Multiple igneous-related hydrothermal systems and related IOCG mineralization, near Copiapó, Chile

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Abstract. The composite, Early Cretaceous Copiapo batholith and adjacent, broadly coeval volcanic rocks host many IOCG systems notably Candelaria and the Punta del Cobre district. New geologic mapping (>200 km²) and U-Pb geochronology has elucidated the character and time-space development of hydrothermal alteration and its relationship to a complex igneous history. These observations demonstrate that each magmatic center generated its own hydrothermal system with voluminous sodic-calcic (Na-Ca) associations and variable, but widely recognized K-silicate suites. Shallow hydrolytic alteration is common. Hydrothermal characteristics correlate with the composition of coeval magmas. Na-Ca (± Ca) is most intense with dioritic rocks and weakens inward from intrusive margins. Consistent with petrologic predictions, intrusion-hosted K-silicate styles vary: widespread K-Ca (+ local hydrolytic) relates to upflow (cooling) of Na-Ca fluids; rarer, week porphyry-like K-Si reflects cooling of magmatic fluids and forms only with felsic plutons; stratabound types might reflect recharge. Lab studies show that magmas were calcalkaline, mantle-dominated, and emplaced in the uppermost crust. Most exsolved little fluid yet all circulated voluminous external brines (δ7Sr/δ6Sr). Questions remain about metal sources and traps, however similar patterns in many Cordilleran and global IOCG districts suggest a common genesis.

Keywords. IOCG, alteration, Candelaria, Punta del Cobre, zoning

1 Introduction

Three distinct hydrothermal origins have been proposed for IOCG deposits reflecting fundamental differences in fluid, material, and energy sources: (1) materials and fluids expelled from intrusions presumably of distinctive character; (2) non-magmatic brines circulated by magmatic or other heat sources deriving materials along the flow path; (3) fluids generated from atypically Cl-rich rocks during metamorphism (Barton and Johnson 2004; Williams et al. 2005). This paper highlights some geologic and a few geochemical results from a multi-year, multi-part study designed to test these ideas (and aid exploration) in the well exposed and well preserved IOCG cluster in the Candelaria-Punta del Cobre region, near Copiapó, Chile (Fig. 1). Past and ongoing studies have documented numerous vein, manto and breccia style deposits hosted in Late Mesozoic volcanic rocks and rocks of the adjacent Copiapo Batholith (Fig. 1; e.g., Segerstrom and Ruiz 1962; Marschik and Fontboté 2001; Kreiner and Barton this volume).

New mapping, petrology, geochemistry, and geochronology have focused on determining the character and distribution of hydrothermal alteration, its timing with respect to multiple magmatic and structural events, the temporal and spatial evolution within individual systems, the conditions of alteration, the sources and drives for hydrothermal fluids, and an evaluation of controls on Fe and Cu-Au mineralization. These are motivated by the fact that in a well-exposed, geologically varied system such as that near Copiapó, it should be possible to test the multiple hypotheses regarding the origin of IOCG systems – such as the role of contrasting fluid sources that make fundamentally different predictions about the hydrothermal features (Barton and Johnson 1996, 2000, 2004). The pyroxene diorite to biotite monzodiorite to granodiorite spectrum in the area (Fig. 1) was expected – and found – to have fundamentally different relationships among alteration types.

Figure 1. Copiapó Batholith and Location Map. Inset of northern Chile showing the Copiapó region. Copiapó Batholith map showing plutonic units (highlighted), supracrustal rocks, and principal mining districts. La Brea diorite = brown; San Gregorio monzodiorite = pink; Los Lirios tonalite = flesh. Geologic map compiled from Tilling (1963) and Arevalo (1999) as modified by our new mapping.

