

THE CENOZOIC FOREARC EVOLUTION IN NORTHERN CHILE: THE WESTERN BORDER OF THE ALTIPLANO OF BELEN (CHILE)

Marcelo GARCIA*, Gérard HERAIL*, Reynaldo CHARRIER*.

* Convenio ORSTOM-Departamento de Geología, Universidad de Chile, Casilla 13518, Correo 21, Santiago.

KEY WORDS: Andes, Altiplano, Tectonic, Chile.

INTRODUCTION

The Altiplano is a 3.500 - 4.500 m high plateau located between 15° and 27° South latitude. This mesostructural unit characterizes the Bolivian Orocline in the Central Andes. It is composed by thick Tertiary continental, detritic sedimentary series, which were deformed under compressive stresses (Semperé et al., 1990). The Altiplano is not an homogeneous back arc basin (i.e. Lavenu, 1986; Semperé et al., 1990; Hérail et al., 1992; Kennan et al., 1995). In the eastern border the remaining sedimentary series are rather thin (less than one to few kilometers) and remnants of erosion surfaces attain the Eastern Cordillera. Deformation occurred essentially before 13-10 Ma. In the Central Altiplano the deposits reach thicknesses of more than 10.000 m in the Corque-Rosapata syncline (Meyer and Murillo, 1961), their source being the uplifted margins of the basin after compressive deformation. Highest reliefs and bigger structural displacement are located to the East (Rochat et al., 1996).

The composition and structure of the sedimentary infill evolve from east to west (Rochat et al., 1996). In Bolivia, these structures can only be described partially on the basis of seismic information. In Chile, on the West margin of the Altiplano, good exposures permit a more complete analysis of the stratigraphic series that register the tectonic evolution of this side of the plateau. In this paper we describe the structure of the West margin of the Altiplano in the region near Belén (Fig. 1) and intend to reconstruct the chronology of its tectonic evolution.

THE DEFORMED SERIES

a) The substratum and the Cenozoic volcanic series. The basement outcropping in this region is the Belén Metamorphic Complex (Complejo Metamórfico de Belén = CMB) consisting of metamorphic and magmatic units (Montecinos, 1963; Pacci et al., 1980), dated at 1.000 Ma (Pacci et al., 1980). Recent age determinations indicate early Paleozoic ages and a complex evolution (Basei et al., 1995, 1996). The CMB is unconformably covered by sandstones of the Jurassic Livilcar Formation (Muñoz et al., 1988), which were deposited on the East margin of the Jurassic backarc basin (Muñoz and Charrier, 1993).

The Cenozoic stratigraphic series begins with the accumulation of volcanic deposits and some volcano detritic intercalations. The approximately 500 m thick Oxaya Formation (Montecinos, 1963; Salas et al., 1996; García, 1996) is a dacitic to rhyolitic, welded ignimbrite, with several kinds of fluidal structures and containing big pumice fragments, some of which attain 20 cm in diameter. All xenoliths are of volcanic origin. A K/Ar age on a biotite from the upper part of the formation gave ages between 19.0 ± 0.6 and 19.9 ± 1.1 Ma (Naranjo and Paskoff, 1985; Aguirre, 1990; Muñoz and Charrier, in press). A K/Ar age on biotite from an ignimbrite level located 300 m below the top of the series gave 21 ± 0.6 Ma (Table 1, Fig. 1).

The 1.500 m thick Lupica Formation, defined by Montecinos (1963), was assigned a Cretaceous age. García (1996) differentiated three members in this unit: a lower member composed of breccious and porphyric andesites with tuffaceous intercalations, a middle member composed of ignimbrites and volcanoclastic intercalations, and a mainly sedimentary upper member consisting of sandstones, shales, limestones, and andesitic and tuffaceous intercalations. The lava flows and breccias of the lower member were deposited in an extensional environment. In fact, East of Belén (Fig. 1) the lower part of this

