

GEM ZOISITE FROM TANZANIA¹

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ABSTRACT

Strikingly pleochroic gem-quality crystals of zoisite were found in Tanzania in 1967. They are remarkably well formed; on 12 crystals 40 forms were identified, 17 of them new. The morphological axial ratios are $a:b:c=0.6173:1:0.3426$. The unit-cell dimensions (X-ray orientation) are $a=16.20$, $b=5.55$, $c=10.00\pm 0.01$ Å. The indices of refraction by minimum deviation: $\alpha=1.6925$, $\beta=1.6943$, $\gamma=1.7015\pm 0.0001$ Å (Na light); $X=b$ red-violet $Y=c$ deep blue, $Z=a$ yellow-green; opt (+); $2V=53^\circ$; $r>v$. Heat-treated crystals become sapphire-blue. Density 3.355 (meas), 3.358 (calc); hardness $6\frac{1}{2}$ -7. Chemical analysis yields: SiO₂ 39.55, Al₂O₃ 33.39, V₂O₅ 0.20, Fe₂O₃ 0.04, CaO 22.44, MgO 0.07, SrO 0.05, H₂O 2.00 Total 99.69. The color is attributed to vanadium.

INTRODUCTION

In 1967 gem quality crystals of violet-blue zoisite from Tanzania attracted the attention of gem and minerals dealers. Because of a striking red, blue, yellow-green pleochroism and orthorhombic symmetry, they were at first thought to be cordierite or dumortierite. Their correct identity was established by X-ray photographs made independently at the University of Heidelberg (Bank, Berdesinski, Nuber, 1967) and at the British Geological Survey and Natural History Museum (Anderson, 1968). For the handsome gem stones that have been cut from this material, the name *zoisite*, it has been argued, is rather unexciting, and "tanzanite" has been suggested as a varietal name. (Liddicoat and Crowningshield, 1968).

Published accounts of these unusual crystals are at variance regarding the location of their source. At first the locality was given only as East Africa (Bank, *et al.* 1967), then (Meen, 1968) more specifically as "... Arusha in the Gerevi Hills in Tanzania near the Kenya border." Later in a letter to the editor of the *Lapidary Journal* (in Liddicoat and Crowningshield, 1968) Dr. E. Gubelin points out that the Gelevi Hills are near Tanga a long way from Arusha and states "... zoisites are found in the upper part of the Uмба Valley, nearer to Usambaru Mountains."

The geological occurrence is even more nebulous than the geographical; nothing is in print regarding it. I have been told by gem dealers that the crystals are alluvial but this seems highly unlikely since none of them is water worn and the faces are sharp and clean. On only one crystal was there adhering matrix observed. This belonged to a dealer and I was privileged to examine it in a cursory fashion for only a few minutes. The

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matrix appeared to be composed of angular sand grain size fragments of zoisite cemented by calcite. This may indicate that the crystals are recovered from an eluvial deposit but gives no clue to their ultimate origin.

CRYSTALLOGRAPHY

The traditional or *morphological* orientation of zoisite is such that the axial lengths are $c < a < b$, with c usually the axis of elongation. X-ray crystallographers have reoriented zoisite in order to more easily show the relation between its cell parameters and those of related monoclinic epidote. The X-ray orientation is the first inversion of the morphological with the relation: morphological axes a , b and c become respectively X-ray axes c , a and b . Expressed as a matrix the transformation, morphology to X ray, is 010/001/100. Because of these two orientations some confusion has resulted in recent papers on Tanzanian zoisite. Unless otherwise stated, the morphological orientation is used here.

Twenty-six crystals of zoisite from Tanzania were available for morphological study. The largest of these weighs 52 grams; it is illustrated in Figure 2 (a) and its major forms are shown in Figure 1 (a). This and two other crystals are in the Harvard collection; the remaining were loaned by the U. S. National Museum. Most of the crystals are well formed with the only fracture surface at one end of the axis of elongation. Twelve showing the best form development were measured on the two-circle goniometer. All these crystals were remarkable for their profusion of high quality faces.

Figure 1 (a) represents the appearance of the majority of the crystals,

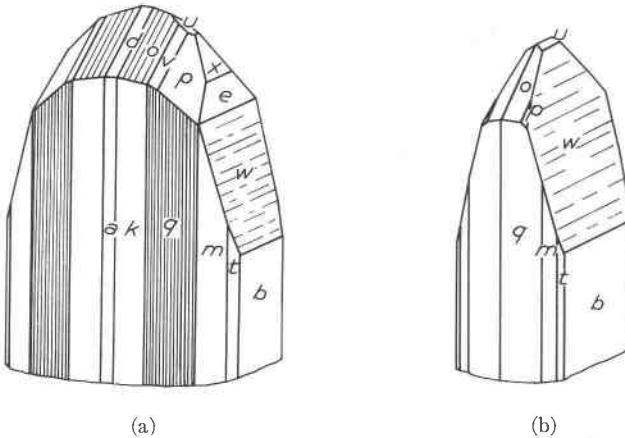


FIG. 1. Zoisite crystal. (a) Typical habit; (b) Wedge-shape characteristics of about 20 percent of crystals examined

