HYPERSPECTRAL CORE IMAGING APPLICATIONS

- LOW SULPHIDATION EPITHERMAL DEPOSITS -

October 2021

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Contents

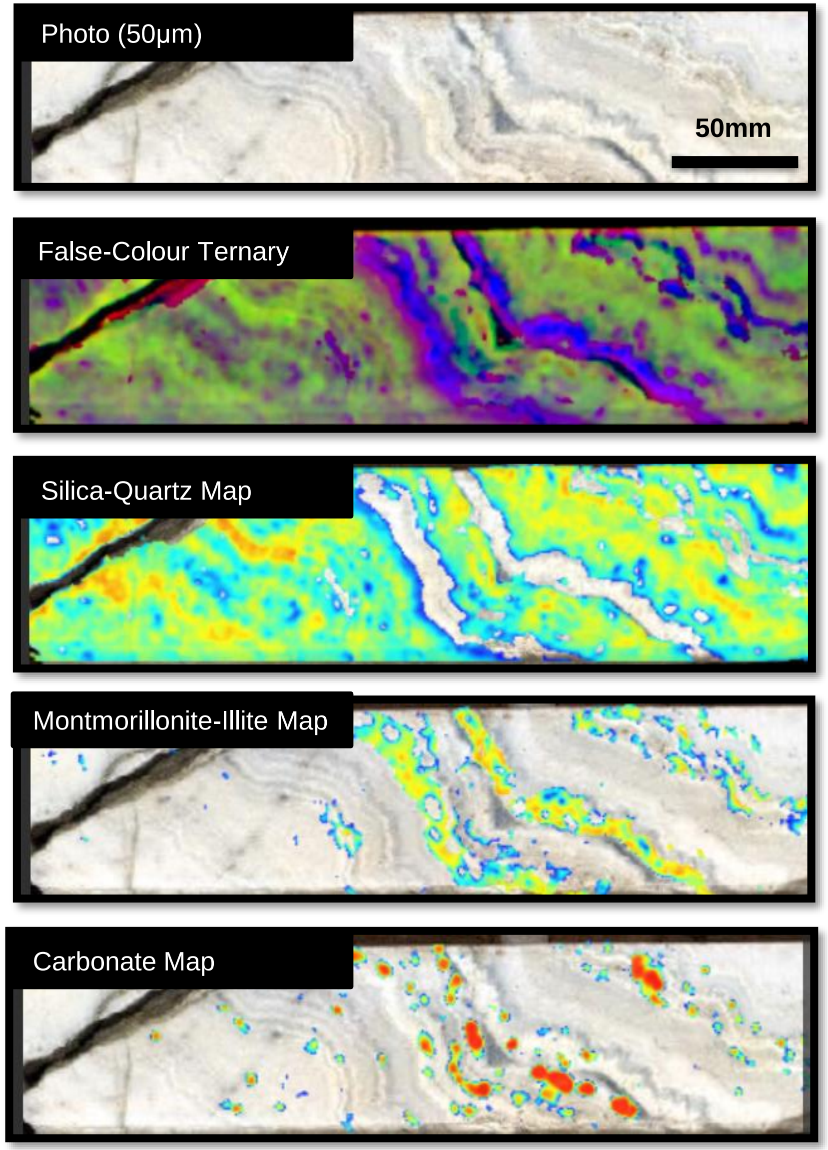

Photo (50µm)
50mm
False-Colour Ternary
Silica-Quartz Map
Montmorillonite-Illite Map
Carbonate Map

Hyperspectral Core Imaging Services

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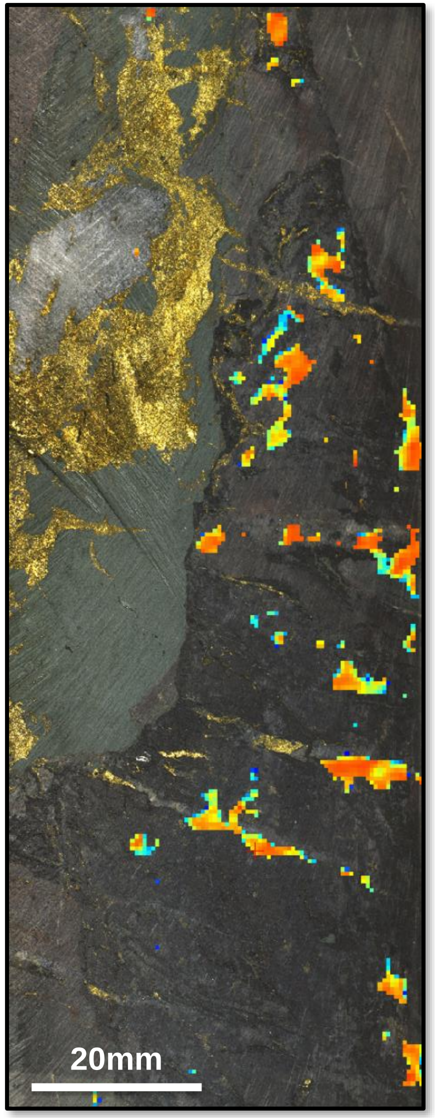
Mineral identification and mapping across the mining cycle:

- 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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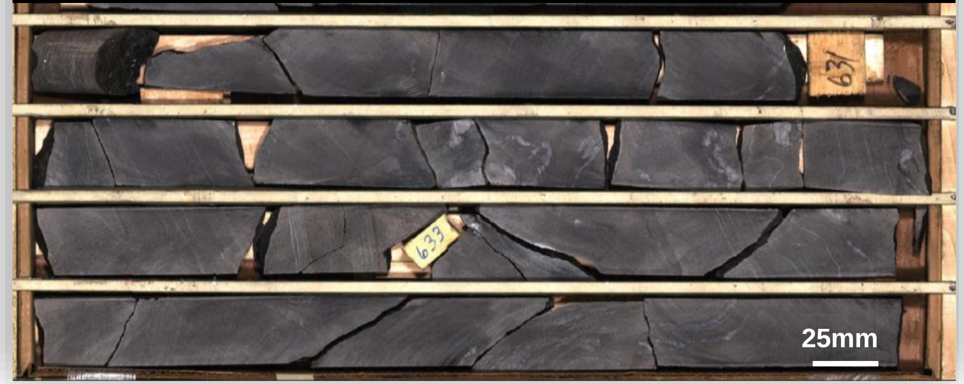
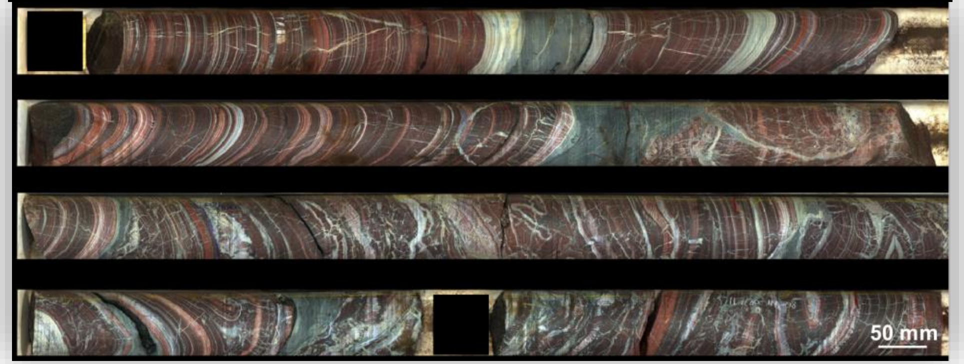
Cut / split core



Hand samples

Soils

Uncut / whole core



Chips, cuttings, blast holes

AP0001

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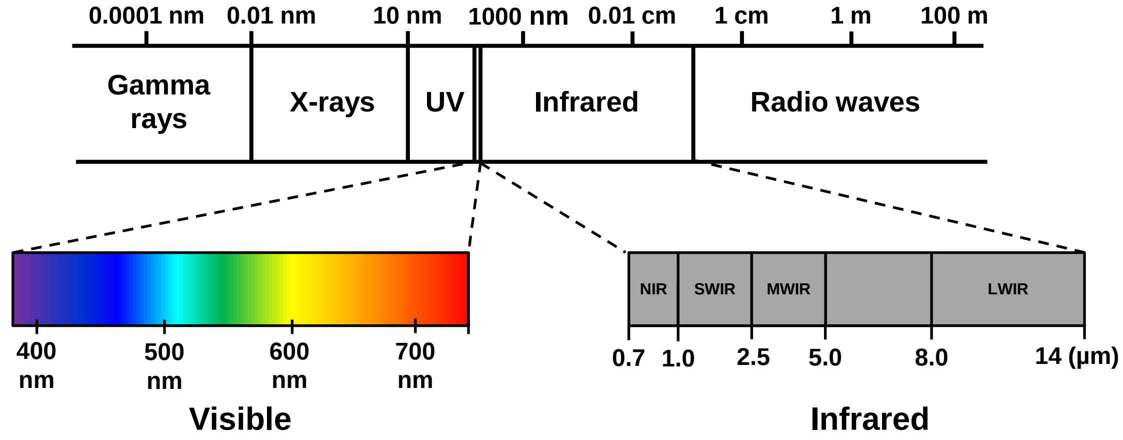
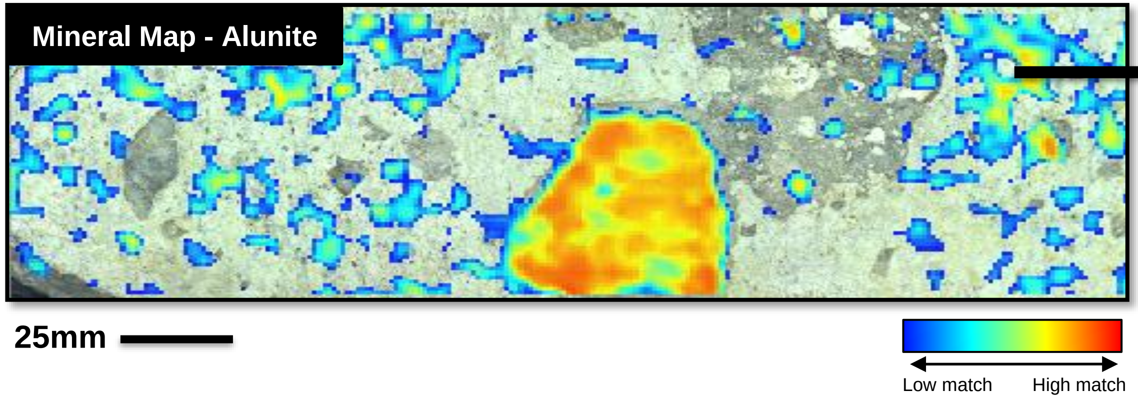
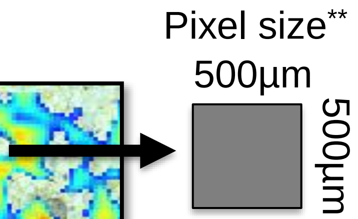
- Corescan's proprietary spectrometers measure hundreds of contiguous, narrow bands across the electromagnetic spectrum from 450nm to 2500nm, covering the Visible-Near Infrared (VNIR) and Short-Wave Infrared (SWIR) regions.

