HYPERSPECTRAL CORE IMAGING APPLICATIONS

- PORPHYRY DEPOSITS -

September 2021

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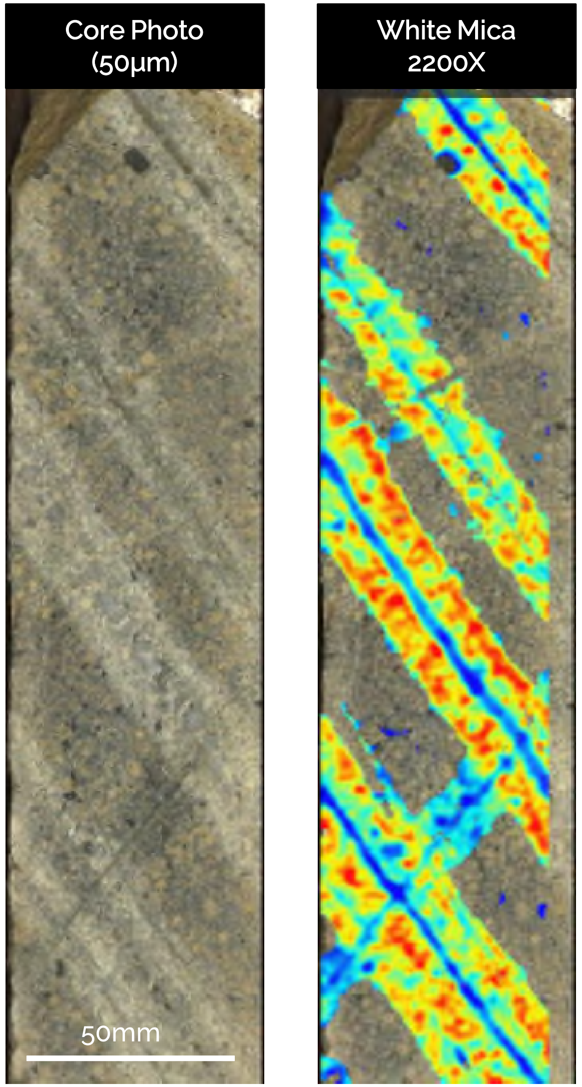
Contents



Hyperspectral Core Imaging Services

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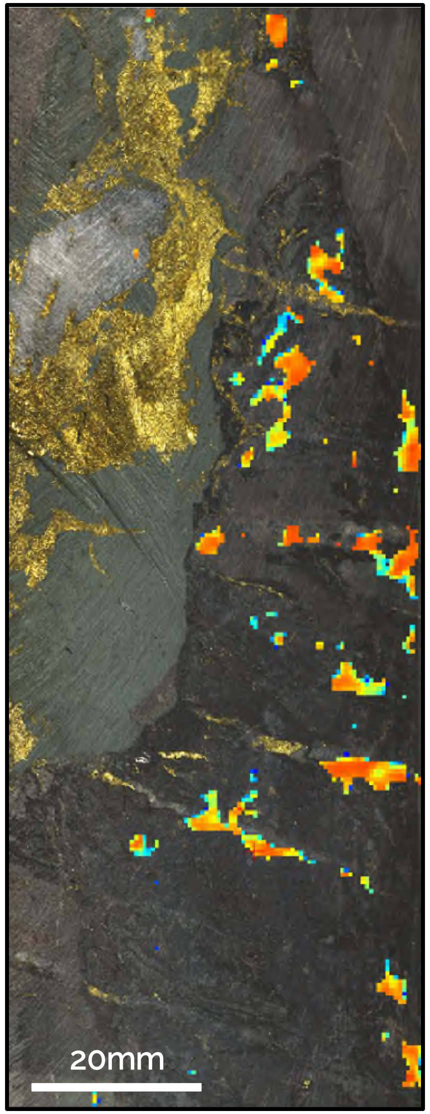
Mineral identification and mapping across the mining cycle:

- 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) integrates high resolution reflectance spectroscopy, visual imagery and 3D surface 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 / 1.5 million metres successfully scanned, processed and delivered…



Hyperspectral Core Imaging: Material Types

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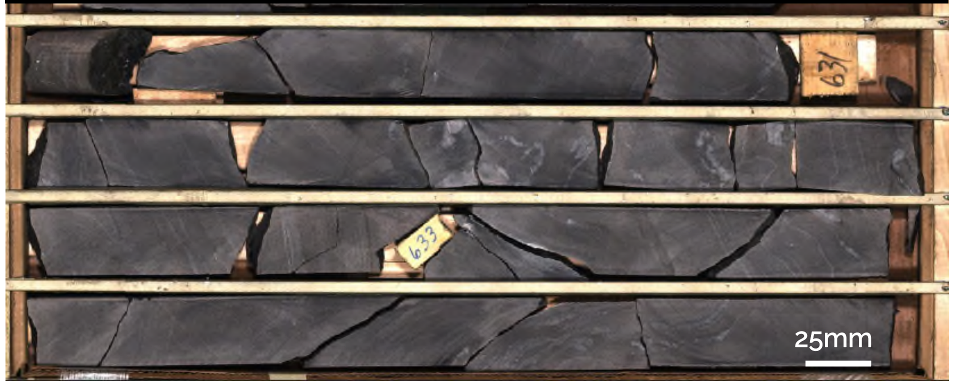
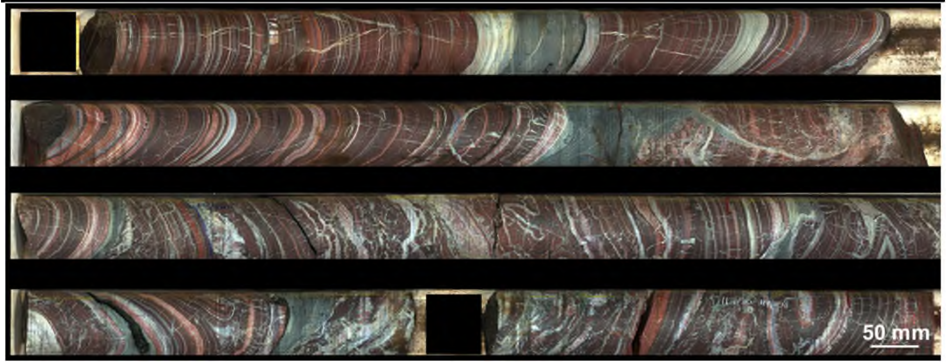
Cut / split core



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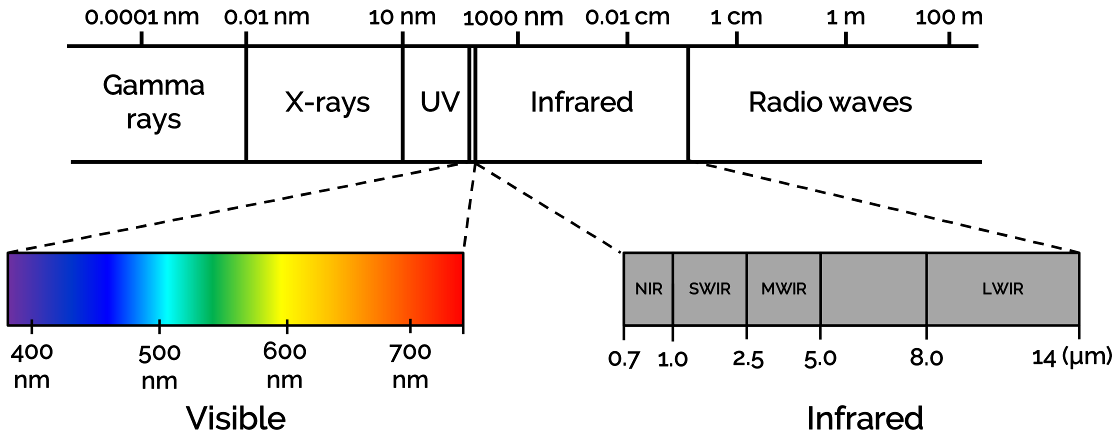
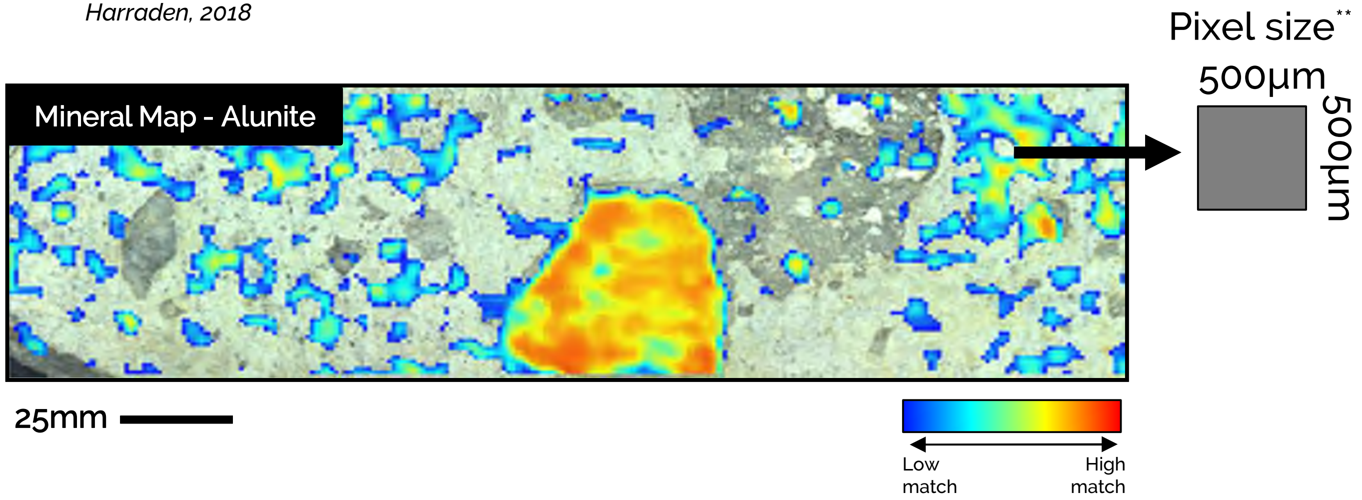
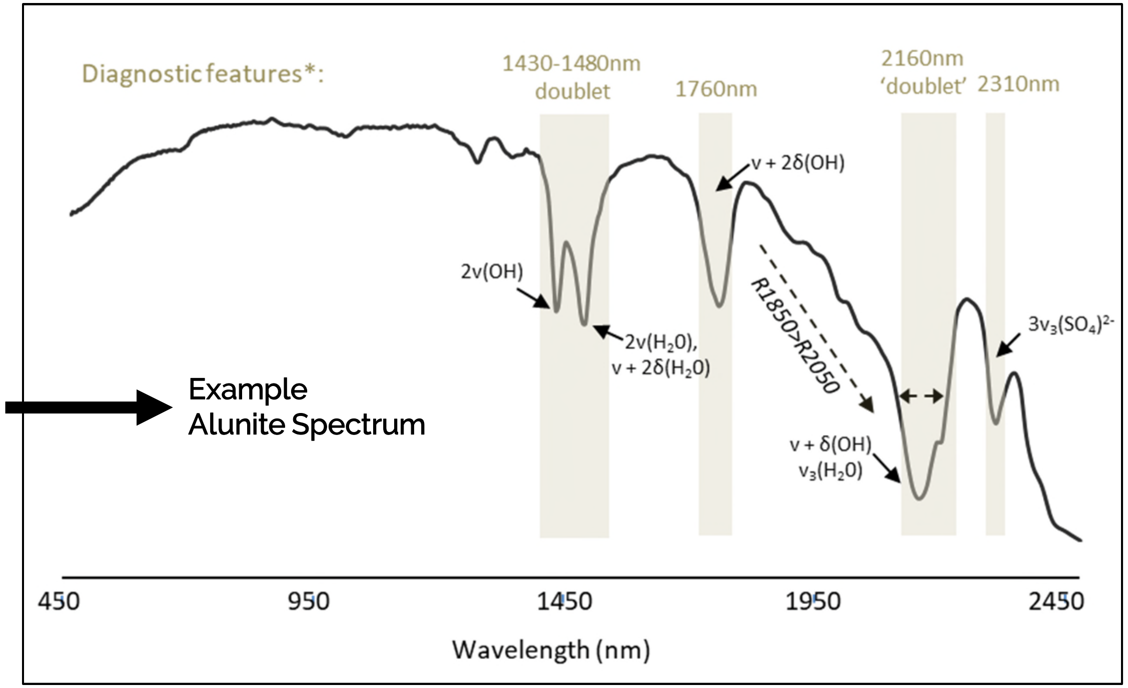
- Corescan's proprietary spectrometers measure hundreds of contiguous, narrow bands across the electromagnetic spectrum from 450nm to 2500nm, covering the Visible-Near Infrared (VNIR) and Short-Wave Infrared (SWIR) regions.



Harraden, 2018

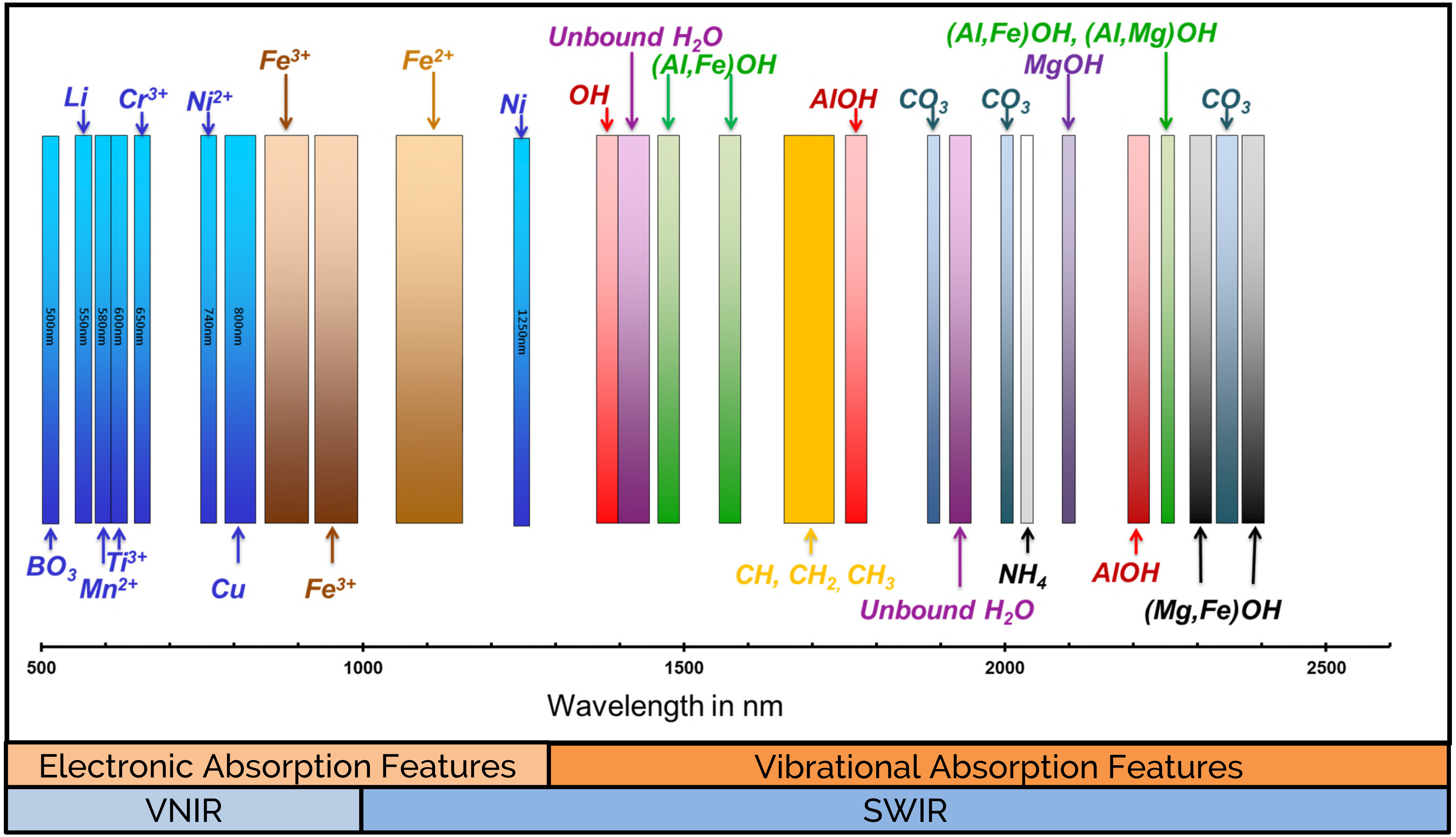
- The surface of the core is imaged at ~250,000 pixels per meter*; with each 500µm x 500µm pixel* measuring a unique spectral signature.





