Notes on Hornblende as a Rock-forming Mineral.

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THE part played by hornblende (*i.e.* the monoclinic amphiboles) in the constitution of rocks, and the relation of that mineral to augite (including all the monoclinic pyroxenes), are subjects which, in recent years, have occupied much attention. It has been recognised that the early notions of paragenesis cannot be applied, without many reservations, to rock-forming minerals. Some petrologists have gone so far as to suppose that augite and hornblende "are two different crystallographic forms of essentially the same molecule, of which the former is most stable at high, the latter at ordinary temperatures."[1] If this view receives any extensive confirmation, the well-known conversion of augite into hornblende must be regarded as a purely paramorphic change due to altered conditions. The chemical identity of the augite and its resulting hornblende is, however, to be proved or disproved in any given case, and meanwhile the analyses seem to indicate a fairly consistent difference of composition between the two minerals, so that the change in question is rather a pseudomorphic than a paramorphic one.

Further, petrologists are coming to admit that neither colour nor internal structure affords a certain criterion to discriminate between original and secondary hornblende. In particular, hornblende produced by the pseudomorphic alteration of pyroxene may be brown, compact, and well cleaved, so as to be identical in appearance with original hornblende crystals in the same slide: the two can be distinguished only by their mode of occurrence and their relation to adjacent pyroxenic minerals.

The various modes of occurrence of hornblende are well illustrated by the "hornblende-diabases" &c. of Western Caernarvonshire and Anglesey, in which, excluding fibrous and actinolitic forms of amphibole, we find the following varieties, two or three of them often being seen in the same thin section:—

(i.) Original hornblende in idiomorphic crystals.—This shows the usual

[1] G. H. Williams, *Amer. Journ. Sci.*, Vol. XXVIII. p. 259, 1884. See also "The Gabbros and Associated Hornblendic Rocks of Baltimore," by the same author. *Bull. U.S. Geol. Surv.*, No. 28, 1886.

prismatic cleavage, and more rarely one parallel to the clinopinacoid. It has the normal brown colour, with the ordinary pleochroism, but sometimes passes gradually into greenish or colourless hornblende in a manner suggestive of subsequent alteration. The crystals rarely show terminal planes: the cross-section is bounded by the prism-faces, with often the clinopinacoid and sometimes the orthopinacoid.

(ii.) Original ophitic plates of hornblende with its other characters as before.—It is not always possible to distinguish these with certainty from pseudomorphic hornblende completely replacing plates of augite. Sometimes, however, they are seen to include imperfect crystals and rounded grains of augite without any crystallographic relation between the two minerals. They also enclose crystals of earlier-formed hornblende. Original hornblende is very rarely found in these rocks as a definite inclusion in plates of augite.

(iii.) Original enlargement of hornblende crystals.—This is a bright grass-green variety, forming an addition to idiomorphic crystals of brown hornblende, and in crystalline continuity with them. From its always presenting good crystal faces, it appears to have been formed prior to the final consolidation of the rock. It grows chiefly upon the clinopinacoidal faces of the brown crystals, and often entirely obliterates those planes.

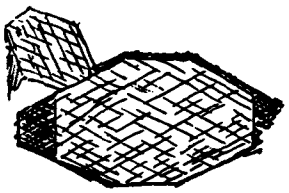

FIG. 1.

Fig. 1 shows two cross-sections of brown hornblende thus augmented by green hornblende-substance, from Lys-einion, Anglesey.

(iv.) Complementary (*ergänzende*[1]) hornblende, also original.—This is a growth of brown hornblende surrounding a nucleus or kernel of augite, or sometimes forming a partial border on the edge of an augite plate. The two minerals have their orthopinacoids and clinopinacoids parallel, differing thus from the hornblende which merely includes grains of augite. The boundary of the augite nucleus, though often less regular than that of mere included grains, is never so ragged as that of an augite core surrounded by pseudomorphic hornblende. A section of the picrite of

[1] *Rohrbach, Tscherm. Min. u. Petr. Mitth.* (*N.F.*) Vol. VII. p. 24, 1886.

Penarfynydd shows a plate of augite surrounded by complementary hornblende, with rounded olivine grains, the earliest product of consolidation.

(v.) Pseudomorphic or perimorphic ("paramorphic") hornblende.—The amphibolisation of the augite takes places either in capricious patches, or in streaks or shreds following the cleavage; but very often the process begins at the exterior of the crystal or plate, and extends inward. This marginal alteration has been styled perimorphism. When well-formed crystals of augite have been altered in this manner, the secondary nature of the hornblende is very apparent. In the case of shapeless plates, the origin of the hornblende is usually indicated by the very irregular and intricate boundary which it presents to the remaining core of augite. Further, it often happens that several isolated cores or patches of augite remain, which, from their optical continuity, are seen to have formed part of one original augite plate. This cannot be the case where augite is embedded in complementary hornblende. A plate of pseudomorphic hornblende and the remains of the augite from which it has been derived are related in such a way that the clinopinacoid and orthopinacoid are common to the two minerals; but in some cases the two are in reverse position to one another, the extinction-angles in a clinopinacoidal section being about 40° for the augite and 20° for the hornblende on the same side of the vertical axis.

(vi.) Secondary enlargement of hornblende crystals.—This is a later growth of amphibole, sometimes green, but usually colourless, forming an extension to crystals or plates of hornblende, with crystalline continuity. It gives rather higher polarisation-tints and a very slightly wider extinction-angle than the original mineral. It is certainly posterior to the consolidation of the rock, and may often be seen to occupy the place of felspar, olivine, or some other original mineral, at the expense of which it is in part formed. This secondary hornblende is usually a narrow fringe with a ragged edge; at other times it extends so as to fill up the space between the crystal from which it grows and some neighbouring crystal. Again, the interstices between two or three original crystals may be filled by colourless hornblende, which between crossed nicols is seen to consist of portions belonging to the several adjacent crystals. The new growth is much more apt to be developed on the ends than at the sides of the original crystals.

(vii.) Hornblende as a secondary enlargement of augite.—F. Becke[1] and Van Hise,[2] who first described the secondary enlargement of horn-

[1] *Tscherm. Min. u. Petr. Mitth.* Vol. V. Part II.; 1883.

[2] *Amer. Jour. Sci.* (3) Vol. XXXIII. p. 385; 1887.

blende crystals, have also pointed out the growth of a similar fringe of hornblende around augite. Such a growth is found, though perhaps not very frequently, in the Welsh diabases.

It is to be noticed that the original hornblende constituting the idiomorphic crystals, the proper ophitic plates, and the crystals and ophitic plates complementary to augite nuclei, is all of the compact brown variety named, not very appropriately, basaltic. The hornblende pseudomorphic after augite, though sometimes rather paler, is usually identical in appearance with the first-mentioned brown hornblende. The green hornblende of "original enlargement" was deposited after the magma had been altered in composition by the abstraction of the earlier constituents; and the very pale or colourless hornblende of "secondary enlargement" must have grown mainly at the expense of other minerals, mostly poor in iron. In fact, this colourless fringe, although continuous with original hornblende or augite, is to be regarded as a secondary product derived from the felspar and olivine of the rock.