Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989)
IAHS Publ. no. 184, 1989.

Placer mining operations and modifications of the physical chemical nature of the waters of the Rio Kaka drainage basin (Andes, Bolivia)

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ABSTRACT Exploitation of gold placers in the Bolivian Andes leads to a modification of the rivers physico-chemistry. The impact of the mining activity is evaluated for the River Tipuani where extraction is intense in low water, compared to the River Challana which is lightly exploited.

INTRODUCTION

In Bolivia, the gold placers of the Royal Cordillera, located in the North of the country (Fig. 1), provides several tons of gold a year. The most important exploitations are located along the Rivers Challana, Tipuani and Consata-Mapiri, that join the River Coroico to form the River Kaka. Gold is produced from the treatment of alluvial deposits contained in Miocene paleovalleys, of alluvial deposits from Quaternary terraces, but mainly of alluvial deposits of present riverbeds or low terraces. Mining activity is particularly important during the low water season, between April-May and November-December. Indeed, the deposits contained in the bottom of the valley are inaccessible during the high water season.

The purpose of this paper is the evaluation of the influence of placer exploitation on water quality. Three rivers have then been studied: the River Challana, the River Tipuani and the River Consata-Mapiri. Along the River Challana, gold exploitation is yet little developed. This river is then used as a reference, because it intersects the same geological, geomorphological and biogeographical structures as the River Tipuani, where mining exploitation is very important. Along the River Consata-Mapiri, the extraction is located on terraces and effluents are not directly poured to the river. The part of the suspensions due to mining activity in the solid discharge of the River Kaka is discussed.

HYDROCHEMICAL CONTEXT

Geology

The rivers of the River Kaka drainage basin, where sandstone and pyritic slates from Ordovician build up the largest outcrops (Martinez, 1980), granites, granodiorites and orthogneiss that outcrop along the crest line (Zongo-Yani block, Illampu block), as well as the contact metamorphic aureole, that line them to the North-East (Bard & al., 1974) are only drained by the most upstream tributaries. These rocky set-ups are intersected by narrow and sloping valleys covered by vegetation below 3000 m. Below 1500 m topographical features are softer and the Ordovician substratum is partially covered by Tertiary Cangalli conglomerates (Fornari & al., 1987) and Quaternary alluviums. Out of these mining areas, these deposits are entirely covered by forest, and form a buffer between pyritic slates and run-off waters. Along the River Consata-Mapiri, the same geological formations outcrop, but the vegetal coverage is very discontinuous on the slopes, and numerous landslides affect ordovician schists and alterites that cover them. Upstream of the Consata and Camata drainage basin, volcanic series and limestones outcrop, but on limited areas.

