NUMERICAL MODELLING OF PLATEAU KINEMATICS IN THE CENTRAL ANDES

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ABSTRACT (TO BE TRANSLATED INTO FRENCH)

The numerical simulation of plateau formation in the Central Andes suggests that the material flux directions with respect to the plateau control the asymmetry of its flanks. On the E side the plateau grows by accretion of foreland material while the W side is essentially a product of backthrusting of the plateau onto the forearc region. The different kinematics result in different geometries: large taper in the W, small taper in the E.

INTRODUCTION

Asymmetric kinematics and topography of orogens are well known from collisional setting. These orogens inherit their fundamental asymmetry from the preceding subduction zone. After initial collision subduction of the leading edge of the lower plate proceeds and the corresponding crust moves towards the subduction zone. In contrast, the upper plate crust initially remains fixed with respect to the subduction zone. It is this asymmetry of the mass flux directions for the two sides of the collisional mountain belts that controls their different kinematic and topographic evolution (Wang and Davis, 1996; Willett et al., 1993). On the lower plate side where the material moves towards the orogen the resulting pro-wedge is characterised by a small taper, a low surface slope and high shortening rates. In contrast, in the upper plate retro-wedge the material is pushed away from the subduction zone and exhibits a large taper, a high surface slope and much lower shortening rates.

The plateau orogen of the Central Andes shows a similar asymmetry of its flanks. However, the polarity is reversed: on the western - lower plate - side the taper of the marginal wedge is large and deformation rates are slow; on the eastern - upper plate - flank the taper is small and deformation rates are high.

In contrast to the collisional orogens the two flanks of the Central Andes are separated by a wide plateau region. The plateau is the result of vertical decoupling at crustal scale weak zones (Pope and Willett, 1998; Wdowinski and Bock, 1994a; Wdowinski and Bock, 1994b). These weak detachments at or near the base of the crust prevent the formation and conservation of orogenic-scale topographic gradients. In a set of numerical experiments we test the influence of detachment expansion and contraction on the kinematics of plateau orogens in general and compare the kinematic evolution of the resulting end-member plateau types to the geology of the Central Andes. We show how the boundary conditions of the plateau orogen control the contrasting evolution of the two flanks including their kinematics and topography.

NUMERICAL METHOD

For our numerical experiments we make use of the distinct element technique that easily handles the large strains involved in orogeny but restricts the rheology to non-cohesive Navier-Coulomb behaviour of perfectly plastic behaviour. The starting configuration is a rectangular box, 800 x 300 km in size, containing some 5500 disk-shaped elements and represents a vertical crustal profile. The lower boundary of the box is cut in two, in order to allow convergence of the model boundaries (fig. 1). The deformation of the model material is driven by kinematic boundary conditions applied as fixed velocities of the right side wall and lower boundary. The properties of the disks are homogeneous and the lower boundary contains a decoupled- (zero shear stress-) section in its center. During convergence of the model halves the size of the decoupling zone may be changed arbitrarily in order to test detachment widening or narrowing.

RESULTS

Figure 1A shows the reference **experiment A** simulating the collision of two pieces of laterally and vertically homogenous continental crust after 175 km of convergence. This experiment lacks a central detachment and generates a doubly vergent orogen which owes its asymmetry to the unequal boundary conditions of the two model halves as described above. Continuous frontal accretion broadens the pro-wedge thrust belt on the right side forming average surface slopes of 8% and a taper angle of 29°. The retro-wedge on the left side grows by underthrusting and uplift at its back which allows larger surface slopes (26%) and larger tapers (~48°). Deformation rates are up to 3 times higher on the pro-side on the right than on the retro-side on the left.

Experiment B introduces a fixed width detachment into the lower boundary of the crust that extends over a distance of 75 km from the subduction point to the sides. In the detached section no shear stresses are interchanged between the model material and the lower boundary segments. In this experiment the right side foreland (lower plate) moves towards the detachment while the left side foreland (upper plate) remains fixed.

After 250 km of convergence (fig 1.B) the configuration of the model sides has developed an asymmetry in both geometry and deformation rate. Deformation is focused to the right side of the orogen where the marginal wedge grows by accretion of thrust slices at high shortening rates. In contrast, the left flank of the plateau is pushed outward onto the unmoving foreland at very slow rates. The taper angles / surface slopes are 50° / 10% and 35° / 6.6% for the right and left sides respectively.

In **experiment C** an initial, 100 km wide decoupling zone at the base of the crust starts to spread towards the right side foreland after 125 km of convergence. The speed of the lateral expansion is equal to half the convergence velocity. The early model evolution is identical to experiment P2. Subsequently, shortening localizes exclusively to right flank of the orogen as soon as the subcrustal detachment starts to expand towards the right side. Plateau deformation and uplift dies down after ca. 150 km of convergence and the orogen grows solely towards the foreland.

SUMMARY AND DISCUSSION

The experiments on simplified plateau orogens performed in this study suggest that

(1) The material flux directions with respect to the plateau detachment control the asymmetry of the plateau flanks. A plateau margin where material moves into the detached zone (the right side of the plateau experiments) develops a pro-flank with a small taper and a high rate of shortening due to the accretion of foreland material. Plateau flanks where the material is pushed out of the plateau zone produce large tapers and slow deformation rates; accretion of foreland material is negligible.

(2) The kinematic patterns observed in the geological record reflect the evolution of the detachment width. A widening subcrustal detachment below the plateau enables the lateral growth of the orogen without simultaneous vertical uplift.

