ACTUAL EROSION BY RIVERS IN THE BOLIVIAN ANDES

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INTRODUCTION

In Bolivia, the Andean Mountain belt is very large and deformed by thin-skinned tectonics (Baby et al., 1997). The back arc orogenic wedge is formed by the Cordillera Oriental – which limits the Altiplano enigmatic high plateau (Rochat et al., 1999) - and the Subandean zone, and characterized by an elbow shape of the mountain range (Bolivian orocline) and high relief (several summits over 6000 m). It over thrusts and supplies its adjacent foreland sedimentary basin with sediments since upper Oligocene times. The present axis of the Bolivian orocline separates the High Amazonian drainage basin in the north from the Pilcomayo drainage basin in the south. Little data is available to measure the actual erosion of the Andes cordillera. However, the measurement of sedimentary yields at the hydrological stations makes it possible to estimate these actual rates of erosion and their geographical variability.

DATA AND METHODS

In the Andes of Bolivia, the data obtained at the hydrological networks of various national services (ENDE, SENAMHI, SEARPI) made it possible to select 42 gauge stations (Figure 1) including 23 on the Amazon River basin, 13 on the basin of the Paraguay River and 5 on the endoreic Altiplano basin. In spite of different observation times and durations, the great quantity of samples collected on the Andean rivers (28 167) allows a realistic estimate of sedimentary flows. With extreme altitudes of 170 m (station of piedmont) to 6400 m (tops of the Real Cordillera), the studied basins show very contrasted characteristics, with mean basin altitude varying from 1175 to 4925 m (Guyot et al., 1990, 1996). The selected hydrological stations drain nested basins, of variable area (from 160 to 81 300 km^2) and slope (from 7 to 37%). Basin area extraction followed the methodology described in Seyler et al. (in press). The GTOPO30 DEM, river network extracted from JERS 1 mosaic (TRFIC project) , digitalized maps, and D8 algorithm were used. The flow accumulation threshold has been chosen as the minimum area necessary to delineate the streams gauged. For each delineated basin, the slope has been calculated, and used in the statistical exploration. Processing involved Arc-View, Erdas Imagine, and avenue scripts developed by the University of Texas at Austin (Maidment et al., 1997).

These basins, distributed on the whole of the Andean domain of Bolivia, are subjected to very contrasted climates: of 350 mm/yr in the arid regions of the altiplano, with more 3800 mm/yr in the Andean piedmonts of the Amazonian basin, and present runoff coefficients from 10 to 72% (Roche et al., 1992). The lithological index was calculated by using the Probst indices. The lithology of each basin was extracted from the geological map of Bolivia by using a SIG. The forest cover index (from to 0 to 100% depending of the sub-basin) was also extracted with the SIG from the Bolivian chart of vegetation.

RESULTS

The results obtained show a very strong heterogeneity, with suspended sediment concentrations varying from 46 to 19600 mg.l^{-1} during the hydrological cycle, and a rate of current erosion varying from 21 to 18200 t.km^{-2}.yr^{-1} according to the basins (Guyot et al., 1990, 1996). Using a forward stepwise multiple regression analysis with the whole dataset, the significant control variables are only drainage area and slope, with a multiple regression coefficient r=0.53. The same trend was observed with a smallest dataset not including the Altiplano Rivers (Aalto et al., in press).

