Corundum twins from Transvaal.

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LAMELLAR twinning is of frequent occurrence in corundum, as evidenced by rulings on the surfaces and by the well-marked pseudo-cleavages (or partings) parallel to the faces of the primary rhombohedron and also parallel to the basal plane. Distinctly developed juxtaposition and interpenetration twins would, however, appear to be rare, for only a few isolated examples have hitherto been described.

There are two twin-laws for corundum crystals, the twin-plane being either r $(10\bar{1}1) = (100)$ or c $(0001) = (111)$. The former of these is the one considered in the present note. Of these r-twins only six small ($\frac{1}{4}$ to 1 inch across) isolated crystals have previously been figured and described in detail. References to these are given under Barvíř, Bowman, and Nies and Goldschmidt in the following:

Bibliography of corundum twins (apart from lamellar twinning).[1]

P. V. EREMYEEV, Verh. Russ. Min. Gesell., 1878, ser. 2, vol. 13, p. 440; 1879, vol. 14, p. 227; Gornyi Journ., 1887, vol. 3, p. 263. [Russian; Abstracts in Zeits. Kryst. Min., vol. 2, p. 505; vol. 3, p. 438; vol. 15, p. 537.] r- and c-twins, from Ural.

A. VON LASAULX, Zeits Kryst. Min., 1885, vol. 10, p. 362, pl. 12, figs. 12 and 13. r-twin, from Buncombe Co., North Carolina.

W. E. HIDDEN and H. S. WASHINGTON, Amer. Journ. Sci., 1887, ser. 3, vol. 33, p. 507. r-twin, from Ceylon.

H. BARVÍŘ, Zwei Sapphirzwillinge. Ann. Naturhist. Hofmus. Wien, 1892, vol. 7, pp. 135–139, 3 figs. Two r-twins, from Ceylon.

M. BAUER, Neues Jahrb. Min., 1896, vol. ii, p. 213, fig. A. c-twin, from Burma.

O. MÜGGE, Tschermaks Min. Petr. Mitt., 1899, vol. 19, p. 165, 1 fig. c-twin of artificial corundum.

H. L. BOWMAN, A twin crystal of sapphire. Min. Mag., 1900, vol. 12, pp. 355–358, 1 fig. r-twin, from Kashmir?

[1] On lamellar twinning see, for example, J. W. Judd, On the structure-planes of corundum. Min. Mag., 1895, vol. 11, pp. 49–55.

G. MELCZER, Math. Természettud. Értesítő, Budapest, 1901, vol. 19, p. 482, pl. 9, fig. 4, pl. 10, figs. 22–24 ; Zeits. Kryst. Min., 1902, vol. 35, p. 571, pl. 14, fig. 4, pl. 15, figs. 22–24. *c*-twin, from Burma ; *c*-twinning in artificial corundum shown by the reversed orientation of etch-figures on the basal plane.

W. E. HIDDEN, Corundum twins. Amer. Journ. Sci., 1902, ser. 4, vol. 13, p. 474, 1 fig. *c*-twins, from Macon Co., North Carolina.

R. BRAUNS, Neues Jahrb. Min., 1906, vol. i, p. 47, fig. 10. Twin on $d(10\bar{1}2)$?, from Ceylon.

A. NIES and V. GOLDSCHMIDT, Neues Jahrb. Min., 1908, vol. ii, pp. 108–112, pl. 9, fig. 3, pl. 10, figs. 4–5. Three *r*-twins, from Ceylon and Kashmir. A coloured picture of one of these small crystals in the Seligmann collection is given by R. Brauns in 'Das Mineralreich' 1903–4 ('The Mineral Kingdom', translated by L. J. Spencer, 1908–12), pl. 42, fig. 7.

A. L. HALL, Corundum in the northern and eastern Transvaal. Mem. Geol. Survey South Africa, Pretoria, 1920, no. 15, 223 pp. Mention of *r*-twins on pp. 66–68, 150, 155, pl. 17, fig. 8. [Min. Abstr., vol. 1, p. 210.]

