13. *On INCLUSIONS of TERTIARY GRANITE in the GABBRO of the CUILLIN HILLS, Skye; and on the PRODUCTS resulting from the PARTIAL FUSION of the ACID by the BASIC ROCK.* By JOHN W. JUDD, F.R.S., V.P.G.S., Professor of Geology in the Royal College of Science, London. (Read January 25th, 1893.)

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1. THE LITERATURE OF INCLUSIONS IN IGNEOUS ROCKS.

THE striking results of extreme contact-metamorphism, displayed by fragments of rock which have lain for a time in the bath of a molten igneous magma, have been frequently described by geologists and petrographers. Among sedimentary materials which have been thus acted upon, we may refer to the more or less perfectly vitrified products formed from arenaceous rocks (*verglaster sandstein*); the greatly altered and highly crystallized forms of argillaceous masses—so often mistaken for basalts, before the application of the microscope to their study—(*jaspisschiefer*, *kieselschiefer*, ‘phthanite, lydite, hydrotachylyte,’ etc. of different authors); and the calcareous or dolomitic rocks, so wonderfully rich in beautifully crystallized minerals that have resulted from the action of molten lavas or fragments of limestone entangled in them. Such extreme results of contact-metamorphism may be studied, either in the localities where the operations have taken place, as at Monzoni in the Tyrol;¹ or among the fragments thrown out from volcanic vents, as at Monte Somma and the Eifel.

The phenomena displayed, when fragments of an igneous or other crystalline rock are caught up and enveloped in a molten material of different chemical composition, have received no less attention from petrographers. Some of the results of this extreme action have been regarded as so anomalous that they have given rise to much discussion. Without attempting to make an exhaustive list of works on this question, I may refer to the following memoirs as especially bearing on the point discussed in the present paper.

¹ Geol. Mag. for 1876, pp. 211-213.

As long ago as 1859 Mitscherlich brought forward the results of his studies of the rock-fragments entangled in the lavas of the Eifel, though his memoir was not published in full till 1865.¹

Between the years 1862 and 1865 an animated controversy was carried on with respect to some of the very highly-altered materials found enclosed in igneous rocks of the Kaiserstuhl by H. Fischer, von Hochstetter, and Kenngott;² and in 1880 John Arthur Phillips very fully discussed the points of distinction between greatly altered and recrystallized foreign inclusions and the remarkable segregation-nodules found in many granites.³

We are indebted to J. Lehmann for a very interesting memoir, published in 1874, in which he fully described the alteration of the several minerals in the various aqueous and igneous rocks found among the ejected materials, or enclosed in the lavas, of the Eifel volcanoes: 'a subject which had, as we have seen, earlier engaged the attention of Mitscherlich. In 1880, L. Van Werveke returned to the discussion of the foreign fragments enclosed in the igneous masses of the Kaiserstuhl, and described a clear case of gneiss caught up in nephelinite.'⁴ In 1884, F. von Sandberger gave an account of fragments of rock caught up in the basalt of Naurod;⁵ in the following year von Chrustschoff described the enclosures of granite in the basalt of Striegau,⁶ while still more recently, in 1890, A. Lacroix has given a very full and interesting account of fragments of foreign igneous rocks contained in the lavas of Auvergne.⁷ In the same year there appeared the valuable memoir of H. Bäckström on the inclusions of augite-granite and other rocks in basic eruptives in Scandinavia.⁸ Within the last year (1892), Fr. Graeff has again taken up the discussion of the included masses in the Kaiserstuhl eruptives.¹⁰

A series of phenomena somewhat similar to those found in natural lavas were described by E. Hussak, in 1880, as resulting from the fusion of basalt and the enveloping of pieces of granite by

¹ E. Mitscherlich, 'Ueber die vulkanischen Erscheinungen in der Eifel, und über die Metamorphie der Gesteine durch erhöhte Temperatur,' Abhandl. d. königl. Akad. d. Wissensch. Berlin (Phys.), 1865, pp. 1-68.

² See Verh. Naturf. Gesellsch. Freib.-i.-B. vol. ii. p. 407, vol. iii. pt. 2, p. 1, pts. 3 & 4, p. 165, and also Verh. d. k. k. geol. Reichsanst. 1865, pp. 3-7.

³ 'On Concretionary Patches and Fragments of other Rocks contained in Granite,' Quart. Journ. Geol. Soc. vol. xxxvii. (1880) pp. 1-22.

⁴ 'Untersuchungen über die Einwirkung eines feurig-flüssigen basaltischen Magmas auf Gesteins- und Mineral-Einschlüsse, angestellt an Laven und Basalten des Niederrheins,' Verh. des Naturh. Vereins der preuss. Rheinl. u. Westf. 1874, pp. 1-40.

⁵ 'Gneiss-Einschlüsse aus Nephelinit von Oberbergen am Kaiserstuhl,' Neues Jahrb. 1880, vol. ii. p. 283.

⁶ 'Neue Einschlüsse im Basalt von Naurod bei Wiesbaden,' Verhandl. d. k. k. geol. Reichsanst. 1884, p. 17.

⁷ 'Mikropetrographische Mittheilungen,' Tschermak's Mineral. u. Petrogr. Mitth. vol. vii. (1885) p. 295.

⁸ 'Sur les Enclaves Acides des Roches Volcaniques de l'Auvergne,' Bull. des Serv. de la Carte Géol. de France, No. 11 (vol. ii).

⁹ 'Ueber fremde Gesteinseinschlüsse in einigen Skandinavischen Diabasen,' Bihang till Svenska Vetensk.-Akad. Handlingar, vol. xvi. pp. 1-38.

¹⁰ Mitth. der Grossherzogl. Badischen Geol. Landesanst. vol. xiv. p. 405.

the fused mass, which was observed by him in the walls of a disused limekiln.¹ Mr. Rutley's investigations upon various rocks which had been submitted to the action of heat in a glass-furnace for considerable periods of time,² and Doelter and Hussak's researches on the action of molten magmas on various minerals,³ also throw light upon some of the questions raised by the study of rock-inclusions in liquid lavas; nor are the well-known observations of Sir James Hall, Gregory Watt, Sorby, Waller, and many others who have experimented on the fusion of rocks, without bearing on these enquiries.

These observations have made tolerably familiar to geologists the nature of the changes which are induced in the several minerals of rocks, when they are exposed to a temperature sufficiently high to produce partial fusion; they have at the same time shown how frequently spherulitic structures are developed in the groundmass of rocks placed under such conditions, and caused to soften if not actually to fuse.

The interesting question of the changes produced in igneous rocks that have been subjected to partial re-fusion has also been discussed in some other memoirs to which I must call especial attention, seeing that the phenomena described have a very close analogy indeed with those that are considered in the present paper. In 1877 Prof. Bonney showed that, at two points in the Island of Arran, a remarkable spherulitic structure has been developed in acid rocks (quartz-felsites) where they are in contact with other igneous masses that have been intruded into them.⁴ On the Corriegills shore this effect has been produced by the intrusion of a mass of pitchstone; while north of Drumadoon the agent of alteration is a basic protrusion. At both localities I have been able to verify the very interesting observations of Prof. Bonney.

2. THE PRODUCTS OF THE RE-FUSION OF QUARTZ-FELSITE FRAGMENTS BY THE BASALT OF ASCHERHÜBEL, SAXONY.

The geologists of Saxony have long been acquainted with a remarkable case of the enclosure of fragments of an acid rock in one of basic composition, and the results in that case are so similar to those here described from the Western Isles of Scotland that I must refer to it at somewhat greater length; more especially is this necessary as the details which enable us to make the comparison have only very recently been laid before the scientific world.

