IOCG Deposits: A Cordilleran Perspective

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Abstract. During the latter part of the Phanerozoic, numerous iron oxide(-Cu-Au) (IOCG) systems formed in parts of the Cordillera of North and South America. They occur in diverse tectonic and magmatic settings with considerable variety in deposit associations and characteristics. Although there are general patterns, there is no simple, all-encompassing descriptive model; a comparison with the diversity of epithermal and other ore-forming systems is informative. Observations on many districts demonstrates that IOCG systems are clearly distinct in character and origin from magmatic hydrothermal systems (e.g., porphyries) although they may overlap in space and time. Ongoing field-based studies in Chile and the USA illustrate this spectrum of deposit styles and the overlap with other types. Useful predictive tools follow from the data and a sound understanding of geologic processes. Based on these results, Cordilleran IOCG systems result from voluminous flow of highly saline, metal-rich, sulfur-poor fluids in the upper crust. Typically, flow is magmatically driven and dominated by non-magmatic fluid sources. Unlike the case for typical porphyry Cu systems, concentration of Cu in IOCG systems requires favorable circumstances, notably an independent source of sulfur. In the Cordillera, overlap with marine volcano-sedimentary sequences may be a key contributing factor to Cu-Au productivity.

IOCG, American Cordillera, characteristics, genesis

1 Introduction

The nature and origin of iron oxide (-copper-gold) (IOCG) systems remains contentious (Williams et al. 2005). The extensive, relatively young IOCG-bearing terrains in the Cordillera of North and South America (Fig. 1) provide a useful framework for examining the diversity of IOCG systems, their regional geologic context, and their relationships to other types of mineral deposits. The Cordilleran region contains thousands of occurrences including a number of deposits that have been mined for various combinations of Cu, Au and/or Fe. Andean IOCG occurrences are predominantly Late Mesozoic (ca. 150-90 Ma) and Neogene (ca. 20-0 Ma) and occur in orogen-parallel belts coincident with coeval magmatism (Sillitoe, 2003). Southwestern North America contains at least three major episodes of IOCG-type mineralization: Jurassic (ca. 200-160 Ma), Laramide (ca. 80-50 Ma), and Neogene (ca. 25 Ma to present), all in broadly margin-parallel zones that are complicated by superimposed tectonism (Barton et al. 2000). These IOCG-bearing domains overlap with belts containing porphyry copper and allied styles of mineralization (Barton, 1996; Sillitoe, 2003). This contribution touches on this diversity, refers to recent work on IOCG systems in Chile and the USA (including nearby porphyry systems), and highlights the importance and outcomes of testing genetic hypotheses beginning with well-constrained field relationships.

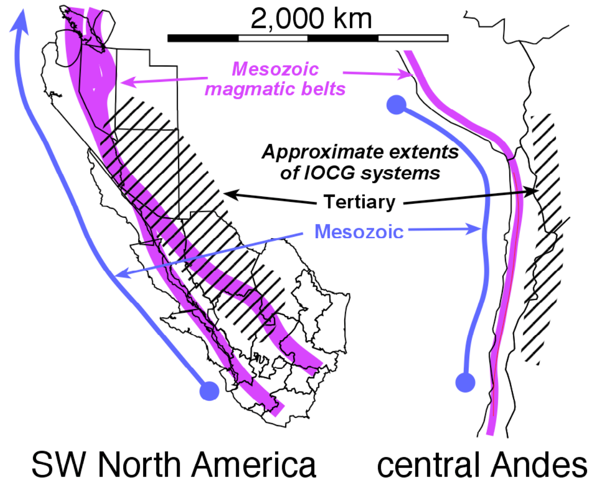

Figure 1. Extents of Mesozoic magmatism and Mesozoic and Cenozoic IOCG-bearing belts in North and South America. North America is shown on early Tertiary palinspastic base.

2 Diversity of IOCG Systems

Apart from the ubiquitous hypogene low-titanium iron oxides (magnetite and/or hematite) with anomalous–but not necessarily economic–contents of copper and gold, Cordilleran IOCG systems exhibit varied geometries and mineralogy similar to the diversity seen globally (Williams et al. 2005). Most are closely related in broadly coeval intrusive centers, likely exceptions being the "detachment" Cu-Au-hematite deposits of the southern Basin and Range province (Barton et al. 2000). Unlike porphyry systems in the same region, Cordilleran IOCGs lack a demonstrated intimate relationship to particular intrusive phases; rather they exhibit a diverse set of structural and stratigraphic styles of mineralization. These styles include stratabound disseminated and massive replacement bodies (mantos), discordant to semi-concordant breccias, (exo)skarns in carbonate rocks, a variety of veins, and even exhalative (Fe only?). All of these can extend over multiple kilometers in favorable cases. Dioritic intrusions are the most common associated igneous rocks, nonetheless coeval associated intrusive rocks vary from gabbros to granites and deposits show no systematic correlations with magmatic alkalinity or oxidation state.