*HCI-3 instrument specifications ** Not to scale

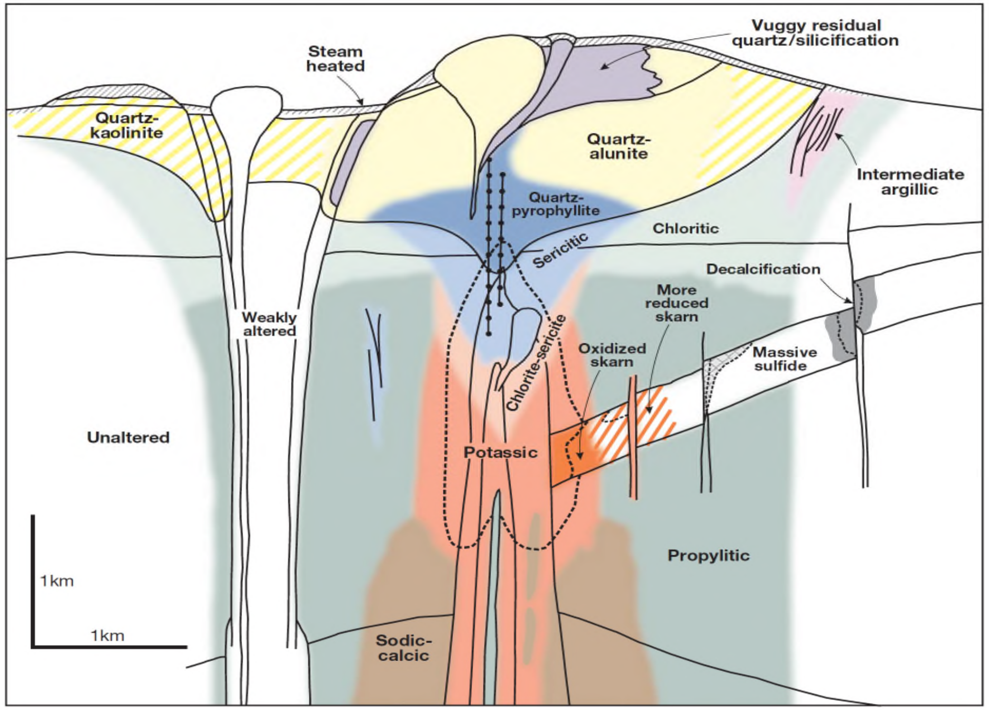
VNIR-SWIR: Electronic and Vibrational Features



ACON0014

Porphyry Deposits

- Porphyry deposits are associated with subduction zone magmatism and are broadly grouped into calc-alkaline and alkaline sub-types.
- They are formed in arc-related settings and associated with subduction zone magmas.
- They are clustered in discrete mineral provinces, which implies that there is some form of geodynamic control or crustal influence affecting the location of porphyry formation. They tend to occur in linear, orogen-parallel belts.
- The style of mineralization varies greatly between deposits (stockwork veining, breccias, disseminated), characterized by a porphyritic intrusive complex that is surrounded by a vein stockwork and hydrothermal breccias.
- Magmatic-hydrothermal alteration is characterized by abundant sulfides zoned from Cu sulfide rich in ore zones to pyrite rich in upper zones (Halley et al., 2015).
- They tend to be low grade but large tonnage.



Sillitoe, 2010

Porphyry Deposits - Alteration Mineralogy

Alteration Zonation in Porphyry Deposits

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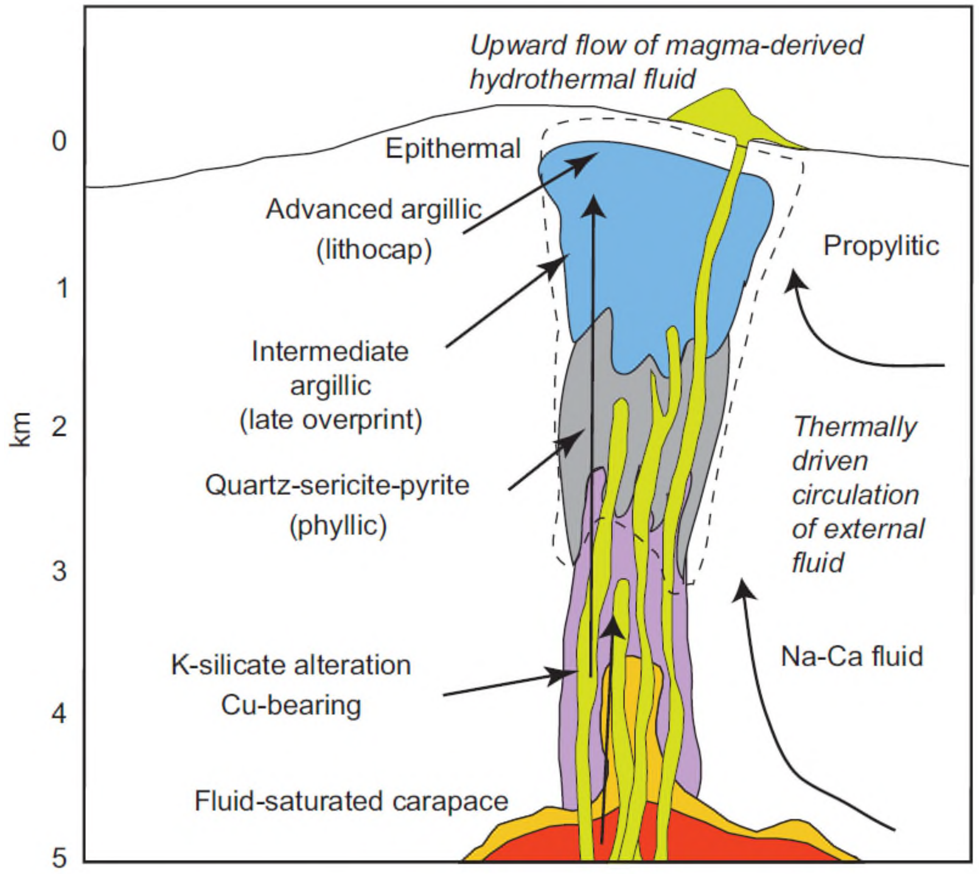
- High-temperature fluids alters the rock to mineral assemblages consisting of quartz, K-feldspar, biotite, anhydrite and magnetite (potassic alteration assemblage).
- Superimposed on the high-temperature alteration assemblages in the upper parts of the porphyry system are alteration assemblages that reflect progressive cooling and changing physicochemical conditions (Tosdal et al., 2009):
  - Quartz + white mica ± chlorite
  - Advanced argillic lithocap
  - Overprinting intermediate argillic alteration.



(Tosdal et al., 2009)

Alteration Zonation in Porphyry Deposits

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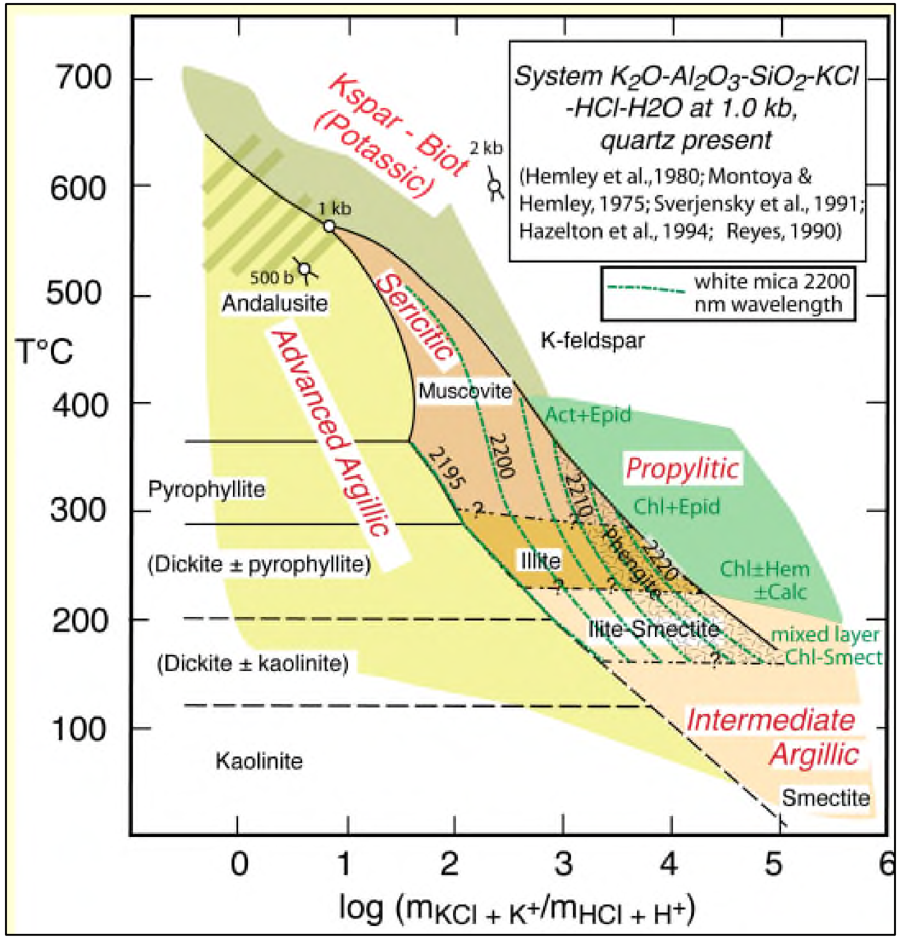
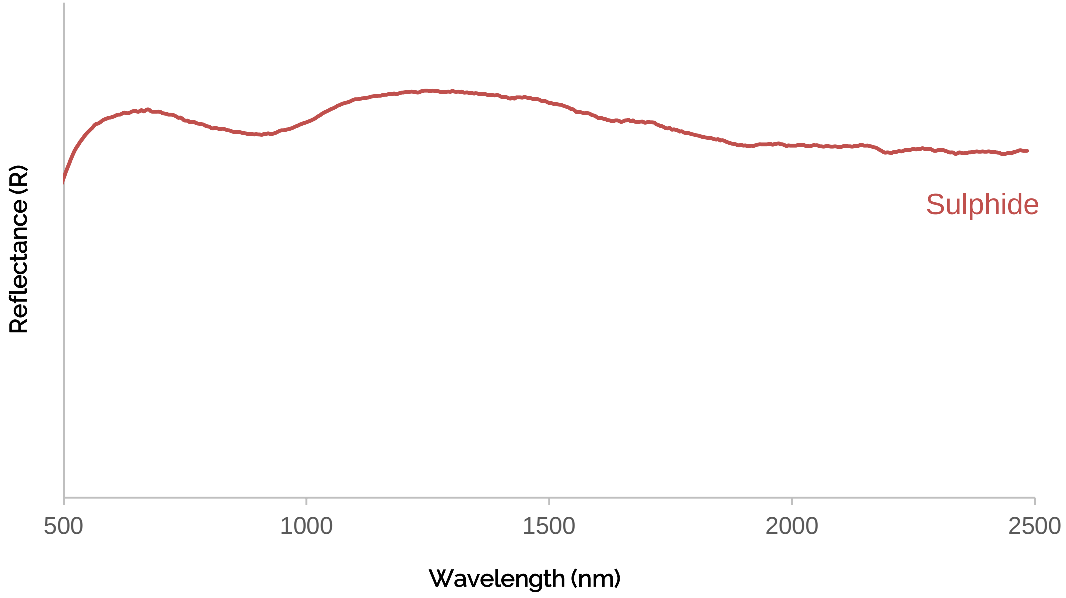
- Explanations of the physicochemical conditions to form porphyry style assemblages are explained in detail below and highlighted in the diagram at right, which includes white mica wavelengths measured in the SWIR.
- Quartz, white mica (either muscovite, phengite or in rare cases paragonite) and pyrite (i.e. phyllic alteration); when rocks are Mg/Fe-rich chlorite is present. This assemblage forms through cooling of the fluid as it rises buoyantly (Tosdal et al., 2009).
- Pervasive clays represent a low-temperature (<250˚C) intermediate argillic alteration assemblage formed during the cooling and collapse of the hydrothermal system (Tosdal et al., 2009).
- Intense acid leaching at shallow depths forms advanced argillic alteration that may or may not be associated with epithermal deposits. This alteration is characterized by the total destruction of primary minerals, leaving an insoluble residue of quartz, clays (kaolinite or pyrophyllite), aluminum hydroxides (diaspore) and alunite; this is also known as a leach cap (Tosdal et al., 2009).
- Late intermediate argillic alteration (smectite-illite-chlorite or smectite-chlorite) forms at low temperature and introduces little sulfide but may extensively overprint higher-temperature assemblages (Halley et al., 2015).

