of the same rules which have been employed in satisfactorily determining the order and the characteristic organic remains of the more recent systems. Surely it is not too much to hope that the day is fast approaching when these Eozoic formations will be reduced to their natural order as fossil-bearing systems, comparable in all respects (except in the greater paucity of their organic remains) with the Post-Archæan systems which at present form the accepted members of our great geological scale.

EXPLANATION OF PLATE XIV.

- FIG. 1. *Olenellus Callavei*. Glabella in relief, showing the characteristic shape, the lobes and furrows, and the broken base of the occipital spine.
 FIG. 2. ———— Do. Side elevations.
 FIG. 3. ———— Occipital lobe with base of central process. Posterior aspect.
 FIG. 4. ———— Fragment of hinder part of glabella, etc., from above, showing size and length of a broken occipital spine.
 FIG. 5. ———— Do. Side elevation.
 FIG. 6. ———— Fragment of part of head, showing marginal and interior ridges.
 FIG. 7. ———— Terminal part of free cheek with marginal ridge, and genal and "interocular" spines.
 FIG. 8. ———— Do. Another and smaller example.
 FIG. 9. ———— Eye lobe.
 FIG. 10. ———— Do. Smaller example.
 FIG. 11. ———— One of the anterior segments of the axis, showing the form and position of the median spine.
 FIG. 12. ———— Do. From central parts of axis.
 FIG. 13, 14. ———— Do. Profile views.
 FIG. 15. ———— Segment of axis near posterior end.
 FIG. 16. ———— Sub-terminal (?) segment of axis, showing central and lateral tubercles.
 FIG. 17. ———— Pygidium.
 FIG. 18. ———— One of the proximal pleuræ, showing general form, pleural groove, and falcate extremity.
 FIG. 19, 20. ———— Pleuræ from near posterior end of thorax.
 FIG. 21. ———— Superficial ornamentation of test. (Magnified.)
 FIG. 22. ———— Ditto. (Magnified.)
 FIG. 23. ———— Doublure for attachment of hypostoma.
 FIG. 24. Young form of *O. Callavei*, showing general form and characters of the glabella, eyes, frontal margin, etc.
 FIG. 25. Do. Another example.

(All the fragments figured, except Figs. 21 and 22, are of the natural size.)

Figs. 18, 19, 20, 24, are from my own Collection, the remainder are in the Collection of the Woodwardian Museum, Cambridge.

PLATE XV.

- FIG. 26. *Olenellus Callavei*, Lapw. Theoretical restoration, natural size.

II.—PETROLOGICAL NOTES ON SOME LAKE DISTRICT ROCKS.

By W. MAYNARD HUTCHINGS, Esq.

DURING the last three years I have at various times collected and studied rocks from the Lake District. Some of them are, I think, of sufficient interest to render them worth describing. It is my opinion that a great deal of very interesting petrological work still remains to be done among these rocks, and that when they are

more studied in detail they will be found to present more diversity of type than is usually supposed.

I will first note the occurrence of a variety of rock not previously recorded in this district. It is a quartz-andesite, or dacite. It is exposed on the ridge between Greenburn and Wytheburn, not very far from Dunmail Raise, and near to a new wire-fence which bounds, I believe, the property of the Manchester Waterworks. It is a dark-coloured rock, on a newly-fractured surface of which are seen numerous light spots of porphyritic feldspars, and some of calcite, with many grains of quartz, some of good size. It was the grains of quartz which instantly attracted my attention to this rock when a bit was chipped off it in passing the exposed crag.

Under the microscope these grains of quartz are seen to be corroded and eaten out into "bays and gulfs," and their nature as true constituents of the rock, and not extraneous fragments, is vouched for by their enclosures of ground-mass. None of them show definite crystalline form. In addition to the larger porphyritic grains, some very small ones are seen among the ground-mass, but not abundantly.

The many porphyritic feldspars are fairly well preserved. They are plagioclase, mostly well twinned, sometimes on both albite and pericline systems. So far as may be inferred from the extinction-angles of symmetrically-extinguishing twins, the chief feldspar present appears to be oligoclase.

