OLIGOCENE-NEOGENE TECTONIC EVOLUTION OF THE ALTIPLANO OF NORTHERN CHILE (18-19°S)

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INTRODUCTION

The Oligocene-Neogene tectonic evolution of the eastern Altiplano (Bolivia) is characterised by important compression (Sempere et al., 1990; Lamb et al., 1997) with an horizontal shortening from 190 to 240 km (Roeder, 1988; Baby et al., 1997). By contrast, in the western Altiplano (northern Chile), studies are few and, in part, contradictory (Muñoz and Charrier, 1996; García et al., 1996; Lamb et al., 1997; Wörner et al., 2000a). Here, we describe the evolution of the western Altiplano at the latitude of Arica, based on new balanced cross-sections and chrono-stratigraphic data. In this region four physiographic units are recognised (Fig. 1). The Coastal Cordillera (up to 1200 m in altitude) is a smooth relief. In the Central Depression the altitude increases from 500 to 2300 m. The Precordillera (1900-3600 m high) is an elongated plateau. The Western Cordillera is mainly volcanic, with an irregular topography (altitude of 3800-4500 m and maximum of 6350 m).

DEFORMED SEQUENCES: COMPOSITION AND AGE

The extensive Oligocene-Neogene sequence (more than 90% of the area; Fig. 1) is formed by volcanic and continental sedimentary rocks, which overlie unconformably a Precambrian-Paleocene substratum.

Pre-Oligocene substratum. In the Western Cordillera, in Belén, this corresponds to blocks of Precambrian-Paleozoic metamorphic rocks (Basei et al., 1996; Wörner et al., 2000b). To the west the substratum is of Mesozoic-Paleocene intrusive and sedimentary rocks (Salas et al., 1966; Muñoz et al., 1988).

Oligocene-Neogene sequences. To the east they are thick (<5000 m), essentially volcanic, and locally strongly deformed. To the west they are horizontal, essentially sedimentary, and their thickness decreases to 0-200 m. The Azapa Fm. (Salas et al., 1966; Parraguez, 1998), in the Central Depression, consists of up to 500 m of Oligocene fluvial conglomerates and sandstones, proceeding from the NE and E. It is covered by the Oxaya Fm. (Salas et al., 1966; García, 1996), which is constituted by large ignimbrites and minor sediments; its thickness decreases from 1000 m (Precordillera) to 50 m (Central Depression). Several K-Ar and Ar-Ar determinations give a 26-19 Ma age (Naranjo and Paskoff, 1985; Parraguez, 1998; Wörner et al., 2000a; this work). In the Central Depression, the Oxaya Fm. is covered by the El Diablo Fm. (Tobar et al., 1968; Parraguez, 1998), less than 400 m in thickness. The lower part of the El Diablo Fm. is composed of distal-fluvial and lacustrine deposits. The upper part is formed by fluvial gravels coming from the Western Cordillera; two fresh andesitic

clasts were dated (K-Ar whole rock) in 14.7±0.8 and 11.9±0.6 Ma. To the south these gravels are covered by a 8.4±0.6 Ma lava flow (Naranjo and Paskoff, 1985; Muñoz and Charrier, 1996), indicating end of the deposition between 12 and 9 Ma. In the Coastal Cordillera, small Oligo-Miocene basins are filled by alluvial sediments and minor tuffs,similar in composition and age to the Oxaya tuffs. In the eastern Precordillera, the upper Oxaya Fm. is interstratified with the 20-18 Ma Quevilque andesites (Wörner et al., 2000a), and is covered by the Sucuna (15-12 Ma) and Marquez (11-9 Ma) volcanoes and the16-12 Ma andesites of the Zapahuira Fm.. The east-dipping Oxaya and Zapahuira Fms. are onlapped, in low-angle progressive unconformity, by the fluvial Huaylas Fm. (Salas et al., 1966; García et al., 1996). In the upper gravels an ignimbrite has been dated (Ar-Ar biotite) in three sites, giving a mean age of 10.7±0.3 Ma. Uppermost gravels (9-7 Ma) cover partly the Lupica Fm. (to the E). The east-derived Huaylas gravels are coeval to the uplift of the Western Cordillera.

