WHITE MICA GEOCHEMISTRY AS A VECTORING TOOL APPLIED TO EXPLORATION OF PORPHYRY SYSTEMS

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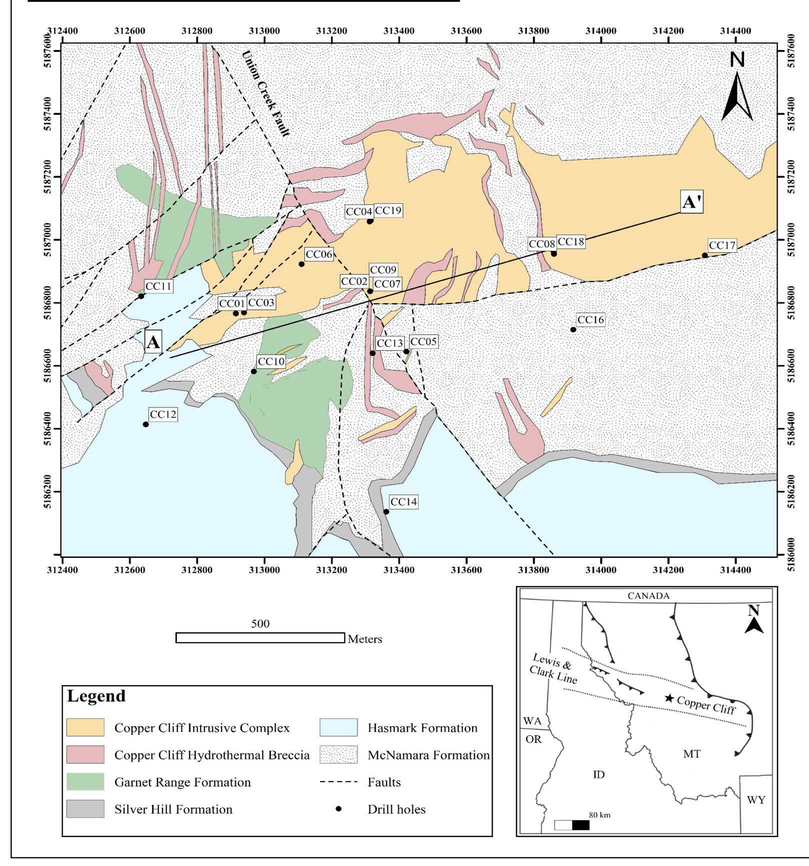
SUMMARY

