

# Mineralogical and Geochemical Characteristics of Porphyry-Fertile Plutons: Guichon Creek, Takomkane and Granite Mountain Batholiths, South-Central British Columbia

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## Introduction

The fundamental relationship of porphyry Cu (Au, Mo) deposits with bodies of intrusive rocks is well established (e.g., Sillitoe, 1973), but distinguishing metal-fertile from barren plutons remains a significant challenge for exploration. Information that contributes such *a priori* knowledge provides guidance early in the exploration process to make decisions more effectively and efficiently on focusing exploration resources on more prospective targets. This research project, therefore, provides tools and strategies that emphasize porphyry fertility in the British Columbia context (see Figure 1 for project location).

The most fundamental process in the formation of porphyry copper deposits is the exsolution of metal-rich magmatic hydrothermal fluids from large crystallizing batholiths and their transport to the site of the deposit (e.g., Dilles and Einaudi, 1992). These buoyant fluids are focused in cupolas above the batholiths to form perched porphyry copper deposits, but in many districts large deposits are hosted within or adjacent to the large plutons that form part of the mineralizing system. In all cases, these plutons will host evidence that records porphyry fertility characteristics. The relationship between magmatic processes and ore deposits has long been the focus of ore deposit research, but past studies have generally concentrated on the deposit scale. This project looks at the district to batholith scale, which will provide a level of assessment not previously documented in BC.

The characterization of fertility features is of particular importance for BC porphyry exploration. In BC, many porphyry systems occur within or around the edges of large

batholiths, or have been tilted such that the deeper plutonic parts of the system are exposed. This paper summarizes 2015 summer fieldwork and provides preliminary results on a subset of samples.

## Field and Laboratory Works

Field and laboratory work is focused on characterization of accessory minerals in various intrusive bodies of three well-documented and mapped batholiths, the Guichon Creek, Takomkane and the Granite Mountain batholiths, located in southern and central BC (Figure 1). In total, 113 samples were collected during the 2015 summer season: 52 from Guichon Creek, 35 from Takomkane and 26 from the Granite Mountain batholith. Samples were collected from various intrusive phases of each batholith. Samples were disaggregated using the electric pulse disaggregator (EPD) at Overburden Drilling Management (Nepean, Ontario), to break the rock along mineral grain boundaries, providing a larger number of unbroken mineral grains. Subsequently, mineral separation was performed at the Mineral Deposit Research Unit (MDRU) using Frantz<sup>®</sup> magnetic separation and heavy liquids. Grains are selected by hand-picking to be mounted and polished in preparation for electron microprobe and trace-element laser analyses. Rock samples were analyzed for whole-rock major- and trace-element analysis at Acme Analytical Laboratories Ltd. (Vancouver) to characterize the geochemical signature of each intrusive unit and to compare the mineral chemistry with whole-rock chemistry. Polished thin sections were prepared from representative samples for petrography. This paper summarizes preliminary results from 6 samples based on 133 spot electron microprobe analyses on apatite grains.

