varieties - with hornblende and biotite showing up in clots or prominent crystals. The grain-size is usually 2 - 3 mm. with plagioclase crystals reaching 3 - 4 mm. by 2 mm. and occasional hornblende prisms of hornblende as large as 8 - 10 mm. by 1-2 mm. The proportion of mafic minerals varies widely (Table III; 10, 14, 16-18, 29-41), some specimens from near the south margin and the south-west and north-west corners of the mass being very rich in these minerals (32%, 25%, 28%), while others collected near the contacts on the north-east and east, are poor in dark minerals (15%, 14%, 17%)

Microscopic Features

The texture is crystalloblastic throughout; where the grain is more or less even it is granoblastic; but in most of the rocks some of the crystals of plagioclase, biotite and hornblende have grown to an average size of 2 - 3 mm. and stand out as porphyroblasts in a matrix/averaging only 0.5 mm. in grain-size/
grain-size (Fig. 36). Occasionally neither the contrasting 
grain-sizes of the porphyroblasts and matrix, nor the even 
granularity of the granoblastic types is seen, but the constitu-
tuents show a seriate variation in sizes from 2.3 mm. to about 
0.5 mm. (Fig. 37).

Plagioclase, quartz, orthoclase, hornblende and biotite 
are the main constituents of the granodiorites; chlorite is 
common in altered specimens; iron ore, apatite, and occasional 
zircon and sphene are found as accessories. Generally the horn-
blende and biotite occur as cumulophyric aggregates, and some-
times the clotting is extremely prominent, small diffuse areas 
of about 3 mm. by 2 mm. consisting entirely of these minerals, 
together with abundant iron ore and some apatite. The plagioc-
 clase resembles that of the diorites, though the composition 
tends to be more uniform. The various minerals are described 
individually in a later section (p. 99 et seq.)

Varieties of granodiorites

Three varieties of granodiorites can be distinguished 
according to the relative abundance of hornblende and biotite, 
viz:

1. Hornblende-biotite-granodiorite;
2. Hornblende-granodiorite; and
1. **Hornblende-biotite-granodiorite** is the most abundant type, and is the characteristic rock of most of the exposures; the greater part of the exposed interior of the complex consists exclusively of this type. The hornblende and biotite are present in about equal proportions, though their total amount is rather variable. The textural and mineralogical features are as already described for the granodiorites in general. Mafic minerals constitute from 11% to 23% of the rocks, the average of eight determinations being 15% (Table III).

2. The **Hornblende-granodiorite** contains more hornblende than biotite, which may locally be lacking entirely. This type occurs in a number of small exposures, all confined to within 100 yards of the margin of the complex:

   (a) a small patch in the north-west corner of the complex (No. 13);

   (b) a similar patch in the south-west corner (No. 153);

   (c) three different exposures within 50 yards of each other in the Faseny Water in the south margin (Nos. 104, 19, 33, 53);

The hornblende-granodiorite most closely approaches the bluish-grey diorite in appearance and texture. It is the most basic of all the granodiorites - mafic minerals 18% to 32%, the average of five determinations being 25% (Table III) - and is generally more or less even-grained.

3. /
3. The biotite-granodiorite contains little or no hornblende, and occurs only near the margins:

(a) in a number of exposures in the same area as 2(c) above (Nos. 34, 35, 58, 87, 166);

(b) in the north-eastern margin where the contacts have already been described (p. 64), (Nos. 324, 325, 328);

(c) near the extreme eastern margin at the foot of Hungry Snout (cf. pp. 71-73), (Nos. 205, 212).

The specimens in (a) above resemble the hornblende-granodiorites in their more or less even grain and in containing 23% of mafic minerals (Table III, 34). Those in (b) and (c) are poor in dark minerals - 14% to 17%, averaging 15% from four determinations (Table III, 10, 16-18) - and correspondingly richer in quartz and orthoclase; the texture in these is porphyroblastic, the matrix often resembling the hornfelsic mosaic of the aureole rocks described (pp. 65, 72) in the two areas. Apatite is notably abundant in Nos. 205 and 212.

Constituent Minerals

The constituent minerals are found to be uniformly similar throughout the granodiorites, and hence it is appropriate to give a general description of each.

Plagioclase usually has a grain-size of 2 - 3 mm., and in the porphyroblastic types smaller grains occur down to about 0.5 mm./
0.5 mm. in length. It has fairly good crystal form with the usual square or rectangular outlines in section, but often it shows crenulate margins towards the other minerals, especially towards the orthoclase and quartz; elongated laths are also common, mainly among the smaller grains of the matrix (Figs. 38 - 42). Mosaic structure, and occasional patches showing inclined or bent twin-lamellae are often seen, as in the diorites (pp. 82, 83). Combined Carlsbad and Albite twinning is very general; pericline twinning has not been seen. Gradational zoning from An_{45}-50 at the core to An_{25}-30 at the margin is fairly common. Oscillatory zoning is sometimes seen, and in one case 38 bands were counted in a crystal 2 mm. x 1.5 mm., the composition ranging from An_{45} to An_{25} in the different bands; the exact determination of successive zones has not been made, however, because sections normal to Z were not available, and other sections cannot give equally correct results since one determination only is possible in each band in one zoned crystal. In one complex crystal (about 2 mm. x 1 mm. in No. 153) combined Carlsbad-Albite twinning was seen with one Carlsbad component alone showing gradational zoning (excluding even one set of Albite lamellae in that Carlsbad component) from An_{40} to An_{25}. The composition of unzoned plagioclase is fairly uniform throughout the granodiorites; about 120 determinations in the different sections using
(1) the maximum extinction angle \((X \wedge 010)\) in zones normal to 010,

(2) \(X \wedge 001\) in sections normal to \(Z\), and

(3) combined Carlsbad-Albite twins giving symmetrical extinctions \((X \wedge 010)\),

gave values between \(\text{An35}\) and \(\text{An45}\), the majority being between \(\text{An40}\) and \(\text{An45}\). Thus the average plagioclase can be taken as andesine, mostly within the range \(\text{An40-45}\).

Inclusions of mafic minerals are common in the plagioclase, occurring as minute prisms or flakes, shapeless grains or rounded blebs, often between the individuals of a plagioclase mosaic, but sometimes distributed haphazardly. Minute rounded areas of quartz or orthoclase are sometimes seen near the margins of the plagioclase. No clouding, such as occurs in the diorites, has been met with; but a few crystals are found to have a series of hair-like rods of an opaque mineral arranged parallel and perpendicular to the 010 cleavage, which seems to be similar to the "fine rods of an opaque mineral, possibly iron ore", described by D.L. Reynolds (1936, p. 341) from the Newry area.

Biotite occurs as ragged flakes and as skeletal and irregular prismatic sections showing good basal cleavages (Figs. 37, 41); it is generally associated with hornblende and iron ore in groups which are seen in hand specimen as clots of mafic /
mafic minerals. In some specimens biotite has been partly altered to chlorite. Pleochroic haloes are present, but are not abundant. The biotite has strong pleochroism, generally $X = \text{brownish yellow} < Y = Z = \text{dark brown}$, but in the partially chloritized examples the pleochroism is $X = \text{greenish brown} < Y = Z = \text{dark greenish brown}$. Here the greenish colour seems to indicate an early stage in the compositional changes leading to chlorite. The biotite from one specimen near the central parts of the complex gave a value for refractive index $Y = 1.644$ (Table II).

Hornblende often shows an approach towards good euhedral forms. The mineral is generally seen as roughly prismatic and lath-shaped sections, frequently with sieved and skeletal internal structures (Figs. 37, 43, 44); occasional basal sections show the usual six-sided outlines with the two sets of prismatic cleavages. The prisms of hornblende are usually 1 - 2 mm. long and 0.5 to 1 mm. broad, but are occasionally as large as 8 - 10 mm by 1 - 2 mm. Generally the hornblende is in intimate association with biotite and iron, groups of these minerals forming clots 3 or 4 mm. across. Parallel growth with biotite is also very common, one set of 110 cleavages of the hornblende being continued into the biotite as basal cleavages. Multiple lamellar twinning is sometimes seen. In the specimens that are poor in biotite /
biotite, the hornblende often forms aggregates (Fig. 43) about 2 mm. across, made up of individual prisms and fragments 0.2 to 0.5 mm. in size.

The hornblende is moderately pleochroic; the usual colours observed are:

\[ X = \text{pale green, yellowish green, pale brownish green, rarely colourless;} \]
\[ Y = Z = \text{dull green, olive green, dull grass green; occasionally bluish green;} \]

The composition also seems to vary slightly, as indicated by the extinction angle \( Z \wedge C \) which ranges between \( 23^\circ \) and \( 26^\circ \) in different crystals even in the same rock-slice, irrespective of the colour and pleochroism. The refractive index of the hornblende in one specimen from the central part of the complex is found to be \( Y = 1.647 \) (Table II).

Inclusions of quartz and feldspar are occasionally present in the hornblende as rounded blebs or as crenulate embayments near the margins.

The hornblende has undergone alteration in some specimens, where it is recognized only by its form and cleavage the mineral itself having been replaced by shreds of chlorite or dark greenish turbid material that cannot be resolved.

Chlorite is prominent only in the more highly altered specimens (which are mostly found near the southern margin /
margin of the complex where a number of dykes cut the gran-
diorites, cf. pp. 120, 121, ) and appears always to be a secondary
product. It is generally pseudomorphous after biotite or
hornblende, but sometimes it occurs only as irregular shreds.
It is pleochroic from pale green to dark green, and gives
bluish interference colours.

Orthoclase is rather variable in amount, but is always
present, occasionally up to 20% in some sections. It is
anhdral in form, occurring as interstitial patches and blebs,
as small embayments into plagioclase, biotite and hornblende,
and occasionally as poikiloblastic plates enclosing laths of
plagioclase, flakes of biotite, and grains of hornblende.
Sometimes the orthoclase encloses rounded areas of quartz, but
integrowths of the two minerals are rarely seen.

Quartz is present in all sections as interstitial
patches, and as blebs, rounded areas or crenulate embayments
in plagioclase, and occasionally in biotite and hornblende.
Sometimes a small patch 2 - 3 mm. across is made up of a
granulitic mosaic of quartz grains, and since such patches are
more often seen in the marginal biotite-granodiorite from near
the north-east and east, they are likely to be relict hornfelsic
structures.
Iron ore is invariably present as irregular grains, mostly associated with the other mafic minerals.

Apatite occurs as minute prisms or grains, but is never abundant except in the biotite-granodiorite (Nos. 205 and 212, p. 99) where stout prisms 0.3 to 0.4 mm. are common. It is colourless and non-pleochroic.

Zircon, as stumpy prisms, is present sparsely.

Sphene is seen only in one or two specimens from near the central part of the complex, and occurs as brown lozenge-shaped crystals.

Heavy Minerals (see Table I, Sp. No. 68). The only additional mineral detected is pale green augite, which occurs rarely.

Basic Inclusions

Basic inclusions are occasionally met with in the granodiorites, but are more frequent near the margin of the complex. All sizes are represented from very minute (less than 5 mm.) to some that reach 3 cm. across. Near the contact on the north-east margin the inclusions become more abundant (cf. pp. 64, 70-71), and some are as large as 6 to 8 cm. across. Generally the inclusions are rounded with sharp or merging borders against the granodiorites. However, on the north-east margin /
margin they show a marked orientation parallel to the strike of the country rocks outside the complex; the inclusions here are variously shaped like irregular veins, lenses or flattened ovoid patches, but the elongation always trends approximately north-east - south-west.

The inclusions from near the contact (Nos. 325, 330, 331) and from the central parts of the complex (Nos. 349, 366) are exactly similar in appearance and texture. They are dark grey to black in colour and fine in grain, like the biotite-hornfels of the aureole. The texture is typically hornfelsic (Figs. 45, 46), and closely resembles that of the hornfels associated with the pods of granitic material described earlier (pp. 64 - 69). The grain-size of the smaller constituents varies from 0.1 to 0.3 mm., while the biotite and plagioclase porphyroblasts are larger and reach 1.5 mm. by 0.3 mm.