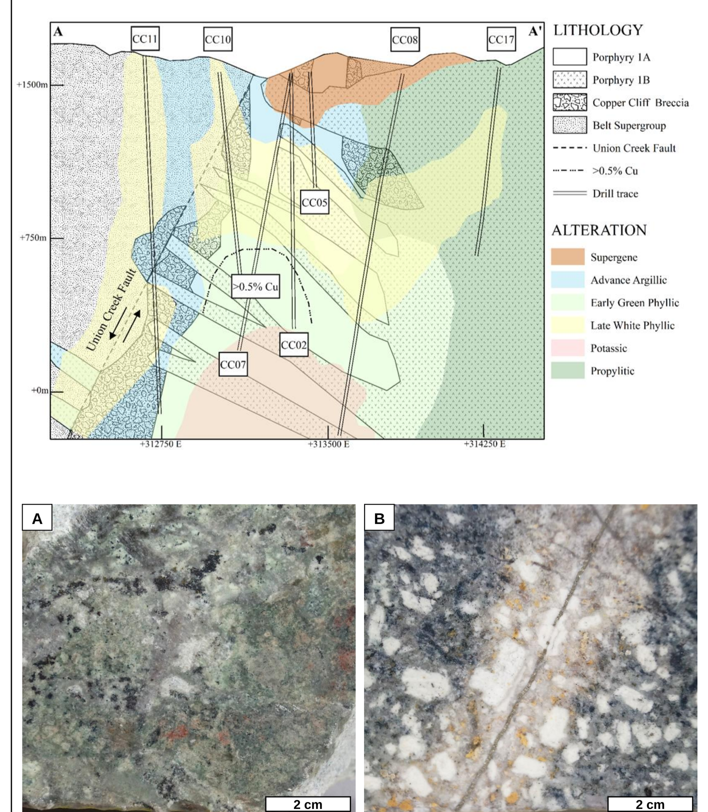
Over the last decade, significant advances have been made in the research of alteration mineral geochemistry relative to the targeting of poorly exposed porphyry copper deposits. This work provides new constraints on the identification of signatures and distance indicators for mineralized porphyry ore bodies based on geochemical variations present in white micas within the phyllic alteration zone. This is the first systematic study of the white mica vectoring tool grounded in the differentiation of distinct phyllic alteration events. An important consideration of this study is that porphyry deposits can present multiple phyllic alteration events with similar textural features but distinct geochemical footprints. Therefore, studies of alteration mineral chemistry require evaluation on the basis of a careful paragenetic understanding of the alteration. Careful analyses using petrographic, short-wave infrared spectroscopy, electron microprobe, and laser ablation-inductively coupled plasma-mass spectrometry methods of white micas from early and late phyllic alteration assemblages were undertaken to unravel exploration potential in two porphyry systems in Montana, USA. Analytical data indicate that white micas from the early phyllic events display long-wavelength Al-OH absorption features, which are correlated with higher content of Fe and Mg, and lower content of V and Sc. In contrast, white micas from the late phyllic events are characterized by short-wavelength Al-OH absorption features, with lower Fe and Mg, and enrichment in V and Sc. Variations of trace element concentrations in white micas from the distinct phyllic events show clear patterns in relationship with distance from the hydrothermal center, and are suggested to be dominantly thermally controlled. At the Copper Cliff porphyry system, Cu concentrations decrease with distance from the deposit center, in contrast to B, Sr, and Zn that show an exponential concentration increase with distance from the deposit center. The application of the Cu/Zn ratio of white micas in a manner analogous to the chlorite proximitor equation of Wilkinson et al. (2015) provide an indicator of distance to the center of the hydrothermal system within approximately 710 m in samples of the early phyllic alteration event, and within approximately 1,300 m in samples of the late phyllic alteration phase. At the Grasshopper prospect, increases with proximity toward the center of the system were observed in elements including, V, Cu, Sc, Sn, W, and Zn, whereas increasing trends with distance from the deposit center are observed in Li and Cs. Comparison of the trace element concentrations of white micas from the early phyllic style from the poorly mineralized system of Grasshopper, and the mineralized system of Copper Cliff indicates significant differences in Zn, Cr, B, Tl, Sn, and Cs. Therefore, a preliminary discrimination diagram (Zn+Cr+B vs. Tl+Sn+Cs) is developed to differentiate white micas from the early phyllic alteration between mineralized and barren systems.

1) COPPER CLIFF DEPOSIT



- The Copper Cliff deposit is an intermediate stage exploration project of Kennecott Exploration Company located 48 km ESE from Missoula, Montana.
- The prospect consists of a deep, high-grade copper gold porphyry target hosted within the metasediments of the Middle Proterozoic Belt Supergroup.
- The Copper Cliff intrusive complex comprises several small and elongated quartz latite bodies, characterized by medium grained, sub-equigranular textures with a phenocryst to groundmass ratio of 70:30, where the phenocrysts are mainly composed of plagioclase, hornblende, biotite and quartz.

Phyllic Alteration Subtypes:



