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RECONNAISSANCE OF SEDIMENTATION IN THE RIO PILCOMAYO BASIN, MAY 1975, ARGENTINA, BOLIVIA, AND PARAGUAY

U.S. GEOLOGICAL SURVEY
Open-File Report 77—327

Prepared in cooperation with the Government of Argentina, Bolivia, and Paraguay, under the auspices of the Organization of American States

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By JOHN R. RITTER

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1977

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CONVERSION FACTORS

Factors for converting from the International System of Units (SI) used in this report to English units are given below to three significant figures. However, when converting from metric to English equivalents, use only the number of significant figures consistent with the values given in metric units.

Metric (SI) units	Multiply by	English equivalents
millimeters (mm)	0.0394	inches (in)
meters (m)	3.28	feet (ft)
kilometers (km)	.621	miles (mi)
square kilometers (km^2)	.386	square miles (mi^2)
cubic meters per second (m^3/s)	35.3	cubic feet per second (ft^3/s)
tonnes (t) (megagram-Mg)	1.10	tons, short (2,000 lb)

RECONNAISSANCE OF SEDIMENTATION IN THE RÍO PILCOMAYO BASIN, MAY 1975, ARGENTINA, BOLIVIA, AND PARAGUAY

By John R. Ritter

ABSTRACT

The Río Pilcomayo "Alto" (Bolivia) and "Superior" (Bolivia, Argentina, and Paraguay) transport large quantities of sediment for the size of the basin. The Río Pilcomayo "Inferior" (Argentina and Paraguay) seems to carry little sediment. The large loads of the "Alto" and "Superior" must be considered before dams or irrigation projects are started. The shifting channel and flooding of the Río Pilcomayo "Superior" also are problems to be considered before development. The Río Pilcomayo "Alto" basin has relatively little deposition whereas the "Superior" basin has considerable deposition. A part of the "Superior" channel is filled with sediment to the top of its banks. The upstream limit of filling is moving farther upstream each year causing the place of overbank flooding to move upstream also.

More data must be collected and more observations made before a complete analysis of the sediment movement in the basin can be made.

INTRODUCTION

The Río Pilcomayo has its headwaters in Bolivia and flows between Paraguay and Argentina to the Río Paraguay (fig. 1, pl. 1). Upstream from Villa Montes, Bolivia, where the river breaks out of the Andes Mountains, the river is called Río Pilcomayo "Alto". From Villa Montes to its point of disappearance, a few kilometers (km) downstream from Laguna Escalante, Paraguay the river is called Río Pilcomayo "Superior". About 160 km southeast from the point of disappearance, another river appears. This river is known as the Río Pilcomayo "Inferior".

This report covers a reconnaissance of sedimentation of the basin carried out during April and May 1975 and chiefly concerns the Río Pilcomayo "Alto". The Río's Pilcomayo "Superior" and "Inferior", however, had been previously visited on a trip during August and September 1974. That trip, which was described in reports by Maddock (1974) and Ritter (1976), was made during a period of low flow; the more recent trip was made during a time of flooding.

The purpose of this report is to describe the reconnaissance in general with emphasis on the erosion and deposition of sediment observed in the basin. The reconnaissance was supported by the Organization of American States (OAS) and conducted in cooperation with the governments of Argentina, Bolivia and Paraguay.

