PIGGY-BACK BASINS OF THE SUBANDEAN ZONE (BOLIVIA) : A VIEW FROM NUMERIC AND ANALOGUE MODELS.

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INTRODUCTION

The Eastern zone of the Andean chain is formed by the Subandean belt. The syn-orogenic sedimentation in this zone is located in either a flexural through or in large and deep piggy-back basins. We want to understand the role of the superficial mass transfer on the kinematical evolution of this thrust belt. It has already been shown that superficial processes are of great importance in the evolution of a thrust wedge considered at large scale, but can erosion and sedimentation control tectonics at a smaller scale, and what are the consequences of this control on the final geometry of a thrust system? To investigate those interactions, two kind of modellisations are proposed.

The first approach consists in "sand-box" models which have been scaled to have a realistic mechanical behaviour. The second approach uses numerical models in which forward kinematical models are coupled to erosional processes.

GEOLOGICAL SETTING

The Subandean Zone of Bolivia forms the external border of the Andean chain. This zone is 140-150 Km large, and is bound at the east by the CFP ("Cabalmiento Frontal Principal"), and at the west by the present foreland basin. Shortening structures separate Tertiary basins more than 25 Km large and more than 6000 m thick. This zone was characterised since Oligocene by sedimentation ahead of the Andean belt. Its deformation is not very important until 6 Ma, (Baby, 1995): only a few anticlines began their growth in the Sub Andean zone whereas thrust tectonics mainly affects the Eastern

Cordillera from 21 Ma to 9 Ma. After 6 Ma the structuration is intense in the Subandean Zone, and the average shortening velocity is about 7 mm/yr. in southern Bolivia and in northern Bolivia.

The variation from north to south of the thickness and lithologies of the series implies some differences in deformation style (Baby and *al.*, 1989). In the northern part of the Bolivian Subandean Zone, the basal detachment is located in the Ordovician formation. In the southern part, the basal detachment is located at the base of the Silurian formation. These variations in the sedimentary wedge from north to south also implies a variation in the basal detachment slope. In the north, its dip is about 5°, while in the south it is only 2°. The topographic slope of the Subandean belt also varies from 1.4-1.7° in the north to 0.6-1.3° in the South.

ANALOGUE SANDBOX EXPERIMENTS

Analogue sandbox experiments were undertaken to investigate interaction between sedimentation, erosion and tectonics. Initial geometry, shortening rate and sedimentation rate have been defined from the regional studies of the Subandean Zone.

Modelling has been realised in a normal gravity field with the "Structurator" sandbox. It conception was especially realised by IFP (Institut Français du Pétrole) to fall in the investigation field of an X-ray tomograph (medical scanner). The apparatus is formed by a basal rigid plate associated with two step by step motors that respectively moves a lateral border and tilts the basal rigid plate. Experiments were made using 4 materials: glass micro beads, silicone, sand, and pyrex. The model is constituted, from bottom to top, by : one glass micro beads layer for the basal decollement, one sand layer for the lower competent series, one layer of silicone for an intermediate decollement, one sand layer for the upper competent series.

Four experiments have been performed to investigate erosion, sedimentation and tectonic interactions: we made one experience with basement tilting, without erosion and without sedimentation; one with basement tilting, sedimentation and without erosion; two with erosion and sedimentation and respectively with and without basement tilting.

A NUMERICAL MODELLING

This numerical method is based on a forward kinematical model, a progressive tilting of the basement, a superficial short range transport and a Coulomb wedge theory. This code (Chalaron et *al.*, 1995) allows to study a wide range of parameters.

The mechanical parameters has been fixed from the equilibrium study of the critical taper of northern Bolivia. The best fit to fill the basins of north Bolivia is obtained, from a trial and error procedure, with a high value of transport capacity (500 m^2/yr.).

During this experiment, two piggy-back basins develops above the wedge and have different evolutions.

The extension of the external basin is nearly the same from the beginning to the end.

The extension of the internal basin always reduces during the deformation. In the eastern part of the basin, sediments are continuously eroded, whereas in the western part some onlaps are preserved from erosion. Toplaps mark a very extended unconformity related to change in the thrust sequence and in the development of duplexes.

CONCLUSION

Concerning the modellisations:

1) The two approaches show that the evolution of a thrust wedge considered at large scale is controlled by the growing of a shortened Coulomb wedge. The change imposed along it upper boundary by surface transport influences the nucleation of ramps, the propagation of decollement along weak layers and partitioning of displacement along the fault system.

2) Analogue models without surface transport are characterised by a forward breaking sequence for the ramps in the duplex between the two decollement levels, and by a forward breaking sequence for the emergent faults. Displacement mostly occurs along the outer and deeper trajectory of the thrust system when there is no surface transport.

3) Analogue models show that superficial processes are important for the nucleation of new faults and for the partitioning of displacement along the fault system. Erosion favours tectonic indentation that restrains the forward propagation of the thrust system. This tectonic indentation is induced by the development of major emergent back-thrusts, and out-off sequence reactivation in the duplex between the two decollement.

4) Wedge shaped sedimentation, induced by the increase of subsidence from the foreland to the front of the thrust belt, favours a forward shift of this front. This shift occurs abruptly when the tilt of the basement reaches a given value, and is followed by out-of sequence reactivation.

5) Anteorogenic wedge shaped body located above a weak layer could propagate deformation far in the foreland and a backward sequence reduces the backward topographic slope created at the back limb of the frontal ramp anticline.

6) Numerical models show that several duplexes develop in a thrust system where three decollement levels are linked by irregularly spaced ramps. In this case, several independent culminations bump the topographic surface, and delimit depressions. Out-of sequence reactivations attempt to reduce the bumpy aspect of the topography, but the culminations persist at the hanging-wall of the ramps that transfer displacement from deep decollements to higher decollements. The out-off sequence reactivation could even increased the high of the inner culmination.

7) Numerical models show that the superficial processes smooth the topography by erosion of the antiforms and sedimentation in the depressions. Augmentation of the efficiency of surface transport increases the erosion rate and the sedimentation rate until

a state where all the depressions are filled and the topographical effects of the culminations are nearly hidden. greater augmentation have no more influence.

Piggy-back-basin development could be induced by: 1) the increase of the foreland basin taper; 2) the incorporation of an ante-orogenic wedge taper in the thrust belt; 3) relative depression between two independent anticlines related to two ramps located along a unique thrust trajectory; 4) a change in mechanical parameters and most probably increase of fluid pressure.

Concerning the thrust belt of the Subandean Zone of Bolivia:

1) Angular unconformity of growth strata above fold structures in the Southern Subandean Zone show that a strong sedimentation is synchronous with the tectonics, and the piggy-back basins are separated from foreland by weak relief. The development of the piggy-back basins could be linked to the progressive tilting of the basement, and/or to the increase of the pressure along the decollement zone during a phase of hydrocarbon generation due to tertiary deposits.

2) In the Subandean Zone of North Bolivia, this study suggests that the Tertiary sediments presently located above the thrust belt were deposited in a piggy-back basin separated from the foreland by a relief affected by erosion since 10 Myr (Quendeque formation).

Reflectors evidenced in the inner piggy-back basin seems comparable to the large unconformity that marks in the numerical models a change in the thrust sequence.

The cause of the early development of the piggy-back-basin is the wedge-shaped Silurian-Ordovician rocks. Furthermore, this study supports the interpretation, still debated, that the displacement related to the duplex at the boundary between Subandean zone and Eastern Cordillera, is transferred eastward to the external thrust system of the Subandean belt, whereas back-thrusts at the roof of this duplex are minor structures.

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