River Sedimentation, IRTCES, Pekin, June 1989

TRANSPORT OF SUSPENDED SEDIMENTS TO THE AMAZON BY AN ANDEAN RIVER : THE RIVER MAMORE, BOLIVIA

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With a 590,000 km^2 area and a 8,930 $m^3.s^{-1}$ mean discharge, the Rio Mamore is, together with the Rio Beni, one of the most important rivers that form the Rio Madeira. A part of the Mamore River drainage basin (16%) lies in the Bolivian Andes Eastern Cordillera. At the foothills of the Andes, the sediment discharge of the Grande River at Abapo is 134.10^6 $tons.year^{-1}$. With the supply of its main affluents, the Mamore River at its confluence with the Beni River, carries 63.10^6 $tons.year^{-1}$ of sediments to the Madeira River. It amounts to a global mechanic erosion rate of 110 $tons.km^{-2}.year^{-1}$ for its whole drainage basin.

Introduction

The amount of suspended sediments and the regime of the sediment and salt exportations by the Mamore River have been studied by the PHICAB (Climatological and hydrological program of Amazonian drainage basin of Bolivia, project ORSTOM/SENAMHI/IHH) from the andean basin to the Madeira River. Hydrometrical and suspended load values come from six stations of SENAMHI (National Meteorology and Hydrology Service of Bolivia) and SEARPI (Channel water service of the Pirai River) for the andean zone, one station of DNAEE (National water and Electric Energy Service of Brazil) for the Brazilian Shield and seven stations of PHICAB for the Amazonian plain (table 1). We are presenting here first results, that will be precised with the continuation of the

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measurements on the PHICAB network, taking into account the variability of the observation periods and heterogeneity of the data.

Table 1 : gauging stations characteristics

Code	Station	River	Alt. (m)	Sup. (km^2)	Period Obs.	Number of samples	Service
HU	Huayrapata	Chayanta	1500	11200	76-82	282	Senamhi
AZ	Pte Azero	Azero	1100	4360	75-82	556	Senamhi
AP	Abapo	Grande	450	58900	76-87x	807	Phicab
SA	Sn Antonio	Parapeti	550	7500	76-83	641	Senamhi
ES	Espejos	Espejos	600	202	77-81	1760	Searpi
AN	Angostura	Pirai	650	1420	77-81	1760	Searpi
LB	La Belgica	Pirai	350	2880	77-81	1760	Searpi
PV	P.Villarr.	Ichilo	170	7580	83-87	67	Phicab
PA	P.Almacen	Ibare	150	5320	83-87	101	Phicab
PG	P.Ganadero	Mamore	150	159000	83-87	79	Phicab
PS	P.Siles	Mamore	130	216000	83-87	71	Phicab
PL	P.Lacerda	Guapore	300	2500	79-84	17	Dnaee
VG	V.Grande	Itenez	130	340000	83-87	201	Phicab
GM	Guayarame.	Mamore	125	590000	83-87	182	Phicab

x data of Rositas project for the 1976-1982 period (in Garcia, 1985).

<u>The drainage basin</u>

The Mamore River together with the Beni River, form the Madeira River, whose discharge is the most important of the River Amazon south tributaries. At its confluence with the Beni River near Guayaramerin, the Mamore River drains a 590,000 km^2 basin, 16% of which is located in the Bolivian Andes Eastern Cordillera and 35% in the Brazilian Shield. The Mamore River drainage basin is divided into two sub-basins (Fig. 1) : the Mamore River basin, at its confluence with the Itenez River near Puerto Siles (216,000 km^2), and the Itenez-Guapore River basin (340,000 km^2 of which 31% is located in Brazil).

Topography is very contrasted, with almost 5,000 m high summits in the Cochabamba and Chayanta Cordilleras (Tunari,...), and an altitude of the order of 130 m at Guayaramerin (Garcia, 1985). The drainage basin is then divided into a steep mountainous zone and a subhorizontal amazonian plain (Fig. 2).

