6th International Symposium on Andean Geodynamics (ISAG 2005, Barcelona), Extended Abstracts: 582-585

A finite element model for the early to middle Miocene evolution of the Patagonian Andes at 47°S

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The Southern Andes, as defined by Gansser (1973), encompass the orogen developed along the Pacific margin of South America between 46°30'S (Gulf of Penas) and 56°S. The segment to the North of the Strait of Magallanes is known as the Patagonian Andes. Subduction has been continous since early Cenozoic times, although the main development of this segment took place after the late Oligocene. The sudden change in plate kinematics and the strong acceleration in the convergence rate (Somoza, 1998) controlled the deformation until the late Miocene-Pliocene (Ramos, 1989), when an oceanic spreading ridge was subducted (Cande and Leslie, 1986).

The Southern Patagonian Batholith is considered the backbone of the Patagonian Andes. It runs with a NNW trend continously along all the segment and has an average width of 120 km (Hervé et al., 2000). Ages of intrusion range from late Jurassic to Miocene (Nelson et al., 1994) (Pankhurst et al., 1999). The exhumation of the batholith indicates that it has suffered an extreme denudation that can be explained by the establishment of an orographic rain-shadow by the middle Miocene. The rain-shadow caused drastic climatic and ecologic changes as a result of the more than 1 km of uplift (Blisniuk et al., 2005). The total denudation estimated by fission track analysis (Thomson et al., 2001) ranges from 4 to 9 km west of the present-day water divide and decreases to less than 3 km to the east.

The facts that the batholith is located in the present forearc and that the Punta Daphne (around 48°S) early Miocene pluton is around 120 km from the present trench are considered to be evidence for subduction erosion occuring in this segment. Otherwise, a subduction angle of approximately 45° would be required, which is unlikely because of the oceanic crust age being subducted at that moment (Thomson et al., 2001). Considering an angle of subduction of 25°-30°, as presently observed to the north of the triple junction (Bourgois et al., 1996), and a depth of 100 km for the production of this magma, the amount of the forearc crustal erosion should be about 100 km. This implies an approximate rate of more than 3 km/Ma of trench retreat. Crustal erosion has been shown in different segments of the Andes controlling the magmatic arc shifting as proposed by Kay et al. (2005).

In this paper, we present a new numerical model developed to investigate the topographic evolution in a transect near 47°S from the early to middle Miocene. The model consists of two parts that take into account both tectonic deformation and erosional (surface and subduction) processes. The design of the tectonic model is based on the resolution of the Stokes equations for visco-plastic flows using an Eulerian formulation (Bathe, 1996). Finite element methods are used to numerically solve the equations (Girault and Raviart, 1986) and to compute upper crustal deformation. The model uses the same variational principles as the one proposed by Fullsack (1995). This model was latter enhanced and used to study collisional orogens by Beaumont et al. (1992), Willett

(1999) and others. The model is treated in a 2-D plain-strain state. The rheology is considered to be strain-rate dependent (Pysklywec and Beaumont, 2004) (Behn et al., 2002), but with a strong influence of the thermal conditions imposed by the position of the magmatic arc. The parameters relating viscosity and strain-rate are those calculated by Jaoul et al. (1984). Temperature is considered with a 2-D distribution as proposed by Ernst (1975). The transect at 47°S is represented with a mesh of 1881 nodes (figure 1). The western limit is located at the late Oligocene trench and the eastern about 700 km east of the trench.

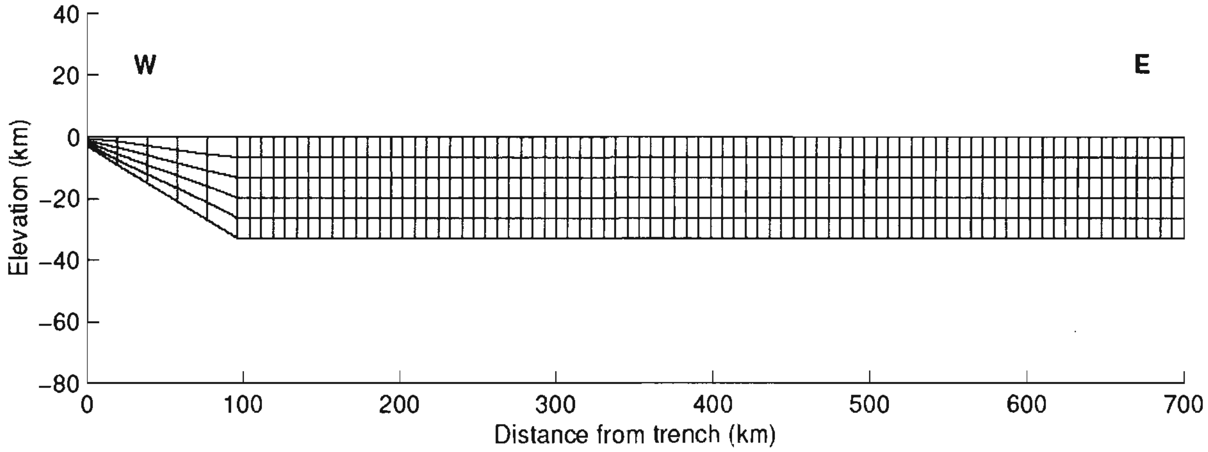

Figure 1 - Mesh representing the vertical section at 47°S

It is known that a large increase in the convergence took place at approximately 26 Ma (Somoza, 1998) with velocities ranging from 11-15 cm/yr. After that peak of convergence, velocity gradually slowed down to 7-8 cm/yr. The eastward displacement imposed by the subduction in the western boundary of the South American plate was supposed to range from 2-5 mm/yr in order to be consistent with the amount of shortening measured in the zone.

