THERMOMECHANIC SEGMENTATION OF THE ANDES (15°-50°S): A FLEXURAL ANALYSIS APPROACH.

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KEY WORDS: Andean Segmentation, Elastic Thickness, Yield Strength Envelope, Thermomechanic State.

INTRODUCTION

The Andes is the classical example of an active non-collisional orogen. Its most prominent characteristic is the along-strike segmentation in its tectonic regime [e.g. Jordan *et al.*, 1983; Cahill & Isacks, 1992], that resembles the long-term segments of the Andean geological evolution (Middle Mesozoic to present) [Mpodozis & Ramos, 1990]. The continental topography and Bouguer anomaly (long-term Moho morphology) are related one each other by the elastic thickness *Te*, a flexural parameter that conditions the degree of compensation of the orogen, allowing an indirect characterization of its segmentation. This study have evaluated the spatial *Te* variations of The Andes between 15° and 50°S latitude applying a flexural analysis to the continental margin. Then, the observed along-strike *Te* systematics are interpreted in terms of the compositional and thermomechanic state of the lithosphere. The link between this state and the tectonic segmentation of the margin, allow us to infer some controlling factors in the construction and evolution of The Andes.

FLEXURAL ANALYSIS METHODOLOGY AND ELASTIC THICKNESS INTERPRETATION

The flexural analysis assumes the lithosphere is a 2D elastic plate, downward deflected by topographic loads [e.g. Turcotte & Shubert, 1982]. The degree of deflection is controlled by the elastic thickness *Te*: minimum (no compesation) for infinite *Te*, and maximum (Airy compensation) for zero *Te*. The Bouguer anomaly is used as a signal of the lithospheric deflection, reproduced through a forward modelling of the elastic lithospheric thickness, assuming topographic loads. Analyssing 15 topo-gravimetric sections, homogeneously distributed on the continental margin (see Figure 1), we obtained a 3D characterization of *Te* and the associated crustal thickness between 15° to 50°S latitude (Figure 1).

These results were semi-quantitatively studied using the Yield Strength Envelope (*YSE*) concept [e.g. Burov & Diament, 1995]. The *YSE* gives, at a particular depth z, the maximum stress absorbed elastically by a compositionally given lithosphere (<u>quartzitic or non-quartzitic crust</u> with an olivinic mantle) before the elastic yield stress, for a given crustal thickness, <u>heat flow</u> and <u>strain rate</u>. The underlined parameters are the free ones that define the <u>thermomechanic lithospheric state</u>. When a stress gradient is applied to this lithosphere by loading, the depth range where this stress is lower than the yield stress will define the elastic thickness *Te*. According to this brittle-elasto-ductile rheology, *Te* is proportional to the strain rate, and inversely proportional to the crustal thickness, quartzitic content of the crust and heat flow. With this relation it is possible to evaluate the thermomechanic state of the margin from the flexural analysis observations. The along-strike variations of this state is finally linked with the tectonic segmentation of The Andes.

THE ANDES: FLEXURAL ANALYSIS AND TECTONIC SEGMENTATION

Between 15° and 50°S, The Andes can be divided in two main segments, subdivided in five sub-segments. Following the Figure 2, the 34°S is the border line between the Central Andes to the north and the Austral Andes to the south. The former is characterized by elevations over 4000 m (maximum of 6500 m) with a width of 400 km at the Northern Segment (15°-23°S) that narrows southward to ~150 km at the Central Segment (28°-34°S). This topography shows very good correlation with a Bouguer anomaly lower than -350 mGal (minimum of -450 mGal), that is an expression of a 55-60 km crustal thickness (maximum of ~70 km, see Figure 1). Consequently, the predicted *Te* shows values lower than 10 km at the main axis of the orogen. The main tectonic features of the Central Andes are (Figure 3): a) along-strike changes in the deep angle of subduction from ~30° at the Northern Segment to subhorizontal at the Central Segment [e.g. Cahill & Isacks, 1992], b) 200 km wide, acidic high-potassium calcalkaline to shoshonitic volcanic arc (Central Volcanic Zone, CVZ) from 13° to 28°S, c) volcanic gap from 28° to 34°S, and d) along-strike variations in the foreland deformation styles, from the Subandean foldthrust belt (Northern Segment), through the basement involved Santa Barbara thrust belt (Northern Transitional Segment, 24°-28°S), to the coupled Frontal Cordillera, thin-skinned Precordillera and thick-skinned Sierras Pampeanas system (Central Segment) [e.g. Jordan *et al.*, 1983].

