Lypaczewski P, Rivard B, Gaillard N, Perrouty S, Linnen RL, 2017, Hyperspectral characterization of white mica and biotite mineral chemistry across the Canadian Malartic gold deposit, Quebec, Canada, Extended abstract, Society for Geology Applied to Mineral Deposits (SGA), Québec, QC, 3, 1095-1097

NSERC-CMIC Mineral Exploration Footprints Project Contribution 135.

Hyperspectral characterization of white mica and biotite mineral chemistry across the Canadian Malartic gold deposit, Québec, Canada

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Abstract. The Canadian Malartic gold deposit is located in the highly endowed Abitibi region of Québec. A large part of the mineralization is located within Archean metasediments, which are often challenging to characterize by conventional core logging. Hyperspectral imaging of 168 meta-sedimentary samples from Canadian Malartic reveals that, in addition to ubiquitous biotite, 70% of the samples contain significant amounts of white mica, which was previously not recognized. Additionally, compositional changes in white mica and biotite composition within the deposit reflect the degree of hydrothermal alteration. The presence of phengitic white mica (>2206 nm, <3.3 ^{VI}Al per 22 O) is indicative of altered and potentially mineralized samples, whereas distal samples are more muscovitic in composition (<2202 nm, >3.5 ^{VI}Al). Biotite composition, also derived from spectral data, similarly shows variability in Mg# with respect to distance to mineralization, but to a spatially more limited extent than white mica. The most Mg-rich biotite (Mg# > 70) occurs spatially associated with mineralized intervals, and no Mg-rich biotite occurs outside of the open pit.

1 Introduction

Canadian Malartic is a gold mine located in the Malartic area of Québec, immediately south of the NW-SE trending Cadillac-Larder Lake Tectonic Zone, which separates the Pontiac and Abitibi subprovinces of the Canadian Shield. It is a high-tonnage, low-grade open-pit mine (13.4 Moz Au in 372.9 Mt ore averaging 1.02 g/t Au: Helt et al. 2014), which sits atop and consolidates numerous historical underground workings. The distribution of the mineralization at Canadian Malartic is in part controlled by the E-W striking Sladen fault (De Souza et al. 2015), and is shown on figure 1. A large part of the mineralization occurs within Pontiac Group meta-sediments (greywacke to mudstone) (Perrouty et al. 2017).

Core logging of the metasediments can be a challenging task to do visually; we therefore aim to use hyperspectral imaging (or imaging spectroscopy) to characterize the mineral chemistry and alteration patterns of samples in and around the deposit.

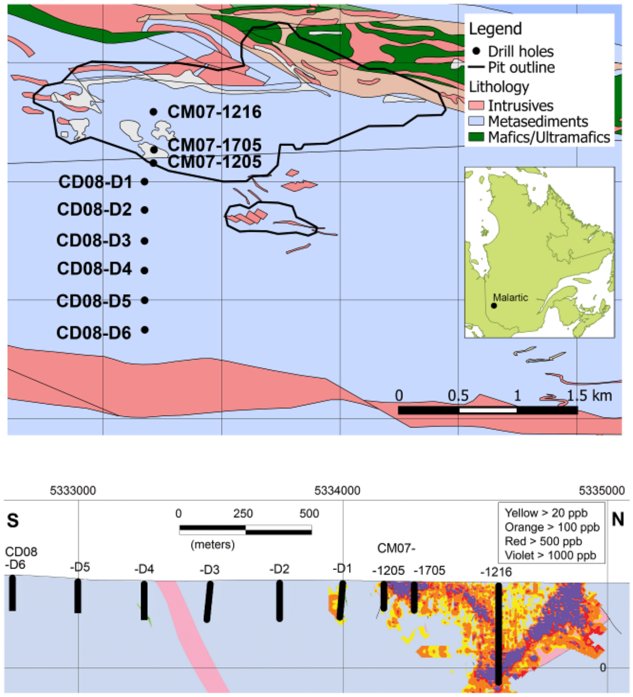

Figure 1. a Geological map (from SIGEOM, MERN) showing the location of the Canadian Malartic gold deposit. Sampled drill holes locations are indicated. **b** Cross section (S-N) along the drill hole transect, showing the depth and location of the 168 samples, as well as gold grades in the mineralized zone.

2 Methodology

2.1 Sampling

Data were collected on 168 metasediment samples from 9 drill cores on a N-S section across the deposit and its footprint (Fig. 1b), forming a section that extends from the central portion of the mineralized zone to approximately 1.5 km south of the mine. They include a wide range of alteration types, sedimentary protoliths (greywacke, mudstone), and metamorphic grades (biotite to garnet zones). For each sample, both the core pieces and associated thin section block were scanned with a SisuROCK hyperspectral core scanner.