Biotite, plagioclase and quartz are the most important minerals of the inclusions, with subordinate hornblende, and accessory iron ore and apatite.

**Biotite** generally makes up more than 40% of the rock (Table III; 10, 11; 14, 15), and often more than 50%; together with hornblende and iron ore it forms 60% of the total minerals in No. 366 (Table III; 14, 15) and 50% to 55% in some others. The pleochroism of the biotite is X = brownish yellow,
Z = dark reddish brown near the north-eastern margin, and X = brownish yellow, Z = dark brown in the inclusions from other parts of the complex. Pleochroic haloes are fairly common.

The biotite occurs

(1) as porphyroblasts which are thin blades, and elongated, skeletal flakes with a tendency to decussate arrangement (Fig. 46), except near the north-east margin, where the elongation tends to be oriented parallel to that of the inclusion as a whole;

(a) in the matrix as skeletal or irregular flakes showing decussate arrangement; sometimes the biotite wraps round the plagioclase or quartz.

Plagioclase builds lath-like forms both in the porphyroblasts and in the matrix; occasional decussate arrangement is seen; combined Carlsbad-Albite twinning is often present, but repeated Albite twinning is the most common. The composition is variable from one crystal to another, the range being from An_{45} to An_{30}.

Quartz is next in abundance to biotite in the inclusions, forming 15% to 25% of the sections. It is generally present as a conspicuously sutured granulitic mosaic, and occasionally forms poikiloblastic grains enclosing the biotite and plagioclase. Sometimes angular grains are seen which probably represent relics of sedimentary quartz.

Hornblende occurs only in the inclusions from the central parts of the complex; it is seen as prismatic crystals, highly /
highly irregular and sieved in structure, and often intergrown with the biotite.

Iron ore and apatite have their usual forms, as described on p. 105.

Basic enrichment of the contact of the inclusions against the granodiorite is not very marked, basification of the inclusions having usually already reached its limit; but in Nos. 349 and 366 it can be seen that biotite has been concentrated at the rim of the inclusion (Fig. 45), as elongated flakes, up to 1 mm. in size, which are often aligned parallel to the contact. This is obviously an enrichment of the rim in biotite and is comparable to the basic rim that develops around inclusions as a consequence of the granitization of the host rock.

Mode of Origin of the Inclusions

The basic inclusions near the margin of the complex are demonstrably relics of the country rock; this is shown not only by the mineralogical and textural similarity of the inclusions with the biotite-quartz-plagioclase assemblage of the hornfels of the aureole, but also by the fact that the inclusions still retain some evidence of their sedimentary parentage as shown by (a) their elongation parallel to the strike /
strike of the country rocks, and (b) the occasional preservation of relict-structures. Since there is no noticeable difference in the textures and mineral association between the basic inclusions from various parts of the complex, and further, since the hornfelsic textures with decussate and skeletal biotite, sieved hornblende and occasional relics of sedimentary quartz, give clear evidence of a country rock derivation, it is concluded that all the basic inclusions met with are remnants of original sediments which have been left behind during the course of formation of the granodiorites.

There is abundant confirmation of this view from descriptions of like occurrences in other areas. D.L. Reynolds (1943, p. 217) has noted abundant basic inclusions in the exposures of granodiorites in the Goraghwood Quarry in the Newry area; in some cases these inclusions approach the grey porphyritic granodiorite of the same area, but often they are more basic. She has proved them to be relics representing various preliminary stages towards the development of the granodiorites. Similar inclusions had already been described from the Eastern end of the Newry complex (Reynolds, 1934, pp. 598, 624), and there also the inclusions are clearly recognizable as sedimentary relics.

Malcolm MacGregor (1937, p. 464) briefly mentions
the abundance of inclusions in the quartz-diorite and granodiorites of the Griffell-Dalbeattie mass, and suggests that they may be derived from the country rocks.

W.A. Deer (1937, pp. 361-376), dealing with the marginal rocks of the Carsphairn complex, gives a detailed account of the "xenoliths" derived from arenaceous greywackes (p. 367) which appear to be very similar to those met with at Priestlaw, the figures of these inclusions (Figs. 3a and 3c, p. 370) further emphasising this resemblance, except for the fact that no cordierite is seen in the inclusions in the Priestlaw mass. Deer suggests (p. 371) that a gabbro magma was responsible for the initial recrystallization and reconstitution of the "xenoliths", and that the later tonalite intrusion gave rise to the basic "hybrid" rocks of the margin of the complex. This point will be fully discussed in the section on Petrogenesis, but here it may be suggested that it would be more in accord with the results of later researches to regard the so-called xenoliths as basified relics of the country rocks, as at Priestlaw, and to interpret the marginal "hybrids" as having had an origin akin to that of the diorites discussed earlier in this thesis (pp. 94-95).

The inclusions of hornfelsed sediments in the tonalite of the Loch Doon Granite (Gardiner and Reynolds, 1932, p. 11) /
p. 11) recall the abundant basic inclusions that occur in the granodiorites of Priestlaw near the north-east margin of the complex.

Basic inclusions are common in the granodiorites of the Distinkhorn complex (A.G. MacGregor, 1930, p. 49), but MacGregor regards some of these as contact-altered igneous fragments, while of others he states that they may "have been recrystallized to a fine-grained hornfels mosaic, and their original nature is obscure". It seems more probable in the light of later work that all are hornfelsic relics some of which have been basified and completely made over to types resembling metamorphosed igneous-looking rocks.

**Origin of the Granodiorites**

The textures as seen under the microscope provide important criteria for deducing the mode of origin of the granodiorites. The most remarkable and significant feature of the granodiorites is their crystalloblastic texture. The significance of the latter lies in the clear evidence it provides that crystallization of the rocks as we now see them must have taken place in a solid medium. Such textures can be developed under two distinctly different set of conditions:

(1) /
(1) contact metamorphism due essentially to the thermal effect of a neighbouring intrusion without material additions, and

(2) reconstitution produced not merely by heat but also by migrating materials, involving introductions, exchange, fixation and driving out of certain constituents, with consequent change of composition.

That condition (1) does not apply in the case of Priestlaw is very easily shown. There is no intrusion in the complex or its neighbourhood that could induce contact metamorphism. The bluish-grey diorite and the even-grained granodiorites, where the crystalloblastic texture is less conspicuous, cannot be cited as later intrusions having this function because

(a) the distribution and occurrence of the crystalloblastic textures have no relation to these diorites and granodiorites;

(b) the crystalloblastic texture, though less conspicuous, is met with in these rocks also; and

(c) as will be shown later (pp. 157-59), the processes that are believed to lead to the formation of the granodiorites involve the complementary production of even-grained relatively basic rocks of the type represented by the bluish-grey diorite, as well as the production of even-grained granodiorite such as occurs at Priestlaw.

Hence it is concluded that the crystalloblastic textures are the result of recrystallization and reconstitution of the sediments of the area by geochemical introductions, the nature of which will be discussed in the section on Petrogenesis.
The other textural features that are consistent with and lend support to this hypothesis are:

1. the internal irregularities and the mosaic structure of the plagioclase, which are common in all the rocks of the complex, as well as in the plagioclase-biotite-hornfels of the aureole;

2. the inclusion by the plagioclase of relics of the hornfels-stage, e.g. minute patches of the hornfelsic mosaic and grains of mafic minerals;

3. the sieved and skeletal nature of the biotite and hornblende;

4. the variation in the amount of mafic minerals in the granodiorites, this variation having no relation to the distribution of the different types except the general tendency of the variation richer in mafic minerals to occur near the margins of the complex;

5. the clotting of the mafic minerals, and their general occurrence as cumulo-phyric aggregates;

6. the resemblance of the highly crystalloblastic matrix of the porphyroblastic granodiorites to the texture found in the igneous-looking marginal rocks as well as to that of the high-grade hornfelses of the aureole.

It will be instructive at this stage to compare the granodiorites with the leucocratic pods already described on pp. 67-70. These pods are richer in feldspars and quartz than the granodiorites, and free from hornblende; they are accurately described as biotite-granodiorite. Comparison of corresponding specimens and thin sections reveals no recognizable difference between the biotite-granodiorite of the pods and the biotite-granodiorite /
biotite-granodiorite that forms parts of the main complex (e.g. those described from near the north-east and eastern margins of the complex, p. 99). Evidence has been presented (pp. 64-71) to show that the pods have actually developed in situ in the solid sedimentary framework, and it has also been shown that towards the contact the pods rapidly increase in abundance and size until they eventually merge into the main granodioritic complex. The obvious conclusion is that the rocks of the complex itself has been formed in the same manner.

However, the plutonic complex is largely composed of hornblende-bearing types, which have apparently been developed not through a biotite-granodiorite stage, but through the diorite stage. This is shown by the resemblance of the hornblende-rich granodiorite to the diorite (see p. 98), and will be further discussed after the chemical evidence has been presented (p. 145 et seq.)
VIII. APLITES AND QUARTZ VEINS

The Priestlaw area does not contain many aplites and quartz veins, and a detailed examination has revealed only the following occurrences:

Aplites (marked in Fig. 2 as Al, A2, &c.)

1. An irregular lens-like patch, about 1 ft. broad and 3-4 ft. long, in the granodiorite on the slopes of Penshiel Hill near the west side of the complex (No. 83);

2. A small fine-grained lenticular patch 6-8 ins. across, in the granodiorite, about 300 yds. south-west of Priestlaw farm (No. 254);

3. A vein 3-4 ins. thick, about 6 ft. long in the exposure seen, occurring vertically in the fine-grained quartz-diorite north-west of Kingside School (No. 156);

4. A vein 1 ft. to 1 ft. 6 ins. thick, striking east-north-east and dipping south-south-east at about 30°, in the diorite near the north-east of the complex, on the side of the Whiteadder river (Nos. 179, 189, 245, 249).

Quartz veins:

A number of quartz veins, ranging in thickness from less than a tenth of an inch to 6 ins., cut the diorite, and in some cases the aplite vein also, in exposure (4) above (Nos. 183, 191, 195).

Petrography

Quartz veins: Only one section of a quartz vein (a 3 mm. vein in diorite No. 195) has been studied. The vein is white /
white in hand specimen and similar in appearance to the other veins of quartz collected; besides quartz, only occasional specks of biotite are visible to the naked eye.

Microscopically the vein consists of well-satured interlocking anhedral grains of quartz up to 2 mm. in size, generally elongated parallel to the direction of the vein, and bounded sharply against the diorite. Small irregular or subhedral grains of altered feldspar, occasional shreds and fragments of biotite and chlorite, and minute grains and prisms of apatite are found included in the quartz crystals, or lying between them.

Aplites

The aplites occurring at localities (1) and (2) of the above list (Nos. 83 and 254) appear as fine-grained areas in the porphyroblastic granodiorites, and are not sharply separated from the latter, but grade into them. The others have sharp margins against the diorites. All are fine-grained and light pink in colour, but occasional prisms of feldspar about 2 mm. across can be noticed standing out from the sacha-roidal matrix.

Microscopically, Nos. 254 and 156 are found to be, apart from the rare occurrence of muscovite, merely leucocratic variants /
variants of the diorites and granodiorites; they consist of plagioclase, orthoclase, and quartz, with occasional flakes of biotite or, rarely, of muscovite, and sparse specks of iron ore. The texture is granulitic, the grain-size being about 0.5 mm., but occasional porphyroblasts of plagioclase, and poikiloblastic grains of quartz are present. The matrix plagioclase is anhedral, while the larger crystals tend to be subhedral. Nevertheless, the latter have highly crenulate margins towards the quartz and orthoclase. The plagioclase, which has the composition of sodic andesine, $An_{30-35}$, shows Albite and combined Carlsbad and Albite twinning, and is free from zoning. Inclusions of minute blebs of quartz and orthoclase occur near the margins.

In the other sections of the aplites (Nos. 83, 179, 189) the texture is markedly porphyroblastic, with plagioclase tablets about 2 x 2 mm. and occasional grains of quartz 0.5 to 2 mm. in size set in a granulitic mosaic of quartz, plagioclase and orthoclase of grain-size about 0.05 mm. Orthoclase forms occasional poikiloblasts in No. 83, but not in the others. Muscovite and biotite are seen sparsely as small flakes or fragments; no other mineral has been seen.