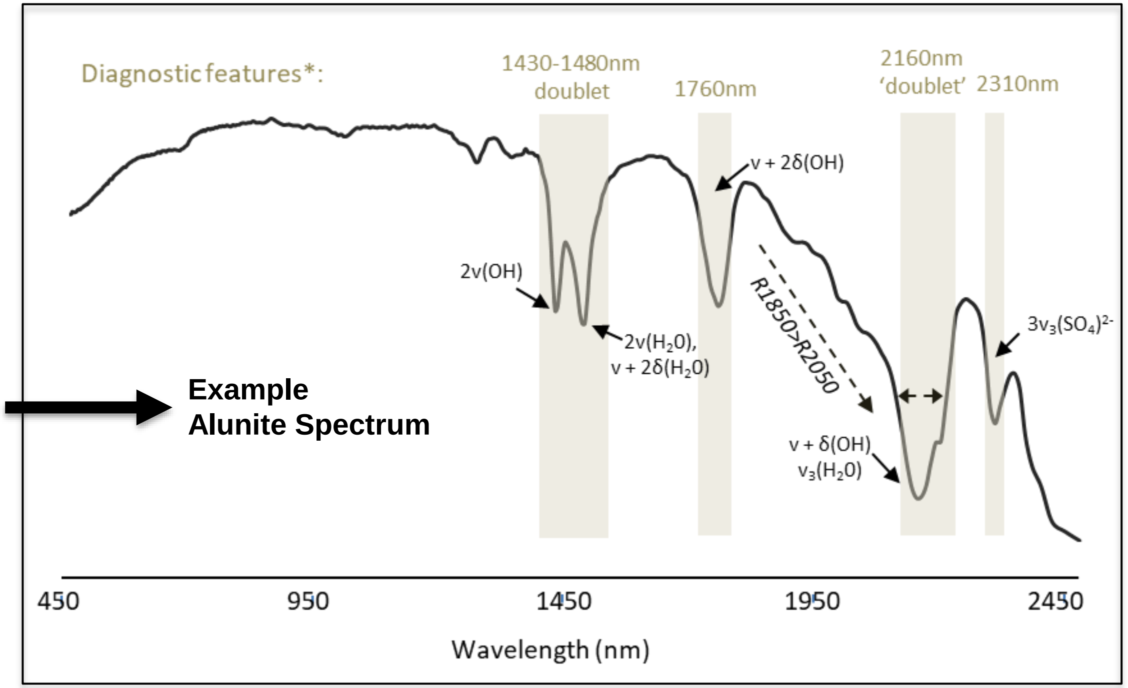


Harraden, 2018

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

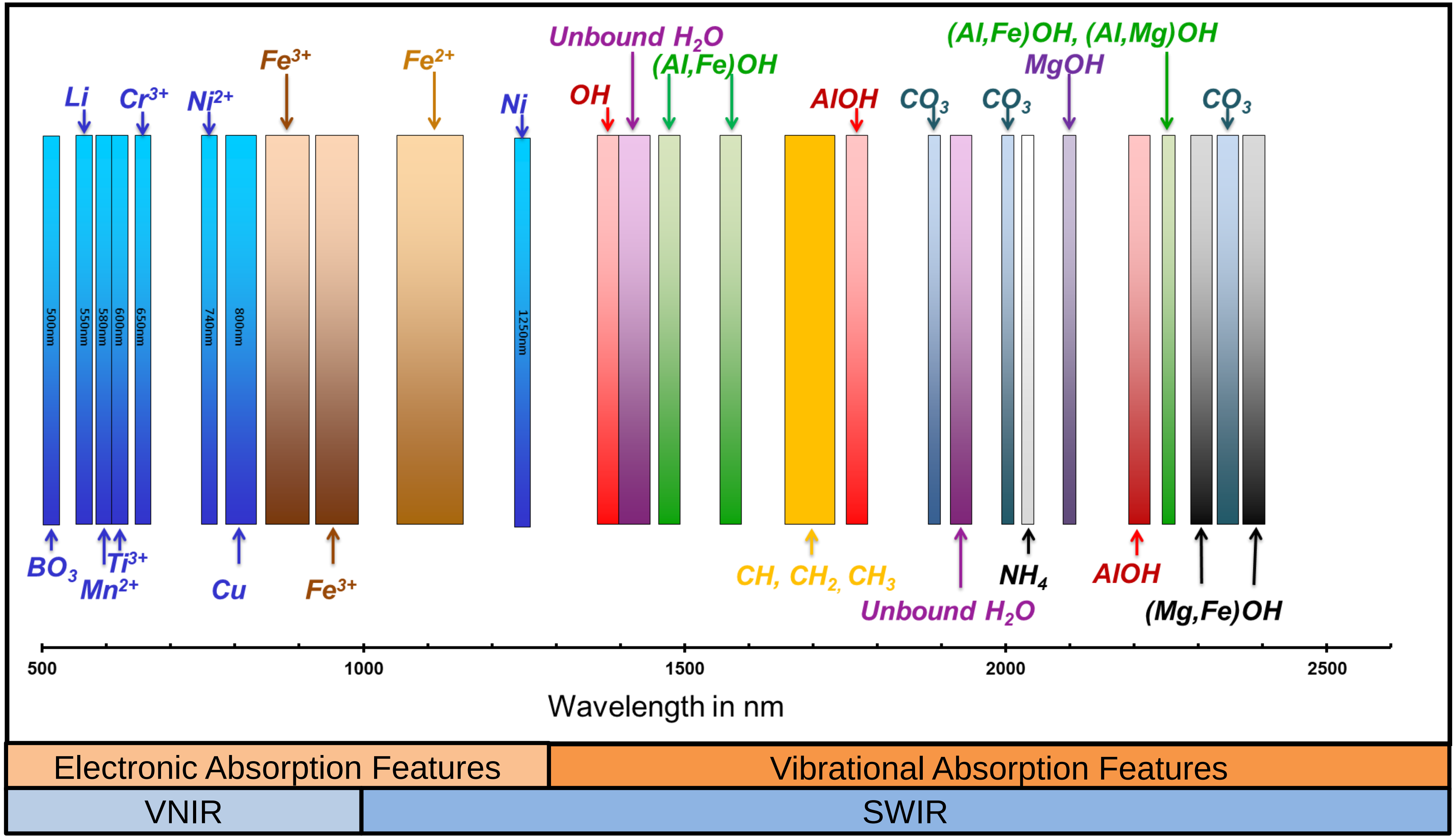






HCI-3 instrument specifications* * Not to scale*

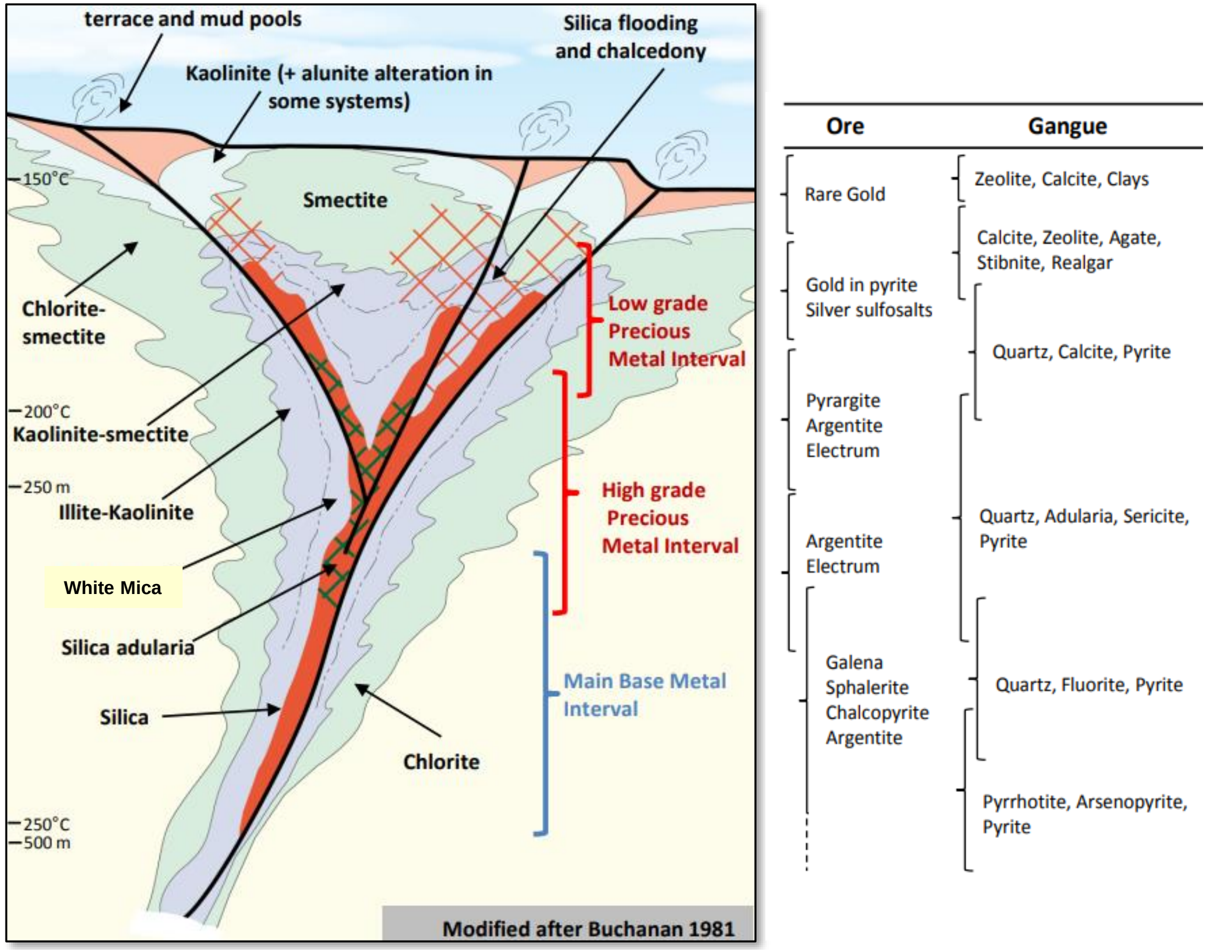
VNIR-SWIR: Electronic and Vibrational Features



Low Sulphidation Epithermal Deposits

- Low sulphidation (LS) epithermal deposits represent major resources of gold and silver.
  - Lead and zinc are common at depth and copper can also occur in the deepest parts of some systems.
- Deposits form in geothermal or hot-springs environments, at shallow depths (typically <500m).
- Mineralization occurs dominantly in veins and stockworks with minor disseminations.
  - Structures are fundamental controls on vein development and location of mineralization.
  - Metal distribution is zoned with respect to boiling level.
- Gangue mineralogy is dominated by quartz (and other forms of silica), adularia +/-calcite with illite, clays and more distal chlorite, epidote, carbonate.
  - Typical of low temperature, near neutral pH alteration.