With one exception, all the line-drawings given in the papers quoted above are reproduced in Professor V. Goldschmidt's monumental 'Atlas der Krystallformen'.[1] Of the 139 figures of corundum crystals there collected together, 16 represent twinned crystals, and of these 9 are of *r*-twins.

The twin-crystals of corundum to be here described have already been mentioned by Dr. A. L. Hall in his exhaustive memoir on corundum occurrences in the Transvaal. There he gave an accurate account of the essential features together with a photographic reproduction (though unfortunately rather poor and inadequate) of one of the twins. These details, of special interest to crystallographers and mineralogists, are, however, buried in a book of some size written from a geological and economic point of view, and they have been overlooked in notices and abstracts. Dr. Hall concurs with me that this matter merits more detailed notice, and for this purpose he has generously supplied me with abundant material for description.

The main material on which I started work was, however, independently supplied by a fortunate find that I made at the British Empire Exhibition at Wembley in 1925. There amongst the large economic display of corundum from the Transvaal I noticed a block of rock, weighing $33\frac{1}{2}$ lb., which showed the impression of a large twinned crystal, together with numerous other twins throughout the mass. Through the kind offices of Captain W. W. Luffman, who had been left in charge of the exhibits at the close of the Exhibition, this remarkable specimen was secured for the mineral collection of the British Museum.

[1] V. Goldschmidt, Atlas der Krystallformen, 1918, vol. 5, pls. 18–26. *r*-twins are shown in figs. 47, 56–59, 89, 119–121 ; *c*-twins in figs. 71, 88, 94, 96, 104–106.

Thinking that a corundum twin of this size (6 × 6 inches)[1] might be unique, a plaster mould and cast were first prepared and skilfully coloured by Mr. P. Stammwitz, preparator in the Department of Zoology. A photograph taken by Mr. H. G. Herring of this coloured model is re-

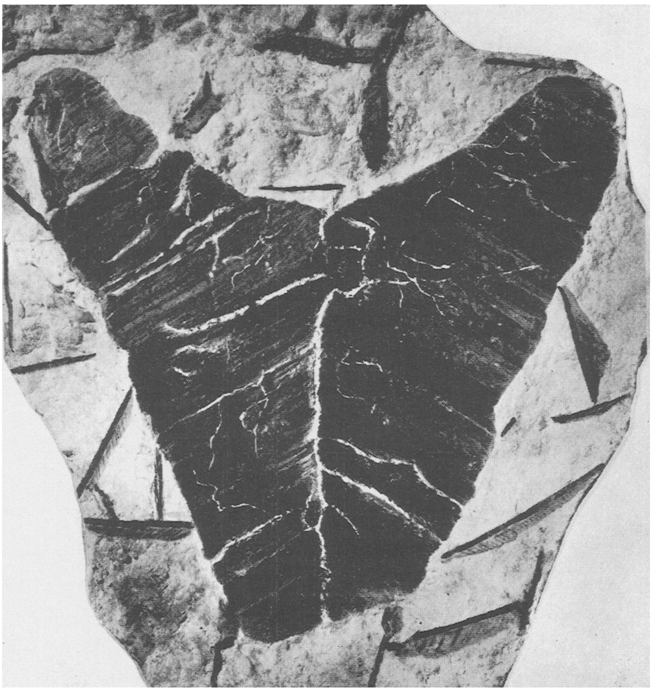

FIG. 1. Corundum twin from Transvaal. (Photograph of plaster cast.) Reduced to ½ natural size.

produced in fig. 1. The block of rock was then broken up, still preserving the large impression, with the object of exposing other twin-crystals.

