

# GEOCHEMICAL SIGNATURES OF METASOMATIC ORE SYSTEMS HOSTING IOCG, IOA, ALBITITE-HOSTED URANIUM AND AFFILIATED DEPOSITS: A TOOL FOR PROCESS STUDIES AND MINERAL EXPLORATION

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## Abstract

Iron oxide copper-gold (IOCG) deposits include a wide range of hydrothermal alteration types that intensely replace their host rocks. These deposits and affiliated deposits, notably iron oxide-apatite (IOA), IOCG, skarn, albitite-hosted uranium or Au-Co-U, and polymetallic vein deposits, form through prograde, tectonically telescoped, and cyclical metasomatic paths within regional-scale iron oxide and alkali-calcic alteration (IOAA) ore systems. From the roots of the systems at the base of the upper crust to the epithermal caps, these alteration types form distinct alteration facies that prograde from: 1) Na (albitite) and local skarn to 2) high-temperature Ca-Fe, 3) high-temperature K-Fe, 4) transitional K (brecciated felsite) and K-Ca-Mg (potassic skarn), 5) low-temperature hydrolytic K-Fe and Ca-Mg-Fe, and 6) epithermal alteration. Each alteration facies has a distinct chemical composition from which to assess system maturity and potential fertility. The best geochemical discriminants for each alteration facies are the Na-Ca-Fe-K-Mg molar proportions. In parallel, the proportions of (Si + Al) in lieu of Mg best discriminates IOAA systems from those hosting epithermal, porphyry, volcanogenic massive sulphide and sedimentary-exhalative deposits. Reporting molar barcodes of characteristic cations on the IOCG discriminant diagram yields a first-order identification of metasomatic processes that affect whole-rock composition and ore deposition.

In this contribution, we investigate the footprints of key metasomatic systems from Olympic Dam, Acropolis, Punt Hill and other systems of the Olympic Copper-Gold Province, as well as similar systems from the Great Bear magmatic zone, Romanet Horst, and Singhbhum Shear Zone. The footprints of these systems provide novel tools to discriminate least-altered rocks from metasomatites, assess alteration intensity and probable protoliths, follow the incremental alteration of a host at a specific alteration facies, characterize the sequential depth-to-surface development of intense alteration, and identify tectonically telescoped metasomatic paths. Metal contents vary significantly according to alteration facies, and can be used to record metal pathways from sources to deposits. The results provide innovative exploration vectors for IOCG and affiliated deposits, and the means to assess the mineral potential of prospective settings. In addition, distinct signatures emerge for each system, enhancing the ability to model and detect these mineral systems, particularly through the processing of large corporate databases.

## Résumé

Les gîtes à oxydes de fer cuivre-or (IOCG) comportent une large gamme de faciès d'altération hydrothermale qui transforment intensément les roches hôtes. Ces gîtes et leurs gîtes affiliés, notamment ceux à oxydes de fer-apatite (IOA),

IOCG, skarn, albitite uranifère ou à Au–Co–U, et veines polymétalliques se forment au cours de parcours métasomatiques progrades, télescopés, et cycliques au sein de systèmes minéralisés à oxydes de fer et altération alcali-calcique d'échelle régionale. De la racine de ces systèmes à la base de la croûte supérieure jusqu'à leurs toits épithermaux, ces types d'altération forment des faciès d'altération distincts qui évoluent de : 1) Na (albitite) et skarn local, 2) Ca-Fe à haute température, 3) K-Fe à haute température, 4) transitionnelle à K (felsite bréchifiée) ou K-Ca-Mg (skarn potassique), 5) hydrolytique à K-Fe ou Ca-Mg-Fe de faible température et 6) épithermale. Chaque faciès d'altération a des compositions chimiques distinctes à partir desquelles il est possible d'évaluer la maturité des systèmes et leur fertilité potentielle. Les compositions molaires en Na-Ca-Fe-K-Mg sont utilisées comme discriminants pour identifier les différents faciès d'altération. Les proportions molaires en silice et aluminium sont également utilisées pour discriminer les zones d'altération liées à des gîtes épithermaux, des porphyres, des sulfures massifs volcanogènes ou des systèmes sédimentaires exhalatifs. L'utilisation de ces compositions molaires au sein de codes-barres permet une visualisation rapide des différents processus métasomatiques affectant les différents encaissements.

