On the Relations between the Gliding Planes and the Solution Planes of Augite.

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NONE of the mineralogical problems of the present day are of greater importance than those which deal with the nature and causes of the modifications which crystallised bodies undergo as a consequence of changes in their environment. It is above all things necessary that we should clearly discriminate in every case between the characters of minerals which are *original* and *essential*, and those which are *accidental* and *secondary*, and which result from the action of various mechanical and chemical forces upon crystals, subsequently to their formation. No fact is more certain than that crystallized minerals, without losing their identity, may have their chemical composition altered within certain (often very wide) limits; and that, as the result of chemical action or mechanical strains, profound changes may take place in all their optical and other physical properties.

It has long been known that certain augites—especially varieties pale in colour and poor in alumina and iron—often exhibit a lamellar twinning parallel to the basal plane {001}. These varieties, which are especially abundant in crystalline limestones, are also found in certain igneous rocks; and Rosenbusch proposes to group them under the name of malacolite. In 1886, Mügge showed that when untwinned crystals of this variety of augite (which he calls diopside) are subjected to deforming stresses by Daubrée's method of enclosing the crystal in lead and subjecting it to pressure, lamellar twinning on the basal plane was produced artificially. The varieties operated upon by Mügge were the well-known malacolites (diopsides) of Ala and Achmatowsk.[1] As long ago as 1827 a distinguished pioneer in crystallographic research, William Phillips, showed that the Whin-Sill of Teesdale contains an augite, which besides

[1] *Neues Jahrb. für Min. &c.* 1886, I. p. 185. *Ibid.* 1889, I. p. 238.

presenting a somewhat unusual development of certain faces, also exhibits a lamellar structure parallel to the basal plane.[1]

In 1875 Dr. Hawes described an augite occurring in a diabase from the Connecticut Valley, which exhibits the same structure.[2] An analysis was given of this variety by Dr. Hawes, and a section reproduced by photography is contained in Rosenbusch's well-known work.[3]

In 1884, Dr. Osann showed that an augite with lamination parallel to the basal plane occurs at Költer and other localities in the Faroe Islands, and that this is really a variety, like that of the Connecticut Valley, rich in iron and magnesia. In the same year Mr. Teall re-examined the augites of the Whin Sill, and showed that Phillips's determinations were correct; he also proved that in chemical composition these Whin-Sill augites agree very closely with those of the Faroe Islands described by Osann,[4] and those of the Connecticut Valley described by Hawes.

In my study of the rocks of the Western Isles of Scotland, I have found that augites exhibiting a lamellar structure parallel to the basal plane are extremely common, especially in Ardnamurchan, both among the older tertiary lavas (those erupted before the basalts of the plateaux) and in those of newer tertiary age (lavas that made their appearance at the surface subsequently to the basalts). These augites agree very closely with the forms described from the Faroe Islands by Dr. Osann. They differ from those described by W. Phillips and Mr. Teall in rarely, if ever, exhibiting the simple twinning parallel to the orthopinacoid {100}, and thus the "herring-bone" structure of Mr. Teall is very seldom seen in them.

My study of the Scottish gabbros long ago led me to the conclusion that the lamination parallel to the orthopinacoid, which is found in diallage, was the result of chemical action, taking place at great depths, along certain definite planes (solution-planes) in the crystals of ordinary augite.[5]

I showed that the planes first acted on are those parallel to the orthopinacoid {100}; that next the planes parallel to the clinopinacoid are affected {010}; and that finally a similar action is set up along the planes parallel to the base {001}. In this way the structures are eventually produced which characterise the so-called "pseudo-hypersthene."

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1 *Camb. Phil. Trans.* Vol. II. p. 166. *See also* Phillips's Mineralogy, 3rd ed. (1823), p. 59.

2 *Am. Journ. Sc.* 3rd ser., Vol. IX. (1875) p. 187.

3 *Mikroskopische Physiographie der petrographische wichtigen Mineralien*, 2nd edition (1885), table xix. fig. 6.

4 *Quart. Jour. Geol. Soc.* Vol. XL. (1884) pp. 647-8.

5 *Quart. Jour. Geol. Soc.* Vol. XLI. (1885) p. 367.

Every petrographer is familiar with the fact that the common twinning of augite upon the orthopinacoid {100} shows a tendency towards repetition, so that we find one or more twin-lamellæ running through the middle of the crystal. Recently Professor Renard, in his studies of the rocks of Teneriffe, has been able to show that numerous twin-lamellæ are sometimes formed parallel to the orthopinacoid, there being a curious tendency towards the crowding of the twin-lamellæ towards the middle of the crystal.[1]

These facts, showing the intimate relation which exists between the simple twinning of a crystal and the lamellar twinning which may be brought into existence by mechanical means, are of very great interest.

Now it is a very interesting circumstance that in some of the most highly crystalline varieties of andesite from Mingary Castle, in Ardnamurchan, we find in the porphyritic augites the planes of alteration parallel to the basal plane well developed, and the commencement of a second plane of lamination parallel to the orthopinacoid.

Let us proceed to consider the explanation of these facts. Even if the view put forward by Van Werveke,[2] and to some extent supported by Rosenbusch, be the true one, that the lamellar structure in diallage is itself determined, in the first instance, by pressure, then we must conceive of augite as being capable of lamellar twinning either parallel to the basal plane or to the orthopinacoid. If the former are produced, chemical action results in the formation of a laminated augite like that of Teesdale, Connecticut, Faroe, and Ardnamurchan. But if the latter are produced, then the result is an ordinary diallage. If this explanation be the true one, then there is a very remarkable analogy between the lamellar twinning of the augites and that of the plagioclases.

