LII.—*Contributions to the Petrology of the Cheviot Hills.* By HERBERT KYNASTON, B.A., F.G.S. (Plates XXIV and XXV.)

(Read 21st April 1890.)

1. Introduction.
2. The Cheviot Granite.
3. The Dykes and Sills.
4. The Relations between the Granite, the Dykes and the Andesites.

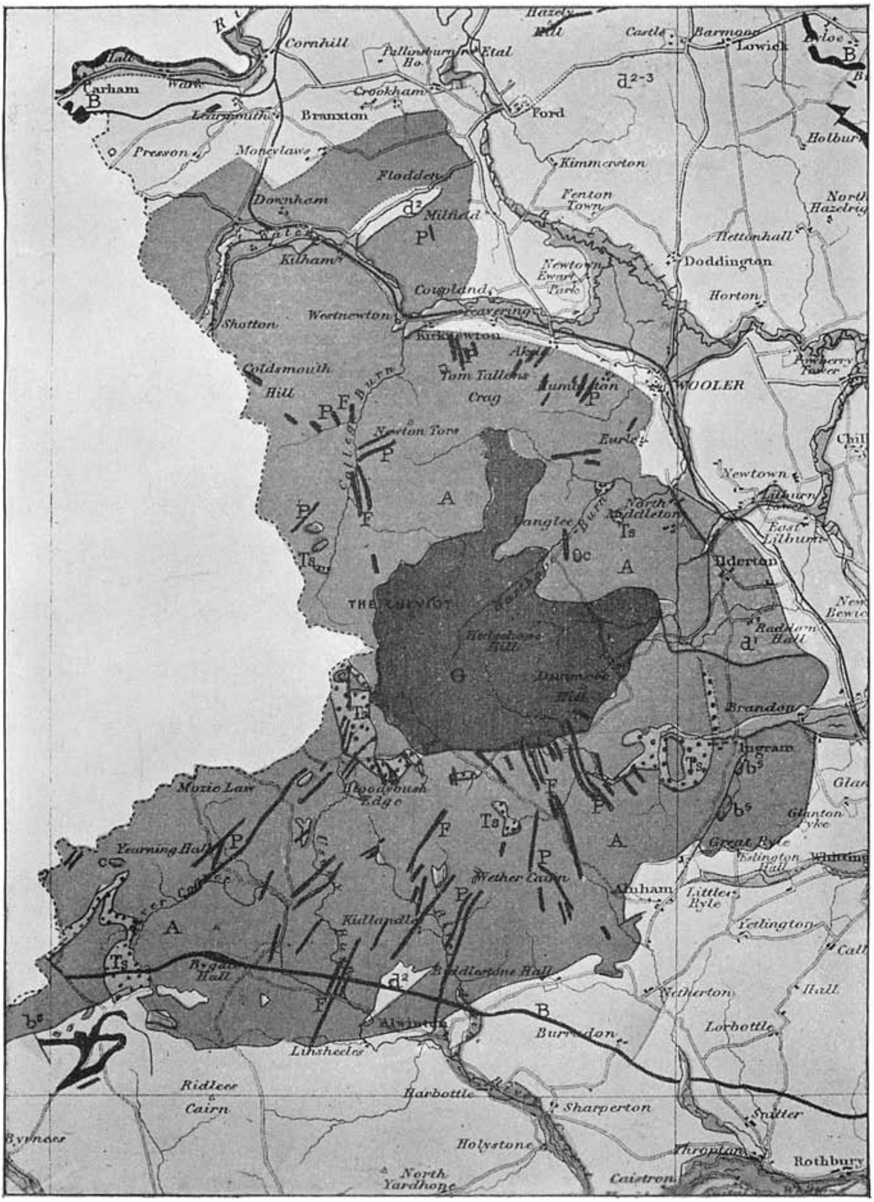
1. *Introduction.*—It has now been known for some time that the Cheviot district constitutes a fairly extensive area of andesitic lava-flows of Lower Old Red Sandstone age, surrounding an inner mass of augite-granite, while both are traversed by a large number of associated dykes and sills. But until the English side of the Cheviots was mapped for the Geological Survey by Mr C. T. Clough, not very much detailed petrographical work had been done amongst the igneous rocks of this area by earlier observers. Before, however, the Survey Memoir was completed, Mr J. J. H. Teall had visited the district, and published the results of his observations in a series of papers in the *Geological Magazine.*[1] The principal varieties of the contemporaneous lavas are therein fully described, and some of the more characteristic types of the granite; but only one type of the more acid intrusives is noticed in any detail.

In the course of several visits to the Cheviots, I devoted special attention to the intrusive rocks of the district, and their relation to the andesitic lava-flows. And it is the object of the present paper to describe certain features exhibited by the former, which do not yet appear to have been previously noticed in this district, and to point out the relationships between the various types of igneous rock that are here met with.

I would take this opportunity of acknowledging my indebtedness to the detailed and careful mapping and descriptions of Mr C. T. Clough, while examining the rocks in the field. I would also thank Messrs A. Harker and J. J. H. Teall for valuable hints and suggestions.

2. *The Cheviot Granite.*—The Cheviot Granite, which occupies the central and more elevated portion of the district, was first

[1] *Geol. Mag.*, Dec. 2, vol. x. (1883), pp. 100, 145, 252, 344; *Geol. Mag.*, Dec. 3, vol. ii. (1885), pp. 106-121.



GEOLOGICAL MAP OF THE CHEVIOT DISTRICT (English Side)

From the published Map of the Geological Survey (Scale, 4 miles to 1 inch).

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examined by modern petrological methods and described, by Mr. J. J. H. Teall,[1] and it was shown by him that the normal type was an augite-biotite-granite, possessing strong affinities to the augite-bearing granitites of Laveline and Oberbrück in the Vosges, described by Rosenbusch and Cohen. The augite was shown to be a non-aluminous iron-bearing species of the diopside type (malacolite of Rosenbusch), allied to that of the augite-syenite of Monzoni. A considerable amount of variation is exhibited in the mass, both in texture, structure, and the relative proportion of the different constituents.

The normal or most common type is a pale pink or greyish granite of fairly coarse grain and usually non-porphyritic, containing a soda-orthoclase as the dominating felspar. Sometimes, however, the rock becomes finer-grained, and, owing apparently to an increase in the relative proportion of the ferro-magnesian constituents, assumes a dark, syenitic or dioritic aspect. This variety is especially well exposed towards the margin of the main mass, in the neighbourhood of Linhope, and in the river Breamish above Linhope. On the other hand, fine-grained varieties often occur, also towards the marginal portions of the mass, of a pinkish or flesh-coloured tint, in which the ferro-magnesian element plays but an insignificant part. And between these two extremes every gradation may be found, showing a gradual passage from the one to the other. The dark varieties near Linhope appear to have strong affinities with the rocks of Markfield and Groby in Charnwood Forest; hornblende, however, is not known to occur as an original constituent in any Cheviot rock. The more acid fine-grained varieties may be compared with the well-known augite-bearing granophyres of Charnwood Forest, Carrock Fell, Craig-Craggen in Mull, and those of the Carlingford district and the Mourne Mountains in Ireland, etc. In the Cheviot district, then, we may say that the more coarse-grained type occupies, as a rule, the more central part of the granite area, about Staindrop Rig, Hedgehope, Cheviot, and Comb Fell, while the finer-grained varieties, whether more, or less, acid than the normal type, occur mainly towards the margin of the mass.

Some of these finer-grained varieties are occasionally porphyritic, though this feature is not conspicuous or by any means common.

The microscopic examination of a large series of slides prepared from rocks collected in different parts of the granite area entirely confirms the observations already made by Mr Teall, and also brings out several additional points of interest.

