Neogene to Present tectonic and orographic evolution of the Beni Subandean Zone

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Introduction / Geological setting

The Tertiary evolution of the Central Andes is characterised by the Eastward progression of the deformation, from the Western Cordillera to the Interandean Zone, and to the Subandean zones (Sempéré et al., 1990; Suárez et al., 1983) (fig. 1).

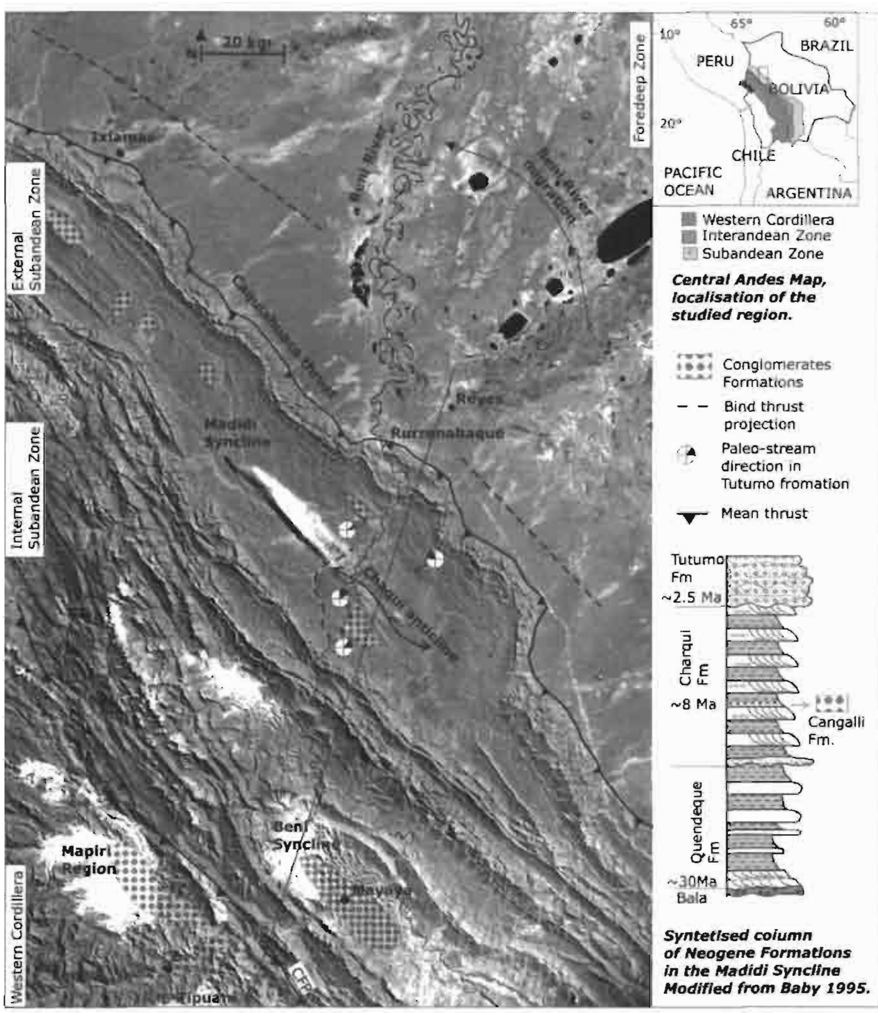

Fig. 1: Localisation of the studied area: North Subandean Zone of Bolivia. Localisation of the three conglomerates Formations, **Cangalli** in the Mapiri Region, **Mayaya** in the Beni Syncline and **Tutumo** in the Madidi Syncline.

This deformation spreads by thin tectonic of fold and thrust propagation. In the North Subandean Zone of Bolivia, the deformation expresses itself as large piggyback synclines (Alto Beni and Madidi). They are separated by localised thrust propagation anticlines (Baby et al., 1993). During the Neogene, the Subandean synclines passed from foredeep zone to piggy-back basin, and actually they are incised. A new dating of a tertiary tuff deposition helps to understand the propagation of the deformation from early Miocene to Present.

The crustal shortening of the North Subandean zone of Bolivia is more important than in the rest of the Subandean Zones of the North Central Andes (Gil Rodriguez, 2001), but nowadays the shortening rate seems to be the weakest (Bevis et al., 2001). To understand the evolution of the shortening velocity in this area we observe the transitional phases between distal fluvial sedimentation and coarse conglomeratic deposit in the different synclines as testimonies of relief development. We also describe the present deformation to compare it with the deformation rate given by gps measurements of (Bevis et al., 2001).