The porphyritic ferro-magnesian constituent appears to have been mainly, if not wholly, biotite, which was abundant. The outlines and cleavages of the numerous large individuals are still quite preserved, but great alteration has taken place into chlorite, epidote, and indeterminate matter, probably partly carbonates and ferric oxides.

I have not met with any other andesite in the district in which biotite can be recognized as present, or formerly present, nor am I aware of any such rock having been recorded. My impression is that biotite-andesite was very sparingly represented, though of course it is possible that the chlorite, so abundant in some cases, may partly represent former biotite; but in that case we should expect to sometimes see recognizable pseudomorphs, as one so frequently does in these rocks after augite.

The ground-mass of this quartz-andesite consists of a network of small feldspar-laths, intermixed with, and at places more or less obscured by, grains of chlorite, epidote, sphene, calcite, and other matter, as is usual in all these rocks. In the greater portion of it the feldspars are very distinct and fresh, and allow of optical measurements. They are largely untwinned, the rest being binary twins. Extinctions are either quite parallel or at very low angles. We may conclude that there is oligoclase, and most likely some orthoclase present. So far as can now be made out, very little, if any, glass was present in the original rock. There are many good-sized crystals of apatite, and zircons are much more numerous than in the usual local andesites. The sp. g. of the hand-specimen

brought away is 2.74, and the silica-percentage is 60.45. Roth gives as the outside figures for silica recorded for dacites, 68.18 per cent., and 55.91 per cent. respectively, the latter being from an altered rock. It is not likely that the figure obtained by me for this Lake District dacite quite represents the *original* percentage, which, judging by the alterations, was probably a little higher, though certainly not nearly high enough to place the rock among the rhyolitic andesites. We have here, then, a well-characterized biotite-dacite, and it is likely that this or a similar rock will be found exposed at other points besides the one indicated.

Another rock occurring above Easedale Tarn, Grasmere, on the side towards Langdale, is a conspicuous representative of the other extreme of the series of Lake District rocks. It is a dolerite, a good deal more basic than any described by Mr. Ward, and differing in other ways from any hitherto recorded in the district. It is a very dark-coloured rock, easily recognized with a pocket-lens as a rather coarse-grained dolerite, without any porphyritic structure. Microscopic examination shows it to be made up of augite and plagioclase-felspar, with usual alteration-products. Augite is abundant, and much of it is still quite fresh. It existed originally, apparently, wholly as irregular grains, mostly of good size. The rock has undergone considerable crushing and shearing, and many augite-grains are cracked in several places, the cracks being cemented with chlorite. In some cases large grains have been completely shattered into small fragments, now lying among chlorite and calcite, due to subsequent infiltration. Here and there augite is fringed with secondary hornblende, but chlorite is the more usual alteration-product.

The felspar is in the form of relatively broad laths, tabular sections, and many irregular grains; it has been a good deal affected mechanically, like the augite, but is very fresh otherwise. There is no ophitic structure and no trace of ground-mass of any description. The rock is distinctly a holocrystalline, non-porphyritic dolerite, verging towards *granitoid* structure. The sp. g. is 2.95, and the percentage of silica is 45.65.

Another totally different type of basic rock examined is from near the summit of Scarf Gap Pass. Mr. Ward mentions a bed of basic lava on the east side of the pass, and gives description and figure of it. I do not know whether this is the same rock, and his figure is of very little use in deciding, while some points in his description do not agree with the occurrence here noticed.

It is a vesicular rock, the vesicles being now infilled with chlorite and other alteration-products. It has comparatively few porphyritic feldspars, all very much altered. There is abundant porphyritic augite in good-sized crystals and grains, much of which is still perfectly fresh, though much fractured in some cases. The ground-mass consists of very small felspar-laths, perfectly fresh, nearly all binary twins. They are mainly if not wholly labradorite. There is the usual abundance of alteration-products throughout the ground-mass, but a good deal of augite in small grains is still dis-

tinguishable. There appears to have been a good deal of interstitial glass originally, but it is now devitrified, and obscured by alteration. The sp. g. is 2·82 and the silica-percentage 51·35. This rock, then, corresponds to a porphyritic augite-dolerite, or probably, more correctly, basalt.

