

II.—THE LAMPROPHYRES OF THE NORTH OF ENGLAND.

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THE north-country lamprophyres occur usually as dykes of no great magnitude, sometimes as sills, more rarely as small bosses or laccolites. They are scattered over an area extending from Teesdale to Furness, from Bassenthwaite to Ingleton. A circle thus defined has a diameter of about fifty miles, and embraces all the known occurrences, though others may exist beyond these limits concealed by post-Silurian strata. In the centre of the circle is the Shap granite, and the probable genetic connexion between the lamprophyres and this granitic intrusion has already been urged by Mr. Marr and the present writer. The chief grounds for such an opinion are as follows:—

(i.) The arrangement of the intrusions, as just noticed, and the radial grouping of the dykes in the central part of the area about the granite.

(ii.) The common age of the intrusions, so far as can be fixed; both granite and lamprophyres being post-Silurian but pre-Carboniferous, and both being connected with the same crust-movements.

(iii.) Certain general chemical relations, to be noticed below; to which may be added some special chemical characters, such as the notable quantity of manganese in the granite and in most of the dykes analysed.

(iv.) The special mineralogical resemblance of many of the dykes to the Shap granite, shown by the occurrence in them of characteristic minerals such as sphene (rarely found in the lamprophyres of other districts), and especially of the well-known porphyritic feldspars of the granite. Some of these points are brought out more strongly by comparing the lamprophyres with the dark basic patches so common in the granite.

(v.) The arrangement of the different varieties of lamprophyres, the more basic and characteristic ones occurring especially in the outer parts of the area, the more acid varieties and those having most in common with the granite chiefly in the central tract.¹

(vi.) The close association with the lamprophyres of acid intrusions of types more normal for apophyses of granites, and the existence of transitional varieties between these acid rocks and the lamprophyres.

Many of the individual rocks have been described by different writers,² and it will be sufficient here to recall some of the more significant characters which they have in common. The typical

¹ It may be remarked here that the lamprophyre of Sale Fell, near Bassenthwaite, which is of a somewhat acid variety, may possibly have had a quite distinct origin.

² Bonney (analyses by Houghton), *Q.J.G.S.*, vol. xxxv. p. 165; Rutley, *ibid.* vol. xxxiv. p. 29, and *Mem. Geol. Surv. Ingleborough* (97 S.W.); Tate, *Proc. Yorks. Geol. Pol. Soc.* vol. ix. p. 372, vol. xi. p. 311, and *Rep. Brit. Assoc. for 1890*, p. 814; Hatch, *ibid.* p. 813, and *Mem. Geol. Surv. Mallerstang* (97 N.W.); Balderston, "*Naturalist*," 1889, p. 131; Harker and Marr, *Q.J.G.S.*, vol. xlvii. p. 285; Harker, *ibid.* p. 521; see also Teall, "*Brit. Petr.*" chap. x.

lamprophyres of the region are exceedingly rich in brown mica, which shows a characteristic mode of alteration by internal bleaching with separation of magnetite or limonite; often also the interposition of little wedges of calcite or dolomite. The mica is often accompanied by augite in well-formed crystals but usually quite decomposed, and in the Sedbergh district Dr. Hatch records pseudomorphs after olivine. Original magnetite may occur in variable quantity, but in very many cases is entirely wanting. Apatite in fine needles is universal. The ground-felspars include both monoclinic and triclinic species, the relative proportions of the two not being a character of importance. In the more altered rocks the felspars are not to be made out at all, unless the carbonates have been dissolved out of the mass. Original quartz occurs in the ground-mass of the lamprophyres in the central part of the area only (the Sale Fell intrusion being excluded).