The plagioclase forms rectangular tablets and stout laths with highly crenulate margins against the granulitic mosaic.
mosaic. Combined Albite-Carlsbad twins are common; zoning is not seen. The matrix plagioclase also has similar characters. The composition is variable, from An$_{30}$ to $45$, but on the whole it is more sodic than in the associated granodiorites and diorite. The plagioclase porphyroblasts, together with the occasional large quartz grains, make up about 30% of the rock. The larger quartz grains show rounded forms, with the margins sometimes embayed by a minutely granulitic mosaic of quartz and orthoclase. In the matrix the quartz is interstitial or sometimes minutely granular.

In No. 83 orthoclase occurs as anhedral poikiloblasts enclosing laths of plagioclase and grains of quartz, or areas of the granulitic mosaic of quartz and orthoclase. In the other sections the orthoclase is anhedral and occurs in granulitic intergrowths with quartz.

In No. 189 the aplite is seen in contact with the diorite against which it has a sharp margin; the diorite differs from the typical rocks described earlier from the same exposure (Nos. 187, 188, &c. pp. 79, 80-86), in having undergone almost complete alteration, the feldspars being sericitized and the mafic minerals reduced to an aggregate largely composed of zoisite.

With the meagre evidence available it is hardly possible to reach firm conclusions as to the mode of origin of the /
the aplites. While the first type described (Nos. 254 and 156) appears to have originated in the same manner as the granodiorites and diorite, but with local enrichment in alkalis and silica, the others have features which seem to suggest that they were later replacements brought about by addition of alkalis with simultaneous removal of most of the femic constituents. Some support is lent to this suggestion by the last example (No. 189) where the alteration of the diorite would require the addition of potash and the removal of the femic constituents. Whether this is the real mode of origin or not, however, cannot at present be verified.
IX. **PORPHYRITE DYKES**

Several fine-grained dykes of varying thicknesses have been found cutting the country rocks as well as the plutonic mass in the Priestlaw area. There is a marked concentration of these dykes in the south margin of the complex, while others occur further south and a few near the northern margin. Geikie (1866, p. 16) has mentioned their abundance along the southern margin, and the Geological Survey map of 1910 (Sheet 33) indicates some of the dykes exposed along the Faseny Water.

During the present investigation at least 33 different dykes have been mapped, with a total estimated thickness of 190 feet, measured across the strike. They are distributed as follows:

<table>
<thead>
<tr>
<th>Locality</th>
<th>Number</th>
<th>Thickness ft.</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near north margin of complex</td>
<td>5</td>
<td>3-4</td>
<td>N.E. - S.W.</td>
</tr>
<tr>
<td>Centre of complex, across the Faseny Water</td>
<td>1</td>
<td>5-6</td>
<td>N.W. - S.E.</td>
</tr>
<tr>
<td>South margin, inside the complex</td>
<td>8</td>
<td>4-8</td>
<td>N.W. - S.E.</td>
</tr>
<tr>
<td>South margin, outside the complex</td>
<td>8</td>
<td>5-25</td>
<td>N.W. - S.E.</td>
</tr>
<tr>
<td>Do. Do.</td>
<td>3</td>
<td>5-15</td>
<td>N.E. - S.W.</td>
</tr>
<tr>
<td>Others, further south</td>
<td>8</td>
<td>4-10</td>
<td>N.E. - S.W.</td>
</tr>
</tbody>
</table>
The majority of the dykes are between 3 and 6 ft. in thickness, but a few are thicker; one, about 150 yards south of the southern margin of the complex, across the sharp bend in the Faseny Water, has a thickness of about 25 feet, and another, about 50 yards further south, is about 15 feet thick.

The dykes follow two conjugate directions - one parallel with the strike of the country, and the other normal to it. The latter occur inside the complex and near its southern margin. In no case was any dyke of one set found cutting any of those of the other set.

All the dykes are in a highly altered condition. Their contacts with the plutonic rocks and the country rocks give no indication of any chilling or baking or other interaction of one by the other, except possibly near the southern margin of the complex where several exposures of granodiorites are found highly altered - mafic minerals chloritized and feldspars sericitized (cf. p. 104) - in the vicinity of the dykes. Here it seems likely that the alteration of the granodiorite was associated with the emplacement of the dykes or with their subsequent alteration.

**Petrography**

The dykes are brownish pink to dull brown in hand specimen, the colouring in all cases being mainly due to the presence /
presence of ferruginous matter. The rocks are extremely fine-grained, and few phenocrysts are seen, but in one or two cases crystals of quartz and feldspar 2–3 mm. are found sparsely distributed through the hand-specimen. Hollow cavities averaging 2–4 mm. across are commonly seen. Some of them are lined with limonite, and other spaces of similar size and form are found partly or wholly filled by limonitic matter with which shreds of pale green chlorite are sometimes found associated. These casts and cavities probably represent the spaces originally occupied by phenocrysts of a mafic mineral, but no other evidence as to the nature of the latter has been found.

In thin section the dykes are seen to be sericitized porphyrites. The occasional phenocrysts are stout laths and plates, about 2–3 mm. in size, of oligoclase and rarer orthoclase, both of which have been sericitized. Occasionally rounded and corroded quartz also occurs as phenocrysts. The matrix is generally less than 0.005 mm. in grain-size, but is sometimes slightly coarser. In the least altered examples it seems to be chiefly made up of feldspathic and sericitic matter, but what is generally seen looks like a mass of clayey matter through which shreds of sericite are scattered. Faint spherulitic structure has been noticed in two specimens from the south of the area.

Rarely /
Rarely shreds of chlorite have been seen partly filling oblong areas of about 2 - 4 mm., and is occasionally associated with limonite; these possibly represent the relics of what were biotite or hornblende phenocrysts. In one dyke from the north margin, No. 185, greenish specks seen in the hand-specimen are found to be chloritic aggregates 2 - 3 mm. across, made up of flakes of penninite 0.5 - 1 mm. each. The pleochroism is X = colourless, Y = Z = green; extinction is straight, and interference colours ultra-blue. The penninite may be a derivative from original biotite or hornblende.

Age relationships of the dykes

Since all the dykes of the area are sericitized porphyrites showing little variation they can be assumed to belong to a single phase of the history of the complex. They are definitely post-Silurian, as some of them cut across the general strike of the sediments. Three facts further suggest that they were emplaced after the formation of the granodiorites:

1. A similar porphyrite dyke occurs near the centre of the complex;

2. At least two dykes near the south margin apparently cut right across the granodiorite margin, the north-west parts being inside the complex and the south-east sides in the aureole;

3. The possible correlation of the alteration of the granodiorites near the south margin with the numerous dykes there.
In this connection, it will be instructive to compare the occurrence of porphyrite dykes in and around other Caledonian plutonic masses. J.E. Richey (1939, pp. 393-435) has discussed the Caledonian dykes of the Southern Uplands as part of a detailed examination of "The Dykes of Scotland". Porphyrite dykes are very common among the Caledonian plutonic masses, and their general north-east and north-north-west trends in the Southern Uplands and the Cheviot area agrees well with the north-east - south-west and north-west - south-east trends noticed in the Priestlaw area. From a discussion of the Minor Intrusions of Kirkcudbrightshire by B.C. King (1937, pp. 252-306) it appears that the Priestlaw dykes show some resemblance to the altered albitophyres of the former area (pp. 291-296). King has advanced the view (p. 304-305) that a process of "autolysis" was responsible for the extensive alterations of hydrothermal type that he has described; it is not improbable that similar processes might have contributed to the alteration of the porphyrite dykes and the associated granodiorites of Priestlaw. Among other descriptions of the porphyrite dykes of the Southern Uplands and neighbourhood, those by Teall (1899, pp. 625-27), A.G. MacGregor (1930, pp. 32-34), Gardiner and Reynolds (1932, pp. 22-23), W.A. Deer (1935, pp. 63-64) and M. MacGregor (1937, pp. 465-67) may be mentioned /
mentioned. Comparative study of these contributions leads to the probable conclusion that the dykes in the Priestlaw area are also of Caledonian age. However, as to their supposed genetic connection with the granodiorites, there is no evidence other than association.
A. Copper Ores

In the Geological Survey map of 1910 a copper-bearing vein is indicated across the "Priestlaw Granite". References to the occurrence of copper ores in the "Granite" are many. The earliest is that by Cunningham (1835, pp. 101-103) who wrote that veins of "sulphate of barytes" associated with the green carbonate of copper and prismatic copper-glance, occur also in one or two places (in the Priestlaw area), but never of a size sufficient to be of importance from the economic point of view. Geikie referred to Cunningham and added (1866, p. 17) that veins of barytes containing copper have been worked to a small extent in the Priestlaw Granite; and practically the same words were repeated in the Memoir on the Silurian Rocks (1899, p. 655). G.V. Wilson (1921, p. 132) has written: "The old mine is situated on the banks of the Whiteadder about one-quarter mile west of Priestlaw;" mentioning in this connection the 6-inch map, Sheet Haddington 20 N.E. This map and the neighbouring sheets have been examined; the Whiteadder river does not flow one-quarter mile west of either Priestlaw farm or Priestlaw Hill; in fact only the south part of Priestlaw Hill and the Faseny Water are on this sheet. And no copper ores or old workings have been found in the area. Enquiries made among the local people /
people revealed clearly that at no time in their memory have copper ores been worked in the area. But reference continues to be made to "old workings". After Wilson in 1921, Pringle (1935, p. 96) and Pochin Mould (1947, p. 180) have mentioned the occurrence of copper ores.

B. Barite Veins

The greywackes near the "Priestlaw Granite" have long been known to contain veins of barite. Ogilby (1808, pp. 126-130) and Cunningham (1835, pp. 101-103) mentioned the occurrence of "sulphate of barytes" in veins of 1 in. to 4 in. in thickness. Stevenson (1849, pp. 33-46) described similar veins in the country rocks around the Cockburnlaw mass. During the present investigations barite veins have been met with in only one locality - in the greywackes below the plantation on the western slopes of Priestlaw Hill. The veins vary in thickness from 1 in. to about 6 ins., and are generally parallel to the strike of the greywackes, though highly irregular in detail. Only three or four veins have been seen, and these sometimes coalesce and then branch off into very thin veinlets which apparently die out longitudinally. The barite is cream-white to very pale brown in colour; the crystals are less than 5 mm. in length, and occur in radiating sheaf-like aggregates. In thin section (No. /
(No. 375) the barite is sharply banded against the siliceous
greywacke; the sheaf-like aggregates are made up of slender
prismatic crystals 3 -4 mm. long and 0.5 to 0.05 mm. across, and
are colourless with moderate relief and birefringence.

These veins do not continue into the rocks exposed
100 yards further along the strike, and seem to be of limited
extent. They are unfortunately of no practical value.
XI. QUANTITATIVE DATA

A. Heavy Mineral Separation

Bromoform separation has been carried out on nine powders, distributed among the rock-types as follows:

1. Four typical medium grained greywackes powdered together; Nos. 356, 351, 141 and 120 at distances of one-quarter to one-half mile from the plutonic mass (p. 23)

2. Typical biotite-hornfels, No. 145 (p. 36)

3. Do. Do. No. 312 (p. 36)

4. Fine-grained biotite-hornfels, No. 18 (p. 39)

5. Pyroxene-granulite, No. 6 (p. 47)

6. Basified biotite-hornfels, No. 316 (p. 65)

7. Diorite, No. 187 (p. 81)

8. Quartz-diorite, No. 159 (p. 87)

9. Hornblende-biotite-granodiorite No. 68 (p. 98)

The results are tabulated in Table I.

The powder of the greywackes was boiled for fifteen minutes in dilute hydrochloric acid; a longer treatment was not given since it was desired to preserve as much as possible of the apatite and iron ores. The separation was very incomplete, a considerable amount of the quartz also being carried down with the heavy minerals. The powders of the hornfelses were, therefore, vigorously boiled for thirty minutes in dilute hydrochloric acid.
acid; this acid-digest was probably responsible for the poor crops obtained in many cases. The diorites and granodiorite were not treated with acid.

