

20. *The PROPYLITES of the WESTERN ISLES of SCOTLAND, and their RELATION to the ANDESITES and DIORITES of the DISTRICT.* By Prof. JOHN W. JUDD, F.R.S., F.G.S. (Read February 5, 1890.)

[PLATES XIV. & XV.]

- I. Introduction.
- II. Previous Literature.
- III. Physical Characters and Chemical Composition of the Scottish Propylites.
- IV. Microscopical Characters.
- V. Relations of the Scottish Propylites to the other Rocks of the District.
 - A. *Geological Age.*
 - B. *Structure.*
 - C. *Nature of Rock-masses.*
 1. *Lava-streams.*
 2. *"Cupolas."*
 3. *"Laccolites."*
- VI. Nature of the Original Rocks from which the Propylites have been formed.
 - A. *Amphibole- and Mica-andesites and Diorites.*
 - B. *Pyroxene-andesites and Pyroxene-diorites.*
- VII. Causes by which the Propylitic Modification of these Rocks has been brought about.
 - A. *Solfataric Action.*
 - B. *Contact-Metamorphism.*
- VIII. Light thrown by the Study of these Tertiary Lavas on some of the Older Volcanic Rocks (Porphyrites, Felstones, &c.).
- IX. The Younger Augite-andesites ("Tholeites," "Pitchstones," &c.) of the Western Isles of Scotland.
- X. Summary of Results.

I. INTRODUCTION.

THERE exists in the Western Isles of Scotland a great series of lavas which, for the most part, underlie the ophitic olivine-basalts, and constitute the oldest of the ejections of the great Tertiary volcanoes of that district. These rocks were distinguished by me in 1874 under the old English field-name of "Felstones," and it was stated that they "vary in colour from black, through various shades of green and grey to white; but in almost all cases their surfaces acquire a white crust in consequence of weathering action"*.

In attempting, at that date, to define more exactly the characters of these lavas, by studying them microscopically in thin sections, I was confronted by two difficulties. In the first place, it soon became manifest that these more acid lavas of the Western Isles include a great variety of types—differing widely from one another in mineralogical constitution and in structure; and in the second place it was found that the minerals of which those rocks were built up were in a remarkably altered condition.

In both these respects, the "felstones" present a very striking contrast to the overlying series of ophitic olivine-basalts. The latter, as I have shown †, are remarkable for their uniformity of composition

* Q. J. G. S. vol. xxx. (1874) p. 236.

† *Ibid.* vol. xlii. (1886) p. 49.

and character, and, except where influenced by surface-agencies, seldom present any great signs of alteration; they are indeed, as a rule, singularly fresh and unchanged in their appearance.

But in the "felstones" which underlie the basalts the most extreme metamorphism is seen to have taken place; the felspars are found to be so completely kaolinized that it is sometimes impossible to decide whether they should be referred to orthoclase or to plagioclase; the pyroxenes, amphiboles, and micas are converted into isomorphic mixtures or into minerals of the chlorite group; while in many cases the formation of epidotes and other secondary minerals at the expense of the original constituents of the rock has gone on to such an extent as to completely obliterate their distinctive characters. It may be safely asserted of many of these rocks that they are at the present time entirely made up of *secondary* minerals, the porphyritic constituents being represented by pseudomorphs, while the ground-mass has been completely recrystallized.

In 1874 I had been able to study only a few of the leading types of these rocks microscopically, and consequently did not feel justified in attempting a complete diagnosis of their varieties; therefore I contented myself with the grouping them under a convenient field-name.

During the last fifteen years, however, I have devoted much time to the study of these rocks both in the field and in the laboratory. The result of these studies is to show that among these "felstones" there are presented to us many interesting types of rhyolites, dacites, and sanidine-trachytes, intercalated with which are a few basalts, some of them of the same ophitic type as those so abundantly poured out at a somewhat later date. With these there also occur certain rocks which are so remarkable in their mineralogical constitution and structure that they do not seem capable of being referred to any of the accepted petrographical types; and these anomalous rocks I hope to describe on a future occasion.

But the great majority of these Hebridean "felstones" prove to belong to the family of the andesites, and to that "pathological variety,"* to use Rosenbusch's expressive term, to which the name of "propylite" has been given.

The delay in publishing the results of my researches upon these curiously altered rocks has not been unattended with advantage. Many interesting details concerning the propylitic rocks of other areas have been published in the interval both in Europe and in America: and during the same period there have appeared several very important memoirs on the rocks of the Faroe Isles, Iceland, and Greenland—districts in which the Tertiary igneous rocks present the most marked analogies with those of our own Western Isles †. The comparison of the much altered Scottish rocks with the very fresh examples in these several districts has often afforded valuable aid in the interpretation of the former.

* Rosenbusch, 'Massige Gesteine,' 2nd ed. p. 691.

† See Q. J. G. S. vol. xli. (1886) p. 53.

II. PREVIOUS LITERATURE.

In his great work on the Geology of Hungary, Beudant, as early as 1822, distinguished a series of rocks presenting very well-marked features, to which he gave the name of “porphyres trachytiques”*.

In 1860, Baron von Richthofen proposed to separate these rocks from the ordinary trachytes (andesites) of Hungary and Transylvania under the name of “greenstone-trachytes”†; and this term—indicating their analogies both with plutonic and with volcanic rocks—was very generally accepted by von Hauer, Stache, and the other geologists of Austria.

In 1868, however, von Richthofen was led by his study of the volcanic rocks of California and Nevada to abandon the term “greenstone-trachyte” in favour of that of “propylite;” he was induced to make this change from his conviction that, in Hungary and Transylvania, as well as in the western districts of the North-American continent, the rocks in question were the earliest erupted of the whole series of Tertiary lavas‡.

In 1875 the late Mr. Poulett Scrope, who was well acquainted with the Hungarian rocks, pointed out to me the close similarity between many of the features exhibited by the volcanic rocks of that country and those which I had described in the Western Isles of Scotland. In consequence of his advice, and with his friendly assistance, I visited Hungary and Transylvania in that year, and some of the general results of the comparisons then made were submitted to this Society shortly afterwards. The conclusion at which I arrived with respect to the “greenstone-trachytes” or “propylites” of Eastern Europe was that, while they have intimate relations on the one hand with the andesites, and on the other hand with the diorites of the same district, yet many of their peculiarities are certainly due to their having undergone great alteration, especially in consequence of having been acted upon by acid vapours§.

The name “propylite,” as distinctive of a well-marked group of rocks, was adopted by Mr. Clarence King and other members of the United-States Geological Survey engaged in the exploration of the Western Territories, and the term thus became familiar to all students of American geological literature, while its use in Europe still continued to be very restricted.

In 1876, however, Prof. Zirkel published the results of his microscopical study of the North-American rocks; and in this work he endeavoured to define the particular characters which seemed to justify the retention of the “propylites” as a distinct type of rocks||. Dr. Zirkel pointed out that, while in their geological relations the propylites are clearly associated with the Tertiary

* Voyage Minéralogique et Géologique en Hongrie, tome iii. p. 344.

† Wien. Geol. Verhandlungen, xi. (1860) pp. 91–94, and Jahrb. k.-k. geol. Reichsanstalt, Wien, xi. (1860) pp. 154–276.

‡ Mem. California Acad. of Sci. vol. i. (1868).

§ Q. J. G. S. vol. xxxii. (1876) p. 298.

|| Microscopic Petrography, vol. vi. of the U. S. Geol. Expl. of the Fortieth Parallel (1876), pp. 110–121.

lavas, yet in the characters of their constituent minerals and in the enclosures which these minerals exhibit they present the most remarkable analogies with some of the older dioritic rocks. Vom Rath also adopted the same view as Zirkel as to the close relations existing between the propylites and plutonic rocks and their distinction as a group from the andesites.

In the first edition of his very valuable work '*Mikroskopische Physiographie der Massigen Gesteine*,' published in 1877, Professor Rosenbusch not only refused to accept the term "propylite" as distinctive of a group, but classed many of the rocks that had been described under that name by other authors among the andesites. In 1879, Dr. Doelter showed that the Hungarian rocks which present the peculiar features held by von Richthofen and Zirkel to be characteristic of the propylites, could be seen to pass by insensible gradations into ordinary andesites*; and the view that the propylites were really altered forms of the andesites, was very forcibly upheld by Rosenbusch in a review of Doelter's memoir, published shortly afterwards†.

In the same year Dr. Wadsworth strongly insisted that the distinction between propylites and andesites could not be maintained in the case of the North-American rocks‡.

Dr. Szabò of Buda-Pest, Dr. Anton Koch of Klausenburg, and Dr. E. Hassak of Gratz, have all expressed the opinion that the propylites of Eastern Europe are really altered forms of the andesites.

The publication in 1882 of Mr. George F. Becker's "Geology of the Comstock Lode and the Washoe District" marks an important epoch in the history of the propylite controversy§. Mr. Becker, while still continuing to classify the diorites and other plutonic rocks as Pre-Tertiary, maintained that the propylites could not be regarded as a distinct group of rocks, but only as a distinct "facies" or "habitus" of the andesitic lavas. As the result of a microscopic study of a large series of specimens obtained during the construction of the Sutro Tunnel, and the numerous deep workings of the Comstock Lode, Mr. Becker was able to show how, by the gradual alteration of their constituent minerals, the hornblende- and augite-andesites could be seen to gradually acquire those peculiar characters which had been held to be distinctive of the propylites.

Not less important as a contribution to this interesting question is the very remarkable memoir of Messrs. Arnold Hague and J. P. Iddings, "On the Development of Crystallization in the Igneous Rocks of the Washoe District"||. The authors of this memoir, while fully accepting the conclusions of Mr. Becker that the propylites of the Washoe district are simply altered forms of the andesitic lavas, went much further, and proceeded to show that the

* Verhand. d. k.-k. geol. Reichs. 1879, p. 27.

† Neues Jahrb. für Min. &c. 1879, p. 648.

‡ Bull. Mus. Comp. Zool. vol. v. (1879) p. 285.

§ United States Geol. Surv. Monograph iii. (1882).

|| Bull. of the U.S. Geol. Surv. No. 17 (1885).

distinction between the Tertiary hornblende- and augite-andesites and the supposed older diorites and diabases could no longer be maintained. This conclusion they were able to establish by a careful examination of the extensive materials collected by the officers of the United-States Geological Survey. They proved that the diorites are only deep-seated portions of the rocks, which are poured out at the surface as hornblende- or mica-andesites, and that both alike are of Tertiary age; the differences between them were shown to be due, not to the *period* of their formation, but to the more perfectly developed crystallization in the deeply seated masses. The "diabases" of the district were also proved to be similarly related to the augite-andesites.

In the second edition of his 'Massige Gesteine,' published in 1886 and 1887, Professor Rosenbusch admirably summarizes the results which have been obtained by the study of both the European and the American propylites. Admitting, with von Richthofen and Zirkel, the extreme modification of the constituent minerals, and the frequently well-developed crystallization, that recall so strikingly the characters of the diorites and diorite-porphyrates, he shows that the former characters are unquestionably due to the *peculiar kind of alteration* that the rocks have undergone. The term "propylite" is therefore accepted only as serving to distinguish a well-marked and interesting facies of the andesitic type of rocks—"a pathological variety," employing Rosenbusch's apt designation. Used in this way, the term propylite may still be of great service to petrographers and field-geologists as a descriptive name; just as the terms shale, melaphyre, and porphyrite are convenient, and even necessary to us, for describing peculiar modifications of clay, basalt, and andesite respectively. It is in this sense that I propose to use the term propylite in the present memoir.

I shall be able to show that a careful study of the oldest Tertiary igneous masses in the Western Isles of Scotland makes us acquainted with a series of rocks presenting all the distinctive features of the "greenstone-trachytes" of Hungary and Transylvania, and of the "propylites" of California and Nevada.

I shall endeavour to illustrate the exact nature of the processes by which ordinary andesites (and rocks which in their structure and degree of crystallization are intermediate between andesites and diorites) have been converted into the curious varieties that present all the characters of the "greenstone-trachytes" or "propylites"; and it will be my especial aim to investigate the exact *causes* to which these peculiar modifications must be assigned.

III. PHYSICAL CHARACTERS AND CHEMICAL COMPOSITION OF THE SCOTTISH PROPYLITES.

In colour these rocks vary from a very dark grey, almost black tint, through many lighter shades, to varieties that are nearly white. Usually, however, more or less marked green tints are exhibited by them, and in some cases this colour becomes very pronounced.

Though often very dark-coloured, their lustre is usually dull, and they seldom if ever exhibit the jet-black tint and velvety aspect so often found in the olivine basalts of the district. The rocks are usually, though by no means invariably, of porphyritic structure, and the crystals of felspar have the opacity and the absence of vitreous lustre so often seen in the more ancient and plutonic rock-masses. Not unfrequently rocks that appear at first sight to be perfectly compact are shown by their mode of weathering to have been originally made up of angular or rounded fragments, a conclusion which is confirmed by microscopic study. Under the microscope, indeed, many compact and seemingly homogeneous rocks are seen to present all the characters of volcanic agglomerates and tuffs, and are found to be composed of a great variety of ejected fragments.

On freshly fractured surfaces or on faces that have been weathered, these rocks often exhibit evidence of possessing a strikingly banded and fluidal structure, and, under the same conditions, the porphyritic habit which is so general in these rocks becomes very conspicuous. It is very remarkable to find that many rocks which are of a uniform dull grey colour, and apparently quite homogeneous or compact in texture, must originally have presented all the characters which distinguish flowing lava-streams or beds of scoriæ and lapilli. These conclusions as to the original characters of the volcanic materials are fully confirmed, as we shall see when we come to study their microscopical characters. It is evident that the alteration, attended in many cases with an almost complete recrystallization of their materials, has effectually masked their original characters.

Many of these rocks were evidently originally scoriaceous; and, as the result of weathering, these often assume at the surface their pristine slaggy appearance. In many cases the cavities are occupied by aggregates of epidote- (pistacite) crystals usually enveloped in zeolites; and these clusters of green crystals, by the weathering-out of the surrounding zeolites, stand up in relief on the exposed surfaces of the rocks. Veins and nests of epidote also abound in many of these rocks. In other cases the black enclosures (originally green) to which Macculloch gave the name of Chlorophaeite are very conspicuous.

Vitreous varieties of these rocks sometimes occur, and such perfectly glassy parts of the rocks often exhibit but little alteration. The same fact is illustrated in the andesites of the Cheviot Hills, where the glassy portions are far less altered than the associated stony portions of the same mass. It would seem that these glassy varieties resist the percolation of solvents through their mass to a much greater extent than rocks made up of aggregates of dissimilar particles, and thus remain in a comparatively unaltered state.