The surface erosion model is a modification of the one proposed by Beaumont et al. (1992) combined with a stream power erosion law (Willett, 1999). Our model takes precipitation, slope, elevation and wind direction into account. An initial atmospheric water (vapour) flux is considered to be controlled by the westerlies. Elevation determines how much of the available water is precipitated at every point and the slope of the topography determines the effectiveness of the erosion. After that, the water precipitated is discounted from the total water flux and the latter is moved to the east. The calibration of the model was done using present-day precipitation and topography taken from Blisniuk et al. (2005).

Numerical experiments show that the surface uplift in the middle Miocene explain the establishment of the orographic rain-shadow that caused the high rate of erosion west of the present divide (figure 2). The material eroded from the surface and the subduction zone is in agreement with the figures calculated by Thomson et al. (2001). The estimated subduction erosion rate is consistent with a progressive eastward migration of the locus of maximum denudation. The latter, in combination with the higher rates of convergence at that moment, developed most of the present-day topography. Finally, the volume of material eroded is within one order of magnitude of that deposited in the Santa Cruz Formation on the eastern side of the water divide and in general accordance with the estimated trench fill.

The present numerical model shows a great potential to adjust to different conditions of the distinctive inputs in a subduction system. As such, it is becoming an important tool to understand and quantify the geological processes in an Andean system.

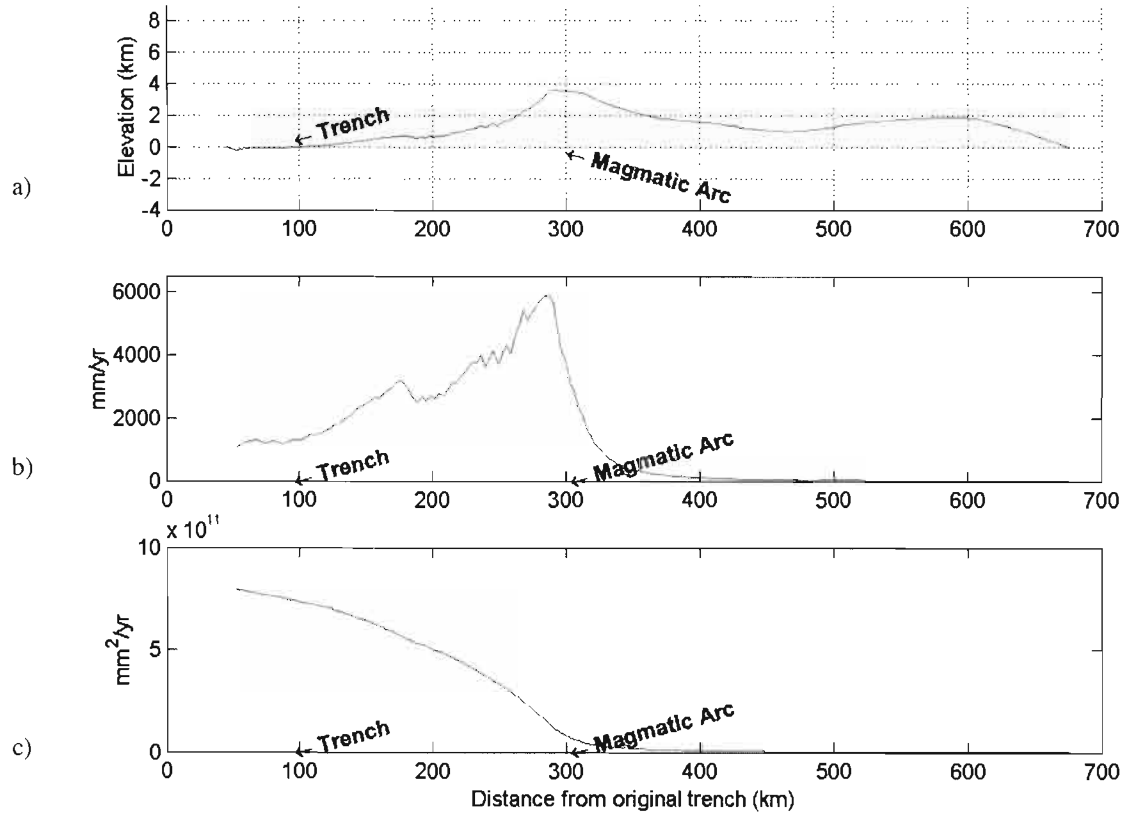

Figure 2 – Topography (a), precipitation (b) and available (atmospheric) water flux (c) calculated by the model at approximately middle Miocene

Acknowledgements

This research was funded by "Fundación Antorchas". Javier Quinteros wants to thank the financial support from CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina).

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