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

F. Bouzari, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC, fbouzari@eos.ubc.ca

C.J.R. Hart, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC

T. Bissig, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC

Bouzari, F., Hart, C.J.R. and Bissig, T. (2015): Mineralogical characteristics of porphyry-fertile plutons: Guichon Creek, Takomkane and Granite Mountain batholiths, south-central British Columbia; *in* Geoscience BC Summary of Activities 2014, Geoscience BC, Report 2015-1, p. 63–68.

Introduction

Distinguishing metal-fertile from barren plutons continues to be a significant challenge for geologists exploring for porphyry Cu (Au, Mo) deposits. 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. However, geologists do not have access to such tools that can effectively identify features of enhanced fertility and prospectivity. This research project, therefore, provides tools and strategies that emphasize porphyry fertility in the BC context (see Figure 2 below for project location).

The most fundamental process in the formation of porphyry copper deposits is the exsolution of metal-rich magmatic hydrothermal fluids in large crystallizing batholiths below the site of the deposit (Dilles and Einaudi, 1992). These buoyant fluids stream through the crust to form perched porphyry copper deposits, but in many districts large deposits are hosted directly within or adjacent to the large causative plutons. In all cases, these plutons will host evidence that record 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. The purpose of this project is to look 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 are in systems that have been tilted such that the deeper plutonic parts of the system are well exposed. These combined features make BC an exceptional locality to test and utilize such porphyry fertility indicators. In addition to the evaluation of such plutons on the basis of rock characteristics, fertility can also be assessed using mineral concentrates from stream sediments and glacial till.

Mineral Recorders of Fertility

Previous studies have indicated a range of preferable melt characteristics and ore-forming processes that influence the porphyry fertility of a crystallizing magma. Information about these features and processes, such as oxidation state, fractionation, magma mixing and the amount and saturation of water, metal, chlorine and sulphur and so forth, are variably recorded in crystallizing accessory minerals of the parent pluton. Evidence of these features may be recorded as particular mineral assemblages or as minerals having particular characteristics or chemical composition. The most apparent features would include zoning, mineral or fluid inclusions, or resorbed zones or margins. Examples include the following:

- Apatite crystals from fertile systems can be zoned with sulphur-rich cores and sulphur-poor rims, indicating early sulphate saturation and the crystallization of anhydrite (Figure 1a, b). Such observations have been made at the Yerington batholith, Nevada (Streck and Dilles, 1998) and Galore Creek porphyry Cu-Au deposit, BC (Liaghat and Tosdal, 2008).
- Apatite trace-element compositions can record the degree of fractionation and oxidation state of the magma (Belousova et al., 2002).
- Zircons from porphyry fertile intrusions in northern Chile have Ce and Eu compositions with significantly higher oxidation states than barren intrusions (Ballard et al., 2002).
- Co-existing hornblende and magnetite is a diagnostic feature of mineralized silica-undersaturated igneous complexes in BC (Lueck and Russell, 1994).

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

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the Geoscience BC website: http://www.geosciencebc.com/s/DataReleases.asp.

