The Secret Life of Kyanite

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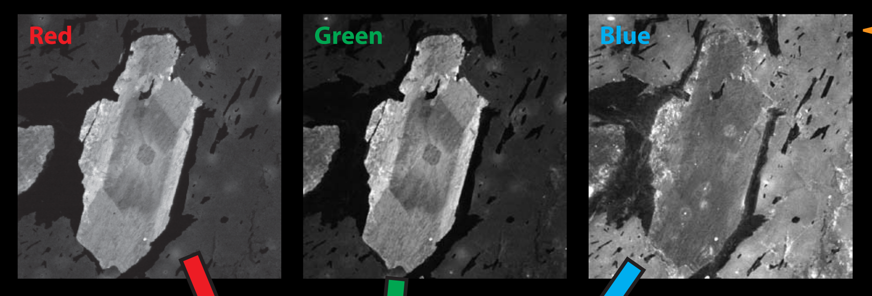
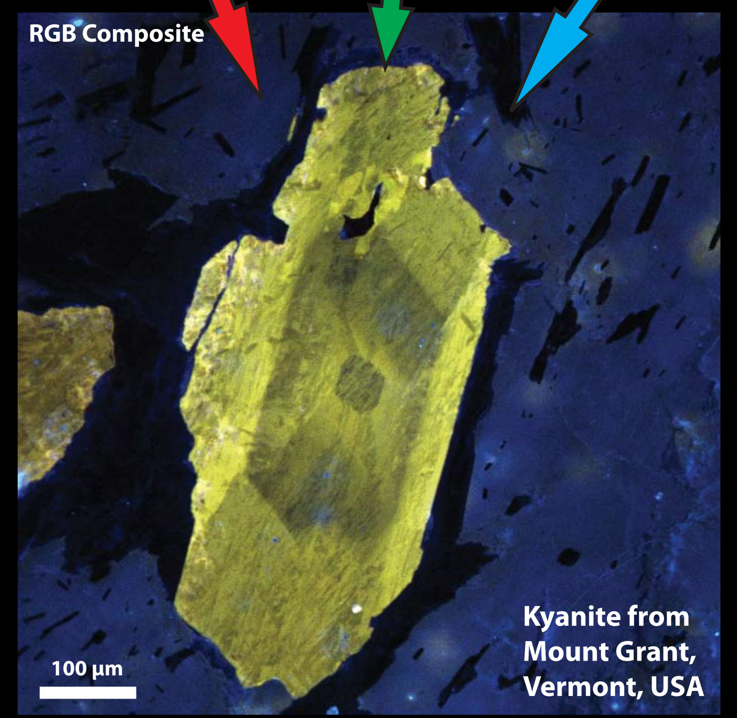
Introduction

Kyanite from lower amphibolite to upper eclogite facies conditions from a variety of terranes has been analyzed by cathodoluminescence (CL) to characterize trace element zoning geometries. All studied kyanite clearly reveal trace element zoning patterns in CL, which grouped into four main types: chemomorphs, sector zoning, growth zoning, and irregular zoning (flame-like or curved, resorption or overgrowth, and stripey or boxy). This poster details methods of characterization with inherent pitfalls, correlation with trace elements, and potential applications of trace element zoning data.

Gatan MonoCL3 vs. Luminoscope

Gatan MonoCL3





Gatan MonoCL3

Red, green and blue color filtered images, displaying submicron detail, are collected individually and combined to produce a RGB composite, false color image.

ELM-3R Luminoscope

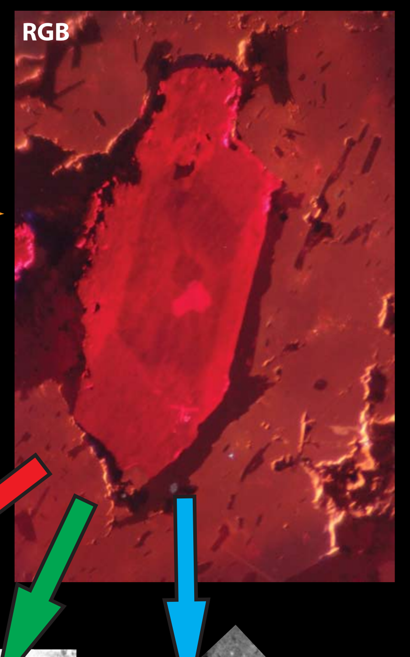
True luminescent color images are split into red, green and blue color channels to produce images corresponding with the red, green and blue luminescence.

