claim them as Silurian. At present the disproof of the "*visible ascending succession*" of the Murchisonian party is a brilliant triumph for the Nicolites. But the truth lies, I cannot help believing, between the two views. If I can prove my case, we shall find:—

(1) That there is no recognizable chronological sequence (or invariable succession of superposition) in the metamorphic Highland area corresponding to that among the sedimentary formations (for the planes dividing the truly metamorphic layers are not planes of deposition, but planes of shearing and cleavage).

(2) Many of its (the Highland) schists are composed of Archæan materials (rocks), which have received their present pseudo-bedded arrangement since Ordovician times.

(3) What proportion of its schists and gneisses is composed of Archæan, sedimentary, or intrusive materials respectively is in all probability an insoluble question.

(4) Its *gneisses* may be either Archæan or (some) possibly formed by intrusion (injection of plutonic rocks) in later ages.

(5) Its *schists* may be composed either of crushed *Archæans*, crushed *intrusives*, or of a mixture of these with sedimentaries.

(6) Its (so-called) *slates* may be (according to the locality, either normal slates or) crushed rocks not yet crystallized (and) of either Archæan, sedimentary, intrusive, or of mixed origin.

II.—ON SOME QUARTZ-FELSITES AND AUGITE-GRANITES FROM THE CHEVIOT DISTRICT.

By J. J. HARRIS TEALL, M.A., F.G.S.

IN previous communications to the GEOLOGICAL MAGAZINE¹ I have described at some length the petrographical characters of the lavas and tuffs of the Cheviot District. It was proved that they are, at any rate for the most part, of an andesitic character, and that some of them are so little altered as to be thoroughly entitled to the term andesite, unless we are prepared to adopt the unphilosophical system of making geological age, *per se*, a factor in petrographical nomenclature. If we leave out of account the modifications in structure and composition which have been superinduced on the rocks by the various agents of change, then the Cheviot lavas and tuffs belong to the three fairly well characterized groups of the augite-, hypersthene-, and mica-andesites.

It is interesting to note that pumice and ash having essentially the same chemical and mineralogical composition as the Cheviot hypersthene-andesite was erupted in immense quantities by the volcano of Krakatoa in the autumn of last year: a fact which testifies in a striking manner to the uniformity in volcanic phenomena during immense periods of geological time.

In the present communication I propose to describe some intrusive rocks that occur in the Cheviot district. They belong to two well-marked groups—the quartz-felsites and the augite-biotite-granites.

¹ Notes on the Cheviot Andesites and Porphyrites, GEOL. MAG. 1883, pp. 100, 145, 252.

It is necessary to state that my visit to the Cheviots was made after the reading of a paper on the geological structure of the district at the Geological Society by Mr. Clough, at which I was present. I was guided to many of the localities mentioned in this communication by information obtained from that paper. I regret very much indeed that it has not yet been published. It deals with the mutual relations of the rocks referred to in the present communication, but so far as I can remember, it does not contain detailed petrographical descriptions.

THE QUARTZ-FELSITES.

I have observed these rocks in three localities in the porphyrite region; in the Ridlees Burn about $1\frac{1}{2}$ mile from its junction with the Coquet; in the Coquet itself about 1 mile above Shillmoor Farm; and in the Usway rather more than $\frac{1}{2}$ mile from its junction with the Coquet. In each case the rocks occur as dykes in the porphyrites, and they are well exposed in the actual banks of the several streams. There is no marked variation in the rocks from the different localities, and they may therefore be described collectively. In colour they vary from pale red to dull purple. In texture they are not conspicuously porphyritic, the individual crystals rarely exceeding a length of two mm. Examined with a hand lens the most conspicuous mineral is seen to be biotite, which is evenly scattered through the rock in the form of beautiful hexagonal tablets. Crystals of felspar, usually of the same colour as the ground-mass, but occasionally weathering white, may be recognized. Grains of quartz are also seen to be present, but their importance as constituents of the rock is not recognized until the thin sections are examined. The matrix presents the usual felsitic character.

Under the microscope the biotite is seen to be of a perfectly normal character. Its boundaries are intact; a fact which shows that in the case of this rock the magma exerted no corrosive action on the mineral. The only inclusions are apatite and magnetite. Quartz is the next mineral in importance. It usually occurs in irregular grains, but occasionally in the form of more or less regular crystals. It contains inlets and inclusions of the ground-mass, and sometimes the form of the grain is as irregular as the island of Celebes. The relation of the quartz to the ground-mass is therefore seen to be that which is so especially characteristic of the rhyolites. Mica occasionally occurs as an inclusion in the quartz. The feldspars are so similar in appearance to the ground-mass on account of the presence of irregular and ill-defined brownish flecks and scales (ferrite: *Vogelsang*) that they may sometimes be overlooked when examining the rock by ordinary light. Under polarized light they become at once apparent, and in the majority of cases may be identified as orthoclase, a conclusion which is confirmed by Mr. Waller's analysis (see p. 111). The ground-mass is perhaps the most interesting portion of the rock so far as microscopic characters are concerned. It presents several very interesting modifications; but before proceeding to describe these, it seems advisable to make a few general

remarks on the subject of the ground-mass of the quartz-porphyrries¹ in order that the terms employed may be clearly understood.