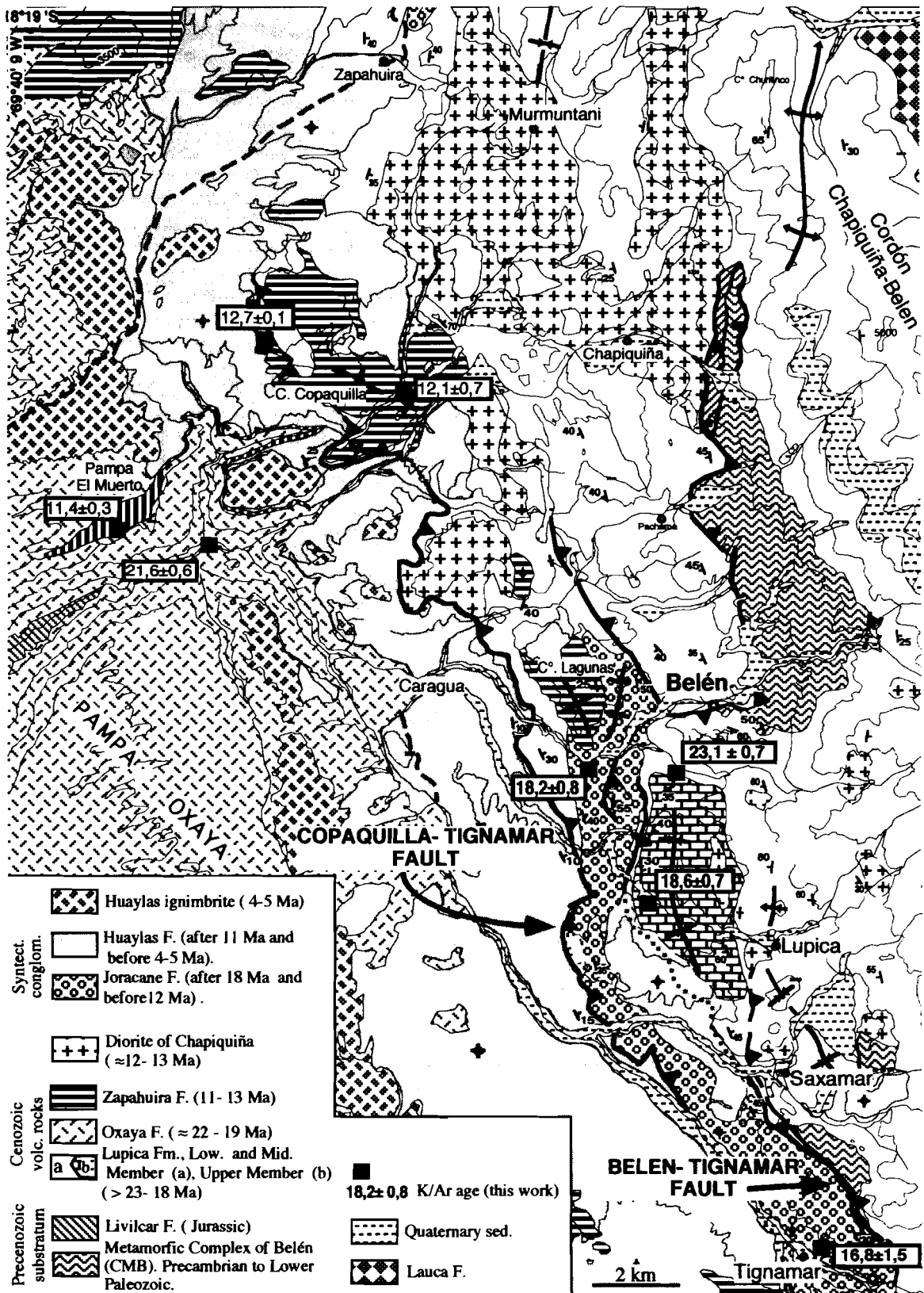


Figure 1: Geological map of the Belén Altiplano border.

member is in tectonic contact with the CMB. The lower layers of the Lupica Formation are more deformed than the upper ones. This indicates syntectonic deposition during extensional conditions and suggests that deformation ceased during deposition of the Lupica Formation. The presence of lacustrine deposits in this unit is an evidence for endoreic basins developed in active volcanic environments, probably caused by collapse of a caldera. These events occurred between 23 ± 0.7 Ma and 18 ± 0.7 Ma ago according to radioisotopic ages obtained in an ignimbrite layer from the floor of the middle member, and a tuff from the middle part of the upper member. We finally conclude that the Oxaya and Lupica Formations are coeval and that they were deposited during a long lasting episode of explosive volcanism and caldera development.

