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Towards a geodynamical model for the "middle" Cretaceous very low-grade metamorphism in Central Chile: The geochronological approach

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Introduction

During the Late Jurassic - Early Cretaceous large volumes of volcanic and volcaniclastic rocks were deposited in central Chile between 25° and 36°S in a 1200 km long ensialic basin characterized by alternating marine and terrestrial conditions along the pre-Andean continental margin of South America. The Upper Jurassic - Lower Cretaceous sequences display as two parallel belts in the western and eastern flanks of a Mesozoic synclinorium (Fig. 1); the western belt conforming the present day Coastal Cordillera and the eastern one along the Andean Cordillera. The model of a coeval existence of an intra-arc/back-arc pair has been proposed in order to explain the existence of these two different belts in central Chile (Vergara *et al.* 1995).

The use of multiple geochronological methods applied to different minerals has proved to be a useful tool in trying to unravel the evolution and origin of the very low-grade metamorphism affecting the Upper Jurassic - Lower Cretaceous volcano-sedimentary successions in this region, and consequently to reconstruct the geodynamical setting of the entire arc/intra-arc/back-arc evolution.

Geological setting

The flanks of the Mesozoic synclinorium consist of two belts of homoclinal sequences dipping towards each other (Fig. 1). Major differences between the two belts are: cumulative thickness (7-14 km in the west vs. 3-7 km in the east), proportion of volcanic rocks relative to sedimentary rocks (around 80% in the west vs. 15% to 50% in the east), and abundance of silicic magmatic rocks, *i.e.* ignimbrites and epizonal granitoids (common in the west but virtually absent in the east). In both flanks the volcano-sedimentary sequences have been affected by very low-grade metamorphic events akin to prehnite-pumpeyllite facies and responsible for the local formation of actinolite-epidote metabasites. Typical mineral assemblages include epidote, chlorite, prehnite, pumpellyite, celadonite, titanite, quartz, K-feldspar and calcite, with minor actinolite. Lower Cretaceous plutonic rocks intrude the volcano-sedimentary sequences to the west, whereas in the east only Miocene plutons are present (Fig. 1).

In the Coastal Cordillera the Veta Negra and Lo Prado formations contain the majority of Lower Cretaceous volcanic rocks outcropping in this area –partly metamorphosed andesitic to basaltic-andesite lava flows, tuffs and breccias- whereas the Las Chilcas Formation is mainly sedimentary. In the Andean Cordillera, metamorphosed basic flows are present at the lower middle part of the marine Upper Jurassic-Lower Cretaceous Lo Valdés Formation which concordantly overlies the Río Damas Formation (Kimmeridgian) (Hallam et al

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1986), this last being predominantly volcanic with numerous lava flows of andesitic composition. The Colimapu Formation (upper Lower Cretaceous) is in turn mainly sedimentary with minor volcaniclastic rocks intercalated in a series of coarse to fine grained red beds (Fig. 1). The Oligocene-Miocene volcanic activity that took place in the present Andean Cordillera is represented by the Abanico, Coya-Machali and Farellones formations (Fig. 1). These units have been also affected by very low-grade metamorphism at the zeolite and prehnite-pumpeyllite facies.