The Austral Andes elevation decrease along the Southern Transitional Segment (34°-38°S) from 3000 m to 1500 m over a ~250 km wide range. At the Southern Segment (39°-50°S) the range shows a constant elevation of 1500 m with a wider wavelength (~500 km). The Bouguer anomaly lose correlation with the topography and gradually decrease the amplitude of its minimum from -200 mGal to -100 mGal, reflecting a southward crustal thinning from 45 km to 35 km. *Te* increases from 20 km to 40 km at 38°-39 °S, value that is kept constant towards the south. The tectonic elements of the Austral Andes are: a) constant ~30° deep slab angle, b) volcanic arc (Southern Volcanic Zone, SVZ) with a progressively less crustal geochemical signature [e.g. Hildreth & Moobarth, 1988] toward the characteristic intermediate to basic calcalkaline to tholeitic Southern Segment volcanism, spaltial and genetically linked with c) the Liquiñe-Ofqui Fault Zone (LOFZ), a dextral strike-slip lithospheric structure [e.g.Hervé, 1994].

LONGITUDINAL VARIATIONS ON THE THERMOMECHANIC STATE OF THE ANDES

Following the previous section, the two main segments of The Andes represent two different lithospheres. The high elevation, thick crust and low elastic thickness of the Central Andes, contrasts with the lower elevation, thinner crust and higher elastic thickness of the Austral Andes. From the *YSE*, this is mainly associated with a first order compositional difference, regardless of any particular along-strike variation on heat flow and strain rate. Accordingly, the very low *Te* values of the Central Andes reflects a very weak, quartz-rich crust. On the other hand, the comparatively rigid Southern Segment lithosphere, reflects a non-quartzitic, feldspar-rich crust. The Southern Transitional Segment probably represents some compositional mixture between both end members. This main configuration is in agreement with the complex pre-Andean (mostly pre-Mesozoic) collisional history of the margin.

Given the along-strike compositional structure of The Andes, the *Te* systematic of each segment should reflect the variations of the heat flow and strain rate along the margin. The assumed quartz-rich and thick crust of the Central Andes are necessary, but not sufficient conditions, to reproduce its low *Te*. In addition, there must be a favorable combination of high heat flow and/or low strain rate. Heat flow measurements on the Northern Segment [Henry & Pollack, 1988] indicates anomalously high values (~100 mW/m^2), probably associated with a very active asthenospheric wedge almost in contact with a partially molten crust. This high heat flow by itself can reproduce the *Te* range, keeping a fixed strain rate (mean geological number of 10^{-15} s^{-1} in our *YSE* computations). The near zero *Te* observed over the Northern Transitional Segment can be explained by an unreported higher heat flow, probably produced by the proposed 4-2 Ma lithospheric delamination [e.g. Kay & Kay, 1993]. However, the deformational difference between both segments could reflect a lower strain rate, that in part may explain the lower *Te*. This argument can be applied to the Central Segment, where the subhorizontal subduction preclude the high heat flow shown by the segments where an active asthenospheric wedge is present. If this is true, to reproduce the low *Te* of the Central Segment, it is necessary to assume a lower strain rate than the adopted to the Northern Segment. The particular deformation style of the Central Segment could be intrinsically linked with this probably lower strain rate. In fact, Jordan & Allmendinger [1986] report a

~10^{-17} s^{-1} average deformation rate (=strain rate?) for the last 10 My Sierras Pampeanas uplift, a lower limit in geological strain rates. Alternatively, the low *Te* -- low heat flow combination of the Central Segment could represent a weaker crustal composition than the previously assumed, compositional difference that is only partially supported by others independents observations.