TABLE 1. ZOISITE FROM TANZANIA—FORM LIST
ORTHORHOMBIC; $2/m\ 2/m\ 2/m$

$$a:b:c=0.6173:1:0.3426 \quad p_0:q_0:r_0=0.5550:0.3426:1$$

$$q_1:r_1:p_1=0.6173:1.8018:1 \quad r_2:p_2:q_2=2.9189:1:6200:1$$

Form	Form	Form	Form	Form	Form
<i>b</i> 010	870*	510*	081*	<i>d</i> 101	144*
<i>a</i> 100	430*	011	0.10.1*	<i>o</i> 111	313*
<i>l</i> 140	320	<i>u</i> 021	<i>w</i> 0.12.1*	221	323*
<i>t</i> 130	530	<i>x</i> 041	0.14.1*	<i>v</i> 121	211*
<i>r</i> 120	<i>q</i> 210	051	0.16.1*	<i>p</i> 131	1.11.2*
230*	<i>k</i> 310	0.11.2*	0.18.1*	141	
<i>m</i> 110	<i>h</i> 410	<i>c</i> 061	0.24.1*	151	

* Designates a new form.

Only those forms are lettered that appear in the drawings, Figures 1a and 1b.

many of which are striated parallel to [001], $[\bar{1}01]$, and [100]. A few have a squarish habit with equal development of $\{100\}$ and $\{010\}$ and others are wedge-shaped (Fig. 1 (b) with steep $\{0kl\}$ faces dominated by $w\{0.12.1\}$. Of the forty forms identified, seventeen are new and are designated with * in the list of forms, Table 1. Because of the large number of forms, a complete angle table is omitted.

The morphological axial ratios calculated using the angular data derived from only those faces giving superior reflections are $a:b:c=0.6173:1:0.3426$.

The unit-cell dimensions were determined from precession photographs (Mo/Zr) with *a* and *c* (X-ray orientation) as precessing axes. The resulting values, $a=16.20$, $b=5.55$, $c=10.00 \text{ \AA} \pm 0.01 \text{ \AA}$, yield the axial ratios $a:b:c=2.919:1:1.802$. These agree well with the morphological axial ratios, $a:b:c=2.913:1:1.806$ (converted to X-ray position).

OPTICAL AND PHYSICAL PROPERTIES

From a flawless crystal, prisms were cut to measure the refractive indices by the method of minimum deviation. By using $\{100\}$ and $\{010\}$ as

TABLE 2. OPTICAL PROPERTIES OF ZOISITE

Indices	Orientation and Pleochroism	
$\alpha=1.6925$	<i>X</i> = <i>b</i> red-violet	Opt (+)
$\beta=1.6943$	<i>Y</i> = <i>c</i> deep blue	2V = 53°
$\gamma=1.7015$	<i>Z</i> = <i>a</i> yellow-green	$r > v$

reference faces for orientation, the A.D. Jones Optical Co. of Burlington, Mass. cut two 50° (approx.) prisms with prism axes the *a* and *c* crystal axes. The measured refractive indices and other optical properties are given in Table 2.

Two optical orientations were noted by Termier (1898). He designated as β , that zoisite with the orientation given in Table 2; and as α , zoisite with $X=c$, $Y=b$, $Z=a$. On the basis of four chemical analyses Becke (Doelter, 1914) concluded that α -zoisite is iron-free. He observed that both types may occur in the same specimen, but the percentage of α -zoisite decreases with increasing iron; and the specimen with 4.60 percent Fe_2O_3 contained only β -zoisite. Since the publication of Becke's observations many writers of textbooks without further verification, have in effect stated: α -zoisite is iron free and β -zoisite contains about 5 percent Fe_2O_3 . Such a statement is obviously incorrect since the essentially iron free (0.04 % Fe_2O_3) mineral described herewith is β -zoisite. The reason for the two optical orientations of zoisite remains unexplained.

In reflected light the zoisite crystals show a variety of colors: yellowish green, brown, blue, colorless. However, about half of those examined have an amethystine color. It is these that show the most pronounced pleochroism, and when viewed parallel to the crystallographic axes in ordinary white light they transmit: *a* brownish-red to yellowish-green, *b* blue, *c* violet-red. However, the pleochroism is far more striking in plane polarized light as shown in Figure 2b.

It has been found that when the zoisite is heat-treated, it becomes an intense sapphire-blue and it is this color that is most popular for cut gems (Fig. 2d). The heating also brings about a change in pleochroism. Before heating X =red-violet, Y =deep blue, Z =yellow-green; after heating X =violet-red, Y and Z =deep blue. Thus to produce the richest blue in a gem stone, crystals are cut with the X direction (*b* axis) perpendicular to the table. Some untreated crystals, show throughout the deep blue color and the same pleochroism as the heat-treated; in others these properties are present only toward the terminated end while the base of the crystal still transmits the yellow-green in the Z direction. Although strong pleochroism is observed in all macroscopic crystals no differential absorption is seen in microscopic grains.

