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Tectonic evolution of northern Ñirihuau basin, northwestern Patagonia, Argentina

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INTRODUCTION

The study area is located in northwestern Patagonia, towards the southwest of *San Carlos de Bariloche* town, from 41°09´ to 41°28´ SL, and 70°56´ to 71°20´ WL (figure 1a). At these latitudes, intensely deformed volcanic and sedimentary Tertiary rocks crop out on the eastern border of the Northern Patagonian Andes, conforming the Ñirihuau Fold and Trust Belt. During Oligocene-Miocene times the Ñirihuau basin was developed in the area. A number of previous studies were carried out in the region, but there is not consensus regarding the tectonic origin of the Ñirihuau basin. First interpretations mentioned Ñirihuau as a typical foreland basin developed in response to Andean uplift (Ramos and Cortés, 1984), theory that was later adopted by Giacosa and Heredia (1999). Dalla Salda and Franzese (1987) and Spalletti and Dalla Salda (1996) interpreted the basin as a pull-apart related to regional strike-slip movements. However, Mancini and Serna (1989) noted the presence of normal faults limited depocentres, favoring an extensional origin.

The aim of this work is to contribute with new stratigraphical and structural data that will help to better understand the Tertiary tectonic evolution of the area, specially the tectonic framework on which the Ñirihuau basin was originated and developed. We integrate our observations with previous studies to have a more complete panorama of the basin evolution.

CENOZOIC TECTONIC EVOLUTION

Oligocene: Extensional tectonic regime

The main volcanic arc was first developed along the NO striking Pilcaniyeu Belt (60 to 40 Ma), and migrated later westward to the NNO striking El Maitén Belt (33 to 23 Ma, Rapela *et al.*, 1988). The Pilcaniyeu Belt latest products are Upper Oligocene retroarc olivinic basalts (Dessanti, 1972; Rapela *et al.*, 1988). The geochemistry of both belts shows calcalkaline characteristics (Dalla Salda *et al.*, 1981), but rocks evolve to more basic and Fe-enriched terms, interpreted as the result of progressive cortical thinning (Rapela *et al.*, 1983). In addition, El Maitén Belt volcanics have geochemical characteristics similar to rocks associated with a normal oceanic source (Kay and Rapela, 1987). On the other hand, there are marine sedimentary rocks deposited during a Pacific ingression (Ramos, 1982) interbedded within El Maitén Belt volcanic rocks.

We propose as an hypothesis that the volcanic arc migration toward the west in the Early Oligocene was associated to a Farallon oceanic plate steepening, which was being obliquely subducted below the Sudamericana plate (figure 1b). The above mentioned petrographical and geochemical characteristics of the Paleogene volcanic rocks and their evolution toward oceanic affinity terms, suggest that during Middle to Late Oligocene the study

area was under an extensional tectonic regime that caused a progressive cortical thinning. We also associate the marine ingression to the cortical extension, because there is no evidence of a strong contemporaneous compressive deformation that could allow us to link it to an important load type subsidence, as occur with the Miocene Atlantic ingressions (Paranaense Sea).

Several basins with Upper Oligocene - Lower Miocene volcaniclastic, marine and/or volcanic infill were developed between the 33° and 45° SL (Jordan *et al.*, 2001). These basins were located at forearc, arc and retroarc positions, and some of the best known are Coya-Machalí, Cura-Mallín, Osorno-Llanquihue and Ñirihuau basins. This simultaneous basin opening along an extended Andean segment is another strong evidence of an extensional tectonic regime active during Late Paleogene.

