Imaging spectroscopy for metal resource exploration: a case study of the Shadan porphyry copper deposit, Iran

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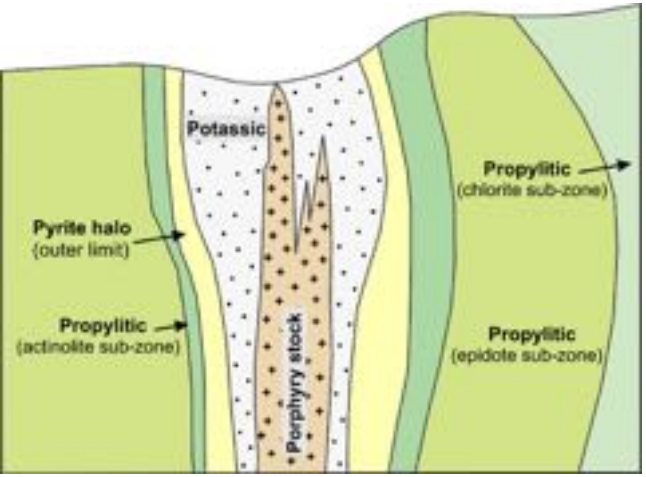
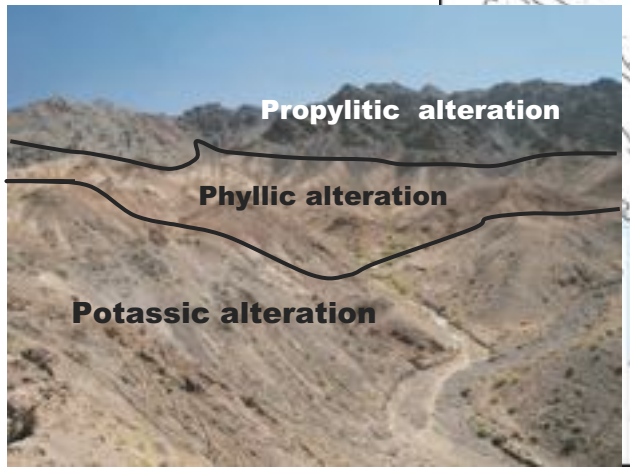
Motivation

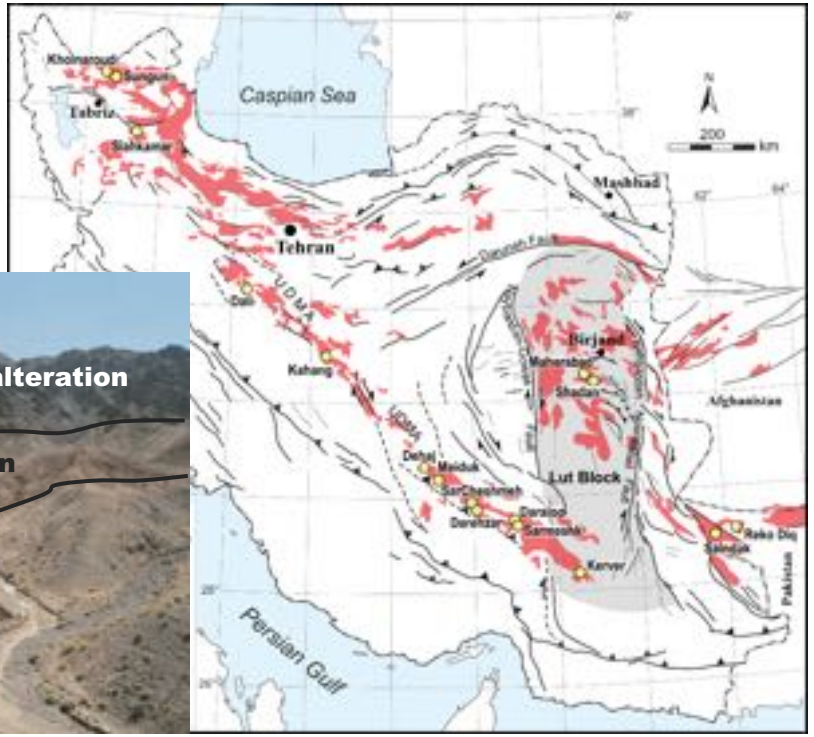
- To take a step forward in using imaging spectroscopy for mineral exploration by mapping the physicochemical gradients and zonation within alteration mineral assemblages.
- To provide vectors toward prospective zones and contribute to area reduction and operational efficiency.

Shadan Porphyry Cu-Au deposit

- The deposit is deeply eroded.
- It contains >135 Mt of ore with Cu and Au grades of 0.3%, and 0.4 g/t.