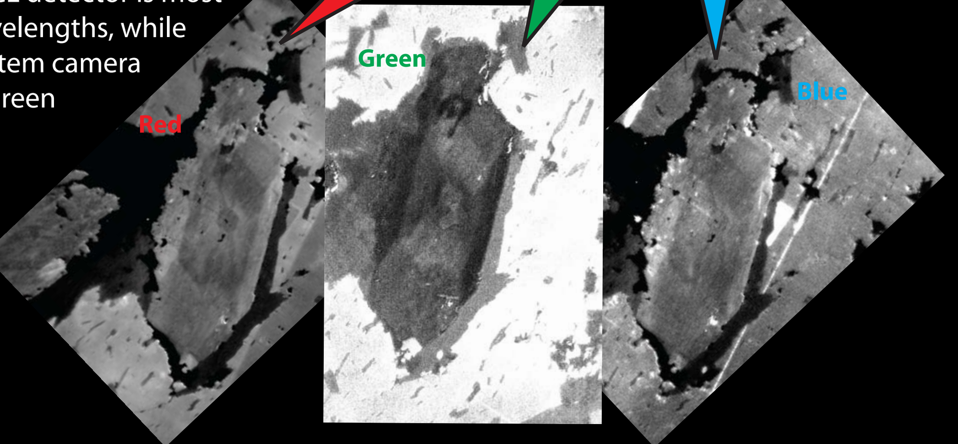
Method Comparison

Red and blue luminescence images correlate from both CL detection methods, while green images do not correlate. Differences in the green images are due to contamination of the green signal by other wavelengths. Analysis of the color filters and detection windows for the CL detection methods are compared below. It must also be noted that the SEM CL detector is most sensitive to blue wavelengths, while the luminoscope system camera is most sensitive to green wavelengths.

