

LETTER

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The Candelaria (Cu-Fe-Au) and Punta del Cobre (Cu-Fe) deposits (Copiapó, Chile): a case for extension-related granitoid emplacement and mineralization processes?

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Abstract The Lower Cretaceous volcanic formations of Copiapó (Chile) host major stratiform, disseminated, vein, and stockwork mineral deposits. Among these are the Punta del Cobre district (Cu-Fe) and the neighbouring, large Candelaria deposit (Cu-Fe-Au). These deposits are likely to have formed during a major extensional event that was accompanied by granitoid emplacement that triggered important contact metamorphism, metasomatic activity and mineralization processes. We suggest here that alteration-mineralization processes developed within the upper-plate domain of a NNE-trending, ESE-dipping extensional system, while granitoids were accommodated within the lower-plate. If this model prove to be right, 'Candelaria-type' deposits may be hidden beneath the present, higher structural position of the Punta del Cobre district.

Introduction

The Copiapó region of Chile is one of the richest in terms of mineral deposits. The Lower Cretaceous Formations host major deposits and districts of copper, iron and silver. The zone, famous for the presence of the Punta del Cobre (Cu-Fe) (Fig. 1) and Chañarcillo (Ag) districts, gained new attention in the 1980s due to the discovery of the large Candelaria deposit (Fig. 1), a complex Cu-Fe-(Au) mineralization containing about 370 Mt of minable reserves at 1.08% Cu and 0.26 g/t Au. Some 5 km to the east of Candelaria lies the Punta del Cobre district (Fig. 1), which has recorded mining activity since the early 19th century. Although a genetic connection

between Candelaria and Cretaceous granitoids seems likely, the origin of Punta del Cobre has been a matter of debate. We offer a model which relates both cases of mineralization in terms of the emplacement of granitoids under extensional conditions. The model accounts for the structural position of these deposits, and opens new insights for mineral exploration in the zone.

Geology

The Chañarcillo Group (Berriasian?-Aptian) (Fig. 1), hosting the Punta del Cobre, Abundancia, Nantoco, Totoralillo, and Pabellón Formations, comprises about 4500 m (maximum thickness) of volcanic rocks, limestones and minor intercalations of shales and cherts (Seegerstrom 1968). The Punta del Cobre Formation hosts the Candelaria (Cu-Fe-Au) deposit and the Punta del Cobre district (Cu-Fe). This Formation comprises volcanic and volcanoclastic rocks, and sediments, and is subdivided into the following units (Pincheira et al. 1994; Marshick and Fontboté 1996) (from base to top): (1) the Lavas Inferiores (lower lava flows), of andesitic composition; (2) the so-called Albitófiro, fine-grained, highly altered dacitic rocks; (3) the A and B horizons, breccias and silica sinters; (4) the Trinidad Member, cherts and carbonate intercalations; and (5) the Lavas Superiores (upper lava flows) of basaltic and basaltic/andesitic composition. Mineralization at the Punta del Cobre district is found in the Lavas Inferiores, the Albitófiro, and within horizons A and B.

Mpodozis and Allmendinger (1993) were the first to recognize the full importance of extensional processes in the Copiapó region, where they described a major extensional event of Aptian-Cenomanian age. This event was characterized by the development of regional-scale, low-angle extensional detachments that led to a chaotic array of allochthonous tectonic blocks (the so-called Chaos of Puquios; Mpodozis and Allmendinger 1993). Extensional processes are not restricted to the Puquios area only (50–60 km to the NE of the study zone), but extend well into the Candelaria zone, where a series of low-angle detachment surfaces are now recognized (Ryan et al. 1995). These are possibly the SE expression of the extensional systems described in Puquios. Further evidence regarding extensional processes in the Candelaria-Punta del Cobre zone is provided by the emplacement of granitoid bodies, which was controlled by a major NNE-trending, extensional fault (Martin et al. 1997), which is part of a large NNE-trending, east-dipping detachment system.

The granitoids (Fig. 1) belong to the so-called Ojanco-Los Lirios batholith (K/Ar: 109.6 ± 1.7 Ma, hornblende; Farrar et al. 1970). The plutonic history was complex, initiating with the emplacement of dioritic bodies and ending with felsic, granitic facies (Tilling 1976). The emplacement of these rocks induced important contact metamorphism in the Chañarcillo Group, generating a wide (~2.5 km) NNE-trending band of hornfels rocks, i.e., the TKc