The characters of this ground-mass have been made the subject of elaborate researches by many observers, and the most diverse opinions have been expressed as to their true significance. The whole subject has been discussed by Rosenbusch, with his usual critical ability, in his work "*Die massige Gesteine*,"² and in the following communication I propose to adopt his terms.

In any attempt to acquire definite ideas as to the nature of this ground-mass, it is advisable to remember that there are in this, as in every branch of petrography, two more or less independent points of view; the descriptive and the ætiological. We may consider the actual characters of the ground-mass without reference to their origin, or we may attempt to form some notion of the manner in which they have been produced. From the first point of view two modifications of the ground-mass stand out as the antitheses of each other, and present no difficulty in the way of description. On the one hand we have an isotropic glass, and on the other an aggregate which is capable of resolution, either with a hand lens or with the microscope, into a congeries of perfectly definite crystalline grains. The terms vitrophyre and granophyre were proposed by Vogelsang³ to include those quartz-porphyrries in which the ground-mass is present in one or other of these forms. Rosenbusch,⁴ however, has shown that the granophyres of Vogelsang may be subdivided into two groups, to which he proposes to apply the terms micro-granite and granophyre. The rocks of these two groups are distinguished from each other by the mutual relations of the crystalline constituents of the ground-mass. In micro-granites these constituents are related to each other in the same way as the constituents of granite or granulite. They consist of crystalline grains, mostly of felspar and quartz, which are arranged without any regularity. In granophyres, on the other hand, the quartz and felspar are intergrown according to more or less definite laws, so that definite structures, such as micro-pegmatite, may be recognized in these rocks. One special type of structure which is frequently present in these rocks, and is often seen in association with the true micropegmatite, is termed by Rosenbusch pseudo-spherulitic. True spherulites, according to him, are composed of crystalline fibres of one and the same substance, all radiating from a common centre, and having an axis of elasticity parallel with the length of the fibre. They are therefore characterized under the microscope with crossed Nicols by a perfectly definite four-armed cross, the arms of which lie parallel with the vibration planes of the Nicols, and remain stationary as the stage is rotated. The spherulitic structures of the granophyres are, however, composed of quartz and felspar, so that the axes of elasticity in the

¹ It must be remembered that the terms quartz-porphyr and quartz-felsite are not synonymous. The former term is the more comprehensive, as it includes such rocks as the porphyritic pitchstones (*Vitrophyr* of Vogelsang).

² Page 60.

³ *Die Krystalliten*, Bonn, 1875, p. 160.

⁴ *Zusammensetzung und Structur granitischer Gesteine*, Z.D.G.G. 1876, p. 369.

different elements of the spherulite may have different positions in relation to the spherulite as a whole. Under crossed Nicols such a structure may give rise to more or fewer arms than the number characteristic of true spherulites, and these arms may not lie parallel to the vibration planes of the Nicols. Such structures, wherever they may occur, Professor Rosenbusch proposes to call pseudo-spherulites.

The granophyres, then, are distinguished by the presence of a micro-pegmatitic, pseudo-spherulitic or some allied structure in the ground-mass; whereas the ground-mass of the micro-granites is an irregular aggregate of crystalline grains. Rosenbusch also uses the adjective granophyric to express the various modifications of structure which occur in the ground-mass of the granophyres. It is somewhat unfortunate that the term granophyre should have been used in two senses, but no confusion will arise if we remember that the granophyre of Vogelsang comprises the micro-granite as well as the granophyre of Rosenbusch. It is always advisable in describing rocks and rock-structures to refer to typical examples. The rock from the summit of Carrock Fell, Cumberland, which was well described by Ward¹ as a spherulitic felsite, is a most beautiful granophyre, as that term is employed by Rosenbusch. The ground-mass sometimes shows the micro-pegmatitic structure only, and sometimes the pseudo-spherulitic; the two structures often co-exist and together they produce the granophyric structure of Rosenbusch. This rock is also interesting on account of the presence of well-formed crystals of a monoclinic pyroxene. It is identical with the granophyre² of the Fontaine Laquainte, Kirneckthal, Dep. des Vosges, which occurs as a dyke in the andalusit-hornfels of that district.

Between the micro-granites and granophyres on the one hand, and the vitrophyres on the other, we have a group of rocks (the felsophyres of Vogelsang) about which the most diverse opinions have been held. It is with reference to these that the terms micro-felsite and crypto-crystalline have been used. They can be defined only by employing negative characters. Their ground-mass is neither a true glass nor a recognizable aggregate of crystalline grains. When examined under polarized light, it may or may not appear perfectly isotropic. If isotropic, it is distinguished from a glass by the fact that it appears to be composed of ill-defined flecks, scales, fibres, and granules. To this Rosenbusch proposes to restrict the term micro-felsite, and there is no doubt that if this proposition be generally accepted, it will tend to facilitate very greatly the precise description of rocks of this class. If not isotropic, then it is distinguished from the micro-crystalline ground-mass by the apparent absence of definite boundaries to the doubly refracting particles. The term crypto-crystalline is applied to this structure.

Now in dealing with this crypto-crystalline ground-mass, we experience precisely the same difficulties as those experienced by the older petrographers in dealing with the felsitic base. The introduction of the microscope has not removed the difficulties; it has only

¹ Q. J. G. S. vol. xxxii. p. 20.

² Die Steiger Schiefer, p. 345.

pushed them a little further back. Let us endeavour to take stock of our present position in relation to this subject.

