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The beginning of the Andean subduction system: $^{40}Ar/^{39}Ar$ dating of magmatic activity and subsequent very low-grade metamorphism / hydrothermal alteration in a Jurassic volcanic arc, Coastal Range, northern Chile (18°30'-23°30'S, 70°-70°30'W)

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INTRODUCTION

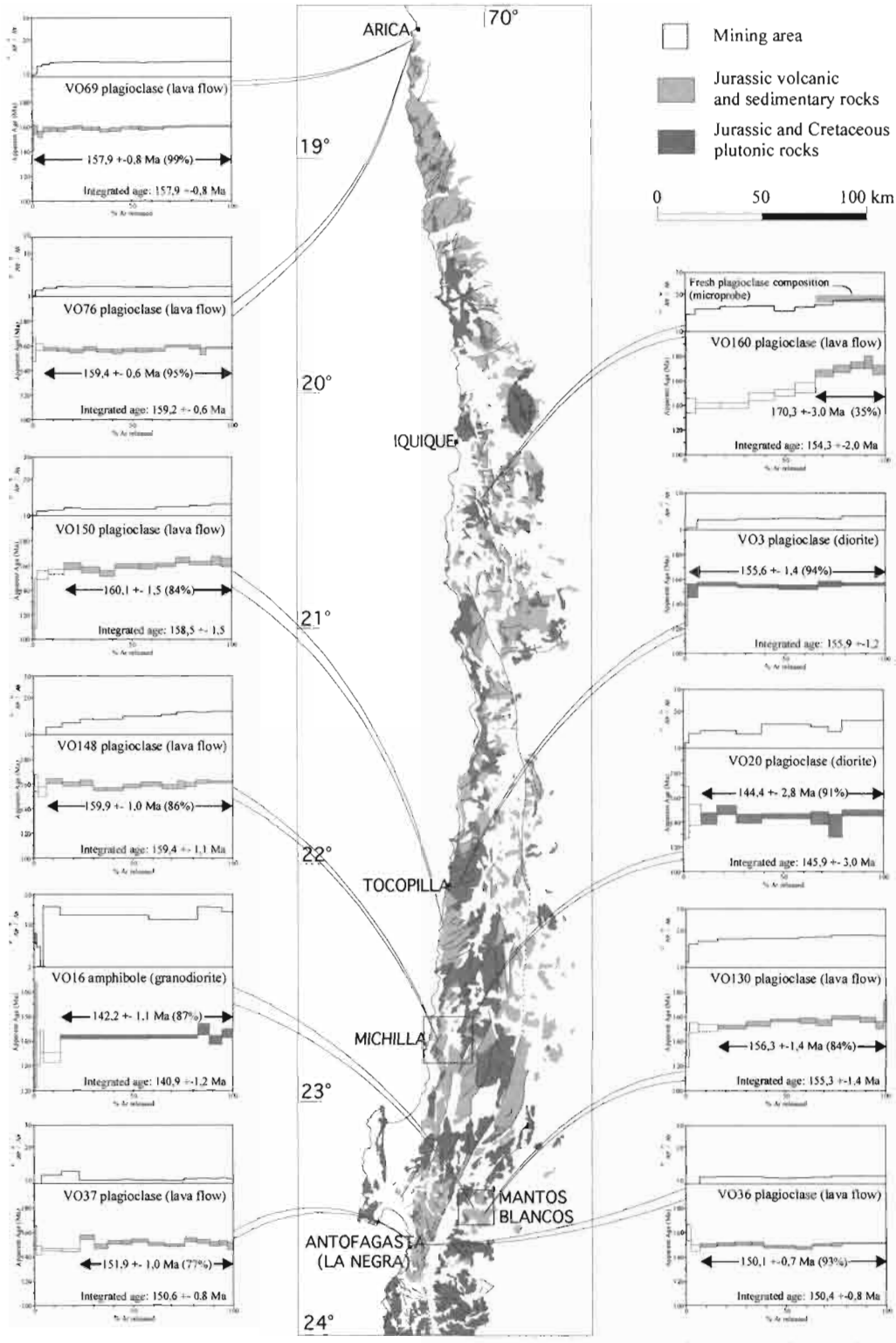
The La Negra Formation, and its equivalents Camaraca, Oficina Viz and Cuya Fms, crops out as a 7 km thick homoclinal sequence of intermediate volcanic and sedimentary Jurassic rocks along the Coastal Range of northern Chile between 18°30' and 23°30' (ca. 800 km long). Cretaceous plutons, intermediate to acidic in composition, intrude this sequence together with numerous small basic to acidic dykes and stocks (Fig. 1). These geologic units represent a Jurassic - Early Cretaceous volcanic arc generated under a transtensional regime due to oblique plate convergence (Scheuber & González, 1999) and correspond to the first stages of Andean subduction. The time span for plutonic activity is well constrained in some localities along the Coastal Range, several pulses of intrusive magmas would have occurred from early Jurassic to early Cretaceous (Dallmeyer et al, 1996). The time of extrusion of volcanic rocks is known mainly from stratigraphical relations or interbedded sediments indicating Early Jurassic to Oxfordian ages for the volcanism along the arc (Charrier & Muñoz, 1994, Kramer et al. 2005). A Rb-Sr isochrone on whole rock of 186 ± 13 Ma was obtained from andesite lava flows in the Tocopilla area (Rogers & Hawkesworth, 1989). The whole volcanic sequence and a minor part of the plutonic rocks have been affected by several alteration processes. All along the Coastal Range, a very low to low-grade alteration can be found; its main assemblage is chlorite-epidote-quartz-calcite-titanite-sericite-actinolite-Kfeldspar-zeolite-prehnite-pumpeyllite. This regional alteration event could be related either to burial metamorphism or alteration by hydrothermal events more or less related to plutonic intrusions (Losert, 1973).