The white crust which covers the weathered surfaces of the Scottish propylites has been already referred to as one of their most distinguishing characteristics. The origin of this white crust appears to be as follows:—by changes, which will be hereafter described, much of the iron has separated as secondary magnetite. Almost

everywhere in the Western Isles the rock-surfaces are acted upon by peaty waters; and just as brown sandstones and other ferruginous rocks become bleached by this action, so do the igneous masses, which have been rendered more permeable by the extensive alteration of their constituent minerals, become bleached to the depth of a few millimetres from the surface. That this is the true explanation of the phenomenon is confirmed by a microscopic study of these white crusts themselves, and of the parts of the rock where they graduate into the dark-coloured mass.

Another distinguishing characteristic of the Scottish propylites is the presence of considerable quantities of pyrite and other sulphides diffused through their mass. Certain rocks about Salen in Mull, and in Ardnamurchan, for example, when broken, are seen to be studded all through their mass with pyrite-crystals. In other cases marcasite and chalcopyrite are found, and these sulphides are often present in such quantity as to constitute an important constituent of the rocks. All who are acquainted with the "greenstone-trachytes" of Eastern Europe and the "propylites" of the Western Territories of the United States will recognize this as a feature which they present in common with the Scottish rocks. In one case I have found metallic copper forming thin plates scattered through the rock.

One of the readiest means of distinguishing the dark-coloured, much-altered andesites from the overlying olivine-basalts is by a determination of their specific gravity. While the gabbros, dolerites, and basalts have a density which always approaches to and sometimes exceeds 3, the propylites and their deep-seated representatives have a distinctly lower specific gravity, ranging from 2.4 to 2.9*.

During the last fifteen years, I have been able to compare the results of a great number of determinations of the specific gravities of the Scottish propylites, which have been carried out by various methods, in the geological laboratories of the Normal School of Science and Royal School of Mines. Some of these determinations have been kindly made for me by Mr. Grenville Cole, F.G.S., or by students working under his supervision; others have been contributed by Mr. W. B. D. Edwards, Mr. T. H. Holland, Mr. J. W. Evans, F.G.S., and Mr. W. F. Hume, F.G.S., working in the Research Laboratory of the school, and these gentlemen have spared no pains in obtaining and verifying their results.

A comparison and analysis of the great mass of specific-gravity determinations thus placed at my disposal shows that the propylites of the Western Isles of Scotland may be roughly classed in two great groups—those in which the specific gravity ranges from 2.4 to

* Shortly after the appearance of my first memoir on these rocks in 1874, Mr. W. Walker, F.G.S., wrote to inform me that, having visited the district described by me, in company with Mr. James Durham, he had been led to devise a portable balance for the purpose of obtaining rapid and approximately accurate determination of the specific gravity of rock-specimens. This balance proves to be of great service, as it can be employed by the geologist when he is far away from the resources of a laboratory. (See *Geol. Mag.* dec. ii. vol. x. p. 109, and *Proc. Geol. Assoc.* vol. viii. p. 278.)

2·7, and those in which the limits are 2·7 and 2·9. As a general rule (though colour is often a very unsafe guide) the former group comprises pale-coloured rocks, while the latter are generally dark-coloured.

The less dense, pale-coloured rocks, we shall presently see, were originally hornblende- and mica-andesites, and the heavier dark-coloured rocks are, for the most part, pyroxene-andesites.

Looking more closely into the results, we find that differences in specific gravity in each of these classes of rocks is dependent *first*, on the degree of development of crystallization in them, and *secondly* on the amount of chemical alteration which they have undergone.

As an example of difference of density in the more acid types, I may cite the case of the hornblende-propylite of Beinn Talaidh (Beinn Talla) in Mull. In the deep Corry of Tomsleibe the rock is highly crystalline, and, indeed, approaches a diorite, having a specific gravity of 2·68; while in the upper and superficial portions of the mass the rock is compact, and has a density of 2·60. Glassy varieties of the amphibolic rocks have a density of only a little over 2·4.

Among the more basic types, I may cite the pyroxene-propylites of Mingary Castle in Ardnamurchan. Highly crystalline forms of this rock have a density of 2·88, while the specific gravity of the compact varieties of the same rock is only 2·75. At Bealach a' Mhàim, in Glen Brittle, we find a rock of this type with a specific gravity of 2·89, which passes locally into a glass with a density of only 2·63.

The effect of the processes of alteration upon these rocks is generally to lower their specific gravity. Thus the much altered hornblende-propylites, with abundant chlorite and epidote developed in their mass, are found to have a density of 2·5, or even less, while the similarly altered pyroxene-propylites have a density which seldom much exceeds, and sometimes does not reach 2·7.

In cases where it is not practicable to make a complete chemical or microscopical study of the rocks, a determination of specific gravity affords a much safer criterion for their discrimination than colour. Some of the hornblende-propylites are of a very dark grey, and indeed almost black colour, though seldom exhibiting the lustrous jet-black of the olivine basalts; while, on the other hand, extreme alteration may sometimes cause the pyroxene-propylites to assume a pale grey and almost white colour.

The distinction of the Scottish propylites into two groups is borne out when we examine their chemical composition. A number of chemical analyses have been made for me by Mr. T. H. Holland in the Geological Research Laboratory of the Normal School of Science, and for some silica determinations I am indebted to Mr. Grenville Cole, F.G.S., and Mr. J. H. Power. I am also under great obligations to my colleague Professor Thorpe, F.R.S., for allowing a number of analyses of these interesting rocks to be carried out under his direction in the chemical laboratories of the same Institution. These analyses enable us to make comparisons between the different types

of propylites of the Western Isles of Scotland and those of Hungary and Transylvania, on the one hand, and of the Western States of North America, on the other, the chief districts in which they have been studied.

As a type of the analyses of the more acid varieties of the Scottish propylite we may cite that of the rock of Beinn Talaidh—a hornblende-andesite passing into a diorite—placing side by side with it a European and an American rock of analogous constitution.

	I.	II.	III.
Silica	62·89	63·05	63·13
Alumina	14·84	14·18	16·00
Ferric oxide	9·20	....	4·34
Ferrous oxide ....	....	6·71	1·52
Manganic oxide ..	trace		
Lime	3·61	5·40	4·45
Magnesia	0·37	1·12	2·07
Soda	4·01	5·65	3·87
Potash	2·91	3·49	2·65
Loss on ignition ..	1·41	2·04	2·00
Total	99·24	101·64	100·03

I. Analysis of highly crystalline hornblende-propylite from the deep Corry in Beinn Talaidh, Mull, made by T. H. Holland, 1889.

II. Analysis of hornblende-andesite (propylite) from Tokay (Banhof), Hungary, by K. v. Hauer, Verh. k.-k. geol. Reichsanst. 1869, p. 146.

III. Analysis of hornblende-mica-andesite (propylite) from Cross Spur Quarry, Washoe, made by R. W. Woodward, 1875.

A good type of the more basic pyroxene-propylites of the Western Isles of Scotland is found in the much altered rocks exposed on the western slopes of the Beinn More in Mull, and between that mountain and A Chioch. Analyses of European and American rocks are added for comparison with it.

	I.	II.	III.
Silica	58·07	59·56	58·44
Alumina	17·62	20·38	18·17
Ferric oxide	4·97	5·87	
Ferrous oxide	3·09	....	6·03
Manganic oxide ..	traces		
Lime	5·23	6·82	6·19
Magnesia	1·46	3·71	2·40
Soda	3·31	1·49	3·20
Potash	2·15	1·25	1·97
Loss on ignition ..	4·15	1·85	3·63*
Total	100·05	100·93	100·03

* Including 2·87 per cent. of Carbonic Acid.

I. Analysis of much altered pyroxene-propylite from Beinn Morc, Mull. Made by G. H. Perry in the Chemical Laboratory, Normal School of Science.

II. Analysis of augite-andesite, Gyetva, Hungary, by Wymietal in Tschermak, Min. Mittheil. 1868.

III. Analysis of pyroxene-andesite (containing hornblende) from the north-east of American Flat, Washoe. Made by W. G. Mixter, 1875.

While, however, it is convenient to make a broad general distinction between the usually pale-coloured and lighter amphibolic varieties and the dark-coloured and heavier pyroxenic forms of these rocks, it must be confessed that the division into acid and basic types of propylite is of no great value. Even when there is no free quartz present, either of primary or secondary origin, the variations in the proportion of porphyritic crystals to base lead to wide variations in the ultimate chemical composition of the different rocks. In this way we often find that pyroxenic rocks are of more acid character than amphibolic ones. The extreme modification, too, which many of these lavas have undergone leads to most remarkable changes in their colour, specific gravity, and chemical composition, and still further leads to breaking down the distinction between the two types which, for convenience of description, we have sought to institute.

IV. MICROSCOPICAL CHARACTERS.

The microscopical characters presented by these lavas may be summarized as follows:—

Although many of the rocks must have originally contained much vitreous or uncrystallized material in their ground-mass, yet in almost every instance this glassy substance has disappeared through secondary devitrification. In the majority of cases, the development of secondary minerals in the substance of the ground-mass has completely obliterated the original micro-structure of the rock; but in some instances we find traces of spherulitic, fluidal, and perlitic structures; while in others the structures known as “granophyric” can be detected—such as the micro-pegmatitic, the centric, and the pseudo-spherulitic.

As a general rule, it may be said that the ground-mass is the most highly altered portion of these rocks, this being doubtless due to the fact that the glassy matrix is less stable than the crystallized constituents of a rock. The matrix frequently acquires a green colour from the development of minerals of the chlorite group, and is sometimes studded with crystals of the metallic sulphides.

The porphyritic crystals of feldspar, though so greatly altered, can usually be found to show, here and there, traces of the plagioclastic twinning. They are never, however, in the vitreous condition of the feldspars of ordinary andesitic rocks (microtine), but exhibit the opacity and dull lustre characteristic of the diorites and other deep-seated rocks. It was this condition of the porphyritic feldspars, with the state of the ground-mass and the features

presented by the ferro-magnesian silicates, that led von Richthofen and Zirkel to insist on the analogies of these rocks with plutonic rocks, which were, at the time when these authors wrote, generally believed by Continental petrographers to be of Pre-Tertiary age. Any glass-inclusions that the felspar-crystals may once have contained have, of course, like the glass in the matrix, undergone devitrification, while, as Zirkel has shown in similar rocks in North America, bands of cavities containing liquids are abundant. This character is also conspicuously exhibited by the quartz, which either as a primary or secondary constituent is not unfrequently found in these rocks. I have already stated the grounds that lead me to conclude that these bands of liquid-inclusions are of secondary origin. In many cases, however, the felspar-crystals, while preserving their outward form, have been completely transformed, and now only exist as pseudomorphs. The minerals which replace the original substance of the plagioclase feldspars are pistacite, zoisite, and other minerals of the epidote group, with some new feldspars of secondary origin. Occasionally quartz and calcite have resulted from the extreme alteration which the feldspars have undergone.

The ferro-magnesian constituents of these rocks,—whether pyroxenes, amphiboles, or micas,—are almost always in a more or less altered state. A fibrous structure and a green colour have been developed in them, and, as this change goes on, curious modifications of the optical properties of the minerals are brought about. Frequently we find, as the result of this action, green isotropic materials are formed to which the name of “Viridite” may be properly applied. But, in most instances, we find that from the products of the decomposition of the original ferro-magnesian silicates, various minerals of the chlorite group are developed, and crystallize out from the mass. A still further change is marked by the destruction of these chlorites, and the formation at their expense of various epidotes, among which the varieties known as pistacite and a lime-epidote with a little manganese are conspicuous.

The pyroxenes of these rocks are usually the monoclinic forms or augites; the rhombic enstatites, though not unfrequently present, being, as in the case of the associated basic rocks of this district, usually subordinate and seldom, if ever, a predominating constituent of the rocks. The amphiboles were probably hornblendes, long acicular and tufted forms abounding. It is clear that in the unaltered rocks these crystals of amphibole and those of biotite were surrounded by zones (resorption-halos) composed of pyroxene and magnetite grains, the latter mineral only remaining in the altered state of the rock. Many of the rocks contained biotite as an original constituent; but I shall show in the sequel that much biotite has been developed in these rocks as a secondary constituent.

That titanoferrite was often present in these rocks, as well as magnetite, is shown by the forms of the opaque crystals and by the way in which, as the result of alteration, they become surrounded by the dense white product and the colourless substance derived from it, known as “leucoxene.” Sometimes the abundant magne-

tite, much of which is of secondary origin, has been converted into various forms of hydrous brown oxide, and not unfrequently we find great quantities of pyrite and marcasite developed, doubtless at the expense of the magnetite and ilmenite. In the thin white crust that so constantly covers these rocks the iron has been reduced and, in some cases, removed in solution by the action of water containing organic matter, as already pointed out. In some cases this removal of iron-oxides has gone on throughout the whole substance of the rocks, which become completely bleached.

While in most cases the alteration of the ground-mass and the conversion of the porphyritic constituents of the rock into pseudomorphs has not wholly destroyed its original aspect, yet, under certain circumstances, as I shall point out, the whole structure and character of the mass is found to be completely transformed. This is effected by the crystallizing-out of different minerals (among which the epidotes and chlorites are the most conspicuous) at the expense of the various secondary minerals that have been developed in the mass by the alteration of the felspars and ferromagnesian silicates. These excessively altered varieties frequently constitute rocks of very great beauty and interest*.

From this general account of the chemical, macroscopical, and microscopical characters of these Scottish rocks every one familiar with the accurate descriptions given by von Richthofen, Zirkel, Doelter, Becker, and other petrographers of the "greenstone-trachytes" of Hungary and Transylvania, and of the "prophyrites" of California, Nevada, and Utah, will at once perceive their complete identity†.

[Since this paper was read I have had an opportunity of showing Mr. J. P. Iddings, of the U.S. Geological Survey, a series of specimens and sections of the Scottish prophyrites. He was able to satisfy himself of the close similarity between these rocks and those of the Washoe district in Nevada, which he has so carefully studied; and he has permitted me to state his conviction of their identity in character.]

I shall show that, as in the districts mentioned, the curiously modified prophyrites of the Western Isles of Scotland have been produced from dacites and andesites, and from the deeper-seated and more highly crystalline representatives of those rocks, by the operation of certain well-defined agencies.

* Dr. Hatch, to whom a number of sections cut from these rocks were submitted by Dr. A. Geikie, has fully recognized the completely altered character of the materials he examined. Unfortunately he had no means for judging of the real nature of the rocks from which these were derived (*Trans. Roy. Soc. Edinb.* vol. xxxv. 1888, pp. 77, 167).