In discussing the question it is necessary to remember that the microscope does not enable us to approach the limits of the molecular world. There is room for a universe of phenomena, so to speak, between the limit of microscopic visibility and that of molecular structure. Hence, many structures and modes of association in minerals which we observe macroscopically and microscopically, as well as others which we cannot observe, may exist in this ultra-microscopic universe. Now many rocks which show a crypto-crystalline structure, when examined in thick sections and with low powers, may be resolved, by reducing the thickness of the sections and by using higher powers, either into a micro-crystalline aggregate or into doubly refracting particles, and a glassy or micro-felsitic base. If the doubly refracting particles are small in comparison with the thickness of the slide, then, owing to their superposition, they will give rise to the indefinite aspect under crossed Nicols which is the special characteristic of crypto-crystalline matter.

These considerations lead us, therefore, to the conclusion that the term crypto-crystalline includes different things and is useful merely for the purpose of expressing our ignorance as to the precise condition of the matter to which it is applied. It is an expression which is rendered necessary in consequence of imperfection in our methods of observation, and does not correspond with anything definite in the nature of things. It is a subjective and not an objective term, and one that we must therefore use for the purpose of expressing our ignorance, and not for the purpose of concealing it. In concluding this discussion it is well to remark that the felsophyres, granophyres, and micro-granites cannot be distinguished from each other by macroscopic examination. All that we can do in the field is to separate the quartz-porphyrries with a vitreous from those with a felsitic ground-mass. The former may be termed vitrophyres, while for the latter our own term, quartz-felsite, is very appropriate.

If we consider the porphyry ground-mass from the ætiological point of view, then we have to recognize the fact that the micro- and crypto-crystalline ground-masses may owe their double refraction either to crystallization at the time of consolidation or to the subsequent devitrification of an original glassy substance. Perlitic structure, so far as we know, can only arise during the consolidation of a glass, and we may therefore fairly conclude with Mr. Allport¹ and others that rocks which show this structure were originally in the glassy condition. In many cases, however, a perlitic rock will split up under crossed Nicols into a micro-crystalline aggregate. So far as I know, we have at present, in the absence of perlitic or some other structure equally characteristic of a glass, no test by which we can distinguish an original micro- or crypto-crystalline ground-mass from one which has been produced by subsequent devitrification. Here again we have to make a confession of ignorance.

If we look at the quartz-porphyrries in their relations to other

¹ On Devitrified Pitchstones and Perlites of Shropshire, Q.J.G.S. vol. xxxiii. p. 449.

rocks, we see that they shade off on the one side into rhyolites, and on the other into granites. As a whole, they occupy the same position in the acid series as the diabases and dolerites in the basic series; they are intermediate between the volcanic and the plutonic rocks, but without well-defined limits.

The subdivisions as well as the general relations of the quartz-porphyrries may be expressed as follows :

<i>Volcanic.</i>	RHYOLITE.		
<i>Intermediate.</i>	QUARTZ- PORPHYRY	{ Vitrophyre { Quartz-felsite	{ Felsophyre. { Granophyre. { Micro-granite.
<i>Plutonic.</i>	CERTAIN GRANITES.		

I now proceed to give a description of the ground-mass of the Cheviot quartz-felsites. Examined by ordinary light it never presents the appearance of a true glass. Ill-defined specks, flecks, fibres, and scales of a brownish substance (ferrite), are everywhere present and lie superposed over each other in the thinnest sections. As a rule these are scattered uniformly throughout the substance of the ground-mass, but in some instances they give rise to small spherical aggregates exactly as in certain rhyolites from Hungary and the Ponza Islands. Under crossed Nicols the ground-mass is seen to be micro- or crypto-crystalline; no portion appears to remain dark under crossed Nicols. In one case a very interesting structure occurs. The ground-mass presents a perfectly normal appearance when examined by ordinary light, but under crossed Nicols it splits up into a coarse-grained crystalline aggregate. The boundaries of the different doubly-refracting grains are perfectly irregular, and are not recognizable by ordinary light. Every quartz crystal in the rock forms the nucleus of one of these grains, so that the space surrounding it extinguishes simultaneously with the crystal itself. This fact seems to show that the substance which has determined the definite optical characters of the ground-mass is quartz, although other substances must be present in considerable quantity. I incline to the view that we have here a case of true devitrification; but as there are no structures especially characteristic of glass, it seems impossible to be certain on this point.

In some slides the pseudo-spherulitic structure may be detected in places, and this may be taken as indicating an approach to the granophyric structure of Rosenbusch.

Mr. Waller kindly analyzed a specimen from a point in the Coquet about $\frac{1}{2}$ mile above Shillmoor Farm, with the following result :

[illegible]

100·3

In addition to the quartz-felsites above described, there are others in the granitic region; but as these, at any rate in places, appear to me to be of the nature of contemporaneous veins, I will refer to such as I have observed in describing the granitic rocks.

THE AUGITE-BIOTITE-GRANITE.

It has long been known that in the sparsely populated but by no means inhospitable recesses of the Cheviot Hills extensive tracts of granitic rocks occur. The precise relations of these rocks to the porphyrites have not yet been described, and we must wait until the Survey Maps and publications are out before we can obtain detailed information on this subject. My own knowledge of these rocks, as they occur in the field, was obtained during two short excursions; one to Linhope Spout, the other involving a walk from Usway Ford round the head-waters of the Breamish, by Staindrop Rigg and Hedgehope, to Langley Ford in the valley of the Harthope Burn. As it was necessary to get from Usway Ford to Wooler in one day, there was no time available for a search for junctions, and I had to content myself with collecting specimens of such rocks as came in my way.

