



Figure 2: This 1.45 ct stone consists of intense blue ceruleite with dark brown, white and green impurities. Gift of Mauro Pantò; photo by B. Williams.

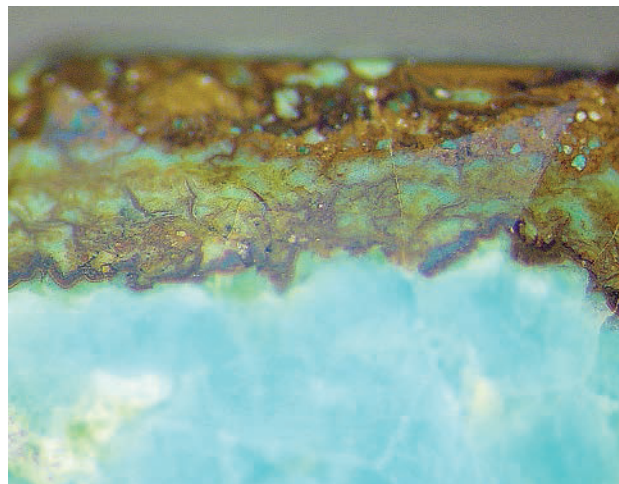


Figure 3: This closer view of the pavilion side of the stone in Figure 2 shows the veined appearance of the iron staining and associated matrix material, as well as the green and white impurities in the ceruleite. Photomicrograph by C. Williams; magnified 50x.

typically reported for ceruleite, but is similar to the SG of 2.70 determined by Schmetzer et al. (1978) on polycrystalline material. The blue areas of the sample were confirmed as ceruleite using an En-wave 785 Raman spectrometer, by comparing the spectra to the RRUFF database.

Microscopic observation of the blue areas revealed a polycrystalline texture, while the dark brown areas showed vein-like patterns (e.g. Figure 3) that resembled the iron-stained matrix commonly seen in turquoise and the white areas locally contained tiny open vugs. According to analytical work done by German mineralogist Gunnar Farber, the green inclusions consist of schlossmacherite, a sulphate mineral of the alunite group with the formula  $(\text{H}_3\text{O})\text{Al}_3(\text{SO}_4)_2(\text{OH})_6$ .

The reported hardness of 5–6 on the Mohs scale makes ceruleite sufficiently durable for cutting and use in jewellery. Like turquoise, however, it may be sufficiently porous to require sta-

bilization. Schmetzer et al. (1983) documented plastic-impregnated ceruleite, which was easily identified because its SG was distinctly lower (2.58) than that of untreated material, and infrared spectroscopy showed a diagnostic absorption band at  $1725\text{ cm}^{-1}$ , as seen in stabilized turquoise.

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## Yellow Danburite from Namalulu, Tanzania: Gemmological Properties and Chemical Composition

Danburite is a calcium borosilicate  $[\text{CaB}_2(\text{SiO}_4)_2]$  that is an uncommon collector's stone. It typically ranges from colourless to light brown or light yellow, although less commonly it can exhibit intense yellow coloration. In early 2008, significant

amounts of gem-quality yellow danburite entered the market, mined from granitic pegmatites in the Morogoro region of central Tanzania (Chadwick and Laurs, 2008). A few years later, another deposit of yellow danburite was discovered near



Figure 4: These two vivid yellow danburites (8.72 and 7.86 ct) are from the Namalulu area of north-east Tanzania. Courtesy of the Somewhere In The Rainbow Collection; photo by Bilal Mahmood, AGL.

Namalulu village in north-east Tanzania. According to a Tanzanian supplier of this material to gem dealer Werner Radl (Mawingu Gems, Niederwörresbach, Germany), mining of the Namalulu deposit began in 2012, and production consisted of hundreds of kilograms of mainly tumble- and cabochon-grade material, as well as several kilograms of facet-grade rough.

