Updating the Andean Porphyry Copper Alteration Model: Integrating new information from hyperspectral core imaging and applying machine learning methodologies to start the conversation.

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The influx of super-volumes of quantitative data into the exploration and mining industries necessitate a porphyry model refresh. Applied throughout the mining value chain, the traditional porphyry alteration model includes potassic, phyllic, propylitic, and argillic alteration assemblages, as well as variations within these groups. While typically forming the basis of logging and alteration codes (and subsequent models), many empirical observations (often deposit-specific) are inconsistently observed and utilized across porphyry districts. The use of codes relating to non-specific mineralogy, such as sericite (white and green), sericite-chlorite-clay and A-type veins, are some of the more common classifications in exploration and mining culture. The applicability of these codes is clear, but the addition of semi-quantitative mineralogical datasets (such as the continuous, fine-scale mineralogical analyses afforded by hyperspectral core imaging) highlights the need for porphyry model evolution (Fig. 1).

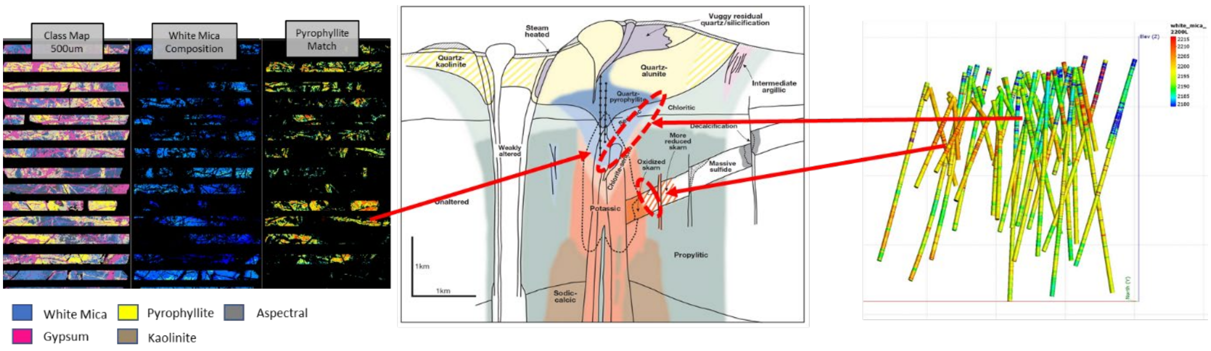

Fig. 1. Comparison between one of the conventional schematic models (Sillitoe, 2010) that is useful for vectoring, simple alteration and mineralization models versus hyperspectral data plotted downhole in a South American epithermal-skarn-porphyry that demonstrates real-world complexities (e.g. interlayered skarns and greater than 900m-deep fluid pathways that contain pyrophyllite) that geologists are faced with when creating a model that requires consistent, accurate quality and quantitative data that drives resource, mining and processing decisions.

Hyperspectral core imaging (HCI) is applied to a range of deposit types and its usefulness in mapping hydrothermal alteration systems for both exploration and mining/geometallurgical purposes is repeatedly proven (Swayze et. al., 2014; Martini et. al., 2017; Graham et. al., 2018; Harraden et. al., 2019 *in press*). The HCI outputs are imagery and data files that contain semi-quantitative mineral and mineral chemistry data. Instead of 'sericite,' HCI details the percentage of montmorillonite, illite and white mica; within the white mica and montmorillonite classes, the mineralogy is further subdivided into paragonite-muscovite-phengite and montmorillonite-beidellite. White mica and illite also, have crystallinity calculations which provide information on the order of the crystal structure that is a proxy for the temperature of formation. This level of detail applies to a range of minerals and has provided new insights into highly specific mineral assemblages that can be used as a vector towards high-grade zones; many of which are not accounted for in the existing genetic models for porphyry deposits.

In many porphyry deposits, the central potassic domain hosts the bulk of the ore (Cooke et al., 2014 and references therein), however, 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). In fact, the high-temperature green/gray sericite observed in Andean porphyries is both a vector to high grade and grade-bearing (Fig. 2). The paradox of the high-temperature green sericite phyllic assemblage is not unrecognized by geologists, but further marks the requirement to move away from conventional schematic models towards one that incorporates real world complexities. Incorporating these complexities is possible now due to the large volumes of continuous hyperspectral mineralogical data.

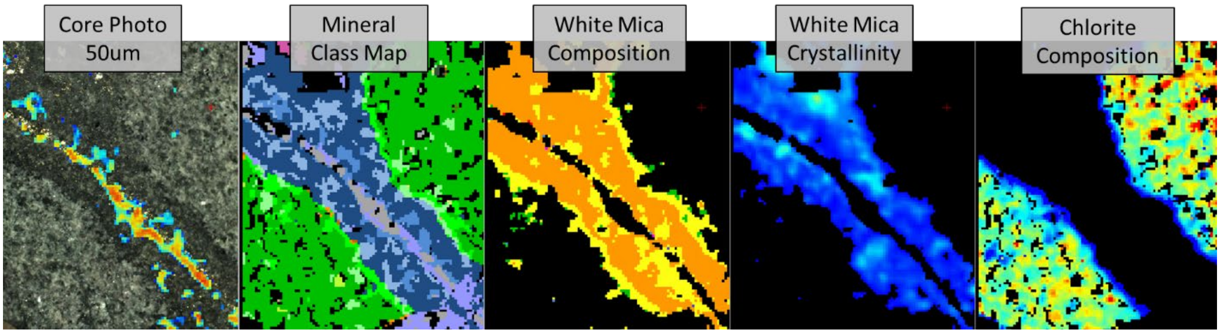

Fig. 2. High temperature "green sericite" vein in a chlorite altered matrix from an Andean Cu-Mo porphyry. White mica compositions are binned into 4nm ranges, whereby green is 2196-2200nm, yellow is 2200-2204nm, orange is 2204-2208nm, and red is 2208-2212nm; compositions are mostly muscovitic, but trend towards phengite (Fe-rich end-member).

Integrating the HCI results from porphyries globally, as well as the spatial-temporal location and endowment of the deposits, similarities and differences are investigated using an an unsupervised learning model that naturally groups the deposits, instead of applying the porphyry model to them. This exercise explores porphyry mineral assemblages globally and within belts, as well as comparing the results of the individual belt studies to those of other belts with particular focus on "phyllic" assemblages in Andean porphyries. The goal of this study is to promote discussion towards the evolution of the porphyry model, integrating real world complexities.

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