Turning to the andesites, there is a type of them abundantly represented at one part of the district, and apparently recurring at several other points, which is very interesting and differs in several ways from the usual varieties as described by Mr. Ward, or as summarized by Sir A. Geikie (Presidential Address to Geol. Soc. 1891). It consists of rocks of mostly a grey-green or grey-blue colour,—a colour not easy to exactly describe,—with resinous lustre and extremely splintery fracture. On a newly-broken surface small dark spots are seen, but hardly ever any sign of a felspar, and when seen these are very small. These particular rocks are exposed largely at Harter Fell, Mardale, making the main part of the cliff facing towards Haweswater; on the ascent from Nan Bield Pass on to High Street; and in cliffs on the right side of Kentmere Valley, some distance below the reservoir.

A series of sections prepared from specimens taken at all three of the above localities shows that the rock is essentially the same in nature at all of them. There are numerous felspar-crystals, sharp in outline, though inwardly much altered, porphyritic in a ground-mass which originally varied from a wholly glassy base to an intimate mixture of glass and exceedingly minute felspar-microlites. There are chlorite-pseudomorphs after augite, distinct in form, as well as indefinite patches and streaks of chlorite. The entire ground-mass is permeated by chlorite in minute flakelets, with small granules of epidote, calcite, and other matter.

Sections from the summit of Harter Fell, close to the double cairn, show a good deal of perfectly fresh augite as well as many pseudomorphs. The ground-mass here consists nearly wholly of devitrified glass; a dimly-polarizing, speckly, felsitic mass with scarcely any felspar microlites at all. Sections from Kentmere, again, have a ground-mass of the most typical “hyalopilitic” nature, wherein the same devitrified glass is quite full of tiny laths and needles of felspar, showing well-developed flow-structure round the porphyritic felspar-crystals. The largest and most clearly-developed of these felspar-needles are close around $\frac{1}{1000}$ th inch in length and extinguish quite parallel. The average size is very much less.

There is no doubt that, though varying more or less in detail from place to place, and even within very short distances, we have here an altered augite-andesite of a much more vitreous nature than the dominant type of lavas of the Lake District. A characteristic specimen from above Nan Bield has the sp. g. 2·65 and a silica-percentage of 57·55.¹

¹ Mr. Ward refers to rocks of a grey-blue colour, very compact, which are outwardly not unlike those above described. The closest resemblance is in a lava from near Lodore Hotel, which is singled out by him on account of its non-porphyritic nature and the smallness of its felspar-needles. He gives the average

Rocks closely similar to the above, macroscopically and microscopically, are exposed on both sides of Easedale Tarn, Grasmere. One specimen, from the right side of the Tarn, is very much altered and impregnated with calcite and other secondary matter, reducing its silica-percentage to 52.45. Its ground-mass appears to have been wholly vitreous, and porphyritic feldspars, etc., are very scarce. Specimens from the opposite side of the Tarn are again full of minute feldspar-needles, are less altered (free from calcite), and have a silica-percentage of 60.75; but here also the porphyritic constituents are much less abundant than at Harter Fell, etc.

From these vitreous and minutely "hyalopilitic" varieties, we may see all gradations of development of crystals in the ground-mass, up to the more usual, much coarser-grained andesites, as we mainly have them in Mr. Ward's descriptions.

An interesting example is exposed in a small disused quarry by the side of the road from Seatoller to Seathwaite. The rock is grey tinged with green, showing dark spots of chlorite, but no feldspars to eye or lens. It is very fissile, splitting into tolerably thin plates, and approaches more nearly to a slaty cleavage than any other lava known to me in the district; though I am told there are cases of lavas which are sufficiently cleaved to be worked for roofing-slates. The ground-mass-feldspars in sections from this quarry are still small, but larger than in the rocks just described, ranging up to $\frac{3}{16}$ of an inch as maximum. Porphyritic feldspars are greatly altered, being almost wholly replaced by calcite, and deformed by pressure and shearing; but the pseudomorphs after augite are mostly but little damaged, and show more numerous recognizable forms than in any other slides I have. The ground-mass is completely permeated by infiltrated calcite, of which there is so much present altogether that the silica-percentage of the rock now only reaches 51.6, though originally it must have been fully as high as in the average local andesites, if not higher.

