HYPERSPECTRAL CORE IMAGING APPLICATIONS

- GREENSTONE GOLD DEPOSITS -

February 2021

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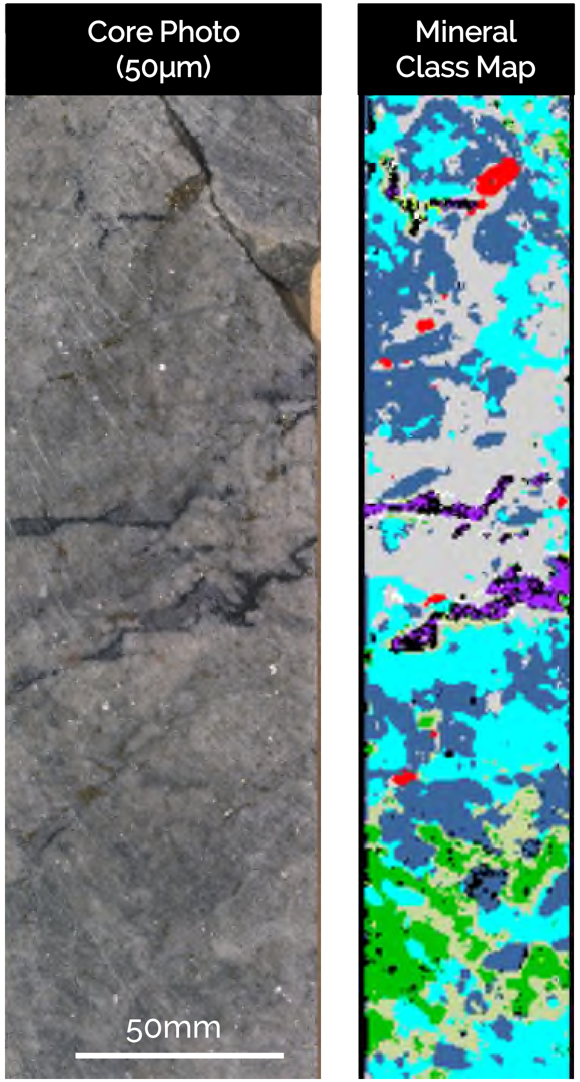
Contents



Hyperspectral Core Imaging Services

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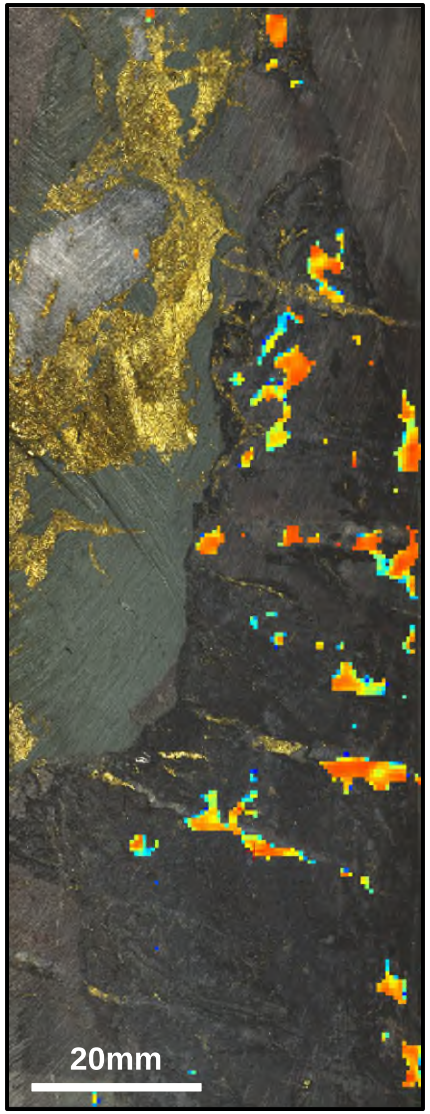
Mineral identification and mapping across the mining cycle:

- Improved alteration domains and mineral assemblages
- Metallurgical and geochemical sample selection and characterization
- Geotechnical measurements for mine design and engineering
- Identification of alteration vectors for exploration targeting
- Ore and gangue characterization for mineral processing and optimisation
- Ground truthing of airborne hyperspectral surveys

Corescan's Hyperspectral Core Imagers (HCI) integrate high resolution reflectance spectroscopy, visual imagery and 3D laser profiling to map mineralogy, mineral composition and core morphology, delivering enhanced geological knowledge.

Summary timeline:

- Sensor engineering commenced 2001
- Commercial operations commenced 2011
- 580+ projects / 1.2 million metres successfully scanned, processed and delivered…



Hyperspectral Core Imaging: Material Types

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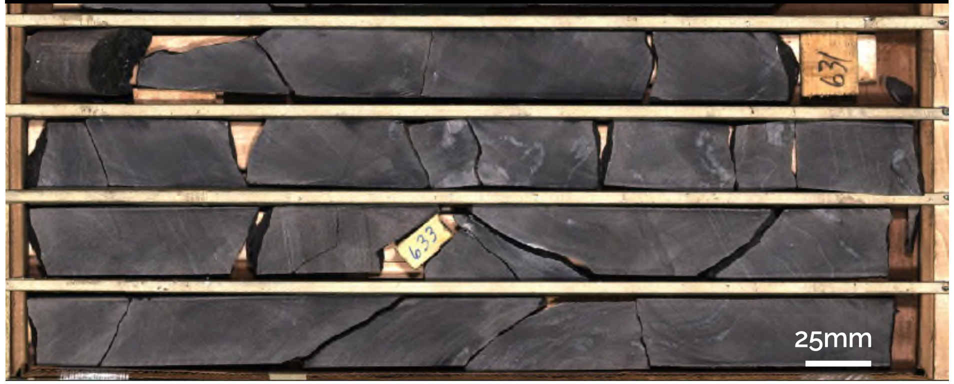
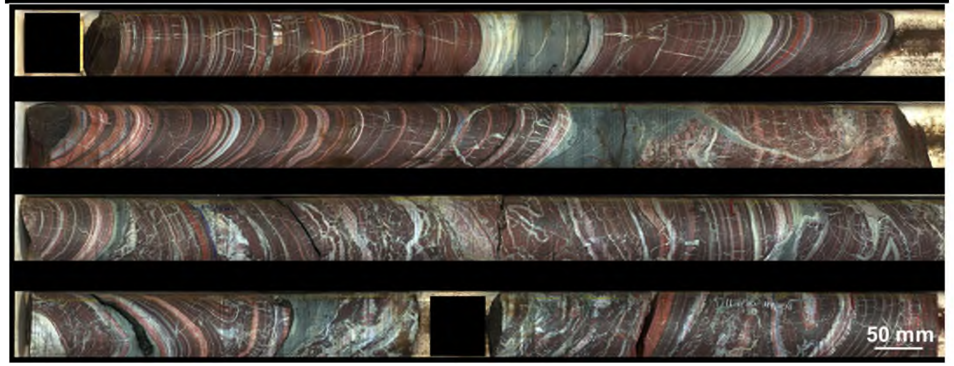
Cut / split core



Hand samples

Soils

Uncut / whole core



Chips, cuttings, blast holes

Hyperspectral Core Imager: Models 3 & 4

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Specifications	HCI-3.2	HCI-4.1	HCI-4.2
RGB photography - spatial resolution	50 µm	25 µm	25 µm
Surface profiling - spatial resolution	500 µm	50 µm	50 µm
Spectrometer type	Imaging	Imaging	Imaging
Imaging spectrometer - spatial resolution	500 µm	500 µm	250 µm
Spectra per meter (1000mm x 60mm)	240,000	240,000	960,000
Spectral range – VNIR (nm)	450 – 1,000	450 – 1,000	450 – 1,000
Spectral range – SWIR (nm)	1,000 – 2,500	1,000 – 2,500	1,000 – 2,500
Spectral resolution (nm)	4nm	4nm	2nm
Core tray length (maximum)	1,550mm	1,550mm	1,550mm
Core tray width (maximum)	600mm	600mm	700mm
Supports material weighing	-	-	Yes
Supports pass-through workflow	-	-	Yes
Scanning speed	~10mm per second	~25mm per second	~18mm per second

For further information please visit: https://corescan.com.au/products/hyimager/

Continuous Hyperspectral Mineralogy

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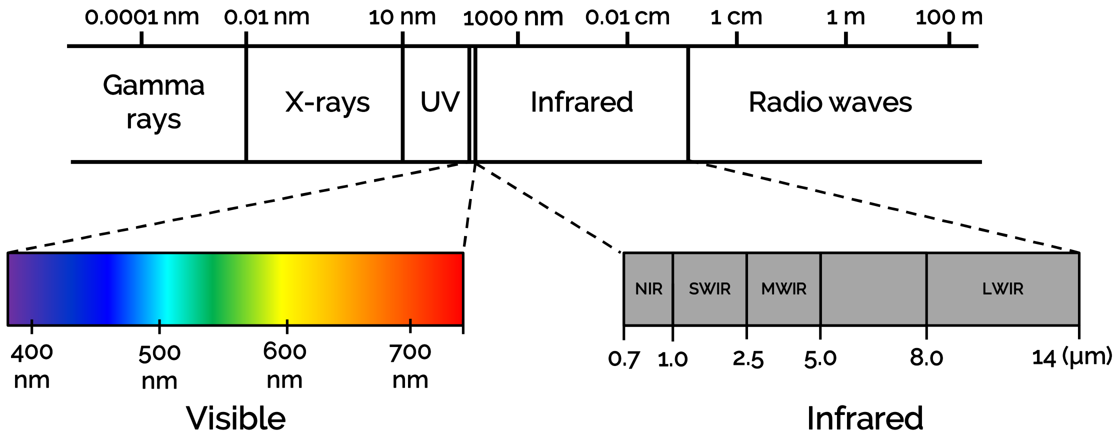
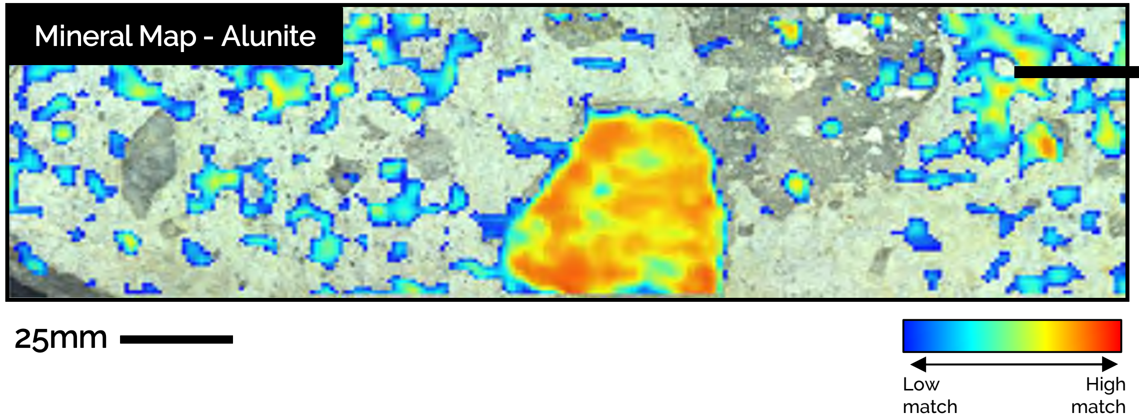
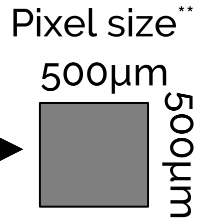
- Corescan's proprietary spectrometers measure hundreds of contiguous, narrow bands across the electromagnetic spectrum from 450nm to 2500nm, covering the Visible-Near Infrared (VNIR) and Short-Wave Infrared (SWIR) regions.



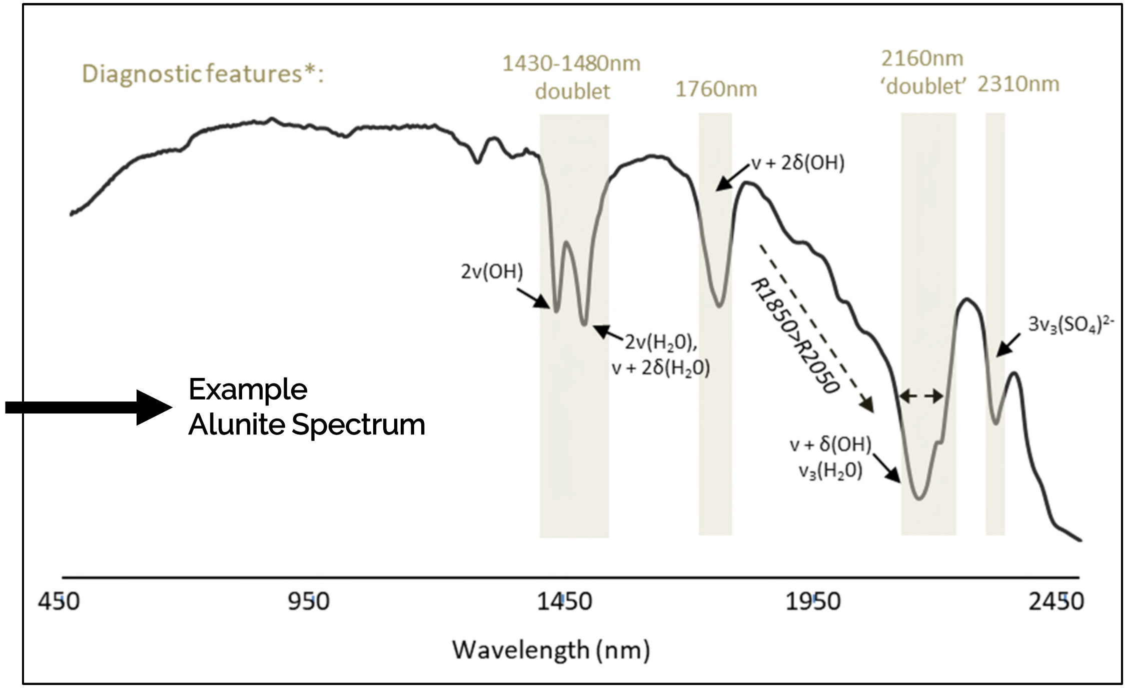
Harraden, 2018

- The surface of the core is imaged at ~250,000 pixels per meter*; with each 500µm x 500µm pixel* measuring a unique spectral signature.