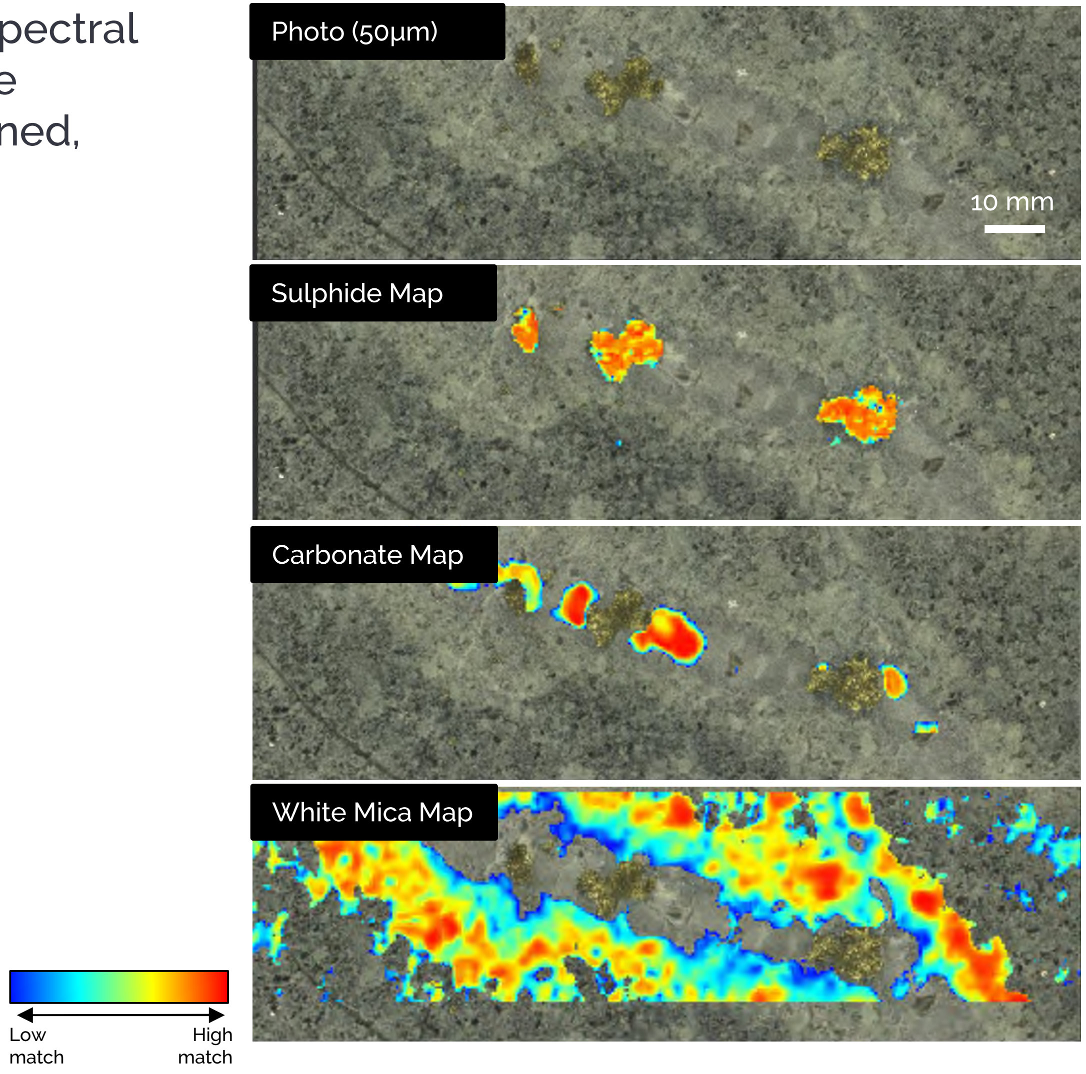


(Halley et al., 2015)

Ore Zone Alteration & Mineralization: Fe-Sulphides

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





Ore Zone Alteration & Mineralization: Molybdenite

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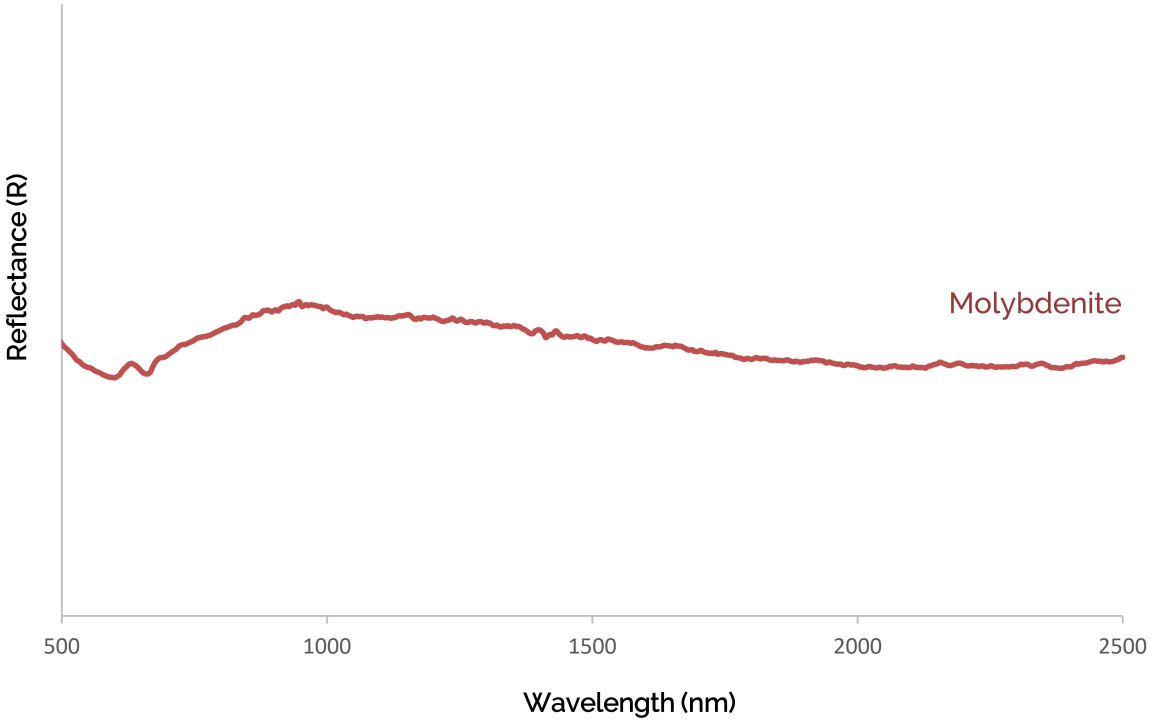
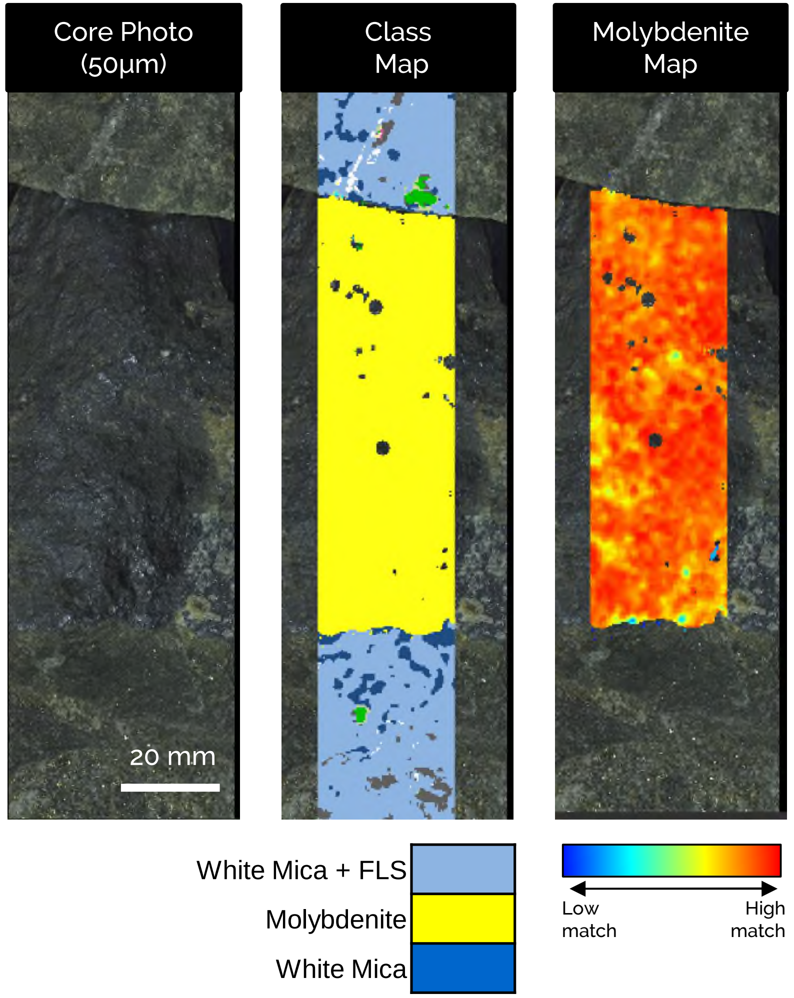
- Molybdenite is one of the few sulphides that has diagnostic spectral absorption features in the VNIR-SWIR range with spectral features attributed to Mo.





Ore Zone Vectors: White Mica Chemistry

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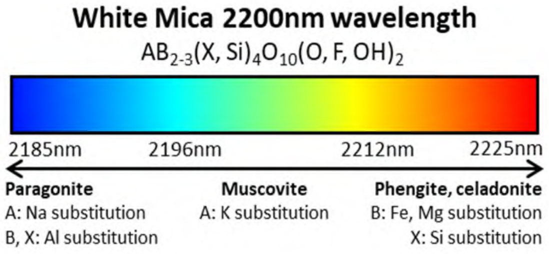
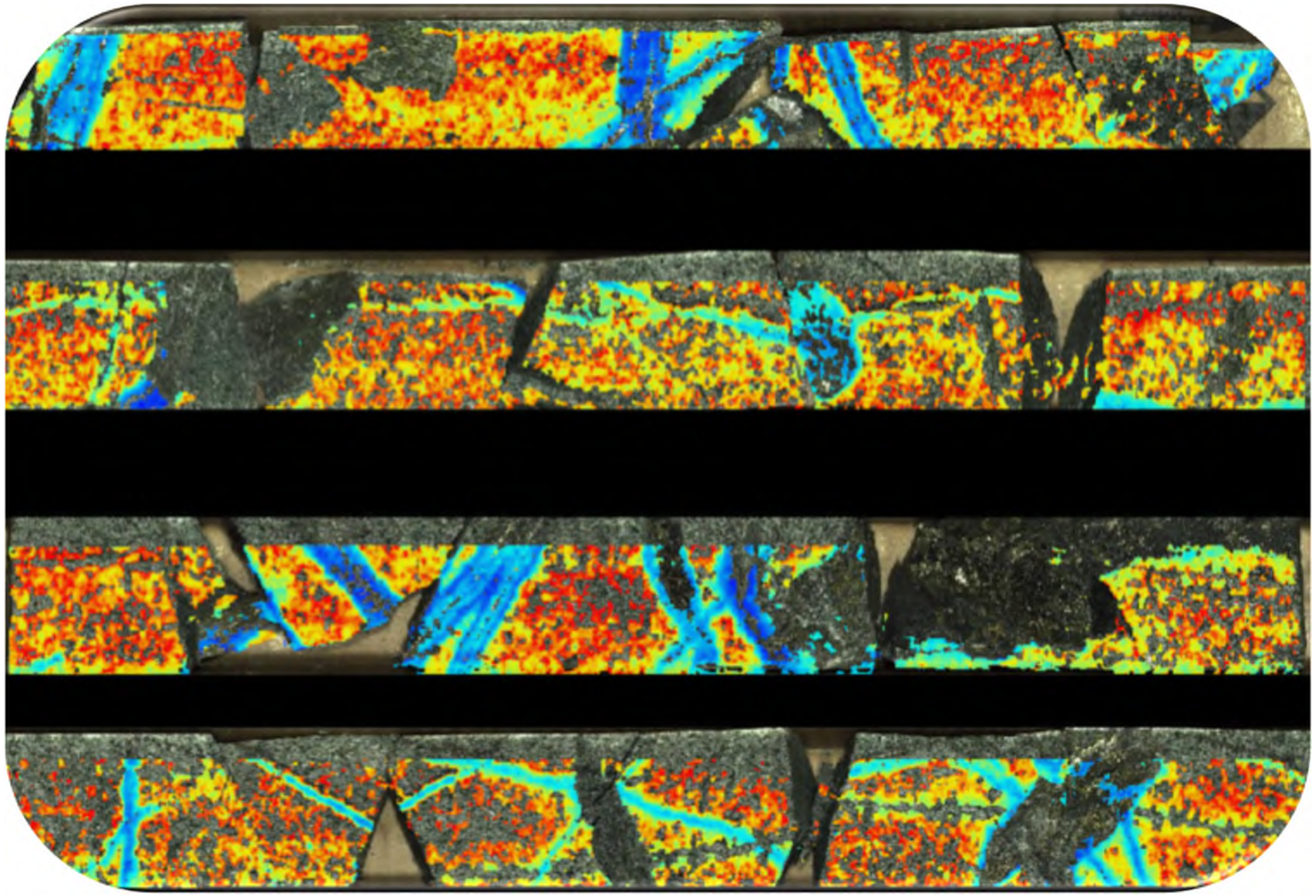
- In many porphyry deposits, the central potassic domain hosts the bulk of the ore (Cooke et al., 2014 and references therein).
- Increasingly the “phyllic” domain (quartz-muscovite-pyrite+/-chalcopyrite) and “sericitic” alteration is recognized as a significant contributor to the resource of a deposit (Benavides et al., 2018).
- High-temperature green / gray sericite often observed in Andean porphyries can be a vector to high grade and grade-bearing intervals.





White mica wavelength map from a Cu-Mo porphyry deposit, Chile. Lower wavelength white micas can be seen to halo sulphide veins.

