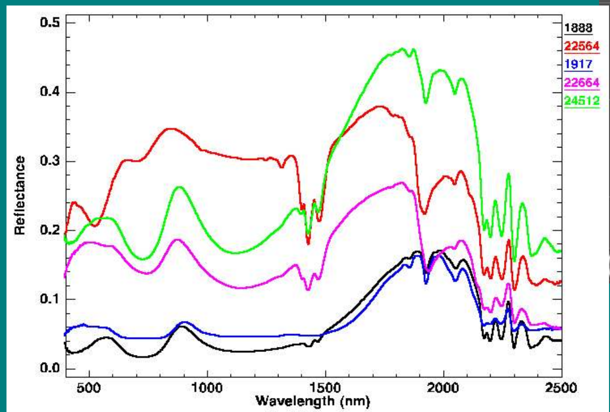
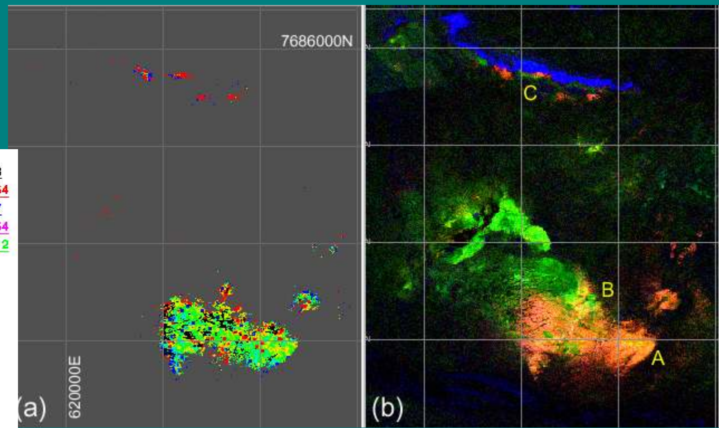
Laboratory and imaging spectroscopy of tourmaline – a tool for mineral exploration





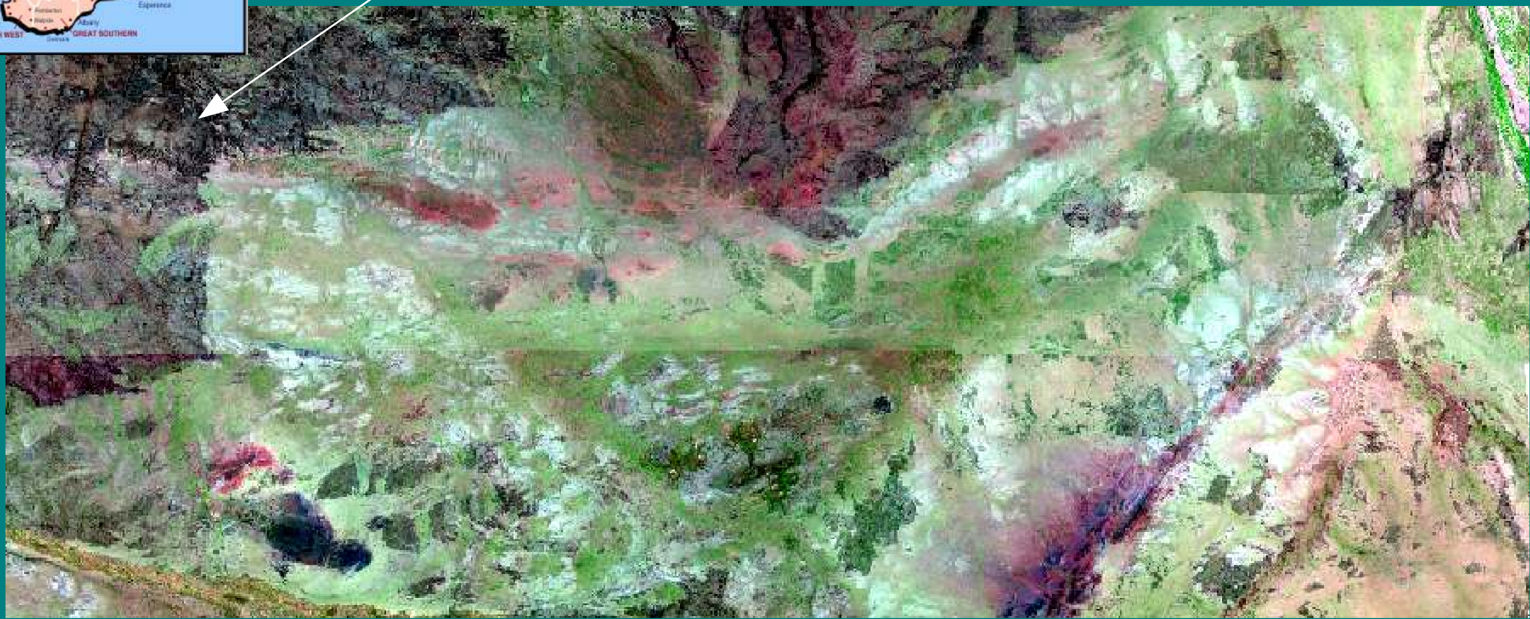
Phil Bierwirth
Defence Imagery and Geospatial Organisation (DIGO)