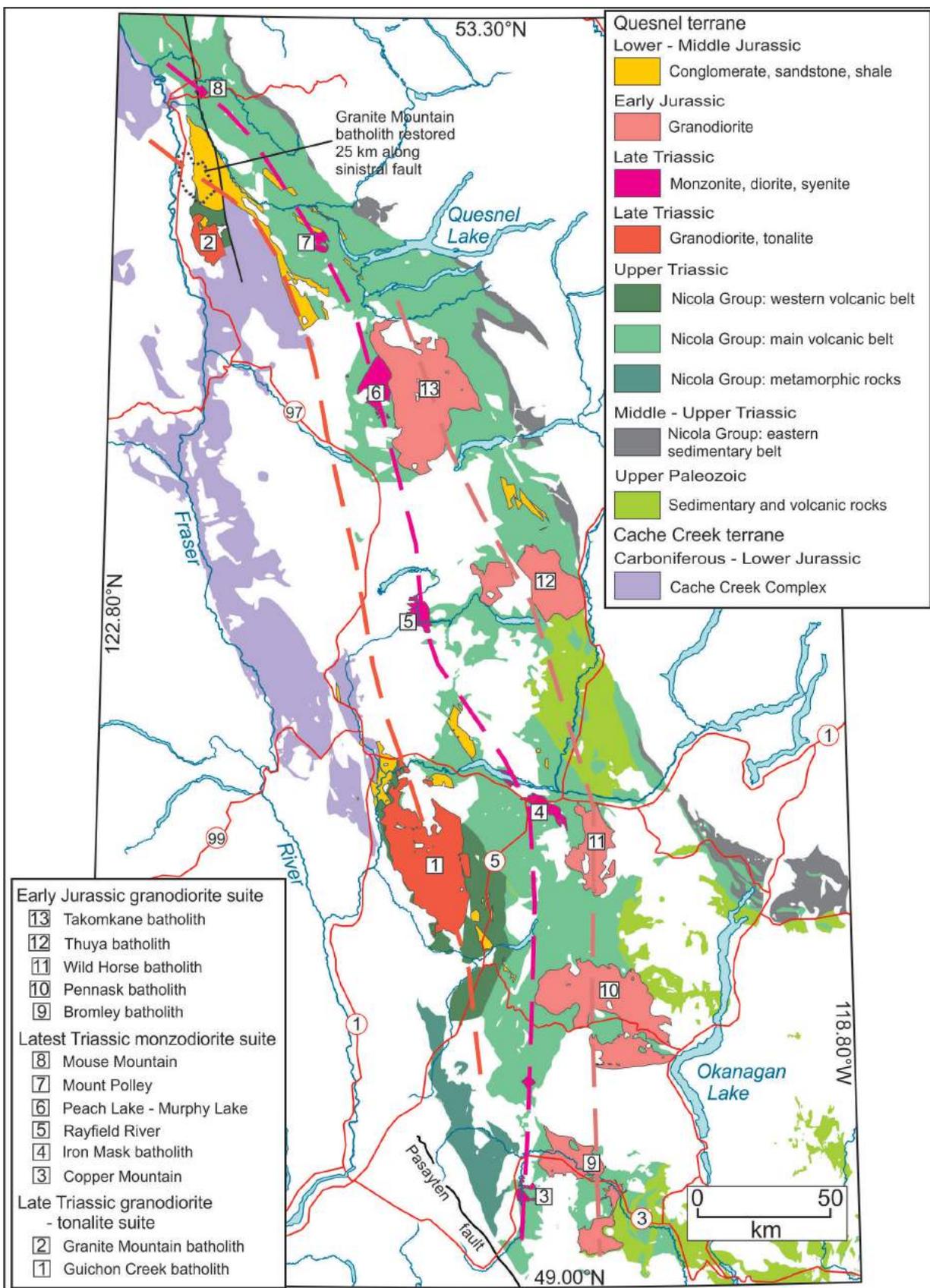
## Guichon Creek Batholith

The Late Triassic Guichon Creek batholith is north trending, approximately 65 km long by 30 km wide. The batholith is composite and ranges from diorite and quartz diorite

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**Keywords:** *fertile plutons, porphyry copper, British Columbia*

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**Figure 1.** Simplified geology map of south-central British Columbia showing location of major plutonic bodies. Dashed lines illustrate parallel belts of calcalkaline or alkaline plutons that show a progressive younging from west to east (from Schiarizza, 2014).

compositions at the border, to younger granodiorite in the centre (Casselmann et al., 1995; Byrne et al., 2013). These phases from the margins inward, are named: the Border phase, the Highland Valley phases (consisting of Guichon and Chataway subphases); the Bethlehem phases (consisting of Bethlehem and Skeena subphases); and the Bethsaida phase. Bethlehem, Skeena and Bethsaida phases host most of the Highland Valley porphyry Cu-Mo deposits (Valley, Lornex, Highmont, Alwin, Bethlehem and JA).

### Takomkane Batholith

The Takomkane batholith is a large (40 by 50 km) Late Triassic–Early Jurassic composite intrusive body that hosts several mineralized centres including the Woodjam porphyry camp (Megabuck, Takom, Southeast and Dehorn). The Takomkane batholith records a magmatic evolution lasting 11 m.y., with three separate mineralizing events at Woodjam (del Real, 2015). Moreover, the presence of Cu-Au and Cu-Mo deposits together with the regional north-west tilting of geological units provides an insight into different levels of exposure and potentially subtle geochemical variations within the intrusive bodies.

### Granite Mountain Batholith

The Granite Mountain batholith (18 by 10 km) occurs near McLeese Lake in south-central BC and hosts the Gibraltar porphyry Cu-Mo mine. The Late Triassic Granite Mountain batholith is subdivided into three main units, namely from southwest to northeast: Border phase diorite to quartz diorite; Mine phase tonalite; and Granite Mountain phase leucocratic tonalite. The Burgess Creek stock (Panteleyev, 1978), occurring at the northeast of the Granite Mountain batholith, comprises a heterogeneous assemblage of tonal-

ite, quartz diorite, and diorite that intrudes the Nicola Group. Panteleyev (1978) considered the stock to be younger than the Granite Mountain batholith, but Ash et al. (1999) concluded that the assemblage represents part of the batholith, and referred to them as border phase quartz diorite.