More than twenty years ago, when visiting Freiberg, I obtained

¹ 'Umgeschmolzene Basalte und Granite von Edersgrün bei Karlsbad,' Verh. d. k. k. Reichsanst. 1880, p. 314.

² 'Notes on the Alteration induced by Heat in certain Vitreous Rocks, based on experiments of Douglas Herman and G. F. Rodwell,' Proc. Roy. Soc. vol. xl. (1886) pp. 430-441.

³ 'Ueber die Einwirkung geschmolzener Magma auf verschiedene Mineralien,' Neues Jahrb. 1884, vol. i. pp. 18-44.

⁴ Geol. Mag. for 1877, pp. 505-509.

from E. Neumann, an optician in that town, who was one of the earliest makers of microscopic slices of minerals and rocks, a thin section which at the time arrested my attention and has often since been referred to with interest. It bore the label *Dopp. geschm. Porphyry, Gröllenburg*; but the maker of the section was unable to afford me any information concerning the origin of the specimen or the authority on which it had been described as a 'doubly-melted porphyry.' The microscopic examination of the specimen, however, seemed to indicate that it had been correctly labelled, and that it was indeed a rock of very considerable interest. While parts of the section show the characters belonging to the well-known 'quartz-porphyry' of Specthausen and Tharandt, there are other portions which pass into a perfect glass. In this glassy part there are traces of flow-structure, with incipient spherulites and perlitic cracks. Every gradation, indeed, can be traced from nearly unaltered 'porphyry' to a perfectly vitrified material, and from a clear glass to one in which all the earlier stages of devitrification can be unmistakably recognized.

For a long time I was quite foiled in my endeavours to obtain any trustworthy information concerning this remarkable specimen—of the source from whence it was derived, or the authority on which it was labelled. Some time ago, however, Prof. Zirkel and Prof. Credner kindly interested themselves in the matter, and as a consequence of the communications which they have made to me I have been enabled to clear up my doubts on the subject. The specimen must evidently have been obtained, not from the locality named, but from Ascherhübel, which lies about 3 kilometres north of a village now known officially as Gröllenburg, but which was formerly called Gröllenburg. This locality is in the kingdom of Saxony, and is nearly equidistant from Freiberg and Tharandt.

At Ascherhübel, the well-known *quartz-porphyry* and the *quartz-armour-porphyry* of the Tharandt Wald are partially covered by Quadersandstein, the whole being penetrated by basaltic outbursts which form the cupola (*quellkuppe*) of Ascherhübel, and the lava-current of Landberg. In the midst of the Ascherhübel basalt there are found numerous inclusions of 'porphyry,' in all stages of vitrification and fusion up to a perfect glass, and it is one of these which has yielded the interesting section to which I have referred.

Subsequently to receiving this information from Prof. Zirkel, I was favoured by the same friendly correspondent with an advance copy of the 'Erläuterungen zur geologischen Spezialkarte des Königreichs Sachsen—Section Tharandt, Blatt 81.' In this work Herr A. Sauer has given a short but very interesting account of the eruptive mass of Ascherhübel and its inclusions, from which the following particulars are derived.

Ascherhübel is a small *quellkuppe* of an elliptical form, with a diameter of from 200 to 300 metres. The rock of which it is composed is a nepheline-basalt, and consists of a groundmass almost wholly made up of microlites of augite and grains of magnetite, between which a few particles of nepheline can be detected.

Very sparsely scattered through this groundmass are small phenocrysts of augite and olivine, seldom more than 1·5 millimetre in length, the former sometimes exhibiting the hour-glass structure, and the latter forming interpenetrant twins. The rock is so poor in aluminous-alkaline silicates that it approaches an augitite in composition.

Very great interest attaches to this rock from the circumstance, pointed out by Herr Sauer, that it contains inclusions of pyrrhotite (magnetic iron-pyrites) and, in addition, one fragment, the size of a walnut, of *native iron* covered by an oxidized crust. This iron is perfectly malleable and of a tin-white colour, but it does not exhibit the Widmanstätten figures when etched. The mode of occurrence of iron in this basalt appears to resemble that in the basalt of Ovifak and other localities in Greenland, and those of the nickel-iron alloys of New Zealand (Awaruite) and of Oregon (Josephinite).

The basalt of Ascherhübel is described by Herr Sauer as being so rich in inclusions of foreign rock that it is scarcely possible to find a large fragment of the igneous material which does not contain one or more foreign fragments. These belong in part to the Pläner- and Quadersandstein and in part to the underlying 'porphyry,' while the formations which form the foundation of the surrounding country are also represented: all these rock-masses having been penetrated and replaced by the basalt. Among the foreign fragments, those of the 'porphyry' are most numerous, though they are generally small in size. They are for the most part perfectly vitrified, but nevertheless often show indications of the characteristic structures of the 'porphyry.' The whitish grey, dirty violet, or reddish spotted fragments are compact or bubbly, and near the basalt are generally bounded by a greenish-coloured seam of augite-microlites. On the surface they are covered with a thin weathered crust resembling kaolin.

On a microscopic examination, we find a glass with distinct perlitic structure and colourless or brownish spherulites. This glass contains feldspars which are occasionally still recognizable, and are generally changed into a granular substance sometimes acting uniformly under polarized light; there are also minute crystals of magnetite with particles of hæmatite, and more rarely crystals of spinel. Besides the glass there are dull, undefinable patches representing the 'porphyry' in a less changed condition. Herr Sauer's description so completely agrees with the section to which I have referred as being obtained at Freiberg that there is no room for doubt as to the origin of the specimen from which it was cut.

I have noticed at some length the enclosures at Ascherhübel, for here we have, as in the Cuillin Hills, masses of acid plutonic rocks entangled and altered by a magma of basic material. In this rock, as in the cases so well described by Prof. Bonney from the Island of Arran, we get clear proof that not only are characteristic alterations produced in the porphyritic crystals, but that spherulitic structures are developed in the groundmass of such acid rocks when

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re-fused, a conclusion which has also been arrived at by Whitman Cross,¹ Bäckström,² and other authors.

In the Cuillin Hills, however, the phenomena are exhibited on a far grander scale than in Saxony or in Arran. The enclosures are of much larger dimensions, and the mass of molten basic rock in which they have been enveloped is of much grander proportions, while the period during which it has retained its high temperature must have been far longer—as is shown by the highly crystalline character of the gabbro.

3. THE GRANITES AND GABBROS OF THE CUILLIN HILLS.

The Tertiary granitic rocks of Skye, Mull, Rum, and St. Kilda, with their southern developments in Arran and the Mourne Mountains, were carefully described by Zirkel in 1871, under the names of 'quartz-syenite' and 'quartz-porphry,'³ and in 1874 I gave some further account of their nature and relations, referring them to granites and quartz-felsites.⁴ More recently, in 1888, Mr. Teall referred to one of the most widely-distributed types of the rock, his notice of it being illustrated by an excellent figure and a full petrographical description;⁵ in the same year, too, Sir Archibald Geikie and Dr. Hatch contributed interesting details concerning many of the varieties assumed by these rocks.⁶

As I hope shortly to lay before this Society an account of the whole series of acid rocks of Tertiary age as developed in Scotland, the study of which has occupied much of my time and attention during the last twenty years, I will content myself here with a short summary of their principal characters.