Most Cordilleran IOCG systems are developed as part of the convergent margin tectonic regimes during the last 200 m.y., generally though not universally accompanying arc-related magmatism. Although they are perhaps most common in extensional or neutral tectonic settings linked to arcs, important examples on both continents of systems formed in compressional settings or rifting. In contrast to the tectonic and magmatic diversity, these systems universally formed in (semi-)arid belts that had or were permissive of saline basinal or surface-derived waters (i.e., evaporitic fluids).

Where adequate data are available in the third dimension (as is present in a number of districts), it is clear that these systems zone from relatively oxidized, commonly more sulfide- and acid- and/or K(Na)-rich assemblages at high levels to relatively reduced (magnetite-rich), sulfide-poor assemblages with extensive sodic(-calcic) alteration at depth. These observations are consistent with the generalized descriptive models for these systems (Hitzman et al. 1992; Barton and Johnson, 1996, 2000; see Fig. 2). Geological, geochemical, and petrologic data on unmetamorphosed systems indicate that these form in the upper 5 km of the crust from high-salinity (10-35 wt % NaCl equivalent), low CO_2, rock-buffered fluids.

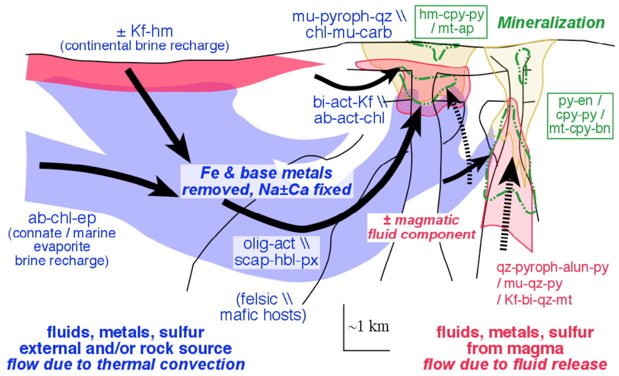

Figure 2. Conceptual model (Barton and Johnson, 2000) that contrasts igneous-related mineral deposits dominated by: (1) magmatic hydrothermal fluids (on right, = porphyry type) with (2) those dominated by non-magmatic (external) brines (on left, = IOCG type). Volumes and types of alteration vary in a predictable manner with fluid path and composition (e.g., heating vs. cooling [*cf.* Fig. 3], S-rich vs. S-poor). Plumbing systems and fluid driving forces will also differ. Hybrid districts featuring a mix of fluids, and system types, should be common (and are). External fluids and solutes will vary in composition, just as magmatic fluids do.

In some areas, IOCG systems form in the same regions as porphyry-type mineralization (SW US; coastal Chile) and their mutual features can be directly compared, for example, levels of formation, magmatic and aqueous fluid compositions, and nature of structural controls. In the Cordillera, IOCG belts pass through regional metamorphic domains (western US) or have superimposed brittle deformation and contact metamorphism (Chile, SW North America). In the effect of later events can be evaluated by comparison with nearby systems that lack the overprinting features.

3 Ongoing Field-based Studies

Ongoing field-based studies in Chile and the western USA highlights the diversity of IOCG environments, their contrasts with and relationships to other deposits

3.1 Coastal Batholith of Chile

The Copiapó area in the Atacama region of Chile is well known for the important manto and breccia style IOCG deposits of the Punta del Cobre and nearby districts as well as magnetite-apatite-actinolite-type IOCGs, and numerous small Cu-Au-rich vein systems (e.g, Marschik and Fontbote, 2001; Kreiner and Barton, this volume). Ongoing field and analytical studies demonstrate a complex, >50 m.y. history with multiple IOCG-type hydrothermal systems. These systems have compelling geochemical evidence for major involvement of non-magmatic fluids (Barton et al. 2005 and unpubl. data; Chiardia et al. 2006). These hydrothermal systems were generated by multiple, compositionally diverse phases of the Chilean coastal batholith. New deposit to transect-scale mapping demonstrates that alkali-rich (Na, Na(Ca), K, K(Ca)) hydrothermal alteration formed with all major phases of the coastal batholith and during early/pre-batholith volcanism (Barton et al. 2005 and unpubl. data). Porphyry-type and other demonstrably magmatic hydrothermal systems are present as well, but are restricted to only those plutons (quartz monzodiorite to tonalite/granodiorite) that petrological reasoning predicts produced significant water on crystallization.

