Recognizing IOCG alteration facies at granulite facies in the Bondy Gneiss Complex of the Grenville Province

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Abstract. The Bondy gneiss complex in the southwestern Grenville Province of Canada, hosts a series of granulite facies 1.4–1.35 Ga mafic to felsic volcanic rocks. Metamorphosed hydrothermal alteration zones constitute large sectors of the complex and have mineral occurrences. Mineral assemblages and lithogeochemical analysis of meta-hydrothermal zones have attributes of Na, Ca-Fe, K-Fe, K, Mg, argillic, phyllic and advanced argillic altered volcanic rocks. In alteration discrimination diagrams, the hydrothermal system shares attributes of IOA-IOCG systems that evolve toward epithermal caps (e.g., Great Bear magmatic zone, Canada; Central Andes, Chile). The Bondy footprint is significantly distinct from VMS deposits and other deposit types. We thus interpret the Bondy hydrothermal system as prospective for the variety of mineralisation types typical of Proterozoic IOA-IOCG-epithermal systems.

Keywords. granulite, IOCG, metamorphosed alteration zones, Grenville.

1 Introduction

The discovery of SEDEX, VHMS, epithermal, porphyry, IOCG, and IOA deposits metamorphosed at upper amphibolite to granulite facies (Corriveau and Spry 2014) calls for a re-evaluation of historically under-explored mineral occurrences in high-grade metamorphic terranes. In known deposits, the meta-alteration zones preserved the imprint of the chemical changes undergone by the protoliths during pre-metamorphic hydrothermal alteration. Consequently, petrological and lithogeochemical tools to identify and quantify hydrothermal alteration associated with ore deposits can be applied to environments metamorphosed to high grades. In this contribution, we compare the composition of metamorphosed hydrothermal alteration zones in the Bondy Gneiss Complex of the southwestern Grenville Province to a variety of deposit types and illustrate that they are significantly similar to those of IOCG deposits that evolve to epithermal caps.

2 The Bondy Gneiss Complex

The Bondy Gneiss Complex represents a 1.4–1.35 Ga volcano-plutonic edifice metamorphosed to granulite facies between 1.2 and 1.18 Ga (Corriveau and van Breemen 2000; Blein et al. 2003; Wodicka et al. 2004; Corriveau 2013). Its outcrop forms a structural window of Laurentian basement within the northern half of the Central Metasedimentary Belt in Québec, Canada (Fig. 1).

In the complex, granitic to tonalitic orthogneisses dominate. Units of amphibolite, mafic granulite and quartzofeldspatic gneiss locally preserve primary layering and fragmental textures. The northern half of the complex consists of a hydrothermal system at granulite facies with, from north to south: (1) tourmalinites among phlogopite-sillimanite gneisses; (2) plagioclase-cordierite-orthopyroxene white gneisses; (3) gneisses rich in biotite, cordierite, garnet, K-feldspar, orthopyroxene and/or sillimanite; (4) laminated quartzofeldspathic gneisses; (5) a series of magnetite and garnet-rich gneisses, garnetites, biotite-orthopyroxene gneisses and locally magnetite-rich amphibolites; (6) a hyperaluminous sillimanite-quartz gneiss unit with pyrrothite; (7) biotite-rich garnetites and garnet-rich gneisses; and (8) a diverse array of layered, garnet amphibolites (Corriveau 2013).

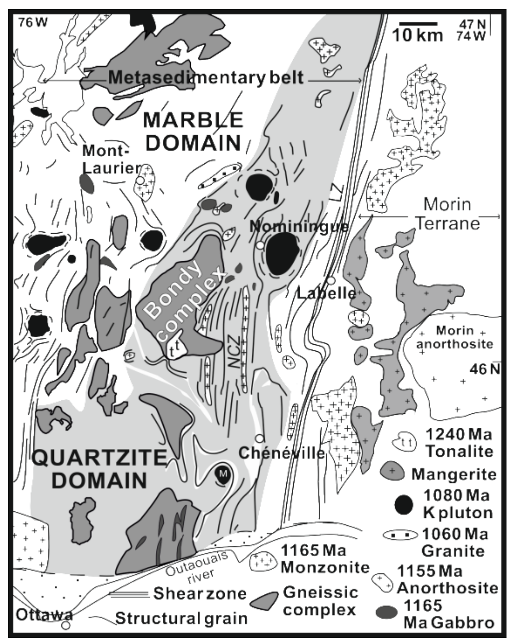

Figure 1. Location of the Bondy complex within the Central Metasedimentary Belt of the southwestern Grenville Province in Québec (modified from Corriveau and van Breemen 2000).