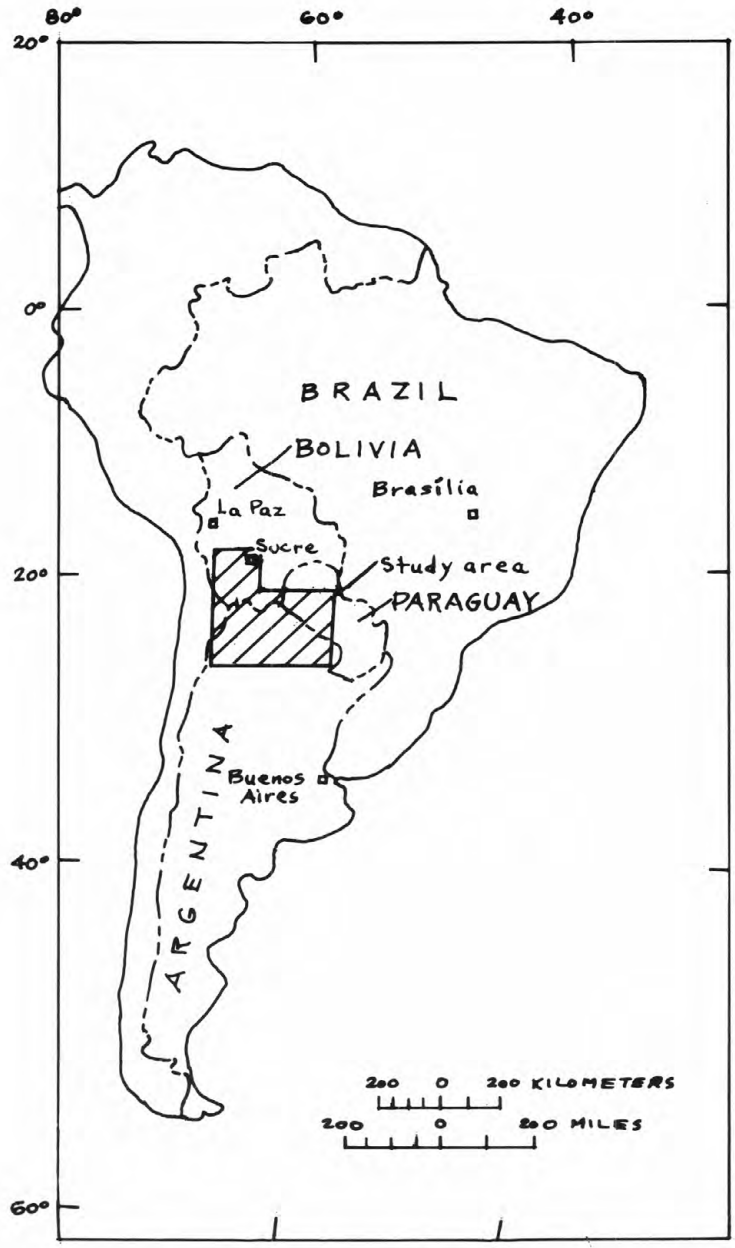

Figure 1.--Sketch map of South America showing the general location of the Río Pilcomayo basin.

Description of the Basin

The drainage area of the Río Pilcomayo is about 200,000 square kilometers (km^2) according to Barclay (1974). This figure, however is probably a very rough estimate as the drainage divide in the lower part of the river is hard to define because of the flat terrain.

Average annual rainfall in the basin ranges from about 140 millimeters (mm) at Pampa Grande, Bolivia, to about 1,400 mm at the mouth of the river. In general, the rainfall in the basin decreases westward. Rainfall variability on the Río Pilcomayo " Alto" basin is illustrated by data for 16 stations given in table 1.

The elevation of the basin ranges from about 5,000 meters (m) in the Andes Mountains in Bolivia to 52 m at the mouth of the river, which is its junction with Río Paraguay. The gradient of the Río Pilcomayo "Alto" is greater than 5 percent in places, but the slopes of the Río Pilcomayo "Superior" and "Inferior" are much less (table 2). The relatively high slope between Villa Montes and D'Orbigny (table 2) reflects the area of deposition where the river breaks out of the mountains. East of D'Orbigny the terrain of the basin is extremely flat.

TABLE 1.--Rainfall in the Río Pilcomayo "Alto" Basin

(from records of the Comision Boliviana Proyecto Pilcomayo, Tarija)

Location	Years of Record	Annual rainfall, in millimeters		
		Maximum	Minimum	Average
Pampa Grande	9	211	66	142
Tomave	6	789	331	528
Potosi	16	632	255	412
Camargo	10	526	169	353
Ajtara	8	705	309	438
Punutuma	7	402	114	304
Tacobamba	8	505	361	448
Yocalla	9	525	222	349
Quila Quila	11	803	486	635
Cruce	8	827	345	481
Talula	10	818	469	613
Ravelo	11	1,276	809	862
Potolo	7	656	131	439
El Puente	7	400	104	230
Villazon	9	497	128	297
Villa Montes	9	1,206	570	838

TABLE 2.--Slopes of the Ríos Pilcomayo "Superior"

and "Inferior (Volpi, 1956)

Location	Altitude, meters	Distance, Kilometers	Slope
Villa Montes	400	-	-
D'Orbigny	266	130	0.001
Esmeralda	250	40	.0004
Horqueta	144	350	.00031
Salto Palmar	100	150	.00030
Junta Fontana	63	204	.00018
Puerto Pilcomayo	52	186	.00005

The annual flow of the Río Pilcomayo at Villa Montes from 1942 through 1955 averaged about 200 cubic meters per second (m^3/s). Most of the flow at that point occurs from January through March whereas most flow in the Río Pilcomayo "Inferior" occurs from April through June (Sioli, 1974). The flow downstream at La Paz and Fortín Nuevo Pilcomayo, Argentina, from 1962 through 1967 averaged 146 and 127 m^3/s respectively. Although the period of record at Villa Montes is not concurrent with that of the other two stations, indications are that the flow decreases in downstream direction. Furthermore, Sioli (1974) stated that the flow of the Río Pilcomayo "Superior" is 25 times that of the "Inferior". However, the Río Pilcomayo "Inferior" is only one of several streams that emerge below the point of disappearance of the "Superior". Overflow from the Río Pilcomayo "Superior" may feed water into any or all of them. Although the basin has high mountains in its headwaters, there is little precipitation in the form of snow and high runoff is caused by rainfall and not by snowmelt.

