THE CROSSDONEY IGNEOUS COMPLEX.

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Description of Figures 1 - 8.

Fig.1. Map of the Crossdoney Complex, showing the boundaries of the various rock-types.

Fig.2. Metamorphosed Greywacke (No.38) from Drummora Great, showing aggregates of quartz grains (Q), porphyroblasts of andesine (F), a single porphyroblast of hornblende (lined and dotted) in the lower half of the figure with inclusions of quartz and orthoclase (O), colourless apatite (heavy line and stipple) and pyrite.

Fig.3. Quartz-diorite (No.36) from Drummora Great quarry. The field shows porphyroblasts of hornblende (lined and dotted) with inclusions of quartz, biotite (closely lined) and andesine (stippled).

Fig.4. Quartz-diorite (No.35) from Drummora Great quarry.(white This shows a large crystal of andesine in the south-west quadrant and smaller andesine crystals (stippled) hornblende (lined and dotted), biotite (closely lined) orthoclase, interstitial quartz (clear) and pyrite.

Fig.5. Quartz-diorite (No.32) from Cloggy Bridge, showing porphyroblasts of plagioclase (stippled) and hornblende (lined and dotted), biotite (closely lined), large quartz crystals (white) and the fine-grained quartz-orthoclase matrix.

Fig.6. Monzonite (No.64) from Lismore Demesne, showing a large plate of orthoclase (white) enclosing hornblende (lined and dotted) and plagioclase (stippled), and biotite (closely lined) and interstitial quartz (white, rounded) and magnetite.

Fig.7. Fine-grained granodiorite (No.7) from Coolnacarrick, showing porphyroblasts of plagioclase (white) with the characteristic band of fine inclusions (stippled), hornblende (lined and dotted) and biotite (closely lined). Note the "clot" of hornblende and biotite in the south-west quadrant. The fine-grained quartz-orthoclase matrix is shown clear.

Fig.8. Coarse-grained granodiorite (No.6) from Gaweel. This shows large quartz crystals (white)(rounded borders), lath-shaped plagioclase crystals, hornblende (lined and dotted and biotite (closely lined) with interstitial orthoclase (white).

I. - INTRODUCTION.

Crossdoney, the village from which the igneous complex takes its name, is situated some five miles to the south-west of Cavan town in County Cavan, Irish Free State. The complex, hitherto known as the Crossdoney "granite", extends from the townlands of Drummora Great near Lough Oughter on the north-west to Lisnamandra on the north-east, Leam on the south-west and Ballinagh village on the south-east. It is three miles long (north to south) and varies from a mile to two-and-a-half miles in width (east to west).

The area was originally mapped and briefly described by Leonard, Cruise and Hull some sixty years ago, for the Geological Survey of Ireland (1873, p.10, 1878, p.8). These writers interpreted the sequence exposed in Drummora Great as a transition from metamorphosed sediment to granite, which they regarded as a product of metamorphism; the origin of the Newry "granite" was similarly interpreted at that time.

As far as can be ascertained, no other work on the area has been published since 1878. In the present investigation the area has been mapped on the six-inch scale. It has been found necessary to make only minor alterations in the boundary of the complex, notably along the east and south junctions. What was previously regarded as 'granite' has been found to consist of several rock-types, the distribution of which is shown on the accompanying map (Fig.1).

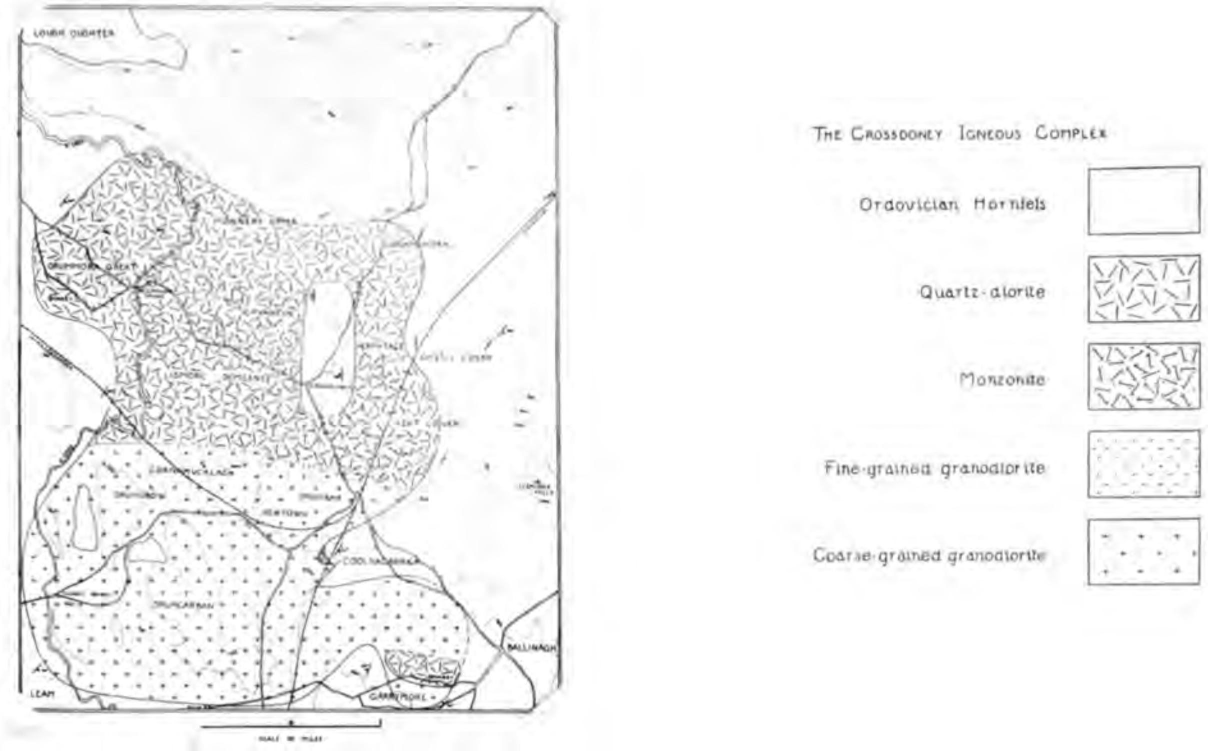


Fig. 1.

II. - FIELD DESCRIPTION.

The topography is largely governed by the fact that the area forms part of the basin of the River Erne which follows a generally northerly course, within and roughly parallel to the western boundary of the complex. The area over which the "granite" outcrops is thus low-lying, and there is, in consequence, little opportunity of viewing the relation between complex and sediment in three dimensions. Moreover, observations are restricted by the prevalence of blanketing deposits of boulder clay and peat.

The highest point in the district, Fleming's Folly (532 feet), is close to the eastern boundary of the complex and is composed of metamorphosed Ordovician sediment. To the west of the Folly the level of the ground falls rapidly to between 100 and 200 feet, and along the western boundary of the complex (that is, near the River Erne) there are numerous drumlins over 200 feet in height which have a dominantly north-south trend. Fortunately, good exposures are provided by the railway cuttings north and south of Crossdoney station and along the Killeshrandra branch line, and also by quarries in Kevit Lower and Ballinagh and west of Bellahillan Bridge.

(a) Geological Setting.

The sediments in which the Crossdoney complex occurs consist of Ordovician greywacke and shale, the greywacke predominating. Fossiliferous bands are lacking but exposures of the same series in the Ballyhaise road north of Cavan town reveal the presence of graptolites of Llandeilo age (1878,p.9).