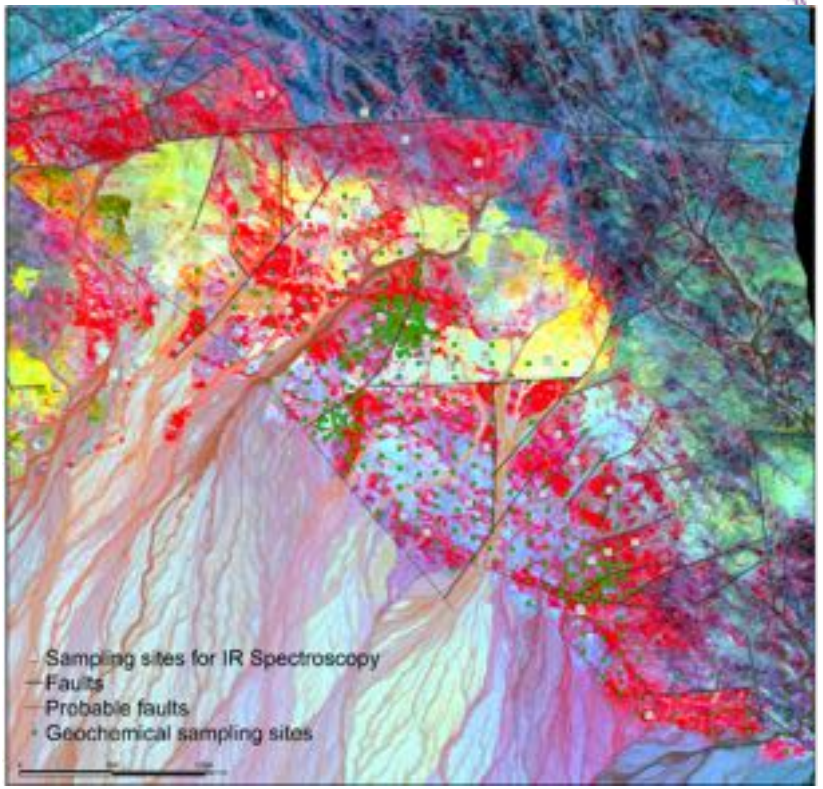






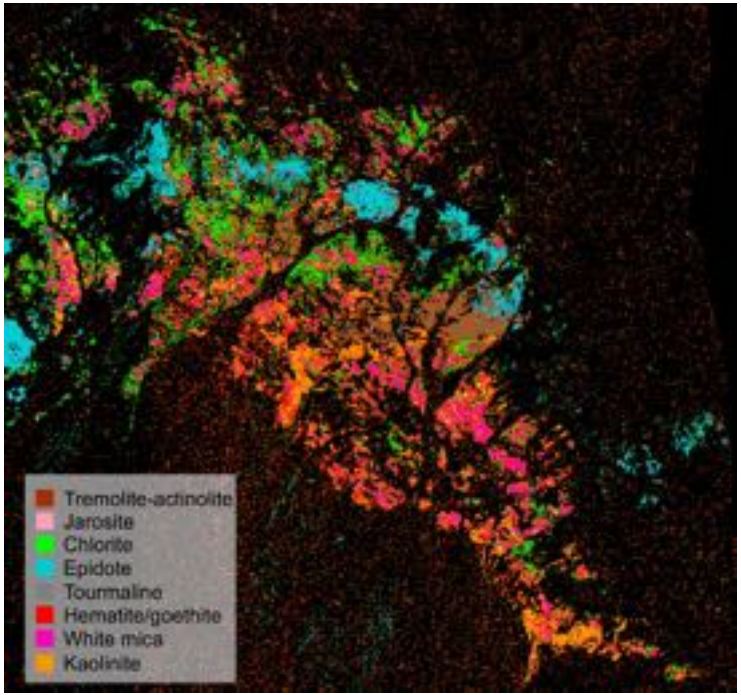
HyMap/EnMAP hyperspectral datasets

- Airborne HyMap data collected in 2006 at ~5m spatial resolution.
- A simulated EnMAP hyperspectral scene (using the EnMAP end-to-end simulator) at 30m spatial resolution.
- 470 lithogeochemical samples.
- 40 samples measured spectrally in the lab.



Mineral classification map

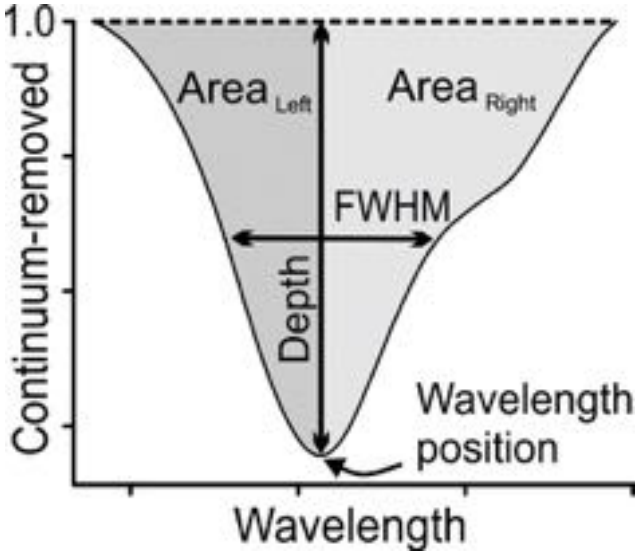
- The **EnGeoMap** module embedded in the EnMap toolbox was used to generate a quick mineral classification map.
- Image classification, although very informative, it does not use the full capabilities of imaging spectroscopic data in geologic studies.



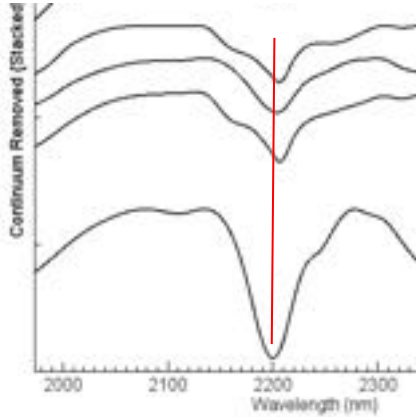
EnGeoMap is a spectral processing tool for material detection and characterization from hyperspectral imaging data.

