Cathodoluminescence of Sierran Feldspars: Crystallization Histories, Mixed Populations, and Alteration

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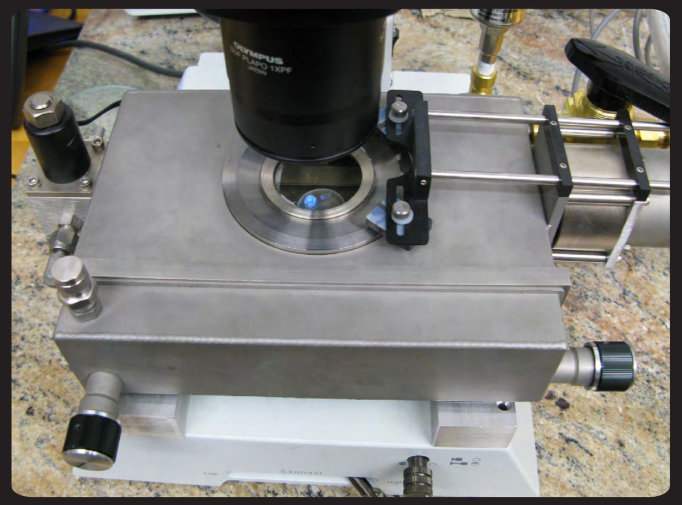
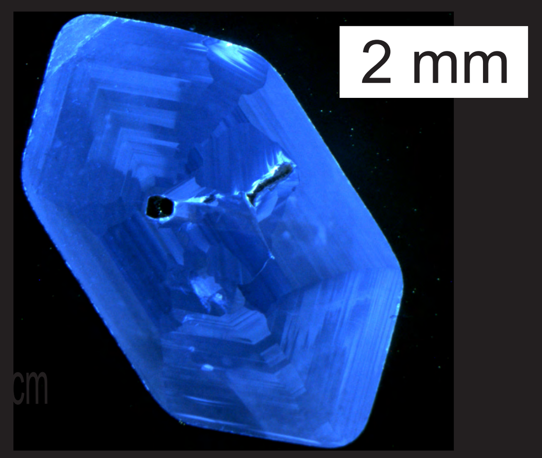
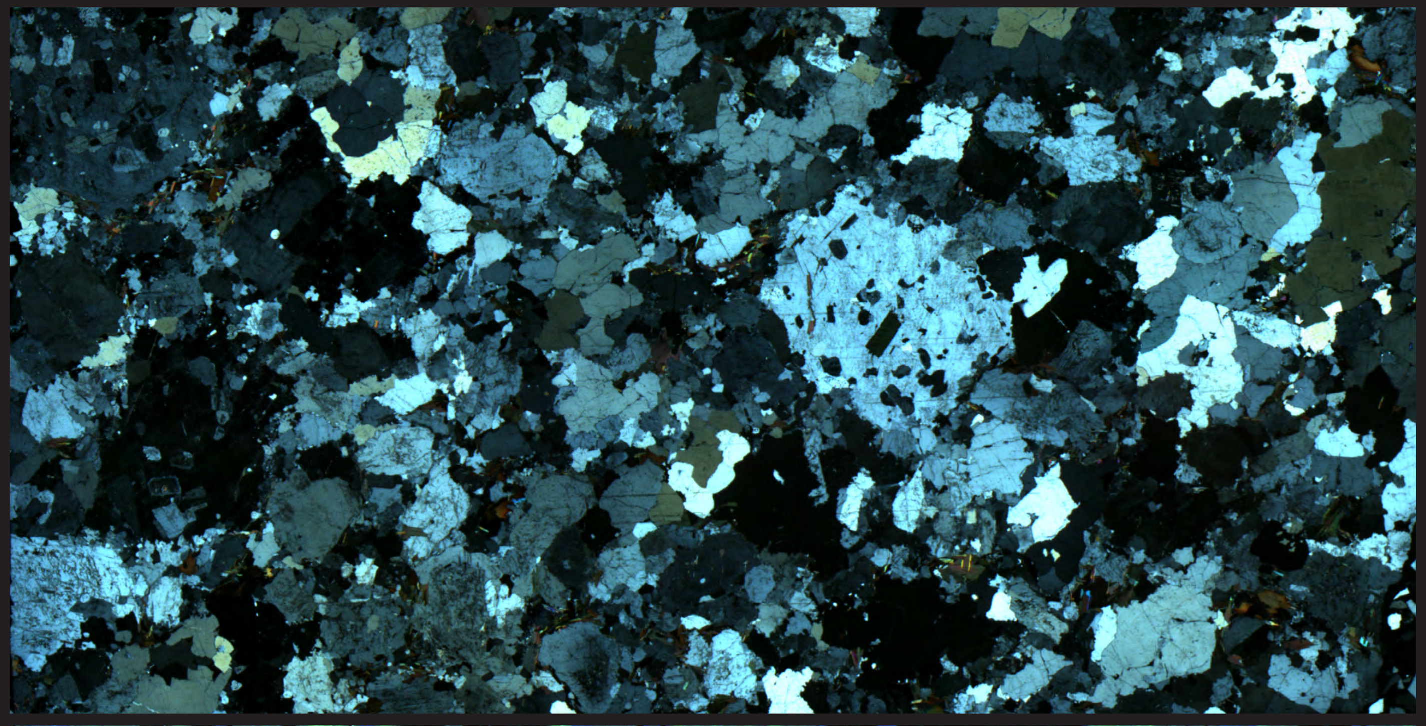
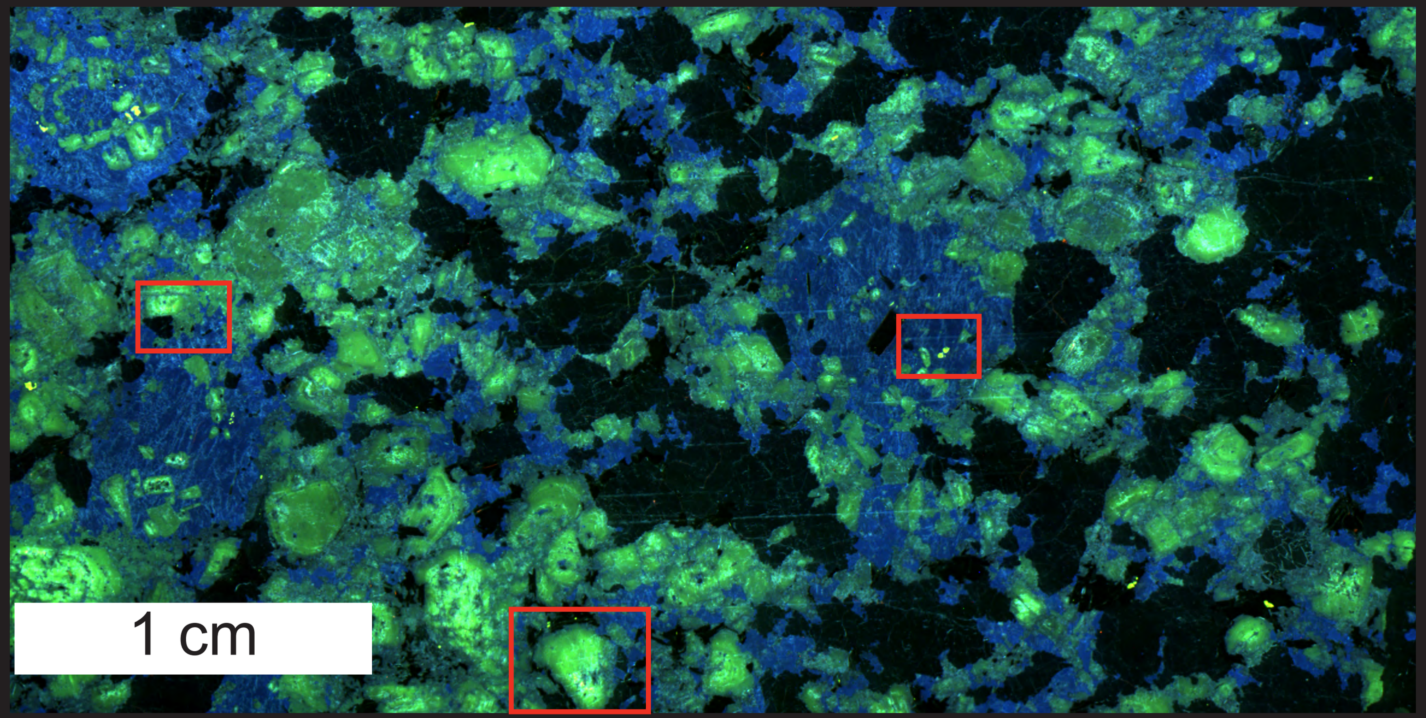
1. OPTICAL CL IN FELDSPARS: Bombarding the surface of a feldspar grain with high-energy electrons from a cathode source excites electrons within conduction bands of specific trace elements, activating electromagnetic luminescence (Marshall, 1988; Pagel et al. 2000). In feldspars, visible light emissions and their attendant substitution/ defect occur in the blue (~450 nm, Al-O—Al defect), green (~565, nm, Mn^{2+}), and red/near-infrared (~700 nm, Fe^{3+}) domains of the visible light spectrum (Götze et al. 2000). Plagioclase typically has a characteristic yellow-green color whereas K-feldspars exhibit distinct blue hues. Apatite, zircon, and some other accessory minerals luminesce yellow-blue but at higher intensity and calcite commonly luminesces orange. Domains in the thin sections that are black are non-luminescing minerals (e.g., biotite, hornblende) or minerals whose luminescence is subdued compared to feldspars and thus appear black. Thus, CL produces a map of the feldspar content and arrangement in a granitoid rock. Variation in CL within the rock shows considerably more detail of growth zoning than a standard polarized view along.