In the northern part of the area, that is, between Drummora Great, Lisnamandra and Castle Cosby, massive greenish greywacke with occasional shaly partings are exposed, while in the southern part, near Ballinagh and Garrymore, greenish greywacke and dark blue slate occur. Fleming's Folly lies within the metamorphic aureole of the intrusion and is composed of green quartzose greywacke with occasional intercalations of fine conglomerate. Generally speaking, the strike of the beds follows the N.E.-S.W. Caledonian trend, and only slight deviations from this direction have been noted, as shown in the map, Fig.1.

The dip varies in direction, as the beds are folded isoclinally, and is generally steep.

In Lisnamandra, sandstone of Carboniferous age overlies the Ordovician strata and is in turn overlain by Carboniferous limestone which occupies the northern part of the area shown on the map. Neither sandstone nor limestone comes into contact with the complex.

Although the Ordovician sediments are variable in colour and composition, near the contact with the igneous complex all types take on a purple hue, a change which can be correlated with enrichment in biotite (cf.p. 16). Where freshly fractured, the contact rock has a schistose rather than a hornfelsic appearance.

The age of the complex can be roughly determined by the fact that the Ordovician rocks are metamorphosed, whereas the overlying Carboniferous rocks are not, although the latter are close to and within the aureole of the intrusion. The mineralogy and textures of the rock-types, (described in detail below) closely resemble those found in the rock-types of the Newry complex, which is known to be post-Silurian. The endence thus suggests that the Crossdoney complex can be assigned to the Old Red Sandstone period of igneous activity.

(b) Igneous Rock-types and their distribution.

Three main rock-types are exposed in the complex, namely

(i) quartz-diorite;

(ii) quartz-monzonite; and

(iii) granodiorite, of which fine and coarse-grained varieties can be distinguished. Microscopic examination was resorted to in order to discriminate with certainty between the quartz-diorite and the monzonite, as in the field, only a slight difference can be seen, the monzonite being of a somewhat lighter grey colour and more even grain than the quartz-diorite.

QUARTZ-DIORITE. occurs in the extreme north of the complex and extends in a semi-circular outcrop across the townlands of Drummora Great, Drummora Little, Monnery Upper, Lisnamandra, Hermitage and Castle Cosby. Its appearance in the field is patchy owing to changes in the proportion of light to dark coloured minerals. Generally speaking, it is a massive, light grey, fine-to-medium-grained rock, in which felspar, quartz and black mica can be recognised. Hornblende, sometimes associated with a little biotite, occurs as clots which are usually 3 to 4 mm, in diameter. In every exposure much larger rounded black clots are present; in thin section these are seen to be composed of hornblende and biotite invariably accompanied by a little felspar.

A variety occurring in the roadside quarry west of Bellahillan Bridge deserves special description. The quartz-diorite at this locality differs in appearance from the normal type owing to the presence of numerous large, irregular crystals of pink felspar. Hornblende occurs in rounded aggregates of small crystals and tiny flakes of biotite are scattered through the matrix; the latter is of finer grain than that of the quartz-diorite described above. This pink rock is veined by a light grey quartz-diorite which has abundant large crystals of felspar. A more detailed description of this quarry is given on p. 18.

Another variety of quartz-diorite is exposed in a small quarry west of Ballinagh village and occurs as a large inclusion in coarse-grained granodiorite near Cloggy Bridge. In both cases it is a pink rock in which large crystals of quartz and felspar can be easily recognised. In Ballinagh quarry, numerous calcite-chlorite veins cut irregularly through the quartz-diorite.

Except at the localities already mentioned, exposures of the quartz-diorite are poor. In what exposures there are, the jointing of the rock is seen to be finely spaced and very confused.

The actual contact between quartz-diorite and hornfels is nowhere visible. It is possible in places to fix its position within fairly narrow limits, as, for example, at the north-west corner of the complex in Drummora Great where exposures of hornfels and quartz-diorite are twelve yards apart.

The petrography of the neighbouring country rocks is described on pps. 12 ~~and~~ to 18, and the nature of the contact is discussed in detail on pp 35-36 (petrogenesis).

QUARTZ-MONZONITE occupies the area within the semicircular outcrop of quartz-diorite and is exposed at a few localities in Cavanfin, Hermitage, Lismore Demesne and Kevit Lower. At the last of these localities, an exposure of quartz-monzonite occurs only some 400 yards from an outcrop of hornfels. Comparison with the remainder of the northern half of the complex suggests that quartz-diorite may be present between the two, but unfortunately there is no exposure on the intervening ground.

In the field, as already mentioned (p.5.), the quartz-monzonite differs in appearance only slightly from the quartz-diorite. It is light grey in colour and medium in grain. Hornblende characteristically occurs in small rounded aggregates, about 5mms. in diameter, but a few isolated crystals can also be recognised. Phenocrysts of felspar are not so conspicuously developed as in certain members of the quartz-diorite group. All the exposures of quartz-monzonite are notable for the occurence of numerous dark coloured inclusions, three varieties of which have been recognised:

(a) biotite-hornblende aggregates with a little felspar:

(b) fine-grained granodiorite; and

(c) hornfels.

Xenoliths of quartz-diorite or coarse-grained granodiorite have not been found.

The largest mass of sedimentary material within the quartz-monzonite is about three quarters of a mile in length by about 300 yards in width. The beds strike due north and south and dip to the west at 50^{o}.

Examination of thin sections indicates that there is a continuous and gradual passage from quartz-monzonite to quartz-diorite; this is best illustrated by a traverse from Hermitage to Drummora Great, as exposures over the remainder of the area are poor. At the southern border of the monzonite the junction with the coarse-grained granodiorite occurs somewhere between the townlands of Lismore, Demesne, and Cornamucklagh, Newtown and Drumbar. This part of the area is partly under cultivation and partly wooded, and no exposures are visible.

<u>GRANODIORITE</u> occurs in both fine-grained and coarse-grained varieties.

The fine -grained facies is of very limited occurence and is exposed in the small railway cutting south of Crossdoney station. Hull, (1878, p.33) describes the exposures at this locality in the following terms,
"The blue quartzose grits becoming indurated and saccharoid, then small black mica flakes make their appearance;----- felspar becomes developed in rounded blebs and ultimately the rock emerges into a fine-grained granite consisting of quartz, felspar, black mica and hornblende".

The fine-grained granodiorite is a massive rock and is darker in colour than either the monzonite or the quartz-diorite. It is possible to recognise felspar, biotite and hornblende. As in the rocks described above, hornblende occasionally occurs in rounded aggregates. At the southern end of the railway cutting, coarse-grained granodiorite is exposed, and is seen to make an intrusive contact with the fine-grained variety.

The coarse-grained granodiorite outcrops over the southern half of the complex, between Cloggy Bridge ad Ballinagh and as far north as the Killeshandra railway line. Good exposures occur in Drumcrow and Drumcarban bogs. It is a light grey, coarse grained, unfoliated rock with fewer ferro-magnesian minerals than any of the rocks previously described, and so can be easily distinguished from them in the field. The minerals are all of roughly equal size, and hornblende and biotite generally occur as individual crystals. The granodiorite is so cut up by finely spaced and irregular jointing that it is quite unsuitable for building stone.

The contact between granodiorite and hornfels is exposed at intervals along the southern margin of the complex, and the igneous rock is everywhere intrusive. Dykes of granodiorite penetrate the hornfels and can be traced for many feet from the actual junctions. Quartz veins and calcite-chlorite veins cut both granodiorite and hornfels. Xenoliths of hornfels are numerous in every exposure of the granodiorite, becoming more abundant as the contact is approached. Xenoliths of fine-grained granodiorite and of quartz-diorite also occur. The granodiorite itself is traversed by narrow pink aplite veins which are distributed haphazardly across each outcrop. No felspathic veins have been observed.