In some of the more central parts of their mass, these rocks present themselves as true biotite-granites, but there is a constant tendency for the biotite to be replaced wholly or in part by hornblende. When, as not unfrequently happens, the quantity of plagioclase increases in amount, the biotite- or hornblende-granite passes into a common granitite or a hornblende-granitite. Towards the peripheral portions of the intrusive masses, however, a very marked change takes place in the characters of the rock. Micropegmatitic ('granophyric') intergrowths of felspar and quartz make their appearance between the phenocrysts of the rock, the mica and hornblende are gradually replaced by augite, magnetite becomes a prominent constituent of the rock, and a remarkable drusy ('miarolitic') structure is developed in it. It is this variety of the rock, which is indeed the most widely distributed, that has been called by Mr. Teall and Sir Archibald Geikie (following the nomen-

¹ Bull. Phil. Soc. Washington, vol. xi. (1891) p. 433.

² *Op. supra cit.*

³ 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxiii. (1871) pp. 1-124.

⁴ Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 234-236.

⁵ 'British Petrography,' 1888, p. 327, pl. xxxiii. fig. 1.

⁶ Trans. Roy. Soc. Edinb. vol. xxxv. (1888) p. 148.

clature of Rosenbusch) 'granophyre.'¹ This drusy and micropegmatitic variety of the rock passes in turn into ordinary quartz-felsites (*quartz-porphyr*).

The gabbros of the same district have been already described at some length in a former volume of this Journal, and I may therefore refer to that memoir for full petrographical details.² The rocks are very typical gabbros, exhibiting every gradation from augite-gabbro to common or diallage-gabbro; and the monoclinic pyroxene is to a greater or less extent liable to be replaced by a rhombic variety (bronzite or hypersthene), so that the rocks pass into norites.

4. THE POSITION AND GENERAL CHARACTERS OF THE GRANITE-INCLUSIONS IN THE GABBRÖ.

The locality where the inclusions of granite can be seen lying in the midst of the gabbro of the Cuillin Hills is known as Druim-an-Eidhne (see the sketch-map on the preceding page, which has been reduced from the latest edition of the six-inch Map of the Ordnance Survey). That ridge, which is rather more than 1000 feet in height, is situated in the angle formed by the valley in which the well-known Loch Coruisk lies, by the scarcely less famous Harta Corrie, and by the continuation of Glen Sligachan called Strath-na-Creitheach. The ridge itself is composed of a great intrusive sheet of gabbro overlying the acid rocks, which rise from beneath it northward into the mountain of Meall Dearg. At many points the junction between these bare and strongly-contrasted rocks may be easily followed. The gabbro at this locality presents all its usual features; the only noteworthy peculiarity being the great abundance in it of contemporaneous or segregation-veins, an occurrence long ago pointed out by Macculloch. The granitic rock of Meall Dearg is the drusy and micropegmatitic variety of augite-granite, so widely developed in this district, and it passes in places into a true quartz-felsite or 'quartz-porphyr' with idiomorphic crystals of quartz and felspar.

Well within the boundary of the gabbro, and sometimes at the distance of many yards from it, there occur a number of irregular patches of pale granitic rock, which are seen to be completely enclosed in the gabbro-mass. These enclosed patches are sometimes at least 20 or 30 yards from the line of junction between the

¹ Unless the terminology of petrography is to be allowed to fall into a state of utter confusion, a confusion ten times worse confounded than that which has characterized it in the past, a protest and a firm stand must be made against the practice—especially prevalent in Germany—of taking old names and re-defining them so as to express ideas totally different from those of the original authors. It may now be too late to restore to 'gabbro' and 'syenite' their original significations; but 'granite' and 'granophyre,' if used at all, must surely be employed with the meaning given them by their respective authors, Gustav Rose and Vogelsang. See on this point the admirable remarks of Whitman Cross (Bull. Phil. Soc. Washington, vol. xi. p. 430, note).

² Vol. xlii. (1886) pp. 49-97.

granites and gabbros. As the granite weathers so much more readily than the gabbro, these patches of granite form depressions in the great rusty-brown mass of the basic rock, which are usually filled with *débris*; some of the patches show a section several square yards in area. Within these depressions the acid rock can be clearly traced, while the boundary of the surrounding gabbro may be followed without difficulty, and the complete isolation of the patches of granite is very obvious. The acid rock within the depressions is at once seen to present a very different appearance from the normal granite; although the phenocrysts of quartz and felspar are often conspicuous, the rocks exhibit the general aspect of a *rhyolite* rather than that of a granite. They are compact in texture and splintery in fracture, and sometimes almost glassy in appearance. The greatly weathered surfaces reveal the peculiar structures of the rock in a most admirable manner. Banding is very manifest on these weathered surfaces, and in many instances the banding can be seen to be due to a parallel disposition of spherulites in the mass (see Pl. II. figs. 1 & 2). Spherulitic structures, of all dimensions from a pin's head to a small orange, are everywhere conspicuous (Pl. II. figs. 3, 4); they often show the characters of lithophyses (hollow spherulites; see Pl. II. fig. 5), and not unfrequently exhibit the crushed and distorted appearances which have been so well described in the case of the very fresh rhyolitic rocks of the Western Territories of the United States. On breaking open the larger nodules, they are seen to present the arborescent forms characteristic of the complex spherulites of the districts just referred to. These spherulites often weather out as perfectly rounded bodies like 'marbles,' which can, in places, be collected in considerable numbers. The general examination of the enclosed masses indicates that they are rocks originally of a glassy character, but converted into 'lithoidite' by the development throughout the mass of every variety of spherulitic structure, while scattered through the whole may often be seen the phenocrysts of quartz and felspar. At one or two points I have found the same phenomena displayed, though in a less striking manner, at the junction of the gabbro with the granite.

The general conclusions concerning the nature and origin of these beautiful rocks, which we arrive at from their macroscopic study, are fully confirmed when we apply the microscope to the examination of thin sections prepared from them; while many new and remarkable facts about their structure are then revealed.

The rocks are seen to contain in many places phenocrysts of quartz, felspar, and magnetite, embedded in a more or less devitrified, glassy base. These phenocrysts exhibit many interesting features, showing that they have been exposed to a high temperature. The micropegmatitic groundmass, the last to solidify among the constituents of the original rock, has been the first to fuse; and the liquefaction has often been sufficiently perfect to allow of the development of flow-structures in the mass. It is worthy of notice, however, that

certain of the larger micropegmatite groups have in places escaped complete fusion, and some of these masses of micropegmatite form the nuclei of large composite spherulites. Re-solidification, however, has been accompanied by devitrification, resulting in the development of a great variety of the spherulitic structures, often on a very grand scale. During and after the fusion, new minerals (pyrites, fayalite, etc.) have been formed, and the whole rock has undergone sufficient change to lead to the formation of many secondary products, such as chalcedony, chlorite, etc.

5. THE ALTERATIONS WHICH THE MINERALS IN THE INCLUSIONS HAVE UNDERGONE.

Beginning with the characters of the phenocrysts, we find the grains of *quartz*, as we might expect, the least altered of all the minerals. Their contours, whether the idiomorphic and corroded forms of 'quartz-porphyrtes' or the allotriomorphic forms characteristic of granite, are admirably preserved, and the crystals appear quite clear and transparent. Careful examination, however, shows that the crystals are not unfrequently traversed by a number of fine cracks, though these cracks have only occasionally been developed in such numbers as to seriously impair the transparency of the quartz (Pl. III. fig. 1). That these cracks are new features which have been developed by the heat to which the crystals have been exposed is unquestionable. Occasionally the crystals have opened along these cracks, and the glassy matrix has penetrated through them, breaking up the quartz-crystal into a number of isolated fragments, in the manner so well described by Lehmann in his account of the Eifel rocks (Pl. III. fig. 2; compare Lehmann, *op. supra cit.* Tab. I. figs. 1 & 2). When we come to examine the enclosures, we find that the granitic quartz sometimes shows cavities containing liquids with moving bubbles, which occur in streams and bands traversing the crystals. In some cases, however, these cavities appear empty or filled with a black opaque substance. The idiomorphic quartzes have cavities, sometimes of considerable size, which are filled, not with *stony* matter, as in the original rock, but with *glassy* material. This glass sometimes occupies well-marked negative crystals, and at other times cavities of most irregular form, the connexion of which with the surrounding matrix is sometimes clearly visible.