Since 2014, one of the authors (CPS) has examined a number of the vivid yellow danburites from Namalulu, ranging from less than 1 ct to more than 18 ct (e.g. Figure 4). Their standard gemmological properties were: RIs— $n_{\alpha} = 1.628\text{--}1.629$ ,  $n_{\beta} = 1.631\text{--}1.634$  and  $n_{\gamma} = 1.634\text{--}1.637$ ; birefringence— $0.006\text{--}0.008$ ; hydrostatic SG— $2.97\text{--}3.01$ ; and fluorescence—inert to both long- and short-wave UV radiation. These data for Namalulu danburite are consistent with the material from Morogoro reported by Chadwick and Laurs (2008). Microscopic features consisted of small colourless crystals, pinpoint particles, series of fine etch tubules, open fractures with a frosted surface appearance and partially healed fissures. (The absorption spectra and colour stability of Namalulu danburite are described in the following Gem Note entry.)

We measured the chemical composition of three samples of faceted yellow danburite from Namalulu, as well as three faceted yellow danburites from Myanmar for comparison. Energy-

dispersive X-ray fluorescence (EDXRF) spectroscopy was performed on one sample each from Tanzania and Myanmar with a Thermo Scientific Quant'X instrument, using a series of seven excitation energies from 4 to 50 kV (SSEF silicate routine). Laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) was performed on all samples with a GeoLas 193 nm excimer laser, coupled with a PerkinElmer Elan 6100 DRC mass spectrometer (see Table I footnote for details of the procedure).

EDXRF spectroscopy revealed the expected major elements Si and Ca; B could not be measured due to limitations of the technique for detecting light elements. In addition, low concentrations of Sr were detected in samples from both Tanzania and Myanmar. The trace-element data obtained by LA-ICP-MS are shown in Table I; overall, the analysed specimens had similar compositions. Rare-earth elements (REE) were present in all the samples, with a general enrichment of light REEs (La, Ce, Pr, Nd and Sm), as also found by Huong et al. (2016) in danburite samples from Tanzania, Vietnam and Mexico. Our data for the Namalulu danburites were similar to the selected elements reported by Chadwick and Laurs (2008). However, our Tanzanian danburites contained higher concentrations of heavy REEs (including Y) compared to the samples from Myanmar.

Due to the fact that elements with even atomic numbers are naturally more abundant than those with odd atomic numbers (so-called Oddo-Harkins rule), REE data are often plotted in a diagram normalized to a chondrite standard (stony meteorite; data from Anders and Grevesse, 1989). This diagram for our samples clearly shows the higher abundance of heavy REEs in danburite from Tanzania compared to the Burmese samples (Figure 5). The so-called europium anomaly, a deficiency or enrichment of Eu relative to the other REEs<sup>3+</sup>, is a common feature in minerals and rocks, and is linked to the fact that this element can be found in two valence states: Eu<sup>3+</sup> and Eu<sup>2+</sup> (Weill and Drake, 1973). The danburites from Tanzania were characterized by a distinct negative Eu anomaly, whereas two of the three Burmese samples showed no such anomaly. However, the presence of an Eu anomaly in one of the Burmese samples precludes the use of this element for separating danburites from these two localities.

Table 1: Average trace-element concentrations in danburite analysed by LA-ICP-MS.\*