Geochronology and stratigraphic data

In the Mapiri Region, the Cangalli (fluvial conglomerate formation) presents a tuff layer (Chontalorni tuff). This tuff gives an Ar/Ar age on biotite of 7.96±0.6 Ma (Hérail et al., 1994). In the Charqui Fm (fluvial sand and clay formation of the Madidi syncline, fig.1), an interlayed tuff gives an Ar/Ar age in biotite of 8.7 +/- 0.9 Ma. It confirms the synchronous deposit of Charqui and Cangalli Fms. The Charqui Fm is therefore the distal facies of the Cangalli Fm as it was suggested (Hérail et al., 1994).

The stratigraphic evolution (stratigraphic column fig.1) is very similar in the three piggyback basins of the Subandean Zone; but the facies transition is diachronic along the basin. The Tipuani region has been hardly incised during middle Miocene. Rivers dug ~1Km deep valleys. During the Upper Miocene, these valleys were infilled by the conglomerates of the Cangalli Fm (Hérail et al., 1994). Nowadays, this region is dug again; ~1km deep valley cuts the Cangalli Fm and the Palaeozoic substratum. The Mapiri region gives evidences of regional tilt: the actual talweg slopes lesser than the Miocene paleo-talweg(Hérail et al., 1994).

In the Beni syncline, the Quendeque Fm begins with distal fluvial facies and ends with Mayaya conglomerates deposition. This transition occurred during the Beni Syncline deformation. It is characterized by growth strata progressive discordances in this piggyback basin, observable on seismic cross section (Baby et al., 1995).

In the Madidi Basin, the Quendeque Fm is a distal fluvial facies. It evolves to a more proximal facies, including some thin channels of thin conglomerates, in the Charqui Fm and then, the deposit of the Tutumo conglomerate (Oller, 1986). Charqui Fm is dated in its middle by a tuff at 8.7+/- 0.9 Ma (Ar/Ar). The Tutumo Fm crop out in the Madidi Syncline; it is slightly deformed. The measured paleo-currents indicate that the paleo-rivers ran along the frontal fold and thrust bend. But the Tutumo Fm does not show discordance with Charqui Fm. The tectonic activity of the frontal fold and thrust belt was just starting growing during the Tutumo deposition (fig.1).

In the Beni flat plain the transition between sand and conglomeratic fluvial deposits is buried. Nowadays, conglomerates do not arrive to the foredeep zone; they stop in the plain some km after the Susi Snia (fig.2), that means in the quaternary frontal piggy-back basin. Indeed, the deformation seems to spread also to the Beni plain. Slight deformation could be observed ahead of the frontal thrust, in the Beni plain (see fig.1). In the Ixiamas area, the rivers are clearly deviated by a feature parallel to the Subandean Front. This feature is interpreted as the result of a blind thrust propagation fold. South-East to Rurrenabaque, the fans coming from the Frontal bend has been translated some km to the North-East, following a belt parallel discontinuity. This migration occurred after 4ka ^{14}C BP.

Quaternary evolution tectonic activity is also registered by the fluvial terraces. Evidences of Quaternary thrusting are observed in two terraces. In the San Miguel syncline (fig. 2), the terrace accumulation was dated at 4 ka ^{14}C BP; this terrace is thrusted.

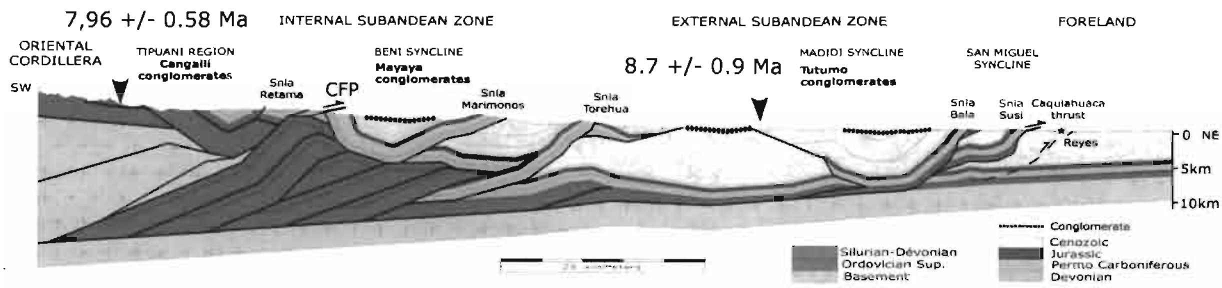

Fig.2: cross section of the Beni Subandean Zone (Baby et al., 1993), Ar/Ar ages and location of the tuff layer.