The locality of the specimens, as described in Dr. Hall's memoir, is a corundum pit, the Turkaspost mine, on the Turkaspost farm (no. 941, formerly no. 1621), immediately to the west of Bandolier Kop railway station in Zoutpansberg district, northern Transvaal. The corundum-bearing rock represents modified apophyses of granite intrusive into

[1] Dr. A. L. Hall in his memoir (loc. cit., p. 67) mentions such twins measuring 6 inches across with a thickness of one-eighth of an inch, and he has informed me that twins of this size are by no means uncommon at the locality.

serpentine, pyroxenite, and other ultra-basic rocks. The corundum has the form of hexagonal prisms or irregular nodular masses, but in certain parts of the pit the platy form only is present.

This is the only locality mentioned by Dr. Hall for corundum of this type, but I am informed by Professor Charles Palache of Harvard University that while on a visit to South Africa in 1922 he collected specimens, practically identical with those from Turkaspost, from a small opening in the south-west corner of Waerkum farm (no. 717), about 10 miles SW. of Mara railway station, and about 20 miles NW. from Bandolier Kop.

The large ($33\frac{1}{2}$ lb.) block showed numerous large platy crystals of corundum penetrating the rock in all directions. The crystals are often in contact with one another, and they would appear to form a very open network with the snow-white coarsely-crystallized felspar filling the interspaces. This felspar was determined by Dr. Hall to be an acid plagioclase near andesine, and the rock he described as plumasite-pegmatite.[1] In this and in other similar specimens sent by Dr. Hall from Turkaspost no biotite was seen. Biotite is, however, often present in the plumasite from other localities in the Transvaal, and is, for example, well shown in a large block weighing $88\frac{1}{2}$ lb. from Palmietfontein farm (no. 374) (10 miles north of Bandolier Kop) which was presented to the British Museum collection by Messrs. A. W. Collet and S. Snertinge in 1919 ; here the large corundum crystals are of the normal hexagonal habit. The rock usually breaks along the corundum crystals, leaving impressions of their striated and corrugated surfaces on the felspar; and on these felspar surfaces there are often black dendritic markings of manganese oxide or brown stains of limonite.

The corundum crystals are dark greyish-brown in colour and opaque in mass. Their faces are rough and corrugated, and unfortunately not suitable for measurement on the reflecting goniometer. All that could be obtained were approximate measurements with a protractor or a contact-goniometer of the angles between striae and the somewhat rounded edges. The crystals range from 1 to 5 mm. in thickness, being usually 2–3 mm. ; and on the flat face they vary considerably in size, up to 6 inches (15 cm.) across for the large impression (fig. 1). As described by Dr. Hall these arrow-head twins have a face of the primary

[1] Plumasite was first described from Plumas Co., California, by A. C. Lawson in 1903 as an oligoclase-corundum rock. It has been formed by the desilicification of granitic magma intrusive into ultra-basic rocks. [Min. Abstr., vol. 1, pp. 16, 210, 282; vol. 2, p. 80 ; vol. 3, p. 84.]

rhombohedron, $r\,(10\bar{1}1) = (100)$, as twin-plane and are flattened parallel to the pair of prism-faces that are perpendicular to the twin-plane. This habit being so unusual for corundum and at first rather puzzling, an attempt has been made to represent it diagrammatically in figs. 2–5. These figures are simple elevations and plans, with (in the elevations) the twin-axis and the flattening of the crystals in the plane of the

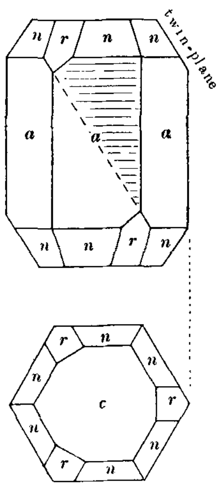

FIG. 2.

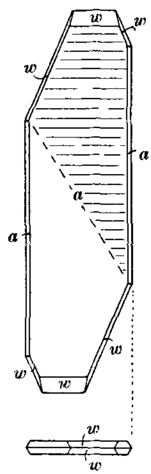

FIG. 3.

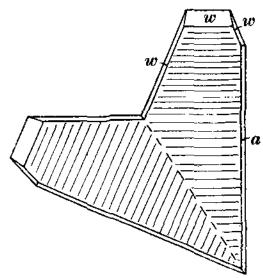

FIG. 4.

