Characterizing Skarn Mineralogy and Texture Using Hyperspectral Core Imaging: Essential Data for Accurate Geometallurgical Assessment

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1. Abstract

Skarn deposits display complex mineralogical and textural relationships as a result of the range of geological processes involved in their development. Mineral associations can be further complicated by supergene leaching and oxidation. Both exploration and mining require an understanding of the type, relative abundance, spatial occurrence, and textural relationships of both prograde and retrograde minerals. Hyperspectral core imaging (HCI) can consistently and continuously map key skarn mineralogy while simultaneously capturing textural and paragenetic data. This information is critical for exploration and mine modelling but also when considering the processing behavior of a skarn deposit. Mapping the mineralogy and texture in complex skarn deposits provides key information to make informed geometallurgical sampling and modelling decisions.

1. Resumen

Los depósitos tipo skarn muestran complejas relaciones mineralógicas y texturales como resultado de la variedad de procesos geológicos involucrados en su desarrollo. Las asociaciones minerales pueden complicarse aún más por la lixiviación y oxidación supergénicas. Tanto la exploración como la minería requieren la comprensión del tipo, abundancia relativa, ocurrencia espacial y relaciones de textura de los minerales progrados y retrógrados. Las imágenes de núcleos hiperespectrales (HCI) pueden mapear de manera constante y continua la mineralogía clave de skarn mientras captura simultáneamente datos de textura y paragenéticos. Esta información es crítica para la exploración y el modelado de mina, pero también cuando se considera el comportamiento de procesamiento de un depósito skarn. El mapeo de la mineralogía y la textura en depósitos tipo skarn complejos proporciona información clave para tomar decisiones de modelado y muestreo geometalúrgico.

2. Introduction

Skarns deposits represent a significant global resource for base and precious metals and are the world’s primary source for tungsten (Einaudi et al. 1981, Meinert 1993). Skarns are distinct from many other types of ore deposits and represent a great variety of mineralizing conditions from Fe, Au, W, Cu, Zn, Mo, to Sn dominant resources. The mineralogy within each system is the result of lithologic compositions, structural pathways, and prograde vs retrograde mineral reactions. Mineral associations can be further complicated by supergene leaching and oxidation. These processes result in complex mineralogy and intricate textural relationships.

Understanding the type, relative abundance, spatial occurrence, and textural relationships of both prograde and retrograde minerals is vital to assessing the characteristics of the deposit both for exploration and mining applications. Hyperspectral core imaging (HCI) can consistently and continuously map key skarn mineralogy while simultaneously capturing textural and paragenetic data. This information is critical when considering the processing behavior of a skarn deposit and provides key information to make informed geometallurgical sampling and modelling decisions.

3. Hyperspectral Core Imaging

Characterizing skarn mineralogy can be difficult. Visual logging, combined with traditional analytical techniques (including petrography, XRD, and SEM-based methods) can be effective for major calc-silicate minerals in many cases. However, it is difficult to distinguish phyllosilicate mineral species using these techniques and the range of mineralogical and textural variability may not be adequately represented.

Hyperspectral analysis can provide consistent information regarding both calc-silicate and phyllosilicate mineral proportions and geochemistry over large volumes of geological material (Martini et al., 2017). This mineralogical data generated combined with the imaging capabilities of an HCI system gives the added information about the texture and paragenesis of these minerals (e.g. grain size, mineral associations, Fig. 1).

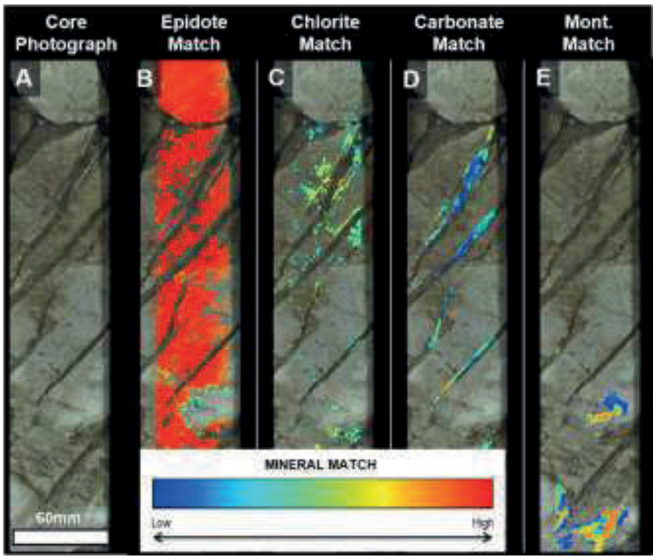

Figure 1. (A) Example of complex paragenetic relationships observed in skarn core that is highlighted by HCI data. Pervasive epidote alteration (B) is cut by carbonate +/- chlorite veins, (C, D). Late-stage montmorillonite occurs as an overprint (E).

