OPPOSITE THRUST-VERGENCIES IN THE PRECORDILLERA AND WESTERN CORDILLERA IN NORTHERN CHILE AND STRUCTURALLY LINKED CENOZOIC PALEOENVIRONMENTAL EVOLUTION

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INTRODUCTION

Morphologic units in the northern Chilean Andes are parallel to each other and align parallel to the trench. These are, from west to east: Coastal Cordillera, Central Depression, Precordillera, Western Cordillera and Altiplano (Fig. 1). The development of the west part of the Western Cordillera (Chapiquiña-Belén Ridge), in the Chilean Altiplano, was controlled by two diverging, parallel-to-trench systems of thrusts and folds, one located along the Precordillera and the other along the east side of the Western Cordillera. Although total shortening associated with these systems is only 12 to 14 km, their activity determined the development of fluvial and lacustrine basins that registered the synorogenic paleoenvironmental evolution of this region. We describe here facies, geometry and chronology of the deposits associated with both systems and provide an explanation for the different environments developed on the Precordillera and the Western Cordillera.

STRUCTURE OF THE PRECORDILLERA AND WESTERN CORDILLERA

During the Early Miocene (approx. 18 Ma) a compressive episode began in this part of the Andes. Along the Precordillera a west-vergent thrust system developed in normal sequence: the Belén-Tignámar and Copaquilla-Tignámar thrust faults. Proximal to these faults, coarse sedimenatry wedges were deposited: the Joracane (18 to 16 Ma) and Huaylas (post-11 Ma to pre-5 Ma) Fms. Small landslides of parts of the Huaylas Ignimbrite (4.5 Ma), that cover unconformably the Huaylas Fm. suggest that compressive conditions lasted until the Pliocene. At the west side of the Chapiquiña-Belén Ridge an east-vergent thrust system caused the development of progressive unconformities and associated syntectonic sedimentary deposits: Chucal Fm.

Syntectonic fluvial deposits along the Precordillera: Joracane and Huaylas Fms.

The strong erosion of the relief generated by the activity of the Belén-Tignámar and the Copaquilla-Tignámar thrust-faults supplied abundant detritic materials towards the depressed areas located west of the faults. The Joracane Fm., close to the Belén-Tignámar

fault, corresponds to coarse, proximal fluvial facies deposited by braided river systems with low sinuosity. No fossils (plants or animals) were reported from this unit.

The fluvial, upward fining and coarsening Huaylas Fm. is associated with the Copaquilla-Tignámar fault. The lower levels are composed of thin layers deposited in a flood plain environment. Grain size increases gradually upward and at the top it contains blocks of 50 cm in diameter. Lower layers are slightly tilted to the west, while the upper levels are horizontal. To the east they locally cover the Copaquilla-Tignámar fault as well as the deformed late Oligocene?-early Miocene Lupica Fm. To the west they cover the scarps at the foot of the fault and they onlap on the Oxaya Fm. at the east-flank of the Oxaya Anticline (Fig.1a,b). The thickness of the Huaylas Fm. varies considerably. It fills a net of west draining paleovalleys that reached the present Central Depression. The present depressed area that contains the most of the outcrops of the Huaylas Fm. never was an endorreic basin. The lower levels contain fossil mammal remains (Notoungulates) (Bargo and Reguero, 1989; Salinas et al., 1991) of the Huayquerian (Salinas et al., 1991) South American Land Mammal Age (SALMA) of about 9 to 7 Ma (Flynn and Swisher, 1995).

Syntectonic fluvial and lacustrine deposits on the east side of the Chapiquiña-Belén Ridge: Chucal Fm.