It was originally thought that the Granite Mountain batholith intruded the Cache Creek terrane (Bysouth et al., 1995). But recent mapping by Schiarizza (2014) recognized Nicola Group strata occurring on the northeastern margin of the batholith and suggested that it is more likely a part of the Quesnel terrane. This is also supported by recent interpretation of aeromagnetic data that assign the Granite Mountain area to the Quesnel terrane (Sánchez et al., 2015). Thus, the Granite Mountain batholith is correlative with the Late Triassic, calcalkaline Guichon Creek batholith, host to the Highland Valley porphyry Cu-Mo deposits, 250 km to the south-southeast.

### Geochemical Characteristics

Samples were analyzed for whole-rock major and trace elements at Acme Analytical Laboratories Ltd. (Vancouver). Results of 19 samples from the Guichon Creek batholith and 15 samples from the Granite Mountain batholith were obtained so far. Total alkali-silica (TAS) diagram (Figure 2) shows that samples from both batholiths are calcalkaline arc rocks ranging from granodiorite to diorite. Within the batholiths, border phases are more mafic than central portions. Trace-element data were normalized to the compositions of C1 carbonaceous chondrite meteorites using the normalization values of Sun and McDonough (1989). Normalized rare-earth element (REE) diagrams show that all Guichon Creek samples display patterns typical of subduc-

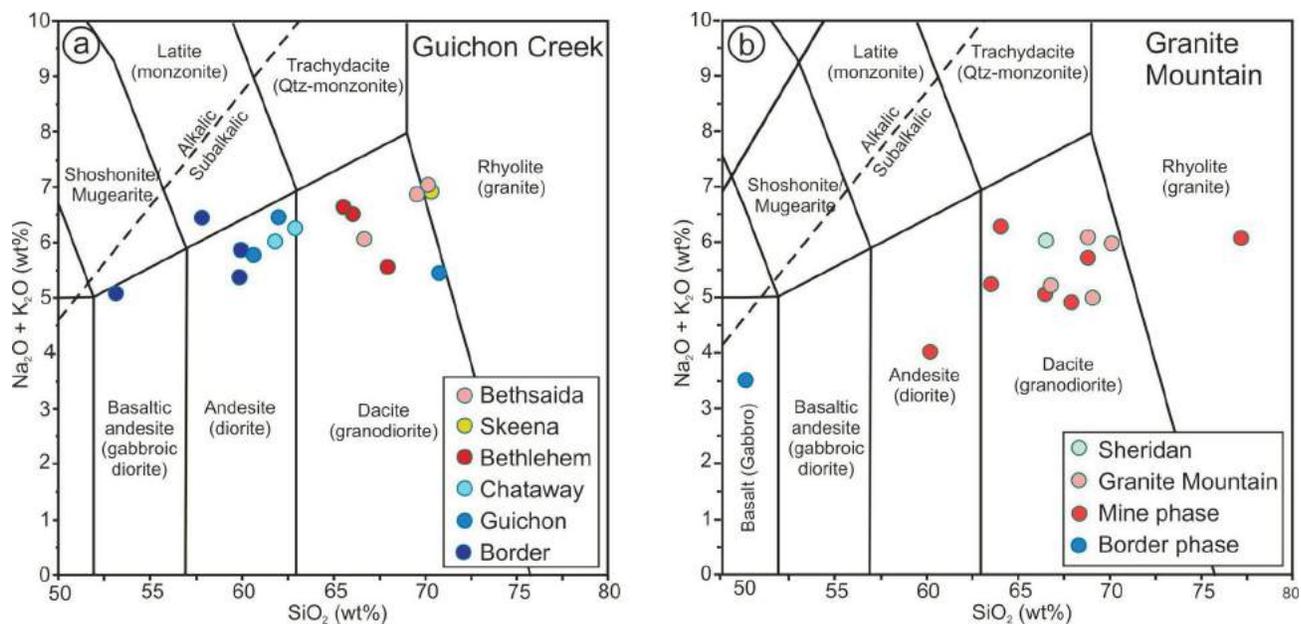


Figure 2. Total-alkali diagram showing the composition of intrusive units.

