Chapter 26 The Galloway granites and associated igneous rocks

Granite masses

In the following descriptions the three main masses of granitic rock will be referred to as the Criffel [NX 92513 63134] mass, the Cairnsmore of Fleet mass [NX 56402 70224], and the Loch Dee mass [NX 45886 80232].

The general characters of the Criffel mass have already been described in the Memoir on Sheet 5, but in order to make clear its relation to the other masses it is desirable to repeat the descriptions already published.

Criffel and Dalbeattie Mass. — [NX 95773 62044], [NX 84020 60966]The prevailing type of rock in this mass is a moderately coarse-grained grey granite or quartz-diorite, essentially composed of biotite, hornblende, oligoclase, an alkali-felspar and quartz; iron-ores, apatite, and sphene are almost always present as accessory constituents, and a pale-coloured augite is occasionally found. The biotite is of the type usually occurring in granites. The basal plane is often well developed, but the prismatic planes are very imperfect, and it is rare to find a section showing even an approach to the hexagonal form. The pleochroism is very intense, varying from yellowish or reddish brown to nearly opaque. The first stage in the alteration of this mineral is seen in the replacement of the deep brown, characteristic of the β and γ axes, by a green colour, and this may occur without any change in the colour, for rays vibrating parallel to the α axis. The final stage of alteration, both in the biotite and hornblende, is the formation of chlorite and epidote.

The hornblende, like the biotite, is not markedly idiomorphic, though traces of the prismatic faces and the clino-pinacoid may occasionally be observed. The colour of the hornblende in the normal rock is green, but in the more basic modifications and in the dioritic inclusions, greenish-brown, and even brown varieties may sometimes be observed.

The dominant felspar in all the rocks, except those which represent the acid veins, is a plagioclase allied to oligoclase in composition. It is white in the hand specimen, and frequently shows a somewhat pearly lustre on the striated cleavage faces. Idiomorphism is a marked feature of the plagioclase, so that it evidently belongs to an early phase in the consolidation of the magma. A zonal structure may frequently be seen, and this is most marked in the basic varieties of rock. The external portions of the zoned individuals are frequently more acid than the central parts, but there is no rigid law as to the increase of acidity from centre to margin. Narrow zones of a basic felspar may recur again and again in one and the same individual (S6565)<ref>The figures within brackets refer to the numbers of the microscopic sections in the collection of the Geological Survey.</ref>. Inclusions are comparatively rare in the plagioclase.

Both plagioclase and alkali-felspar become turbid by the development of minute flakes of a micaceous mineral.

The alkali-felspar contains both potash and soda, and is rich in the latter alkali. It never shows any trace of idiomorphism, but forms, together with quartz, the matrix or ground mass, if that term may be applied to a granitic rock, in which the other constituents are embedded. The extinction is often wanting in sharpness, and in a few cases microcline structure has been observed. The alkali-felspar may be easily distinguished from the oligoclase, when both are unaltered, by its lower refractive index and by the absence of crystalline form.

Quartz occurs in irregular grains and as ophitic patches. In the basic rocks, and in the inclusions, the interstitial character of the quartz is seen in the most marked manner; small patches wedged in between the idiomorphic constituents often extinguish simultaneously over a wide area. The mineral is rich in inclusions containing bubbles.

The accessory constituents do not require detailed description. The sphene is widespread, and may often be detected in the hand specimen. Under the microscope it is seen to be deeply coloured, pleochroic, and idiomorphic. It is very abundant in some of the inclusions. The augite deserves more than a passing mention. It is the pale-green or nearly colourless variety characteristic of the augite-granites, and usually occurs as a core in hornblende. In some of the more basic rocks it becomes sufficiently abundant to deserve recognition as an essential constituent.

Biotite, hornblende, augite, when present, and oligoclase, belong to the earlier phases of consolidation; quartz and alkali■felspar to the final stages. The relative proportions of the different constituents vary in different parts of the mass, and it is doubtful whether the prevailing type of rock is a hornblende-biotite-granite or a quartz-diorite of the tonalite-type. In any good exposure, such as that seen at the granite quarries near Dalbeattie, the normal granite or quartz-diorite is seen to contain basic inclusions, and to be traversed by acid veins. The basic inclusions, so far as they have been examined, always consist of a quartz-diorite richer in the minerals which belong to the earlier phases of consolidation, and poorer in quartz and alkali-felspar than the main mass of the rock. Sphene and apatite are especially abundant in many cases. The acid veins, on the other hand, consist almost entirely of quartz and alkali-felspar. The narrow veins are formed of a fine-grained aplite, but the broad veins assume the character of pegmatite, and frequently show the graphic intergrowth of quartz and felspar. These broad veins may sometimes be broken down the median plane, so as to disclose the presence of drusy or miarolitic cavities containing crystals of smoky quartz. A section through one of the pegmatitic veins in the Craignair Quarry [NX 81939 60780] (S6596) shows the presence of a narrow band of nearly pure quartz running through the middle of the vein. The main mass of the vein is formed of quartz and alkali-felspar, sometimes intergrown so as to form a coarse variety of micro-pegmatite. Oligoclase and biotite occur as accessory constituents. The alkali-felspar occasionally shows the structure of micro-perthite, but microcline-structure is absent. The following table gives the specific gravity of each of the rocks occurring in the Craignair Quarry:

Acid vein	2.60
Normal granite	2.66
Normal granite	2.67
Basic inclusion	2.77
Basic inclusion	2.71

So far we have been referring only to the massive rocks. As a type of the foliated rocks we may select a specimen from Criffel (S1217) [NX 95773 62044]. This is a medium-grained gneissose rock. The ferro-magnesian constituents form somewhat ill-defined flaser round phacoids of felspar or of quartz and felspar. Sphene is easily recognisable with a lens. Under the microscope the essential constituents are seen to be biotite, hornblende, oligoclase, alkali-felspar, and quartz. A pale-green augite (0.4mm.) occurs as a core in one of the patches of hornblende. Brown idiomorphic sphene occurs in crystals of considerable size (0.3 to 0.75mm.). The alkali-felspar shows occasionally a distinct microcline-structure, and contains inclusions of oligoclase and quartz. Small patches of felspar, intergrown with vermicular quartz, are present, and also one or two grains of a mineral somewhat doubtfully referred to orthite. The interstitial movement which has resulted in the production of foliation, and which is proved by the field evidence to have been produced by earth stresses operating after the rock had reached its present position, and after the formation of the acid veins, has not affected all the constituents alike. The quartz and alkali-felspar, which, as we have already seen, were the last constituents to solidify, are those which have yielded most in the deforming stresses. They show signs of crushing, and frequently pass into thin micro-crystalline or even crypto-crystalline streaks, which wind round the comparatively uncrushed crystals of oligoclase. The distribution of the ferro-magnesian constituents has been modified by the movement. Instead of being irregularly distributed through the rock they tend to form flaser in association with the micro-crystalline aggregate of quartz and alkali-felspar. The oligoclase has been little, if at all, affected by the movement. These facts clearly prove that the minerals which yield most readily to the deforming forces are those which consolidate last. It is highly probable that the pressure acted before the rock-mass had actually cooled. (See (Plate 24)., fig. 2.)

Two specimens taken from a large block occurring about half a mile north by east of Kells Farmhouse near Southwick ca. [NX 94412 58056] (S6572) and (S6573) represent the effects of deformation in a more extreme form. The rock loses the gneissose character, and finally passes into a grey granulite. The secondary micro-crystalline aggregate forms a much larger proportion of the main mass of these rocks, and cataclastic structures are strongly marked.

The foliation not only affects the normal hornblende-granite or quartz-biotite-diorite, but also the veins of aplite and the basic inclusions, which are exceptionally abundant near the junction ca. [NX 94272 58081](S6576), (S6589), and (S6574). Even the quartz veins are foliated (S6575). In all cases the foliation maintains the same general direction. The foliated veins of aplite are largely composed of the secondary micro-crystalline aggregate of quartz and felspar, and the large irregular grains of alkali-felspar, which have escaped crushing, show strain-phenomena under crossed nicols. The fact that the foliation in these veins has no reference whatever to the direction which they take is a striking proof that it

cannot be due to fluxional movement during intrusion. It must be the result of dynamic forces operating after the intrusion of the granite and after the formation of the veins. A section prepared from a specimen collected at a point about a quarter of a mile north of Kells Farmhouse (S6589) [NX 94209 57672], has been cut through the junction of an acid vein with the normal granite. The Junction line is nearly at right angles to the direction of foliation, which is seen to pass from one rock to the other without a break.

The principal portion of the Criffel mass is a tonalite rather than a true granite, but in view of the fact that it is identical in general appearance with a typical grey granite, it has been considered undesirable to change the name by which it has always been known. A special feature of this mass is the extraordinary abundance of sphene. It is rare to find a hand specimen in which the characteristic clove-brown crystals of this mineral may not be detected with a pocket lens.