† See the excellent summary of these results given by Rosenbusch, 'Massige Gesteine' (1887), pp. 690-693.

V. RELATIONS OF THE SCOTTISH PROPYLITES TO THE OTHER
ROCKS OF THE DISTRICT.

A. Geological Age.

That the great mass of "felstones" or propylites (as I have now shown they ought properly to be called) were the earliest erupted of all the rocks in the Western Isles of Scotland, I have already pointed out in my memoir of 1874.

That the propylites are older than the granitic masses of the district ("granophyres" of Dr. A. Geikie) is shown by the fact that the latter are seen to send off numerous veins into them, and to enclose portions of them in their mass, producing all the phenomena of contact-metamorphism where in apposition with them. These are all facts that I strongly insisted upon in the memoir referred to.

That the gabbros are younger than the propylites is equally obvious. Sheets and dykes of gabbro and dolerite connected with the mountain-like masses can be traced traversing the propylites in all directions, and also giving rise to the phenomena of contact-metamorphism.

That the "felstones" of the Western Isles of Scotland are invaded by the extrusions of granite ("granophyre") and of gabbro is confirmed by many sections described by Dr. A. Geikie*: but, in considering the descriptions given by this author, it must be borne in mind that under the same general name "bedded basalts" he has confounded two totally distinct petrographical types, namely, the ophitic olivine-basalts of the plateaux, which I described in detail before this Society in 1886, and the andesites and associated rocks of the central areas, of which I am treating in the present memoir. He has supposed that the rocks which we are now considering are really basalts which have acquired their peculiar and distinctive characters as a consequence of the metamorphism they have been subjected to through contact with great intrusive igneous masses†.

It will thus be seen that the great cause of the conflict of opinion between Dr. A. Geikie and myself, concerning the relations of the igneous masses of the Western Isles of Scotland, is to be found in the different interpretation we place on these propylitic rocks. Dr. Geikie has clearly noticed these propylites, which he describes in such a way as to avoid possibility of doubt concerning what he refers to. He states that they weather, not like the basalts, but with a "thin white crust, beneath which the rock appears dull, black, and splintery. They are generally veined with minute threads and strings of calcite, epidote, and quartz, which form a yellowish-brown network that projects above the rest of the weathered surface. Where they are amygdaloidal, the kernels no longer decay away or drop out, leaving the empty, smooth-surfaced cells, but remain as if they graduated into the surrounding rock by an interlacing of their crystalline constituents"‡. Unfortunately, however, Dr. Geikie

* Trans. Roy. Soc. Edinb. vol. xxxv. pp. 151-181. + *Ibid.* pp. 167, 168.

‡ *Ibid.* p. 167, and pp. 77 & 168.

appears to have left all exact petrographical study of the materials till after the completion of his field-work, and this led him to the erroneous conclusion that the propylitic rocks were simply the plateau-basalts altered by contact-metamorphism. Two dozen slices made from specimens collected by Dr. Geikie were placed in the hands of Dr. Hatch for microscopical study, and that gentleman's notes are characterized by his usual accuracy and acumen. He noticed the extreme alteration of the originally glassy base with the development of secondary feldspars, the complete change of the porphyritic crystals, and the development of chlorite, epidote, and other secondary minerals in the rock at the expense of the original constituents. But Dr. Hatch's notes afford no support whatever to the idea that these rocks are simply the plateau-basalts altered by contact-metamorphism.

B. *Structure.*

That the rocks which in their altered form we now refer to the propylites were, some of them, effusive (lavas and cupolas), while others were intrusive (laccolites, sheets, and dykes) there cannot be the smallest doubt. No warrant can be found from the study of these rocks for making a fundamental distinction of certain petrographic types, as belonging to the effusive or volcanic series (*Ergussgesteine*), and others as belonging to the intrusive or Plutonic series (*Tiefengesteine*). On the contrary, the central portions of some of the very thick lava-currents poured out at the surface are more highly crystalline than the rock of many eruptive masses. Still less ground can I find, in this district, for instituting a class of "dyke-rocks" ("Ganggesteine"); for while dykes and veins are sometimes found exhibiting very coarsely crystalline texture, others finely grained and even glassy may be seen side by side with them.

C. *Nature of Rock-masses.*

The rocks of the Western Isles of Scotland now referred to the group of propylites are found exhibiting three kinds of relations to the surrounding rock-masses:—

1. *Lava-streams.*—That these rocks often constituted ordinary lava-currents there cannot be the smallest doubt. Flat masses covering considerable areas and presenting at their upper and under surfaces the most strikingly scoriaceous and slaggy appearance abound, and are found piled one upon another to the depth of many hundreds or even thousands of feet. As a general rule, to which, however, there are a few exceptions, the lava-currents composed of porphyritic rocks are short and bulky, and they can seldom be traced to a distance of many miles from their point of emission. In this respect they present a most striking contrast to the olivine-basalts, which, as a rule, must have been poured out as lavas of great liquidity, and probably flowed distances of twenty, thirty, or even forty miles from their points of emission.

Professor J. D. Dana, in his suggestive memoirs on the Hawaiian

volcanoes, has clearly pointed out the important consequences which follow from the extreme liquidity of certain types of basalt; and in the Western Isles of Scotland, as in Iceland, we find many illustrations of the contrast between the features arising from the outflow of viscous lavas of acid and intermediate composition, on the one hand, and extremely fluid basic lava-currents on the other.

There is every reason for concluding that the ejection of the more acid lavas which constitute thick and bulky currents, and surround the five great centres of igneous action in the Western Isles of Scotland, took place, as a whole, before the appearance of the mass of the ophitic olivine-basalts which form the mass of the great plateaux. But, as I have already pointed out, we have evidence on the one hand that occasional streams of olivine-basalt were poured out during the earlier eruptions of the andesites; and, on the other hand, we find that occasional but very interesting outflows of andesite occurred during the ejection of the olivine-basalts; and such sheets of andesite-lavas are now found intercalated among the basalts of the plateaux. One such outflow of andesitic lava was referred to by Dr. A. Geikie in 1871 as occurring in the Island of Eigg, and I have noticed several similar in the same island. In Mull they also occur; and in the district of Mishnish, which I have somewhat closely studied, a very considerable number of such andesitic lavas have been detected by me intercalated with the basalts of the plateaux. The same is also the case in Skye, and about the other centres of igneous activity.

2. "*Cupolas*."—Under the name of "*Quell-Kuppen*," Dr. E. Reyer* and other authors in Germany are in the habit of describing more or less dome-shaped masses of lava, like the domitic-puys of Auvergne, the phonolite-hills of Bohemia, and the Chodi-Berg and similar andesitic masses in Hungary. Such "*cupolas*," "*domes*," or "*mamelons*" may vary in size from mere hummocks with an area of only a few square yards, to mountain-masses of the grandest dimensions. Externally such masses may have entirely lost the scoriaceous covering with which, in all probability, they were originally invested. But internally they often exhibit a markedly concentric structure; and there is a striking gradation from the true lava-type ("*hyalopilitic*" texture of rock) in the exterior portion to highly crystalline ("*hypidiomorphic-granular*") varieties, approaching Plutonic types, in the interior. Dr. Reyer has shown by plaster models how such masses were probably formed by a kind of endogenous growth. Dr. A. Geikie refers to some of those masses under the term "*bosses*."

Among the largest and most striking of these "*cupolas*" is that which constitutes the grand mountain of Beinn Talaidh (Beinn Talla) in Mull, which, rising to the height of 2496 feet above the sea, is remarkable for its smooth and graceful outlines. Specimens taken from the flanks and summit of this mountain show the rock to be a hornblende-andesite in a more or less altered condition. But examples

* Theoretische Geologie, pp. 79-99.

obtained in the deep Corry of Tomsléibe, on the north-western side of the mountain, are found to be a true diorite; and a series of specimens can easily be obtained exhibiting every gradation from the one type to the other. Some of the intermediate types exhibit the various kinds of "granophytic" structure in a very beautiful manner. The composition of this dioritic mass, which, in its upward development, gradates into a hornblende-andesite, is illustrated by the analysis given at p. 349.

3. "*Laccolites*."—In 1874 I described acid, igneous rocks as being intruded among the strata of the Western Isles, and stated that they tend to form thick, lenticular masses, which are generally confined to within moderate distances from the great centres of eruption*. Mr. Gilbert has since proposed to call intrusive masses of this type by the name of *Laccolites*†. Like the "cupolas" they are much more highly crystalline in their central than in their peripheral portions; the outside of such masses may be a true andesite, while the central portions exhibit the holocrystalline or granitic structure of a diorite. Where the country has undergone much denudation, it may often be impossible to state if a particular mass should be referred to the class of "*Quellkuppen*" or of "*Laccolites*," but that both types occur in the Western Isles of Scotland, there cannot be any doubt.

VI. NATURE OF THE ORIGINAL ROCKS FROM WHICH THE PROPYLITES WERE FORMED.

In endeavouring to determine the exact nature of the rocks grouped under the general name of "felstones," in the Western Isles of Scotland, very great difficulty is experienced owing to the excessively altered state both of the "phenocrysts" (to use Iddings's useful term) and of the ground-mass in which they are imbedded. Determinations of specific gravity and the partial or complete analysis of the rocks are, of course, of much value in deciding the place of the several varieties in a classificatory system, yet it is chiefly upon other methods that I have been led to rely in making a study of these very obscure rocks. The alteration which has gone on in them, though often extreme, is not unfrequently found to be more or less *local* in character; and, in the same mass, portions exhibiting very different stages of the change may often be found. It has been my object, in the repeated visits I have paid to the district during the last fifteen years, to trace the much altered and obscure rocks to points where their phenocrysts and ground-mass can be studied in a less altered form; and although in some instances it has been long before I was able to resolve all the difficulties that have presented themselves, yet in the great majority of cases this method has led to more or less satisfactory results.

Fortunately, too, several very able investigators have been engaged, during the same period, in the investigation of the very

* Quart. Journ. Geol. Soc. vol. xxx. (1874), p. 268.

† Geology of the Henry Mountains, U.S. Geol. Survey, 1877.

similar rocks which occur in the Faroe Isles, in Iceland, and in Greenland,—districts in which the volcanic products present such remarkable analogies with those of the Western Isles of Scotland. The results of some of these researches have afforded me invaluable aid, for they deal with materials some of which are almost absolutely unaltered, belonging to the same types as those which we find in such an altered condition in our own country.

In 1874 K. Vrba described some rocks from Southern Greenland, and among them certain diorites of somewhat remarkable character, which may not improbably be of the same geological age with rocks to be referred to in the present paper*.

In 1882, P. Schirlitz published the result of his studies, in the Petrographical Laboratory of Leipzig, of the Icelandic rocks collected by Professor Zirkel in 1860. In addition to the basalts and rhyolites, a number of very interesting rocks, called by Zirkel augite-andesites, was described by this author. He rightly insists, however, on the distinction between these and the Santorin lavas and the glassy andesites of Java (the vitrophyric augite-andesites of Rosenbusch), and is in favour of grouping them with the basalts †.

In 1884, Dr. A. Osann undertook an examination of the series of specimens from the Faroe Islands contained in the collection of the University of Heidelberg. He showed that, besides the black lustrous olivine-basalts, there exist dark grey rocks of very different aspect, containing an augite of a somewhat remarkable character, and he is disposed to place these among the andesites ‡. The distinction of these dark grey rocks, poor in olivine, which Osann pointed out in the case of the Faroe Isles, and Schirlitz in the case of those of Iceland, was also made by H. Reusch in the case of the Jan-Mayen rocks §, and by Nauchoff in the case of the Greenland lavas ||.

Last, and most important of all, must be mentioned the very valuable researches made upon the rocks of Iceland and the Faroe Islands by M. Rene Bréon¶. These researches were carried on in the Laboratory of Prof. Fouqué in the Collège de France. M. Bréon has described a number of lavas of intermediate composition which present the most striking analogies with some of the rocks now found in such an altered condition in the Hebrides. The wonderful freshness of the Icelandic rocks enables us to explain many points of difficulty which confront us in the case of their greatly altered British representatives, and I am much indebted to M. Bréon for his kindness in sending me a series of specimens of his Icelandic types for comparison with the rocks of Scotland.

* Sitzungsber. Wien. Akad. lix. (1874), pp. 109–115.

† Tsch. Min. und Petrogr. Mittheil. iv. (1812), p. 414.

‡ Neues Jahrb. für Min. &c. 1884, i. pp. 45–49.

§ 'The Norwegian North-Atlantic Expedition of 1876–78' (Christiania, 1882).

|| Min. Mittheil. 1874, pp. 109–176.

¶ Notes pour servir à l'étude de la Géologie de l'Islande et des Iles Færøe, par R. Bréon, 1884.

Without laying any great stress upon the value of the distinction, it may be convenient to group the propylites of the Western Isles of Scotland in two series. In one of these, the prevailing ferro-magnesian silicate was originally hornblende or biotite, and this we may speak of as the "Amphibolic Series." In the other group a pyroxene (augite or enstatite) was the predominating ferro-magnesian silicate in the original rock, and this may be called the "Pyroxenic Series."

The rocks of the Amphibolic Series include most of the types already spoken of as being distinguished by a paler colour, a lower specific gravity (ranging from 2·4 to 2·7), and a higher silica-percentage. The rocks of the Pyroxenic Series are usually darker-coloured, have a higher density (2·6–2·9) and a lower percentage of silica. But many varieties occur in which both pyroxenes and amphiboles or mica are present, and in the case of the very highly altered forms it is difficult and sometimes impossible to refer the rock to either of these series.

In both of these series we find rocks of highly crystalline character (true diorites) passing through various hypocrystalline ("pilotaxitic" and "hyalopilitic") varieties, into perfectly vitreous rocks. Both the amphibolic and pyroxenic rocks sometimes contain free quartz, and then pass into quartz-andesites and quartz-diorites.

The chief types of the andesites and their Plutonic representatives in the Western Isles of Scotland may be conveniently grouped as follows :—

A. AMPHIBOLE- AND MICA-ANDESITES.

Hornblende-andesites.
Hornblende-mica-andesites.
Hornblende-mica-andesites with enstatite.

Diorites and Quartz-diorites.

B. PYROXENE-ANDESITES.

1. "Vitrophyric" Pyroxene-andesites.
2. "Trachytoid" Pyroxene-andesites.
 - a. Stikkisholmür Type.
 - b. "Diallage-andesites."
 - c. Labradorite-andesites.

Pyroxene-diorites and Quartz-pyroxene diorites.

