Black elbaite from Corrego do Urucum, Minas Gerais, Brazil

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SUMMARY. Black tourmaline from Corrego do Urucum, Brazil, is an elbaite coloured by iron and manganese with blue, green, and pink regions. Polarized spectra show the absorption bands expected in elbaite (Fe-caused blue and green, and pink, which is probably caused by Mn). The colour distribution in the transverse sections does not conform to the symmetry of tourmaline and changes along the length of the crystals. Two distinct growth stages are indicated, separated by a partial dissolution and followed by another dissolution.

BLACK tourmaline was collected from the Corrego do Urucum pegmatite by R. E. Gaines in 1974. The material was found to transmit some light when thin crystals were strongly illuminated and showed a deep smoky purple coloration. Black tourmaline is usually the iron-rich schorl, while the Li tourmaline, elbaite, is usually a pale colour. A transverse slice showed a colour distribution pattern unusual for tourmaline.

According to R. E. Gaines the locality is about 12 km NNE. from Galilea in Galilea County, Minas Gerais, Brazil. The zoned lithium pegmatite contains, among other minerals, spodumene, much muscovite, some lepidolite, cleavelandite, and some quartz. Two large vugs containing about three tons of spodumene, including some 500 kg of fine pink gem material, were mined from 1965 to 1970. Also found were several hundred large tabular morganite crystals, up to 25 cm across and 10 cm thick. Additional materials present were gemmy green as well as cats-eye tourmaline, stokesite crystal (Anon., 1973), and the black elbaite here described. The visit of R. E. Gaines was arranged by one of three owners of the mine, Mr. Neylson Barros.

Experimental and results. Several black tourmaline crystals up to 12 mm in diameter and 48 mm in length were lent to us for examination. The prisms showed the usual partly rounded triangular cross-section, strongly striated, and one showed simple pyramid terminations of the $02\bar{2}1$ (o) type. There was some light transmitted through thin crystals under strong illumination.

Permission was obtained to cut transverse 1 mm slices from each end of the large 11 mm diameter crystal as well as from a smaller 6 mm diameter crystal. The drawings of fig. 1 show the colours, some of the details visible in the transverse slices under the microscope, and cross-section diagrams.

These slices show several interesting characteristics. The outer skin, a fraction of a millimetre thick in the crystal sections A and B, fig. 1, is a bright pink to purple colour. This is followed by a series of coloured bands (blue, green, and blue-green of
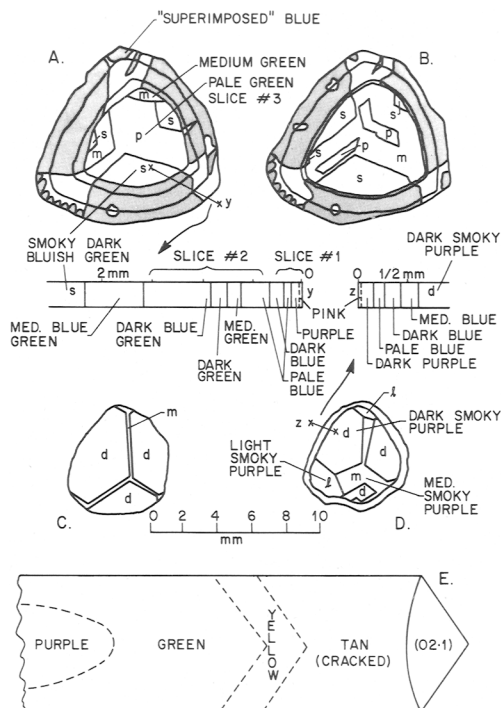

FIG. 1. Drawing corresponding to slices including s–y and z–d cross-sections. The lower millimetre scale applies to slices A–D, as well as to the terminated crystal shown in E.

quite deep colour), which total about 2 mm. Within the central green region are roughly triangular sectors, which, however, do not show the threefold symmetry expected in tourmaline.

The lack of full threefold symmetry in the colour banding can be attributed to an initial growth period, a partial dissolution, another growth period, and a final slight dissolution step. This can be most clearly seen in the transverse section of the smaller crystal. Fig. 1C shows what was obviously once an almost fully symmetrical tourmaline crystal that has been partly dissolved. At this end of the crystal only a trace of overgrowth banding is present, part of which has been again dissolved. At the other end of the crystal, fig. 1D, more second-stage growth occurred. A similar interpretation can be applied to the large crystal, fig. 1A and B. Here the second growth banding is more prominent and the symmetry of the central region is only slightly distorted if one recognizes that dissolution occurred unevenly, probably due to a non-symmetrical flow of the dissolving solution. Here there was only a little of the second dissolution, e.g. at the lower right in fig. 1B.

To the eye, sections 1A and 1B give the impression of a composite layered structure. It is as if the areas labelled smoky dark bluish-green as well as the 'superimposed' blue in the outer band areas were continuous, and had been formed by a layer of patchy blue material superimposed on the green centre and banded outer regions. This impression is quite deceptive, however, since the same appearance is seen in these two slices, which were 48 mm apart. In addition, close examination shows that although in some places these colorations in the central and outer banded regions appear to have continuous boundaries, in other places they definitely do not.

