

MINERAL SYSTEMS WITH IOCG AND AFFILIATED DEPOSITS: PART 2 – GEOCHEMICAL FOOTPRINTS

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Abstract

Regional iron oxide and alkali-calcic alteration systems generate a wide variety of ore deposits, including iron oxide-apatite (IOA), iron oxide copper-gold (IOCG), iron oxide Co, Bi, REE or U, skarn, and albitite-hosted uranium and Au-Co ± U deposits. The Great Bear magmatic zone (Canada), Cloncurry district and Olympic Copper-Gold Province (Australia) are used as examples to illustrate the lithogeochemical footprints of these mineralizing hydrothermal systems. Plotting metal contents on a diagram that discriminates the iron oxide and alkali-calcic alteration facies (AIOCG plot) highlights the coupling of V, Sc, Ni ± Pb ± Zn with Ca and Fe, as Facies 1 (Na) alteration evolves to Facies 2 (high-temperature Ca-Fe) alteration and IOA mineralization. In metasedimentary rocks, propagation of fluid-rock reactions towards Facies 3 forms a transitional Facies 2–3 (high-temperature Ca-K-Fe) alteration that is marked by enrichment in cobalt and gold and onset of copper precipitation. Au-Co-Bi ± Cu deposits with iron-rich end-members are associated with the precipitation of As, Bi and W (e.g. NICO deposit, Great Bear). Facies 3 (high-temperature K-Fe) alteration containing biotite may also be rich in cobalt and arsenic (Ernest Henry, Cloncurry), whereas Facies 3 alteration in which K-feldspar prevails over biotite is associated with precipitation of Ag, Au, Bi, Cu, Mo, REE, ± U and locally Ni. Facies 4 (K-felsite) alteration is either barren or locally enriched in thorium. Alternatively, in carbonate units and carbonate-altered units, zones of K-skarn may form and host polymetallic mineralization. Facies 5 (low-temperature K-Fe to Ca-Mg-Fe) alteration is associated with the formation of mineralized zones containing variable proportions of Ag, Au, Cd, Cu, Mo, Pb, REE, U and Zn. The sequence of alteration facies records the pathways followed by metals during deposit formation within the system. The resulting footprints provide mappable criteria in outcrop and drill core for mineral potential assessments and facilitate vectoring to IOCG and affiliated mineralization, including variants enriched in critical metals.

Résumé

Les systèmes régionaux à altération alcali-calcique et à oxydes de fer génèrent une grande diversité de types de gîtes, incluant à oxydes de fer-apatite (IOA), oxydes de fer cuivre-or (IOCG), oxydes de fer Co/Bi/ETR/U, skarn et U et Au-Co± U au sein d'albitite. La zone magmatique du Grand lac de l'Ours (Canada), le district de Cloncurry et la province Cuivre-Or d'Olympic (Australie) illustrent l'empreinte lithogéochimique de ces systèmes minéralisateurs. En reportant leurs métaux sur un diagramme discriminant des faciès d'altération alcali-calcique et à oxydes de fer (diagramme AIOCG), on y observe un couplage du V, Sc, Ni, ± Pb, ± Zn avec Ca+Fe lorsque le Faciès d'altération 1 évolue au Faciès d'altération 2, et la minéralisation à IOA. Dans des séquences sédimentaires, la transition vers le Faciès 3 consiste en un Faciès d'altération

2–3 à Ca-K-Fe à haute température marqué par un enrichissement en cobalt et en or, un début de précipitation du cuivre. À l'atteinte des pôles plus riches en fer, un enrichissement en As, Bi et W donne lieu aux gîtes à Au-Co-Bi ±Cu (p. ex. gîte de NICO, Province de l'Ours). Le Faciès d'altération 3 (K-Fe à haute température) riche en biotite peut être enrichi en cobalt et arsenic (p. ex. Ernest Henry, Cloncurry) alors que le Faciès 3 avec feldspath potassique est marqué par la précipitation d'Ag, Bi, Cu, Mo, ETR, ±U, ±Ni. Le Faciès 4 inclue des brèches de felsite potassique largement stérile ou localement enrichie en thorium ou, au sein de séquences carbonatées, du skarn potassique à minéralisation polymétallique. Le Faciès d'altération 5 (K-Fe à Ca-Mg-Fe à basse température) est associé à des enrichissements en Ag, Au, Bi, Cd, Cu, ETR, Mo, Pb, U et Zn. La séquence de faciès d'altération enregistre le parcours des métaux vers les gîtes alors que leurs empreintes lithogéochimiques fournissent des critères cartographiables pour l'évaluation du potentiel minéral et facilitent l'élaboration de stratégies d'exploration pour la vectorisation vers les gîtes IOCG et affiliés, y compris de nombreuses variantes enrichies en métaux critiques.