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

3 km

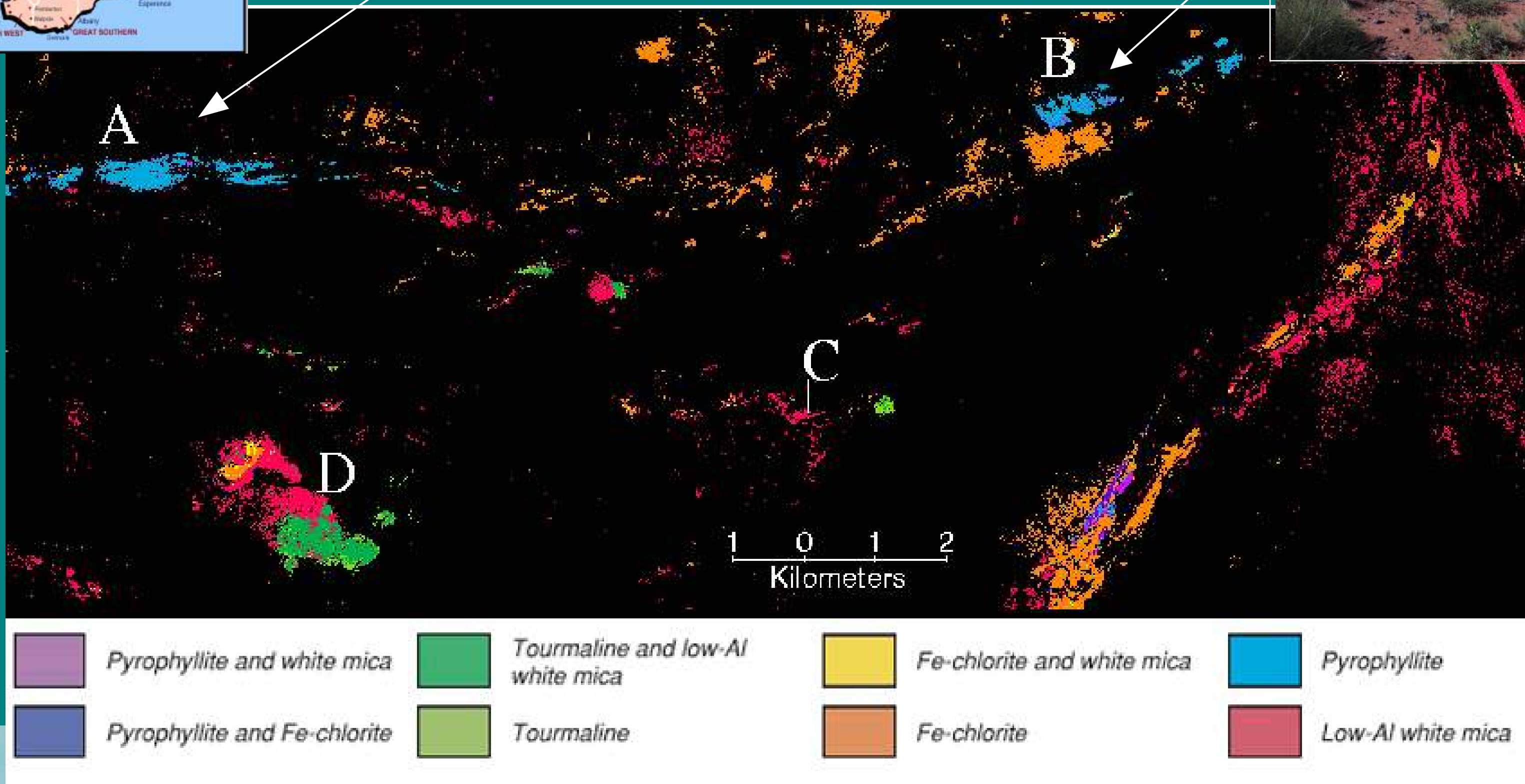


Airborne HYMAP – visible band composite

Hyperspectral analysis of hydrothermal minerals - Pilbara, W.A

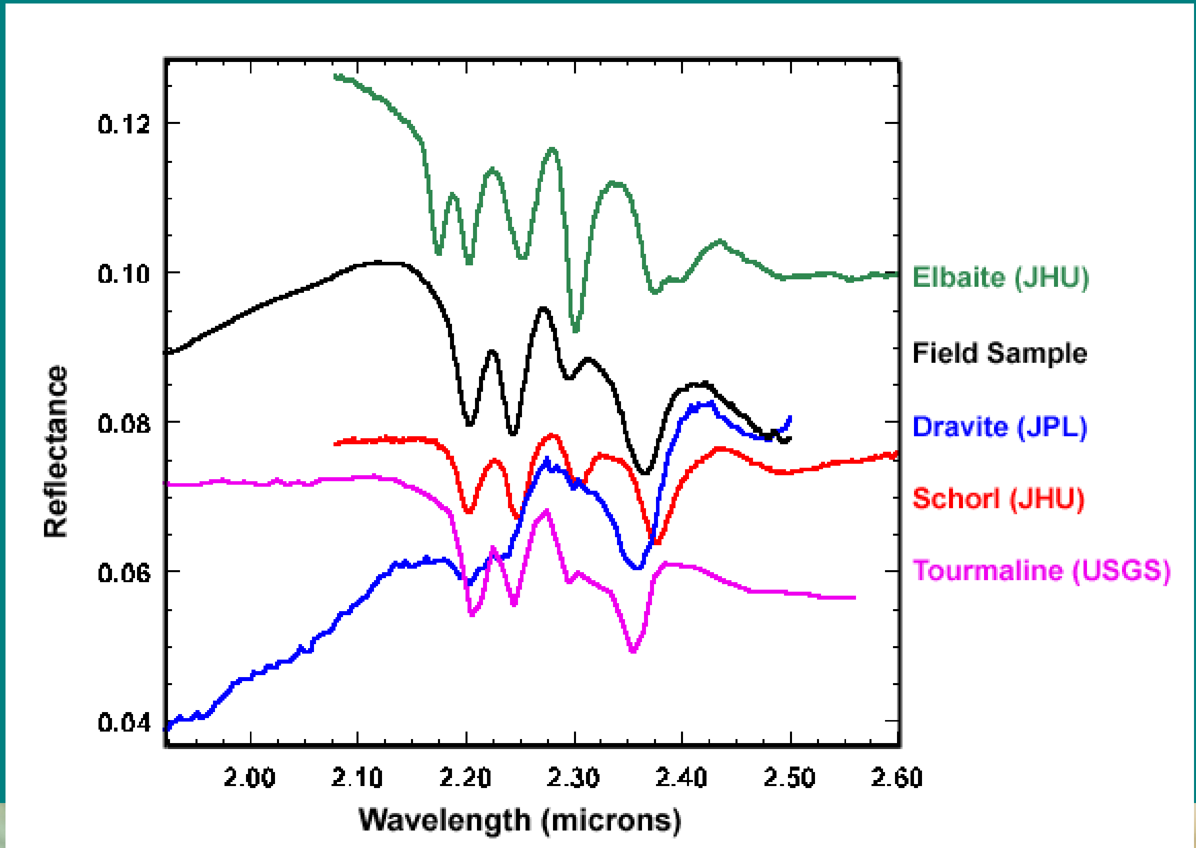
- Initial study of mineralogy, detected by HyMap, associated with a gold prospect
- Airborne hyperspectral VIS-NIR-SWIR (126 bands)
- followed up with ASD lab spectral analysis
- focus on tourmaline
- black tourmaline sample at “D” – species?