We are unable to suggest any explanations for the irregularly shaped 'superimposed' blue areas in the outer banded regions, or for the partial coincidences of some of the edges of these areas within the darker areas in the central regions. The terminated crystal is shown, as it appears with strong sidelight, in fig. 1E. The final tan section is heavily cracked and it was not feasible to prepare a longitudinal slice of this specimen.

A composite sample containing material from the different colour regions of the fig. 1A slice was analysed by semi-quantitative emission spectroscopy and gave: major ingredients ($> 10\%$), Al and Si; minor ($1-10\%$), B, Fe, Li, Mn, and Na; impurity ($0.1-0.01\%$), Ba, Ca, Cr, and Pb; trace ($0.01-0.001\%$), Ag, Cu, Sn, and Ti. This material is clearly an elbaite (lithium) tourmaline (Deer et al., 1962) with iron and manganese as the probable major colour-causing impurities.

Slabs were also cut parallel to the length of the crystal from which slices 1A and 1B were obtained. A radial slice was cut so that we could examine the blue-purple-pink region at its end (no. 1 in fig. 1). An outer tangential slice close to the surface included the blue-green area (no. 2), and a central slice (no. 3) was cut from the pale green centre. The dichroism shown in these slices between polarizers was:

	σ (ordinary ray)	π (extraordinary ray)
Slice 1	black	pink-purple
Slice 2	very dark blue-green	smoky purple
Slice 3	dark blue-green	pale blue-green

Since the optic axis is located in the plane of these longitudinal slices, both π and σ absorption spectra (extraordinary and ordinary ray, respectively) could be determined as shown in fig. 2. These spectra were taken on a Cary 14R double-beam spectrophotometer.

The green and blue colours in tourmaline are primarily due to iron impurities, with d–d transitions or charge transfer invoked by various authors as is well summarized by Smith and Strens (1976). Note that the 1100 nm σ absorption band is strongest in the green spectrum of fig. 2 (when allowance is made for the varying thicknesses), as is also seen for green in figs. 4 and 5 of Wilkins et al. (1969). The 730 nm π band is strongest in the green,

RADIAL SLICE #1
PINK-PURPLE
t=2.57 mm
σ
π

TANGENTIAL SLICE
#2
BLUE-GREEN
t=1.37 mm
σ
π

CENTRAL SLICE #3
GREEN
t=0.93 mm
σ
π

ABSORBANCE

V B G Y O R
4.13   2.48   1.77   1.38   1.13   0.95   0.83   0.73   0.65
ELECTRON VOLTS (eV)
300   500   700   900   1100   1300   1500   1700   1900
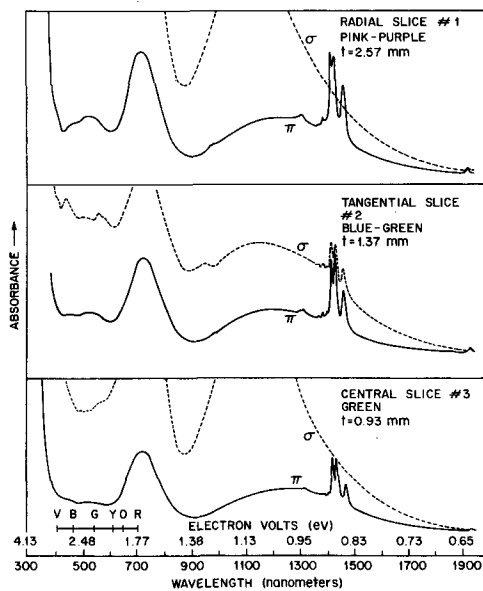WAVELENGTH (nanometers)

FIG. 2. Polarized absorption spectra for three longitudinal slices, nos. 1–3, as shown in fig. 1.

intermediate in the blue-green, and weakest in the pink-purple slice. The specific absorbances $(1/t)$ $\log_{10} (I_0/I)$, where t is in cm, are 9·4, 8·0, and 5·1, respectively, indicating concentration variations. The only real difference between the green and blue-green slices is that in the green σ spectrum the absorption increases more rapidly in moving from 500 to 400 nm as has been previously noted in green as against blue elbaite (Voskresenskaya and Grum-Grzhimailo, 1967). The pink colour in tourmaline has been ascribed to Mn or Fe (Wilkins *et al.*, 1969); to Mn (Manning, 1969); or to a colour centre (Bershov *et al.*, 1969); in all instances the absorption band being near 530 nm, a band clearly visible in the pink-purple slice. Considerable Mn is present in our specimen. It should be noted that one of us has recently shown at least seven differently behaving pink colours in the examination of a large number of tourmaline specimens (Nassau, 1975). The sharp absorptions near 1400 nm in fig. 4 are overtones of the OH stretching vibrations and are not related to the colour.

The spectra of fig. 2 are thus consistent with previously published elbaite spectra based on the observed Fe and Mn impurities, with the dark-coloured regions owing their colour to the simultaneous presence of both pink-causing and blue-green-causing absorption bands.

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