(c) Form of Intrusion.

The boundary of the complex can be fixed within narrow limits along the south and east and around the north-west bulge and in Drummora Great. Along the north, the land is entirely under cultivation and yields no exposures of the contact.

In Lisnamandra, the boundary swings round from an approximately east-west trend to a north-south direction and can be mapped fairly closely as far as the railway cutting in Castle Cosby. In Kevit Lower, quartz-monzonite outcrops in a small quarry and in Kevit House yard, while the hornfels is exposed at the foot of Fleming's Folly, the junction being somewhere between these localities. The contact turns towards the south-west as far as the railway cutting in Coolnacarrick. At this point, a small fault displaces the junction, throwing purple hornfels against fine-grained granodiorite. An outcrop of coarse-grained granodiorite in the Ballinagh-Crossdoney road indicates that the contact extends eastwards from the fault and beyond, outcrops of hornfels in Ballinagh village show that it again swings round to the south. Until the quarry and roadside exposures in Garrymore are reached, the continuation of the contact is hidden by cultivated ground, In Garrymore, the road rises over a low ridge (B.M. 328.6.). At 270 feet o.d. on either side, coarse-grained granodiorite is exposed, while along the top of the ridge, metasomatised greywacke outcrops; this suggests that, at this point, part of the roof of the complex remains. Along the southern boundary, the contrast in colour between coarse-grained granodiorite and purple hornfels is so marked that the contact can be mapped with ease as far as Leam and northwards to Drumcrow. North-west into Drummora Great its exact position is doubtful, but at the north-west corner of the complex the contact is parallel to the strike of the sediments and can be closely followed. The boundary of the large enclosed mass of hornfels in Crossdoney and Hermitage can be fixed within narrow limits except at the southern end, where it is hidden by

Crossdoney village.

As explained above, exposures are seen only in two dimensions, and no extensive vertical contacts are available. Several intrusions of similar petrographic content have been termed "laccoliths" despite the fact that a laccolith is essentially a concordant intrusion. The available evidence for the Crossdoney Complex indicates that it is a boss rather than a laccolith. The decisive criterion is the cross-cutting relation between intrusion and invaded formation, such as is clearly exposed in the townlands of Leam, Garrymore, Castle Cosby and Lisnamandra. The strike of the sediment remains practically constant right up to the contact where it is sharply truncated by the intrusion.

III. PETROGRAPHY.

1. Metamorphosed Sediments.

Greywacke forms roughly 80 percent of the sediment through which the igneous complex is intruded. Specimens have been collected from many points around the contact. In no case was it possible to follow the individual band right up to the contact with the igneous rock, but specimens taken from a series of outcrops to the north-east of Fleming's Folly give an indications of the width of the metamorphic aureole. A mile from the contact, in Drumheel townland, the greywacke shows no signs of metamorphism and in thin section is seen to be composed of grains of quartz, individually and in mosaics, cemented together by a greenish, almost opaque, indeterminate matrix. The Folly is made up of bands of fine conglomerate which lie within the contact aureole, since a small amount of recrystallisation is evidenced by the presence of tiny flakes of biotite in the matrix.

The greywacke near the contact is represented by specimens from Garrymore (19, 20 and 72); Drummora Great (38); Bellville (12); Drumcrow (78); Lisnamandra (54):

Specimens 19, 20 and 72 have a dull purple colouration and contain easily recognisable crystals of quartz and felspar, up to 1 cm. in length. In thin section, the constituents are seen to be of widely varied materials. Grains of quartz, shale, sandstone -like mosaics of quartz, clastic hornblende and rounded aggregates of felted actinolite crystals which appear almost opaque in transmitted light, are present. These are cemented by a very fine-grained matrix of granular quartz crystals and abundant wisps of reddish biotite. Porphyroblasts of Andesine An_{32}, with crenulate margins are present. Apart from the edges, which are clear, they are clouded with dust-like inclusions and sericite fibres. A few small porphyroblasts of hornblende are also present and differ from the clastic hornblende in having crenulate margins and sieve texture.

Specimen 38 is dark gray in colour with abundant pink felspar crystals and is megascopically indistinguishable from quartz-diorite. In thin section, (see Fig.2) the felspar shows square to tabular outlines and is found to be andesine, An_{32}, zoned to oligoclase, An_{26}.

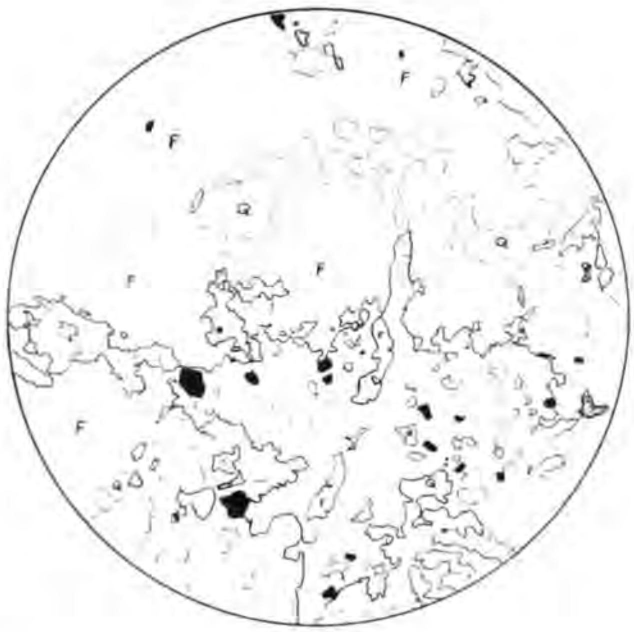


Fig. 2.

The smaller felspars have sieve texture and crenulate margins, whereas the larger crystals exhibit a closer approach to euhedral forms. Traces of cleavage and of the albite twin lamellae are almost completely obscured in the smaller plagioclase porphroblasts by a felted mass of sericite fibres, but with increase in crystal-size the sericite tends to develop in bands parallel to the crystal edges and the composition zones. Porphyroblasts of hornblende, often intergrown with sphene, are as abundant as those of plagioclase and together they make up about 60 per cent of the volume of the rock. The porphyroblasts of plagioclase enclose colourless apatite, epidote and occasional quartz grains, and those of hornblende enclose grains of quartz and orthoclase, and crystals of biotite, epidote, colourless apatite and pyrite.

The remainder of the rock is medium-grained matrix composed of granular quartz and orthoclase, together with small flakes of biotite. Pyrite, apatite, and sphene occur as accessories. The apatite is of two varieties, one being colourless while the other is pleochroic from purple (X) to pale brown (Z). Both types are present in the quartz-felspar matrix but only the colourless type has been found as inclusions in porphyroblasts of plagioclase and hornblende. The colourless apatite occurs in squat hemihedral crystals, up to 0.15 mm. long whereas the pleochroic apatite occurs in tiny needles. The sphene occurs in small grains and is slightly pleochroic in tints of brown. The presence of porphyroblasts is taken to indicate that matasomatism had modified the original compartion of the ~~horni~~ hornfels.

Specimen 78 is very like 38 and megascopically it has quite an igneous apparance. Microscopically, however, it is found to consist of a matrix of granular quartz, the individuals being commonly coated with limonite, in which are set porphyroblasts of plagioclase and hornblende characterised by intricately crenulate margins and sieve texture. In describing the quartz-diorite it was stated that one of the characteristic features of the rock is the occurence of small rounded aggregates of hornblende and biotite. Specimen 78 shows abundant development of similar clots. The appearance in thin section of one of these clots can be seen in the south-west quadrant of Fig. 7.