The principal interest attaching to these rocks centres in the fact that they present us with a type hitherto unknown in Britain, and by no means widely recognized in other parts of the world. They are true augite-bearing granites similar in all essential respects to the augite-granite of Laveline in the Vosges, described by Rosenbusch,¹ and that of Oberbruck also in the Vosges, described by Cohen.² Prof. Rosenbusch has seen my specimens, and agrees with me in my determination; he has also very kindly supplied me with specimens of the rocks from Laveline and Oberbruck.

As the augite is the most interesting constituent, I will describe it before proceeding to refer to the rocks in which it occurs. It is present in the form of irregular grains, granular aggregates, and sometimes, though rarely, in more or less definite crystals. It is almost colourless in thin section, exhibiting only a slight inclination to a pale green tint. Inclusions of magnetite are not uncommon. Cross sections show the characteristic cleavages of augite, and longitudinal sections give a maximum extinction of 43° or 44°. Twinning may occasionally be observed. Alteration tends to develop serpentinous and not chloritic products, and the separation of iron-oxide appears to accompany the change. In appearance the mineral is identical with the augite of the Vosges rocks above referred to, and we may safely conclude that it has an analogous composition.

Dr. Alphonse Merian³ has recently isolated and analyzed the augite of the Laveline rock, and he finds that it possesses the following composition:—

¹ Z. D. G. G. 1876, p. 369.

² Neues Jahr. 1883, vol. i. p. 200.

³ Studien an gesteinsbildenden Pyroxenen. Neues Jahrbuch III. Beilage Band, p. 262.

SiO ₂	...	...	...	...	...	...	...	...	50.63 _d °
Al ₂ O ₃	...	...	...	...	...	...	...	...	.87
Fe ₂ O ₃	...	...	...	...	...	...	...	...	3.33
FeO	...	...	...	...	...	...	...	...	8.39
MgO	...	...	...	...	...	...	...	...	13.01
CaO	...	...	...	...	...	...	...	...	21.30
Na ₂ O	...	...	...	...	...	...	...	...	1.02
K ₂ O	...	...	...	...	...	...	...	...	.50
TiO ₂	...	...	...	...	...	...	...	...	.79

99.84

Sp. Gr. 3.372.

It is therefore a non-aluminous iron-bearing augite of the diopside type allied to the augite of the augite-syenites. The tendency of the mineral to pass into serpentinous rather than chloritic alteration products is of course due to the absence of alumina.

I now proceed to describe the rocks in which the above mineral occurs. They are usually coarse-grained, holocrystalline, non-porphyrific rocks, which vary considerably in aspect and in the relative proportions of the different constituents. Some of the varieties are dark and syenitic-looking; others resemble a grey or pink granite of normal aspect. Owing to the variability of the rocks, it will be advisable to describe the special types which have been examined.

Linhope Burn, $\frac{1}{2}$ mile above *Linhope Farm*.—A dark-coloured syenitic-looking variety, composed of orthoclase, plagioclase, with low extinction angles, quartz, augite, biotite, magnetite, apatite and serpentinous alteration products. Felspars of both kinds very abundant. Augite well represented. Quartz in moderate quantity.

Linhope Spout.—In the immediate neighbourhood of the waterfall several very interesting rocks may be observed. The augite-granite is here traversed by dykes and veins of quartz-felsite, which sometimes show under the microscope the micro-granitic, at other times the granophyric structures. These two structures often co-exist in the same slide, but as a rule one or other predominates. Biotite and augite are occasionally present, but the latter mineral is decidedly rare. I incline to the view that these are of the nature of contemporaneous veins, and if so, a very interesting conclusion, which will be referred to later on, may be drawn from this fact. They are evidently more acid in composition than the normal rock. The augite-granite of *Linhope Spout* is a coarse-grained rock, in which flesh-coloured orthoclase, light-coloured plagioclase, biotite and a dark green mineral (the augite) may be recognized by macroscopic examination. Under the microscope quartz is seen to occur abundantly, the augite may be identified, and magnetite and apatite may be recognized. One very interesting feature is the tendency of the quartz and felspar to form micro-pegmatite. This is also noticeable in the augite-granites of the Vosges, and it may therefore be regarded as a characteristic feature of this class of rocks.

Staindrop Rigg.—On the high ground between the *Het Burn* and *Staindrop Burn* there are two conspicuous craggy bosses of a greyish granite. These form *Staindrop Rigg*. A similar rock occurs low

down to the S.E. of this exposure, so that in all probability it forms an extensive tract in this district. Examination with a hand lens enables one to recognize easily a pink potash felspar, a light-coloured almost white plagioclase, biotite and quartz. The felspars sometimes measure $\frac{1}{2}$ of an inch across, and so give the rock a slight porphyritic aspect. They may be easily isolated and examined by Szabo's method. I give below the results of my own examination of these felspars and also those obtained by myself and Dr. Szabo on some typical felspars.

EXAMINATION OF FELSPARS BY SZABO'S METHOD.