Origin	Tanzania			Myanmar		
Weight	2.10 ct	2.93 ct	3.01 ct	1.50 ct	1.60 ct	1.70 ct
Element						
Be	188 (5)	169 (4)	136 (1)	81.3 (22.3)	29.8 (4.2)	202 (11)
Na	11.8 (0.2)	13.5 (0.1)	10.1 (0.4)	164 (56)	24.2 (1.4)	156 (8)
Mg	4.56 (0.43)	5.55 (0.58)	4.60 (0.22)	5.38 (0.32)	4.91 (0.18)	4.98 (0.46)
Al	178.8 (0.6)	129.3 (0.4)	146.9 (1.0)	89.6 (20.5)	474 (53)	82.9 (1.4)
P	29.3 (5.0)	36.8 (3.0)	28.2 (0.7)	39.8 (0.9)	31.3 (5.0)	36.5 (6.2)
K	<2.0	<1.4	<1.5	1.60 (0.12)	<2.5	5.5 (0.9)
Sc	0.66 (0.08)	0.78 (0.04)	0.39 (0.12)	0.80 (0.12)	0.68 (0.10)	0.49 (0.03)
Ti	<18	<6.0	14.8 (1.5)	<6.3	<20	<19
Mn	1.35 (0.19)	0.50 (0.08)	<0.6	<0.45	1.56 (0.12)	<0.8
Fe	25.7 (3.8)	26.5 (2.1)	21.3 (3.0)	31.3 (3.4)	23.1 (3.2)	25.2 (3.9)
Ga	5.89 (0.62)	10.07 (0.22)	4.07 (0.38)	2.19 (0.27)	4.60 (0.12)	5.08 (0.70)
Ge	7.38 (0.24)	6.75 (0.46)	7.07 (0.17)	2.14 (0.17)	3.42 (0.28)	2.48 (0.31)
Sr	343 (2)	203 (1)	181 (2)	612 (38)	226 (20)	1037 (12)
Y	19.2 (0.3)	13.04 (0.09)	14.68 (0.23)	1.48 (0.14)	5.99 (0.81)	2.11 (0.03)
Sn	2.05 (0.15)	1.63 (0.13)	2.00 (0.14)	1.44 (0.26)	2.33 (0.60)	2.01 (0.09)
Ba	<0.22	<0.14	<0.20	1.75 (0.32)	<0.25	9.89 (0.74)
La	192 (3)	333 (1)	99 (2)	84 (6)	157 (26)	234 (5)
Ce	297 (4)	475 (1)	203 (3)	95 (8)	229 (19)	266 (4)
Nd	68.6 (0.8)	91.0 (0.3)	62.4 (0.6)	24.7 (1.6)	42.7 (1.7)	57.4 (2.3)
Eu	0.84 (0.03)	0.61 (0.02)	0.56 (0.03)	0.74 (0.13)	0.26 (0.01)	1.32 (0.03)
Gd	7.33 (0.20)	6.00 (0.12)	5.91 (0.14)	1.19 (0.21)	2.47 (0.32)	2.10 (0.07)
Dy	3.17 (0.04)	2.16 (0.08)	2.58 (0.09)	0.40 (0.01)	1.00 (0.10)	0.55 (0.07)
Er	0.96 (0.09)	0.65 (0.01)	0.83 (0.01)	0.077 (0.002)	0.32 (0.04)	0.10 (0.01)
Yb	0.50 (0.09)	0.32 (0.02)	0.52 (0.03)	<0.08	0.12 (0.03)	<0.14
Lu	0.055 (0.003)	0.035 (0.004)	0.062 (0.007)	<0.01	<0.02	<0.02
Pb	8.34 (0.11)	11.04 (0.09)	19.16 (0.46)	6.12 (0.51)	7.26 (0.27)	5.82 (0.06)
Th	1.39 (0.08)	0.438 (0.012)	0.54 (0.015)	0.009 (0.004)	<0.007	0.024 (0.003)

\* Three analyses were done on the polished girdle of each sample, using a 60 µm spot size. Values are shown in parts per million by weight, and standard deviations are given in parentheses. The raw data were standardized using NIST 610 glass as an external standard and Si as an internal standard. Before each analysis, a short pre-ablation was performed with the laser to avoid surface contamination effects. The concentration calculation of the transient LA-ICP-MS signals was carried out with SILLIS data reduction software (Guillong et al., 2008). The isotopes were carefully selected to ensure there were no interferences, and special care was taken in the data processing to correct for any artefact (spike) or contamination (surface or inclusions). The following elements were analysed but were below the detection limits: Li, V, Cr, Co, Ni, Cu, Zn, Rb, Zr, Nb, Mo, Sb, Hf, Ta, W, Bi and U; not analysed were the REEs Pr, Sm, Tb, Ho and Tm.