Separation was also tried with a powdered shale to compare with the fine-grained biotite-hornfels formed from the shale-bands. But no residue heavier than bromoform was obtained, probably because of the fineness of the powder that was found necessary to isolate the grains of different minerals.

The heavy minerals separated are discussed after the corresponding petrographic description of the rock-type concerned. Here it is appropriate to note the general features.

Green hornblende (described in detail on p. 26) is found in the biotite-hornfelses (Nos. 145 and 312) as well as in the pyroxene-granulite (No. 6). The thin sections of these specimens had not revealed any hornblende.

Augite is very rare in the greywackes; fresh augite begins to develop in the biotite-hornfels, becomes very abundant in the pyroxene-bearing granulite and in the diorites, and is again rare in the granodiorite. The augite in the granodiorite is obviously a relic of the diorite-stage through which the granodiorite has formed, and the resemblance of the pale green augite in the greywackes to the augites in the other rock-types must be accidental.

Zircon /
Zircon is present as angular to sub-angular crystals, and is rounded but rarely (p. 27). Throughout the series of rocks the grain sizes generally fall within the limits of 0.05 mm. and 0.2 mm. This is probably suggestive of the persistence of the detrital zircon into the granodiorites.

The Heavy Minerals of the granodiorites and diorites

Table I brings out the similarity of the heavy mineral assemblage of the plutonic rock-types. Sphene, however, has been found only in the granodiorite. W. Mackie (1928, pp. 22-40) has discussed the heavier accessory minerals in the granites of Scotland, and the present study is in general accord with his findings in the Galloway granites (p. 39), though Mackie's report took into consideration only the "granites".

B. Refractive Indices

The refractive index (\( \gamma \)) of biotite from a series of rocks, and that of plagioclase and hornblende in a few of the rocks, have been determined by the method of immersion in liquid. Crushed powders (90-100 mesh) were used; 001 cleavage flakes of biotite and 110 or 010 fragments of hornblende give \( \gamma \)-values when \( Z \) is parallel to the direction of vibration of the polarised light used; plagioclase gives approximate \( \gamma \)-values on 001 cleavage plates when the composition is more sodic than about An50 /
The results obtained are shown in Table II, and the $\gamma$-values of biotite are diagrammatically indicated in Fig. 5. Further, in the petrographical descriptions already given, the refractive index has been reported in each appropriate place.

An examination of Table II and Fig. 5 reveals that the biotite generally shows a similar range of values for $\gamma$ throughout the series of rocks - with one notable exception: that for No. 306. Here, as described on p. 61, the biotite is the deep reddish brown type, with strong pleochroism, and very rich in pleochroic haloes; on p. 75 it has been suggested that No. 306 represents a biotite-hornfels enriched in biotite by the metasomatic addition of felsic constituents, and D.L. Reynolds (1946, p. 392) has assembled data to prove that basification (by addition of felsic constituents) can be expected to produce increments in the minor constituents (TiO$_2$, P$_2$O$_5$, MnO) as well. The reddish brown colour of the biotite in No. 306 can perhaps be correlated with an increased TiO$_2$ content (Hall, 1941, pp. 29-33), and this would be expected to give a higher refractive index also (Hall, 1941, pp. 34-41), as noted in the present instance ($\gamma = 1.650$). It may be objected that the same high refractive index should have been observed in the reddish brown biotite of the biotite-hornfels, and of the basified biotite-hornfels; but if we accept the arguments put forward by Hall (pp. /
(pp. 32, 34) it is possible to have reddish brown biotite with high MgO and low FeO which will have a lower value for $\gamma$; while the colour seems to be influenced by the TiO$_2$ content, the value of $\gamma$ will vary with the relative amounts not only of TiO$_2$, but also of FeO and MgO.

It will also be noticed that biotite, as well as hornblende, shows a range of values for $\gamma$ even within a single specimen; this range is not due to any experimental error, as such variation is a persistent feature in almost all the specimens. G. Wilson (1938, pp. 206-207) has found a similar range for the values of $\gamma$ in the amphiboles of the Kopaonik granodiorites of Jugoslavia. S.N. Sarkar (work in progress on the Spango "granite") also finds that biotite and amphibole in the same rock specimen both show considerable ranges of values for $\gamma$. However, without a more thorough investigation of various rock types with a larger number of refractive-index determinations - preferably in monochromatic light - no general conclusion can be expressed as to the significance of such variations.

C. Micrometric Measurements

The percentage of mafic minerals (i) in a series of 36 rock slices, (ii) in the leucocratic veins contained in one of
of the above slices, and (iii) in 3 basic inclusions enclosed by the fine-grained quartz-diorite and granodiorites have been determined micrometrically (with a Shand micrometer). The data, with relevant details, are listed in Table III, and are diagrammatically shown in Fig. 6. The data have also been included in the descriptions of the appropriate rock specimens, with necessary discussions.
XII. COMPARISON WITH COCKBURNLAW

Introduction

The Cockburnlaw plutonic complex, emplaced in Silurian greywackes, is situated about three miles north of Duns, across the junction of one-inch sheets 33 and 34 of the Geological Survey of Scotland (see Fig. 1). Hutton (1795, p. 454) visited the area with Hall and Playfair in 1788, and noted (Hall, 1815, pp. 84-85) the alteration of the greywackes adjacent to the plutonic mass. Stevenson (1849, pp. 33-46) described the mass in detail as already mentioned earlier in this thesis (pp. 7-8). Geikie (1864, p. 29) recognised that the plutonic rocks grade imperceptibly into the greywackes when he wrote: "..... the granite will be found to become finer in grain, and to show an increasing resemblance to some of the more altered Silurian grits, until, at last, the true Silurian grits are reached". This "..... gradation of these so-called igneous rocks into ordinary sedimentary strata ....." (loc. cit.) was so striking that Geikie concluded: "..... the felspathic masses of the district have not been the actual cause of the metamorphism of the Silurian strata. I believe we must seek for a less obvious, but more potent agency, and regard the felstones, granites, and metamorphosed grits as being but various stages in the same process of change " (loc. cit. p. 33).
Walker (1925, pp. 357-360) has given a brief description of the mass, and later (1928, pp. 153-162) he supplied two analyses (V and VI p. 161) of the plutonic rocks of the complex. Midgley (1946, pp. 50-66) has recently provided much more detailed account of the complex, but the features noticed during the present investigations cast doubt both on the accuracy of some of Midgley's observations and on the validity of his interpretations.

Field Observations.

The scope of the present study is strictly limited (see page 13), only the north-eastern margin of the complex having been examined in detail (Fig. 2A). The dioritic rocks of the margin are seen to grade rapidly into the hornfelsed greywackes; and though in the field an approximate line can be mapped separating the "igneous-looking" rocks (granular, lustrous, dioritic) from the hornfelsed sediments (dull, dark grey to black, compact), microscopic examination soon reveals a typically hornfelsic mosaic even in the dioritic types. When followed towards the central parts of the complex, these fine-grained dioritic rocks grade progressively, by way of medium-grained diorites, into grey and pink granodiorites. In the aureole, altered and unaltered sediments with sharp or gradational /
gradational margins are found in close proximity, indicating that the metamorphism has been patchy and irregular. The distribution of the igneous rocks is also irregular and patchy, as shown by the wide variations in colour, grain-size and amount of mafic minerals as seen in field-exposures, but generally the mass tends to become lighter in colour and more homogeneous in appearance towards the central parts of the complex as exposed on the northern and north-western slopes of Stoneshiel Hill. Clots of mafic minerals are very common in all the types, and hornfelsic relics are not infrequent. The plutonic rock-types are thus closely comparable to those of Priestlaw, and apparently have the same internal relations. In view of this, the strict delimitation of the rock-types suggested by Midgley (1946, map and section, pp. 52-53) is misleading.

Petrology

1. Hornfelsed sediments. Below Hemmel Knowe (see Fig. 2A) on the right bank of the Whiteadder river (about a quarter of a mile north-east of the approximate plutonic margin) slightly altered greywackes occur as nearly vertical beds striking north-east - south-west. Specimens 279, 280 and 281 collected here are exactly similar to the slightly altered greywackes described from the Priestlaw area (Nos. 120, 121, 131; p. 34) /
p. 34). A few yards to the south-west, nearly along the strike, No. 278 was collected from a patch of compact dark hornfels which grades laterally into the greywacke; in thin section this is seen to be a cordierite-biotite-hornfels similar to Nos. 342, 343 &c. described on pp. 43-47. On the opposite bank of the river, about 100 yards south of the locality of No. 278, slightly hornfelsed greywacke (No. 294), typically composed of angular quartz grains and composite rock-fragments set in a slightly biotitized matrix, is again seen (cf. Nos. 279, 280, 281 above). Following the same massive bed a few yards to the south-west, the patchy nature of the metamorphism is seen clearly in specimen 293 which in thin section is seen to be in part a slightly biotitized greywacke grading rapidly (within 1 mm.) into greywacke that is completely free from any trace of reconstitution.

Fine-grained biotite-hornfels (No. 288) is seen further to the south-west; it has reddish-brown biotite forming irregular flakes, often wrapping around the quartz which begins to lose its elastic appearance; highly irregular skeletal crystals of tourmaline with $O = \text{dark greenish brown} > E = \text{greenish brown}$ are occasionally seen. Approaching the so-called plutonic margin (Nos. 283 and 284) are seen to be typical biotite-hornfels (cf. No. 145, pp. 35-38); the reddish-brown biotite /
biotite shows good basal faces, and is often in decussate arrangement; quartz shows signs of recrystallization, the grains tending to become granulitic, or occasionally showing rhombic outlines; the feldspars have been completely sericitize and some of the biotite decolourised, possibly by post-metamorphic alteration.

2. Feldspathization of the hornfelsed sediments.

About ten feet to the south-west of the biotite-hornfels (No. 283) described above, in the next exposure available, a fine-grained, dark, lustrous "igneous-looking" rock (No. 297) is seen. It is highly crystalloblastic in texture and closely resembles the biotite-hornfels in thin section, though it is slightly coarser in grain; it also resembles the pyroxene-granulite (pp. 47 et seq.) and the fine-grained quartz-diorite (pp. 87 et seq.) described earlier in this thesis.

The rock consists of porphyroblasts of plagioclase, augite and hornblende set in a hornfelsic matrix of plagioclase, biotite, augite, hornblende, quartz and accessory iron-sphene and apatite; the porphyroblasts are as large as 2 mm. x 1 mm., while the matrix has a grain-size of 0.1 to 0.8 mm. The irregularities, gradational and oscillatory zoning, and the highly variable composition of the plagioclase (both in the porphyroblasts as well as in the smaller laths) recall the assemblage /

139.
assemblage of characters already discussed on pages 82 and 88. The pale green augite, green hornblende and dark brown biotite have structures and habits which are exactly similar to those of the component minerals occurring in the fine-grained quartz-diorites of Priestlaw (pp. 87 et seq.).

Such dioritic rocks near the margin show some variation in their mineral assemblage. Thus, although Nos. 269 and 270 (collected close to each other from the north bank of the Whiteadder river) are similar in appearance and texture to the specimen (No. 297) described above, yet the important mafic minerals are different in each case. While No. 270 has hypersthene, colourless augite and dark brown biotite as its chief mafic minerals, No. 269 contains colourless and green hornblende and reddish-brown biotite with only rare relict pyroxenes. Comparable mineralogical variations have already been noted in the diorites of Priestlaw (p. 81). Midgley (1946, pp. 54-59) failed to note such variations within short distances when he demarcated the areas occupied by the different rock-types that he described.

Passing further into the plutonic complex, the diorite becomes coarser-grained and more homogeneous with hornblende occurring to the exclusion of pyroxene, apart from the occasional presence of the latter as relics in the hornblende. Plagioclase /
Plagioclase, generally forming more than 50% of the rocks, occurs both as porphyroblast and in the matrix, and always shows its peculiar assemblage of structural and compositional features. Biotite (Z = generally dark brown, but occasionally reddish-brown) is subordinate to hornblende.

