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Relationships between very low-grade metamorphism and Cu-stratabound ore deposits in the Coastal Range of central Chile

Salvador Morales [1], Mauricio Belmar [2], Diego Morata [2], Javier Carrillo [1], Katherine Hasler [2], Luis Aguirre [2], & Purificación Fenoll [1]

[1] Departmento de Mineralogía y Petrología, Facultad de Ciencias, Universidad de Granada, Avda. Fuentenueva, s/n, 18002 Granada España; smorales@ugr.es
[2] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile.

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Introduction

One of the large copper concentrations of the Earth is located in the Chilean's Andes, with numerous Cu-bearing mineralizations in the Jurassic and Lower Cretaceous volcano-sedimentary sequences in the Coastal Cordillera of Chile. In central Chile, the Lower Cretaceous conforms an almost continuous ≈1200 km north-south trending (from 25°20' to 35°40'S) and narrow (≈30 km average) belt, with average thickness of 3-5 km. The Lower Cretaceous units are represented by thick volcano-sedimentary sequences of bi-modal lavas (mostly acidic at the bottom and basic and subareal lavas at the top) with marine sedimentary rock intercalations (*e.g.* Vergara et al., 1995; Aguirre et al. 1999). Some Cu stratabound deposits occurs hosted in these volcano-sedimentary sequences.

Most of the ore deposits in the Andes have an hydrothermal origin, showing a temporal relationship with the magmatic activity, being most of the metallic content derived from subduction-related processes. Meanwhile, a wide range of genesis for the Lower Cretaceous stratabound Cu deposits, ranging from volcanogenic to fluid related with crustal thinning and low-grade metamorphism or fluid derived from granitoid plutons, have been found (see recopilation of Maksaev & Zentilli (2002) and references therein).

In this work we have selected three volcanogenic massive deposits (from south to north: Melipilla, Lo Aguirre and La Serena -Talcuna mining district-) hosting in Lower Cretaceous volcanic rocks from the Coastal Range in central Chile. The aim of this study is to search common (and distinctive) characteristics that could inform us about the relationship between mineralizations and magmatism, regional alteration (low-grade metamorphism) and local (=hydrothermal) alteration.

Cu stratabound deposits

Copper and Cu(-Ag) mineralisation (Carrillo Rosua et al. 2004) has been found at the Melipilla area hosting in carbonates from *Lo Prado Formation (Upper Berriasien-Hauterivien)* as well as in andesites and basaltic andesites from the lower part of the *Veta Negra Formation (Hauteriviense-Barremiense)* According to these authors, two different mineral associations can be observed:

(i) Chalcocite and bornite intergrowths usually exhibiting a mirmekitic texture (Fig. 1a), sometimes with a covellite rim, with quartz, prenhite, pumpellite and minor chlorite, calcite and epidote as associated gangue

minerals (Fig. 1b). This silicate paragenesis is typical of the very low-grade prenhite-pumpellyite metamorphic facies.

(ii) Massive chalcopyrite and pyrite (coarse-grained and framboidal) as major phases (Fig. 1c), with fahlore, sphalerite, galena, arsenopyrite, marcasite and cobaltite minor phases, postdating the first type. The deduced ore paragenetic sequence is: arsenopyrite + pyrite + marcasite + cobaltite ⇒ chalcopyrite + sphalerite + fahlore + galena ⇒ fahlore + sphalerite. In this second type, the gangue mineralogy consists mainly in calcite + phyllosilicates with minor quantities of quartz and chalcedony.

In the Lo Aguirre area, copper mineralization is hosted in volcanic (dacites and andesites) and volcaniclastic rocks from the lower units of the *Veta Negra Formation*. Pyrite, chalcopyrite, bornite, chalcocite and covellite conforms the main sulphide ores, being chlorite, carbonate, quartz and phillosylicates. Prenhite and pumpellyite has been also found. As in the previous case, this silicate association is typical of the prehnite-pumpellyite metamorphic facies.

Finally, Cu-Ag mineralisation in the La Serena -Talcuna mining district- appears as disseminations in volcanic rock of the *Quebrada Marquesa Formation* (Upper Barremian-Albian) as well as in veins, bands, or fillings vacuole, spatially associated with hydrothermal alteration of the host rock (Carrillo et al. 2003). According these authors, the main mineralisation consists of bornite and chalcopyrite, with significant quantities galena, sphalerite and fahlore (Fig. 1d). Ag-Cu sulphides, cobaltite and hematite have also been found as accessory minerals. The most abundant gangue minerals are calcite, barite, albite and sericite. Moreover, another mineral association characterized by bornite-chalcocite intergrowth with a symplectitic texture similar to first mineral association described in the Melipilla area is detected, showing common intergrowths of sulfides with prenhite crystals from vacuoles in volcanic rocks (Fig. 1e). Native copper and not-defined Cu-silicates are also present as small inclusions in prehnite crystals (Fig. 1e).

Discussions and conclusions

Textural relationships showed in the three studies area indicate a genetic relationships between very low-grade metamorphic minerals and some Cu-sulphide ores. P-T conditions of this very low-grade metamorphism can be established based on the P-T grid proposed by Frey et al (1991). In this sense, values of P ≈ 2-3 kbar and T = 200-280°C could be proposed for this metamorphism. In this sense, Morata et al. (2003) describe the presence of a regional pervasive and non-deformative very-low grade metamorphism in Lower Cretaceous volcanic rocks from the La Serena area, founding low-P conditions and temperatures close to 250°C. This metamorphism transforms primary plagioclase crystals into albite and sericite and neoforms prenhite, pumpellyite, chlorite and epidote mostly in open spaces and in the groundmass of these volcanic rocks.