GEOCHRONOLOGY

$^{40}Ar/^{39}Ar$ analyses have been carried out in primary and secondary mineral phases belonging to volcanic and plutonic rocks all along the Coastal Range of northern Chile. Results are as follows:

1) Age of volcanism. Primary plagioclase yielded plateau ages of 157.9 ± 0.8 and 159.4 ± 0.6 Ma in Arica, 160.1 ± 1.5 to 164.9 ± 1.7 Ma in Tocopilla, 159.9 ± 1.0 Ma in Michilla mining district, 156.3 ± 1.4 Ma in Mantos Blancos mining district, and 150.1 ± 0.7 and 151.9 ± 1.0 Ma in Antofagasta (Figs. 1,2). The youngest ages correspond to the uppermost volcanic rocks of the La Negra Fm in the Antofagasta area, therefore they indicate the last period of volcanic activity in the Jurassic - Early Cretaceous arc in this region. These ages are in the range of the biostratigraphical ages proposed for volcanic rocks (explosive submarine volcanism: Los Tarros, El Godo Fms.) and interbedded sediments in Iquique and Arica, also interpreted as the last episodes of volcanism in the Jurassic arc (Kramer et al 2005). South of Iquique plagioclase from two strongly altered samples of basaltic-

andesite lava flows yielded miniplateau ages (about 30% of gas released) of ca. 170-175 Ma at high temperatures (Figs. 1,2). Microprobe analyses of unaltered plagioclases within theses rocks show that their Ca/K composition correspond to $^{37}Ar_{Ca}/^{39}Ar_K$ for high temperature steps (Fig .1), therefore the mini plateau ages are likely close to



the extrusion age of the volcanic rocks. Furthermore, stratigraphical relations with overlaying sedimentary rocks indicate a maximum middle Bajocian age for the Jurassic Oficina Viz Formation (Kramer et al. 2005).

Figure 1: Simplified geologic map of the Coastal Cordillera, northern Chile. $^{40}Ar/^{39}Ar$ apparent ages and $^{37}Ar_{Ca}/^{39}Ar_K$ ratio spectra for volcanic and plutonic rocks. Errors at 2-sigma confidence level.

2) Age of intrusions. Primary biotite, amphibole and plagioclase yielded ages at ca. 155.6 ± 1.4 in Tocopilla, 144.4 ± 2.8, 147.1 ± 2.2 and 154.1 ± 3.9 Ma in Michilla area and from 142.2 ± 1.1 to 148.2 ± 0.5 Ma in Mantos Blancos area (Figs. 1,2). These ages agree with previous radiometric data obtained for plutonic rocks in the Coastal Range (Rogers & Hawkesworth, 1989; Dallmeyer et al, 1996; Scheuber & González, 1999) and correspond to a Late Jurassic plutonic event.

3) Alteration events. Plateau ages ranging between 101.6 ± 5.0 to 161.1 ± 0.9 Ma (Fig. 2) have been obtained on sericite in situ in plagioclase, K-feldspar and actinolite from veins and amygdales, which are supposed to be products of hydrothermal alteration or very low-grade metamorphic event(s) on a regional scale. Locally, differences in ages obtained for alteration minerals can be up to 40 Ma, like in Mantos Blancos and Iquique areas (Fig. 2), therefore, either several alteration events must have occurred during the Middle Jurassic - Early Cretaceous interval, or a single long-lasting process took place.