A. Amphibole- and Mica-andesites and Diorites.

The hornblende- and mica-andesites are perhaps more numerous in the Western Isles of Scotland than the pyroxene-andesites. While the former most commonly exist as quellekuppen and laccolites, the latter more frequently constitute lava-schists and intrusive sheets ("sills" of the miners of the North of England); but this distinction is far from being an absolute one, there being not a few lava-streams, some broad and far-spreading, composed of hornblende- and mica-andesites, at the base of, or intercalated among, the plateau-

basalts. It is among these lava-sheets, at a considerable distance from the great eruptive centres, that these rocks can be studied in their least altered condition. Around the great igneous centres the extreme of alteration is seen to have taken place, not one of the original minerals of the rocks being recognizable except as pseudomorphs. The feldspars are usually completely kaolinized, the ferromagnesian minerals represented by chlorites, while even the titanoferrite is converted into white opaque products, and finally into the transparent leucoxene or titanomorphite (sphene?).

Rosenbusch has proposed to divide the amphibole-andesites into two groups—those which in addition to the amphibole or mica, also contain a pyroxene, and those in which pyroxenes are absent. Both of these groups appear to be well represented in the Western Isles of Scotland. Rosenbusch has also proposed to divide the amphibole- and mica-andesites containing pyroxene into two groups—those in which the pyroxene is an augite or monoclinic variety, and those in which it is an enstatite in rhombic form. The latter type, which is so abundantly represented in the recent volcanic rocks of the Western Territories of the United States, and southward in the Republic of Salvador, according to Hague and Iddings *, is beautifully illustrated in the district which we are describing.

In the *Hornblende-andesites* proper we find a “microlitic felt” of feldspar needles, through which are scattered groups of green hornblende crystals, often assuming sheaf-like and tufted groupings. In most cases it is clear that each hornblende crystal or group of crystals was originally surrounded by a resorption-halo, that is, a sheath composed of pyroxene and magnetite, the result of the action of heated magma on the hornblende. But in most cases the pyroxene has been converted into isotropic viridite or into a chlorite of feeble double refraction, while the granules of magnetite still surround the more or less altered hornblende. In many instances, the hornblende can be seen to have been completely changed into a chlorite, with the separation all through its substance of granules of magnetite. These chlorite-pseudomorphs after hornblende, with granules of magnetite crowded along their sides and also scattered through their midst, are very characteristic of the propylites which are derived from the hornblende-andesites (see Plate XIV. fig. 7).

One of the best types of this group is found in the rock of Beinn Talaith (Beinn Talla) in Mull. This rock varies in specific gravity from 2.60 in the least crystalline types to 2.68 in those more highly crystalline. In the deeper corries of the mountain, andesites are found exhibiting a distinctly dioritic habit. The chemical composition of this rock is shown by the analysis given at p. 349.

The hornblende-andesites of the Western Isles of Scotland exhibit the widest diversity in the proportions of their constituent minerals. Some of the rocks of this class, good examples of which may be seen near Salen, Mull, consist very largely of feldspar crystals

* Amer. Journ. Sci. vol. xxvi. (1883) p. 233, vol. xxvii. (1884) p. 460, vol. xxxii. (1886) p. 28.

and a little glass, with only a few scattered crystals of ferromagnesian silicates. These rocks are usually pale-coloured or nearly white and have a low specific gravity (2·55). Other hornblende-andesites, like those of Mhàim Clackaig in Mull and of Glen Brittle in Skye, exhibit a dark green, often nearly black colour, and have a much higher specific gravity (2·7 to 2·8).

I have not detected any completely glassy forms of these rocks, nor any examples in which primary quartz occurs. Some of the more highly crystalline types, however, exhibit the granophyric structure and contain free quartz, which I believe is of secondary origin.

Hornblende-mica-andesites, with or without pyroxenes, are very abundant in the district. They constitute rocks of a pale grey colour and a more or less fissile character, which form well-marked lava-streams, some of which are found intercalated among the basalts of the plateaux.

In some of the best-preserved of these rocks, crystals of unmistakable enstatite (bronzite) make their appearance; and, as what may be the products of alteration of this mineral are seldom absent in the more altered varieties, it may probably be assumed that the majority of the rocks of this type in the Western Isles of Scotland must be referred to the hornblende- and mica-andesites containing enstatite.

Some of these rocks exhibit a character lately referred to by Dr. Osann* and by Mr. Teall†. Gas-cavities are found filled with glassy matter that seems to have oozed out of the ground-mass of the rocks into these empty cavities. In the case of some of the Scottish rocks it is curious to find that the glass in these cavities exhibits a markedly banded structure.

Mica-andesites.—While there are probably some examples of true mica-andesites it must be remembered that a dark brown biotite is among the commonest of the secondary minerals in these propylitic rocks. Good examples of true mica-andesites occur at certain points at Mull and also in Eigg. These biotite-andesites pass by insensible gradations into the hornblende-andesites; in some cases the amphibole being the predominating constituent, in others the mica. As a rule among the altered rocks, the hornblendes tend to disappear by passing into chlorites, with or without the separation of magnetite, while the biotite seems to increase in amount, either by the growth of original crystals of the mineral or by the development of new secondary crystals.

Diorites.—Of the common or hornblende-diorites we cannot find better examples than those which occur in the deep Corry exposing the central mass of Beinn Talaidh in Mull. From an almost perfectly holocrystalline rock every gradation can be traced, through beautiful granophyric varieties, into the lava constituting the peripheral portions of the mass, which is, as we have seen, a typical hornblende-andesite.

* Zeitschr. d. deutsch. geolog. Gesellsch. xli. (1889) p. 304.

† Geol. Mag. dec. iii. vol. vi. (1889) p. 481.

Quartz-diorites have a tolerably wide distribution in Mull and some of the other centres of eruption; the rocks in it, frequently exhibited granophyric structures and other peculiarities, recalling in the most striking manner the quartz-diorite of Doire na Each and other bosses in Arran so well described by Professor Zirkel*.

B. Pyroxene-andesites and Pyroxene-diorites.

These rocks contain as phenocrysts (or minerals of the first consolidation) feldspars which are always plagioclastic, and which, by their characteristic extinctions, their specific gravity, and their flame-reactions, are shown to belong to labradorite or to a variety between labradorite and anorthite. These porphyritic crystals are noteworthy as very constantly displaying a zoned structure, and are usually full of glass and stone-enclosures, for the most part arranged parallel to the sides of the crystals. The crystals often exhibit the evidences of growth after the consolidation of the rock, a phenomenon which has been already described. Sometimes in addition to porphyritically developed feldspars we find large crystals of augite, belonging to a variety very rich in magnesia and iron, and often exhibiting the structure to be hereafter described as the "pseudo-diallagic;" enstatite not unfrequently accompanies the augite, a ferriferous variety—between bronzite and hypersthene—being the most common form of the mineral. Olivine is either entirely absent or is so rare in these rocks that it must be regarded as an accessory or accidental constituent only. Magnetite, however, is always present, though in very varying quantities.

The minerals of the ground-mass, or those of the second period of consolidation, consist of feldspars (usually showing lath-shaped sections and more or less lamellar twinning), which by their extinctions are referable to oligoclase, but may sometimes be orthoclase; intercrystallized with the rod-like feldspars is a pale brown variety of augite, usually occurring in more or less rounded granules, and many opaque magnetite grains.

The glass, which sometimes is almost absent in these rocks, and at other times forms the greater part of their mass, is usually full of crystallites, and in the arrangement of bands and flecks of different colours, or the distribution of the crystallites, shows striking evidence of flow-structure. This is especially manifest in the varieties which contain porphyritic constituents and much glass. Skeleton crystals and rods of magnetite are very abundant in these glassy bases of the andesite-rocks.

The pyroxene-andesites of the district fall naturally into two groups, between which, however, many connecting-links may be found.

Those rocks in which the quantity of glassy base is reduced to a minimum, and which consist largely of the minerals of the second period of consolidation, with or without porphyritic constituents, undoubtedly approximate to the basalts. But their real analogies,

* Zeitschr. d. deutsch geol. Gesellsch. vol. xxiii. (1871) p. 30.

as I shall show in a subsequent part of this paper, are so clearly with the vitrophyric pyroxene-andesites, that it is quite impossible to remove them from the group of the andesites. We must regard them therefore as the most basic type of the andesite series,—forms which constitute a real connecting-link between the andesites and the true or olivine-basalts. I am still inclined to follow Zirkel's original rule of confining the name basalt to those rocks of which olivine forms are essential constituents. This plan is followed by Rosenbusch in the case of the leucite and nepheline-bearing rocks, though of late years he has departed from it in the case of the felspar-bearing types.

Augite-andesites of the vitrophyric type of Rosenbusch appear at many points in the Western Isles of Scotland, and are particularly abundant about the north-western part of Beinn-à-Ghraag in Mull.

In these we find crystals of augite and enstatite, of a felspar allied to labradorite, and of magnetite, embedded in a glassy ground-mass, which may be large or small in quantity compared with the crystalline constituents of the mass. As in almost all similar rocks, we may notice that the crystals are often by no means uniformly scattered through the glassy base, but are collected into groups which often appear like portions of a holocrystalline mass.

At Mhàim Clackaig in Mull I have found a vitrophyric augite-andesite in which crystals of labradorite (usually much rounded on the angles and sometimes corroded), of a brown augite, and of magnetite are somewhat sparsely scattered through a glassy base. This glassy base is crowded with black rods (trichites), much twisted and bent, which in places become so abundant as to render the glass nearly opaque, except in very thin sections. This rock has a specific gravity of 2.64 (see Plate XIV. fig. 3).

In Beinn-à-Ghraag similar glassy rocks are highly spherulitic, the spherulites being arranged in definite bands, evidently produced during the movement of the viscous mass (see Plate XIV. fig. 4). One of these spherulitic rocks has a specific gravity of 2.49. In other cases, the fluidal structure, indicated by the way the micro-lites of the second period of consolidation are arranged around the porphyritic felspar and pyroxene crystals (see Plate XIV. fig. 6), is very strikingly shown.

For the determination of the specific gravities of a series of the vitrophyric augite-andesites I am indebted to my assistant, Mr. F. H. Hume, F.G.S.

Although no augite-andesites with free quartz have been detected in the district, yet some of these very glassy varieties must have a silica-percentage as high as that of the quartz augite-andesites or augite-dacites.

The best type of the more basic, stony pyroxene-andesites ("trachytoid andesites" of Rosenbusch) is afforded by the rocks which exactly resemble the lavas of Stikkisholmur and other points in Iceland, and are so well described and figured by Bréon*. The rock

* *Loc. cit.* pp. 23 & 24, pl. iii. fig. 1.

consists essentially of a mesh of oligoclase and perhaps of anorthoclase microlites entangling granules of augite (with some enstatite) and of magnetite, glass being present in small quantities only and quite inconspicuous.

This *Stikkisholmur type* is well represented at many points in the Western Isles of Scotland. Good illustrations of the type occur in the promontory stretching out to Salen Pier in Mull, at Beinn Uaig, and Creagach Beinn, in the same island, in Ardnamurchan, and in many other places.

Like the Icelandic rocks, those of our Western Isles are "compact and dark-coloured . . . the fracture is often nearly conchoidal, and certain specimens present a semi-vitreous appearance" (Bréon, *loc. cit.* p. 23).

In his reference of these rocks of the *Stikkisholmur type* to the augite-andesites, Bréon is supported by Rosenbusch, who, in the last edition of his 'Massige Gesteine' (p. 682), refers to these rocks as presenting some analogies with the augite-andesites described by Foerstner as occurring in Pantellaria, and containing anorthoclase and the triclinic amphibole—cossyrite (æigmatite).

Some of the augite-andesites of the *Stikkisholmur type* contain large scattered crystals of anorthite or labradorite, and thus pass into the labradorite-andesites.

Another variety of the "trachytoid" pyroxene-andesites is presented when, in addition to the porphyritic crystals of felspar, large phenocrysts of augite make their appearance. These augites appear to belong to a variety rich in iron and magnesia, but which, considering their composition, are of remarkably stable character, often remaining comparatively unaltered when all the crystals in the rock have been profoundly changed. Such porphyritic augites often show a tendency to assume the form of stellar aggregates, and sometimes are of such dimensions as to be quite conspicuous on the fractured surfaces of the rocks. Beautiful examples of lavas of this type are found about Mingary Castle in Ardnamurchan, and I have also detected them at many other points in the Western Isles.

The porphyritic augites in these rocks present a character of very considerable interest, which it is necessary to notice here, though I have discussed it in detail in another place (*Min. Mag.* vol. ix.).

The augite-crystals exhibit lamellar twinning and subsequent schillerization parallel to the basal plane (001). Similar varieties have been described by William Phillips, Osann, and by Mr. Teall. The forms found in the Western Isles of Scotland differ from those described by the first and last-mentioned authors in not exhibiting simple twinning parallel to the orthopinacoid (001), but in showing some traces of lamellar twinning and subsequent schillerization parallel to that plane. (See Plate XIV. figs. 1 & 2.)

The occurrence in certain andesites of augite crystals exhibiting lamellar twinning with schillerization has led to a group being established by some authors bearing the name of "Diallage-andesites." It is probable that, in many, perhaps in all, of the cases in which diallage is stated to exist in andesitic lavas, augite twinned and

altered on the basal plane has been mistaken for true diallage with schillerization on the orthopinacoid.

The rocks called by the French geologists *labradorites*, and which I propose to term "*labradorite-andesites*," consist of a base which is, in all essential respects, identical with that of the last-described rocks; but they contain numerous and sometimes very large porphyritic crystals of *labradorite*, or of a *felspar* which is intermediate between *labradorite* and *anorthite*.

Good types of such rocks may be found at Dun-da-Ghaoith (Dun-da-Gu) in Mull, around the southern flanks of Glamaig in Skye, and at Beinn Suardil in the same island. They agree in every respect with the Icelandic varieties so clearly described by Bréon. The general features of these rocks, and the evidence they afford of the growth of the *felspar* crystals subsequently to the consolidation of the rock, have been discussed in a previous communication to this Society*.

In their altered condition these *labradorite-andesites* present the most complete analogy with the *labradorite-porphyrtes*, such as the *Verde antique* of Greece, and the *Lambay-Island porphyrite* so well investigated by Von Lasaulx.

Occasionally rocks of the "*trachytoid*" type are found passing locally into a perfect glass. An example of this was discovered some years ago by the late Mr. Grieve, and I am indebted to my friend Professor Bonney for calling my attention to it. The locality where this is found is at Bealach a' Mhàim, at the head of Glen Brittle in Skye. The mode of occurrence of this glass is somewhat obscure, but it appears that the glass does not exist like the *tachylite*-selvages to *basalt-dykes*, but as local patches in the midst of the *andesite*. Probably in this, as in cases to be more fully described in a later portion of this paper, a separation has occurred between the glassy and the crystalline portions of the *andesite*. The glass has a specific gravity of 2·63, while that of the *labradorite-andesite* in which it is enclosed is 2·89.