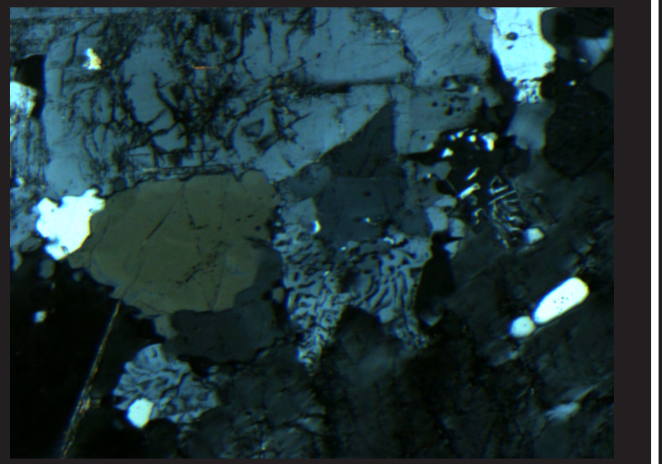
2. IMAGING SET-UP: A Reliotron "cold-cathode" luminescence system and is mounted on an Olympus SZX-16 research stereomicroscope to allow for infinite magnification settings, including large fields of view of up to 1.4 cm, which allows an uncoated, polished, thin section (standard size) to be mapped in six images. Imaging is typically done at 75–100 mTorr, 6–10 kV and 0.2–0.8 mA of beam current. A low light QICAM CCD by QImaging is used to acquire images, with feldspar rich granitoid rocks typically being collected for 4–8 s. A large gem zircon standard is used for color correction if necessary.

