

THE MINERALOGICAL MAGAZINE
AND
JOURNAL
OF THE
MINERALOGICAL SOCIETY.

No. 50.

SEPTEMBER 1895.

Vol. XI.

On the Structure-Planes of Corundum.

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[Read April 10th, 1894.]

WHILE examining the fine series of corundums brought from Burma by Mr. C. Barrington Brown, F.G.S., and comparing them with specimens obtained from Ceylon, Southern India, the United States and other localities, I have been led to devote especial attention to the curious "parting-planes" which are sometimes found in crystals of this mineral, but which, in other cases, appear to be entirely wanting. In making these comparisons, I have had the great advantage of being able to refer to the fine collection of corundums in the British Museum (Natural History) at South Kensington, and have to gratefully acknowledge the advice and assistance which have been so freely afforded to me at all times by Mr. Fletcher and Mr. Miers.

According to the statements made in most treatises on mineralogy, corundum is a mineral with two cleavages, one parallel to the basal plane *OR* (111), and the other to the primitive rhombohedron. In recent years,

however, this statement has been modified by some mineralogists. The Count de Bournon, indeed, in his original memoir on the mineral (*Phil. Trans.* 1802, p. 266) pointed out that corundum exhibits cleavage only in certain cases, and that the less altered the mineral is the more difficult is it to produce "cleavage fractures." In 1874 Max Bauer, as the result of his observations on the series of corundums in the Berlin collection, was led to conclude that all the partings or divisional planes of the mineral are distinct from cleavage-planes.¹

Tschermak in 1888 refers to these division-planes as "planes of parting" (Absonderung),² and this course is also followed by Dana in the 6th edition of the *System of Mineralogy*.³

In his classical paper on corundum, published in 1802,⁴ the Count de Bournon pointed out that some corundums (especially sapphires) show no appearance of possessing cleavage, but break with a fracture which is either conchoidal or splintery. Experiments which I have made with a great number of specimens confirm this observation of de Bournon, and show that, when unaltered, corundum is quite destitute of any trace of cleavage, and further that the tendency to break up along certain planes is due to incipient change, resulting either from the action of mechanical or chemical forces, or from both of these in combination. The fracture of *unaltered* corundum is, according to my experience, strikingly similar to that of quartz, and not unfrequently is beautifully conchoidal.

Let us now proceed to consider the crystallographic planes along which "parting" has been observed in corundum.

I. Specimens of corundum are continually found terminated by basal planes $OR\{111\}$, which have evidently been produced by the transverse fracture of crystals. It is noteworthy that in these cases the basal planes often exhibit a pearly lustre, markedly different from the vitreous or adamantine lustre of the proper crystal-faces. Not unfrequently, however, the lustre of this parting plane parallel to the base is sub-metallic, being sometimes accompanied by schiller-phenomena. That this breaking up of crystals is not due to cleavage is at once shown by the fact that it is usually quite impossible to produce any parallel partings, the corundum often breaking with an irregular or conchoidal fracture like quartz. It is noteworthy, also, that perfect as is this parting along

¹ *Zeitsch. d. d. geolog. Gesellsch.* Vol. XXVI. (1874), pp. 186-193.

² *Lehrbuch der Mineralogie.* 1st Ed. (1883), p.

³ *System of Mineralogy*, 6th Ed. (1892), p. 211.

⁴ *Description of the Corundum Stone and its varieties, &c.* *Phil. Trans.*, XCII. (1802), pp. 233-326.

the basal plane, it is liable to interruption, the separation often deviating from the original plane, and following another which is near to, but parallel with it. This is especially well seen when the surfaces are studied under the microscope by reflected light.

II. The remarkable separation of some specimens of corundum along the rhombohedral planes $\{100\}$ is well known to all mineralogists. Tschermak calls attention to the fact that this parting parallel to the rhombohedron in corundum often shows itself strongly developed along two only of the rhombohedral faces, and not at all, or very feebly, along the third, and he interprets this as indicating a monosymmetric structure of the crystals. (*Min. und Petr. Mittheil.* Vol. I. (1878), p. 364.) Upon weathered crystals and basal sections the traces of these parting planes are often seen very conspicuously as deep striæ; and in the case of much altered corundum crystals—like those found in the Eastern United States—the crystals yield to pressure when placed in a vice, in just the same way as does calcite when subjected to the Baumhauer experiment. There appears to be a certain amount of variation in the position of these parting planes. Mügge, to whose researches on the structure-planes of minerals we are so greatly indebted, at one time thought that the deviations from the normal angles of the primitive rhombohedron were so great as to indicate a separation along the planes of a more acute rhombohedron ($-2R \{\bar{1}11\}$)¹; but his subsequent studies led him to abandon this view, though his measurements show some striking discrepancies, amounting in some cases to several degrees between the true and observed angles in these parting planes.