Like the topography, the Mamore River basin climate is very diverse. The Grande River basin, upstream of Abapo, as well as the Parapeti River basin, is subject to a semi-arid climate with rainfalls ranging from 450 to 800 mm. Most of the rainfall (70 to 80%) occurs during the four months from December to March (Herbas, 1987). On the contrary, the

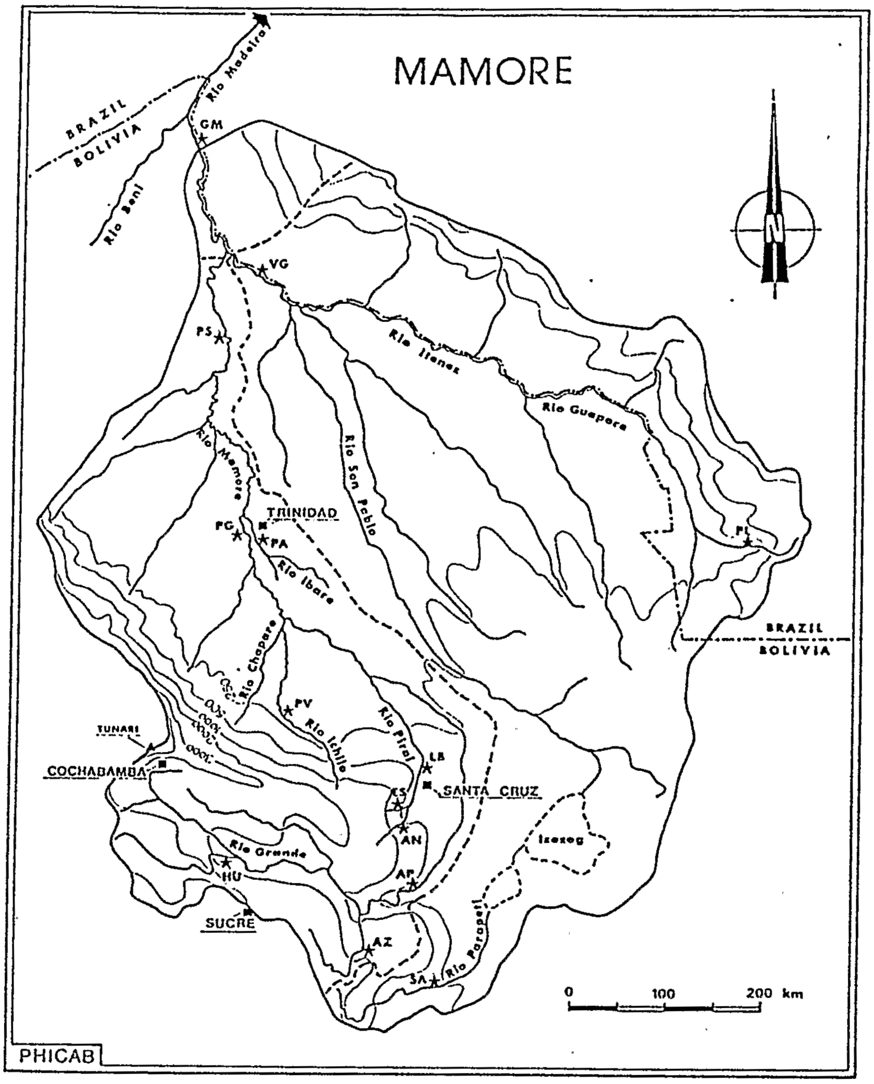

Fig. 1 : Mamore drainage basin map
(see table 1 for station codes)

Northern andean basins (Chapare, Ichilo,...) get 2,000 to 6,000 mm a year, which make them the wettest region of Bolivia, with an average yearly rainfall of 3,000 mm (Roche & al., 1986). The Amazonian plain gets 1,000 mm rainfall in the South to 2,000 mm in the North, and the average rainfall for the whole Itenez River basin is 1,500 mm (Cruz, 1987).

Vegetation evolves quickly from unexisting or short cover at high altitudes to wet tropical forest in the Northern basins of the Cordillera (Chapare). To the South, the basins cross semi-arid high mountainous areas (Grande and Parapeti River basins), before getting into the wet tropical plain, where forest often gives way to savannah.

The andean part of the drainage basin intersects mostly Paleozoical detrital series, with some Mesozoical scraps. The

Precambrian outcrops of the Brazilian Shield form the Northern relief of the Itenez River basin. The Amazonian plain is totally occupied with Quaternary and Plio-quaternary sediments.

