Laboratory and imaging spectroscopy of tourmaline – a tool for mineral exploration

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Hyperspectral analysis of hydrothermal minerals - Pilbara, W.A

- Initial study of mineralogy, detected by HyMap, associated with a gold prospect
- Airborne hyperspectral VIS-NIR-SWIR (126 bands)

Mallina gold lode

Airborne HYMAP – visible band composite
Hyperspectral analysis of hydrothermal minerals - Pilbara, W.A

- Initial study of mineralogy, detected by HyMap, associated with a gold prospect
- Airborne hyperspectral VIS-NIR-SWIR (126 bands)
- Followed up with ASD lab spectral analysis
- Focus on tourmaline
- Black tourmaline sample at “D” – species?

Mallina gold lode
Spectral analysis of a tourmaline field sample

- tourmaline a mineral group – potentially multiple species
- limited available spectral signatures
- lack of description of tourmaline spectral features
- further study required – spectral study of different tourmalines at ANU
- potential significance to mineral exploration - tourmaline composition can indicate proximity to ore-zones
Tourmaline Chemistry

Tourmaline is a group name for minerals that are the main host for the element boron in the Earth’s crust

\[ X \ Y_3 \ Z_6 \ B_3 \ Si_6 \ O_{27} \ (O,OH,F)_4 \]

\[ X = Na, \ Ca, \ K \]
\[ Y = Fe^{2+}, \ Mg^{2+}, \ (Al \pm Li), \ Fe^{3+}, \ Mn \]
\[ Z = Al^{3+}, \ Fe^{3+}, \ Cr^{3+}, \ Mg^{2+}, \ V^{3+} \]

Table 1. Cation chemistry for individual tourmaline species (after Dietrich, 1985)

<table>
<thead>
<tr>
<th>Tourmaline Species</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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<tr>
<td>Dravite</td>
<td>Na</td>
<td>Mg_3</td>
<td>Al_6</td>
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<tr>
<td>Schorl</td>
<td>Na</td>
<td>Fe(2+)_3</td>
<td>Al_6</td>
</tr>
<tr>
<td>Elbaite</td>
<td>Na</td>
<td>(Al,Li)_3</td>
<td>Al_6</td>
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<tr>
<td>Liddicoatite</td>
<td>Ca</td>
<td>(Li,Al)_3</td>
<td>Al_6</td>
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<td>Buergerite</td>
<td>Na</td>
<td>Fe(3+)_3</td>
<td>Al_6</td>
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<tr>
<td>Uvite</td>
<td>Ca</td>
<td>Mg_3</td>
<td>Al_5Mg</td>
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</table>
Selecting museum tourmaline samples for analysis

- 12 samples chosen from a large range of tourmaline species in ANU Geology museum
- range of colours
- already identified in within the dravite-schorl-elbaite composition field - most common species of greatest relevance to remote sensing and spectroscopic studies.
- analysed with a scanning electron microscope (microprobe) - to determine element abundance and number of ions
- Analytical Spectral Devices (ASD) analysis in the spectral range 350 to 2500 nm
## SEM Microprobe results on museum samples

A solid solution series exists between dravite and schorl & between schorl & elbaite

<table>
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<tr>
<th>Sample</th>
<th>T_br</th>
<th>24198</th>
<th>1934</th>
<th>R266</th>
<th>22619</th>
<th>1410</th>
<th>T_bl</th>
<th>22664</th>
<th>24512</th>
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<td>green</td>
<td>green</td>
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<td>dravite</td>
<td>dravite</td>
<td>schorl</td>
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<td>elbaite</td>
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<td>SiO₂</td>
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<td>36.20</td>
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<td>34.96</td>
<td>35.06</td>
<td>34.66</td>
<td>34.28</td>
<td>36.88</td>
<td>36.58</td>
<td>36.34</td>
<td>35.66</td>
<td>36.07</td>
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<td>1.10</td>
<td>0.26</td>
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<td>0.77</td>
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<td>0.58</td>
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<td>0.01</td>
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<td>Al₂O₃</td>
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<td>MgO</td>
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<td>0.02</td>
<td>0.05</td>
<td>0.03</td>
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<td>0.38</td>
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<td>0.38</td>
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<td>1.70</td>
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<td>H₂O*</td>
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<td>3.30</td>
<td>2.68</td>
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<td>3.15</td>
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<td>Total</td>
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<td>97.75</td>
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</table>