Red=Red
Green≠Green
Blue≈Blue

ELM-3R Luminoscope

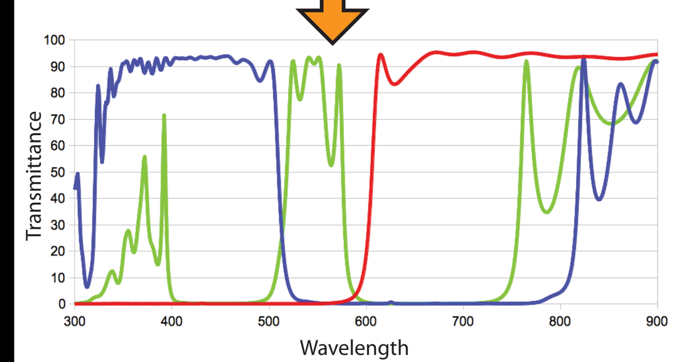




Filter Analysis

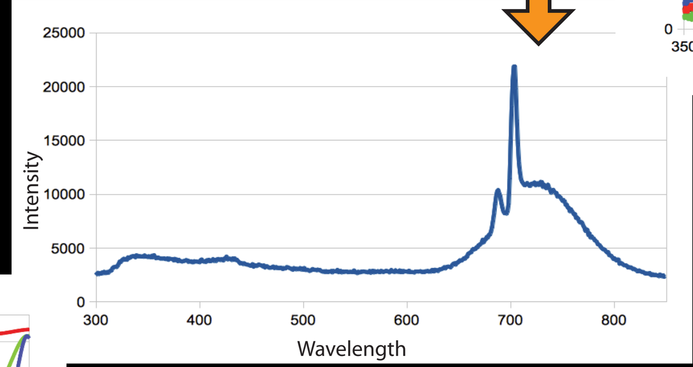
SEM CL Filter Analysis

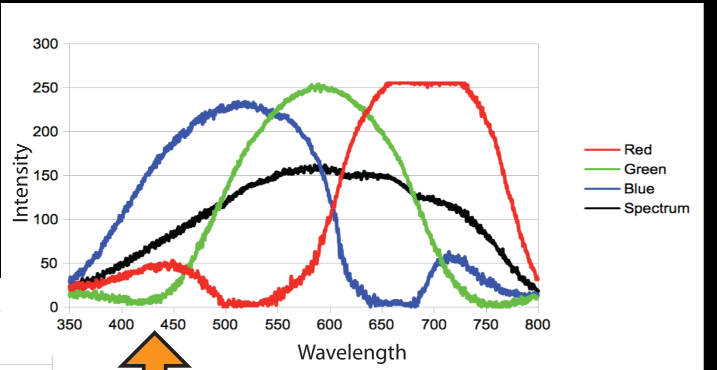
Photospectrometer analysis of the red, green and blue color filters, represented by the red, green and blue lines, respectively. Displayed are the wavelengths of light transmitted and absorbed by each filter. Both the red and the blue filters function well, allowing just the desired wavelengths to transmit, with only minor unwanted transmittance windows. Conversely, the green filter contains transmittance windows in UV, blue, red and IR wavelength regions, allowing unwanted wavelengths to contaminate the green signal. In the case of kyanite, luminescent wavelength emission is much greater in the blue and especially red wavelengths such that the green signal becomes overwhelmed. As seen above, the green filtered image becomes a product of unwanted wavelengths.



Characteristic Kyanite Spectrum

Characteristic CL wavelength spectral analysis of kyanite displaying the relative prominence of red, green and blue wavelengths. The two sharp peaks near 700 nm are attributed to Cr, while the broad peaks in the red and blue correlate to other CL activators.