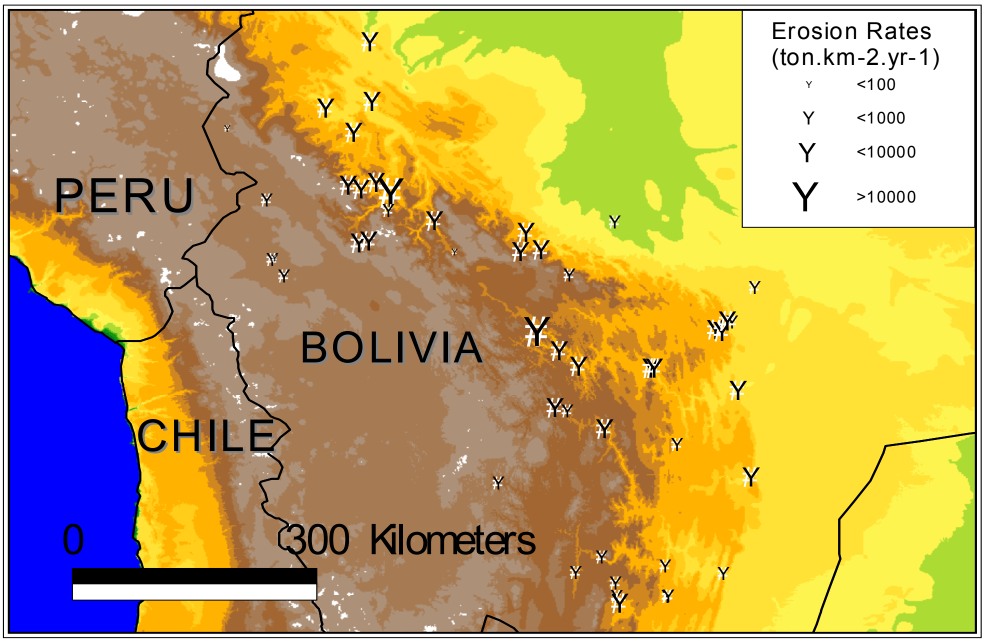

Figure 1 : Gauge stations location in the Bolivian Andes, with Erosion Rates values.

Table 1 : Drainage basin characteristics and Erosion rates

	Code	River	Gauging Station	Area (km2)	Slope (%)	Rainfall (mm.yr-1)	Runoff (%)	Lithologic Index	Forest Cover (%)	Erosion Rate (t.km-2.yr-1)
Altiplano	ESC	Suchez	Escoma	3 100	10	498	16	24	0	21
	TIW	Tiwanaku	Tiwanaku	320	7	669	22	36	0	107
	MAU	Mauri	Calacoto	9 420	20	450	16	16	0	640
	CAL	Desaguadero	Calacoto	9 770	11	580	29	36	0	59
	ULL	Desaguadero	Ulloma	22 800	20	510	20	28	0	289
Amazonas	MAP	Mapiri	A.Quercano	9 400	22	1 284	42	7	44	3 920
	COR	Coroico	Santa Rita	4 700	26	1 886	57	6	78	1 620
	VBA	Tamampaya	V.Barrientos	1 900	31	1 283	46	6	9	4 120
	CAJ	La Paz	Cajetillas	6 500	32	808	43	10	1	18 200
	COT	Cotacajes	Cotacajes	5 600	34	1 129	41	7	0	7 250
	AIN	Alto Beni	A.Inicua	29 900	37	1 366	47	11	38	3 850
	AB	Beni	A.Bala	68 000	37	1 615	50	12	57	3 220
	LOC	S.Isabel	Locotal	200	19	2 610	69	8	84	3 340
	ICO	J.Corani	Icona	2 300	17	3 450	67	7	70	4 940
	PAL	E.Santos	Palmar P.	160	21	3 470	72	7	97	6 660
	SEH	Ivirizu	Sehuencas	420	22	1 400	59	6	16	227
	PV	Ichilo	P.Villarro	7 580	21	3 800	65	20	99	712
	ANG	Pirai	Angostura	1 420	12	1 000	24	6	100	2 080
	TAR	Pirai	Taruma	1 590	12	1 050	15	8	100	840
	BEL	Pirai	Belgica	2 880	12	1 300	10	17	86	792
	AMO	Caine	A.Molinero	9 200	21	654	20	13	0	13 700
	HUA	Chayanta	Huayrapata	11 200	27	664	35	9	0	1 260
	PAR	Grande	P.Arce	23 700	28	659	28	10	0	6 500
	PNA	Grande	P.Nava	31 200	28	650	34	10	0	6 620
	MIZ	Mizque	P.Nava	10 800	21	653	20	7	3	1 310
	PAZ	Azero	P.Azero	4 360	21	780	19	8	10	520
	AP	Grande	Abapo	58 900	28	750	18	10	18	2 110
	SAN	Parapeti	S.Antonio	7 500	17	800	19	24	83	2 590
Paraguay	ATA	Pilcomayo	A.Talula	6 340	23	480	23	8	0	1 910
	NUC	Cachimayu	Nucchu	1 600	19	720	23	14	0	661
	VQU	Pilcomayo	V.Quemada	13 200	24	490	20	10	0	1 670
	SLE	Yura	S.Leon	4 200	17	370	13	9	0	106
	ELP	SJ.Oro	El Puente	20 100	20	345	18	15	0	120
	CHI	Pilaya	Chillcara	42 900	23	360	11	12	0	323
	SJO	Pilaya	S.Josecito	47 500	32	390	14	11	5	645
	VIL	Pilcomayo	Villamontes	81 300	32	478	14	12	15	890
	ERI	S.Ana	Entre Rios	290	11	912	27	14	43	223
	PAJ	Pajonal	Entre Rios	220	13	917	30	16	66	499
	CAN	Chamata	Canasmoro	230	12	834	37	11	6	197
	OBR	Guadalquivir	Obrajes	920	19	810	30	14	2	439
	SJA	Tolomosa	S.Jacinto	460	21	1 020	45	18	0	3 340