tion-related magmas, characterized by enrichments in large-ion lithophile elements (Figure 3a) relative to heavy rare-earth elements (HREE). All rock samples from Guichon Creek lack Eu anomalies. Late central more felsic phases have listric-shaped patterns with depleted middle rare-earth elements (MREE) and HREE suggesting hornblende and garnet fractionation. These features are characteristics of typical porphyry-fertile suites and indicate high magmatic water content and high oxidation state (Lang and Titley, 1998; Richards, 2012; Loucks, 2014). Rare-earth element signatures of the Granite Mountain and Mine phases of the Granite Mountain batholith differ from those at Guichon Creek by having less depleted HREE, possibly due to lack of significant garnet fractionation (Figure 3b). More importantly, samples from Granite Mountain show an Eu anomaly that ranges from minimal to negative. This indicates variable degrees of plagioclase fractionation which incorporates  $\text{Eu}^{2+}$ . A possible explanation for the observed REE patterns could be fluctuation in magmatic water content and/or oxidation state. Two samples from the Burgess Creek and Border phases display distinctly flat REE patterns typical of more primitive magmas. Further detailed petrographic work is required to better interpret the observed variations at Granite Mountain.

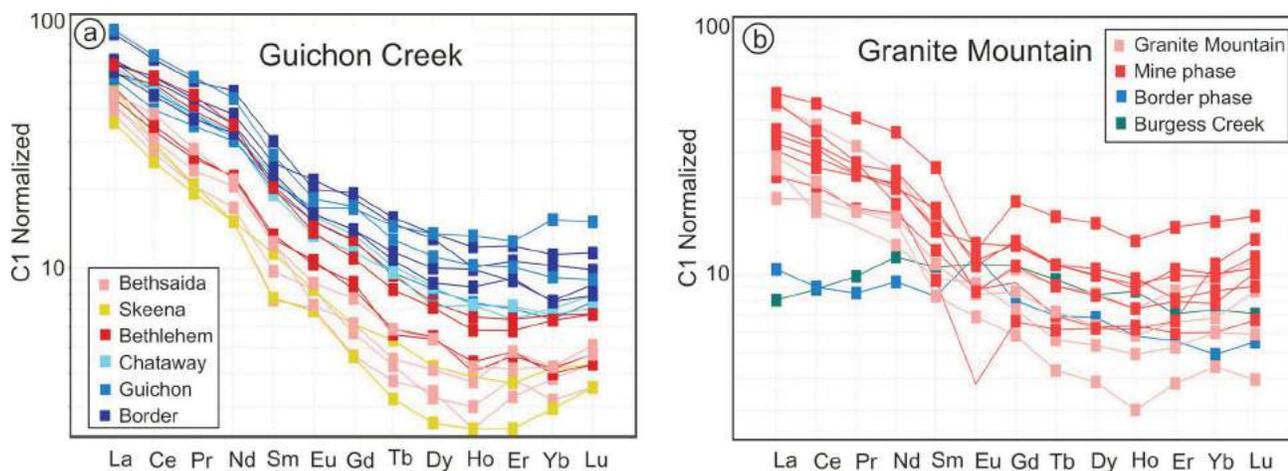
### Mineralogical Characteristics

Preliminary results of electron microprobe analysis on apatite of six samples from the three batholiths are presented. Apatite petrography was studied using a cathodoluminescence (CL) microscope. Apatite grains display brown, pale brown, brownish-green and yellow luminescence (Figure 4). The brown luminescence colour is more common in rocks from the Granite Mountain and Takomkane batholiths and mafic phases of the Guichon Creek batholith, whereas yellow luminescence is common in the felsic Bethsaida phase of the Guichon Creek batholith. Apatite grains with yellow luminescence from the Bethsaida phase

have higher (>0.2%) MnO concentrations and are chemically similar to the apatite occurring in felsic (>70%  $\text{SiO}_2$ ) I-type granite at Lachlan Fold Belt, Australia (Sha and Chappell, 1999; Bouzari et al., 2011). Apatite grains with brown luminescence have lower Mn concentration (<0.2% MnO). Apatite texture varies from uniform to zoned. The zoned apatite grains commonly have a more brownish CL core surrounded by a less brownish to yellow-green CL rim, and locally multiple zones occur (Figure 4b, c).