Secondary Ore Minerals

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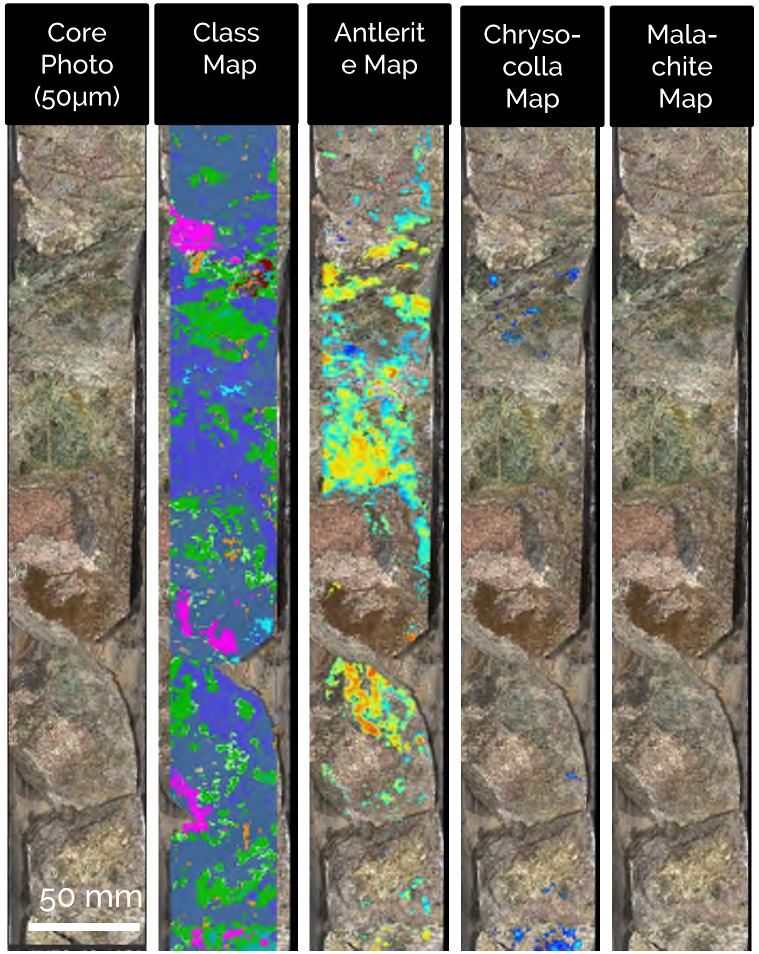
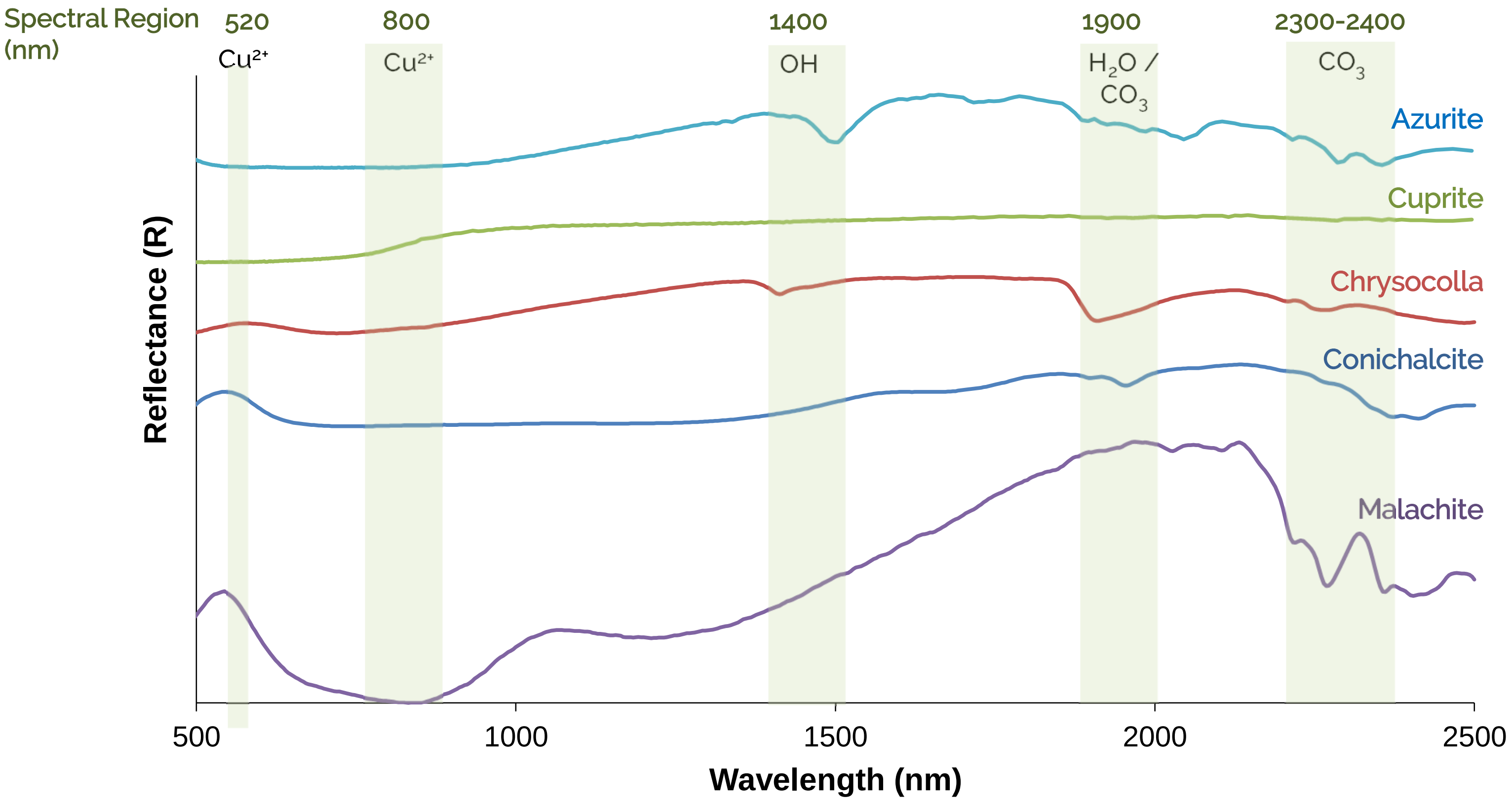
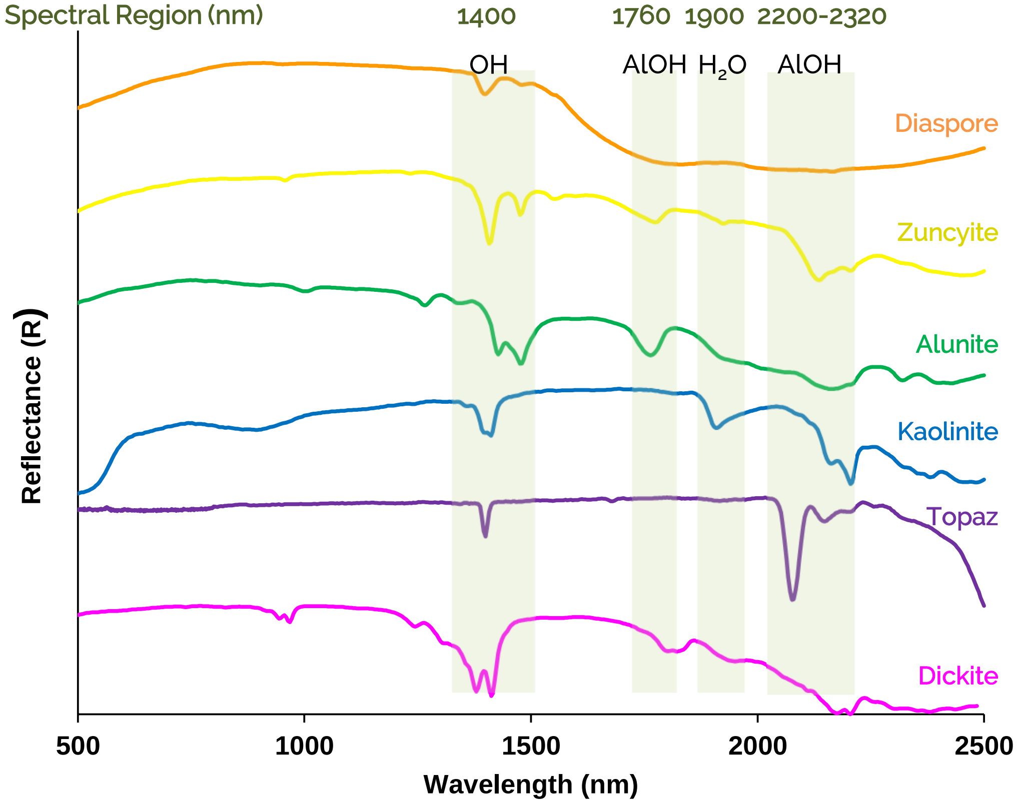


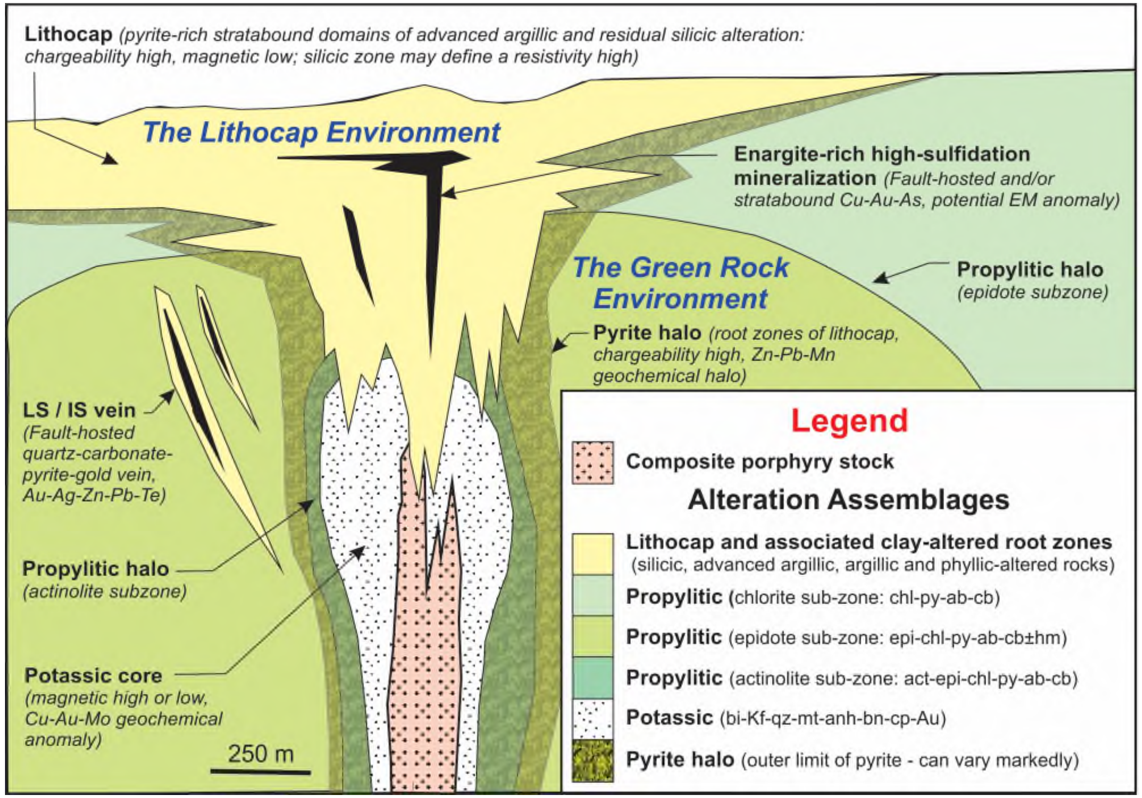
- Corescan is able to map a range of secondary copper oxides, carbonates and sulphates commonly found in porphyry supergene environments.



Lithocap Mineralogy

- Lithocaps are broadly stratabound alteration domains that are laterally (>10km) and vertically (~1km) extensive that may overlay porphyry deposits.
- The application of VNIR-SWIR spectroscopy is an effective vectoring tool for lithocaps.

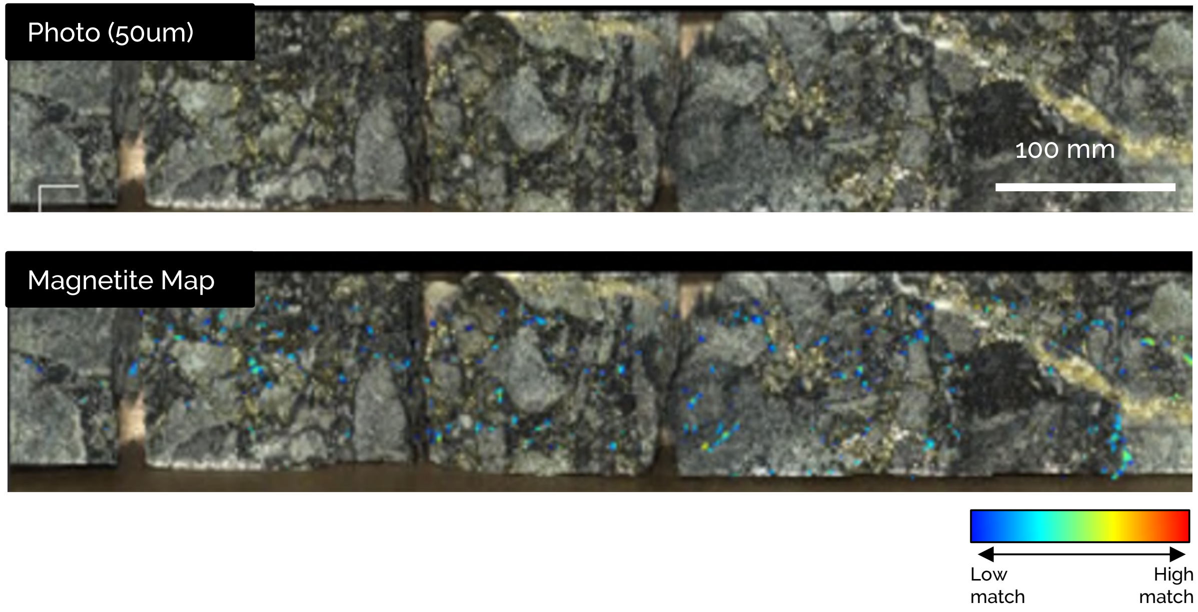


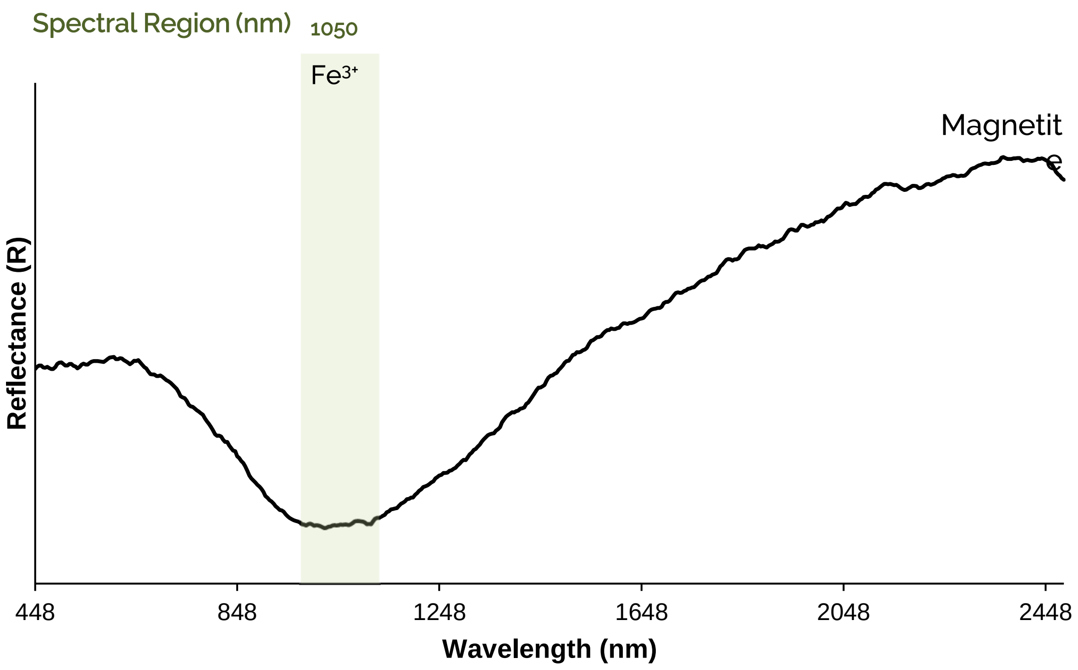


Cooke et al., 2015

Proximal Mineralogy: Magnetite

- Magnetite has a single distinct absorption feature in the VNIR-SWIR range, and when present in a mixture with other Fe-bearing minerals, can be difficult to identify.
- With high spatial resolution hyperspectral imaging, magnetite is more readily identifiable, particularly when coarser-grained and/or present in veins.