The glass-cavities in the idiomorphic quartz-crystals are so big and so numerous that it is scarcely possible to avoid the conviction that some of them have been enlarged during the re-fusion of their contents, and there is at least a suspicion that new cavities may have been formed, like the secondary glass inclusions described by Chrustschoff as occurring in the quartzes of *verglaster sandstein*.¹ The corrosion of the outside of these crystals by the surrounding glass may also have been produced, or at all events increased, during the second fusion to which the rock has evidently been subjected.

¹ Tschermak's *Min. u. Petr. Mittheil.* 1882, p. 473, and 1885, p. 64.

Some of the quartz-crystals are surrounded by radiating filaments of brown oxide of iron ('ferrite') which greatly resemble the products of alteration of the pyroxene, and it seems very probable that they indicate the former existence of zones of augite and magnetite, like those which surround the quartzes in the 'quartz-basalts.' In some cases I have found distinct evidence of the formation of zones of secondary quartz around the corroded fragments of the mineral. This is precisely similar to the *pyrogen-quarz* which Lehmann¹ and Chrustschoff² have shown to be so characteristic of inclusions (see Pl. III. fig. 3). It is, of course, not necessary to suppose that the secondary quartz has been produced by direct fusion, as the evidences of the presence and action of water are sufficiently obvious in these rocks.

The *felspars* of these included masses are almost always kaolinized and more or less opaque, as indeed is the case in the original rock. The most conspicuous feature about them is the occurrence of cracks, parallel to the orthopinacoid (010), to the basal plane (001), and perhaps also to the clinopinacoid (100), which have opened and been filled with a secondary deposit of felspar (see Pl. III. fig. 4). A similar rim of secondary felspar also surrounds the whole crystal in some cases, the secondary felspar being in approximate, but seldom in complete, optical continuity with the original and altered material. Occasionally the whole crystal is broken up into a multitude of dice-like fragments, and these are in some cases displaced, the circumstance being revealed by the mass behaving like a mosaic in polarized light. These altered felspars with their infilled 'contraction-rifts' offer a close analogy with the 'perthites,' but there does not appear to be a very marked difference in character between the original and altered portions and the new and infilling veins which traverse the crystal. Bäckström and other authors have frequently described a similar alteration of the felspars in inclusions.

The large 'stone cavities' which occasionally occupy considerable spaces in the original crystals have sometimes been fused and partially or wholly devitrified. In some cases the whole of the centre of the crystal has been honeycombed by the surrounding matrix, and in these cases the mixture of felspar and glassy material has easily fused and then become devitrified. It is in this way that the interesting appearances illustrated in Pl. III. fig. 5 have evidently been produced. The felspars, like the quartzes, are sometimes surrounded with radiating trichites, now converted into limonite (Pl. III. fig. 6).

With respect to the optical properties of the felspars, I have made many attempts to determine the position of the optic-axial plane, but, owing to the opacity of the crystals, have not succeeded in obtaining trustworthy results.

The *ferro-magnesian silicate* in this particular variety of the

¹ Verh. des Naturh. Ver. d. preuss. Rheinl. u. Westf. 1877, p. 203.

² Tschermak's Min. u. Petr. Mittheil. 1885, p. 295.

granite is a green pyroxene. As a rule, however, few traces of this mineral remain in the fused product, it having for the most part been broken up into various secondary minerals, among which magnetite is usually very prominent. The magnetite thus produced can always be distinguished from the original magnetite and titanoferrite of the rock; the secondary mineral tends to form branched and radiated filaments, and not unfrequently gives rise to the extremely delicate trichites which, as we shall see hereafter, are so conspicuous in many of the spherulitic growths. The change is very similar to that produced in the hornblendes of the Corriegills pitchstone by the long heating of that rock in a glass furnace, as shown by Mr. Rutley. Bäckström, in the work already quoted, has pointed out that the ferro-magnesian minerals of inclusions of granite in basic rocks are less capable of resisting the action of the molten magma around them than are the felspar-fragments, and that they are often entirely dissolved, leaving scarcely a trace of their former existence. The cores left by the removal of these minerals are, he says, sometimes surrounded by magnetite, and possibly also by secondary quartz and biotite.

The original magnetite and titanoferrite are apparently unaltered, except that the latter mineral sometimes shows the beginnings of change into sphene ('leucoxene'), and the crystals are scattered through the vitrified mass. Some of the magnetite may, however, be acted upon to produce the pyrite which is in certain cases tolerably abundant.

The condition of the minerals in these masses of curiously altered rock will thus be seen to be strikingly different from that of the former minerals in the granite and its apophyses, and the changes they have undergone are precisely those which have been described as occurring in enclosures of acid in basic rocks by Mitscherlich, Lehmann, Bäckström, Sauer, and other authors.

6. THE SPHERULITIC GROWTHS DEVELOPED IN THE INCLUSIONS.

If we now turn our attention from the porphyritic crystals to the base or groundmass, we shall find in the fusion of the micro-pegmatite and the development of spherulites in the glass resulting from this fusion an exact parallel to the changes which have been produced in plutonic acid rocks by the action of heat, as described by Sauer, Bonney, Bäckström, and others.

In studying the remarkable spherulitic growths which have been formed in the glassy mass produced by the fusion of the micro-pegmatitic groundmass of the acid rock I have been greatly aided by the valuable memoirs of Mr. Iddings¹ and Mr. Whitman Cross,²

¹ J. P. Iddings, 'Obsidian Cliff, Yellowstone National Park,' Washington, 1888, issued with the Seventh Annual Report of the U.S. Geological Survey for the years 1885-6; 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. xi. (1891) pp. 445-464.

² Whitman Cross, 'Constitution and Origin of Spherulites in Acid Eruptive Rocks,' Bull. Phil. Soc. Washington, vol. xi. (1891) pp. 411-444; see also F. Rutley, 'On a Spherulitic and Perlitic Obsidian from Pílas, Jalisco, Mexico,' Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 530-533.

of the U.S. Geological Survey, on the spherulitic rocks of Obsidian Cliff in the Yellowstone Park, and on the similar rocks of Silver Cliff, Custer County, Colorado. The former gentleman has greatly facilitated my task by supplying me with a series of specimens illustrating the chief types which he has so well described.

The spherulites of the Cuillin Hills sometimes attain a diameter of nearly $2\frac{1}{2}$ inches (60 centimetres); they present examples of all the varieties described by Messrs. Iddings and Whitman Cross, with some forms not previously noticed. So far as size goes, they fall far short of the spherulites described by the latter observer from Silver Cliff, which are said to sometimes attain a diameter of 10 feet; the Cuillin-Hills spherulites, however, I believe, surpass in size any hitherto described in the British Isles, with the exception of the fine hollow spherulites of Boulay Bay, Jersey, while they are in a much less altered condition than these latter.