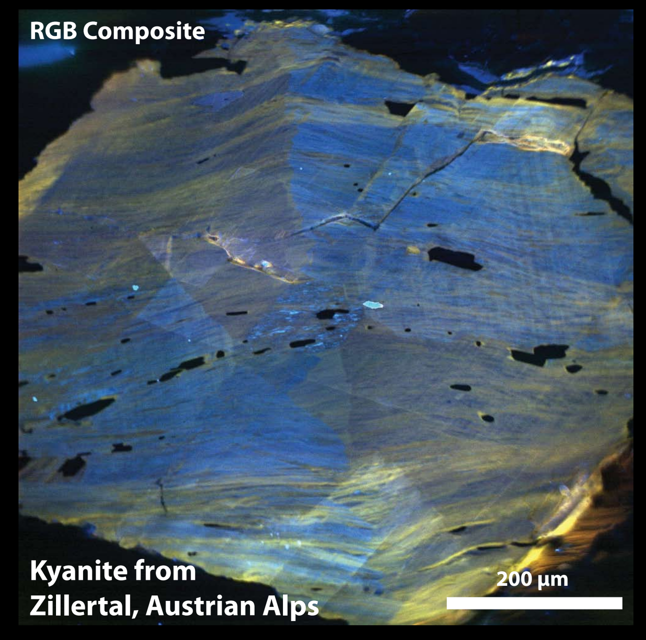
Luminoscope Camera Filter Analysis

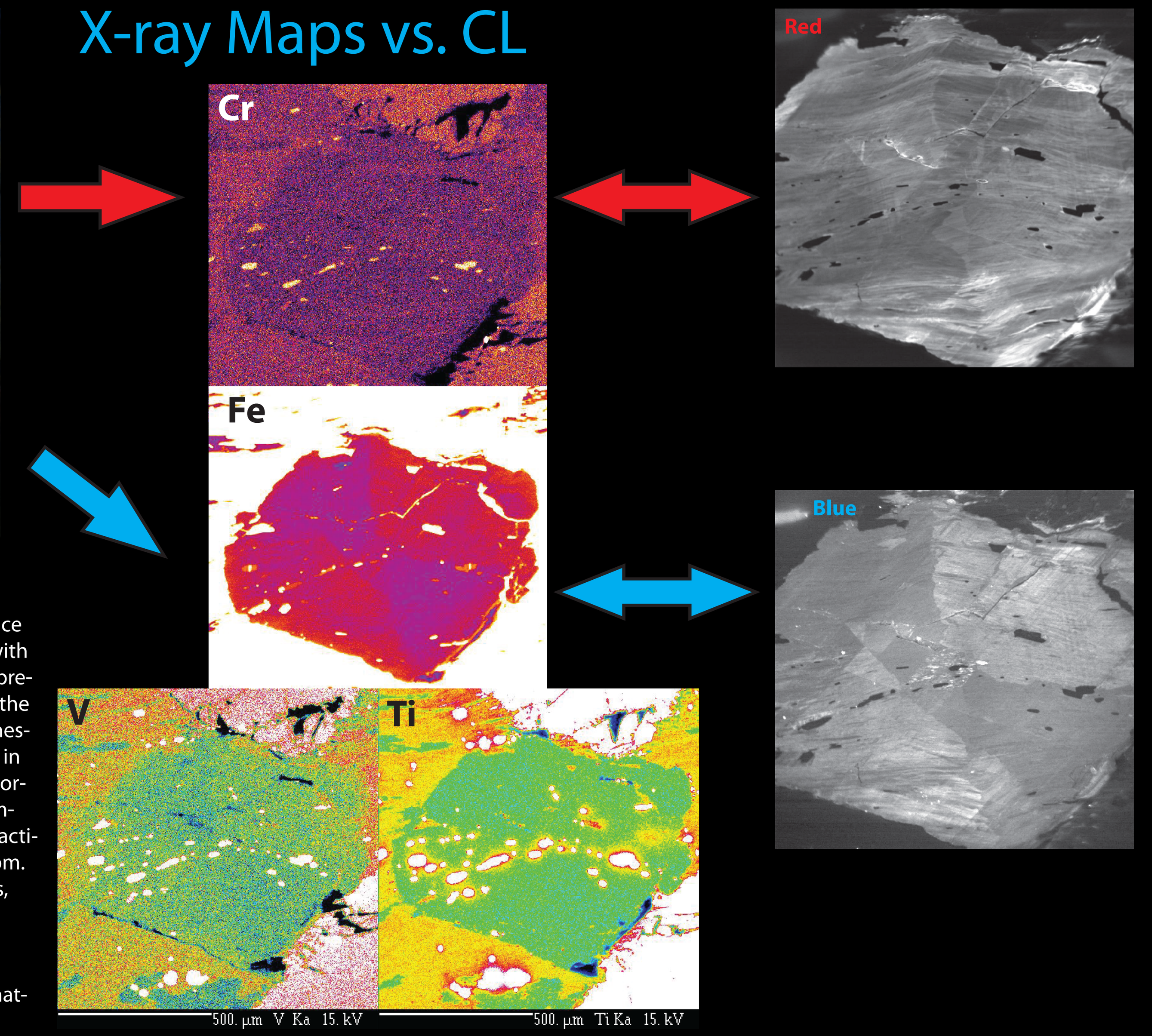
Luminoscope camera images of the visible spectrum are split into color channels and plotted versus wavelength to access the color response of the camera color filters, represented by red, green and blue curves above. Red, green and blue peaks are distinct, producing images of each wavelength, yet the color peaks also overlap and allow contamination from unwanted wavelengths. The spectrum curve displays total camera response.

Filter Comparison

Red luminescent images appear the same using both filter methods. Sensitivity of the SEM CL detector to blue wavelengths as well as the broad blue peak of the luminoscope camera, allowing unwanted wavelength contamination, results in more accurate blue images from the SEM CL system. Similarly, increased sensitivity in the green wavelengths, broader wavelength inclusion in the green and yellow wavelength regions and significant transmittance windows in unwanted wavelengths results in more accurate images of green luminescence by the luminoscope system.