The suspended-sediment discharge of the Río Pilcomayo "Superior" has been measured since 1962 at La Paz, Argentina. The average annual discharge there is about 100 million tonnes [1/] per year (t/yr). That figure is calculated from the sediment-transport curve and the flow duration for the periods 1962-65, 1967-69 and 1971-72 and coincides with that given by Ritter (1976), which was based on a shorter period. The average concentration of suspended-sediment is about 19 grams per liter. The discharge was also measured at Fortín Nuevo Pilcomayo from 1953 to 1967, at which time the station was discontinued because the river ceased to flow at that point. The suspended-sediment discharge averaged 60,850,000 t/yr, as calculated from the annual discharges for the period, published by Aqua y Energía Eléctrica of Argentina (1970). Barclay (1974) stated that the discharge at Villa Montes averaged 58,500,000 t/yr. This figure seems much too low in comparison with the suspended-sediment discharges downstream. The area between Villa Montes and La Paz is an area of deposition; therefore, the suspended-sediment discharge at Villa Montes should be higher than at La Paz.

1/ Tonnes in this report are metric tons.

The suspended-sediment discharges in the Río Pilcomayo "Alto" basin also are large. A network of sediment stations was established in recent years in Bolivia, and the preliminary results from the Comision Boliviana Proyecto Pilcomayo show that large concentrations of sediment are being carried by the river. For example, the concentration of suspended-sediment measured in the Río Pilcomayo at Angosto Talula has several times surpassed 100 grams per litre (g/l). The maximum concentration was 210 g/l; the minimum 0.036 g/l.

The Río Pilaya at Chilcara over a short period (July-November 1972) had a maximum concentration of 63 g/l. Although the data are insufficient for drawing final conclusions, the Pilcomayo seems to carry greater concentrations of suspended sediments than the Pilaya.

The soils near the river above Villa Montes average 70 percent sand, 20 percent silt and 10 percent clay; downstream the soils become finer and are about 2 meters deep (data from the Comision Boliviana Proyecto Pilcomayo). This indicates that the river is probably carrying mostly sand, but that the load becomes finer as it moves downstream from Villa Montes.

The channel of the Río Pilcomayo "Superior" often changes. For example, the river now flows into Laguna Escalante whereas, according to the priests at Mission San Leonardo, the river 2 years ago was 7 km south of there. Some of the shifts in the channel are due to meanders being cut off and new ones being started. The many oxbow lakes near the present channel indicate the many times that the river has cut off a meander.

Shifts in the channel are caused also by floods breaking over the banks and eroding or finding new channels. This is the probable cause for relocation of the river several kilometers from its former channel, as near Laguna Escalante.

OBSERVATIONS

The observations of the previous reconnaissance of the Río Pilcomayo (August - September 1974) can be found in the reports by Maddock (1974) and Ritter (1976). The observations in this report are limited to those made in May 1975.

Río Pilcomayo "Superior" and "Inferior" Flight, May 5

A flight was made on May 5 from Asuncion to Fortín P. P. Peña, Paraguay. It had rained for several days the previous week and the land along the Río Pilcomayo "Inferior" was covered with standing water. Most of that water probably was ponded rainfall and there was no evidence of the river having flooded. In appearance, the area between the Río Pilcomayo "Inferior" and the Río Pilcomayo "Superior" was drier than that to the southeast.

Laguna Escalante, through which the Río Pilcomayo was flowing on May 5, 1975 was much larger than it was in September 1974. The outlet channel from Laguna Escalante contained all the flow for a few kilometers downstream, but near and below Laguna Tres Palmas the area was flooded (fig. 2). Above Laguna Escalante the water was flowing in several channels, but most of the water was flowing in two major channels - one which was wide and braided; the other narrow and meandering (fig. 3). Those channels paralleled each other for many kilometers. The banks of the meandering channel were overtopped, and the overflow entered the braided channel. Farther upstream the meandering channel disappeared, but the braided channel extended on upstream to a lagoon. Above the lagoon there was general flooding over a large area (fig. 4).