Using the same forward stepwise multiple regression analysis, but separating in different geographical groups, the multiple regression coefficients present better values, and it becomes possible to calculate a rate of erosion for each sub basins (Figure 2). For the Altiplano basin rivers (r=1.00), the control factors are drainage area, slope and rainfall. For the Pilcomayo basin rivers (r=0.98), the control factors are also drainage area, runoff and lithologic index. In the Amazon basin, erosion rates in the Beni (r=0.96) and Chapare (r=0.99) basins are controlled by rainfall and runoff, whereas in the Grande (r=0.97) basins, these erosion rates depend of lithologic index and forest cover.

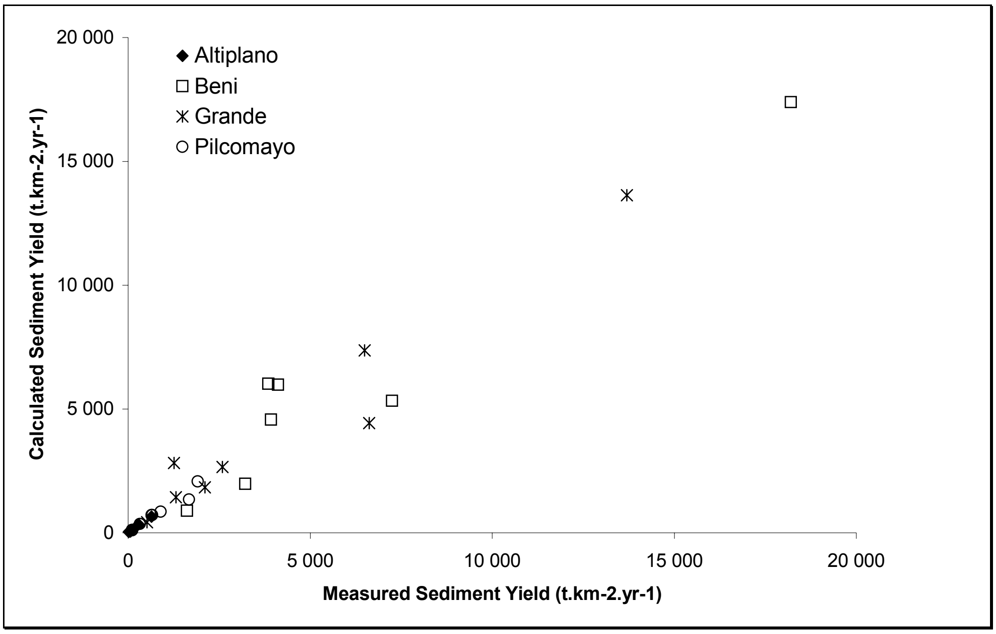

Figure 2 : Calculated vs. Measured Sediment Yield

For each geographical group, the largest basin corresponds either to the Andean piedmont (Angosto del Bala for the Beni river, Abapo for the Grande river, Villamontes for the Pilcomayo river), or to the station of Ulloma on Altiplano. The