Biotite and Chlorite

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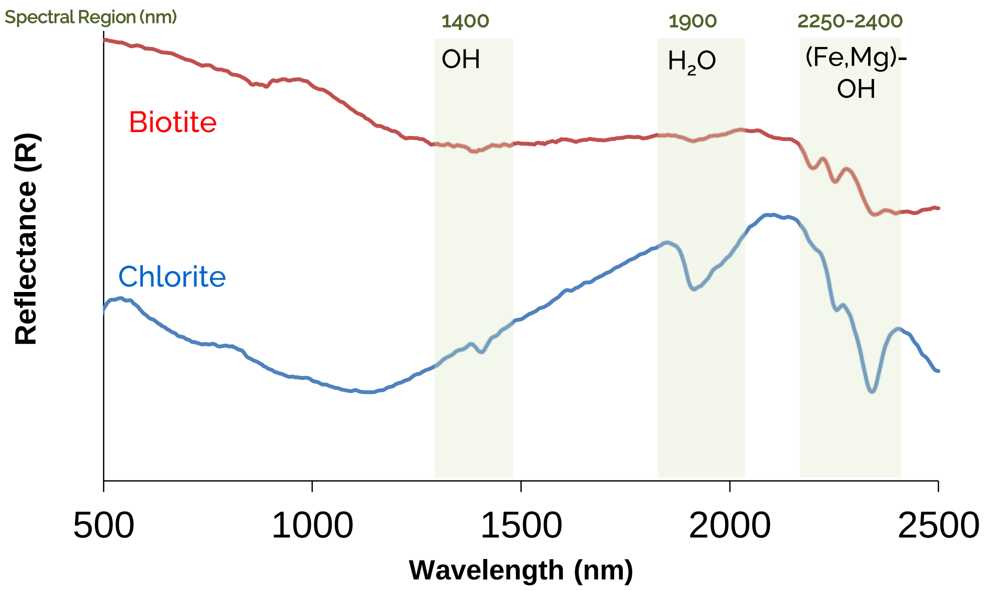
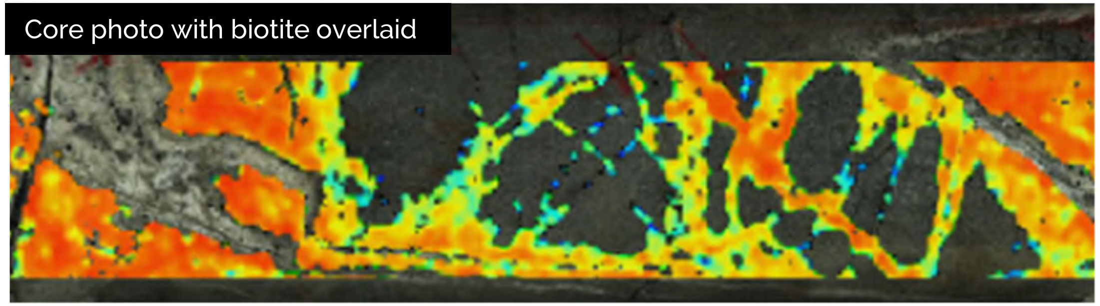
- Biotite is a characteristic potassic zone mineral of global porphyries; either as a primary mineral or as hydrothermal "shreddy" biotite; an alteration product of biotite or amphibole. Chlorite may also reside in the potassic alteration zone as a retrograde overprint of mafic minerals, in particular biotite.
- Biotite and chlorite-group minerals are readily identifiable using high resolution VNIR-SWIR spectroscopy, with features that correlate to Fe/Mg content.





Proximal Mineralogy: Gypsum / Anhydrite

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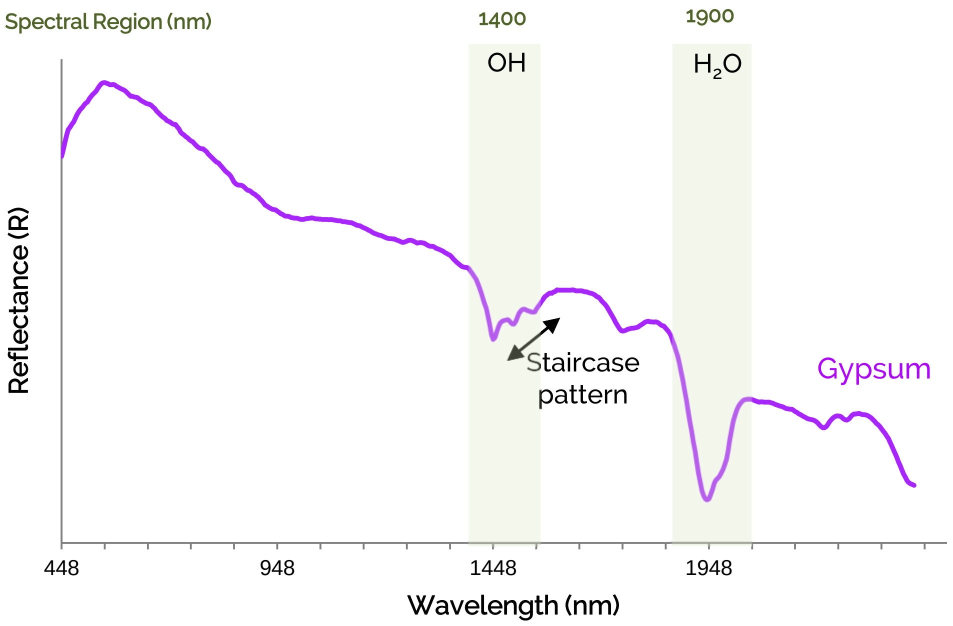
- In porphyry copper systems, anhydrite is a common hypogene mineral occurring in both the matrix and veins. Gypsum is a common fracture-filling mineral.
- The anhydrite/gypsum VNIR-SWIR spectrum is characterised by multiple H_2O absorption features, the most characteristic being the 'triplet' feature around 1440nm.
- Although visually a mineral may resemble anhydrite, the hydration of the mineral during the drilling process readily transitions anhydrite to gypsum, making it difficult to identify original anhydrite (from gypsum) using VNIR-SWIR.



Proximal Mineralogy: White Mica

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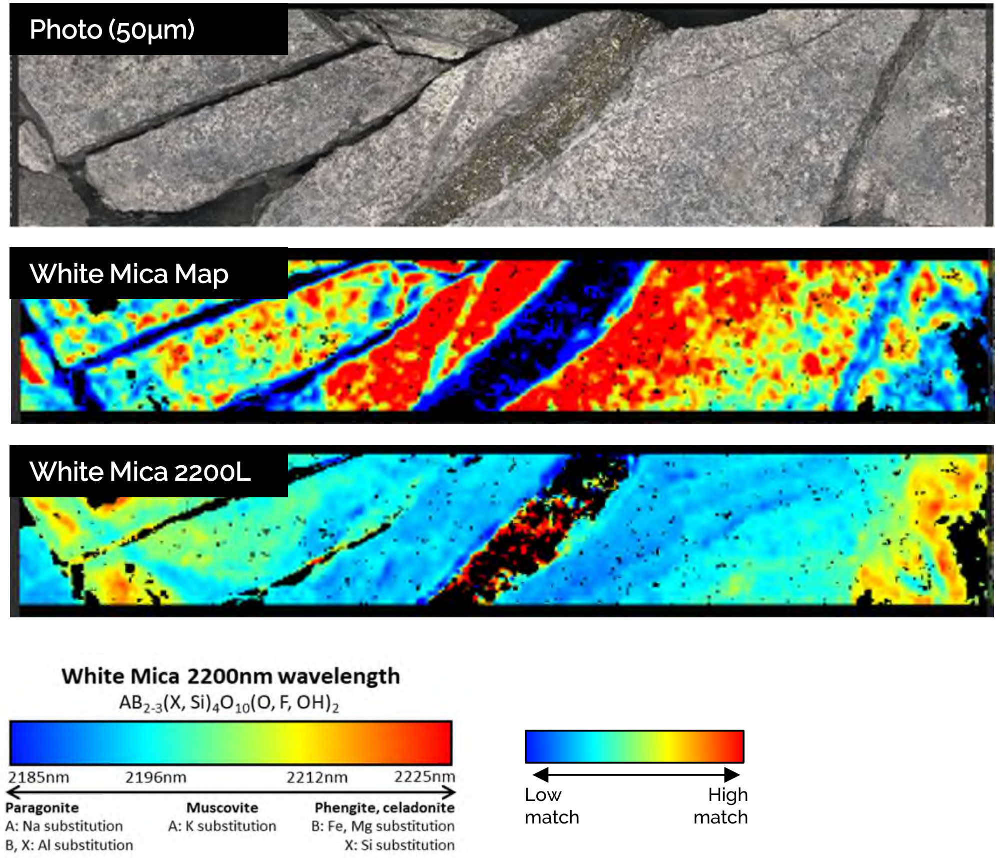
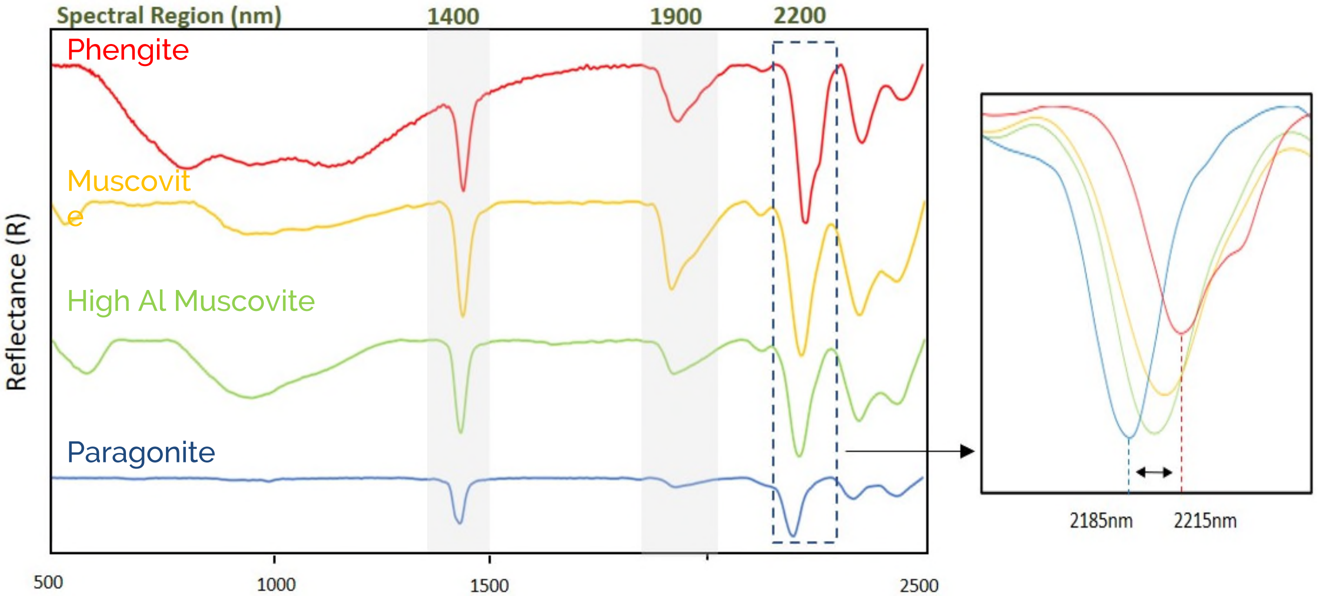
- Compositional variations in white mica group minerals are measured using the ~2200nm absorption feature.





- The wavelength position of the 2200nm 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, are measured using the wavelength of the 2200nm absorption feature.

