Geodynamic implications of the regional very low-grade metamorphism in the Lower Cretaceous of the Coastal Range in Central Chile

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Introduction

Magmatic and metamorphic features of the Lower Cretaceous volcanic formations of central Chile strongly contrast with those found in younger units in the same segment. Some km thick of bi-modal K-rich calcalkaline volcanism with widespread basalts and basaltic andesites morphologically emplaced as extensive flood basalts (trapps) under an extensional regime, absence of volcanic centres, mantle-rich plutonism, and regional non-deformational very low-grade metamorphism of the burial type under moderate vertical thermal gradients, characterize most of the evolution of this segment of the Pacific margin. In sharp contrast with this, starting from the 'mid-Cretaceous,' a dramatic change in scenary is recorded. Magmatic foci moved toward the east along several basins where central volcanism predominated with products close to a tholeiitic composition giving rise to large scale hydrothermalism.

In this paper we will focuse on the nature of the metamorphism which affects the Early Cretaceous formations in the Coastal Range of central Chile (≈32° 35' – 33°10'S, fig. 1). These formations are known as the *Lo Prado*, *Veta Negra* and *Las Chilcas* (fig. 1). Our purpose is to put in evidence the genesis of this metamorphism, its relation with the rather coeval plutonic magmatism in the region and with the geodynamic 'mid-Cretaceous" event that closed the Early Cretaceous evolutionary process.

Metamorphic facies and P-T conditions

Metamorphism in this segment of the Coastal Range is non-deformative and characterized by sub-greenschist to greenschist facies mineral associations, increasing in grade with stratigraphic depth from pumpellyite-bearing zeolite facies at the top to greenschist facies at the base (Levi *et al.*, 1989). Nevertheless, the more widely represented metamorphic facies belong to the prehnite-pumpellyite mostly present in the mafic rocks of the *Veta Negra Formation*. The most common metamorphic minerals are pumpellyite, chlorite, K-feldspar, white-mica (sericite) and epidote. Other metamorphic minerals are quartz, albite, prehnite, and, at the bottom of the studied sequence, actinolite is present. Metamorphic minerals appear as pseudomorphs of primary minerals, as groundmass replacement, and filling amygdales. Based on chlorite composition and thermodynamic calculations, P-T conditions obtained from low-variance assemblages contained in the amygdules in the prehnite-pumpellyite facies of ≈ 250-300°C and ≤ 3 kbars are proposed. A gradient of about 40-45°C km^{-1} was calculated in Parada et al (2005) based on data of Aguirre et al. (1999).