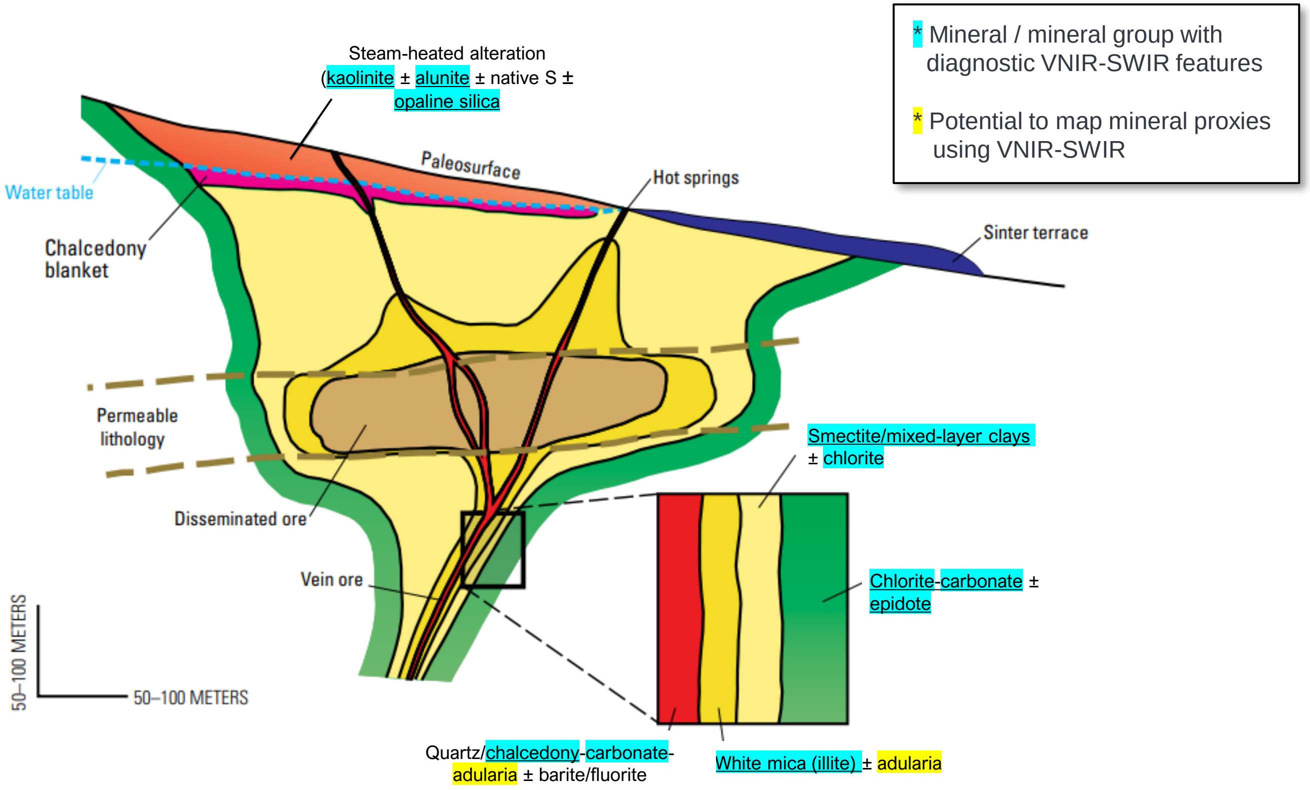
Schematic Model: Low Sulphidation Au-Ag Vein System



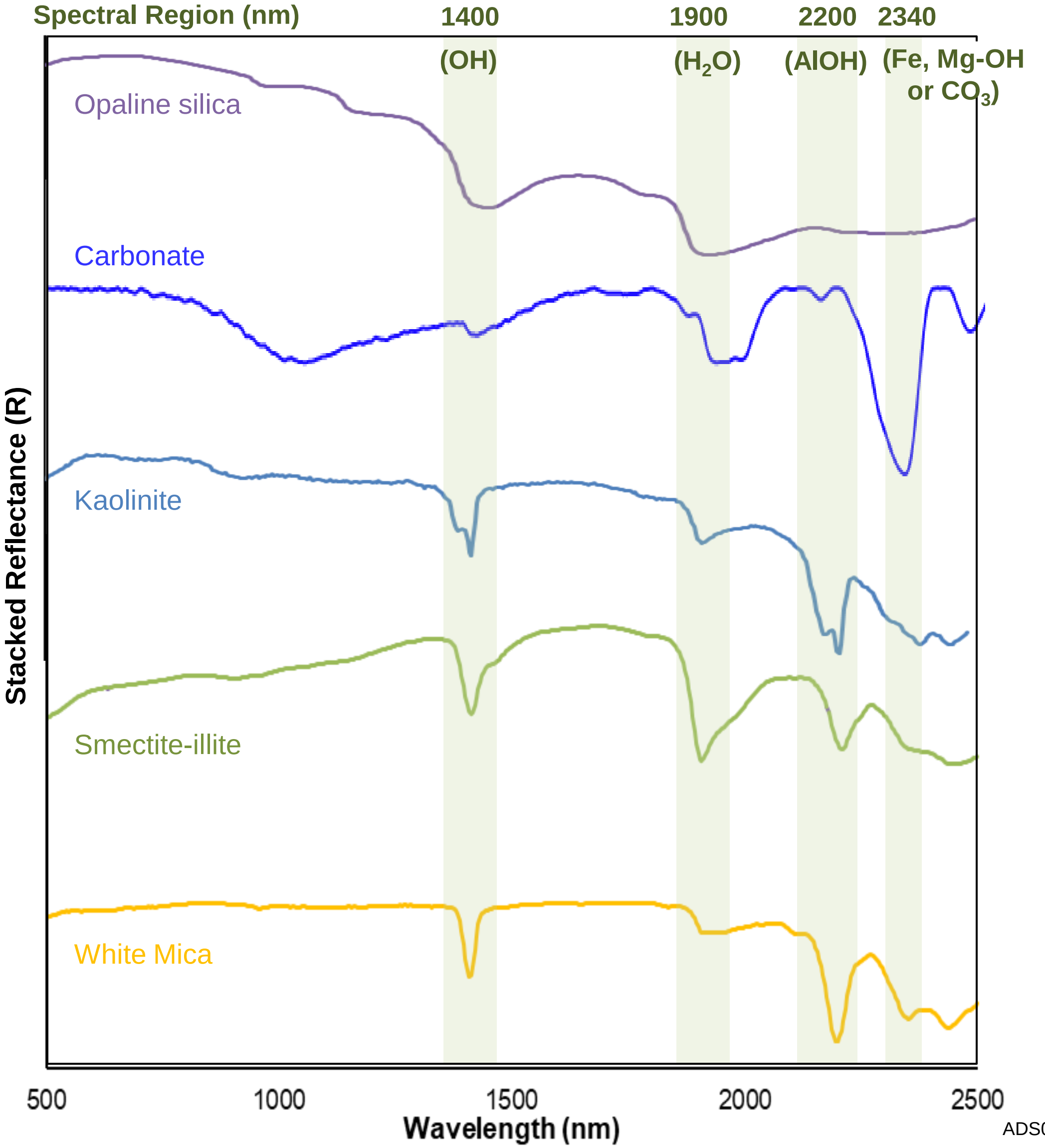
(Wilson and Tunningley, 2013)

LS Epithermal Deposits: Alteration Mineralogy

- Alteration mineralogy in low sulphidation systems is dominated by clays, micas, carbonates, silica species and zeolites.
- These mineral groups are ideally suited to SWIR spectroscopy with diagnostic absorption features in the ~1400nm to 2400nm range.



Schematic model of low sulphidation vein deposit (John et al., 2018, adapted from Hedenquist et al., 2000)



ADS0006

LS Epithermal Deposits: Alteration Zonation

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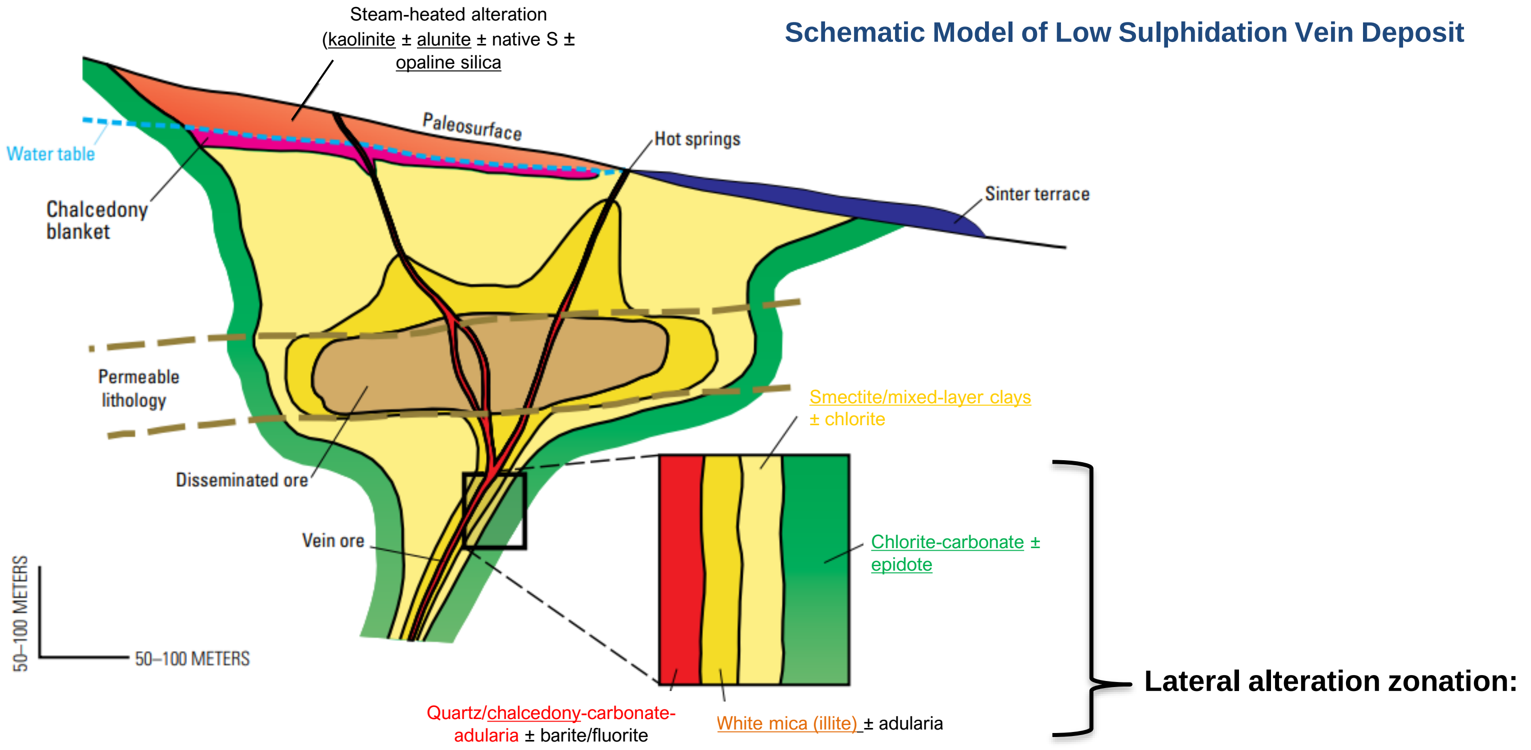
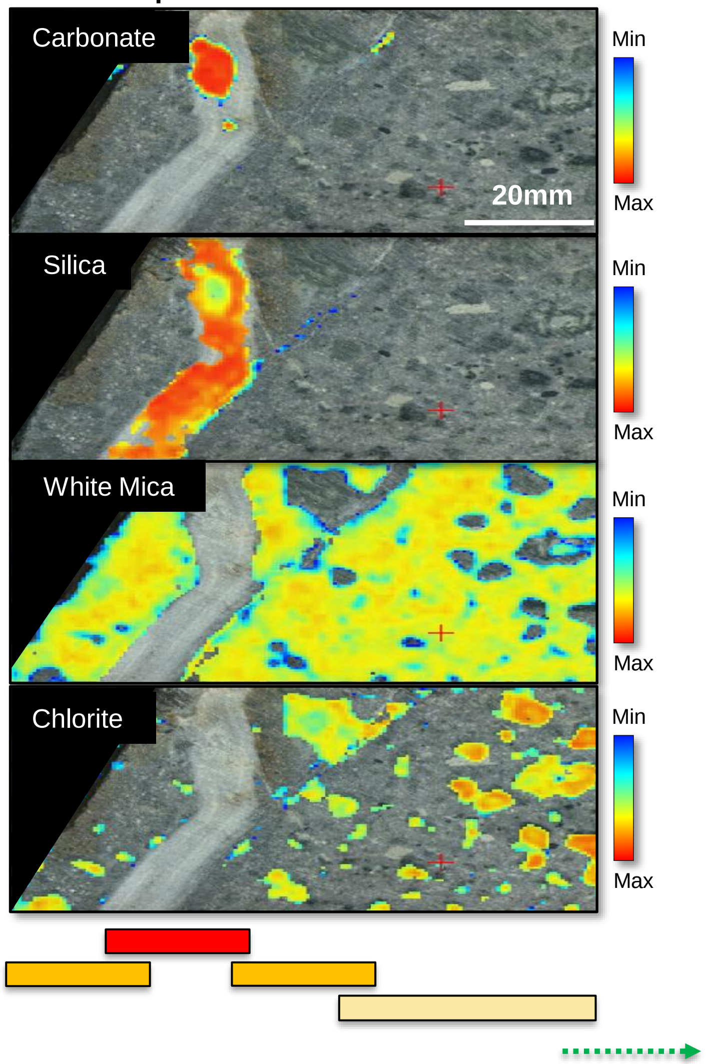
- LS epithermal deposits are characterized by strong vertical and lateral alteration zonation away from feeder structures.
- This zonation reflects the progressive migration of hydrothermal fluids away from primary conduits and is coincident with metal and geochemical zonation.