If we were to follow the geographical order from south to north the Cairnsmore of Fleet mass would next engage our attention, but as the Loch Dee mass [NX 46838 79988] occupies petrographically an intermediate position it will be more convenient to take it next.

The dominant rock, as in the case of the Criffel mass, is a moderately coarse-grained grey granite. Biotite and hornblende are the principal ferro-magnesian constituents, and they vary in amount in different specimens. Plagioclase, alkali-felspar, and quartz occur, and bear the same structural relations to each other as in the Criffel mass. Taking the mass as a whole, the ferro-magnesian minerals and plagioclase are less abundant than they are in the Criffel mass. Nevertheless it is possible to obtain specimens from many localities which are identical with the rock of Criffel, except in one respect. The sphene, which is such a marked feature in the southern mass, is here comparatively rare. Another feature which tends to give the Loch Dee granite mass a more or less distinctive character is the frequent absence of hornblende over considerable areas. As hornblende disappears the rocks become lighter in colour, and alkali-felspar and quartz increase relatively to the plagioclase. Moreover, the alkali-felspar passes through the stage of moiré-orthoclase to typical microcline. The dominant rocks of the Loch Dee mass may therefore be classed as quartz-diorite of the tonalite type, hornblende-biotite-granites, or hornblende-granitites and biotite-granite or granitites. These different varieties shade into each other by imperceptible gradations, and the alkali-felspar and quartz always belong to the later phases of consolidation, even when the former are developed as large pseudo-porphyritic crystals, which is sometimes the case.

Typical quartz-diorite (tonalite) occurs at White Laggan [NX 46642 77481] (S214), (S215), south of Loch Dee, near the southern end of the mass, and south of Craiglea Hill, near the head of Loch Doon [NX 48148 92471], at the northern end of the mass. Hornblende-granitites, in which, however, plagioclase is generally the dominating felspar, occur at the Glenhead Lochs [NX 44827 80606], N.N.W. of Loch Dee (S7033), at the southwest end of Loch Enoch [NX 44038 84724] (S2522), at Craignaw, 2½ miles north of Loch Dee [NX 46027 82794] (S7035), at Craigeazle Hill, two miles E.N.E. of Loch Dee [NX 49177 82294] (S7032), at the foot of Polmeadow Burn [NX 49695 95117], four and a half miles west by north of Carsphairn, and near Portmark on Loch Doon. Biotite-granites or granitites occur in Glenhead Burn, west of Loch Dee [NX 43908 78929] (S722), in the Kirreoch Burn 5½ miles southwest of Carsphairn [NX 47509 89671] (S690), on the hill-top N.N.W. of Craigrarson [NX 48133 87175], six miles south-west of Carsphairn (S697), at Lochhead [NX 48558 92708], five miles west of Carsphairn (S687), on the hill slope west of Slaethornrig [NX 42312 91559], five miles south-west of Loch Doon. Head (S2535), at Loch Cornish [NX 41026 93959], 5½ miles west of Loch Doon Head (S714), and on Craignaw [NX 46005 82804], east of Loch Neldricken. (S2523).

The last-mentioned rock is a typical biotite-granite, with pseudo-porphyritic crystals of microcline, and as it departs widely from the tonalite-type, which is so extensively developed both in the Criffel and Loch Dee areas, a detailed description of it may be given. It is a light grey rock with a faint tinge of pink. Biotite is comparatively rare; quartz is abundant and shows traces of idiomorphism; pseudo-porphyritic crystals of alkali-felspar, having a pearly lustre on their cleavage planes and measuring a quarter of an inch across, are fairly numerous. Under the microscope the essential constituents are seen to be biotite, oligoclase, microcline and quartz. The biotite is of the type characteristic of granitites. The oligoclase shows the usual tendency to idiomorphism, but it occasionally contains inclusions of quartz. The alkali-felspar occurs in large patches with irregular borders. It is a typical microcline with laminae of plagioclase (oligoclase-albite) and inclusions of oligoclase, quartz, and biotite. Twinning on the Carlsbad plan is common, so that the patches divide under crossed nicols into two halves. The quartz, which is very abundant, occurs in large grains, as granular aggregates and as rounded blebs. The large grains occasionally show traces of idiomorphism. The small rounded grains are found as inclusions both

in the microcline and in the oligoclase.

A second specimen from the same locality (S7035), already referred to in the list of hornblende-granites, deserves mention in this connection, as it connects the above rock with the more basic granites which constitute the greater portion of the Loch Dee mass. This is a normal grey granite in appearance, containing a few crystals of pseudo-porphyritic felspar, which, however, do not stand out prominently from the other portions of the rock. Under the microscope the main differences between this rock and the one just described are seen to be due to the greater abundance of biotite and the presence of hornblende in the former rock. Both contain microcline under the same conditions and in considerable quantity. The normal hornblende-granitites and tonalites contain only a very small proportion of interstitial alkali-felspar. As these merge into the biotite-granites the amount of alkali-felspar and quartz increases, and the hornblende disappears. Moreover, the alkali-felspar, which is present as a soda-orthoclase in the tonalites, is replaced by moiré-orthoclase, and finally by microcline-microperthite. The evidence furnished by the Loch Dee mass of the gradual passage from tonalite to granitite with microcline is of great importance, as serving to connect together the three large granitic areas of the Galloway district; for the latter rock, which is rare or absent from the Criffel mass and forms a subordinate part of the Loch Dee mass, is the dominant type of the Cairnsmore of Fleet mass. There can be no doubt that all three masses belong to the same petrographical province, and it is highly probable that the differences observed between the different masses are due to differentiation in the subterranean magma-basin, and that the differences observable in one and the same mass are in part at least due to differentiation *in situ.*

So far we have been referring to the dominant types of rock occurring in the Loch Dee area. There are, however, some subordinate masses of great interest. In the description of the Criffel mass it was pointed out that a pale-coloured augite sometimes occurs as an accessory constituent in the hornblende-granitite and quartz-diorite, and is occasionally present in sufficient quantity to deserve recognition as an essential constituent, thus giving rise to quartz-augite-diorites. Examples of quartz-augite-diorite may be obtained on the west slope of Ben Gairn [NX 77058 54516], five miles south of Castle Douglas (S1220), and at a point two-thirds of a mile east by north of Ben Gairn ca. [NX 76613 55424] (S6568). In the last-mentioned locality it forms part of a basic mass which occurs at the contact of the main mass with the Silurian sediments.

Similar rocks occur in the Loch Dee mass, and also in the small mass at Burnhead [NS 45838 09093], which may be regarded as subsidiary to that of Loch Dee. Here, however, they are associated with a rock hitherto unrecognised in the Criffel area, for which the term hyperite is proposed. This term was employed by Tornebohm in his well-known paper, Ueber die wichtigeren Diabas und Gabbro-Gesteine Schwedens (Neues Jahr, 1877, p. 377), for a rock of the gabbro family in which both hypersthene and augite (diallage) occur either with or without olivine. The essential constituents of these Swedish rocks are plagioclase, augite, hypersthene, titaniferous iron-ore, and apatite. Quartz and probably also orthoclase occur as interstitial matter. When olivine is present the rock is termed olivine-hyperite. Many subsequent writers have ignored the term hyperite in favour of norite, which, however, may be more appropriately applied to rocks devoid of augite or possessing it only in very small quantity. The typical Swedish hyperites are evidently more basic than the rocks we are now concerned with, but as they resemble them in containing both hypersthene and augite in nearly equal proportions, and also in other respects, to which reference will be made in the sequel, it seems desirable rather to extend the use of the old term than to invent a new one.

Hyperites (see (Plate 25)., fig. 1) occur in direct association with the Loch Dee mass on the north face of White Laggan Hill ca.[NX 40784 92711]? (S2521), south of Ballochbeattie, 4½ miles west of Loch Doon Head (S709), (S2539), (S2540), on the hill-face west of Tunskeen [NX 41051 90582], five miles south-west of Loch Doon Head (S712), and on Craignasheenie Hill [NX 41493 92898], five miles west by south of Loch Doon Head (S2541). They are all dark-coloured medium to coarse-grained massive rocks, essentially composed of plagioclase, hypersthene (enstatite), augite, and biotite. Quartz and orthoclase occur as interstitial matter in all the more granitoid members of the group. Hornblende and iron-ores are present as accessories. The plagioclase has been definitely determined to be labradorite in one case, and it is probable that this is the dominant felspar; but as zonal structure is not infrequent, it is evident that the plagioclase is not always uniform in composition. In many specimens the mineral is crowded with minute opaque inclusions, which give a cloudy appearance to the thin sections when viewed with low powers. Idiomorphism is more marked than it is in typical rocks of the gabbro family. The sections in the more granitoid specimens are usually in the form of broad laths, but the boundaries are rarely straight lines, and contiguous individuals interfere with each other. In some specimens there is a

decided tendency to a porphyritic structure, and two generations of plagioclase differing in size may be observed. The sections frequently show the presence of twinning on the Carlsbad and albite types, but pericline twinning has not been observed.