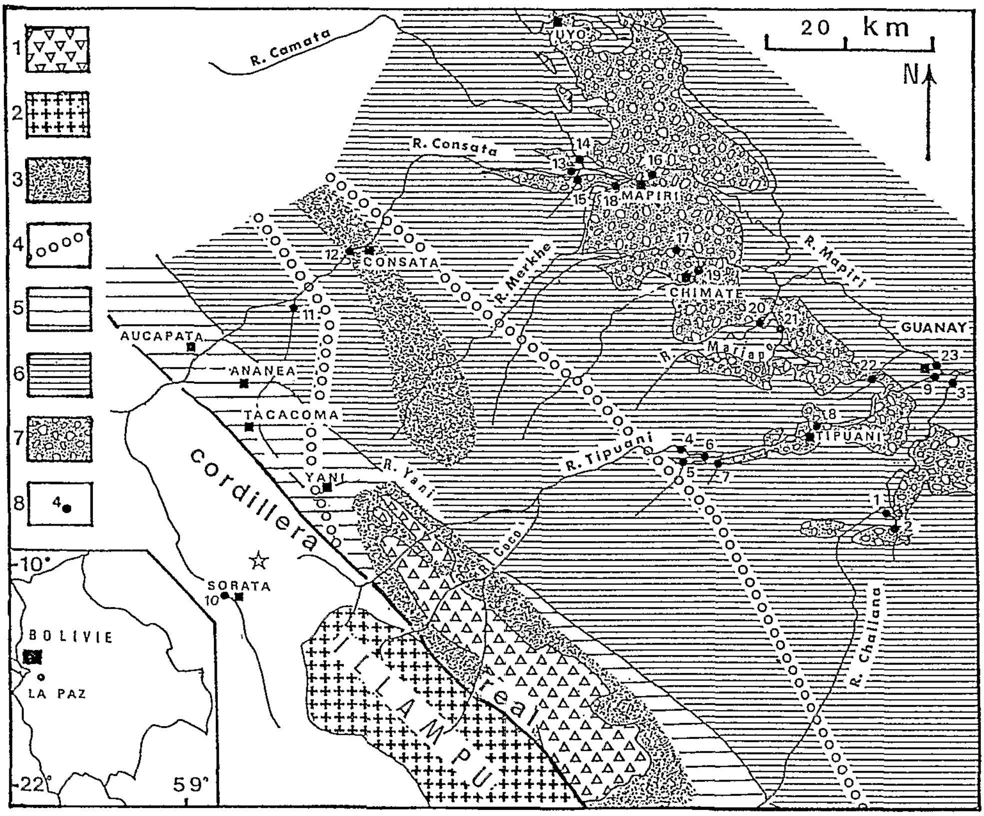

Fig. 1 Localization and geology of the studied area
1: syntectonic granite of Zongo-Yani, 2: Illampu granodiorite, 3: medium to high grade thermal metamorphism, 4: biotite boundary, 5: slates and sandstones (Late Ordovician), 6: black slates (Middle Ordovician, 7: Cangalli formation (Neogene conglomerate), 8: sample points (see table 1).

Hydrology

The River Kaka is the main affluent of the River Alto-Beni and drains a 21400 km^2 basin, lying from almost 6500 m (Illampu) down to below 400 m at its confluence with the River Alto-Beni. Summits of this basin receive from 800 to 1000 mm of precipitation a year, whereas rainfalls reaching 4000 mm are observed in the upper parts of the tropical valleys. The average rainfall for the whole River Kaka drainage basin is of the order of 2500 mm a year (Roche & al., 1986).

Mostly formed by the Rivers Mapiri, Tipuani, Challana and Coroico, the River Kaka shows a 1220 $m^3.s^{-1}$ mean discharge for the 1968-1983 period at the station of Nube. This mean discharge represents 52% of the River Alto-Beni discharge at the footsteps of the Andes (Angosto del Bala), whereas the area of the River Kaka drainage basin represents only 30% of the total area of the Alto-Beni basin (Espinoza, 1985). The hydrological regime of the River Kaka (Fig. 2) is characterized by a well defined high water period from December to April, and a low water period from May to November. The five months of the rainy season are responsible for 75% of the annual mean discharge, and the three rainiest months only, from January to March, provide more than half (55%) of the mean annual discharge. The same regime, of torrential type, is observed on the whole of the basin rivers, such as the River Tipuani at the Tora station (Fig. 3), located upstream of the exploitation zone.

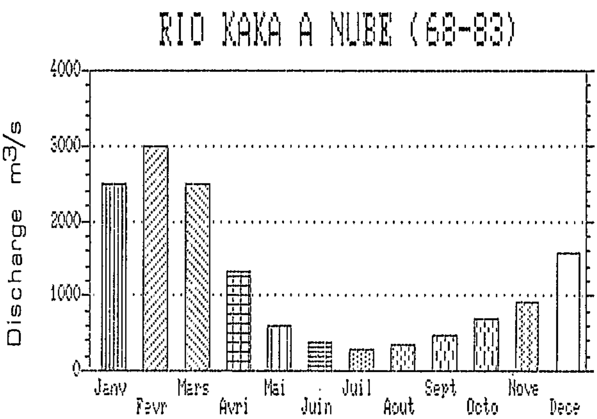

Fig. 2 Hydrological regime of the River Kaka at Nube, 1968-1983 (from SENAMHI).