Specimen 12 is a biotite-diopside hornfels in which are set porphyroblasts of both andesine, An_{34}, and brown hornblende. The amphibole is pleochroic in shades of brown, Z=dark brown X = Y = very pale brown. The optic sign is negative with 2V large; the optic plane is parallel to (010) and $Z \wedge c = 22°$. Measurements of $\gamma - \alpha$ in sections parallel to (010) gave the value 0.027. These characters indicate an amphibole between grunerite and hastingsite, that is to say, an iron-rich variety with a little soda. Only this one occurence has been noted. The diopside occurs in small anhedral crystals and is faintly pleochroic from pale green (Z), to pale gray (X). A great deal of the pyroxene, however, shows alteration to fibrous uralite.

Veins of quartz cut the specimen and in section these appear as strings of large plate-like crystals which enclose little crystals of andesine and reddish biotite and fragments of uralitised pyroxene. The quartz shows the undulose extinction characteristic of vein-quartz.

Specimen 54 resembles 72 (already described), but has a higher proportion of plagioclase. Megascopically, 54 is a dark gray rock in which minute white felspar crystals can be recognised. In thin section, it is seen that the felspar, turbid with felted fibres of sericite, is abundantly developed in anhedral crystals which closely resemble the quartz grains in shape. Quartz is less abundant than in unmetamorphosed greywacke.

The slate near the contact is represented by specimens from the railway cutting; Coolnacarrick (4); the railway crossing west of Ballinagh (18); Drummora Great (40 & 85); Coolnacarrick (8); waterfall, Crossdoney village (2); and Kevit Lower (60). With these may be considered an inclusion in quartz-monzonite from Lismore Demesne (62).

Specimen 4 has a very fine-grained matrix of quartz, with orthoclase and a little andesine. The purple colour of the outcrop is seen to be due to the abundant development of a reddish coloured biotite which occurs in tiny flakes wrapping round the quartz grains. The rock has a banded appearance owing to the alternation of streaks relatively rich and poor in mica. Comparison with thin sections of specimens collected farther from the contact indicates that only a small proportion of the biotite in 4 can have been derived from original constituents. A small amount of pleochroic and zoned purple apatite is present.

Specimens 18, 40, and 85 are very similar in their general appearance and composition. Enrichment in biotite is not so conspicuous as in 4, and the matrix of coarser grain. The thin section of specimen 85 is peculiar in showing the presence of two narrow veins cutting the hornfels: one is 0.2 mm. wide and is composed of tiny quartz grains; cutting it in turn, is a vein 1.5 mm. wide consisting of anhedral crystals of pyrite and chlorite both of which enclose grains of quartz, colourless apatite and biotite.

Specimens 2 and 8 megascopically resemble 4, but are found in thin section to have a different texture. Specimen 8 contains oval quartz grains, up to 0.25 mm. in length, arranged with their long axis parallel to the bedding and set in a fine-grained matrix of quartz, orthoclase, a little andesine, diopside and reddish biotite. The mica flakes, too, are arranged parallel to the bedding so that the whole rock has a schistose appearance. In addition, there are a few oval or rounded crystals of andesine, An_{32}, centrally clouded with a turbid felt of sericite, (cf. Quirke and Collins, 1930 p.43). Thus the felspars can be easily distinguished from the similarly shaped quartz grains. Numerous inclusions of dust-like particles, too small to be determined, also occur in the felspar. A small amount of porphyroblastic hornblende is present; comparison with specimens collected farther from the contact shows that both hornblende and rounded plagioclase imply magmatic additions to the hornfels.

Specimen 2 resembles 8 in texture but is extensively altered.

Specimen 60 has afine-grained matrix composed of quartz, orthoclase, unzoned adesine, An_{38}, and flakes of reddish biotite.

The latter are individually of the same order of size as the grains of quartz, but aggregates of several flakes are also common. Pleochroic apatite and tiny zircon crystals are present. The rock has a banded appearance, seen in thin section to be due to alternations of biotite-bearing and biotite-free bands. Porphyroblasts of augite, hornblende and epidote occur, together with a few squat crystals of andesine containing the usual internal cloud of dust-like inclusions. The ferro-magnesian minerals all show well-developed sieve texture and crenulate margins, such as are typical of porphyroblasts, and reach 0.15 mm. in length.

Finally, specimen 62 differs from those described above in having large rounded quartz crystals, and aggregates of similar large crystals, in addition to the more usual angular grains. The grain-size varies considerably even in a single section, some patches being medium-grained, while adjacent areas are very fine-grained.

2. Quartz-diorite.

The localities where outcrops of quartz-diorite can be found are listed on p.5, and a short description has been given of the varieties exposed in the quarry west of Bellahillan Bridge, (p.5).

The greater part of the floor of this quarry is composed of a dark gray rock with large pink crystals of felspar; specimen 36 is representative. In thin section it is seen to be mineralogically a quartz-diorite although the texture of its matrix is reminiscent of that of specimen 38 (hornfels) previously described, (p.13). There is no direct evidence to prove a definitely igneous origin for 3y, but it is described among the rocks thought to be 'igneous', on account of its smaller proportion of quartz as compared with specimens of hornfels such as 38 and 78. The matrix of 36 is highly variable even in a single section, some patches having small quartz and felspar grains, while others have larger quartz and felspar grains and only a small amount of interstitial quartz. In this matrix are set porphyroblasts of plagioclase and ferromagnesian minerals with sieve texture and crenulate margins (see Fig.3).

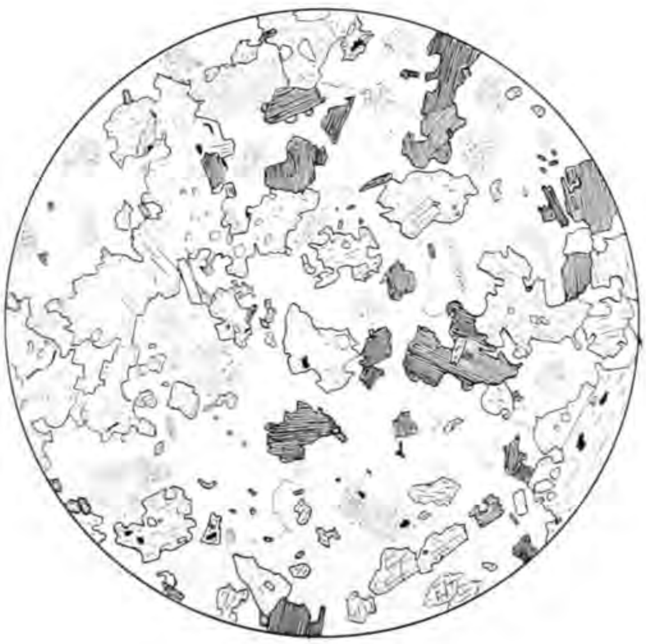


Fig. 3.