The rhombic pyroxene occurs as grams, as prisms with more or less rounded angles, and, more rarely, as fairly idiomorphic crystals. Two or more individuals frequently occur together, forming a polysynthetic group. The intensity of the pleochroism varies in different specimens. Inclusions of brown plates, similar to those which occur in the well-known paulite variety, have been observed in one or two cases. The individuals sometimes have a narrow irregular edging of green hornblende.

The monoclinic augite occurs as grains, imperfect crystals, and polysynthetic aggregates. It is nearly colourless in thin section, and is usually free from inclusions. Sometimes, however, it contains the brown plates which are characteristic of some varieties of diallage.

Biotite is a constant feature of the hyperites, and is often as abundant as either of the other two ferro-magnesian constituents. It occurs in ragged plates, which are very strongly pleochroic, and which usually contain iron-ores and sometimes also augite and hypersthene as inclusions. Hornblende is present only as an accessory in the typical hyperite. It occurs as a narrow irregular fringe in association with both the rhombic and monoclinic pyroxenes.

Orthoclase may be clearly recognised in many of the sections, and is probably present in all lit forms, together with quartz, the matrix, so to speak, in which the other constituents are embedded, and therefore occupies the same position in the hyperites as it does in the tonalites and hornblende-granites. It occurs in the form of large irregular plates and as granular aggregates. A special feature of many specimens is the presence in the orthoclase of an extraordinary number of long acicular prisms of a perfectly colourless mineral, which appear to possess a lower refractive index than apatite. Quartz may generally be recognised, but is not abundant. It occurs as grains and interstitial patches. A small patch of micro-pegmatite was observed in one slide, but this substance is evidently very rare. The point is one of some interest, because the "norites" of Klausen in the Tyrol, described by Teller and Von John (Jahrb. d.k.k Geol. Reichsanstalt, 1882, p. 499), have many points in common with the rocks under consideration. The occurrence of micro-pegmatite is a common feature. In his descriptions of the Swedish hyperites, Törnebohm refers to the presence of quartz and probably orthoclase, and regards them as the latest products of consolidation. There can be no doubt that both these minerals are present in the hyperites associated with the Loch Dee mass, and that they occupy in relation to the other constituents the position assigned to them by Törnebohm. This feature, and the occurrence of the minute inclusions in the plagioclase, are subsidiary points which serve to connect the rocks under consideration with the Swedish hyperites.

We have now to consider the connection between these rocks and the more common quartz-diorites (tonalites) and hornblende-granitites. Evidence on this point is furnished by specimens from White Laggan Hill, one mile south-west of Loch Dee, and from the small detached mass of Burnhead. In both localities we find biotite-hyperites associated with quartz-augite-diorites, that is with rocks which are intermediate between the ordinary quartz-diorites and the hyperites. The presence of augite as an accessory constituent, both in the Criffel and Loch Dee masses, has already been referred to. By an increase in the amount of this augite and a corresponding diminution in the quantity of hornblende, the quartz-thorites pass into quartz-augite-diorites, and by a further modification of the same kind, coupled with the introduction of a rhombic pyroxene, we have a gradual passage from the quartz-augite-diorites into the biotite-hyperites. These biotite-hyperites, therefore, represent the most basic phases of the granitic magma known to us at present. If subsequent research should bring to light still more basic rocks they will doubtless be found to consist of norites and gabbros.

The association of basic rocks containing rhombic and monoclinic pyroxenes with quartz-augite-diorites (augite-tonalites), quartz-diorites (tonalites), and biotite-granites (granitites), has been already noticed in other areas. Thus Lossen<ref>Jahrb. d. k. Preuss. Landesanstalt, 1887, p. xxvii.; 1890, p. xxv.; 1891, p. xxix.</ref> has described such an association in the Brocken mass in the Hartz. The normal biotite-granite which forms the main mass of the Brocken sometimes contains augite as an accessory constituent, and these augite-granitites pass over into augite-biotite-quartz-diorites, and even into acid gabbro (biotite-augite-gabbro). In some of these more basic phases a rhombic pyroxene occurs.

Similar phenomena are recorded by Teller and Von John in the paper already cited. These authors point out that the intrusive rocks of the Klausen district do not readily group themselves under a collective name. They form rather a connected series, having at the one end quartz-mica-diorite, and at the other end a "norite" containing both monoclinic and rhombic pyroxenes. The two extremes are connected together by augite-bearing quartz-diorites and quartz-bearing enstatite-augite-plagioclase rocks ("quartz-norites").

This definite association of similar petrological types in widely separated districts, and in rocks of different geological age,<ref>The Galloway granites are post-Silurian and pre-Carboniferous; the Brocken granite is post-Carboniferous.</ref> clearly points to the conclusion that plutonic rocks, like minerals, are subject to laws of paragenesis. It is opposed to the idea which has recently been resuscitated in France that the granites have largely assimilated the sedimentary rocks into which they have been intruded, but is in accord with the differentiation hypothesis.

We have now to refer to some subsidiary rocks which are more acid than the main mass. They are light in colour, comparatively free from ferro-magnesian constituents, and sometimes contain muscovite. They occur as apophyses of the main mass, and may be well observed on the southern slopes of Craigrarson, where the Silurian grits and greywackes have been largely recrystallised under the influence of the hydrothermal agencies consequent on the intrusion of the granite. A junction specimen (S2533) shows the contact of a medium-grained light-coloured aplite, containing muscovite, with a somewhat finer-grained biotite-hornfels. A few flakes of biotite occur in the aplite, but some, if not all, of these appear to be of the nature of inclusions, and to belong really to the metamorphic rock. The contact rock is composed of quartz, turbid and altered felspar, and the characteristic brown mica, which forms aggregates between the larger grains of quartz and felspar. The aplite is a medium-grained rock essentially made up of orthoclase, quartz, and white mica, with a certain amount of oligoclase. Small patches resembling the contact rock in structure and containing biotite occur in the aplite. These patches are not sharply defined from the igneous rock, and they point to the conclusion that to a small extent the igneous magma may have incorporated and even assimilated portions of the surrounding rocks. M. Michel Lévy, in his memoir entitled "Contribution a l'étude du granite de Flamanville et des granites Francais en général"<ref>Bull. des Services de la Carte Geol. do la France. No. 36 1893.</ref>, and elsewhere, has called attention to facts of the kind here referred to, and has been led to the conclusion that they represent on a small scale phenomena which may take place on a large scale in deeper zones in the earth's crust. Without entering into a discussion on this question, we may remark that, so far as the granites of Galloway are concerned, phenomena of this kind are certainly local and unimportant.

In some cases the more acid veins pass into coarse-grained pegmatites. A second specimen, also taken from the slopes of Craigrarson [NX 48066 87206], on the south side of the Kirreoch Burn (S7028), serves to illustrate this point. One portion of the specimen is a medium-grained granite containing very little biotite; the other portion is a coarse-grained pegmatitic phase of the same magma. There is no sharp line of demarcation between the two varieties of rock. Under the microscope quartz and orthoclase are seen to be the two principal constituents, with oligoclase and biotite as comparatively unimportant accessories. The orthoclase shows traces of micro-perthitic structure, and does not give perfectly definite extinction.

Before leaving the Loch Dee mass, it is desirable that some reference should be made to the small subsidiary mass of Burnhead [NS 45604 09059], which occurs about five miles S.S.W. of Carsphairn, and about 2½ miles east of the main mass. It is more basic than the main mass, and illustrates the passage of quartz-augite-biotite-diorite into quartz-biotite-hyperite.

A specimen from the north-east margin of the mass, about 600 yards north-west of Burnhead [NS 45467 09542] (S6679), is a dark grey massive rock containing a few felspar-phenocrysts. Under the microscope the rock is seen to be mainly composed of plagioclase, enstatite, augite, and biotite. There is also a small quantity of interstitial quartz, with which some alkali-felspar is probably associated. The plagioclase occurs as large more or less idiomorphic individuals, and crystalline groups, and also as small crystals, giving lath-shaped sections. The enstatite is but faintly pleochroic. It occurs both as grains and prisms, but the latter have their angles rounded off. The augite is nearly colourless, non-pleochroic, and like the enstatite shows only slight traces of idiomorphism. Biotite is present in the form of very ragged plates. Iron-ores and apatite occur as accessories. When placed in a diffusion column the felspar of this rock is seen to lie between 2.68 and 2.71. A piece of labradorite floats in the middle of the space occupied by the felspar. It agrees,

therefore, approximately with labradorite, but as the individuals are often zoned it is certainly not of uniform composition.

It is especially interesting to note that this specimen from the margin of the mass shows a marked tendency to a porphyritic structure.