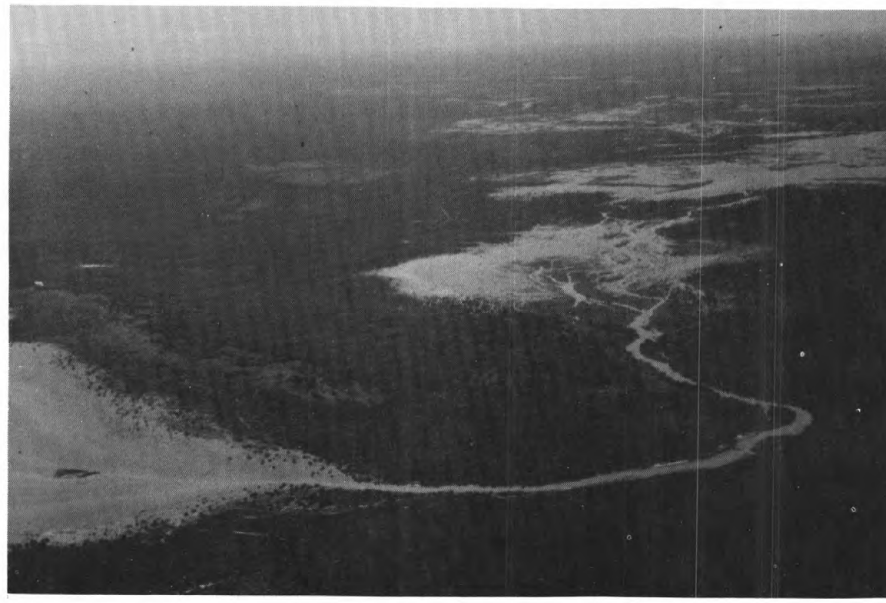

Figure 2.--Outlet of Laguna Escalante. Flow from Laguna Escalante (left) is contained in channel for a few kilometers but overtops the banks and floods the areas downstream such as Laguna Tres Palmas (right background).

Figure 3.--Braided channel and meandering channel upstream from Laguna Escalante. The channels parallel each other for many kilometers. The braided channel may be an overflow channel.

Figure 4.--Flooding west of Laguna Escalante. The channels are those shown in figure 3.

After passing over many kilometers of flooded lands we saw an abandoned channel filled with sediment and covered with vegetation to the south (fig. 5). The vegetation in the channel became sparser as we flew westward (upstream) until a point was reached where the channel was filled with recently deposited sediment as denoted by the lack of vegetation (fig. 6). This recent deposition continued upstream for about 15 km, at which point the Río Pilcomayo "Superior" was seen spilling over to its banks causing the wide-spread flooding noted previously (fig. 7). In other words, the river was contained within its banks until it reached the area where sediment deposition had plugged the channel forcing the river to overflow (fig. 8). The flooding was not only into Paraguay but also into Argentina where the flooding was reported to have reached almost to Laguna Yema and to have isolated Fortín Soledad. The sediment plug was located near Sombrero Negro. From there upstream to Fortín P.P. Peña the river was contained within its channel which is perhaps 100 m wide. At one spot, where there is a hairpin meander, the river has broken through the apex of the meander and formed a narrow channel that parallels the old channel for several kilometers before reentering it. Both the new and old channels had flowing water. Between Fortín Cabello and Fortín P. P. Peña the channel has considerable deposition and in several places, the deposition almost closes off the channel (fig. 9).

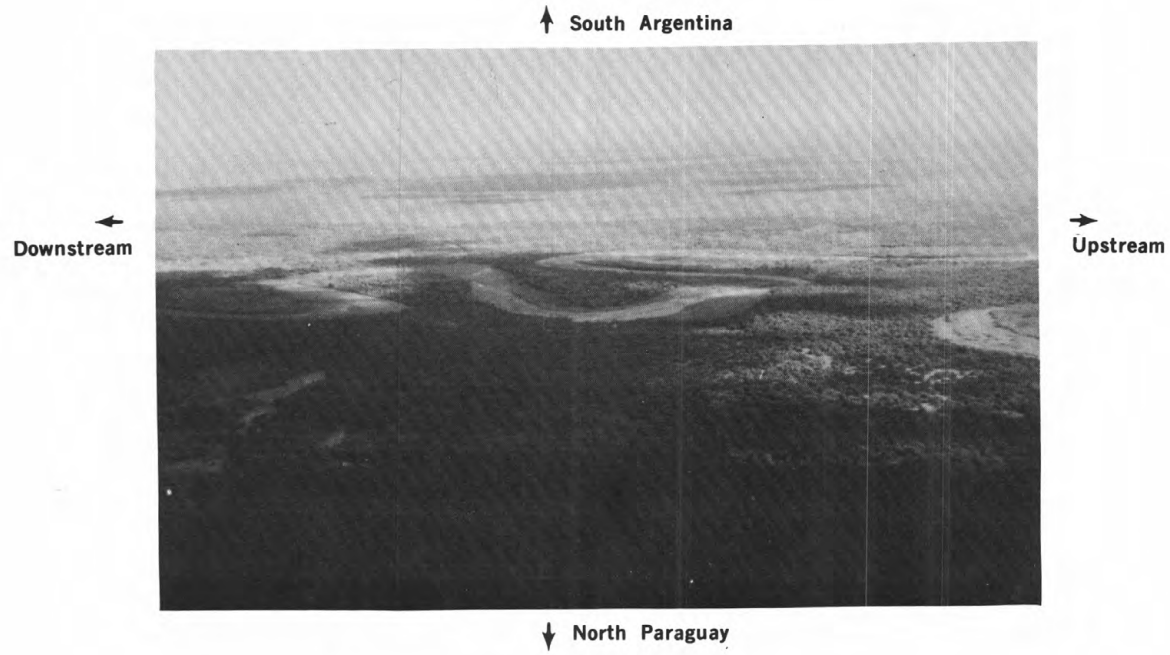

Figure 5.--Channel filled with sediment and becoming covered with vegetation. The vegetative cover decreases to the west (upstream, right).

