

# CHEMICAL VARIATION IN HYDROTHERMAL MUSCOVITE COMPOSITION AROUND THE VALLEY PORPHYRY CU-MO DEPOSIT, HIGHLAND VALLEY DISTRICT, BRITISH COLUMBIA, CANADA – LATERAL FOOTPRINT USING MINERAL MAPPING AND LITHOGEOCHEMISTRY

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## ABSTRACT

Muscovitic micas are a common alteration component in porphyry Cu(-Mo-Au) deposits. At the Valley porphyry Cu-Mo deposit in the Highland Valley porphyry district, southern British Columbia, muscovitic micas form as part of the high-temperature K silicate assemblage in association with quartz-K feldspar-biotite-bornite-chalcopyrite. Muscovitic micas also form peripheral to the Valley deposit, in the adjacent low-grade Bethsaida zone porphyry center, and at the abandoned Alwin Mine, some 4 km to southwest. The muscovitic micas form as several textural varieties, including veins selvages where they replace the rock, replacement of igneous biotite and feldspar in the host porphyry of the Bethsaida phase of the Guichon Creek batholith. Petrography, SEM and electron microprobe data indicate that the micas in the core of the Valley deposit are sodium-bearing muscovite (ca. 0.6%Na<sub>2</sub>O, 0.8%MgO) whereas muscovite micas are more phengitic (ca. 0.2%Na<sub>2</sub>O, 1.29%MgO) in the other areas. Laser ablation-ICP-MS spot analyses detect Ti, Li, Sn V and Sr at higher concentrations in muscovite from the Valley pit compared to those elsewhere. In contrast Tl, Rb, Cs, B, Mn, Co and Zn concentrations are higher in muscovite from Alwin and Bethsaida zone in comparison to the Valley pit. The variability in the chemistry of muscovite is also detected using short-wave infrared spectra (SWIR). An absorption feature between 2200 nm to 2202 nm characterizes the Na-bearing muscovite from Valley, whereas more phengitic-muscovite from Alwin and Bethlehem deposits have an absorption feature between 2205 nm to 2209 nm. Major and trace element chemistry of the muscovite reflects temperature decrease and pH changes from the central porphyry zones at Valley and to peripheral hydrothermal systems. Muscovite chemistry varies laterally in porphyry Cu-Mo districts and is also reflected in SWIR spectra technique widely used in exploration.

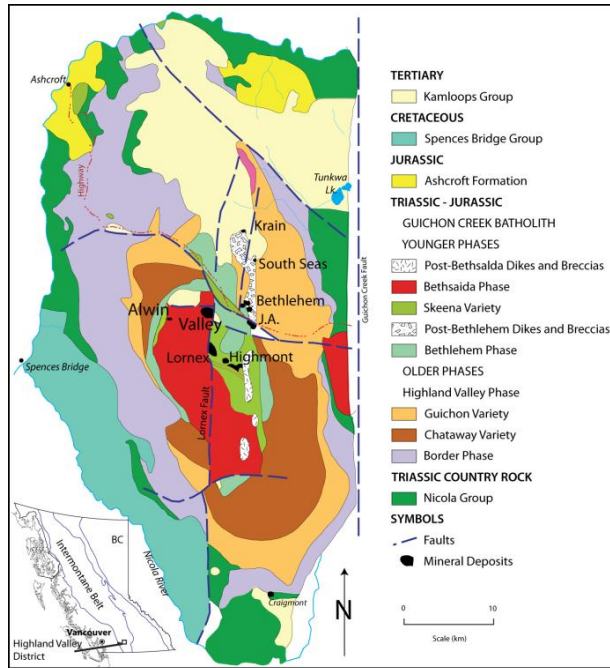
**Keywords:** muscovite, Highland Valley, porphyry copper, alteration

## INTRODUCTION

Muscovite is a common mineral that forms in a range of hydrothermal, igneous and metamorphic environments. The mineral is useful for deciphering processes involved in diagenesis, regional deformation and hydrothermal environments (Frey et al., 1980; Johnson and Oliver, 1990; Guitierrez-Alonso and Nieto, 1996). In this context, the limited compositional variation of the host rock in the Highland Valley porphyry Cu-Mo district provides an excellent opportunity to examine the range of muscovite compositions associated with large scale hydrothermal alteration that constitutes mineralizing porphyry environments.