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)

Tourmaline Species	X	Y	Z
Dravite	Na	Mg_3	Al_6
Schorl	Na	$Fe(2+)_3$	Al_6
Elbaite	Na	$(Al,Li)_3$	Al_6
Liddicoatite	Ca	$(Li,Al)_3$	Al_6
Buergerite	Na	$Fe(3+)_3$	Al_6
Uvite	Ca	Mg_3	Al_5Mg

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

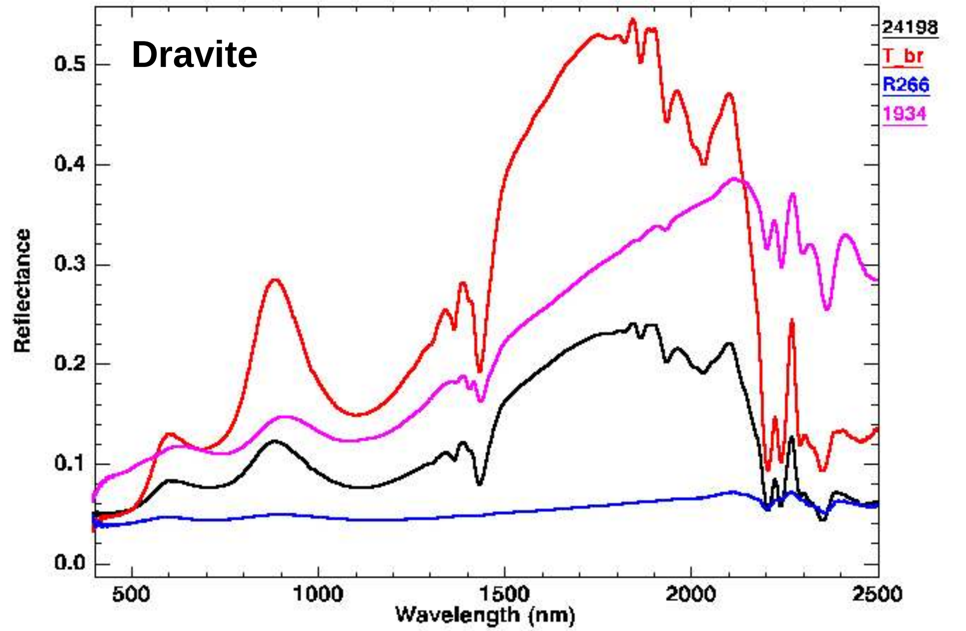
SEM Microprobe results on museum samples