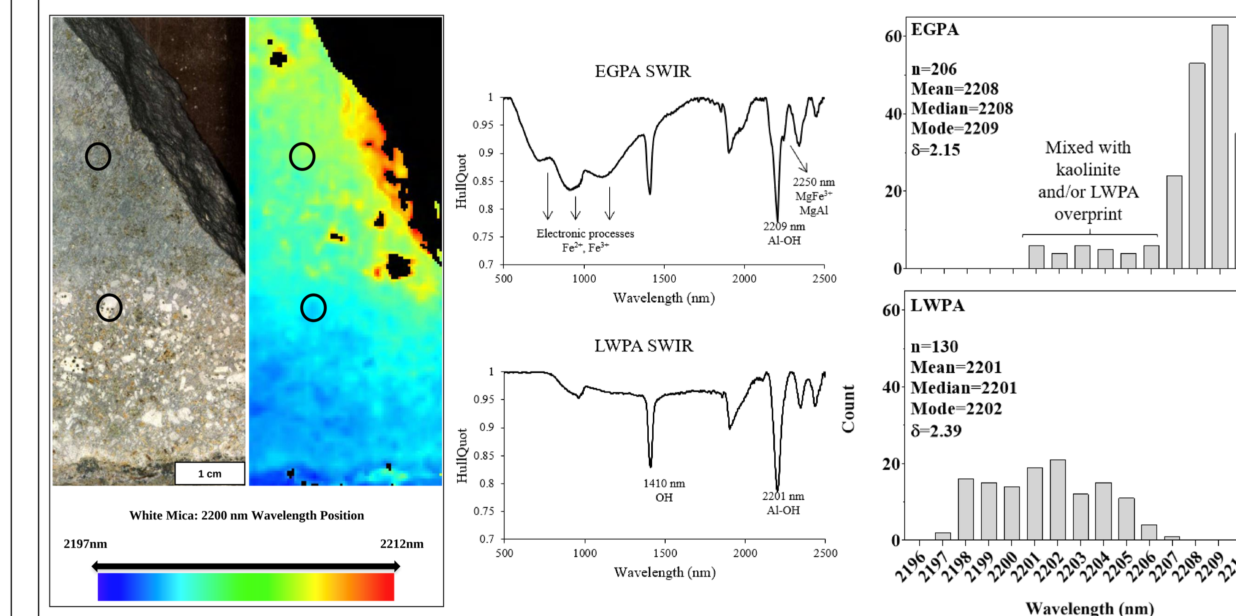
1. Early Green Phyllic Alteration

- Pervasive and texturally destructive phyllic event that occurred early in the evolution of the porphyry system, as it is observed around the deep potassic core.
- Mineral assemblage characterized by green colored mica ± quartz ± iron-oxides (usually specular hematite), and locally andalusite, chlorite, anhydrite and/or calcite.
- Related with the highest hypogene copper grades (>0.5% Cu), mainly chalcopyrite ± bornite with lesser pyrite.

2. Late White Phyllic Alteration

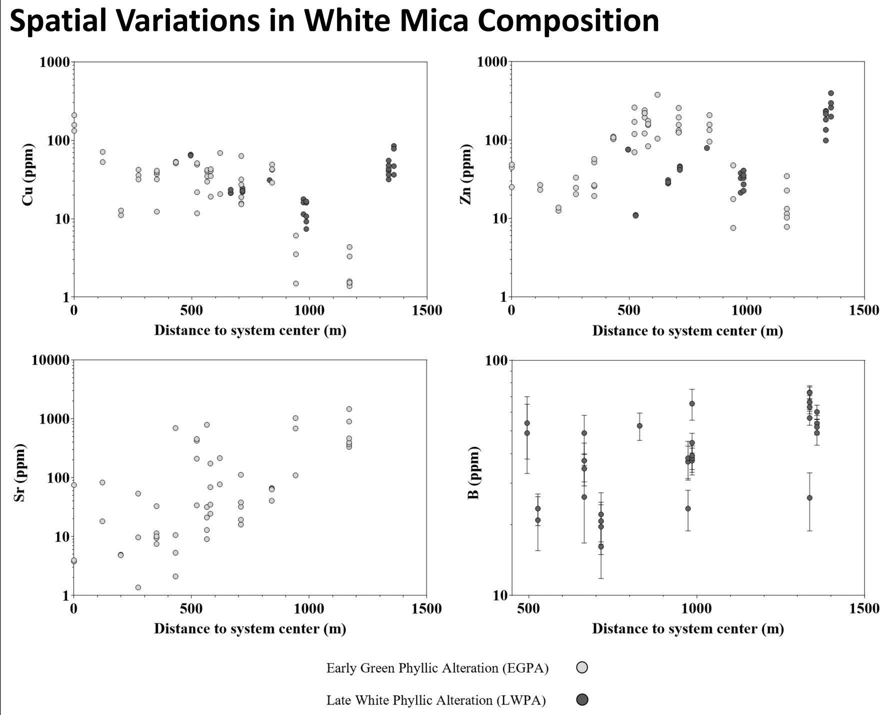
- Non-texturally destructive event characterized by white-colored mica replacing plagioclase phenocrysts and yellow-colored mica ± pyrite ± rutile replacing mafic silicates.
- It is present as up to 10-cm-thick halos about late quartz-pyrite veins, overprinting potassic, early phyllic, and propylitic alteration phases.
- Copper concentrations are typically low; only trace amounts of chalcopyrite (and locally molybdenite) are present in the quartz-pyrite veins.

Characterization of the White Mica SWIR Spectra:



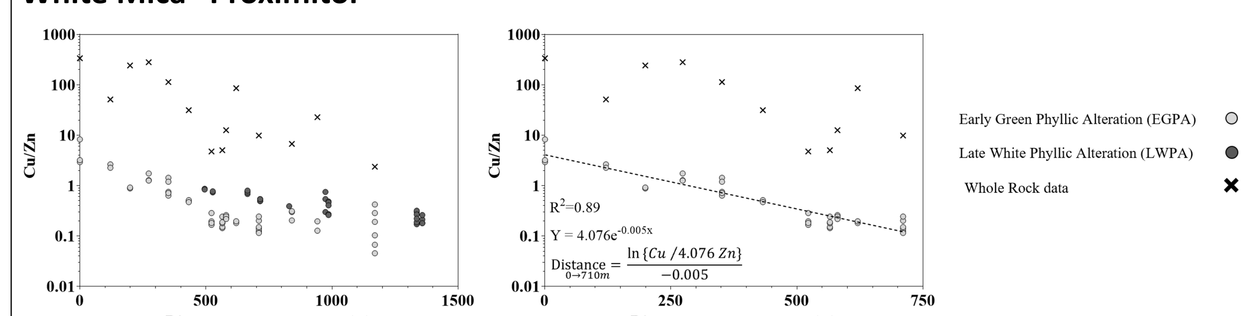
- The histogram of the white mica Al-OH wavelength position from the early green phyllic alteration (EGPA) shows a normal distribution between 2,206 and 2,210 nm, with the mean absorption feature located at 2,208 nm.
- Samples from the EGPA with white mica Al-OH wavelength position shorter than 2,206 nm present late white phyllic alteration overprint and/or IR absorption evidence for kaolinite..
- The late white phyllic alteration (LWPA) is characterized by Al-OH wavelength absorption features ranging from 2,197 to 2,207 nm.

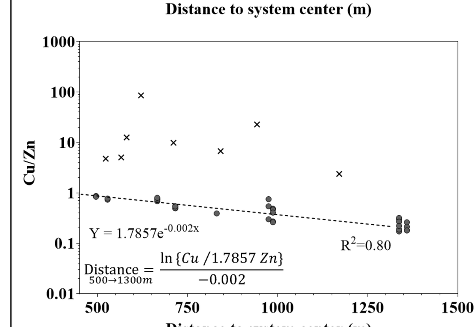
Spatial Variations in White Mica Composition



- Elements were plotted as a function of radial distance out from the deposit center.
- Copper shows relative enrichment proximal to the mineralized center.
- Zinc shows depletion proximal to the center and enrichment at the margins.
- Strontium concentrations increase with distance from the deposit center only in EGPA samples.
- Boron concentrations increase with distance from the deposit center only in LWPA samples.

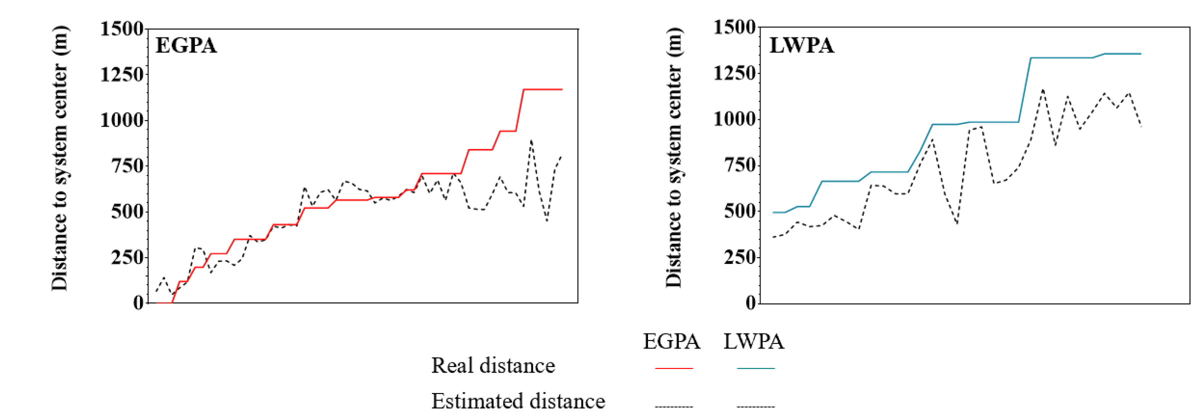
White Mica "Proximitor"