The Highland Valley district located 350 km northeast of Vancouver in south-central British Columbia, Canada, contains the largest open pit mine in Canada. The district has been actively explored since 1896 with a historical production to 2010 of 1.428 Bt containing 5.181 Mt Cu and 83,000 t Mo (British Columbia Geological Survey, 2010) with a probable and proven reserve of 440 million tonnes at 0.35% Cu and 0.008% Mo (www.teck.com). The district lies in the southern portion of the Quesnel Terrane within the Intermontane Belt, which hosts many of British Columbia's porphyry deposits. The district is hosted in the late Upper Triassic calc-alkaline Guichon Creek batholith (210±3 Ma; Mortimer et al., 1990) that intruded the Carnian to Norian marine volcanic to sedimentary rocks of the Nicola Group (Casselmann et al., 1995). The batholith is a multiphase pluton in which the intrusions at the border are older and more mafic whereas in the central part they are younger and more felsic (Casselmann et al., 1995; Fig.1). The Valley deposit and the Alwin mine (4 km southwest of the Valley deposit) are two of the six principal copper centers known in the central part of the batholith. They

both are dominantly hosted in Bethsaida porphyritic granodiorite.



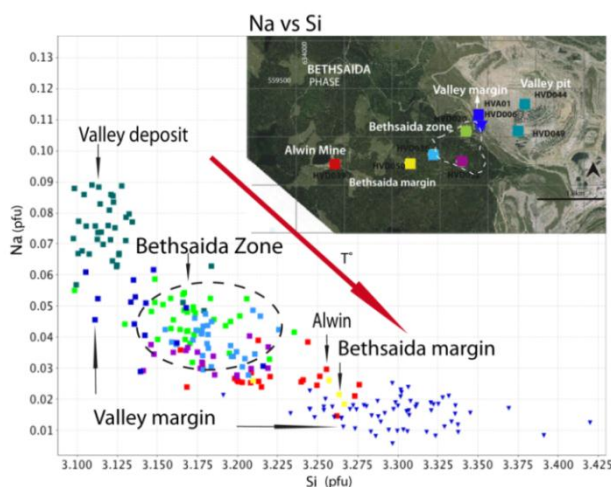
Within the Highland Valley district, in the core of the Valley deposit, muscovite is abundant as part of the K-silicate alteration assemblage. Outside of the Valley deposit, muscovite is associated with quartz-sulfide D veins in the hydrothermally altered rocks. In this paper we present electron microprobe and laser ablation inductively coupled plasma–mass spectrometry (LA-ICP-MS) results from muscovite collected along a transect from the core of the Valley deposit to the distal Alwin Mine (Fig. 2). We intended to demonstrate if the stoichiometry of hydrothermal muscovite varies considerably with distance across the hydrothermally altered centers.

**Figure 1.** Geology of the Guichon Creek Batholith with the location of the major mineral deposits of the Highland Valley District (Modified after McMillan, 1976). Inset at lower left shows the location of the district in British Columbia (BC).

