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Foreland basins evolution and lithospheric rigidity: 2D flexural modelling along an E-W profile in the Central Andes

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INTRODUCTION

Since the late Oligocene ongoing shortening produced fold and thrust belts in the backarc region of the Central Andes, which led to the development of foreland basins. The formation of foreland basins is related to regional isostatic compensation of fold–thrust belt loading, involving numerous processes: crustal thickening, mass transport by erosion-sedimentation, regional isostatic subsidence, possible mechanical decoupling between crust and mantle, etc. Many authors have previously applied 2D flexural models to study the evolution of the Central Andes foreland basin systems (e.g. Flemings and Jordan 1989, DeCelles and Horton 2003). The isostatic compensation considered by these authors assumes that the lithosphere behaves as an homogeneous elastic plate with laterally constant rigidity. However, the rigidity of the Andean lithosphere shows strong variations (e.g. Tassara and Yáñez 2003).

We used tAo software (García-Castellanos *et al.*, 1997). This program permits to apply different lithospheric rheologies and varying rigidities along the modelled profile. It allows to carry out comparisons between elastic thicknesses calculated by completely different techniques and at the same time to model the evolution of the foreland basins. We modelled an E-W profile along 21.4°S in order to reproduce the Subandean basins evolution and the Cordillera Oriental and Sierras Subandinas uplift history through time (Fig. 1)

METHODOLOGY

The program tAo is designed to model the formation of foreland basins, applying the finite-difference technique. The main advantages of this code are: (1) the possibility to use time-varying load distribution (simulating thrust tectonics and orogen kinematics; (2) to account for erosion and sedimentation; (3) to use different lithospheric rheologies (elastic and elastic-plastic) accounting for lateral variations of lithospheric rigidity or elastic thickness; and (4) to use the elastic-plastic model and the concept of yield-stress envelope to calculate the elastic thickness.

To further constrain the final crustal geometry, the program computes gravity anomalies corresponding to the final mass distribution. The gravity field is assumed to be affected only by crustal geometry, load units (thrusts), sediment and water.

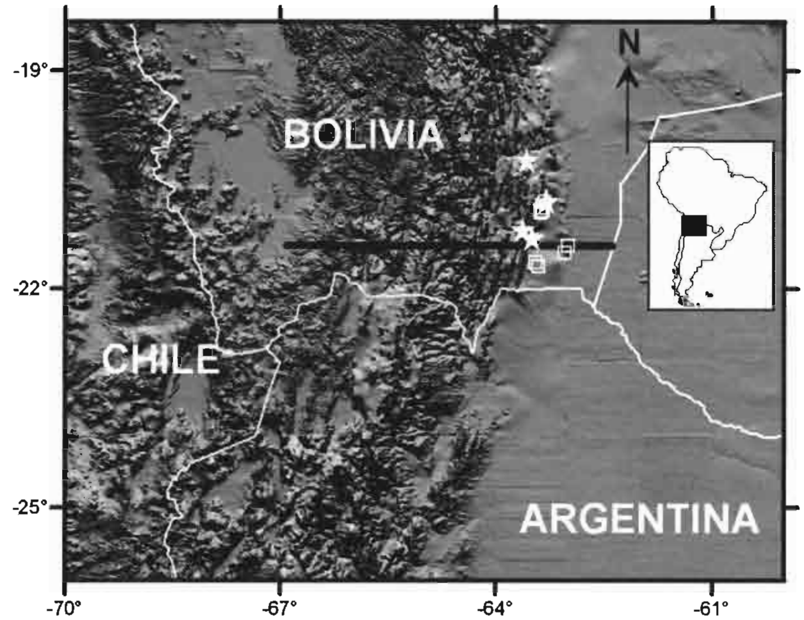

Figure 1: Location map. Black line: modelled profile. Stars: sedimentary thicknesses measured in the field. Squares: sedimentary thicknesses from well logs.