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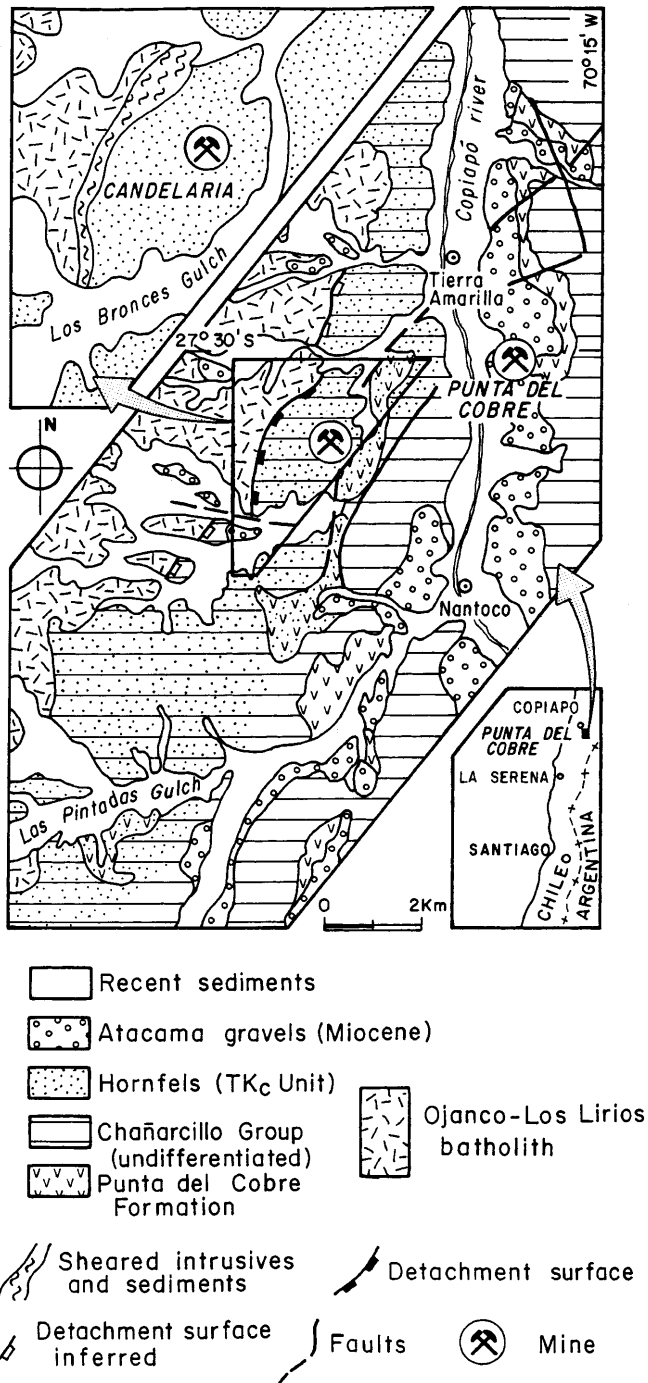


Fig. 1 Geological map and location of mineralizations (modified after Segerstrom 1968; Marshick and Fontboté 1996; Martin et al. 1997). See inset (top left) for a closer view of the sheared rocks at the tectonic contact between the Chañarcillo Group (TKc unit) and the Ojanco-Los Lirios granitoids. (Simplified after Ryan et al. 1995)

unit of Segerstrom (1968), which partially coincides in space with a mylonitic shear zone (Fig. 1).

Ore deposits

Although Candelaria is located within the TKc unit, the rocks hosting the deposit can be truly regarded as Punta del Cobre For-

mation volcanic facies that underwent deformation, contact metamorphism and metasomatism during the tectonic emplacement of the Ojanco-Los Lirios granitoids (Martin et al. 1997). The Candelaria deposit (Ryan et al. 1995) hosts 366 Mt of copper (1.08%), gold (0.26 g/t) and iron ores that occur as veins, breccia fillings, and disseminations. The paragenesis includes magnetite, chalcopyrite, gold-rich electrum, and pyrite. According to Martin et al. (1997), mineralization-alteration processes began with the extensional emplacement of granitoids, which triggered early, deep ductile deformation and a wide aureole of hornfels rocks, biotitized metavolcanic rocks and marbles. Part of the ore is associated with foliation and formed during this event. Later magmatic differentiation processes in the granitoids were accompanied by the introduction of the main stage of economic mineralization. The Punta del Cobre District (Camus 1980; Pincheira et al. 1994, 1997; Marshick and Fontboté 1996; among others) comprises a diversity of mineralization styles including veins, stratiform orebodies, and stockworks, hosted by andesites, Albitófiro facies, and breccias of the Punta del Cobre Formation. The district consists of 14 mines (Camus 1980), although only a few are presently in production. Production during the period 1800–1975 amount to some 3.5 Mt, with an average grade of 6% Cu. Present grades, however, are much lower (e.g., 1.5% Cu; Flores 1997). Main minerals are chalcopyrite, pyrite, magnetite and hematite. In contrast to Candelaria where mineralizing processes can be related to the intrusion of the Ojanco-Los Lirios granitoids, at Punta del Cobre the origin of mineralization has been a matter of debate. Although for a long time the district was thought to be of the exhalative type, formed under submarine conditions (e.g., Camus 1980), later studies (e.g., Marshick and Fontboté 1996; Rabbia et al. 1996; Pincheira et al. 1997) have revealed a deeper origin related to the emplacement of hidden plutonic rocks, probably belonging to the Ojanco-Los Lirios batholith.