By the kindness of Prof. Thorpe I have been supplied with analyses of the glassy portions of this rock made in the Chemical Laboratory of the Normal School of Science and Royal School of Mines.

	I.	II.	III.
Silica	31·51	62·10	61·80
Alumina	14·83	15·00	14·91
Ferric oxide	8·41	8·14	8·27
Lime	3·58	3·07	3·33
Magnesia	0·28	0·27	0·27
Soda	6·58	6·42	6·50
Potash.....	5·17	5·21	5·19
Loss on ignition ..	0·88	0·86	0·87
	<hr/> 101·24	<hr/> 101·07	<hr/> 101·14

* Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 175-186.

I. Analysis of glass in labradorite-andesite from Bealach a' Mhàim, Skye, by S. Parrish.

II. Analysis of second specimen of the same rock by H. J. Taylor.

III. Mean of these two analyses.

It appears from these analyses that this glass is richer in silica than the andesite (a labradorite-andesite) in which it occurs.

Studied microscopically, this vitreous rock is found to consist of a glassy base, less black and opaque than ordinary tachylyte, through which porphyritic crystals of plagioclase (labradorite) are somewhat sparsely scattered. The glass often contains incipient and sometimes well-formed spherulites, and the arrangement of these and of darker streaks of glassy material give it a marked fluidal structure. The felspar phenocrysts are remarkable for the amount of corrosion by the fluid magma which they have undergone, and spherulitic fringes have often been developed all round the edges of the crystals. Sometimes the incipient spherulites are seen to yield to weathering influence much more readily than the enclosing glass, and a peculiar banded appearance then becomes very conspicuous on weathered surfaces (see Plate XIV. fig. 5).

The Augite-diorites.—In 1866 Zirkel* proposed the use of this term, and in 1877 Strong described an important class of rock of this type as occurring in Minnesota†. Mr. Cole has also strongly advocated the use of this term‡, which has, moreover, been adopted by Rosenbusch, in the last edition of his 'Massige Gesteine.'

The type is beautifully exemplified, especially in Ardnamurchan, where great mountain-masses, like that of Meal nan Con, are made up of it. The augite often exhibits, partially or throughout, the diallagic striation, and the rocks differ from the gabbros only in the absence of olivine and magnetite. Every gradation can be followed from rocks with a glassy magma, though various granophyric types, into a perfectly holocystalline rock.

Quartz-augite-diorites occur at several points, as in the great sheets under Beinn More. They contain both rhombic and monoclinic pyroxene, and also quartz, both primary and secondary.

As it has been asserted that the "felstones" or propylites of the Western Isles of Scotland are really nothing more than basalts altered by contact-metamorphism, I may point out that, associated with the andesites and more acid rocks, are a few ophitic-olivine-basalts, which have been subjected to the same kind of modification as the propylites. These are found to exhibit characters very strongly contrasted to those of the rocks in question. In all, or nearly all, these cases the distinctive characters of the basalts can still be clearly recognized, namely, the olivine grains, reduced to pseudomorphs, and the ophitic structure, traces of which can be detected even when both the felspar and the pyroxenes have undergone the most profound change.

* Lehrbuch der Petrographie, vol. ii. p. 7.

† Neues Jahrb. für Min. &c. 1877.

‡ Geol. Mag. dec. iii. vol. iii. (1886) p. 225.

VII. CAUSES BY WHICH THE "PROPYLITIC" MODIFICATION OF THESE ROCKS HAS BEEN BROUGHT ABOUT.

In studying the relations of the propylites to the other rocks of the Western Isles of Scotland no fact strikes the observer more forcibly than that of their being constantly invaded by igneous intrusions, composed of granite and felsite on the one hand, and of gabbro and dolerite on the other hand. Beautiful examples may be studied, at many points, of the ramification of granite veins through the propylites, and portions of the propylite may even be seen caught up in the midst of granite. On the other hand, the currents of propylite may be seen to be broken up by numerous sheets of gabbro and dolerite, which are generally intruded between them; and from these sheets numerous veins and dykes of dolerite and basalt can often be traced intersecting the propylite masses. In places the intrusions, indeed, outbulk the rocks among which they have been thrust. These relations were fully explained by me in 1874*, and have been confirmed by numerous illustrative examples given by Dr. A. Geikie in 1888†.

Impressed by the number of these intrusions among the propylite- ("felstone"-) lavas I was led, in 1874, to refer the remarkable alteration which they have undoubtedly undergone to contact-metamorphism‡, and the same view was adopted by Dr. A. Geikie in 1888§.

But subsequent and more detailed study of the propylites has convinced me that contact-metamorphism, while producing very striking results close to the planes of junction of the lavas and the intruded sheets, has seldom operated to any great distances from the latter, and that the widespread modifications which have been effected in the minerals and the ground-mass of the propylites must be referred to a widely different cause. In the case of the analogous rocks of Eastern Europe and North America, it has been abundantly proved, by the researches of geologists in these districts, that the cause of the curious alteration of the andesitic and dioritic rocks and their impregnation with metallic sulphides (some of which are of great commercial value in those two districts) must be referred to the action of steam and of various acid gases, which have permeated the whole substance of the lava-masses, giving rise to profound chemical alteration of their constituents.

At the same time the contact-metamorphism, to which I called attention in 1874, has undoubtedly been a noteworthy and, in some instances, an important contributory factor in bringing about the results. I showed that "in proximity to the gabbros, these felstone-lavas are seen . . . to have acquired a peculiar platy structure and splintery fracture, combined, in many cases, with the development of a probably preexisting banded coloration"¶. I particularly dwelt

* Quart. Journ. Geol. Soc. vol. xxx. p. 246.

† Trans. Roy. Soc. Edinb. vol. xxxv. (1888) pp. 165-171.

‡ Quart. Journ. Geol. Soc. vol. xxx. p. 251.

§ Trans. Roy. Soc. Edinb. vol. xxxv. (1888) p. 167.

¶ Quart. Journ. Geol. Soc. vol. xxx. p. 251.

upon the evidence of the contact-metamorphism produced around the intrusive mass of S. Airde Beinn (Sarsta Beinn), and the facts then pointed out have been confirmed by Dr. Geikie and Dr. Hatch*.

In many cases the solfataric action and the invasion of the lavas by great molten masses of rock can be shown to have produced effects which are strikingly contrasted. The effect of the contact-metamorphism is to induce a remarkable splintery fracture and jointed structure in the rocks affected. But this effect is only seen to extend to the distance of a few inches, or at most feet, from the actual planes of junction. As the result of the contact-metamorphism the rocks acquire, in a very remarkable manner, a power of resisting denudation; and in consequence of this, we find sheaths of altered rock standing up above the general surface, and enveloping the intrusive masses†.

The more widely spread changes which have affected the oldest Tertiary andesites and diorites are of a totally different kind. The action appears to have taken place in a sporadic and seemingly capricious manner. Highly altered rocks may sometimes be found to pass into comparatively unaltered rocks, within a few feet or yards, and no direct relation can be detected between the greatly altered masses and any particular intrusions of either acid or basic rock. The effect of the chemical changes in the rock is usually to disintegrate its constituents, and thereby render it less able to withstand the action of denuding agents upon the mountain-sides. The chemically altered rocks, rendered soft and porous and coated with a friable white crust, are often covered up and concealed by peat and vegetation, while the intrusions among them, and their surrounding sheaths produced by contact-metamorphism, retain the marks of glacial action, and stand up prominently above the peat and heather.

In many places it can be clearly shown that the widely spread chemical action has preceded the action of contact-metamorphism, while in other instances the opposite may perhaps have been the case. As might be expected, the results of these two kinds of action are often curiously complicated and involved. Microscopical and chemical study enable us, however, in most cases to define and explain the exact nature of the results which follow from either kind of action, and these I now propose to consider.

A. Effects of Solfataric Action.

To this cause must be assigned the alteration both of the phenocrysts ("Einsprengunge") and the ground-mass of the porphyritic rocks already described.

The order in which the several changes take place is often capable of exact definition, when a large series of sections made

* Trans. Roy. Soc. Edinb. vol. xxxv. (1888) pp. 103, 104.

† Q. J. G. S. vol. xxx. (1874) pp. 265-266, figs. 4, 5, & 6.

from carefully selected specimens, and taken from different portions of a propylite-mass, are examined microscopically.

We are able to see how clear plagioclase with vitreous lustre (microtine) becomes gradually clouded and opaque, and in the end completely kaolinized; the changes being, in the first instance, developed along the planes of chemical weakness between the twin lamellæ; but the extension of this action very frequently results in the complete obliteration of all traces of the original twin-lamellation. In some instances the felspar substance then breaks up into a mosaic of different minerals, among which zoisite and a secondary felspar usually appear to play the most important part. But in other, and perhaps the majority of instances, the results are modified by the impregnation of the products of the felspar alteration with ferro-magnesian secretions derived from the decomposition of other minerals in the rock. The consequence of this is that the necessary materials for the formation of an epidote are brought together and tufted masses of pistacite, or some other variety of that species, are formed and replace a part or the whole of the felspar crystal.

The ferro-magnesian silicates at the same time lose their distinctive character, and green isotropic products (viridite) are formed at their expense. Out of these decomposition-products various chlorites are formed with the separation of secondary magnetite. These, in turn, yield to further chemical action, and pistacite and other epidotes are produced, forming more or less distinct pseudomorphs after the pyroxene, amphibole, or mica*.

The ground-mass is often one of the earliest portions of the rock acted upon. Any glassy matter that may be present disappears as the result of secondary devitrification, and the whole matrix of the rock is frequently converted into a mass of secondary minerals. Among these, various metallic sulphides are often very conspicuous.

When steam-holes abound in the rock the epidotes and other secondary minerals crystallize out freely; and in these situations they are conveniently displayed for careful study and determination. Beautiful amygdules, composed of epidote and other secondary minerals, and filled in with still later deposits of zeolites, calcite, and chalcedony, are, indeed, among the most conspicuous features presented by the surfaces of such of these propylitic rocks as have originally possessed a scoriaceous character.

There are localities in which the kind of change which I have been describing seems to have been carried to its farthest extreme. In these cases epidote has been developed to such an extent, at the expense of the other constituents, that it is now quite impossible to determine the original mineralogical constitution and structure of the rock. The most marked example of this is seen in the eastern spurs of the great mass of Beinn More in Mull, and around A Chioch. Here the epidotization of the rock-constituents and the formation of numerous volcanic minerals has gone on to

* Compare Q. J. G. S. vol. xlii. (1886) pp. 430, 431.

such an extent that it is often impossible to distinguish between * lavas and tuffs.

The characters of the propylites of this particular district, as we now see them, are most remarkable, not one of the minerals of the original rock being present in it. The ground-mass has been completely altered, all traces of glass having disappeared by secondary devitrification, and many secondary minerals being developed in it. The *outlines* of the original felspar-crystals can sometimes be made out, but this is all. Their substance has been converted into aggregates, among which epidote, zoisite, secondary felspar, and even quartz, play the most important part. The ferro-magnesian silicates usually appear as pseudomorphs in isotropic "viridite" or in some species of chlorite. The resorption-halos of the hornblendes and micas can often be detected by the clustered magnetite grains; and certain forms of biotite may be seen developed at the expense of the secondary chlorites. Lastly, in addition to the original magnetite grains of the rock, we find enormous quantities of the same material produced during the breaking up of the ferro-magnesian silicates, a process which is so frequently attended with the separation of magnetite grains (see Plate XIV. fig. 7).

As "epidotization" is the ulterior and most marked change of which the propylite rocks exhibit evidence, it may be well to consider the nature of the mineral species which result from the change.

From one of the extremely altered augite-andesites of Beinn More, in Mull, Mr. W. B. D. Edwards isolated, by means of Klein's solution, a considerable quantity of the beautiful green epidote, the material proving, on microscopic examination, to be remarkably free from foreign admixture. The specific gravity of the mineral proved to be 3.42, and a partial analysis made by Mr. Edwards showed it to be a lime-iron-epidote or pistacite. I find that all the optical characters confirm the identification of the epidote in question with this variety.

Besides the beautiful deep green epidote which is most abundant, pale-coloured lime-epidotes occur, and some which have a pale pink colour, probably due to manganese. The highly coloured withamite, however, has not yet been detected in these rocks.

It is a most suggestive circumstance that this solfataric action is found to have been developed around each of the five great centres which I have identified as the sites of the great volcanoes of the Western Isles of Scotland. In most cases where this action can be shown to have taken place intrusive masses of granite and felsite can be shown to be in tolerably close proximity to the altered rocks.

In a very interesting memoir, M. de Lapparent has insisted on

* I believe that there cannot be any reasonable doubt that the district lying immediately to the east of the summit of Beinn More must have existed underneath what was the great central active crater of the Mull volcano, and in this way the excessively altered condition of its rocks and the production of the remarkable volcanic minerals described by me in 1874 is accounted for.

the close connexion that always appears to exist in different volcanic regions between solfataric action and eruptions of rock of acid composition *. The same fact has also been pointed out by Schmidt †. While the ejection of basaltic lavas is followed by actions that lead to the formation of carbonates, the extrusion of great masses of highly silicated materials is attended and followed by the escape of steam containing sulphurous and other gases, which give rise to the phenomena of solfataric action.

The rocks of the Western Isles of Scotland afford a very striking illustration of this connexion between solfataric action and the ejection of highly silicated rocks.

B. Contact-Metamorphism.

Studied microscopically, the sheaths of altered "felstone" that surround the intrusion of granite or gabbro enable us to understand the succession of changes which place as the result of the contact of these rocks with great bodies of fused materials. As already pointed out, these effects are strikingly contrasted with those resulting from solfataric action.

We are, in the first place, forcibly reminded of the resorption-halos which are seen surrounding hornblendes, micas, and other minerals as the result of the action of a heated magma upon them. But this action, instead of being confined to the immediate proximity of the crystals affected, may extend to the distance of some inches or even feet from the planes of contact.

All the ferro-magnesian silicates—pyroxenes, hornblendes, and micas—break up into finely granular aggregates, which seem to consist of an almost colourless pyroxene and of magnetite grains, though other minerals may not improbably be present. In some cases, however, the very minute granules appear to have the colour, pleochroism, and other optical properties of melilite (see Plate XIV. fig. 8).

In the midst of these granular aggregates we sometimes find scales of a deep brown, highly pleochroic biotite making their appearance; and these increase in size and in number as the igneous mass is approached. Clear colourless needles can also be detected, and these may not improbably be referred to some species of secondary feldspar.

