

Sapphirine crystals from Blinkwater, Transvaal.

By EDGAR D. MOUNTAIN, M.A.

Professor of Geology and Mineralogy, Rhodes University College,
Grahamstown, South Africa.

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SOME time ago, Mr. F. C. Partridge, Mineralogist to the Geological Survey of South Africa, gave me some crystals of sapphirine which he thought might be of interest for goniometric examination. They come from the farm Blinkwater 1037, about 47 miles NNW. of Pietersburg and 45 miles WSW. of Louis Trichardt in northern Transvaal, and were collected by him in July 1930, after he had identified some specimens of sapphirine sent to him by Mr. A. Ruskovitch of Abrasive, northern Transvaal. They occur in a coarse granitic rock rich in brown mica, and are associated with small prismatic crystals of pink corundum.

The sapphirine crystals are almost invariably tabular or platy in habit, although occasional crystals possess a rhomb-shaped cross-section. The largest crystal measures $50 \times 35 \times 5$ mm., while the thickest one is only 7 mm. in thickness. They are generally six-sided in outline with a strong suggestion of orthorhombic symmetry.

Chemical tests on fused material showed the crystals to consist essentially of silica, alumina, and magnesia. The average specific gravity of several isolated crystals was determined as 3.35, and the hardness on a freshly fractured surface as $6\frac{1}{2}$. As the material, however, showed considerable alteration when examined optically, neither of these figures could be regarded as characteristic. The crystals are normally dull in lustre and of a pale grey colour or various shades of green, red, and purple on the surface. In addition, they sometimes carry tiny mica flakes, in various stages of alteration, adhering parallel to the large faces. A few crystals, however, possess fairly bright faces which then appear greyish-black with a bluish tinge. Even these faces rarely give sharp images, so that interfacial angles can generally be determined only to the nearest whole degree; and where the angles can be more accurately determined corresponding readings show discrepancies considerably greater than half a degree. In some cases where faces were smooth but dull, attempts were made to determine interfacial angles by attaching tiny pieces of cover-glass to them, but the results again showed but

little agreement. The results, then, can be relied upon only to the nearest degree.

The crystals are really monoclinic and the common habit, shown in fig. 1, consists of the following forms: b (010), u ($\bar{1}32$), m (110), e (102), q (011), f (012), a (100), c (001), and d ($\bar{1}02$), while tiny faces were observed parallel to k (270), s ($\bar{1}12$), t ($\bar{1}22$), and v ($\bar{1}42$). In lettering the faces, I have adopted the suggestions of T. V. Barker ('Graphical and tabular methods in crystallography', 1922, p. 97). Two less common habits are shown in figs. 3 and 4, projected on the clinopinakoid face. Nearly all the crystals show prominent striations, ridges, and furrows, due to parallel growth, on the clinopinakoid faces parallel to the [201] zone. The crystals show two very imperfect cleavages parallel to a (100) and c (001), which are, however, not recognizable in thin section.

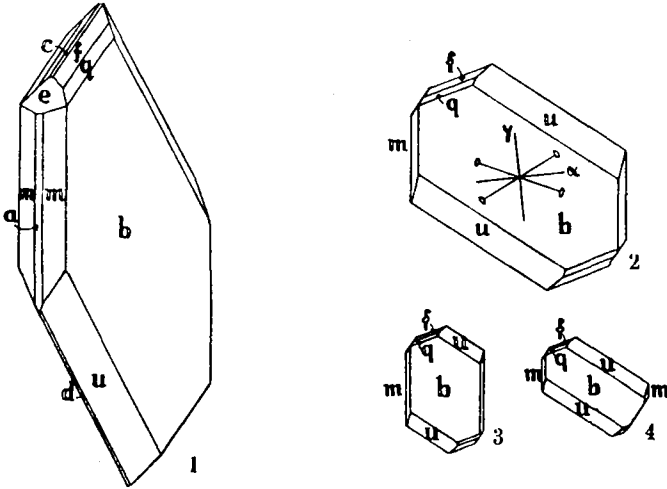
The values obtained for the interfacial angles are given in the first column of the following table:

	E. D. Mountain (1938)		A. Lacroix (1913)	
	measured.		measured.	calculated.
$ae = (100):(102)$	34°	33° 53'
$ec = (102):(001)$	34	34 40
$cd = (001):(\bar{1}02)$	55	56 33
$bk = (010):(270)$	25	24 1
$bm = (010):(110)$	57	57 20
$ba = (010):(100)$	90	90 0
$bq = (010):(011)$	38	37 2
$bf = (010):(012)$	58	56 49
$bc = (010):(001)$	90	90 0
$bv = (010):(\bar{1}42)$	24	23 31
$bu = (010):(\bar{1}32)$	31	30 7
$bt = (010):(\bar{1}22)$	42	41 2
$bs = (010):(\bar{1}12)$	61	60 7
$bd = (010):(\bar{1}02)$	90	90 0