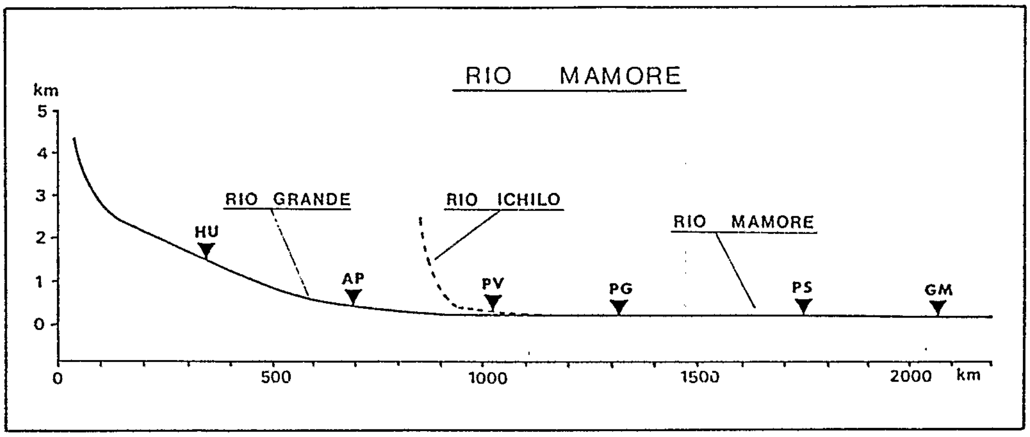

Fig. 2 : Longitudinal section of the Mamore River (see table 1 for station codes)

Hydrological regimes

Under the same pluviometrical regime, hydrological regimes show the same distribution of monthly discharges in the Andes. A high water period from December to April is opposed to a low water period from May to November (Fig. 3). On the other hand, in the Amazonian plain, the maximum flood is progressively displaced from upstream to downstream : it is in February-March at Puerto Ganadero, in March-April at Puerto Siles and in April-May at Vuelta Grande and Guayaramerin. This time evolution of the maximum flood, which is not observed on the Beni River (Guyot & al., 1988a) is due to the influence of the flood-plains, that are widely spread out (100,000 to 150,000 km^2) on the drainage basins of the Mamore and Itenez Rivers (Roche & al., 1988).

In the Andes, the three months of high water (January, February and March) represent from 37% (Ichilo River at Puerto Villàrroel) to 59% (Parapeti River at San Antonio) of the annual flow. The minimum discharges in the Andean stations occur between July and October. The three months of low water represent from 5% (Parapeti River at San Antonio) to 15% (Ichilo River at Puerto Villarroel) of the annual flow. This distribution is then more spread out downstream with the yield of the rivers of the flood-plain like the Ibàre and Itenez Rivers.

For some stations like the Mamore River at Guayaramerin, the mean discharge for the studied period (8,930 $m^3.s^{-1}$ for the 1983-1987 period) is different from the mean discharge calculated over longer periods : 8,530 $m^3.s^{-1}$ for the 1971-1986 period (Bourges & al., 1987) and 8,105 $m^3.s^{-1}$ for the

1968-1982 period (Roche & al., 1988).