The plagioclase is andesine, An_{32}, regularly zoned outwards to oligoclase, An_{25}; the crystals never exceed 3 mm. in length. Sericite fibres are arranged parallel to the albite twin lamellae, and are distributed through the whole of the crystal. Hornblende crystals with sieve texture and elaborately crenulate margins have the following optical properties: Pleochroism is X = brownish green; Y = darker brownish green; Z = grass green. The optic axial plane is parallel to (010) and Z c = 27°. The birefringence insections parallel to (010) gives a maximum value of $\gamma - \alpha = 0.020$ The optic sign is negative with 2V large. These optical properties indicate that the amphibole is a normal hornblende although the value of $\gamma - \alpha$ is rather low (cf. Winchell, 1927 p.213). Small inclusions of magnetite and biotite are common and are arranged parallel to the cleavages. In addition to the hornblende, a small amount of pale green amphibole is present in anhedral crystals; its colour, slight pleochroism and extinction angle (18°) indicate that it is actinolite. Alteration has occured to chlorite, canary-coloured epidote and calcite. The grains of these secondary minerals first develop parallel to the prismatic cleavages, and gradually spread until, in the most advanced stage, they form a granular aggregate with the form of hornblende.

The prophyroblasts of biotite differ from the reddish-brown sedimentary biotite in being pleochroic from pale straw-brown to deep vandyke brown. This variety occurs as short, stout flakes in the matrix, and also as long blade-like crystals enclosed in the hornblende and actinolite. Numerous dark, coarsely-crystalline clots are present in the matrix, many of which reach 1.5 mm. in diameter. They are composed mainly of hornblende and biotite, but are never entirely free from plagioclase. Centrally the amount of felspar is small but towards the outside it increases and the clots merge imperceptibly into quartz-diorite. Colourless apatite is a constant accessory.

The quartz-diorite of the quarry is veined by a light-gray rock which also contains large pheno-crysts of felspar; specimen 35 is representative. In thin section, it has a texture which can be described as more characteristically 'igneous', since the hornblende crystals, and to a less extent those of plagioclase, show only traces of sieve texture, (see Fig. 4).

Fig. 4.

A clue to the mode of origin ofthe rock is thus afforded. The most abundant mineral is plagioclase, occasionally reaching 10 mm. in length, and so tending to be porphyritic. Measurements on sections parallel to (010) indicate that the zoning is often rhythmic, the core and alternate zones being andesine, An_{34}, while the remainder is oligoclase, An_{24}, apart from the periphery which is oligoclase, An_{19}. Hornblende occasionally shows sieve texture, but the margins are hypidiomorphic to idiomorphic in outline. Biotite, extensively altered to chlorite, is present in anhedral crystals and does not show sieve texture. Quartz occurs as interstitial wedges between the other constituents and as inclusions in hornblende crystals. A subordinate amount of orthoclase is present in hypidiomorphic plates. The accessory minerals are colourless apatite, apatite which shows pleochroism frompurple (X) to pale brown (Z), flakes of reddish biotite with pleochroic haloes, sphene, zircon, pyrite, magnetite and limonite.

The relations exposed in the quarry (p.6) indicate, therefore that a mass of quartz-diorite with a hornfelsic texture, is traversed by veins of quartz-diorite having a nearly igneous texture.

The quartz-diorite near the margin of the complex is represented by specimens from Drummora Great, (34, 39, 82, 83 and 84) and Monnery Upper (67). These resemble 35 (above) in the presence of large phenocrysts of plagioclase, but differ from it in having biotite crystals which show sieve texture and in having a greater proportion of quartz in the matrix. The nature of the contact which occurs between quartz-diorite and hornfels in Drummora Great will be discussed below (pp 35-36).

The quartz-diorite exposed in Lisnamandra and Castle Cosby has a similar texture to that of 35 and differs from it in composition only in having a slightly greater proportion of orthoclase to plagioclase.

Inclusions of hornfels are common throughout the quartz-diorite and consist of lenticular masses of quartz, orthoclase and reddish biotite with porphyroblasts of plagioclase. The boundary of the enclaves can only be recognised by the abundant presence of reddish biotite in the sediment and its almost complete absence from the quartz-diorite.

Specimens 37 and 80, from outcrops between Bellahillan Bridge and quarry already mentioned (p.5), are quartz-diorites having a slightly greater proportion of ferromagnesian minerals than any of the specimens described above. They also have more orthoclase in the matrix and so are transitional towards the monzonite of Lismore Demesne and Cavanfin. Rocks outcrop in Garrymore and at Cloggy Bridge; specimens 21, 22, 23 and 70 are typical of the first outcrop; 32 represents the second. In thin section they all resemble specimen 36, (p.19), in having a matrix with a hornfelsic texture. This matrix makes up about 10 per cent of the volume of the rock and consists of a mosaic of quartz and orthoclase without any flakes of reddish biotite, (see Fig. 5). Large rounded quartz crystals occur which are reminiscent of those in the hornfels of specimen 62 (p.18); they have finely crenulate margins where they come into contact with the fine matrix. Porphyroblasts of plagioclase up to 5 mm. long are abundant and most of them show crenulate margins and sieve texture. In composition they consist of andesine, An_{34}, zoned rhythmically with oligoclase, An_{28}. A band of dust-like inclusions arrange parallel to the periphery is usually present. Porphyroblasts of hornblende and biotite with the usual sieve texture and irregular margins also occur.

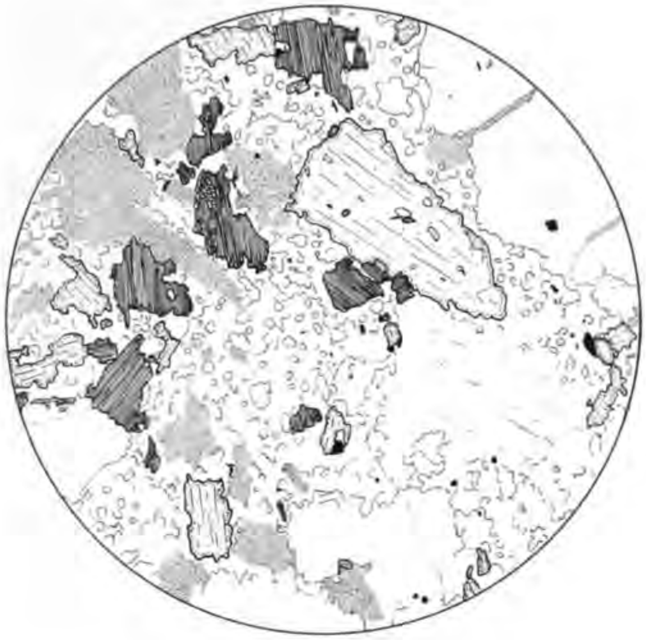


Fig. 5.

In specimens 23 and 32, plates of orthoclase are also present, often 5 mm. in diameter, with crenulate margins and inclusions of quartz and plagioclase. In 32 the matrix is somewhat patchy, some areas having the coarser grain typical of highly recrystallised hornfels.

Erratics of quartz-diorite are common in the boulder clay that overlies the greater part of the complex, and a thin section of one of these is noteworthy in containing relatively large crystals (up to 0.6 mm. long) of pleochroic apatite.

Micrometric analyses of certain specimens of quartz-diorite were made, with the following results, (percentages by volume):-

Specimen No.	26.	39.	10.	35.
Locality.	Castle Cosby.	Drummora Great	Erratic. Ballinagh.	Drummora Great.
Hornblende.	29.3	19.6	16.8) =	= 22.3
Biotite.	3.1	7.4	6.5)	
Quartz.	11.2	15.3	15.4	17.1
Felspars.	51.7	55.0	57.0	56.4
Accessories.	3.4	2.6	2.8	3.6
	98.7%	99.9%	98.5%	99.4%

3. Quartz-Monzonite.

The rocks of this group differ from those described as quartz-diorite in having much more orthoclase and generally less quartz. The combined orthoclase and plagioclase may be a little more abundant than the total felspar of the quartz-diorites, but the difference is not great, (see p. 30). The rocks vary from a type with about equal amounts of orthoclase and plagioclase to one in which the ratio of plagioclase to orthoclase is about 2.1. Specimens with a still higher proportion of plagioclase are quartz-diorites.