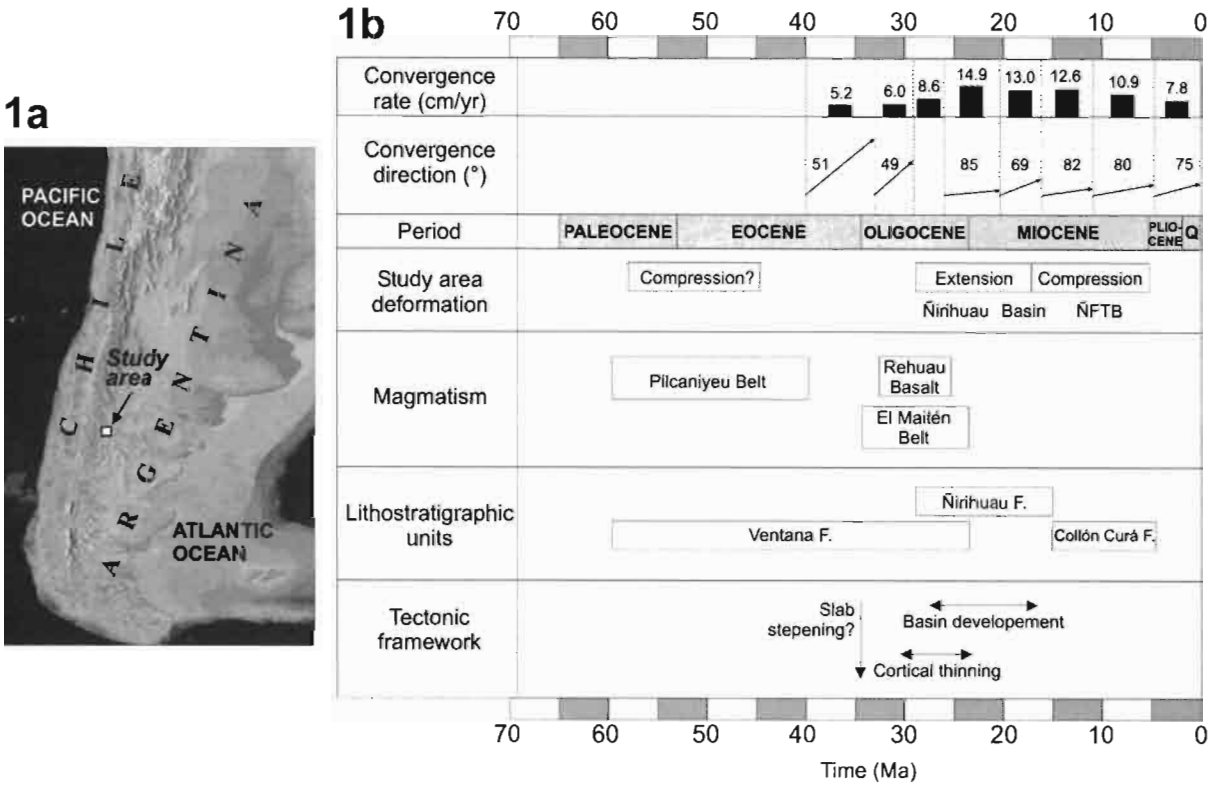

Figure 1. a) Shaded relief map of southern South America, showing the study area location. **b)** Schematic chart with the general evolution of the study area (convergence data obtained from Somoza, 1998).

Ñirihuau basin origin

During Late Oligocene, between 41° and 43° SL, the elongate N to NW striking Ñirihuau basin was originated at the eastern side of the El Maitén Belt. The basin is strongly asymmetric, and the main depocentres are located at its westernmost sector. They are limited by normal faults, and their infill starts with Upper Oligocene fan-delta and associated lacustrine deposits, which show great lateral changes and scarce areal development (Mancini and Serna, 1989; Bechis, 2004). The basin infill continues with meandering river deposits (Bechis, 2004), followed by another lacustrine sedimentary rocks characterized by considerable areal expansion and onlap relationship

with previous deposits (basal Low Miocene; Mancini and Serna, 1989; Bechis, 2004). Later on, deltaic and fluvial deposits prograded over the lacustrine sedimentary rocks, completely filling the basin (Bechis, 2004).

The normal faults which limit depocentres suggest that the origin of the basin was linked to the extensional processes that affected the region in the Middle to Late Oligocene. The basin asymmetry evidences that cortical thinning or extension was more important in the western sector, probably due to a greater thermal gradient in Oligocene volcanic arc location (El Maitén Belt). Fan-delta and associated lacustrine sedimentary rocks are interpreted as sinrift deposits, while the second lacustrine environment was probably associated to a sag period related to thermal subsidence due to lithosphere cooling after the end of extension.

Miocene compressive deformation

The study area includes the eastern border of the Northern Patagonian Andes, characterized by the development of the Ñirihuau Fold and Thrust Belt. In the westernmost part of the area there is a basement block composed by Colohuincul Complex metamorphic rocks and Patagonian Batolith plutons, which is uplifted by a moderate angle inverse fault. In the central area strongly deformed volcanic and volcaniclastic Tertiary rocks (Ventana and Ñirihuau Formations) crop out. Structures are generally east vergent NNW-striking, and show a subparallel arrangement of varied wave length, generally asymmetric folds, thrusts and some backthrusts.

The Ventana and Ñirihuau Formation sequences have been deformed together, as is evidenced by the presence of a basement wedge that can be clearly seen on seismic lines (Bechis, 2004). The Collón Curá Formation sedimentary rocks lie over the Ñirihuau Formation deposits through an angular unconformity and do not present any evidence of deformation in the study area, indicating that compressive deformation started before its deposition, during the basal Middle Miocene. Therefore, Ñirihuau Formation upper levels (basal Middle Miocene) and the Collón Curá Formation volcaniclastic rocks (Middle to Upper Miocene) are interpreted as synorogenic deposits associated with the Miocene tectonic uplift.

During Pliocene times orogenic activity ended at the eastern border of the Northern Patagonian Andes and migrated to the Chilean territory, accommodating deformation in a N-striking dextral transpressive system, the Liquiñe-Ofqui Fault Zone (Lavenu and Cembrano, 1999; Folguera and Ramos, 2002). Volcanic arc activity also moved westward during the Pliocene, and now is located in the eastern border of the Chilean Central Valley.

CONCLUDING REMARKS

New geological evidences, integrated with previous ones and analyzed together into a regional tectonic framework, support the theory of a cortical extension origin for the Ñirihuau basin during the Middle to Late Oligocene. From basal Middle Miocene to Lower Pliocene (?) the basin acted as a foreland basin. Therefore, the Ñirihuau basin suffered changes in its subsidence main mechanism along its span life, as a result of the change from an extensional basin to a foreland one.

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