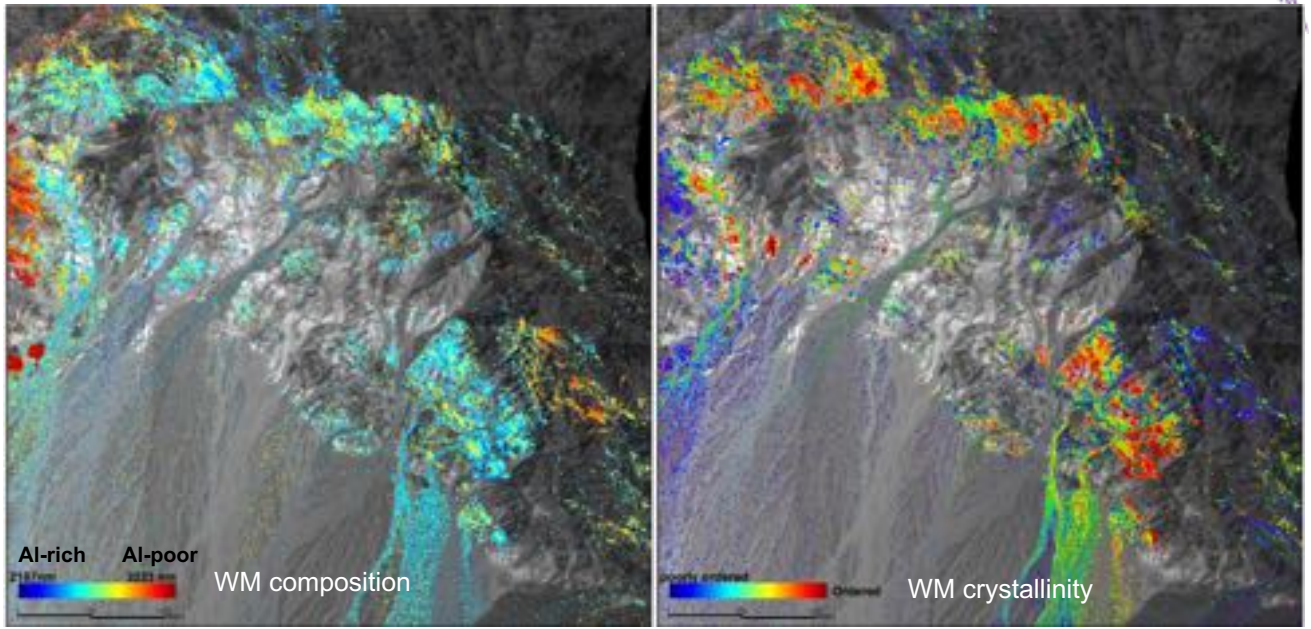
Feature extraction approach

- Feature extraction approach relies on absorption feature characterization (polynomial fitting) to extract mineralogical information.
  - Wavelength position: proportional to the cation composition.
  - Depth: proportional to mineral abundance.
- This approach can reveal changes within minerals/mineral groups.



White mica composition and crystallinity



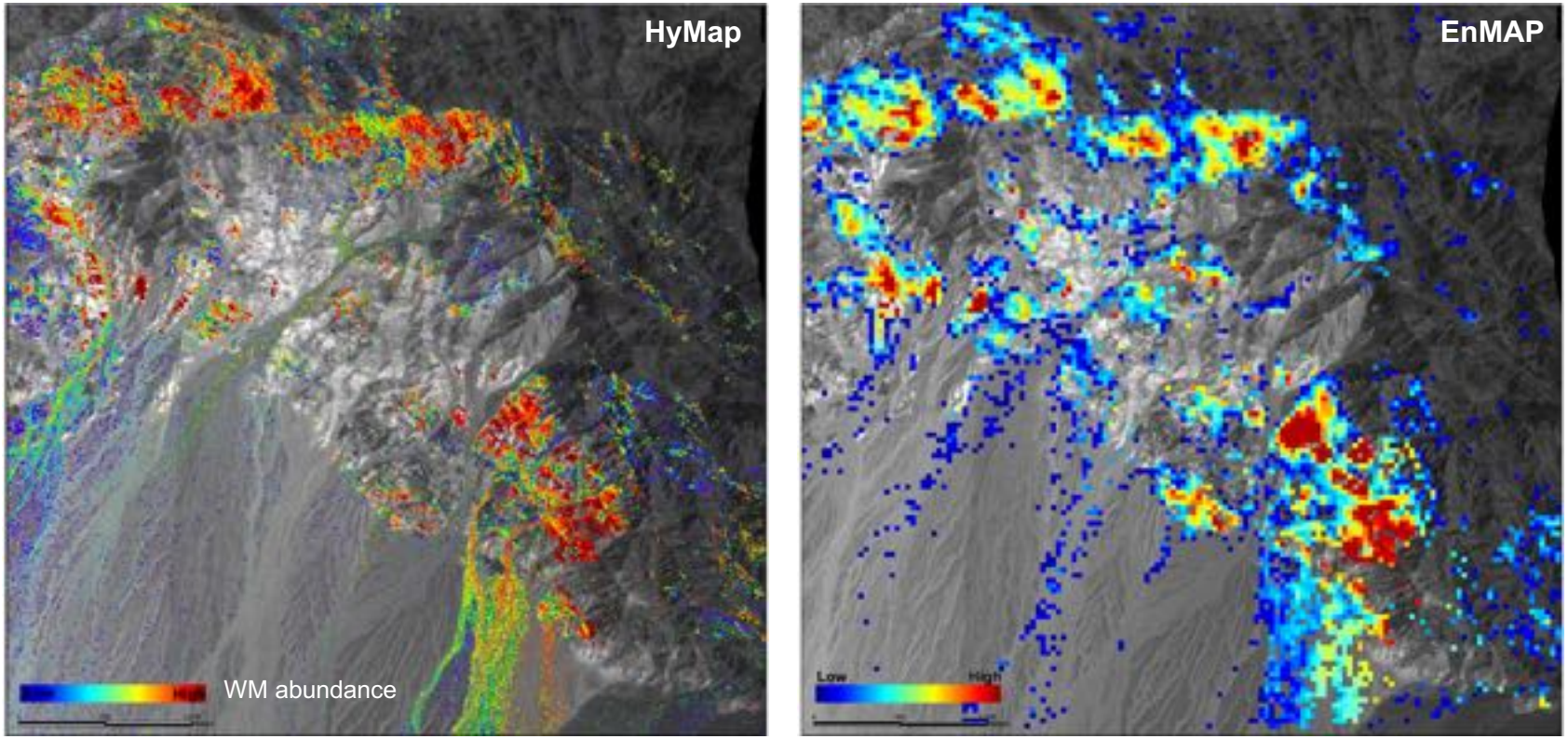


- Phyllic alteration formed at <400°C (illitic white mica with low-crystallinity).
- Acidic fluid (muscovitic in composition).
- Proximal to ore zone