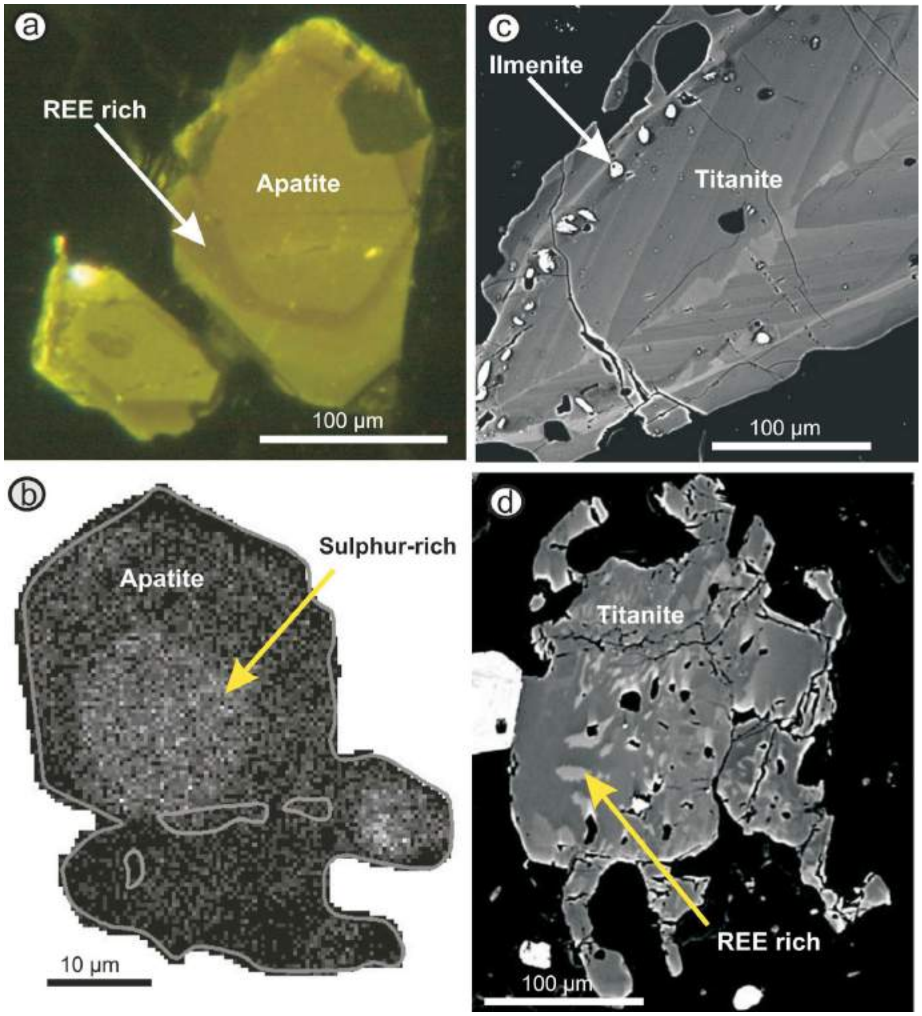

Figure 1. Examples of mineralogical features that can be used to characterize porphyry fertility of igneous bodies: **a)** apatite grain from Bethlehem granodiorite (Highland Valley) of the Guichon Greek batholith displays zoning reflecting changing magma compositions and enrichment, in this case recorded by rare-earth element (REE) and probably sulphur content (Bouzari et. al., 2011); **b)** X-ray intensity of apatite from Yerington batholith showing a sulphur-poor rim indicating sulphur extraction from the magma (Streck and Dilles, 1998); **c)** titanite with concentric oscillatory and sector zoning, which records redox changes and instability in the melt, particularly a distinctly reducing event that deposited ilmenite grains near the margin (Russ of Mull granite, Scotland; McLeod et al., 2011); **d)** patchy zoning in titanite with interstitial and marginal growth indicating the introduction of late fluids and modification of REE compositions (McLeod et al., 2011).

- Titanite displays concentric oscillatory zoning and rare-earth element–rich patches that represent changes in melt composition from magma mixing and late sub-solidus modification by fluids (Figure 1c, d; McLeod et al., 2011).

Therefore, mineralogical characteristics observed in the plutonic rocks hosting porphyry stocks can record processes that led to the generation of porphyry copper-gold mineralization.

Objectives

This project identifies field, mineralogical and geochemical characteristics of known porphyry-fertile plutons and develops exploration tools for the subsequent identification of new fertile plutonic terrains of BC. Physical and chemical features in common accessory minerals, (e.g., apatite, titanite, zircon) that show evidence of magmatic processes such as high oxidation state, evidence of fluid saturation, magma fertilization by mafic melt injection, and sulphate saturation and depletion in the melt will be characterized. Specific objectives of this project are to

- determine the mineralogical features of common accessory minerals that characterize and distinguish porphyry-fertile intrusions;
- assess geochemical features of common accessory minerals that indicate fertility;
- document fertility evidence over time and space in an evolving composite zoned pluton;

- assess the utilization of rapid mineralogical characterization tools; and
- construct a toolkit to provide a predictive decision-making framework to assess fertility in rocks, stream sediment and till-heavy mineral concentrates.

