IOCG systems: just a problem of ore traps

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Introduction

IOCG mineralization *sl* encompass a wide range of, dominantly replacive, hydrothermal deposits that share the presence of iron oxides (magnetite and hematite), actinolite, and alkali feldspars along with variable amounts, if present, of chalcopyrite and gold. Hydrothermal alteration, relationships with igneous rocks and structures or origin of fluids seem to vary between districts. Genetic hypotheses include derivation of fluids from the crystallization of underlying intermediate-mafic igneous rocks (Pollard, 2006; Tornos et al. 2010) and convective circulation of basinal brines (Barton et al. 2006). Some studies emphasize the relationship with magnetite-(apatite) rocks and propose that magnmetite-(apatite) rocks and IOCG mineralization are part of the same magmatic hydrothermal system (Sillitoe, 2003). However, magnetite-(apatite) systems are found worldwide but only in some districts (Andean Coastal Cordillera, Carajas and Cloncurry) they coexist with IOCG mineralization.

Our worldwide study shows that the, so called, IOCG style of mineralization deposits embrace a wide range of hydrothermal systems. The mineralization formed by: (a) reaction with previous magnetite-(apatite) rocks and other ironstones; and, (b) skarn-like stratabound replacements of Si-Al-Ca-rich rocks (usually volcanic) with a zonation from feldspar + actinolite ± biotite to actinolite/biotite-rocks when in mafic rocks and feldspar-tourmaline when in felsic rocks; feeder structures include both faults and shear zones that channelize magmatic-hydrothermal fluids till interaction with reactive and permeable favorable rocks.

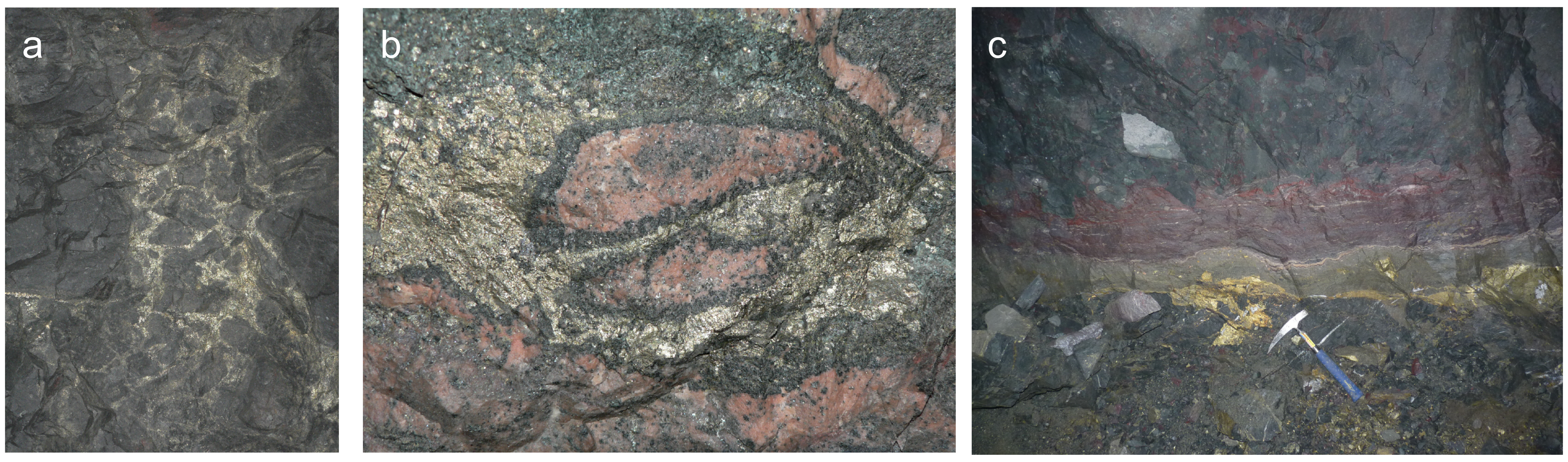

Fig. 1. IOCG systems replacing volcanic rocks. (a) Feeder zone in highly altered (actinolite-rich) volcaniclastic andesite. Alcaparrosa Mine. (b) Zoned alteration with albite + actinolite + magnetite, actinolite + magnetite and chalcopyrite + magnetite. Alcaparrosa Mine. (c) Uppermost contact of stratabound mineralization along the tectonic contact between highly altered and mineralized volcaniclastic breccias and overlying massive andesite. Carola Mine. Punta del Cobre district (Chile).