Example Alunite Spectrum



HCI-3 instrument specifications* * Not to scale*

VNIR-SWIR: Electronic and Vibrational Features

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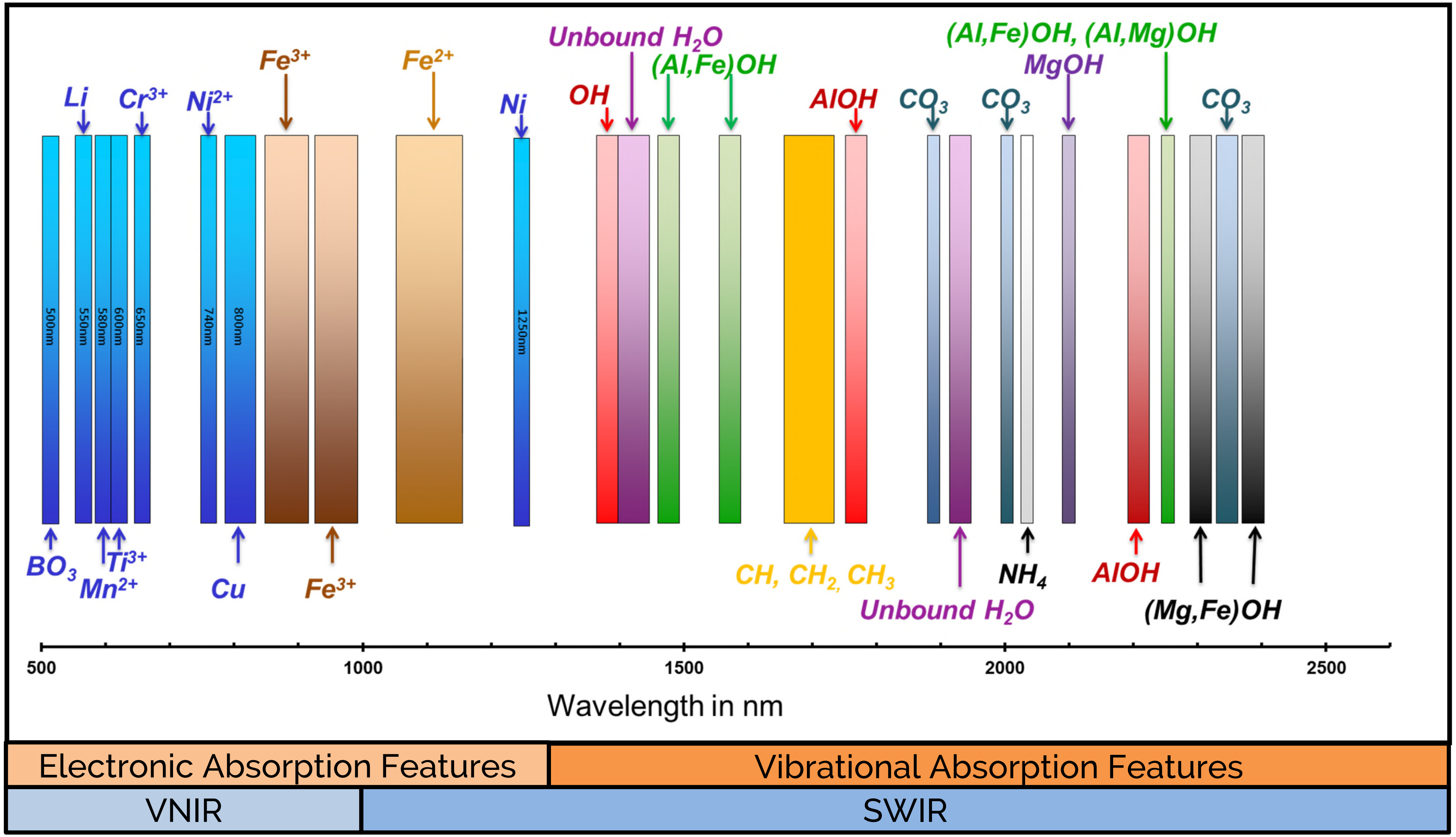

Greenstone Gold Deposits

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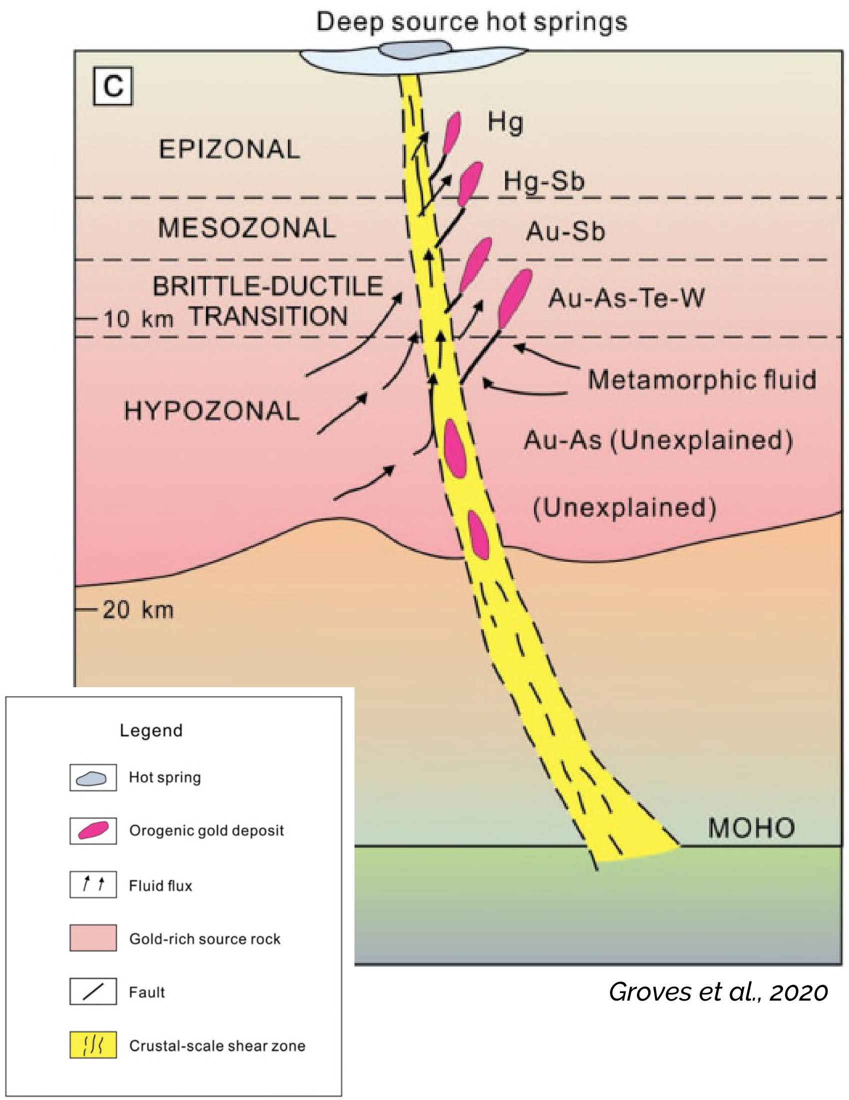
- Greenstone (*or orogenic*) gold deposits are associated with variably metamorphosed mafic to ultramafic volcanic sequences and associated sedimentary and felsic rocks.
- Tectonic and structural controls are key to emplacement and deposit characteristics.
- The style of mineralization varies greatly between deposits (stockwork veining, breccias to disseminated/replacement deposits).
- Lateral alteration zonation, from proximal to distal assemblages, are dependent on the type of wallrock and degree of metamorphism.
- The scale and geometry of alteration systems are highly variable.

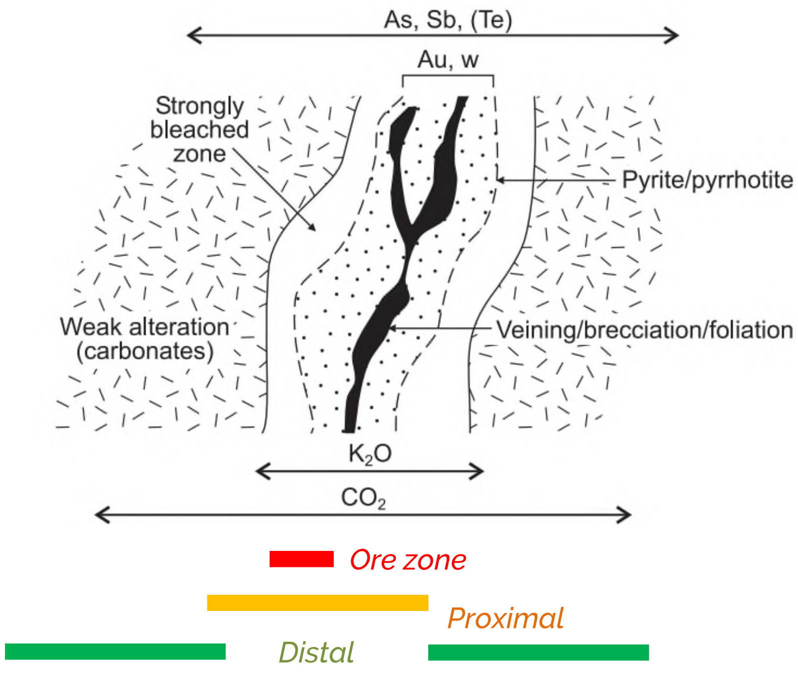


Groves et al., 2020

Greenstone Gold Deposits – Alteration Mineralogy

Greenstone Gold Deposits: Alteration

- Characteristic wall rock alteration varies according to host rock and metamorphic grade, but typically includes:
  - Formation of Fe sulphides
  - Carbonate alteration (ferroan dolomite, ankerite, subordinate calcite)
  - K metasomatism (alkali feldspar, biotite, white micas)
  - ± local silicification



Typical Alteration Mineralogy In Mafic Rocks

	Metamorphic Terrane: Low Grade	Metamorphic Terrane: High Grade
Ore zone	white mica, V- and Cr-bearing micas (± quartz, carbonate, ± tourmaline)	
Proximal	white mica, carbonate (siderite, ankerite, dolomite)	biotite-amphibole-plagioclase ± magnetite-epidote
Distal	chlorite-calcite ± magnetite-epidote	hornblende-biotite, plagioclase

(McQueen, 2005; adapted from Yeats and Vanderhor, 1998)

Ore Zone Alteration & Mineralization: Micas

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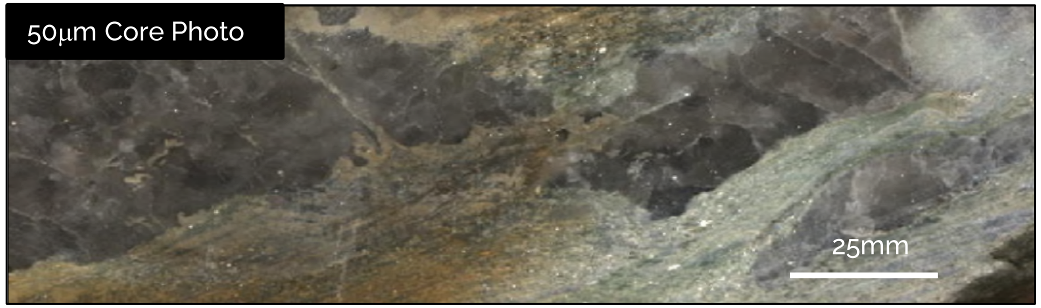
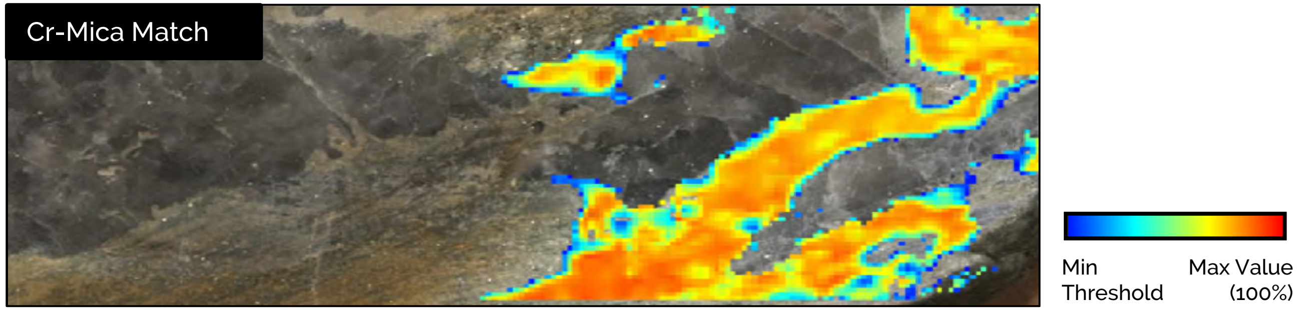
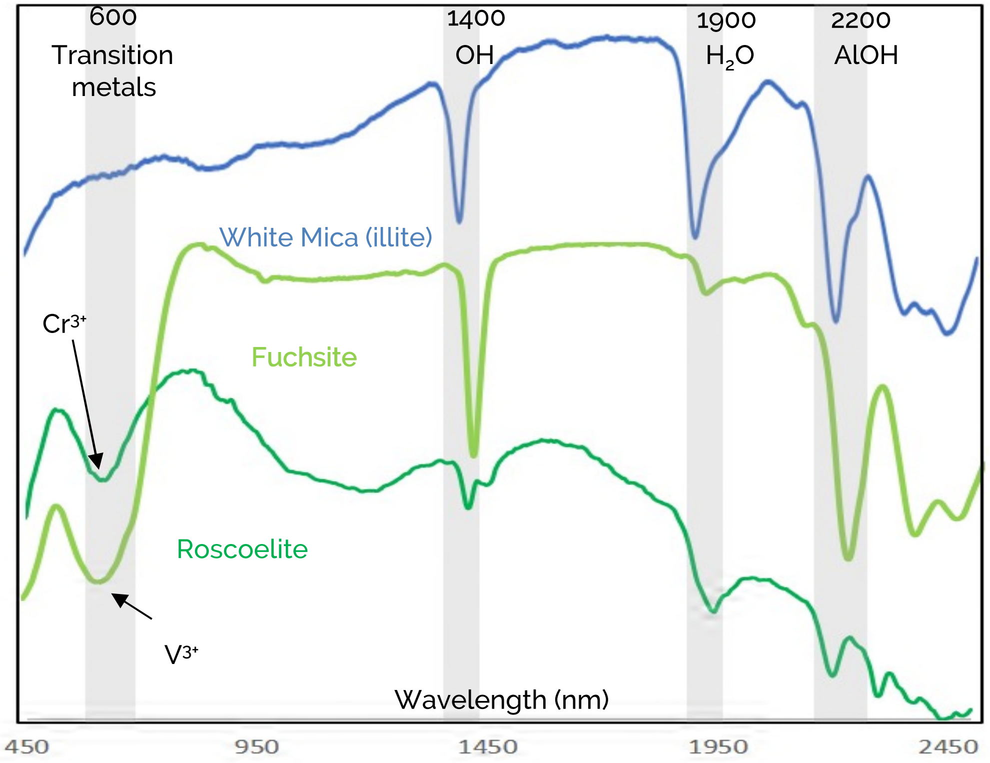
- The substitution of transition elements (Cr^{3+}, V^{3+}, etc.) in white micas results in absorption features in the ~600nm region that are readily identified by the Corescan HCI systems.