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

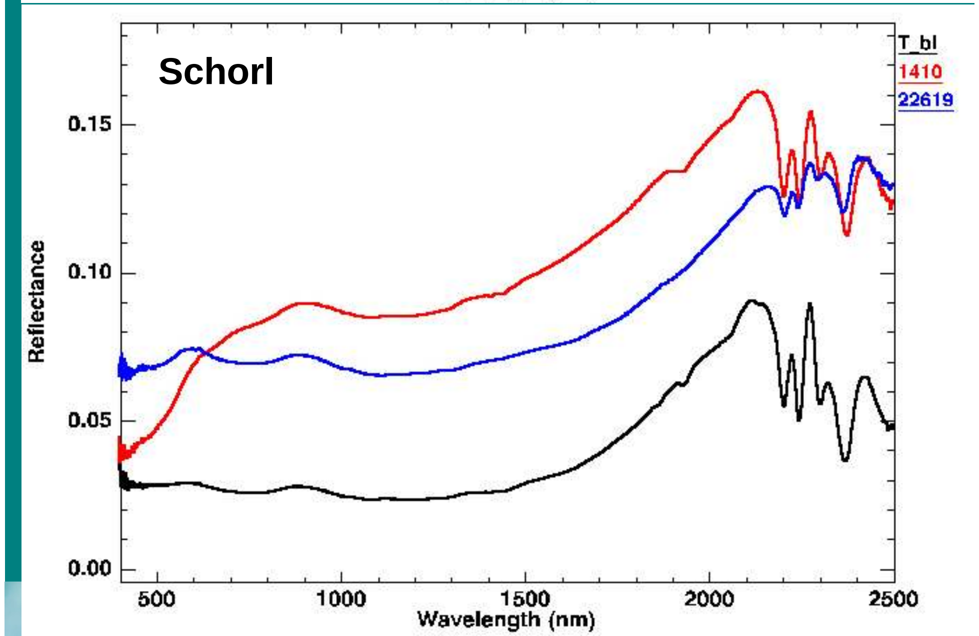
Sample	T_br	24198	1934	R266	22619	1410	T_bl	22664	24512	1888	1917	22564
Colour	brown	brown	black	black	black	black	black	green	green	green	blue	pink
Species	dravite	dravite	dravite	dravite	schorl	schorl	schorl	elbaite	elbaite	elbaite	elbaite	elbaite
SiO_2	36.55	36.20	34.99	34.96	35.06	34.66	34.28	36.88	36.58	36.34	35.66	36.07
TiO_2	0.97	1.10	0.26	0.41	0.77	0.93	0.58	0.02	0.01	0.08	0.00	0.00
B_2O_3*	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.63
Al_2O_3	31.73	31.22	33.70	29.12	30.78	32.58	33.56	40.16	39.71	37.29	37.07	40.62
FeO	0.49	0.57	8.61	8.41	10.99	10.37	12.51	1.91	2.54	4.98	4.51	0.19
MnO	0	0.03	0.14	0.10	0.27	0.10	0.06	1.34	1.32	1.20	1.64	2.32
MgO	11.26	11.13	4.98	7.43	5.27	4.49	2.49	0.05	0.00	0.18	0.00	0.00
CaO	0.39	0.53	0.54	0.13	0.14	0.47	0.19	0.06	0.09	0.26	0.23	0.13
Na_2O	2.74	2.64	1.83	2.78	2.58	2.01	1.96	2.51	2.18	2.67	2.71	2.03
K_2O	0	0.05	0.02	0.05	0.03	0.01	0.07	0.22	0.00	0.04	0.00	0.00
Li_2O	-	-	-	-	-	-	-	-	-	-	-	-
F	0.05	0.35	0.75	1.88	0.38	0.98	0.38	0.93	1.14	1.70	2.13	1.05
H_2O*	3.65	3.30	3.30	2.68	3.41	3.16	3.40	3.28	3.15	2.85	2.63	3.18
Total	98.46	97.75			100.3	100.4	100.1	97.99	97.35	98.22	97.21	96.22

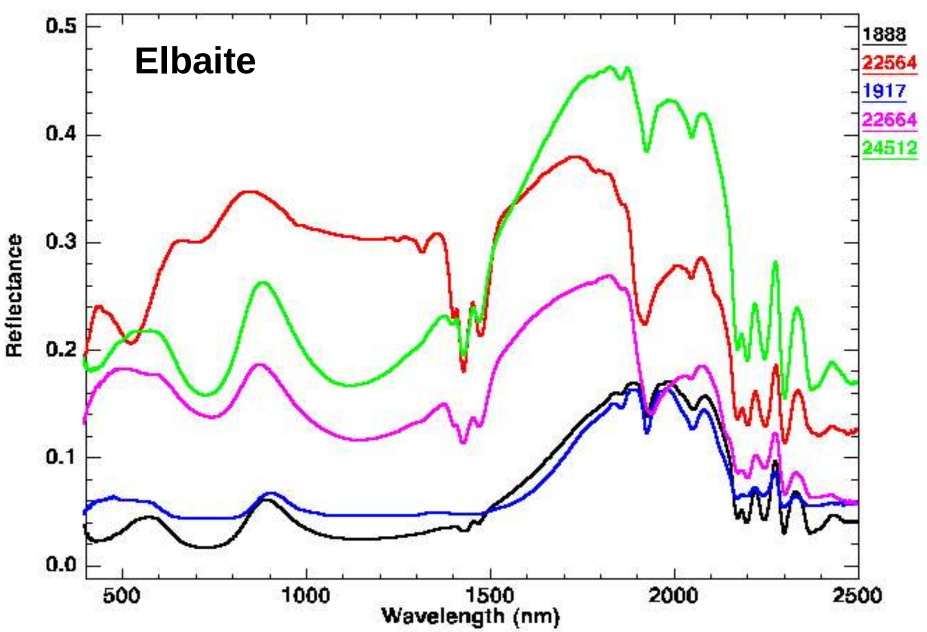
* By estimation; H_2O is estimated based on (F + OH) = 4 with F not more than 1/3 OH