	1st Experiment.			2nd Experiment.			3rd Experiment.	
	Na ₂ O 1—5	K ₂ O 1—3	Fusibility. 1—4	Na ₂ O 1—5	K ₂ O 1—3	Fusibility. 1—5	Na ₂ O 1—5	K ₂ O 1—4
A (T)	4—5	0	3—4	4—5	0	4—5	5	1—2
B (S)	4—5	0	3—4	4—5	0	4—5	4—5	1—2
C (S)	3—4	0	2—4	3—4	0	3—5	3—4	1—2
D (T)	3	0	2—3	4	0	4	4—5	1
E (T)	4	0	2—3	4—5	0	4	5	1
F (T)	3	2	2—3	3	2—3	4	4	3
G (S)	3—4	2	2	3—4	2	4	3—4	3

A. Oligoclase Twedstrand (Teall).

B. Oligoclase (Szabo).

C. Andesine (Szabo).

D. Andesine, Seourie Dyke (Teall).

E. Plagioclase, granite, Staindrop Rigg (Teall).

F. Orthoclase, granite, Staindrop Rigg (Teall).

G. Perthite group (Szabo).

Mr. Waller, of Birmingham, appears to have been the first observer who applied Szabo's method to the practical determination of minerals in this country, and I am indebted to that gentleman for instruction in the working of the method. There is no doubt that it is a quick and reliable method for obtaining very valuable information as to the nature of the constituents of rocks. The above experiments prove clearly that the plagioclase belongs to the oligoclase-andesine group and the potash felspar to the perthite group of Szabo; a group which is characterized by the presence of from 4 to 6 per cent. of soda.¹

The two felspars occur in about equal proportions in the rock from Staindrop Rigg. Augite and magnetite may be recognized under the microscope, but they are far less abundant than in the syenitic-looking varieties from Linhope Spout. Quartz on the other hand is more abundant. The microstructure of the rock is thoroughly granitic. Narrow contemporaneous veins of quartz and felspar with

¹ It is interesting to note that the augite-syenites and their porphyritic equivalents of the Christiania district contain felspar rich in soda which appears to be sometimes monoclinic and sometimes triclinic, with a cleavage angle differing but slightly from 90°. Brögger has described these two forms in great detail (Die Silurischen Etagen 2 und 3, p. 203, et seq.). He names them soda-orthoclase and soda-microcline.

very little biotite may be observed in the mass of the rock at Staindrop Rigg.

Comb Fell.—I collected several specimens from the western side of Comb Fell. They are all varieties of a pinkish biotite granite, in which orthoclase appears to be the dominant felspar. Augite is present only in very small quantity.

Hedgehope.—This mountain is largely if not entirely composed of granite. Specimens from the eastern side are similar in character to those from Staindrop and therefore require no special description.

In taking a general view of the holocrystalline granitic rocks of the Cheviot District one fact stands out in a prominent manner. They are by no means uniform in composition. Some are rich in basic minerals, others are comparatively poor; some contain plagioclase, others a soda-orthoclase, as the dominating felspar. The different varieties do not appear to be in all cases sharply separated from each other. A possible explanation of this variability will be referred to later on.

COMPARISON OF THE CHEVIOT AUGITE-GRANITES WITH ALLIED ROCKS OF OTHER DISTRICTS.

The occurrence of augite rocks containing quartz and orthoclase is such a striking violation of one of Breithaupt's laws of paragenesis as to give these Cheviot granites a special interest.

This occurrence was first recognized according to Rosenbusch¹ by Vom Rath in the case of a quartz-porphyrity from Campiglia (Tuscany), which contains orthoclase, plagioclase, augite, magnetite, mica, and quartz. In North Saxony, near Leipzig, there is an extensive development of augite-bearing quartz-porphyrities. These rocks have been investigated by Tschermak, Naumann, Kalkowsky, Rosenbusch, and Penck. They are classed with the upper portion of the middle Rothliegende by the last-mentioned author.² Rosenbusch³ has identified a rhombic as well as a monoclinic pyroxene in these rocks, and I may mention that in one case I observed in a Cheviot granite a mineral that was most probably enstatite or bronzite.

Then again there are the remarkable pyroxene-granulites of the granulitic region of Tuscany which have been described by Stelzner,⁴ Dathe,⁵ and Lehmann.⁶ These have been divided by Dathe into orthoclase- and plagioclase-diabase-granulites, according to the nature of the dominant felspar. They contain monoclinic and rhombic pyroxenes, and in this respect resemble the quartz-porphyrities of North Saxony. Until recently they have always been regarded as Archæan, but the work of Dr. Lehmann has destroyed much of the evidence on which this conclusion was based.

In the same connexion we must mention the quartz-less augite-syenites of Monzoni, described by Vom Rath,⁷ and those of Norway

¹ *Massige Gesteine*, p. 58.

² *Die pyroxen-führenden Gesteine des nord-sächsischen Porphyrygebietes*, Min. Mitth. 1881, p. 72.

³ *Massige Gesteine*, p. 58.

⁴ *Neues Jahr.* 1871, p. 246.

⁵ *Z. D. G. G.* 1877, p. 285.

⁶ *Die Entstehung der alt-krystallinischen Schiefer-gesteine*, p. 228.

⁷ *Z. D. G. G.* 1875, 343-357.

described by many observers, but especially by Brögger.¹ The orthoclase in these rocks, like that of the Cheviot granites, is rich in soda. The augite-granites of the Vosges have been already referred to, and as they are very closely related to the Cheviot rocks, it is necessary to quote their analyses.