A specimen from the centre of the mass about 700 yards west of Burnhead ca [NS 45140 09103] (S6681), is a medium-grained grey massive rock. It is composed of enstatite, augite, hornblende, plagioclase, alkali-felspar, and quartz. The plagioclase does not belong to two fairly well-marked periods of consolidation, as in the last specimen, and the quartz and alkali-felspar are well-developed, and were evidently the last minerals to consolidate. The occurrence of green hornblende shows that this rock is intermediate between the hyperites and the quartz-diorites.

Another exposure, from a point about 1000 yards south of west of Burnhead ca. [NS 44471 09092] (S6682), does not contain enstatite. Hornblende and biotite are the most abundant ferro-magnesian constituents, but augite, precisely similar to that of the hyperites, occurs frequently as cores in the hornblende. This rock is therefore a quartz-augite-biotite-diorite or augite-tonalite. Like the last, it contains interstitial quartz and alkali-felspar.

Rather less than half a mile south of the Burnhead mass [NS 45686 08150], a very small boss of granite rock occurs on Mid Hill (S6684). It is composed of plagioclase, enstatite, biotite, and hornblende, together with a small quantity of interstitial quartz and alkali-felspar, and is therefore intermediate between a quartz-augite-biotite-diorite and a quartz-biotite-hyperite.

We have now to consider the third large, mass of granite occurring in the district of Galloway. The contact alteration produced by this mass has been the subject of communications by Mr. Allport and Dr. Bonney<ref>Report on the Effects of Contact Metamorphism exhibited by the Silurian Rocks near New Galloway. By S. Allport and T. G. Bonney. Proc. Royal Soc., London. Vol. xlix. (1889), p. 79.</ref> and by Miss Gardiner,<ref>Contact Alteration near New Galloway. By Miss M. I. Gardiner. Quart. Jour. Geol. Soc. Vol. xlvi. (1890), p. 569.</ref> but none of these communications gives a detailed description of the granite. Professor Bonney, in describing the specimens collected by Mr. Allport, remarks that "some are granophyres, more or less porphyritic; others true granites". One specimen contained wine-red garnets. The term granophyre in the above quotation is evidently not used in the sense in which that term is generally employed in this country and in Germany. Miss Gardiner gives an excellent description of the veins of aplite and pegmatite which traverse the highly altered rocks in the vicinity of iinock nairling Hill, but she does not describe the main mass of the granite itself. The only description, based on microscopic examination, which has hitherto been given, occurs in the Explanation of Sheet 5.<ref>Memoirs of the Geological Survey of Scotland. 1890.</ref> The two specimens there referred to come from the south-east corner of the mass. The one from the railway cutting near the viaduct over the Little Water of Fleet [NX 58696 67077] (S1221) is a moderately coarse-grained grey granite composed of biotite, muscovite, one or two grains of hornblende, oligoclase, microcline, and quartz, together with apatite, zircon, and iron-ores as accessories. The oligoclase is white in this specimen, and the microcline pink, so that the two felspars are easily distinguishable; but this is evidently only a local peculiarity, for another specimen from the same locality (S7024) does not show it. The other specimen from Sheet 5 was taken from Laughenghie Hill ca. [NX 60845 66353], about six miles north of Gatehouse of Fleet. It is a moderately coarse-grained biotite-granite, also containing interstitial microcline. Except that original muscovite is absent there is the closest possible resemblance in structure and composition between the rocks from these two localities. It was pointed out in the memoir already referred to that the specimens from that portion of the Cairnsmore of Fleet mass, which occurs within Sheet 5, were more acid than those from the main mass of Criffel. More extensive observations prove that the Cairnsmore of Fleet mass as a whole is more acid than either of the two other masses. Specimens from Bennan Hill [NX 64724 72469] (S7025), on the west side of Loch Ken, and also from the wood near Lochside [NX 64823 73811] (S7030), on the west side of Loch Ken, from Knocknairling Hill (S7027) [NX 62228 76951]?, near New Galloway, from a point south of Craigdews [NX 50060 72310] (S7029), about five miles south by east of Loch Dee, and from Clatteringshaws [NX 55243 76276] (S7031), six miles west of New Galloway, all bear a very close resemblance to the two rocks above referred to. They are medium or coarse-grained light grey granites, which occasionally show a gneissose structure. A slight tendency to a porphyritic or rather pseudo-porphyritic structure may sometimes be noticed. The felspars which give rise to this porphyritic aspect do not, as in typical porphyritic rocks, belong to the earlier phases of consolidation. Their cleavages are interrupted by inclusions of oligoclase, quartz, and biotite, and they can be found by microscopic examination to be, at any-rate in most cases, microcline or microcline-microperthite. Their cleavage surfaces

often show a pearly lustre. When the fractured surface of a specimen of the normal granite from this mass is examined with a lens quartz may be readily detected in great abundance, and the grains not unfrequently show a rude tendency to idiomorphism at the expense of the felspar. The rocks are in most cases massive, but occasionally, as at Clatteringshaws Bridge, a distinctive foliation may be observed.

The principal constituents of this granite mass are oligoclase, biotite, alkali-felspar, and quartz. Muscovite is occasionally present, and the rock then becomes a typical muscovite-biotite■granite. Hornblende has been observed only in one or two cases. Rocks of the tonalite type, which are so common both in the Criffel and Loch Dee masses, have not been observed in the Cairnsmore of Fleet mass. Apatite, zircon, iron-ores, and in one case (S7030) monazite, occur as accessories.

The mutual relations of the principal constituents are essentially the same as in the other granite masses. Oligoclase and biotite belong to the earlier, quartz and alkali-felspar to the later phases of consolidation. There is, however, a marked difference in the relative proportions of the different constituents.

The average proportion of the quartz and alkali-felspar to the oligoclase and biotite is much greater in this mass than in the other two masses, although portions of the Loch Dee mass are practically identical with the dominant rock from the mass now under consideration.

As regards the individual constituents, the oligoclase and biotite do not call for special description. The latter mineral is occasionally replaced by chlorite and epidote, and the former is aften rendered turbid by the development of small scales of a micaceous mineral. In those rocks which contain original muscovite this mineral is developed either in independent plates or is found associated with the biotite. The alkali-felspar is either moiré-orthoclase or microcline, generally the latter. It is abundant, and often occurs in large more or less irregular individuals, which are sometimes twinned on the Carlsbad plan. The fact that these large individuals give a kind of porphyritic aspect to the rock as a whole has already been referred to. They contain biotite, oligoclase, and sometimes quartz as inclusions. Quartz is abundant. It occurs as irregular grains, often of considerable size, and two or more grains usually occur in juxtaposition. In describing the hornblende-granitites and tonalites reference has been made to the fact that the quartz of these rocks often possesses an ophitic character; portions wedged in between the other constituents frequently give uniform extinction in the same way as the augite of ophitic dolerites. In the rocks now under consideration this feature is not noticeable, although the quartz is certainly on the whole of later date than the oligoclase and biotite. In the gneissose varieties of rock the polysynthetic character of the quartz is more marked than in the massive varieties, and the individuals composing the aggregates are often elongated in the direction of the foliation, as if the interstitial movement which accompanied the development of the parallel structure had affected the quartz more than any of the other constituents. The junctions of contiguous individuals in these polysynthetic aggregates are very irregular, and of the kind for which Professor Blake has proposed the term "sutural", because they are somewhat similar to the sutures of the skull.

In the Annual Report of the work of the Survey for 1895, a preliminary account of the older Cairnshee granite of Deeside has been published, and special attention has been called to the alkali-felspar, as it is developed in that rock. Almost all that has been there said will apply equally to the alkali-felspar of the Cairnsmore of Fleet mass. In both rocks we find the same relation between moire-orthoclase and microcline, the same tendency- to pseudo-porphyritic structure, and the same relation to the other constituents.

The accessory minerals, apatite, zircon, and iron-ores, do not call for special description, but the monazite deserves more than a passing notice. Unfortunately only one crystal has been observed in the thin section. It occurs in a specimen collected near Lochside [NX 64857 73826], on the west side of Loch Ken (S7030). It is honey-yellow in colour, and shows faint pleochroism, together with very high refraction and double-refraction. Traces of crystalline faces may be seen, but they cannot be identified. The crystal measures only one mm. across. That it is monazite is proved not only by the characters above referred to,. but also by the presence of the more important of the two didymium absorption bands in the spectrum of the light which has passed through the crystal. The rocks from the main mass exhibit only slight variations in composition. They are all true granites, with a considerable amount of quartz and microcline. Most of them are biotite-granites or granitites, but true muscovite-biotite-granites also occur. This latter point is interesting, because, as a rule, the biotite-granites and granites with two micas do not occur together as parts of the same mass.