The Zapahuira Formation (García, 1996) forms an approximately 500 m thick series composed of andesitic, basaltic lavas and laharic flows of similar composition, that unconformably overlie the Oxaya and Lupica Formations, and the syntectonic conglomerates of the Joracane Formation. Three ages obtained in this newly defined unit fall between 11.4 ± 0.3 and 12.7 ± 0.1 Ma.

b) The syntectonic conglomerate deposits. The Joracane Formation (García, 1996) is composed by nearly 1.600 m thick conglomerates and rare volcanic intercalations. To the East, this unit is westwardly thrust by the Lupica Formation and the CMB, while to the West it thrusts also westwardly the Huaylas Formation (Fig. 1). These conglomerates are essentially composed by volcanic fragments of the Lupica Formation; calcareous clasts of the upper member of the Lupica Formation are locally present, as well as clasts of the CMB (Tignámar region). The conglomerates are of fluvial origin. They form metric to more meters thick, rather soft, layers. Measures of imbrication and the granulometric pattern indicate a sediment supply from areas located to the East. These areas were uplifted by activation of the Belén-Ticnamar. K-Ar ages on biotites from tuff levels intercalated in this conglomeratic series gave 18.2 ± 0.8 and 16.8 ± 1.5 Ma.

The Huaylas Formation (Salas et al., 1966) consists of conglomeratic deposits that unconformably overlie the Oxaya Formation and cover with progressive unconformity the units located to the East of the Copaquilla-Tignámar fault; to the west the Huaylas Formation onlap the Oxaya Formation. These conglomerates are also of fluvial origin. The sediment supply directions and the clast composition indicate a western provenance and an origin from the Lupica Formation and the CMB. The lower levels of this unit are deformed by the Copaquilla-Belén fault, while the upper levels are not deformed and extend to the East of the fault (Fig. 1). The Huaylas Formation lies over the Pampa El Muerto basalts which were dated 11.4 ± 0.3 Ma and contains Huayquerian fauna (Salinas et al., 1991). It is covered with strong angular unconformity by the 30 m thick Huaylas ignimbrite dated at 4.4 ± 0.3 and 4.8 ± 0.3 Ma (Naranjo and Paskoff, 1985).

AGE AND SEQUENCE OF THE CENOZOIC DEFORMATION

The early Miocene deposits lie directly on top of the Precambrian-early Paleozoic metamorphic complex and the marine Jurassic deposits. Cretaceous as well as early Cenozoic rocks, well exposed on the East side of the Altiplano, are not present in this region. It is, therefore, possible to conclude that the West margin of the Altiplano remained elevated and exposed to erosion for most of the Mesozoic and the early Tertiary. Early Miocene deposits accumulated in an extensive tectonic regime (most probably a caldera environment). After approximately 18 Ma the western border of the Altiplano was subjected to compressive deformation. The compressive episode, that came to an end between 8 Ma and 4-5 Ma, caused a series of westvergent folds and thrusts, and triggered the deposition of syntectonic conglomerates: Joracane and Huaylas Formations (Fig. 1).

The Joracane Formation is associated to activity of the Belén-Tignámar fault. This fault cuts across the conglomeratic series and no progressive unconformity was observed, suggesting a late reactivation phase. The activity of the Belén-Tignámar fault started at 18 Ma and stopped around 12 Ma.

The Huaylas Formation is associated to the Copaquilla-Tignámar fault. The activity of this fault began after 11 Ma and ended before 4-5 Ma, but well after 8 Ma. The synsedimentary deformation in this unit is well developed; its lower levels are folded and thrust, while the subhorizontal upper levels cover with erosional unconformity the upthrust block. The conglomeratic filling has been strongly eroded and an erosional level 100 to 150 m below the top of these conglomeratic series is sealed by the Huaylas ignimbrite. The remnants of the ignimbrite East of the Copaquilla-Tignámar fault (NW of Cerro Copaquilla) lie nearly one hundred meters above the general level of the ignimbrite, suggesting a late reactivation of the fault after 4-5 Ma.

The thrust faults, Belén-Tignámar, to the East, and Copaquilla-Tignámar, to the West are developed in sequence.

REFERENCES.