Distinct green mica (Cr-bearing) from a Canadian greenstone gold deposit.

Spectral Region (nm)



Ore Zone Alteration & Mineralization: Tourmaline

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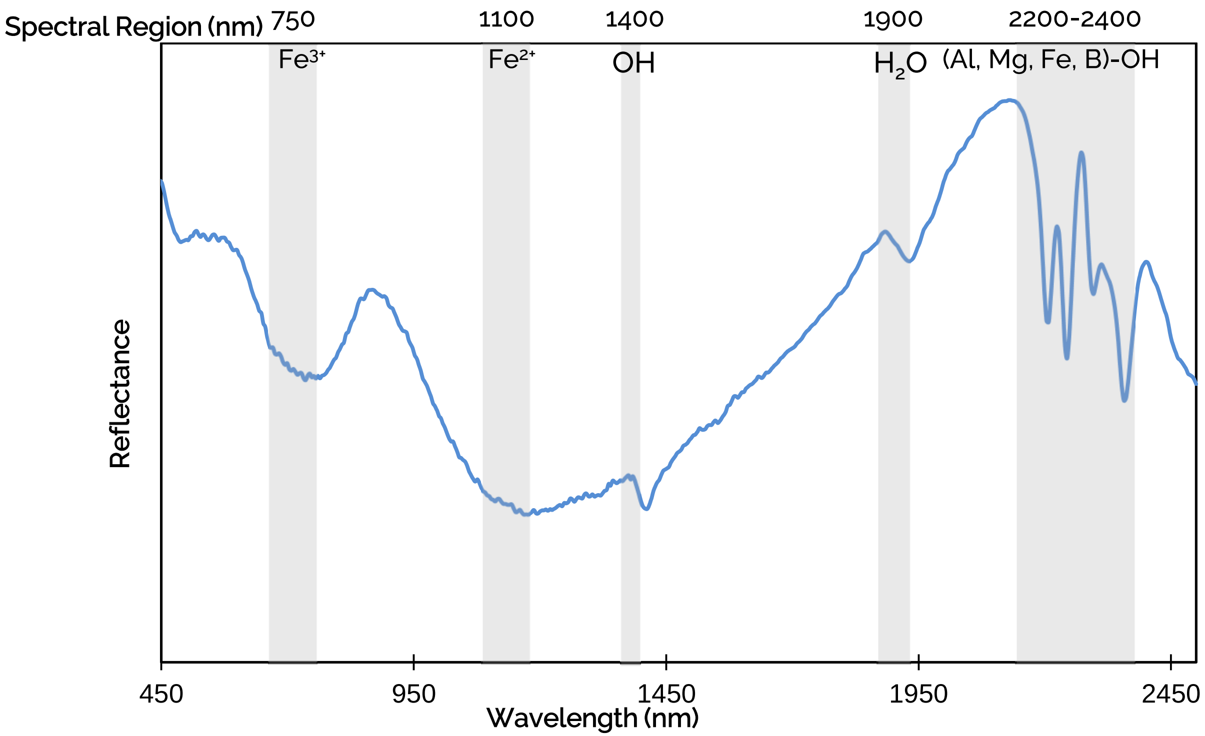
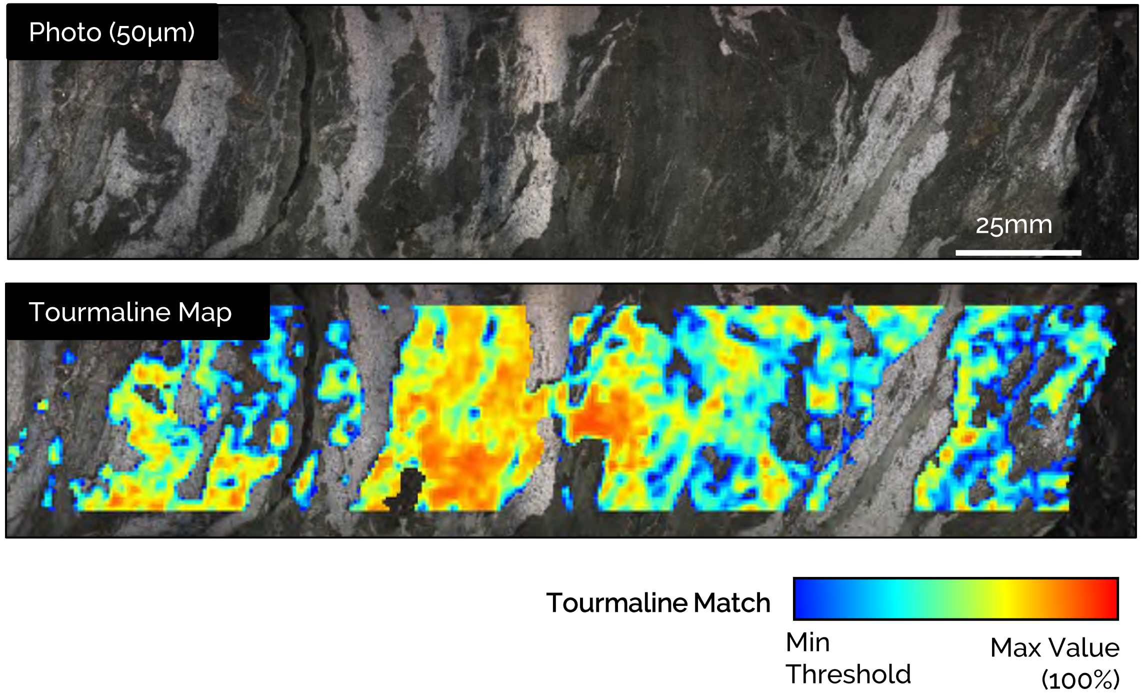
- Tourmaline is a common accessory phase in greenstone gold veins and in proximal alteration zones.
- Tourmaline has several diagnostic SWIR features and is readily identified by Corescan HCI systems.





- Note: since tourmaline is stable over a very wide P-T range and is very resistant to alteration post-deposition, it can also occur distal to mineralization ± in zones unrelated to gold deposition.

Ore Zone Alteration & Mineralization: Carbonates

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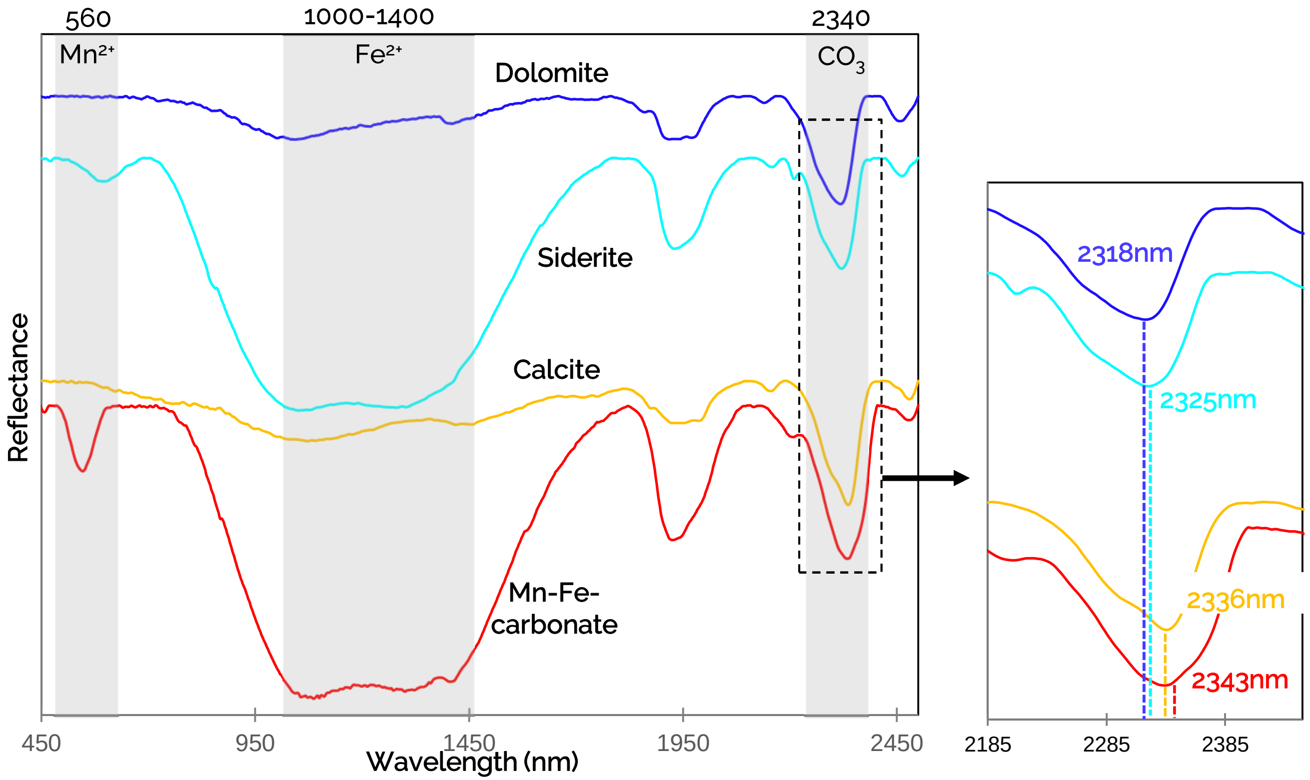
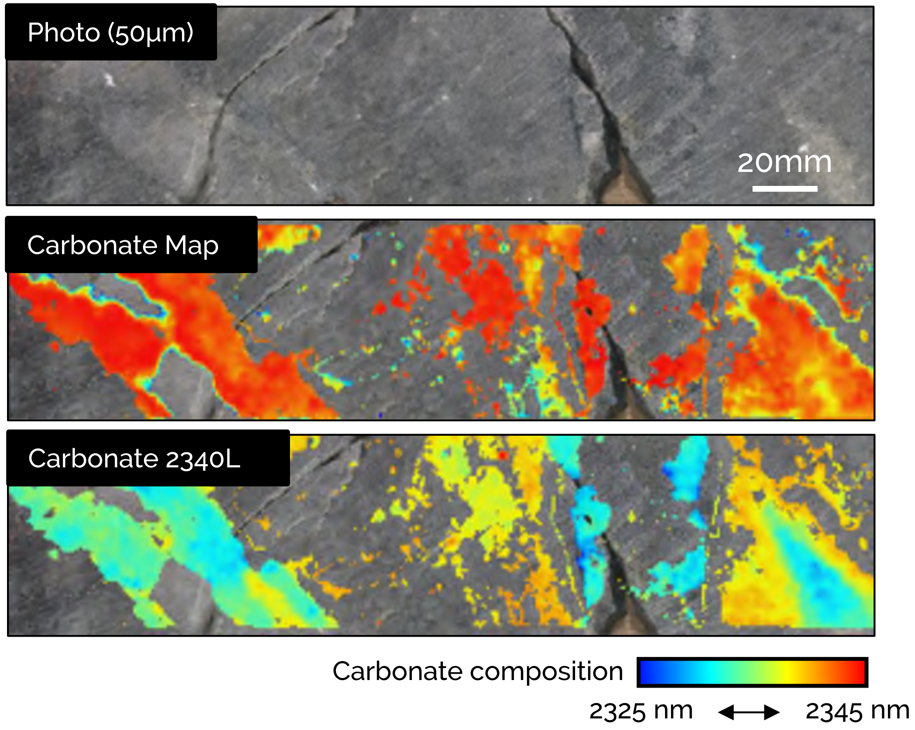
- Carbonates of many different types (e.g. magnesite, ankerite, dolomite, calcite) are common throughout regional deformation zones in greenstone gold systems.
- This group also represents the most prominent gold-related alteration mineralogy at the deposit-scale.





- Mg-metasomatism (calcite to dolomite) is easily traced in Ca-Mg carbonate varieties using variations in the ~2340nm absorption feature.
- Fe substitution in carbonate also results in a very distinctive spectral feature in the VNIR that is readily mapped using the Corescan HCI system.