Proximal Mineralogy: Tourmaline

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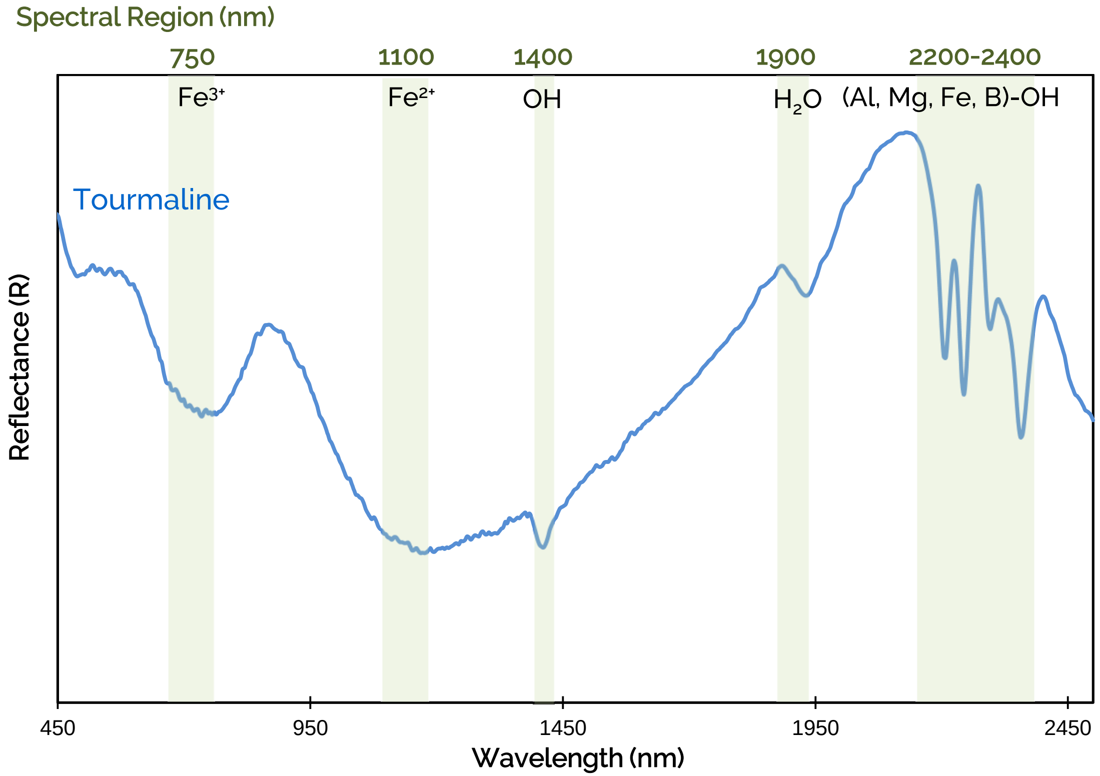
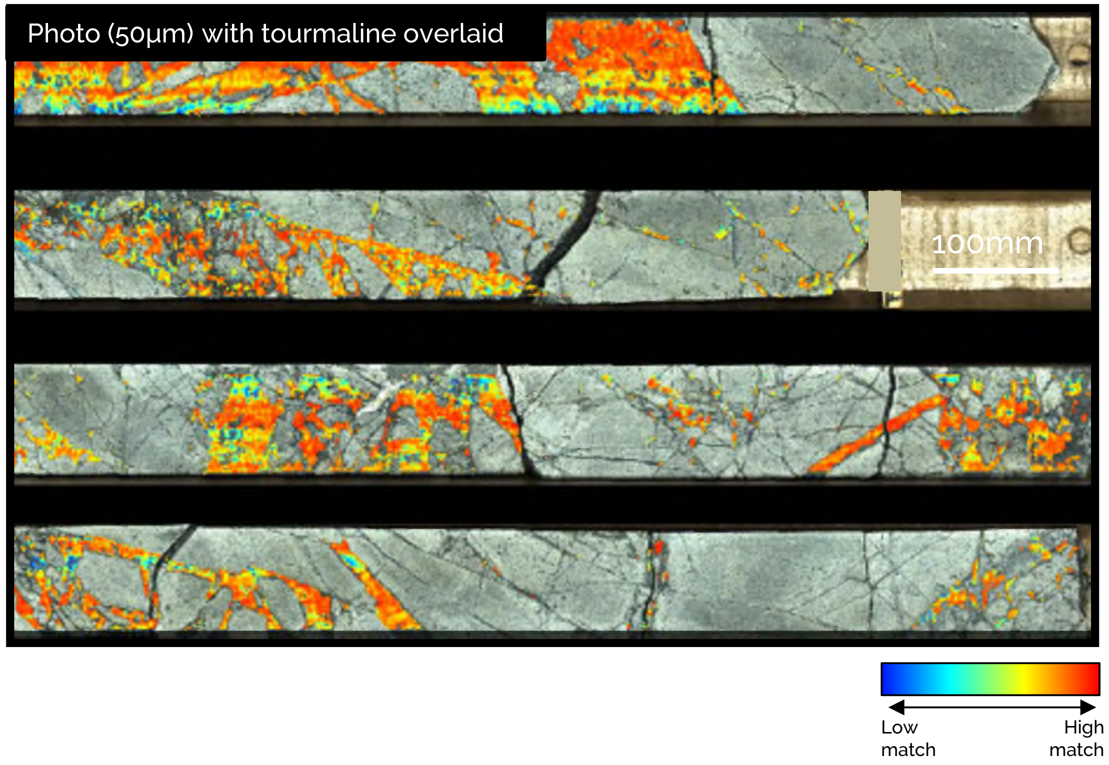
- Tourmaline is a common phase in porphyry deposits, particularly in hydrothermal breccias. It can be associated with grade.
- Tourmaline has several diagnostic SWIR features and is readily identified using high resolution imaging.





“Featureless Slope”: Quartz and Feldspar

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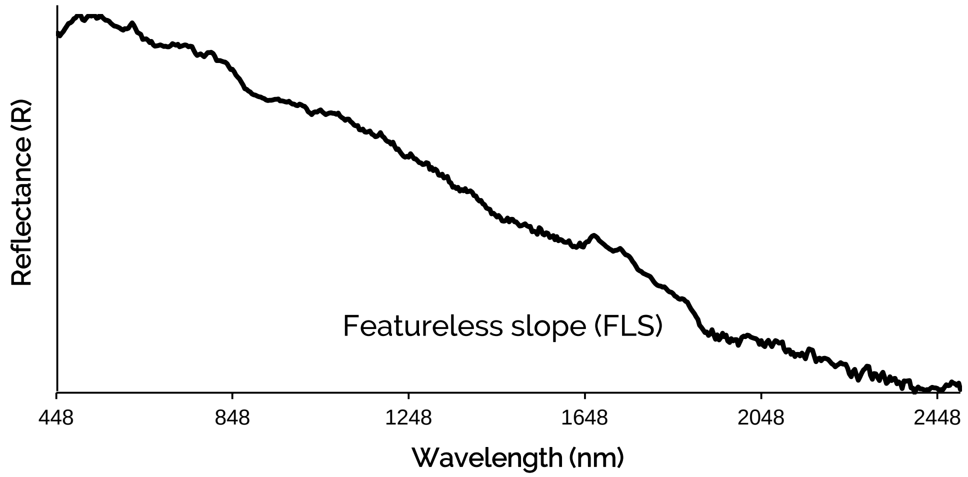
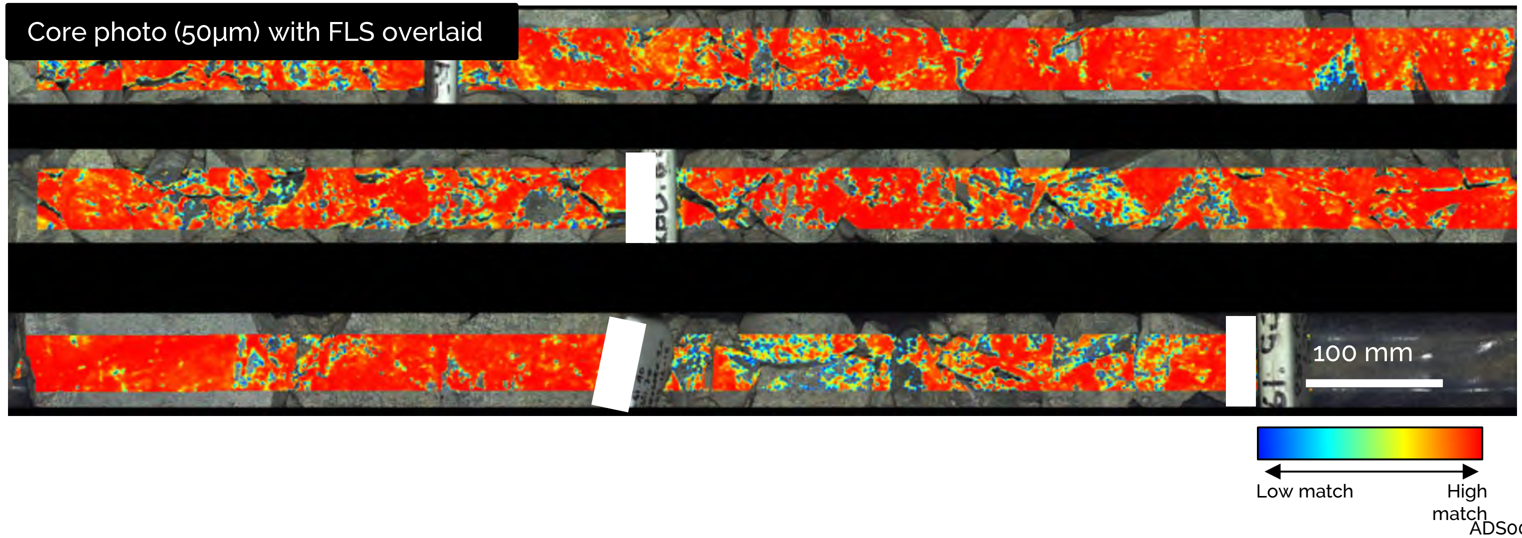


- The spectrum of the featureless slope (FLS) class displays no distinguishable absorption features, although the negative slope between ~850nm and ~2400nm is the diagnostic feature.
- The presence of FLS may indicate **silicification** and/or be attributed to **feldspar**.

- The interval shown on the image to the right, is silicified and is mapped by the FLS class.
- It is unknown whether the silica was added hydrothermally or was produced as the result of another alteration event



ADS0005

Overprinting and Distal Alteration: Smectites

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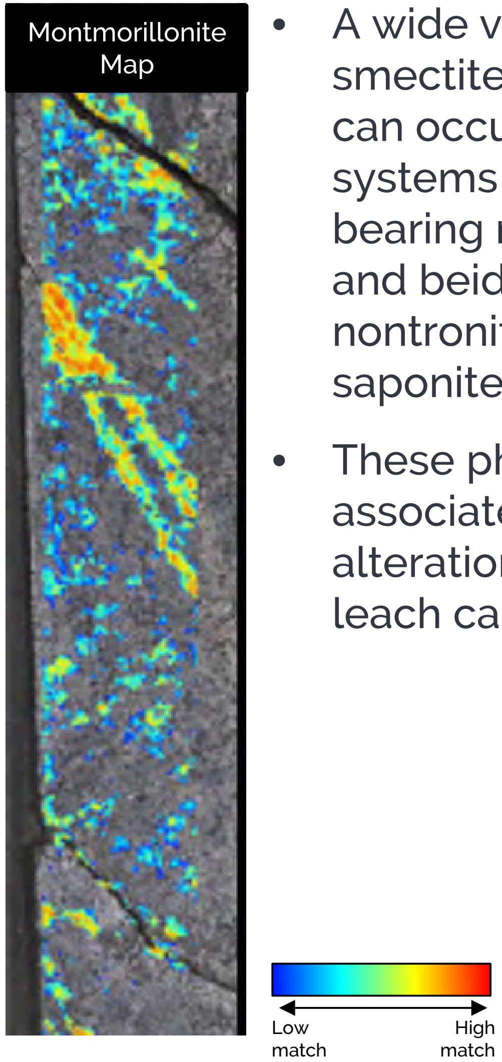
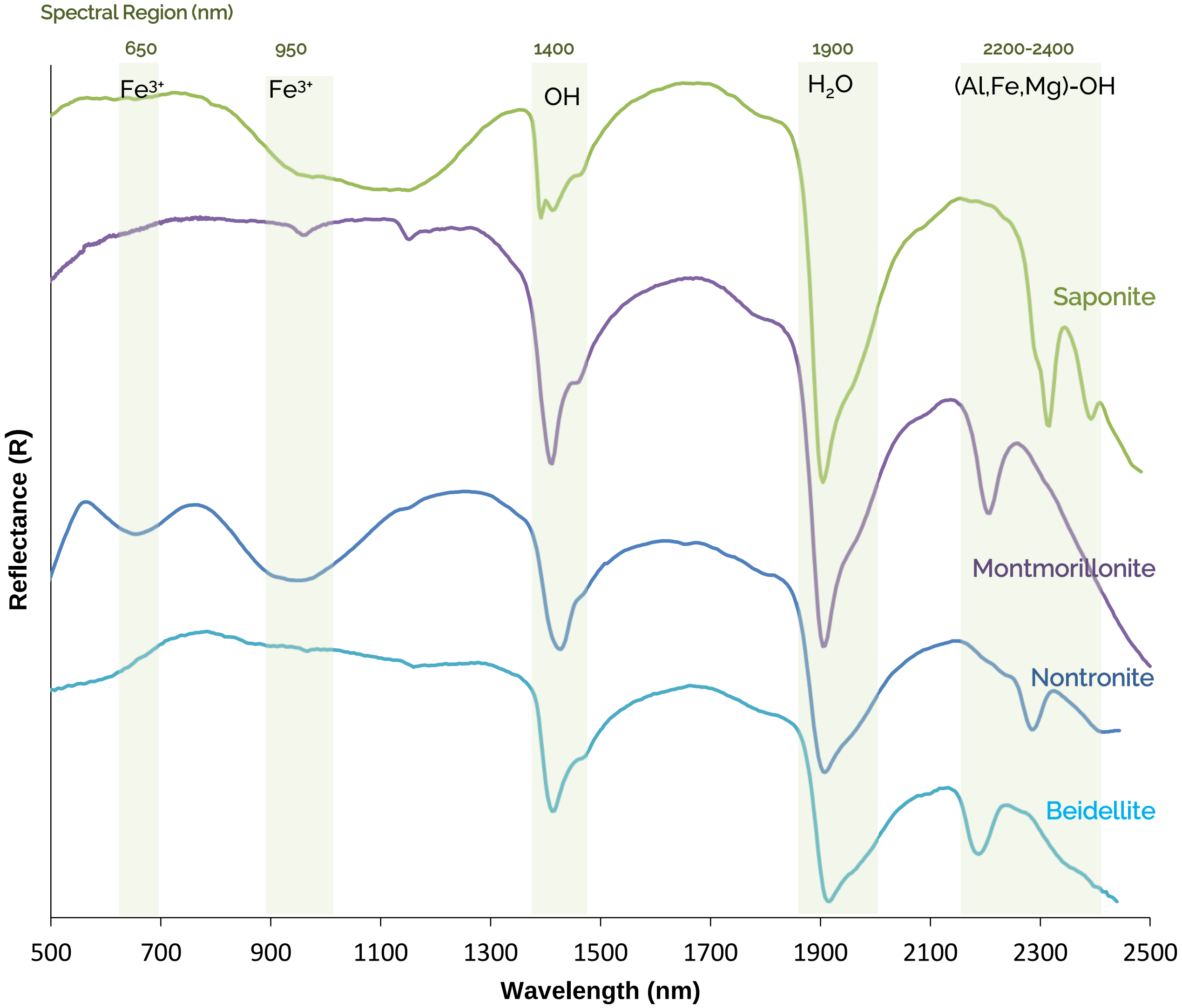


- A wide variety of smectite-group minerals can occur in porphyry systems from Ca±Na-bearing montmorillonite and beidellite, to Fe-rich nontronite, to Mg-rich saponite.
- These phases are often associated with distal alteration phases and in leach caps.