* By estimation; H₂O is estimated based on (F + OH) = 4 with F not more than 1/3 OH
Tourmaline museum samples – laboratory spectroscopy

- complex features across spectrum
- VNIR features mostly Fe2+ charge transfer energy transitions
- presence and position of SWIR features diagnostic of species
- examine relationships between spectral features and microprobe results
Spectral features in the 2100 to 2500 nm spectral range

- Four main features near 2200, 2245, 2300 and 2360 nm
- exact positions vary considerably
- Elbaite feature at 2173 nm

Al-OH, Mg-OH, Fe-OH, B-0, B-OH stretching vibrations

- wavelength positions are indicators of tourmaline species
- shifts due to Y-site substitutions
- 2200 nm shifts similar to white micas

\[
\begin{align*}
\text{Mg}^{2+} & \rightarrow \text{Fe}^{2+} = \lambda \text{ increase} \\
\text{Mg}^{2+} & \rightarrow \text{Al}^{3+} = \lambda \text{ decrease}
\end{align*}
\]
Spectral features in the 1700 to 2100 nm spectral range

- significant and unusual feature occurs at 2033 nm for dravite, 2050 nm for elbaite
- part of the spectrum is normally devoid of absorption features for most minerals
- AlOH or water feature?
- features varying in position around 1850 nm and 1930 nm are probably due to H₂O
- small feature at 1822 nm for dravite probably due to MgOH
Spectral features in the 1300 to 1500 nm spectral range

- fundamental stretching modes of two different OH groups
- feature at 1470 nm due to MnOH - wavelength position influenced by Fe content
- 1400 and 1430 nm positions influenced by Fe $+$ Mg
- small features - 1365 and 1306 nm for dravites, 1316 nm and 1248 nm for the Mn-rich elbaite
Airborne hyperspectral (HYMAP) mapping of tourmaline

- massive quartz-tourmaline veining – field sample spectra identified as schorl
- hydrothermal tourmaline alteration may be a proximity indicator for mineralization
- tourmaline abundance image derived by matching the 28 SWIR bands (of the corrected HyMap data) to field spectral data
- occurrence unknown at B
- can we identify tourmaline compositional variations using laboratory spectra?
Image mapping of tourmaline compositional variation

- largest wavelength shift near 2360 nm – dravite at 2353 nm, schorl at 2369 nm
- Matched Filter used on range 2287 – 2433 nm to generate abundance results using the laboratory end-members dravite and schorl
- results compared for each tourmaline pixel
- image pixels confirm wavelength shifts
- Mg-tourmaline may indicate exploration targets

(a)
Red = dravite
(Mg) rich
green = schorl
(Fe) rich

(b)
R = tourmaline
G = white mica
(low Al),
B = talc
Conclusions

- Wavelength positions of multiple absorption features are diagnostic for tourmaline species, e.g., near 2360, 2300, 2245, 2200, 2040, 1930, 1850, 1430, 1400nm.

- Presence of MgOH features are diagnostic for dravite (Mg-rich): 2320, 1822, 1365 and 1306 nm.

- MnOH related absorption features are diagnostic for elbaite - located at 2390, 2173, 1470, 1316 and 1248 with a Mn$^{3+}$ feature at 526 nm.

- Fe related features appear at 720 and 1100 nm.

- Based on the laboratory study, the band positions for the field spectra at 2204 nm, 2244 nm and 2366 nm identify this tourmaline as schorl.

- The 2360 nm absorption feature is the most useful for hyperspectral remote sensing due to the wide range of position variation.

- Tourmaline species spectroscopy results are important for mineral exploration studies both for field spectroscopy and airborne hyperspectral mapping.