Influence of piedmont sedimentation on the erosion dynamics: an experimental approach and implications for the Andes

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Introduction

Mountain belts mean elevation is set by the competition between tectonics, which thicken the lithosphere in collisional mountain belts and uplift landscape surfaces, and erosional and transport processes that export eroded products through the river network to the topographic lows (Piedmonts). In mountain belts the elevation to which the eroded products deposit on the piedmonts sets the potential energy for erosion (base level). The erosional dynamics of mountain belts will therefore be different depending on the nature of the surrounded sedimentary basins: underfilled or overfilled (e.g. Flemings and Jordan, 1989). Moreover, as a foreland basin commonly evolves from underfilled to overfilled, changes in the base-level elevation has to control the denudation dynamics during mountain building. Hence piedmont sedimentation appears as a fundamental parameter to understand long term morphological dynamics in mountain belts and especially within mountain belts bounded by highly elevated piedmont such as the Andes.

Experimental modeling

We use an experimental device to simulate erosion of reliefs submitted to constant uplift and rainfall rates. The material eroded is a silica paste made of silica powder (D50 = 10μm) mixed with water. The silica paste fills a rectangular box with a moveable base, upward or downward within the box. During an experiment, the base moves upward at a constant rate and pushes the silica paste outside the top of the erosion box at a rate defined as the uplift rate (U). The erosion box is located in a rainfall simulator.

When the experiments start, the top surface of the model is approximately flat. As uplift progresses topographic incisions develop along the four borders of the model and propagate inward until the complete dissection of the initial surface is achieved (Figure 1A, 1B and 1C). The graphic in figure 1 (from A to C) shows the typical evolution of the mean elevation $\langle h \rangle$ during such an experiment. During a first stage, the mean elevation progressively increases, corresponding to the growth phase of the landscape. In a second stage, the mean elevation stabilizes around a constant value. It defines a macroscale steady state of the relief (Hack, 1960) and implies that the output eroded flux equals the input uplift flux (Figure 1, graph).

As soon as a steady state is achieved, a plateau is added (Figure 1C). Pictures of Figure 1 (from D to G) show that when the piedmont develops the upstream topography is erased by a smoothing. Just after the addition of the plateau the <*h*> curve shows a sudden increase (Figure 1, graph). It implies consequently a break of the previous steady state and a decrease in the denudation rate (Babault et al., 2005).

