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## Chromium-bearing kyanite from Mozambique

CHROMIUM-BEARING kyanite occurs in a pegmatite at Serra do Menucué (Mozambique) associated with barian chromium-bearing hydromuscovite (Neiva, 1978), biotite and andesine ( $An_{36}$ ). The crystals can reach  $30 \times 5 \times 3$  mm in size, occurring in pinacoids with {010}, {110} and {110}. They are blue in colour with specific gravity 3.70. In thin section the mineral is slightly pleochroic,  $\gamma$ -very light blue to  $\alpha$ -colourless, and contains many inclusions of rutile. The refractive indices are  $\alpha = 1.720$ ,  $\beta = 1.730$ ,  $\gamma = 1.753 \pm 0.002$ ;  $2V_{\alpha} = 82 \pm 1^{\circ}$ . Optical examination showed that the kyanite contained inclusions of rutile needles.

The unit cell dimensions of the kyanite are:  $a = 7.125 \pm 0.006$ ,  $b = 7.846 \pm 0.002$ ,  $c = 5.569 \pm 0.001$  Å,  $\alpha = 89.846 \pm 0.027^{\circ}$ ,  $\beta = 101.336 \pm 0.061^{\circ}$ ,  $\gamma = 106.012 \pm 0.043^{\circ}$ ,  $V = 292.965 \pm 0.002$  Å<sup>3</sup>, calculated from a powder photograph, using Si as the internal standard. An X-ray diffraction photograph of the apparently pure kyanite heated to 1000 °C showed mainly kyanite but with a small amount of muscovite.

The d.t.a. curve up to 1000 °C of the kyanite does not show any peak, in agreement with Eitel (1954). However Houldsworth and Cobb (1923) found an endothermic peak at 850 °C, which may have been due to impurities. At atmospheric pressure, kyanite started to convert to mullite about 1300 °C, the conversion becoming complete by 1400 °C.

The electron probe analysis of the kyanite was obtained on a Microscan 9 wavelength-dispersive

instrument, using the following standards: Al, jadeite; Si, wollastonite; Ti, rutile; Cr and Fe, pure metal. The trace elements were determined with an AEI MS7 spark source mass spectrograph using the technique of Nicholls *et al.* (1967), with Re as internal standard; the limit of detection is 0.01 ppm and a precision of  $\pm 7\%$  is obtained. The chemical analysis, structural formulae and the trace elements are given in Table I.

The kyanite from Menucué contains slightly less  $Cr_2O_3$  than the coexisting barian chromium-bearing hydromuscovite.  $Cr_2O_3$  is not common in kyanite, but Ozerov and Bykhover (1936) have reported a green chrome-kyanite with 1.81%  $Cr_2O_3$ ; Herz and Dutra (1964) studied a greenish kyanite with 2200 ppm Cr; Sobolev *et al.* (1968) found blue kyanites with different  $Cr_2O_3$  contents (maximum  $Cr_2O_3 = 12.86$  wt. %) and Cooper (1980) reported blue kyanites with  $Cr_2O_3$  from 0.17 to 2.85 wt. %.

Ti can replace Al in the kyanite structure. V (167 ppm) can substitute for Al if V is in the high oxidized state. Ba (82 ppm) and Pb (10 ppm) are almost certainly due to the associated hydromuscovite. Ge (59 ppm) probably substitutes for Si. Sc replaces Al; but Zn, Zr, and Cu are probably too large to replace Al. The V, Zn, Zr, Sc contents of kyanite could not be explained by the hydromuscovite impurities, which are very small.

The kyanite from Menucué has higher specific gravity, refractive indices and  $b$  dimensions than

TABLE I. *Chemical analysis of chromium-bearing kyanite from Mozambique*

Chemical composition		Trace elements (ppm)			
SiO <sub>2</sub>	37.09	Be	—	Er	0.56
Al <sub>2</sub> O <sub>3</sub>	62.59	Ge	59	Y	0.15
TiO <sub>2</sub>	0.02	Ga	15	Ho	—
Cr <sub>2</sub> O <sub>3</sub>	0.40	W	5	Dy	—
FeO	0.09	V	167	Tb	—
Total	100.19	Mo	0.24	Gd	—
		Nb	3.0	Eu	—
		Zn	41	Sm	—
		Sn	0.45	Nd	—
		Ni	9	Pr	0.25
		Zr	32	Ce	0.50
		In	0.25	La	0.35
		Cd	4	U	—
		Sb	0.35	Th	—
		Co	0.36	Sr	3.0
		Cu	13	Pb	10
		Sc	24	Ba	82
		Bi	1.1	Rb	1.4
		Lu	—	Tl	0.17
		Yb	0.33	Cs	0.17
		Tm	—		

Dash: below the limit of detection.

those of other kyanites (Deer *et al.*, 1962),  $\alpha$  and  $\gamma$  refractive index values are in the range of those of blue chromium kyanites of Sobolev *et al.* (1968), but both indices are smaller than those of blue kyanite with Cr<sub>2</sub>O<sub>3</sub> = 12.86%. The cell parameters *a* and *b* have values between those for the chromium-poor and chromium-rich blue kyanites of Sobolev *et al.* (1968).

The high specific gravity, refractive indices and *b* cell parameter of the kyanite from Menucué may be due to its high Cr content. According to Langer (1974), Cr<sup>3+</sup> gives a deep emerald green colour to kyanite. White and White (1967) found that as little as 50 ppm Ti generates a deep blue colour in kyanite. Rost and Simon (1972) also attributed the blue colour of kyanite to Ti. However, other investigators attributed the blue colour to Cr and Fe (Sobolev *et al.*, 1968), to Fe<sup>2+</sup> → Fe<sup>3+</sup> charge transfer (Faye and Nickel, 1969), to Fe<sup>2+</sup> → Ti<sup>4+</sup>

charge transfer (Smith and Strens, 1976), and to a combination of Fe<sup>2+</sup> → Fe<sup>3+</sup> and Fe<sup>2+</sup> → Ti<sup>4+</sup> charge transfers and Fe<sup>2+</sup> and Fe<sup>3+</sup> field transitions (Parkin *et al.*, 1977). The blue colour of the kyanite from Menucué may be due to its Ti content, because there is enough Ti present to form needles of rutile by exsolution.

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