compared hypsometry of these four basins show different stages of evolution (Fig. 3). The Altiplano basin presents a more advanced stable profile, with erosion stopped by the regional endoreism. The Beni, Grande and Pilcomayo basins correspond to different levels of erosion, with a positive gradient from South towards North: profile of Beni River being more advanced than that of Pilcomayo.

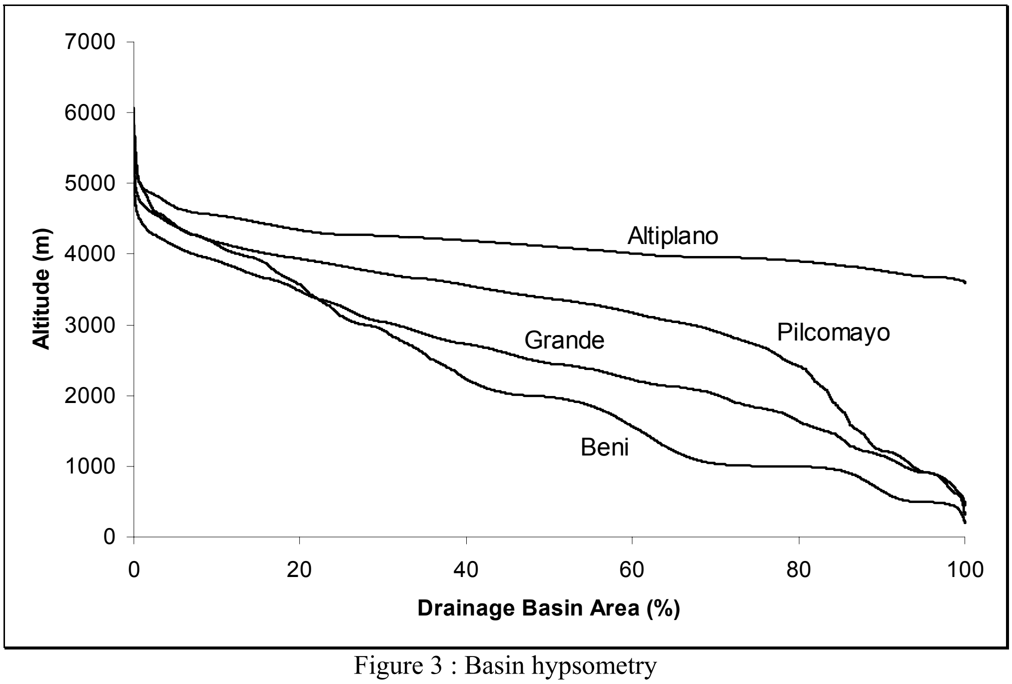

Figure 3 : Basin hypsometry

It is interesting to compare the degree of evolution of the basin with the current rate of erosion measured at the hydrological gauging stations. For that, we calculated the volume of the basin comprised between the today curve and a theoretical initial profile. Considering the current rates of erosion, the time that had been necessary to obtain the observed profiles varies from 1.4 to 2.4 MY. The results (fig. 4) show a good adjustment between current measurements (few years observation) and evolution of topography related to long scales of time.

