IX. *On some Tuffs associated with the Andesitic Lavas of Lorne.*
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IN the course of my work among the volcanic rocks of Lower Old Red Sandstone age in the district of Lorne, in Argyllshire, I have had occasion to map some interesting fragmental rocks in the neighbourhood of Taynuilt, about twelve miles from Oban. These rocks are Tuffs, and are associated with the andesitic lavas of the district, and evidently belong to a high horizon in the volcanic series. Numerous exposures of precisely similar rocks, which appear to be referable to the same horizon, have also been mapped by my colleague, Mr R. G. Symes, between Taynuilt and Oban, and also on the north side of Loch Etive in the district of Benderloch. These have been noticed from time to time in the pages of the Annual Summary of the Geological Survey,¹ and the following notes are the result of a more detailed examination of some of the more typical examples.

Mode of Occurrence.—In the field the Tuffs are found covering fairly large irregularly shaped tracts, frequently capping the entire upper portion of a hill and standing out above the lower ground in bold escarpments. They are often closely associated with hornblende-andesites and lava-flows which are decidedly more acid than the normal andesites of the district and allied to rhyolites. These latter rocks occur below the Tuffs, and it is probable that it is owing to the breaking up of these and rocks of similar chemical composition that the present characters of the Tuffs are mainly due.

The rock is hard and varies in colour from purple to almost brick-red, and shows numerous broken crystals of felspar, flakes of biotite, and rock fragments or lapilli of various sizes in a compact groundmass. Some portions may be thickly studded with lapilli, while other parts again may be almost entirely free from them. So that the rock sometimes has the aspect at first sight of a mass of porphyry or biotite-porphyrity. A thorough examination, however, of the rock in the field will soon convince the observer of its truly bedded nature and thoroughly pyroclastic origin. The normal type may be termed a crystal-tuff, with lapilli. The lapilli are as a general rule of small size, seldom measuring over 3 or 4 inches in diameter, while the average size is, in most cases that have come under my

¹“Ann. Rep. Geol. Survey for 1896,” p. 54. “Summ. Prog. Geol. Survey for 1897,” pp. 83, 84, and for 1898, pp. 73-75.

observation, a good deal smaller. A number of specimens of these rocks from various localities, collected not only by myself but by my colleague Mr R. G. Symes, have been examined under the microscope.

Microscopic Characters.—When we consider the peculiar liability of volcanic rocks of the fragmental class to undergo changes under the influence of the various agencies of metamorphism, it is interesting to find that these tuffs, when examined under the microscope, have, for palæozoic rocks, retained their original characters remarkably well. Sections of the more typical examples [7247], [7598], [7404], [7706], etc.¹ collected in the neighbourhood of Tynnuilt, show numerous broken and more or less corroded crystals of sanidine, some plagioclase, biotite flakes, grains of magnetite, and lapilli. The sanidine is clear and remarkably fresh. It is often traversed by cracks, and shows the normal twinning on the carlsbad plan. The amount of plagioclase (oligoclase or andesine) varies in different sections, and the mineral is usually more or less turbid from alteration. The biotite is of the variety characteristic of the hornblende-andesites and trachytes. It is sometimes bent and often bleached from alteration, and occasionally partly or entirely replaced by granules of iron-ore. Hornblende is also sometimes present, but is usually represented by chloritic alteration products.

The *lapilli* appear to be mainly andesitic, but they are often so charged with secondary magnetite dust that it is difficult to make out the nature of their original characters. Those of definitely andesitic character contain plagioclase phenocrysts in a groundmass rendered dark and sometimes almost opaque by minute magnetite granules. The ferro-magnesian constituents, in these more basic fragments, are usually too decomposed for identification. It is probable, however, that they represent pyroxene-andesites of the type so common in the surrounding area. Occasionally a lapillus is seen (7247) of more decidedly acid, or rather trachytic, character, containing phenocrysts of sanidine felspar, doubtless representing a portion of the parent-rock, from which the numerous broken sanidine crystals in the tuffs were derived. Sometimes again the lapilli consist of hornblende-andesite (7246, 7722), and resemble the rock with which the tuffs are often found associated. A section of one of these fragments shows (7722) phenocrysts of idiomorphic hornblende, biotite, plagioclase, and some quartz grains. The hornblende shows the characteristic sections and outlines of the brown variety characteristic of the hornblende-andesites, and as

¹ The numbers in brackets refer to micro-sections in the collection of the Geological Survey at Jermyn Street, London.

Fig. 1. $\times 22$.

Fig. 2. $\times 22$.

ASH-STRUCTURE IN TUFFS FROM THE VOLCANIC SERIES OF LORNE.

is so frequently the case in these rocks, it is now almost entirely replaced by granules of iron-ore. The biotite shows a deep border of similar secondary material, within which the original substance of the mineral is bleached and almost colourless. The quartz grains are undoubtedly original; they are more or less corroded, and show characteristic inlets and inclusions of the groundmass. Their presence allies the rock to the dacites. In another section of a lapillus of hornblende-andesite (7246), biotite is seen to be in excess of hornblende. It is fairly fresh, and of a deep brown variety, with strong dichroism. There is no quartz. This variety might be termed hornblende-mica-andesite. The groundmass in both slides is much obscured by specks of iron-ore and alteration products, but is seen to consist largely of small felspar microlites.