In the external flank of the Snia Susi fold and thrust bend, one terrace accumulation was dated at 10 ka ^{14}C BP, this terrace is also thrusted. These two thrusts show a recent activation of the frontal thrusts.

Discussion on Neogene and Quaternary evolution of the Beni Subandean Zone

The stratigraphic evidences and the recent deformation point out the deformation propagation from the Interandean Zone to the Beni Plain during the Neogene:

The incision of the paleao-Tipuani valley took place during the Middle Miocene. The corresponding proximal sedimentation occurred in the Beni Syncline by deposition of Mayaya conglomerates. The progressive discordance present in the older formations in the Beni syncline shows that this syncline played as a piggyback basin (Baby et al., 1995). Furthermore the Mayaya conglomerates are limited to the upper part of the Beni syncline, they did not deposit downstream. The depositional zone could have been limited by the rise of the central thrust of the Beni Syncline (Snia Marimonos and Toregua, fig. 2). So, the Subandean zone was already deforming in its internal part, during the Middle Miocene.

The infilling of the paleo-Tipuani valley by the Cangalli conglomerates occurred around 8Ma. It was produced by the blockage of the sedimentation flow, due to the growing of the relief in relation with the activation of the CFP (Mean Frontal Thrust). The thinner sediments go through this gate. Actually, Cangalli formation is essentially coarse and does not presents lake deposit (Hérail et al., 1994).

The thinner sediments went straight to the Madidi syncline to form the Charqui Fm. Occasional powerful fluvial episodes provide to carry centimetres pebbles of quartzite to the Madidi syncline. These incursions managed ribbon of pebbly sandstone in the Charqui Fm.

The deformation going eastward and up, the regional slope increased and the Mapiri region was re-incised. The slope increase provided to carry coarse sediments deposited in the Madidi Syncline, the Tutumo Fm. When the conglomerate deposited in the Madidi syncline, the frontal fold and thrust belt was already slightly constructed and the rivers had their present-day geometry.

The deformation is still active as we can see it in with the birth of blind thrusts on the Beni plain. Two thrusts moved after 4ka Bp in the Frontal bend. Horizontal displacement associated with these faults is ~2m, so the averaged displacement velocity since 4ka, is higher than 0.5 mm/year. Using the balanced cross section, horizontal shortening in the external Subandean Zone (Snias Susi and Bala fold and thrust bend) from 8 Ma to present is around 1.4 mm/yr. The two rates are around 1mm/yr to the North-East. Gps deformation data do not indicate major rates but they are in the opposite direction. While the margin of error is very high for the gps data (Bevis et al., 2001), the quaternary thrusts put in evidence the North-Eastward millimetres deformation.

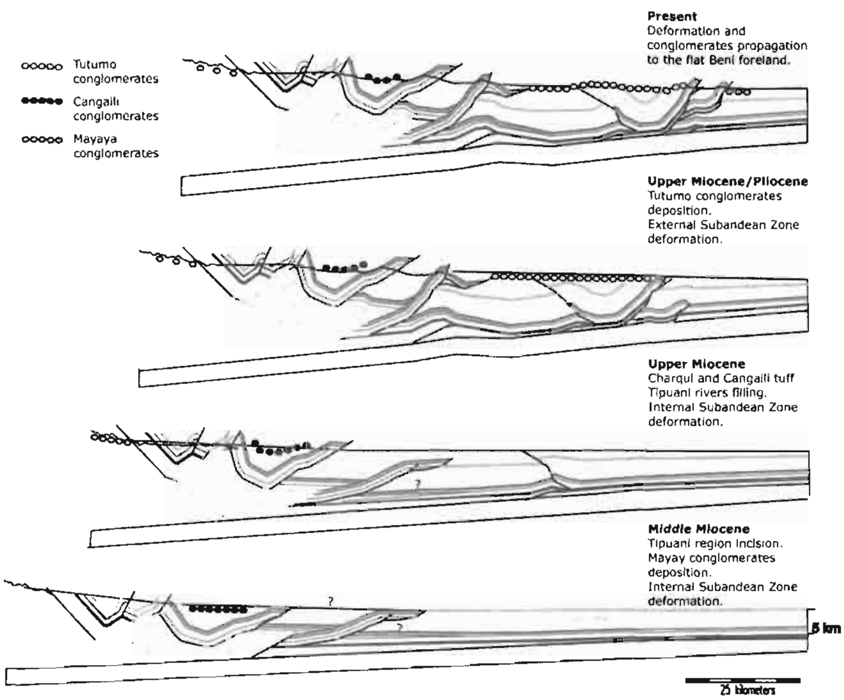

Fig.3: Evolution of the North Subandean Zone of Bolivia during the Neogene. Unfolding was realised by 2Dmove program from the Baby cross section (Baby et al., 1993).