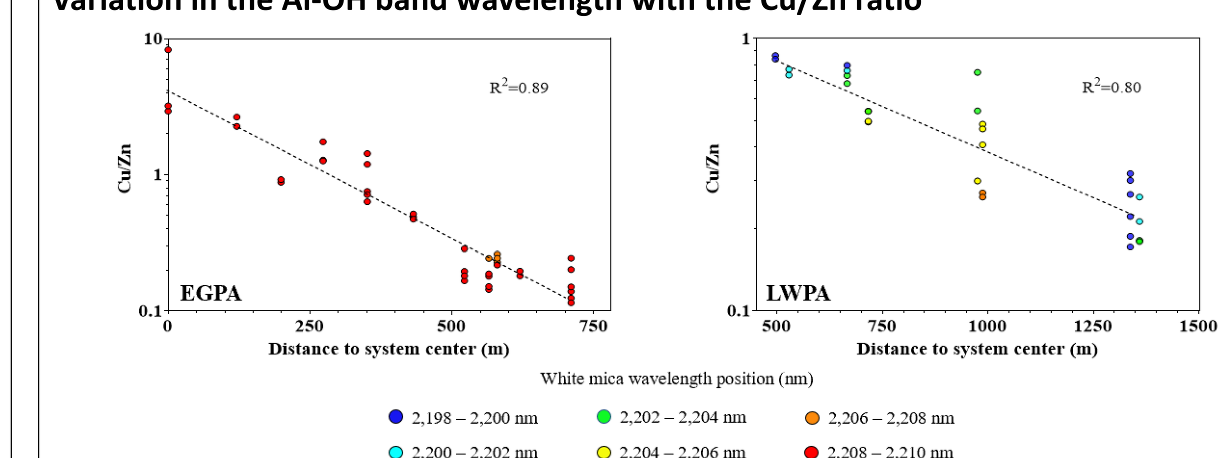
- The spatial variations of trace elements in white mica can be amplified for exploration purposes by comparing the ratio of elements with decreasing outward patterns to those showing increasing outward patterns (Wilkinson et al., 2015).
- In the early green phyllic alteration, the exponential decay of the Cu/Zn ratio as a function of distance from the deposit center is described by the equation $y = 4.076e^{-0.005x}$ to distances between 0 and 710 m.
- In the case of the late phyllic alteration, the exponential decay has the form of $y = 1.7857e^{-0.002x}$ to distances between 500 and 1,300 m.

Accuracy of the White Mica "Proximitor"



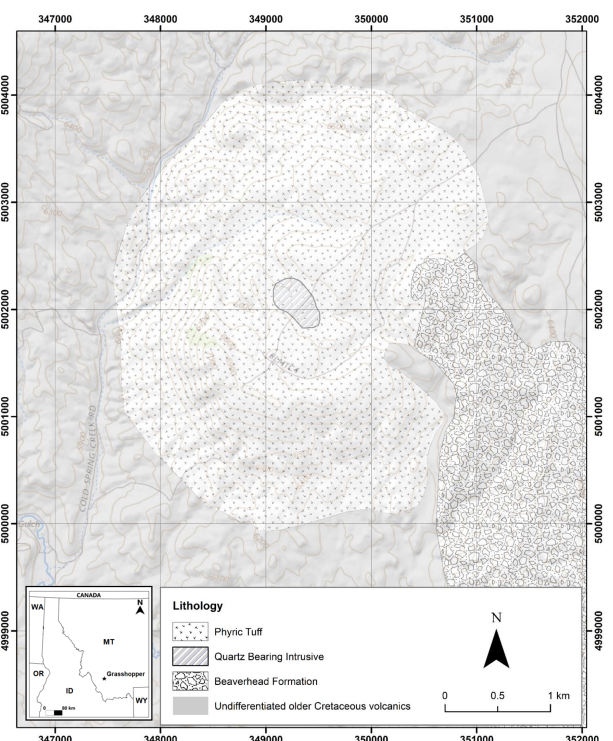
- Comparison of real distances vs. estimated distances based on the Cu/Zn proximitor equation.
- The Cu/Zn ratio for samples with early green phyllic alteration located within a 710 m radius of the deposit center, predicts the distance to center within ±50 m radius error. Beyond the 710 m radius, distances to center are underestimated within approximately 400 m.
- The Cu/Zn ratio for samples with late white phyllic alteration located within a radius between 500 and 1,300 m of the deposit center, underestimates distances to center within ±200 m radius error.

Variation in the Al-OH band wavelength with the Cu/Zn ratio



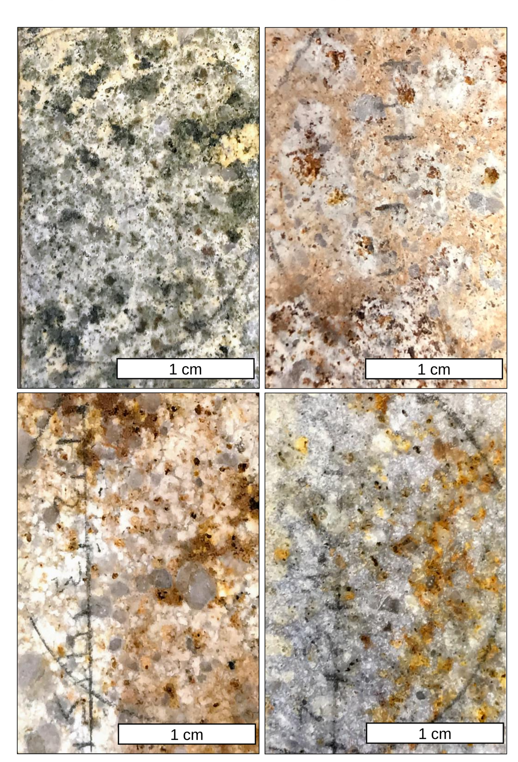
- Variation in Cu/Zn from spot LA-ICP-MS analyses relative to distance, plotted by Al-OH band centers.
- Samples from the early green phyllic alteration show no significant variation in Al-OH band center.
- Samples from the late phyllic alteration within a radius between 500 and 1,300 m show an exponential decay of the Cu/Zn ratio as a function of distance from the deposit center and seem to be associated with a decrease of the position of the Al-OH combination band center.