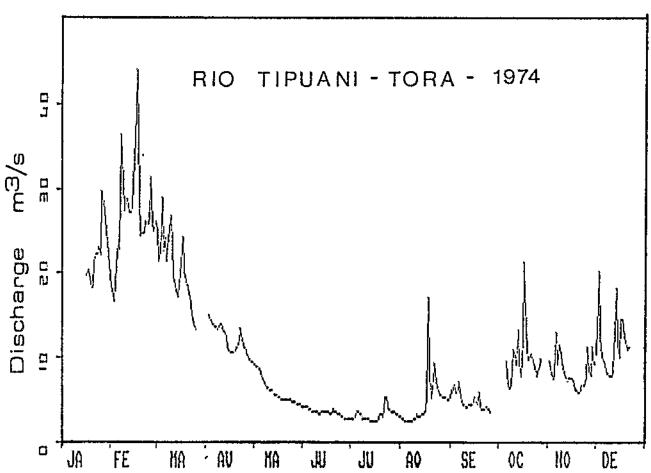

Fig. 3 Discharge hydrography of the River Tipuani at Tora, 1974 (from SENAMHI).

The flow of total suspended sediments (TSS) has been measured by the SENAMHI (Bolivian National Climatological and Hydrological Service) on the River Coroico (1976-1977) and the River Mapiri (1975-1979). The regime of this sediment discharge can be compared to the hydrological regime, but the influence of the rainy season is much more important (Fig. 4). Indeed, most of the sediment discharge occurs during the rainy season from January to March, which provide up to 95% of the annual global volume (Guyot & al., 1988).

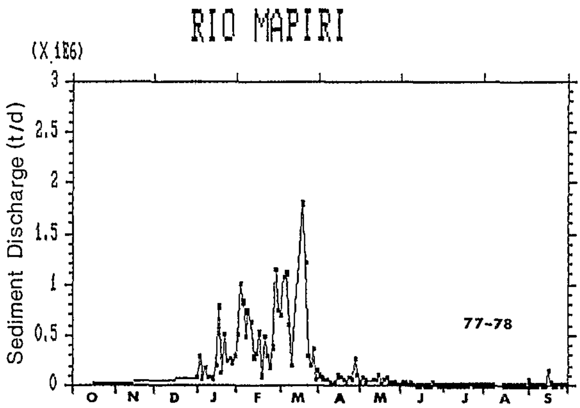

Fig. 4 Sediment discharge regime of the River Mapiri at Angosto Quercano, 1977-1978 (from SENAMHI).

HYDROCHEMICAL CHARACTERISTICS

Natural waters

A sampling collection made on the whole River Mapiri drainage basin in low water (July 1987) allowed a hydrochemical characterization of the different rivers (tabl. 1). The bicarbonated calcic or magnesian waters of the basin, weakly mineralized (20 to 40 $mg.l^{-1}$) and with low suspended matters contents (lower than 10 $mg.l^{-1}$), are opposed waters that are much more mineralized (from 50 to 500 $mg.l^{-1}$), with generally higher suspended matters contents and of calcic or magnesian sulfated type, which correspond to the High Mapiri basin (Rivers Consata, Camata and Mapiri).

Influence of mining activity

In order to know the influence of mining exploitation on the River Tipuani, a comparative study of the Rivers Challana and Tipuani, that bear the same initial chemical composition, has been realized from upstream to downstream. It appears (Fig. 5) that total dissolved solids (TDS) do not evolve significantly from upstream to downstream for these rivers. On the other hand, the suspended load increases notably from the beginning of the exploitation zone. In Guanay, the TSS of mining origin in the River Tipuani is 130 times superior to the Challana natural TSS. In this low water period, the River Tipuani yields to the River Kaka 8.4% of the

Table 1 Characteristics of the sampling water points (July 1987)