The fine-grained diorites are thus seen to grade from an obviously hornfelsic type to more normal "igneous-looking" types. The growth of porphyroblasts of plagioclase (accompanied by formation of pyroxenes and hornblende and decrease in the amount of biotite) seems to be the preliminary stage in the conversion of the biotite-hornfels into dioritic rocks. Since the formation of so much plagioclase implies the introduction of adequate amounts of CaO (with Na₂O), the formation of pyroxenes and hornblende at the expense of part of the biotite becomes clear. With further increase of plagioclase, and concomitant coarsening of grain, the diorites assume a more normal aspect. That the diorites have actually formed by this process of metasomatic transformation of the hornfelsed sediments, is made quite evident from the study of the hornfelsic inclusions still remaining in the diorites.

3. **Hornfelsic inclusions**. The specimen of diorite with hornfelsic texture (No. 297) described above contains a finer-grained, dark-coloured hornfelsic relic about two inches across /
across, with rounded outlines and fairly sharp margins. It consists of abundant flakes of biotite and skeletal prisms of hornblende (both similar in properties to those in the enclosing rock) in a hornfelsic quartz mosaic; the mafic minerals constitute more than 50% of the rock, and hence the inclusion is relatively more basic than both the enclosing diorite and the original hornfelsed sediment. This is clearly a case of basification of the hornfelsic relic complementary to the formation of diorite from the original hornfels.

No. 271 was collected from an inclusion, about eight inches by six inches, in the diorite No. 270 described on p. 140 above. It consists of streaks and veinlets of dark and light material which in thin section is seen to be biotite-rich and quartz-rich veinlets and patches grading into each other. Microscopically the rock strikingly resembles the biotite-hornfels associated with leucocratic streaks and veinlets occurring on Penediel Hill in the Priestlaw area (cf. pp. 59-63). The texture is typically hornfelsic, with the decussate biotite forming skeletal flakes with good basal faces; the biotite contains abundant pleochroic haloes, and shows strong pleochroism with X = very pale yellow < Y = light reddish brown < Z = intense reddish brown. Quartz is seen as angular clastic grains and also as rounded and sutured grains. Occasional tourmaline /
tourmaline forms irregular, skeletal crystals with pleochroism 0 = greenish brown > E = brownish yellow. Sericitic aggregates and turbid material in the matrix probably represent altered feldspars. This inclusion shows by its texture and its sedimentary quartz that it is a relic of the hornfels from which the enclosing diorite has been formed; but while the inclusion does not wholly appear to be basified, the biotite-rich streaks are obviously more basic than both the original hornfels and the diorite.

The inclusions described are comparable with those occurring in the quartz-diorites and granodiorites of Priestlaw (pp. 92-94, 105-108), and as the relict nature of the latter has been proved in this thesis (pp. 108-111) it would be unreasonable not to conclude that the Cockburnlaw inclusions also represent the early stages in a similar sequence of changes leading to the formation of diorites and granodiorites from hornfelsed sediments.

It has already been suggested that the Priestlaw diorites were formed from the hornfelsed sediments by the addition and fixation of CaO and Na2O (to form the plagioclase, pyroxenes and hornblende) and by the driving out of the excess of mafic constituents (pp. 94-95). That the diorites in the north-east corner of the Cockburnlaw complex owe their origin to /
to a similar process of transformation of biotite-hornfels is clearly shown by the preservation of the intermediate stages which have been described - e.g. the diorites with hornfelsic texture and the basified inclusions. The irregular distribution of pyroxene-bearing and hornblende-bearing types, the structural peculiarities of the different minerals - particularly of the plagioclase - and the gradation of the diorites to pink and grey granodiorites when followed towards the centre of the complex are features to be expected if the rocks had been formed by metasomatic changes of the kind inferred from the evidence presented in this thesis.
XIII. GEOCHEMISTRY AND PETROGENESIS

1. Chemical Analyses

Six representative specimens from the Priestlaw area have been chemically analysed by W.H. Herdsman. They are as follows:

1. No. 356. Typical greywacke, about half a mile south of the plutonic complex (p. 23).

2. No. 145. Biotite-hornfels, about 100 yards south of the complex (p. 36).


4. No. 187. Bluish grey diorite, right bank of the Whiteadder river, near the northern margin of the complex (p. 81).

5. No. 159. Fine-grained quartz-diorite, north-west of Kingside School (p. 85).


Two other analyses of the Priestlaw rocks are available (Walker, 1925, pp. 364-365):

II. Augite-biotite-quartz-diorite, margin of Priestlaw mass in Faseny Water (analyst W.H. Herdsman); this specimen would correspond to the fine-grained quartz-diorite (cf. No. 5 above) as described in this thesis.

I. "Porphyritic" biotite-hornblende-granodiorite, centre of Priestlaw mass (analyst F. Walker); this corresponds to No. 6 above.

These eight analyses, with their respective molecular proportions and /
and percentages, norms and von Wolff parameters, and the approximate modes of five of the analysed rocks, are given in Table IV.

In Fig. 8 the analyses are plotted in the order of field occurrence, on a silica basis. The desilication of the country-rocks (biotitization and feldspathization) is represented by the left-hand part of the diagram, up to the diorite, in which silica decreases to a minimum; the subsequent stages of granitization are represented by the right-hand part of the diagram.

Within the field of desilication, the biotitization and feldspathization can be clearly distinguished. Biotitization is represented by increase of Al₂O₃, total FeO and K₂O, with decrease of CaO; while feldspathization is indicated by increase of CaO, Na₂O and Al₂O₃ constituents that correspond to the development of plagioclase. The diorite is the most basic type of the rocks analysed, and in this rock CaO is seen (Fig. 8) to reach its maximum value, while K₂O decreases to a minimum.

Increase of SiO₂ and total alkalis, accompanied by decrease of all the other constituents then leads to granitization with eventual production of granodiorite.

In Fig. 9 the analyses are plotted on a von Wolff diagram, the advantages of which have been emphasized by D.L. Reynolds as follows: "..... not only is it possible to plot both /
both chemically understaurated and chemically oversaturated rocks in this diagram, but the diagram also has the additional advantage of separating the feldspathic and ferromagnesian constituents ......." (1943,B, p. 237; also 1946, p. 393). The genetic relationships of the sequence of rock-types are strikingly displayed by the diagram. Progressive desilication of the greywacke (No. 1 of Fig. 8) through biotite-hornfels (No. 2) and biotite-enriched hornfels (No. 3) leads to the formation of diorite (No. 4) which is granitized to give rise to the granodiorites. Granitization of the biotite-enriched biotite-hornfels leads to the formation of biotite-granodiorite (p. 113) as shown by the line connecting No. 3 to the granodiorite field (Nos. 6 and 6a).

The chemical changes involved in the different stages in the evolution of granodiorites from the country rocks are thus clearly revealed. Comparison between the analysis of the greywacke and those of the final granodiorites - facilitated by Fig. 8A - shows that the latter differ from the former mainly in the higher content of alkalis and alumina and in the lower content of SiO₂. Hence the metasomatic changes postulated can be visualised as starting with the introduction of K₂O, Na₂O and Al₂O₃ into the country rocks; the fixation of part of these constituents will use up some of the excess of SiO₂ and will at the same time liberate FeO, MgO and CaO which will migrate forward/
forward with part of the alkalis and Al₂O₃. Part of these materials gives rise to the biotitization of the country rocks, by the fixation of Al₂O₃, FeO, MgO and K₂O, while the fixation of CaO and Na₂O, together with other available constituents, gives rise to the pyroxene-bearing granulites. These desilicated country rocks in their turn - apart from those that still remain in the aureole - are overtaken by the main alkali-alumina front, and so converted into diorites and granodiorites. The excess of mafic constituents released during the process migrate forward producing the cordierite-biotite-hornfels and the biotite-enrichment of the biotite-hornfels. Since the mafic constituents released during granitization would vary in concentration in different zones of the complex, and as their migration would proceed along certain definite channels determined by the various physical factors, the patchiness in the formation of cordierite-biotite-hornfels will be a feature to be expected in view of the very nature of the process (cf. p. 44).

It was mentioned above that mafic constituents migrate forward with part of the alkalis and alumina, and dependent on whether or not CaO is fixed with the other constituents, biotite-hornfels or pyroxene-granulites is formed. From Fig. 8 it is seen that the diorite-stage is marked by geochemical culminations of CaO and geochemical depression of K₂O. The formation of pyroxene- and hornblende-bearing rocks thus seems
seems to depend on the fixation of CaO in preference to K₂O, while the reverse case would produce mainly biotite-bearing varieties. The hornblende-bearing granodiorites may have been formed either

(a) by granitization of hornfelses in which CaO had been fixed, or

(b) by the addition and fixation of alkalis and silica to the diorites, with concomitant driving out of excess of felsic constituents and alumina.

The likelihood that the hornblende-bearing granodiorites should have passed through a diorite-stage has already been mentioned (p. 114).

The evidence presented in this thesis therefore leads to the conclusion that the formation of the plutonic complex of Priestlaw and its metamorphic aureole has been brought about by a metasomatic process involving the introduction, migration, fixation and driving out of various parts of a series of chemical constituents; and that the different rock-types of the area represent various intermediate stages in the sequence of changes.

2. Comparison with other areas

There is abundant evidence in petrological literature of comparable sequences of changes initiated by the incoming of minor amounts of appropriate chemical constituents. Eskola (1914) /
(1914) in a detailed study of the petrology of the Orijarvi region in South-western Finland described the metasomatic change of limestones into skarn, and leptites and other siliceous rocks into cordierite-anthophyllite rocks in the contact zones of the oligoclase-granite of Orijarvi. Eskola demonstrated that "these changes have, for the greatest part, consisted in a metasomatic replacement of lime, soda and potash by iron oxides and magnesia" (p. 262).

Sederholm's magnificent work in the Pre-Cambrian rocks of Finland offer convincing evidence of granitization and associated phenomena on a large scale. In south-western Finland, in the Pellinge Region (1923) and in the region around Berösundsfjärd (1926) Sederholm traces the gradual transformation of the leptites, which are of mixed volcanic and sedimentary origin, to a grey gneissic granite by progressive granitization. A number of basic dykes, cutting obliquely across the foliation of the country-rock, were emplaced after the formation of the grey gneissic granite. A second period of granitization then ensued, and transformed in situ part of the grey granite and the remaining leptites to the red Hangö granite with its associated migmatites. The earlier basaltic dykes are found within the Hangö granite in various stages of dissolution. Often, individual dykes can be traced from the leptites and
and grey granite into the Hangö granite within which they become increasingly fragmentary and finally disappear. These transformations were accompanied by considerable chemical changes especially the addition of alkalis and decrease of other constituents. Sederholm recognised the "migration of the basic mineral constituents into certain parts of the schistose rock" (1923, p. 86), and in 1926 he made the significant suggestion: "The basic rocks dissolved in the granite seem to disappear as by magic ..... Only in rare cases phenomena are observed that seem to give an indication of what happened. So the 'basic halos' around fragments in the Obnäss granite tell of a diffusion extending to a certain limit. In greater fragments in the same granite the feric constituents have been concentrated in certain parts, which have even received an ultrabasic composition" (p. 138).

A.L. Anderson (1934, pp. 376-392) studying the Cassia batholith emplaced in Pre-Cambrian quartzites in Idaho, U.S.A., found that the batholith exhibited some extraordinary variations in texture and composition. Near the contacts with the quartzites, the granodiorite of the batholith become porphyritic, the colour becomes darker, and relict bedding structures are seen. At the very margins - 50 - 100 feet from the contacts of the quartzites - the porphyritic granodiorite is even darker-coloured /
coloured and hybrid-looking, with marked banding and schistose structure. Streaks, lenses and irregularly shaped masses of interlocking quartz-grains - similar to those of the quartzite - occur as inclusions in the porphyritic granodiorite, and these inclusions become more abundant near the outer margin eventually uniting to form part of the quartzite. The marginal porphyritic rock shows enrichment in biotite, zircon, and magnetite. From the evidence thus afforded Anderson concluded that the marginal varieties of the granodiorite were formed in situ from the quartzite by metasomatic change. He mentions the "impregnation of igneous material" and continues: "These emanations first caused widespread formation of biotite in the quartzite, and thus, as the solutions became sodic, extensive albition of the biotite-bearing quartzite. As the emanations continued to stream through the wide border of the contact zones, they apparently became enriched in potash as a result of which large crystals of microcline were deposited by replacement throughout most of the contact zone and produced a granitic rock with marked porphyritic texture" (p. 390).