Schematic Model of Low Sulphidation Vein Deposit



(John et al., 2018, adapted from Hedenquist et al., 2000)

Example: Small-scale alteration zonation around epithermal carbonate-silica vein



LS Epithermal Deposits: Alteration Zonation

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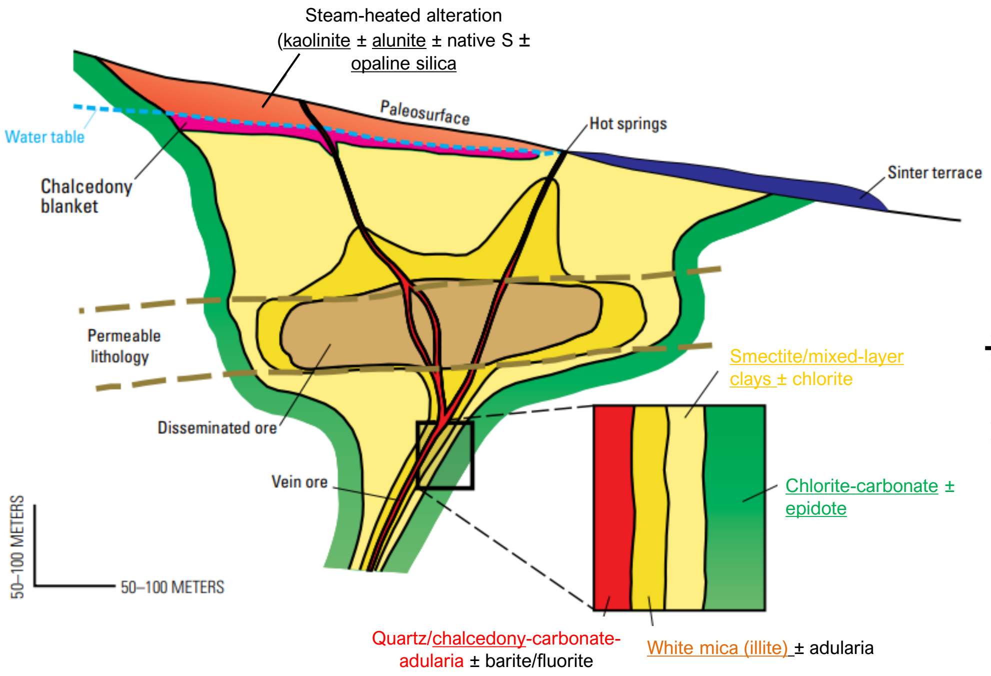
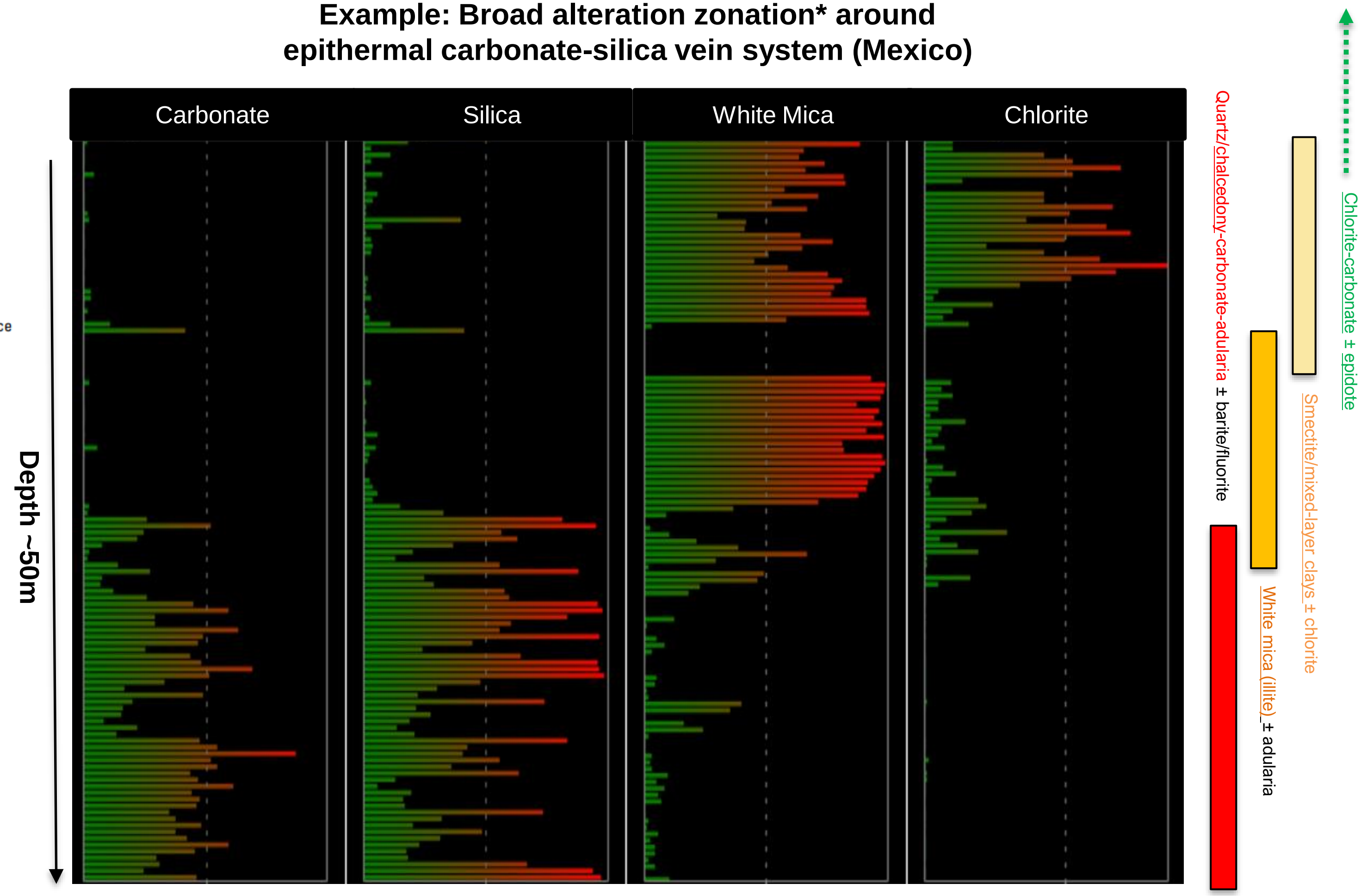
Schematic Model of Low Sulphidation Vein Deposit



Example: Broad alteration zonation* around epithermal carbonate-silica vein system (Mexico)



*Downhole relative abundance of mineralogy mapped by Corescan HCI-3.

(John et al., 2018, adapted from Hedenquist et al., 2000)

LS Epithermal Deposits: Adularia Proxy

- Adularia is a key component of most Au-Ag LS vein deposits, however, unlike many other gangue minerals in these systems, adularia (e.g., low temperature variety of K feldspar) does not have diagnostic absorption features in the VNIR-SWIR region.
- Hyperspectral analysis can however be used to generate proxies to map variations in adularia - and other SWIR inactive minerals. Methods may include band ratios, absorption feature parameters and mineral associations in order to map for a range of assemblages and/or vein types.

