

YELLOWISH GREEN DIOPSIDE AND TREMOLITE FROM MERELANI, TANZANIA

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Four similar-appearing yellowish green samples from Block D at Merelani, Tanzania, were identified as diopside and tremolite. The gems are identical in color, but their standard gemological properties are typical for calcic pyroxene and amphibole. The identification of the diopside was made with Raman spectroscopy, while single-crystal X-ray diffraction and electron-microprobe analyses were used to confirm the amphibole species as tremolite. Absorption spectroscopy (in the visible–mid-infrared range) revealed that the two gem materials are colored by V^{3+} , Cr^{3+} , or both.

At the 2006 Tucson gem shows, Steve Ulatowski showed one of the authors (BML) some yellowish green crystals that he purchased as diopside while on buying trips to Tanzania in August and November 2005. The material was reportedly produced during this time period from Block D at Merelani, in the same area that yielded some large tsavorite gem rough (see Laurs, 2006). Mr. Ulatowski obtained 1,200 grams of the green crystals, mostly as broken pieces ranging from 0.1 to 50 g (typically 1–5 g). More recently, in May 2007, he obtained some additional pieces of gem-quality material weighing 0.1–2 g. The “mint” green color is quite attractive, but most of the rough is not cuttable due to the presence of cleavage planes and, in some cases, the flat morphology of the crystal fragments.

In 2006, Mr. Ulatowski was informed by a few of his customers that the flatter crystals might be tremolite, rather than diopside. This was consistent with the diamond-shaped cross-section of these crystals (typical of an amphibole), which was distinct from the blocky cross-section

(typical of diopside, which is a pyroxene) shown by other crystals in the parcels.

Mr. Ulatowski loaned one example of both types of crystals to GIA for examination (figure 1), and we also

Figure 1. These yellowish green crystals were recovered from Block D at Merelani in the latter part of 2005. A blocky morphology is shown by the diopside crystal (1.6 cm tall; left and bottom), whereas the tremolite crystal has a flattened, diamond-shaped cross-section. Photos by Robert Weldon.



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Figure 2. This diopside (3.39 ct) and amphibole (probably tremolite, 0.63 ct) were cut from two yellowish green crystals recovered from Merelani. Photo by Robert Weldon.

studied two gemstones (0.63 and 3.39 ct) that were cut from Mr. Ulatowski's stock (figure 2). Gemological properties and various types of spectra (visible–near-infrared, Raman, and energy-dispersive X-ray fluorescence [EDXRF]) were collected on the faceted stones at GIA by one of us (EAF). Electron-microprobe analyses (Cameca SX50 instrument, 15 kV accelerating voltage, 10 nA current, 10 mm defocused beam, natural mineral standards) and single-crystal X-ray diffraction analysis were performed on the amphibole crystal at the University of Arizona; this sample was donated by Mr. Ulatowski for inclusion in the RRUFF Project (ID no. R070422 at <http://rruff.info>).

Results and Discussion. The gemological properties of the cut stones are shown in table 1. Their optical properties and SG values are consistent with those reported for calcic pyroxene (larger stone; see Deer et al., 1978) and calcic amphibole (smaller stone; Deer et al., 1997), but further work was needed to determine the particular mineral species. Raman analysis of the pyroxene (faceted stone as well as crystal) identified it as diopside, and the RI values indicated that it contained very little iron. The specific amphibole species could not be identified by Raman analysis, but single-crystal X-ray diffraction and electron-microprobe analyses of the crystal proved that it was tremolite. Although the cut amphibole was not analyzed by these techniques, its properties are consistent with tremolite.

EDXRF spectroscopy of the faceted amphibole showed major amounts of Si, Mg, Ca, and Al, and traces of Mn, Fe, V, Ti, K, and Cr. However, since there is overlap in the EDXRF peaks for V and Cr (as well as for Na and Zn), and since this technique is only qualitative, there are some uncertainties regarding the presence of the minor/trace elements that were detected in the cut stone. Using an electron microprobe, wavelength-dispersive X-ray spectroscopy (WDS) of the tremolite crystal showed the presence of Si, Mg, Ca, Al, Na, K, V, and F (listed in order of relative peak intensity). An average of 15 point analyses of the same sample by electron microprobe provided the fol-

lowing composition (wt.%): $\text{SiO}_2=52.34$, $\text{Al}_2\text{O}_3=6.70$, $\text{MgO}=21.81$, $\text{CaO}=13.05$, $\text{Na}_2\text{O}=0.73$, $\text{K}_2\text{O}=0.67$, $\text{V}_2\text{O}_5=0.32$, $\text{F}=0.47$, and total 96.05; this corresponds to the chemical formula: $(\square_{0.74}\text{Na}_{0.15}\text{K}_{0.11})_{\Sigma=1}(\text{Ca}_{1.96}\text{Na}_{0.04})_{\Sigma=2}(\text{Mg}_{4.55}\text{Al}_{0.41}\text{V}_{0.04})_{\Sigma=5}(\text{Si}_{7.33}\text{Al}_{0.67})_{\Sigma=8}\text{O}_{22}[(\text{OH})_{1.80}\text{F}_{0.20}]_{\Sigma=2}$. The elements Cr, Ti, Fe, Mn, and Zn did not show detectable peaks in the WDS scan, so their concentrations (if present) are at or below the detection limits of the electron microprobe. Since the faceted stone was not cut from the same crystal that was analyzed by microprobe, differences in the presence of Mn, Fe, Ti, and Cr in these samples may be attributed to natural chemical variations in the material. By comparison, EDXRF spectroscopy of the faceted diopside showed major amounts of Si, Ca, and Mg, and traces of Mn, Fe, V, Cr, Ti, Zn, and Al.