III. The third parting plane in corundum is less marked than the other two, and was, I believe, first noticed by von Lasaulx.² This parting, which is parallel to $\infty P2 \{101\}$, seldom gives rise to an actual breaking up of the corundum crystals, but can be well observed in thin sections under the microscope. It has been especially noted in corundums from Ceylon, and in the variety found in the granite of the Riesengebirge. It is in the beautiful corundums exhibiting concentric growth from the Chantabun Hills in Siam, and in others said to come from Thibet, that this parting is, however, most noticeable. Certain concentric shells of these remarkable crystals are conspicuous owing to the internal reflections produced by these parting planes, while other portions in the same crystal appear to be equally or quite

¹ *Neues Jahrb. für Min., &c.*, 1884, I. 220.

² *Zeitschr. für Krystall.* X. (1885), pp. 351, 353, 364.

destitute of this peculiarity. The traces of this parting appear on the basal plane, when their sections are studied with the microscope, as a series of very thin but remarkably sharp rectilinear rifts which are parallel to the sides of the hexagonal prism $\propto P2 \{10\bar{1}\}$.

It is the presence of these rifts, as pointed out by von Lasaulx, which gives rise to the remarkable asterism so conspicuous in certain varieties of corundum. It is certain, however, that the phenomenon of asterism is in other cases due to the presence of needles and plates of rutile¹ or other minerals intersecting at angles of 60° , and forming the so-called "sagenite-web" and similar structures. Such a "sagenite-web" may be detected in some corundums under the microscope, and is precisely similar to the structure which gives rise to the asterism in the phlogopite from Burgess County, Canada, and other localities.

That these three parting planes are not due to cleavage is perfectly clear. They are certainly altogether absent from corundum which has not undergone incipient alteration.

It may be well to remark at the outset of our inquiry concerning these three parting planes, that while II. (the parting parallel to the rhombohedron R follows a twinning plane of corundum, I. (the basal plane OR) is one which, though a possible twinning plane, has never been observed as such in this mineral; while III. (parallel to the hexagonal face $\propto P2$, which is a plane of symmetry), can never be a twinning plane.

IV. Corundum crystals sometimes appear to break up along planes passing through the vertical axis at right angles to the prism-faces. These are probably due to the twin combinations (trillings) described by DesCloizeaux, Mallard, Tschermak, von Lasaulx and other authors.

We will now proceed to consider the nature and origin of each of these parting planes of corundum.

I. When thin sections of corundum are studied under the microscope, a series of rifts, more or less sharp and rectilinear, can be seen lying parallel to the basal plane $OR \{111\}$. By employing high powers these rifts can be resolved into cavities having a slight thickness as compared with their area, and often assuming the form of negative crystals. The cavities are sometimes empty, at other times filled with the products of alteration—either diasporic or some hydrated silicate formed from it. It is the presence of these cavities, either empty or filled with diasporic or hydrous silicates,

¹Tschermak has in some cases proved the needles present in corundum to be rutile, by their tetragonal symmetry and their prism angles. *l.c.*, p. 361.

which gives rise to the pearly lustre on the *OR* face of parting. More rarely, compounds having a metallic or submetallic lustre are developed in the cavities, and these give a metallic lustre to the cleavage face, as in varieties from Siam and Thibet. The fact that in other parts of a crystal which is thus traversed by partings along the basal plane, the ordinary conchoidal fracture may be exhibited, is evidence that the production of the cavities is a more or less local phenomenon.

It is clear, therefore, that the parting along the basal plane of corundum is of the same nature as that produced in the variety of orthoclase known as murchisonite, and in the variety of augite known as diallage. The plane *OR* (111) is a solution plane, and parallel to this plane cavities are produced, of the nature of negative crystals, which have a great development in that plane but are of very insignificant thickness. These negative crystals sometimes appear to have the triangular form so characteristic of the natural etched figures (Verwitterungs-figuren) which are frequently exhibited on the basal plane of corundum. At other times they exhibit remarkable irregularities of form, but always show a tendency to be bounded by the rhombohedral faces.