Ore Zone Alteration & Mineralization: Sulphides

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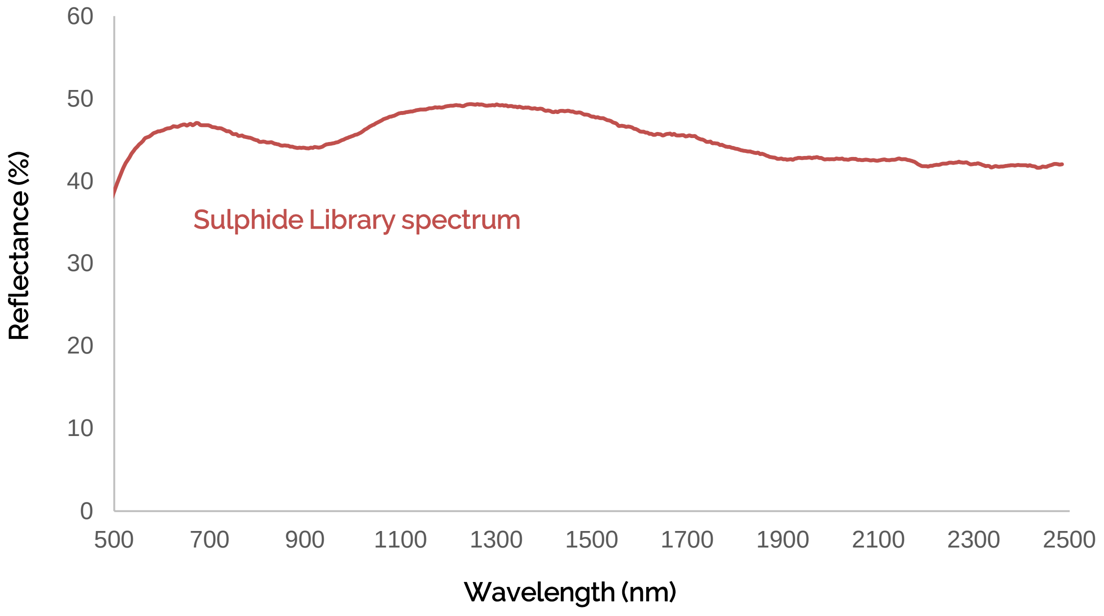
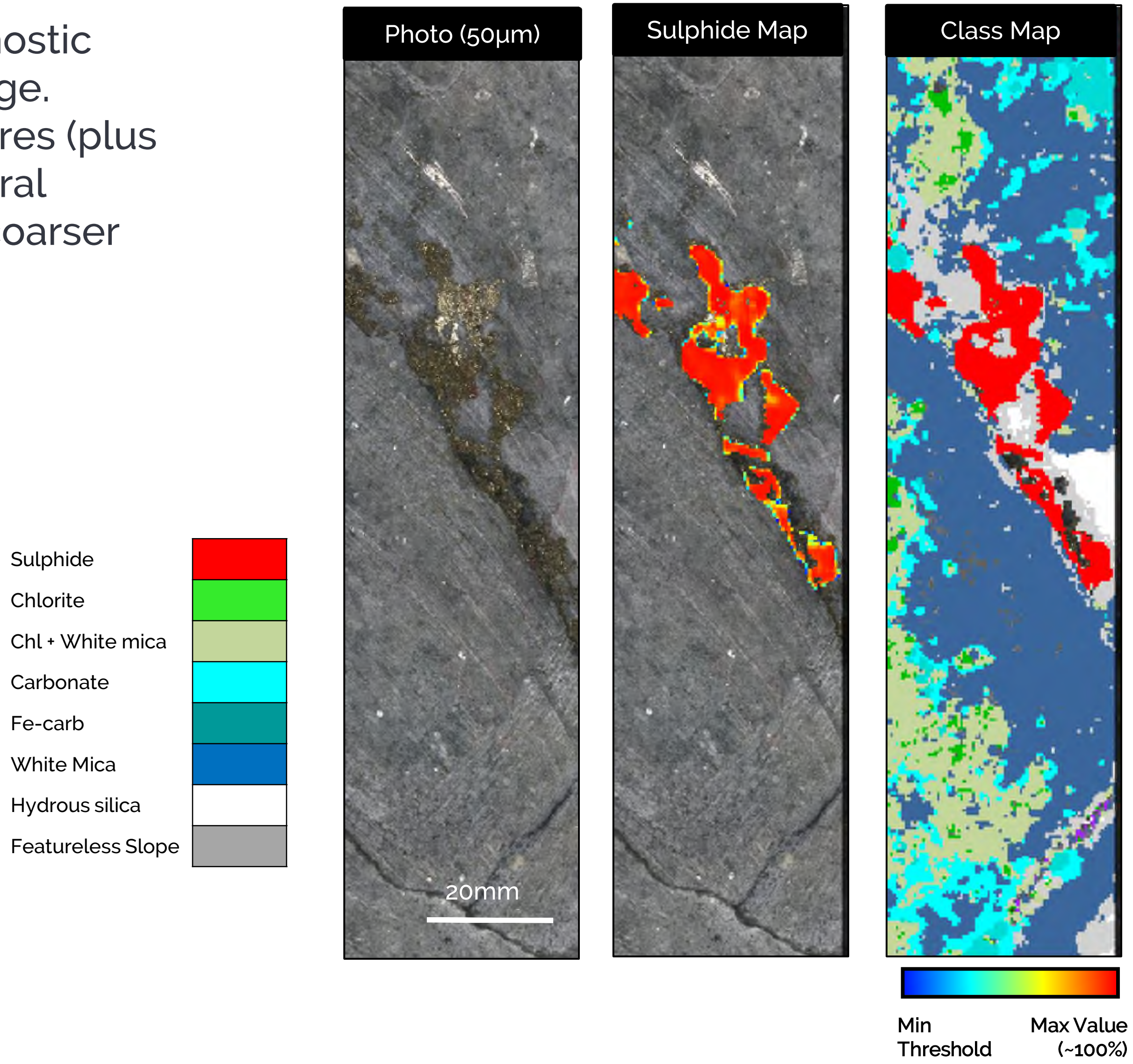
- Iron Sulphides (e.g., pyrite, chalcopyrite) lack diagnostic spectral absorption features in the VNIR-SWIR range. However, the overall shape of the spectral signatures (plus texture – veined, massive, etc.) *may* allow for general discrimination and identification – particularly for coarser grained materials.





ADS0001

Proximal Alteration: Biotite-Amphibole

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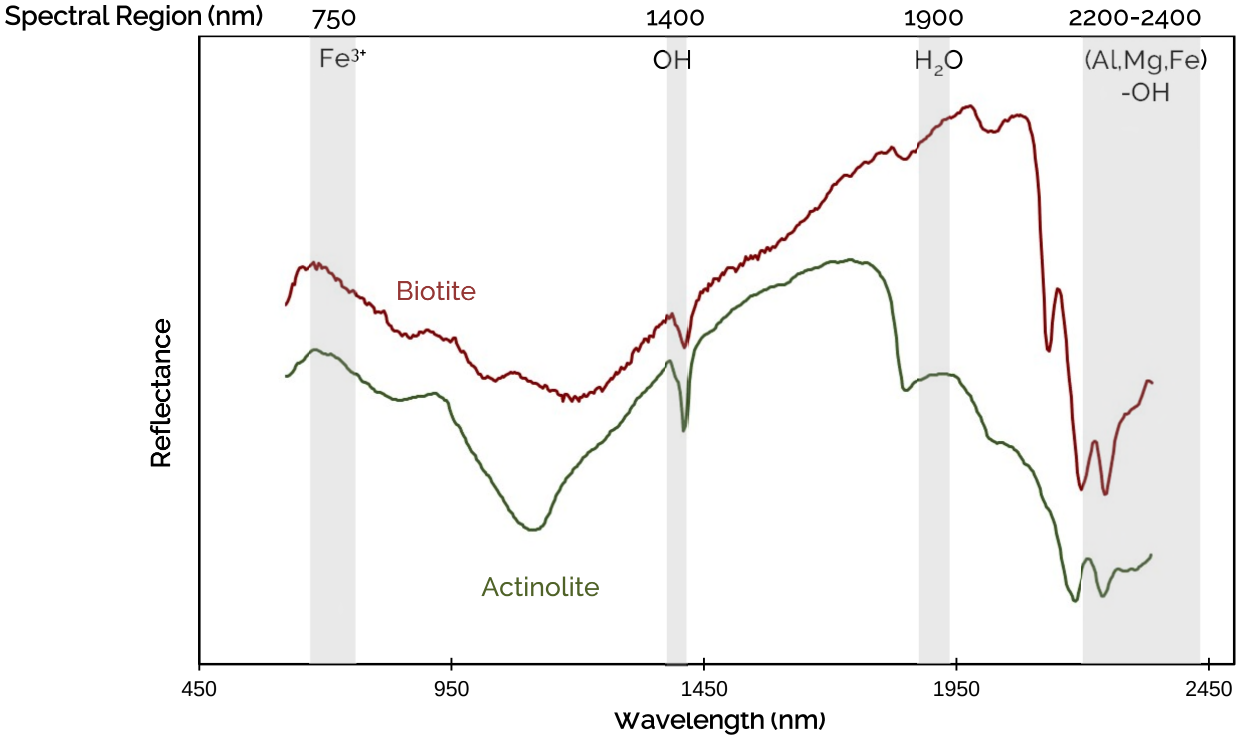
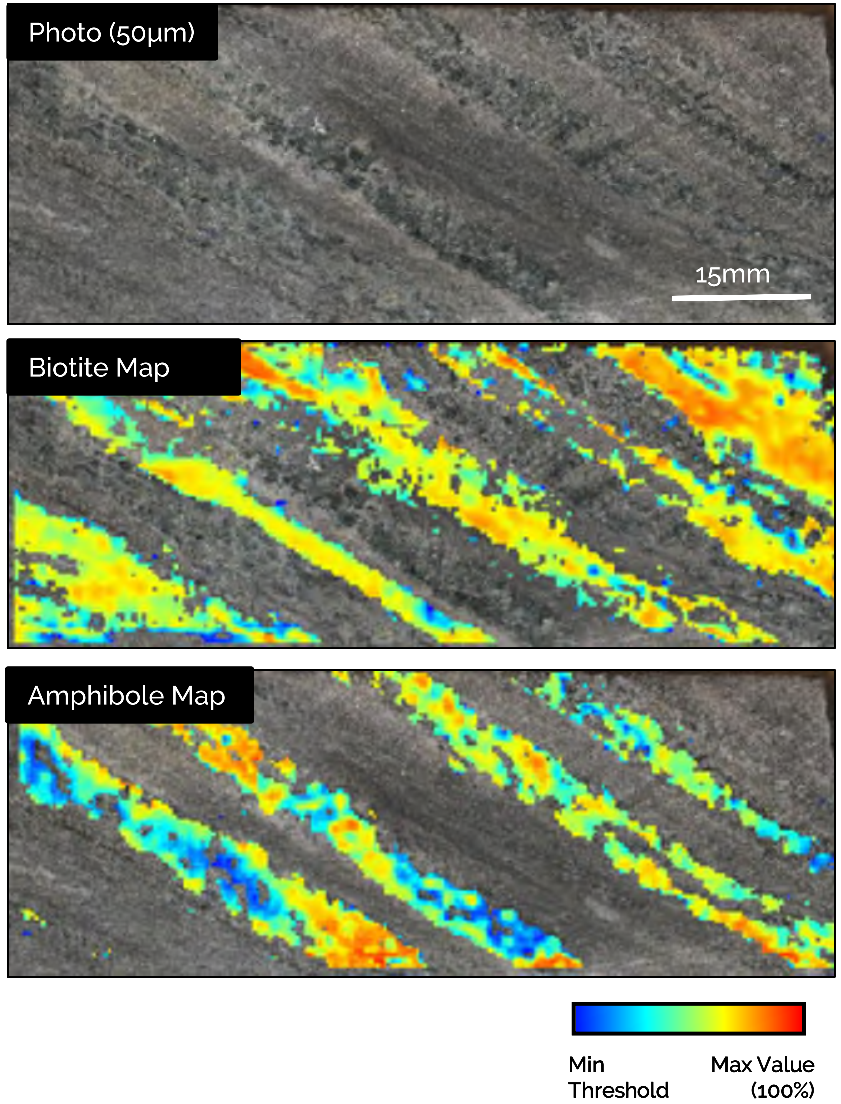
- At relatively high metamorphic grades, alteration proximal to greenstone gold ore typically results in an assemblage of biotite ± amphibole and sulphides, carbonates (and variable alkali feldspars).
- Biotite- and amphibole-group minerals are readily identifiable using VNIR and SWIR features. Their spectra have distinct features that correlate to Fe/Mg content.