INPUT DATA

1. ***Structure:*** The deformation by shortening was kinematically introduced in the model, each fault having its own geometry, position, amount of shortening and timing of activity. It was considered that the Cordillera Oriental underwent a shortening of 50km between 40–30Ma, the Interandean Zone was shortened 40km between 30-11Ma and the Sierras Subandinas suffered a shortening of 100km between 11– 0Ma (e.g. Kley *et al.* 1997, Ege 2004) . Balanced cross sections were taken into account to define the thrust loading process through time along the profile (e.g. Kley *et al.* 1997, McQuarrie and DeCelles 2001).

2. ***Erosion and sedimentation:*** Published values of the diffusive erosion constant, and of sedimentation rates were used [Diffusive erosion constant: $3x10^9$ m^2/My (Flemings and Jordan 1989), Sedimentation rates below water level in the Subandean basins: $7x10^2$ m/My (Echavarria *et al.* 2003)]. A continental erosion rate of 0.01 m/mMa was considered.

3. ***Densities***: Sediments: 2200 kg/m^3, Crust: 2900 kg/m^3, Mantle: 3330 kg/m^3, Loads: 2800 kg/m^3.

4. ***Rheology:*** Two different rheological behaviours for the lithospheric plate were applied: pure elastic and elastic-plastic. In the first case varying values of elastic thickness along the profile were considered (we used the present day values proposed by Tassara and Yáñez 2003). In the second case the initial geotherms for the Cordillera Oriental and the Sub Andean basins before deformation proposed by Springer (1999) were used. An initial crustal thickness of 35 km and an initial upper crustal thickness of 15 km were considered.

CONSTRAINING DATA

1. ***Uplift History***: Updated paleoelevation curves are used for comparison with the modelled paleoelevations.
2. ***Subandean basins evolution:*** New stratigraphic data obtained from industrial well logs and collected in the field through the measurement of type sections in the Sierras Subandinas along the Pilcomayo river are used for comparison with modelled sedimentary thicknesses along the profile through time (Fig. 1).
3. ***Actual Topography***: The predicted topography is compared with digital elevation models.

4. ***Bouguer Anomaly:*** Calculated gravity anomalies corresponding to the final mass distribution along the profile are compared with the corresponding measured ones.
5. ***Actual elastic thicknesses:*** For the elastic-plastic rheology (Tassara and Yáñez 2003).
6. ***Actual crustal thickness:*** Moho depths (Tassara and Yáñez 2003, Yuan *et al.* 2002)

RESULTS AND CONCLUSIONS

We compared the model predicted and the measured thicknesses along the profile at 14 Ma (Petaca Fm.), 6 Ma (Petaca, Yecua and Tariquia Fms.) and 0 Ma (Petaca, Yecua, Tariquia, Guandacay and Emborozú Fms.). Figure 2 presents a comparison between our model results and topography, gravity anomaly, Moho depths, sedimentary thicknesses, elastic thicknesses and structure for the final stage (0 Ma) for elastic-plastic rheology. A reasonable fit is obtained between measured and modelled sedimentary thicknesses at 6 Ma. To fit the measured thicknesses along the profile at 14Ma we had to use a lower sedimentation rate (0.5-0.7 x10^2 m/My) than for the other Fms., elastic thicknesses of approximately 60-65 km (notably larger than the actual ones), and a geotherm "colder" than the present day one under the Cordillera Oriental (similar to the actual geotherm under the Sierras Subandinas) between 40-14 Ma. Such lower sedimentation rates roughly coincide with the measured ones. The model also predicts that Petaca Fm. was deposited in the forebulge area. Such prediction is supported by the identification in the field of well developed and highly condensed pedogenic horizons near the base of Petaca Fm.

These results suggest that a major event took place between 14 and 6 Ma, which generated a decrease of the elastic thicknesses simultaneously with a thermal structure change along the profile. These changes would be coeval to the onset of huge ignimbritic magmatism in the Altiplano-Puna and the development of crustal scale convection and partial melting beneath the Altiplano-Puna.

Our modelling shows that it is possible to reproduce the present day elevation, gravity anomaly, Moho depth, structural setting, elastic thicknesses and sedimentary thicknesses using the available information about the structural evolution (e.g. Kley *et al.* 1997, McQuarrie and Decelles, 2001).