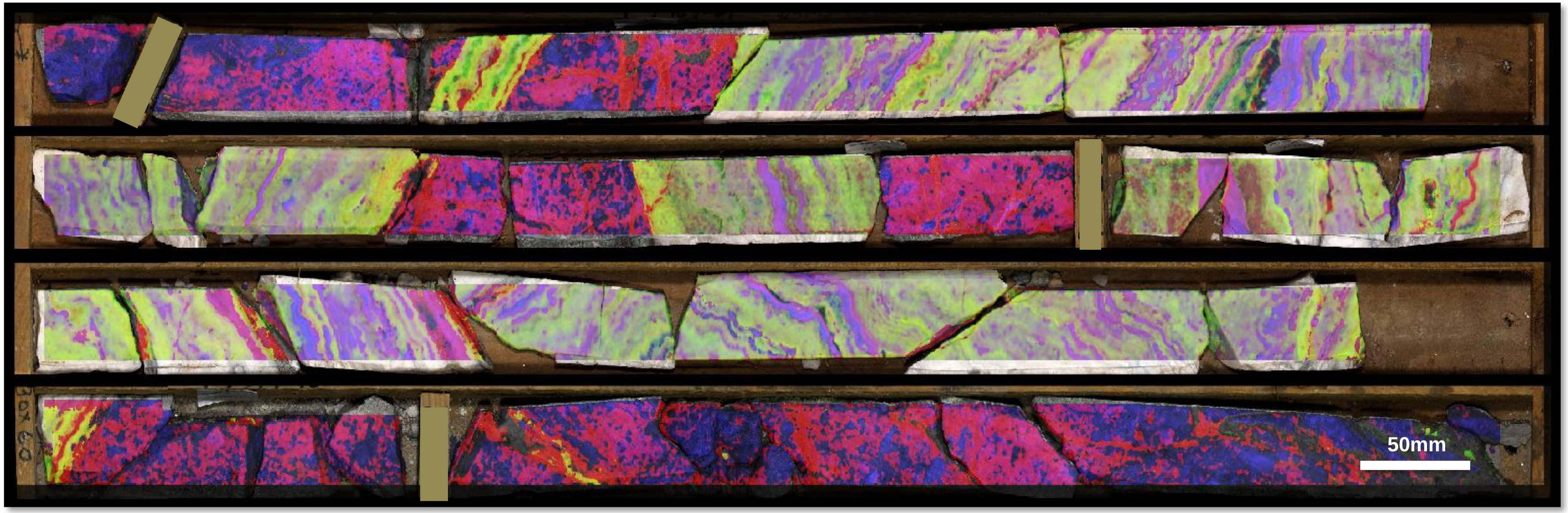


Image band assignments:

Red = Reflectance 1850nm / 1350nm

Green = Hydrous silica match intensity

Blue = 2200nm absorption feature depth

Example: Hyperspectral imagery from banded quartz (silica) – adularia vein

LS Epithermal Deposits: Ammonium

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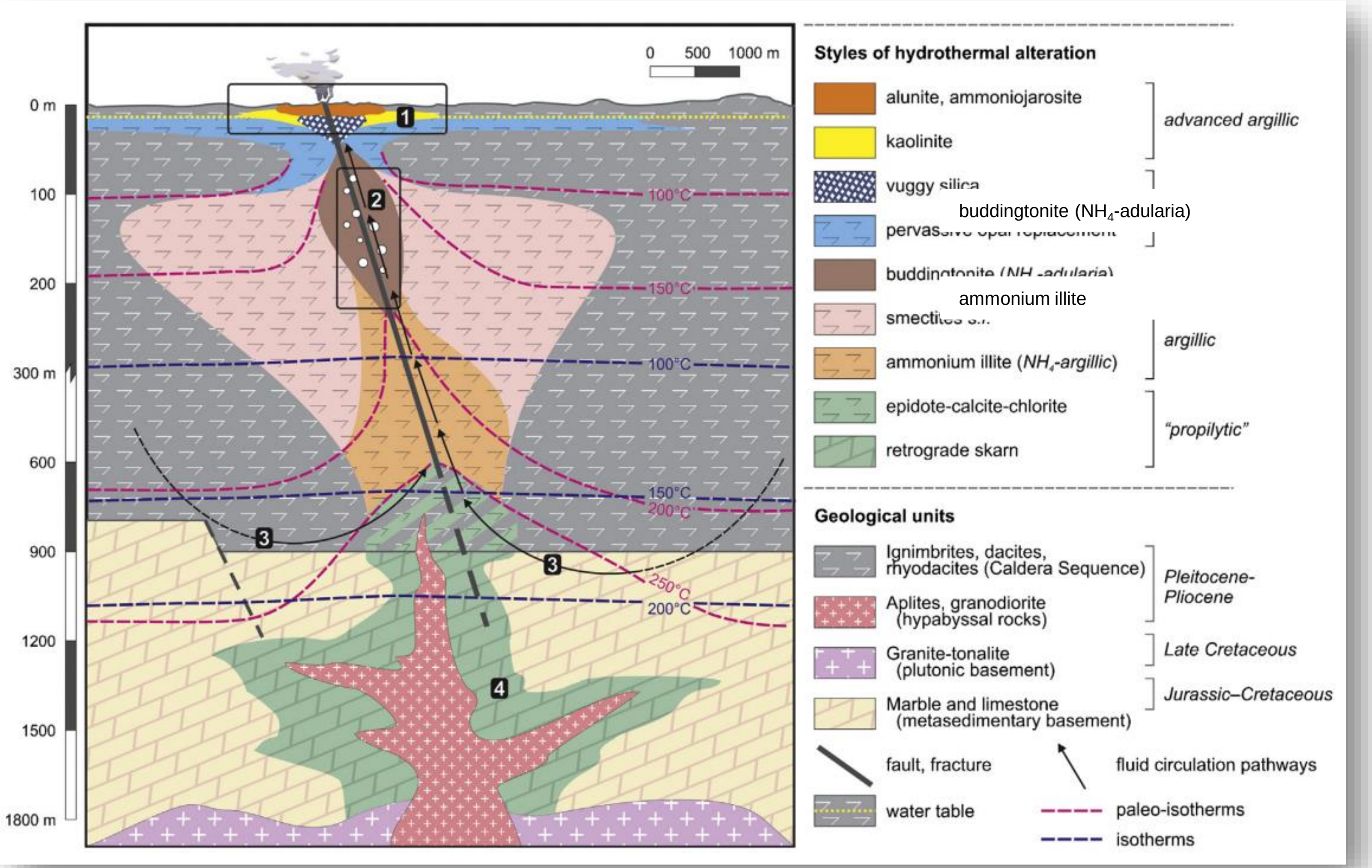
- In certain LS epithermal deposits, the occurrence of NH_4-bearing mineral species is of interest.
  - Requires the presence of organic-rich sedimentary sequences as a source of ammonium.
- Buddingtonite, NH_4-illite & NH_4-jarosite are the most commonly mapped species.
  - Readily mapped using distinctive SWIR features.

Model of hydrothermal alteration for the Acoculo geothermal zone, Eastern Mexico



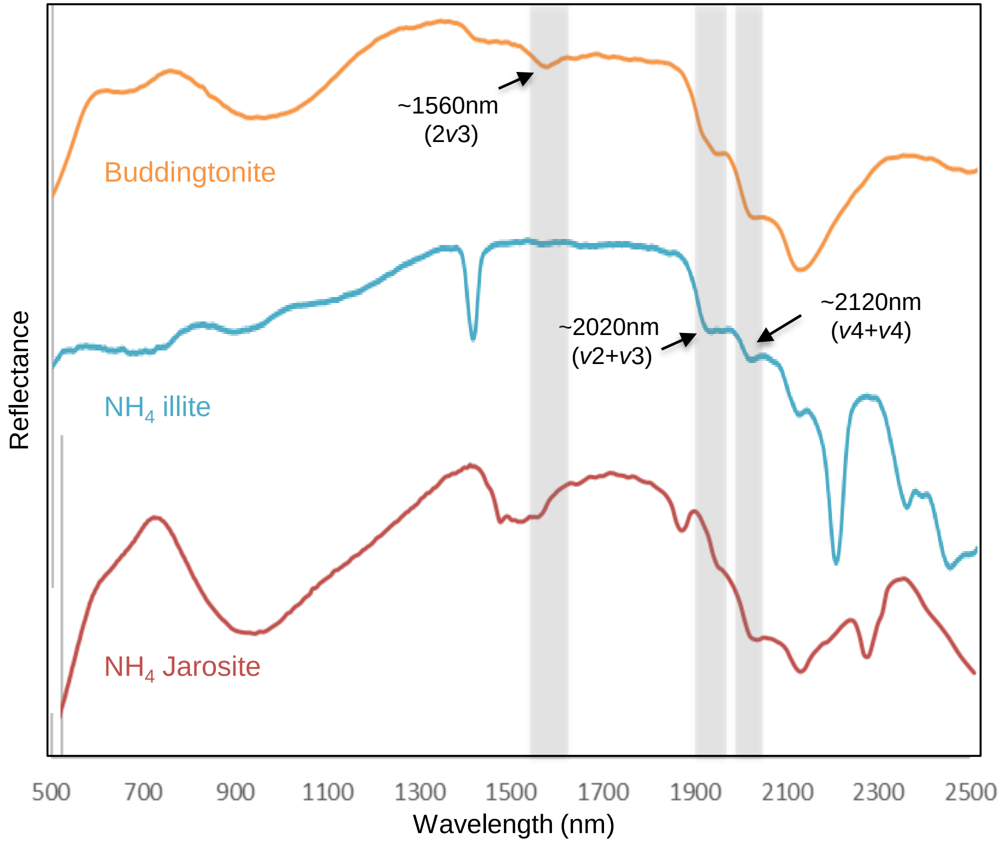
(Canet et al, 2015)

LS Epithermal Deposits: Ammonium

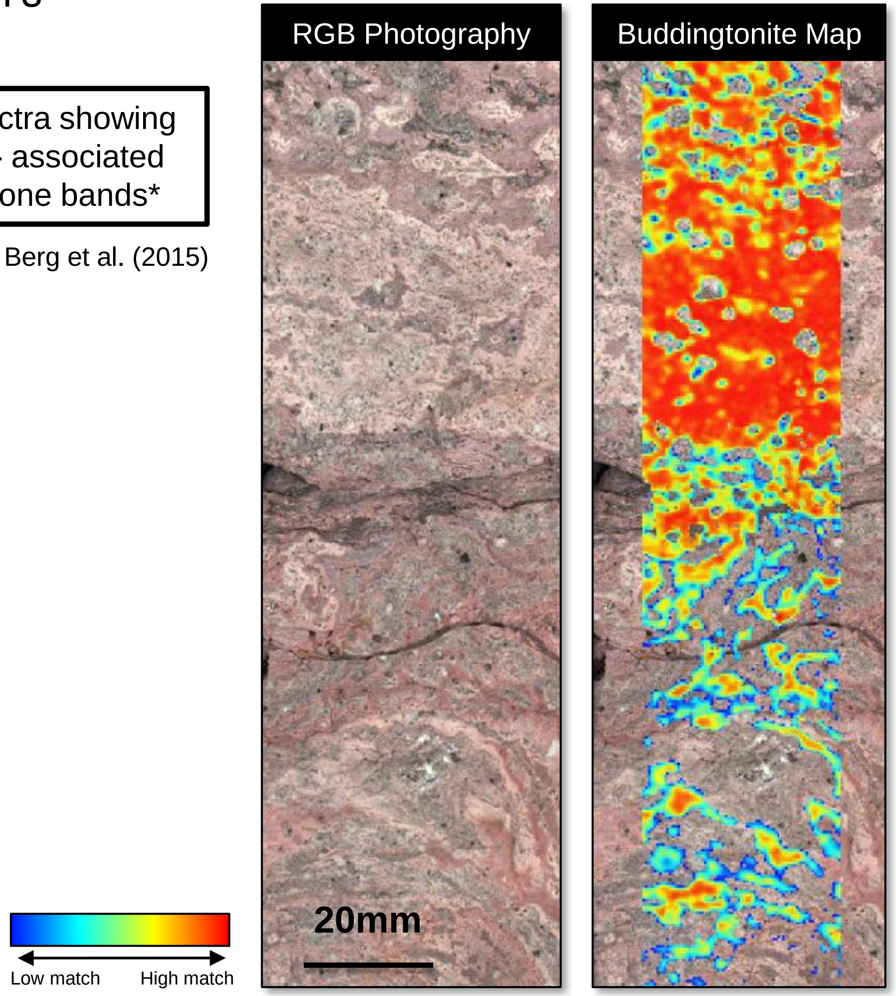
- Ammonium-bearing clays, sulphates and feldspar (buddingtonite) have diagnostic features in the SWIR range and can easily be identified using Corescan's hyperspectral imaging technology.