	I.	II.
SiO ₂	61.93	62.09
TiO ₂	—	.56
Al ₂ O ₃	13.18	16.43
Fe ₂ O ₃	3.63	2.34
FeO	2.31	2.03
CaO	3.48	2.32
MgO	4.59	3.08
Na ₂ O	2.67	4.07
K ₂ O	6.11	4.66
H ₂ O	1.14	.85
	99.04	98.43

I.² Augite-Granite from Laveline. Sp. Gr. 2.723.
 II.³ Augite-granite from Oberbruck. Analyses by Werveke.

Rosenbusch⁴ has also recognized fresh pyroxene in the Vosges, porphyries of Etival, Rothau, Rochesson, and in a rock which is sometimes a quartz-porphry and sometimes a granite from the Titisee in the Schwarzwald. He remarks that the mineral is absent as a rule from massive granites, but that he has observed it abundantly in one case, viz. that of a rock from the Julier Pass.

MUTUAL RELATIONS OF THE IGNEOUS ROCKS OF THE CHEVIOT DISTRICT.

The facts, so far as they are known at present, appear to show that the first period of volcanic activity in this district was marked by the eruption of immense quantities of andesitic lava and tuff.

The andesites fall into three groups, characterized respectively by the minerals hypersthene (bronze), augite, and mica. Most of them are now much altered, and to these altered forms I have restricted the term porphyrite. The presence of tuffs, vesicular and amygdaloidal varieties of lava, and actual evidences of flow, proves that the conditions of eruption were substantially identical with those of modern times.

The eruption of andesitic material was followed by the intrusion of quartz-felsite dykes. If the magma which produced these dykes ever reached the surface, it must unquestionably have formed rhyolites and rhyolitic tuffs. Do such rocks occur anywhere in the Cheviot District? The dykes of quartz-felsite occur in the porphyrite region, so that we have conclusive evidence to show that the eruption of acid followed that of andesitic material in the history of the Cheviot Old Red Sandstone volcanoes.

The intrusion of quartz-felsite appears to have been the concluding phase of the volcanic activity of Old Red Sandstone times; for such dykes as those of Acklinton, which cut the Carbon-

¹ Die silurischen Etagen 2 und 3.

² Studien an gesteinsbildenden Pyroxenen, Merian.

³ Neues Jahr. 1883. I. 201.

⁴ Z.D.G.G. 1876, p. 369.

iferous rocks of North Northumberland as well as the igneous rocks of the Cheviot district, and are intermediate in composition between basalts and andesites, may be referred with a considerable amount of confidence to the Tertiary period.

In the present communication it has been shown that the district about Hedgehope, Comb Fell, Staindrop and Linhope Spout is occupied by holocrystalline, non-porphyrific rocks of the plutonic type. Are these rocks due to the consolidation, beneath the surface, of the magma which produced the andesitic lavas and tuffs? Do they occupy the same position in relation to the Cheviot lavas as the gabbros and granites of Mull do to the lavas of Mull according to Prof. Judd? 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 questions.

The augite-granites are evidently not characterized by a high percentage of silica. Some of them strongly resemble syenites in appearance; but as quartz is present in all my specimens, the term syenite cannot be applied to any of them. True augite-syenites may of course occur in the district, as my observations were necessarily of a very limited character. The analyses of the Vosges augite-granites show that these rocks belong to the intermediate, rather than to the acid class; and that the bases, if we except the alkalis, are present in approximately the same relative proportions as in the Cheviot lavas. With regard to the alkalis, I would remark that we have no analyses of the Cheviot plutonic rocks; but it is certain that the orthoclase is rich in soda, and that plagioclase of the oligoclase-andesine type is sometimes present in greater quantity than the orthoclase. I have little doubt that in some of the plutonic rocks the relative proportions of the two alkalis is the same as in the normal andesites. Again, Mr. Waller's analysis of a porphyrite from Shillmoor¹ shows an excess of potash over soda.

There is another point in connexion with the volcanic history of the Cheviot district in Old Red Sandstone times which seems worthy of special attention. Why did the quartz-felsites succeed the andesites?

One of the most fascinating problems of geology is to account for the variation in the composition of the material erupted at different periods in the volcanic history of a district. Now in considering the possible causes of this variation careful attention should be paid to the changes brought about in the composition of a magma by the successive crystallization of different constituents.

Information on this subject may be obtained in at least three different ways: (1) by observing the order in which minerals have crystallized in different magmas; (2) by examining the chemical and mineralogical composition of the ground-masses of porphyritic rocks; (3) by examining the so-called contemporaneous veins which are especially characteristic of plutonic rocks.

Prof. Rosenbusch² and others have shown that as a general rule

¹ *GEOL. MAG.* Dec. II. Vol. X. p. 151.

² *Neues Jahr.* 1882, ii. p. 1.

the minerals separate out in the order of their basicity; the more basic minerals, or those which do not contain silica, being the first to form. This being admitted, we see at once that the tendency of the progressive crystallization must be to render the magma more and more acid.

Dr. Petersen has isolated and analyzed the glassy base of the Cheviot hypersthene-andesite and the devitrified base of a porphyrite from Allerhope Burn. His analyses appear to me to have such an important bearing on the sequence of volcanic phenomena in the Cheviot district that I quote them below, together with two analyses of the Cheviot lavas.