G.H. Anderson (1937, pp. 1-74) dealing with "Granitzation, albitization, and related phenomena in the Northern Inyo Range of California-Nevada" believes that the dark grey Pellisier granite (which occurs between the white uniform Boundary Peak granite/
granite and the limestones, argillites and schists which form the country rock) "was formed in situ, partly by recrystallization and partly by replacement of older rocks of both sedimentary and igneous character" (p. 45). The main evidences with which Anderson supports his arguments are (a) similarity in composition and texture between the Pellisier granite and the partly recrystallized and replaced rocks of the contact zone, (b) the gradational contacts between the Pellisier granites and the older rocks, (c) abundance of schist and argillite inclusions in various stages of digestion in the Pellisier granite, the inclusions becoming more in number as the contacts are approached, (d) the variability of the Pellisier granite in texture and composition, and (e) the preservation of the initial structural orientation in the inclusions. That many of these features are well-displayed in the diorites and granodiorites of the Priestlaw area will be obvious from the descriptions in the previous pages.

In a series of studies of the complex suite of rocks in Sutherlandshire, Scotland, Read (1925, 1931) has described the gradation from sedimentary rocks to banded granites and permeation gneisses and has proved the process to be one of feldspathization. Cheng (1943, pp. 107-154) describing the migmatization of pelitic, semi-pelitic, siliceous and hornblendeic rocks
rocks of the Moine series in the area around Bettyhill, Sutherland, has shown that the production of permeation gneiss "not only involves the addition but also the subtraction of material" and that "the changes are essentially of the nature of metasomatism" (p. 143). In a very illuminating account of the agmatite in the Rogart migmatite area (in the neighbourhood of Bettyhill), Sutherland, Ma (1948, pp. 1-18) has confirmed the metasomatic changes described by Cheng.

M. MacGregor (1938, pp. 481-496) has described the formation of quartz-diorite in the Caledonian complex of Criffel, Dalbeattie by a process of granitization. Metasomatism brought the greywackes and shales, which form the country rocks, nearly to the composition of the quartz-diorite, but mechanical mixing with a hypothetical "parent-magma" of alkali feldspar composition is said to have taken place in the final stage of the process. MacGregor was led to this unnecessary conclusion because he assumed that the emanations responsible for the metasomatism were themselves derived from a postulated "parent-magma".

D.L. Reynolds has provided abundant evidence of metasomatic changes in connection with Caledonian orogenesis in Scotland and Ireland. Albite-schists characterise the Ben Ledi and Pitlochry groups of the Dalradians in Antrim, Northern Ireland.
Ireland (Reynolds, 1942, pp. 43-66). Comparison of analyses of biotite-schist and albite-schist collected from the same bed within two feet of one another (pp. 50-51) makes it evident "that sodium silicate and $P_2O_5$ have been introduced into the biotite-schist to convert it into the albite-schist, and that potash, iron, magnesia, and possibly alumina, have been driven out". Further the abnormal composition of the biotite-schist suggests that there was introduction of at least potash before the introduction of sodium silicate. After detailed comparison with the albite-schists of the Cowal area, south-west Scotland, of which the Antrim occurrence is a continuation, Reynolds concludes: "The albite-schists bear witness to geochemical migration in the Caledonian fold region of Scotland and Ireland. Not only were Na and Si introduced into the rocks in which albite porphyroblasts appear, but this Na-Si "front" was preceded by a K-Fe "front". Moreover, when Na and Si were introduced into the rocks K, Fe, Mg and probably Al were driven out, and one can only conclude that these constituents will have been fixed at some other level" (p. 61).

In Coraghwood Quarry (Newry Complex, Co. Armagh) irregular but isolated bodies of granitic rocks (including trondhjemite) have developed within a 60-foot wide band of hornfelsed Silurian sediments (Reynolds, 1943A, pp. 231-267). Some
of the bodies of granitic rocks are vein-like in form and vary from 3 to 6 inches in width, while others are lenticular, ranging in size up to two or three feet in greatest diameter. In every instance they cut abruptly across the bedding of the hornfels, which maintains its normal dip and strike, and small patches of hornfels, in undisturbed position, commonly occur within them. The granitic replacement veins and bodies are bounded by narrow rims, up to about half an inch in width, in which the enclosing hornfels is considerably enriched in biotite. The preliminary change was found to be the metasomatic development of porphyritic trondhjemite from the biotite-hornfels involving the fixation of soda, lime and silica, with concomitant driving out of \( \text{Al}_2\text{O}_3 \), total \( \text{FeO} \), \( \text{MgO} \), \( \text{K}_2\text{O} \), \( \text{H}_2\text{O} \), \( \text{TiO}_2 \), \( \text{P}_2\text{O}_5 \) and \( \text{MnO} \). The second major change in the granitization of the hornfelsed sediments was the development of granodiorite, adamellite and granite-pegmatite involving the driving out of total \( \text{FeO} \), \( \text{MgO} \), \( \text{Na}_2\text{O} \), \( \text{H}_2\text{O} \), \( \text{TiO}_2 \), \( \text{P}_2\text{O}_5 \) and \( \text{MnO} \). Chemical study of one of the basified rims showed that the constituents introduced were those driven out during the granitization of the hornfels.

The assemblage of constituents here is closely similar to that required to bring about the metasomatic changes of the Silurian sediments of Priestlaw to diorites and granodiorites. The granitization in the solid state described from Goraghwood corresponds /
corresponds to the development of granitic pods and veinlets in the solid framework of the hornfelsed sediments in the exposures on the slopes of Summer Hill (pp. 64-71).

Later, Reynolds (1943B, pp. 205-246) has shown that the granodiorites of the Newry complex have developed in situ from the Silurian sediments. She writes: "... the process of granitization is metasomatic, and dependent jointly on the introduction, migration, fixation and expulsion of certain constituents, materials expelled from one rock type commonly being fixed within another ..." (p. 225). Further, inclusions of porphyritic granodiorite in the biotite-granodiorite, and the inclusions of the latter in the form "find an explanation as relict structures, granitization having ceased before the mass as a whole attained equilibrium" (p. 225).

The detailed study of the biotite-granodiorite, hornblende-granodiorite and the porphyritic granodiorite exposed at the western end of the Newry complex leads to the conclusion "that a porphyritic texture characterizes the early stages of evolution of each of the granodiorites" (p. 233). Since progressive granitization would lead to homogenization of the rocks undergoing change, the final granodiorite produced would tend to have an equigranular texture. In the Priestlaw area the even-grained granodiorites and the bluish-grey diorite would /
would seem, by analogy, to have reached the final stages of granitization for each rock-type.

It has been shown that the most basic rock-types of Priestlaw are concentrated around the margins of the plutonic complex (p. 80, Figs. 6, 7). The hornfelses of the aureole have been shown to be desilicated relative to the country-rocks with enrichment in total FeO, MgO, K₂O and Al₂O₃. Since these are part of the constituents expelled from the zone of granitization, the basic rocks including the hornfelses around the margin represent the zone of fixation of the migrating basic constituents. This conclusion is in agreement with that of Reynolds (1943B, p. 234-238) concerning the Newry area, where the basic wall- and roof-rocks of the granodiorite complex are shown to represent the basic front that advanced ahead of the zone of granitization. Similar basic fronts have been recognized in the relatively basic marginal rocks of the Loch Doon complex (D.B. McIntyre, 1947, Ph.D. Thesis submitted to Edinburgh University) and in the Spango Granitic complex (S.N. Sarkar, work in progress) in the Southern Uplands, and in the Cnoc nan Cuilean area of Ben Loyal Igneous complex (B.C. King, 1942, pp. 147-179).

Within this broad basic front the concentration of different constituents was differential, each constituent culminating in a different rock-type. Thus in the Priestlaw area total /
total FeO, K2O and Al2O3 culminate in the hornfels-stage, CaO and MgO in the diorite stage, and K2O shows a second culmination in the alkali front in the zone of granitization, represented by the granodiorites.

3. Caledonian Complexes in the South of Scotland

Earlier in this thesis (pp. 14-15) a series of observations was listed as being explicable only on the basis of a "transformist" hypothesis for the origin of the plutonic complex. It now remains to examine whether similar observations in other Caledonian complexes of the Southern Uplands are capable of being explained according to the concepts of multiple intrusions and magmatic differentiation that have been generally assumed by many petrologists, or whether these observations also are more consistent with the hypothesis put forward in the present thesis.

From the descriptions of the Distinkhorn Complex (A.G. MacGregor, 1930, pp. 39-52), the Loch Doon Complex (Gardiner and Reynolds, 1932, pp. 1-34), the Cairnsmore of Carsphairn Complex (Deer, 1935, pp. 47-74 and 1937, pp. 361-376), the Cairnsmore of Fleet Granite (Gardiner and Reynolds, 1937, pp. 290-300), the Griffell-Dalbeattie Complex (M. MacGregor, 1937, pp. 457-484 and 1938, pp. 481-496), the Portencorkie Complex (Holgate, 1943, pp. 171-195) and the Cockburnlaw Complex (Midgley /
(Midgley, 1946, pp. 49-66) the following facts become evident:

1) There is little evidence of any structural displacement of the country-rocks that can be ascribed to magmatic intrusion;

2) The most basic rocks of the complex - norite, diorite, quartz-diorite and the "basic hybrids" - invariably occur around the margins of the complexes, and have in many cases been recognized as wall- and roof-rocks (cf. Deer, 1935, p. 64);

3) Gradational contacts are very common between the sediments and the plutonic rocks as well as between the different rock-types of the plutonic complex.

4) The hornfelsed sediments in the aureoles have been desilicated or basified relative to the original sediments as is evident from the respective petrological descriptions;

5) Inclusions of hornfelsed sediments - the so-called "xenoliths" - are met with in most cases, and have often been basified relative to the original hornfels as far as that can be made out from the descriptions supplied. In many cases the inclusions have been described as "xenoliths" of an earlier basic "intrusion" which strongly supports the possibility that they have been basified.

6) Crystalloblastic texture and relict hornfelsic texture are so common in the marginal varieties that they have often been described as "basic hybrids" on the assumption that they represent basic intrusions contaminated by sediments (see especially Deer, 1937) or as "early basic intrusions" that have been "contact-metamorphosed" by the later "intrusions" of granodiorite (see especially A.G. MacGregor, 1930).

It is clear that this remarkable assemblage of features can be satisfactorily explained only on the hypothesis that
that all the complexes in question have originated in situ from sediments by processes of metasomatic metamorphism akin to those that have been shown to operate in the evolution of the Priestlaw Complex. From the description of part of the Cockburnlaw complex already given (pp. 135-144) it will be seen that the diorites and granodiorite there actually contain ample and unequivocal evidence of having formed by metasomatism. But the authors in the works cited above have vainly sought to explain the various features they have noticed by assuming that there were intrusions of successive magmas, becoming progressively more acid in composition, and by appealing to differentiation and hybridization. Thereby they have created for themselves new difficulties, such as the space problem and the impossibility of accounting for the very large proportion of granodiorites relative to the basic types in all the complexes, while still leaving the main points unexplained. How far one may be led astray by uncritical adherence to the magmatic hypothesis is shown by the fact that no less than ten different intrusions were found necessary in the case of the Garabal Hill-Glen Fyne complex (Nockolds, 1940, pp. 451-511). The sheer impossibility of such multiple intrusions has been ably pointed out by D.B. McIntyre (1947, pp. 119-123). In view of this discussion, the generalised /
generalised conclusions of A.G. MacGregor (1930, pp. 51-52) and S.R. Nockolds (1940, p. 507) regarding the origin of the Caledonian plutonic complexes of the South of Scotland must be regarded as lacking in confirmatory evidence. The remarkable assemblage of similarities shared in common by these complexes is due to the fact that they have all been formed through metamorphic metamorphism of similar assemblages of sediments during the same orogenic phase, all of them being Caledonian apotectonic complexes.