In these greatly altered rocks it is only possible to state what was the nature of the original rock, by tracing the alterations step by step from the comparatively unchanged mass at a distance from the intrusions right up to the planes of contact.

VIII. LIGHT THROWN BY THE STUDY OF THESE TERTIARY LAVAS ON SOME OF THE OLDER VOLCANIC ROCKS (PORPHYRITES, FELSTONES, &c.).

It was pointed out, in my former memoir, that in Scotland we have brought close together remarkable masses of volcanic materials

* Bull. Soc. Géol. Fr. sér. 3, vol. xvii. pp. 282-290.

† Zeitsch. d. deutsch. geol. Gesellsch. 1885, p. 737.

of very different geological ages. We can readily compare the altered or unaltered rocks of the Tertiary periods with Palæozoic lavas like those of Lorne, and of the great Central Valley of Scotland. At the time when I wrote, all these Palæozoic lavas were generally considered by geologists to be of Devonian age; but since the publication of my paper in 1874 I have had the opportunity of studying the remarkable volcanic rocks and conglomerates of Ballantrae in Ayrshire, and I cannot help thinking that a part at least of the Lorne rocks may prove to be of the same age. I am at all events fully prepared to subscribe to the opinion so clearly expressed by Mr. Dugald Bell, namely, that the question of the age of the Lorne lavas is still *sub judice* *.

Among these Palæozoic lavas we find just the same contrast between almost wholly unaltered and greatly altered rocks, as in Skye, Mull, or Rum in the case of Tertiary volcanic rocks. Mr. Teall has shown that the glassy rocks of the Cheviot Hills are really enstatite-andesites, which differ in no essential respect from the recent lavas of Santorin and Krakatoa. Mr. Durham and I have described in Fifeshire enstatite-andesites and glassy dacites, which, though as old as the Carboniferous, are as fresh and unaltered as the modern enstatite-andesites of Japan. In the Garlton Hills near Haddington there occur sanidine-oligoclase-trachytes, of Pre-Carboniferous age, which are strikingly analogous with those of the Siebengebirge.

On the other hand, we find in the Pentland and Braid Hills rocks, which, while of the same general ultimate chemical composition as the modern andesites, are remarkable for their obscure structure and peculiar mineralogical constitution. A comparison of these with the Tertiary propylites of the Western Isles of Scotland is most instructive, for it shows that some of the "porphyrites" are really andesites that have been subjected to the propylitic modification, and then further modified by surface-agencies. It may, indeed, be asserted of many of the propylites of Mull that, if their abundant magnetite-granules, some of which are original and others secondary, were changed to a red colour by peroxidation, they would be quite undistinguishable from the obscure porphyrites to which I have referred. These latter have such a peculiar constitution that they have been classified by Dr. A. Geikie as "felspar-magnetite rocks."

IX. THE YOUNGER AUGITE-ANDESITES ("THOLEITES," "PITCHSTONES," &c.) OF THE WESTERN ISLES OF SCOTLAND.

While the older Tertiary andesitic rocks which we have been describing are remarkable for the extraordinary and often extreme changes which they have undergone, there exist other lavas of similar composition in the district, which present the most marked contrast with them, by the wonderful freshness of their appearance. That these lavas are younger than all the plateau-basalts is shown

* Trans. Geol. Soc. of Glasgow, vol. viii. (1886) p. 116.

by the fact that they are found intersecting the basaltic sheets as veins or dykes, while at other times they can be shown to lie upon their greatly eroded surfaces, as lava-currents. Of the same late age are certain other rocks, some of more basic and others of more acid composition, which will be considered in greater detail hereafter. The whole of these rocks belong to the latest of the three periods to which, as I showed in 1874, the Tertiary volcanic rocks of the Western Islands must be assigned.

The lavas in question are of very considerable interest as having been undoubtedly the latest-erupted volcanic masses in the British Islands. A careful study of them shows that they present the most striking resemblances to some of the recent volcanic rocks of Iceland. Dykes and veins of these lavas are found traversing the thick ophitic olivine-basalts of the Western Isles of Scotland and of Antrim. But other dykes of remarkably similar rock occur cutting through the Palæozoic rocks of the lowland districts of Scotland, and these reappear in the north of England, where some of them can be shown to intersect Jurassic strata. Some of the Scottish examples of these rocks have been well described by Dr. A. Geikie*. The English examples have been admirably studied by Mr. Teall†.

I have already pointed out‡ that along these lines of fissure now occupied by dykes there is evidence of the outburst of a volcanic material giving rise to lines of volcanic cones, which bore the same relation to the great volcanoes of the Western Isles, that the chains of "pays" in Auvergne did to the great volcanic mountains of Mont Dore, the Mezen, and the Cantal.

At two points only, so far as I know, have the lava-currents and tuffs of this period been preserved. This is accounted for by the fact that the amount of denudation in the district since the formation of these small, subsidiary volcanic cones has been excessive; and only where the lava-currents were of unusual dimensions, or were of such a character as to resist the action of denuding agencies in an exceptional manner, was there any chance of their being preserved for our study at the present day.

The first case of the kind noticed was that of the Sgùrr of Eigg, which was so well described by Dr. A. Geikie in 1871§. His explanation of the mode of preservation of several successive lava-sheets, by their being poured out into a valley that had been eroded in the basaltic plateau, is one that must commend itself to every one who has studied the district. Equally convincing is the evidence he adduces of the enormous amount of denudation that has taken place since the formation of these lava-flows, seeing that the basalts forming the sides of the valley have all been removed, leaving the later lavas as a mass crowning the summit of a long ridge.

* Proc. Roy. Phys. Edinb. vol. v. (1878-80) pp. 219-254; and Trans. Roy. Soc. Edinb. vol. xxxv. (1889) pp. 24-73.

† Q. J. G. S. vol. xl. (1884) p. 209.

‡ Q. J. G. S. vol. xxx. (1874) pp. 260-272.

§ Quart. Journ. Geol. Soc. vol. xxvii. (1871) pp. 303-309.

Not less interesting and remarkable are the sheets of lava with the great masses of underlying tuffs that form the mountain of Ben Hiant (Beinn Shiant) in Ardnamurchan. The general structure of this mountain will be understood from the accompanying map and section, which have been constructed on the basis of the recently published 6-inch maps of the Ordnance Survey (figs. 1 & 2), see pp. 374 and 375.

Lying in part upon the much eroded basalt of the plateau, in part on the underlying Jurassic strata, and in part on the fundamental crystalline schists, we find thick masses of volcanic agglomerate. These volcanic agglomerates can be especially well studied on the northern face of the mountain, and on the southern sea-washed promontory known as Sron Mhor, or Maclean's Nose. They vary in character from ordinary andesitic tuffs, to very coarse breccias made up of fragments derived from all the underlying rocks (crystalline schists, liassic shales, sandstones, and limestones, and andesitic and basaltic lavas), with varying quantities of other volcanic materials.

The preservation of these agglomerates has been clearly due to the fact that they were covered by currents of a peculiar lava, often of a columnar habit, which cap all the spurs of this singularly outlined mountain; only the lower and more crystalline portions of these lava-currents having in most cases escaped removal by denudation. These lavas are found by careful study to be an andesite presenting many remarkable varieties, to which I propose to call especial attention in the sequel*.

The rocks of Ben Hiant find their closest analogues in the augite-andesites of the Tertiary dykes of the north of England ("tholeites" of Rosenbusch), so well described by Mr. Teall, and in the rock of Eskdalemuir, for a very careful and accurate account of which we are indebted to Dr. A. Geikie. Mr. Grenville Cole, F.G.S., has kindly supplied me with a series of specimens collected by him from the Eskdalemuir rock, which have proved of great service to me in my comparisons.

Dr. A. Geikie has shown that in the case of the Eskdalemuir dyke a marked separation has often taken place between the more acid, vitreous parts of the rock and the more basic, crystalline materials. In consequence of this, as shown by Mr. Grant Wilson's analyses, different portions of the dyke come to present wide divergencies in composition and appearance†.

* The main features of the remarkable mass of Ben Hiant were accurately described by me in 1874. Dr. A. Geikie, as the result of what must surely have been a superficial examination of the locality, asserts that the lava of Ben Hiant is a single intrusive sheet, and that it consists of the ordinary ophitic dolerite of the "sills" that were erupted at the same time as the plateau-basalts. My statement of 1874 that the rocks consist of a very remarkable augite-andesite is borne out by the microscopic study of a very large series of specimens derived from various parts of the mountain; and the statement that the rock is neither glassy nor vesicular is contradicted by the study of this large series of rocks (see Plate XV.).

† Proc. Roy. Phys. Soc. Edinb. vol. v. (1880) p. 256; and Trans. Roy. Soc. Edinb. vol. xxx. (1888) pp. 40-44.

Fig. 1.—Sketch-map of Ben Hiant, Ardnamurchan.

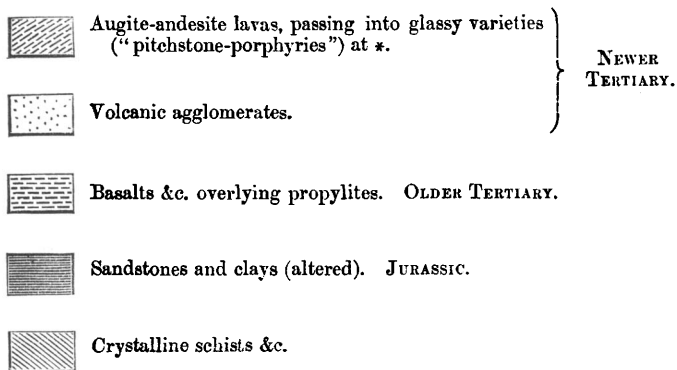
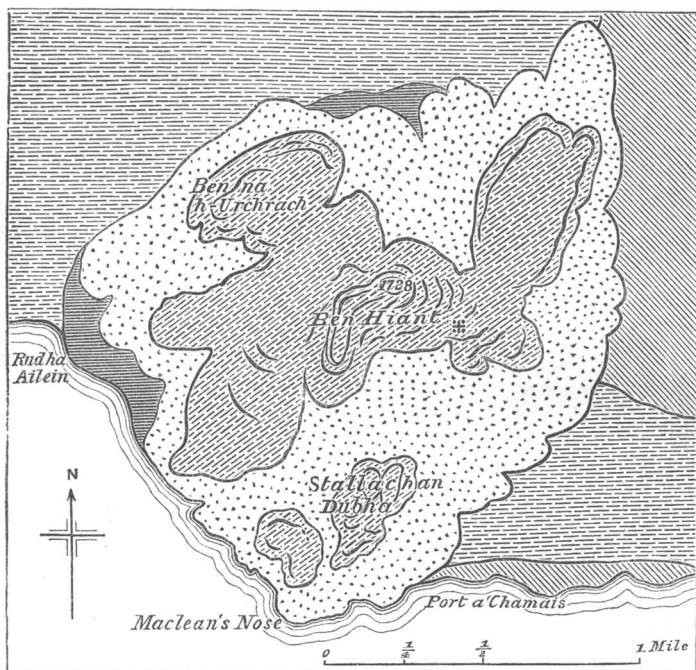
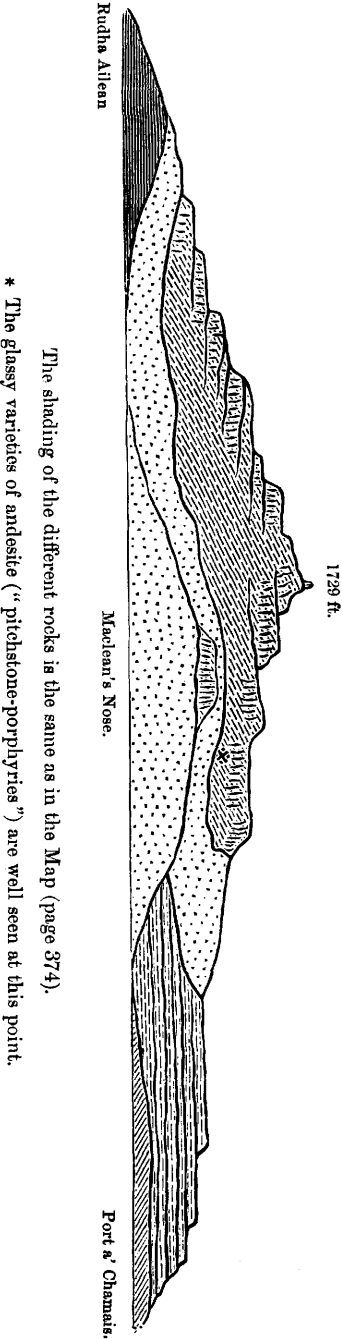


Fig. 2.—*Profile Diagram, illustrating the Structure of Ben Hiant, Ardnamurchan.*
(Viewed from the South.)



The shading of the different rocks is the same as in the Map (page 374).

* The glassy varieties of andesite ("pitchstone-porphyrises") are well seen at this point.

Now the separation that has taken place within the Eskdalemuir dyke, on a small scale, has evidently gone on on a grand scale beneath Ben Hiant. The result of this has been that, while in some of the lava-sheets of the mountain we find a glassy lava through which porphyritic constituents are somewhat sparingly distributed (the result being a "pitchstone-porphry" similar to that of the Sgùrr of Eigg), in other cases masses of crystals with only a comparatively small matrix of glass have been poured out, giving rise to a rock of far more basic character than the pitchstone varieties.

In studying the Krakatoa lavas I was led to point out the remarkable differences in the composition and appearance of rocks resulting from variations in the proportion of acid ground-mass to basic phenocrysts in a rock. My examples in illustration of this principle were taken from Santorin, the Cheviot Hills, and Krakatoa*. But here in Ben Hiant we find, among the ejections of the same vent, the most wonderful illustrations of the same principle, one that has been too much overlooked in our petrographical studies.

I shall show that among the lavas of Ben Hiant we have varieties that are distinctly basic in composition, with a specific gravity of over 3 and a silica-percentage of a little above 50. But among the same rocks are others with a distinctly acid character, having a density of only 2.45 and a silica-percentage of over 65. Yet the minerals in all these rocks are identical; the same feldspars, the same pyroxenes, magnetite, and a similar glass, are found in all; it is the *variation in the relative proportion* of these several mineralogical constituents which gives rise to the very wide diversity alike in the aspect and in the ultimate chemical composition of these rocks.

Mineralogically these rocks exhibit, as I have said, a remarkably uniform character. They consist of:—

1. *Felspar*, which is almost always either anorthite or labradorite, or some form intermediate between these species. This is proved by the extinctions which they give in the several zones, and is confirmed when we examine specimens of them, isolated by the use of heavy liquids, for their specific gravity, and the flame-reactions which they give by Szabó's method. The felspar-crystals are often zoned, the different zones giving evidence of being of different composition, the more basic being in the centre. Inclusions are often arranged parallel to these zones, and the first traces of schillerization are sometimes exhibited. Although the twin striation is often very marked, cases of simple Carlsbad-twinning are not uncommon.