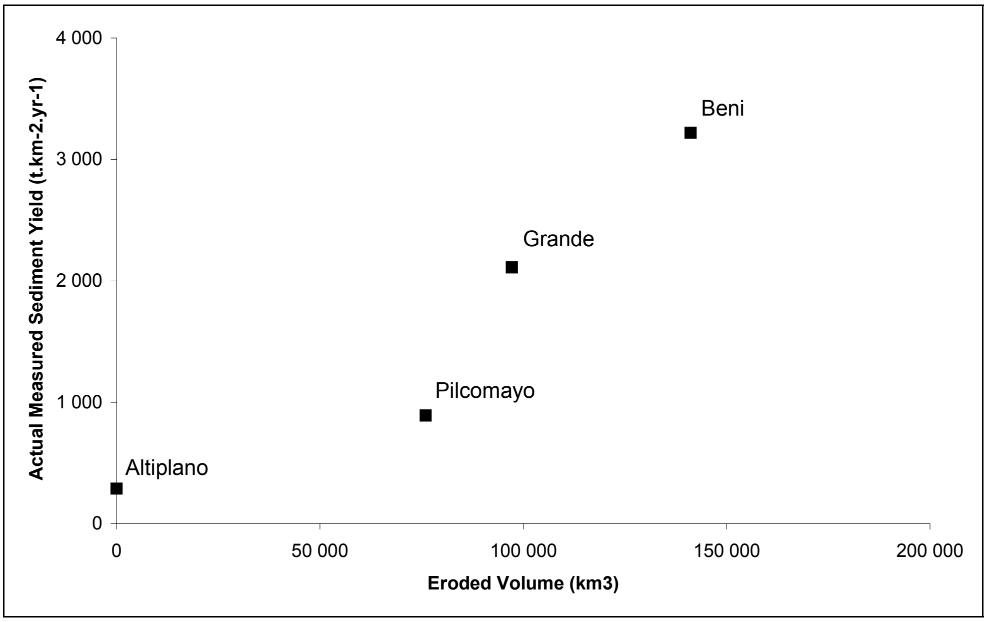

Figure 4 : Actual erosion rates vs. Basin eroded volume

REFERENCES (alphabetical order)

Aalto R., Dunne T., Guyot J.L. in press. Geomorphic controls on Andean denudation rates. Journal of Geology.

Baby P., Rochat P., Mascle G., Hérail G. 1997. Neogene shortening contribution to crustal thickening in the back arc of the Central Andes. Geology 25: 883-886.

Guyot J.L., Calle H., Cortes J., Pereira M. 1990. Transport de matières dissoutes et particulaires des Andes vers le Rio de La Plata par les tributaires boliviens (rios Pilcomayo et Bermejo) du Rio Paraguay. Hydrological Sciences Journal, 35(6), 653-665.

Guyot J.L., Filizola N., Quintanilla J., Cortez J. 1996. Dissolved solids and suspended sediment yields in the Rio Madeira basin, from the Bolivian Andes to the Amazon. Erosion and Sediment yield : Global and Regional Perspectives, IAHS Publ. 236, 55-63.

Guyot J.L., Roche M.A., Noriega L., Calle H., Quintanilla J. 1990. Salinities and Sediment Transport in the Bolivian Highlands. Journal of Hydrology, 113, 147-162.

Maidment D.R., Reed S.M., Akmansov S., McKinney D.C., Olivera F., Ye Z. 1997. Digital atlas of the world water balance. Center for Research in water Resources, University of Texas at Austin.

Rochat, P., Hérail G., Baby P, Mascle G. 1999. Bilan crustal et contrôle de la dynamique érosive et sédimentaire sur les mécanismes de formation de l'Altiplano. *C. R. Acad. Sci. Paris, Sciences de la terre et des planètes/ Earth and Planetary Sciences,* **328**: 189-195.

Roche M.A., Fernandez C., Aliaga A., Peña J., Salas E., Montaño J.L. 1992. Balance hídrico de Bolivia. Publ. UNESCO-PHICAB, 16 p.

Seyler F., Muller F., Cochonneau G., Guimarães V., Guyot J.L. (in press). Watershed delineation of the Amazon sub-basins system using GTOPO30 DEM and a drainage network obtained from JERS SAR images. Hydrological processes.