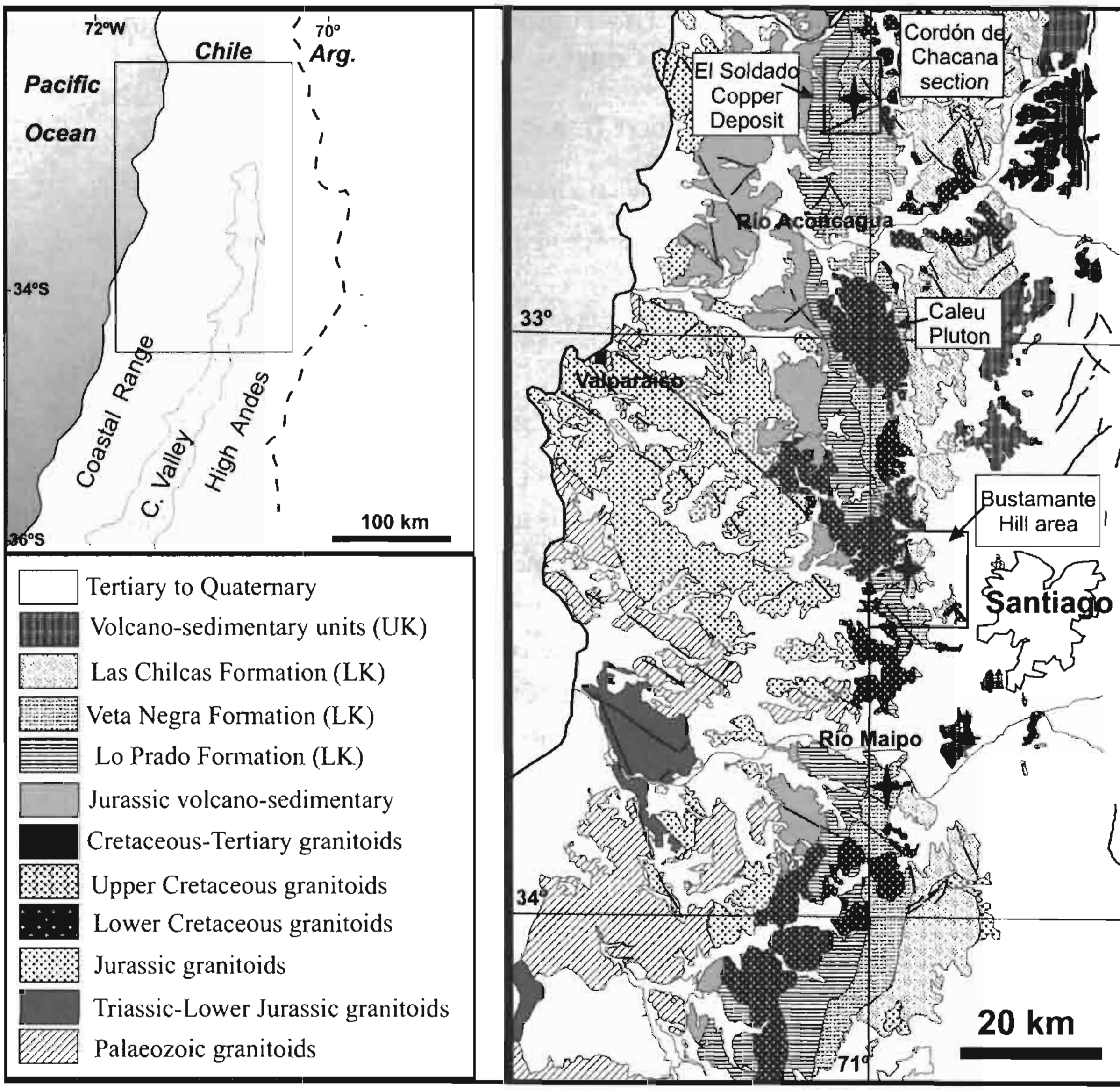

Figure 1. Geological map of the Coastal Range between 32°30'S and 34°10'S showing the Lower Cretaceous formations (simplified from the 1:1.000.000 geological map of Chile, Sernageomin 2002). Black stars: prehnite-pumpellyite facies.

Age of metamorphism

For the *Veta Negra Formation*, $^{40}Ar/^{39}Ar$ ages obtained from (i) adularia ($Or_{97}Ab_3$) in low variance assemblages filling amygdales together with pumpellyite, chlorite, epidote and minor prehnite and (ii) strongly sericitized plagioclase gave plateau ages of 93.1 ± 0.3 Ma - 96.8 ± 0.2 and 97.0 ± 1.6 Ma, respectively (Aguirre et al., 1999; Fuentes et al., 2005). The older ages were obtained at the Cordón de Chacana section (see fig. 1). With these figures, a period of 25-22 Ma between volcanism ($^{40}Ar/^{39}Ar$ ages obtained in primary plagioclase ≈ 119 Ma, Aguirre et al., 1999; Fuentes et al., 2005) and metamorphism was proposed (Aguirre et al., 1999; Fuentes et al., 2005). These ages are slightly younger than the $^{40}Ar/^{39}Ar$ ages displayed by K-feldspars (microcline and orthoclase) related to the mineralizations of the nearby strata-bound El Soldado copper deposit (Fig. 1) emplaced in volcanic rocks of the uppermost levels of the *Lo Prado Formation* (Wilson *et al.* 2003).