Owing to the similarity in angles and development between the prism and clinodome zones, it was felt that there was in the case of most crystals insufficient evidence to discriminate definitely between the two zones on goniometric data alone. For this reason, several sections were cut parallel to the clinopinakoid in order to orientate the crystals according to their optical properties. The material is never perfectly fresh and is generally altered to a yellowish decomposition product along a network of cracks, so that only thin sections up to second- or third-order interference-colours were sufficiently transparent for optical determination. The optical orientation is shown in fig. 2.

A section, parallel to the optic axial plane, which gave first-order

sensitive tint when examined in convergent light, showed that the α vibration-direction corresponds to the acute bisectrix, thus demonstrating its optically negative character.¹ These sections parallel to the clinopinakoid show very conspicuous dichroism in blue and buff.



FIGS. 1-4. Sapphire crystals from Transvaal.

Another section was prepared parallel to the orthopinakoid a (100) and when examined with a high-power objective exhibited both optic axes within the field but somewhat unequally inclined to the normal. This section was used to determine the optic axial angle both by the Mallard method and on the universal stage, the two results agreeing perfectly. In this section dichroism was only slight.

The optical characters determined on the same crystal may be summarized as follows:

γ to vertical axis c [001] = 6° in the obtuse axial angle; $\beta = b$ [010].

α 1.714, β 1.719, γ 1.720 (by immersion).

α pale pinkish-buff, β pale cerulean-blue, γ Italian-blue.

$2V_\alpha = 50\frac{1}{2}^\circ$, negative, $r < v$, inclined dispersion.

The optical characters enabled the crystallographic orientation to be determined in all cases, and the following general distinctions were then drawn between the prism and clinodome zones:

- (1) a (100) well developed, c (001) poor.
- (2) re-entrant angles rare in prism zone, common in clinodome zone.
- (3) rounded faces rare in prism zone, common in clinodome zone.

¹ E. D. Mountain, South African Journ. Sci., 1929, vol. 26, p. 70. [M.A. 4-443.]

(4) $bk = 25^\circ$, while $bq = 38^\circ$.

(5) faces in the prism zone are generally better developed than in the clinodome zone.

The crystal which had been used for the optical properties was then further used for chemical analysis. The specific gravity determined by the pycnometer method on $3\frac{1}{2}$ grams of material gave 3.398 at 11°C . and the following figures were obtained for the chemical composition (first column):

	I.	II.	III.	IV.
SiO ₂	12.95	13.9	12.9	13.1
Al ₂ O ₃	62.38	67.0	65.7	66.5
Fe ₂ O ₃	1.69	—	—	—
FeO	3.09	—	—	—
MnO	trace	—	—	—
MgO	15.22	19.1	21.4	20.4
Na ₂ O	trace	—	—	—
K ₂ O	0.10	—	—	—
H ₂ O (+110° C.) ...	4.80	—	—	—
H ₂ O (-110° C.) ...	0.05	—	—	—
	<u>100.28</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>

The fusion in sodium carbonate took several hours even after fine grinding, and owing to the very slight solubility the value for ferrous oxide may not be quite reliable. Another crystal which possessed a specific gravity of 3.146 was found to contain 10.41% combined water. In the second column the analysis has been recalculated to a water-free basis, the iron oxides being represented by an equivalent amount of MgO.

For comparison, in the third column of the above table, are given the figures corresponding to $5\text{MgO} \cdot 6\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, the generally accepted formula for sapphirine. Gossner and Mussgnug¹ have shown that the crystal-structure of sapphirine corresponds to the formula $\text{Mg}_2\text{Al}_4\text{SiO}_{10}$ in which MgSi is further indefinitely replaced by Al₂. Actually, this agrees more closely with our recalculated composition when, in $4\text{Mg}_2\text{Al}_4\text{SiO}_{10}$, just one MgSi is replaced by Al₂. This would actually be equivalent to $\text{Mg}_7\text{Al}_{18}\text{Si}_3\text{O}_{40}$, and the percentage composition corresponding to it is given in column IV.