Num.	River	Place	Area (km2)	Discharge (m3.s-1)	Temp. (°C)	pH	TDS (mg.1-1)	TSS (mg.1-1)
1	Challana	Upstream	1850	18.3	21.0	6.2	22.9	0.2
2	Sapukani		24	<0.2	22.7	6.7	20.7	0.4
3	Challana	Guanay	2070	24.9	21.7	6.3	26.0	6.2
4	Tipuani	Cfl.Tora	911	12.4	18.4	6.0	30.3	6.2
5	Tora	Cfl.Tipuani	109	3.2	19.4	6.6	27.0	0.3
6	Tipuani	Mine			18.0	6.1	30.6	8.5
7	Bartolo		17	<0.2	18.7	5.4	18.4	0.2
8	Tipuani	Tipuani			21.7	6.1	30.6	466
9	Tipuani	Guanay	1350	17.4	20.7	6.2	26.2	826
10	S.Cristobal	Sorata	264		15.0	7.8	117	6.3
11	Gunduraya			<0.2	17.0	4.9	69.8	0.5
12	Consata	Consata			18.0	7.8	388	813
13	Consata	Cfl.Camata	3590	17.9	23.0	7.4	508	439
14	Camata	Cfl.Consata	2530	29.1	23.7	6.4	50.4	9.6
15	Tarapo			<0.2	22.7	6.1	26.8	5.3
16	Mapiri	Mapiri			22.9	7.8	131	100
17	Korijahuira		245	2.0	20.1	4.7	38.6	4.7
18	Merkhe		595	7.1	22.3	4.1	27.1	0.1
19	Chimate		107	3.7	19.8	5.2	28.1	1.4
20	Dinamarca		52	0.6	21.0	5.6	21.6	0.6
21	Mariapo		208	1.9	22.6	6.6	20.0	0.4
22	Charoplaya		34	<0.2	22.3	7.3	30.7	0.1
23	Mapiri	Guanay	11600	82.3	23.0	6.9	80.6	41.5
24	Mapiri	Cfl.Coroico	15000	125	22.7	6.9	56.9	382
25	Coroico	Cfl.Mapiri	5640	83.1	22.5	7.0	30.3	6.6
26	AltoBeni	Angosto Bala	67200	501	26.0	8.0	90.6	119

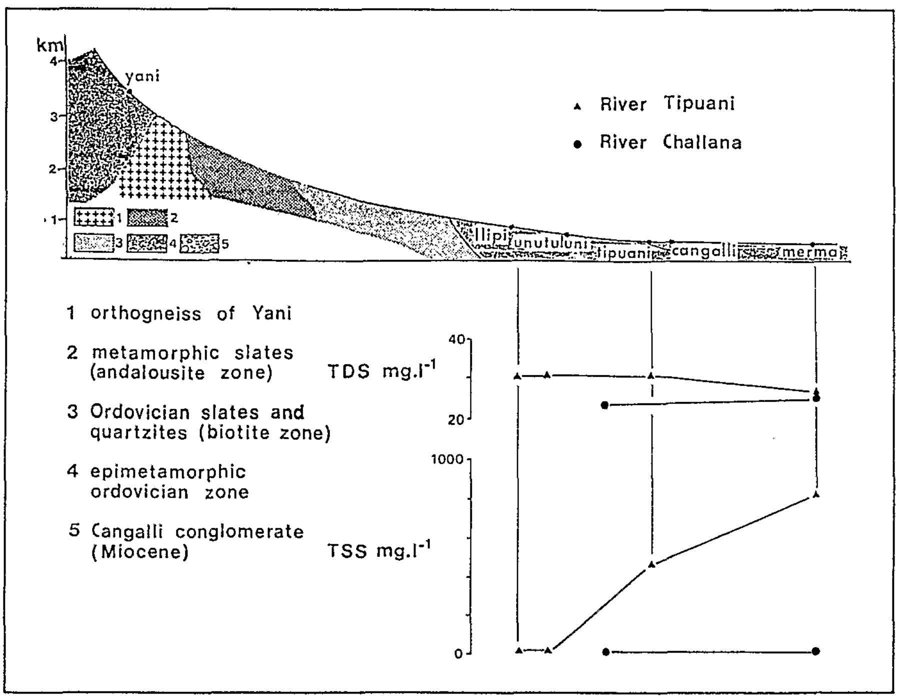

Fig. 5 TDS and TSS evolutions along the Rivers Tipuani and Challana in low water season (July 1987).

discharge, 4.4% of the TDS, but 77.8% of the TSS. The River Challana, then represents 12.0% of the discharge, 0.8% of the TSS and 6.3% of the TDS of the River Kaka (tabl. 2). This very strong influence of mining exploitation in low water upon the sediment discharge is still noticeable at the footsteps of the Andes, at Angosto del Bala, where the River Tipuani alone is responsible for 24.1% of the sediment discharge, admitting that there is no deposit neither retake of sediments between these two stations. The influence of gold mining upon the suspended load of the River Mapiri is difficult to quantify because of the high natural concentrations that are observed in this river.