That augites exist with two systems of lamellar twinning, one parallel to the orthopinacoid and the other to the basal plane, and hence cutting one another at a high angle, I have been able to satisfy myself upon many occasions. Beautiful examples of the kind occur among the pale coloured augites in the "hemithrène" (red marble) of the island of Tiree. Some of the sections of these doubly twinned augites exhibit the most startling resemblance to sections of plagioclase felspars, with both albite and pericline twinning; so that but for their higher refraction and double refraction, mistakes might easily arise in their identification.

In 1886, I showed by experiments with calcite that when lamellar-

[1] Report on Rock Specimens collected on Oceanic Islands. *Challenger Report. Physics and Chemistry*, Vol. II. (1889) p. 1.

[2] *Neues Jahrb. für Min. &c.* 1883, II. p. 97.

twinning has been developed in a crystal, the gliding planes become the "solution-planes," which are first attacked, in preference to the normal solution-planes of the crystal.[1]

These considerations enable us, I believe, to give a complete explanation of the curious anomalies presented by augite-crystals. If, as I incline to believe, the orthopinacoid {100} is the principal normal solution-plane of augite, then chemical action operating at great depths along planes parallel to the orthopinacoid, leads to the development of secondary inclusions along them and results in the formation of ordinary brown diallage. If, as chemical action becomes more intense with increased pressure, a second solution-plane is attacked, this is the clinopinacoid {010} ; and next the third plane of chemical weakness, the basal plane {001}, is subjected to the same action. Thus in the end we get pseudo-hypersthene.

But if, previously to the commencement of chemical action, lamellar twinning parallel to the basal plane has been set up by pressure, then this becomes the first solution-plane, and is attacked before the normal solution-plane—the orthopinacoid.

As the result of the development of gliding planes parallel to the base, and the chemical action which takes place along them, the augite-crystals in the much altered rocks of Mingary Castle are often found broken up into fragments, which are more or less displaced, and thus a curious faulted appearance is given to the crystals.

In many cases, too, the development of the enclosures along the planes attacked has been followed by still further and very profound alteration ; chloritic and serpentinous products being formed in abundance along these planes. These much altered augites have just the same relation to the less altered ones that the green diallages have to the ordinary brown diallage.[2]

It is often asserted that the diallagic modification of augite is determined by a peculiar chemical composition ; and a similar suggestion has been made in the case of those augites which present a laminated structure parallel not to the orthopinacoid, but to the basal plane. But for these conclusions I must confess that I am totally unable to find any warrant. The pale green diopside of Rum, containing only 5 per cent. of iron-oxides, assumes the diallagic condition equally with the dark black

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[1] *Mineralogical Magazine*, Vol. VII. (1886) p. 81.

[2] The altered augites of Mingary Castle are figured in Plate XIV. figs. 1 and 2 of Vol. XLVI. *Quart. Jour. Geol. Soc.* (1890). Professor G. H. Williams has recently called attention to the importance of a similar parting parallel to the basal plane which is found in the hornblende of St. Lawrence County, New York. *Am. Jour. Sc.* ser. iii. Vol. XXXIX. (1890) p. 352.

augites of Loch Scavaig, in Skye, with 15 per cent. of iron-oxides. Indeed, every variety of augite, so far as my experience goes, may be found, when subjected to the proper conditions, to assume the diallagic modification. In the same way, the twinning and chemical alteration parallel to the basal plane is found equally developed in the pale coloured, slightly ferriferous malacolites and in the black, highly ferriferous augites of Teesdale, Költer, and Ardnamurchan. This is illustrated by the following table :—

COMPOSITION OF AUGITES EXHIBITING LAMELLAR TWINNING PARALLEL TO THE BASAL PLANE (001).

	Achmatowsk. *Hermann.*	Ala. *Wackenroder.*	Whin Sill. *Teall.*	Költer. *Osann.*	Connecticut Valley. *Hawes.*
Silica	53·97	54·15	48·41	50·21	50·71
Alumina	—	0·20	4·05	3·24	3·55
Ferric Oxide	—	—	2·36	—	—
Ferrous Oxide ..	2·00	2·51	15·08	17·40	15·30
Manganous Oxide ..	—	0·18	0·37	—	0·81
Lime	25·60	24·74	15·98	13·92	13·65
Magnesia	17·86	18·22	12·14	14·05	13·63

These analyses prove conclusively that a tendency to the development of lamellar twinning parallel to the basal plane is not confined to any one variety of augite. It is equally certain that the separation along the planes parallel to the ortho pinacoid which is characteristic of diallage is found alike in aluminous and non-aluminous augites, and in varieties with different proportions of lime, magnesia, and ferrous oxide.

For the sake of clearness, it is very desirable that a tendency to separation along certain planes in a crystal, which has been developed by mechanical action, (gliding planes) or by chemical operations (schiller planes), should not be confounded with the original planes of least cohesion (cleavage planes). Nothing can be more incorrect or misleading than to speak of diallage as a variety of augite which exhibits an additional "cleavage"; or murchisonite as a variety of orthoclase which exhibits a new "cleavage." The induced structures in these minerals have nothing whatever in common with the original structure of the crystals, which gives rise to their characteristic tendency to break up parallel to certain planes, and is indicated by the term "cleavage."