# INTRACONTINENTAL SEISMICITY AND NEOGENE DEFORMATION OF THE ANDEAN FOREARC IN THE REGION OF ARICA (18.5°S-19.5°S)

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## INTRODUCTION

The superficial crustal seismic activity in Chile is remarkably moderate. Almost all the Chilean earthquakes are located on the subduction plane, and most of the intracontinental seismicity that results from the growth of the Cordillera occurs on the Eastern side of the Andes, in Bolivia and Argentina. Geological data, indeed, in agreement with the seismological measurements, show that the Chilean forearc suffered very moderate deformations in the Neogene [e.g. Lamb et al., 1997; García et al., 1997], in spite most of the surrection of the Altiplano probably occurred at that time [e.g. Gregory-Wodzicki, 2000]. The only region in Chile where significant crustal seismicity has been reported in the forearc is the northernmost part of the country, near Arica, where a permanent seismic network evidences an intracontinental forearc seismicity that vanishes south of 19.7°S. In this work, we describe the main characteristics of this seismicity, the associated tectonics of the area, and its possible relations with the growth of the Altiplano.

## GEOLOGICAL DATA

The forearc and volcanic arc of the Andes near Arica can be divided in four main longitudinal morphological units, which are from west to east: (1) The Coastal Cordillera composed by Jurassic and Cretaceous volcanic rocks, (2) the Central Depression filled by Cenozoic sediments, (3) the Precordillera mainly composed by Miocene ignimbrites and detritic series overlying Mesozoic rocks, and (4) the Western Andean Cordillera behind which the present-day volcanic arc is developed. The Precordillera corresponds to a regular slope that joins the Central Depression whose mean elevation is 1000 m, with the 4000 m high Western Cordillera.

Active folds, thrusts and faults are scarce in the forearc of the Arica zone [e.g. Muñoz and Charrier, 1996; Lamb et al., 1997]. The Quaternary activity of the East-vergent thrust-faults and related growth anticlines that separate the Western Cordillera from the Altiplano (Lauca Basin) [Riquelme, 1998] is not well documented, although near Guallatire, the Quaternary sediment of the Lauca river is deformed. The so called "west vergent Thrust System" [Muñoz and Charrier, 1996] that emerges in the Putre-Belen area West of the Western

Cordillera may also be active, as suggested by the vertical displacement of the Upper Pliocene ignimbrites. The Precordillera is bounded to the West by the Ausipar fault, that has essentially been active during the Miocene. Anyway, the Neogene shortening accommodated by all these thrust-faults has been smaller than 10 km, which represents only a marginal part of the shortening accommodated in the Central Andes, and cannot explain much of the thickening of the continental crust below the Western Cordillera at that time [e.g. Rochat et al., 1999; Rochat, 2000; García, 2001].

## SEISMOLOGICAL DATA

The data used in this work can be divided into two sets, 12000 events registered by the Arica permanent network, and 3000 events registered during temporary field works. The Arica permanent network (Fig. 1) is composed of 13 telemetric short period stations and is operating since December 1994. The two additional temporary field works (Fig. 1) deployed dense local short period seismic networks, providing reliable data that permit to better constrain the shallow seismicity recorded by the permanent network. Hypocenters were determined using a modified version of the HYPOINVERSE program [Klein, 1978]. We located about 60 intracontinental earthquakes West of the Altiplano at depths between 10 km and 60 km, and obtained 30 well-constrained focal mechanisms with good azimuth coverage.

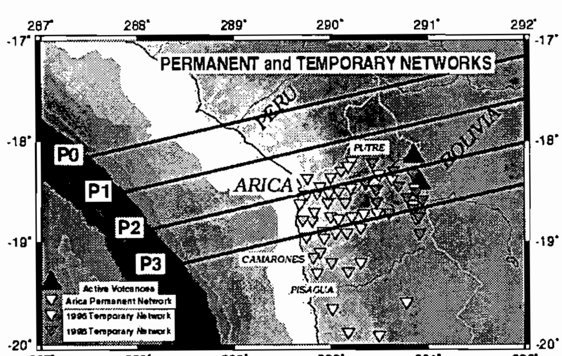


Figure 1 : Spatial distribution of the permanent and temporary networks in the Arica region.

## INTRACONTINENTAL SEISMICITY OF THE ARICA REGION

The two cross sections presented in Fig. 2 show that most of the earthquakes occur on the east-dipping Wadati-Benioff zone, where a double-layered seismic zone appears at intermediate depths [Comte et al, 1999]. Many earthquakes, however, are located above the subduction zone, and evidence seismic deformations within the South America continental plate. In the Altiplano, seismicity is very shallow (0-10 km). Although some earthquakes could be correlated with the activity of volcanoes (e.g. Guallatire), most of them should result from the activation of crustal faults. In the forearc below the Precordillera and the Central Depression, crustal events are defining a seismic zone that dips about 45° toward the trench, and that is almost perpendicular to the dip of the subducting slab at that depth (David et al., 2001).