Tourmaline museum samples – laboratory spectroscopy

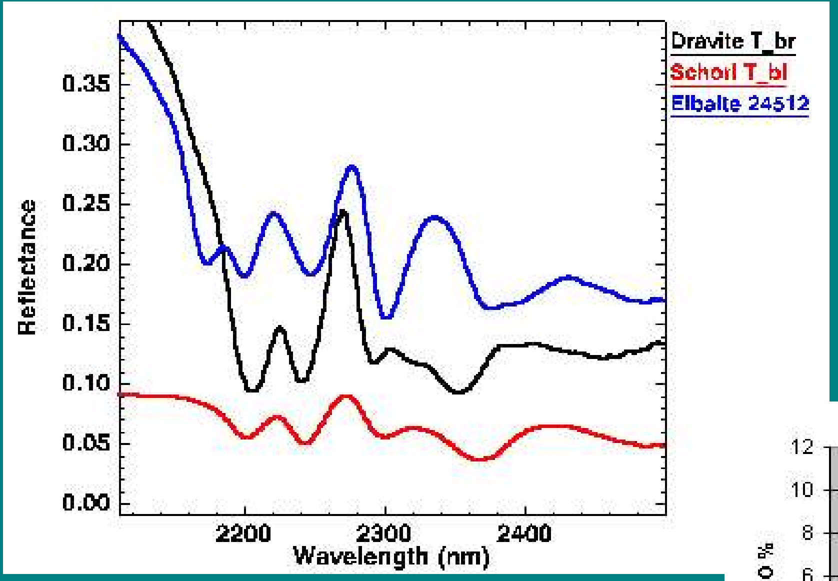


- complex features across spectrum
- VNIR features mostly Fe2+ charge transfer energy transitions
- presence and position of SWIR features diagnostic of species
- examine relationships betweens spectral features and microprobe results





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

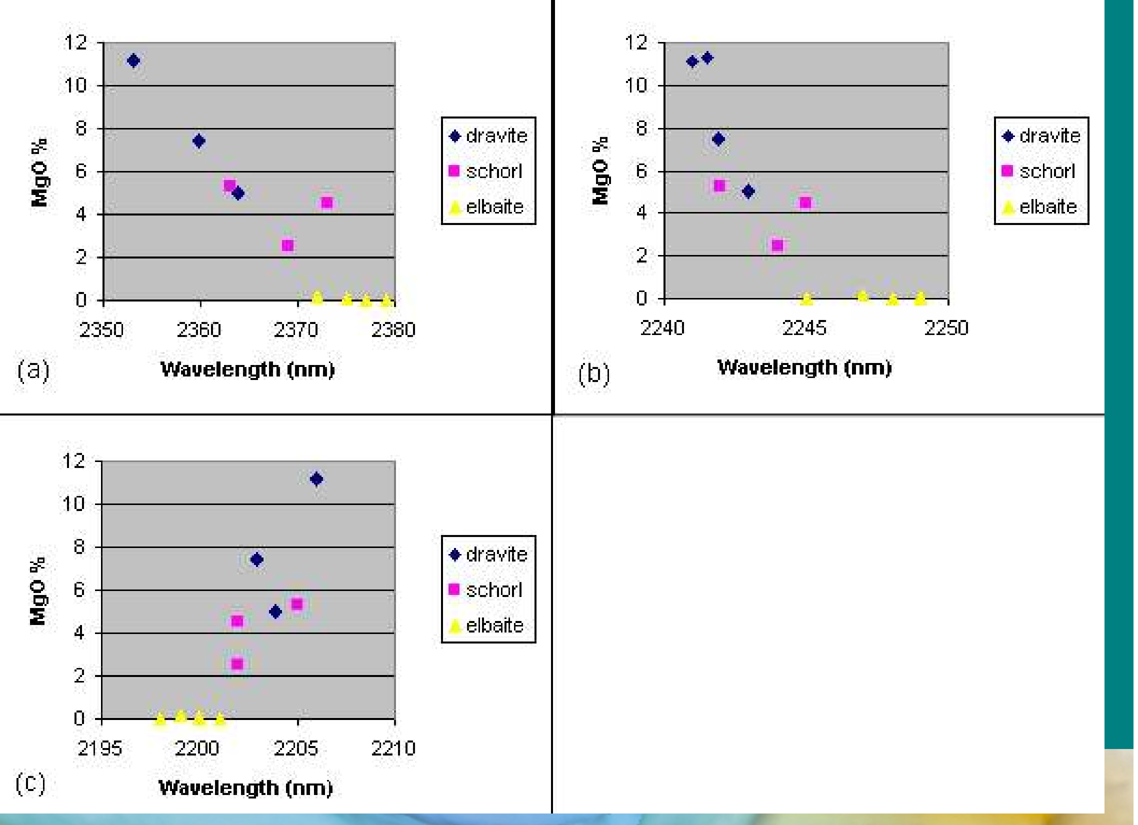
Al-OH, Mg-OH, Fe-OH, B-0,B-OH stretching vibrations