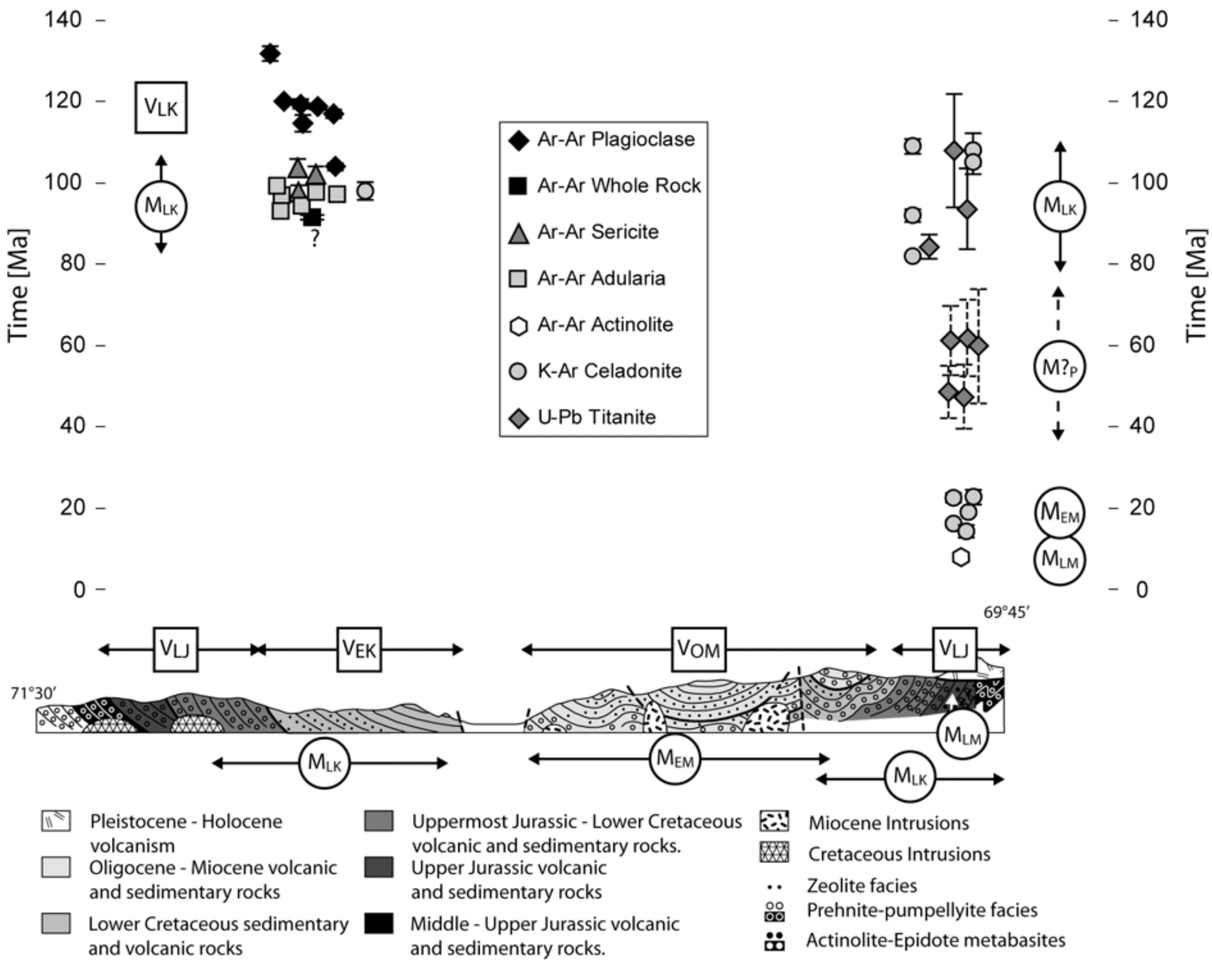

Figure 1. Idealized, schematic geological profile of central Chile between 33ºS and 35º (modified after Levi *et al.* 1989) versus ages of igneous and metamorphic minerals from the Coastal and Andean cordilleras. Ages are from: Boric & Munizaga 1994, Aguirre *et al.* 1999, Fuentes *et al.* 2005, Morata *et al.* 2006a,b, Oliveros *et al.* 2008a,b; Belmar *et al.* submitted, and this work. V_{LJ}: late Jurassic volcanism; V_{EK}: early Cretaceous volcanism; V_{OM}: Oligocene-Miocene volcanism. M_{LK}: late Cretaceous metamorphic event; $M?_{P}$: Paleocene metamorphic event? M_{EM}: early Miocene metamorphic event; M_{LM}: late Miocene local metamorphic event (after Oliveros *et al.* 2008a and Belmar *et al.* submitted).