Porphyry copper-gold deposits in BC provide an excellent opportunity to study the relationship between ore deposits and hosting plutons and batholiths. This is because many of the BC porphyry deposits are hosted in stocks within a composite zoned batholith of similar age (Lang et al., 1995; McMillan et al., 1995). Various phases of the batholith and mineralized stock are exposed at or near surface and accessory minerals such as apatite, titanite, zircon, magnetite and garnet (melanite) occur in various proportions in different plutons and associated alteration zones.

Methods

Field and laboratory work will focus 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 2).

Guichon Creek Batholith

The Late Triassic Guichon Creek batholith (65 by 20 km) is a composite batholith that ranges from diorite and quartz diorite compositions at the border, to younger granodiorite in the centre (Casselman et al., 1995), which hosts most of the several Highland Valley porphyry Cu-Mo deposits (Valley, Lornex, Highmont, Alwin, Bethlehem and JA). The geology of the footprint regions surrounding the mineral deposits is currently being evaluated through a project funded by the Canadian Mining Innovation Council (CMIC), and the alteration mineralogy and geochemistry of Valley, Bethlehem and Alwin deposits were the subject of past Mineral Deposit Research Unit (MDRU) projects on alteration footprints and porphyry indicator mineral projects. These studies provide an excellent basis for this project.

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 Deerhorn). Previous investigations of these rocks (e.g., Schiarizza et al., 2009), and a recent MDRU study (Bouzari et al., 2011; del Real et al., 2014) provide a strong foundation for the geology, geochronology and mineralization of this region. The Takomkane batholith records a magmatic evolution lasting 11 m.y., with three separate mineralizing events at Woodjam. Moreover, the presence of Cu-Au and Cu-Mo deposits together with the regional northwest 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. It was originally thought that the Granite Mountain batholith had intruded into the Cache Creek terrane (Bysouth et al., 1995). But recent study 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, and correlative with the Late Triassic, calcalkaline Guichon Creek batholith, host to the Highland Valley porphyry Cu-Mo deposits, 250 km to the south-southeast.

Rock samples from different intrusive units will be examined to characterize each unit. Minerals will be examined in situ but also extracted initially using nondestructive crushing. The focus of this work will be on examining the physical and chemical features of accessory minerals such as apatite, titanite, zircon, magnetite or garnet.

Techniques used to study these samples will emphasize observational methods such as binocular microscopy, petrography, cathodoluminescence, infrared/ultraviolet light and scanning electron microscopy (SEM). In cases where features are observed, trace-element–geochemical analysis of these minerals will be performed using electron microprobe and laser-ablation, multiple-collector, inductively coupled plasma–mass spectrometry (LA-MC-ICP-MS) methods. Automated SEM techniques such as mineral liberation analysis (MLA) will be tested to provide a fast method to record textural and chemical characteristics. In addition, all other aspects such as physical properties, whole rock lithogeochemistry, redox state and age of crystallization (for unknown units) will be determined. Relative and absolute timing is also an important factor. Thus, characterizing the evolution and differences between intrusive phases within a single mineralizing system that form slightly before and after mineralization (which is common in porphyry deposits) is important.

Current Work

Sampling was initiated in late August 2014 and will continue in summer 2015. Archived sample material in MDRU's rock collection from previous projects as well as current mapping projects in Granite Mountain batholith by the British Columbia Geological Survey (BCGS) will also be utilized to complement this year's fieldwork.