In the Western Cordillera, the Belén Metamorphic Complex is directly overlain by the Lupica Fm. (Salas et al., 1966), constituted by 1500-2500 m of andesitic to rhyolithic flows and alluvial-lacustrine sediments. Ar-Ar, U-Pb and K-Ar ages give Late Oligocene-Early Miocene (18.6±0.6 to 25.5±0.6 Ma) (García, 1996; Riquelme, 1998; this work). The Lupica and Oxaya tuffs are identical in composition and age. In Chucal, the Lupica Fm. is overlain by sediments (Chucal Fm.) with Lower-Middle Miocene vertebrates (Flynn et al., 2002), which are overlain by the 17-10 Ma old Macusa Fm.. In the eastern Western Cordillera, the Lupica Fm. is unconformably covered by Late Miocene-Quaternary volcanoes (Wörner et al., 1988) and Plio-Pleistocene (5-1 Ma) sediments and tuffs of the Lauca Fm. (Kött et al., 1995). The <150 m thick Lauca Ignimbrite, extending over most of the region, yield reliable ages close to 2.7 Ma (Kött et al., 1995; Wörner et al., 2000; this work).

GEOMETRY OF DEFORMATION

The Oligocene-Neogene sequences of Arica are affected by essentially west-vergent compressive structures striking N-S to NNW-SSE (Muñoz and Charrier, 1996; García et al., 1996, 1999; Riquelme, 1998).

Western Cordillera. Structures form a complex fold-and-thrust belt affecting the Lupica Fm. and partially covered by Neogene sediments and volcanics. In the eastern part, gentle deformation is represented by the east-vergent growth Churiguaya Anticline, with flanks dipping less than 35°; Neogene shortening is about 1 km. To the west, a high-deformed domain is developed, with a west-vergent system in the north (Putre-Belén) and an east-vergent system in the south (Chucal-Macusa). The Putre-Belén System produces a great change of altitude (from 3000 to 5300 m). In Socoroma area, a west-vergent syncline is thrust (30° east-dipping) over the subhorizontal Oxaya Fm. and Quevilque Volcano. In Belén-Tignámar area, the system is characterised by a large involving-basement anticline (wavelength of 35 km) associated, in the front, to folds and thrusts that include sheets of syntectonic conglomerates and volcanics, dipping 20-60° east. East Belén, the basement is in contact with the lower Lupica Fm. by a local high-angle east-dipping fault, which is covered by the middle Lupica Fm. For the Putre-Belén System, the minimum Neogene shortening is estimated from 8.3 to 6.4 km. In Chucal, an east-vergent growth anticline (flanks dipping from 10 to 80°), 5 km in wavelength, interprets as a fault-propagation fold. To the west, this anticline is cut by an important thrust (40-50°W) that places the lower Lupica Fm. over Chucal Fm.. More to the west, the Macusa folds are short, tight and west-vergent. For the Chucal-Macusa System the shortening is of 6.6 km. Thus, the Western Cordillera is characterised by west-vergent basement-involved deformation whose Neogene shortening is estimated of 8 km.; this deformation is geometrically compatible with that observed in the eastern Altiplano, but of lesser magnitude.

Precordillera. It is a domain of gentle deformation, affecting essentially the Oxaya Fm. To the north the large Huaylillas Flexure is exposed. To the south (Sucuna Monocline), the west-dipping (2-4°) surface is very gently folded. In the central part the Oxaya Anticline is a well-developed west-vergent fold (flanks of up to 10°W and 4°E). Its shortening is very negligible (<100 m) respect to the vertical displacement (<850 m). The straight western border of the fold is a very open half-syncline. It corresponds to the surface projection of an east-dipping subvertical blind reverse fault (Ausipar Fault), whose upward propagation formed the anticline.

Central Depression and Coastal Cordillera. The deformation is gentle, represented by large flexures and minor faults affecting the El Diablo Fm. The Humayani Flexure is west-vergent, producing vertical displacement up to 500 m and minor shortening (<50 m). It formed by movement of a blind subvertical reverse fault (Taltape Fault) in the western border. Other flexures produce up to 100 m of displacement. In the Coastal Cordillera, locally curved subvertical faults are reverse, normal and strike-slip, and strongly controlled by pre-Oligocene tectonics. These faults show displacements less than 50 m in the Oligo-Miocene deposits; some laterally separate intermittent valleys. The western part of the Arica region is strongly incised (up to 1000 m) by exorreic rivers (Lluta, Azapa, Vitor and Camarones) after the deposition of the El Diablo Fm.

TIMING OF DEFORMATION

It has been constrained from radiometric ages of the syntectonic volcanic and sedimentary horizons.