The warning recently given to all petrologists by Holmes and Reynolds is worth remembering at this stage: "The minds of most petrologists have been so conditioned by training and practice that "granite" inevitably suggests "granite magma". This psychological tyranny should be consciously realised and deliberately resisted" (1947, p. 63).
XIV. ACKNOWLEDGMENTS

This work was carried out under the supervision of Professor Arthur Holmes and Dr. A.M. Cockburn. I acknowledge my indebtedness to Professor Holmes for inspiration, help and encouragement throughout the course of the work, and for the correction of the manuscript. I am grateful to Dr. Cockburn for help with the practical work and for many pleasant hours of discussion. I am very much obliged to Dr. Doris L. Reynolds for helpful suggestions about many aspects of the work.

I express my gratitude to the Government of India for the Scholarship that enabled me to study in Edinburgh, and for generous financial assistance in connection with the work.
XV. REFERENCES


Boué, Ami, 1820. Essai géologique sur l'Écosse.


1821. Manual of Mineralogy.


Playfair, J., 1822. "Illustrations". *Collected Works.*


1936. The two monzonitic series of the Newry complex. Geol. Mag., 73, pp. 337-364.


1946. The sequence of geochemical changes leading to granitization. Q.J.G.S., cii, pp. 389-446.


Fig. 1.

General map of south-east Scotland, showing the four Caledonian plutonic masses (numbered 1 - 4) that are exposed in the Lower Palaeozoic rocks of this area.

Fig. 2.

(See pocket in back cover)
Fig. 2A.

Scale: 6 inches to 1 mile.

Map of the north-eastern part of the Cockburnlaw complex; the approximate margin of the plutonic rocks is shown by heavy broken line.
Fig. 3.

Pink granodiorite exposed along the Faseny Water, about 450 yards south-west of Priestlaw farm. ca 1:80.
Normal jointing shown by granodiorite, by the side of the Faseny Water about 400 yards west-north-west of Priestlaw farm. ca 1:50.
# TABLE I.

**Heavy Mineral Residues.**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Description of specimen</th>
<th>Biotite</th>
<th>Hornblende</th>
<th>Pyroxene</th>
<th>Magnetite</th>
<th>Zircon</th>
<th>Apatite</th>
<th>Garnet</th>
<th>Pyrite</th>
<th>Sphene</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>356) 351) 141) 120)</td>
<td>Medium-grained siliceous greywackes</td>
<td>C</td>
<td>C</td>
<td>VR</td>
<td>G</td>
<td>R</td>
<td>R</td>
<td>VR</td>
<td>R</td>
<td></td>
<td>Green hornblende common, colourless hornblende rare</td>
</tr>
<tr>
<td>145</td>
<td>Biotite-hornfels derived from greywackes</td>
<td>A</td>
<td>G</td>
<td>R</td>
<td>A</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Green hornblende; similar to those of greywackes</td>
</tr>
<tr>
<td>312</td>
<td>Biotite-hornfels, similar to No. 145</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Green hornblende</td>
</tr>
<tr>
<td>18</td>
<td>Fine-grained hornfels, probably formed from shale</td>
<td>c</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Very poor crop. Tourmaline present - rarely</td>
</tr>
<tr>
<td>6</td>
<td>Pyroxene-granulite, apparently derived from greywacke</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>G</td>
<td>VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pyroxenes include Hypersthene and Augite</td>
</tr>
<tr>
<td>316</td>
<td>Biotite-hornfels with Plagioclase porphyroblasts near plutonic margin</td>
<td>C</td>
<td></td>
<td>VR</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Poor Crop</td>
</tr>
<tr>
<td>187</td>
<td>Diorite, margin of complex</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>R</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>Pyroxenes include Augite abundant. Enstatite rare</td>
</tr>
<tr>
<td>159</td>
<td>Fine-grained quartz diorite, near N.W. part of complex</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>R</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>Pyroxene-Augite</td>
</tr>
<tr>
<td>68</td>
<td>Granodiorite centre of complex</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>C</td>
<td>R</td>
<td>C</td>
<td></td>
<td></td>
<td>R</td>
<td>Pyroxene is Augite</td>
</tr>
<tr>
<td>Specimen No.</td>
<td>Biotite</td>
<td>Hornblende</td>
<td>Plagioclase</td>
<td></td>
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<tr>
<td></td>
<td>Min. &amp; Max. limits</td>
<td>Mean</td>
<td>Min. &amp; Max. limits</td>
<td>Mean</td>
<td>Min. &amp; Max. limits</td>
<td>Mean</td>
<td></td>
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</tr>
<tr>
<td>126</td>
<td>1.640</td>
<td>1.642</td>
<td></td>
<td></td>
<td>1.549</td>
<td>1.553</td>
<td></td>
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</table>
Fig. 5.

Diagrammatic representation of the $y$-values of biotite given in Table II (see also page 132).
TABLE III.
Micrometric Measurement of the Percentage of Mafic Minerals (see Fig. 6).

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Specimen No.</th>
<th>Brief Description and Locality</th>
<th>Percentage of Mafic Mineral</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>356</td>
<td>Unaltered Greywacke, (\frac{1}{2}) mile S. of plutonic mass (p. 23)</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>141</td>
<td>Do. Do. (\frac{1}{4}) mile S. of Do.</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>351</td>
<td>Do. Do. (\frac{1}{2}) mile E. of Do.</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>145</td>
<td>Biotite-hornfels about 100 yds. S. of plutonic mass (p. 36)</td>
<td>38</td>
</tr>
<tr>
<td>5</td>
<td>343</td>
<td>Cordierite-biotite-hornfels, from a band of metamorphosed country rock about (\frac{1}{2}) mile S. of plutonic mass (p. 44)</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>316</td>
<td>Biotite-hornfels (excluding leucocratic portions in veinlets and streaks) at contact, N.E. margin of plutonic mass (p. 65)</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>317</td>
<td>Feldspathized biotite-hornfels, 6 inches from No. 316 (p. 67)</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>306</td>
<td>Biotite-hornfels, outside the W. margin of plutonic mass (p. 60)</td>
<td>44</td>
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<tr>
<td>9</td>
<td>306</td>
<td>Leucocratic veins and streaks in above (p. 60)</td>
<td>25</td>
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<tr>
<td>10</td>
<td>325</td>
<td>Biotite-granodiorite, N.E. margin of plutonic mass (p. 70)</td>
<td>15</td>
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<tr>
<td>11</td>
<td>325</td>
<td>Hornfelsic relic in above (p. 70)</td>
<td>43</td>
</tr>
<tr>
<td>12</td>
<td>216</td>
<td>Fine-grained quartz-diorite, near S.E. part of plutonic mass (p. 87)</td>
<td>27</td>
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<tr>
<td>13</td>
<td>216</td>
<td>Basic inclusion in above (p. 93)</td>
<td>44</td>
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<tr>
<td>14</td>
<td>366</td>
<td>Hornblende-biotite granodiorite, near S. part of plutonic mass</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>366</td>
<td>Basic inclusion in above (p. 106)</td>
<td>60</td>
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<td>16</td>
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<tr>
<td>Serial No.</td>
<td>Specimen No.</td>
<td>Brief Description and Locality</td>
<td>Percentage of Mafic Mineral</td>
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<tr>
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<td>-------------------------------------------------------------------</td>
<td>-----------------------------</td>
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<tr>
<td>16</td>
<td>205</td>
<td>Biotite-granodiorite, near E. margin of plutonic mass (<em>p. 99</em>)</td>
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<tr>
<td>17</td>
<td>212</td>
<td>Do. Do. near above</td>
<td>17</td>
</tr>
<tr>
<td>18</td>
<td>328</td>
<td>Do. Do. near No. 325 above</td>
<td>15</td>
</tr>
<tr>
<td>19</td>
<td>171</td>
<td>Diorite, near N. margin of mass (<em>p. 80</em>)</td>
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<td>20</td>
<td>187</td>
<td>Do. Do.</td>
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<td>21</td>
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<td>22</td>
<td>195</td>
<td>Do. Do.</td>
<td>36</td>
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<tr>
<td>23</td>
<td>159</td>
<td>Fine-grained quartz-diorite, near N. part of plutonic mass (<em>p. 87</em>)</td>
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<tr>
<td>24</td>
<td>156</td>
<td>Do. Do.</td>
<td>23</td>
</tr>
<tr>
<td>25</td>
<td>103</td>
<td>Do. Do. near S.E. part of mass</td>
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<td>26</td>
<td>215</td>
<td>Do. Do.</td>
<td>32</td>
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<tr>
<td>27</td>
<td>252</td>
<td>Do. Do. S. part of plutonic mass</td>
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<td>28</td>
<td>161</td>
<td>Do. Do.</td>
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</tr>
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<td>Hornblende-granodiorite, N.W. corner of mass (<em>p. 98</em>)</td>
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<td>Hornblende-granodiorite, S. part of plutonic mass (<em>p. 98</em>)</td>
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<td>31</td>
<td>33</td>
<td>Do. Do.</td>
<td>25</td>
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<td>53</td>
<td>Do. Do.</td>
<td>18</td>
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<td>19</td>
<td>Do. Do.</td>
<td>21</td>
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<tr>
<td>34</td>
<td>35</td>
<td>Biotite-granodiorite Do. Do. (<em>p. 99</em>)</td>
<td>23</td>
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<td>Serial No.</td>
<td>Specimen No.</td>
<td>Brief Description and Locality</td>
<td>Percentage of Mafic Minerals</td>
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<td>----------------------------</td>
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<td>35</td>
<td>79</td>
<td>Hornblende-biotite-granodiorite, central part of complex (p. 98)</td>
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<tr>
<td>36</td>
<td>68</td>
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<td>Do. Do. Do. Do.</td>
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<td>Do. Do. S. part of complex</td>
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<td>41</td>
<td>12</td>
<td>Do. Do. near W. margin of complex</td>
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</table>
The percentages of mafic minerals (Table III) in the rocks of the Priesstaw area are plotted diagrammatically on a plan (Scale: 6 inches to 1 mile) of the area. The distribution of the more basic rocks around the margin of the complex is clearly brought out.
Plan of the Priestlaw complex (Scale: 6 inches to 1 mile) showing the distribution of the different types of plutonic rocks of the area. The average percentage of mafic minerals is indicated in each case.
### TABLE IV

No. 356. Greywacke, about half a mile south of the plutonic complex of Priestlaw.

(All analyses by W.H. Herdsman except where otherwise stated.)

<table>
<thead>
<tr>
<th></th>
<th>Wt. %</th>
<th>Mol. Props.</th>
<th>Mol. %</th>
<th>NORMS</th>
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<tr>
<td>SiO₂</td>
<td>71.24</td>
<td>1.1862</td>
<td>76.20</td>
<td>Q</td>
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<tr>
<td>Al₂O₃</td>
<td>11.64</td>
<td>0.1142</td>
<td>7.34</td>
<td>or</td>
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<tr>
<td>Fe₂O₃</td>
<td>0.48</td>
<td>0.0030</td>
<td>0.20</td>
<td>ab</td>
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<tr>
<td>FeO</td>
<td>4.45</td>
<td>0.0619</td>
<td>3.98</td>
<td>an</td>
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<tr>
<td>MgO</td>
<td>2.72</td>
<td>0.0675</td>
<td>4.34</td>
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<td>CaO</td>
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<td>0.0688</td>
<td>4.42</td>
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<tr>
<td>Na₂O</td>
<td>2.17</td>
<td>0.0350</td>
<td>2.25</td>
<td>mt</td>
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<tr>
<td>K₂O</td>
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<td>0.0083</td>
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<td>H₂O</td>
<td>1.52</td>
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<td>H₂O-</td>
<td>0.32</td>
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<td>water</td>
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<tr>
<td>CO₂</td>
<td>Nil</td>
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<tr>
<td>TiO₂</td>
<td>0.83</td>
<td>0.0104</td>
<td>0.67</td>
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<tr>
<td>P₂O₅</td>
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<td>0.0005</td>
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<tr>
<td>MnO</td>
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<td>0.0009</td>
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\[100.14 \text{ Wt. %} \quad 1.5567 \text{ Mol. Props.} \quad 100.02 \text{ Mol. %}\]

\[\text{VON WOLFF FACTORS}\]

\[L = 40.06\]
\[M = 16.76\]
\[Q = 43.20\]
**TABLE IV (Contd.)** - (2)

No. 145. Biotite-hornfels, about 100 yards south of the Priestlaw complex.