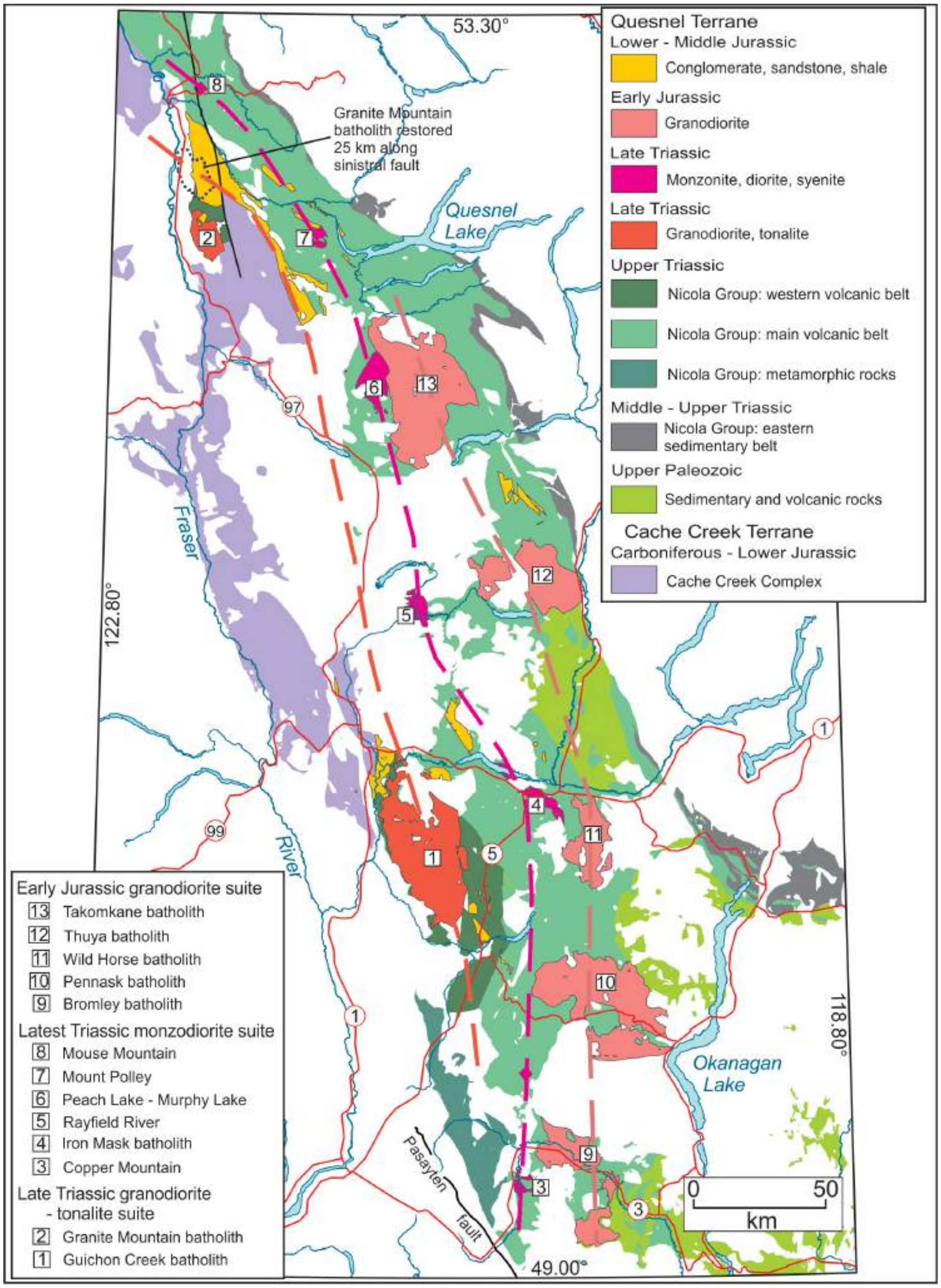

Figure 2. Simplified geology map of south-central British Columbia showing location of major plutonic bodies. Dashed lines illustrate parallel belts of calcalkaline or alkaline plutons that show a progressive younging from west to east (from Schiarizza, 2014).

Rocks will be well documented and processed to obtain thin sections and mineral separates that will be evaluated using a range of observable techniques including binocular and petrographic microscopes, SEM and by cathodoluminescence. Selected samples will be evaluated for mineral chemistry using the electron microprobe and LA-MC-ICP-MS to characterize previously observed features. Mineral liberation analysis techniques will be utilized to assess rapid automatic detection of key features of interest. Results, including poster displays and articles for the *Geoscience BC Summary of Activities* series, will be released in the winter of 2015 and 2016.

Acknowledgments

Geoscience BC is thanked for its generous financial contribution in support of this project. The authors also thank M. Allan of the Mineral Deposit Research Unit for his review of and comments on this report.

References

Ballard, J.R., Palin, J.M. and Campbell, I.H. (2002): Relative oxidation states of magmas inferred from Ce(IV)/Ce(III) in zircon: application to porphyry copper deposits of northern Chile; Contributions to Mineralogy and Petrology, v. 144, p. 347–364.