On the other hand, the observed *Te* southward increment along the Southern Transitional Segment, to the characteristic 40-50 km of the Southern Segment, is the effect of the observed crustal thinning coupled with a probably southward decrease in the quartzitic crustal component and in the heat flow (lesser crustal participation in the SVZ magmagenesis). The high *Te* shown by the Southern Segment, expression of a hard composition and thin crust, reflects a non-vertically decoupling crust-mantle lithosphere, that keeps an elastic behavior over its entire thickness. This behavior probably is perturbed at the LOFZ axis, where there is localized a high heat magmatic advection and dextral simple shear deformation, that does not have an expression on the long wavelength flexural analysis.

CONCLUSIONS.

The first order compositional configuration of the continental margin is the dominant factor not only in its present thermomechanic state, derived from its Late Cenozoic evolution, but probably through all of its Meso-Cenozoic history [Yáñez, 1995]. In this context, the present tectonic segmentation of The Andes, is the geodynamic reply of the convergence system to the thermomechanic evolution of an anisotropically configured continental lithosphere.

AKNOWNLEDGEMENTS.

This project was supported by FONDECYT grant NO 1930164, and is a contribution of IGCP No 345, "Andean Lithospheric Evolution".

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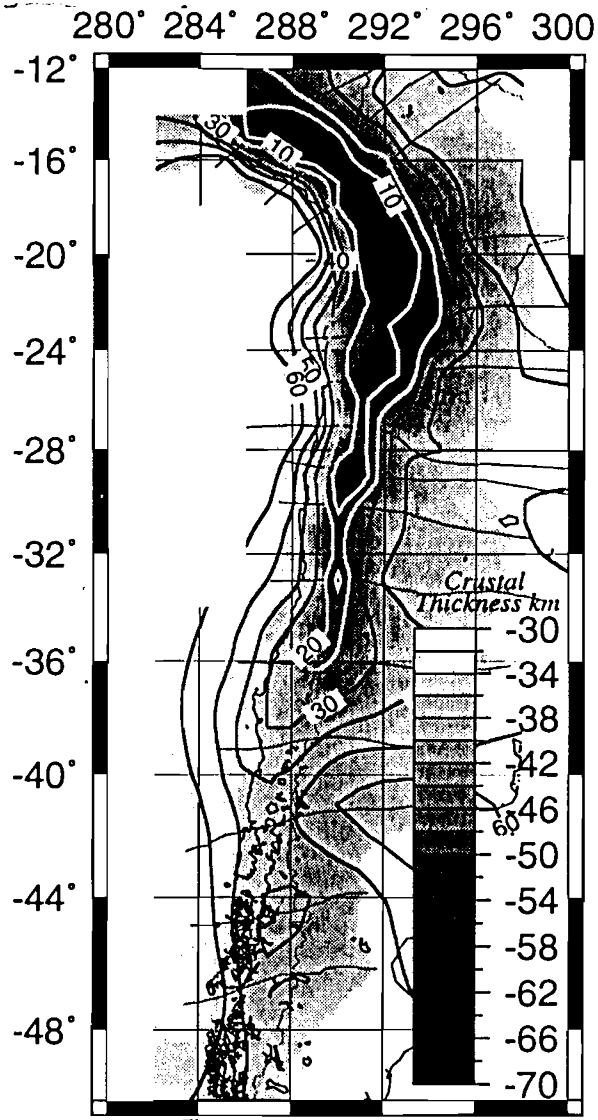

Figure 1. Elastic Thickness (contour) and Crustal Thickness (shade-grey)