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Proximal Alteration: White Micas

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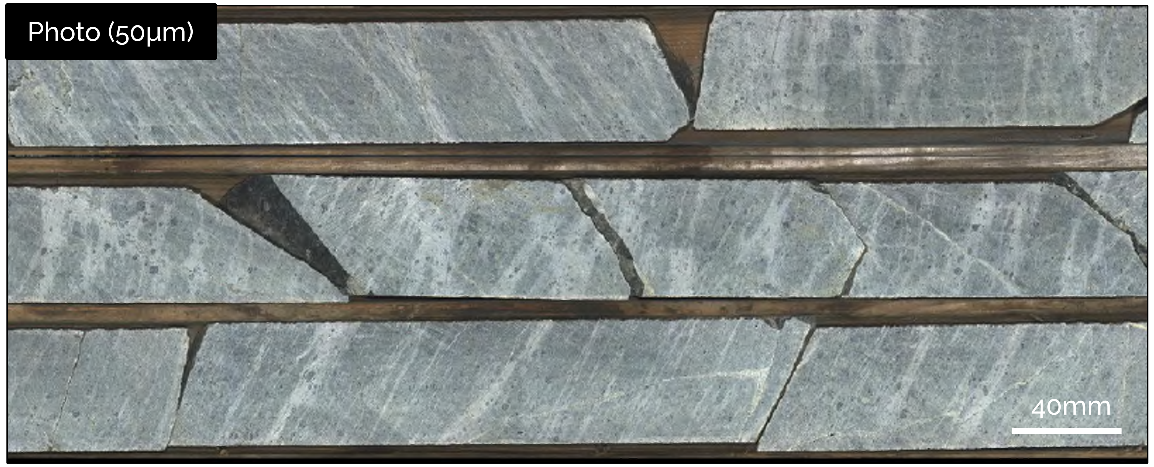
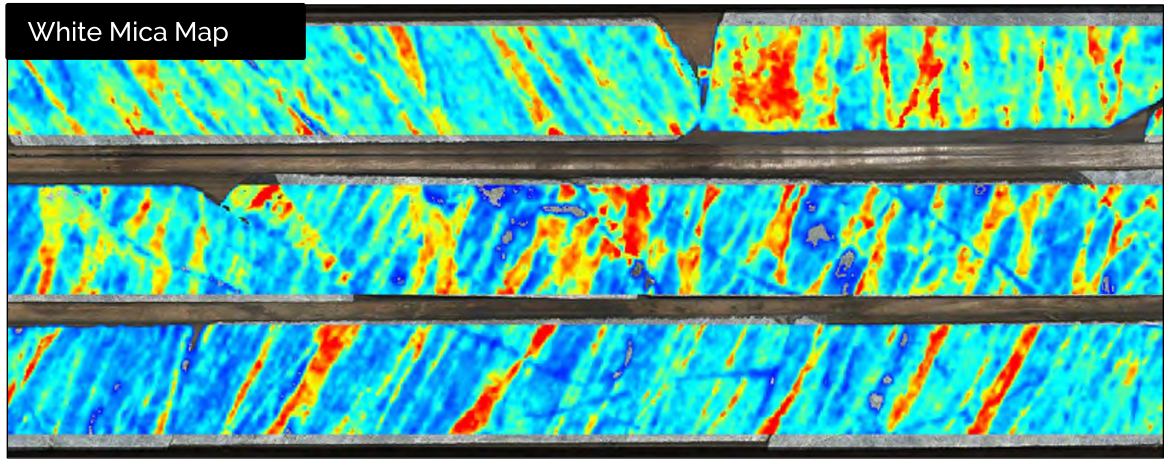
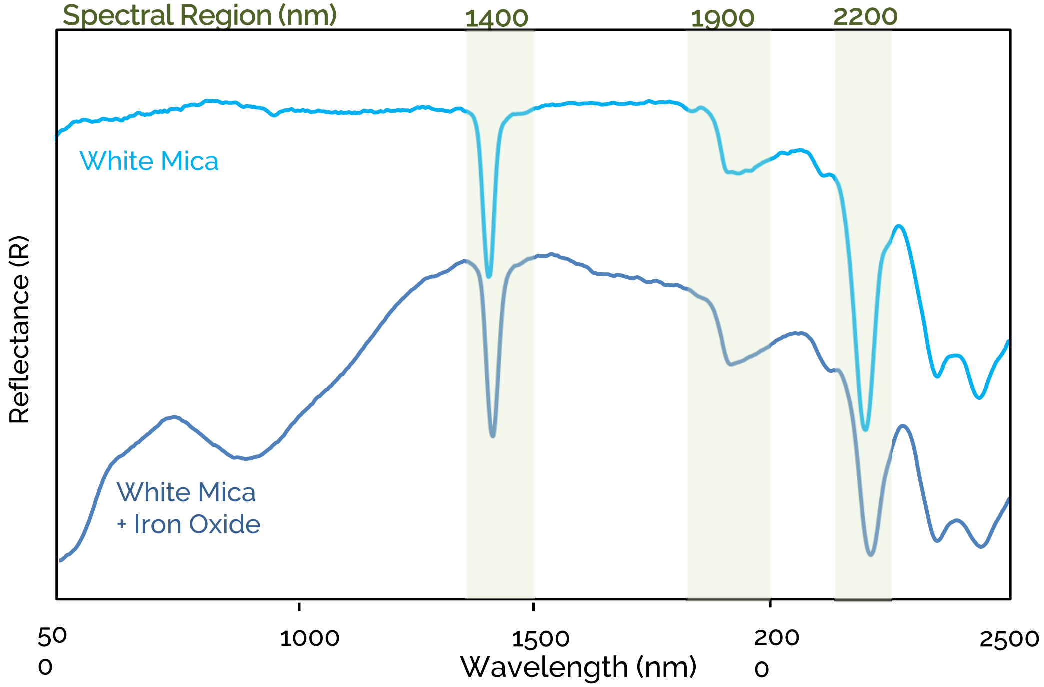




- The term 'white micas' includes mica-group minerals (muscovite, phengite, paragonite, etc.) as well as illite.
- Diagnostic SWIR features include three absorption features at ~1400nm (OH), ~1900nm (H_2O) and ~2200nm (Al-OH). The position and shape of the ~2200nm Al-OH feature are indicative of the composition (paragonite, muscovite or phengite) and crystallinity of the white mica.



Distal Alteration: Chlorite-Epidote

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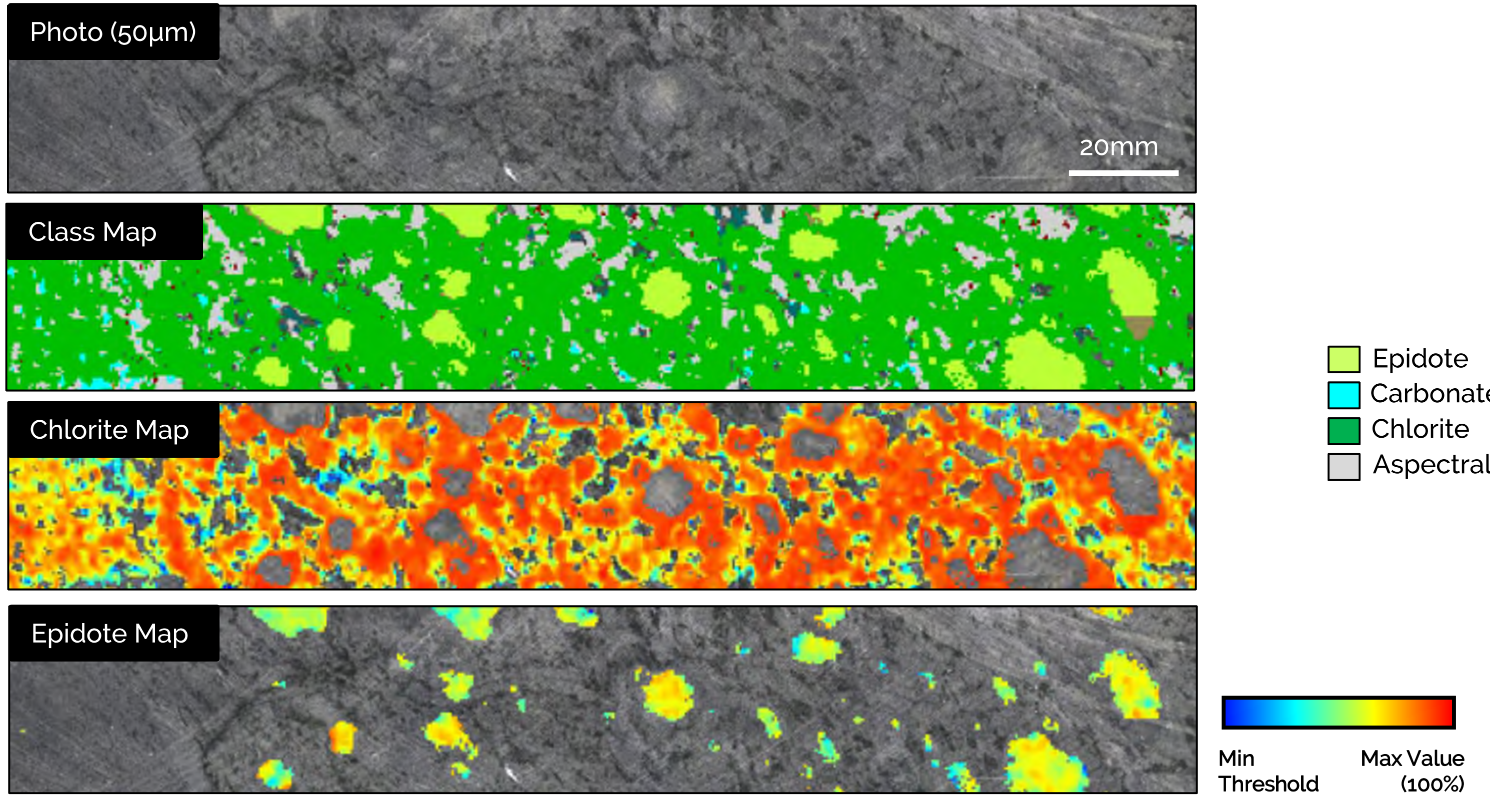
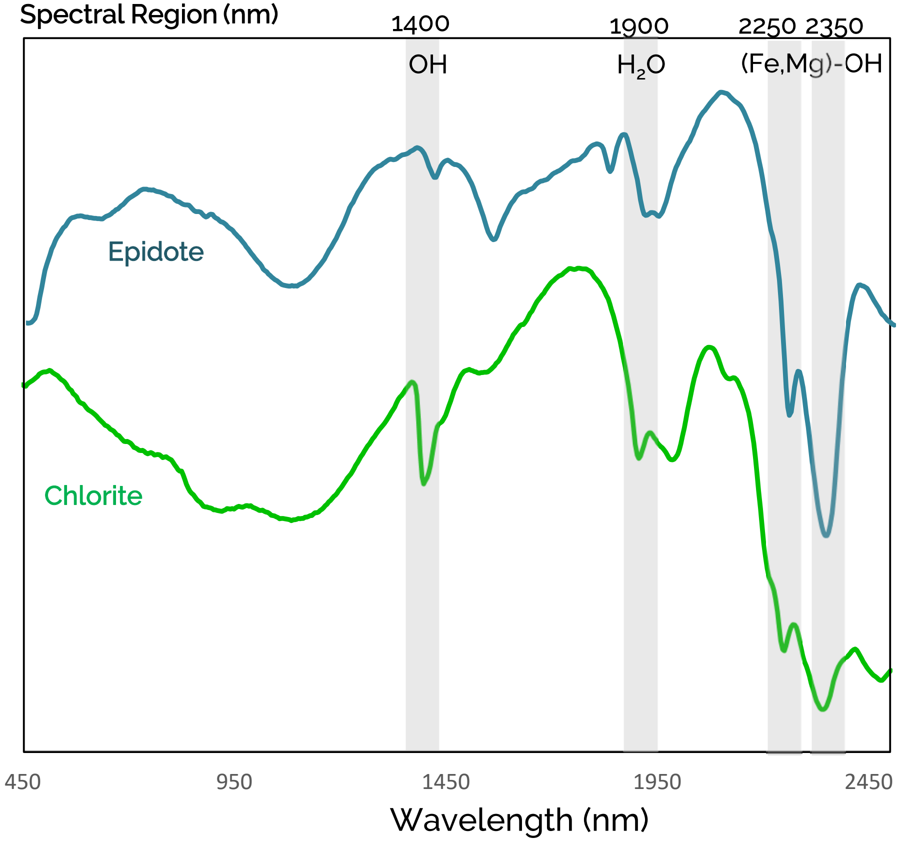
- Chlorite and epidote are common regional alteration minerals in greenstone terranes. These phases may be genetically related to mineralizing events – depending on host lithologies, metamorphic grade and mineralizing conditions.





- Both chlorite and epidote have distinctive SWIR features and chemical variations; they can be tracked using the wavelength positions of key absorption features.