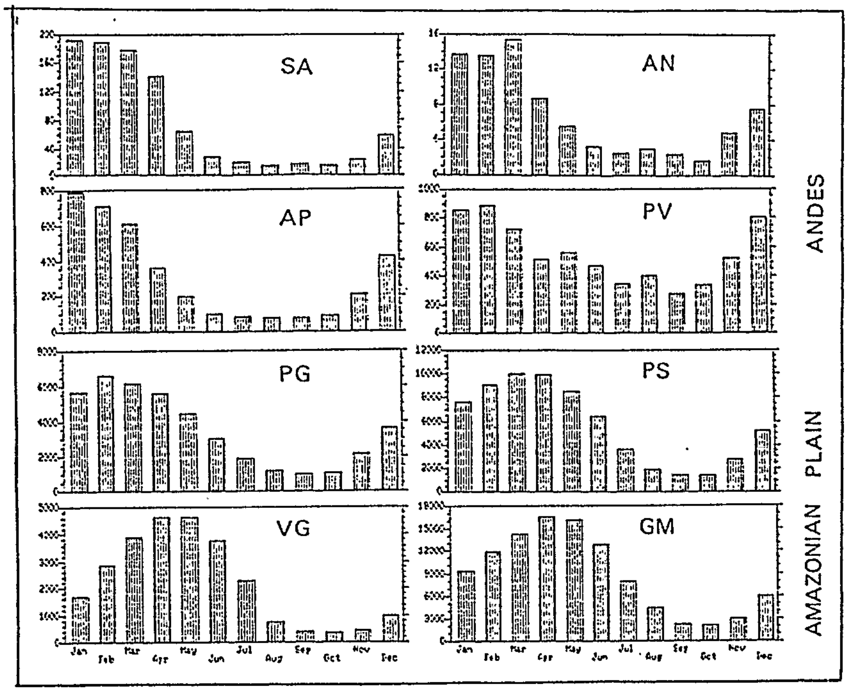

Fig. 3 : Discharge regimes ($m^3.s^{-1}$)
(see table 1 for station codes)

Suspended matters

The data from the different networks, are obtained from samples collected with an integration sampler, on 3 to 12 verticals depending on the width of the river.

The study of the distribution of monthly sediment volumes exported from the Andes (Fig. 4) show that most of the sediment discharges occur from December to April, in high water periods. The three months of January, February and March yield from 50% (Ichilo River at Puerto Villarroel) to 79% (Pirai River at Angostura) of the annual sediment discharge. Some exceptional floods of a few days, observed on the Pirai River basin (from 01/14 to 01/16/78) are responsible for 54% (Angostura station) to 81% (Espejos station) of the annual sediment exportations (Molina, 1986).

The sediment regimes evolution from upstream to downstream is similar to the hydrological regimes : crossing the plain provokes a regulation of the Total Suspended Sediment (TSS) regime and a more homogeneous distribution of the contents (Guyot, 1986). As well as for the discharges, a gap in time from upstream to downstream is observed for the maximum sediment discharge.

The maximum erosion rates are observed at the foothills of the Andes which represent a total sediment discharge of the order of 161.10^6 $tons.year^{-1}$ (Parapeti, Grande, Pirai and Ichilo Rivers). In the Andes, the observed erosion rates are very variable (310 to 2,600 tons.km^{-2}.year^{-1}) and depend strongly on the rainfall regimes, on the topographical and geological characteristics and on the vegetation of the drainage basins. The Southern Andes basins (Grande and Parapeti Rivers), with a semi-arid climate and a limited vegetation, show high erosion rates. On the contrary, to the North, in the Chapare, where climate is always humid and vegetation is tropical, erosion rates remain low (Table 2).

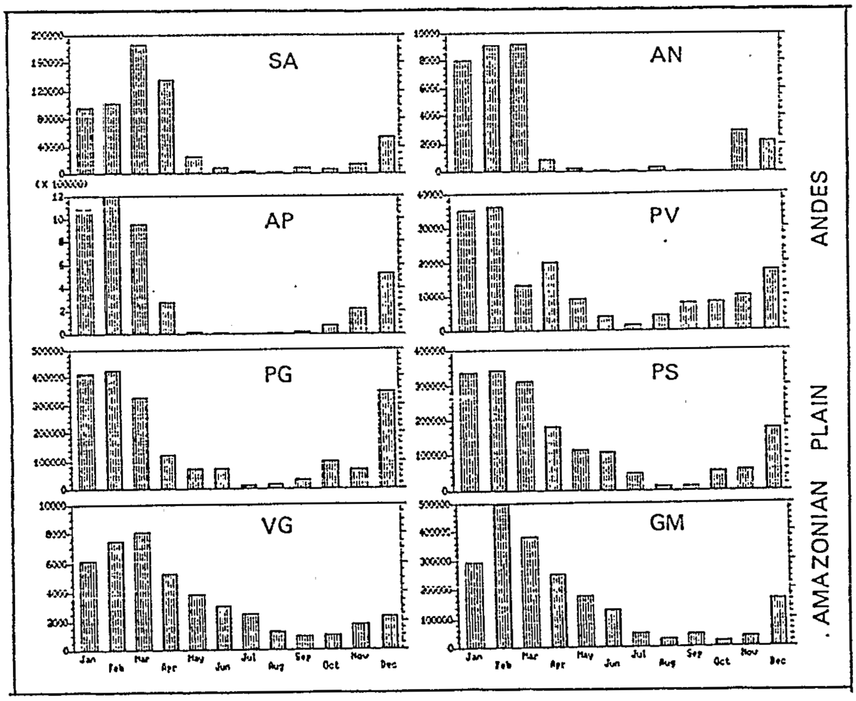

Fig. 4 : Sediment discharge regimes (tons.day^{-1})
(see table 1 for station codes)