Dans cette publication, les empreintes de systèmes métasomatiques clés de la Laurentie au Canada, du craton Gawler en Australie et d'autres exemples globaux sont décrits en utilisant des milliers d'analyses d'Olympic Dam, d'Acropolis, de Punt Hill et d'autres systèmes de la province cuivre-or d'Olympic ainsi que des données de la zone magmatique du Grand Lac de l'Ours, du Horst de Romanet et de la zone de cisaillement de Singhbhum en Inde. Les empreintes de ces systèmes fournissent de nouveaux outils pour discriminer les roches peu altérées et altérées, d'évaluer l'intensité de l'altération et la nature des protolites probables, de suivre le degré d'altération d'une roche hôte à un faciès d'altération spécifique, de caractériser le développement séquentiel depuis la profondeur jusqu'à la surface d'altération très intense et d'identifier les parcours métasomatiques télescopés tectoniquement. Les teneurs en métaux varient suivant le faciès d'altération et enregistrent les parcours métasomatiques des métaux de leurs sources jusqu'aux gîtes. Les résultats fournissent des vecteurs d'exploration innovants pour les gîtes IOCG et affiliés, et des moyens plus globaux pour évaluer le potentiel minéral de contextes d'exploration. De plus, des signatures distinctes émergent d'un système minéral à l'autre, améliorant les capacités de modélisation et de détection des systèmes minéralisés grâce au traitement de vastes bases de données.

## Introduction

Iron oxide and alkali-calcic alteration ore systems (IOAA), as defined by Porter (2010) and Corriveau et al. (2016), form through a self-propagating series of alteration facies each associated with or serving as host to distinct deposit types: iron oxide-apatite (IOA), iron oxide copper-gold (IOCG), skarn, K-skarn and albitite-hosted polymetallic deposits as well as their REE, Co, Bi, Mo, Re and U-rich variants (Corriveau et al., 2022a–e). The last decade of mapping and exploration of these mineral systems have greatly enhanced the understanding of their evolution and the range of deposit types they form as well as their global distribution and ages (Fig. 1; Hitzman et al., 1992; Barton and Johnson, 1996; Hitzman and Valenta, 2005; Williams et al., 2005; Chen, 2013; Wilde, 2013; Barton, 2014; Montreuil et al., 2015; Corriveau et al., 2016, 2018b, 2022c).

The alteration facies are defined by diagnostic mineral assemblages that show a progressive, systematic evolution from the roots of the IOAA systems to the paleosurface epithermal caps distal from heat sources (Corriveau et al., 2016). This systematic evolution is marked by significant changes in bulk-rock compositions from one facies to another (Fabris et al., 2013; Montreuil et al., 2013; Corriveau et al., 2022b; Fabris, 2022). Disruption to the prograde metasomatic path (e.g. heat or external fluid ingress to the main fluid plume) resets the physicochemical conditions of the fluid plume and results in permutations of the prograde alteration facies. Faulting can lead to telescoping or repetition of alteration facies and local disruption of the prograde sequence. The juxtaposition, overprinting, tectonic telescoping, renewal and retrogression of alteration facies can be identified and mapped using diagnostic chemical signatures (Montreuil et al., 2013, 2015, 2016a–c;

Corriveau et al., 2016, 2022a–d). Mineralization formed through prograde metasomatism consists first of IOA and local iron skarn deposits that mark the most intense development of magnetite-dominant high-temperature (HT) Ca-Fe alteration after early Na and HT Na-Ca-Fe alteration. Rare earth element (REE)-rich variants form within systems that were able to evolve to potassium-bearing facies. Other deposit types include: 1) cobalt-rich IOCG variants that are coeval with transitional HT Ca-Fe-K alteration; 2) magnetite-group IOCG deposits that form during HT K-Fe alteration; 3) polymetallic K-skarn and magnetite-to-hematite group IOCG deposits that form at the magnetite-to-hematite HT to LT transition during K-Fe alteration; and 4) hematite-group IOCG deposits that form at the LT K-Fe to LT Ca-Mg-Fe facies (Williams, 2010a; Corriveau et al., 2022c).

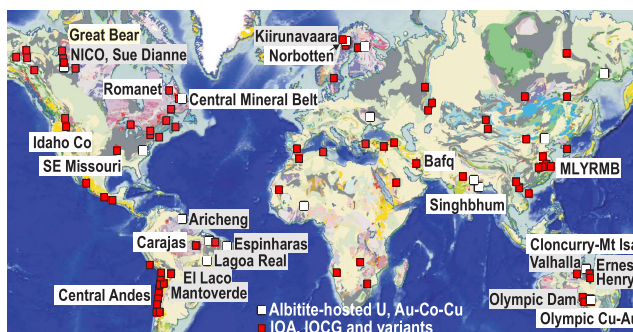


FIGURE 1. Distribution of IOCG, IOA and affiliated deposits (red squares) and albitite-hosted uranium deposits (white squares) (Williams et al., 2005; Corriveau et al., 2018b and references therein) on geological map of the world (Chorlton, 2007). MLYRMB: Middle-Lower Yangtze River metallogenic belt.