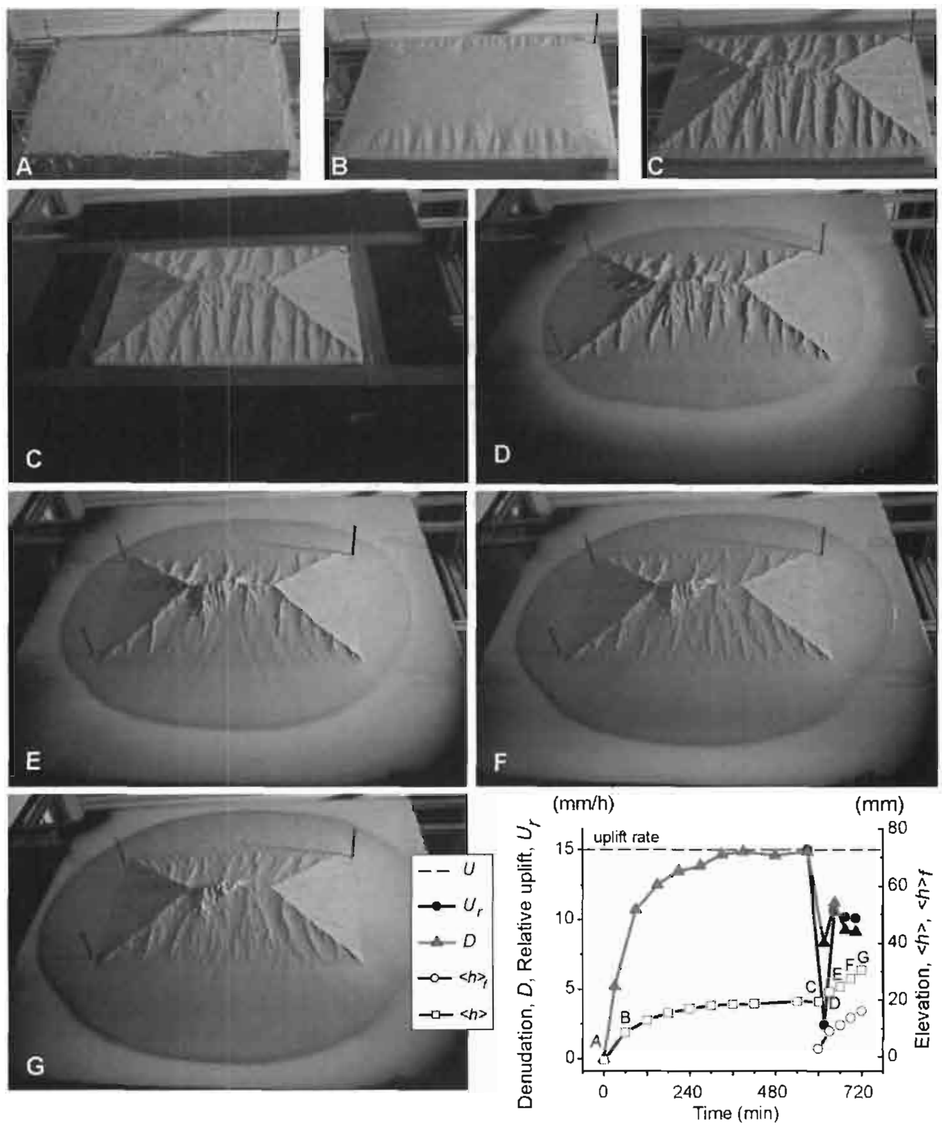

Figure 1: A: Oblique views of the experiment (erosion box, size 400 × 600 mm and 500 mm deep) running under constant uplift and precipitation rates (U = 15 mm/h, Rainfall rate = 120 mm/h). From A to C, growth and development of a steady state topography. From D to G, oblique views of the experiment surrounded by piedmont deposition at intervals of 30' (size of the deposition zone is 250 mm). (Bottom right) Graphs showing mean elevation <h> of topography and mean fan apex elevation (<h>$_f$) evolutions. Steady state is defined by constant mean elevation of relief through time and by denudation rate (D) that equals uplift rate (U). Also shown on the graph is the relative uplift rate (U_r) evolution. U_r is defined as the difference between the uplift rate and the piedmont surface uplift rate induced by the accumulation of sediments.

Discussion - Conclusion

In nature a fundamental parameter that controls erosion rate in rivers and hillslopes is the local slope: the higher the slope, the higher the erosion rate (Montgomery and Brandon, 2002). At laboratory scale we show that the local slope (or the local relief) of an upraising area decreases when uplift decreases: so that the erosion rate decreases (Babault, 2004).

The main effect of piedmont deposition is to shift the elevation of the drainage basins upward because relief denudates at a lower rate than the uplift rate. This results in the increase of the absolute elevation of the whole topography by an amount equal to the mean elevation of the fan apex which defines the base level of the upraising relief. Finally the effect of piedmont sedimentation is to reduce the relative uplift rate *(U_r)*, defined as the difference between the uplift (U) and the piedmont surface uplift ($\langle h \rangle_f$) induced by the accumulation of sediments (Figure 1, graph). In fact the decrease of the relative uplift controls erosion dynamics of a system by lowering the slopes and local relief and inducing a smooth of the topography.

Finally, the results of these experiments suggest that in nature:

(1) piedmont sedimentation may contribute to the very high elevation of mountain peaks that surround high plateaus (eg. Tibet, Altiplano) (Figure 2).

(2) the transition from underfilled foreland basins to overfilled foreland basins will result in the lowering of the denudation rate of upraising mountain belts without involving any reduction of the tectonic uplift rate, or climate change.