Certain porphyritic elements enclosed in the general mass of the rocks, despite their insignificant bulk, are of the highest interest: they are quartz and felspars. Quartz is found in some abundance in the intrusions very near the Shap granite; at greater distances it occurs only sparingly and sporadically, but isolated grains are found even in the dykes at Cronkley in Teesdale. In the acid sills and dykes near the granite the mineral forms sharply-defined pyramidal crystals, in the transitional varieties of rock the crystals are more or less rounded, and in the most typical lamprophyres the quartz occurs in rounded blebs rarely showing any relic of crystal outline. The rounding is clearly due to corrosion by the enveloping magma, and the blebs are commonly bordered by a narrow pale-green rim of rather fibrous hornblende, converted in the more decomposed rocks into a chloritoid substance. Isolated quartz-grains with a corrosion-border of augite or hornblende are known in the lamprophyres of other districts, and have usually been regarded as mechanically caught up from the walls of the dyke. Such a view seems to be merely an *à priori* one, based on the improbability of original quartz-grains occurring in basic rocks, and we shall see that the facts are susceptible of a different reading. It may be noted in passing that similar grains of quartz with a corrosion-border of augite are found in various American olivine-basalts, and are clearly shown to be original constituents.¹

Very similar in many respects are the phenomena of the porphyritic felspars in our rocks. Both orthoclase and oligoclase are found, as in the Shap granite. In the dykes and sills nearest the granite these minerals occur plentifully; elsewhere they are, as a rule, sparingly distributed. In the intrusions in the Cross Fell inlier, for instance, an ordinary hand-specimen may show perhaps one crystal, perhaps none; in Teesdale the felspars are absent, but near Ingleton, at an equal distance from the granite, they occur in some of the dykes. The crystals of both kinds of felspar are always well rounded by corrosion in the typical lamprophyres, less markedly so in the more acid varieties and the transitional rocks, and quite intact in the

¹ Iddings, Amer. Journ. Science, vol. xxxvii. p. 208 (1888).

normal quartz-porphyrries. Within a mile of the Shap granite the sills and dykes sometimes enclose large flesh-coloured crystals of orthoclase identical with those in the granite itself, but more or less rounded as in the dark basic patches of the granite. There is, however, a significant difference. The large orthoclase crystals in the dark patches of the granite have a corrosion-border of plagioclase and quartz: in the lamprophyres this feature is not found, but on the other hand the rounded crystals of oligoclase are often bordered with orthoclase. The enveloping magma was in the former case rich in soda, in the latter case rich in potash. It is likely that in other districts special mineralogical relationships exist between lamprophyres and the plutonic masses near which they occur, but unfortunately the rocks have rarely been studied from this point of view. Doss,¹ in describing the lamprophyres of Dresden, remarks that they enclose orthoclase crystals similar to those of the well-known Plauen'schen Grunde syenite, but rounded by corrosion, and these he regards as mechanically caught up from the syenite. Since the dykes which he studied actually traverse that rock, the explanation is of course a possible one, but it does not appear from his description that the crystals have the form of broken fragments, and the case may well be a parallel to that of the Westmoreland rocks.

Having in common the general features outlined above, the north-country lamprophyres still show very considerable variations. The silica-percentage in Mr. Houghton's eight analyses ranges from 60 to less than 40, that of the Shap granite being 69. The figures for the more basic rocks are necessarily unsatisfactory, owing to extreme decomposition, some examples having nearly 30 per cent. of carbonates. The associated acid intrusives and transitional varieties occur well characterized in the centre of the area and to a considerable distance from the granite, but they do not extend so far as the true lamprophyres. They are well developed in the Cross Fell inlier; but some of the acid rocks there are not demonstrably connected with the post-Silurian intrusions, and are possibly Ordovician. In the Sedbergh district the lamprophyres and the acid intrusives are quite distinct, though closely associated, and Mr. Strahan remarks that the former intersect the latter. Rosenbusch makes the same observation in Alsace, and it is probably of some generality. The two sets of rocks, though genetically connected, were derived from different portions of the heterogeneous parent-magma, and the general rule appears to be that the injection of the quartz-porphyrries, microgranites, etc., slightly antedated that of the lamprophyres. Where transitional varieties occur, we may suppose either that they were supplied from an intermediate portion of the magma-reservoir, or that an intermixture of the acid and lamprophyric magmas took place during the injection. The striking variability of the rocks in some localities must be due to the latter cause, for in some cases the commingling of the two magmas has been very incomplete. A dyke near Gill Farm exhibits abrupt transitions from quartz-porphyry to lamprophyre, such as admit of no other explanation than

¹ Tsch. Min. Mitth. (2) xi. p. 27 (1890).

that offered. Again, Mr. Houghton's analyses of two rocks from the same locality on Docker Fell show a sharp contrast, their silica-percentages differing by more than 10. Professor Bonney concludes that the two specimens cannot be really from the same dyke, but Mr. Collins in his analyses of Cornish lamprophyres shows an even greater difference between two specimens taken *in situ* from one mass.