The 31 reliable focal mechanisms of intracontinental events show a wide variability of focal mechanisms between nearby events (Fig. 2), which is the usual expression of microseismic events. We performed formal inversions of the best fitting stress-tensor, following the technique developed by Rivera and Cisternas [1990], first for the profile P2 forearc events, then for those of profile P3, and finally for all the forearc seismicity. The three calculated stress tensors show the same compressive regime, with a maximum stress axis $\sigma_1$ oriented N75E° and dipping 30° to the West. This result suggests that the intracontinental west-dipping seismic corresponds to an east-vergent reverse fault (Fig. 3).

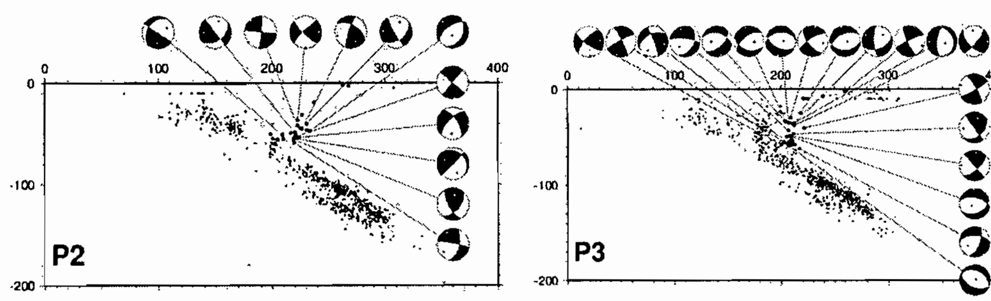


Figure 2 : Cross-sections showing the seismic events localized on profiles P2 and P3 (see Fig. 1 for the location of the cross sections). Focal mechanism solutions are projected on the northern hemisphere.

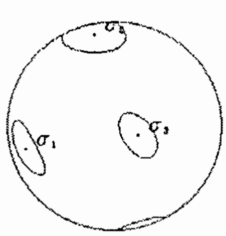

Figure3 : Stress Tensor obtained from the intraplate forearc seismic events.

## DISCUSSION AND CONCLUSIONS

Forearc earthquakes are located between 2 km and 59 km depth with a large concentration of earthquakes at the largest depths, between 50 km and 59 km. The intracontinental seismicity belongs therefore both to the upper lithospheric mantle and to the crust of the South America plate, the depth of the Moho varying from 40 km under the coastal Cordillera to 60 km under the volcanic arc. The contrast between the seismic behavior of the forearc on the one hand, and that of the Western Cordillera and Altiplano on the other hand, is remarkable. The western Altiplano does not show any seismicity at depths larger than 10 km, while in the forearc earthquakes are observed from the surface up to 60 km depths. This different behavior probably results from the difference between the rheological profile of the forearc, that remains cold, rigid and brittle at large depths, and that of the Altiplano and Western Cordillera, that is characterized by a ductile low viscosity middle and lower crust. The west-dipping forearc seismic plan may correspond to the thermal and rheological boundary between the rigid forearc block and the soft crust of the magmatic arc (David, 2002).

This seismic plan emerges in the Western Cordillera (Fig. 4). Its position suggests that the superficial thrust-faults that have been reported on both sides of the Western Cordillera may be associated with this deep east-vergent reverse fault. The geometry of the superficial Western Cordillera tectonic structures does not constrain the vergence of the deep related thrust-fault. The Neogene thrust-faults of the Western Cordillera are minor accidents that do not accommodate much shortening, and they cannot have accommodated much of the surrection of the Altiplano. This surrection has essentially been accommodated west of the volcanic arc, by the weak tilting of the entire chilean forearc, and in the Altiplano by the flow of weak ductile crust coming from the

East and resulting from the underthrusting of the Brazilian Craton [Lamb et al., 1997]. Then, we propose that the deep thrust-fault that results in the shortening of the Western Cordillera in the Arica region dips to the West below the forearc. This fault may be expected to result from the westward flow of lower crust below the Altiplano. The surrection of the Altiplano resulting from this deep flow, in turn, may have been accommodated by the tilting of the forearc above this deep east-vergent thrust fault (Fig. 4).

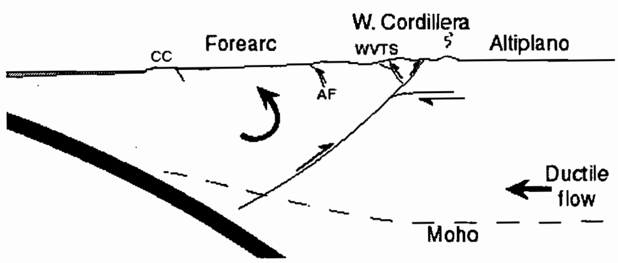


Figure 4 : Diagram illustrating the Neogene to recent kinematics of the western Margin of the Central Andes.

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