Alteration: Ultramafic Lithologies

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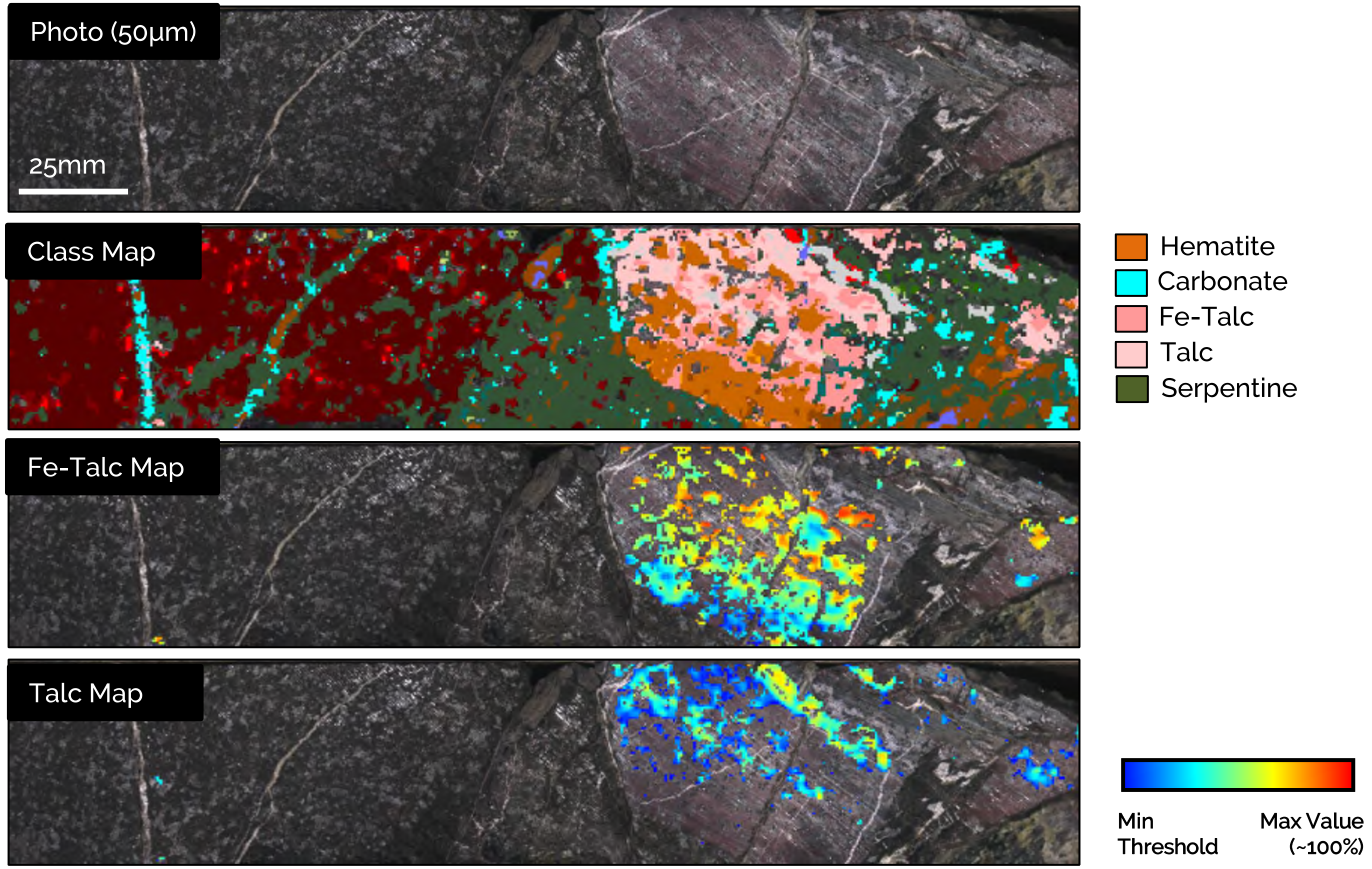
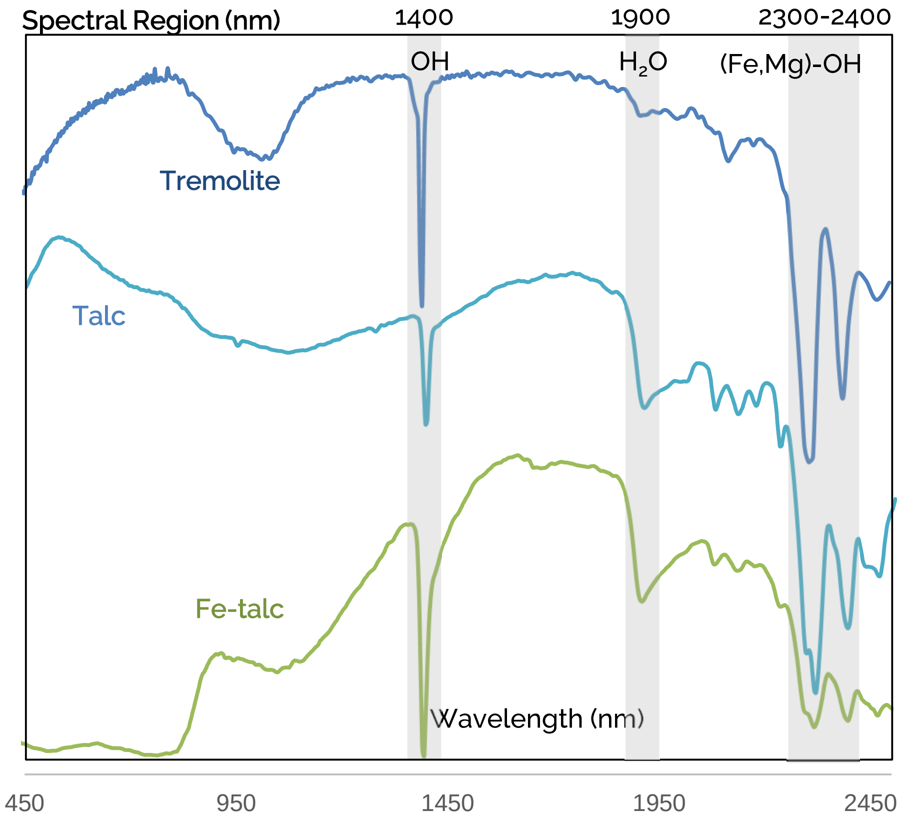
- Ultramafic units are common hosts for greenstone (orogenic) gold mineralization in many districts. Alteration typically results in Mg-rich assemblages that include minerals such as talc and tremolite (in addition to more common biotite, anthophyllite and white micas).





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Alteration Vectors: White Mica Chemistry

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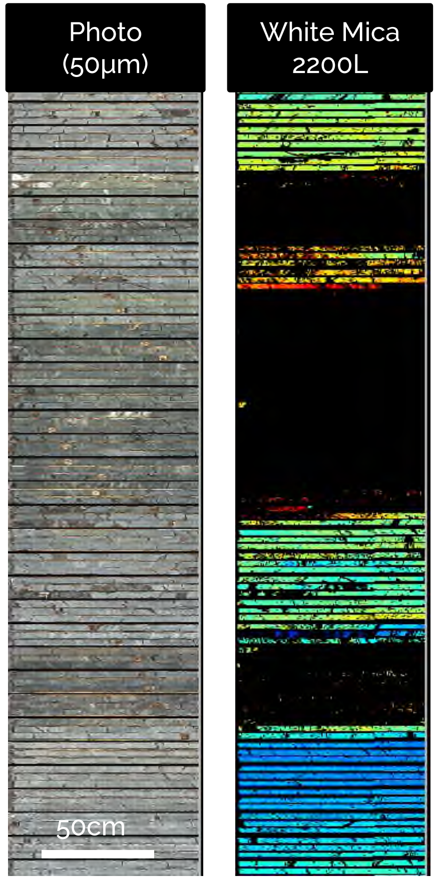
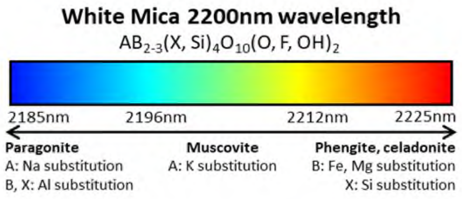
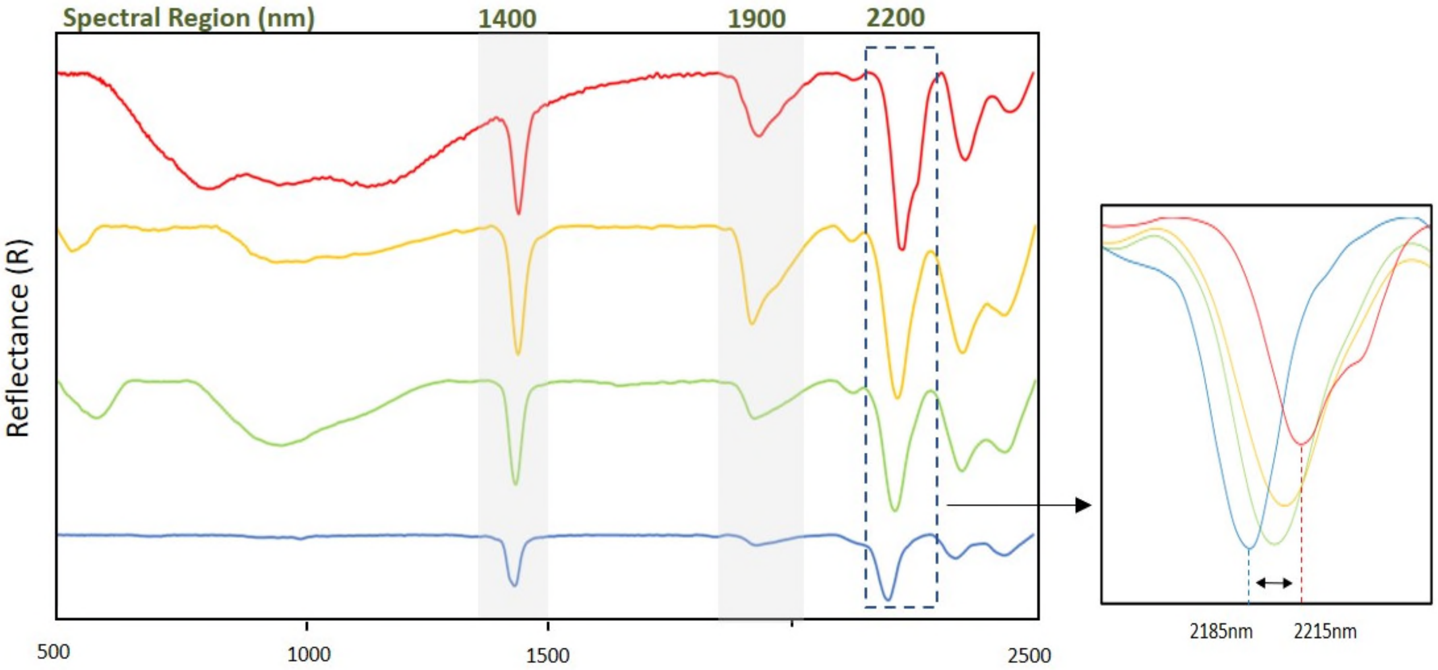
- Chemical variations in white mica group minerals are tracked using the ~2200nm absorption feature.







- The minimum wavelength position of this feature is positively correlated with Fe (+Mg+Mn) content and negatively correlated with total Al; corresponding to Tschermak substitution in both muscovite and illite.
- A range of white mica compositions, from phengite to muscovite to paragonite, can be detected based on wavelength variations of the 2200nm absorption feature.

Alteration Vectors: White Mica Chemistry

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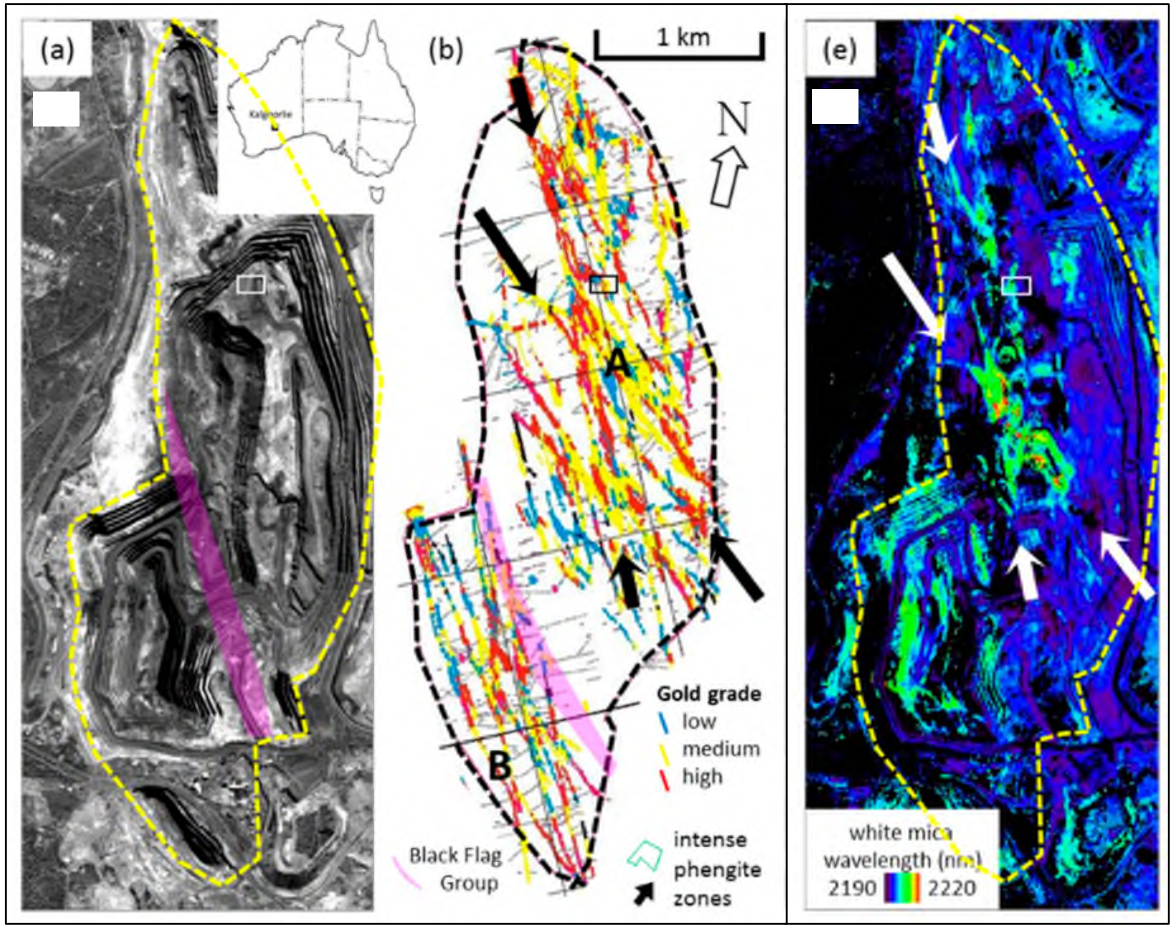
- White mica chemical variations have been recognized as effective vectors in several greenstone gold systems.
- The actual wavelength values and nature of the trend is variable, however in general, longer wavelength white micas (Al-poor micas to phengitic micas) tend to occur in proximity to gold mineralization (Neumayr et al., 2004). In some cases, however, the opposite trend may occur.
- **These factors depend on the type of ore fluids, but the occurrence of *gradients* is key for effective exploration.**



Cudahy, 2016

Kalgoorlie Superpit, Western Australia with mapped Au grade (middle) and white mica compositions (right). Major linear zones of phengite are highlighted by white arrows (Cudahy, 2016).