Nevertheless, the analysed samples from Myanmar and Tanzania could be effectively distinguished by plotting the concentrations of the elements Gd, Dy and Ge (Figure 6).

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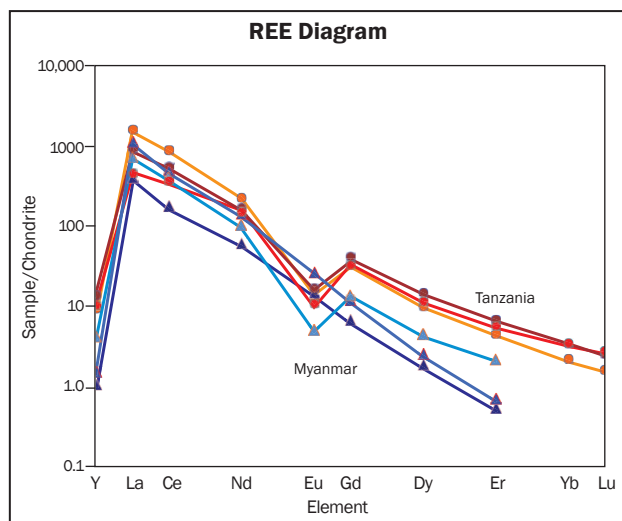


Figure 5: This chondrite-normalized REE diagram of the danburite samples analysed by LA-ICP-MS reveals their general enrichment in light REEs (La to Sm). The three specimens from Tanzania show distinctly higher amounts of heavy REEs (Gd to Lu) than the Burmese samples. All but two of the samples (from Myanmar) show a negative Eu anomaly.

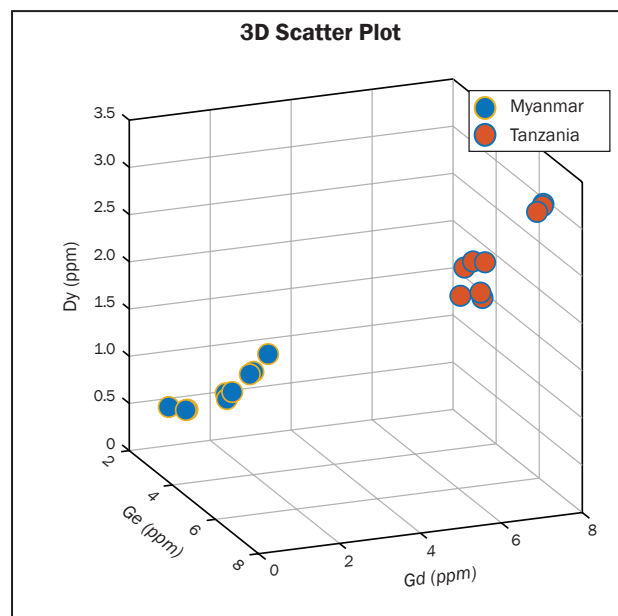


Figure 6: The analysed danburites from Myanmar and Tanzania are clearly distinguished in this three-dimensional scatterplot of germanium, gadolinium and dysprosium.

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## Yellow Danburite from Namalulu, Tanzania, and Myanmar: Origin of Colour and Its Stability

The origin of the yellow colour in danburite is not fully known. However, some researchers have speculated that it may be due to didymium, a name referring to a mixture of light REEs including praseodymium (Pr) and neodymium (Nd), and sometimes cerium (Ce). These and other REEs can replace  $\text{Ca}^{2+}$ .

When viewed with a desk-model spectroscope, typically no absorption features were observed for yellow danburites from Tanzania and Myanmar

(see preceding Gem Note for sample descriptions). However, in the larger and more intensely coloured samples, a very faint line at approximately 584 nm could be seen. Using a Perkin-Elmer Lambda 950 spectrometer, several weak bands were recorded in the visible region at approximately 525, 567, 577, 584, 732, 744 and 792 nm, as well as two dominant bands in the UV region positioned at approximately 275 and 315 nm (Figure 7).