Trace Element Correlation
X-ray Maps vs. CL

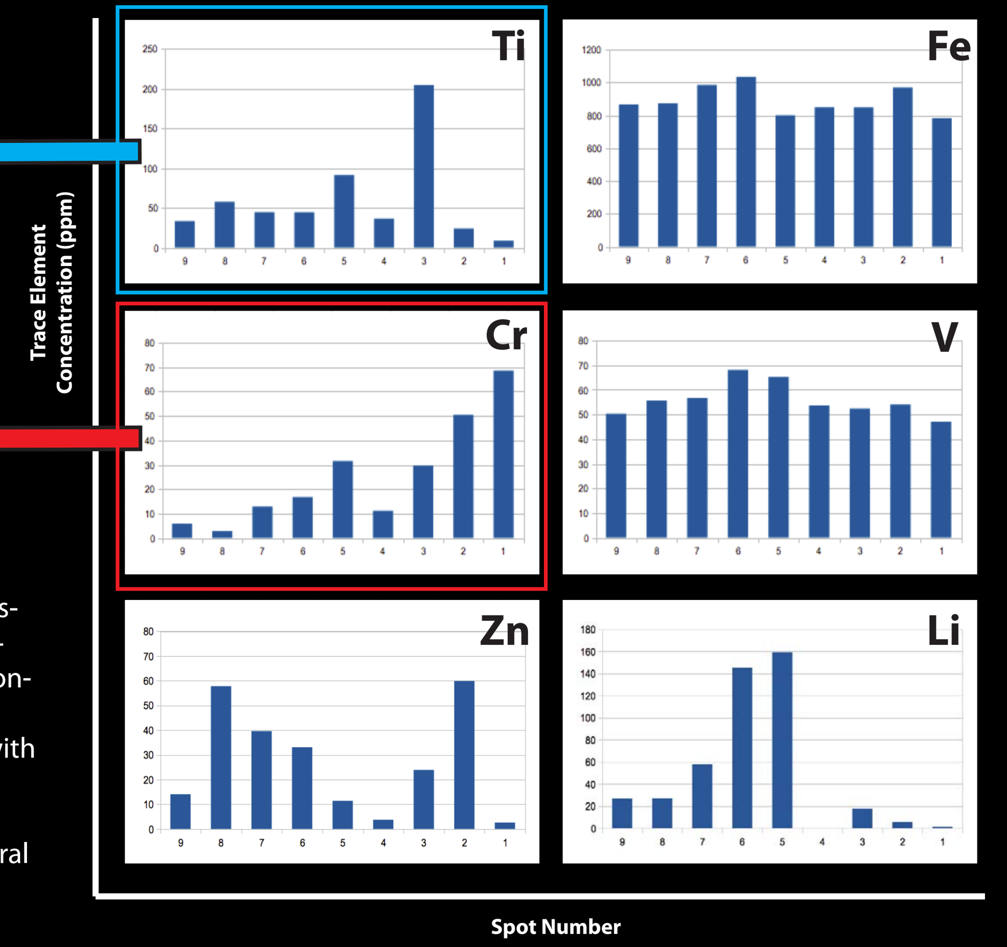




X-ray Maps vs. CL

X-ray maps of kyanite are correlated with specific luminescence colors. The Cr map is correlated with red luminescence from cross grain bands. Banding in this kyanite correlates with biotite and chlorite matrix foliation and is interpreted to represent chemomorphs of matrix mineral foliation replaced by the kyanite. X-ray maps of Fe, V and Ti correlate with blue luminescence. Both luminescence and X-rays display sector zoning in this kyanite. X-ray maps and CL images correlate well, but correlation is limited by the resolution of X-ray mapping parameters and the trace element concentrations. Trace element activators range in concentration from tens to thousands of ppm. Fe in this sample correlates well due to high concentrations, whereas Ti and V display weak correlation. Trace element zoning can be examined at much higher spatial resolution, hundreds of nanometers scale, and at lower trace element concentrations, as low as several ppm, as are reasonably unattainable by X-ray methods.

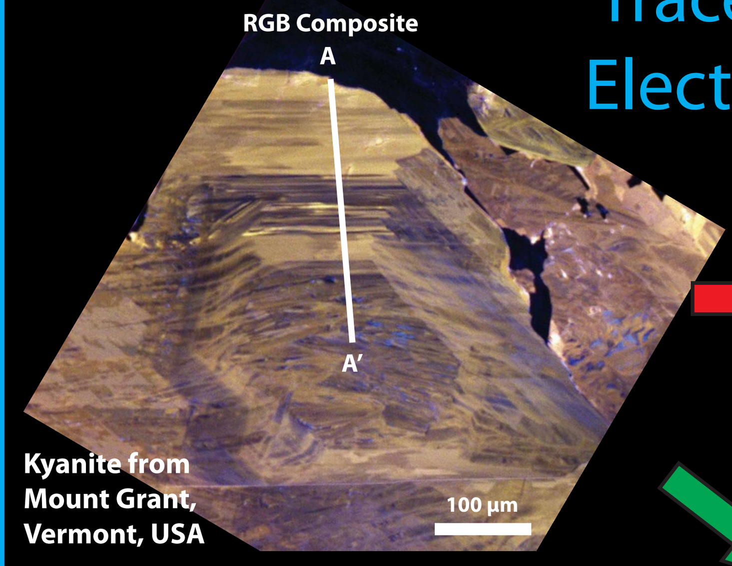
Trace Element Correlation
LA-ICPMS vs. CL