Alteration Vectors: Chlorite Chemistry

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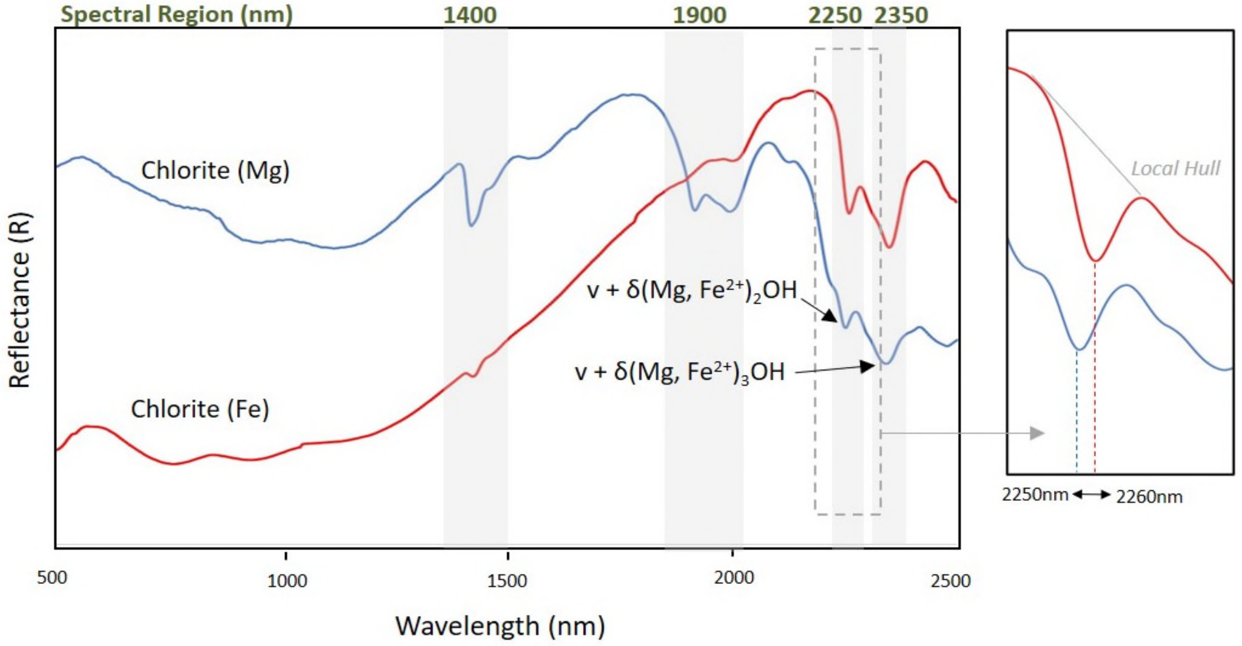
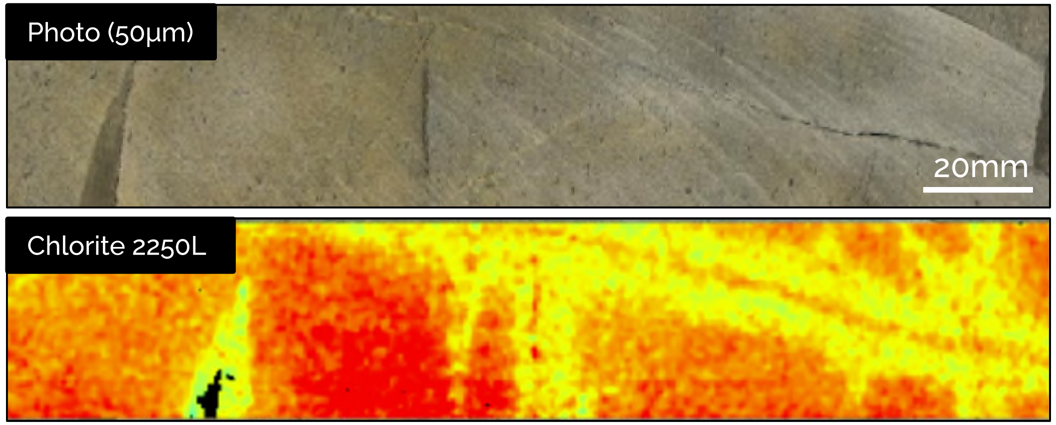
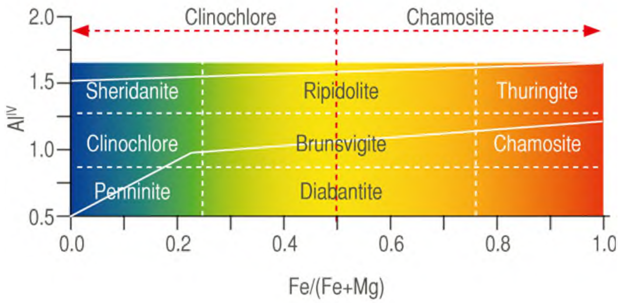
- The two main diagnostic absorption features for chlorite at ~2250nm and ~2350nm are associated with Fe-OH and Mg-OH bonds.
- The shape and position of these features vary with mineral composition (Fe/Mg substitution): Mg-rich chlorite features occur at shorter wavelengths than in Fe-rich chlorite.





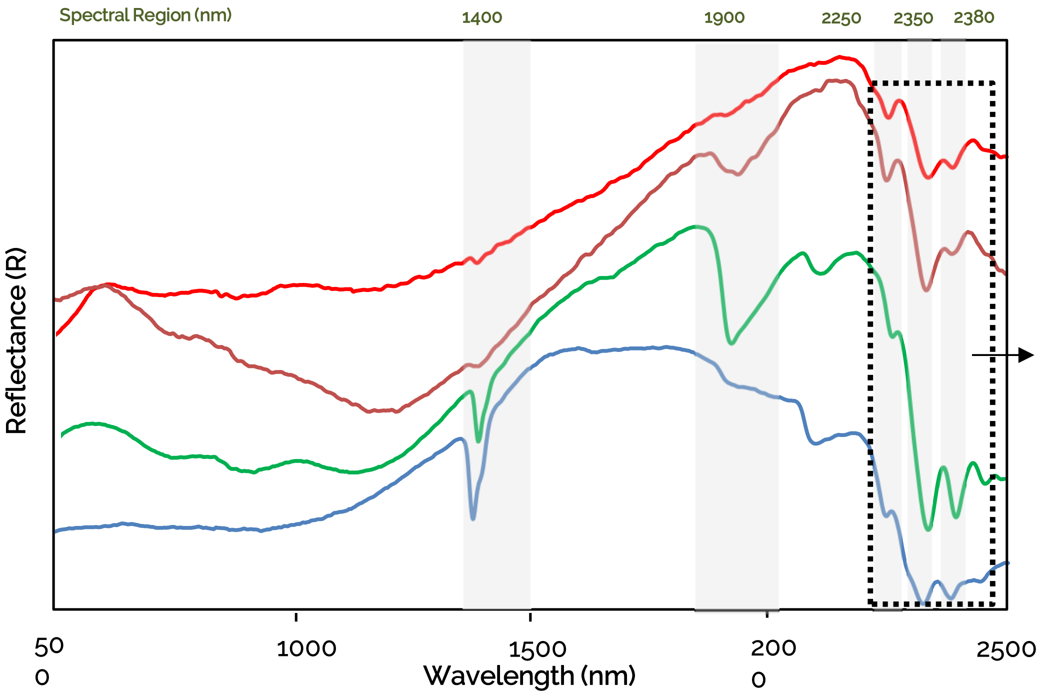
Chlorite Composition:

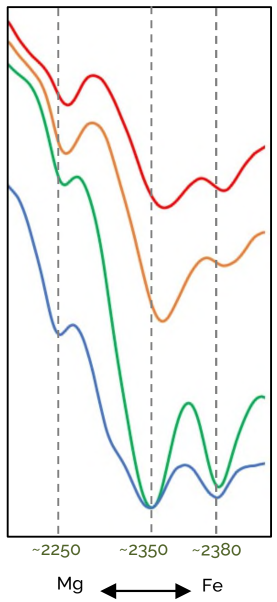


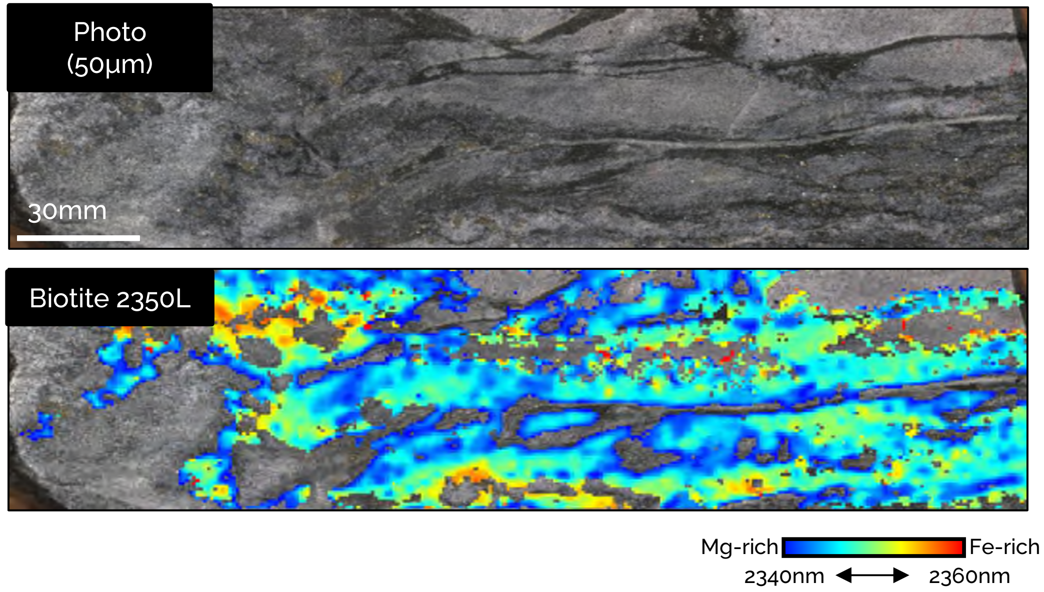
- Mg-enrichment in chlorite can occur proximal to the ore zone due to sulphidation of mafic host lithologies and the breakdown of Fe-silicates in areas of mineralization.

Alteration Vectors: Biotite Chemistry

- Variations in biotite chemistry (Fe- to Mg-rich compositions) can be determined by wavelength shifts of diagnostic features at either ~2350nm or ~2380nm, which trend to shorter wavelength values with increased Mg.







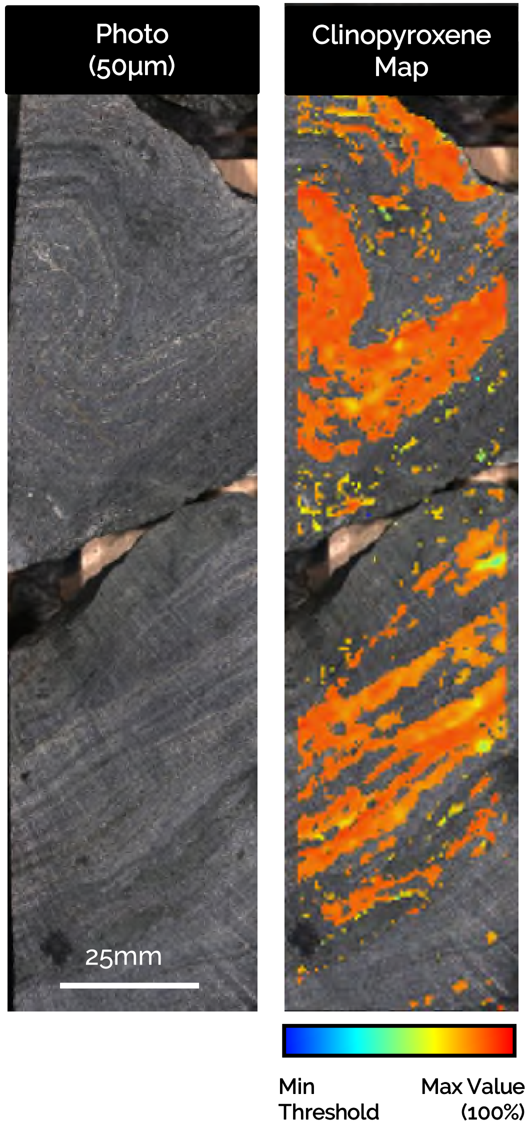
- In certain deposits, a shift in biotite chemistry is recognized as intense sulfidation within the ore zone and results in the formation of Mg-rich biotite (grading to more Fe-rich biotite away from the mineralized zone).
- *Note: The scale of these chemical trends is highly variable and are dependent on lithology, fluid pathways and intensity of alteration within each system*

Structural Features

Structural Features in Greenstone Terranes

- Greenstone deposits are characterized by strong structural controls. The nature of ore zones will vary depending on the metamorphic grade, host rocks and stress regimes (local and regional).
- Key structural features typically include:
  - Zones of anomalously high strain within a deformation zone.
  - Pre-existing structural anisotropies.
  - A preferred lithology, where a strong competency contrast exists between adjacent rock types.
  - Fold limbs and fold noses.

The imaging capabilities of the Corescan HCI systems allow for the integration of mineralogical data with textural information to better define and understand structural characteristics.