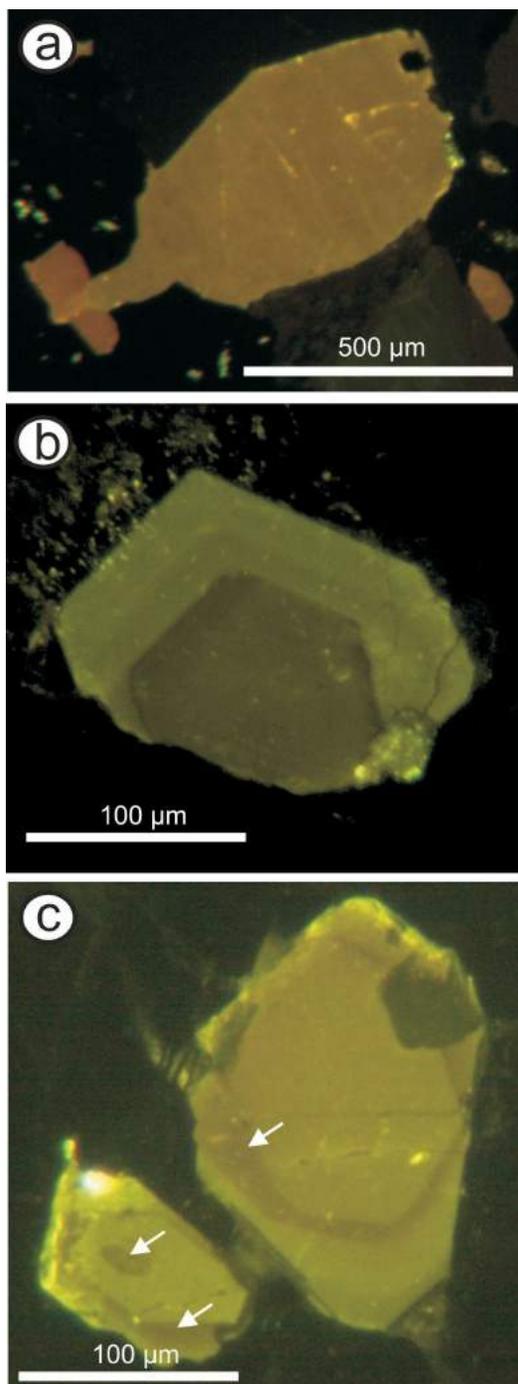
Chemical analysis of apatite grains by electron microprobe analysis shows distinct variations between mineralized and barren phases of the batholiths (Figure 5). At the Guichon Creek batholith, the Bethsaida phase, main host to the Highland Valley porphyry deposits, has less Cl and S relative to the Chataway phase. The Cl concentration of apatite in both phases is significantly less than Cl concentrations in the Border phase apatite, but the Border phase apatite has very low S concentration (Figure 5a). Similarly, the mineralized Woodjam Creek unit of the Takomkane batholith and the Mine phase of the Granite Mountain batholith have lower Cl and S concentrations than the unmineralized phases of the batholiths (Figure 5b, c). The zoned apatite grains show a similar trend for Cl and S. The core of apatite with the more brownish CL colour has higher concentrations of Cl and S relative to the less brownish luminescence at the rim (Figures 4b, 6).

These preliminary observations suggest that in each batholith, the intrusive bodies evolved to phases with less Cl and S, and even the mineralized intrusive body became progressively depleted in Cl and S. Sulphur in magma can form sulphide phases or be incorporated into minerals such as anhydrite. Chlorine is the main constituent for forming copper complexes in hydrothermal fluids. The depletion in sulphur is attributed to the evolution of early magma that is oxidizing and sulphate-rich to a melt that is sulphate-poor as a result of crystallization of anhydrite (Streck and Dilles,



**Figure 3.** Chondrite-normalized rare-earth element (REE) spider diagrams: **a)** Guichon Creek batholith; **b)** Granite Mountain batholith (normalization values of Sun and McDonough, 1989).