These ages, ranging from 100.5±1.5 to 106.1±1.1 Ma, were interpreted by these authors as representing a local hydrothermal event (at the origin of the copper deposit) that followed a regional burial metamorphic episode in the zeolite facies which took place *c.* 110 Ma which is the age of the oldest K-feldspars apparently not related to mineralizations. This assumed age is then consistent with a model of progressive subsidence of the Cretaceous basin, achieving progressively higher metamorphic grade with time.

Finally, a K-Ar age of 100±3 Ma has been obtained from celadonite in amygdule (paragenetic with chlorite, quartz and calcite) in lavas of the *La Chilcas Formation*, which is also consistent with the variation of metamorphic ages during subsidence and increasing metamorphic degree.

Discussion and conclusions.

The fact that the ages of the metamorphism and of the various granitoid plutons intruding the volcanic rocks fall in the same time interval (see Fig. 1) raises the possibility of a direct cause/effect relationship between metamorphism and plutonism in which the latter would be the acting agent for the metamorphic reactions. However, several studies (*e.g.* Levi, 1969, Levi *et al.* 1982, 1989) have demonstrated that the metamorphic pattern of the Lower Cretaceous volcanic units in the Coastal Range of central Chile is quite constant through outcrop distances of hundred of kilometres along the trend of the belt as also shown in Fig. 1. Moreover, the metamorphic grade increases with the stratigraphic depth, the regional facies boundaries (isograds) being parallel to subparallel to bedding and not to the contact with coeval or later granitoids. This metamorphism is non-deformative with primary volcanic fabrics completely preserved which contrast with the granoblastic textures and mineral assemblages found in neat contact aureoles in close proximity to the Cretaceous plutons.

The coincidence in the metamorphic and plutonic ages in the region studied suggests, however, that additionally to burial, an anomalous thermal gradient reflected by regional magmatism was present during the metamorphic event and originated the granitoid plutons. The epizonal emplacement (*c.* 2.0 kbar) of plutons with fast cooling and exhumation (*e.g.* Caleu Pluton, Parada *et al.*, 2005) would not provide enough thermal capability to produce by itself the regional metamorphism. On the contrary, the regional magmatic event would be rather related to asthenospheric upwelling during extension and crustal attenuation taking place during the generation of the Early Cretaceous basins in the region. In this context, a precise dating of the very low-grade metamorphism allows to constraint the maximum ages of the subsidence and extension (dating the climax of metamorphism) and, consequently, the timing of closure and inversion of basins as a consequence of changes in the regional geodynamic setting from extensional to compressional.

The difference in ages obtained from very low-grade minerals dated (adularia and/or sericite) in rocks of the Cordón de Chacana (*c.* 97 Ma, prehnite-pumpellyite facies, *Veta Negra Formation*) and El Soldado (*c.* 110 Ma, zeolite facies, *Lo Prado Formation*, about 3000 m below the Chacana level), may outline the same effect of burial (Fuentes *et al.* 2005). Based on these data, Fuentes *et al.* (2005) calculated a subsiding rate of about 0.24 mm/year for the *Veta Negra* basin. All these characteristics point to the importance of burial as a leading parameter in the metamorphic process.

Finally, the difference in the $^{40}Ar/^{39}Ar$ ages obtained in adularia between the Cordon de Chacana (96.8±0.2 Ma) and Bustamante (93.1±0.3 Ma) sections (see fig. 1) can be interpreted in terms of its thermochronological significance. In this sense, the plateau age of 93.1±0.3 Ma obtained in the Bustamante section (Aguirre et al.,

1999) could represent not the climax of metamorphism but the time at which adularia crossed its closing temperature along the retrograde branch of its P-T-t path as a consequence of exhumation. According this hypothesis, 93.1±0.3 Ma would represent a minimum age for the prograde metamorphism. Moreover, this interpretation would be also consistent with the thermochronological evolution established by Parada et al (2005) for the Caleu pluton (see fig. 1), where exhumation started coevally with its emplacement (94.2-97.3 Ma) and continued to about 90 Ma in association with the closure of the Early Cretaceous rifting.

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