ADS0005

Distal Alteration: Chlorite-Epidote

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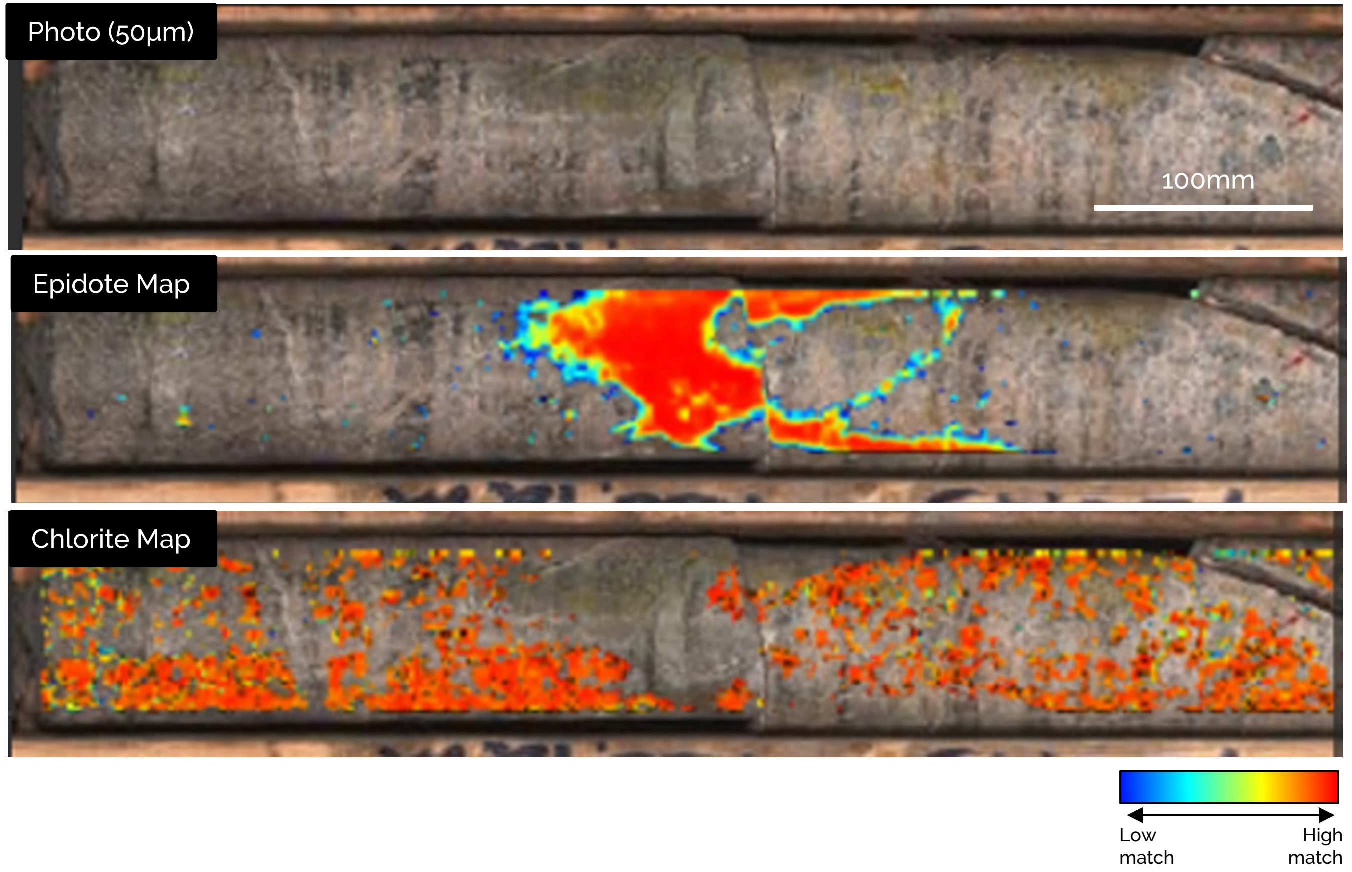
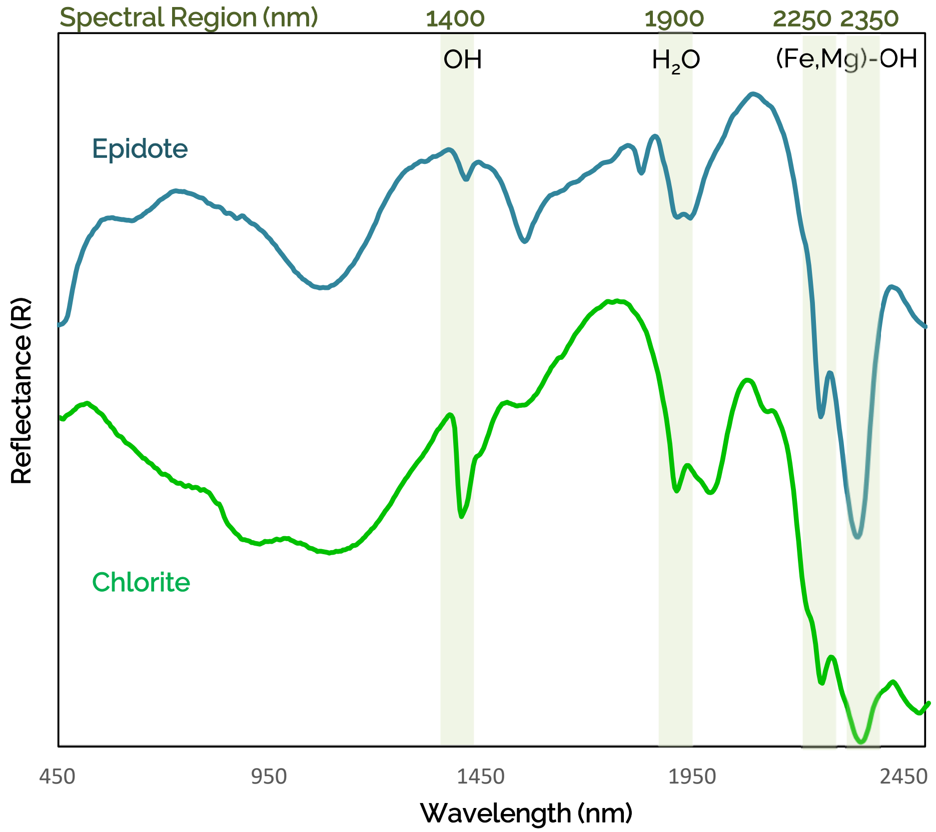
- Chlorite and epidote are common hydrothermal alteration minerals in porphyry systems, particularly in the green rock distal alteration environment. Chlorite is also a common retrograde phase after amphibole and biotite and within the phyllic zone.



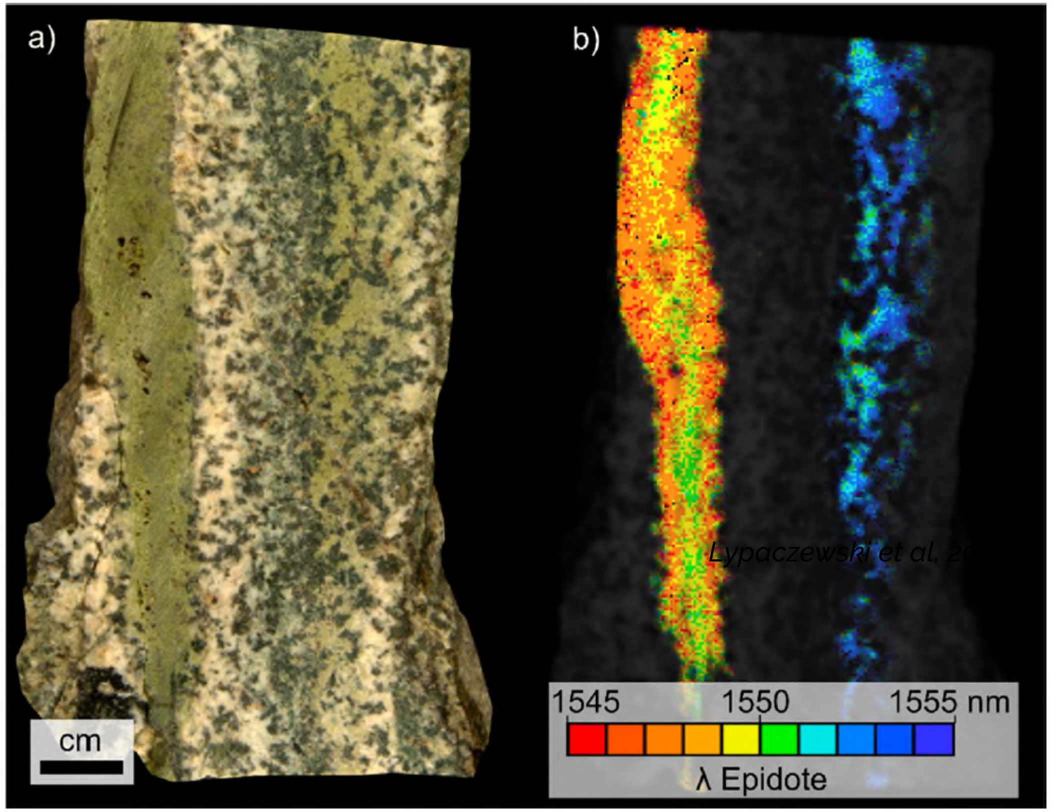


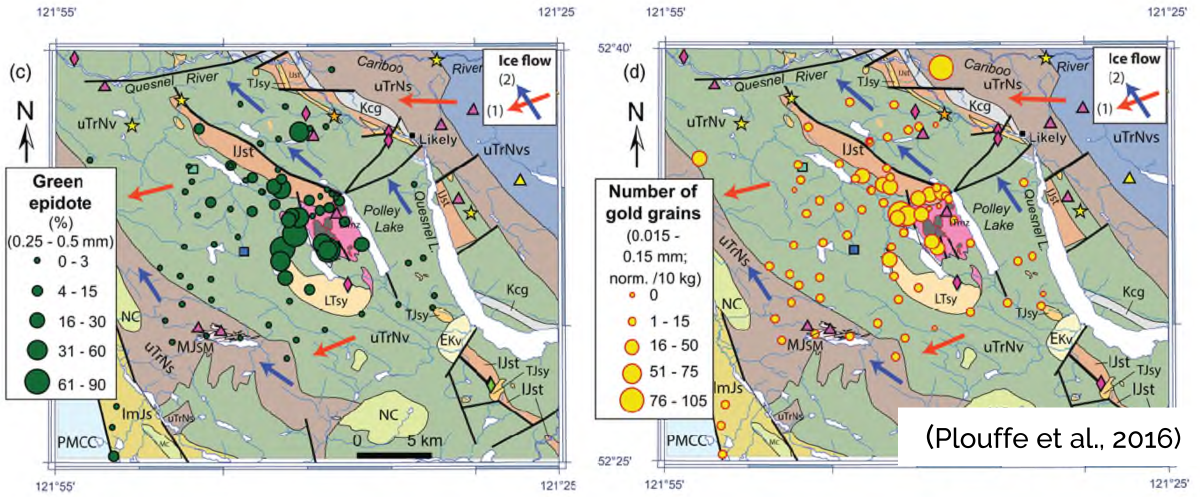
- Both chlorite and epidote have distinctive VNIR-SWIR absorption features. Compositional variations can be tracked using the wavelength positions of key absorption features.

ADS0005

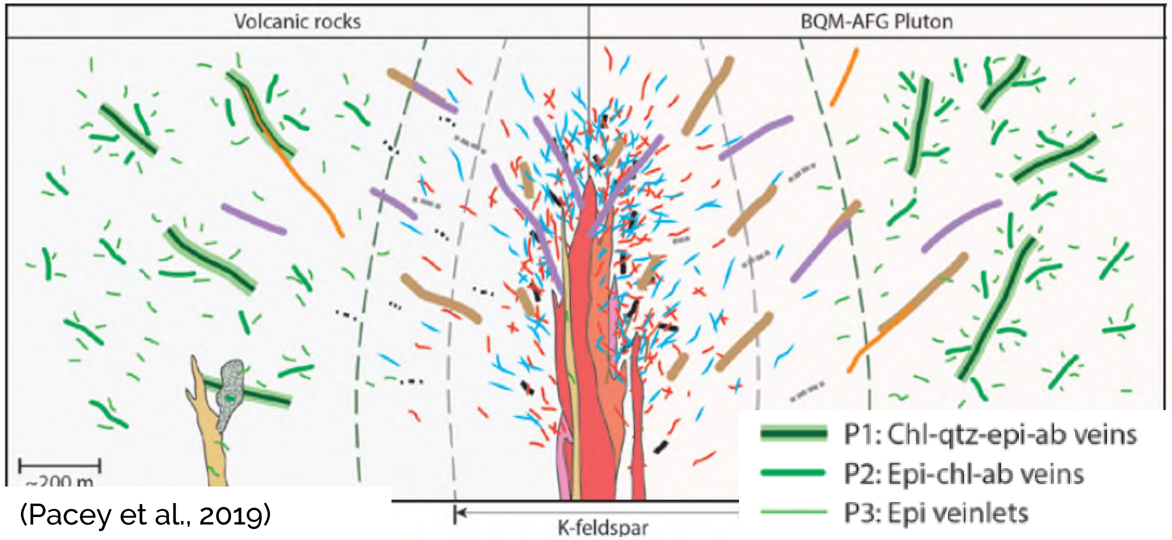
Distal Alteration Vector: Epidote

- Epidote is a common alteration mineral in and around alkalic porphyry systems.
- Epidote is an important porphyry vectoring and fertility tool and porphyry indicator mineral (Cooke et al., 2020).





(Plouffe et al., 2016)



(Pacey et al., 2019)