Pontes e Lacerda station, even though there are very few measurements, gives an indication on the erosion rate of the Brazilian Shield (16 tons.km^{-2}.year^{-1}). The Itenez and Ibare Rivers show that the yield from the plain is weak or null. The Ibare River waters are contaminated by the Mamore River waters during floods (Corbin & al., 1988).

Even taking account yields of the different tributaries, the observed flow along the Mamore River show a progressive decrease due to dilution effects by the yield of the plain and sedimentation. So the Mamore River at Puerto Ganadero, then at Puerto Siles, i.e. after a 500 and 900 km course in the flood-plain, shows a flow of 61 and 53.10^{6} tons.year^{-1}. Continuing the observations on the PHICAB network is going to allow a better knowledge of the sedimentation rates in the Amazonian plain. The Mamore River, at its confluence with the Beni River, yields 63.10^{6} tons.year^{-1} of suspended matters, i.e. 4.3 times more than the exportation of dissolved matters to the Madeira River (Roche & al., 1988).

Table 2 : Discharge, sediment discharge and erosion rates

Code	Discharge ($m^3.s^{-1}$)	T.S.S. ($mg.l^{-1}$)	Sediment discharge (10^6 $t.yr^{-1}$)	Erosion rate ($t.km^{-2}.yr^{-1}$)
HU	70	4100	14.1	1260
AZ	32	1210	1.35	310
AP	310	8670	134	2280
SA	79	4270	19.5	2600
ES	2.8	1170	0.36	1780
AN	6.8	1040	1.01	710
LB	13	2220	2.20	760
PV	560	220	5.10	670
PA	(140)	78	(0.34)	(64)
PG	3540	460	60.9	380
PS	5660	260	53.3	250
PL	50	25	0.04	16
VG	2240	30	1.33	4
GM	8930	220	62.8	110

Data in parentesis have been estimated

The flow of sediments exported by the Mamore River for the 1983-1987 period is 2.4 times less than observed on the Beni River for the same period (Guyot & al., 1988b). The Beni and Mamore Rivers (212.10^6 $tons.year^{-1}$) represent from 49% (Richey & al., 1986) to 135% (Gibbs, 1967) of the volume that has been observed on the Madeira River at its confluence with the Amazon River.

Conclusion

Variable erosion rates, due to the conditions of topography, geology, pluviometria and vegetation, have been observed in the Andes (from 310 to 2,600 $tons.km^{-2}.year^{-1}$). The Ichilo River, coming from a basin that bears high rainfalls and tropical vegetation, shows an erosion rate of 670 $tons.km^{-2}.year^{-1}$ for a sediment discharge of 5.10^6 $tons.year^{-1}$. On the contrary, the Grande River, which crosses a semi-arid mountainous zone, shows a sediment discharge of 134.10^6 $tons.year^{-1}$, corresponding to an erosion rate of 2,280 $tons.km^{-2}.year^{-1}$, one of the highest in the Andes. Finally, the Mamore River at its confluence with the Beni River, yields 63.10^6 $tons.year^{-1}$ of sediments to the Madeira River, i.e. a global mechanic erosion rate of 110 $tons.km^{-2}.year^{-1}$.

Continuing the observations and measurements on the PHICAB network in the Bolivian Amazonia should allow a more precise evaluation of erosion rates in the Andes and of sedimentation rates in the plain, during the next hydrological cycles, for this high drainage basin of the Amazon.

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Proceedings of the Fourth International Symposium on

RIVER SEDIMENTATION

June 5-9, 1989

Vol. 1

with Central Theme: Effects of Erosion Control Measures on Sediment Yield

International Research and Training Centre on Erosion and Sedimentation

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