2 Character and time-space distribution of hydrothermal alteration

Figure 2 shows the generalized distribution of hydrothermal alteration and its time-space development with respect to magmatism. Ca-rich assemblages are extensively developed near the border of the batholith; the carbonate rocks host andradite-dominated skarn whereas the edges of the large intrusive units have calcic...
Figure 2. Maps (a-d) showing generalized distribution of hydrothermal alteration at the current surface based mainly on new mapping – see Fig. 1 for the geologic framework; (e) simplified time-space relationships for magmatism and hydrothermal alteration projected along a WNW-ESE transect (times based on published data and new U-Pb work by our group); and (f) spatial distribution of initial strontium isotope ratios and calculated percentage of non-magmatic strontium for unaltered igneous and sedimentary rocks and hydrothermal alteration within the batholith and adjacent rocks.
A variety of sodic-calcic (Na-Ca) assemblages are present throughout much of the batholith and are common in the adjacent volcanic rocks. (Fig. 2b) These are dominated by combinations of sodic plagioclase, scapolite, actinolite, titanite and, locally, (in upwelling zones?) magnetite. Na-Ca alteration is most intense in the more mafic (and drier) intrusive phases near the sides or, more rarely, along the tops of individual intrusive units. Lower-T albite-intrusive phases near the sides or, more rarely, along the alteration (~endoskarn; Fig. 2c) where they are commonly overprinted by other types of alteration.

As with Na-Ca, K-silicate and hydrolytic assemblages are varied and widespread; both groups tend to be more common at higher structural levels whether within veins or widely distributed. Three groups of K-silicate alteration are present (Fig. 2c). Intense stratabound K-silicate alteration is widespread in the Early Cretaceous volcanic rocks where it takes the form of disseminated biotite or K-feldspar; it overlaps but is not confined to the areas with IOCG mineralization (Fig. 1, 2c; Marschik and Fontboté 2001). High-T (Bi-Qz±Kf, Kf-Qz-Tur) veins are restricted to the more felsic plutons. Weak porphyry Cu-style K-alteration occurs with Los Lirios tonalite dikes and contacts, whereas Cu-absent Qz-Kf-Tur veins and mioralitic cavities typify parts of the Qz-Bi-Px monzodiorites. Lower-T, vein-related K-silicate alteration is common in the IOCG veins in the batholith (Kreiner and Barton this volume), and in analogous settings in the volcanic rocks (Marschik and Fontboté 2001). These transition into chloritic, sericitic, and local advanced argillic types of hydrolytic alteration (Fig. 2d; see Kreiner and Barton, this volume). The most intense acid alteration is localized in structures or porous strata.

The spatial distribution of alteration and many cross-cutting relationships show that each of the major intrusive events generated its own hydrothermal system as summarized in the time-space diagram (Fig. 2e). Each episode, beginning with the Early Cretaceous volcanic sequence (Punta del Cobre Fm) generated significant alteration and at least some mineralization. Our field work indicates that the most intense IOCG mineralization events were associated with the more mafic episodes, including pre-batholith andesitic intrusions in the Punta del Cobre area. IOCG styles are present with the monzodiorites and tonalites, but are weakly developed and overprint the high-T K-silicate features. New mapping along an E-W transect across the full coastal batholith (~80 km) shows that similar patterns occur throughout this trend (Barton et al. 2010).

Barometry and structural reconstructions indicate depths of at most a few km at the time of formation; conditions consistent with the widespread (nearly ubiquitous) presence of moderately saline (ca. 20-50 wt.% NaCl equiv.) and CO2-poor, vapor-rich fluid inclusions. Although numerous isotopic studies have been performed in the area, Sr isotopes (Fig. 2f) provide one of the key insights because among those systems examined these clearly distinguish magmatic from external (basinal) reservoirs. Our recent results in the batholith and aureole (Fig. 2f) show that the IOCG systems have considerable non-magmatic Sr; a result compatible with the results of Chiaradia et al. (2006) on the volcanic-hosted deposits.

3 Implications

The geologic (and geochemical) results summarized here show that repeated emplacement of varied calc-alcaline, indeed rather primitive magmas can generate IOCG-related hydrothermal systems including some with major economic deposits. There is no evidence for either special (e.g., alkaline) magma types or other unusual (e.g., enriched) sources. Moreover, the only intrusions in this area, of the many examined, that generated (consistently) unequivocally magmatic hydrothermal features are just those for which such systems would be expected – relatively felsic and water-rich. Conversely, the volumes of alteration, the zoning controlled by contacts, stratigraphy, and structure, and the non-ambigous geochemical and petrological evidence all point to a major involvement of external fluids. These types of observations, along with evidence and geochemical reasoning that make an evaporitic (external brine) source plausible for many IOCG systems (Barton Johnson, 1996, 2000), and most important testable, especially in well preserved and exposed terranes such as those of the American Cordillera.

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