Table 2 Exports by the River Kaka (July 1987)

River	Place	Discharge ($m^3 \cdot s^{-1}$)	% Ang. Bala	TDS ($mg \cdot L^{-1}$)	Dissolv. discharge ($t \cdot d^{-1}$)	% Ang. Bala	TSS ($mg \cdot L^{-1}$)	Suspend. discharge ($t \cdot d^{-1}$)	% Ang. Bala
Mapiri	Guanay	82.3	16.4	80.6	573	14.6	41.5	295	5.7
Tipuani	Guanay	17.4	3.5	26.2	39	1.0	826	1240	24.1
Challana	Guanay	24.9	5.0	26.0	56	1.4	6.2	13	0.3
Coroico	Cf. Mapiri	83.1	16.6	30.3	218	5.6	6.6	47	0.9
Kaka		208	41.5	—	886	22.6	—	1595	31.0
Alto-Beni	Ang. Bala	501	100.0	90.6	3920	100.0	119	5150	100.0

From physico-chemical data of the PHICAB (Climatological and Hydrological program of Bolivia, ORSTOM/SENAMHI/UMSA), it appears that TDS seasonal evolution of the Rivers Tipuani and Challana (Fig. 6) presents low and almost constant concentrations during the hydrological cycle. On the contrary, the River Mapiri, with higher dissolved concentrations, shows important variations, where concentration is the lowest in high water and the highest in low water. TSS seasonal evolution for the River Challana is identical to the TDS, i.e. low and constant during the whole hydrological cycle. The River Mapiri shows a TSS evolution synchronous to the discharge evolution, with a maximum sediment discharge in high water and a minimum in low water. The River Tipuani, with a

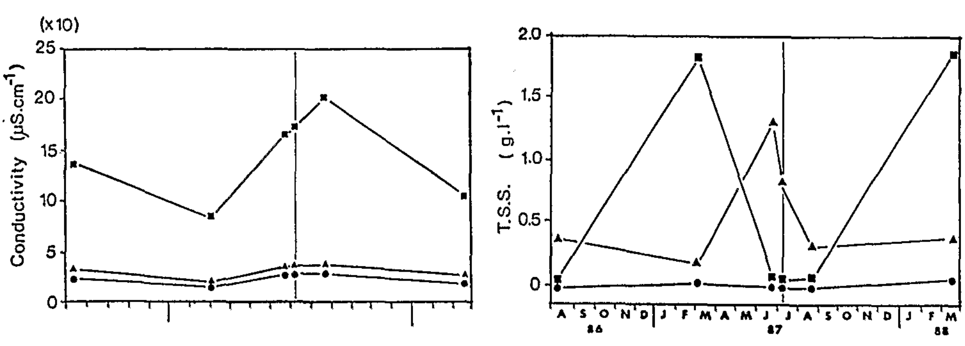

Fig. 6 TDS and TSS seasonal evolution for the Rivers Challana, Tipuani and Mapiri.

maximum TSS concentration in low water and a minimum in high water, presents an artificial sediment regime. The low contents that are observed in high water, although higher than the ones measured in the River Challana, correspond to a slower mining activity during the rainy season. On the contrary, in low water periods, when the exploitation in the river bed is intense, the maximum loads are measured. The gold exploitation influence on the TSS balance of the River Kaka drainage basin is then maximum in low water period, when the natural TSS are the lowest.

CONCLUSION

The exploitation of gold bearing deposits in the River Tipuani alluvium yields strong modifications of this andean river water quality. The importance of the contamination has been evaluated by the physico-chemical behavior of the River Tipuani and the River Challana, where gold extraction is very low, during the hydrological cycle. So, in low water periods, when mining activity is maximum, the River Tipuani suspended load increases strongly, up to represent 130 times the natural value observed in the River Challana. This influence is still noticeable at the footsteps of the Andes, 200 kms downstream. On the other hand, no noticeable modification of the TDS has been observed.

ACKNOWLEDGEMENTS This research was supported by ORSTOM. Special thanks to the SENAMHI and IIQ-UMSA (Institute of Chemical Research of the University of La Paz) laboratories that have realized the analysis.

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