The most marked deviations from the dominant type are to be found in the contact zone. These have been described by Miss Gardiner as aplite veins in the paper already cited. She says, "The rock is usually very coarse, but here and there becomes fine-grained. It consists of felspar (often in large masses), quartz, and a considerable quantity of white mica. Tourmaline and granet [*sic* garnet] are accessory minerals. "The felspar is mostly microcline. In some veins it forms a micro-pegmatite with quartz, in others it forms the bulk of the rock. In one vein, to the west of the granite, there are masses of it two or three feet across, with continuous cleavage planes some inches long.. The felspar often includes garnets. The quartz is traversed by many lines of small inclusions. That associated with the large felspar masses just mentioned can be seen with a hand lens to consist of small, flattened, hexagonal prisms, with pyramids at one end built up in parallel zones. The white mica is often in hexagonal plates, as much as half an inch in diameter. Along the edge of one of the veins on Knocknairling Hill there are triangular flakes arranged in a plumose manner. The mica feathers point inwards from the edge of the dyke, and are three to four inches long.

"The small garnets are sometimes of a brownish red, as in the altered grits, and sometimes of a bright wine-red colour. Large yellow garnets occur occasionally.

"Tourmaline occurs in the Knocknairling Hill vein in patches curiously intergrown with quartz, so as to form what looks like a graphic granite, with the little hooked letters in dark tourmaline instead of quartz. The tourmaline needles are parallel with each other instead of radiating as in luxullianite. Some of it is an indigo, and some a bottle-glass brownish-green colour. These tourmaline-quartz patches have an area of one or two square inches. Groups of tourmaline sections extinguish together, but the quartz grains have their axes at all angles.

"The fine-grained variety of aplite has a sparkling saccharoidal look, and the little pink garnets show conspicuously on the white surface of a freshly broken specimen. It consists of about equal quantities of felspar and quartz in grains. There is a good deal of white mica; garnets are common, and small needles of tourmaline occur occasionally. In some places coarser veins shade off in parts into this fine-grained material, and in others it occurs in veins by itself".

These veins of aplite and pegmatite occur in a zone of intense metamorphism. They are essentially composed of that portion of the granite magma which consolidated last in the main body of the rock. Mr. Barrow has called attention to the tendency of the mother liquor of granitic magmas in the Central Highlands to penetrate the surrounding rocks, and to form pegmatite veins which often contain white mica. Similar phenomena may be seen in Cornwall, as, for example, at Trewavas Head, where there is the same association of fine-grained aplite and coarse-grained pegmatite with tourmaline as at Knocknairling Hill. The phenomena in question occur on a much smaller scale in the Galloway district than they do either in Cornwall or in the Southern Highlands. They are specially developed on a large scale in association with muscovite-biotite-granites, and, as we have already noticed, these rocks are rare in the Cairnsmore of Fleet mass.

We may now summarise the principal results obtained from this petrographical study of the Galloway granites. The Criffel mass [NX 95718 61909], taken as a whole, appears to be the most basic. Plagioclase felspar predominates, and a large portion of the mass is a tonalite rather than a true granite. Dark basic inclusions of a dioritic rock are common, and acid veins essentially composed of quartz and orthoclase also occur. Clove-brown crystals of sphene are scattered through the mass, and it is rare to find a hand specimen in which one or more crystals of this mineral may not be detected with a lens. Hornblende, biotite, and oligoclase are the dominant minerals, and belong to the earlier phases of consolidation. Quartz and orthoclase play the role of ground mass. Augite is present as cores in the hornblende, thus giving rise to augite-granitites and quartz-augite-biotite-diorites.

The Loch Dee mass [NX 47091 79057] presents in many respects a close resemblance to the Criffel mass, and large portions of it are composed of hornblende-granitite and granitite. Augite is occasionally found, and by its local increase, coupled with a corresponding diminution in the amount of hornblende, the augite-granites pass into quartz-augite-biotite-diorites. By a further modification in the same direction, along with the coming in of enstatite and a decrease in the quartz and felspar, the quartz-augite-biotite-diorites merge into quartz-biotite-hyperites. Certain other portions of the same mass illustrate a change in the opposite direction. The ferro-magnesian constituents and oligoclase decrease in amount, and the quartz and alkali-felspar increase. Moreover, the alkali-felspar may be developed as microcline, and may take on the form of pseudo-porphyritic crystals with inclusions of biotite, quartz, and oligoclase. Rocks of this latter type have not been observed in the Criffel mass, though it is perhaps scarcely safe to assert that they

do not occur. The most acid rocks of the Loch Dee mass occur as apophyses of aplite and pegmatite in the contact zone. The mass of Burnhead, which is subsidiary to that of Loch Dee, is more basic than the main mass, and consists of quartz-biotite-hyperite and quartz-augite-biotite-diorite.

Biotite-granite or granitite with microcline, which is locally developed in the Loch Dee mass, forms the dominant rock of the third or Cairnsmore of Fleet mass [NX 56445 70726]. Hornblende, which is often present in the Loch Dee mass, and extremely common in the Criffel mass, is only locally present in the Cairnsmore of Fleet mass, and may, in all the specimens examined, be regarded as an unimportant and accessory constituent. A point of great interest in connection with this mass is the evidence it affords of the relation between granites with one mica only and those with two micas. The biotite-granites with microcline are here definitely associated with typical muscovite-biotite granites. Beyond the presence of muscovite there is no difference either in structure or composition betwen the two types of rock. Veins of aplite and pegmatite occur as apophyses, and contain muscovite, tourmaline, and garnet. The white-mica-bearing pegmatites are especially characteristic of a zone of intense metamorphism in the surrounding rocks.

It appears, therefore, from the preceding account that the three great masses, which must all be approximately of the same geological age, present certain points both of resemblance and difference. The Criffel mass appears to be the most basic, and the Cairnsmore of Fleet mass the most acid, whilst the Loch Dee mass occupies an intermediate position. This remark, however, can only be regarded as true in a broad and general sense when reference is made to the average composition of each of the three masses. In each we find rocks which are more basic and more acid than the general average. It is probable that the aplite veins of the Criffel mass do not differ markedly in composition from the corresponding rocks of the Cairnsmore of Fleet mass. They should, indeed, be substantially identical if in each case they represent the mother liquor of the granite magma, for this is proved by microscopic examination to have yielded quartz and alkali-felspar in all the rocks.

The different varieties of rock occurring in each mass, and in the three masses regarded as a whcrle, are closely bound together by transitional forms. If we leave out of account the veins of aplite and pegmatite, then the most basic rocks are represented by the diorites of the Criff el mass and the hyperites of the Loch Dee mass. The most acid rocks are represented by the muscovite-biotite-granites of the Cairnsmore of Fleet mass. Between these extreme types we have a continuous series of intermediate varieties.

In concluding this account of the Galloway granites it seems justifiable to offer some remarks on the bearing of the facts on the more or less rival theories of assimilation and differentiation. If one or other of these theories must be accepted to account for the facts above described, the preference must undoubtedly be given to the latter. Neither the local differences observed in one and the same mass, nor the general differences which become noticeable when the three masses are compared with each other, can be correlated with the nature of the rocks into which the granite has been injected. Moreover, the junctions of the granite with the surrounding rocks are in general perfectly sharp, and furnish no support to the view that the granite either represents the sediment crystallised in place or has even had its composition appreciably modified by the assimilation of portions of the surrounding rock. On the other hand, the aplite veins, corresponding as they do in composition with those portions of the granite magma which consolidated last, seem, to furnish direct evidence that some at least of the differences which we observe are to be accounted for by the differentiation hypothesis. In the absence, however, of any well-established physical laws which will satisfactorily account for the differentiation, the hypothesis cannot be said to rest on an assured basis. There can, however, be no doubt that even in its present unsatisfactory state it has an enormous advantage over its rival, so far as the phenomena of the Galloway granites are concerned. On this hypothesis the differences in the average composition of the three great masses would be explained by differentiation in a deep-seated reservoir or magma basin; whereas the differences observed in one and the same mass might be explained partly by the intrusion of a heterogeneous magma and partly by differentiation after the magma had reached its present position. In addition to the three large masses of plutonic rocks above referred to there are several smaller masses, which will now be briefly described.

In the extreme west a small granite mass occurs a few miles north-west of the Mull of Galloway (Sheet 1). This is represented in the Survey Collection by four specimens. One from Crummag Head [NX 08876 34033] is a grey hornblende-granitite with sphene; another form Portencorkrie Bay [NX 08935 35282] is a pinkish rock containing the same minerals, but having a larger amount of alkali-felspar, which is sometimes developed as micro-perthite; a third from

Lagantalluch Head [NX 08353 36237] is an augite-biotite-diorite containing a small quantity of enstatite, and therefore having affinities with the hyperites; the fourth from a point 300 yards north of Portencorkrie is similar to the last in composition, but contains a larger amount of biotite, which is conspicuous in the hand specimen, and gives the rock the appearance of a kersantite.

Several small granitic masses occur in Sheet 4. That south of Glenluce [NX 20176 56933], coloured on the map as diorite, contains quartz-diorite (tonalite), augite-diorite with micro-poikilitic brown hornblende, and an augite-diorite with enstatite, and is therefore allied to the hyperites.