A few words on lamprophyres in general will not be out of place at this point. From quite early days such rocks as minette and kersantite have been recognized as interesting types, not very sharply divided from one another, but collectively occupying a position somewhat apart from what may be regarded as more normal igneous rocks. It is true that the principle of classifying rocks by a mere enumeration of their constituent minerals has led some geologists to confuse these types with the mica-bearing syenites and diorites; but such a view is not in harmony with either chemical relationships or geological occurrence. To the field-geologist the rocks in question have always been known as characteristically "dyke-rocks"; more recently they have been shown to occur also as special marginal *facies* of certain deep-seated bodies of rock.

Rosenbusch (1887) distinctly recognizes the individuality of the group, for which he adopts von Gümbel's name lamprophyre.¹ He points out its peculiarities, and separates from the two types already mentioned two others, under the names vogesite and camptonite, in which the dark mica is more or less replaced by hornblende or augite. He makes, however, a division of the group into a 'syenitic' and a 'dioritic' family, which seems to be quite artificial. It is noteworthy that most of the best known lamprophyres are found in association not with syenites or diorites, but with granites. A glance over Rosenbusch's lists of localities makes this fact at once apparent. In what follows, the lamprophyres will be regarded not as an independent group, but as a special basic modification of rocks of the normal plutonic series. This point of view is scarcely a novel one. Thus we find Hunter and Rosenbusch² describing as a new type "monchiquite, a camptonitic dyke-rock associated with the elæolite-syenites" of Brazil and Portugal, while J. F. Williams³ has given an account of such rocks and others (fourchite and ouachitite) in Arkansas, and has demonstrated their genetic relations with the elæolite-syenites of that state. The varied series of rocks studied by Brögger in the Christiania district seem in several instances to run to lamprophyric modifications, and we may expect much light to be thrown on the subject in that eminent geologist's forthcoming monograph.

In endeavouring to explain the multiplicity of igneous rocks, and the evident genetic relations between widely different types, geologists have been led to speculate on the separation, by gravity or otherwise, of a large reservoir of molten magma into more acid

¹ The name mica-trap evidently cannot be made to cover all the types here included.

² *Tsch. Min. Mitth.* (2) vol. xi. p. 445.

³ *Rep. Geol. Surv. Ark.* for 1890, vol. i.

and less acid portions, which, if gravity be the controlling agent, must form upper and lower strata within the reservoir. There can be little doubt that such a hypothesis provides a *vera causa* for many of the phenomena. Now if we compare a more acid with a more basic type in the normal series of igneous rocks, we find certain chemical relations to hold with a high degree of generality. As the silica-percentage diminishes, the proportion of iron-oxides increases (especially at the most basic end of the series), the magnesia increases steadily, the lime increases and then falls off again, the total alkalis diminish, and the proportion of potash to soda also in general diminishes. All systematic treatment of ordinary igneous rocks which is in any degree 'natural' (as opposed to Linnæan) is tacitly based upon these general laws.

We are regarding the lamprophyres as basic modifications of various plutonic rocks, and it is easy to see that tested by the above laws they are abnormal, the exceptional characters being found in the behaviour of the alkalis. This appears on comparing the analysis of a lamprophyre with that of the plutonic rock with which it is certainly or presumably connected. Take, for instance, the biotite-granite of Durbach in the Black Forest, and the remarkable lamprophyre (the durbachite of Sauer¹) which forms a marginal modification of it. The analyses give—

	Silica.	Soda.	Potash.
Granite ...	67.70	3.22	5.78
Lamprophyre ...	51.05	1.85	7.24

showing that with a heavy falling off in silica the total of the two alkalis remains closely the same as in the normal rock, while the ratio of potash to soda, instead of diminishing, rises from 1.79 in the granite to 3.91 in the lamprophyre. Again, the quartz-bearing augite-syenite of Ramnäs passes at its margin into a lamprophyric rock, and the figures are as follows:—

	Silica.	Soda.	Potash.
Akerite ...	58.48	5.52	3.06
Lamprophyre ...	46.40	4.81	3.84

Here, as before, the total alkalis remain nearly the same, and the ratio of potash to soda increases from 0.56 to 0.80. The augite-minette of the Plauen'schen Grunde may fairly be compared with the syenite which it cuts through, and the results stand thus—

	Silica.	Soda.	Potash.
Syenite ...	59.83	2.44	6.57
Lamprophyre ...	50.81	1.01	7.01

the total alkalis only falling from 9.01 to 8.02, and the ratio of potash to soda rising from 2.69 to 6.94.