Although in the majority of the exposures the lapilli in the tuffs appear to be mainly andesitic, felsitic fragments have also been observed.¹ Non-volcanic fragments derived from the older platform of crystalline schists are occasionally met with, a specimen taken from an exposure half a mile south of the Free Church Manse at Taynuilt showing (7717) a lapillus consisting of biotite, sericitic mica, quartz, and some felspar, with a few small garnets. When, however, the tuffs overlap beyond the margin of the older andesites, and are found resting directly upon the underlying schists, as in the district of Benderloch, we may find a large proportion of non-volcanic material among the lapilli.

We will now consider the groundmass in which these lapilli and ejected crystals lie embedded. The general matrix seems to be almost purely volcanic. In many cases it is a good deal altered, but the clastic character is nearly always still evident. The important and characteristic feature of this matrix is the beautiful ash-structure (*aschen* and *bogen-structur* of German petrographers), which it frequently presents. Some sections (7706, 7716, and 7592) show the structure in a very perfect manner. (See Plate III., figs. 1 and 2.) The appearance is more or less similar in each section. We see numerous, small, more or less clear, irregular fragments and particles, sometimes concavo-convex in outline, and sometimes bi-concave, packed closely together. Sometimes they may enclose infilled vesicles. In some cases (7706) many of the smaller lapilli consist of highly vesicular fragments up to $\frac{1}{4}$ inch in length with ragged outlines. Occasionally the fragments as well as the finer particles may lie with their longer axes approximately parallel, indicating a lamination of the material, or again they may alternate with a still finer and more dust-like type of

¹ *Summ. Prog. Geol. Survey for 1898*, p. 74.

matrix. There seems to be no doubt that these fragments were originally glassy, and were derived from the shattering of a highly vesicular lava resembling pumice. The structure, so characteristic of these Lorne tuffs, has been well described and illustrated by Mügge in his description of some acid tuffs associated with soda-rhyolites in the Devonian of the Lenne district in Westphalia.¹ These rocks show very clearly the characteristic form of the constituent ash-particles, bounded by concave curves, which are so suggestive of broken-up pumice. Recently a similar structure has been described in a brecciated soda-felsite from Wicklow Head in Ireland.² In this case, however, the structure is apparently due to the breaking up of a glass by brecciation *in situ*. In the case of our Lorne rocks, however, and tuffs in general, there can be little doubt that the "ash-structure" is the product of showers of minute glassy particles ejected from a volcanic orifice by discharges of a highly explosive character. Thus, in the case of a paroxysmal eruption such as that of Krakatoa, water is present in the liquid magna, in great quantities, and, by its violent escape in the form of steam, blows the lava into the condition of spray. The minute particles of lava, thus violently discharged into the air, will consolidate in the form of glass, and fall to the ground as a shower of fine glassy fragments, mingled with ejected crystals that had already consolidated in the magma previously to the eruption, and fragments of lava and other rocks, shattered by the violence of the discharge. The characteristic form of the glass particles is due to the immense quantity of gas bubbles and steam cavities present in the molten mass at the time of eruption.³

EXPLANATION OF PLATE III.

FIG. 1. [7716.] Section of Tuff, showing the characteristic ash-structure, which constitutes the greater portion of the rock, from a specimen collected $\frac{3}{4}$ mile S. of the F.C. Manse, Taynuilt, Argyll. The groundmass consists of numerous small fragments frequently with concavo-convex or bi-concave outlines, produced by the shattering of a highly vesicular rock, such as pumice. These fragments are embedded in a fine dusty matrix. One or two turbid and corroded fragments of plagioclase felspar are also shown; also specks of magnetite, and a few small andesitic lapilli, $\times 22$.

FIG. 2. [7592.] Tuff, $1\frac{1}{2}$ miles S.E. of Taylor's Leap, near Taynuilt, Argyll. The section illustrates a similar ash-structure, but of a slightly coarser type. The devitrified fragments show very clearly the highly vesicular nature of the rock from which they were derived. Lapilli of andesite are seen near the top of the figure, rendered opaque by disseminated iron-ore. Fragments of plagioclase felspar are also present, $\times 22$.

¹ O. Mügge. "Untersuchungen über die 'Lennenporphyre' in Westfalen und den angrenzenden Gebieten."—*Neu. Jahrb. Beil. Bd. viii.* (1893) p. 648, and pl. xxiv., figs. 20 and 21.

² *Summ. Prog. Geol. Survey for 1899*, p. 179.

³ See Teall, "British Petrography," pp. 408, 409; also Harker, "Petrology for Students" (2nd ed.), p. 266.