2.2 Hyperspectral imaging

Imagery was acquired for all samples at a spatial resolution of 0.2-0.5mm/pixel, where every pixel contains an infrared reflectance spectrum in the range 1000-2500 nm (Short Wave Infrared - SWIR). Typical spectra for biotite and white mica are shown in figure 2. In this spectral range, most phyllosilicates show several characteristic absorption features due to the presence of specific cation-OH bonds (Hunt 1977).

The position of -OH related absorption features varies with mineral chemistry. For example, the 2200 nm Al-OH absorption feature of white mica varies from about 2192 to 2220 nm (Fig. 3), and is correlated to its ^{VI}Al content (i.e., muscovite to phengite: Duke 1994). Similarly, the 2250 nm absorption for biotite varies with Mg#, from 2240 nm for Mg-rich biotite to 2260nm for Fe-rich biotite.

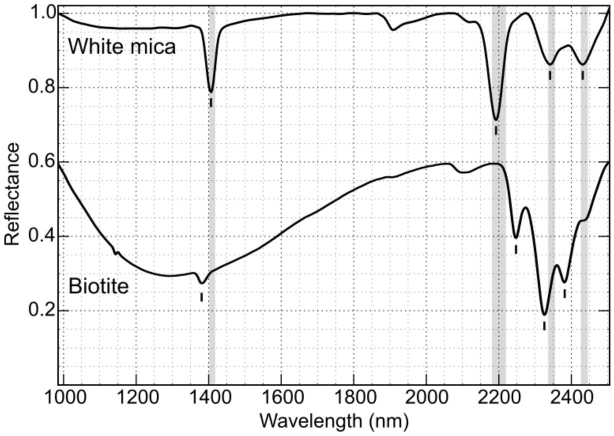

Figure 2. Spectra of biotite and white mica, continuum removed and offset for clarity. The position of the 2200 nm (white mica) and 2250 nm (biotite) absorptions can be used to determine mineral chemistry.

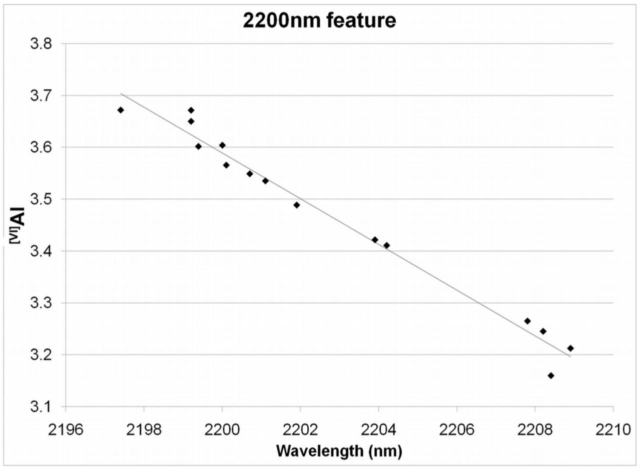

Figure 3. Correlation between ^{VI}Al content of white mica (from EPMA data, for 22 O atoms) and position of 2200 nm absorption feature.

3 Results

3.1 Thin-section blocks

The 168 thin-section blocks are displayed in figure 4a with the same relative spatial arrangement as shown on figure 1b; each column represents samples from a single drill core. Samples are colour-coded according to the position of the white mica and biotite absorption features. Almost 70% of the samples contain significant amounts of white mica. End-member muscovite has shorter absorption wavelengths (2192 nm) and is displayed in red colours, whereas more phengitic muscovite (from Tschermak-like substitution) has longer absorption wavelengths (>2205 nm) and is displayed in blue to purple colours.

Biotite is ubiquitous, with variable amounts of retrograde chlorite. The position of its 2250 nm absorption feature varies with Mg#, and is displayed in blue-purple colours for Mg-rich compositions (2240 nm) and red colours for Fe-rich compositions (2260 nm).

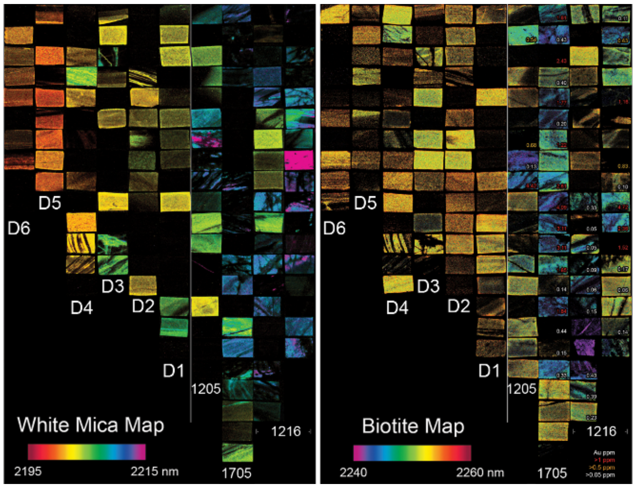

Figure 4. **a** Thin-section block hyperspectral imagery processed to display the position of the 2200 nm absorption feature of white mica. **b** Same data, processed to display the position of the 2250 nm absorption feature of biotite, reflecting its Mg#.