Many of the spherulites in question are beautiful examples of what Mr. Rutley has proposed to call 'composite spherulites,'¹ in which globular spherulites formed round a number of sporadic centres have been enclosed in other radially-formed masses of much larger dimensions—they are, in short, spherulites within spherulites.

The smaller spherulites nearly all belong to the ordinary type (the 'compact spherulites' of Iddings), in which microlites, arranged radially, give with crossed nicols the usual black cross or sometimes a greater number than four dark brushes not at right angles to one another (the so-called 'pseudo-spherulites').

Not unfrequently, these ordinary spherulites consist of several concentric layers, the microlites of each of which exhibit some differences in colour, opacity, or other characters. These spherulites are found to be involved in peculiar arborescent growths, which have been compared to foxes' tails; and these start from one or sometimes several centres, and involve alike the ordinary spherulites and the phenocrysts of the original rock, which have escaped fusion. The bodies built up by these arborescent growths constitute the 'porous spherulites' of Iddings² (see Pl. III. fig. 7).

When the curious plume-like or brush-like bodies are examined, especially in polished surfaces of the spherulites, which can be viewed by reflected light, we see that there are two varieties of them, which are strongly contrasted in colour (Pl. III. fig. 7). In one case the colour is bluish grey, while in the other it is creamy white. Microscopic sections of extreme thinness show that the blue-grey plumes are composed of felspar and quartz, through which grains of magnetite are uniformly distributed (Pl. III. fig. 8). The creamy white plumes are also composed of felspar and quartz, but are destitute of the scattered grains of magnetite; they exhibit, however, a quantity of hydrous brown oxide of iron lying between the felspar-fibres of the plumes (Pl. III. fig. 9). Careful study of very thin sections with high powers shows that this brown oxide

¹ 'Composite Spherulites in Obsidian, from Hot-Springs, near Little Lake, California,' Quart. Journ. Geol. Soc. vol. xlv. (1890) pp. 423, 424.

² 'Obsidian Cliff, etc.,' p. 278.

of iron, which is so uniformly distributed, has been produced by the oxidation and hydration of trichites of magnetite which have clearly been formed at the same time as the felspar-needles between which they lie. These plumes, which are now of a creamy white colour, are evidently identical with the 'trichitic spherulites' described by Mr. Whitman Cross.¹

The foxtail-like plumes all exhibit the beautiful radial structure combined with a concentric arrangement so well described, alike by Messrs. Iddings, Whitman Cross, and Rutley (Pl. III. figs. 8 & 9). Between the portions of the mass formed by the phenocrysts, the ordinary spherulites, and the two kinds of plumes, we sometimes find other growths which would seem to be analogous to the 'supplemental spherulitic growths'² of Whitman Cross.

The centres of all the spherulites, both large and small, appear to be very generally formed by original crystals of quartz or felspar, or sometimes by well-developed micropegmatite groups which have escaped fusion. In some very interesting cases, however, masses of the original micropegmatitic rock, from 8 to 10 millimetres in diameter, seem to have almost entirely escaped obliteration, and they form the centres of great compound spherulites (Pl. III. figs. 10 & 12). These masses of micropegmatite are usually surrounded by a crust of glass with fluidal structure, which is stained by iron oxides, while outside the whole we find the great mass of the complex spherulitic growth (Pl. III. figs. 11 & 13).

If any doubt existed as to these spherulitic masses having been formed by the partial fusion of the micropegmatitic granite of the Cuillin Hills, such doubt would be at once removed by the examination of those fragments of granite which are thus curiously preserved as the nuclei of spherulites. In the drawing on the opposite page, Miss M. Reeks has succeeded in giving an admirable representation of one of these granite-fragments, as seen with a low-powered objective.

There is considerable diversity in the general appearance of the sections of these complex spherulites. This is caused by the varying extent to which the several kinds of spherulitic growth take part in the formation of the compound masses. In some cases rounded and irregular masses are found to be built up of an aggregation of ordinary spherulites, with only a small amount of intermediate or 'supplementary' spherulitic growth between them. In other cases, like that figured in Pl. III. fig. 7, a few scattered spherulites of the ordinary type are seen to be enclosed in the plume-like masses building up the 'porous spherulite.' Others, and these perhaps constitute the most abundant type, consist wholly of plume-like or arborescent masses radiating from one or several centres and enclosing the phenocrysts of the original rock.

In some cases the oxidation of the outer zones of a spherulite has given rise to a very marked contrast between its brown outer

¹ 'Constitution and Origin of Spherulites, etc.,' Bull. Phil. Soc. Washington, vol. xi. (1891) p. 423.

² *Ibid.* p. 424.

portion and the bluish-grey mass in the centre, which appears to be coloured by magnetite and finely-divided pyrite.

Spherulites from less than 1 millimetre up to 60 centimetres in diameter and of all intermediate sizes can be found; and sometimes, as may be well seen in weathered surfaces of the rock, the mass is made up of crushed and distorted spherulitic growths like those occurring in Silver Cliff, Colorado¹ (Pl. II. fig. 3). These indicate, as has been shown, that the mass was subject to internal

Section of the Granite-nucleus of a Spherulite (see Pl. III. figs. 12 and 13), as seen with a magnifying power of 14 diameters.

The quartz and the micropegmatite groups are almost unaltered and retain their relative position, only a small quantity of glass having been produced by the fusion of intervening materials.

movement during the time that the spherulites were being formed. Hollow spherulites or lithophyses, especially types like the beautiful forms that have been compared to an expanding rose,² are by no means uncommon (see Pl. II. fig. 5). There are examples in which globular aggregates of small spherulites up to 25 millimetres

¹ Whitman Cross, *op. supra cit.* pl. v. fig. 1.

² J. P. Iddings, 'Obsidian Cliff, etc.,' pl. xii.

(1 inch) in diameter have been formed, and then a complete change in the mode of development has taken place, the outer zones of the spherulite being formed by the separating concentric layers of a lithophyse (see Pl. II. fig. 4).

Although the state of preservation of the plume-like masses in the spherulites of the Cuillin Hills is very much inferior to that of the spherulites from the western districts of the United States, microscopical study proves that they are identical in character and origin with the objects so well described by Messrs. Iddings and Whitman Cross. I have no doubt that those observers are correct in referring all the fibres of these arborescent growths to felspar; they have shown, by the use of the quartz-plate à *teinte sensible*, in the manner suggested by M. Michel-Lévy, that the positive or negative character of the spherulitic growth may be accounted for by regarding the former as felspars elongated parallel to the vertical axis and with the so-called 'anomalous' optical orientation, and the latter as being also felspar-crystals, but elongated parallel to the clino-axis and with the normal optical orientation. These felspar-microlites are frequently Manebach twins, and this accounts for the very regular forking of the fibres at definite angles. The whole character of the spherulites of the Cuillin Hills is in complete harmony with this explanation.

Although quartz does not enter directly into the composition of these spherulitic growths, as was formerly supposed, free silica takes a small, but by no means unimportant part in the building-up of such structures. Mr. Iddings has shown that the fibres of felspar entangle numerous, small, rosette-like aggregates of tridymite, while Mr. Whitman Cross points out that the spaces between such fibres may be filled in with colloid silica, probably hydrated. Both tridymite and colloid silica have of course long since disappeared in the altered spherulites of the Cuillin Hills; but the crystallized quartz between the felspar-fibres probably represents the silica which has been redissolved and has crystallized in the stable form. We find an interesting proof of the former existence of the tridymite rosettes when we attempt to polish the sections of these spherulites, the polishing powder finding its way into and rendering very conspicuous the cavities formerly occupied by tridymite.