The mass about three miles north of Kirkcowan [NX 32686 65193], also coloured diorite, is composed of similar rocks. On the east side of the estuary of the Cree, south of Creetown, is an important granite quarry [NX 48025 56501]. The principal rock in this quarry is a moderately coarse-grained grey granitite, the felspars of which contain a considerable amount of secondary white mica.<ref>Since this was written, Mr. J. S. Flett has described (Geol. Mag., 1898, p. 388) orthite from this rock which he regards as a true granite with muscovite and epidote as original constituents</ref> On the south side of the quarry there is also a fine-grained grey rock of somewhat earlier date than the normal granite. It is composed of small phenocrysts of zonal plagioclase and aggregates of biotite and epidote in a micro-crystalline ground mass, also containing small patches of biotite and grains of epidote.

Some interesting gneissose rocks, formed by injection and superposition, occur at the south junction in this quarry. The pure sediment is represented by a brown biotite-hornfels, traversed by narrow green bands and lenticles composed of hornblende, epidote, grossularia, sphene, quartz, calcite, and perhaps malacolite. The garnet, which gives a brown colour to the bands, and is normally present only in the central portions, is of the type common in altered limestones, and often shows double refraction. The original rock was probably a sandy shale containing impure calcareous layers.

The mixed rock (248) is composed of broad bands of biotite-hornfels containing prisms of green hornblende and thin folia of a syenitic rock formed of green hornblende similar to that occurring as pseudo-porphyritic crystals in the biotite-hornfels, alkali-felspars, quartz, and sphene. The specimen on which this description is based resembles a gneiss in appearance, and is bounded on one surface by a band of calc-silicate hornfels containing brown garnet.

The small mass of the Cairnsmore of Carsphairn [NX 58973 98020] which occurs on the north-east corner of Sheet 8, and enters also into the adjacent Sheets, has yielded specimens of granitite, hornblende-granitite with sphene, quartz-augite-biotite-diorite, and quartz-biotite-hyperite.

Some altered rocks from this mass contains pyrrhotite. In view of the fact that the pyrrhotite associated with norites and hyperites often contains from three to five per cent. of nickel, a small quantity of this mineral was isolated from one of the rocks and tested for that metal. Only somewhat doubtful traces were found. Although the amount of pyrrhotite employed was small, it was quite sufficient to prove that nickel is not present in anything like the same quantity as it is in the mineral which is used as an ore in Sweden and in the Sudbury district of Canada.

All the localities above referred to lie within the ancient district of Galloway. There are, however, one or two small granitic masses situated outside this district in Sheet 15, near New Cumnock. The Polshill mass [NS 65781 12287], [NS 65512 10207] is formed of hornblende-granitite or tonalite, with a margin, at any rate at one point, where the Polshill Burn crosses the junction, of quartz-biotite-hyperite. The granite of Spango Water is represented by one specimen (S6543), which is a, granitite of the true Galloway type.

It thus appears that the plutonic rocks which lie between Spango Water[NS 78355 19623] and the Mull of Galloway, and between Loch Doon and the Solway Firth, are all intimately related. The same types reappear in widely separated localities, and there can be no doubt that they all belong to the same petrographical province.

The Survey collection contains several specimens from the small mass of granite at Priestlaw [NT 64628 63386] on the Southern slopes of the Lammermuir Hills, of which, three have been sliced. The first No. (S7808) from the Faseny Water, Priestlaw ca. [NT 64523 63329], is a hornblende-biotite-granite; the second No. (S7809) from the same stream, near the edge of the mass, is a more basic rock than the preceding one, with porphyritic, zoned plagioclase in a micro-granitic aggregate of biotite, hornblende, felspar and quartz. It might almost be termed a hornblende-biotite-porphyrite, but the

ground-mass is somewhat coarser in grain — more granitic — than in the typical porphyrites. The specimen is interesting us showing that the physical conditions, under which the marginal portions of the Priestlaw mass consolidated, approximated to those under which the porphyrite dykes were formed. The third specimen No. (S7810) also from the edge of the mass in the Faseny Water [NT 64314 62644] is a quartz-augite-biotite-diorite. This rock differs from the quartz-biotite-hyperites, only in not containing hypersthene. The pale-green augite (malacolite), which occurs to the almost entire exclusion of hornblende, and the general structure of the rock, are precisely similar to the corresponding features in the hyperites.

Dykes

Dykes are extremely abundant in the Galloway district, and especially so in the neighbourhood of the Criffel and Loch Dee masses. Those which occur in Sheet 5 have already been described in the Memoir on that sheet, and the main facts are here reproduced.

1. Porphyrites

The dykes occur not only in the sedimentary rocks but also in the granitic masses, and the same petrological types are found in both areas. The vast majority is formed of rocks to which the term porphyrite has been applied. This term has hitherto been employed in a different sense in the publications of the Geological Survey, and a word or two of explanation is therefore necessary. Recent research has established the fact that the so-called porphyrites which occur as lavas in association with Palaeozoic sediments are merely altered andesites. The continued use of the term in its old sense is therefore undesirable, and will accordingly be dropped. The word may, however, be conveniently employed in accordance with the usage adopted by American petrographers (Prof. J. P. Iddings, "The Eruptive Rocks of Electric Peak and Sepulchre Mountain", *Twelfth Annual Report of the U.S. Geological Survey,* 1890–1891) for rocks of the type now under consideration, Such rocks occur for the most part as dykes, sills, and laccolites. They bear the same relation to the andesites that the porphyries do to the liparites.

These rocks are, as a rule, markedly porphyritic in structure. Plagioclase, hornblende, and biotite commonly occur as phenocrysts; quartz is occasionally found; orthoclase is very rare. The ground-mass is usually compact. The rocks vary in colour from grey to red; the latter tint being characteristic of the most highly altered varieties. The proportion of phenocrysts to ground-mass is liable to considerable variation, some rocks containing so little ground-mass as to resemble granites; others containing so few phenocrysts as to have the character of felsites. These extreme types are, however, comparatively rare.

In the typical rocks of the group, plagioclase is always the most conspicuous phenocryst, both on account of its abundance and of the size of the individuals. It occurs in single crystals, in crystalline groups, and as crystal fragments. Twinning on the Carlsbad-, pericline- and albite-plan may often be observed. The individuals are often beautifully zoned, and by employing the Becke-effect it can frequently be demonstrated that narrow zones of a highly refractive and therefore basic felspar, are repeated several times in a single individual. The plagioclase is liable to the micaceous type of decomposition, and many rocks are so highly altered that the optical characters of the mineral can no longer be observed.

Orthoclase phenocrysts have not been identified with certainty in any of the microscopic sections, but one or two large, irregular grains, measuring half-an-inch or more across, were observed in a dyke from the south-east spur of Criffel.

The phenocrysts of hornblende and biotite are not so large as those of plagioclase. The hornblende is usually of the green type common in the granites and quartz-diorites, but a brown variety has been observed in one or two instances. As compared with the hornblende of the granite, it is remarkable for the perfection of its crystalline form. The faces of the prism and of the two vertical pinacoids are often present. Twinning of the common type may frequently be observed. The biotite is also remarkable for the perfection of its crystalline form. It occurs in hexagonal tablets, but in other respects resembles the biotite of the granites and quartz-diorites.

Quartz, when present as a phenocryst, possesses the same characters as the quartz of the porphyries. It occasionally shows an approach to the dihexahedral form, but as a rule occurs only as corroded grains. It contains inclusions with bubbles.

The ground-mass varies in different rocks. In some cases the minerals which occur as phenocrysts — plagioclase, hornblende, and biotite — may all be recognised together with quartz and alkali-felspar; in others the constituents of the ground-mass cannot be definitely determined, on account of the small size of the individuals and the confused nature of the crystallisation. Micro-poikilitic, micro-pegmatitic, and in one case, spherulitic structures have been observed. It is highly probable that quartz and alkali-felspar enter largely into the composition of this part of the rock.

It follows, from the above description, that there is very little difference in composition between the dykes of this type and the granitic rocks of the Criffel and Dalbeattie mass. This is confirmed by the following table of specific gravities:

One mile N.N.E. of Red Bank Farm (S6584), dyke in granite	2.65
Three-quarters of a mile E.S.E. of the top of Screel	2.657
One mile north of Dalbeattie (S1262)	2.67
Near the summit of Ben Gairn (S6578)	2.67
North of Croft-Head; six miles north of Dalbeattie (S1233)	2.65

It is probable, therefore, that the structural differences between the porphyrites and the hornblende-granites or quartz-diorites are due to differences in the conditions under which the magmas consolidated. If we suppose that an intrusion of the granitic magma took place in dyke form after the greater part of the hornblende, biotite, and plagioclase had separated out, we shall have a satisfactory explanation of the difference in structure between the porphyrites and the granitic rock. In applying this theory, however, it must be remembered that dykes of the type now under consideration occur not only in the sedimentary rocks but also in the granitic masses. Moreover, dykes are found in the foliated area unaffected by the foliation. Such dykes cannot be regarded as in any way representing apophyses of the granite. They belong to a later phase of igneous activity. The source of supply was probably the same as that from which the main igneous mass was derived; but if so, it must have been tapped at a time when crystal building had proceeded to a considerable extent.