That the basal plane is a *solution plane* of corundum is shown by the fact that the crystals from Burma and other localities which have undergone partial conversion into diaspore and hydrous silicates exhibit a remarkable step-like structure (resembling that of "Babel-quartz" on a very minute scale), showing that the chemical disintegration of the crystal has been governed by the existence of these solution planes. This fact is beautifully illustrated in the fine ruby presented to the British Museum by Mr. Ruskin, which exhibits the shaly structure due to corrosion and the natural etched figures in a very striking manner. I have no doubt that this fine ruby came from Burma, and many small specimens which I have examined from the same locality exhibit similar characters. As in the case of murchisonite and diallage, the multiplication of cavities along certain planes gives rise to a plane of weakness or a parting plane in the crystal along which it readily divides.

II. The planes parallel to $R\{100\}$ are twinning planes of corundum, and *lamellar twinning* on these planes is very common in crystals of this mineral. As has been so well shown by Mügge, there is every reason to believe that the lamellar twinning of corundum is, like that of calcite, feldspar, and other minerals, of mechanical origin, and has been developed by pressure.¹ It may be, however, as suggested by von Lasaulx,² that

¹ *Neues Jahrb. für Min.*, 1886, I., p. 147.

² *Zeits. für Krystall.*, X. (1885), pp. 364-5.

the strains set up in a crystal during its gradual growth may produce alike the optical anomalies and the twin-lamellæ. But whether produced during the growth of the crystal or long subsequently, the *lamellar twinning* is certainly not an essential character, but a secondary and accidental one. The whole crystal may be destitute of any trace of lamellar structure; or the lamellæ may be developed in certain concentric shells or patches of the crystal, and be absent from others; or it may be well shown in the case of one or two of the rhombohedral planes, and almost or quite wanting in the others, as pointed out by Tschermak. Moreover, in their irregularities and flexures, as well as in the capricious mode of their development, these lamellæ exactly resemble the often curved and distorted lamellæ found in calcite, felspar and quartz.

That the planes bounding the twin lamellæ parallel to $R\{100\}$ become *solution-planes* there cannot be the smallest doubt, and crystals are sometimes found in which more than one-third of the corundum has been converted into diaspore and various hydrous silicates by chemical changes set up along these planes. Beautiful examples of sapphire thus altered were brought from Ceylon by Mr. C. Barrington Brown and by Mr. Baddeley.

The production of negative crystals and other cavities along these rhombohedral faces, and the manner of their infilling by diaspore, hydrous silicates and sometimes by material having a metallic lustre, can often be studied under the microscope.

III. Thin sections of corundum show that the rifts parallel to $\infty P2\{10\bar{1}\}$, when intersected, appear as fine lines. These under the microscope are seen to be sections of negative crystals, either empty or partially or wholly filled with decomposition products. The cavities in question are generally developed on a smaller scale than those parallel to the basal plane, but are perhaps more numerous. They are often the cause of the very distinct sheen ("schiller") which is exhibited by many varieties of corundum. When such varieties are cut *en cabochon*, with the centre of the curve opposite to the apex of the crystal, the phenomenon of asterism is exhibited. Light traversing the mass is reflected from the surfaces of these negative crystals, owing to the difference between the refractive index of the contents of these cavities and that of the mineral in which they occur. Owing to the symmetrical disposition of these enclosures parallel to the hexagonal faces, the well-known six-rayed star is produced when a strong light falls upon them. In some cases the different zones of which the corundum crystal is built up show remarkable differences in their susceptibility to alteration. In these cases we find zones exhibiting

a very striking "schiller" alternating with others which retain their perfect translucency. Nowhere do we find this better illustrated than in some of the corundums from Ceylon, of which there are fine examples in the British Museum. In many other cases, like the crystals from Siam and Thibet, we find the zoned structure of corundum crystals strikingly intensified by the development of schiller and other structures in certain of the zones, while other zones are comparatively unaffected. It is sometimes difficult, however, to determine whether the structures in different zones of the corundum crystals are of primary or of secondary origin.

IV. The rarer partings at right angles to the prism-faces, and marking the planes of composition of the trilling combinations, also appear to be due in the same way to chemical alterations taking place along these structure-planes of the complex crystal.

Taking all these facts together, we are led to conclude that corundum has at least three sets of structure-planes, but that none of these can be regarded as true *cleavage*. Two of these structure-planes, those parallel to OR $\{111\}$ and to $\infty P2$ $\{10\bar{1}\}$, are normal solution-planes; the third set of structure-planes, those parallel to R $\{100\}$, are gliding planes, which, when developed, become secondary solution-planes.

We thus see how complete is the parallelism between the phenomena of the structure-planes in corundum and those exhibited by calcite feldspars, augite, hornblende, sphene and many other minerals, which have been studied from the same point of view.