Figure 6.--Channel of the Río Pilcomayo "Superior" recently filled with sediment. This picture was taken a few kilometers upstream from the site in figure 5.

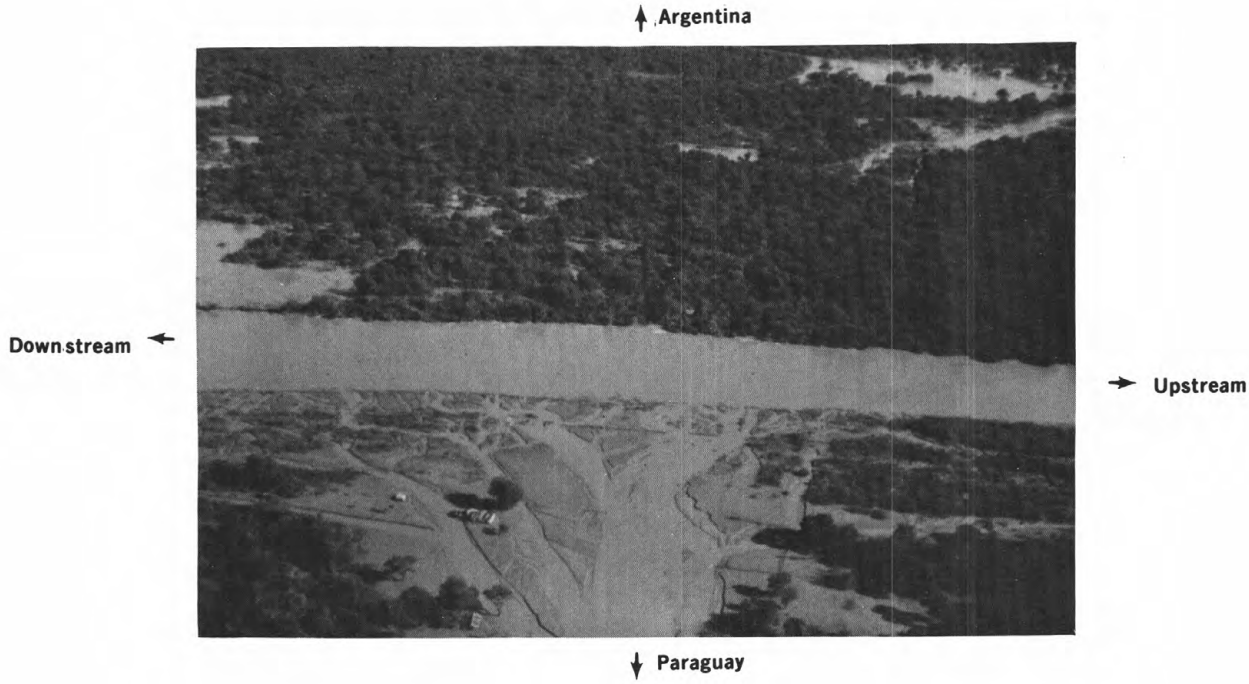

Figure 7.--Río Pilcomayo "Superior" overflowing its banks near the end of the sediment plug. This site is upstream of that shown in figures 6 and 8. Argentina is in the background; Paraguay in the foreground.

Figure 8.--Bank overflow near the site shown in figure 7. This shows the upstream end of the sediment plug.

Figure 9.--Río Pilcomayo "Superior" downstream from Fortin P. P. Peña, Paraguay.

Río Pilcomayo "Alto"

Field Trips in Bolivia, May 10-13

From Tarija, Bolivia, three trips were made to the Río Pilcomayo basin. On May 10 a flight was made from Tarija to D'Orbigny on the Río Pilcomayo "Superior" which was followed upstream to Villa Montes. From Villa Montes the Río Pilcomayo "Alto" was overflown to Huaclaya. At Huaclaya the place turned southwest and flew to the Río Pilaya, a major tributary, near Pampa Grande. The Río Pilaya was followed to Villa Abecia where the flight turned southward and the Río San Juan del Oro was followed to Tojo, where the plane turned back to Tarija.

On May 11-12 an overland trip was made from Tarija to Villa Montes and back by way of Yacuiba. Another overland trip was made on May 13 from Tarija to Camargo. Most of that trip was along the Río San Juan del Oro and the Rio Tumusla.