The occurrence of augite is always extremely characteristic.

[1] *Ibid.*, 1885, pp. 106-121.

When fresh, it is practically colourless, but often has a greyish dusty appearance, owing to minute inclusions, or, when altered, it may be converted into a pale green slightly pleochroic fibrous amphibole [29] [33] [35] [44]. Further decomposition results in the production of pseudomorphs of chlorite or calcite. Mr Teall noticed in one case what was most probably a rhombic pyroxene,[1] and this observation I can fully confirm, as I find a pale enstatite, very similar to that so characteristic of the andesites, to be of by no means uncommon occurrence in some of the granites, especially those of Staindrop Rig, Linhope and Dunmoor Hill [27] [33] [35] [47a]. As a rule, it does not show any definite crystal form, but occurs, generally in association with the augite phenocrysts, as more or less irregular patches. It can be distinguished from the augite by its characteristic, though faint, pleochroism, and by its tendency in the less fresh examples to be replaced by bastite-like pseudomorphs.

The biotite generally occurs as rather ragged plates, frequently in association with the pyroxene. It often has the appearance of having been subjected to a certain amount of magmatic corrosion, having a ragged edge, which is often partially surrounded by small granules of magnetite and pyroxene [29] [33] [34]. Acccording to Rosenbusch,[2] such corrosion is by no means uncommon in porphyritic rocks, in which, "if the older biotite has been subjected to magmatic corrosion, it is surrounded, like basaltic hornblende, with a dark border, which consists of a mixture of magnetite and augite." Under the action of decomposing agencies the biotite loses its characteristic colour and becomes greenish and chloritised [31] [44], etc.

The quartz and orthoclase nearly always show a marked tendency to form the characteristic intergrowth known as micropegmatite, which plays the rôle of groundmass. In the normal type of granite this micropegmatite is of a relatively coarse and ill-defined character, but in the finer-grained varieties it nearly always shows the fine delicate structure so characteristic of the typical granophyres. In fact the ordinary and coarser type of granite from the more central portion of the area can frequently be traced into granophyres towards the margin of the mass, while similar granophyric types are found in numerous dykes and veins.

The constituent minerals of these granophyres are the same, in slightly varying proportions, as these of the normal granite,

N.B.—The numbers in square brackets throughout this paper indicate slides in the author's collection.

1 *Geol. Mag.*, 1885, p. 115.

2 Rosenbusch and Iddings. Microscop. Physiog. of Rock-forming Minerals, p. 260.

while they usually have a decidedly porphyritic aspect owing to the much finer texture of the later-formed portion. They vary from a pink to a greyish colour. The microscope shows that this difference is due to the fact that the darker varieties contain a larger proportion of pyroxene and biotite [61], while the pink or flesh-coloured granophyres show more felspar and quartz. There is no sharp line of demarcation, however, between the two. A slide from one of the more acid varieties from the river Breamish shows [31] much porphyritic plagioclase and biotite, of which the latter, however, has been almost entirely converted into chloritic alteration products. Only a very little augite is present, and that much decomposed. The ground mass of the rock consists of a delicate and finely intergrown micropegmatite, which is often associated with the porphyritic felspars in the characteristic manner so frequently observed in granophyric rocks.

A fairly similar well-marked micrographic variety of the normal granite occurs in the burn about half mile west of Dunmoor Hill. Under the microscope [70] porphyritic orthoclase is seen to be present in almost the same quantity as the plagioclase. Augite is very scarce, and much decomposed. The biotite is chloritised from alteration, and occurs in fair-sized plates. The greater proportion of the rock consists of a micropegmatite of medium texture, playing the rôle of ground mass. As an accessory tourmaline is also observed in irregular grains and crystal groups, and longitudinal sections show the characteristic pleochroism, pale brown passing through bluish-brown to a deep indigo.

Towards the northern portion of the granite area, near the head of Bazzle Burn, and on the N.E. side of Cheviot, granophyres are again well exposed. A hand specimen is of a pink colour and moderately fine-grained in appearance, and shows prominent hexagonal plates of biotite, often of a greenish colour from decomposition. Under the microscope [60] a slide shows a few fair-sized phenocrysts of plagioclase, and long, thin, lath-shaped sections of biotite, sometimes over $\frac{1}{8}$ inch in length, embedded in a fine-grained ground mass, consisting of small idiomorphic plagioclase crystals, flakes of biotite, quartz grains, and micropegmatite. Pyroxene is apparently only represented by one or two small patches of greenish decomposition products. Tourmaline occurs here also in irregular crystalline grains scattered throughout the rock. It varies in colour from brown to bluish brown and dull bluish green, and shows the characteristic resorption phenomena. Tourmaline is also found in the Cheviot granites in considerable quantity in certain areas where a good deal of faulting has taken place, especially near the headwaters of Lambden and Hawsen Burns, and here a curious quartz-tourmaline vein-rock is very common, in which the tourmaline usually occurs as acicular microlites, often aggregated into radiating groups, in the manner so characteristic in Luxullianite. In such rocks, as well as in the tourmaline-bearing granophyres, this mineral would seem to be of secondary origin, and the fact of its occurring in greater quantity in the neighbourhood of faults would seem certainly to support the idea of its origin being connected, as is supposed to be the case in some of the Cornish granites, with exhalations of boracic and fluoric acids. In the Cheviot district, with the exception of the areas of faulting referred to, the occurrence of tourmaline seems to be limited to the more marginal portions of the granite mass, and this is also the case in the tourmaline-bearing granites of Cornwall and Devon.

Such are the principal varieties of rock which compose the central granitic mass of this district. As regards the chemical composition of the Cheviot granite, Mr Ivison Macadam, F.R.S. of Edinburgh, has kindly analysed for me specimens of two different varieties, viz., the normal type from Staindrop Rig, and the dark, finer-grained variety from near Linhope, and the results of these analyses are here given:—

	I.	II.
SiO_2	66·02	67·12
Al_2O_3	21·43	20·12
Fe_2O_3	4·62	3·71
FeO	0·63	0·28
CaO	1·81	1·79
MgO	1·77	0·82
K_2O	3·17	3·38
Na_2O	0·15	1·53
SO_3	0·04	0·05
CO_2	0·08	0·03
H_2O	0·16	1·01
	99·88	99·84
Sp. Gr.	2·731	Sp. Gr. 2·701

I. Fine-grained dark grey granite, Black Lynn, Linhope.
II. Fairly coarse granite, Staindrop Rig.

One sees that there is not so much difference between these two varieties, as one would at first be led to expect from their appearance. One would have perhaps expected rather a lower silica percentage in the dark, dioritic-looking type, which I think may fairly represent the least acid type in the district.

Some of the granophyres, noticed above, are doubtless a good deal more acid than the Staindrop Rig rock, as they contain far more quartz and orthoclase, and in many cases only a very small amount of augite and biotite, so that they would probably show at least 70 per cent. of silica. There does not, therefore, seem to be any very considerable amount of variation in chemical composition throughout the mass of the Cheviot granite, certainly not nearly so much as in many cases described, such, for instance, as is found in the granitic mass of Garabal Hill and Meall Breac, described by Dakyns and Teall.[1]

It may not be out of place before leaving the granite to refer briefly to certain supposed cases of a gradual passage between the augite-granite and the surrounding andesites. Mr Clough in the Survey Memoir on the English side of the Cheviot district says[2]: "In certain places near the margin of the area . . . . the rock (*i.e.* the granite) is dark grey or brown in colour, and so finely crystallised that it is hard with the eye to separate it from the darker porphyrites. Indeed, one could not help suspecting that they occasionally passed into one another." But if we are to regard the granite as intrusive in the surrounding andesites, and the presence in these latter of undoubted contact metamorphism, and other phenomena, prove distinctly that this is the case, then it is certainly difficult to see how any gradual passage between the two rocks can possibly exist.