Conclusion

Ar/Ar dating of the Charqui Fm tuf provides a new age for the Tertiary series of the Beni Subandean zone. It confirms that, at 8 Ma, the Charqui Fm was the distal facies of the Cangalli Fm (Hérail et al., 1994). This new age enables to constrain the evolution of the Subandean zone. The thrust and fold belt of the Internal Subandean Zone develop at least during the Middle Miocene, with the sedimentation on the Beni piggyback syncline. This sedimentation ended with the deposit of the Mayaya conglomerates. The development of this internal belt locked the coarse sediments in the Tipuani region around 8 Ma. At the same time, the second piggy back basin took place in the frontal Subandean Zone, in the Madidi basin with the sedimentation of the Charqui Fm. As in the Internal Zone, the filling of the Madidi basin finished with the conglomeratic facies, Tutumo Fm. Quaternary deformation evidences show that the deformation spreads to the North-East, affecting the Beni plain. It explains why the GPS result on the Reyes station (Bevis et al., 2001) do not correspond to a stable craton station. Reyes seems to be now in the front of the Subandine zone (fig.1).

Horizontal shortening, in the order of 1 mm/yr in the frontal fold and thrust bent, appears very slow compared to the crustal shortening of the Subandean fold and thrust belt averaged over the past 25 Ma: 8-13 mm/yr (Liu et al., 2000). The deformation spreads to the North-East, but it should be accommodated also in the Internal part of the Subandean zone. Furthermore, it could cast doubt on the acceleration of the deformation rates during the Neogene (Benjamin et al., 1987; Gregory-Wodzicki, 2000).

Bibliographie

Baby, P., Colleta, B. and Zubieta, D., 1995. Etude géomtrique et expérimentale d'un bassin transporté: exemple du synclinorium de l'Alto Beni. Bull. Soc. France, 166(6): 797-811.
Baby, P. et al., 1993. Structural Synthesis of Bolivian Subandean zone, Second ISAG, Oxford (UK), pp. 159-162.
Benjamin, M.T., Johnson, N.M. and Naeser, C.W., 1987. Recent uplif in the Bolivian Andes: evidence from fission-track dating. Geology, 15: 680-683.
Bevis, M. et al., 2001. On the strength of interplate coupling and the rate of back ars convergence in the central Andes: An analysis of the interseismic velocity field. Geochemistry Geophysics Geosystems, 2.
Gil Rodriguez, W., 2001. Evolution latérale de la déformation d'un front rogénique: Exemple des bassind subandins entre 0° et 16° S., Université Paul Sabatier, Toulouse.
Gregory-Wodzicki, K., 2000. Uplift history of the Central Andes: A review. GSA Bulletin, 112(7): 1091-1105.
Hérail, G., Sharp, W., Viscarra, G. and Fornari, M., 1994. La edad de la formacion Cangalli: nuevos datos geocronologicos y su significado geologico, Memorias del XI Congreso Geologico de Bolivia.
Liu, M., Yang, Y., Stein, S., ZHu, Y. and Engeln, J., 2000. Crustal shortening in the Andes: Why do GPS rates differ from geological rates? Geophysical Research Letters, 27(18): 3005-3008.
Oller, J., 1986. Consideraciones generales sobre la geologia de la Faja Subandina norte., Universidad mayor de San Andreas, La Paz, Bolivia, 120 pp.
Sempéré, T., Hérail, G., Oller, J. and Bonhomme, M.G., 1990. Late Oligocène-early Miocene major tectonic crisis and related basins in Bolivia. Geology, 18: 946-949.
Suárez, G., Molnar, P. and Burchfiel, C., 1983. Seismicity, fault plane solutions, depth of faulting, and active tectonics of the Andes of Peru, Ecuador, and southern Colombia. J.G.R., 88(B12): 10,403-10,428.