They show that the ground-mass is richer in silica and alkalis, and that the ratio of potash to soda is much greater in the ground-mass than in the rock as a whole.

	I.	II.	III.	IV.
SiO ₂ ...	66·25	65·16	61·17	59·05
Al ₂ O ₃ ...	13·59	17·49	16·87	15·69
Fe ₂ O ₃ ...	3·11	3·01	2·10	1·80
FeO ...	—	—	2·94	4·72
CaO ...	2·75	0·84	4·86	1·79
MgO ...	·28	2·34	3·00	4·29
K ₂ O ...	4·95	5·54	1·81	2·88
Na ₂ O ...	2·25	3·68	2·67	3·97
H ₂ O ...	5·89	1·76	3·09	3·16
	<hr/> 99·07	<hr/> 99·82	<hr/> 98·51	<hr/> 97·35
Sp.Gr.	2·437	2·640	2·543	

I. Glassy base. Hypersthene-andesite.

II. Devitrified base. Porphyrite. Allerhope Burn.

III. Hypersthene-andesite. Carhope on Coquet.

IV. Porphyrite, $\frac{1}{4}$ mile above Shillmoor Farm.

Mr. Stock¹ has shown that the ground-mass of the Cockfield dyke is also richer in silica than the normal rock. Mr. Waller, of Birmingham, has recently investigated certain contemporaneous veins in the bronzite-dabase of Penmaenmawr. He finds that they contain $6\frac{1}{4}$ per cent.² more silica than the rock in which they occur, and that potash is present in excess of soda, whereas the reverse relation holds in the rock itself. These veins then bear precisely the same relation to the parent rock as the ground-mass of the Cheviot andesite does to the mass of the andesite.

There are veins in the Rowley Rag basalt, also described by Mr. Waller, which contain 9 per cent. more silica than the rock, and possess as much as 11 per cent. of alkalis.

From these and other facts which need not be here enumerated, we may safely draw the general conclusion that the effect of pro-

¹ North of England Dykes, Q.J.G.S. 1884, p. 225.

² Midland Naturalist, 1885, p. 6. Compare the concretionary (?) patches (*e.g.* certain inclusions in granite described by Mr. Phillips. Q.J.G.S., vol. xxxvi. p. 1, and the nodules of peridotite in basalt) with the so-called contemporaneous veins. The former are as a rule more basic, the latter more acid than the normal rock. The former may represent the earliest, the latter certainly represent in many cases the latest products of consolidation of an originally homogeneous magma.

gressive crystallization is to increase the percentage of silica and alkalis, to increase the potash relatively to the soda, and to diminish the lime, iron, and magnesia in the liquid magma. Rocks of rhyolitic composition may represent, so to speak, the mother-liquor out of which the basic minerals have crystallized.

Suppose, now, that the crystallization occurs under conditions which admit of the mechanical separation by gravity of the crystals and the magma in which they are formed. This would give rise to some very interesting results.¹

Consider the case of an internal reservoir of molten-rock, and for the sake of simplicity, suppose the conditions of crystallization to be realized in the upper portion. The basic minerals will form and then fall by reason of their high specific gravity.² On descending to lower levels, they may be dissolved, and thus a variation in the composition of the originally homogeneous magma may be produced. Diffusion will tend to restore homogeneity; but the above cause, operating in the contrary direction, may be the more potent of the two, and if so, a permanent difference in composition will be established. When final consolidation occurs, a mass will be produced which will vary in composition from top to bottom; the most acid portion occurring in the former, the most basic in the latter position. In the Cheviot district the augite granites vary considerably in composition and different varieties sometimes appear to shade into each other. The same feature may be observed in rocks which I cannot but regard as igneous, in the Carrock Fell region in Cumberland. The highly basic gabbros of Mosedale Crags appear to shade into the

¹ Separation may be effected without gravity. Suppose a half-consolidated plutonic mass to become subject to the lateral thrust of which there is such striking evidence in certain districts. The mother-liquor may be squeezed out of the rock as water out of a sponge. In this way contemporaneous veins might be produced in the plutonic rock, dykes in the surrounding rock, and lavas at the surface.

² The subject of the separation of crystals in a molten magma has been discussed by many writers. It is important to notice that it must occur if there be any difference between the specific gravity of the crystals and that of the magma in which they exist. The only question that can arise is as to the geological significance of the operation. Mr. Darwin deals with the subject in his *Geological Observations* (2nd edition, p. 132), where he describes certain phenomena in the Galapagos Islands which he attributes to this cause. He also quotes a statement from Von Buch that M. Drée found, on melting lava, that the felspars always tended to fall to the bottom of the crucible. The Pattison process for separating lead from silver is mentioned by Mr. Darwin, and it certainly has a very interesting bearing on the subject under consideration.

Again, Mr. Clarence King (*Systematic Geology*, p. 678) says: "During an eruption in the crater of Kilauea at the time of my visit, a fluid stream of basalt overflowed from the molten lake at the west end of the crater and poured eastward along the level floor of the pit. Numerous little branchlets spurted out from the sides of the flow and ran along the depressions of the basaltic floor, for a few feet and then congealed. I repeatedly broke these small branch streams and examined their section. In every case the bottom of the flow was thickly crowded with triclinic felspars and augites, while the whole upper part of the stream was of nearly pure isotropic and acid glass." The sinking of felspars in a basaltic magma strikes one at first sight as an impossibility; but the observations of Darwin and King and the experiments of M. Drée appear to prove the fact in a conclusive manner. We must infer, therefore, that the specific gravity of the molten magma is less than that of the felspars.

acid granophyres of the summit of the hill. Is it possible that these facts may be due to an action of the kind above referred to?