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Structural Features: Ductile Deformation

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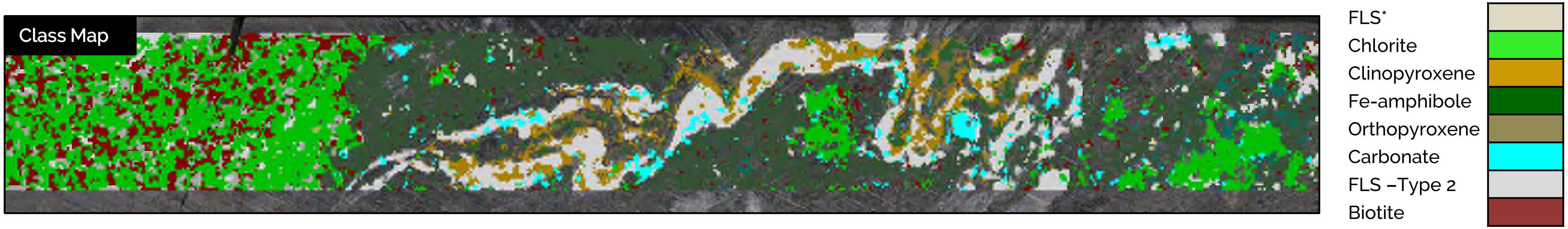
- Greenstone deposits generally have complex structural histories and can involve many different stages of deformation – including ductile shearing and folding.
- Phyllosilicate-rich mineralogy favors a strong ductile response during deformation and the occurrence of micas, chlorite, biotite and serpentine can be mapped using VNIR and SWIR features.



Link to MDNR Dataset

*FLS denotes 'FeatureLess Slope' spectra with no diagnostic absorption features. Likely represents quartz and/or feldspar occurrences.

Structural Features: Brittle-Ductile Deformation

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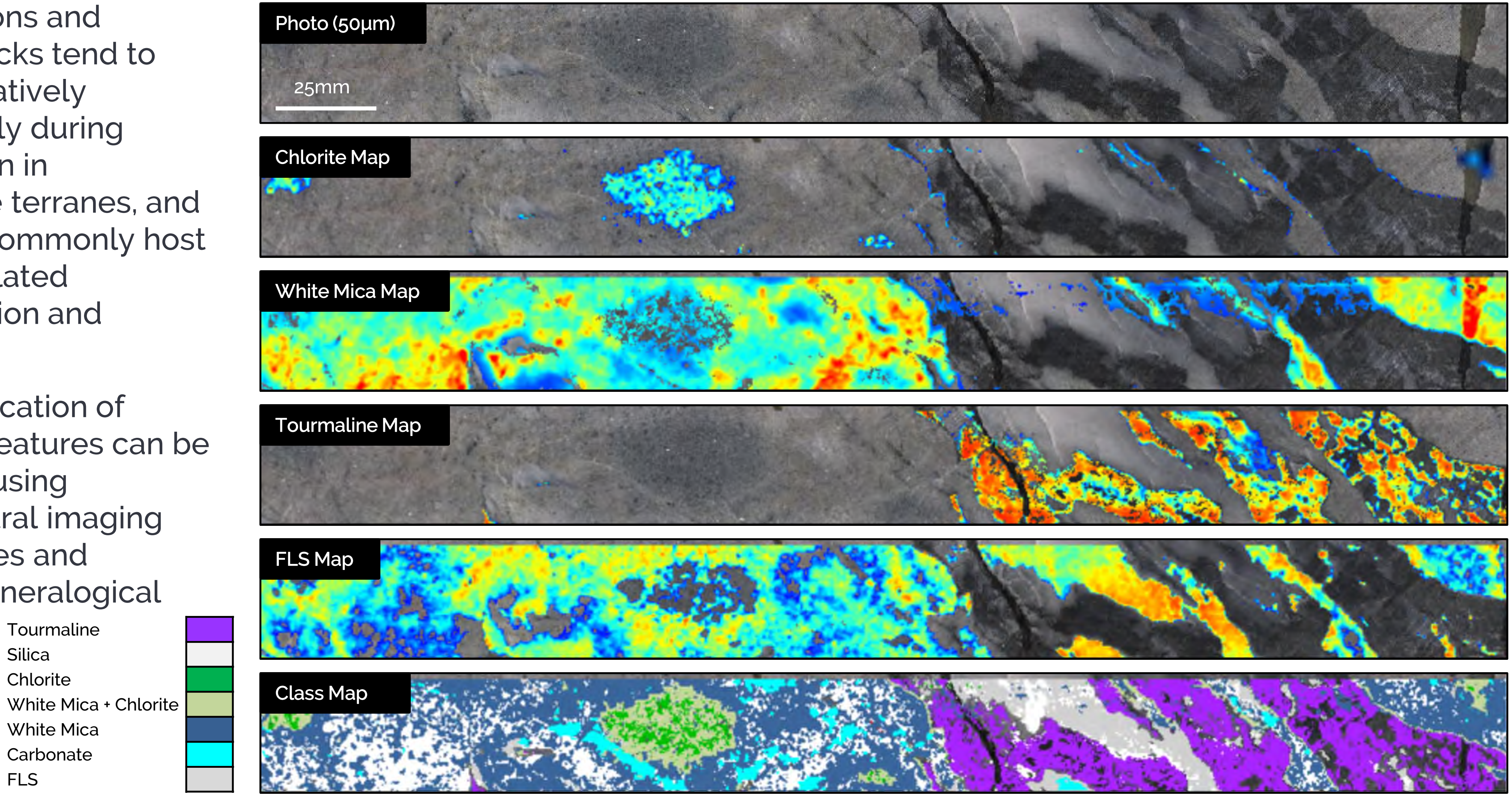
- Felsic plutons and volcanic rocks tend to behave relatively competently during deformation in greenstone terranes, and therefore commonly host fracture-related mineralization and alteration.
- The identification of structural features can be enhanced using hyperspectral imaging technologies and detailed mineralogical mapping.



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Detection and Mapping of Faults

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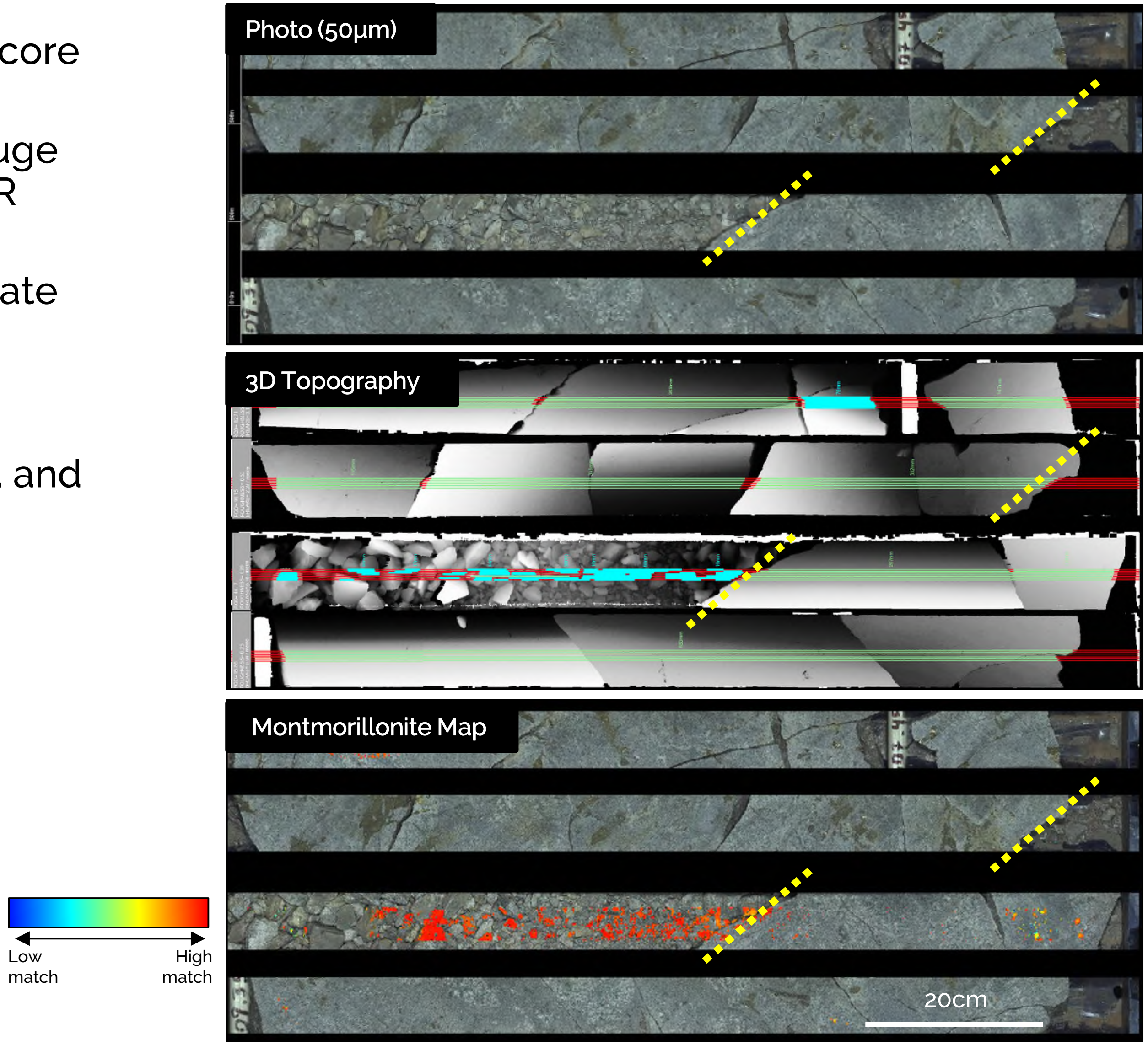
- Sharp mineralogical changes and rubble zones in the core may indicate the presence of faults and fault gouge.
- Clays (smectites, kaolinite, illite) are common fault gouge minerals, all of which are identified by diagnostic SWIR features.
- Laser profiler (3D topography) data can used to calculate simple geotechnical variables (labelled 'pseudo' to distinguish these from traditional geotechnical measurements).
- Average breaks per meter, surface roughness proxies, and pseudo-RQD values are products calculated from the surface profiler measurements.

Image Label	Description
RQD	Σlength core>10cm/total length of core interval (after Deere et al., 1957)
Breaks	Fracture identification via detection of core heights below a set gradient threshold limit (includes both natural and mechanical breaks)
Roughness	Based on variations in height along the core surface (below a set gradient threshold)



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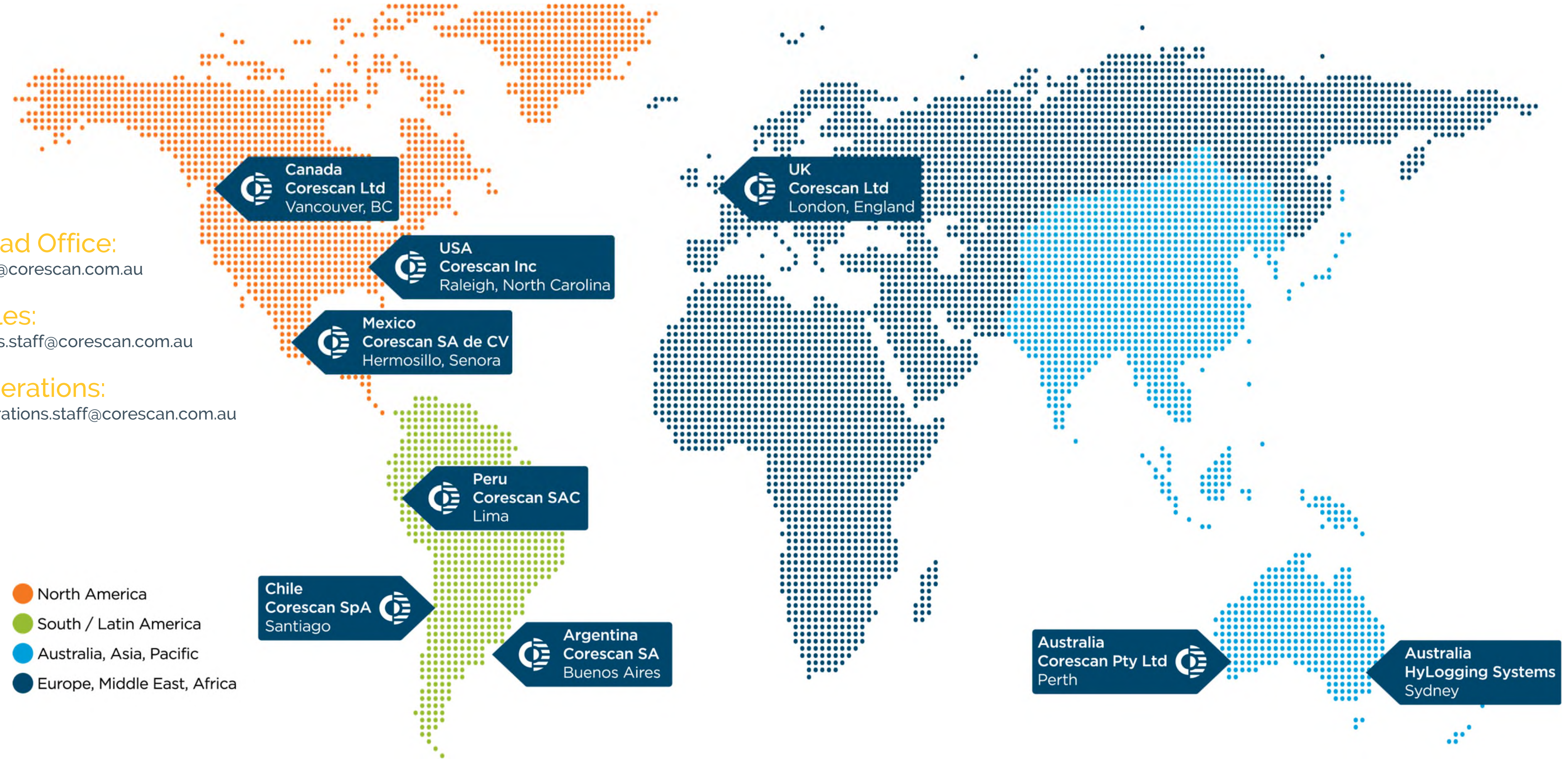

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