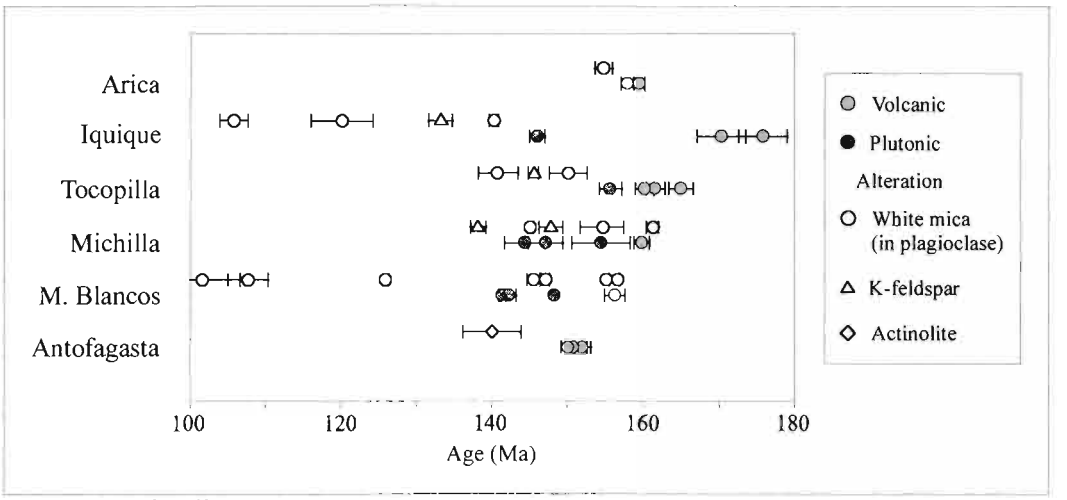


Figure 2. All $^{40}Ar/^{39}Ar$ plateau and miniplateau ages obtained on primary and secondary minerals.

GEOCHEMISTRY OF IGNEOUS ROCKS

The studied rocks correspond to calc-alkaline andesites and basaltic-andesites (based on major and trace elements contents and pyroxene composition). Trace elements and REE patterns indicate fractional crystallization from a mantle-derived parental magma as the mechanism of generation and differentiation of these rocks. Furthermore, isotopic data indicate that minor crustal contamination was involved in the magma genesis though the crustal component in the magmas seems to increase with time (Kramer et al. 2005). Analyzed plutonic rocks are mostly biotite-amphibole quartz diorites to granodiorites and show the same patterns as the volcanic rocks, suggesting they originated from the same magmas.

CHARACTERIZATION OF THE REGIONAL ALTERATION EVENT

A detailed sampling of a volcanic section about 7 km thick was carried out along Quebrada La Negra, close to Antofagasta city. Petrographic study and microprobe analysis of secondary minerals revealed a variation in the mineral assemblages with the stratigraphic depth from pumpellyite-bearing zeolite facies to prehnite-actinolite facies (with an age for actinolite of ca. 140 Ma, Fig. 2), suggesting that a burial metamorphic event would have

affected the volcanic rocks. No similar continuous sections could be sampled in other places of the Coastal Range, nevertheless, the fact that, in some localities, e.g. Michilla and Mantos Blancos, most of the alteration minerals yielded ages younger but close to those obtained for the intrusions would imply that the influence of plutonic intrusion could be reflected in some alteration events.

PRELIMINARY CONCLUDING REMARKS

- Despite a general strong degree of alteration, plagioclase from most analyzed volcanic rocks gave high quality plateau ages. The ages of the volcanic rocks vary widely, with apparent oldest ages (ca. 170-175 Ma, no plateau age) in the region of Iquique and the youngest at Antofagasta (ca. 150-152 Ma).
- Plutonic rocks show a wide range of ages (interpreted as cooling ages below the closure temperature of amphibole, biotite and plagioclase). Some of them are concordant with lava flows ages. These ages are consistent with those obtained by other authors in the Coastal Range.
- Alteration mineral phases yielded plateau ages over a wide temporal range, e.g. up to 40 Ma for some localities such as Iquique. Whether the ages obtained from these alteration minerals represent a single long-lasting alteration process or several overprinted events has not been yet established. A very low-grade metamorphic event would have occurred in the Antofagasta region. Nevertheless, as shown in Figure 2, the alteration event(s) occurred mainly after the intrusion of the huge plutons, and in some areas very close to the extrusion of the volcanic rocks. A high temperature gradient in the arc, due to constant magmatic accretion (pulses of plutonic intrusions) or to an astenopheric upwelling as result of the extensional regime, would have generated appropriated conditions for the formation of secondary minerals from the Middle Jurassic to the Early Cretaceous.

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