Data published in the literature on sapphirine show considerable differences. Some of the original articles were inaccessible to me and I am greatly indebted to Dr. L. J. Spencer for a number of critical summaries. The earliest crystallographic data were obtained on crystals

¹ B. Gossner and F. Mussgnug, Neues Jahrb. Min., Abt. A, 1928, Beil.-Bd. 58, pp. 233-238. [M.A. 4-109.]

from Fiskernæs in Greenland by Ussing,¹ who gives an average value for bm of $57^{\circ} 27'$ and an extinction-angle $\gamma:c$ $8\frac{1}{2}^{\circ}$ in the acute axial angle. This, together with his axial angle of $79\frac{1}{2}^{\circ}$ and an angle of $47\frac{1}{2}^{\circ}$ for (010):(011), suggests that he adopted a different clinoaxis from ours, but the same prism zone. Unfortunately, the axial angle was only deduced from measurements made on different crystals and not determined directly. To add to the confusion, later authors misquote Ussing's data. For instance Dana² is not only himself inconsistent but implies an extinction-angle of 19° in the obtuse axial angle. Walker and Collins³ in 1907 described crystals of sapphire from Vizagapatam, Madras, with an extinction-angle of about 15° , but the orientation is not clear.

In 1913 A. Lacroix⁴ described in some detail crystals of sapphire from near Itrongay in Madagascar. They showed the forms $b a e m f$ and q , and his crystallographic calculations were based on the measured angles am $32^{\circ} 40'$, ef $46^{\circ} 30'$, fm' $92^{\circ} 10'$. From these values he deduced $a:b:c = 0.7310:1:1.4115$, $\beta = 68^{\circ} 33'$, but although the axial angle is correctly calculated the axial ratios should read $a:b:c = 0.6889:1:1.4056$. I have employed these latter figures, and the calculated angles given in the table above have been based on them. The agreement between these calculated angles and my measured angles is reasonably good, so that it can be assumed that the elements upon which the calculations were based are fairly accurate. There seems to be no reason why the length of the vertical axis should be more than twice that of the clinoaxis, and if the vertical axis were halved the indices would actually be simplified; but to avoid any confusion I have refrained from introducing any such change. Lacroix did not determine the optic orientation but adopted Ussing's $8\frac{1}{2}^{\circ}$ and assumed that Ussing's (001) corresponded to our $(\bar{1}04)$. With our orientation, this would correspond to an angle for $\gamma:c$ of $8\frac{1}{2}^{\circ}$ (or 8° after Lacroix) in the obtuse, instead of the acute, axial angle. Lacroix expresses this by saying that the negative acute bisectrix makes an angle of 98° with the vertical axis in the acute angle ph^1 , i.e. $(\bar{1}04):(100)$, a statement quite liable to misconstruction.

A. N. Winchell⁵ has interpreted the foregoing results for the extinction-angle $\gamma:c$ as being $+8^{\circ}$ (Lacroix) and 15° (Walker), thus in the obtuse

¹ N. V. Ussing, Öfversigt K. Vetenskaps-Akad. Förhandl., 1889, vol. 46, pp. 17-26; modified translation in Zeits. Kryst. Min., 1889, vol. 15, pp. 598-605, 2 figs.

² E. S. Dana, System of mineralogy, 6th edit., 1892, p. 561.

³ T. L. Walker and W. H. Collins, Rec. Geol. Survey India, 1907, vol. 30, p. 8.

⁴ A. Lacroix, Min. de France, 1913, vol. 5, pp. 73-74, 1 fig.

⁵ A. N. Winchell, Elements of optical min., 2nd edit., 1927, pt. 2, p. 277; 3rd edit., 1933, pt. 2, p. 427.

axial angle. In the text he gives $\beta = 68^\circ 33'$ following Lacroix, but his figure is drawn with $\beta = 79\frac{1}{2}^\circ$ as given by Ussing. On the other hand, Larsen¹ gives $\gamma:c = -8\frac{1}{2}^\circ$ (i.e. in the acute axial angle), apparently following Ussing and ignoring later authors.

More recently, Gossner and Musgnug (loc. cit.) attempted to reconcile some of these discrepancies. They remeasured Ussing's original crystals, but, as before, the prism zone and the clinodome zone were measured on different crystals. They calculated β as $74^\circ 31'$ and $a:b:c = 0.667:1:0.691$ based on X-ray measurements. They have halved the vertical axis, as suggested above, but their axial angle receives no support from the crystals described in this paper.

In conclusion, it is suggested that Lacroix's measurements be accepted as substantially correct giving $a:b:c = 0.6889:1:1.4056$, $\beta = 68^\circ 33'$; while the optic orientation be defined as optic axial plane parallel to b (010) with $\gamma:c = 6^\circ$ in the obtuse axial angle.

¹ E. S. Larsen, Bull. U.S. Geol. Surv., 1934, no. 848.