East of the Chapiquiña-Belén Ridge the Lupica Fm. is eastwardly deformed by a partially blind, east-vergent thrust system (Chucal thrust-system). This system, interpreted as a backthrusting of the west-vergent thrust system located along the Precordillera (Hérail et al., submitted), caused the development of progressive unconformities and associated syntectonic sedimentary deposits: lower member (post-21 Ma) and upper member (pre-11 Ma) of the Chucal Fm., that transitionally grades to the late to post-tectonic Lauca Fm. The uplift caused by the western fault (Chucal fault) of this system, exposed immediately west of the Chapiquiña-Belén Ridge, supplied the sediments that formed the Chucal Fm. and part of the Lauca Fm. The fluvial and lacustrine Chucal Fm. (Muñoz, 1991; Riquelme and Hérail, 1997) is unconformably deposited on the Lupica Fm. and is deformed by a growth fold. Although the Chucal and Lauca Fms. were deposited in fluvial and lacustrine environments, fluvial facies predominate in the Chucal Fm., while lacustrine environments prevail in the Lauca Fm. The **lower member** of the Chucal Fm. begins with immature conglomerates composed by fragments of ignimbrite and lavas of the Lupica Fm. and fluvial sandstones. Provenance is from the west and southwest. These are followed by siltstones, marls and limestones in decimeter thick layers deposited in flood plain and lacustrine environments. The lacustrine deposits contain well preserved plant stems and leaves. Vertebrate fossils have not been found in this sequence. The series continues with mudstones and siltstones deposited in a flood plain environment, that contain a rich mammal fauna. The **upper member** begins with a coarse fluvial sequence composed of green conglomerates, followed by sandstones and siltstones with limestone intercalations at the top, also deposited in flood plain and lacustrine (more restricted) environments, that contain no mammal fossils. The sequence evolves upward toward higher energy deposits, which are also fossiliferous, and are covered to the west by the Chucal fault and to the east, in the basin, by the 11.2$\pm$0.5 Ma Chucal Ignimbrite. The Chucal Ignimbrite is covered by conglomerates composed of andesitic clasts, on top of which rests the Lauca Fm.

FOSSIL MAMMAL CONTENT

An extensive mammalian fauna has been recently recovered from the Chucal Fm. (Charrier et al., 1994a; Flynn et al., 1999). Specimens were collected from different stratigraphic levels. The current faunal list includes: hegetotheriine hegetothere, at least 2 mesotheriine mesotheres, toxodon, macraucheniid litoptern, chinchillid rodent, armadillo, turtle carapace pieces, and several bird bones (large and small size).

THE MIDDLE CENOZOIC FAUNAS

Taxa in the assemblages found in northernmost Chile range elsewhere from Santacrucian to Chasicoan or Huayquerian, with most overlapping in the "Friasian". As these are the northernmost Cenozoic mammalian fauna(s) known from Chile, these assemblages from the Huaylas and Chucal Formations permit comparisons of an extensive latitudinal series (more than 30 degrees) of middle Cenozoic faunas from west of the Andean crest (Casamayoran? and "Tinguiririca" [pre-Deseadan, post-Mustersan] through Santacrucian and the type "Friasian"). The occurrence of these faunas at a critically important modern biotic disjunction (Atacama Desert – Bolivian Orocline bending axis), directly west of well known Cenozoic faunas from a variety of paleoelevations in the Altiplano and other regions of Bolivia, may allow assessment of the biotic history along an east-west transect from Chile to eastern Bolivia.

CONCLUSION

Tectonic evolution along the western Altiplano occurred under prevailing compressive condition since 18 Ma that caused the development of a west-vergent thrust system and some east-vergent backthrusts associated with growth folds. These diverging systems generated an uplifted ridge located along the Precordillera and the present Western Cordillera. During development of these structures and uplift of the ridge, considerable amounts of syntectonic deposits accumulated at both sides of the ridge which contain mammalian remains.

On the west side of the ridge, the described evolution determined geomorphologic conditions that favored aridity and rapid drainages of rain and melt waters towards the Central Depression, which can explain the relative scarcity of fossil faunas and the absence of fossil flora. At the east side, on the Chilean Altiplano, geomorphologic conditions favored the development of flood plains and shallow lakes with considerable accumulation of finer sediments that contain abundant mammalian remains. This indicates that, as a consequence of the Middle Miocene tectonic activity, a partition of the environmental conditions occurred west and east of the present Western Cordillera. According to the paleofloras known from this Andean region, that indicate for that time a relatively low altitude in Chile (Charrier et al., 1994b) as well as in Bolivia (Berry, 1919, 1922; Gregory-Wodzicki et al., 1998), this partition is to be attributed primarily to a topographic barrier, the Chapiquiña-Belén Ridge, and not to Andean uplift.

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