- wavelength positions are indicators of tourmaline species

- shifts due to Y-site substitutions

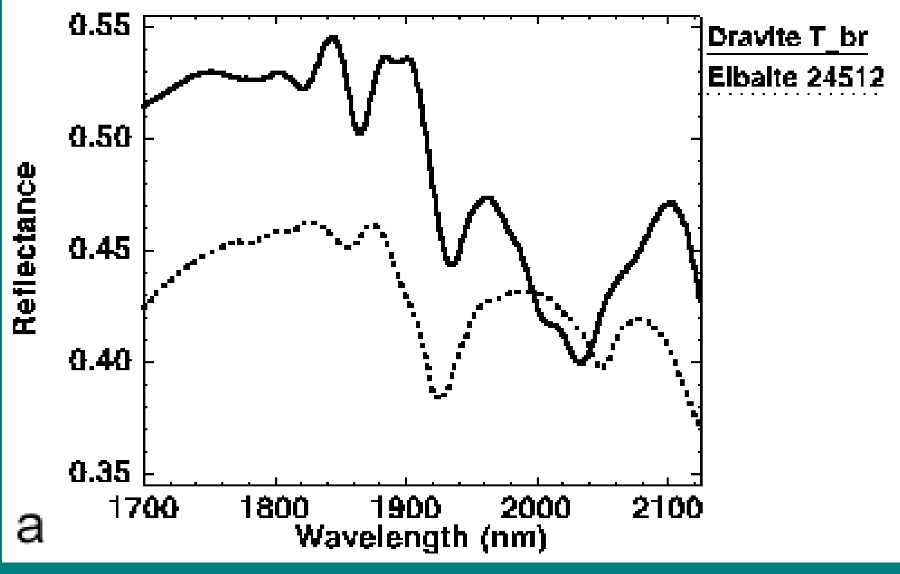
- 2200 nm shifts simliar to white micas

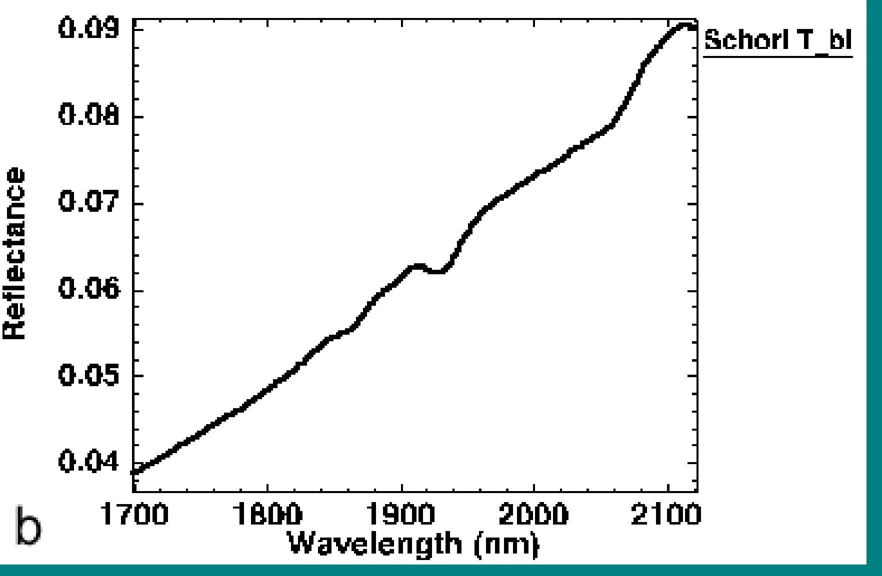
Mg^{2+} → Fe^{2+} = λ increase
Mg^{2+} → Al^{3+} = λ decrease



Spectral features in the 1700 to 2100 nm spectral range

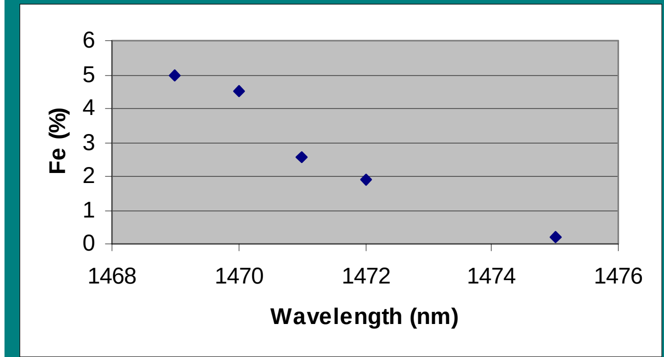
- significant and unusual feature occurs at 2033 nm for dravite, 2050 nm for elbaite
- part of the spectrum is normally devoid of absorption features for most minerals
- AlOH or water feature?
- features varying in position around 1850 nm and 1930 nm are probably due to H_2O
- small feature at 1822 nm for dravite probably due to MgOH