2) GRASSHOPPER PROSPECT



- The Grasshopper prospect is located 23 km west-southwest of Dillon, Montana, immediately north of Grasshopper Creek and east of the Bannack gold district.
- There are only two rocks units exposed at the center of the prospect of consequence to this study. These consist of a quartz andesitic phyric tuff, and a relatively small and central quartz-bearing intrusive body, the latter of which is the focus of hydrothermal alteration in the prospect.
- The quartz andesitic phyric tuff is inferred to be Cretaceous due to the mapping relationship with the Beaverhead conglomerate on the eastern side, although no dating has been undertaken.
- The Grasshopper prospect provides an ideal setting for a study of alteration mineral chemistry since detected variations of the chemical signatures should be product of thermal/chemical gradients of the fluids relative to the deposit center and not due to potential chemical inheritance from varied lithologies

Phyllic Alteration Subtypes



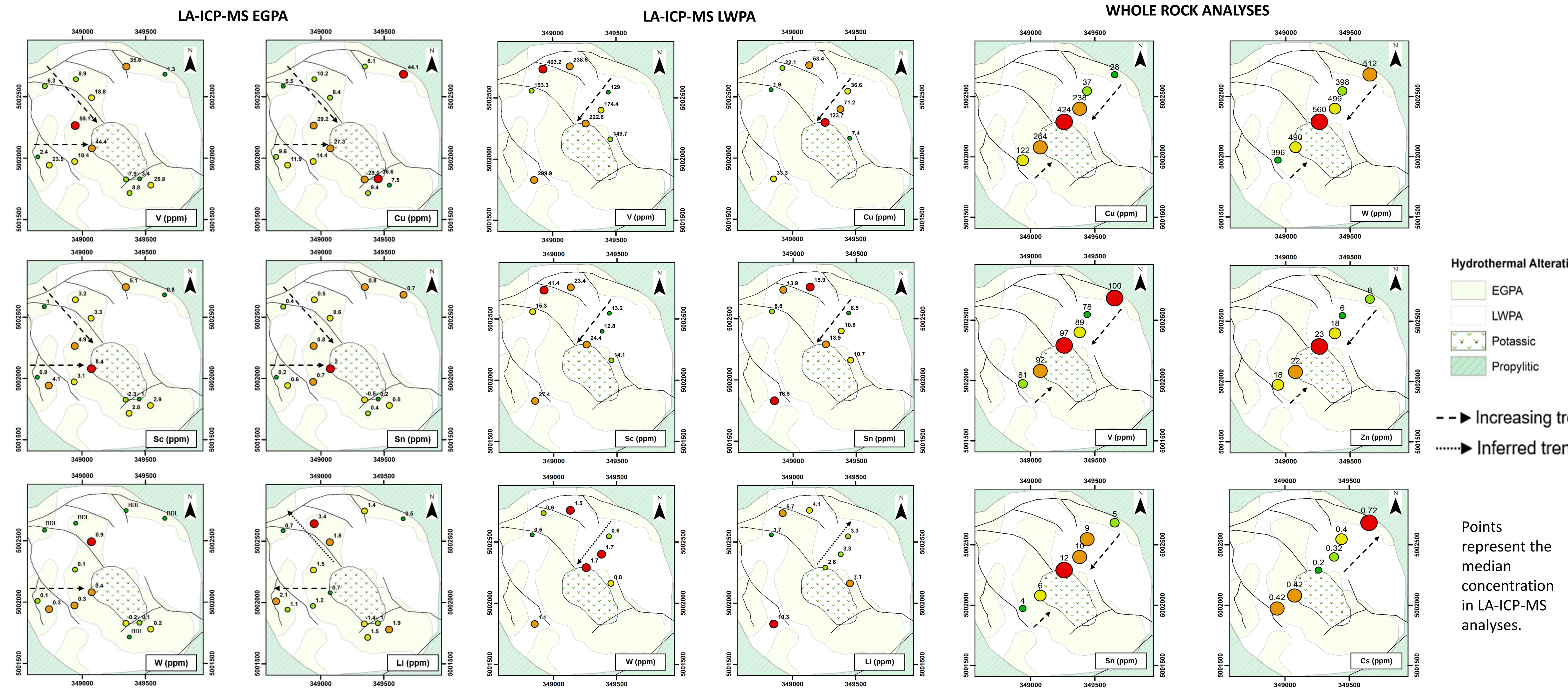
1. Early Phyllic Alteration

- The early phyllic style is a pervasive and texturally destructive alteration characterized by fine grained green to white-colored mica ± quartz ± rutile, and locally magnetite ± chlorite.