In the Central Andes the topography and the kinematic of the plateau flanks at 21°S are asymmetric. At the western margin deformation rates are low (5E-17/s) and the taper is ~50° (Muñoz and Charrier, 1996; Victor, 2000). Accretion of foreland material is restricted to its eastern margin. Here deformation rates are 30 times higher (1.5E-15/s) than at the Western flank and the taper is as low as ~8° (Kley et al., 1997). This suggests that the material flux is directed towards the plateau detachment in the East leading to the formation of a pro-flank. At the western plateau rim the material flux is directed away from the detachment and produces a retro-flank.

The stability of the retro-flank on the W side of the orogen can tentatively be attributed to the mechanical contrast between the forearc and the plateau region. While the plateau is soft and partly molten at depth, the forearc is cooled from below by the subducting Nazca plate and consequently strong. We speculate that the thermal situation at the boundary of the plateau prevents the propagation of the deformation into the forearc and is responsible for the formation of a retro-wedge.

In the last 8 to 10 Ma the unilateral accretion has not induced any shortening of the plateau or the western flank. Concluding from the numerical 2D-experiments this requires widening of the regional weak detachment below the plateau at a rate that is ~ half the convergence velocity. Quicker or slower widening of the detachment would lead to plateau extension or shortening respectively.

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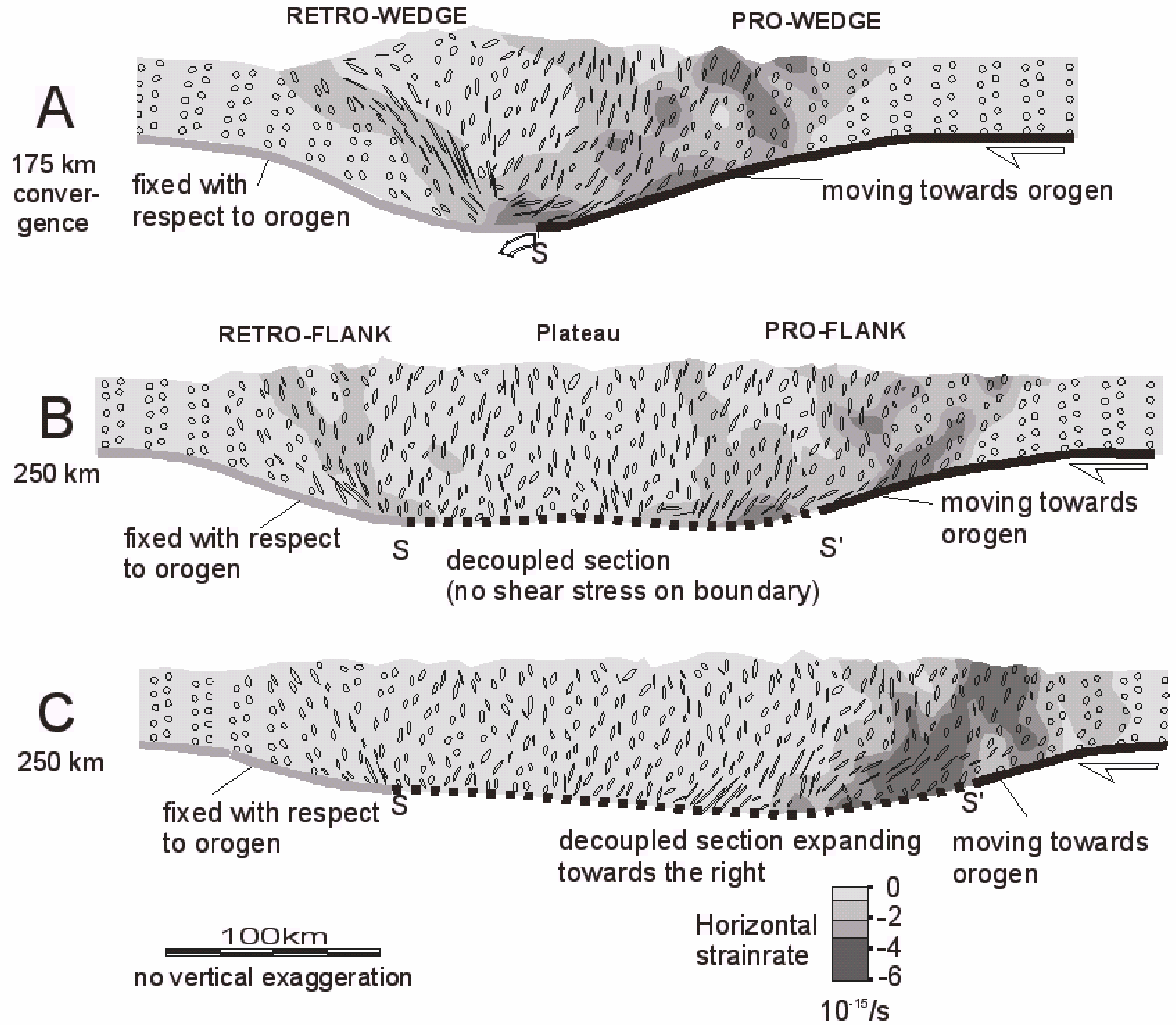

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Fig. 1. Finite strains (ellipses) and horizontal strain rates (shading) of numerical models: A) Collisional orogen, S indicates position of velocity discontinuity. B) Asymmetric plateau orogen with a constant-width decoupling zone at the base of the crust. C) Asymmetric orogen with expanding decoupling zone at the base of the crust. In the plateau experiments S and S` represent the shear stress discontinuities at the tips of the decoupled section of the lower boundary below the plateau.