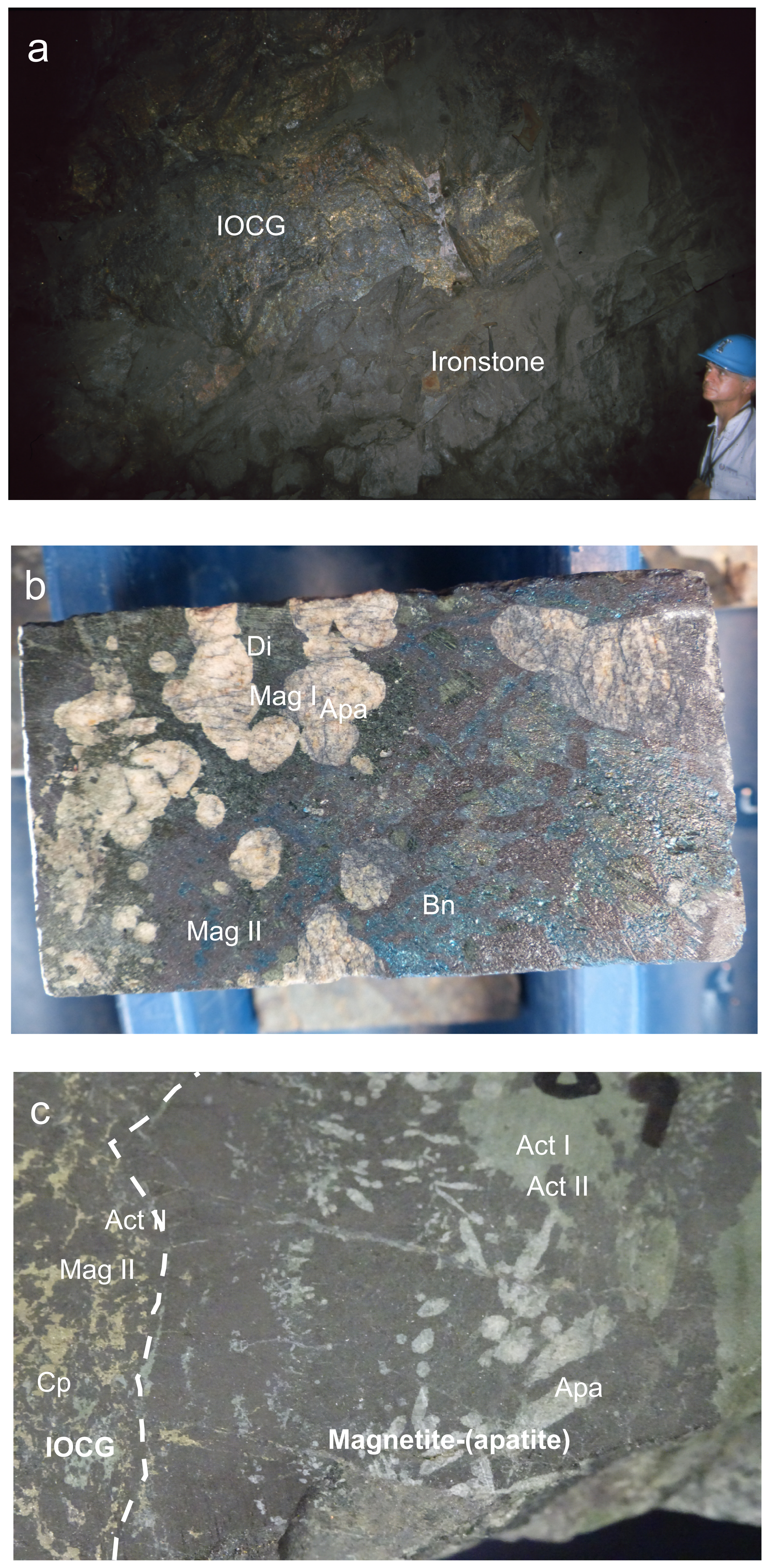

Fig. 2. Relationships between ironstones and IOCG systems. (a) Cu-rich mineralization replacing stratiform ironstone. Osborne Mine (Australia). (b) Magnetite-fluorapatite-pyroxene pegmatite replaced by stratabound bornite-rich IOCG mineralization. Mina Justa (Peru). (c) Magnetite-fluorapatite-actinolite pegmatite crosscut by later IOCG mineralization. Montecristo Mine (Chile).

Fluid geochemistry and ore precipitation

Most IOCG deposits formed by fluid-rock interaction of hydrothermal fluids with ironstones and permeable-reactive Ca-Al-rich rocks (andesite and calc-silicate hornfels). Ore forming fluids are reduced, high temperature (ca. >400°C) and alkaline and form the IOCG system at rather high rock/fluid ratios.

Theoretically, reaction of hydrothermal fluids with a previous ironstone destabilizes Cu-Au-bearing complexes and can precipitate Cu-(Au) mineralization. However, reaction with intermediate-felsic volcanic rocks is not as efficient since is not able to produce a significant change in fO_2 and pH. We postulate that fluid mixing with a reduced basin-derived water stagnant in a confined aquifer is a necessary mechanism for ore formation in the mineralization replacing Ca-Al-rich rocks, something consistent with the radiogenic isotope systematics and the presence of anhydrite and "mushketovite".

Fig. 3. Magnetite-(apatite) system crosscut by ca. 80 My younger shear-zone related IOCG mineralization. Levaniemi open pit, Kiruna.