Distal Alteration Vector: Prehnite

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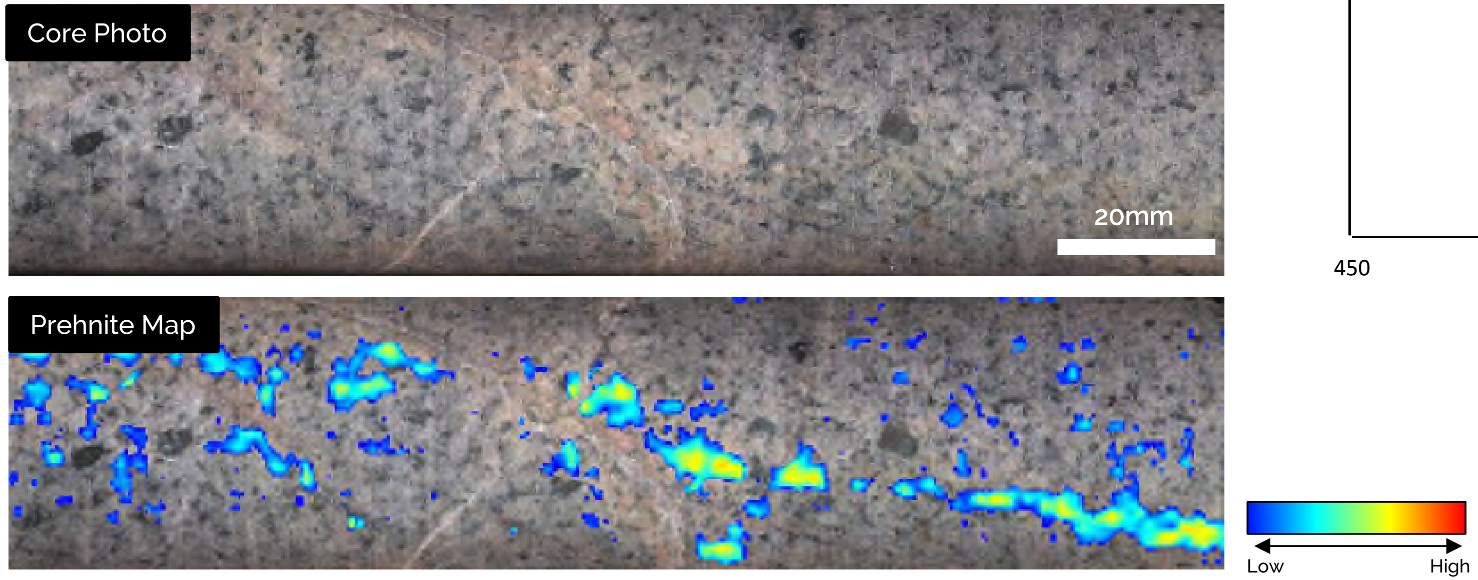
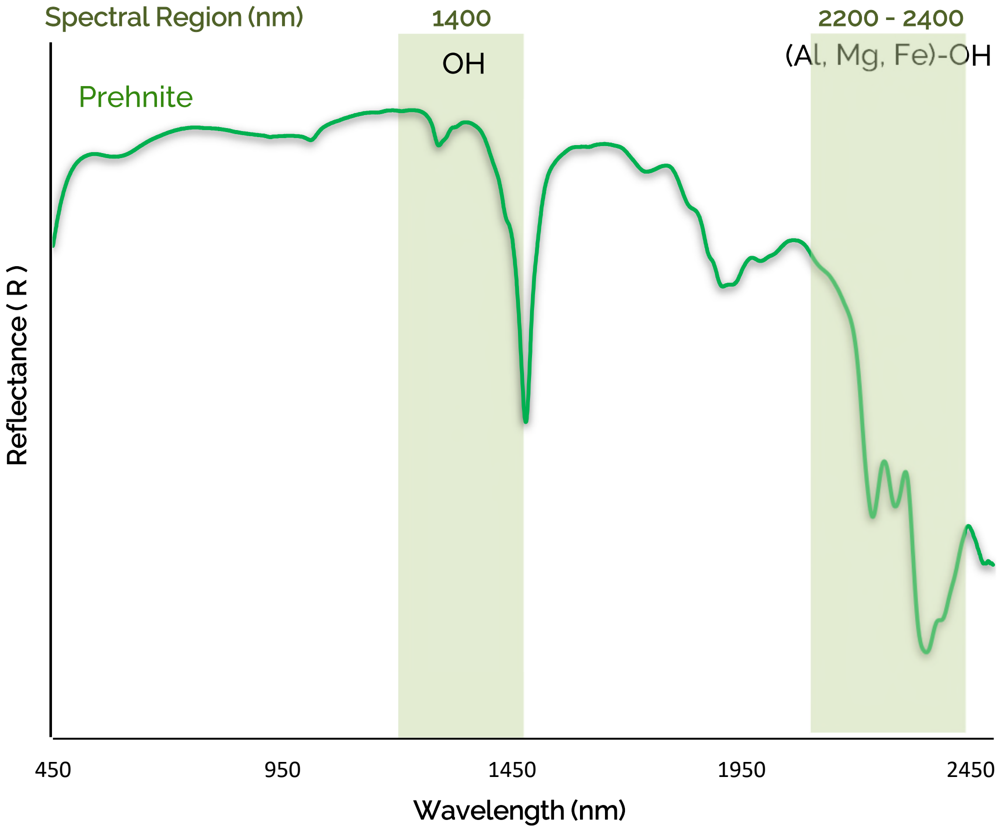
- Prehnite is a common component of 'propylitic' alteration in and around alkalic porphyry systems (Byrne et al., 2020).
- Usually occurs in association with epidote, calcite and white mica.
- Typically forms from alteration of plagioclase to form albite, white mica and prehnite assemblage (in association with chloritization of biotite and/or hornblende).
- Can be difficult to identify visually but has a distinctive SWIR spectra.



Highland Valley



Brecciation

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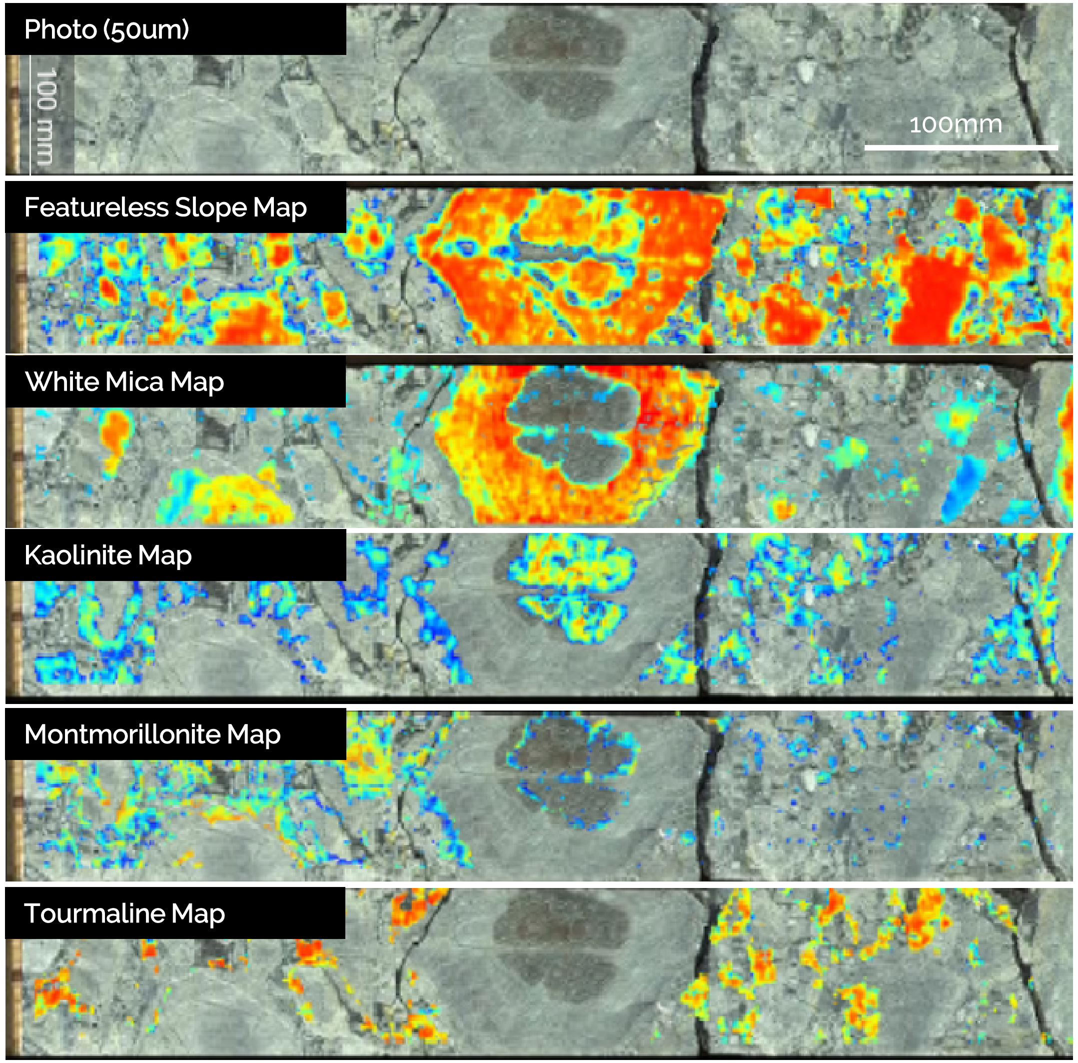
- Brecciation occurs as a result of the large mechanical energy available from ascending, depressurizing, water-rich magmatic-hydrothermal fluids, which form initially under lithostatic pressure and move to hydrostatic pressive conditions (Burnham, 1985).
- Breccias are common in porphyry deposits and depending on when they form, they can either host significant metal grade (early) or are grade destructive (those forming at the end of the hydrothermal system; Tosdal et al., 2009).



Cu-Mo Porphyry, Chile

Structural Features

Detection and Mapping of Faults

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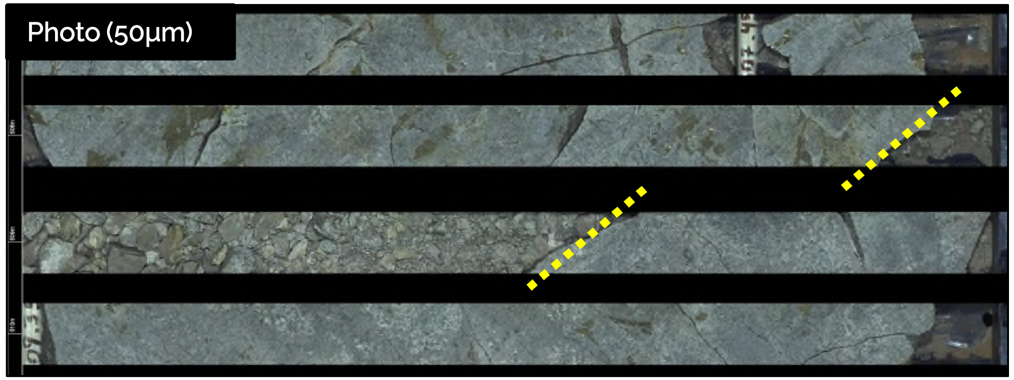
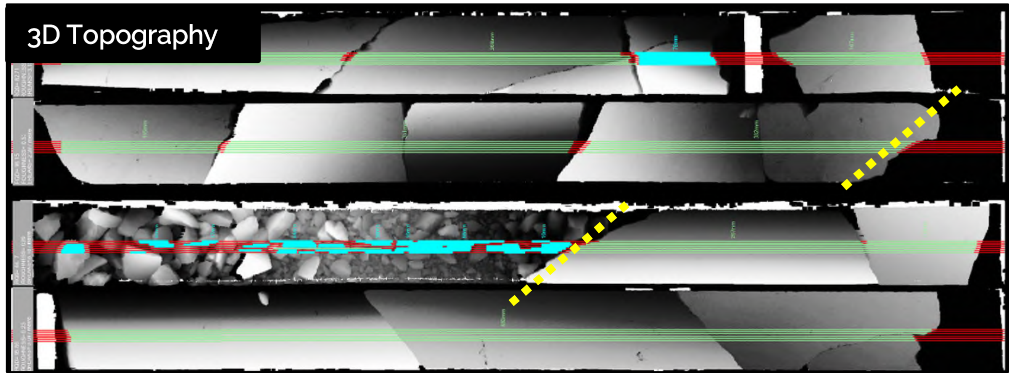
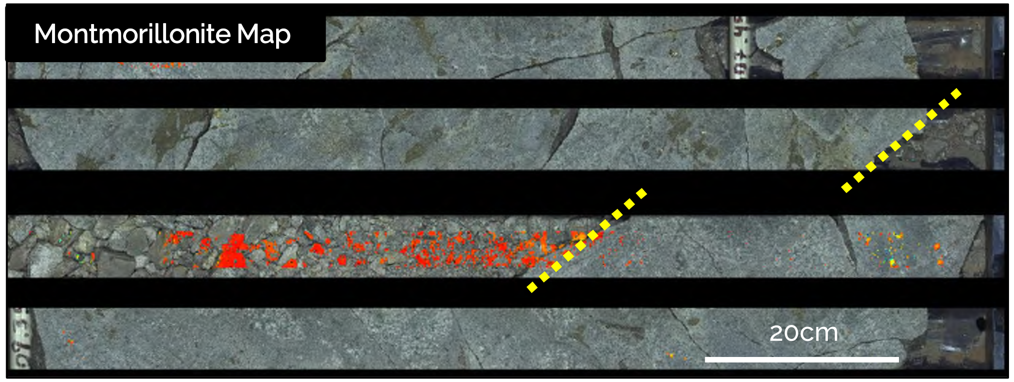
- Sharp mineralogical changes and rubble zones in the core may indicate the presence of faults and fault gouge.
- Clays (smectites, kaolinite, illite) are common fault gouge minerals, all of which are identified by diagnostic SWIR features.
- Laser profiler (3D topography) data can used to calculate 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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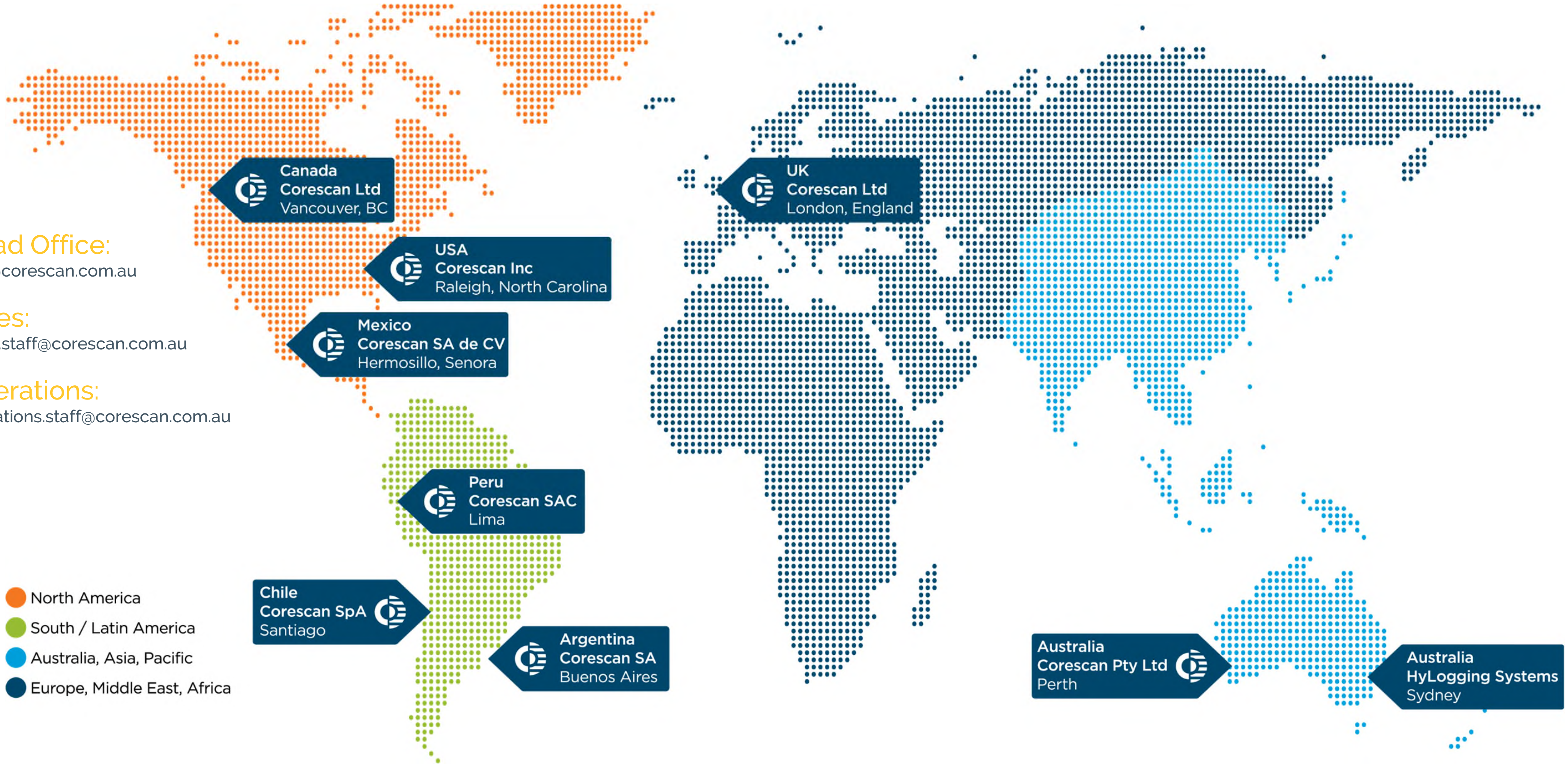

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