The textures are patchy and composite and cannot as a whole be definitely designated as either hornfelsic or igneous. In this feature there is much in common with the quartz-diorites.

The group is represented by fresh specimens from Hermitage (25 and 51); Kevit Lower (27 and 59): Lismore Demesne (61 and 64); Cavanfin (43); and Bellahillan Bridge (42). Quartz is present in small amount and occurs as interstitial wedges between hypidiomorphic crystals of the other constituents (see Fig.6). In places, neighbouring angular or wedge-shaped sections without visible connection are in optical continuity over an area of 1 sq.cm. or more. Orthoclase is usually accompanied by perthite and irregular crystals which are possibly soda-orthoclase. These minerals characteristically occur in large anhedral plates, sometimes 10 mm. across, which have extremely irregular edges. Carlsbad twinning is common. They enclose crystals of apatite, plagioclase, hornblende and biotite, and in some cases, quartz.

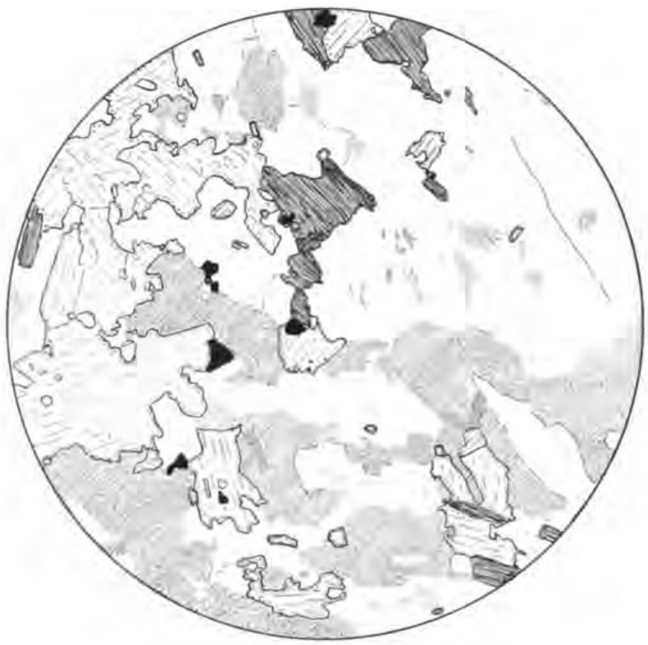


Fig. 6.

The plagioclase is oligoclase near andesine, An_{28}, to An_{16}; the habit is lath-shaped with hypidiomorphic to idiomorphic outlines, crenulate margins being rarely seen. The plagioclase crystals are not so large as the orthoclase plates and rarely exceed 2 mm. in length.

Augite occurs in anhedral crystals and occasionally shows the development of a rim of hornblende. The augite contains numerous inclusions of biotite flakes arranged parallel to the cleavages and of rod-like groups of iron-ore grains, probably magnetite, confined to the central parts. Where unaltered, the pleochroism of the augite is X=Z = pencil gray; Y = pale brownish gray; $Z \wedge c = 45^{\circ}$. The optic sign is positive, 2V is about 50° and the birefringence, though not measured, is clearly high. A small amount of uralite is present as an alteration product, identified by its pale green colour, an extinction angle of 15° and the positive elongation of the fibres.

Crystals of hornblende are present and is characterised by both sieve texture and crenulate margins; the mineral is similar in appearance and optical characters to the hornblende of the quartz-diorite.

Biotite occurs in squat rectangular forms and is a dark brown variety without pleochroic haloes. It is much altered to penninite. Some crystals show sieve texture with inclusions of quartz grains.

Aggregates consisting of hornblende, augite and biotite are common.

The mode of origin of this rock is suggested by the frequent presence of hornfelsic looking patches made up of mosaic of quartz and orthoclase grains with flakes of reddish biotite. These patches pass imperceptibly into areas with interstitial quartz, and together with the sieve texture of hornblende and brown biotite crystals, provided indirect evidence of hybrid origin at a lower level followed by intrusich.

Specimens 43, 42 and 27 deserve special description. Specimen 43, from Cavanfin, is seen in thin section to have somewhat more plagioclase than orthoclase, in a ratio of approximately 3 to 2. The grain is finer than that of the previously described monzonites, this difference being controlled by the relatively small size of the orthoclase and perthite, which is of the same order as that of the plagioclase. The latter occurs in crystals showing anhedral outlines and, occasionally crenulate margins. Orthoclase frequently encloses plagioclase. Interstitial quartz is a relatively subordinate constituent. Augite, with rims of hornblende contains inclusions of biotite and magnetite and tend to occur in clot-like aggregates of anhedral crystals, are characterised by poorly developed sieve texture and crenulate margins. Accessory minerals are colourless apatite, sphene, magnetite and epidote; the latter occurs in anhedral crystals and shows pleochroism from pale-to-greenish-yellow.

Specimen 42, from Bellahillan Bridge, was collected from nearer the quartz-diorite of Drummora Great than 43. It is of still finer grain than 43 and has an extremely uneven texture. In some parts, quartz occurs interstitially between small orthoclase and andesine crystals, while in others it forms a mosaic which may be of either fine or medium grain. Over the entire section, plagioclase is more plentiful than orthoclase, which, however, is more abundant than in the quartz-diorites. The plagioclase shows sieve texture and crenulate margins. The mafic minerals, represented by augite with hornblende rims and brown biotite, are of the size as in the previously described specimens of monzonite, and exhibit fairly well developed sieve texture. Clot-like aggregates of amphibole and biotite are present. Reddish biotite occurs in anhedral plates often 1.5 mm. across; sieve texture is developed with inclusions of quartz. Specimens 51 (Hermitage) and 64 and 61 (Lismore Demesne), 43, 42, 37 and 80, 35 and 36 (Drummora Great), constituting a series from east to west across the northern part of the complex, suggest that there is a gradual passage from monzonite to quartz-diorite, indicated by deacrease in the proportion of orthoclase to plagioclase and increase in the amount of quartz.

Specimen 27, from a quarry in Kevit Lower, resembles 42 in composition but is slightly coarser in texture. The exposure at this particular locality is notable for the abundance of inclusions of hornfels. The difference incomposition from the normal monzonite, exposed two hundred yards to the south-east (No.59), may be correlated with this fact.

Micrometric analyses of typical specimens of monzonite are as follows, (percentages by volume):-

Specimen No.	25	43	27
Locality.	Hermitage.	Cavanfin.	Kevit Lower.
Hornblende.	17.9	26.4	13.0
Biotite.	6.5	8.2	9.3
Quartz.	8.4	9.0	12.9
Felspar.	66.8	55.5	63.7
Accessories.	0.6	0.7	0.8
	100.2%	99.8%	99.7%

4. Fine-grained Granodiorite.

This variety of granodiorite is represented by specimens 5, 7 and 14 from the railway cutting in Coolnacarrick, and by numerous inclusions from both the monzonite and the coarse-grained granodiorite. It is the most finely grained rock of the complex and its texture is hornfelsic rather than igneous. A mixture of igneous material with hornfels is shown by the prevalence of (a) porphyroblasts of plagioclase and mafic minerals, and (b) patches of hornfels in the matrix, see Fig.7.