The aluminous gneisses have mineral assemblages typical of metapelites but their atypical and varied mineral modes and textures are diagnostic of metamorphosed hydrothermally altered rocks (cf. Bonnet and Corriveau 2007; Corriveau 2013). Comparison with petrological models and field attributes of the diagnostic alteration facies of iron oxide and related alkali-calcic alteration systems of the Great Bear magmatic zone (Corriveau et al. 2016, 2017; Trapy et al. 2015) allow the following field interpretation. The garnetites and tourmalinites among sillimanite ± garnet ± orthopyroxene ± cordierite gneisses, and felsic and mafic layered gneisses show very poor layering in contrast to what would be expected of exhalites. They grade into a variety of tourmaline, kornerupine and garnet gneisses that remain atypical of metamorphosed sedimentary rocks. The tourmaline-rich unit hosted by phlogopite-sillimanite-bearing gneisses is a good candidate for a metamorphosed tourmaline alteration zone among argillic or sericitic altered units; the poorly layered cordierite-orthopyroxene-bearing but plagioclase-dominant white gneiss resembles chloritised albitite units; the biotite, cordierite, garnet, K-feldspar, orthopyroxene and/or sillimanite gneisses are good candidates for high- to low-temperature (HT, LT) K-Fe, argillic, and sericitic altered volcaniclastic rocks; the magnetite-rich gneisses and the garnetites are candidates for iron oxide-altered, magnetite dominant and magnetite-phyllosilicate dominant HT Ca-Fe or HT K-Fe alteration types; the sillimanite-quartz-pyrrhotite rocks are typical of advanced argillic or phyllic alteration zones, and the biotite garnetites could either be K-altered amphibolites or HT or LT K-Fe metasomatites.

3 Geochemical signatures

3.1 Lithogeochemistry

The isochemical nature of high-grade metamorphism allows for chemical discrimination of metamorphosed hydrothermal ore deposits based on alteration indices and discriminant diagrams. The alteration index (AI) (Ishikawa et al. 1976) calibrates the intensity of sericitic and chloritic alteration of volcanic rocks, the chlorite–carbonate–pyrite index (CCPI) index (Large et al. 2001) plots carbonate and pyrite alteration proximal to VMS mineralisation, the Benavides et al (2008) index helps to detect IOCG footprints, and the Montreuil et al (2013) discriminant plot distinguishes the key alteration facies in IOCG systems.

In the Montreuil et al. (2013) discriminant plot, the vertical axis discriminates between sodic and potassic alteration facies, while the horizontal axis discriminates alkali alteration from Ca–Fe, K–Fe, and Fe alteration facies. In Figure 2, whole-rock geochemical data of Corriveau (2013) from the Bondy Gneiss Complex are plotted on the Montreuil et al. (2013) plot. The addition of molar proportions of Na (pink), Ca (dark green), Fe (black), K (red), Mg (light green), and Si/8 (yellow) further discriminates the main alteration facies as these cations are excellent proxies for their dominant mineral phases (Corriveau et al. 2016, 2017; Montreuil et al. 2013). Corriveau et al. (2017) further refine the understanding of IOCG footprints by discriminating prograde metasomatic paths of iron oxide and related alkali-calcic alteration from the imprint of retrograde alteration.

