IX.—*Notes on the Occurrence of Chlorite among the Lower Silurian Volcanic Rocks of the English Lake District.*

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THE Volcanic Rocks of Lower Silurian age in the Lake District are interesting in the highest degree on many accounts, and not least so on that of the extreme metamorphism which they have undergone, partly by the deep burial they suffered during the period between the close of the Lower Silurian and the Old Red, when they were once more largely uncovered,* and partly by that never-ceasing action of infiltration, decomposition, solution and replacement to which all rocks are subject during the course of geological time, but to which rocks of an originally volcanic origin seem specially subject.

If there is one feature in this metamorphism of the Cumberland rocks more prominent than another, it is the large degree to which chlorite has been developed among them, and the universality of its occurrence.

Chlorite and its more unstable allies, delessite or chlorophœite, occur in the first place in a diffused or finely divided state in the base of all the old Cumberland lavas, filling up the interstices between the numerous felspar needles so characteristic of these old flows. This abundance of diffused chlorite gives a general diabasic character to the lavas. Under the head of Diabase, Zirkel remarks (Mikroskopische Beschaffenheit, p. 407) that the diffused greenish mineral seems to be chlorite and probably a decomposition product of augite, and the same is very likely the case among the Cumberland rocks, for the larger augitic crystals which occur in considerable abundance among some of the lava-flows are often replaced by chlorite in precisely the same manner as the diffused chlorite seems

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* See "Geology of the Northern Part of the English Lake District," Chap. XII.

to have replaced some previous minutely diffused mineral. The brownish colour sometimes assumed by the chloritic mineral seems to be due to change of the more unstable varieties by exposure. Many of the small intrusive masses of both dolerite and diorite are likewise fully charged with chloritic minerals, chlorite sometimes also lining the fine joints and cracks. The vesicles which occur in great abundance in some of the lavas are often filled with chlorite, or chlorite lines the cavity, which is filled with calcite, chalcedony, or quartz.

The most remarkable mode of occurrence of this mineral is, however, among the beds of volcanic ash in their various stages of metamorphism. In an ash comparatively but little altered, while many of the broken crystals will be represented by chloritic pseudomorphs, chlorite may occur but sparingly developed in the finer dust or granular matrix. But in most cases it occurs in such quantity as to impart a general green colour to the ash rocks, which is seen especially well in the cleaved ashes or "green slates" as they are called.

A curious feature among the altered coarse ash beds is that of a flow of chloritic granules around the larger fragments; this has been illustrated in the Survey Memoir before mentioned (Pl. II, fig. 14), and in my paper on Ancient and Modern Volcanic Rocks (Quart. Journ. Geol. Soc., vol. xxxi, pl. xviii, fig. 13). Such altered ash rocks are often exceedingly compact and trap-like, but the outlines of the original fragments are not seldom plainly discernible on the weathered exterior. When viewed in a thin slice under the microscope the fine matrix appears decidedly granular under a high power, but the granules are frequently collected along lines which sweep round the larger fragments in oftentimes graceful curves, and are mainly composed of green chloritic matter. The universal presence of this structure, with an extreme of alteration, such that the outlines of the original fragments are only barely discernible, convinces me that the granular chloritic flow has been produced subsequently to the formation of the rock by excessive metamorphism.

There are other cases in which the ash being very fine and uniform in grain, an equal amount of metamorphism has taken place without much of the flowing or streaky character being developed. A well-bedded ash in Great Gable is an example; the bedding in the mass is clearly seen, but in hand specimens the very faint lines are with difficulty traceable, garnets are developed in tolerable abundance, the look and texture of the rock is trap-like in the extreme, and throughout the felsitic looking base there appear under the microscope an infinite number of very minute particles of chlorite and brown mica. In some instances there occur fine clouds of these minute chlorite particles only, and in others the particles seem partly chlorite and partly mica. As however, the alteration becomes still more excessive on nearing the large tract of Eskdale granite, the rocks assume a marked purplish hue, and in all such cases the chloritic particles seem to have given way to similar particles of green and brown mica. A stage nearer the granite the altered rocks become distinctly porphyritic, and the mica particles more and more defined and flaky, and are sometimes collected thickly round the edges of imperfectly formed felspar crystals, as if pushed outwards in the growth of the latter.

Have we not here then a gradual passage from chlorite into mica, a hydrous into an anhydrous mica, on approaching the granite tract ? The first step in the metamorphism seems to be the formation of chlorite throughout the rock, often assuming a streaky arrangement around the larger fragments; the second, the conversion of the chlorite into magnesia-mica, or even into potash-mica; and the third, the collection of the mica into groups and larger flakes. Of course, I shall not be understood to mean that this mineral evolution takes place by itself unconnected with the associated minerals; it is the change which is worked in the whole rock, in all the mineral constituents, that enables this conversion of one mineral species or variety into another to take place. Thus the decomposition of one silicated mineral would furnish silica for the further silication of another mineral species or variety, or for the production of another mineral altogether, the formation of garnets in the altered rocks by union of the excess of silica with alumina, being an example of the latter process.

It now remains to mention examples of the occurrence of chlorite on a larger scale among some of the altered rocks surrounding the Eskdale granite. In Eskdale, especially about Harter Fell and neighbourhood, both chlorite and epidote are very abundant in nests and strings. In many places the rock is quite seamed with veins of chlorite, which under the microscope is seen to occur often in fine fan-shaped crystalline groups, showing bright colours under crossed prisms and a well-marked dichroism when the polarizer is alone used and rotated.

Occasionally, the highly altered ash-rocks near Harter Fell, besides being seamed with chloritic veins, are full of small nests of chlorite and quartz, ranging from about ¼in. to 1 inch in diameter. These nests are generally lined with chlorite and filled with quartz, but not unfrequently the two minerals are more or less mixed, and sometimes the whole is composed of fibrous crystalline chlorite. The weathering of the rock brings out these nests in more or less relief upon the surface, which then appears as if studded over with many round black nodules, and these may sometimes be taken out whole from the rock by a little careful hammering.