The paragenetic sequence observed in the Melipilla area, with two mineralisation events, could be generalized to the other two areas and, probably, to the rest of the Lower Cretaceous belt in the Coastal Range of central Chile. In this case, the petrographic relationships showed in this paper indicate that typical calc-silicates forming during regional very low-grade metamorphism as prehnite and pumpellyite are paragenetic with some Cu-bearing minerals (see figs 1b, c and f). According our results, Cu-bearing phases can be them considered as another metamorphic mineral (mineral assemblage), being the Cu origin probable in relation with mobilisation from host rock. Nevertheless, a local hydrothermal event (probably related with granitoid intrusions) is necessary

to concentrate mineralization to produce an ore deposit. The evolution of these hydrothermal fluids produces the formation of "hydrothermal"-type mineralization with textural differences with respect to the previous "metamorphic"-type mineralization.

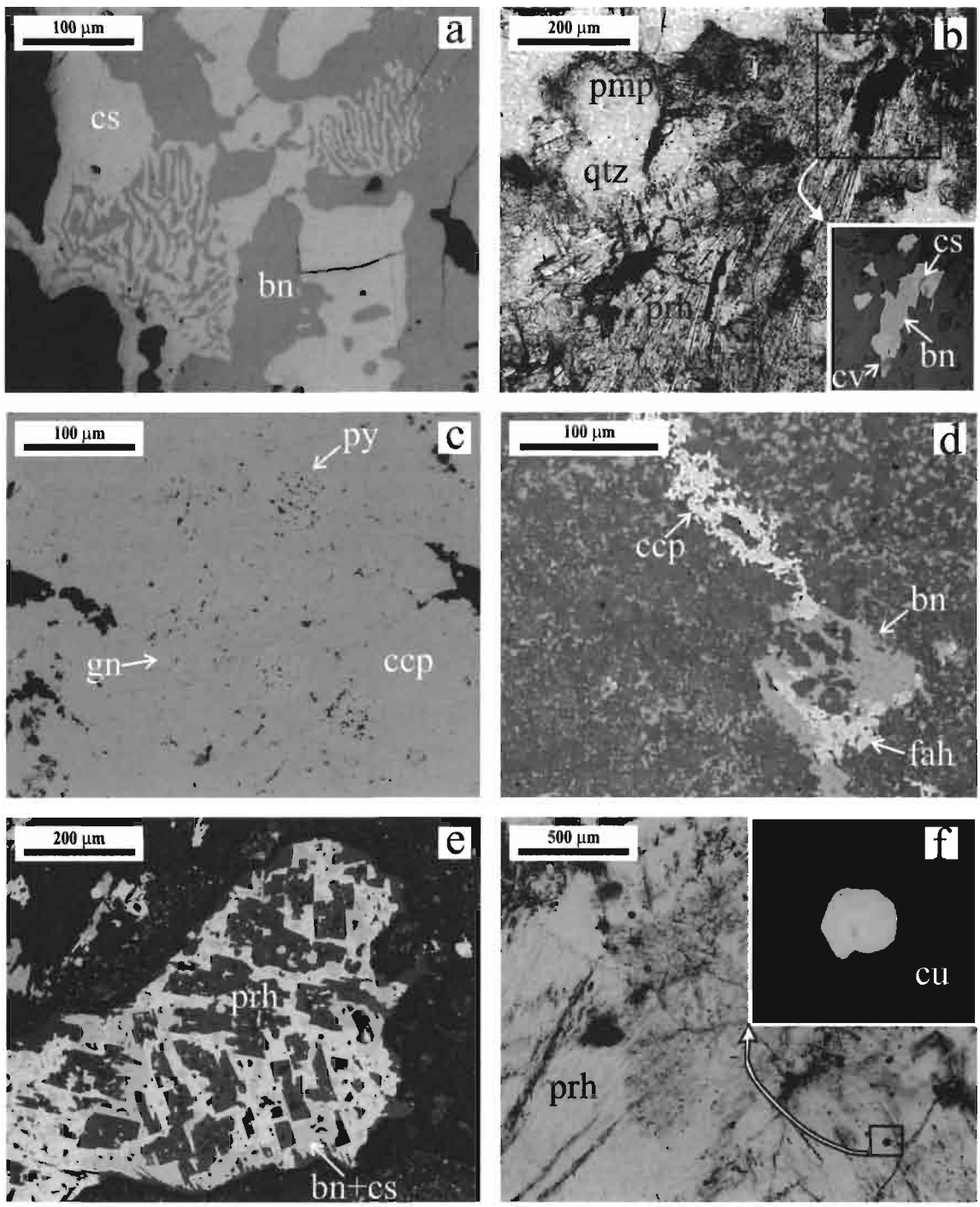

Figure 1. (a) Simplectitic intergrowing of bornite (bn) and chalcocite (cs) from Melipilla Cu(-Ag) deposits. (b) Sulfides intergrowing with prenhite (prh) and pumpeliiyte (pmp) from Melipilla Cu(-Ag) deposits. (c) Massive chalcopyrite (ccp) with framboidal pyrite (py) and galena (gn) from Melipilla Cu(-Ag) deposits. (d) Bornite (bn), chalcopyrite (ccp), overgrowth by fahlore (fah) from La Serena Cu-Ag deposits. (e) Intergrowing of bornite + chalcocite (bn+cs) with prenhite (prh) from La Serena Cu-Ag deposits. (f) Inclusion of native copper (cu) in a prenhite (prh) pocket in the very low-grade metamorphosed volcanic rock of the La Serena mining district.

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