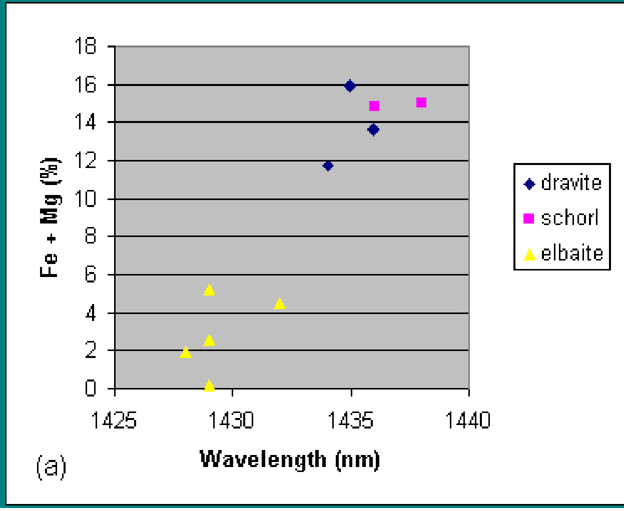


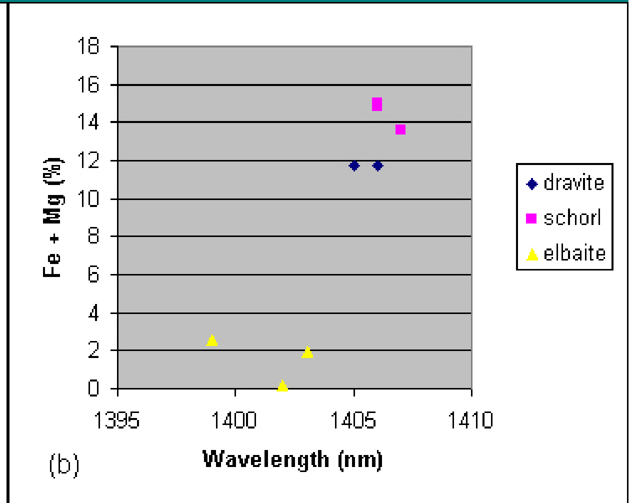


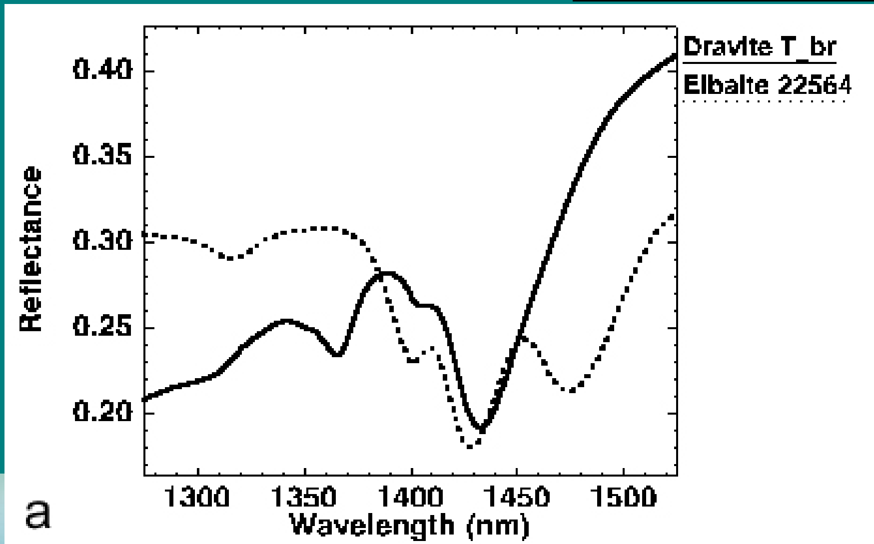
Spectral features in the 1300 to 1500 nm spectral range

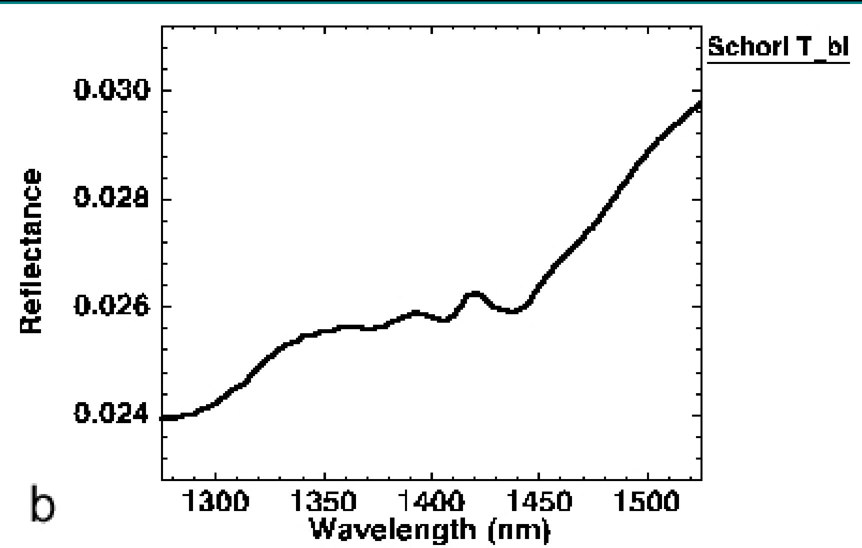
- fundamental stretching modes of two different OH groups
- feature at 1470 nm due to MnOH - wavelength position influenced by Fe content
- 1400 and 1430 nm positions influenced by Fe + Mg
- small features - 1365 and 1306 nm for dravites , 1316 nm and 1248 nm for the Mn-rich elbaite