Two directions of cleavage are observed in the Tanzania crystals: $\{010\}$ and $\{100\}$. They both appear to be of the same quality and are difficult to develop. The common fracture surface is conchoidal. The specific gravity measured on the Berman balance is 3.355 ± 0.001 . The calculated density is 3.358. The hardness is between 6 1/2 and 7. The measurements of specific gravity and hardness agree well with those made by others on similar material.

TABLE 3. CHEMICAL ANALYSIS OF ZOISITE

	Wt %	Wt % recalculated	Atomic proportion	
				Number of atoms with (O,OH) = 13
SiO ₂	39.55	39.67	Si	3.000
Al ₂ O ₃	33.39	33.49	Al	2.985
V ₂ O ₅ ^a	0.20	0.20	V ³⁺	0.012
Fe ₂ O ₃	0.04	0.04	Fe ³⁺	0.002
CaO	22.44	24.52	Ca	1.987
MgO	0.07	0.07	Mg	0.008
SrO	0.05	0.05	Sr	0.002
H ₂ O	2.00	2.01	H	1.012
Total	99.69	100.00		

1. Analyst, Hisayoshi Ichihara, Toshiba, Central Research Laboratory, Kawasaki, Japan.

^a Spectrographic analysis and V₂O₅ and SrO determination by J. Ito.

Spectrographic analysis: Sr (0.0X); B, Cr, Mn (0.00X); Ti, Ga, Sc, In, Yb, Y, Cu, Ni, Zn, (<0.00X%).

CHEMICAL COMPOSITION

A wet chemical analysis of zoisite was made by Mr. Hisayoshi Ichihara on a one gram fragment broken from a transparent but deeply colored crystal. This small amount of material proved insufficient for Mr. Ichihara to analyse for the minor or more unusual elements. Consequently a qualitative spectrographic analysis and a quantitative analysis for vanadium and strontium were made by Dr. Jun Ito of Harvard University. The combined results of analyses are given in Table 3.

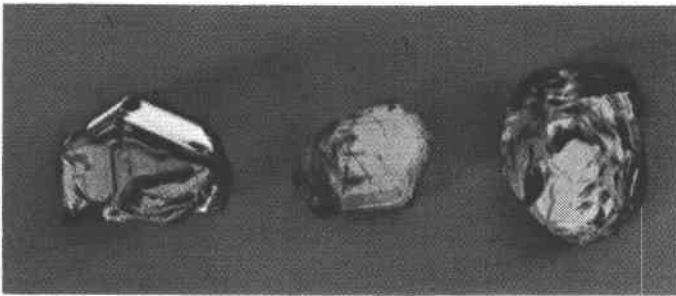
The atomic proportions given in column 4 of Table 3 agree remarkably well with those expressed in Ca₂Al₃Si₃O₁₂(OH), the ideal formula for zoisite. There is no substitution of Al for Si and extremely minor substitution of Fe³⁺ for Al. The only element in significant amount, other than those shown in the formula, is V³⁺ substituting for Al. It is undoubtedly the vanadium that gives the mineral its striking pleochroism and the change from V³⁺ to V⁴⁺ when heat-treated that causes it to turn a sapphire-blue color.

Anderson (1968) because of absorption spectra, also suggested the possibility of the color being due to vanadium. He observed a broad absorption band at approximately 5950 Å and lesser bands at 5280 Å and 4550 Å which were similar to those noted in a vanadium tourmaline.

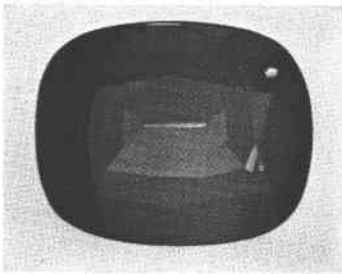
It appears reasonably certain that the zoisite described by Bank, *et al.*



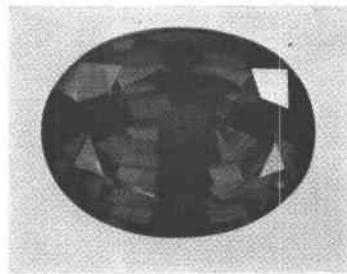
(a)



(b)



(c)



(d)

FIG. 2. Zoisite. (a) Crystal weighing 52 grams. (b) Pleochroism in the three principal optical directions in which Y = c blue, Z = a yellow, X = b red; (c) Cut stone, 30 carats; (d) Cuts tone, heat-treated, 36 carats. (a) and (b) full scale; (c) and (d) approximately $1\frac{1}{2}\times$.

(1967) from East Africa is the same as that considered in this paper. The cell dimensions, specific gravity, refractive indices and pleochroism of the two minerals are in essential agreement. However, there is a slight disagreement in relative percentages of the trace elements. Bank, *et al.* (1967) reported an unusually high strontium content with no mention of vanadium; whereas the spectrographic analyses made for the present study show considerably more vanadium than strontium.

ACKNOWLEDGMENTS

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