Twinning of corundum on $r\,(10\bar{1}1)$.
Elevations and plans: the twin-axis and flattening of the crystals in the plane of the paper.

paper, according to the method of drawing twinned rhombohedral crystals advocated by the late Professor W. J. Lewis.[1]

Fig. 2 represents the familiar text-book figure of a corundum crystal with the second-order hexagonal prism $a\,(11\bar{2}0) = (10\bar{1})$, basal pinakoid $c\,(0001) = (111)$, the primary rhombohedron $r\,(10\bar{1}1) = (100)$, and a hexagonal bipyramid $n\,(22\bar{4}3) = (31\bar{1})$. All these forms, with the exception of the base, were observed on the present crystals, but *r* is only slightly developed, and the hexagonal bipyramid is more often the steeper form $w\,(11\bar{2}1) = (14\bar{2})$. A crystal with only the planes *a* and *w* and flattened parallel to one pair of prism-faces is represented in fig. 3, from which, it is readily seen, the arrow-head twins (fig. 4) are derived by symmetrical repetition (reflection) across the dotted line which

[1] W. J. Lewis, Min. Mag., 1908, vol. 15, p. 62.

represents the trace of the twin-plane. The angle $cr = 57° 34'$ is the angle between the horizontal striations on a and the trace of the twin-plane, so that the angle between these striations in the two portions of the twin is 115° 8′. Angles of 114–116° were measured between the two sets of striations. The outside edges of the arrow are bounded mainly by the prism-edges, and these also form an angle of 64° 52′ (180° − 115° 8′). Usually, however, the point of the arrow presents a more acute angle; measurements gave values ranging from about 30° to 57° (the latter in fig. 1). The reason for this is an oscillation between a and r at the edges, as represented in fig. 5. The re-entrant angle at the opposite end of the arrow-head shows in fig. 1 a concave curvature and is evidently formed by a series of edges. In the few other complete examples the edges of this re-entrant angle are straighter and are bounded by narrow faces of the form $w\,(11\bar{2}1)$. Rough measurements of the angles between these edges and the twin-suture suggest that the following planes in adjacent pairs may form the bounding edges.

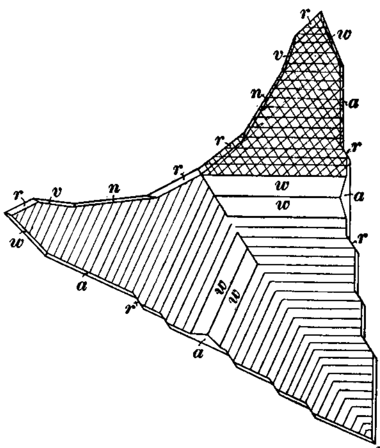

FIG. 5. Diagram of corundum twinned on $r\,(10\bar{1}1)$.

	Slope of edge between adjacent pair of planes.	Angle of edge to twin-suture: Calc.	Obs.
– $(2.2.\bar{4}.15) = (753)$	17° 28′	75° 2′	76°
r $(10\bar{1}1) = (100)$	38 12	95 46	97–99
n $(22\bar{4}3) = (31\bar{1})$	57 34	115 8	117
w $(11\bar{2}1) = (41\bar{2})$	67 2	124 36	124–126
v $(44\bar{8}3) = (51\bar{3})$	72 23	129 57	129
θ $(8.8.\bar{16}.3) = (91\bar{7})$	80 58	138 32	137

As indicated in the figures the prism-faces are prominently striated horizontally, i. e. perpendicular to the prism-edges. This is due to an oscillation with the hexagonal bipyramid, and it sometimes takes the form of coarse corrugations. Angles of 42° and 30° measured over the ridges correspond with the pyramids $w\,(11\bar{2}1)$ and $v\,(44\bar{8}3)$ respectively.