Judged by these examples, the lamprophyres would seem to be special basic modifications of their parent-rocks in which, with a greatly diminished percentage of silica, the total alkalis show little change, while potash becomes more abundant at the expense of soda. We have selected, however, cases of lamprophyres in the

¹ Mitth. Grossherz. Baden Landes, vol. ii. p. 258.

² Brögger, *Syenitpegmatitgänge*, p. 49.

closest connexion with their parent-rocks; going to greater distances, we find the total alkalis falling off, but still far in excess of the amounts proper to rocks of like silica-percentage. The relation between the two alkalis noticed above is by no means universally found in the lamprophyres (cf. those of Cornwall), but it is certainly very common and characteristic. The Shap granite has 8.22 per cent. of alkalis. In Mr. Houghton's eight analyses of the dykes the figure varies from 7.99 to 4.52. The ratio of potash to soda in the dykes ranges from 9.51 to 0.93, and is in every case but one higher than the ratio in the granite (1.01). It is particularly high in the most basic of the lamprophyres.

The chemical peculiarity of the lamprophyres, as compared with other rocks of like basicity, consists then in their relatively large content of alkalis, and in particular of potash. The mineralogical peculiarities of the rocks are, of course, simple consequences of this. The abundance of potash enables nearly all the magnesia and iron-oxides in the magma to be built up into brown mica, so that augite and hornblende occur only as minor accessories, and original free iron-ores are in very many cases not formed. A large part of the potash being taken up in the mica, it follows that the predominance of orthoclase or plagioclase among the ground-felspars will not be related in any very simple manner to the proportions of the two alkalis in the bulk-analysis, and a classification of the rocks based on the dominant species of feldspar will not be a natural one. Further, in so far as any such relation holds, the plagioclase-rocks will, broadly speaking, be more acid than the orthoclase-rocks derived from a similar parent-magma. It may be noticed in the analyses of the typical European rocks that the kersantites are more acid than the minettes. Another consequence of the abundance of the basic silicate mica in the ordinary lamprophyres is that free quartz is often formed in rocks with not much more than 50 per cent. of silica.

If the more ordinary types of lamprophyres are to be regarded as specialized *facies* of granites and syenites—the conclusion to which the foregoing remarks tend—it may be asked whether other families of plutonic rocks may have like modifications connected with them. A few peculiar rocks have been described which might possibly be considered in such a light. I would doubtfully instance Koch's¹ olivine-mica rock forming a small dyke in Kaltenthal in the gabbro-district of Harzburg. This may be compared with the immediately adjacent gabbro of Ettersberg, analysed by Streng, as being conceivably a lamprophyre (in the extended sense) of that rock, thus:—

	Silica.		Soda.		Potash.
Gabbro	50.09	1.39	0.83
Lamprophyre?... ..	34.98	0.17	5.42

Here the large quantity of potash in the second rock is very striking. In the other constituents the relation of the rock in question to the gabbro is that of an ordinary ultrabasic to a basic type.

Returning to the rocks of the North of England, the question naturally arises: how did the lamprophyric magma become ab-

¹ Zeits. deuts. geol. Ges. vol. xli. p. 163 (1889).