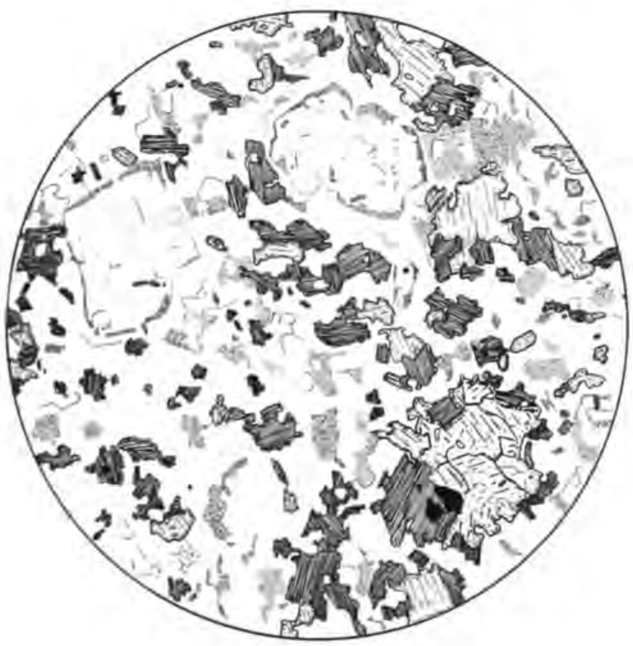


Fig.7.

The matrix makes up about 40 to 60 percent of the rock and is composed of angular quartz grains, orthoclase in anhedral crystals with inclusions of quartz and biotite, and ragged flakes of reddish biotite. Purple, pleochroic apatite in small prismatic crystals is a noteworthy accessory. The grain ofthe matrix, though fine, is coarser than that of the neighbouring biotite-enriched hornfels.

Among the larger constituents, plagioclase is conspicuous. It is zoned from andesine, An_{38}, to oligoclase An_{27}, and in sections parallel to (010) the zoning can be seen to be rhythmic. Small crystals have irregular outlines but larger ones tend to show square, euhedral forms, reaching 1.5 mm. across. Whether large or small, they are peculiar in containing tiny inclusions of biotite and hornblende and in having a narrow band of extremely fine inclusions parallel to the crystal edges; in some cases more than one such band is present.

The hornblende crystals, some of which enclose augite, rarely occur in clots, and invariably show sieve texture with intricate margins. Brown biotite also occurs in porphyroblastic forms with rounded inclusions of quartz. Sphene, colourles apatite and magnetite occur as accessories.

5. Coarse-grained Granodiorite.

This type is characterised by quartz, orthoclase, perthite, plagioclase, hornblende and biotite with apatite, sphene, zircon and magnetite as accessories. The texture is coarse-grained allotriomorphic granular (see Fig.8).

Fig. 8.

Quartz is abundant and typically occurs as anhedral, often wedge-shaped, masses interstitial to the other constituents. Rounded forms showing shadowy extinction are also present. With increase of orthoclase relative to plagioclase the rocks grade from granodiorite to adamellite. Orthoclase occurs in large anhedral plates reaching 10 mm. across, poikilitically enclosing quartz and plagioclase crystals. Soda-orthoclase and perthite accompany the orthoclase and crystallise in a similar form. Myrmekite has not been identified. The plagioclase is oligoclase, zoned from An_{28}, to An_{25}; it characteristically occurs in nearly euhedral lath-shaped crystals about 3 mm. in length . Sericite occurs as a felt of tiny fibres which entirely covers the smaller plagioclase crystals: in the larger crystals, it occurs in narrow bands parallel to the composition zones of the felspar. In occasional specimens, however, the plagioclase builds large anhedral plates with quartz and hornblende inclusions.

Neither hornblende, some of which encloses a core of augite, nor biotite is abundant. In the measured sections the ratio between these minerals is fairly constant, biotite always being in slightly greater amount. Both occur as anhedral crystals of smaller size than those of quartz, and inclusions of colourless apatite are characteristic. The hornblende is the usual green pleochroic variety, similar to that occurring in the quartz-diorites and the monzonites previously described. The biotite occurs in squat forms and is a typical brown "magmatic" variety. Near contacts, against either fine-grained granodiorite or hornfels, the brown biotite is accompanied by irregular crystals of the reddish type. Coloured apatite may be present, as in the rocks of the railway cutting of Coolnacarrick and those of the southern boundary in Drumcarban. Sphene is occasionally present as an accessory and occurs in brownish, hemihedral crystals.

The modes of representative granodiorites, determined by micrometric measurements, are as follows, (percentages by volume):-

Specimen No. Locality.	30 Newtown	6 Coolnacarrick.	16 Gaweel	11 Kilsallagh.
Hornblende.	5.7	4.6	5.8) =	19.7
Biotite.	9.6	7.3	8.5)	
Quartz.	21.4	22.4	21.8	21.5
Felspars.	61.0	61.5	62.0	53.7
Accessories.	1.2	2.8	0.7	3.1
	98.9%	98.6%	98.7%	98.0%

6. Veins.

Numerous veins cut the granodiorite, and the following types have been noted, all being irregular in distribution and following no definite direction.

1. Aplite.
2. Quartz.
3. Calcite, often accompanied by chlorite and pyrite.
4. Pyrite-chlorite.

The aplites consist of quartz and orthoclase, usually in anhedral crystals and sometimes graphically intergrown. Plagioclase is rare. Occasional phenocrysts of quartz are locally present. The proportion of mafic minerals is low, and in some specimens, as for example from veins in Garrymore quarry, they are entirely absent. Limonite, or magnetite partly altered to limonite, is present inaccessory amount.

There is little evidence to indicate the order of injection of the veins; in Garrymore quarry, calcite-chlorite veins can be seen cutting aplite veins, and in thin section (see p.17) a pyrite-chlorite vein cuts one of quartz. There is no direct evidence to indicate the order in which the aplites and quartz veins were injected.

IV. PETROGENESIS.

The data assembled in the foregoing pages and the inferences drawn from them may be summarised as follows:

(a). A gradual transition has been traced in the railside outcrops in Coolnacarrick from a slaty type of hornfels to fine-grained granodiorite. The development of the latter is correlated with the observation that the hornfels of this neighbourhood is dominantly a bioite-enriched slate, greywacke being almost unrepresented. The fine-grained granodiorite appears to have been formed from the hornfels by the growth in situ of porphyroblasts of plagioclase, hornblende and brown biotite.

(b). A similar phenomenon has been observed in Drummora Great, where, however, quartz-diorite was developed. In this case the difference in the result is correlated with the observation that the hornfels is metasomatised greywacke. Both megascopically and microscopically there is a close resemblance between the hornfelses Nos. 38 and 78 (both of which are metasomatised greywacke containing angular quartz and reddish biotite of the greywacke type in the matrix) and the 'hornfels' type of quartz-diorite No.36 (which contains a smaller proportion of quartz and biotite)

(c). The quartz-diorite with 'igneous' texture represents a later stage than the quartz-diorite with 'hornfels' texture. This is made clear by the relations between these two types disclosed in the quarry at Drummora Great (p. 22).