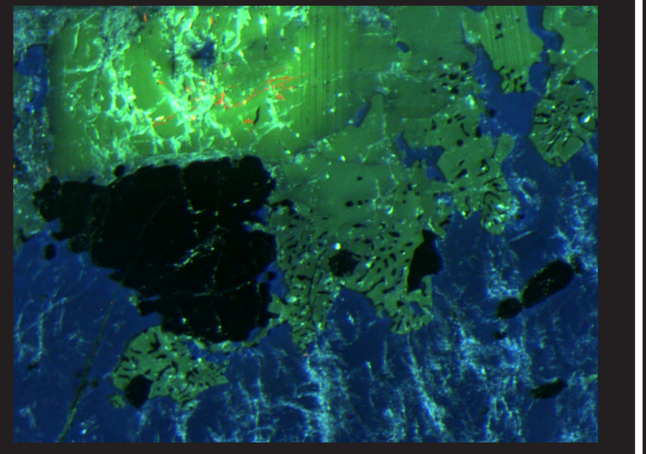


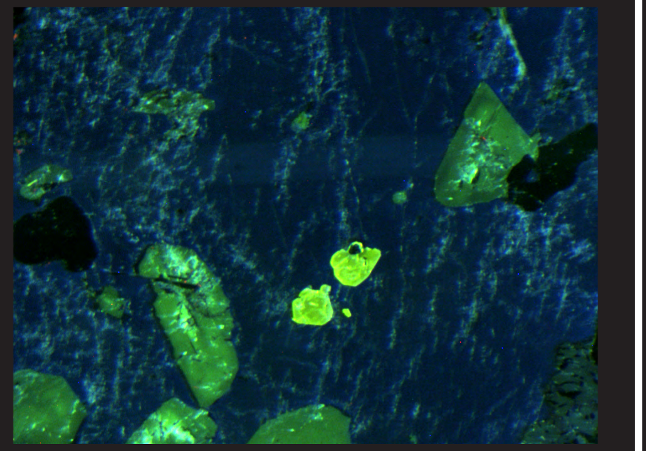


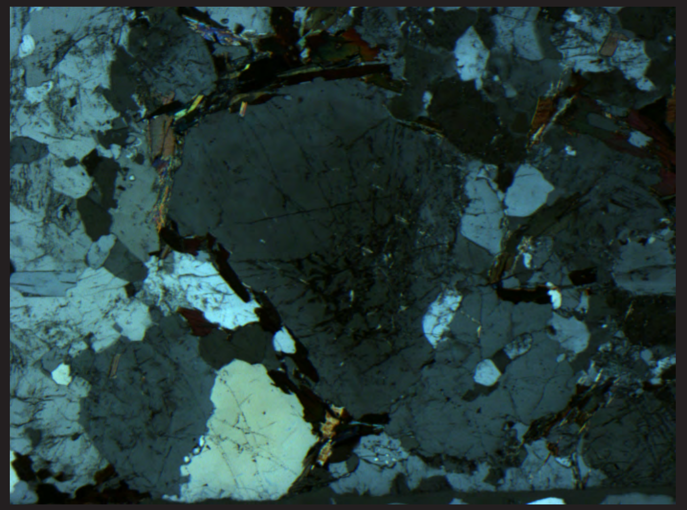


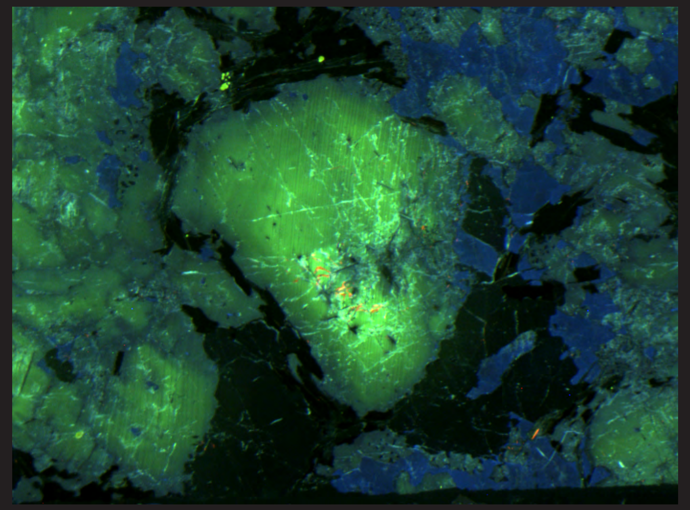






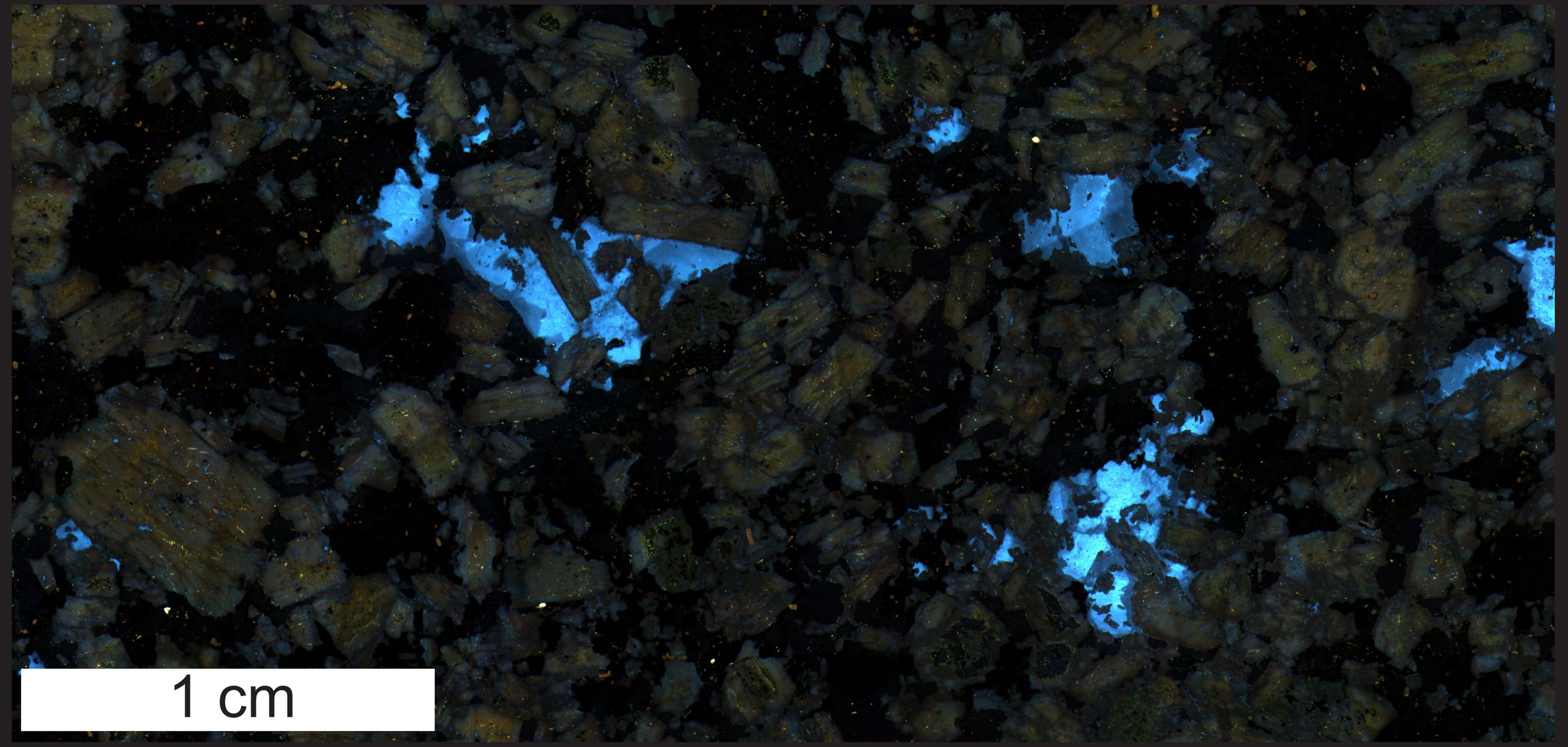


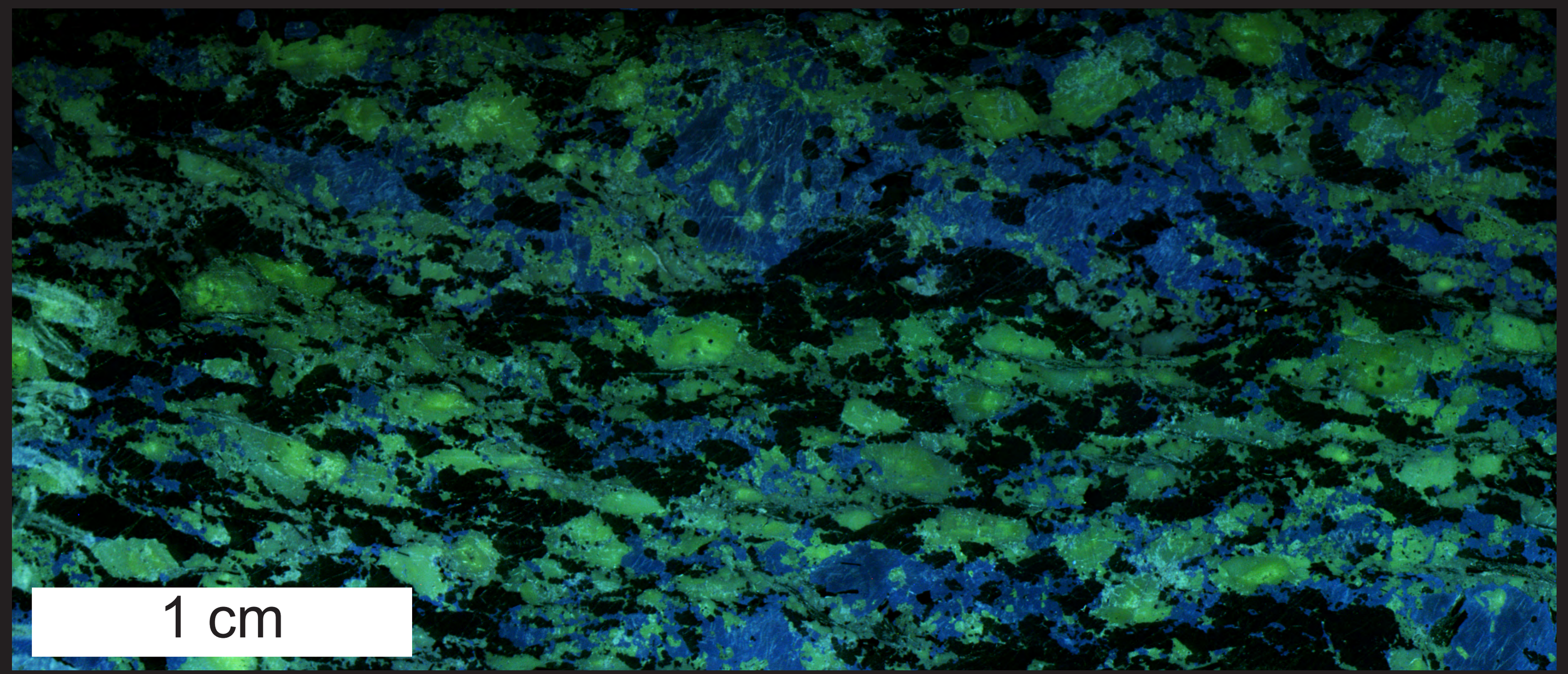


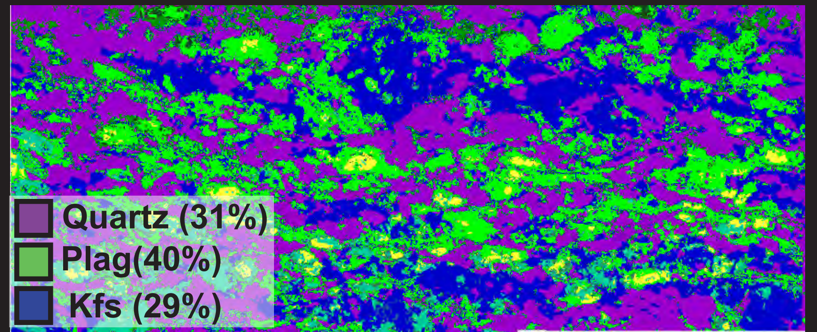


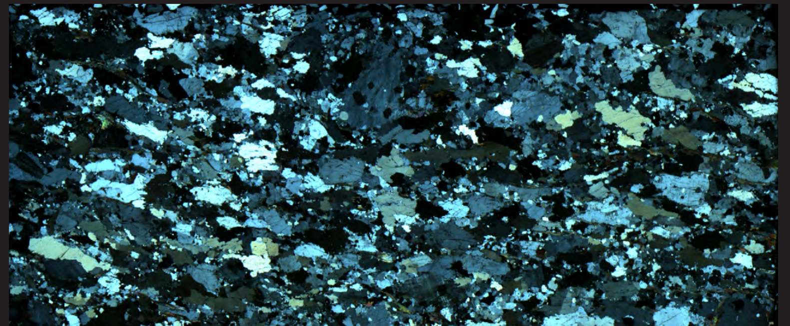
4. The granodiorite of Hensley Lake shows distinct cobalt blue K-spar megacrysts with microcline exsolution and variable yellow-to-green zoning in some plagioclase (e.g., lower outset image pair). Granophyre textures are well-mapped by CL (upper outset image pair). Apatite can easily be located in the CL image based on its intense yellow CL look (middle outset image). The cause of variable yellow color in plagioclase has been found to correlate with high An content in plagioclase, thus indicating domains crystallized from hotter magma. The cause of the brighter yellow CL is thought to be greater concentrations of Mn^{2+} substituting into plagioclase at higher temperature (Goëtze et al., 2000). Orange CL in cracks of yellow-CL plagioclase shows incipient alteration of the high An cores (see both upper and lower outsets).

5. A whole-section map of the Inconsolable quartz-monzodiorite shows a dull green to blue (core-to-rim) zoned CL in plagioclase feldspar, suggesting falling temperatures during growth or possible alteration of grain margins (Götze et al. 1999; Leichmann et al. 2009). Numerous bright yellow and orange CL spots in the section map hundreds of apatite and zircon crystals. Perhaps most striking is the CL appearance of late "intercumulus" K-feldspars that clearly crystallized in pockets. Note the twins and growth domains in the K-feldspar. Locally, K-feldspar shows granophyric textures.