The numerous lavas on Dale Head, High Scawdell, and Seatoller Fell, present an interesting variety, as we find here not only the more normal Lake District andesites, but also types which seem to lie between these and the basic rocks, and to require such terms as doleritic (better basaltic) andesite, or andesitic dolerite (better basalt), to describe them;—that is, if we adhere to the more usual custom of distinguishing between andesites, and dolerites or basalts, as extremes of a series. Of course they all pass imperceptibly into one another, and there are petrologists who call the whole series andesites, as does Professor Cole in his system of classification ("Aids in Practical Geology"), simply distinguishing them at the ends of the line as "trachytic andesites" and "basaltic andesites." Rock-classification, in the present state of the subject, is very much

length of these as $\frac{1}{16}$ th of an inch. They are, therefore, very much larger than in the rocks referred to by me, and from his description the Lodore lava was evidently very much less vitreous than these. It resembles, as Mr. Teall points out, the ground-mass of the average andesites of the district; a ground-mass in which the feldspars are above the average sizes of typical andesites elsewhere.

a matter of individual taste, so many are the systems offered to us. For my own part I think a very much clearer idea of the rocks is conveyed by the more usual method of separate grouping of andesites and basalts (using the name *dolerite* exclusively for non-vitreous rocks); as is exemplified in the classification given by Dr. Hatch ("Introduction to the Study of Petrology"). Various stages of the passage from one to the other extreme may then be clearly indicated by the use of the adjectives *basaltic* and *andesitic* respectively, according to whether we wish to specify an andesite which is tending towards a basalt, or a basalt which is tending towards an andesite.¹

While on this subject, it is difficult to see why we should retain in use the word "porphyrite" for altered andesites like those of the Lake District. The supposed differences between rocks of different geological age being no longer admitted among English petrologists, and bound to vanish also in Germany sooner or later, why retain any of the names which are connected with the obsolete system of classification, and which appear wholly superfluous when once this is discarded? As some writer has said, I think, in effect, why should we have a separate name for an old and altered rock, any more than we have a separate name for a *man* because his hair is grey and his teeth no longer well preserved? Such names only burden the memory, obscure ideas, and open the way for confusion, because they are so liable to be used in different senses by different writers. It is better, and specially so for younger students, to use two words (or a whole sentence if necessary!), and to convey a clear and unmistakeable idea by their means, than to use one word which itself needs a definition attached to it, and very likely has several different ones. Why should not such words as porphyrite, melaphyre, propylite, and very many more, disappear into the lumber-heap? They are only a stumbling-block to beginners, and an unnecessary addition to a nomenclature too much burdened with dreadful names in any case.

The regular types of andesites of the district have in their ground-mass a felspar which shows very small angles of extinction, and sometimes extinguishes parallel.

It seems tolerably safe to assume that oligoclase largely prevails, and it is very probable that orthoclase is also frequently present. But there are also rocks in which these optical tests show a felspar allied to labradorite to be present in the ground-mass. Labradorite does not appear to be usually recorded as existing in the ground-mass of normally acid andesites. In some of the lavas on Dale Head, etc., examples of it may be seen, lavas which are very full of porphyritic felspars and are unquestionably *andesites*.

¹ Mr. Teall uses the term "andesitic dolerite" on several occasions, pointing out that some authors would simply call such rocks augite-andesites; and he adds the very sensible reminder that "it is a matter of indifference what we call them, provided we recognize their true characters and relations" (British Petrography, pp. 194, 195).