- No specular hematite was observed as part of this assemblage, however, disseminated magnetite is locally present and occurs with trace inclusions of chalcopyrite.
- The mottled/texturally destructive expression of the early phyllic alteration extends up to 200 m outward beyond the intrusive contact with the quartz-bearing intrusive.

2. Late Phyllic Alteration

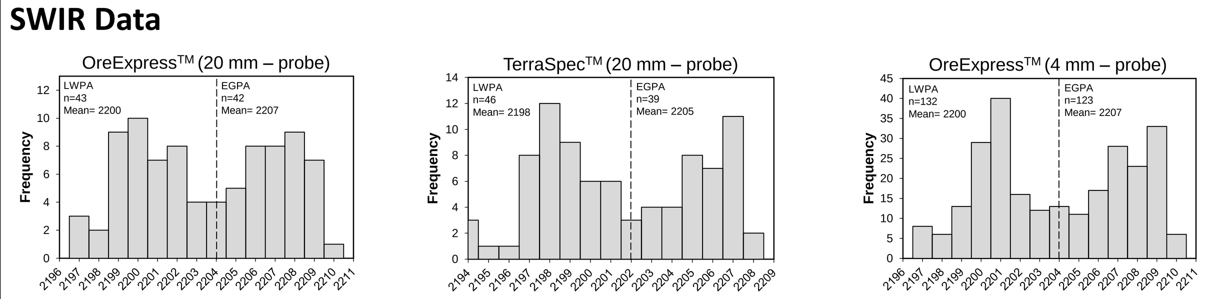
- The late phyllic style is a pervasive late white-colored phyllic event characterized by the mineral assemblage of white colored mica ± quartz ± rutile, and pyrite (disseminated and/or in veins).
- It is differentiated from the early phyllic alteration on the basis of the preservation of the original rock texture, and that it formerly contained high concentrations (estimated 2-5%) of pyrite
- The late phyllic alteration is observed superimposed upon the early phyllic alteration zone starting approximately 200 m from the contact with the quartz-bearing intrusive and extending up to 700 m.

White Mica Vectors



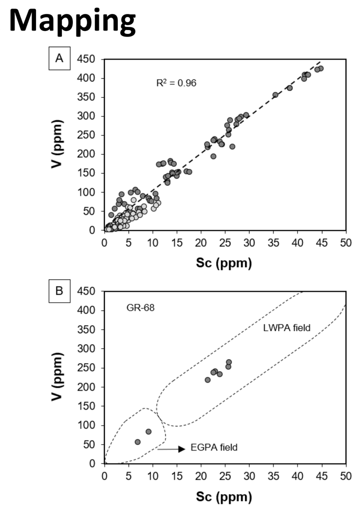
Points represent the median concentration in LA-ICP-MS analyses.

