Permian exhumation of metamorphic complexes in the Calama area: Evidence for flat-slab subduction in northern Chile during the San Rafael tectonic phase and origin of the Central Andean Gravity High

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Abstract. The geology of the Calama area, north Chile, indicates that very different crustal levels of the Permian - Carboniferous continental margin of Gondwana were exhumed and juxtaposed prior to the Triassic. This tectonic event involved 1) exhumation of the high-pressure Limon Verde Metamorphic Complex (LVMC), 2) exhumation of the migmatitic Cerros de Chuquicamata Metaplutonic Complex (CCMC), 3) structural juxtaposition of these metamorphic levels against penecontemporaneous supracrustal volcanic and sedimentary sequences of the Collahuasi Formation, and 4) a gap in magmatism that spanned the Middle Permian to Early Triassic. We infer that this tectonic event is the expression in northern Chile of the San Rafael-Gondwanide orogenic event and at the latitude of Calama occurred as the result of flat-slab subduction wherein the LVMC was structurally underplated and constitutes the surface outcropping of a regionally extensive subsurface unit that is the principal source for the Central Andean Gravity High.

Keywords: Permian, Calama, San Rafael, Gondwanide Central Andean Gravity High

1 Introduction

The geology of the Calama area records a significant Permian-Triassic tectonic event. By analog with the Laramide geology of southwest North America, we infer that this event was the result of flat-slab subduction and is the expression in northern Chile of the San Rafael-Gondwanide orogenic phase.

2 Late Paleozoic - Triassic of Calama

2.1 Limon Verde Metamorphic Complex (LVMC)

The LVMC consists principally of quartz-muscovite-biotite-garnet schist and garnet amphibolite (Lucassen et al., 1999) that crop out in the Pampa Limon Verde, Cerros de San Lorenzo and Río San Salvador canyon, near Calama (Figure 1b). They have a metamorphic paragenesis indicating formation at garnet amphibolite grade, geothermobarometery determinations of 13±1 kbar and 660-720ºC for the conditions of peak metamorphism, and Sm-Nd mineral isochons indicating a mid-Permian, 270±12 Ma, age of metamorphism (Lucassen et al., 1999).

2.2 Cerros de Chuquicamata Metaplutonic Complex

The Cerros de Chuquicamata Metaplutonic Complex (CCMC) is a plutonic and metaplutonic complex composed principally of granites and diorites, lesser granodiorite, gabbro and tonalite, and their schistose and gneissic, locally migmatized, equivalents, exposed in the Cerros de Chuquicamata (Figure 1b). They have an amphibolite metamorphic paragenesis, locally reaching partial melting conditions, but lack high-P mineralogy. A 296.9±2.1 Ma ID-TIMS U-Pb zircon age for a microcline granite is inferred to represent the age of magmatism, and 273±9 Ma K-Ar hornblende and 267±6 Ma K-Ar biotite ages on diorite and metadiorite are interpreted to approximate the time of cooling through the respective closure temperatures to Ar for the minerals dated.

2.3 Collahuasi Formation and epizonal plutons

The Collahuasi Formation is amply distributed in the area (Figure 1b) and is predominately rhyolite and dacite lavas and pyroclastic rocks and lesser andesite. In the Calama area, eight U-Pb zircon ages range from 304 Ma to 274 Ma (Tomlinson and Blanco, 2008 and references therein; Figure 1c). Plutonic bodies, consisting of granodiorites and granites, and subordinate diorites, quartz diorites, quartz monzonites and gabbros, intrude the cogenetic Collahuasi Formation, and have radiometric ages ranging from 313 Ma to 270 Ma.

2.4 Middle-Late Triassic units

Triassic volcanic and sedimentary units include the Quetena, Observatorio and Cerros de Chuquicamata Sequences (Tomlinson and Blanco, 2008). The volcanic
rocks consist of andesite lavas and breccias, and subordinate silicic lavas and tuffs. The sedimentary rocks are continental-facies, coarse-grained conglomerates and sandstones, and in the sectors of Cerro Quetena and Pampa Limón Verde, they are composed of clasts of muscovite schist, metamorphic quartz, and detrital muscovite and rutile derived from erosion of the LVMC. Intrusive units consist of epizonal granodiorite and granite, hypabyssal porphyries and dike swarms. Most radiometric ages range from 238 Ma to 221 Ma (Figure 1c).