(3) topography smoothing (applanation) may develop at high altitude and not necessarily near sea level.

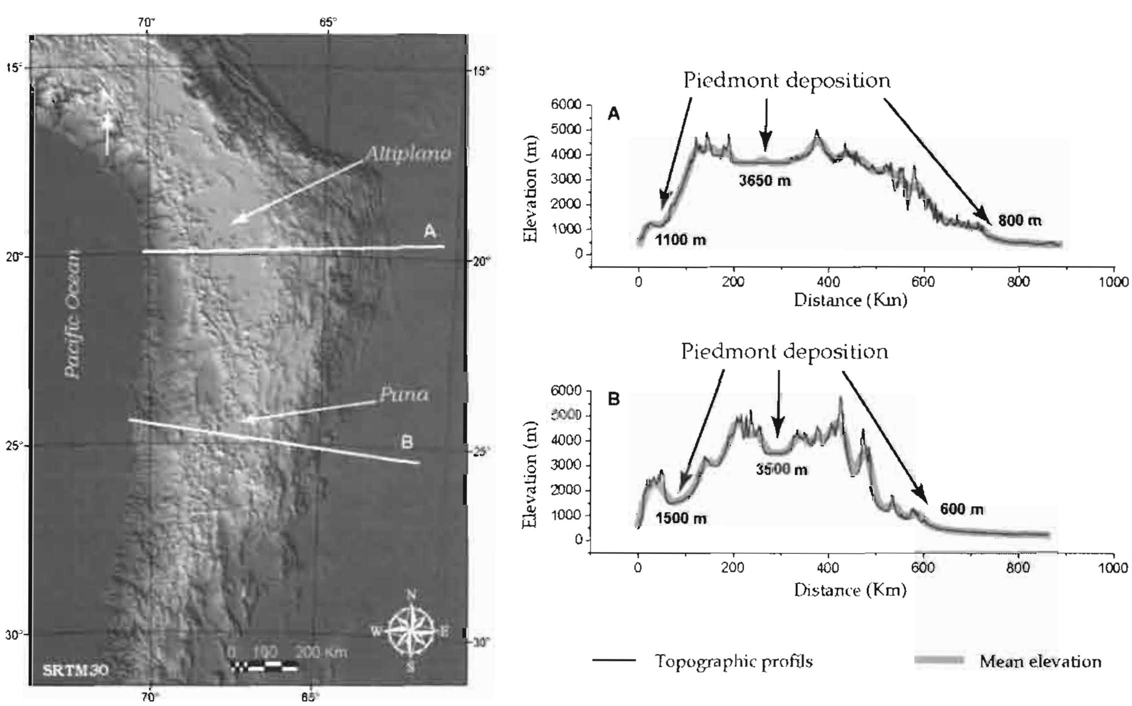

Figure 2 : Digital elevation model of the central Andes and two transverse topographic profiles (A and B). On the profiles the piedmont deposition areas within the chain are underlined. Note that they stand far above the sea level (from 600 to 3650 m) which may contribute to the very high elevation of the Andes mountain belts among other deep processes.

References

Babault, J., 2004, Dynamique de l'érosion dans une chaîne de montagnes : Influence de la sédimentation de piedmont. L'exemple des Pyrénées. [PhD thesis]: Rennes (France), Université de Rennes1.

Babault, J., Bonnet, S., Crave, A., and Van Den Driessche, J., 2005, Influence of piedmont sedimentation on erosion dynamics of an uplifting landscape: an experimental approach: Geology, v. in press.

Flemings, P.B., and Jordan, T.E., 1989, A synthetic stratigraphic model of foreland basin development: Journal of Geophysical Research, v. 94(B4), p. 3851-3866.

Hack, J.T., 1960, Interpretation of erosional topography in humid temperate regions: American-Journal-of-Science, v. 258, p. 80– 97.

Montgomery, D.R., and Brandon, M.T., 2002, Topographic controls on erosion rates in tectonically active mountain ranges: Earth and Planetary Science Letters, v. 201, p. 481-489.