1st derivative of fitted 4th order polynomial: 2120-2245 nm

Relative depth of the clay and water absorptions

Performance of EnMap in mapping white micas



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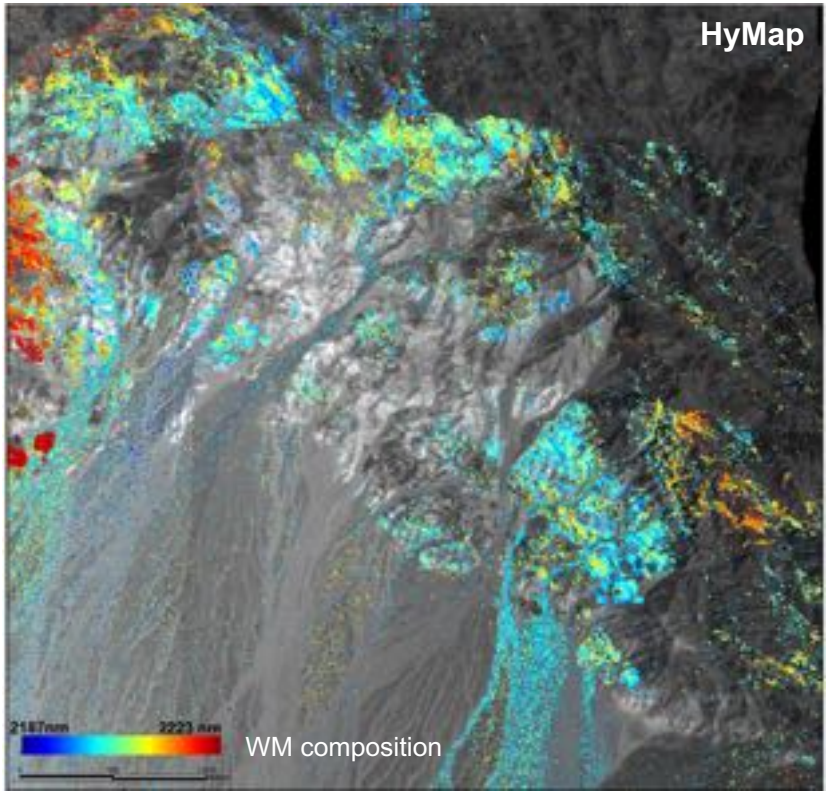
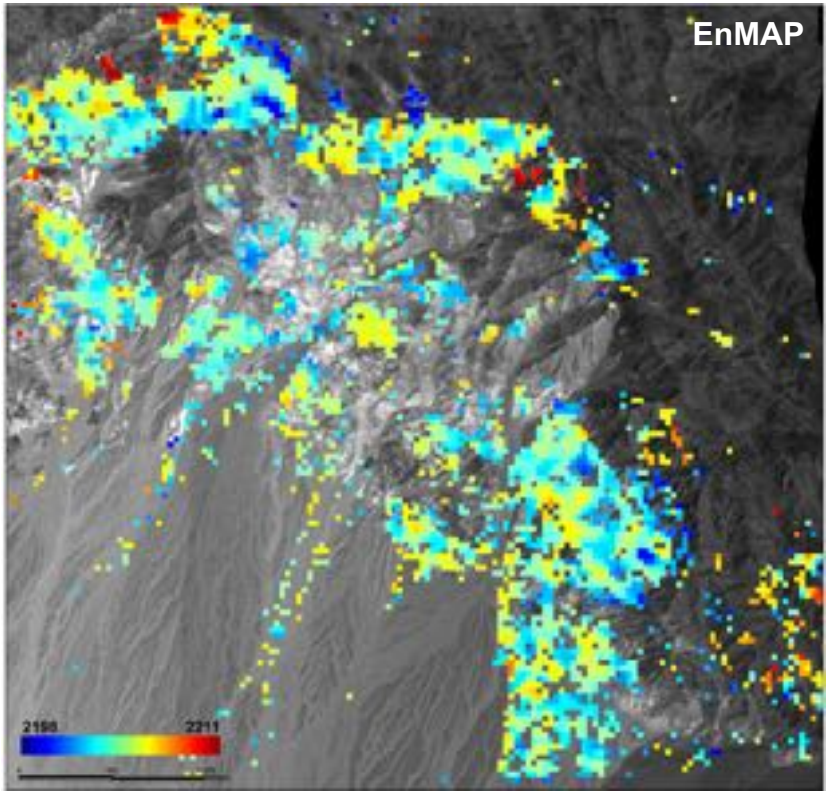
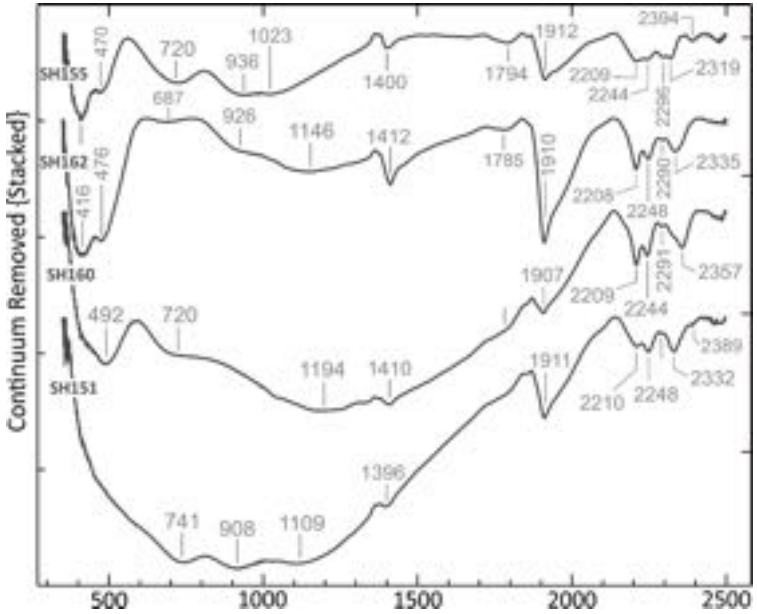
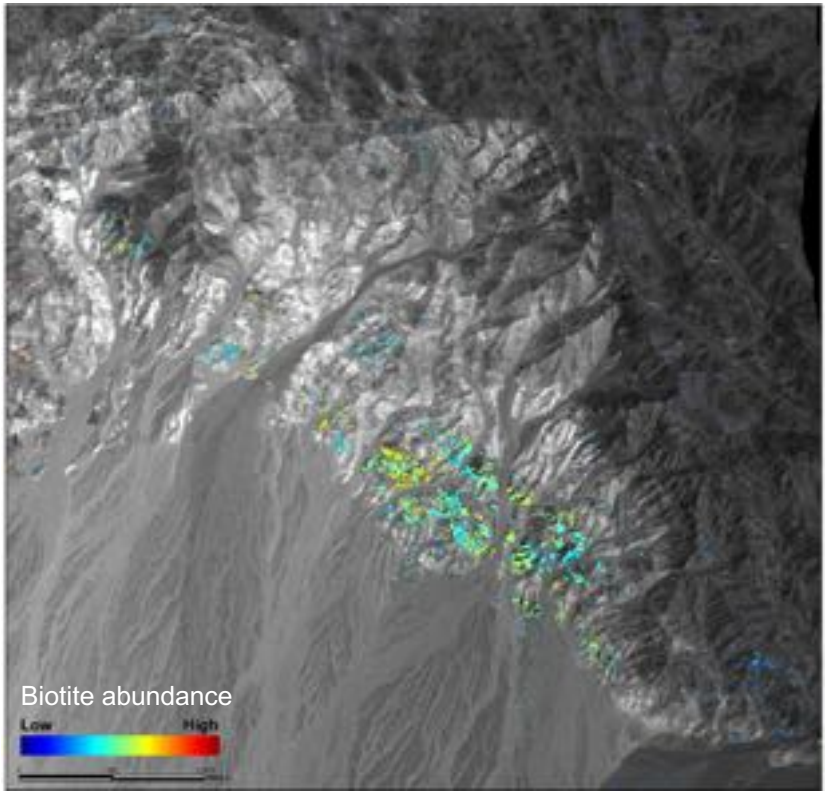