Proposal of a model

Syntectonic emplacement of granitoids within extensional detachment scenarios is now a well-constrained phenomenon, and many examples have been reported from the US Basin and Range and elsewhere (e.g., Gans et al. 1985; Doblas et al. 1988; Rehrig 1986; Lister and Baldwin 1993). The process involves liberation of water from the ascending intrusive bodies, fluid-induced strain softening, and hydrothermal alteration (e.g., Rehrig 1986). Equivalent processes may have played a key role in the development of the Candelaria-Punta del Cobre mineralizing system (Fig. 2). We may summarize the evolution of events for Candelaria in terms of the following simplified scheme: (1) extensional emplacement of granitoids along an extensional detachment, shearing, contact metamorphism, skarn development, early mineralization; (2) as magmatic evolution continued, further hydrothermal activity led to the main mineralization stage. Up to this point we have granitoids that were emplaced below a detachment contact (lower-plate domain), and metamorphic, metasomatic, and mineralizing processes that took place in the upper-plate of the detachment (Fig. 2). Furthermore, part of the TKc rocks (Fig. 1) can be regarded as belonging to an extensionally deformed, metamorphic and hydrothermally altered unit, formed in response to the emplacement of the Ojanco-Los Lirios granitoids (Fig. 2). As shown by the rock sequence present in the TKc unit (Punta del Cobre, Abundancia, and Nantoco facies), we envisage a complex and long-lived process, involving multiple phases of magma emplacement. This is well documented by the superposition of skarn episodes in Candelaria (Ryan et al. 1995). We suggest that granitoid-related metasomatic-hydrothermal processes were not restricted to the Candelaria area, but that they were also responsible for mineralization in the Punta del Cobre district (Figs. 1, 2). This interpretation is well supported by geologic, geochemical, isotopic, and fluid inclusion studies indicating the hidden presence of plutonic rocks beneath the district (Marshick and Fontboté 1996; Rabbia et al. 1996; Pincheira et al. 1997). This, together with the extensional nature of the emplacement of the batholithic body (e.g., Martin et al. 1997) in relation to a

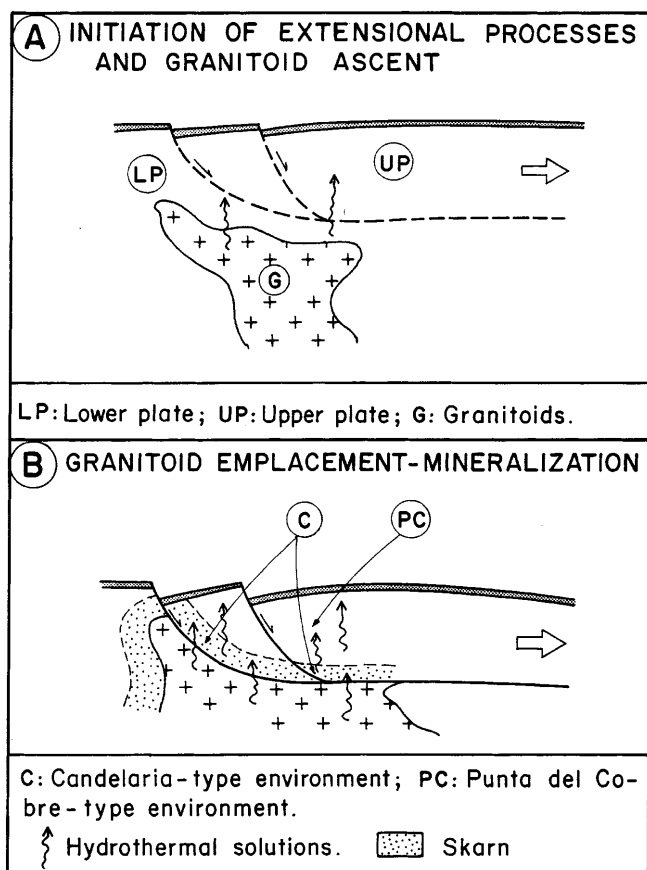


Fig. 2 Highly schematic sections (not to scale) depicting the evolution of the Candelaria-Punta del Cobre system. For simplicity, the complex array of igneous plutonic rocks is represented here by a single plutonic body. **A** Extensional processes begin, incipient release of water from the granitoids (e.g., Rehrig 1986). **B** Emplacement of the granitoids, extension and hydrothermal processes increase, metasomatic activity, skarn formation; note that equivalent conditions to those of Candelaria (C) are expected beneath the Punta del Cobre (PC) district

major detachment system, supports the idea of an eastward continuation in depth of both the extensional system and the granitoid facies (Fig. 2). The precise location of the detachment and granitoids beneath the Punta del Cobre district would require detailed structural work. However, the main point is that these ideas may open new, unsuspected exploration possibilities for the discovery of new 'Candelaria-type' orebodies, lying somewhere beneath the Punta del Cobre district (Fig. 2). The fact that magnetite – a major mineral phase in Candelaria – increases toward the deeper levels of Punta del Cobre (e.g., Marshick and Fontboté 1996) further supports this proposal.

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