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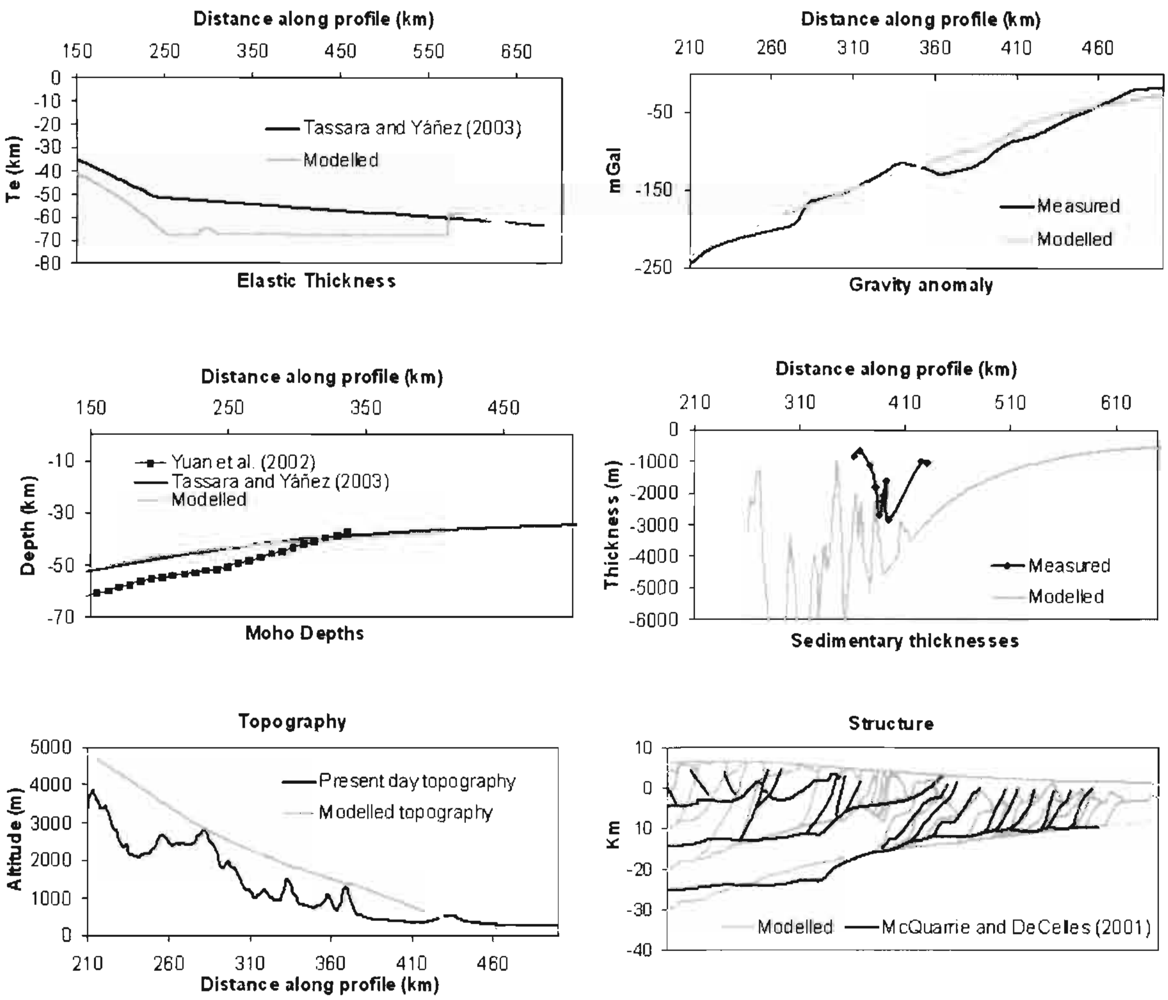

Figure 2: Comparison of our model results and elastic thickness, gravity anomaly, Moho depths, sedimentary thicknesses, topography and structure for the final stage (0 Ma) for elastic-plastic rheology.