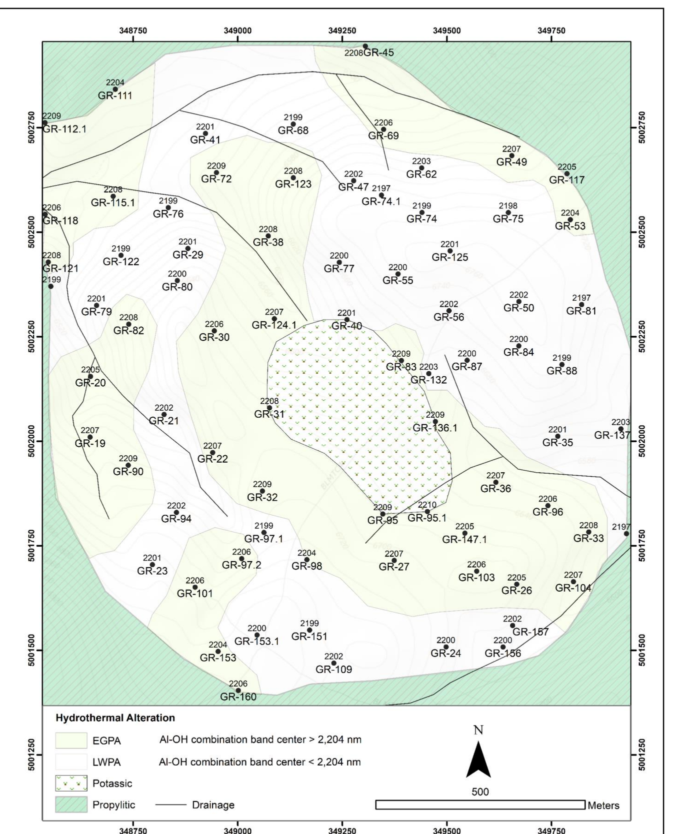
SWIR Data



- Two distinct groups are observed: 1) a late phyllic alteration dominantly related to white micas with short wavelengths, and 2) an early phyllic alteration style predominantly associated with white micas having longer absorption minima wavelengths.
- The cut-off value between the two populations is 2,204 nm, determined by a K-means cluster analysis after two iterations. This value represents the equidistant point between the mean values of the two populations.
- The late phyllic alteration group is represented by a normal distribution of Al-OH absorption feature ranging from 2,197 to 2,204 nm, with a mean value located at 2,200 nm.
- The early phyllic alteration population shows a normal distribution with Al-OH absorption feature between 2,204 and 2,210 nm, with a mean value located at 2,207 nm.
- Reproducibility of the measured band center is ±1.1 nm, shown by the (2σ) standard deviation of fifty repeated analyses on the same spot.

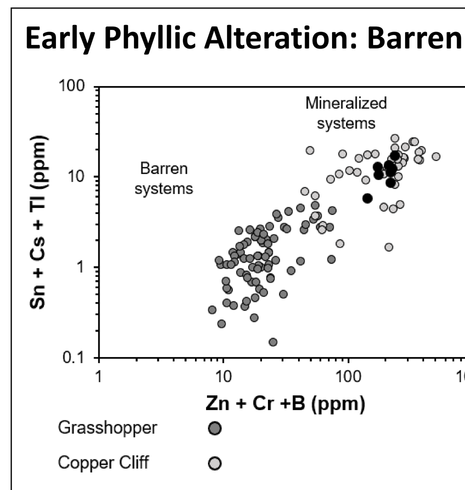
SWIR Mapping





- SWIR mapping identifying the two phyllic alteration events from Grasshopper, supported by LA-ICP-MS analyses based on the scandium vs. vanadium plot (Uribe-Mogollon and Maher, 2018).
- An example of individual spot analyses from sample GR-68 suggesting partial overprinting of early phyllic alteration by late phyllic alteration.

Early Phyllic Alteration: Barren vs. Mineralized Systems



- The trace element data shows that white micas from the early phyllic alteration from the Copper Cliff deposit are significantly enriched in Zn, Cr, B, Tl, Sn, and Cs compared with those of Grasshopper. In general, enrichment factors higher than 3:1 are observed in the mean elemental concentrations.
- In this study we suggest a preliminary discrimination diagram that can be used to identify white micas from the early phyllic alteration among mineralized and barren systems.
- We are not aware of detailed studies utilizing LA-ICP-MS which documents the composition of the early phyllic alteration. Only a sample (HVD06) from the Highland Valley porphyry, Canada, which was described by Alva-Jimenez (2011) seems to have similar textural, chemical and spectral features to those from the early phyllic alteration. That sample plots in the field of the mineralized systems confirming the possible effectiveness of the discrimination plot.

CONCLUSIONS

This work demonstrates that white mica geochemistry is a tool for mineral exploration in the phyllic alteration zone of porphyry systems. In addition, it has characterized the mineralogical, chemical, and spectral differences of the two subtypes of phyllic alteration: 1) an early green phyllic style, and 2) a late white phyllic style. This opens up the possibility of being recognized in more systems. Finally, it has confirmed that spatial trends in white mica compositions exist and can be used as vectors toward the center of the hydrothermal system.

References

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- Uribe-Mogollon, C. and Maher, K., 2018, White Mica Geochemistry of the Copper Cliff Porphyry Cu Deposit: Insights from a Vectoring Tool Applied to Exploration: Economic Geology, v.113, p. 1269-1295.
- Wilkinson, J.J., Chang, Z., Cooke, D.R., Baker, M.J., Wilkinson, C.C., Inglis, S., Chen, H. and Gemmell, J.B., 2015, The chlorite proximitor: A new tool for detecting porphyry ore deposits: Journal of Geochemical Exploration, v.152, p. 10-26.