2. *Pyroxene*, an augite, sometimes of a green colour, at other times brown. There is almost certain evidence that the brown augite is an altered form of the green; indeed every gradation from the one kind to the other can be found, and crystals occur which are in one part green and one part brown. The original colour is certainly

* 'The Eruption of Krakatoa and subsequent Phenomena' (1888), pp. 30-35; and Geol. Mag. dec. iii. vol. v. pp. 1-11.

green, and the brown tint is the result of alteration. Only the faintest trace of pleochroism can be detected. Some of the crystals show the beginning of the development of a structure like that exhibited by the augites in the older andesites of the district, which is described at page 363. Osann has described and analyzed a very similar augite from the augite-andesite of Kolter, in the Faroe Islands *. Its composition is as follows :—

Silica	50·21
Alumina	3·24
Ferrous oxide	17·40
Lime	13·92
Magnesia.....	14·05
	<hr/>
	98·82

Rhombic pyroxene occurs in these rocks, but in small quantities, and it must be regarded as an accessory constituent.

3. *Magnetite* occurs in distinct individuals, as skeleton-crystals, or in roundish grains, and is in some cases remarkably abundant.

Olivine, like enstatite, is an accessory constituent and is very variable in quantity. In some varieties of the rock it is not rare, while in most cases it is wholly wanting.

Brown glass containing microlites of different minerals and often corroding and forming enclosures in the feldspars is usually present. Sometimes, when it is present in considerable quantities, this glass exhibits traces of both the spherulitic and the perlitic structure.

The best way of illustrating the remarkable varieties of structure and chemical composition which can be produced by combining the same mineralogical constituents in varying proportions, and with modification of internal arrangement, will be to describe some of the leading types of the Ben Hiant rocks, and show how they pass into one another by insensible gradations.

1. *Typical Pyroxene-andesites*.—These consist of a more or less perfectly glassy ground-mass crowded with microlites of feldspar and augite, and grains of augite, the whole forming a “microlitic felt.” Through this base are scattered crystals of plagioclase, usually abounding with glass-inclusions, and with remarkable zoned structure. Pyroxene is represented by both augite and enstatite, the former being always the most abundant, though the latter mineral is sometimes by no means rare. Magnetite grains also occur scattered through the base (see Plate XV. fig. 2).

This rock not unfrequently contains vesicular cavities, which are usually filled with concentric deposits of various secondary minerals. The whole rock presents the most remarkable analogy with some of the well-known pyroxene-andesites of Hungary. Indeed, if some of my Ben Hiant and Hungarian sections were accidentally mixed, I know of no characters by which I should be able to separate them.

* Neues Jahrb. für Min. (1884), i. p. 48.

2. At some points, especially near the east side of the mountain, lava-currents composed of a compact rock are found. These, when studied microscopically, are seen to consist of a microlitic felt, in which the large porphyritic crystals are wholly wanting. The rock is vesicular, and the contents of the vesicles appear to be an altered glass. The specific gravity of this rock was found to be 2.89 (see Plate XV. fig. 1).

3. *Glassy (Vitrophyric) Andesite*.—At certain points, especially on the eastern side of the mountain, the rock is found to become perfectly vitreous and to pass into a “pitchstone-porphry.” In this the proportion of the glassy base to the porphyritic crystals is sometimes very great, but the latter present all the characters of the minerals found in the stony types of the rock (see Plate XV. fig. 3).

It is interesting to note that in these glassy forms of the rock the plagioclase crystals only show slight lamellar twinning in many cases, and some of the types of the rock appear to approximate very closely to the pitchstone-porphry of the Sgurr of Eigg.

The glass sometimes exhibits the perlitic structure, and it varies in density from 2.52 to 2.62.

4. When the glassy or microlitic felted base becomes small in amount, it forms isolated masses which are caught up between the crystals, and the rock exhibits the “intersertal structure” of Rosenbusch in a very striking manner, the rock becoming a typical “tholeite” of that author. In many cases the glass of these “tholeites” is crowded with skeleton-crystals of magnetite, as in the case of the rocks figured and described by Mr. Teall* (see Plate XV. fig. 4).

5. *Highly Crystalline Andesites*.—In places, especially in the great central mass of the mountain, in some of the dykes, and in the deepest part of the thick lava-streams, the rock loses almost all trace of glass, and passes into a holocrystalline mass. These holocrystalline varieties sometimes exhibit the *ophitic* structure; while, as in the case of the ophitic basalt of the same district, the breaking up of the augite and felspar crystals into rounded granules, leads to a more or less perfectly developed *granulitic* structure (see Pl. XV. figs. 5 & 6).

6. New varieties make their appearance in consequence of differences in the proportion of the several porphyritic constituents to one another. These varieties are especially seen in the dykes, some of which contain the plagioclase felspar almost to the exclusion of the pyroxenes and magnetites; while in other cases the augite and magnetite are present in preponderating quantities, and a rock of abnormal density and basicity is the result. (See Pl. XV., compare figs. 7 & 8.)

The wonderful variation in chemical composition which may result from admixture in varying proportions of the same mineral constituents is illustrated in the following table of analyses :—

* Quart. Journ. Geol. Soc. vol. xl. (1884) pp. 209–246, pls. xii. & xiii.

Analyses of the Later-Tertiary Augite-andesites (Pitchstone, Tholeites, &c.).

	I.	II.	III.	IV.	V.	VI.
Silica	52·68	57·57	58·67	65·49	66·62	65·81
Alumina	12·66	14·42	14·37	14·66	14·02	14·01
Ferric oxide	17·34	6·04	1·64		5·73	4·43
Ferrous oxide .....	...	3·95	6·94	5·44		
Manganic oxide ...	trace	0·27			trace	
Lime	11·45	6·87	7·39	3·72	2·74	2·01
Magnesia	0·93	4·24	4·65	1·57	0·33	0·89
Soda	2·49	2·98	3·01		6·93	4·15
Potash	1·91	1·08	1·42		1·51	6·08
Loss in ignition ...	0·70	1·55	2·02		2·83	2·70

I. Analysis of augite-andesite (tholeite) with very little glass, from N.W. spur of Beinn Hiant, by W. Tate. Made in the Chemical Research Laboratory of the Normal School of Science, 1888.

II. Analysis of Cleveland Dyke (tholeite), made by Stock.

III. Analysis of crystalline portion of the Eskdalemuir dyke, by Mr. Grant Wilson, 1880.

IV. Partial analysis of kernels of glassy rock in the Eskdalemuir dyke, by Mr. Grant Wilson, 1880.

V. Analysis of glassy andesite from west side of Ben Hiant, made by Mr. T. H. Holland in the Geological Research Laboratory of the Normal School of Science, 1889.

VI. Analysis of the glassy andesite of the Sgùrr of Eigg, made by Mr. Barker North in the Chemical Research Laboratory in the Normal School of Science, 1888.

These younger augite-andesites seem to be remarkable for the tendency of the crystalline to separate from the glassy portions of the mass. This is illustrated in the several ejections from the same volcano, as in the case of Ben Hiant, and even in different parts of the same dyke as shown by the interesting observations of Dr. A. Geikie on the Eskdalemuir dyke, and in those of Mr. Clough in the case of other dykes in Scotland. According to Professor Ditmar's analyses, the mass of the Dunoon Dyke contains only 47·36 per cent. of silica, while the glassy segregation-veins contain 68·05 per cent. of silica*. The contrast in chemical composition between some of the Ben Hiant rocks, which are composed almost wholly of crystals, and others made up almost entirely of glass, must be equally great.

The tendency of the ground-mass in rocks of this kind to ooze out from among the crystals and fill up vesicular cavities in the rock has already been pointed out, and has been remarked upon by Osann † and Teall ‡.

The dykes of pitchstone which traverse the basalt of Mull, near Carsing and elsewhere, and also of the well-known dykes with the same relations in Eigg, are usually glassy andesites, the porphyritic

* Trans. Roy. Soc. Edinb. vol. xxxv. (1888) p. 44.

† Neues Jahrb. für Min. &c. 1889, vol. i. p. 304.

‡ Geol. Mag. dec. 3, vol. vi. 1889, pp. 481-483.

crystals being plagioclase. In this connexion it may be mentioned that recent researches show that many of the rocks of Iceland formerly regarded as rhyolites must really be referred to the group or the very acid andesites.

We have seen that the most glassy varieties of the Ben Hiant rocks have a very close analogy to the so-called "pitchstone-porphyr" of the Sgùrr of Eigg. This latter rock, from the presence of Carlsbad-twins, has usually been regarded as a purely orthoclastic rock. But careful examination in polarized light often proves that some of these felspars show undoubted evidence of plagioclase-twinning. I have already remarked upon the fact that in the glassy variation of these rocks the lamellar twinning of the plagioclase often remains undeveloped. The quantity of glass present as enclosures in these felspars would vitiate any result obtained by their isolation and analysis.

Nowhere can we find such clear evidence as in the rocks of Ben Hiant of the truth of the conclusion that the phenocrysts of such lavas as these were formed under Plutonic conditions, and that there is no direct and necessary relation between the porphyritic crystals of a volcanic rock and the magma by which they are enveloped.

In the case of the glomero-porphyrific rocks, I have shown that the evidence points to the existence of a holocrystalline mass having been broken up and its fragments enveloped and carried up in a magma of different composition. In certain pitchstones from Colorado, for specimens of which I am indebted to Mr. Louis, I have found fragments of micro-pegmatitic rocks enveloped in a perfectly glassy magma. In hornblende-andesites from Auvergne I have found glomero-porphyrific fragments of an enstatite-andesite, and in the case of the Krakatoa lava I have shown that the crystals are not scattered at random, but really form groups derived from a preexistent nearly holocrystalline mass.

Now some of the porphyritic crystals of the Ben Hiant rocks show all those features which I have already pointed out as being characteristic of deep-seated rocks. Both the felspars and the augites show incipient schillerization, and this is found to be the case even in crystals enveloped in a perfectly glassy and vesicular matrix.

In the face of all these facts, I believe that it will be found impossible to maintain that the porphyritic constituents of such rocks as these could have been formed except under Plutonic conditions; and their present condition of corrosion and partial resorption proves that, in the volcanic masses as poured out on the earth's surface, these materials of the Plutonic consolidation are in a condition of instability—very different indeed from that in which they were originally formed.

[Since the reading of this paper I have had the opportunity of studying the remarkable work of Mr. G. F. Becker on the rocks of California. He has shown that, closely associated with the andesites and basalts of the district, are great masses of glass, containing few crystals or none at all, and presenting therefore a higher

silica-percentage and lower specific gravity than the rocks with which they are associated. These cases, though on so much grander a scale, seem comparable to those of the Eskdalemuir and Dunoon dykes and the rocks of Ben Hiant. (See the Quicksilver Deposits of the Pacific Slope, U.S. Geol. Survey, Monograph xiii. pp. 153-162.)]

X. SUMMARY OF RESULTS.

The oldest of the Tertiary volcanic rocks of the Western Isles of Scotland (which were provisionally classed as "felstones" in 1874) prove on closer study to belong, for the most part, to the group called by von Richthofen "propylites." This term is used in the present memoir in the sense proposed by Rosenbusch, namely, as a "pathological variety" of the andesites and of their Plutonic representatives.

The rocks from which these "propylites" of Scotland have been formed find their exact analogues among the andesites of Iceland and the Faroe Islands, which have been so well described by Zirkel, Schirlitz, Osann, Bréon, and other authors. But in their present condition the Scottish propylites agree in all essential respects with the altered andesites of Hungary and Transylvania, which have been described by Dölter, Szabó, Koch, and other petrographers, and no less strikingly with the rocks bearing the same name in the Western Territories of North America—the rocks which have been so well illustrated by the researches of Zirkel, Wadsworth, Becker, Hague, and Iddings.

These Scottish propylites are distinguished by their dioritic aspect, the alteration which their minerals have undergone, and the development of metallic sulphides in their mass. In this way the original characters of their constituent minerals is often completely lost; various epidotes and chlorites with much secondary magnetite, biotite, and other minerals being formed at the expense of the original constituents. In their general aspect, in their specific gravity, and in their chemical composition, the propylites of Scotland strikingly agree with those of Europe and North America.

The propylites are shown to be the oldest of the Tertiary lavas of the district; as a mass, they underlie the ophitic olivine-basalts of the plateaux, though a few lava-currents of andesitic type are found intercalated with the latter. These propylite rocks form lava-currents, which are generally short and bulky as compared with the basaltic flows; they also constitute "cupolas" or "quellkuppen," and lenticular intrusions ("laccolites").

By tracing these much altered rocks to points where the changes produced in them have been less extreme, it can be shown that they represent various types of andesite and of the deep-seated representatives of those lavas, the diorites. Among the amphibolic and mica-rocks, we find hornblende-andesites, hornblende-mica-andesites containing enstatite, mica-andesites, and also true diorites and quartz-diorites. Among the chief types of the pyroxenic rocks described are glassy augite-andesites, labradorite-andesites, stony

augite-andesites, the so-called "diabase-andesites" with augite diorites and quartz-augite-diorites.

The causes by which the "propylitic modification" of these rocks has been brought about are two-fold; namely, *solfataric action*, which produces widely spread results, and *contact-metamorphism*, which is strictly local in its effects. By microscopic study of the rocks, the actions produced by each of these causes can be discriminated and severally studied. The solfataric action appears to have accompanied the intrusion of the highly acid masses (granites and felsites) of the district, and is shown to have taken place at each of the five great volcanic centres previously described.

The study of these greatly altered Tertiary rocks throws much light upon the mode of origin of some of the most obscure among the Palæozoic lavas—rocks to which the names of "felstone" and "porphyrite" have been applied. It is shown that while in some cases these rocks are simply andesites which have undergone slight alteration from the action of surface-waters, in other instances the rocks in question must have been profoundly changed by solfataric action and converted into propylites before the alteration from the surface commenced.

In striking contrast with the older Tertiary and much altered andesites (propylites) of the district are the remarkably fresh volcanic rocks which are everywhere seen to intersect and overlie the eroded masses of the plateau-basalts, and are therefore of much later age than those rocks. These younger rocks which are only preserved as surface lava-flows at the Sgùrr of Eigg and at Ben Hiant in Ardnamurchan are of much interest, as constituting the most recent volcanic rocks of the British Islands. They are shown to have the most striking correspondence in their petrographical characters with the rocks of the Tertiary dykes that traverse the south of Scotland and the north of England, which have been described by Dr. A. Geikie, Mr. Teall, and other authors. These rocks, which were in 1874 referred to the augite-andesites, are shown, both at Ben Hiant and in some of the dykes, to illustrate in a remarkable way the influence produced on the characters and chemical composition of rocks *when the same mineralogical constituents are united in varying proportions*. In this case we find every gradation from highly basic holocrystalline rocks, through various "ophitic," "intersertal," and "pilotaxitic" types of augite-andesite, into quite acid "vitrophyric" andesites (pitchstone-porphyrries).