Selected reference spectra showing positions of free $NH4^+$- associated combination and overtone bands*

*as summarized in Berg et al. (2015)



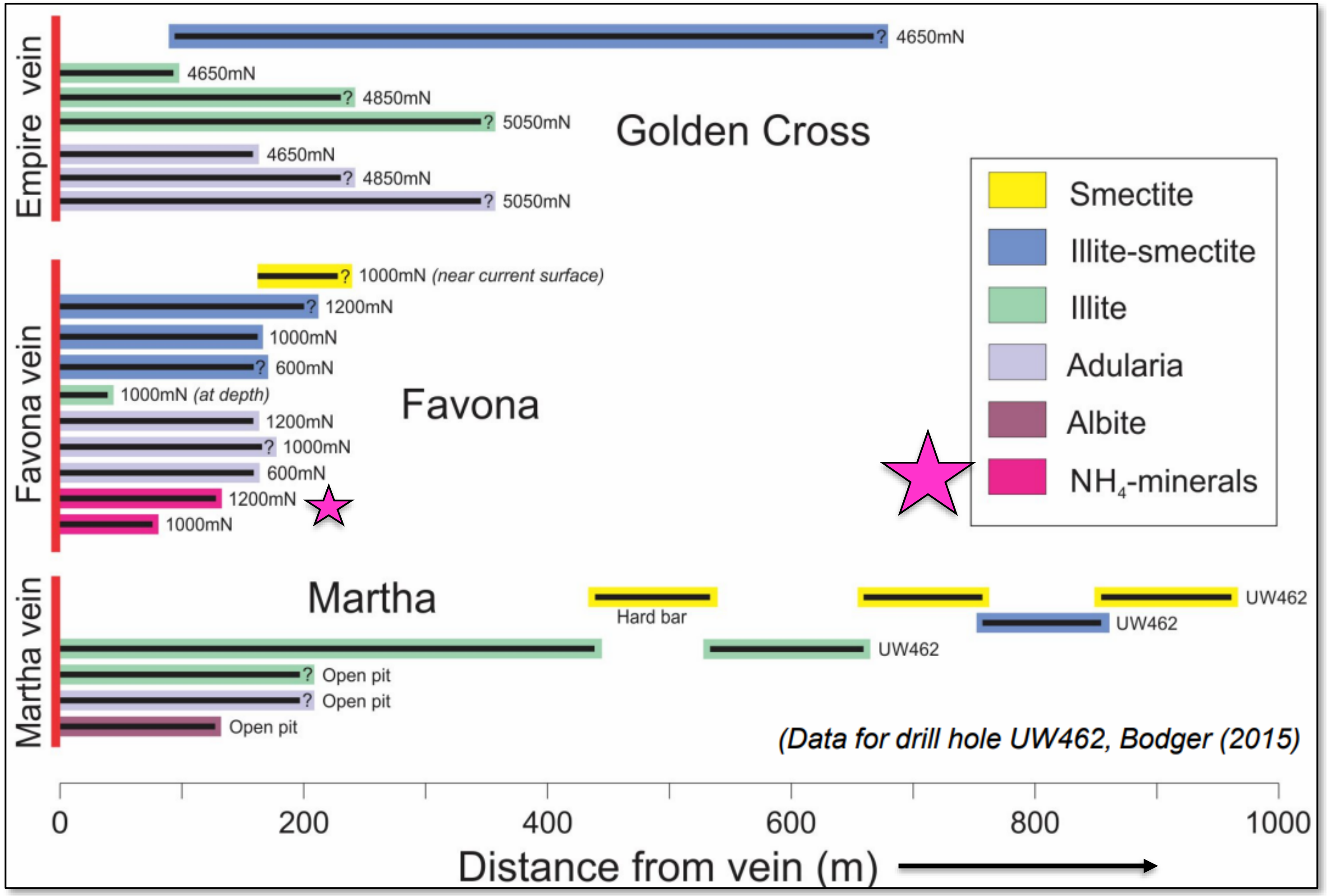
Banded buddingtonite-adularia-silica in Au-rich LS deposit (Mexico)



LS Epithermal Deposits: Ammonium

- NH_4^+ species are known to have a spatial relationship with mineralization in many LS epithermal deposits.
  - These species generally occur above, or proximal to, Au-rich veining.
  - Example: Favona, Hauraki Goldfield, New Zealand (Simpson, 2015).
- Note: Ammonia complexation of Au may also play a role in Au-enrichment of LS epithermal systems (Harlap, 2008).

Alteration Minerals and Vein Proximity, Hauraki Goldfield (NZ)



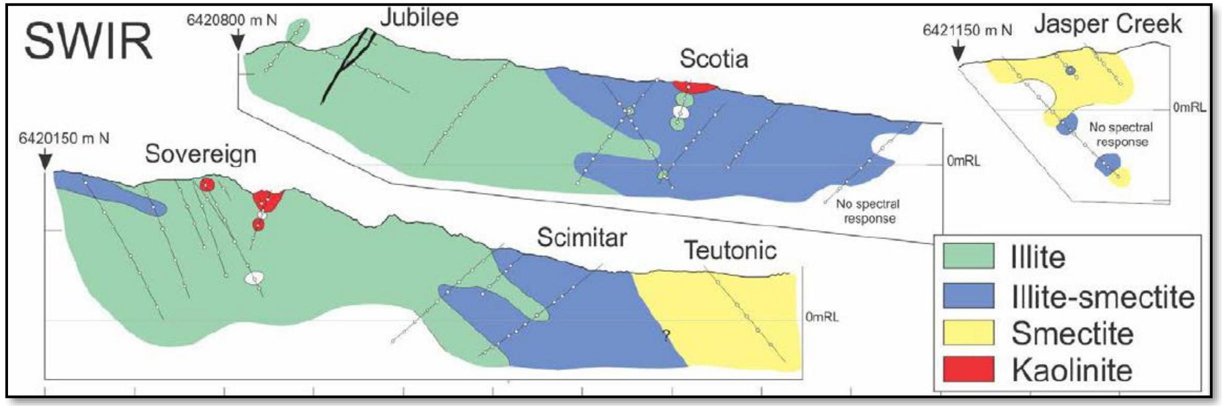
(Simpson, 2015)

LS Epithermal Deposits: Distal Alteration

- In LS epithermal deposits, distal propylitic and near-surface alteration zones can be widespread (up to ~km from source).
- Targeting narrow, high grade ore shoots within these broad zones can be challenging, but hyperspectral mineralogy and careful attention to specific mineral species can provide effective exploration vectors.
- **Example**: White mica and clay (smectite) mineral zoning.

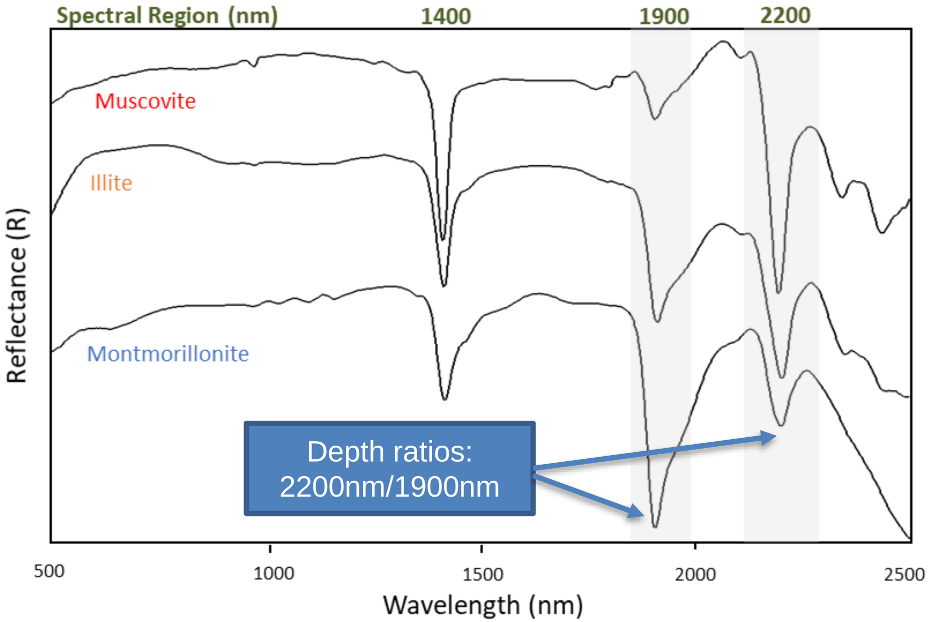
Zoning from illite to mixed layer illite-smectite to smectite may define the broad outline of the alteration system peripheral to the core of system.

Waitekauri deposit ,Hauraki Goldfield (NZ)



(Simpson, 2015)

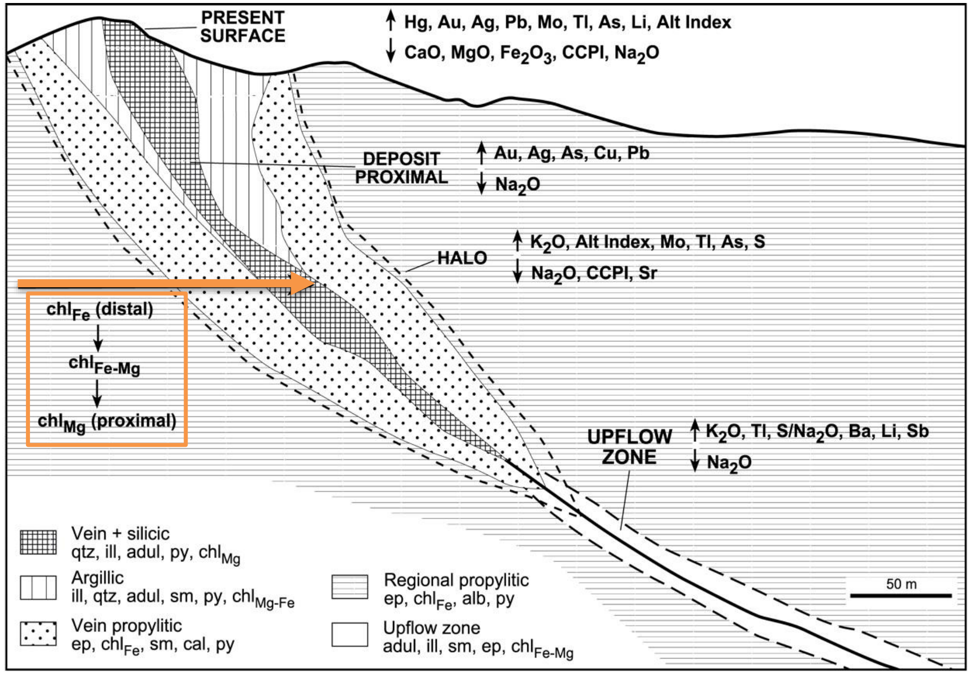
Variations in white micas (muscovite to illite), mixed layer illite-smectite and smectite can be mapped consistently using a combination of spectral feature absorptions and band depths.