A rock from Seatoller Fell is of some interest. It is a very compact, dark rock, quite free from vesicles. Its numerous porphyritic feldspars are all much altered, though still perfect in outline and relationship to the ground-mass. There are no definitely recognizable larger pseudomorphs of chlorite after augite, though good large patches of chlorite are present. The ground-mass consists of perfectly fresh feldspar-laths of a rather larger size than usual, all twinned, and showing by many extinction measurements that labradorite is dominant. These feldspars lie in among a yellow-brown, dimly-polarizing, partially devitrified glassy base, full of minute dark dusty matter. The amount of this base is considerable. In among the feldspars and glass are a large number of good-sized irregular grains of very pale-green hornblende, which is clearly secondary after former augite. In many cases the feldspars penetrate the hornblende in a manner showing that a certain amount of ophitic structure was present, but more usually the grains lie wedged in the angles formed by the feldspars. There are also numerous bits of chlorite occurring in exactly the same manner as the hornblende. Originally the rock must have contained a considerable amount of augite in this form, but none of it is now seen unaltered. There is abundance of finely disseminated chlorite and grains of epidote, some of which appears to represent a smaller generation of augite in the ground-mass. The sp. g. is 2.88, and the silica-percentage 53.55. This rock would have to be classed as "andesitic basalt."

Hornblende secondary after augite is not at all frequently observed in these rocks. There is another lava on Seatoller Fell, a normal andesite, in which it occurs as prismatic grains of deep green colour, this being the only case in which I have observed hornblende in one of the regular local andesites. Original hornblende is never seen nor any sign that it ever was present. It seems probable that hornblende-andesites were never represented in the district.

Enstatite has been shown by Prof. Bonney (*GEOL. MAG.* 1885, p. 77) to have been a constituent of some of the Eycott Hill lavas; and Mr. Teall supposes it probable that the andesites of the district contained it. I have sought carefully for it in many rocks from various localities, but have not found it, nor any secondary product which suggests it, in any undoubted lava. In a rock from Dale Head, of which I am uncertain whether it was a flow or an ash, there are good-sized serpentine-pseudomorphs after some mineral, which I think was very probably enstatite. The secondary mineral is not bastite. Again, in an ash or tuff from the summit of Sargeant Man a good deal of serpentine appears, some of it in the form of small prismatic pseudomorphs, contained in andesitic lapilli, strongly suggestive of original crystals of enstatite; and in a tuff from Glaramara one good-sized serpentine-pseudomorph is also seen, the form being quite that of the enstatites of andesites, etc.

It would seem likely that enstatite was a rare constituent of these rocks.

A rock occurs at Thornthwaite Crag, a little below the tall Cairn, which differs sufficiently from the usual andesites to be worthy of

mention. It is a grey-green, highly vesicular rock, the vesicles now filled with chlorite and chalcedony. In thin sections the difference alluded to is apparent in the feldspars of the ground-mass. These to a very large extent consist of untwinned laths, many very elongated in proportion to breadth, and extinguish mainly quite parallel to their length. Such of them as are twinned are almost without exception binary twins, and of these a large proportion extinguish simultaneously and again quite parallel, or at very low angles. There are a good many square tabular sections also seen, more than in any other local andesites examined. The laths are of various sizes, and pass down to very small ones with mainly forked and ragged ends. So far as optic discrimination in thin sections is a guide, the feldspar in this ground-mass seems to be mainly, if not almost wholly, orthoclase. There is a good deal of devitrified interstitial glass and the usual amount of diffused alteration-products. The porphyritic feldspars are still fairly fresh, and several of them in some of the slides examined appear to be orthoclase, while in others they are wholly plagioclase, the ground-mass remaining as above described. In one hand-specimen there are large groups of feldspar crystals clustered together in the manner described by Mr. Teall in the case of the Tynemouth Dyke; that is, they are *idiomorphic* towards the outside of the group, and *allotriomorphic* inside it. Some of these groups are so large that they give the effect, on fractured surfaces of the rock, of being infillings of good large vesicles with feldspar, but the microscope shows their true nature.

