STRUCTURE OF THE ANDEAN FOOTHILLS, CHOS MALAL REGION, NEUQUEN BASIN, ARGENTINA

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INTRODUCTION

The Neuquén Basin of West-Central Argentina (Fig. 1) was formed in the late Paleozoic to early Mesozoic as a result of continental rifting (Legarreta and Uliana, 1991; Uliana and Legarreta, 1993; Urien and Zambrano, 1994; Vergani *et al.*, 1995). During the Mezosoic and Cenozoic, more than 7 km of sediments were deposited, including marine, continental and volcanoclastic units.

In general, the Neuquén Basin has been well studied, because it produces petroleum (Uliana and Legarreta, 1993; Urien and Zambrano, 1994). However, the western reaches in the Andean foothills are less well known.

We have studied the Chos Malal region, where well-exposed sections provide insights into basin development, inversion and the formation of Andean structures.

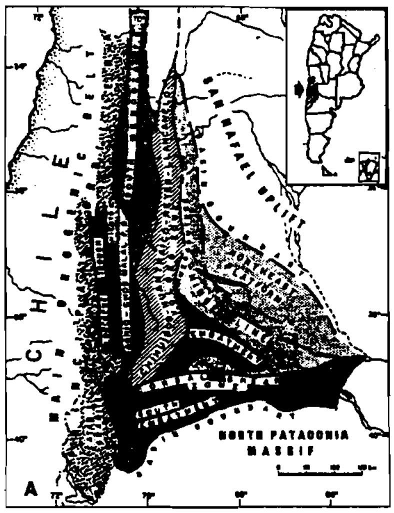


Fig. 1. The Neuquén Basin (after Urien and Zambrano, 1994).

DEVELOPMENT OF THE NEUQUEN BASIN

In the western Neuquén Basin, late Paleozoic volcanic units (Andacollo and Choiyoi groups, Fig. 2) form the top of economic basement (Urien and Zambrano, 1994). They were deposited in an intra-arc setting. From the Triassic to the Early Cretaceous, a phase of extensional tectonics resulted in half-grabens, trending NNE to N (Manceda and Figueroa, 1995; Urien and Zambrano, 1994; Uliana *et al.*, 1995; Vergani *et al.*, 1995). Two major marine cycles (Jurásico and Andico) occurred between the Liassic and the end of the Albian, while the basin was in a back-arc position (Legarreta and Uliana, 1991). Each cycle resulted in thick black shales, passing upwards into sandstones or evaporites (Fig. 2). Near the base of the Jurásico cycle, the Los Molles Fm. contains many layers of tuff and a major turbidite, indicating strong tectonic control on the development of the basin, which was near a volcanic arc.

From the Cenomanian to the Paleogene, continental sandstones of the Riograndico cycle appear to have been deposited in a foreland basin (Barrio, 1990; Vergani *et al.*, 1995). During the Cenozoic, abundant volcanoclastics show that the basin was in an intra-arc setting.

STRUCTURE OF THE CHOS MALAL AREA

Our structural map (Fig. 3) and cross-sections (Fig. 4), drawn on the basis of fieldwork, Landsat images and subsurface data, show two structural domains: one north of Chos Malal, dominated by thick-skinned thrusting; the other, south of Chos Malal, showing only thin-skinned structures.

In the northern domain, two mountains nearly 3000 m high (the Cordillera del Viento and the Tromen volcano) have formed above eastward-verging blind thrusts (Uliana *et al.*, 1993; Urien and Zambrano, 1994; Uliana *et al.*, 1995). The Cordillera del Viento, which started as a ramp anticline and became a pop-up, brings late Paleozoic basement to outcrop. Further east, the Pampa de Tril thrusts detach within Paleozoic basement. Here, the cover has been backthrust westwards (Viñes, 1990), detaching on Aptian evaporites (Huitrín Fm.). The resulting triangle zone forms the current mountain front.

In the southern domain, the basement does not crop out. Thin-skinned structures include thrusts and folds. Anticlines are typically box folds with km-scale wavelengths and their hinges can be followed for several tens of kilometers along strike. Synclines tend to be wider, reaching 15 km in the south. In general, fold axes trend N160° to N170° throughout the area, but there are some anomalies (Fig. 3): (i) the southern edge of the Cordillera del Viento anticline trends N060°, instead of N170° elsewhere; (ii) around Tromen volcano, folds swing from N to NE on the southeastern side and from N to NW on the southwestern side; (iii) SE of Collipili, fold axes trend N060°.