Age of volcanism and metamorphism

Coastal Cordillera

Fresh plagioclase crystals have been dated from volcanic rocks of the Veta Negra Formation in the Coastal Cordillera, yielding Ar-Ar ages between 120 to 114.7 Ma and 104 ± 2 Ma (Fig. 1). K-feldspar from amygdales and sericite replacing plagioclase phenocrysts in those same rocks were also dated by the Ar-Ar method yielding

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ages between 103.9 ± 2.1 and 93.1 ± 0.3 Ma (Fig. 1; Aguirre *et al.* 1999, Fuentes *et al.* 2005, Morata *et al.* 2006b). K-Ar on celadonite filling amygdules from a lava flow in Las Chilcas Formation gave an age of 98 ± 3 Ma (Morata *et al.*, 2006a). Wilson *et al.* (2003) reported two generations of K-feldspar, hosted in amygdales and veins from metamorphosed and hydrothermally altered lava flows of the Lo Prado Fm, with average Ar-Ar ages of 110.3 ±1.7 Ma and 103.3 ± 1.2 Ma (ages not shown in Fig. 1).

Andean Cordillera

So far, no isotopic geochronological data for the Upper Jurassic- Lower Cretaceous volcanic rocks in the main Cordillera of central Chile are available; this is mainly due to the pervasive alteration in those rocks that precludes the posibility of obtaining reliable Ar-Ar ages. The paleontological record indicates a reliable time interval between the Kimmeridigian and Tithonian for the volcanism (Hallam *et al.* 1986). In contrast, several K-Ar, Ar-Ar and U-Pb ages have been obtained for metamorphic minerals present in amygdales, veins, groundmass and replacing phenocrysts of lava flows, tuff and breccias (Fig. 1). Three groups of radiometric data have been interpreted as follows: 1) a late Cretaceous metamorphic event recorded by ages ranging between 108 ± 4 and 82 ± 3 Ma (Belmar *et al.* submitted, Oliveros *et al.* 2008a); 2) an early Miocene metamorphic event at c. 22-15 Ma (Belmar *et al.* submitted), and 3) a late Miocene local metamorphic event at c. 8 Ma (Oliveros *et al.* 2008a). A fourth group of ages ranging between 61.3 ± 8.5 and 47.3 ± 7.9 has been obtained by the U-Pb method applied to metamorphic titanite; it could be interpreted as a Paleocene metamorphic event (Fig, 1) but it remains to determine the validity of the radiometric data (Oliveros *et al.* 2008b).

Geodynamical model of the metamorphism

In spite of the apparent diachronism between the volcanic activity represented by the de Veta Negra (Aptian-Albian?) and the Lo Valdés-Río Damas (Kimmeridgian-Tithonian) formations, in both flanks of the Mesozoic synclinorium these units underwent regional non-deformative very low-grade metamorphism during the early late Cretaceous, from ca. 110 to 83 Ma. This metamorphic process cannot be undoubtedly linked to the plutonic activity in the arc/back-arc pair, since intrusions of this age have been reported only in the western side (Fig. 1). A more likely process that could account for the increasing P-T conditions is the burial of the volcanic pile. Moreover, it is possible that the basin subsidence, astenospheric upwelling and crustal attenuation that characterized the tectonic setting during that time (Aguirre *et al.* 1999, Morata *et al.* 2005) reached their peak during the late Cretaceous, at least in central Chile, leading to the isotopic closure of the dated metamorphic minerals. The scatter of the radiometric data between c. 110 and c. 83 Ma implies two possibilities for the development of the metamorphic process. One is the continuous but not homogeneous burial processes that originated appropriate P-T conditions for the formation of the metamorphic minerals; and the second is the occurrence of two different metamorphic events, the first during the late Albian-Cenomanian and the second (probably only in the eastern part) during the Coniacian. The fact that the range of ages includes U-Pb, Ar-Ar and K-Ar data suggest they represent the closure of the isotopic systems after the crystallization of the metamorphic minerals rather than resetting of these during the subsequent Cenozoic metamorphic events.

While in the Coastal Cordillera the volcano-sedimentary sequences do not seem to be affected by any other significant metamorphic event after the Cretaceous, in the east at least two more processes triggered the transformation of the volcanic rocks, not only Mesozoic but Oligocene-Miocene as well. Thus, very low-grade metamorphism also linked to burial occurred at c. 15 to 22 Ma (Belmar *et al.* submitted).

Finally, the Miocene plutonic intrusions seen in the Andean Cordillera could be responsible for local thermal peaks that affected the hosting volcanic rocks.

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