Biotite abundance

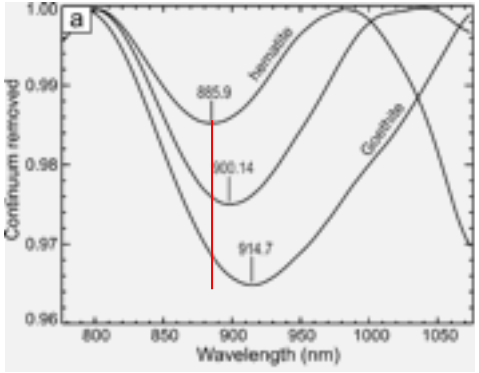
- Biotite (with traces of chlorite) was detected by its low reflectance in the VNIR and the SWIR feature at 2350 nm.
- It represents the potassic alteration and ore zones at the center.

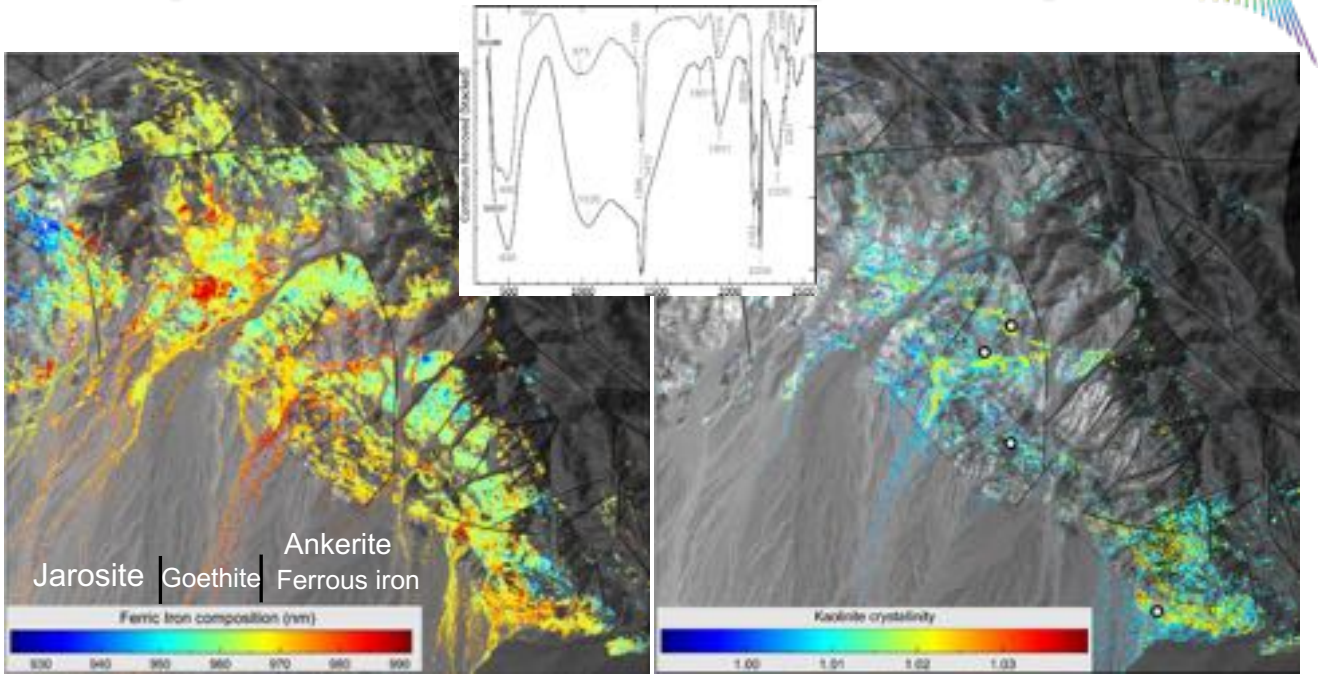




Iron oxides compositions + Kaolinite crystallinity

- Hypogene alteration due to co-occurrences of well-crystalline kaolinite with ferrous iron.
- Slightly acidic, reducing fluid formed at moderate T at later stages of porphyry evolution.
- Not easily detected in the field.