4. Mapping Skarn Mineralogy Using HCI

Prograde mineral phases are dominated by anhydrous calc-silicate mineral groups including garnet and pyroxene (Fig. 2A). Although these minerals have weak or broad absorptions in the short-wave infrared (SWIR) region, visible to near-infrared (VNIR) features (Fig. 2B) can be used to identify Fe- and Ca-rich species of garnet (Izawa et al., 2018) and Ca- Fe/Mg-rich species of pyroxene (Horgan et al., 2014).

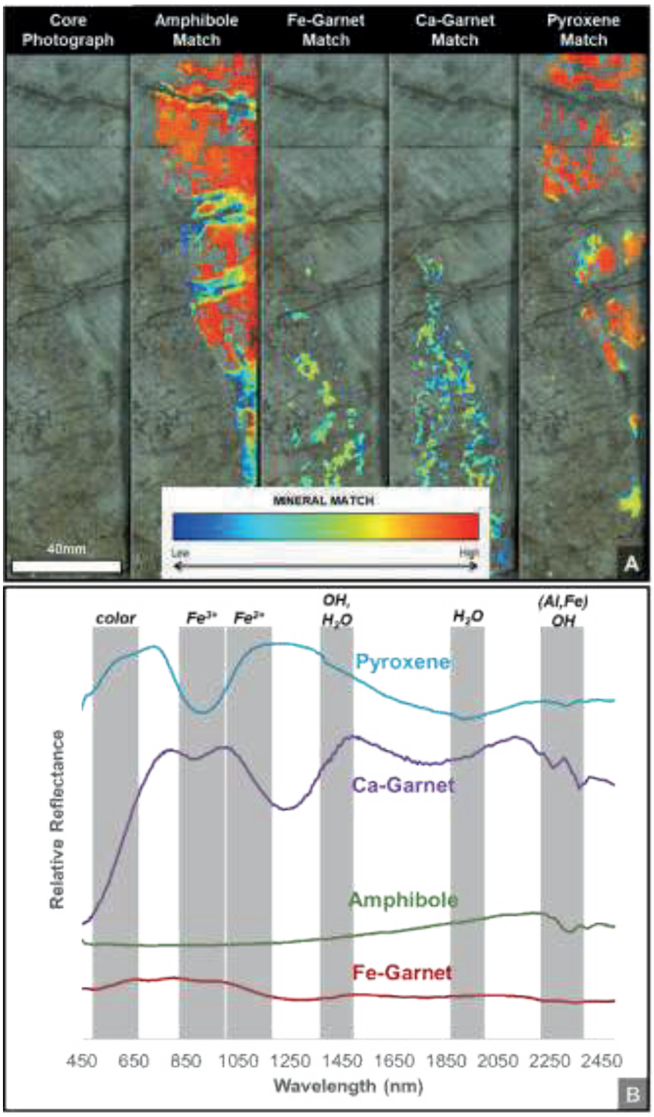

Figure 2. (A) Calc-silicate minerals in skarn mapped using the Corescan HCI-3 system. Representative VNIR-SWIR spectra for pyroxene, amphibole, Fe- and Ca- garnet (B). Note lack of diagnostic SWIR features, although absorption features and spectral shapes in the VNIR can be used to effectively identify these minerals (B).

Retrograde skarn mineralogy commonly consists of ‘hydrous’ mineral phases; epidote, amphibole, chlorite, micas, vesuvianite, prehnite and a range of clays. Kaolinite is common and several varieties of smectite-group minerals (and/or interlayered species) are typical. Montmorillonite is nearly always present, in addition to Fe- (nontronite) and Mg-rich (saponite) species (Fig. 3A). Sauconite may also be significant in Zn-rich systems. Each of these phases have characteristic features in the SWIR (Fig. 3B) which allows for consistent and reliable identification within skarn systems (e.g., Cudahy et al., 2001; de Mesquita et al, 2019).