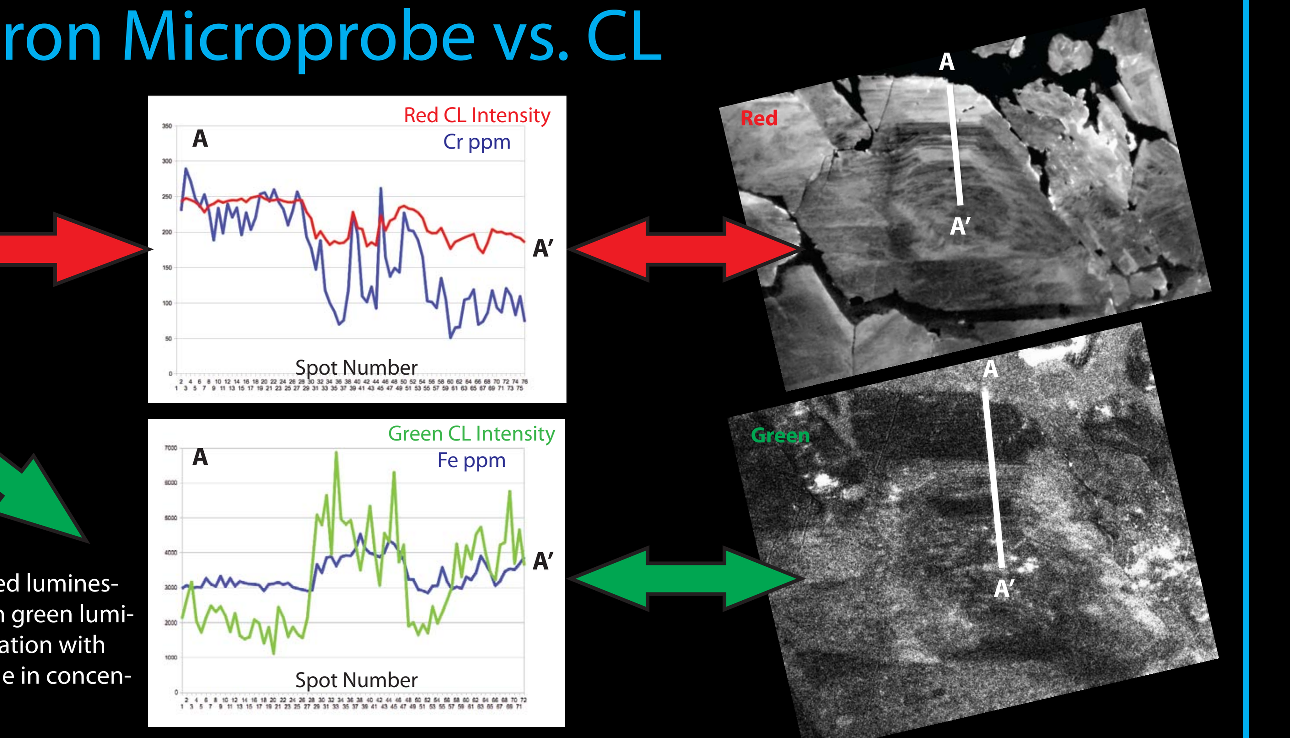


LA-ICPMS vs. CL

LA-ICPMS spot analysis provide broad correlation between individual CL luminescence zones and trace element concentrations. Red luminescence directly correlates with Cr concentrations. Bright, light blue luminescence correlates with Ti concentrations. While there is Ti distributed throughout the kyanite, the light blue zones have significantly higher concentrations. Correlations of Fe, V, Zn, and Li with luminescence are unclear. Generally, Fe is associated with suppression or extinguishing luminescence signal in minerals, and appears to correlate weakly with darker blue bands in the above kyanite. X-ed out laser ablation spots mark mineral inclusions in the kyanite analyzed by LA-ICPMS.