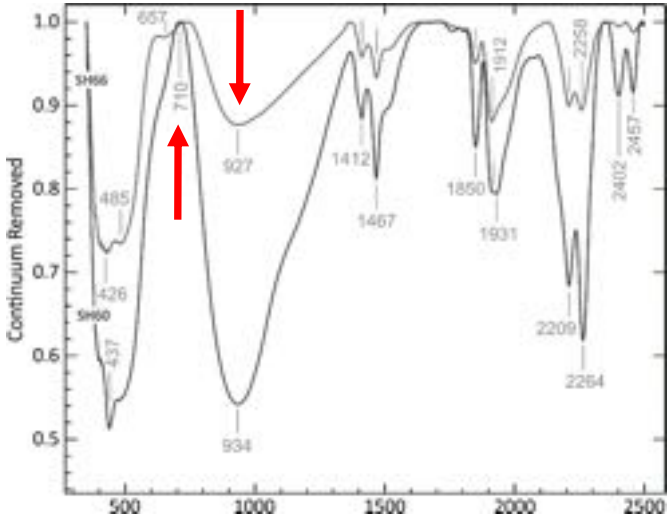


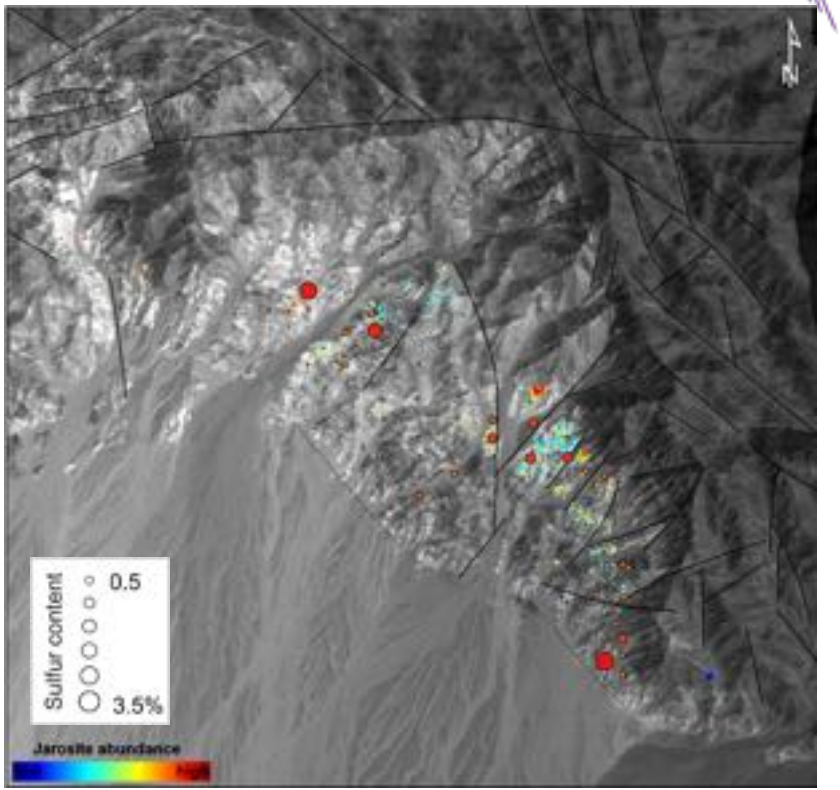
- No hematite, little goethite.
- Abundant jarosite and ferrous minerals.
- No secondary Cu enrichment.

- Highly crystalline kaolinite, no dickite.
- Later stage acid alteration.
- 3rd alteration phase (cross-cuts previous ones).

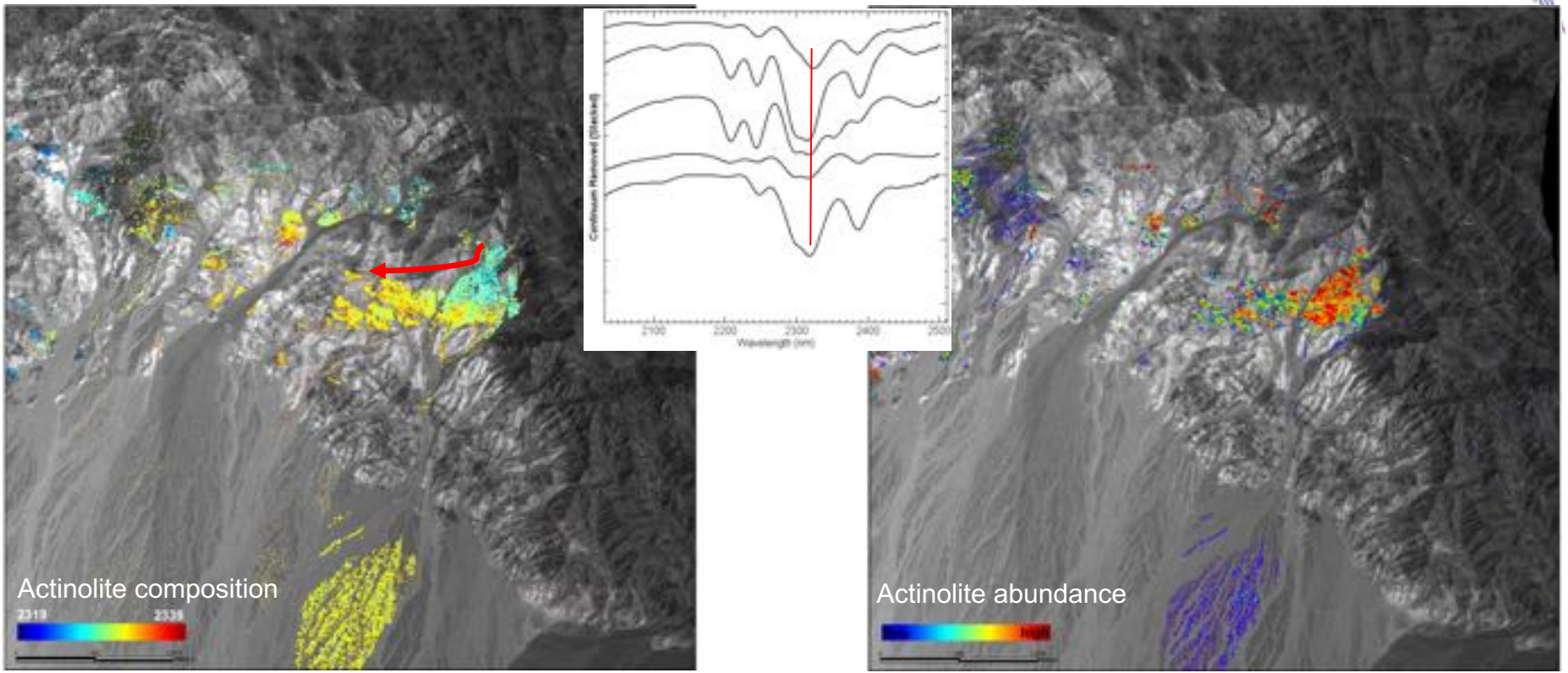
Jarosite abundance and its significance

- Jarosite was detected and mapped using the VNIR features.
- It defines the outline of the pyrite halo overprinted on the potassic alteration.
- Jarosite abundance is correlated to sulfur contents and gold-bearing zones.