## STOICHIOMETRY OF MUSCOVITE IN AND AROUND OF THE VALLEY DEPOSIT

### ELECTRON MICROPROBE RESULTS

Textural and protolith variations for muscovite identified petrographically establish their paragenesis and mineral protolith. Five types are identified: 1) coarse grained pervasive muscovite (Mc) with crystal size of 0.4mm to 0.7mm, 2) medium to fine grained pervasive muscovite with no preferred orientation with individual crystals of 0.1mm to 0.4mm (Mp), 3) muscovite in veins (Mv), and 5) medium-grained muscovite pseudomorphous after biotite (Mb). Scanning electron microscope and electron microprobe analyses demonstrate major element chemical variations in the muscovite textural types as a function of their spatial distribution. Samples from the Valley deposit in which muscovite are Mc have higher sodium content, and thus have a more paragonitic composition (ca. 0.6 wt.% Na<sub>2</sub>O, 0.8 wt.% MgO). These muscovite also have detectable halogens (F, Cl). The Na-rich muscovite together with K-feldspar and Na-plagioclase indicate high temperature of formation from a largely magmatic fluid (Brimhall, 1977; Muñoz, 1984). In contrast, muscovite from the edges of the undeveloped and low-grade Bethsaida zone porphyry copper deposit and abandoned Alwin mine, some 4 km away from the Valley pit, contain less sodium (ca. 0.2 wt.% Na<sub>2</sub>O) and are more phengitic (ca. 1.29 wt.% MgO; Fig.2). The textural varieties Mc, Mv, Mp and Mb are indistinguishable chemically. The chemical variations of the white mica are consistent with changes in physiochemistry across the hydrothermal system(s), and in particular reflect a decline in temperature and increase in pH from Valley to the Bethsaida zone to the Alwin Mine.

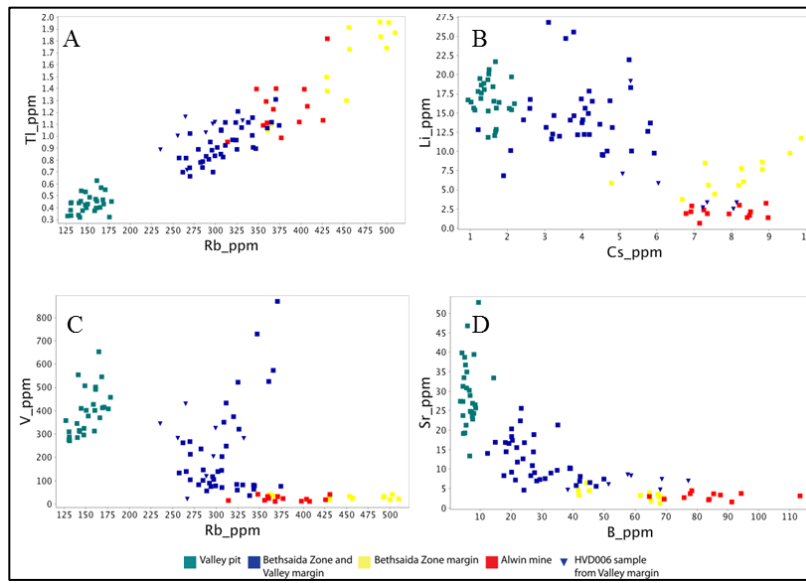


**Figure 2.** Electron microprobe data of Na vs. Si in muscovite altering the Bethsaida intrusive phase. Values given in ions per formula unit, the trend shows sodium distribution of Microprobe data in the Bethsaida phase. Data coloured according to sample location sample (see inset map). Aerial photography base provided by Highland ValleyCopper.

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## LA-ICP-MS RESULTS.