There are two minerals formed in these spherulites which are of especial interest. The first of these is iron pyrites. In my paper of 1874 I pointed out how frequently this mineral is present in the Tertiary igneous masses of the Western Isles of Scotland.¹ At a later date, I described the propylitic modification of the older andesites by the intrusion into them of the granitic rocks.²

The masses of fused granite enclosed in the gabbro of the Cuillin Hills all contain sulphur; this has been shown by a series of careful tests with the blowpipe made for me by Mr. Gilbert Cullis, one of the Demonstrators of the Geological Division of the Royal College of Science. But in addition to the finely-divided iron sulphide we

¹ Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 236-237.

² *Ibid.* vol. xlv. (1890) pp. 341-384.

have pyrites-crystals, sometimes of considerable dimensions. These, in all probability, have been formed at the expense of some of the magnetite of the rock and are found, sometimes attached to comparatively unaltered centres of the spherulites, and at other times scattered promiscuously through their mass. The pyrites-crystals often show every stage of the conversion of their substance into limonite. Bäckström has also found pyrites to be among the secondary minerals developed in the inclusions of granite in diabase.

There are, moreover, grounds for believing that fayalite, the iron-olivine, was a constituent of the spherulites. Mr. Iddings has shown how commonly this mineral occurs in the spherulites of acid rocks.¹ In some of the spherulites of the Cuillin Hills there are masses of brown oxide of iron, which are evidently the product of alteration of another mineral. In the midst of these, particles may sometimes be detected which under the microscope exhibit the lustre and cleavage of partially altered fayalite, like that of the Mourne Mountains. In spite of the minute size of these particles, they can be extracted by a needle-point, and, on boiling with hydrochloric acid, they are seen to be decomposed with separation of gelatinous silica.

7. BEARING OF THE EVIDENCE AFFORDED BY THESE INCLUSIONS ON
THE QUESTION OF THE RELATIVE AGES OF THE IGNEOUS ROCKS
IN THE WESTERN ISLES OF SCOTLAND.

There is one important inference from the phenomena exhibited at Druim-an-Eidhne, which is so obvious that it would not be necessary even to call attention to it, but for the circumstance that opposite conclusions have been persistently and authoritatively put forward. It is perfectly clear from the study of these inclusions that the gabbro of the Cuillin Hills was erupted *after* the granites of the Red Mountains of Skye, and it is further indisputable that the acid rocks must have consolidated and acquired their existing features, including the remarkable micropegmatitic structure, before the gabbros were forced through them and caught up these 'horses' of granite.

As long ago as 1819, Macculloch discussed the relative ages of these two series of igneous rocks, and, although he hesitates about giving a final and definite opinion on the subject, it is clear that he leans towards the view that the granites are the *older* rocks of the two.²

In 1846 Principal J. D. Forbes made a very careful study of

¹ 'On the Occurrence of Fayalite in the Lithophyses of Obsidian and Rhyolite in the Yellowstone National Park,' *Am. Journ. Sci.* ser. 3, vol. xxx. (1885) p. 58; see also Iddings and Penfield, 'Fayalite in the Obsidian of Lipari,' *ibid.* vol. xl. (1890) p. 75; 'The Minerals in Hollow Spherulites of Rhyolite from Glade Creek, Wyoming,' *ibid.* vol. xlii. (1891) p. 39.

² 'A Description of the Western Islands of Scotland,' 1819, vol. i. pp. 362-393. See the order adopted in the legend to the Map of Skye, vol. iii., and also the legend to his general Map of Scotland published in 1832, where 'Diallage Rock' (gabbro) is placed last of all the formations except Alluvium.

the junctions of the two sets of igneous rocks, and the result he arrived at, after a very able and candid discussion of the whole question, was that the gabbros were erupted *after* the granites.¹

In 1871, Prof. Zirkel, after examining the rocks both in Skye and Mull, came to the same conclusion.²

Between the years 1870 and 1874 I repeatedly examined the junctions between the two rocks, and found that there was abundant evidence in support of the conclusions published by my predecessors in the same field, while I failed totally to discover any facts which were opposed to those conclusions. Consequently, in my interpretation of the structure of the district, I adopted the same views (as to the relative ages of these rocks) as those which had been already announced by Forbes and Zirkel.³

In 1888 Sir Archibald Geikie published a memoir in which, while abandoning many of his previous conclusions on the subject, and adopting in their place the views I had put forward in 1874, he nevertheless strongly maintained that all previous observers had been mistaken as to the relative ages of the acid and basic rocks, and that the granites are really *younger* than both the basalts and gabbros of the district.⁴ He, indeed, went much further than this, and intimated that the opposite opinion arrived at by his predecessors was not only one for which there was no foundation, but could be maintained only by those who had not properly examined the evidence.

In his recent Presidential Address to this Society, the Director-General of the Geological Survey has forcibly reiterated these conclusions, and has summed them up in the following words:—"There can be no doubt that they" (*i. e.* the granites and other acid eruptives) "are the last of all the Tertiary volcanic series, except the latest basalt-dykes which traverse them."⁵

I cannot, perhaps, better indicate how absolutely crucial is this question of the relative ages of the granite and the gabbro, with respect to the two interpretations that have been given of the structure of the district, than by quoting the remarks on the subject made by Prof. A. H. Green. In an article which claims to be a perfectly impartial statement of the case, and which no one who reads it can possibly tax with undue leanings to my own side of the controversy, we find the following passage:—

"So far then the views of Dr. Geikie and Prof. Judd may admit of modifications which render them less conflicting than they seem at first sight. But there is one point on which reconciliation is impossible, viz. the nature and relative date of the eruptions of acid composition. Prof. Judd recognizes not only acid eruptions of the

¹ 'Notes on the Topography and Geology of the Cuchullin Hills, etc.,' Edinb. New Phil. Journ. vol. xl. (1846) pp. 76-99.

² 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxiii. (1871) pp. 1-124.

³ Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 249.

⁴ 'The History of Volcanic Action during the Tertiary Period in the British Isles,' Trans. Roy. Soc. Edinb. vol. xxxv. pp. 21-184.

⁵ Quart. Journ. Geol. Soc. vol. xlvi. (1892) *Proc.* p. 167.

massive type—granites and their allies—but he speaks of thick bodies of felstones, disposed in regular sheets and of amygdaloidal structure, which alternate with beds of scoriæ, lapilli, and ashes, that lie upon the skirts of the central bosses of granite. These he believes to be the remnants of a volcano formed mainly of acid lavas, which was piled up and largely ruined by denudation before the discharge of the plateau-basalts began. The existence of the granite-bosses admits of no doubt, but Dr. Geikie has depicted numerous sections which leave no doubt that these rocks intrude into the basalts and gabbros, and are therefore of later date than them. Now that all these details are before us, the question of relative age can admit of only one answer, but it is evidently a point on which observers, who had not opportunities of entering minutely into details, were apt to go wrong. Both Principal J. D. Forbes and Prof. Zirkel seem to have come to the same conclusion as Prof. Judd, and Dr. Geikie has supplied the explanation. 'That there should ever have been any doubt,' he says, 'about the relations of the two eruptive masses is possibly explicable by the facility with which their junction can be observed. Their contrasts of form and colour make their boundary over crag and ridge so clear that geologists do not seem to have taken the trouble to follow it out in detail. And as the pale rock (granophyre or granite) underlies the dark (gabbro), they have assumed this infraposition to mark its earlier appearance.' All this is graphically brought out in fig. 43 of Dr. Geikie's memoir. . . . Anyone trusting to surface-feature might well fancy that the basalts . . . lay upon, and were newer than, the granophyre. . . . Let us all take warning thereby."¹

How anyone reading the memoirs of Principal Forbes and Prof. Zirkel could possibly imagine that they had jumped to conclusions which they published concerning the relations of the two sets of igneous rocks in question, without properly examining the evidence, I am at a loss to conceive. Their memoirs exhibit proofs of the most careful and painstaking study of the lines of junction, and it seems to me needless to combat the idea that they published statements based only on hasty views of the ground from a distance.