The Río Pilcomayo "Superior" from D'Orbigny to Villa Montes has a wide, braided channel (fig. 10). The area has considerable deposition and the channel near D'Orbigny often shifts. The bed material there is probably mostly sand. The channel near Villa Montes is more stable although it is still braided (fig. 11). The bed material is mostly gravel (fig. 12) and there is some lateral erosion and downcutting where the river breaks out of the mountains, just above Villa Montes (fig. 13).

Figure 10.--Braided channel of the Río Pilcomayo "Superior" between D'Orbigny and Villa Montes, Bolivia.

Figure 11.--Río Pilcomayo "Superior" near Villa Montes.

Figure 12.--Gravel bed material at Villa Montes.

Figure 13.--Río Pilcomayo where it breaks out of the mountains. Note erosion of bank.

The Río Pilcomayo from Villa Montes to Huaclaya is narrow and flows between steep mountainsides. The bed material is gravel. What deposition exists is on the bed of the channel. The valley at Puesto Margarita, however, seems to be a site of deposition. Most of the sediment reaching the Río Pilcomayo "Alto" is probably transported by the river to Villa Montes and beyond. Landslides were observed in the mountains (fig. 14) and these may be a major contributor of sediment to the river between Villa Montes and Huaclaya.

In general the vegetation on the mountainsides become sparser in a westward direction and there is little vegetal cover to be seen in the Río Pilaya basin between Pampa Grande and Villa Abecia. The lack of cover in conjunction with the steepness of the mountain slopes is conducive to the erosion and transportation of sediment to the river (fig. 15). The Río Pilaya is narrow and meandering and has coarse bed material. Little deposition was seen.

Figure 14.--Landslide scars on the mountains in the Río Pilcomayo "Alto" basin.