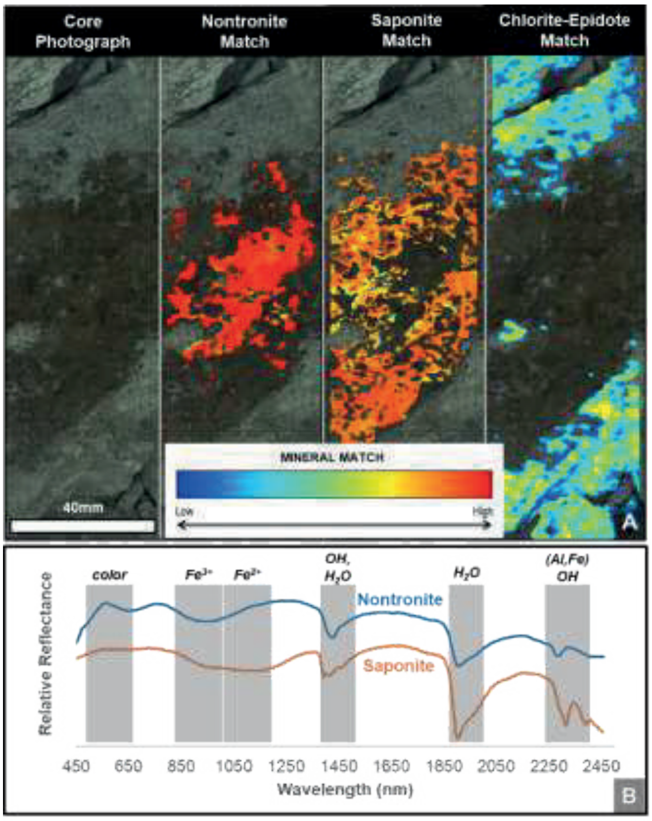

Figure 3. Phylosilicate minerals in skarn (A) with irregular saponite and nontronite textures and pervasive chlorite-epidote alteration (mapped using Corescan HCI-3 system). Representative VNIR-SWIR spectra for saponite and nontronite showing distinct SWIR features that can easily be distinguished from other phyllosilicate and calc-silicate minerals (B).

5. Implications for Geometallurgy

The mineralogical and textural information provided by hyperspectral core imaging can provide significant input into geometallurgical models. Prograde calc-silicate minerals such as garnet, pyroxene, and epidote have higher hardness values than retrograde phases. The abundance, texture and distribution of these minerals within an ore deposit will affect crushing and grinding energy requirements, as well as throughput and residence time in the mill (e.g. Starkey and Scinto, 2010; Hamid et al., 2019). Variations in phyllosilicate mineralogy can affect pulp rheology (Chen and Peng, 2018) and significantly influence flotation kinetics (e.g., Bayraktar et al., 1988, Ndlovu et al., 2014), due to variable compositions, structures, and charge properties of mineral species.

HCI systems provide the opportunity to consistently and continuously map key calc-silicate and phyllosilicate skarn mineralogy while simultaneously capturing textural and paragenetic information (Fig. 4). This combined dataset is critical to assess variability and adequately characterize an orebody in order to make informed geometallurgical sampling and modelling decisions.

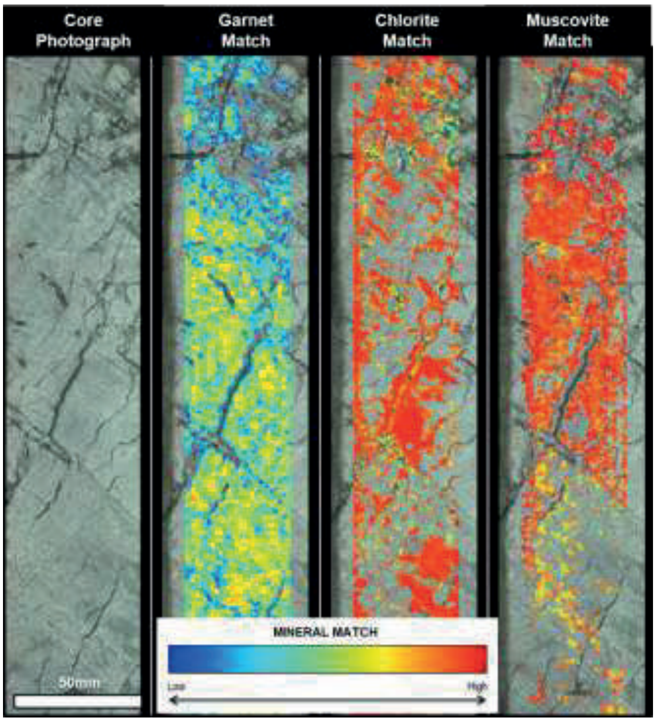

Figure 4. Calc-silicate mineral (garnet) textures relative to phyllosilicate minerals (chlorite and muscovite) in visually homogeneous rock. The ability to distinguish between these phases is attributed to variations in VNIR and SWIR characteristics that can be tracked systematically using hyperspectral imaging.

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