EXPLANATION OF PLATES XIV. & XV.

[The system of notation here adopted to indicate the magnifying-power used for the rock-sections is explained in the Quart. Journ. Geol. Soc. vol. xlii. (1886), p. 88.]

PLATE XIV.

In this Plate an attempt has been made to illustrate the chief characters of the Older Tertiary Propylites, and of some of the Andesites, of which they are the altered representatives.

- Fig. 1 shows a twinned group of Augite-crystals, exhibiting partings, produced by schillerization, along planes parallel both to the orthopinacoid and the basal plane. The crystals occur in a type of rock to which the name of "Diallage-Andesite" has been given by some authors. It is from Mingary Castle, Ardnamurchan. The specimen is shown as seen with a magnifying-power of 100 diameters. (See p. 363 and 'Mineralogical Magazine,' vol. ix.)
- Fig. 2. Transverse section of a prism of the same Augite, showing the cleavage and the secondary twinning parallel to the orthopinacoid, the planes of the latter being crowded towards the centre of the crystal. Showing, as magnified, 250 diameters.
- Figs. 3, 4, 5, and 6, represent a few of the most striking types of the Older Tertiary Andesite Lavas, as seen in parts of the rock-masses that have undergone a minimum amount of chemical alteration. (See p. 356.)
- Fig. 3. Vitrophyric Augite-andesite, showing groups of crystals of plagioclase, augite, and magnetite (with some apatite), sparsely scattered through a glassy base, which is crowded with beautiful trichites. The latter are in many cases resolvable into globulites. The rock is from Mhàim Clackaig, in Mull, and is shown as viewed with a magnifying-power of 25 diameters. (See p. 362.)
- Fig. 4. Spherulitic Augite-andesite, from Beinn-à-Ghraag, Mull. Crystals of plagioclase, augite (much altered), and magnetite are scattered through a glassy base, showing incipient spherulites. These spherulites are seen to affect a parallel arrangement, due to the movement of the mass. Magnified 25 diameters. (See p. 362.)
- Fig. 5. Glassy Andesite, from Bealach a' Mhàim, Skye. The black glass is almost as opaque, in thin sections, as that of the basalts (Tachylite). There are many spherulites, consisting each of two concentric zones; and also spherulitic fringes around the much-corroded plagioclase crystals. This glass is associated with a "labradorite-andesite." Magnified 25 diameters. (See p. 364.)
- Fig. 6. Banded Augite-andesite, from Beinn-à-Ghraag, Mull. The fluidal structure in the base of this rock is very beautifully exhibited, and is rendered conspicuous by the manner in which the bands of microlites are seen to curve around the porphyritic crystals. Magnified 25 diameters. (See p. 362.)
- In figs. 7 and 8 an attempt has been made to show the characteristic differences in the effects of solfataric and contact alteration.
- Fig. 7 is the Hornblende-propylite of Beinn Talaidh, in Mull. Scarcely a trace of the original glassy base and plagioclase crystals can now be seen in it; the colourless ground-mass consisting of secondary feldspars and epidotes, in which only occasionally the outlines of the pseudomorphs of original constituents of the rock can be detected. The hornblende has been converted into mixtures of chlorite and magnetite; but in these pseudomorphs traces of the "resorption-halos" originally formed of pyroxene and magnetite, and constituting sheaths around the crystals, can still be detected. The section is shown as magnified 100 diameters. The peculiarities of the alteration of this rock are undoubtedly due to *solfataric* action. (See p. 369.)
- Fig. 8 is the Augite-andesite from a point near its junction with the intrusive granite ("granophyre") of Beinn Uaig, in Mull. Scarcely a trace of the original crystals of the rock can be detected. In a colourless and structureless base, which is anisotropic but not individualized, we find numerous minute rounded granules of a colourless mineral, usually taken for Augite, with many grains of magnetite. A little, strongly pleochroic, brown biotite makes its appearance, and increases rapidly in quantity as we approach the intrusive rock. Magnified 100 diameters. (See p. 370.)

PLATE XV.

In this Plate an attempt has been made to illustrate some of the varieties of the Pyroxene-andesite of Ben Hiant. In these rocks the minerals and glass composing the different masses are identical; but the proportions in which they are combined and their structural relations are so different as to give rise to some very strikingly contrasted rock-types. They are shown as seen magnified 25 diameters. (See pp. 373-380.)

Fig. 1 is a compact Augite-andesite from the south side of the mountain, and under the microscope is seen to be a "microplitic felt," consisting of lath-shaped felspars, with granules of augite and magnetite, imbedded in a glassy base. The rock contains numerous small vesicles, which are sometimes filled with glass, as described by Osann and Teall. (See p. 378.)

Fig. 2 is a rock with a similar ground-mass, through which numerous porphyritic crystals of plagioclase, with some of augite and magnetite, are scattered. The plagioclase crystals contain many glass- and magnetite-inclusions; and in the ground-mass there are a few vesicles filled with secondary products. In all its essential characters the rock is quite undistinguishable from the Augite-andesites of Hungary. (See p. 377.)

Fig. 3. "Pitchstone-porphyr" from the east side of the mountain (at the point marked * on the map and section). In this rock the quantity of glassy base becomes very large, and the crystals of felspar, augite, and magnetite occur in sparsely scattered groups. The felspar-crystals are sometimes much corroded. The brown glass of this rock is traversed by many cracks, showing a distinct approximation to a perlitic arrangement. (See p. 378.)

Fig. 4. Augite-andesite with portions of glass full of magnetite needles caught up between the numerous crystals, giving rise to the "intersertal" structure of Professor Rosenbusch. (See p. 378.)

Fig. 5. Augite-andesite in which the "intersertal" structure of the last type is combined with the ophitic structure. (See p. 378.)

Fig. 6. Rock differing from the last by the almost complete disappearance of the glassy material, so that the ophitic structure dominates throughout the whole mass. (See p. 378.)

Fig. 7 is a rock in which a glassy base (with a few vesicles in it) encloses numerous large crystals of labradorite (or of a felspar near that species). Augite and magnetite are present only in comparatively small quantity and as minute individual granules in the ground-mass, and the whole rock becomes a good example of a "Labradorite-andesite." (See p. 378.)

Fig. 8 forms a striking contrast to the last. There is little glassy matter and the felspar is present in small proportions. The bulk of the rock consists of augite and magnetite, and, though so closely related with the other types, is remarkable for its low silica-percentage and high density. (See p. 378.)

DISCUSSION.

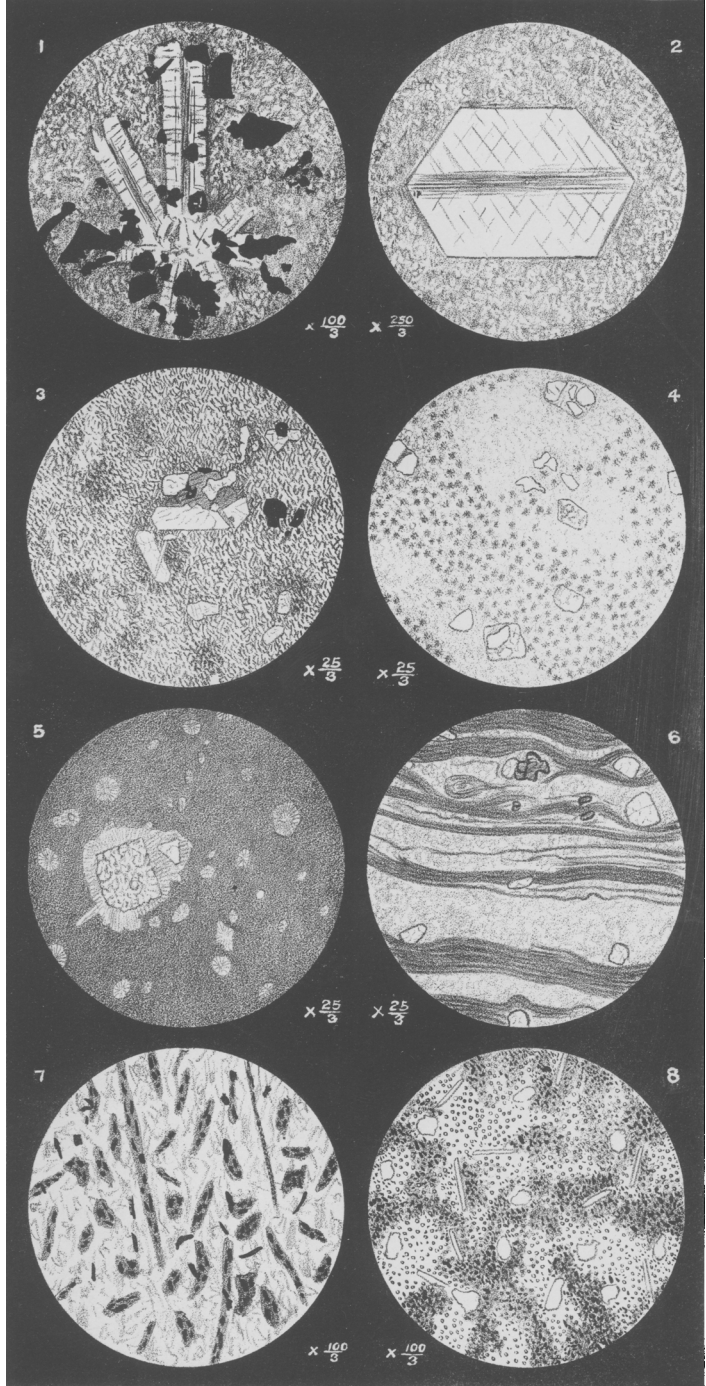
The PRESIDENT said that papers like the present were difficult to discuss. They required to be read and reflected upon.

Mr. BARROW, referring to the amphibole- and pyroxene-andesites, remarked that, in mapping some of the dykes in Scotland, he had come across cases where amphibole prevailed in an acid matrix; secondly, where the prevailing mineral was mica; thirdly, pyroxene; and fourthly, that the three minerals would occur together. All these dykes were parallel to one another, and often formed double dykes with the apophyses of the Dee-Side granite.

He inquired if it were possible to get a connecting-link between the amphibole- and pyroxene-andesites.

Mr. COLE, speaking of the dykes and sheets traversing the plateau-basalts, inquired whether those with selvages of tachylyte might be related to the later andesitic eruptions.

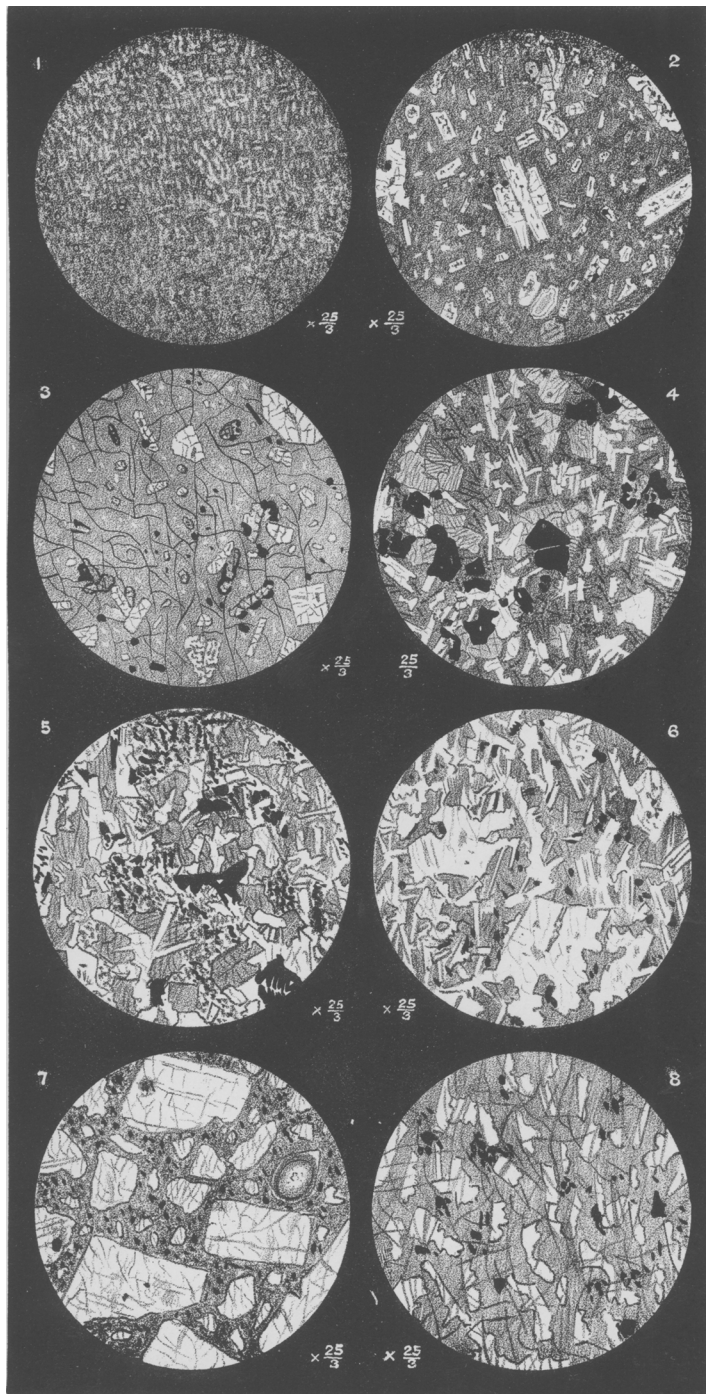
The AUTHOR, in reply to Mr. Barrow, said that the existence of true amphibole-andesites was shown, even when the change was most complete, by the chlorites &c. occupying the place of the original hornblende-crystals showing traces of the "resorption halos" so characteristic of that mineral. He had described rocks which contain amphibole, mica, and pyroxene; but in the district under consideration the distinction between amphibole- and pyroxene-andesites may be fairly made out. In reply to Mr. Cole, he was not aware of any andesitic dykes traversing the basalts which put on a selva of tachylyte.



M P Parker del. et lith.

West, Newman. imp.

Scottish Andesites and Propylites.



M. P. Parker del. et lith.

West Newman imp.

Varieties of Andesite, Ben Hiant.