normally enriched in potash as compared with ordinary basic segregations? On this point some suggestions may be offered. We may imagine beneath the area where the lamprophyres are now exposed, or beneath the central part of it, a deep-seated reservoir of molten magma which was partially separated under the action of gravity, the heavier basic portion forming the lower strata. In this magma, as it cooled, the earlier products of consolidation crystallized out, the most important of these early products being the large crystals of orthoclase. It is a known fact that felspar-crystals will sink even in a basic rock-magma, and thus as the crystals formed, they must have accumulated at the bottom of the reservoir, and thus modified the total composition of the lower basic strata. The examination of the Shap granite proves that a certain portion of the quartz, the sphene, and especially the apatite crystallized out before or simultaneously with the large felspars, and these too would sink to the bottom. The felspars and quartz have been dissolved by the basic magma, but their elements would not be redistributed through the whole magma in the reservoir, except in so far as the dissolution of the crystals was concurrent with their accumulation. The process of solution seems to belong to a later stage, that of a relief of pressure when the injection of the dykes took place. Since the porphyritic felspars occur plentifully in the Shap granite, we must suppose that their sinking to the bottom was finally arrested by a general consolidation of the magma, or at least a certain degree of viscosity in any part which remained molten. Subsequently to this came a partial refusion of the whole and the intrusion of the granite into its present position, closely followed by the injection of the acid dykes and sills and almost immediately the lamprophyres. The diminutive size of the corroded felspars in the latter rocks probably indicates that many others have been entirely dissolved in the containing magma, and this solution is most reasonably referred to the epoch of the injection of the dykes. It corresponds to the "resorption" phenomena in the intratelluric hornblende and biotite of many andesites, etc., effects ascribed to the relief of pressure in the process of extravasation of the lavas. Felspar-crystals, as has been stated, are found, though as a rule sparingly, in some lamprophyres at a considerable distance from the centre of the area; but, in view of the narrowness of many of the dykes, it seems probable that their transportation has been in some measure checked by a sifting or filtering action.

The above considerations may appear very speculative; but in reality, if the magma-reservoir be granted, they scarcely go beyond known facts. If some such hypothesis be found satisfactory in the area considered, it may possibly have a wider application. Certainly the association of mica-lamprophyres with porphyritic granites in numerous districts is rather striking. The porphyritic felspars, however, must not be regarded as essential. All that is requisite is that some constituent rich in alkali should crystallize out at an early stage in a magma more or less separated under the action of gravity. Such constituent may be in different cases a felspar, a

felspathoid (leucite, sodalite, etc.), or a mica, and there may or may not be any undissolved relics of it in the lamprophyre as finally consolidated.

One other remark may be made in conclusion. In rocks containing abnormally large proportions of potash and soda, and having at the same time plenty of alumina, it should not be surprising to find occasionally minerals richer in alkali than the feldspars. Now at Cronkley, on the banks of the Tees, all the dykes contain a mineral which in thin slices shows hexagonal or quadrangular outlines, with a dark border and nucleus. The sections have no very definite action on polarized light, and seem to be more or less completely converted into obscure decomposition-products. Mr. Rutley regarded the mineral as decomposed garnet, but if it occurred in a phonolite or leucitophyre it would probably be put down confidently as nosean. Without expressing an opinion on this point, I will observe that in the most easterly dyke, where the mineral in question is most abundant, there occurs another with square contour, bright blue colour, and single refraction, which I can refer to nothing but haüyne.

III.—AN IMPROVED METHOD OF TAKING IMPRESSIONS OF FOSSILS, ETC.

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PALÆONTOLOGISTS and others concerned with fossils often have need of some method of taking impressions of fossils, which shall at the same time be simple and efficacious, and shall also be of such a nature as not to cause injury of any kind to the original. Many different processes have been tried, with varied success. The following method has stood the test of application to a wide range of subjects, and has answered its purpose well in the hands of a considerable number of workers:—

The only outfit required is a small roll of thin tinfoil of ordinary quality, a small plate-brush, neither too hard nor too soft, a bottle of shellac varnish, and some paraffine wax, with a night light or some such means for melting it.

If the fossil is not in too high relief, say a fossil fish, or such a plant as a Coal-measure fern, all that is needed is to cut a piece of foil rather larger than the specimen, then to press it gently, with the finger tips at first, into all the larger depressions, beginning at the middle and working outwards towards the edge all round. Then, keeping the fingers extended over the impression, go over the whole thing with the plate-brush, using it as gently as possible; and with only a very slight lateral movement. After a few seconds treatment of this kind an almost exact counterfeit of the fossil will appear—even some of the very finest sculpturings being distinctly visible on the upper surface of the foil.

When that stage is reached, the foil should be lifted very gently at each corner so as to free it from any projecting or undercut points. Herein lies the special value of the tinfoil process, inasmuch as this material does not enter the undercut parts as modelling wax,