2.5 Permian exhumation and magmatic gap

Deposition of Triassic volcanic and sedimentary units over the LVMC, CCMC and Collahuasi Formation indicates exhumation of the metamorphic complexes and juxtaposition against the supracrustal rocks prior to the Middle Triassic. The inferred temperatures of metamorphism exceed the Ar closure temperatures of amphibole and other potassic minerals dated, and so the Permian K-Ar ages are interpreted to reflect exhumation-related cooling of the metamorphic rocks in the Permian. Middle Triassic K-Ar ages in the LVMC are interpreted to be a result of resetting during Middle Triassic magmatism (compare to Lucassen et al., 1999).

The geochronological data for the Calama area indicates magmatism ceased ca. 270 Ma, at approximately the same time as peak metamorphism of the LVMC and cooling of the CCMC (Figure 1c). The magmatism restarted in the Middle Triassic, ca. 238 Ma.

3 Laramide analog

The Rand-Pelona-Orocopia Schist (RPOS), of the southwestern US, is a high-pressure, amphibolite to greenschist grade, subduction-related, metamorphic unit that crops out through structural windows in the lower plate of the regional, low-angle, Vincent-Chocolate Mountain Fault, where it has been juxtaposed against penecontemporaneous arc magmatic rocks of the upper plate (Saleeby, 2003). The RPOS is interpreted as the deep parts of the Franciscan Subduction Complex, and/or fragments of the forearc crust, that have been subducted and accreted to the base of the continental crust by low-angle subduction during development of the Laramide orogeny (Saleeby, 2003 and references therein). The process of low-angle subduction tectonically eroded the subcontinental lithospheric mantle and lower part of the continental crust, and structurally underplated the RPOS in their place. This process also produced coeval exhumation of the magmatic arc, which in the Calama case is represented by the CCMC, which is interpreted to be a mid-crustal section of the Late Paleozoic continental magmatic arc that was exhumed during structural underplating of the LVMC (Figure 1d). In the Laramide case, subduction was segmented such that tectonic erosion, structural underplating and arc exhumation were limited to a ca. 400 km long segment of the arc. The northerly limit of this segment corresponds to a deformation belt that strikes across the arc and juxtaposes exhumed arc rocks against supracrustal arc rocks. In the Calama case, a similar relation occurs across the ENE-WSW striking Cere Fault, with the mid-crustal CCMC brought against the supracrustal Collahuasi Formation (Figure 1b, 1e). Middle Triassic epizonal plutons and porphyries are emplaced in both blocks indicated the juxtaposition occurred before the Middle Triassic. The Cere Fault also coincides to the northern limit of the Central Andean Gravity High (CAGH, Figure 1f), a significant regional gravity anomaly that is interpreted as indicating the presence of a 400 km long, 100-140 km wide, dense body at 10 to 38 km depth, with its shallowest portions lying under the Calama Basin (Götze and Krause, 2002). Rocks of the LVMC are dense, consistent with their high-pressure paragenesis, and are a feasible source mass for the CAGH (Lucassen et al., 1999). Likewise the RPOS of southern California have a positive gravity anomaly associated with them.

4 Conclusions

The timing of peak metamorphism and exhumation of the LVMC and CCMC coincides with the San Rafael tectonic phase of west central Argentina, which is part of the larger Gondwanide orogenic event. By analog with the Laramide, we conclude that the Late Paleozoic-Triassic geology of the Calama area records flat-slab subduction during the San Rafael-Gondwanide orogeny, wherein the high-grade LVMC was structurally underplated, a mid-crustal section of the continental arc (CCMC) was exhumed and arc magmatism ceased for ca. 30 Ma. The underplated LVMC constitutes the surface out cropping of a regionally extensive subsurface unit that is the principal source for the Central Andean Gravity High.

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References


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Figure 1. A) Location of study area within South America, B) Calama area map showing distribution of Paleozoic-Triassic units, principal faults, and inferred extent of crustal blocks of contrasting Late Paleozoic paleodepth, C) summative probability density curves for geochronologic data from Late Paleozoic-Triassic units in the area, D) schematic east-west cross section showing the structure of the Permian continental margin during low-angle subduction and structural underplating of the LVMC, E) schematic north-south cross section showing the contrast in Permian crustal architecture across the Cere Fault Zone, F) Map of isostatic residual gravity field showing the northwestern most end of the CAGH and the West and Cere Faults (modified from Riller et al., 2006).