In one locality, viz., in Broadstruther's Burn, a short way above its junction with Common Burn, the granite certainly does appear at first sight to pass gradually into the andesite, as one follows the section exposed down the burn. The granite, which is here porphyritic, gradually becomes dark in colour and fine grained, as one approaches the andesite, which is also of a dark grey colour, and assumes a somewhat holocrystalline appearance in the neighbourhood of the granite. The exposure has decidedly the appearance of a gradual passage to the naked eye, and no definite line of junction between the two rocks can be detected. However, on examining under the microscope a series of slides [23], [24], [25], [26a], [26b], the distinctive characters of the granitic rock on the one hand, and the andesitic on the other, are at once apparent. And, what is more, the andesites show undoubted signs of contact alteration, which would at once negative any idea of a true original passage between them and the granite. It is the general resemblance in the colour and texture of the two rocks which gives the appearance of a gradual transition from the one to the other. It is perhaps possible that we have here a kind

[1] *Quart. Journ. Geol. Soc.*, 1892, p. 104.
[2] Mem. Geol. Survey (Sh. 108 NE.), p. 21.

of blending together of the two rocks at the contact, due to the margin of the andesite having been fused as the granitic magma was intruded into it, though there is hardly the degree of alteration in the andesites that one would have expected if such a refusion had taken place.

On the whole, my own observations, both in the field and with the microscope, lead to the conclusion that all so-called passages in this district between the granites and the andesites are in reality only apparent, and constitute contacts between an intrusive rock, on the one hand, and a contemporaneous rock, on the other hand, of an extremely intimate character.

We may now briefly sum up the chief points that are brought out by a study of the Cheviot granites. Firstly, we may notice the recognition of an enstatite-bearing variety, in the neighbourhood of Linhope, Staindrop Rig, and Dunmoor Hill. The occurrence of enstatite in granitic and granophyric rocks containing quartz and orthoclase has been occasionally noticed by previous observers, but it is by no means a common feature. According to Sir Archibald Geikie,[1] a rock fairly similar to the normal Cheviot granite has been noticed by Professor James Geikie, associated with the Lower Old Red Sandstone volcanic rocks of the east of Ayrshire. And another variety, mapped by Mr B. N. Peach, occurs in the Ochil Hills, above Tillicoultry. "It is a granophyric quartz-diorite, which under the microscope is seen to be composed of short, thick-set prisms of plagioclase, with abundant granophyric quartz, a pleochroic hypersthene, and needles of apatite."

Then we have the enstatite-diorite of Penmaenmawr, and the coarser varieties of the whin sill of Upper Teesdale, which frequently consist of a coarse enstatite-dolerite, in which micropegmatite plays the rôle of groundmass. Mr Alfred Harker tells me that enstatite-bearing granites occur in Norway and Southern India; and one might also mention in this connection certain augite-bearing quartz-porphyries, which contain a rhombic pyroxene,[2] in North Saxony, near Leipzig.

As regards the felspar of the Cheviot granite, we sometimes find plagioclase predominating over orthoclase, while sometimes again it is subordinate; occasionally both may be present in about equal proportions. The strong tendency to the granophyric structure has already been referred to, and recalls the well-known granophyres of Craig Craggen in Mull, Charnwood Forest, the Carlingford district and the Mourne Mountains in Ireland, and the augite-bearing granophyre of Carrock Fell, so

[1] *Q. J. G. S.*, vol. xlviii. p. 77 (Anniv. Address of Pres.). "Ancient Volcanoes of Great Britain," vol. i. p. 277.

[2] Rosenbusch, Massige Gesteine, p. 58.

ably described by Mr Harker.[1] In the Cheviot district the granophyric types are especially noticeable towards the marginal portions of the main mass. Distinctly porphyritic varieties, in which plagioclase is the dominating phenocryst, are occasionally met with [28], etc.

I have not come across any undoubted case of hornblende occurring as an original constituent of any Cheviot granite, though a slide from a granite boulder from this district in the Survey Collection in Jermyn Street shows small brown crystals of idiomorphic hornblende [1391]. The occurrence of tourmaline, however, near the margin of the main mass and in small veins, is extremely characteristic. Its presence, too, in considerable quantity, in the neighbourhood of faults, might possibly throw some light on its mode of origin.

Lastly, the presence of considerable variation in the relative proportion of the different constituents must not be overlooked. This variation would appear, in this district, to be a marginal modification, resulting sometimes, as seen near Linhope, in a rather less acid variety than the normal type, and sometimes, on the other hand, as in the North and North-West of Cheviot, in the more acid and finer-grained granophyres. So that the differentiation, though essentially of a marginal type, is by no means uniform from the centre to the margin of the main mass of the granite, as, for instance, has been shown to be the case with the Gabbro of Carrock Fell.[2] The type of magmatic differentiation, however, which is illustrated in this district, I shall discuss more fully in connection with the relations between the granite, the dykes, and the contemporaneous lavas.

3. *The Dykes and Sills.*—Among the numerous dykes and sills which are found intersecting the Cheviot granite and the surrounding lavas, one may recognise two fairly distinct types: (1) an intermediate, and (2) an acid type. The mode of occurrence of most of these dykes and sills in the field has been well described by Mr Clough,[3] and the microscopic characters of some of them have been described by Mr Teall[4] and Mr Watts.[5] A considerable number, however, have as yet remained unnoticed by any petrologist, many of which show various additional characteristics to those already recorded, and which are well worth noticing. I propose, therefore, to describe the microscopical characters of some of the more interesting dykes and sills that I have examined in the field, and shall also endeavour to show that, in examining a series of thin sections

[1] *Q. J. G. S.*, 1895, p. 125 *et sqq.* [2] *Q. J. G. S.*, 1894, p. 311.
[3] Mem. Geol. Survey. The Cheviot Hills, pp. 26-29.
[4] Teall, *Geol. Mag.*, vol. x. pp. 255-257. Brit. Petrog., p. 281.
[5] Mem. Geol. Survey (¼ sheet 110 SW.), Geology of part of Northumberland, p. 62.

prepared from dyke-rocks occurring in different parts of the district, one will come across varieties which constitute connecting links, or transitional types, between the intermediate and the acid type. We will first of all consider the intermediate series.

(1) *The Intermediate Type.*—These consist mainly of *Mica Porphyrites.* Before describing them, however, it will be as well to explain, as nearly as possible, the exact sense in which the term "Porphyrite" is here used. If we employ the term "Porphyrite," as it has been so frequently used in petrographical literature, to signify a more or less altered (decomposed) rock, showing in other respects the characters and structure of an andesite, we cannot draw any petrological distinction between the dyke-modification of the andesitic magma and the corresponding lavas. I propose then in what follows to employ the term "Porphyrite" in the same sense in which it is used by Mr J. J. H. Teall in describing some of the dykes associated with the Criffel and Dalbeattie granites,[1] that is to say, as referring to a porphyritic rock, usually constituting dykes and sills, in which plagioclase is the predominating felspar, and which may be said to bear "the same relation to the andesites that the porphyries do to the liparites." The only difference between the Cheviot porphyrites and those above referred to, as described by Mr Teall, is that the former belong rather to the class of pyroxene-porphyrites, while the latter would be classed as hornblende-porphyrites.