LS Epithermal Deposits: Distal Alteration

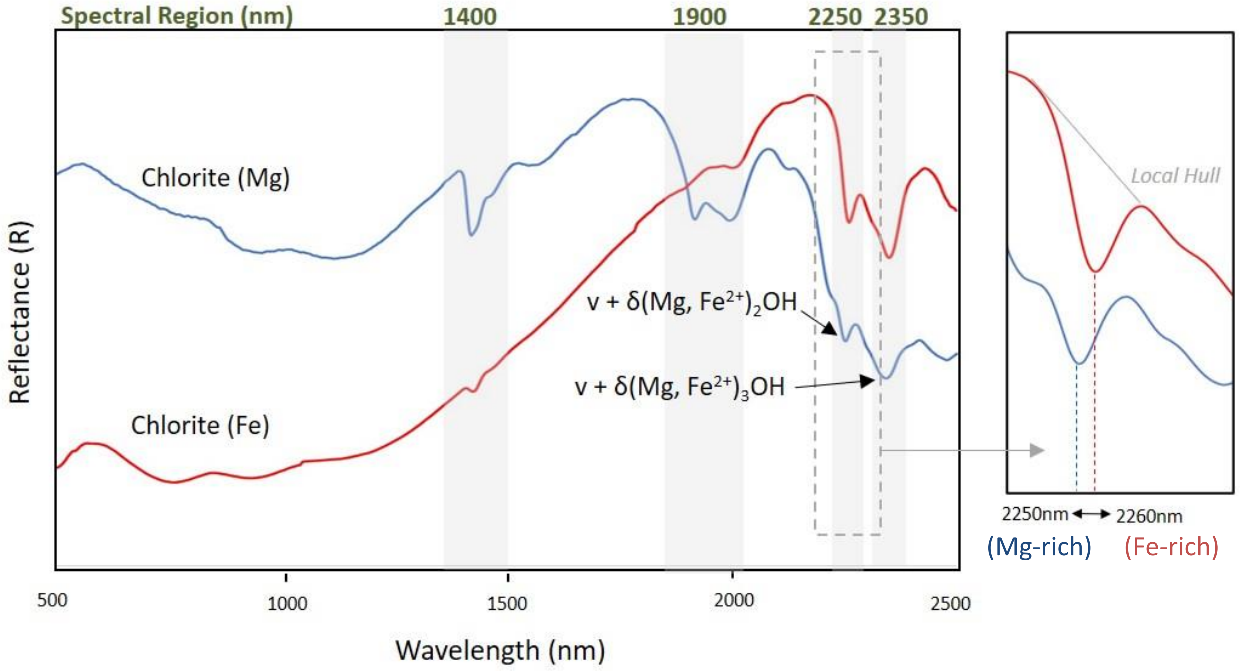
- In some LS epithermal deposits, a consistent zonation in alteration mineral chemistry occurs around the mineralized vein system (coincident with metal zoning and other geochemical vectors).
- Hyperspectral mineralogy and careful attention to specific mineral species can provide effective exploration vectors.
- **Example**: Chlorite Mineral Chemistry

Gosowong Au-Ag deposit, Indonesia



Gemmell (2007)

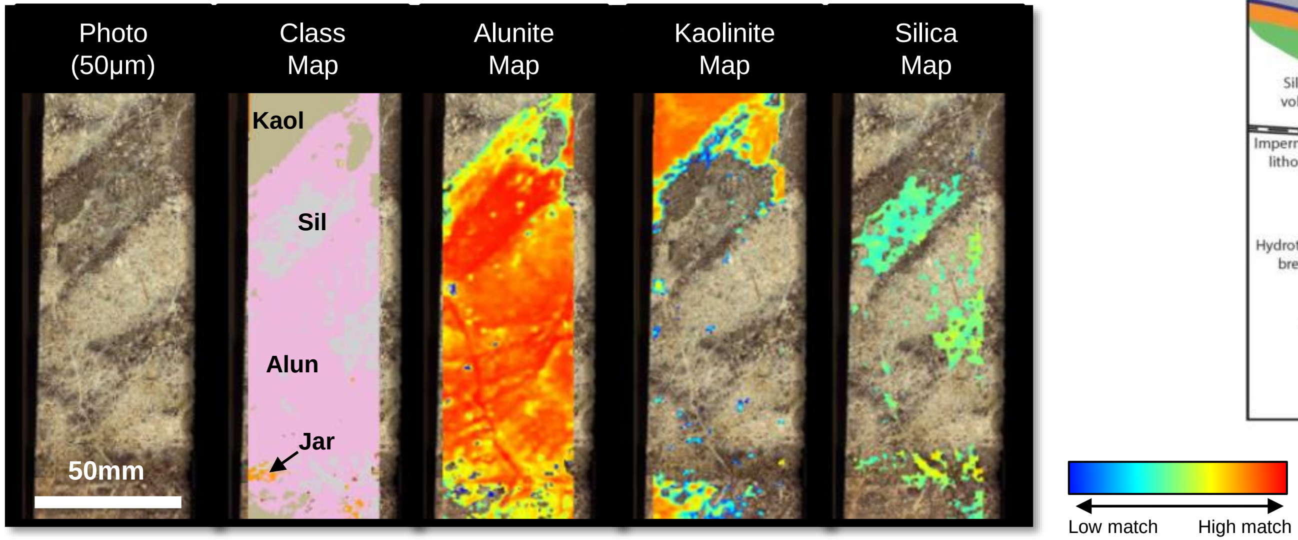
Fe-Mg substitution in chlorite is easily tracked using diagnostic SWIR absorption features at ~2250nm and/or ~2350nm.



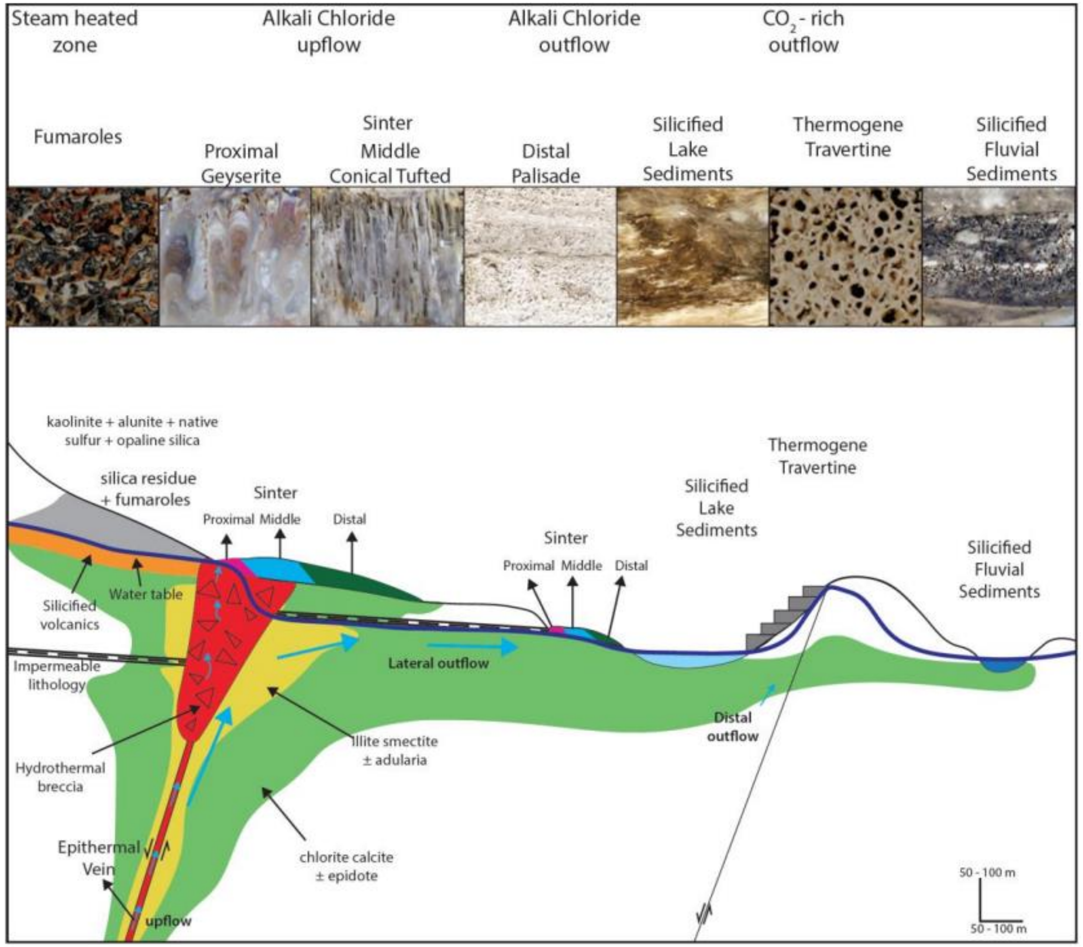
LS Epithermal Deposits: Surface Expression

- The surface expression of LS epithermal deposits can be extremely variable.
- During formation, geothermal fluid upflow and outflow can result in a range of different surface features (siliceous sinters, fumaroles, travertine and others).
- The preservation potential for this material is very low but may still be found in some deposits, particularly in very young systems.
- HSI and mapping of key mineral phases can help differentiate alteration zones and map distribution of complex assemblages.

Example: Alunite occurrences to delineate steam heated alteration



Surface Manifestations of Epithermal Systems

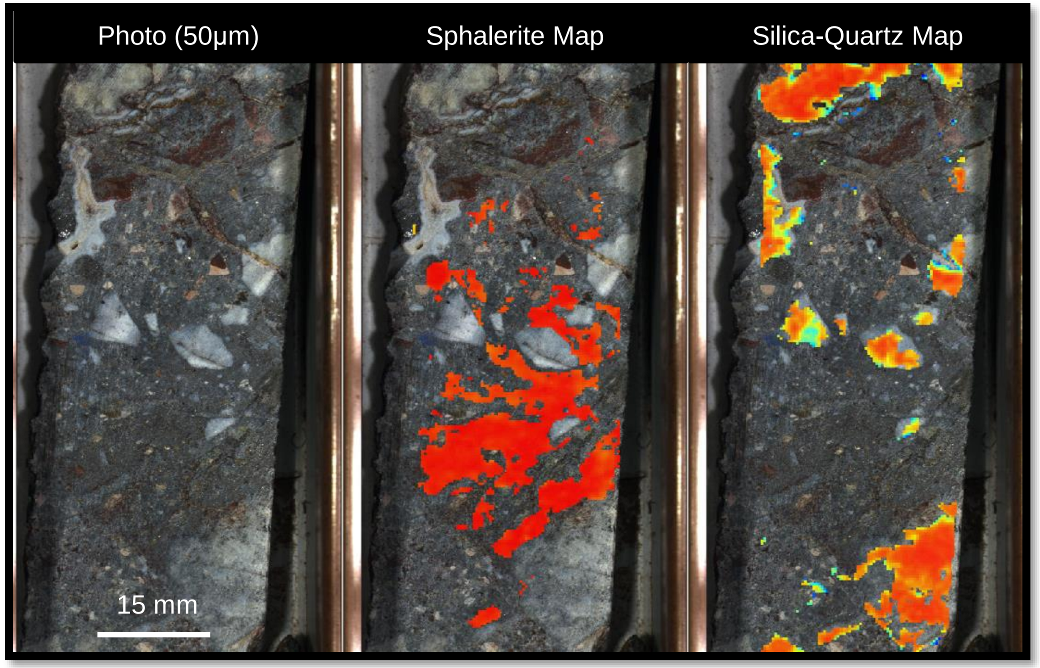


(Hamilton et al., 2019)