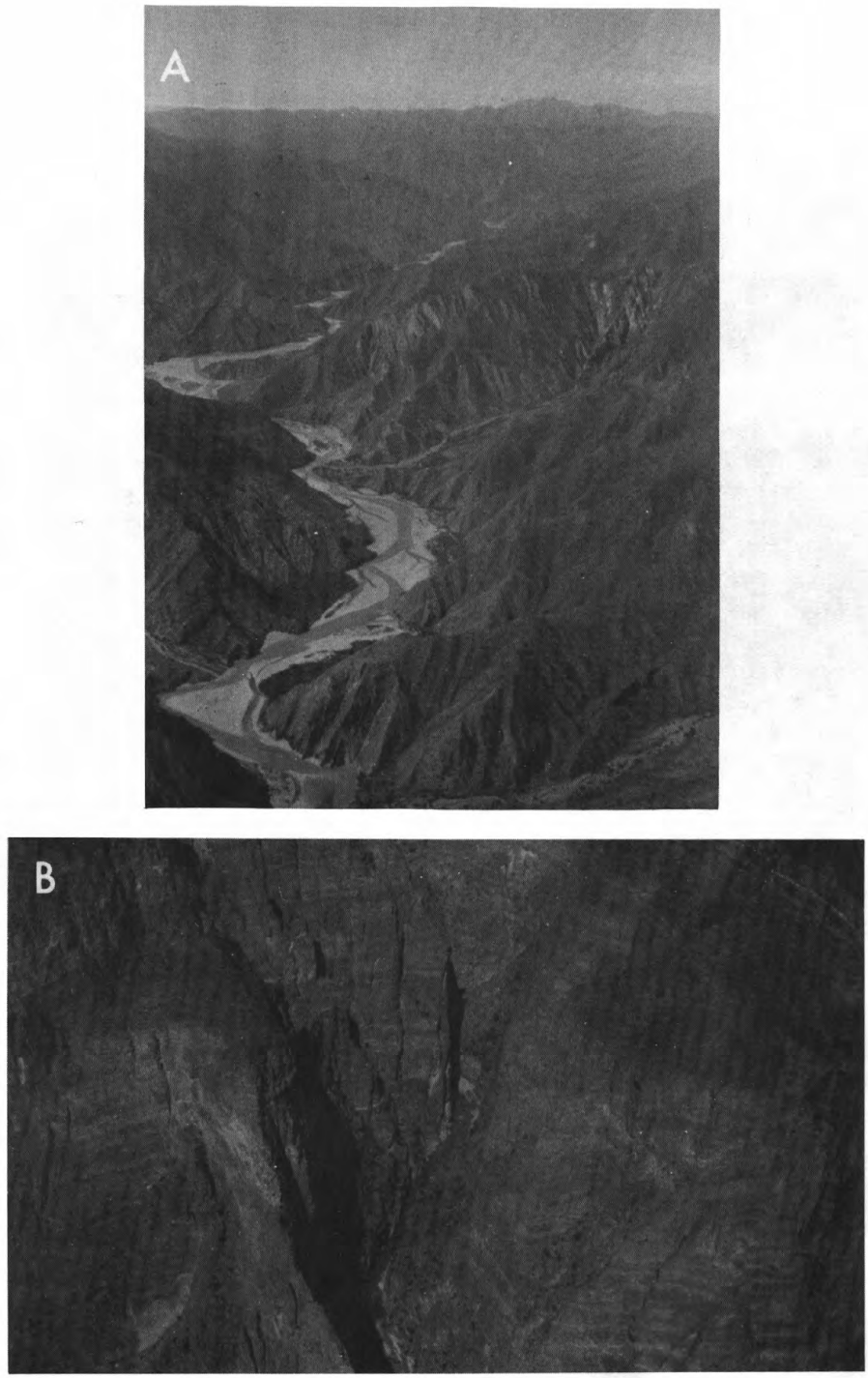

Figure 15.—Río Pilaya. Steep mountains are common along this tributary to the Río Pilcomayo. Oblique (A) and near vertical (B) views.

The Río Pilaya between Villa Abecia and Camargo flows through a valley where there is farming on river deposits and where some of the largest wineries in Bolivia are located (fig. 16). The Río Tumusla at Palca Grande (fig. 17), a gaging station site, was muddy, a condition which perhaps was caused by mining upstream. The Río Chico de Camargo, which joins the Río Tumusla near Palca Grande, was clear.

Between Tojo and Villa Abecia, the Río San Juan del Oro flows in a synclinal valley between a series of hogback ridges where the strata are deeply dipping (fig. 18). The river breaks through several water gaps in the ridges along its course (fig. 19). The valley of the Río San Juan del Oro is relatively wide and the several dry channels of tributaries contained deposited sediments. There is little vegetation except along the river itself. This is an arid part of the basin (the average annual rainfall at El Puente is 230 mm) and sediment, particularly coarse sediment, is probably moved only short distances because of the lack of runoff. This is also true in that part of the basin between Iscayachi and El Puente.

Figure 16.--Winery near Camargo.

Figure 17.--View upstream of the Río Tumusla at Palca Grande.

Figure 18.--Río San Juan del Oro.

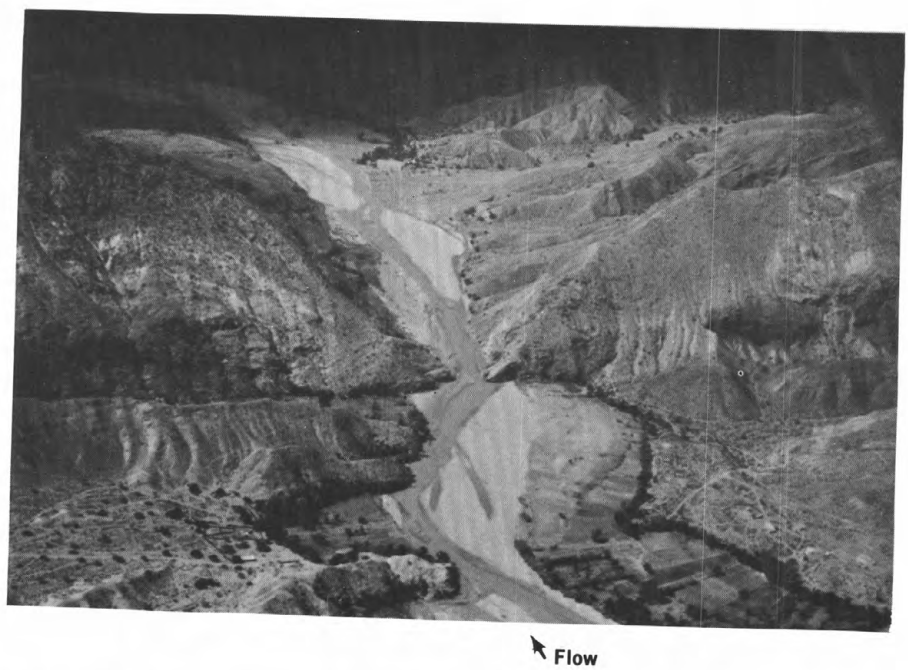

Figure 19.--Watergap on the Río San Juan del Oro.

Flight, May 14

A flight from Tarija to La Paz provided an opportunity to view the Río Pilcomayo basin near Sucre. The landscape there is sparsely vegetated. The Río Pilcomayo is narrow and shows little deposition except at the confluences of tributaries. The bed material is probably gravel.

CONCLUSIONS FROM OBSERVATIONS

Most observed erosion in the Pilcomayo "Alto" basin seems to result chiefly from natural causes, such as weathering and landslides. The mining areas were not visited. The observation of turbid water, however, in the Río Tumusla at Palca Grande indicates that the mines may contribute a considerable quantity of sediment to the river. Other nearby rivers without mining were clear. The effects of grazing and intensive farming on erosion could not be evaluated, but it is possible that these practices may have accelerated erosion in the basin. The combination of the lack of vegetation, steep slopes, and erodible rocks in many areas of the basin could lead to high erosion by rainfall runoff and other natural weathering agents.