In addition to these striations there are also extremely fine rulings in three directions on the prism-faces (represented in fig. 5 at the top right-hand corner). Those parallel to the coarse striations are due to lamellar twinning on *c*; another set parallel to the twin-suture is due to lamellar twinning on the *r*-plane which is the twin-plane; while the third set inclined at 95° 46′ to the twin-suture is due to lamellar twinning on one or other, or both, of the other two *r*-planes. This lamellar twinning gives rise to excellent planes of parting in the crystal, with smooth bright surfaces parallel to both *c* and *r*. As an aid in orientating the crystals it was found that flakes from the *c*-parting gave a central uniaxial optic figure, while flakes from the *r*-partings showed an optic axis at the edge of the field of view in the microscope. Owing to these partings and also to the thinness of the crystals they are very fragile; and for this reason, although some hundreds of crystals were present in the large block, only few more or less completely formed twins were successfully extracted. These measure from $2\frac{1}{2} \times 3\frac{1}{2}$ to 8×10 cm., and remain attached on one side to the rock; without this support the crystals break up into fragments. The fine rulings of the lamellar twinning are impressed on the felspar surfaces. The 'secondary' lamellar twinning was therefore present previous to the crystallization of the felspar; and were not, in this case, the result of later pressures in the rock. The crystals are occasionally bent or broken across, and this evidently happened before the loose aggregate of crystals received the support of the crystallized felspar. The residual melt (with the composition of oligoclase-andesine) left after the crystallization of the corundum was evidently very viscous.

The extreme flattening of these twin-crystals of corundum in a direction perpendicular to the twin-plane is very remarkable. As Dr. Hall has pointed out, the crystals may be as much as thirty to fifty times as wide as they are thick. Untwinned crystals of corundum from other parts of the same mine are equally developed in all directions. A similar but less pronounced flattening perpendicular to the twin-plane is also sometimes, though not always, shown by some other minerals, e. g. the Japanese-twins of quartz, butterfly-twins of calcite, and spinel-twins of diamond. No explanation of this flattening appears to have been given. The corundum twins previously described from Ceylon and Kashmir also show a tendency to the same flattening, though not to such a marked degree. The same is the case with most of the British Museum specimens mentioned below from these localities, but this is not invariably so, for some of the twinned crystals are equably developed.

Distortion in twin-crystals is discussed by H. Tertsch [1] in his recent volume on the habit of crystals.

Twins of corundum are evidently not so rare as previously supposed. At the Turkaspost, Transvaal, locality they could be collected by the thousand, or even by the ton. Also if searched for in collections they are to be found. In the British Museum mineral collection a small set of six well-developed crystals from Ceylon and Kashmir are specially displayed as examples of *r*-twins, and there is also an interesting specimen from Kashmir showing an intergrowth of an *r*-twin of corundum with a crystal of tourmaline. Further, by searching through the large series of isolated crystals from Ceylon several examples can be found showing evidences of twinning. Small crystals with much the appearance of buds can be seen branching out at 65° from the sides of the main crystal. My attention to this fact was first called by Mr. B. W. St. Clair of the General Electric Company at Lynn, Massachusetts, who handles considerable quantities of precious and semi-precious corundum for the purpose of making pivot-supports for electrical instruments. Recently, while in London, he secured a parcel of 1,000 ounces of Ceylon crystals and pebbles that had been rejected by the gem-cutters, but eminently suitable for grinding as pivot-supports. This lot I had the privilege of sorting over, and I was able to pick out eleven crystals showing indications of twinning. These eleven crystals weighed $\frac{2}{3}$ oz., representing 0·06 % of the whole parcel.

[1] H. Tertsch, Trachten der Kristalle. Berlin, 1926 [Min. Abstr., vol. 3, p. 223]. See also F. Becke, Über die Ausbildung der Zwillingskristalle. Fortschr. Min. Krist. Petr., 1911, vol. 1, pp. 68–85; and H. Hilton, The energy of twin-crystals. Min. Mag., 1909, vol. 15, pp. 245–246.