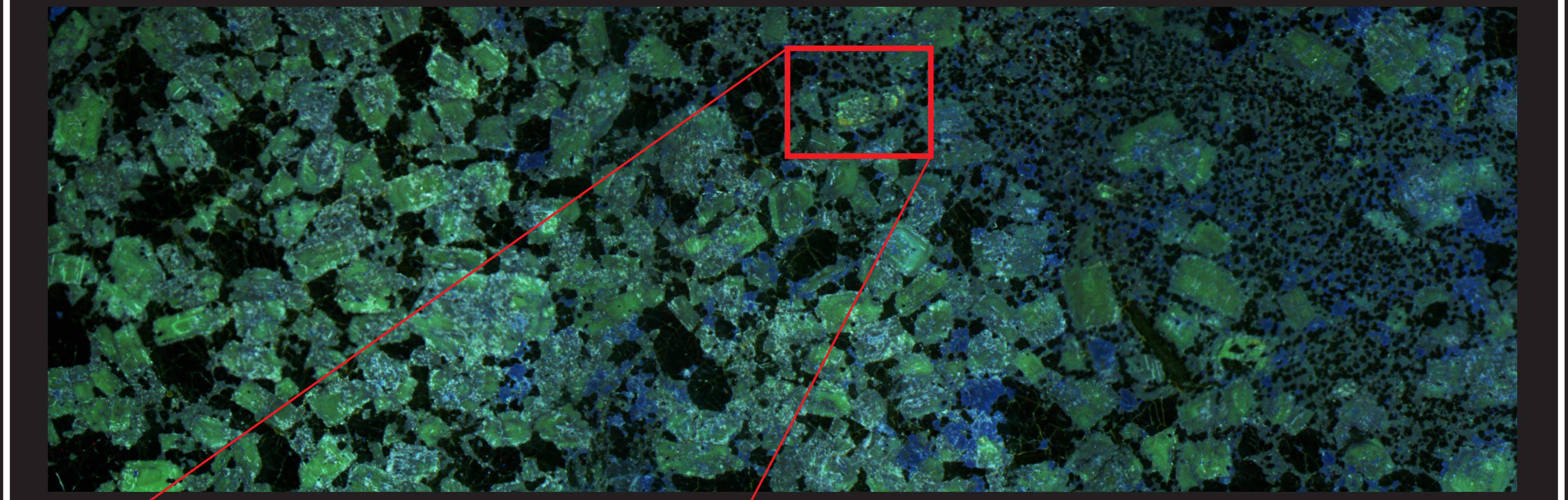


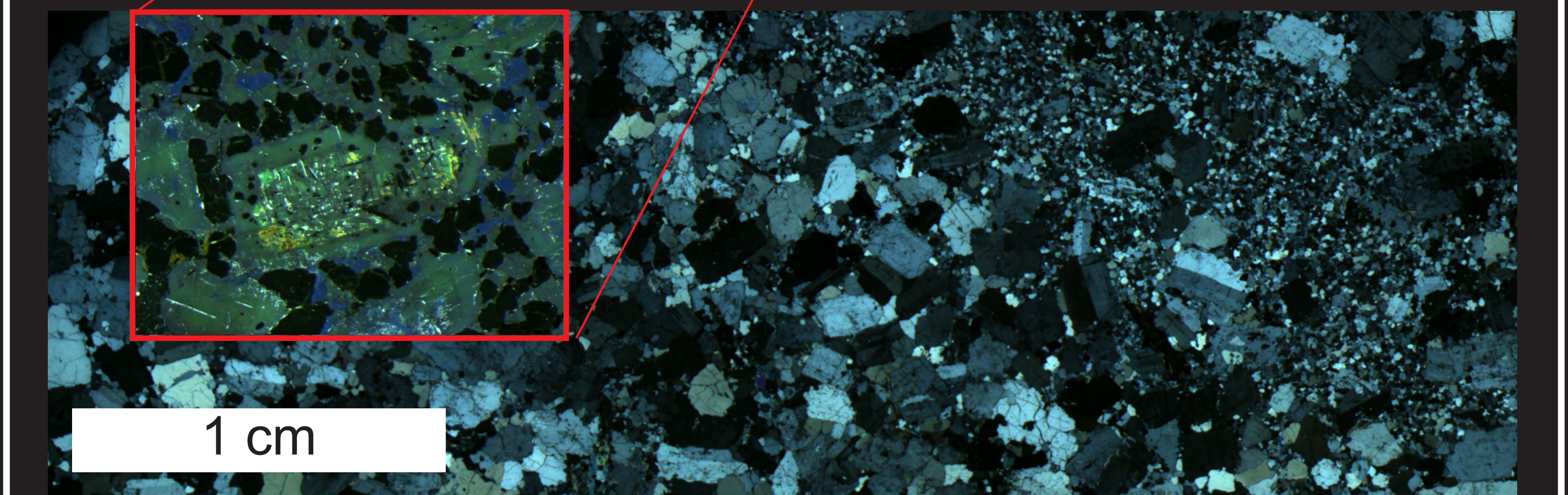




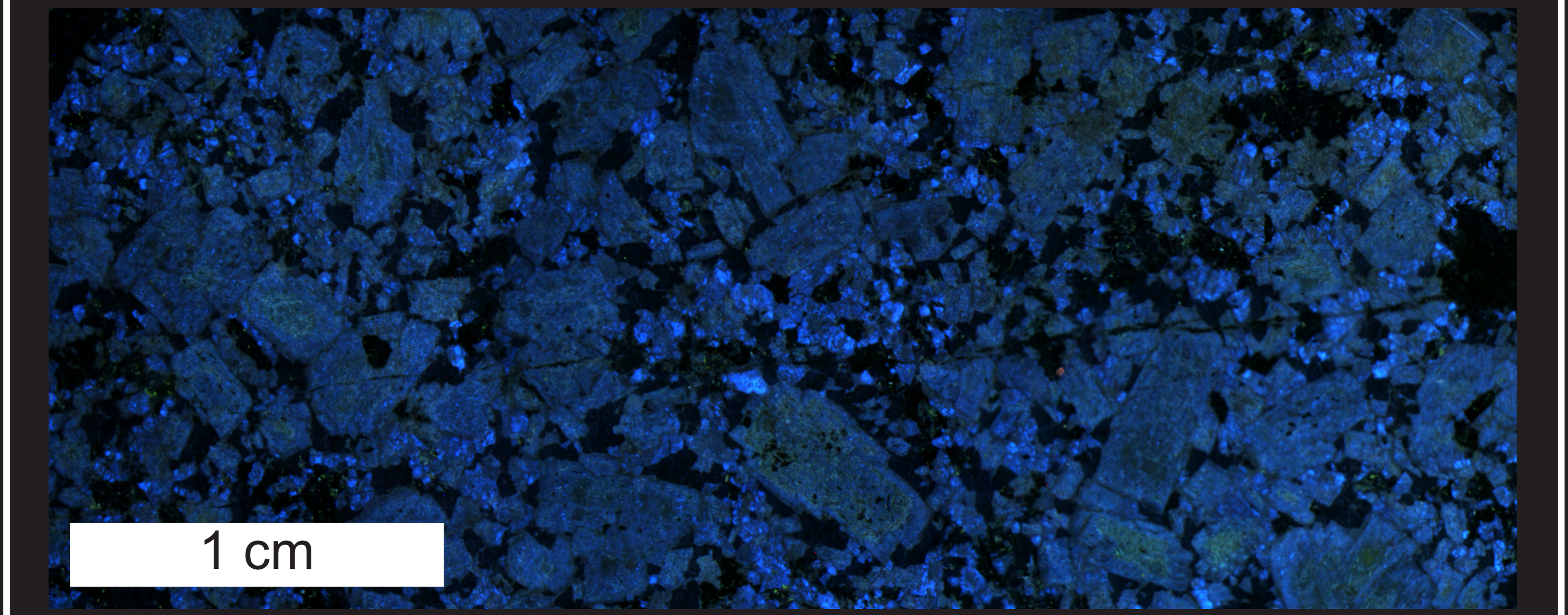


6. Viewed in CL, deformation textures in the Ward Mountain Trondhjemite show intriguing shows grains of K-spar drawn out into the dominant foliation. Dark blue domains in larger K-spar grains may be less strained. Relict zoned plagioclase grains also show preferred orientation. Non-luminescent space shows distribution of quartz bands more clearly than in XPL (right outset). The CL image allows image analysis according to pixel color (e.g., GeoPixelCounter v 1.0 by Mock et al. 2012), showing this rock domain is a granodiorite.