Trace Element Correlation
Electron Microprobe vs. CL

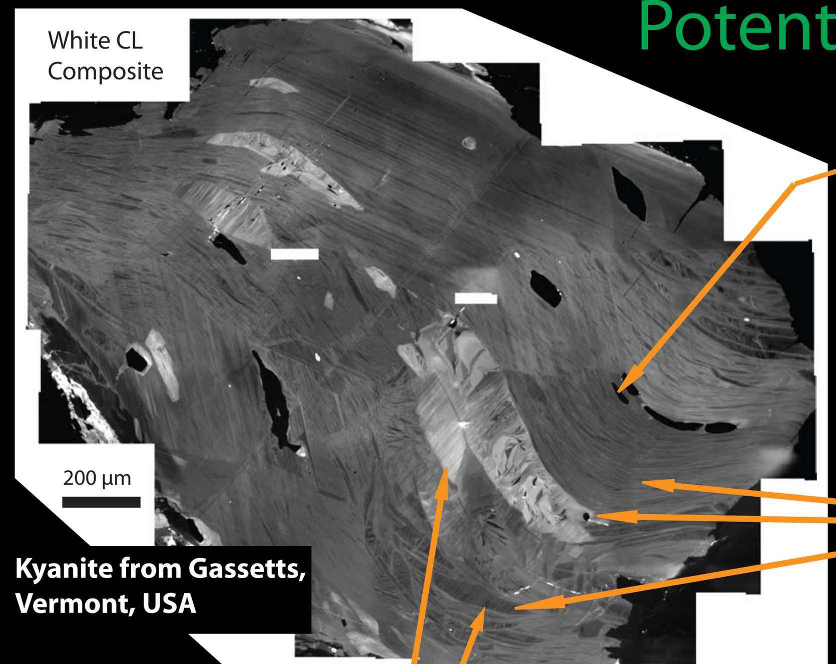




Electron Microprobe vs. CL

Cr spot analysis from the electron microprobe correlate well with red luminescence, as seen above. Additionally, Fe concentration correlates with green luminescence in this sample. V, not displayed above, shows weak correlation with blue luminescence. Major activating trace elements in kyanite range in concentration from tens to thousands of ppm.

Potential Applications



Metamorphic History
Textures

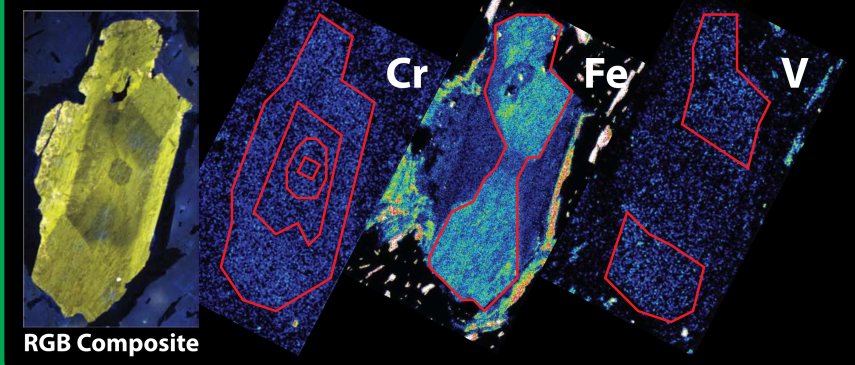
Replacement and preservation of matrix fabrics, especially deformation fabrics, as seen by trace element CL, helps constrain the timing of kyanite growth to pre, syn or post deformation events. This timing information helps to reaffirm or add constraint to pressure, temperature time path evolutions for rocks and terranes.

Metamorphic History
Mineral Phases

Replacement and preservation of matrix mineral phases and habits helps constrain the timing and type of metamorphic reactions progressing during metamorphism. Phases not present in the matrix assemblage may be preserved as chemomorphs and incorporated into a temperature, pressure, time path.