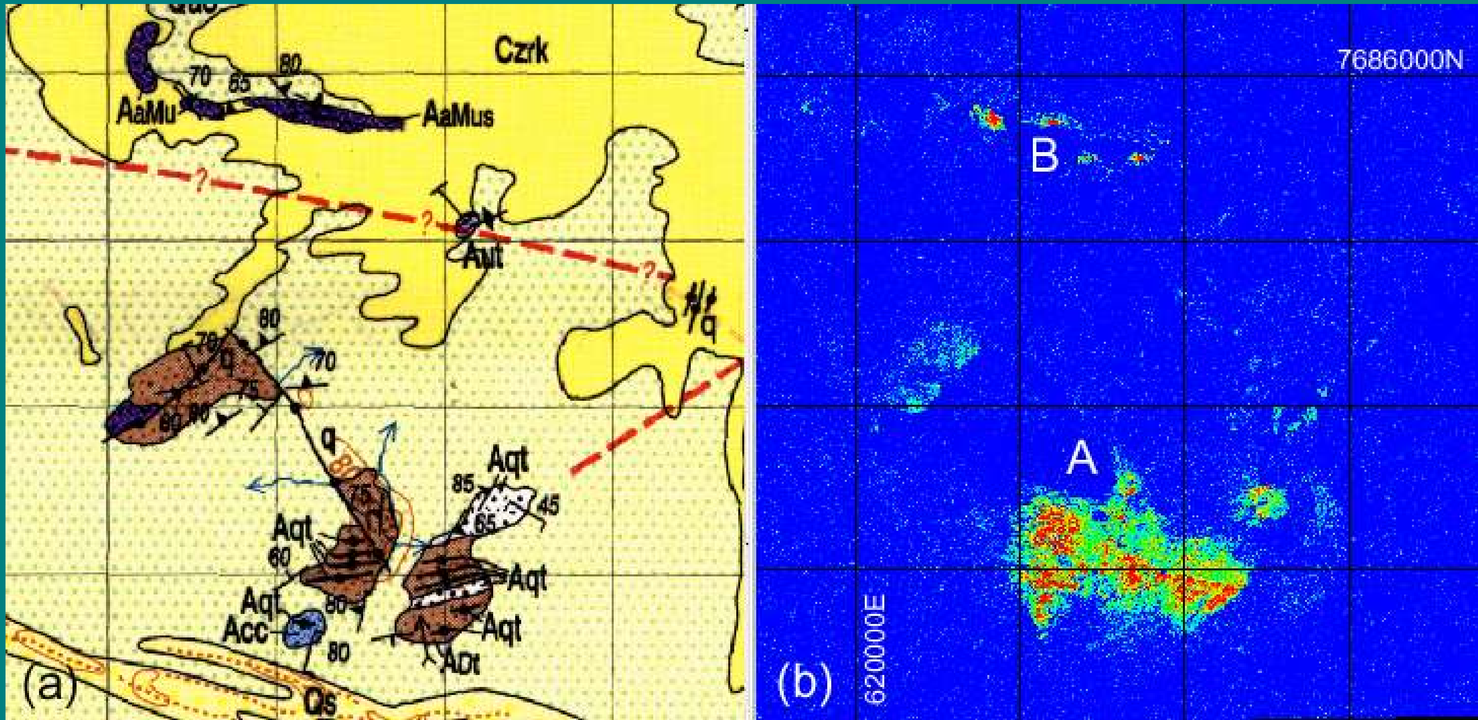








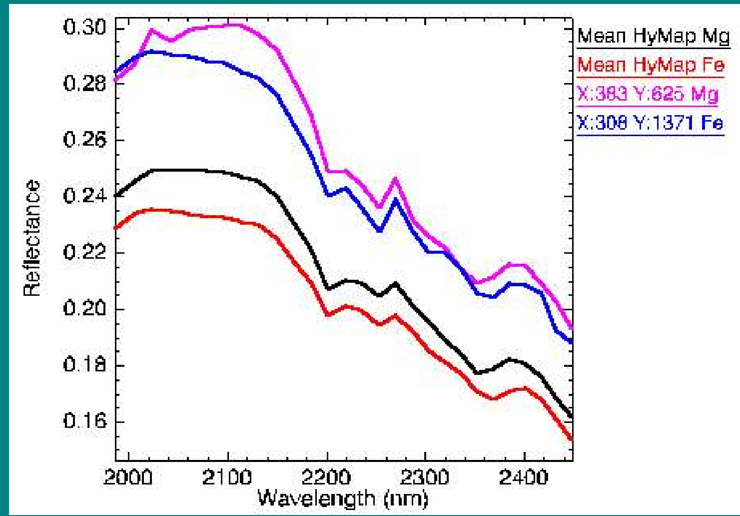
Airborne hyperspectral (HYMAP) mapping of tourmaline



- 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
- occurence unknown at B
- can we identify tourmaline compositional variations using laboratory spectra?

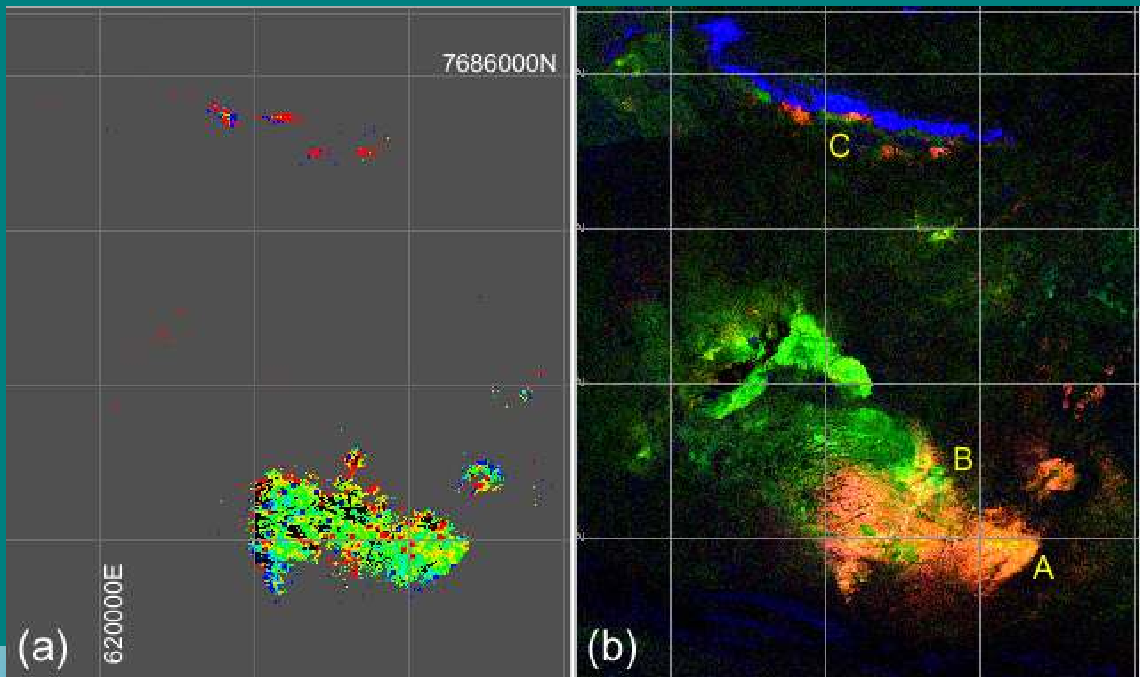
Image mapping of tourmaline compositional variation

- largest wavelength shift near 2360nm – 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.