We find, then, that in the area under consideration the dykes and sills constituting the intermediate type are composed of porphyritic rocks with a groundmass more or less compact to the unaided eye. The rocks vary in colour from a dark grey, when fairly fresh, through various shades of purple to a brick-red, when decomposed. The phenocrysts consist of plagioclase, biotite, and augite; enstatite, of a similar type to that of the enstatite-andesites has occasionally been noted, as well as small grains of quartz. Orthoclase is sometimes present, but is always subordinate to plagioclase. A considerable variation is noticeable in the relative proportion of the phenocrysts to the ground mass, and this I believe is a common character in all rocks of this class.

To take a few examples. At a bend in the Carey Burn, near Wooler, and a short way below the junction of the Common and Broadstruther's burns, a purplish porphyrite occurs as a fairly large intrusive mass. It may possibly represent a neck, or perhaps an intrusion of the laccolitic type. Under the microscope [16], one sees fairly numerous crystals of plagioclase, (probably oligoclase), and plates of biotite. The biotite is fairly

[1] Mem. Geol. Survey, Scotland, sheet 5 (1896), p. 44.

fresh, though commencing alteration is frequently shown at the edges of the phenocrysts and running in along the cleavage cracks. Pyroxene, in crystalline grains, was evidently present in the fresh rock, though in no great quantity, but it is now only represented by chloritic and calcareous alteration products. A few small grains of quartz are also present. The ground mass consists of a microcrystalline aggregate of small crystals of plagioclase, flakes of chloritised biotite, orthoclase and quartz. Magnetite and apatite are both fairly abundant as accessories, and both are common as inclusions in the phenocrysts.

In the Common Burn, especially in the neighbourhood of Common Burn House, several dykes of porphyrite are exposed. Their groundmass varies in structure almost from a confusedly cryptocrystalline [64] to the microgranitic [66]. Small quartz grains resembling those of the quartz-porphyries are sometimes present, and are generally corroded.

The plagioclase phenocrysts are much decomposed and show micaceous alteration products. The biotite is generally entirely converted into chlorite, and a fair amount of pyroxene is present. A few greenish and fibrous pseudomorphs [66] appear to represent enstatite. Sometimes the augite appears fresh and almost colourless, and shows well-defined crystal outline [27], and bastite-like pseudomorphs after enstatite are clearly recognisable [27].

In the valley of the Breamish an intrusive biotite-porphyrite is well exposed just below Linhope House. Augite, in a uralitised condition, is fairly plentiful [67], [68]. Grains of quartz occur, occasionally intergrown with orthoclase so as to form a porphyritic aggregate of micropegmatite [68]. In the ground mass again we find a very fine delicate type of micropegmatite, representing the final phase of crystallisation from the mother-liquor. We thus get two phases during which micropegmatite was formed. Besides the phenocrysts of intergrown quartz and orthoclase simple porphyritic crystals of both minerals also occur. Another rock, which occurs as a dyke in the granite on the S. side of Dunmoor Hill, near Linhope, shows this feature rather better. The rock contains [15a, 15b, 46] phenocrysts of plagioclase, biotite, augite, and occasionally enstatite may also be observed. Towards the margin of the dyke numerous phenocrysts of micropegmatite occur. In many points these structures closely resemble the granophyre groups described by Iddings[1] from the rhyolitic rocks of Obsidian Cliff, and Eureka, Nevada. In the Cheviot slides, however, especially in some of the quartz-felsites to be described, they are considerably larger and show a coarser intergrowth of the two minerals. In the rhyolite from Eureka quartz has been intergrown with

[1] Seventh Annual Report (1886) U.S. Geol. Survey, p. 275.

felspar, and is also enclosed within it, so that the felspar crystals retain their characteristic outline. Hence the form of the phenocryst is determined by the felspar, and shows that it continued to crystallise out after the quartz had ceased. Mr Cowper Reed[1] describes similar granophyre groups in felsitic lavas from Goodwick, near Fishguard, and Mr Reed was good enough to allow me to compare his slides with my Cheviot examples. In the Goodwick rocks the outline of the granophyre groups is more usually determined by the quartz, not by the felspar, so that the marginal portion consists of a series of wedge-like protrusions of quartz, which more or less completely encloses the felspar. The outline in section of such a group will correspond to that of one, or more commonly a group of, quartz crystals.

In all the examples that I have seen from the Cheviots, however, the form of the group is usually determined equally by both minerals, so that the outline is that of a porphyritic aggregate of felspar and quartz, each mineral being idiomorphic along the outer margin of the group.

We thus have a porphyritic individual or phenocryst consisting of a micrographic intergrowth of quartz and orthoclase, the external contour of which may be determined by either the quartz or the felspar, according to whichever continued to crystallise out after the other, or it may be determined by both minerals equally, in which case both probably ceased to crystallise out about the same time.

Plagioclase occasionally occurs in association with these groups, but it does not appear to be intergrown with the quartz. Possibly, as in the example described by Iddings from Eureka, Nevada, the quartz and orthoclase crystallised out about the plagioclase as a kind of nucleus.

There is no doubt that these groups constitute distinct porphyritic elements and are indigenous to the rock in which they occur. They are always sharply and distinctly separated off from the ground mass, and are generally bounded by crystal outlines, as I have already pointed out; so that there is no possibility of confusing them with the micropegmatite, which constitutes such a well-known feature of the groundmass of many granitic rocks. They belong undoubtedly to the earlier or plutonic phase of consolidation of the magma, the conditions of which were suddenly interrupted on the injection of a portion of this magma into a fissure to form a dyke. If this consolidation could have been continued unchecked, in all probability a rock would have been formed closely resembling the normal finer-grained granites of the district, in which a free intercrystallisation of quartz and felspar is a common feature.

[1] *Q. J. G. S.*, vol. li. (1895), p. 162, pl. vi., figs. 3, 4, and 5.

Micrographic structures, essentially similar to the above, have been described and figured by Professor Judd [1] from the Isle of Skye. He regarded them, however, as representing remnants of derived fragments of granophyre, which had been caught up by the Gabbro and refused, the "granophyre groups" being those portions which had escaped refusion. It was, however, conclusively shown by Sir Arch. Geikie [2] that the rock in which these structures occur is to be regarded as constituting small dykes and veins of spherulitic felsite traversing the Gabbro, and not as partially refused fragments. It is interesting to find, therefore, that the petrological evidence of these granophyre groups strongly confirms Sir Archibald's conclusions. They occur in a felsitic rock possessing the type of ground mass commonly known as the "pseudospherulitic," and they are usually found in the nuclei of the pseudospherulites, or in other words, the matrix behaves with respect to these groups in exactly the same characteristic manner as this type of ground mass behaves with regard to phenocrysts of felspar and quartz in so many felsitic and granophyric rocks. They constitute in fact normal porphyritic groups in a felsitic rock of by no means uncommon type. And from the comparative frequency with which these structures occur in the dyke rocks of the Cheviot district and of other areas, and from other facts already noticed, we may infer that they are decidedly original and unaltered structures characteristic of the quartz-felsites and allied rocks, more especially of the granophyric varieties.

The rock from Dunmoor Hill, in which these granophyre groups occur, was analysed for me by Mr Ivison Macadam, F.R.S.E., etc., with the following result:—

SiO_2	60·84
Al_2O_3	20·03
Fe_2O_3	1·47
FeO	0·42
CaO	1·56
MgO	0·45
K_2O	4·43
Na_2O	9·12
SO_3	0·06
H_2O	1·15
CO_2	0·11
	99·64
Sp. Gr.	2·683

[1] *Q. J. G. S.*, vol. xlix. (1893), p. 189.

[2] *Q. J. G. S.*, vol. l. (1894), p. 212.