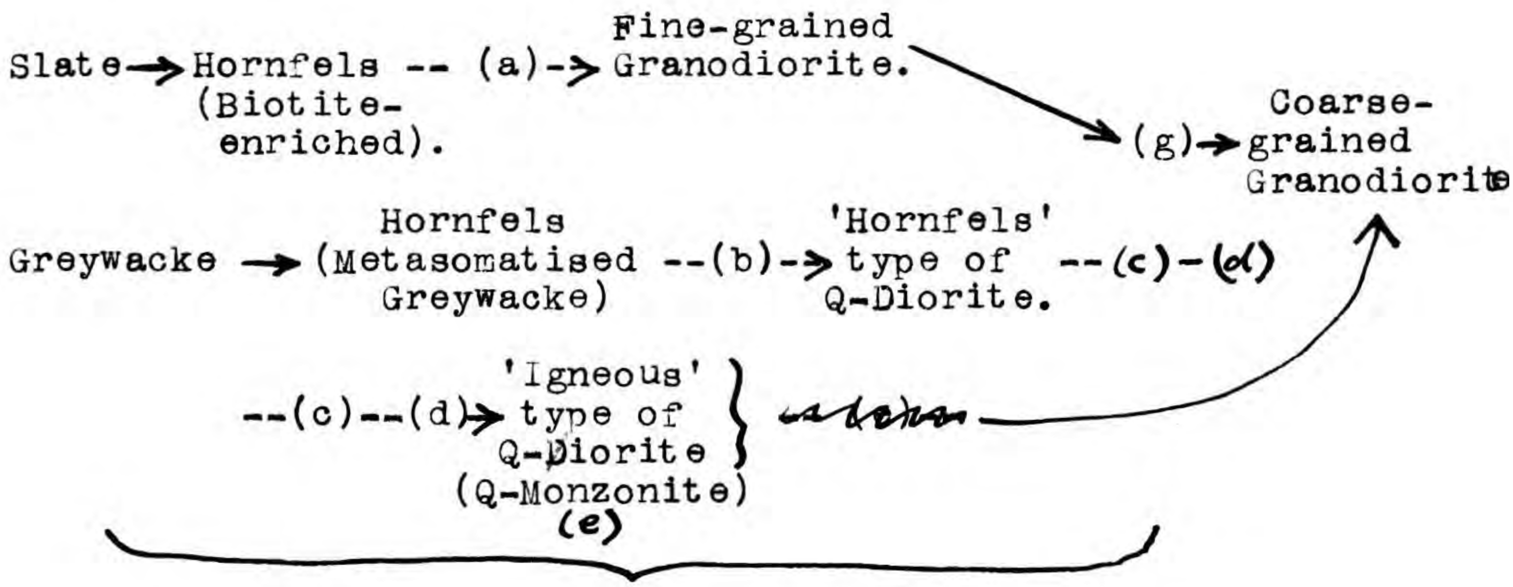
(d). The junction between complex and hornfels at the north west bulge in Drummora Great suggests that the 'igneous' type of quartz-diorite is at least to some extent intrusive. The contact is not parallel to the strike of the hornfels, since in the road-side exposures quartz-diorite (Nos. 83 and 84) is adjacent to metasomatised greywacke, No.38, whereas about a quarter of a mile to the north-east, quartz-diorite (Nos. 39 and 41) is in contact with biotite-enriched slates free from porphyroblasts of plagioclase, hornblende or biotite (see page 16). Combining this evidence with that summarised in paragraph (c), it seems likely that the area now occupied by the 'igneous' type of quartz-diorite was originally occupied by materials of which the 'hornfels' type of quartz-diorite, No.36, and the metasomatised greywacke, No.38, are relics. Through these stages the quartz-diorite can thus be traced back to the Ordovician sediments and it is suggested that the quartz diorite owes its origin to the 'ultra-metasomatism' of the latter.

(e) The emplacement of quartz-diorite and quartz-monzonite represents a single stage. This is shown by the gradual transition from the quartz-monzonite of the interior of the complex to the quartz-diorite of the margins. This emplacement was evidently later than the formation of the fine-grained granodiorite, since inclusions of the latter occur in the quartz-monzonite.

(f) The quartz-diorite and quartz-monzonite contain, in nearly every exposure, dark-coloured coarse grained aggregates of hornblende, (sometimes with augite cores), biotite and a little plagioclase. Similar aggregates have also been found in metasomatised greywacke, No.78. Although their significance is by no means unequivocal, it seems probable from their occurrence in greywacke that they represent localised results of metasomatic introductions. Here it is of interest to recall that on Rough Hill in the Newry Complex (Doris Reynolds, 1934, p.612) quartz-diorite and quartz-monzonite have beeh observed to result from the permeation of sediments by augite-biotite-diorite magma. The migmatites became sufficiently mobile to rise to a higher level since, further north, similar material shows intrusive contacts against hornfels. The Crossdoney aggregates of hornblende, biotite and plagioclase are very similar to the augite-biotite-diorite of Rough Hill and the association in each case with sediments and quartz-diorites may therefore be significant.

(g). The emplacement of coarse-grained granodiorite is later than that of the fine-grained granodiorite and also that of the quartz-diorite, since inclusions of both these types occur in the coarse-grained granodiorite. Moreover, the latter exhibits intrusive contacts against both hornfels and fine-grained granodiorite. However, the genetic relation between the coarse-grained granodiorite and the other types is not clear. Neither megascopically nor microscopically have structures or textures ~~textures~~ been detected which provide any definite clue to the pre-magmatic history of the materials. The rock is, nevertheless, so similar to the coarse-grained granodiorite of the Newry complex (Doris Reynolds, 1934, p.621) which presents evidence of a syntectic origin, that a similar mode of origin seems probable in the Crossdoney example.

The following scheme illustrates diagrammatically the relations that have been made out. The letters refer to the above paragraphs, where the evidence is summarised.



(f)-- Aggregates of hornblende, biotite and plagioclase formed from metasomatic introductions.

Without chemical analyses it is not possible to deduce with any certainty what the metasomatic additions at the various stages have been. It is clear, however, that the early stages (a) and (b), have involved essentially alkali metasomatism, and that the later stages, up to (e) and (f), involved cafemic metasomatism with, finally, sufficient introduction of energy to ensure mobility and true palingenesis.

In a forthcoming paper (Holmes, 1937), from which he kindly allows me to quote, Professor Holmes has suggested the following generalised expression of the factors involved in metasomatism and in the closely related process -- at a higher energy level -- of syntectic magma formation:

(i) Incoming emanations (from other 'active' magmas or the 'substratum').

+

(ii) Energy (secular, radioactive, reactional, etc.)

+

(iii) Crustal rock material, metasomatised, migmatised, or more or less magmatised by (i) and (ii).

-

(iv) Outgoing emanations and associated energy (magmatising agents, transforming other crustal rocks into magmas; migmatising agents generating syntectic rocks; pneumatolytic and and hydrothermal fluids; volcanic gases etc)

In the Crossdoney complex the pre-existing rock material (iii) consisted of the Ordovician slates and greywackes, so far as quartz-diorite and fine-grained granodiorite are concerned; a similar conclusion is probable, but not proved, for the quartz-monzonite and the coarse-grained granodiorite. The nature of the incoming emanations has been indicated above in a qualitative way. Their source, however, has not been recognised. In the Newry complex Doris Reynolds (1936) has been able to trace the emanations responsible for the shonkinite-syenite series of syntectic rocks to magmas now largely represented by biotite-pyroxenite and peridotite. Such ultrabasic rocks, if present in the Crossdoney Complex, have not yet been exposed by denudation.

V. - ACKNOWLEDGMENTS

The investigations of the petrology of the Crossdoney Igneous Complex was carried out under the guidance of Professor Arthur Holmes. It is difficult to know how to begin to express my thanks to him and to Miss Doris Reynolds for their advice, and critical discussion of the petrological problems presented by the complex, especially during the time when this paper was in manuscript. My thanks are also due to Mr. G. O'Neill for rock sections and photographs.

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