Within the cover sequence, there are several detachments. The uppermost is in the Aptian Huitrín Fm. (Viñes, 1990; Vergani *et al.*, 1995), where up to 300 meters of halite are known from subsurface data (Gabriele, 1993). Other detachments are in thick black shales of the Los Molles and Vaca Muerta formations (see Vergani *et al.*, 1995). On reaching the Los Molles, the basement thrust ramp of the Cordillera del Viento passes upwards into a flat, visible on a seismic line. As for the Vaca Muerta shales, they fill the cores of detached anticlines in the southern domain (Fig. 4b) and anomalous thicknesses have been encountered locally in wells. In general, the shales are overpressured (Vergani *et al.*, 1995).

We have measured fault-slip data at 6 localities in Late Cretaceous rocks (Fig. 3) and 19 localities in Jurassic rocks. The data were analyzed using the method of right dihedra (Angelier and Mechler, 1977). In Late Cretaceous rocks, the principal direction of shortening is sub-horizontal. For localities 1, 2 and 3, the principal shortening trends N070°, sub-perpendicular to regional fold trends and sub-parallel to the convergence direction of the Nazca plate since 49 Ma (Pardo-Casas and Molnar, 1987). In contrast, for localities 4, 5 and 6, the principal shortening trends N170°. The significance of this result is not clear. In Jurassic rocks west of Chos Malal, the principal shortening is either sub-vertical (associated with normal faults) or sub-horizontal (associated with strike-slip faults). The principal extension trends NE, but varies with age (from N020° before the Kimmeridgian to N100° in the Kimmeridgian). Negative flower structures and synsedimentary faults are common. The latter show stratigraphic thickness variations (growth) or evidence for burial in the last stages of faulting. Thus the tectonic context was extensional or transtensional during much of the Jurassic.

There is evidence for basin inversion during the Late Cretaceous and Tertiary. 1. On seismic evidence, most eastwards-verging thrust flats and ramps are reactivated Jurassic normal faults (see Manceda and Figueroa, 1993; Urien and Zambrano, 1994; Uliana *et al.*, 1995; Vergani *et al.*, 1995). 2. West of Chos Malal, we have found at outcrop several examples of listric normal growth faults, reactivated as reverse faults. 3. The southern edge of the Cordillera del Viento was a lateral thrust ramp during Andean compression, but may have been an extensional transfer fault during the Jurassic. 4. In the southern domain, linear belts with anomalous northeasterly fold trends may also be reactivated Jurassic transfer faults. Tertiary volcanic sills around Collipilli have two main trends (Llambias and Malvicini, 1978), one parallel to regional fold axes, the other at N040° to N060°, parallel to anomalous fold trends.

As for the fold axis deviations around the southern edge of the Tromen volcano, we suggest that they are due to gravitational collapse during the Tertiary.

On seismic evidence, Andean compression began during the Late Cretaceous (Vergani *et al.*, 1995). It reached a paroxysm during the late Paleocene and early Eocene (Manceda and Figueroa, 1993; Vergani *et al.*, 1995). Thus the Sierra Mayal (Zollner and Amos, 1973), an intrusive andesitic porphyry of Eocene age, cuts a large anticline. The cross-cutting Collipilli volcanic sills are also Eocene in age (Llambias and Rapela, 1989). Deformation induced by collapse of the Tromen volcano appears to be later than Pleistocene-Holocene basalts.

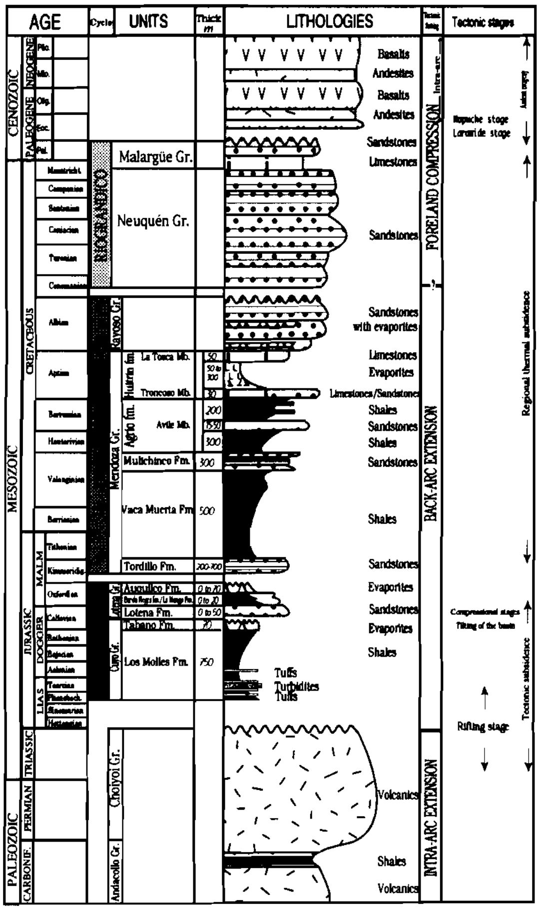


Fig. 2: Stratigraphic chart for the western part of the basin.