The extraordinary high percentage of the soda makes it difficult to doubt that this is not largely overestimated. With this exception the analysis resembles on the whole those of the augite-andesites of the same district described by Teall,[1] the alumina percentage being perhaps in our dyke-rock rather higher.

I have now described the main petrological features of the dyke-rocks of the intermediate or porphyrite type. The occurrence of enstatite in some of these rocks is worthy of note, and serves to show the relations between them and the augite-granites on the one hand, and the andesitic lavas on the other. Another mineral of interest, which I have also noticed in several specimens of the andesites, is a bluish and violet apatite, doubtless similar to that described recently in the Transactions of this Society, by Dr Flett, in an andesite from the Ochils.[2] This is well shown in the Dunmoor Hill dyke, occurring in short stumpy prisms, and showing a distinct pleochroism.

The variation in the relative proportion of the different constituents is well marked in these rocks. Thus while biotite, among the ferromagnesian constituents largely predominates throughout, the proportion of augite and felspar varies considerably. Some may be classed as fairly typical augite-bearing biotite-porphyrites. In others again we find the proportion of ferromagnesian minerals, especially the augite, becoming smaller, while quartz and orthoclase make their appearance among the porphyritic; and these latter, as we have seen, may occasionally be intergrown, to form the granophyre groups. These latter varieties would appear to constitute connecting links between the porphyrites and the quartz-porphyries. The groundmass is usually of the microcrystalline type, consisting mainly of quartz and felspar. This will pass into the cryptocrystalline, or at times it will approach the micropoikilitic [15], while in others again the groundmass might be described by Mr Harker's term 'cryptographic,'[3] an extremely minute micropegmatitic growth appearing to fill up the interspaces between the last formed minerals [11], [19], [92].

Acid Type.—This type of dyke-rock in the Cheviot district comprises two fairly well-marked species, which, however, are closely related through intermediate varieties.

Almost all the rocks belong to the quartz-felsites, but for the sake of convenience we may divide them into (*a*) those without micropegmatite, corresponding to the felsophyres of Vogelsang,

[1] *Geol. Mag.*, 1883, p. 107, and 1885, p. 118.
[2] Trans. Geol. Soc., Edin., vol. vii. p. 292.
[3] See Q.J.G.S., vol. li., 1895, p. 129.

and (*b*) those with micropegmatite, corresponding to the granophyres of Rosenbusch. We will notice those of the felsophyre class first. In the Alwinton district a well-defined dyke occurs in the Usway Burn nearly a mile above its junction with the Coquet. From this point it runs nearly due south-west and is exposed in the Coquet a quarter of a mile above Shillmoor, and again in the Ridlees Burn, east of Quickening Coat. This rock has been well described by Mr Teall.[1] I will here, however, briefly notice some of its more important characters, as I consider that it shows relationships to some of the more acid varieties of the quartz-bearing biotite-porphyrites, such as the dyke from near Linhope House [68], already described above. Under the microscope [55], [56], [57], [58] biotite is at once seen to be the most important mineral. It occurs in numerous small hexagonal tablets and elongated rectangular flakes. Quartz is fairly plentiful and generally occurs as irregular corroded crystalline grains, but occasionally shows crystalline outline. The felspar consists of two varieties, lath-shaped individuals, which are of the same colour as the groundmass from alteration, and which can be recognised as plagioclase, and clear individuals of a tabular habit, but often more or less corroded, and showing Carlsbad twinning. These latter appear to be sanidine, and are well shown in the rock from Ridlees Burn [57]. The ground mass varies from micro- to crypto-crystalline. Another dyke of the same character occurs in the Lambden Burn, near Goldscleugh. These rocks may be termed biotite-quartz-felsites, and resemble in many respects the mica-bearing quartz-porphyries described by Messrs Marr and Harker from the Shap district.[2] The same authors also mention sanidine as occurring in some of the dykes of that district.

At Low Bleakhope we find another rock which forms a connecting link between the porphyrites and the quartz-felsites, and it is difficult to say to which class it should be assigned. Under the microscope irregularly shaped and much corroded quartz grains are seen of the usual quartz-felsite type. Both plagioclase and orthoclase occur; biotite and chloritic pseudomorphs after pyroxene are present in a proportion almost equal to that of the quartz [101], [102], [103]. The ground mass is microcrystalline and resembles that of many of the mica-porphyrites, and consists of small lath-shaped plagioclases, orthoclase, quartz, magnetite granules, and chlorite alteration products. The margin of the dyke has a slightly fresher appearance and shows excellent fluxion structure.

The remaining dyke-rocks which I have classed with the

[1] *Geol. Mag.*, Dec. 3, vol. ii. (1885), p. 107. British Petrography, p. 343.
[2] Q.J.G.S., vol. xlvii. p. 285.

felsophyre type do not call for any special description. They are mostly normal quartz-porphyries of the type so common in granitic regions. As a rule both orthoclase and plagioclase are present, the former being frequently the dominant felspar. Occasionally, when a comparatively small amount of quartz is present, and orthoclase is in excess of the plagioclase, we may get an orthoclase-porphyry or orthophyre, such as has been described by Mr Watts, from the northern portion of the Cheviot area.[1] The proportion of biotite, too, varies considerably in the different slides I have examined [53], [54], [100].

There cannot be said to be any sharp line of difference between the felsophyre type and the granophyric. A distinction based merely on difference of texture in the groundmass of unaltered rocks can only depend upon slightly varying conditions of consolidation. For we may occasionally find the two types of groundmass, the micrographic and the microcrystalline, together in the same slide [50], or again the central portion of a dyke may show the micrographic, while the margin will show the microcrystalline [97], [98], [99]. It will be sufficient therefore to notice the more interesting points in connection with the remaining dyke-rocks, which I have placed provisionally in the granophyre class. Plagioclase generally occurs in addition to orthoclase, but is usually subordinate to it, though in one or two slides the porphyritic felspars are mainly plagioclase [89], [20]. Biotite is usually present, occasionally in very elongated strips and flakes. Sometimes it is almost entirely absent [62], [90]. In decomposed specimens it is wholly or partially replaced by chloritic alteration products. Pyroxene is rare, but occasionally makes its appearance, sometimes as phenocrysts, generally showing more or less alteration [20], [89], or as small grains in the groundmass [95], [70]. A few small grains of brown tourmaline now and then occur as an accessory [100], [95], [70].

But the most interesting feature of these rocks is the frequent occurrence of the granophyre groups, which have already been noticed above as occurring in one of the porphyrites. But in the rocks under consideration we not only have micrographic quartz and felspar constituting phenocrysts of the earlier phase of consolidation in the form of granophyre groups, but we again have an extensive development of micropegmatite of varying texture constituting the later phase of consolidation of the magma in the ground mass. Two or three dykes showing this feature occur about $\frac{1}{2}$ mile below Low Bleakhope on the

[1] Mem. Geol. Survey. [Sheet 110 SW.] Geology of part of Northumberland. Petrological Notes by W. W. Watts, p. 62.

river Breamish. Porphyritic quartz is seen to occur independently, besides taking part in the formation of the porphyritic micropegmatite [51], [62]. Sometimes a section of one of these groups has the appearance of one or more felspar crystals, containing a number of separate, more or less triangular-shaped, inclusions of quartz, which are in optical continuity, or sometimes the inclusions of quartz may extinguish in separate groups, when rotated between crossed nicols. Or again a section may show irregular strips and patches of felspar included in the quartz. The intergrowth constitutes a rather coarse irregular type of micropegmatite, and can be frequently seen to be associated with a crystal of plagioclase. It forms genuine porphyritic groups sharply marked off from the surrounding groundmass. And this ground mass again is of the finely micrographic type, and constitutes a delicate feathery or plumose variety of micropegmatite, of a much finer type than that forming the groups, and fills up the interspaces between the last formed crystals. Biotite is rather scarce in these rocks, and there seems to be no sign of any pyroxene, and only very little magnetite.