The point, however, to which I wish to direct special attention is this. The eruption of andesitic lavas and tuffs in the Cheviot district was followed by the intrusion of quartz-felsite dykes. The plutonic rocks of this district are traversed by veins of quartz-felsite. If these veins be of the nature of contemporaneous veins, as I believe them to be, at any rate in part, then they owe their special chemical characters to progressive crystallization in a magma of andesitic composition, and we may see in this a reason why quartz-felsites succeeded andesites in the history of the Cheviot volcanoes. This view receives strong confirmation from the fact that the ground-mass of the andesitic lavas is substantially identical in composition with the quartz-felsites; as will be seen at once by comparing the two analyses by Dr. Petersen with the analysis of the quartz-felsite by Mr. Waller, which is given in the earlier part of this paper.

If we compare the history of volcanic action in the Cheviots with that of other districts, we are struck by many points of resemblance. The succession, andesite, trachyte, rhyolite, is common to many volcanic regions, including Hungary, the Lipari Islands, and North America.¹

The sequence of volcanic rocks is, however, usually complicated by the introduction of basalt during the later phases of volcanic activity, a fact which shows that the view adopted for the purpose of explaining the volcanic sequence in the Cheviot district is not in itself sufficient to cover all cases. Doubtless, as Captain Dutton has pointed out, many factors are involved in the determination of the sequence.

The phenomena of the Lipari Islands, so admirably described by Prof. Judd,² furnish a very interesting case. The first period of activity in this region appears to have been characterized by the eruption of andesitic material. Then, as time went on, the products diverged, as far as composition is concerned, in opposite directions, and in modern times we see Stromboli erupting basic and Vulcano acid material. The sequence can be explained if we regard the products of Vulcano as formed from the mother-liquor and those of Stromboli as resulting from the refusion of the basic minerals which have separated out of it.

There is one interesting point, almost of the nature of a paradox, to which attention has frequently been directed, but which it seems advisable to refer to in connexion with the present subject. The fusion point of basic rocks is lower than that of acid rocks, and yet minerals separate out as a general rule in the order of their basicity, the more basic being the first to form. How is this to be explained?

¹ Propylite, the rock which has long been supposed to mark the first period of volcanic action in Tertiary times, has been shown by the recent work of Dr. Becker (Geology of the Comstock Lode) to comprise, in America, altered forms of well-known rocks, especially andesite, and a similar conclusion had been previously arrived at by Dr. Wadsworth.

² GEOL. MAG., 1875.

A complete and satisfactory answer to this question remains to be discovered; but there are one or two facts of great significance which bear upon it. In the first place, we notice that there is no connexion between the temperature at which a mineral separates from a magma in which its constituents are held in solution, and its own fusibility further than this—that no mineral can form at a higher temperature than its own fusing point. Graphite, one of the most infusible substances, crystallizes out of molten iron. Quartz must constantly form at a point far below that of its own fusibility. Then, again, there is the great question, first brought into prominence by Scrope, as to the influence of water in determining the liquidity of lavas. Dr. Petersen has shown that the glassy base of the Cheviot hypersthene-andesite is rich in water; the devitrified base, on the other hand, is poor in water.

The whole subject discussed in the last part of this paper is one of great interest; but we must be content to wait for a further accumulation of facts before a perfectly definite judgment can be formed. To those who collect and arrange these facts so as to remove the subject from the region of controversy will belong the chief merit of discovery.

III.—CONTRIBUTIONS TO THE PALÆONTOLOGY OF THE YORKSHIRE OOLITES.

By WILFRID H. HUDLESTON, M.A., F.R.S., F.G.S.

(Continued from Decade III. Vol. II. p. 59.)

(PLATE III.)

74.—TROCHUS MONILITECTUS, Phillips, 1829. Plate III. Figs. 1, 1a, 1b.

1829 and 1835. *Trochus monilitectus*, Bean; Phillips, G.Y., p. 123 (p. 165 as *T. moniliferus*, P.), pl. ix. fig. 33.

1849. *T. monilitectus*, Phil.; D'Orbigny, Prod. p. 265. Ét. Bajoc.

1854. *Ibid.* Phil.; Morr. Cat., p. 281.

1875. *Ibid.* Bean; Phillips, G.Y., 3rd ed. p. 259, pl. ix. fig. 33.

Bibliography, etc.—This somewhat insignificant fossil approaches several of the small granulated or tuberculated species of *Trochus* (or *Monodonta*), which are distinguished by a completely conical outline, resulting from a close suture and perfect flatness of the whorls. Although without description, Phillips's figure is characteristic, and it is somewhat singular that this species was not recognized by D'Orbigny amongst the fossils of the French Jurassic. The typical form is confined, in Yorkshire, so far as I know, to the Scarborough Limestone (zone 3), where it is rare, and, for the most part, so imperfectly preserved, that accurate description is a matter of some difficulty.

A single specimen referred to *T. monilitectus* from the Cornbrash of Scarborough is in the Leckenby Collection. It presents certain differences of ornamentation, and will be described as var. B. To recognize a distinct species founded on a single specimen would be imprudent, when the differences are not great. Should more specimens