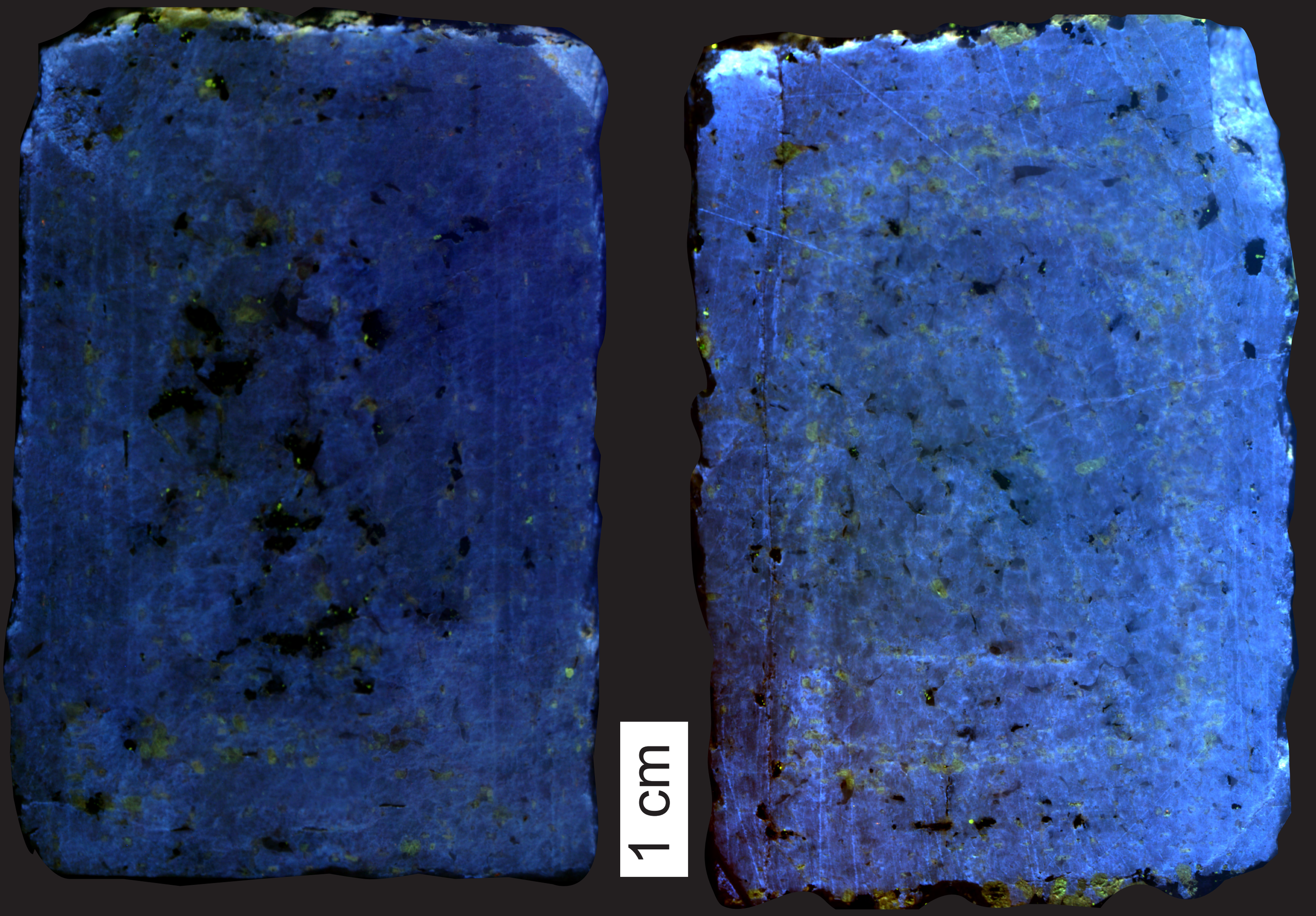




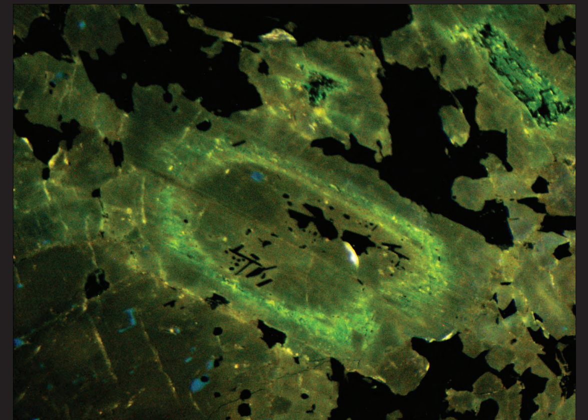
7. CL image above: Magma mixing of an aplitic phase shows random crystal orientation of the coarser grained, equigranular trondhjemite . Serecitic alteration is evident on plagioclase feldspar grains and serves as screen for alteration. Note greater abundance of K-spar within aplitic domain than trondhjemite domain and inclusion of spalled phenocrysts within the aplite. Two or three plagioclase feldspars show bright CL color indicative of origin within a different, presumabley hotter, magma and overgrowth by a lower An rim. The high An core of this grain (inset) is evidently out of equilibium both from inspection of the XPL and CL images.