Evidently we have here a group of distinctly acid rocks consisting for the most part of orthoclase and quartz, and in which micropegmatite has been formed at two distinct periods. We have been accustomed to regard micropegmatite as representing the very final phase of consolidation of a magma; but we have very clear evidence in these rocks that micropegmatite can belong, not only to the final phase, but also to a comparatively early phase of consolidation. Thus after magnetite, biotite was the first mineral to crystallise out of the magma, and it was followed presumably by plagioclase. Then apparently orthoclase and quartz crystallised out at the same time, either to form independent idiomorphic crystals, or to form an intergrowth in association with the already formed phenocrysts of plagioclase, thus constituting the granophyre groups. At this stage, however, crystallisation under plutonic or intratelluric conditions suddenly ceased, a portion of the magma was forced into a fissure, and under these new conditions of consolidation occurred the second formation of micropegmatite to constitute the groundmass of the dyke, and this was naturally of a variety far finer in texture than that already formed, owing to the greater rapidity in cooling which ensued during the fissure-phase.

As to the exact conditions necessary for the formation of micropegmatite, we cannot in the present state of our knowledge make any definite statement. If we are to regard micropegmatite as an eutectic compound, it seems evident that such a compound can be formed by quartz and felspar only under certain conditions of which we are ignorant. Otherwise we should expect to find micropegmatite in the ground mass of any rock in which the mother liquor had the chemical composition of quartz and orthoclase, and we know that this is not the case from the frequent occurrence in granitic rocks of insterstitial quartz and felspar, in which the crystallisation of either mineral may *precede* the other. If, however, a eutectic compound is invariably formed in such a mother liquor, it is evident that it cannot always give rise to the micrographic structure without the concurrence of particular physical conditions. In many cases in the so-called micrigranitic groundmass there may be a certain amount of simultaneous crystallisation without the occurrence of typical micropegmatite or its allied structures.

It is very clear that in the rocks under consideration the physical conditions of consolidation strongly favoured the formation of the granophyric structure, and from the frequent occurrence of the granophyre groups in the porphyritic rocks we may further conclude that these conditions were present during both phases of consolidation.

The micropegmatite of the second generation (or second period of consolidation) may be aptly compared with that described by Mr Harker in his paper on the Granophyre of Carrock Fell.[1] The granophyric structure in this rock, to use the author's own words, "exhibits various stages of gradation from a coarse and irregular micropegmatite to spherulitic intergrowths of a delicacy surpassing the resolving power of the microscope." In the Cheviot rocks, however, I have not noticed any marked tendency to the centric or radiate arrangements. One may observe, however, almost every gradation between a fairly coarse and ill-defined intergrowth to what might be called 'cryptopegmatite,' or, to use Mr Harker's term, the 'cryptographic' structure [62], [100].

Small veins and bands of more acid material are very numerous in the Cheviot granite, and are especially well seen in Linhope Burn and in the river Breamish. At Linhope Spout, for instance, two or three small bands, less than a foot in breadth, traverse the granite just at the top of the waterfall. Mr Clough, in connection with these and other similar exposures, says[2]:—"In some cases they may be contemporaneous veins rather than intrusions, and Mr Teall is inclined to hold this view in respect to the quartz-felsite bands at Linhope Spout. On the other hand, the sides of some of them are distinctly finer-grained than the interiors, as if they had been chilled by

[1] Q.J.G.S., vol. li. (1895), p. 127.
[2] Mem. Geol. Survey (The Cheviot Hills), p. 22.

intrusion into an already consolidated cooler rock-mass. . . . We know also that there are undoubted dykes of much the same character among the contemporaneous rocks." My own observations have led me to agree with Mr Clough that many of these narrow bands must be regarded as true dykes and not as contemporaneous veins. Those, too, of Linhope Spout behave clearly as dykes, maintaining a straight course and uniform thickness for some distance, and the rock resembles many of the dyke-rocks already described. Under the microscope [49] the margin of the band is seen to become very compact, and shows flow structure, while the junction with the granite is extremely sharp and well-defined. Granophyre groups are again of by no means uncommon occurrence [50]. The ground mass is microgranitic to cryptocrystalline, but may sometimes become micrographic. Similar vein-like dykes belonging to the acid series are common in the same neighbourhood [39], [41], [47].

There is no doubt, however, that many other small bands and threads of more acid material are to be regarded rather as contemporaneous veins, such as were squeezed into the granite previous to its complete consolidation, from a deeper-seated and more acid portion of the general magma. Thus several of the pink felspathic bands which traverse the granite in Linhope Burn, a short way below Linhope Spout, would seem to be of this nature. A hand specimen of one of them shows a fairly sharp line of demarcation at its junction with the granite. But under the microscope [38] this line becomes lost, the normal granite simply passing gradually into the vein-rock, while the latter only differs from the former in containing more quartz and orthoclase, less plagioclase, and scarcely a trace of ferro-magnesian constituents. Another small vein, not more than half an inch in breadth, traversing the granite about a mile above Linhope, shows, however, a rather different structure under the microscope [40]. It consists entirely of quartz and orthoclase, with an occasional small pseudomorph after pyroxene. It is not particularly fine-grained in texture, though its junction with the surrounding rock is fairly sharp. In its central portion the orthoclase plays the rôle of groundmass to the quartz, but along the margins the two minerals have crystallised out simultaneously and form a beautiful micropegmatite of a branching dendritic type. This micropegmatite seems to have grown inwards all along the margin of the vein and at right angles to the junction line with the granite; so that the granophyric border appears to act with regard to the parent rock in the same characteristic manner as the micrographic groundmass of the granophyres acts with regard to the porphyritic crystals, *i.e.*, when it forms about them the characteristic peripheral border. We may presume that the margin of the vein consolidated before the central portion. It is interesting, therefore, in connection with the relations of micropegmatite already discussed, to find here a quartz-felspar rock in which the formation of the micrographic structure was *followed* by the formation of the microgranitic. In this case the formation of the granophyric border may have been due to greater rapidity in cooling.

Small veins and dykes, traversing the contemporaneous lavas, are common in some places close to the granite margin. Thus, the Tathey Crags, about a mile SE. of Langleeford, consist of altered andesite traversed in all directions by numerous veins, varying in breadth from half an inch to several feet. Under the microscope [104], [105], [108], [109], they are seen to consist of medium-grained granite, resembling that of the main mass, microgranite and granophyre. In the granitic structure the quartz is of earlier consolidation than the orthoclase. In nearly all these veins, in addition to a fair amount of biotite, tourmaline is invariably present, and sometimes in considerable quantity. It is brown, bluish-green, or of a dark bluish colour, and usually occurs in irregular grains, or sometimes in short stout prisms. The characteristic pleochroism is strongly marked. One vein [105] contains this mineral in such quantity that one might call the rock a tourmaline granophyre. Tourmaline bearing granitic veins are again found in the neighbourhood of the granite margin in the altered andesite of the crags above Langleeford [95], [96], and in the Hen Hole [79].

Thus the chief distinguishing feature between these marginal veins and those within the granite area is the frequent occurrence in the former of tourmaline. I have also occasionally noticed it, as already stated above, in one or two of the granophyre dykes, traversing the granite, not far from its margin, and it occasionally occurs in the granophyres, which appear to form a marginal modification of the granite mass itself (see above, p. 37), and is not uncommon along lines of faulting.