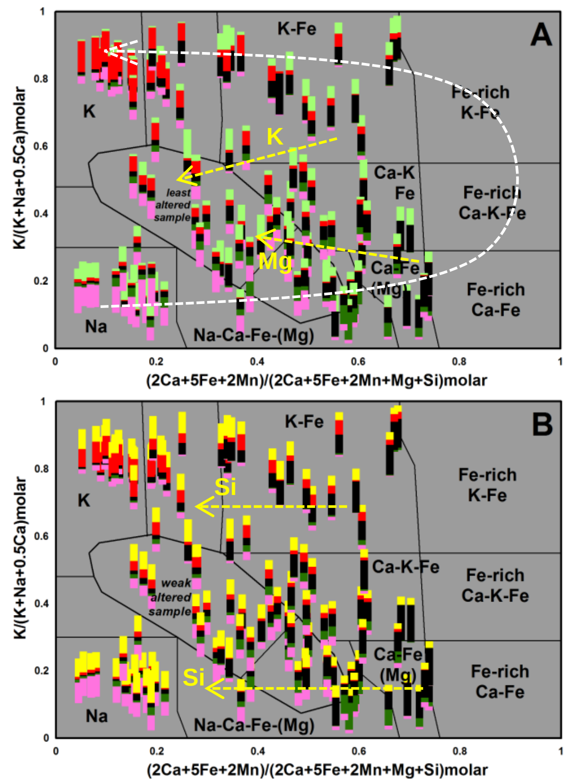

Figure 2. IOCG discriminant diagram of Montreuil et al. (2103) applied to Bondy Gneiss Complex meta-hydrothermal alteration zones. Signatures typical of prograde (white arrow) and retrograde (yellow arrows) paths are shown (see also Corriveau et al. 2017). Analyses can be found in Corriveau (2013). Bar codes reflect Na-Ca-Fe-K-Mg in (A) and Na-Ca-Fe-K-Si/8 in (B).

3.2 Discriminant diagram

In the IOCG discrimination diagram, Bondy metasomatites plot in the Na, HT Na-Ca-Fe, HT Ca-Fe, HT Ca-K-Fe, HT-LT K-Fe and K alteration fields; one or two cations dominate molar Na-Ca-Fe-K-Mg proportions (Fig. 2). Plagioclase-dominant gneisses with cordierite-orthopyroxene layers fall within the field of Na alteration with some Mg addition attributed to chloritization of original amphibole-bearing HT Na-Ca-Fe layers (Fig. 2A). Orthopyroxene-rich aluminous gneisses and some amphibolites fall within HT Ca-Fe alteration. Magnetite-orthopyroxene gneisses outline Fe-rich alteration zones with the development of massive to well-layered magnetite-rich gneisses. Magnetite-rich, garnet-bearing gneisses and biotite garnetites fall within the K-Fe alteration field. Locally, K-feldspar prevails in laminated quartzofeldspathic gneisses that plot within the K alteration facies. These rocks fall on the prograde path of IOA-IOCG systems, though an Mg component typical of LT Ca-Mg K-Fe occurs throughout (Fig. 2A, B).

Some amphibolites and aluminous gneisses exhibit transitional alteration types dominated by two or three elements. These rocks record K alteration of HT Ca-Fe or HT Na-Ca-Fe metasomatites; retrograde overprints skew the signatures towards the field of least-altered rocks (Fig. 2A, B). In Figure 2A and 2B, some altered rocks display bar codes dominated by Mg and/or Si. These reflect intense chloritisation and silicification of earlier Na, Ca-Fe, Ca-K-Fe, K-Fe and K metasomatites.