One fact tells somewhat against the view suggested above, and that is the not infrequent occurrence of quartz and the occasional presence of orthoclase amongst the phenocrysts of the porphyrites. In the granitic masses these minerals invariably belong to the final stage of consolidation. The difficulty, however, may not be serious, for the quartz is almost always intensely corroded, and both minerals have rather the aspect of foreign constituents.

2. Diorites

The typical representatives of this group are medium or fine-grained dark-coloured crystalline rocks essentially composed of hornblende and a plagioclase felspar. In some specimens the hornblende may be clearly recognised with a lens in the form of long slender prisms. These rocks are denser than the porphyrites, the specific gravity ranging from 2.68 to 2.81. The hornblende is often seen to be of a deep brown colour under the microscope. It may be either idiomorphic or ophitic with respect to lath-shaped plagioclase. The idiomorphic hornblende is occasionally zoned (S1269) [[near Slaglaw [NX 74718 58630]]. Green hornblende is also present, and this may arise from the alteration of the brown variety, or, as seems probable in some cases, from the alteration of an original pyroxene. Twinning is not infrequent.

The felspar, which is generally turbid, may occur in forms giving lath-shaped sections or as irregular grains which fit together so as to form the matrix in which the hornblende is embedded. Sometimes there is a little interstitial quartz, but this mineral never forms any large portion of the rock. Biotite is sometimes present. Apatite is often abundant in the form of slender prisms; iron ores are scarce or altogether absent. Chlorite, epidote, and sometimes carbonates, occur as alteration products.

Those rocks in which the hornblende is present in the form of slender prisms, belong to the camptonite division of the lamprophyres (see (Plate 25)., fig. 2).

3. Mica-traps

The specimen from Greenhill, east of Meiklewood [NX 69316 57152], is a dark-coloured rock, composed of numerous tablets of brown mica, embedded in a compact matrix. Under the microscope the mica is seen to possess the usual characteristics of that mineral as it occurs in mica-traps. The tablets are thin in proportion to their breadth; their margins are often more deeply coloured than the central parts; and the absorption for rays vibrating at right angles to the vertical axis is far less marked than it is in the biotite which occurs in the granites. The mineral is biaxial, with a very small optic axial angle. Biotite is the only phenocryst which has preserved its original characters, but there are pseudomorphs in quartz or quartz and carbonates after some other mineral — possibly augite. The groundmass of the rock is composed of small scales of biotite, felspar, carbonates, magnetite, and apatite. The felspar forms the matrix in which the other constituents are embedded. It does not show multiple twinning, and, as the refractive index is lower than that of the balsam in which the section is mounted, it is probably orthoclase. Magnetite occurs in small crystals and grains which are uniformly scattered through the section. The carbonates, as is so frequently the case in comparatively unaltered rocks of this type, cannot be attributed to the decomposition of any one mineral.

The specimen from Nun Mill [NX 66073 48932] is purplish in colour, and much more altered than the one above described. It is composed of biotite, pseudomorphs in carbonate after phenocrysts of augite (?), magnetite, and felspar. The felspar is altered and stained with ferric oxide, so that its precise character cannot be determined.

Both rocks are probably minettes.

The dykes from other portions of the Galloway district agree in general characters with those from Sheet 5. They comprise porphyrites, diorites of the camptonite type, mica-traps, and hyperites. By far the most abundant rock is a porphyrite. The rocks belonging to this type vary in colour, texture, and composition, but the distinctive characters, which are the presence of porphyritic crystals of plagioclase, and one or both of the ferro-magnesian constituents, biotite, and hornblende, in a compact matrix, may generally be recognised. In colour the rocks vary from pale grey to almost black; pink varieties also occur. The felspars are as a rule not conspicuous, one-eighth of an inch being a common size. The rocks are not unfrequently much altered, and the ferro-magnesian constituents are often entirely replaced by chlorite, epidote, and carbonates. The principal differences in composition depend on the presence or absence of quartz or hornblende. Thus arise varieties to which such terms as quartz-hornblende-biotite-porphyrite, quartz-biotite-porphyrite, hornblende-biotite-porphyrite, and biotite■porphyrite may be applied. But these differences are not strongly marked. Quartz-porphyrites are comparatively rare.

All the specimens available have been carefully examined with a view to determine whether true quartz-porphyries occur. In describing the dykes from Sheet 5, attention has been called to the occurrence in one or two of a few large crystals of orthoclase. These are, however, so rare and exceptional that it is doubtful whether they should be separated from the porphyrites, especially as plagioclase, even in these rocks, is the dominant porphyritic felspar. In some other cases the felspars are so much altered as to be indeterminable, but there is no reason to regard these rocks as other than altered forms of porphyrite. We may say that true quartz-porphyries have not been recognised. If they do occur they will probably be found in association with the Cairnsmore of Fleet mass.

A glance at the map (Sheet 8) shows that a vast number of porphyrite dykes occur in the immediate neighbourhood of the Loch Dee mass (Typically [NX 50335 87529]) . These appear to be on the whole somewhat more acid than the corresponding rocks associated with the Criffel mass. The phenocrysts, and especially those of biotite and hornblende, are not so conspicuous. A very common type is a pale grey porphyrite, in which the porphyritic structure is not very marked in the hand specimen, although it is at once evident under the microscope. As a rule, the felspar is turbid, and the ferro-magnesian minerals, which are by no means abundant, have been largely replaced by chlorite and carbonates. Examples of this type occur on the top of Craigrine Hill [NX 50998 88116] (S2531), five miles S.S.W. of Carsphairn; on the top of Meikle Craigrarson, 6¼ miles south-west of Carsphairn; at Cullendoch, 5 miles N.W. of Cairsphairn; at Garryhorn Gairy, three miles west of Carsphairn; on the top of Gairy Craig, 1¼ miles south of Carsphairn. (S707); east of Meadowhead, 4¼ miles N.N.W. of Carsphairn; south and west of Meaul Hill, 4¼ miles south-west of Carsphairn; and on the Coran of Portmark, four miles west of Carsphairn.

Intimately connected with the above are some dark-coloured biotite-porphyrites containing glassy plagioclase. Examples of these occur on the top of Meikle Craigrarson [NX 48196 87200] (S2557), and near the head of Downies Burn [NX 50362 84251], five miles north by east of Loch Dee [NX 48383 87153] (S2555). A specimen from the west side of Meaul Hill [NX 50047 90974] (S7022), which is somewhat intermediate between the two types, so far as general appearance is concerned, may be described in detail. The rock is dark grey or bluish grey in colour. Phenocrysts of felspar, and of a dark ferro-magnesian mineral, may easily be recognised with a lens when the surface is wet. The ground-mass is compact. Under the microscope the phenocrysts of plagioclase are seen to occur in crystals, crystalline groups, and as crystal fragments. They are often beautifully zoned, but in all cases examined they possessed a higher refractive index than balsam, and possibly range in composition from labradorite to andesine or basic oligoclase. Twinning is present, but is not a conspicuous feature. The ferro-magnesian minerals are represented by biotite and by pseudomorphs in carbonate after hornblende. The ground mass is a confusedly crystalline aggregate of quartz and felspars, with which small scales of biotite are associated. Much of the felspar of the ground mass is doubtless orthoclase.