LS Epithermal Deposits: At Depth

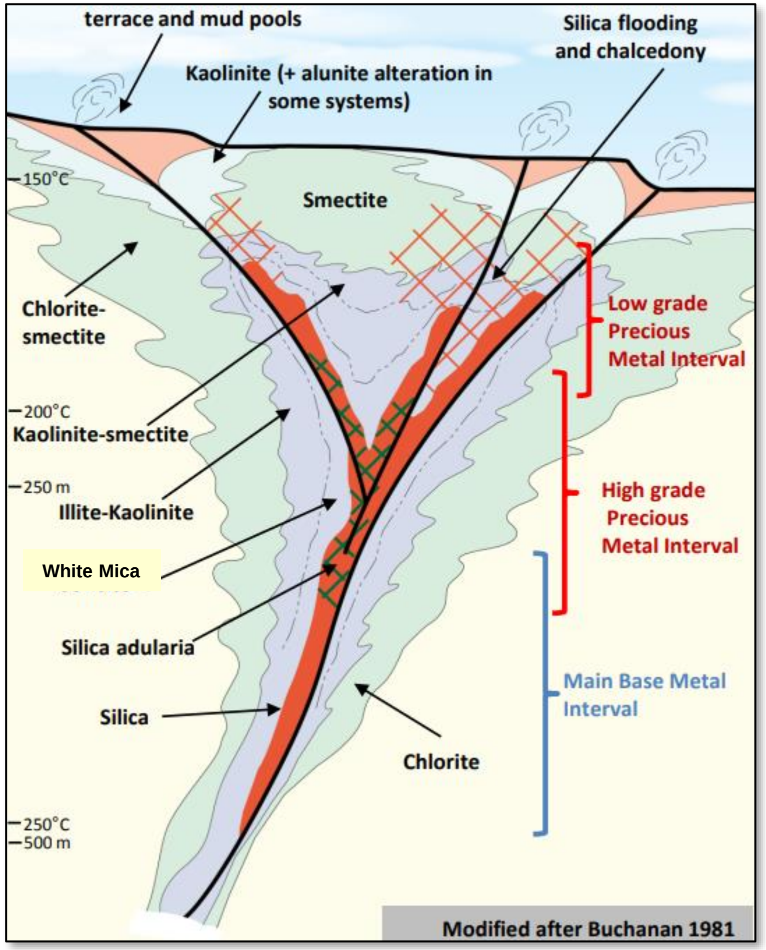
- Metal content and alteration mineralogy in epithermal systems zone with depth to higher temperature assemblages.
- Base metal sulphides (e.g., sphalerite) and higher temperature white micas (e.g., muscovite) are key depth indicators in most systems.

Example: Brecciated silica-Quartz vein and sphalerite infill



Note: Geothermal systems form in dynamic geotectonic and erosional environments – telescoping and overprinting of both alteration and mineralization are typical. Transitions to intermediate sulphidation style deposits is particularly common at depth.

Schematic Model:
Low Sulphidation Au-Ag Vein System



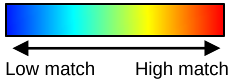
(Wilson and Tunningley, 2013)

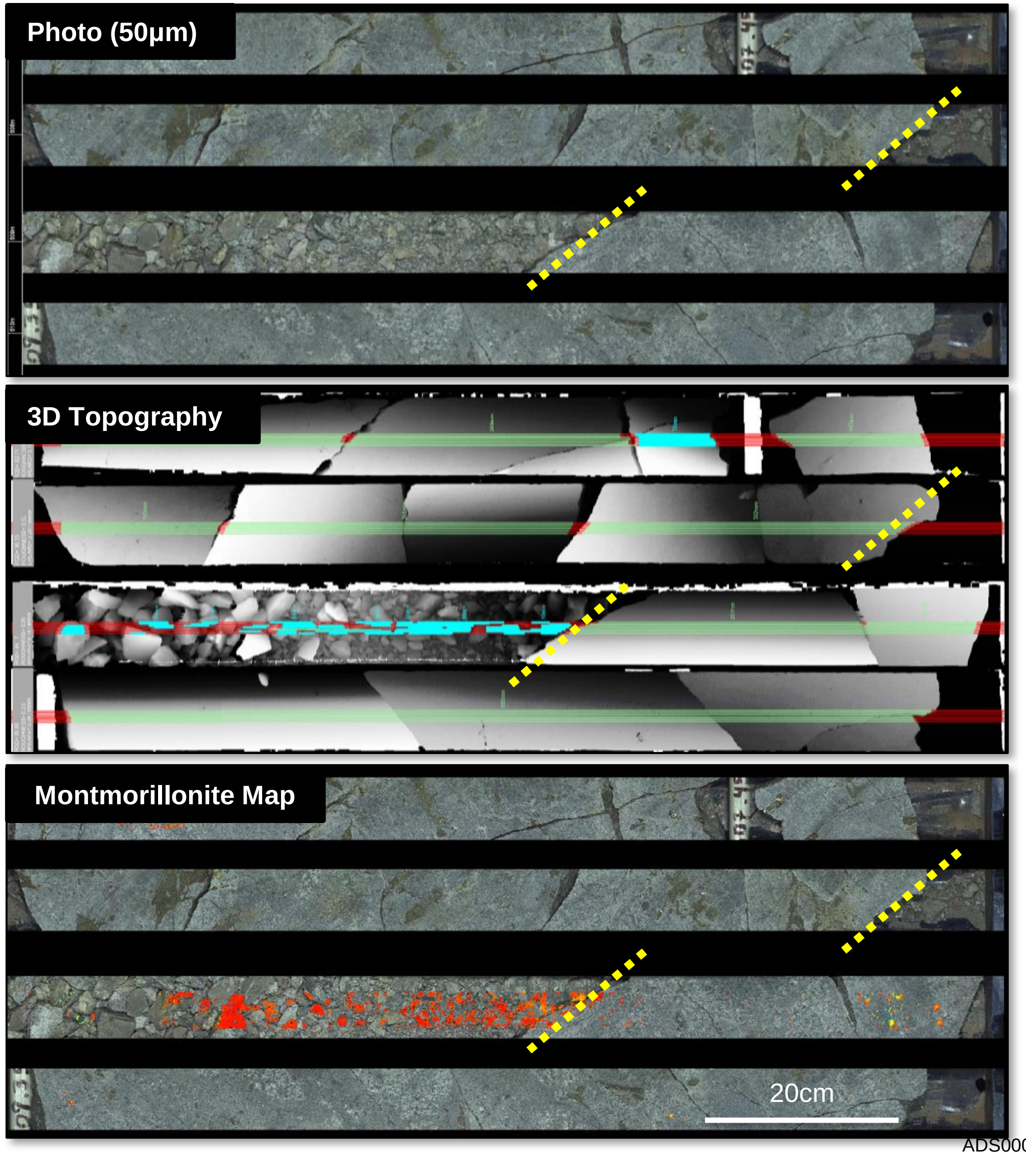
Structural Features

Detection and Mapping of Faults

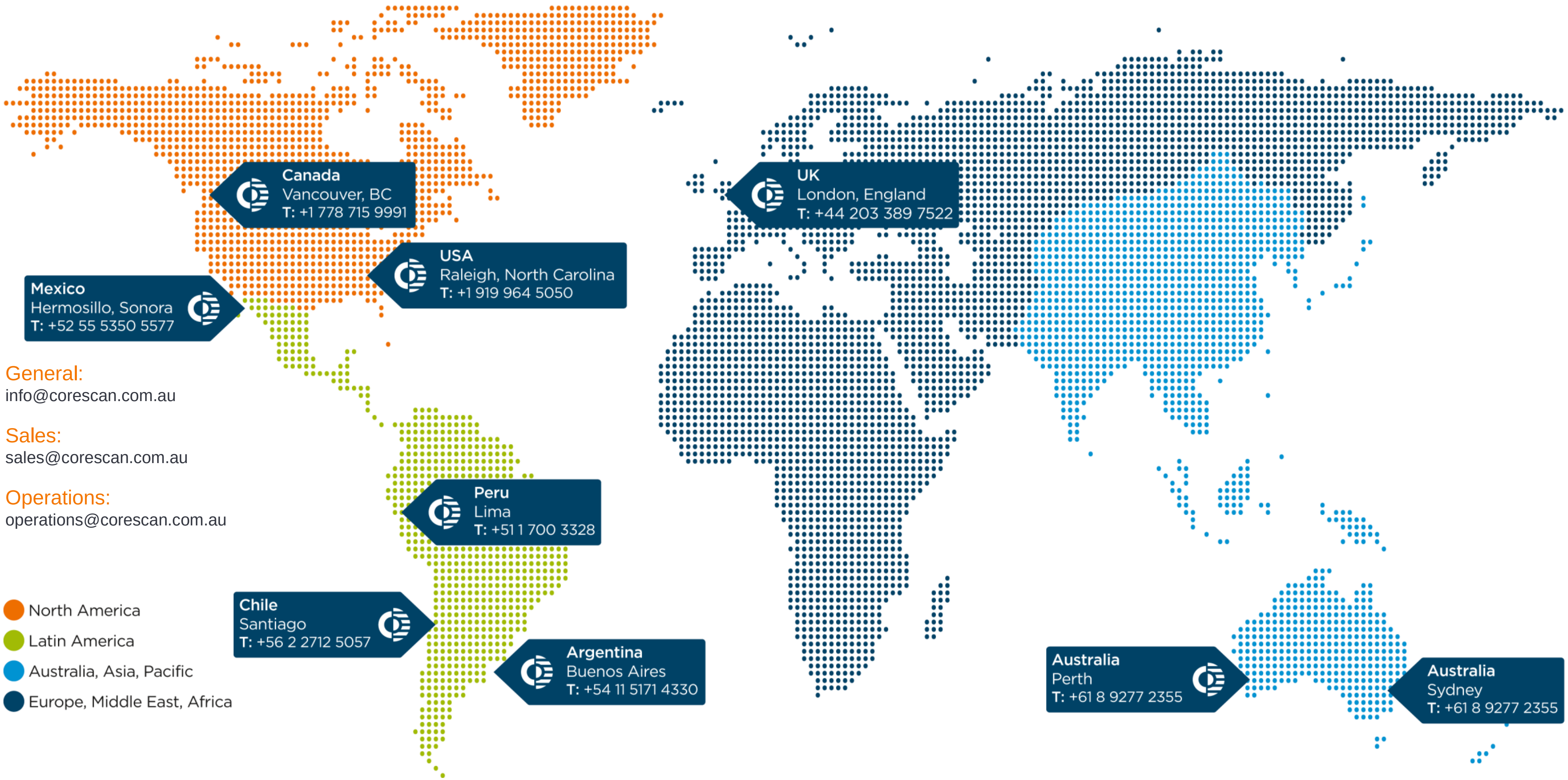
- Sharp mineralogical changes and rubble zones in the core may indicate the presence of faults and fault gouge.
- Clays (smectites, kaolinite, illite) are common fault gouge minerals, all of which are identified by diagnostic SWIR features.
- Laser profiler (3D topography) data can used to calculate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





Contact Us



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