Introduction

Metasomatic iron oxide and alkali-calcic alteration (IOAA) systems generate iron oxide-apatite (IOA), iron oxide copper-gold (IOCG), and a vast array of critical metal deposits (Fig. 1; Williams, 2010; Corriveau et al., 2016, 2022a–d; Hofstra et al., 2021). This Part 2 of three contributions documents the geochemical footprints of alteration facies and mineralization types formed through the ascent, infiltration and physicochemical evolution of voluminous, super-heated, saline to hypersaline fluid plumes through the upper crust. Case studies include those described in Part 1 (mineral systems from the Great Bear magmatic zone, Canada and the Ernest Henry and Olympic Dam deposits, Australia; Corriveau et al., 2022c) with additional information from the Punt Hill deposit in the Olympic Copper-Gold Province (Australia), and various deposits of the Kwyjibo (Canada), Southeast Missouri (USA), Romanet Horst (Canada), Wanapitei (Canada) and Middle-Lower Yangtze River Metallogenic Belt districts (China; Fig. 1).

Part 1 case studies illustrate the geological footprints and space-time relationships amongst the consecutive alteration facies formed in metasomatic IOAA systems (Corriveau et al. (2022c). Part 3 (Corriveau et al., 2022b) summarizes the field

relationships of each alteration facies documented in Part 1, describes the associated mineralization, and links both with the metal associations documented in this paper. Together, Parts 1 to 3 link deposit types formed through the consecutive fluid plume discharge and recharge of metals as IOAA systems evolve towards surface. Thirty of the fifty-one metals listed as critical by the Canadian, United States, European, Japan and Australian governments are economic and potential commodities in IOAA systems (Al, Ag, Au, As, Ba, Bi, Co, Cu, F, Mo, Nb, Ni, PGE (Pd, Pt), Rb, Re, REE (LREE, HREE and Y), Sb, Sc, Sn, Sr, Ta, Te, U, V, W, Zn and Zr in addition to non critical Fe and Cd (lists in Fortier et al., 2019; Austrade, 2020; Emsbo et al., 2021; Natural Resources Canada, 2021).

Principles, Geochemical Tools and Data

Alteration Facies

Following Corriveau et al. (2016, 2022a) and Parts 1 and 3 (Corriveau et al., 2022b, c), metasomatic mineral assemblages and compositional modifications to host rocks in IOAA systems are grouped into six distinct alteration facies (Table 1). Each facies is defined by a specific suite of stable mineral assemblages whose precipitation controls the whole-rock compositions of the metasomatites. The spatial and temporal relationships amongst the consecutive alteration facies reflect the evolution of physicochemical conditions of fluid-rock reactions across the system (e.g. changes in temperature, composition, eH and pH of the fluid plume). Following the field-based timeline of facies and their high-temperature (HT) to low temperature (LT) conditions of crystallization, Facies 1 is 'Na' alteration, Facies 2 is 'HT Ca-Fe' alteration, Facies 3 is 'HT K-Fe' alteration, Facies 4 is 'K-felsite' and/or 'K-skarn' alteration, and Facies 5 is 'LT K-Fe' and/or 'LT Ca-Mg-Fe' alteration (with Si, Ba, CO₂ and F-rich variants). Facies 6 (not detailed in table 1) combines epithermal systems, silicification and carbonate alteration, and later vein systems. Transitional Facies 1–2 comprises HT Na-Ca-Fe and skarn alteration, and Facies 2–3 consists of HT Ca-K-Fe alteration.

The temperature ranges for each alteration facies are empirically established using their stable mineral assemblages (supported by global fluid inclusion studies; see Corriveau et al., 2016, 2022b). 'Low-temperature' is used to refer to mineral assemblages that formed below 375°C, whereas 'high-temperature' refers to mineral assemblages that formed above 375°C. Sericite is used as a general term for fine-grained

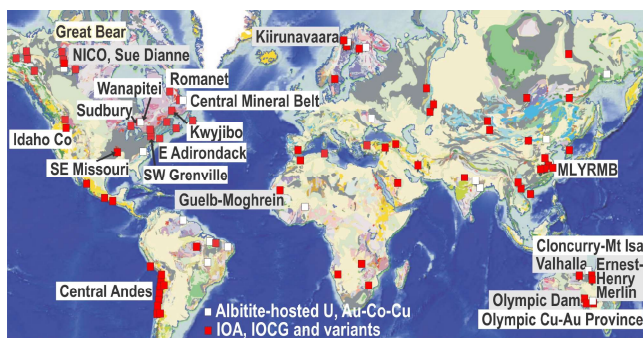


FIGURE 1. Location of case studies, deposits and districts cited in text (a larger and more detailed figure is available in Corriveau et al., 2022d). The Curnamona Province lies to the east of the Olympic Copper-Gold Province in the Gawler Craton. Deposits in the Mount Isa Province and Cloncurry district are shown in Figure 3 of Part 1 (Corriveau et al., 2022c). The Wanapitei district includes the Scadding Au-(Co-Cu-Ni) deposit (Schandl and Gorton, 2007; Corriveau et al., 2022b, c). MLYRMB: Middle-Lower Yangtze River Metallogenic Belt. A description of these deposits can be found in Porter GeoConsultancy (2021).