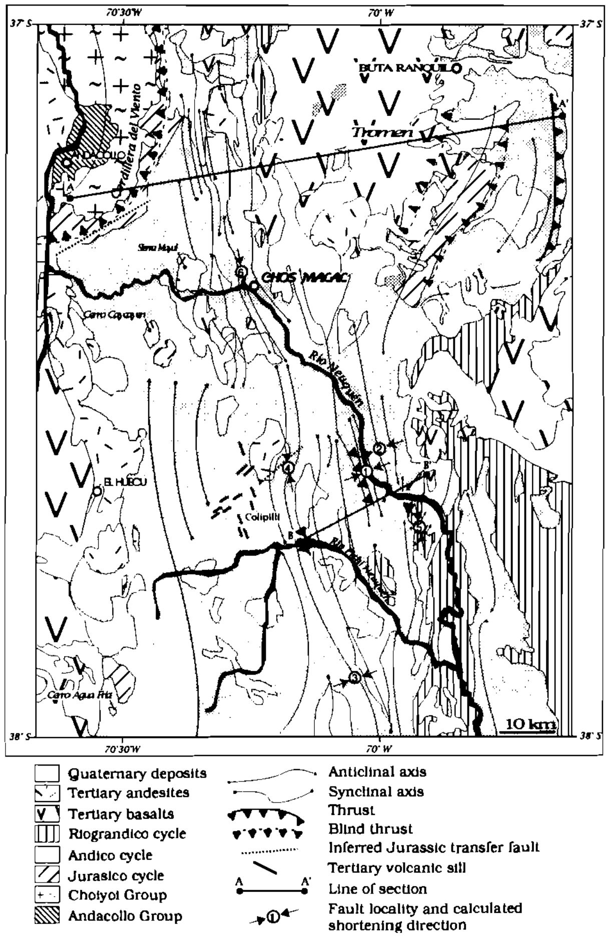
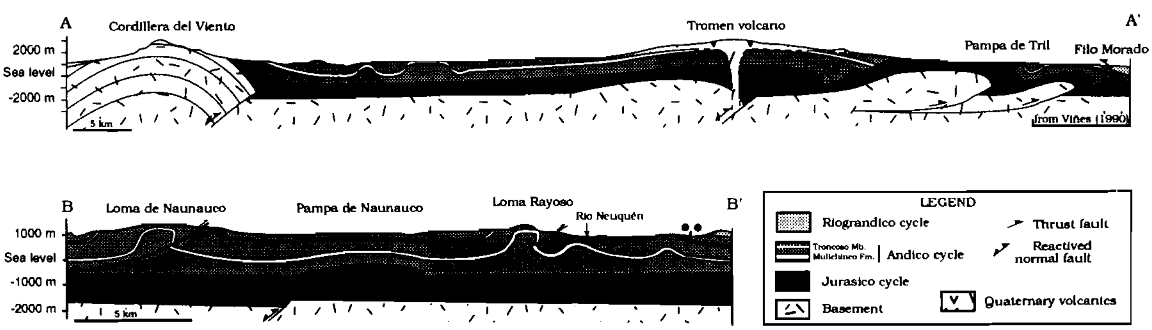


Fig. 3: Simplified geological and structural map of the Chos Malal area.



Figures 4a and 4b: Structural cross sections of the Neuquén Basin foothills (see Fig. 3 for section lines).

CONCLUSIONS

In the Chos Malal area, Andean shortening of Paleogene age is responsible for thin-skinned deformation of the Mesozoic sedimentary cover on at least three levels of detachment. In the northern domain, thick-skinned deformation involved eastwards-verging basement thrusts, formed by reactivation of Jurassic normal faults. Jurassic transfer faults, striking NE, were also reactivated and may be responsible for anomalous fold trends and lateral thrust ramps. The main Andean deformation ended before the Oligocene. The Tromen volcano, formed during the Quaternary, locally modified the structural pattern.

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