The Bondy hydrothermal footprint is distinct from the ones of typical VMS deposits (Fig. 3A, B) in that intense carbonatation, chloritization and silicification are not observed whereas Fe-dominant alteration is abundant. Moreover, extensive albitites are not developed in VMS deposits though albitisation is common. Most of the Bondy hydrothermal footprint is distinct from the ones of typical epithermal deposits (Fig. 4A, B) in that intense K and silicification is only restricted to part of the system. Comparison of Bondy data with the magnetite-dominant IOA-IOCG footprint of the Great Bear magmatic zone (Fig. 5A, B; Corriveau et al. 2017) illustrates that data from Bondy fall within most alteration facies but are slightly off from the prograde metasomatic path of the Great Bear systems, and at current levels of exposure, lacks an IOA component (shown by lower Fe-enrichments). It does display a pervasive and intense Mg footprint which is very typical of low temperature alteration facies, such as chloritization and silicification, over Na, Ca-Fe and/or K-Fe metasomatites. The latter is common in hematite-dominated IOCG deposits such as in the Mantoverde district (Fig. 6) and was not common in the magnetite-dominated IOCG settings of the Great Bear. At Mantoverde, Si and Mg enrichments are superimposed over K-Fe and K alteration facies.

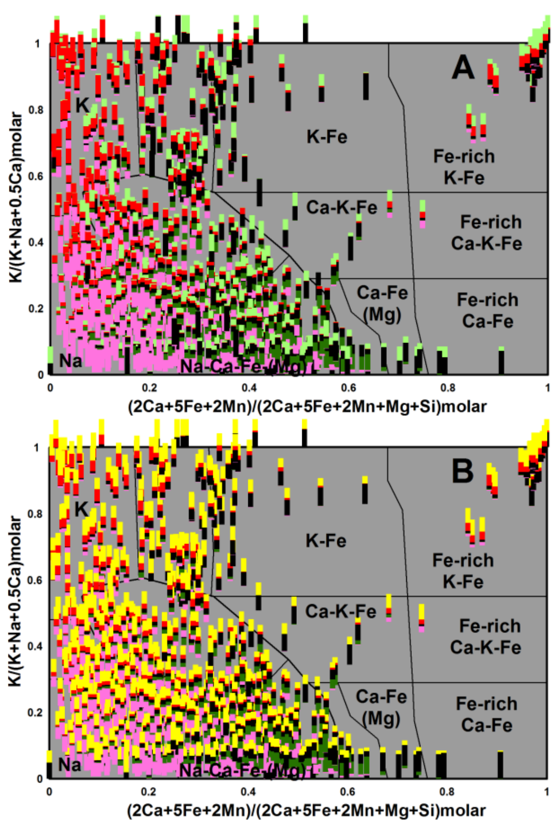

Figure 3. IOCG discriminant diagram of Montreuil et al. (2103) applied to VMS deposit chemical footprints, using data compiled by Duuring et al. (2016). Same symbols as Figure 2.

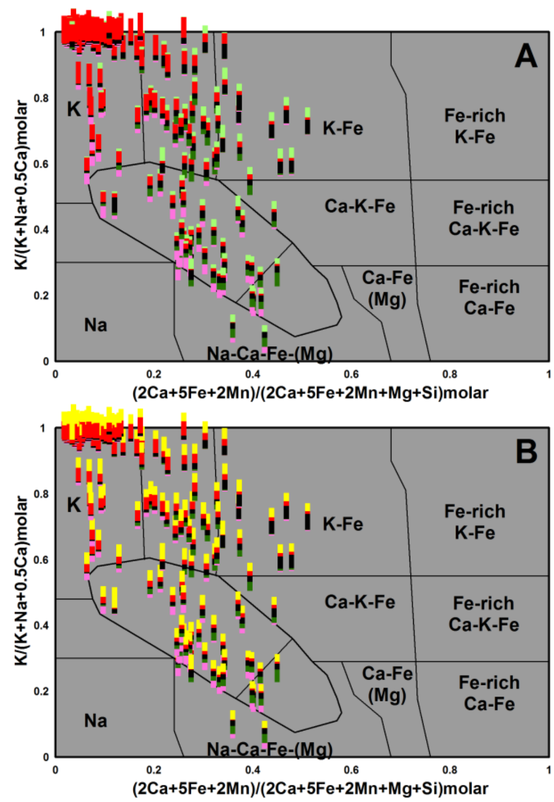

Figure 4. Plot of epithermal deposits (Warren et al. 2007) on IOCG discriminant diagram of Montreuil et al. (2013). Same symbols as Figure 2.