Visible–near-infrared spectroscopy of the two cut stones showed similar absorption features, with broad peaks at 434/455 and 652 nm that are related to V^{3+} or Cr^{3+} , or both (figure 3). Similar absorptions were documented by Schmetzer (1982) in green tremolite from Lualenyi, Kenya, and in green diopside from Merelani. A shoulder at ~690 nm in both samples is due to Cr^{3+} (see, e.g., Cr-diopside spectra at <http://minerals.gps.caltech.edu/files/visible/pyroxene/index.htm>). The yellowish green color of both the diopside and the tremolite appears to be related to the presence of trace amounts of V^{3+} and Cr^{3+} in the octahedral sites; Na and K enter the structure by a coupled substitution such as V^{3+} (or Al^{3+}) + Na^+ (or K^+) $\leftrightarrow$ Mg^{2+} + Mg^{2+} .

The yellowish green color of these stones is unusual in amphiboles and pyroxenes, although a comparable color appearance has been reported for amphiboles (pargasite and edenite) from China and Pakistan (see Kanaan, 2002; Blauwet et al., 2004; Lu et al., 2006). A similar diopside was documented by Koivula and Kammerling (1991) from the Lelatema Hills of Tanzania; its properties were

TABLE 1. Properties of yellowish green diopside and tremolite from Merelani, Tanzania.

Property	Diopside	Tremolite
Weight	3.39 ct	0.63 ct
Color	Yellowish green	Yellowish green
Pleochroism	None seen	None seen
RI	1.670–1.700	1.610–1.635
Birefringence	0.030	0.025
SG (hydrostatic)	3.30	3.07
Chelsea filter reaction	None	None
UV fluorescence		
Long-wave	Very weak orange	Weak orange
Short-wave	Weak greenish yellow	Moderate greenish yellow
Spectroscope spectrum	No features visible	No features visible
Microscopic features	Only minor surface abrasions	Growth tubes and planar fluid inclusions

comparable to those of the diopside described here, except for somewhat different fluorescence behavior (weak reddish orange to long-wave UV, and strong yellow-green to short-wave). Fryer (1992) reported on a yellowish green diopside from Merelani that had a lower birefringence (0.019; RIs = 1.670 and 1.689) and an absorption spectrum typical of "chrome diopside." A somewhat less distinct yellowish green bodycolor is shown by diopside ("Tashmirine") from central Asia (Shor and Quinn, 2002).

Conclusion. Small amounts of gem-quality diopside and tremolite containing traces of V and possibly Cr have been recovered from Block D at Merelani. While pale green diopside is locally present in the Merelani area, the distinct yellowish green color of this diopside and tremolite is unusual. Future production of these

gems is uncertain, and will depend on the mineralization encountered during further mining for tanzanite, green grossular, and other gems at this famous locality.

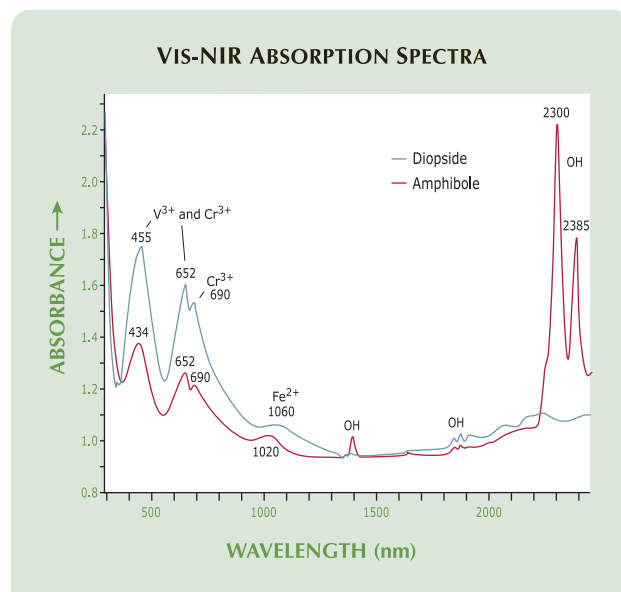
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Figure 3. The Vis-NIR spectra of the faceted yellowish green diopside and amphibole samples are dominated by absorption features related to V^{3+} and/or Cr^{3+} in the visible range and hydrous components in the infrared region (for the amphibole).



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