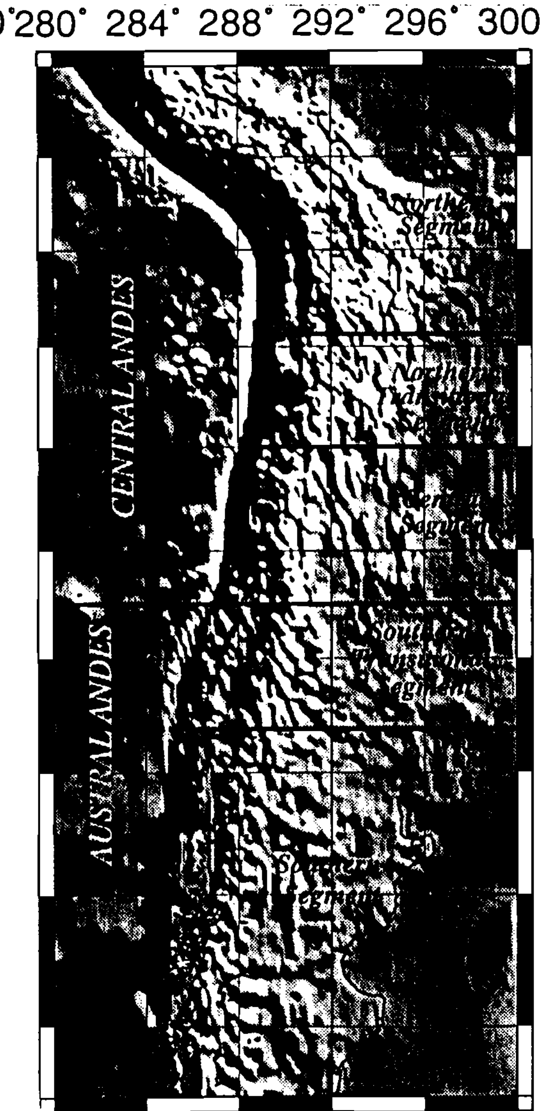

Figure 2. Andean Segmentation on First-Order Topography.

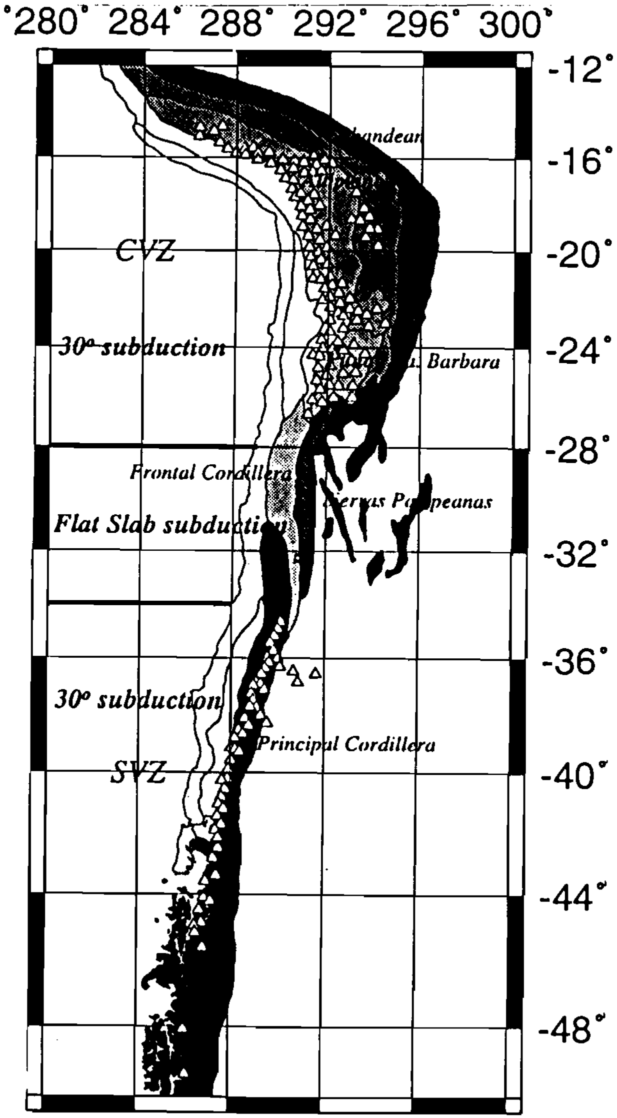

Figure 3. Morphotectonic Units of The Andes