Geochronology and Radiogenic Isotope Geochemistry

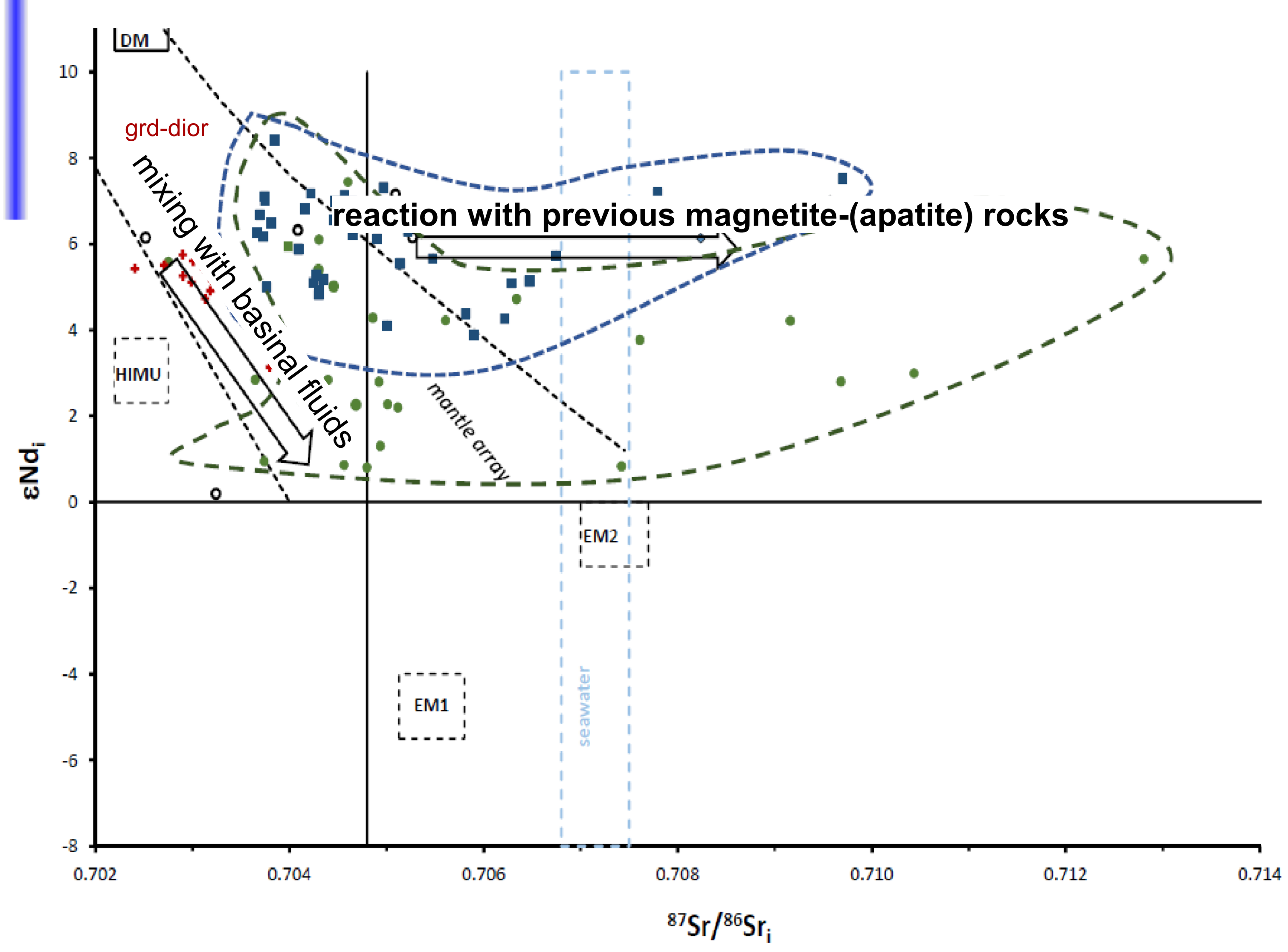

Fig. 4. Sr-Nd geochemistry of magnetite-(apatite) and IOCG systems in the Coastal Cordillera of the Andes

At the Coastal Cordillera of the Andes, the Sr-Nd isotope data (Fig. 4) are compatible with the interaction of magmatic-hydrothermal fluids derived from the crystallization of granodiorite-diorite (ca. 118-110 Ma; Marschik and Söllner, 2006) with previous magnetite-(apatite rocks) or andesite from the early Mesozoic magmatic arc.

The most negative εNd_i signatures (<4) likely track mixing of magmatic-hydrothermal fluids with sedimentary brines equilibrated with crustal sources while the highly radiogenic $^{87}Sr/^{86}Sr_i$ ratios (up to 0.7128) are interpreted as inherited from the ironstones.

Conclusions

Our hypothesis is that "IOCG" systems include a wide variety of styles of replacive mineralization that form in relationship with any magmatic-hydrothermal system associated to intermediate intrusives and do not need an special geodynamic scenario for its formation. They form during the reaction of the deep fluids with previous ironstones or andesite-calc-silicate hornfels, likely assisted by mixing with oxidized and cooler fluids.

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