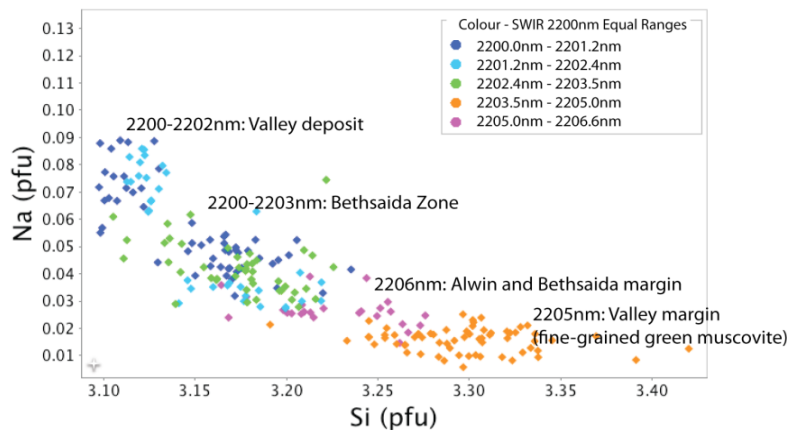
Trace elements contents of muscovite also show spatial variation from the Valley deposit to the Alwin mine. Rb, Cs, B and Tl as well as Mn, Co and Zn concentrations are positively correlated and increase from Valley mine towards the Alwin mine, whereas these elements are negatively correlated with Li, Ti, Sn, V and Sr concentrations which decrease from the Valley mine towards the Alwin mine (Fig.3). Trace elements such as Rb, Cs, Tl and Sr substitute for K in the interlayer cation site in the muscovite mineral structure; B substitutes in the tetrahedral cation site commonly occupied by Si, Al and Fe<sup>+3</sup>; and Li, Ti, V, Zn and Mn substitute into the octahedral site generally occupied by Al and minor Mg, Fe<sup>+2</sup> and Fe<sup>+3</sup> (Deer et al., 1992, 2003).



**Figure 3.** Trace element variations in muscovite altering the Bethsaida phase. A) Rb versus Tl; B) Cs versus Li; C) V versus Rb and D) B versus Sr. Samples from Bethsaida Zone except the Bethsaida margin, is considered as solid blue colour.

## ELECTRON MICROPOBE RESULTS VERSUS SWIR DATA – MUSCOVITE

In the Bethsaida phase, the SWIR data in muscovite varies with composition. Shorter wavelength (2200-2202 nm) corresponds to Na-rich muscovite from the Valley deposit (Fig. 4). Absorption wavelength increases up to 2203nm in the Bethsaida Zone where the Na content decreases and to even higher wavelength (2206nm) in the muscovite from the Alwin mine and Bethsaida margin, which have less Na and more Fe-Mg. The wavelength of 2205 corresponds to the sample of the valley margin that is medium-grained green muscovite.



**Figure 4.** Probe data colour coded by SWIR results for muscovite of the Bethsaida phase. Data coloured according to 5 equal ranges in the 2200 nm wavelength absorption feature. The plot of Na versus Si shows lower wavelength represents Na rich muscovite. Higher wavelength represents Fe+Mg rich muscovite (phengites).

## CONCLUSIONS

Major and trace element composition of muscovite from the Highland Valley district, along a transect from the Valley deposit to the Alwin mine, show a systematic lateral zonation. This zonation is indicative of the effect of the temperature and acidity of the fluid on the composition of the hydrothermal muscovite. Coarse Na-rich muscovite micas are indicative of higher temperature whereas

phengitic-muscovite-micas represent lower temperature and more neutral pH conditions. Muscovite composition also reflects the solubility or mobility of certain elements. Some elements such as Ti (and Sn) are generally not very soluble and can only be moved in a relatively high temperature but low pH fluid. On the other hand, alkalis (Cs, Rb), Tl and transition metals (Mn, Zn) are well known to be mobile at higher pH and at lower temperature. The zonation of major and trace elements in muscovite is part of the alteration footprint for porphyry deposits, and may provide an exploration tool in the future. The chemical variations recorded in the major and trace elements in the muscovite are partly reflected in the SWIR spectra in the muscovite from the Bethsaida phase. Na-rich muscovite has a lower absorption wavelength of 2200 nm to 2202 nm whereas phengitic-muscovite has a higher absorption wavelength of 2205 nm to 2206 nm. Thus, SWIR data can be used as a proxy to estimate the relative Na content in the muscovite in Highland Valley, as Na substituted for K in the muscovite.

## ACKNOWLEDGEMENTS

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