The more arid regions of the Río Pilcomayo "Alto" basin seem to be areas of deposition where the sediment, especially coarse sediment, is not moved very far, except during periods of infrequent floods. No extensive areas of deposition, however, such as those in the Río Bermejo "Superior" basin, which is the adjoining basin to the south, were observed. The Río Pilcomayo system is composed mostly of narrow, steep, commonly meandering streams that flow between extremely rugged mountains (fig. 15). The topography in some areas resembles a gigantic badlands. The bed material is chiefly gravel. Most of the finer sediment (sand, silt, and clay) is probably transported out of the basin and into the Pilcomayo "Superior" basin where a considerable amount (particularly sand) is deposited on the alluvial fan between Villa Montes and D'Orbigny (fig. 10). Sediment is deposited also as the river continues downstream and eventually the river reaches a point where the deposition is filling the channel (fig. 8). That point has been moving upstream, probably several kilometers each year. At that point, the river ceases to have any defined channel and flows in a shallow layer across the flat terrain.

The reason for the initial deposition which plugged the channel is not apparent. Possibly the channel was first dammed by dead trees as suggested by Cordini (1947, p. 24) and the sediment filled in behind that obstruction. Perhaps the meanders of the river (fig. 20) are so tortuous that during high flows the river must drop its load because its velocity is reduced when the river tries to negotiate the bends. Again, perhaps the elevation of the land somewhere downstream (possibly in the area where the river disappears) has been raised by tectonic activity which in turn has decreased the velocity of the river to point where it can no longer transport its load. At the point of plugging or damming by the most recent deposition, the river overflows its banks, flooding large areas, and sometimes picking a new channel or even re-occupying one that has been abandoned previously.

Figure 20.--Meandering channel in the sediment-filled reach of the Río Pilcomayo "Superior".

George C. Taylor, Jr. and Saulo Bastos (oral communication, 1975) observed on a flight over that area in May 1975 that one river between Asunción and Filadelfia, probably the Río Verde, was muddy; the others were clear. That river was probably receiving turbid water from the flooding Río Pilcomayo "Superior". The Río Pilcomayo "Inferior" seems to carry little sediment and to flood infrequently. It is entirely different in those respects from the Pilcomayo "Superior".

The frequent flooding of the Río Pilcomayo "Superior" produces an environment that is different from that in the Río Bermejo Basin. The vegetation seems different and the number and size of lagunas, bañados and esteros in the Pilcomayo basin seems to be larger.

Plans for the dam at Puesto Margarita must consider the quantity of sediment being transported because the rate of its deposition will determine the life of the reservoir. The dam will affect the channel downstream. Without its usual large sediment load the river will probably erode the channel below Villa Montes. The channel between Villa Montes and D'Orbigny may become meandering instead of braided and the meanders downstream may change their patterns. The channel may eventually stabilize somewhat after it has adjusted to the effects of the dam. The reduction or stoppage of the now frequent floods of the Río Pilcomayo "Superior" probably will change the ecology of the Gran Chaco in that region.

RECOMMENDATIONS

The sediment-collection program that is now in operation is a good start. Sediment is undoubtedly the number one pollutant in the basin. The river carries a tremendous load of sediment which will affect any water-oriented project in the basin. It is a major factor to consider in locating damsites. The most important sediment-sampling site is at Villa Montes. Knowledge of loads and size of sediment being transported there will be valuable to plans for development, both upstream and downstream. Sediment data are now being collected at Villa Montes and on the main tributaries. Stations should be established at sites where erosion or sediment transport seems large and below areas where erosion may be accelerated by activities such as mining operations.

An evaluation of the effects of man's activities should be made. This may be based on historical evidence or on a comparison of sediment loads in adjacent similar basins where one is affected by man and the other is not. Knowing this, it is possible that conservation practices could be devised to control erosion created by man.

Much can be learned about the fluvial geomorphology, hydrology and processes of a river and its basin by collection of data on sediments and channel geometry. This is particularly true in alluvial areas. Information on width, depth, velocity, roughness, gradient (slope), concentration and size of suspended sediment, size of bed material and bedload is needed.

The channel below Villa Montes should be studied, historical changes should be noted and channel geometry should be investigated. Aerial photographs and maps would be valuable to detect changes.

Using these data, a prediction may be made about the effects of the proposed dam at Puesto Margarita on the channel downstream. The study should be continued after the dam is constructed. A study of the channel below Villa Montes before and after the dam construction will provide useful data for this and similar basins.

Any dam constructed in the basin must provide for the storage of sediment. The sediment yields in the Río Pilcomayo basin are among the highest in the world. The life of a reservoir is dependent on the rate that sediment is being carried into it. Thus the rate of filling by sediment is a most important factor in the economics of building a dam. If dredging is considered, to increase the life of the reservoir, a spoils area must be considered in a location where the dredged sediment would not return to the reservoir or choke the channel downstream.

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