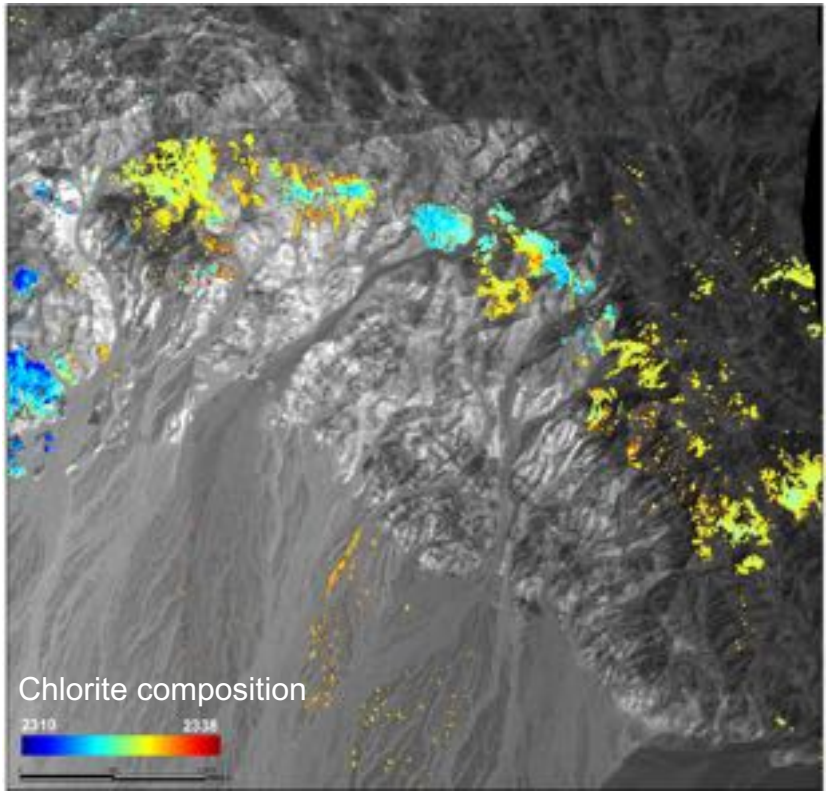
Inner propylitic zone: Actinolite amphibole