Belousova, E.A., Griffin, W.L., O'Reilly, S.Y. and Fisher, N.I. (2002): Apatite as an indicator mineral for mineral exploration: trace-element compositions and their relationship to host rock type; Journal of Geochemical Exploration, v. 76, p. 45–69.

Bouzari, F., Hart, C.J.R., Barker, S. and Bissig, T. (2011): Porphyry indicator minerals (PIMs): exploration for concealed deposits in central British Columbia; Geoscience BC, Report 2011-17, 31 p., URL <http://www.geosciencebc.com/i/project_data/GBC_Report2011-17/GBCReport2011-17_report.pdf> [November 2014].

Bysouth, G.D., Campbell, K.V., Barker, G.E. and Gagnier, G.K. (1995): Tonalite-trondhjemite fractionation of peraluminous magma and the formation of syntectonic porphyry copper mineralization, Gibraltar mine, central British Columbia; *in* Porphyry Deposits of the Northwestern Cordillera of North America, T.G. Schroeter (ed.), Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, p. 201–213.

del Real, I., Hart, C.J.R., Bouzari, F., Blackwell, J.L., Rainbow, A. and Sherlock, R. (2014): Relationships between calcalkalic and alkalic mineralization styles at the copper-molybdenum Southeast Zone and copper-gold Deerhorn porphyry deposit, Woodjam property, central British Columbia; *in* Geoscience BC Summary of Activities 2013, Geoscience BC, Report 2014-1, p. 63–82, URL http://www.geosciencebc.com/i/pdf/SummaryofActivities2013/SoA2013_ delReal.pdf [November 2014].

Dilles, J.H. and Einaudi, M.T. (1992): Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry copper deposit, Nevada: a 6-km vertical reconstruction; Economic Geology, v. 87, p. 1963–2001.

Lang, J.R., Lueck, B., Mortensen, J.K., Russell, J.K., Stanley, C.R. and Thompson, J.F.H. (1995): Triassic-Jurassic silica-undersaturated and silica-saturated alkalic intrusions in the cordillera of British Columbia: implications for arc magmatism; Geology, v. 23, p.451–454.

Liaghat, S. and Tosdal, R. (2008): Apatite chemical composition and textures as a probe into magmatic conditions at Galore Creek porphyry copper-gold deposit, British Columbia (abstract): 18th Annual V.M. Goldschmidt Conference; Geochimica et Cosmochimica Acta, v. 72, no. 12, p. A550.

Lueck, B.A. and Russell, J.K. (1994): Silica-undersaturated, zoned alkaline intrusions within the British Columbia cordillera; *in* Geological Fieldwork 1993, BC Ministry of Energy and Mines, BC Geological Survey, Paper 1994-1, p. 311–315.

McLeod, G.W., Dempster and T.J., Faithfull, J.W. (2011): Deciphering magma-mixing processes using zoned titanite from the Ross of Mull granite, Scotland; Journal of Petrology, v. 52, p. 55–82.

McMillan, W.J., Thompson, J.F.H., Hart, C.J.R. and Johnston, S.T. (1995): Regional geological and tectonic setting of porphyry deposits in British Columbia and Yukon Territory; *in* T.G. Schroeter (ed.), Porphyry Deposits of the Northwestern Cordillera of North America, CIM, Special Volume 46, p. 40–57.

Schiarizza, P. (2014): Geological setting of the Granite Mountain batholith, host to the Gibraltar porphyry Cu-Mo deposit, south-central British Columbia; *in* Geological Fieldwork 2013, BC Ministry of Energy and Mines, BC Geological Survey Paper 2014-1, p. 95–110.

Schiarizza, P., Bell, K. and Bayliss, S. (2009): Geology and mineral occurrences of the Murphy Lake area, south-central British Columbia (NTS 093A/03); *in* Geological Fieldwork 2008, BC Ministry of Energy and Mines, BC Geological Survey, Paper 2009-1, p. 169–188, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/2008/15_Schiarizza.pdf> [November 2014].

Streck, M.J. and Dilles, J.H. (1998): Sulfur evolution of oxidized arc magmas as recorded in apatite from a porphyry copper batholith; Geology, v. 26, p. 523–526.