For myself, I may add that, before adopting the conclusions of my predecessors, I carefully studied the sections they described, as well as others, and satisfied myself that these two authors were perfectly accurate as to their facts and rigidly logical in their conclusions.

The confident statements of our critic led me, however, to re-examine the whole of the junctions again with the greatest care. It then soon became evident how the mistake on the part of Sir Archibald Geikie—for that it was a mistake no one who examines the evidence now adduced can for one moment doubt—has arisen. In his memoir in the Transactions of the Royal Society of Edinburgh there are given a number of sketches—most of them necessarily taken from a distance, as they represent whole mountain-sides—in which the granites are shown as sending off veins into the 'bedded basalts.' On reference to the text, it is seen that the 'basalts' near

¹ 'Nature,' vol. xxxix. pp. 132-134 (Dec. 6th, 1888).

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these igneous intrusions are said to be strangely altered, and converted into a splintery rock which weathers with white surfaces. These rocks, it is obvious, are the lavas which I described under the name of 'felstones' in 1874, and into which, as I then showed, the granites send numerous veins. Two years ago I gave full petrographical details concerning this remarkable series of rocks, and I showed that, so far from their being basalts, they are for the most part andesites, many of them with a very high percentage of silica, but usually converted by solfataric action—probably connected with the intrusion into them of the granites—into the 'propylitic' modification.¹

The description of the beautiful and unmistakable inclusions of granite ('granophyre' of some authors), lying within the gabbro in the area of its best development, now completes the evidence as to the younger age of the latter rocks which has been disputed by Sir Archibald Geikie. I may mention, however, that, when I describe in detail the acid rocks, I shall be able to add many other facts which are scarcely less decisive than this in their bearing on the question.

8. POSTSCRIPT.

[In the discussion which followed the reading of this paper complaint was made that no notice had been taken of the alleged existence—at the locality described—of veins proceeding from the granite into the gabbro. It was a desire not to complicate the very definite issue raised in the title of the paper, with questions upon which a remarkable conflict of testimony exists, that led to my avoidance of the subject; but, as my motive has been misunderstood, I will as briefly as possible state what that testimony is.

Macculloch and Forbes alike called attention to the profusion of pale-coloured, contemporaneous or segregation-veins in the gabbro of the Cuillin Hills; they both assert, however, that veins are never found passing from the granite into the gabbro. The results of my own observations, at this and other localities in the Western Isles of Scotland, were, as I stated in 1874, in complete accord with those of my predecessors. Fragments of basic rock can of course be easily found which are traversed by white veins; but there is no difficulty, especially under the microscope, in distinguishing between the white segregation-veins of the gabbro, composed as they are of lime-felspars, and apophyses of the granite, containing alkali-felspars. It was not until 1888 that Sir Archibald Geikie made the statement that veins of granite do cut through the gabbro at Meall Dearg and other points. I can only add that since this assertion was made I have revisited all the localities referred to, but have never succeeded in finding true granite-veins penetrating the gabbro. It was, in fact, while vainly engaged in searching for such veins that I discovered the very conclusive evidence of the inclusions described in this paper. It appears to me that the existence of these inclusions of granite in the gabbro is absolutely irreconcilable with the occurrence of veins of the same granite cutting through the gabbro.—March 17th, 1893.]

¹ Quart. Journ. Geol. Soc. vol. xli. (1890) pp. 341-354.

EXPLANATION OF PLATES II. & III.

In PLATE II. the very characteristic weathered surfaces of the fused granite of the Cuillin Hills is represented, all the figures being of the natural size.

- Fig. 1. Shows a mass, probably from near the edge of an inclusion, in which the most perfect flow-structure is exhibited. The fine bands, which are slightly different in colour, can in places be seen to be formed of drawn-out spherulites. Microscopic examination shows that, in this case, the phenocrysts have been almost completely absorbed in the glass.
 - Fig. 2. A somewhat similar banded spherulite, in which the bands have, by the movements of the molten mass, been made to assume beautiful puckerings and contortions, so well exemplified in some of the rhyolites of Hungary, the Ponza Islands, and many other districts.
 - Fig. 3. A very striking example of a banded mass, with spherulites of very different sizes, drawn out and crushed. This rock greatly resembles certain varieties of rhyolite from Obsidian Cliff.
 - Fig. 4. A rock showing the puckered banding in union with large spherulites, which are sometimes 'lithophyses.'
 - Fig. 5. Very characteristic 'hollow spherulites,' exposed by weathering.
- (In the last two figures the phenocrysts of the original granite are very conspicuous and stand out in relief.)

In PLATE III. microscopic sections of the altered minerals and the spherulitic growths of these inclusions are represented.

- Fig. 1. Shows quartz-crystals with large glass enclosures, the crystals being much cracked, while in places the surrounding glass has penetrated along and opened out the cracks.
- Fig. 2. Shows a quartz-crystal which, by the corrosive action of the glass penetrating along cracks, has been broken into four fragments. The action of these fragments under polarized light shows that they are parts of the same crystal.
- Fig. 3. A greatly cracked quartz-crystal which has had developed around it a shell of secondary 'pyrogenic' quartz. The secondary quartz is seen filling a crack which traverses both crystal and matrix. The secondary and original quartz show perfect continuity in polarized light.
- Fig. 4. Two orthoclase-crystals, twinned and untwinned, with 'contraction-rifts,' along which secondary felspar-substance has been developed.
- Fig. 5. Orthoclase-crystal similarly altered, but with a nucleus, probably containing stone-cavities originally, which has been completely fused.

(Figures 1-5 are represented as seen with a power magnifying 30 diameters.)

- Fig. 6. Small oligoclase-crystal lying in a mass of glass containing trichites, now converted into hydrous iron oxide; many of these are attached to the edges of the felspar.
- Fig. 7. Section of one of the largest of the complex spherulites, natural size; the dark parts represent the ordinary spherulitic growths (see fig. 8), and the paler-coloured portions the 'trichitic spherulites' (see fig. 9). These spherulitic growths radiate from and enclose smaller spherulites and the original phenocrysts of the granite.
- Fig. 8. Ordinary spherulitic growths forming the smaller dark portion of this spherulite, and showing radiating and concentric structure, with numerous scattered grains of magnetite which give them their dark colour; magnified 30 diameters.
- Fig. 9. Trichitic spherulitic growths, with similar radiating and concentric structure, which make up the larger part of the spherulite. High powers show that the pale creamy tint is due to innumerable trichites which have been converted into brown oxide of iron. The figure shows a tuft seen with a magnifying power of 30 diameters.
- Fig. 10. Spherulite, with nucleus of micropegmatitic granite; natural size.
- Fig. 11. Nucleus of micropegmatitic granite magnified, showing the surrounding vitrified crust with crystals of pyrites.
- Fig. 12. Spherulites, natural size, with two nuclei of micropegmatitic granite.
- Fig. 13. Enlargement of the upper and larger of these nuclei, with its glassy crust. (It is this granite mass which is shown as seen under the microscope in the figure on p. 189.)

DISCUSSION.