<table>
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<th></th>
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<th>Mol. Prop.</th>
<th>Mol. %</th>
<th>NORM</th>
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<tr>
<td>SiO₂</td>
<td>62.24</td>
<td>1.0363</td>
<td>70.57</td>
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<tr>
<td>Al₂O₃</td>
<td>17.17</td>
<td>0.1684</td>
<td>11.47</td>
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<tr>
<td>Fe₂O₃</td>
<td>1.03</td>
<td>0.0065</td>
<td>0.44</td>
<td>ab</td>
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<tr>
<td>FeO</td>
<td>5.49</td>
<td>0.0764</td>
<td>5.20</td>
<td>an</td>
</tr>
<tr>
<td>MgO</td>
<td>2.39</td>
<td>0.0717</td>
<td>4.88</td>
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<tr>
<td>CaO</td>
<td>1.48</td>
<td>0.0264</td>
<td>1.80</td>
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<td>Na₂O</td>
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<td>water</td>
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<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.02</td>
<td>0.0103</td>
<td>0.71</td>
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<tr>
<td>P₂O₅</td>
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<td>0.12</td>
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<tr>
<td>MnO</td>
<td>Tr.</td>
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</tbody>
</table>

**Total:** 99.86  1.4684  100.01

**Mode:**
- Biotite: 36
- Quartz: )
- Plagioclase: 61
- Orthoclase: )
- Iron ore: )
- Apatite: 3

**Von Wolff Factors:**
- L - 50.61
- M - 20.16
- Q - 29.24

*The modes have been corrected to whole numbers and recalculated to 100.*
TABLE IV (Contd.) - (3)

No. 316. Biotite-hornfels, enriched in biotite, and containing streaks and veinlets of leucocratic material, from north-east margin of the complex.

<table>
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<tr>
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<th>Wt. %</th>
<th>Mol. Prop.</th>
<th>Mol. %</th>
<th>NORM</th>
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**MODE**

- Biotite 46
- Quartz 25
- Plagioclase 22
- Orthoclase 5
- Iron ore) 2
- Apatite 100

**VON WOLFF FACTORS**

- L = 63.99
- M = 23.88
- Q = 12.14
No. 187. Bluish-grey diorite, right bank of Whiteadder river, near the north margin of the complex.

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100.17 1.4939 100.02

MODE

Plagioclase 57
Hornblende* 23
Biotite 11
Pyroxene 4
Quartz 2
Iron ore 3
Apatite 1

100

VON WOLFF FACTORS

L = 67.60
M = 29.32
Q = 3.10

*hornblende with minor amounts of biotite.
### TABLE IV (Contd.) (5)

#### II. Augite-biotite-quartz-diorite. Margin of Priestlaw mass in Faseny Water, quoted from Walker (1925, p. 364)

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**FACTORS CO₂**

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**VON WOLFF FACTORS**

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TABLE IV (Contd.) - (6)

No. 159. Fine-grained quartz-diorite, north-west of Kingside School.

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<td>Iron Ore</td>
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<tr>
<td>Q</td>
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TABLE IV (Contd.) - (7)

I. Granodiorite, Centre of Priestlaw mass;
Anal. F. Walker; quoted from Walker (1925, p. 364)

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<th>NORM</th>
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\[\begin{align*}
\text{TiO}_2 & : 0.50 & 0.0063 & 0.42 \\
\text{P}_2\text{O}_5 & : 0.19 & 0.0013 & 0.09 \\
\text{MnO} & : - & - & - \\
\end{align*}\]

\[100.13 \quad 1.4987 \quad 100.00\]

VON WOLFF FACTORS

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<td>Mol. %</td>
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<td>-------</td>
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<tr>
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**Total** 99.79  1.5097  100.01

**MODE**

- Quartz 27
- Plagioclase 46
- Orthoclase 14
- Biotite 9
- Hornblende 3
- Iron Ores 1
- Apatite 1

**VON WOLFF FACTORS**

- L = 65.89
- M = 13.58
- Q = 22.54
Variation diagram of the Priestlaw rocks plotted on a silica basis, in the order of field-occurrence (see page 146).

1. Greywacke (556).
2. Biotite-hornfels (45).
4. Diorite (107).
5. Quartz-diorite (II from Walker).
7. Granodiorite (I from Walker).
8. Granodiorite (68).
Diagrammatic presentation of the variation of the main oxides from Greywacke to Granodiorite.

1. Greywacke (356)
2. Biotite-hornfels (145)
3. Biotite-enriched hornfels (316)
4. Diorite (157)
5. Quartz-diorite (159)
6. Granodiorite (68)
Von Wolff diagram of the rocks of the Priestlaw area. The lines with arrow marks connect the rocks in order of field gradation.

1. Greywacke (356)
2. Biotite-hornfels (145)
3. Biotite-enriched hornfels (316)
4. Diorite (187)
5. Quartz-diorite (159)  
   Do. (II from Walker)  
6. Granodiorite (68)  
   Do. (I from Walker)  

Diorite-field  
Granodiorite  
Field.
All photomicrographs are approximately X 40. Except where stated otherwise, the nicols are not crossed. Slice numbers are given in brackets.

Fig. 10. Typical greywacke (356) with ungraded quartz grains, and composite rock-fragments (seen in the middle of the two quadrants on the left) in a fine-grained matrix. p. 23.

Fig. 11. A shale (381) showing the parallel lamination and fine-grained nature. p. 30.
Fig. 12. Biotite-hornfels (145) with abundant quartz and biotite. p. 36.

Fig. 13. Nicols crossed. Isolated plagioclase porphyroblast in the same slice (145). The plagioclase has irregular margins, and shows combined carlsbad-albite twinning. p. 37.
Fig. 14. Biotite-hornfels (312) with irregular and skeletal flakes of biotite (mostly dark in the photograph) often wrapping round the quartz grains. p. 36.

Fig. 15. Fine-grained biotite-hornfels (172). The biotite is somewhat uniform in grain-size, and tends to occur in parallel layers. pp. 39-40.
Fig. 16. Cordierite-rich band (light areas) in fine-grained biotite hornfels (346) with gradational margins. p. 42.

Fig. 17. Lens of unaltered greywacke enclosed by cordierite-biotite-hornfels (342). The cordierite is seen as light spots in a fine-grained matrix of biotite and quartz. p. 47.
Figs. 18 and 19. Cordierite-biotite-hornfels (342 and 343). Spots of cordierite containing minute inclusions of biotite and iron ore, set in a matrix of minute flakes of biotite and grains of quartz. p. 45.
Figs. 20 and 21. Pyroxene-bearing granulite (6). Skeletal flakes of biotite form porphyroblasts, and are associated with pyroxene grains (well seen in Fig. 21). The feldspar, mostly plagioclase, forms a granulitic mosaic, and the outlines of the individual grains are clearly seen. Iron ore, and minute crystals of biotite and pyroxene are scattered through the sections.
Fig. 22. Marginal dioritic rock (17), showing crystalloblastic texture. Biotite and hornblende form a clot in the upper half of the figure. Plagioclase, with a little quartz and orthoclase, forms the relatively light areas. p. 53.

Fig. 23. Do. Nicols crossed.
Fig. 24. Nicols crossed. Hornfelsic part of biotite-hornfels associated with veins and streaks of leucocratic material (306). The biotite forms well-developed flakes, showing decussate arrangement. The light areas are mostly quartz with some plagioclase and orthoclase. p. 60.

Fig. 25. Nicols crossed. Biotite-hornfels with porphyroblasts of plagioclase (317). On the left side the hornfelsic mosaic is clearly seen, while near the plagioclase, biotite and quartz form larger crystals. This is a preliminary stage in the development of pods of granodiorite in the biotite-hornfels. pp. 65-67.
Fig. 26. Increase in the amount of plagioclase leads to gradual coarsening of texture (318). The fine-grained hornfels forms small disconnected areas in the specimen. pp. 65-67.

Fig. 27. Do. Nicols crossed.
Fig. 28. With progressive feldspathization, biotite also tends to form larger flakes with good crystal form (319). A porphyroblast of biotite is seen in the figure with sieved margins and containing pleochroic haloes. Plagioclase forms a porphyroblast on the right. The texture tends to be more like that of granodiorite. pp. 65-67.

Fig. 29. Do. . . Nicols crossed.
Fig. 30. Nicols crossed. Part of a pod of granodiorite (322). The texture is cristalloloblastic (cf. Figs. 35-41); mineralogically it is a biotite-granodiorite. A zoned, composite crystal of plagioclase is seen in the figure, with smaller laths of the same mineral, irregular quartz and orthoclase, and flakes of biotite forming the matrix. p. 69.
Fig. 31. Crystal of plagioclase in diorite (193) showing inclusions of mafic minerals and iron ore. p. 82.

Fig. 32. Nicols crossed. The same crystal as in the figure above. The patchy nature of the plagioclase is clearly shown. p. 82.
Fig. 33a. Pyroxene, rimmed by hornblende and biotite in diorite (171). Pyroxene has sharper cleavage and is lighter than hornblende in the figure, while biotite appears dark. p. 85.

Fig. 33b. Do. Crossed Nicols. The plagioclase shows the combined carlsbad-albite twinning and mosaic structure clearly.
Fig. 34a. Fine-grained quartz diorite (158), showing clotting of mafic minerals. The hornblende near the centre contains a core of pyroxene. pp. 90-91, 102.

Fig. 34b. Do. Nicols crossed.
Fig. 35. Nicols crossed. Crystalloblastic texture in fine-grained quartz-diorite (103). Plagioclase on the top, hornblende and biotite on the bottom margin form porphyroblasts set in a matrix of the same minerals with quartz and orthoclase. Compare with Figs. 23 and 25-29. p. 87.

Fig. 36. Nicols Crossed. Hornblende-biotite-granodiorite (98) showing porphyroblastic texture. Plagioclase, biotite (very dark), quartz and orthoclase are seen in the section. pp. 96-97.
Fig. 37. Nicols crossed. Hornblende granodiorite (13) showing plagioclase, hornblende, biotite, quartz and orthoclase. p. 97.

Fig. 38. Nicols crossed. A plate of plagioclase in granodiorite (101). Mosaic texture, multiple twinning, and patchy extinction are evident. pp. 99-101.
Fig 37

Fig 39
Fig. 39a. Granodiorite (16) showing normal appearance of plagioclase when nicols are not crossed. pp. 99-101.

Fig. 39b. Nicols crossed. Same field as above. The structure of the plagioclase is well-seen. Smaller plagioclase, quartz, orthoclase and biotite form the rest of the section.
Fig. 40a. A porphyroblast of plagioclase in granodiorite (68). Many inclusions are seen. pp. 99-101.

Fig. 40b. Do. Nicols crossed. The rounded white blebs are quartz.
Fig. 41. Nicol's crossed. Biotite-granodiorite (212) showing plagioclase, biotite, orthoclase and quartz. Orthoclase and quartz (white or very light grey in the figure) form irregular blebs and interstitial patches. pp. 99-101.

Fig. 43. Hornblende forming an aggregate of many crystals in hornblende-granodiorite (19). Smeared and skeletal crystals, as well as prismatic and basal sections with good crystal-outlines are seen. pp. 102-103.
Fig. 44a. Sieved hornblende prisms in granodiorite (77). Biotite and iron ore are also seen. p. 102.

Fig. 44b. Do. Nicols crossed. Note texture. (The black area on extreme top right and its continuation as a vein is a void in the thin section.)
Fig. 45. Contact of basic inclusion with its host-granodiorite (366). The inclusion is a horn-felsic mosaic of biotite, quartz and some feldspars. Note the concentration of biotite and iron ore at the contact. pp. 105, 108.
Fig 45
Fig. 46a. Part of basic inclusion in granodiorite (349). The decussate biotite with abundant pleochroic haloes form a typical hornfelsic mosaic with quartz, plagioclase and hornblende. pp. 106-107.

Fig. 46b. Do. Nicol's crossed.