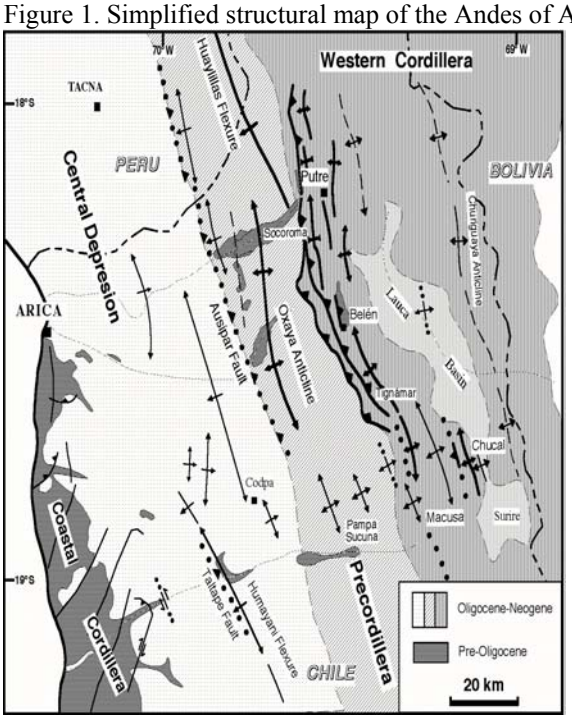
Oligocene. Deformation of this age is registered in the Taltape and Ausipar faults; these show also Miocene reactivation. The Taltape Fault, below the unfolded Upper Oligocene-Miocene (upper Azapa, Oxaya and El Diablo Fms.), places in direct contact the Mesozoic substratum with the lower Azapa Fm. (and probably older), implying an uplift of the eastern block during the Early Oligocene (and probably prior). The Ausipar Fault, below the unfolded Upper Oligocene-Miocene (Oxaya Fm.), places the Mesozoic substratum against the upper Azapa Fm., indicating an Oligocene age (prior to ~25 Ma) for faulting.

Miocene. Miocene deformation has been previously recognised (Muñoz and Charrier, 1996; García et al., 1996, 1999; Riquelme, 1998). In the eastern Western Cordillera, the Churiguaya Anticline involves the overall Lupica Fm. (26-18 Ma), and is covered unconformably by the 7-6 Ma Choquelimpie Volcano, giving a 22-7 Ma age by the folding. In the Chucal area, the Oligo-Miocene sequence is thrust and folded, and the Upper Miocene (17-10 Ma) seals partially the deformation; it is gently folded but covered by 5-1 Ma horizontal Lauca Fm. To the west, Macusa folds involve 17-10 Ma volcanic rocks and are covered unconformably by the 7 Ma Familiani Volcano. Thus, for the Chucal-Macusa System the deformation developed between 21-18 and 5 Ma. In the Putre-Belén System, to the north, folds and thrusts affecting the Lupica Fm. are covered unconformably by Middle Miocene lavas (13 Ma), indicating compression between 18 and 13 Ma. To the south, on the eastern flank of the Belén Anticline, a 20 Ma ignimbrite is unconformity covered by a 16 Ma dacite; this latter is unconformity overlain by the Lauca Fm.. This implies continuous folding between <20 and >5 Ma. The thrusts of Belén cut the 18-15 Ma syntectonic conglomerates (Joracane Beds) and 16-12 Ma Zapahuira Fm., and some are locally sealed by the uppermost Huaylas Fm. (9-7 Ma). The frontal thrust cuts the lowermost Huaylas Fm. (11-10 Ma) and gently displaces the Pliocene. So, the thrusts of the Putre-Belén System were developed in-sequence (to the west) and their major activity is between 18 and 6 Ma. In the Precordillera, the eastern limb of the Oxaya Anticline is covered, in progressive unconformity, by the Huaylas Fm.: the lowermost sandstones being tilted while the

upper gravels are horizontal. This implies that the folding occurred between 11.7±0.7 Ma and 10.7±0.3 Ma. Faults and flexures of the Central Depression and Coastal Cordillera postdate Late Miocene sediments.

Pliocene-Quaternary. Tectonic activity of this age is lesser compared to that Miocene. This is registered in the frontal thrust of Belén, which displace the 2.7 Ma Lauca Ignimbrite vertically about 100 m. Neotectonic activity in the Western Cordillera is confirmed by shallow seismicity, down to 20 km in depth (Comte et al., 1999). In the Coastal Cordillera strike-slip faults separate valleys suggesting a relatively recent activity.

Figure 1. Simplified structural map of the Andes of Arica



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