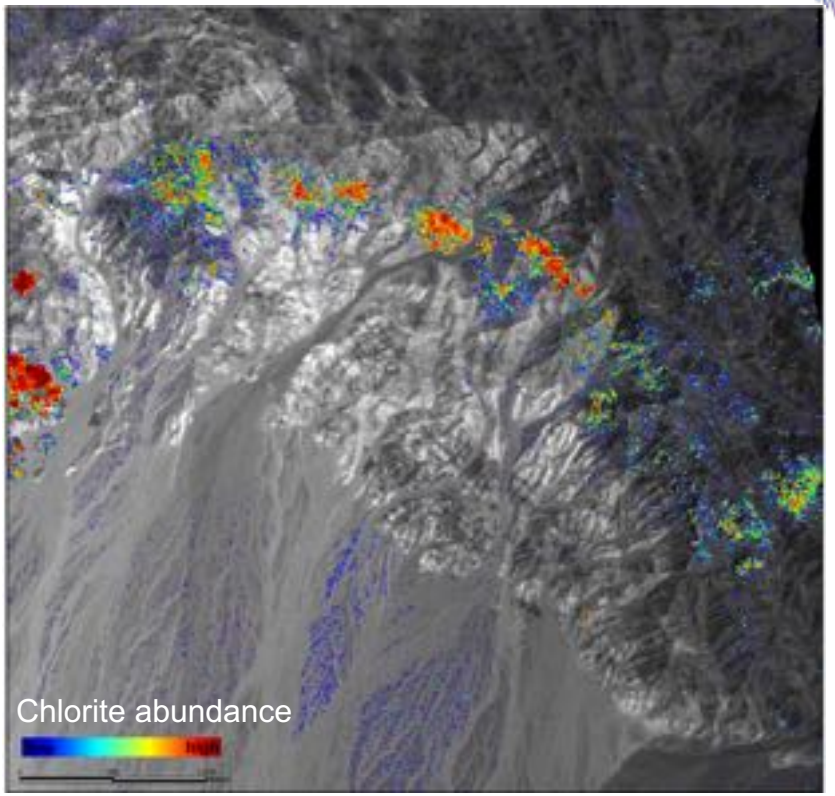


1st derivative of fitted 4th order polynomial from 2225 to 2423 nm

depth of the 2326nm absorption feature

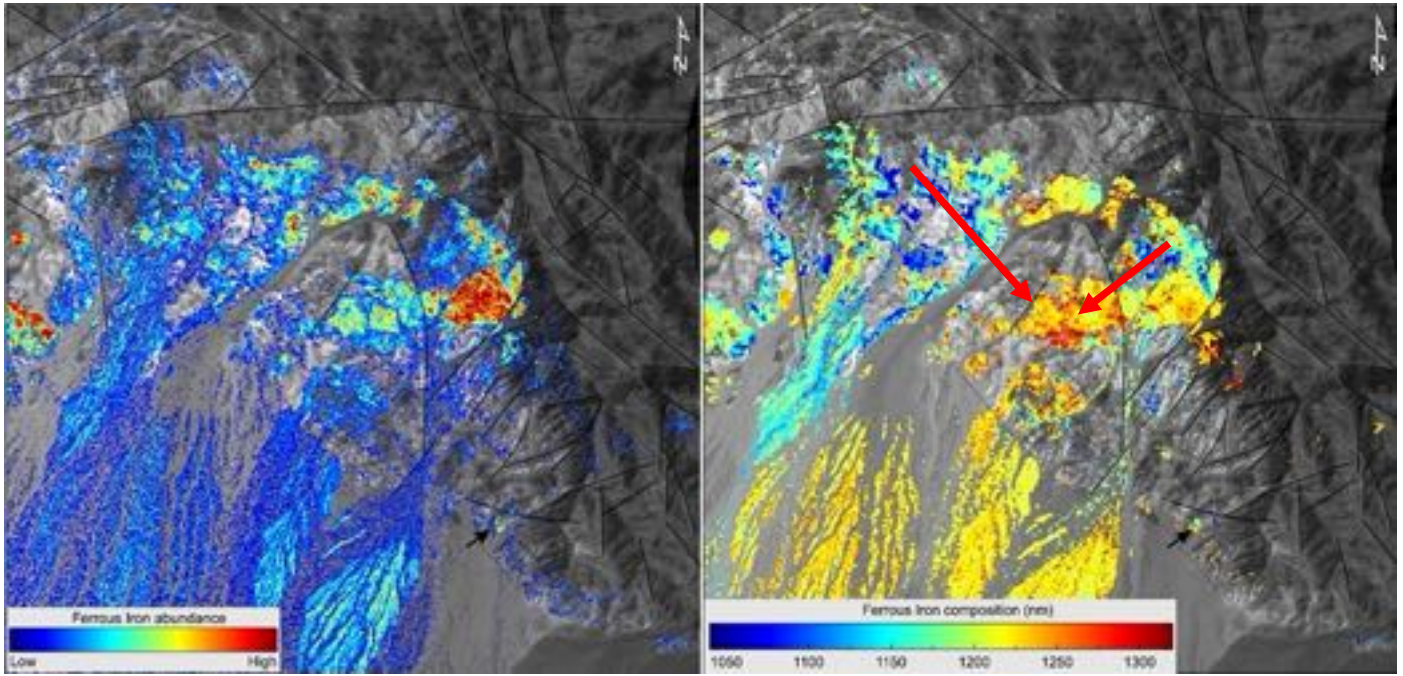
Outer propylitic zone: Chlorite



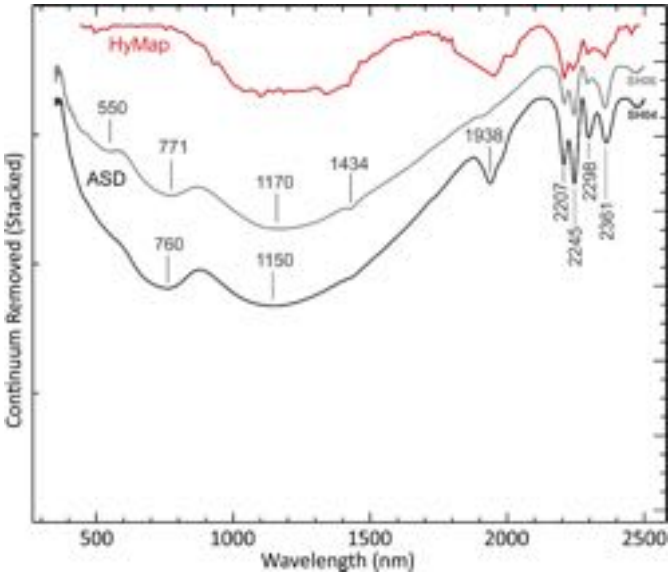


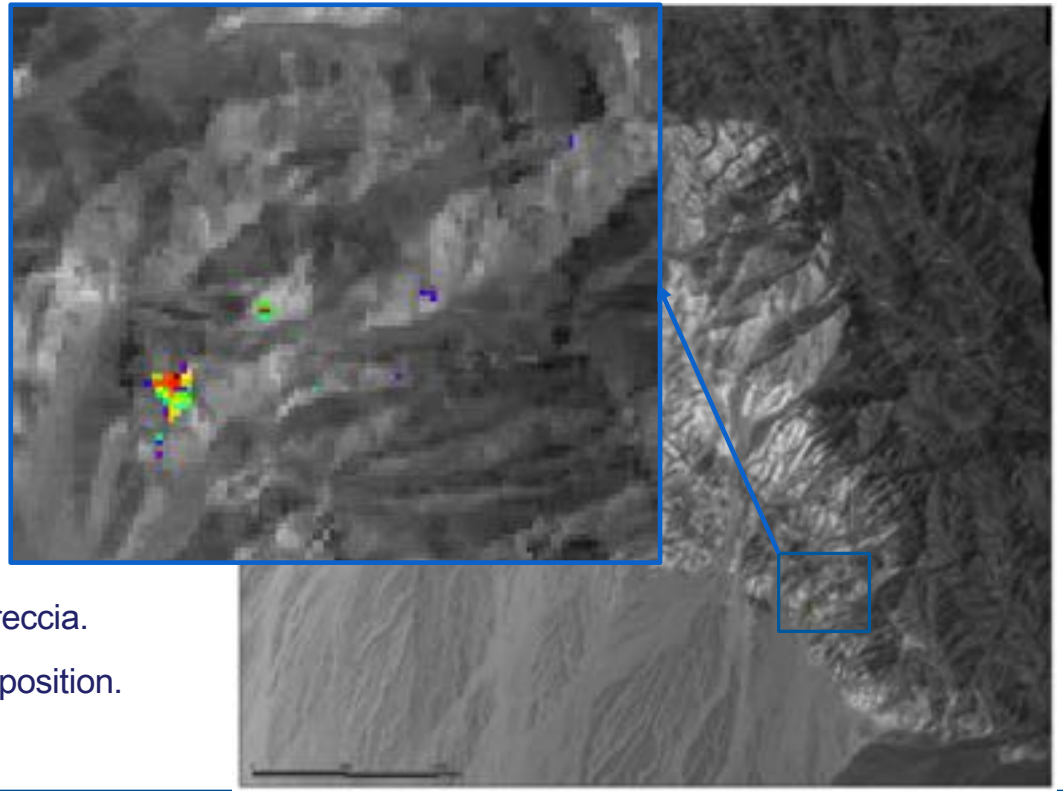
Ferrous iron abundance and composition

- Ferrous iron minerals are highly abundant, which is a characteristics of Au-rich porphyry systems.
- The composition of ferrous iron minerals changes from distal to proximal zones.



Tourmaline occurrences in Shadan





- Tourmaline indicates magmatic-hydrothermal breccia.
- The mapped tourmaline is dravite-schorl in composition.

Summary and conclusion

- Imaging spectroscopy can be effectively used to delineate the architecture and physicochemistry of alteration minerals and pinpoint the most promising zones. It also can help determine
  - The footprints of fluid flow.
  - Phases of alteration/mineralization.
  - The temperature of alteration events.
  - The chemistry of the fluids: oxidation-reduction state and acidity.
- VNIR data is as informative as SWIR bands and should not be overlooked in geologic studies.