3.2 Core and field samples

Larger samples show decimetre-scale variability in both mineralogy and in mineral composition, which is not captured at the thin section scale (2-4 cm). Several hundred meters of continuous drill cores were therefore imaged using the hyperspectral system to illustrate the scale of mineralogical variability in mineralized samples. Similarly, field samples ranging from 30 cm to 1.5m in length were taken from an 8x12 km area around the mine to characterize mineralogical variability in unaltered Pontiac metasediments.

Figure 5 illustrates a meter-long core sample from the mineralized zone (near drill hole CM07-1216, on figure 1), which presents an alternating pattern of phengitic white mica and white mica-free zones, with gradational and texturally complex transitions. Biotite is present throughout the length of the sample, but varies in composition from Mg#80 (2245 nm, purple) to Mg#60 (2252 nm, yellow) within one meter.

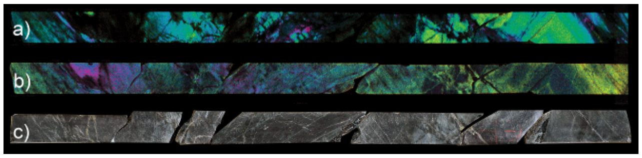

Figure 5. Core sample (1m long) from the mineralized zone (0.5ppm Au on 1.5m), showing dm-scale variations in mineralogy. Same colour scale as previously. **a** White mica hyperspectral image (2200 nm), showing alternating presence and absence of white mica. **b** Biotite hyperspectral image (2250 nm), showing a gradual composition change from Mg-rich (Mg#80, 2245 nm, purple) to intermediate Mg content (Mg#60, 2252 nm, yellow). **c** Photograph.

A typical unaltered distal metasediment sampled 3 km southwest of the deposit is shown in figure 6. Metamorphic white mica in mudstone beds is of muscovitic composition (2196 nm, >3.7 ^{VI}Al), is compositionally homogeneous, and shows sharp contacts to white-mica free greywacke beds. Biotite is present throughout and is compositionally homogeneous (2252 nm, intermediate Mg#)

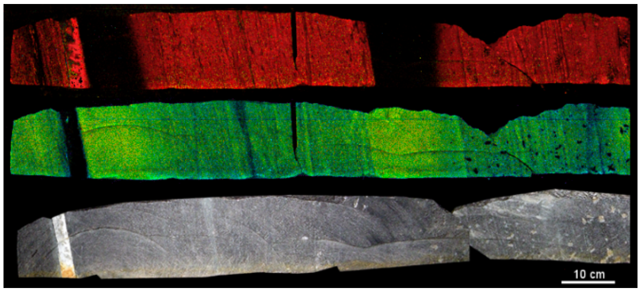

Figure 6. Typical unaltered Pontiac metasediment. Field sample (1m long) located 3 km southwest of the deposit. **a** Occurrence and composition of white mica (2196 nm, >3.7 ^{VI}Al). **b** Occurrence and composition of biotite (2252 nm, intermediate Mg#). **c** Photograph.

4 Discussion and final remarks

Mg-rich biotite (Mg#>70, <2250 nm) in the deposit is associated with hydrothermally-altered and mineralized samples, and rapidly (m-scale) grades into background compositions (Mg# 50-60, >2252 nm). White mica of hydrothermal origin is phengitic in composition (>2206nm, <3.3 ^{VI}Al), but is not always present. Small (dm to 10's of m) scale, texturally complex changes in white mica abundance and composition are observed within the deposit.

Regionally, metamorphic grade affects white mica composition, producing Al-richer muscovite at higher metamorphic grades (Duke and Lewis 2010). From proximal to distal samples (at km scales), metamorphic white mica progressively varies from 2204 nm to 2196 nm, but is homogeneous within a given sample (m scale). Presence or absence of white mica is controlled by protolith composition, as can be seen from alternating layers of white mica-free beds (generally coarser grained greywackes) and white-mica rich beds (generally finer grained mudstones).

As data acquisition is rapid (1 minute per core box or 10 seconds per individual sample), spectrally detectable changes in white mica composition make hyperspectral imaging a useful tool for vectoring towards mineralization in similar geologic environments. Likewise, small-scale changes in biotite composition can be useful for rapidly and accurately delineating mineralized intervals in drill cores.

Acknowledgements

The research team is grateful to the Canadian Malartic Corporation exploration team for support during field work and access to facilities. CMIC-NSERC Exploration Footprints Network Contribution #135.

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