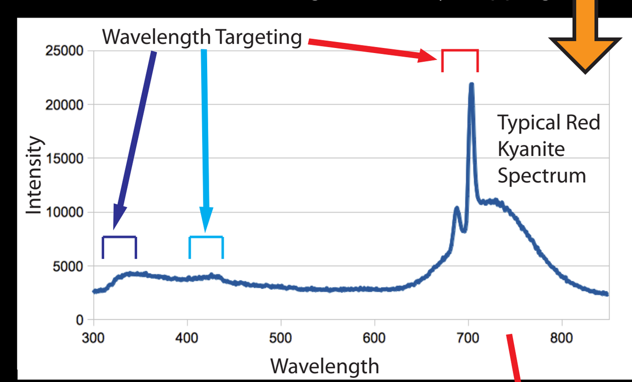
Trace
Element Mobility

CL activation of trace elements reveals relic mineral shapes, or chemomorphs, as seen above, and multiple complex zoning geometries, as seen below. Preservation of chemomorphs with sharp boundaries implies trace element immobility and incorporation during breakdown reactions producing kyanite. Multiple, overlapping zoning geometries indicate that some trace elements are mobile, while other trace elements are immobile during kyanite growth, and that trace elements are incorporated by multiple growth mechanisms. Thus, the cathodoluminescence provide information about trace element mobility during metamorphism.



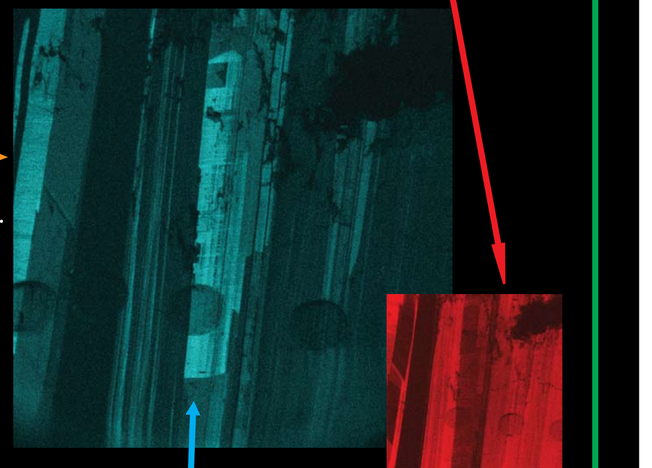
Wavelength Targeting

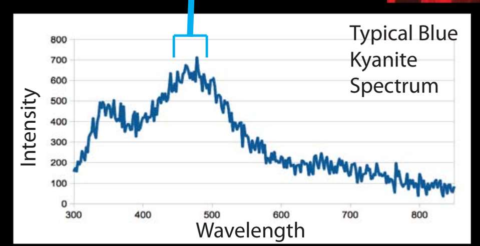
Luminescence colors can be directly related to specific trace elements. For example, there is a strong correlation between Cr and red luminescence. By targeting the wavelengths in the red attributed to Cr, a luminescence map equivalent to an X-ray map is produced. Wavelength targeting and mapping takes a fraction of the time, is more sensitive to compositional variation, has higher spatial resolution and causes less beam damage than X-ray mapping.



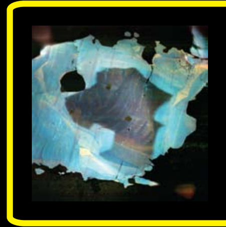
Trace Element CL Map

Wavelength targeting produces a correlated CL to trace element map, analogous to an X-ray map. This is accomplished on the Gatan system by tuning the diffraction grating to a specific wavelength, opening the light slits to capture the desired range of wavelengths and imaging through the diffraction grating. The map to the right displays light blue wavelengths (~469±15 nm) and displays high Ti concentration bands. Similar images are obtained using blue color filters. The difference between color filter images and wavelength targeting is that the blue color filters include all wavelengths in the blue region, a range of several hundred nm, while wavelength targeting are limited to a range of 30 nm in width. This narrow range restricts the wavelengths to those correlated with specific trace element activators.





Acknowledgements



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