- BABY, P., HÉRAIL, G., LOPEZ, M., LOPEZ, O., OLLER, J., PAREJA, J., SEMPERE, T. et TUFÍÑO, D., 1989. Structure de la zone subandine de Bolivie : influence de la géométrie des séries sédimentaires antéorogéniques sur la propagation des chevauchements, *C. R. Acad. Sci. Paris*, 309, Série II, p. 1717-1722.
- BABY, P., SEMPERE, T., OLLER, J., BLANCO, J., ZUBIETA, D. et HÉRAIL, G., 1992. Evidence for major shortening on the eastern edge of the Bolivian Altiplano: the Calazaya nappe, *Tectonophysics*, 205, 1-3, p. 155-169.
- BASEI, M.A., CHARRIER, R. and HERVE, F. 1995. New ages (U-Pb, Rb-Sr, K-Ar) from supposed Pre-cambrian units in Chile: Some geotectonic implication. (Abstract). IGCP Project N° 376 Annual Meeting, 23-24 October 1995, Salta, Argentina.
- GUBBELS, T., ISACKS, B., FARRAR, E., 1993. High-level surfaces, plateau uplift and foreland development, Bolivian Central Andes. *Geology*, 21: 695-698.
- HÉRAIL, G., SOLER, P., BONHOMME, M., LIZECA, J. L., 1993. Evolution géodynamique du contact Altiplano - Cordillère Orientale au Nord d'Oruro (Bolivie) - Implications sur le déroulement de l'orogénèse andine, *C.R. Acad. Sci.* , 317, série II, p. 512-522.
- KENNAN, L., LAMB, S., RUNDLE, C. 1995. K/Ar dates from the Altiplano and Cordillera Oriental of Bolivia: implications for Cenozoic stratigraphy and tectonics. *J. of South American Earth Sciences*, 8,2, p.163-186.
- LAVENU, A. , 1986. Etude néotectonique de l'Altiplano et de la Cordillère Orientale de Bolivie, *Thèse de Doctorat d'Etat-ès-Sciences*, Univ. Paris Sud, Orsay, 434 p.
- MARTINEZ, C., 1980. Structure et évolution de la chaîne hercynienne et de la chaîne Andine dans le nord de la Cordillère des Andes de Bolivie. *Trav. et Doc. ORSTOM*, n°119, 352p.
- MEYER, H. C. et MURILLO, J., 1961. Sobre la geologia de las Provincias Aroma, Pacajes y Carangas, *Bol. Depto. Nat. Geol. La Paz-Bolivia*, 1, 47 p.
- MUNOZ, N. and CHARRIER, R. 1993. Jurassic-Early Cretaceous facies distribution in the western Altiplano (18°-21° 30' S.L.). Implications for hydrocarbon exploration. 2° *Symp. Intern. "Géodynamique Andine" (Oxford)* , ed. ORSTOM, Paris , p. 307-310.
- MUNOZ, N. and CHARRIER, R. in press. Uplift of the western border of the Altiplano on a west-vergent thrust system, Northern Chile. *J. of South American Earth Sciences*.
- NARANJO, J.A. and PASKOFF, R. 1985. Evolución cenozoica del piedemonte andino en la Pampa del Tamarugal, norte de Chile (18°-21° S). *Actas IV Congreso Geol. Chil.* 5. p.149-164.
- ROCHAT, Ph. et al. 1996. Geometry and kinematics of the northern Bolivian Altiplano within the Central Andes. *ISAG 96*, this volume.
- SALAS, R., KAST R., MONTECINOS F., SALAS, I. 1966. Geologia y recursos minerales del Departamento de Arica, Provincia de Tarapacá. *Inst. de Inv. Geol.*, Bol. 21. 130p.
- SALINAS, P., VILLAROEL C., MARSHALL, L., SEPULVEDA, P., MUÑOZ, N. 1991. *Tyotheriopsis* sp. (Notongulata, Mesotheridae), Mamífero del Mioceno Superior en las cercanías de Belen, Arica, Norte de Chile. *Actas VI Congreso Geol. Chil.* . p.314-317.
- SEMPERE, T., HÉRAIL, G., OLLER, J., et BONHOMME, M., 1990. Late Oligocene-early Miocene major tectonic crisis and related basins in Bolivia, *Geology*, 18, p. 946-949.
- SEMPERE, T. , HÉRAIL, G. , OLLER, J. , BABY, P., BARRIOS, L. et MAROCCO, R. 1990. The Altiplano: a province of intermontane foreland basins related to crustal shortening in the Bolivian Orocline area, 1° *Symp. Intern. "Géodynamique Andine" (Grenoble)*, ed. ORSTOM, Paris , p. 167-170.