Some of this rock was prepared for analysis by crushing moderately small and picking out sufficient bits quite free from vesicles or their contents. The analysis was kindly made for me by Dr. J. B. Cohen, of Owens College, and is calculated on dehydrated rock:—

Silica	...	...	= 58.69	per cent.
Alumina	...	...	= 15.84	"
Ferric Oxide	...	...	= 8.62	" (Ferrous Oxide not
Lime	...	...	= 3.43	" determined.)
Magnesia	...	...	= 2.91	"
Manganous Oxide	...	...	= 0.58	"
Potash	...	...	= 3.86	"
Soda	...	...	= 5.06	"
				98.99

These figures would stand equally well for a trachyte or an andesite, the proportions of the alkalis being much the same as in many analyses given of trachytes; agreeing for instance almost completely with one of the "typical analyses" given by Professor Cole in his "Aids in Practical Geology." It appears that whether a magma of certain composition will consolidate as trachyte or as andesite, depends largely on conditions other than purely chemical. The rock in question is not a trachyte, but it would become one by a very moderate degree of further differentiation from the accompanying andesites. Rocks with a closely similar orthoclase ground-

mass, and some apparently orthoclase porphyritic crystals, occur also near Keswick.

It is not at all unlikely that undoubted trachytes may be found in the Lake District. Sir A. Geikie, in his address above referred to, alludes to the general resemblance of these lavas to the "porphyrites" of the Old Red Sandstone in Scotland, and Dr. Hatch quotes the authority of Professor Judd for the fact that "excellent sanidine-trachytes" exist among these rocks at Haddington ("Introduction to the Study of Petrology," p. 100). Some lapilli seen in certain tuffs also suggest that good trachytes exist somewhere among the Lake rocks.¹

Sir A. Geikie states that from the observations of himself and Dr. Hatch on the rocks of the Lake District, he concludes that lavas are much more abundant among them, relatively to "ashes," than was allowed by Mr. Ward in his Survey Memoir and other writings. In this conclusion it is probable that most workers in the district would now agree. But there are, of course, many cases in which it does not seem possible to decide whether they are flows or ashes, either in the field or with the microscope,—certainly not with the latter. The difficulties of this kind of examination are very fully (not to say a little gloomily!) put forth in a paper by Mr. Rutley ("On Community of Structure in Rocks of Dissimilar Origin," *Q.J.G.S.* vol. xxxv. 1879), and anybody who may be in danger of underrating these difficulties, or of getting too much confidence in his power to solve them, or indeed to solve any sort of questions whatever in microscopic petrology, would do well to read that paper.

The chemical and mineralogical changes which have taken place in these rocks are of very great interest in some cases. They are, however, most fully seen in the detrital rocks,—the ashes and tuffs,—and I hope to return to some of them in connexion with a study of the ash-slates, etc., of the district.

¹ Prof. Cole points out ("*Aids in Practical Geology*") that the older trachytes (or quartzless porphyries, orthophyres, etc.) may often be difficult to mark off from the rhyolites, and suggests that the marked absence of porphyritic quartz in some of the "altered rhyolites" may give rise to a suspicion that they were trachytes. There is a "rhyolite" exposed in the plantation in front of Shap Wells Hotel, which differs notably from the other rhyolites near to it. Macroscopically it shows crystals of felspar more prominently than any of the others do. Microscopically it shows an abundance of felspar-laths and microlites, all orthoclase, lying in a rather plentiful cryptocrystalline base, "speckly" in polarized light, apparently devitrified glass. Such laths and microlites are absent from the other local rhyolites. There is none of the spherulitic structure so abundantly developed in these rhyolites, and there is no sign of free quartz or of "granophyre." The silica-percentage of a specimen collected by me is 61.15, as contrasted with over 75 per cent. found in rhyolites of Wasdale Head and Stockdale by Mr. Garwood. The microscope shows nothing whatever to lead to the supposition that the silica-percentage has been lowered by decomposition or infiltration, the rock being very free from chlorite, etc. This was apparently never a rhyolite, but was most probably a trachyte with a large amount of glassy base.