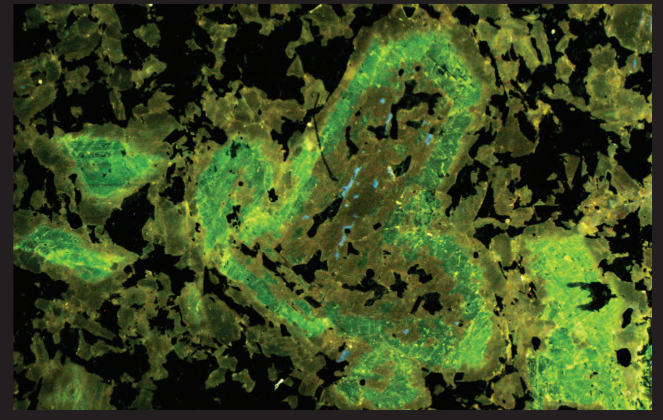


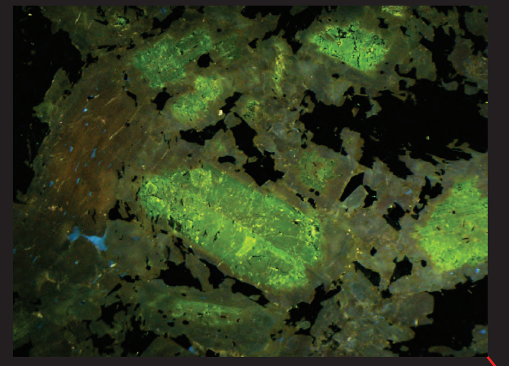
8. The Quartz Diorite of Empire Mountain in the Mineral King pendant is profoundly hydrothermally altered, evidenced by serecitic alteration and a whole rock oxygen isotope ratio of ca. 4.0‰ (D'Errico et al., 2012). In CL the quartz diorite shows nearly all plagioclase having blue CL and faint, diffuse core domains with residual patches hinting at a yellow green CL. When plagioclase to exhibits blue CL, it typically has been in the presence of oxidizing fluids in which REE substitution replaces Mn^{2+} substitution to induce blue CL (Götze et al. 1999), thereby change its typical CL color by exchange. Note the porphyritic texture of the diorite, evidence of hypabyssal intrusion of the Empire Mountain pluton.



9. K-feldspar megacrysts of the Topaz Lake Granodiorite show a dominant blue CL appearance with inclusions of plagioclase feldspar forming scattered green domains. Compared to Ba mapping of K-feldspar textures (e.g., Moore and Sisson, 2008), CL appears less informative about growth history in K-spar megacrysts.





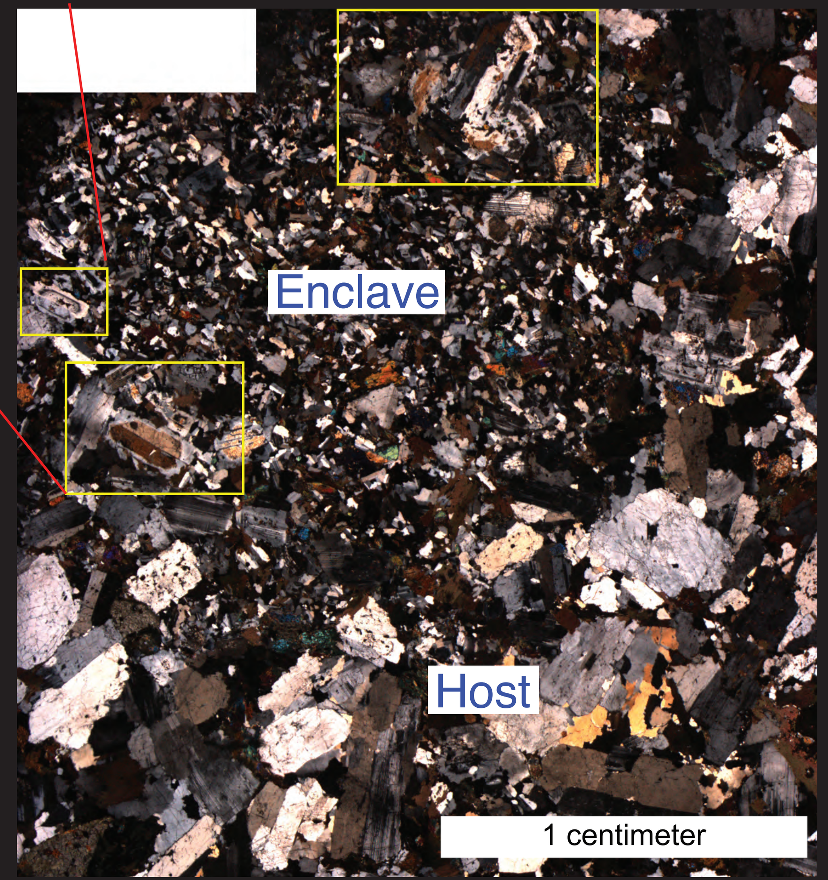


High An Plagioclase
K-feldspar
Low An Plagioclase
Non-luminescing (biotite, hornblende, quartz)

Two Kinds of Plagioclase:

Type 1: Green luminescing cores with normal red-brown luminescence overgrowths.

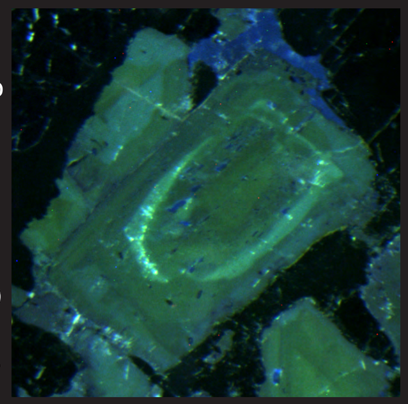
Type 2: sieved cores with normal luminescence, a green luminescing "shell", and normal overgrowths



Cross-polarized image of transition between microgranular enclave to coarser grained host monzodiorite.

10. Bright CL domains in plagioclase from a mafic enclave are interpreted to have grown in a hotter magma and have been overgrown to by Na-rich rims in response to mixing into a colder magma such as the monzodiorite (e.g., Slaby et al. 2008). Type 2, sieved plagioclases likely were incorporated into a hotter magma and partially resorbed before crystallizing their green CL domains. These crystals experienced a second temperature perturbation as their host enclaves mingled with the mozodiorite and they experienced the Type 1 overgrowth.

SUMMARY: A wide range of textures and colors are observed in Sierran Feldspars. The vignettes above show that mixed populations of crystals can be easily recognized, as can compositional zoning. CL also provides a way to screen for alteration of feldspars as well as to evaluate preferred crystal orientations resulting from growth or deformation. For example, CL allows for rapid visual distinction of mixed feldspar populations that can be targeted for further compositional (e.g., LA-ICP-MS of trace elements) and isotopic analysis. It can be used to produce images that are amenable for pixel recognition (e.g., GeoPixel) calculations of modal abundance. Subsitution mechanisms are inherently related to valence states of activating elements and thus CL variations can be used to guide evaluation of magma oxidation state (e.g., Slaby et al. 2009).



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