3.2 Southwestern North America

Recent work on Jurassic and Laramide IOCG systems in the western US demonstrates their diversity and distinct differences from nearby, contemporaneous porphyry systems. This is particularly enhanced by the 3D exposures provided by middle Tertiary extensional faulting which has yielded cross sections through a number of such districts in Nevada and Arizona (e.g., Dilles et al. 2000; Johnson and Barton, 2000; Seedorff et al. 2008). What is seen in these and similar areas is that IOCG systems can form independently of any self-evident magmatic hydrothermal (e.g., porphyry) system (e.g., Humoldt Complex and Cortez Mtns, Nevada; Eagle Mtn and Palen Mtns, California; Buckskin-Rawhide Mtns, Arizona). In other districts, such as Yerington, Nevada and the northern Tortilla Mtns (Ray), Arizona, IOCG systems are genetically related to some of the same igneous centers that generated well developed porphyry and allied magmatic hydrothermal features, but the former distal to and clearly distinct from the latter. In these cases geological, geochemical and petrological evidence all clearly indicate a dominant role for external fluids in the IOCG systems, whereas the magmatic hydrothermal (mainly porphyry) systems exhibit features that are clearly consistent with cooling of magmatic aqueous fluids with or without involvement of minor amounts of external fluids.

4 Comparison with Other Ore Systems

The diversity of Cordilleran (and other) IOCG deposit geometries and controls, their presence and lateral extents in the uppermost crust, their varied igneous connections, and the evidence for a dominant presence of non-magmatic fluids (without excluding a magmatic contribution) provides an interesting parallel with many epithermal systems (high sulfidation Au(-Cu) deposits being an exception). Such patterns are the consequence of the diverse plumbing systems and drives for fluids in shallow terrestrial magmatic settings. Similarly, the abundance of "barren" IOCG deposits compared to the number that have economic quantities of Cu and/or Au suggests a parallel with basin-related Cu and Zn-Pb hydrothermal environments where potentially productive fluids may be present, but scarcity of effective traps makes deposits relatively unusual.

5 Testing Predictions

Building on their earlier work, Barton and Johnson (2000, 2004) argued that there are predictable, systematic differences between alternative genetic models for IOCGs, as compared to porphyry systems (Fig. 2, Fig. 3), and that these can be directly tested by geological observation and other tools. Magmatic-hydrothermal systems should show close geological and geochemical links to particular intrusions and intrusive compositions; they should be relatively insensitive to other local factors. In contrast, systems where external brines dominate will require appropriate fluid sources, suitable plumbing, but would be relatively insensitive to magma type (or even magma presence). Care must be taken in interpreting geochemical data (e.g., isotopic and halogen ratios), as they are often amenable to multiple interpretations in the absence of other constraints.

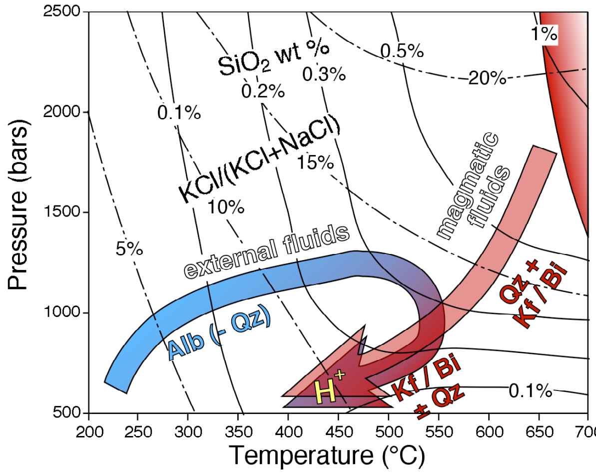

Figure 3. Pressure-temperature diagram showing alternative fluid-flow paths and their metasomatic consequences. Saline aqueous fluids exsolved from most magmas will create quartz-bearing potassic alteration as they initially cool, and then create more acid types of alteration. In contrast, warming brines will create sodic(-calcic) alteration and will remove silica (and many metals). See Barton and Johnson (1996, 2000) and Seedorff et al. (2008) for discussion.

One of the most powerful and yet straightforward approaches is to combine robust field observations (mapping of the time-space distribution and volumes of hydrothermal alteration) with petrologically sound interpretations of the possible origins of different types of alteration (see Fig. 3; Barton and Johnson, 1996, 2000). Consideration of mass balance (based on volumes of alteration and metasomatic changes), geologic setting (diversity and links to igneous rocks, availability of different types fluids), and possible traps for metals (cooling, wall-rock reaction, availability of sulfur for chalcophile metal precipitation) leads to the conclusion that in many IOCG systems, and certainly in most Cordilleran examples, the predominant fluid source is a non-magmatic brine, metals can be principally or solely sourced from rocks along the flow path of this fluid (as they are in some other types of ore-forming system), and trapping of metals to make Cu(-Au)-rich deposits will be selective and a function of the available of sulfur from an additional source.

In the case of the Phanerozoic Cordillera, the pre-eminent Cu-Au belt is that of coastal Chile and Peru. This area, unlike the other Mesozoic domains, overlaps extensively in time and space with variably evaporite- and organic-bearing volcano-sedimentary basins – a juxtaposition that should have been favorable for traps.

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