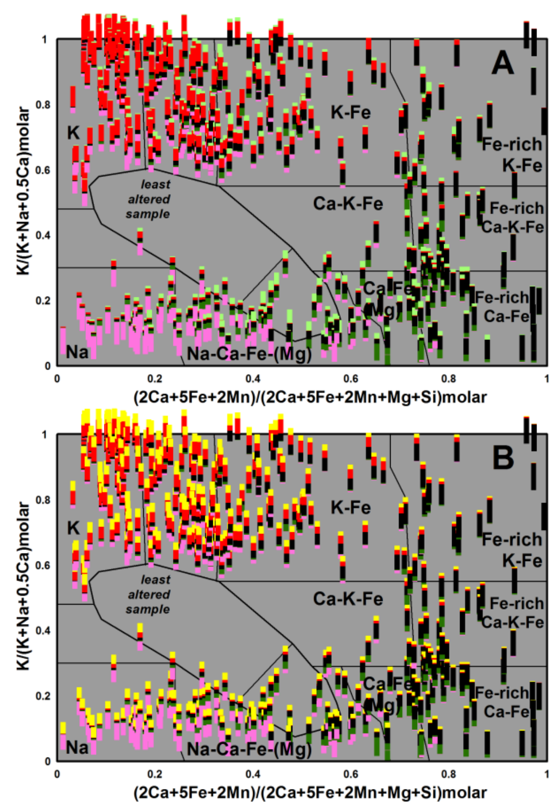

Figure 5. Plot of Great Bear magmatic zone IOA-IOCG-epithermal footprints. Only samples with a single alteration types were chosen from Corriveau et al. (2015) dataset. Same symbols as Figure 2.

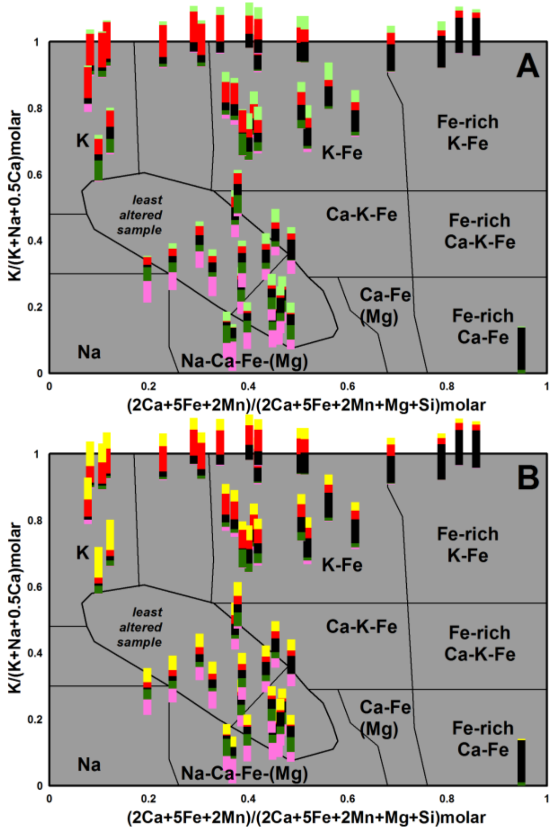

Figure 6. IOCG discriminant diagram of Montreuil et al. (2013) for the Mantoverde district, Chile using data from Benavides et al. (2008). Same symbols as Figure 2.

4 Summary and conclusions

The metamorphosed hydrothermal footprint of the Bondy gneiss complex comprises (i) Na, (ii) HT Ca-Fe, (iii) HT K-Fe, (iv) LT K-Fe, chlorite and epithermal type alteration facies. The chemical changes recorded by these facies have similarities to hematite-group IOCG deposits evolving towards epithermal caps. The study illustrates that IOCG systems can be preserved in the high-grade metamorphic Proterozoic terranes of the Grenville Province. Being within a structural window in the Central Metasedimentary Belt, it is possible that other systems remain to be found in other 1.4 Ga components of the Grenville Province, providing new targets for mineral exploration.

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