The PRESIDENT remarked that those who had followed the subject attentively were well aware that the Author had made the Western Islands of Scotland his own particular study, and the Society was glad to be again favoured with an interesting memoir from him. The paper was distinctly separable into two portions, the first of which, purely petrological, afforded a useful definition of the processes of fusion of acid by basic rocks. The second portion was peculiarly interesting, since it conveyed a direct challenge to those who took opposite views (to those of the Author) as regards the relative age of acid and basic rocks. The geology of the Highlands had ever been fruitful of controversy. It was, however, impossible for any one not thoroughly acquainted with the district to say how matters stood. He was sure that all present were now anxious to hear the other side of the question.

Sir ARCHIBALD GEIKIE observed that a doubt might well be entertained whether the so-called 'inclusions' of the Author were really such; for the petrographical description of them was suggestive rather of obsidian and rhyolite-veins. No account had been given of the structure of the surrounding rock with relation to the 'inclusions' and their supposed metamorphism. He was willing, however, for the sake of argument, to allow them to be actual blocks enclosed within the gabbro. But surely the sweeping generalization drawn from them by Prof. Judd, as to the age of the great acid protrusions of the Western Isles, was not warranted. Geologists have been in the habit of believing that all that can be demonstrated from such evidence is that an enclosed block must be older than the rock immediately enclosing it. Beyond that point all attempt to fix more precisely their relative dates is inference, which may be probable or not according to the circumstances of the case. But the speaker was again ready, for the sake of argument, to waive this objection and to concede that the 'inclusions' were not ancient rocks, but portions of some of the acid masses of the Tertiary volcanic series in the Hebrides. Yet, even with this admission, was the Author entitled to say that he had brought forward any valid proof of the relative ages of the basic and acid bosses of the West of Scotland? Most assuredly not. Sir Archibald Geikie stated that he had shown that there were traces of acid protrusions at an early part of the volcanic history of that region, and that blocks of various acid rocks were abundant in the volcanic agglomerates and in some of the tuffs intercalated among the plateau-basalts. The alleged 'inclusions' of the Author, if truly such, would thus be most naturally assigned to this early series of acid rocks, of which only ejected fragments had yet been found. Hence, even on the Author's own ground, the supposed demonstration that the granitic bosses are older than the gabbro masses entirely failed.

But the true state of the case had not been put before the Society. Quoting from his memoir in the Transactions of the

Royal Society of Edinburgh (which the Author refers to), Sir Archibald Geikie pointed out that from the same neighbourhood where the 'inclusions' are said to occur he had cited a remarkable portion of the junction-line between the granite and gabbro, and had described the occurrence of numerous veins proceeding from the mass of granite there and traversing the gabbro. Why had Prof. Judd kept silence as to these observations? If they were true, they afforded a complete demonstration that he had reversed the order of appearance of the two rocks. Until they were disproved it was idle to bring forward such weak evidence and inconclusive reasoning as had been offered in the present paper. But the case against the Author rested, not on the testimony of this one locality only, but on that of many others throughout the Western Isles. The speaker referred to numerous examples described in his memoir, where, by similar proofs of intrusion, he had demonstrated the posteriority of the granitic masses. The granitic veins and dykes of Skye, Mull, Rum, etc., not only traverse the plateau-rocks which Prof. Judd originally called felstones and now terms propylites, but also the great cores and sills of gabbro. The great granitic bosses are cut only by the youngest basic dykes. Whether these dykes were accompanied by the intrusion of sills or bosses of basic material had not yet been ascertained.

No man could pretend to have exhausted a subject or a region, and Sir Archibald Geikie said he well knew that an observer coming after him, with more time and maps on a larger scale than he had been able to obtain, would correct mistakes into which he himself had fallen, and would supply a multiplicity of detail which he had missed. He could only claim to have sketched an outline of a great subject; but he felt well assured that when this outline was eventually filled in, the position which he had assigned to the granitic bosses of the Inner Hebrides would be amply confirmed.

Dr. DU RICHE PRELLER said that a striking analogy existed between the Tertiary gabbros and granites of Mull and those of Elba, with which latter he was acquainted. In Elba, however, the granite was clearly injected both into gabbro and diabase, and was therefore of a more recent Tertiary period than either of these rocks. These rocks occurred in the schists and associated calcareous strata which Signor Lotti had shown to be Eocene. If the igneous 'greenstone' rock of St. Kilda to which Sir Archibald Geikie referred, and of which he exhibited a specimen showing a distinct intrusive granitic vein, was a true gabbro, the case of Elba undoubtedly tended by analogy to strikingly confirm Sir Archibald's view of the Skye rocks; but the question was whether Sir Archibald and Prof. Judd really referred to the same rocks. Dr. Preller showed, by several sections, the intrusion of the Elban Tertiary granite into diabase and gabbro, and also of diabase into gabbro: both these last-named rocks being in many cases altered into serpentine, which always underlies either one or the other, or both where all three occur together. Some geologists still held that the eruption of diabase was confined to the Palæozoic period, but the case of Elba demonstrated that there the

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Tertiary diabase erupted even after the Tertiary gabbro, and that the Tertiary granite erupted after the diabase, and was thus the last eruptive member of all in that island.

Mr. RUTLEY commented on the close resemblance between the microscopic structures described by the Author and those occurring in vitreous lavas.

Mr. W. W. BEAUMONT and Mr. GEO. BARROW also spoke.

Prof. Bonney being unavoidably absent, the AUTHOR of the paper asked permission (in accordance with a precedent that had recently been established) to read the following statement which had been received from him :—

“The specimens which you showed me recalled to memory certain felstones which had been affected by the heat of later intrusive rocks; they differed from felstones which had cooled in the usual way. The differences became more marked on microscopic examination. It seems impossible to deny that these rocks represent a variety of granite which has been partially melted down again *in situ*. Portions of the granitic original remain here and there, and form nuclei in the spherulites. This does not resemble the ordinary granites of Scotland, such as that of Ballachulish, but appears to be identical with the Tertiary granite (often called ‘granophyre’) of the Western Isles. So the latter must be earlier in date than the gabbro.”

The Author, replying to Sir Archibald Geikie's suggestion that the masses of altered rock might be *veins* and not *inclusions*, pointed out that not only were the forms of the masses lying enclosed in the gabbro quite different from those of veins, but the petrographical evidence—such as the remarkable alteration of the minerals and the occurrence of fragments of micropegmatitic granite as nuclei in the spherulites—were altogether irreconcilable with such an idea. To the assertion that the occurrence of these inclusions at one locality is not sufficient to prove the relative ages of these two great rock-masses, he rejoined that a single and indisputable case of one rock enclosed in another did prove, beyond all controversy, that the enclosing rock is *younger* than the enclosed masses. In this case the inclusions occur near to the line of junction of the largest and most typical areas of granite and gabbro in the whole region—those of the Red Mountains and the Cuillin Hills of Skye, and at a locality selected by Sir Archibald Geikie himself as a most perfectly representative one. With respect to the assertion that, at this place, veins proceed from the granite into the gabbro, earlier writers on the district had looked for and failed to discover such evidence. He had himself gone again and again to the very spots indicated by the Director-General of the Survey, and could find nothing of the kind, while he did obtain abundant evidence opposed to this view. He maintained that loose fragments, like those picked up on the shore at St. Kilda, and now exhibited by Sir Archibald Geikie, do not support his views. They show a dark rock traversed by veins of a light one, but the dark rock is not a gabbro, and the light rock is not a granite.

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M.P. Parker del.

Mintern Bros. imp.

WEATHERED SURFACES OF GRANITE-INCLUSIONS.

M.P. Parker del.

Mintern Bros. imp.