I have now described the main petrological features of the principal varieties of dykes and veins in the Cheviot district. What I would specially call attention to is the large amount of different varieties of rocks which constitute these dykes, and the modifications which they show in texture, structure, and composition. Thus we may have augite-biotite-porphyrites, biotite-porphyrites, quartz-biotite-porphyrites, biotite-quartz-porphyries, orthoclase-porphyries or orthophyres, and granophyres, and these we find to be connected by intermediate varieties, showing a diminution in the proportion of certain constituents, and the increase or appearance of others, so that any strictly systematic classification of them is impossible.

I have already compared the dykes and sills of the intermediate series to the porphyrites associated with the granite masses of Criffel and Dalbeattie, described by Mr Teall, and Mr Teall finds a strong relationship to exist between these porphyrites and the granites which they traverse. And there is no doubt that the Cheviot porphyrites strongly resemble many of the dykes and sills connected with other granite masses of approximately the same geological age as the Cheviot mass, and now known as the Newer Granites of Scotland, as well as many of those traversing the contemporaneous rocks of other well-known volcanic areas of Lower Old Red Sandstone age.

In describing the dykes round the Shap Granite,[1] Mr Harker finds that the intrusions present a considerable range of differences, and have at the same time curious points in common. They have characters, moreover, which connect them on the one hand with the Shap Granite and on the other with the Mica-Traps. In the Cheviot district, too, we find that the dykes and sills not only have points in common, as I have endeavoured to point out, but show distinctive features which connect them on the one hand with the augite-granite, and on the other with the andesitic lava-flows which surround it. Thus the intermediate type of dyke-rock mainly consists of biotite-porphyrites containing more or less augite, which closely resembles the pyroxene so characteristic both of the granites and the andesites. Again, a rhombic pyroxene, presumably enstatite, occurs not only abundantly in the lavas, but also occasionally in the porphyrites and the granite. Pyroxene also sometimes occurs in the quartz-felsites and granophyres. The peculiar violet or bluish apatite is found not only in some of the andesites, but again occasionally in some of the later porphyrites. Micropegmatite may apparently appear in the ground mass of almost any of the Cheviot intrusives. In the less acid type of dyke it is not so common or so freely distributed when present; but it is certainly one of the most characteristic features not only of the more acid dykes but also of the more marginal portion of the granite. Further, the frequent occurrence of two generations of micropegmatite is an interesting feature of many of the dykes.

The following is an analysis of one of the more acid quartz-felsites, containing the granophyre-groups, from the river Breamish, a short way above Linhope, for which I am indebted to Mr Ivison Macadam of Edinburgh. I quote with it for com-

[1] Q.J.G.S., vol. xlvii. (1891), p. 287.

parison the analysis of the biotite-quartz-felsite from the Coquet above Shillmoor, described by Teall:[1]—

	I.	II.
SiO_2	72·66	67·9
Al_2O_3	18·98	15·7
FeO	0·21	—
FeO_3	0·57	3·0
CaO	0·03	1·4
MgO	0·47	1·5
Na_2O	0·21	1·5
K_2O	5·91	5·6
SO_3	0·02	Loss 3·7
H_2O	0·86	—
	99·94	100·3

I. Quartz-felsite dyke, river Breamish, above Linhope.
II. Biotite-quartz-felsite dyke. River Coquet, half a mile above Shillmoor.

This analysis will probably represent that of the majority of the dykes that I have classed with the acid type, and it will be seen that they are thus considerably more acid than the variety rich in biotite, described by Mr Teall, while the latter has slightly higher proportions of lime, iron ores and magnesia.

I will now pass on to discuss certain considerations dealing with the relations between the various igneous rocks of this district.

4. *The Relation between the Granite, the Dykes, and the Andesites.*—The first period of volcanic activity in the Cheviot district was evidently marked by the eruption of immense quantities of andesitic lavas. They are mostly perfectly normal pyroxene-andesites showing little, if any, range of composition. No lavas of the rhyolitic type are known from this district, though it is possible of course that such may have been poured out at the surface during the later phases of the eruptive activity. This, which we may call the extrusive phase, was followed, as is proved by the phenomena of the granite and the dykes, by the intrusion of material partly of intermediate and partly of acid composition. This intrusive phase, which these phenomena characterise, commenced with the intrusion of the augite-granite into the contemporaneous lavas. That the granite was intrusive in the surrounding rocks was fully recognised by Mr Clough, and later by other observers,[2] and

[1] *Geol. Mag.*, Dec. 3, vol. ii. p. 107.
[2] See Sir Arch. Geikie, "Ancient Volcanoes of Great Britain," vol. i. pp. 337, 338.

is, moreover, indisputably proved by the occurrence in the latter of contact metamorphic phenomena along the granite margin. The intrusion of the dykes and sills of porphyrite and quartz-felsite, since they cut, not only the andesites, but the granites as well, constituted therefore the latest phase of the volcanic activity of the district of which we have any record.

Mr Clough[1] considers the Cheviot granite as representing the deep-seated source of the andesites, and Mr Teall, in discussing this question, says,[2] "are these rocks (the granites) due to the consolidation beneath the surface of the magma which produced the andesitic lavas and tuffs? . . . The evidence available is not so complete as we could wish, but, such as it is, it points decidedly to an affirmative answer to the above question." Mr Teall's conclusion is partly based on the supposition that an analysis of the Cheviot granite would approximate very closely to those of the augite-granitites of Vosges, and he shows that there are close connections between the chemical analyses of these latter rocks and those of the Cheviot andesites. I would point out, however, that the analyses that I have already given of two samples of Cheviot granite, one of which I certainly think approximately represents the normal type, both show a considerably higher silica percentage than that of either the andesites or the granites of the Vosges. Further, as regards the alkalies, there is a well-marked excess of potash to soda, whereas the converse is the rule in the normal andesites.

These considerations, I think, would rather seem to show that if, in the granite, we are dealing with the deep-seated source of the andesites, it can only be in a very limited sense. It seems more probable that we have here a portion of the original andesitic magma, which had undergone a certain amount of differentiation previous to intrusion. The granite is on the whole distinctly more acid than the lavas and belongs to a later phase of activity.

As regards the amount of differentiation which the mass shows, this is apparently by no means so great as one might have expected from the very varying aspect of the rocks. Where a slightly more basic modification does occur, as in the neighbourhood of Linhope, it is marginal. This is, however, by no means a uniform, but rather a local character, many of the marginal varieties of rock from other portions of the area appearing, if anything, more acid than the normal type. A somewhat similar type of marginal variation may

[1] Mem. Geol. Survey, "The Cheviot Hills," p. 24.
[2] *Geol. Mag.* (1885), p. 117.

perhaps be found in the case of the granitic rocks of Garabal Hill and Meall Breac, described by Messrs Dakyns and Teall.[1] Here, however, the formation of a basic modification had proceeded to a far greater degree. In the present case the amount of variation exhibited appears hardly to be sufficient to be of any great importance, in comparison with the many examples of extreme variation in igneous masses which have been previously described. The occurrence, nevertheless, of augite-granitites, granophyres, and contemporaneous felspathic veins, as constituents of our granite mass, will suffice to show that a distinct amount of differentiation had taken place in the magma subsequent to the extrusion of the andesitic lavas.

But let us see, now, how the phenomena of the dykes and sills bear upon the sequence of events in the igneous activity of this area.