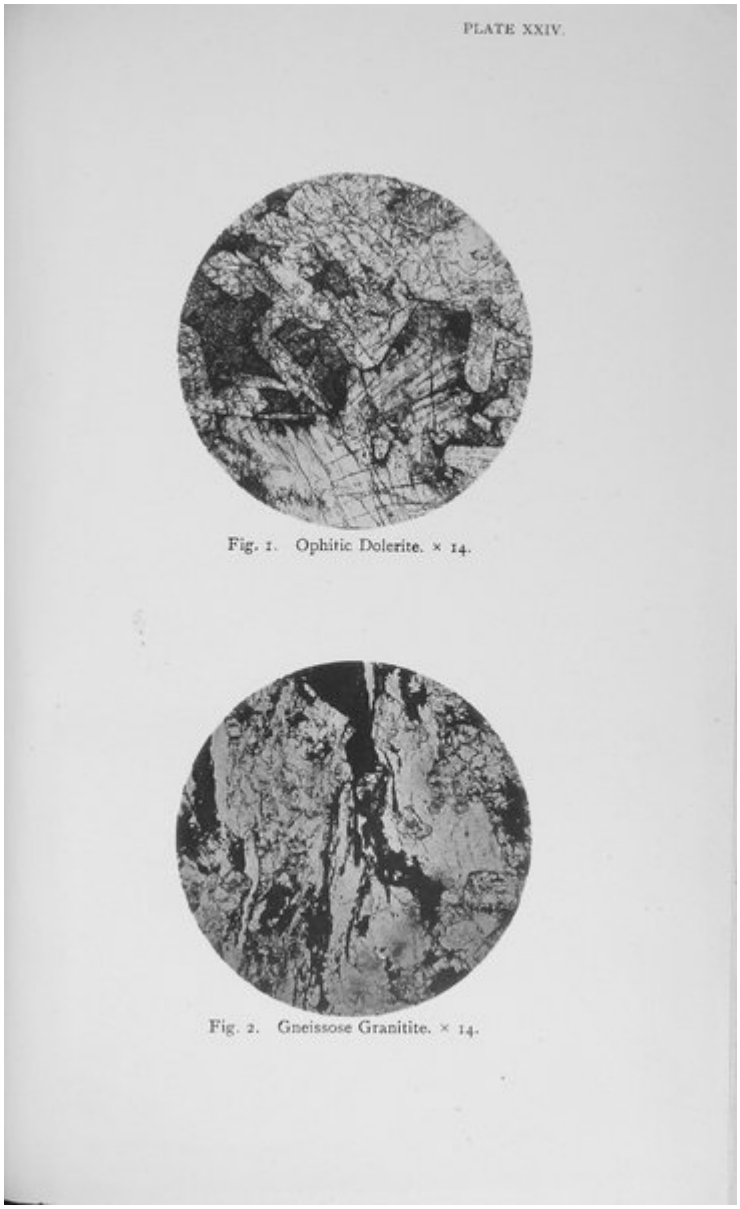
Pink porphyrites occur in the Water of Deugh, two miles north of Carsphairn, south of Thorny Hill, 3¾ miles south of Carsphairn Gairy, south-west of Craigrine Hill (S707), five miles S.S.W. of Carsphairn, in the Lorg Burn (head of Ken), in Polvaddoch Burn (head of Ken Water), and at the head of Barend Burn, south-east of Balmaclellan.

Dykes other than porphyrites are rare. They are represented in the collection by a few specimens. A diorite of the camptonite type occurs at Lorg Hill [NS 66632 02078], Cordorkan Burn, four miles south-west of Loch Dee (S724) and (S2538). In the hand specimen it appears as a dark grey, medium-grained rock, composed of idiomorphic hornblende in a white felspathic matrix. Under the microscope the hornblende is seen to be of a deep brown colour. The dominant felspar is more or less idiomorphic, and there is some orthoclase Pnd quartz. A little augite was probably present in the original rock, but if so it has been replaced by pale greenish chloritic decomposition products.

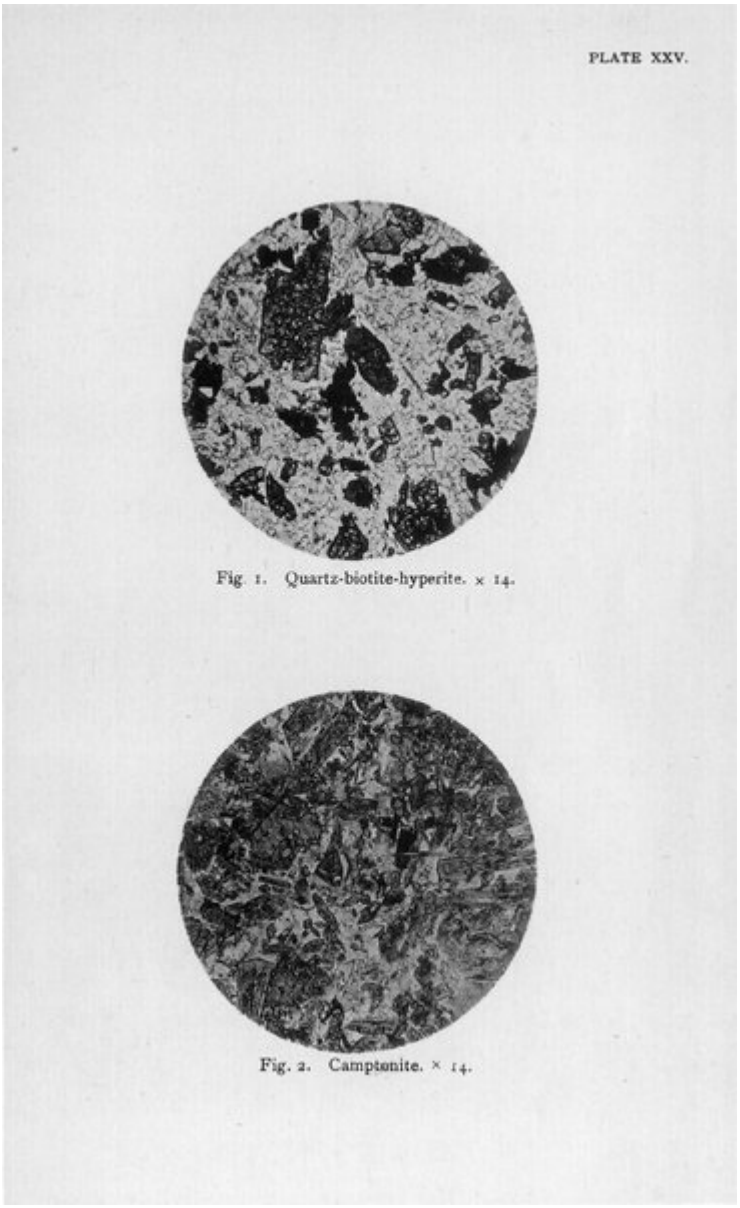
A rock in some respects intermediate between a hornblende-porphyrite and camptonite occurs on Black Gairy Hill [NX 41124 74267], five miles south-west of Loch Dee. It consists of phenocrysts of brown hornblende in a fine-grained ground mass similar to that of many porphyrites. This rock differs from the ordinary porphyrites in the absence of porphyritic felspars. A mica-trap occurs in Kirreoch Burn [NX 48570 88632] (S1612). It consists of ragged plates of biotite and pseudomorphs in carbonate after augite (?). The matrix is felspathic, and the felspars show a tendency to a feathery mode of aggregation. The rock is too much altered for precise determination, but it was probably a minette. There are also other dykes which are intermediate between typical biotite-porphyrites and kersantites. A dyke of hyperite occurs at Braidenoch [NX 56614 90265], two miles south of Carsphairn (S698). It is a quartz-biotite-hyperite, precisely similar to the rocks associated with the Loch Dee mass, and is of special interest as proving that the hyperite-magma was not only formed in connection with the main granitic masses, but was also intruded in the form of dykes.

In many regions where dykes occur in association with plutonic rocks they belong to two fairly well marked groups, the one group being more acid, and the other more basic than the plutonic mass. Professor Brogger has proposed that the two groups taken together should be referred to as complementary dykes. The facts described above prove that in the Galloway district the dykes are not sharply divisible into two groups. It is probable that if we had a sufficient number of analyses of the granites and diorites which make up the masses of Loch Dee and Criffel, and also of the dykes which occur in association with these masses, that the two sets of analyses would closely correspond. Both sets would show variations, but these variations would be similar, and the relative proportions of the different types would be similar. The main difference between the dykes and the granite masses is a structural one, depending on the fact that in the dykes two periods of consolidation are sharply defined, whereas in the granitic mass they merge gradually into each other.

It is somewhat remarkable that true quartz-porphyries have not been detected in the Galloway district. This is doubtless due to the fact that the dominant type of rock in the Loch Dee and Criffel masses is a basic granite or tonalite. Plagioclase is as a rule the dominant felspar. The Cairnsmore of Fleet mass is more acid, but the dykes in its neighbourhood do not appear to be so numerous as they are in the vicinity of the other masses. It is probable that if the more acid portion of the magma which consolidated as the Cairnsmore of Fleet mass had been intruded in the form of dykes, it would have given rise to quartz-porphyries similar to those which occur so abundantly in the West of England in association with the muscovite-biotite-granites of Devon and Cornwall.



(Plate 24) 1. (S6470). Another portion of the same slide.



(Plate 25) 1. (S7050) Quartz-biotite-hyperite. Black Laggan, Loch Dee. Magnified 14 diameters. The minerals represented are hypersthene, biotite, felspar, and quartz. A large crystal of hypersthene occurs in the north-west quadrant, and there are several smaller grains of the same mineral in other parts of the figure. The opaque patches represent biotite, and the colourless portions felspar and quartz. 2. (S7047) Camptonite, Black Gairy Hill. Five miles S.W. of Loch Dee. Magnified 14 diameters. Idiomorphic pale brown hornblende in a felspathic matrix. Under crossed nicols the matrix breaks up into an aggregate of large grains, which mutually interfere with each other. The felspar belongs to the oligoclase-andesine section. Fig. 1. Quartz-biotite-hyperite. x 14. Fig. 2. Camptimite. x 14.