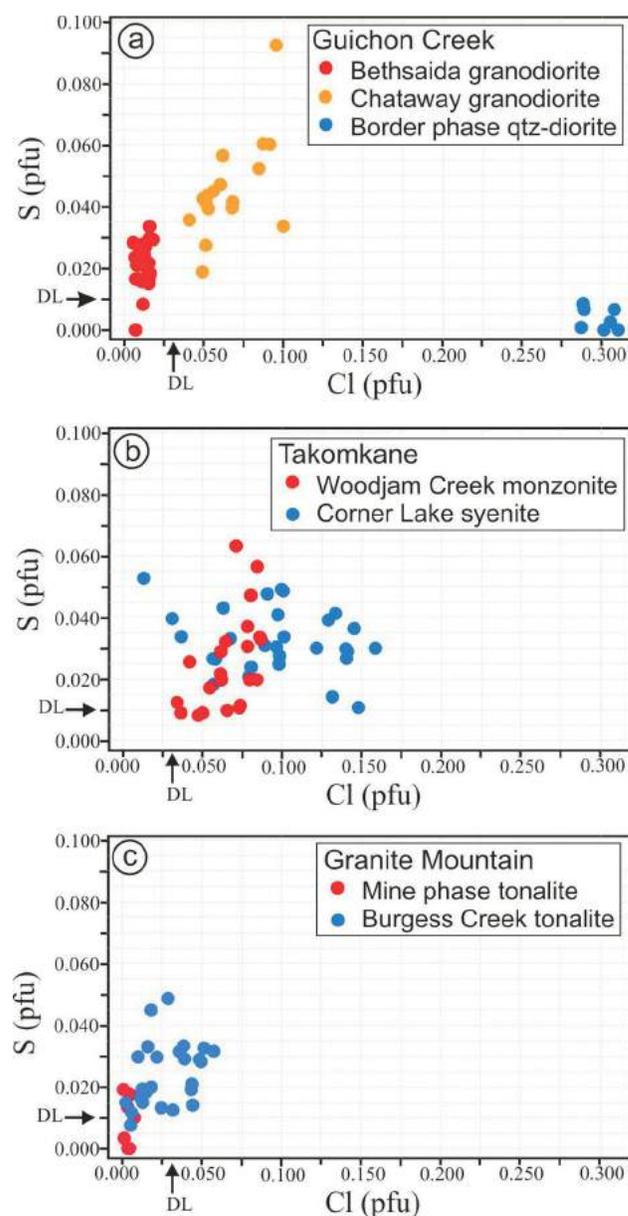
1998; Liaghat and Tosdal, 2008). The depletion of chlorine suggests that both Cl and S were depleted because of exsolution of sulphur-bearing hydrothermal fluids, which eventually generated porphyry copper deposits.



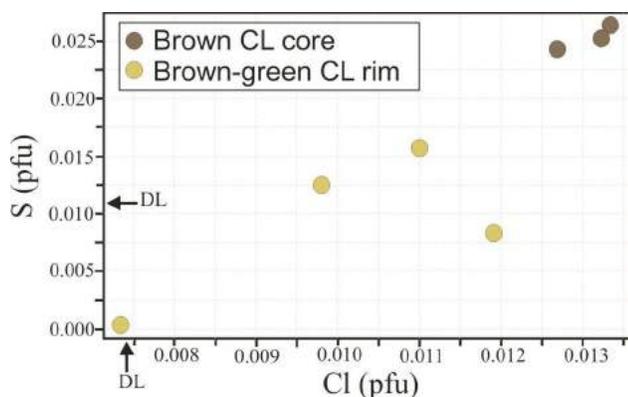
**Figure 4.** Cathodoluminescence image of apatite grains: **a)** large apatite grains from the Woodjam Creek unit of the Takomkane batholith with pale brown luminescence; **b)** zoned apatite grain from the Bethsaida phase with brown luminescence at the core and pale brown-green luminescence at the rim; **c)** apatite grains in Bethlehem granodiorite with a light brown core, a distinct dark brown zone and a more green-brown cathodoluminescence (CL) at the rim.

## Conclusion and Further Work

These preliminary results suggest that both geochemical and mineralogical characteristics of plutons can be used to distinguish fertile phases. Porphyry-fertile plutons commonly display depleted HREE without significant negative Eu anomalies, consistent with hornblende and garnet fractionation, which is favoured by high magmatic water content and oxidation state. Moreover, porphyry-fertile plutons host apatite, which become progressively depleted in Cl and S. Chlorine and sulphur were probably consumed during the orthomagmatic processes which could potentially generate hydrothermal fluids rich in chlorine, sulphur



**Figure 5.** Binary diagram showing correlation of the apatite composition with various pluton phases; Cl and S values are calculated per formula units (pfu). Abbreviations: DL, detection limit; Qtz, quartz.



**Figure 6.** Binary diagram showing correlation of apatite luminescence in a single zoned apatite grain (see Figure 4b) with Cl and S concentrations. Abbreviations: CL, cathodoluminescence; pfu, per formula units.

and copper, capable of producing porphyry copper ores. Further geochemical and mineralogical studies on a complete suite of samples from each batholith is underway. A suite of indicator minerals including apatite, titanite, zircon and hornblende will be studied.

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