Mr Clough observed[2] that the majority of the dykes tend to have a more or less radial arrangement and to point towards the central part of the granite area, and this is at once seen on glancing at the Survey map of the district. Similar instances are, however, not uncommon in other localities. Thus J. P. Iddings has described radiating dykes converging upon a central mass of granular gabbro, which graduates into diorite, in the volcanic area of Crandall Basin, in Wyoming.[3] Radial dykes are also well seen, according to Pirsson, in the Crazy Mountains,[4] and in the Highwood Mountains of Montana.[5] The latter author points out that these dykes represent the very latest phase of the eruptive activity, and that the rocks composing them are more highly differentiated than those of the central masses. Pirsson supposes that such dykes originated owing to cracks being formed by the cooling and consequent contraction of the central mass. Cracks would thus occur also in the heated zone of surrounding rocks, and if these are homogeneous, the cracks will be more or less radial. Radiating fissures, he points out, are most typical, where intrusions have taken place into areas of approximately homogeneous and undisturbed strata. Again, the same author finds that these radial dykes are generally composed in the same district of two main groups, which he terms lamprophyres and oxyphyres, indicating the more basic and more acid series respectively. These constitute "complementary" groups, and the more basic types are usually found further from the centre than the more acid. This we

[1] Q.J.G.S., vol. xlviii. (1892), p. 104.
[2] Mem. Geol. Survey, "The Cheviot Hills," p. 28.
[3] *Geol. Mag.* (1893), p. 559.
[4] Bull. Geol. Soc. Am., vol. iii. (1892), p. 451.
[5] *Op. cit.*, vol. vi. (1895), pp. 389-422. See also *Am. Journ. Sci.*, 3rd Series, vol. l. pp. 116-121.

should expect, on the supposition of the magmatic differentiation having been mainly determined by the migration of the more basic constituents towards the outer margin.

In the Cheviot district it would seem that we have a somewhat parallel case to those described by Pirsson, with certain modifications. We have numerous dykes showing a more or less radial arrangement, and traversing a thick series of approximately homogeneous and undisturbed andesitic lava-beds, and representing moreover the final phase of the eruptive activity of the district. Taken together, these dykes show more extensive differentiation than the main mass of granite.

I have already drawn attention above to the range of composition exhibited by the dykes. Thus we have every gradation from an intermediate rock with strong affinities to the andesites to a distinctly acid rock showing relations to the more acid granites and granophyres of the central area. And since the less acid variety of the granite is considerably more acid than the mica-porphyrites, we have then a greater divergence of differentiation at the time of the infilling of the radial fissures. It is also true to a certain extent that the quartz-felsite and granophyre dykes are most numerous in and about the central core. The porphyrite dykes, however, as we have seen, do not always occur away from the centre, but are frequently seen cutting the granite mass as well.

From these considerations I think, perhaps, we are justified in concluding that the quartz-felsites and porphyrites of the Cheviots are "complementary" rocks, and represent the extremes of a series derived by a process of differentiation from one original magma. It might be urged, however, that if the original magma was of an intermediate composition, we should expect to find more decidedly basic modifications of it among the dykes, and basic dykes are not known as products of the igneous activity of this district. Still there is no reason why such should not have been formed beneath the surface, but not tapped during the dyke-forming phase. And further, the observable succession of igneous rocks in a volcanic area is well known to be of a very varying nature, and at present no general law has been formulated which will apply to all cases alike. No doubt the extremely varying nature of the physical conditions which obtain in different areas, will account for a good many of the apparent discrepancies observed.

Still, however this may be, the study of the petrological features of the Cheviot igneous rocks brings one unhesitatingly to the conclusion that the source of supply for the andesitic lavas, the granites and the dykes and sills, was the same. We cannot ignore the close relationships that have already been pointed out that exist between the three groups of rocks. The structural differences between them are no doubt due to differences in the conditions of consolidation. The variation observable in the granite mass, and the range of composition shown by the dykes, I would attribute to differentiation in the original magma, probably determined to a great extent by the action of progressive crystallisation, as already pointed out by Mr Teall[1] in dealing with the relations of quartz-felsite to andesite.

And if we have in the Cheviot rocks fair samples of all the variations formed in the original magma, the degree of variation in the granite and the dykes will show us the corresponding amount of differentiation, which had been produced at the time of the intrusion of these rocks respectively.

Apparently, a progressive differentiation gradually went on in the original homogeneous magma, a partial result of which we see in the granite, while a further stage is indicated by the dykes. As to how far the illustration is complete, we have no means of judging.

At any rate, it seems certain that in the Cheviot district we are dealing with three distinct and successive phases, belonging to the same geological period, of one original magma: an extrusive phase, characterised by outpourings of andesitic lavas; a plutonic phase, characterised by the intrusion of the granite; and the fissure or dyke phase.

In conclusion I would point out that the central granite mass, as suggested by Sir Arch. Geikie,[2] very probably occupies the site of the main focus of the volcanic activity of this district, and that it has thus been intruded into the lower portion of the old vent or group of vents from which the surrounding andesitic lavas were discharged.

The volcanic cone of Lower Old Red Sandstone times, which reared itself where Cheviot and Hedgehope Law now stand, has long since passed away. But the ceaseless action of denudation has laid bare for us the very heart and core, so to speak, of this ancient volcanic pile, with its surrounding accompaniment of associated dykes. And it is this which has made the Cheviot district unique amongst the volcanic areas belonging to the same geological period.

I am aware that the above account of the petrological phenomena and relations of these interesting rocks cannot profess to be complete, and that there are many questions still left unanswered. We can only hope that further research will throw

[1] *Geol. Mag.* (1885), p. 118.

[2] Q.J.G.S., vol. xlviii. p. 87; also "Ancient Volcanoes of Great Britain," vol. i. p. 338.

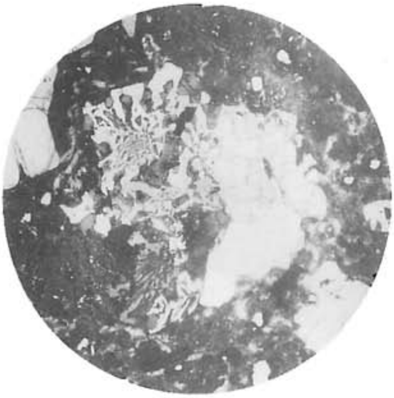

Fig. 1.

Fig. 2.

Fig. 3.

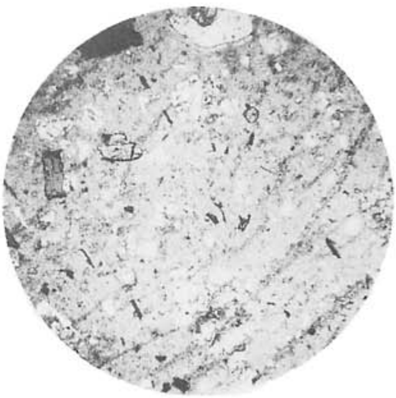

Fig. 4.

Photo-Micro.—H. Kynaston.

more light on many of the interesting problems connected with volcanic areas, and we feel sure that in this branch of geology there is still a very wide field of investigation for the comparative petrologist.

EXPLANATION OF MAP.

Lower O. R. S.	*G*—Granite.
	A—Andesite.
	Ts—Tuffs.
	P—Porphyrite (dykes and sills).
	F—Quartz-Felsite.
	$d^{1\text{-}8}$—Carboniferous.

EXPLANATION OF PLATE.

FIG. 1. Phenocryst of micropegmatite in Rhyolite, from Schemnitz, Hungary.

FIG. 2. Phenocryst of micropegmatite in Quartz-Felsite, from R. Breamish, Cheviots.

FIG. 3. Phenocryst of micropegmatite in Quartz-Felsite, from R. Breamish, Cheviots.

FIG. 4. Section of Porphyrite, with phenocrysts of plagioclase, biotite, augite, enstatite, and micropegmatite, from Dunmoor Hill, Cheviots.