

TRACE ELEMENTS GEOCHEMISTRY IN THE BOLIVIAN PROVINCE OF AMAZON BASIN

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INTRODUCTION

The geochemical studies on river water provide an insight into the weathering processes that control the distribution of elements and their fluxes. The upper drainage basins of the Amazon provide most of the dissolved and sediment yields leading to the Amazonian basin (Gibbs 1972; Stallard & Edmond, 1983, Guyot *et al.*, 1995). The geochemistry of the Bolivian rivers have been extensively studied during the PHICAB (Hydrology and Climatology of Bolivia) program (Guyot *et al.*, 1995, and ref. therein). But, geochemical studies concerned essentially the major element distribution. A limited number of papers investigate riverine transport of trace elements in the upper Amazon basin (Seyler *et al.*, 1998; Elbaz-Poulichet *et al.*, 1999). Our aim in the present work is to gain additional insight into origin and geochemical behavior of trace elements in a tectonically active area within the humid tropics. Because it represents an important part of the largest world river basin and also because it is a relatively pristine region where the contribution of the atmospheric marine source is limited (Stallard and Edmond, 1981), the Mamore and Beni basins are ideally suited to assess the different factors which act to the trace element transport by rivers.

STUDIED AREA AND SAMPLING

The Bolivian Amazon region lies in the upper middle part of the Madeira river basin. The basin extends from the Eastern Cordillera of the Andes to the Amazon Floodplain and the Brazilian Shield. The Madeira basin is large (900 000 km² upstream the Brazilian boundary) and provides most of the yield of the Amazon River for both dissolved loads and sediments (Roche and Fernandez 1988; Guyot *et al.*, 1995). Most of the samples analysed in the present study, have been collected in areas marked by pronounced topographic heights (Fig.1), decreasing from 3000 m to 100 m above sea level.

The Andean tributaries of the Beni River are draining intrusive granitic rocks covered by thick sedimentary deposits from the Ordovician dominated by gray-green to dark shales and sandstones with ages ranging from the lower Paleozoic to Tertiary.

Carbonate rocks and evaporite formations form abundant outcrops in the Mamore subbasin, especially in the Grande river catchment whereas intrusive granites, associated with sulfide mineralization exist in the Beni subbasin.

Surface water samples were collected during three field campaigns, during the rainy season (march 1994), at the end of rainy season (may 1996), and at the end of dry season (November 1994). Trace elements analysis were performed on acidified samples using inductively coupled plasma mass spectrometry technique, according to the method described elsewhere (Seyler & Elbaz-Poulichet, 1996). Organic Carbon (DOC and POC) was determined by a high-temperature catalytic oxidation method (HTCO), using a TOC-5000 Instrument (Shimadzu). More detailed information is given by Cauwet (1994).

RESULTS AND DISCUSSION

Dissolved material

Major constituent data allows us to distinguish two groups of river waters on the basis of pH and alkalinity (Fig 2). The first type has a low pH (<7.5) and low alkalinity (<1meq.l⁻¹) and is represented by 6 rivers from the Beni basin and 3 rivers from the Mamore Basin. Sulfate, which probably results from pyrite weathering, is the major anion in the rivers having pH ≤6.6. The other rivers are dominated by carbonate. The second water type with pH values >7.5 and with variable and often high alkalinity includes 8 rivers from the Mamore basin and 5 rivers from the Beni basin. In these rivers, pH increases regularly with alkalinity. SO₄²⁻ is the dominant anion in some of these waters and tends to increase with chloride and alkalinity. The weathering of sulphur contained in shales is probably a major source for sulfate, however some contribution from gypsum cannot be excluded. The ratio R= Si/(Na+K+Cl) (for most of the analysed

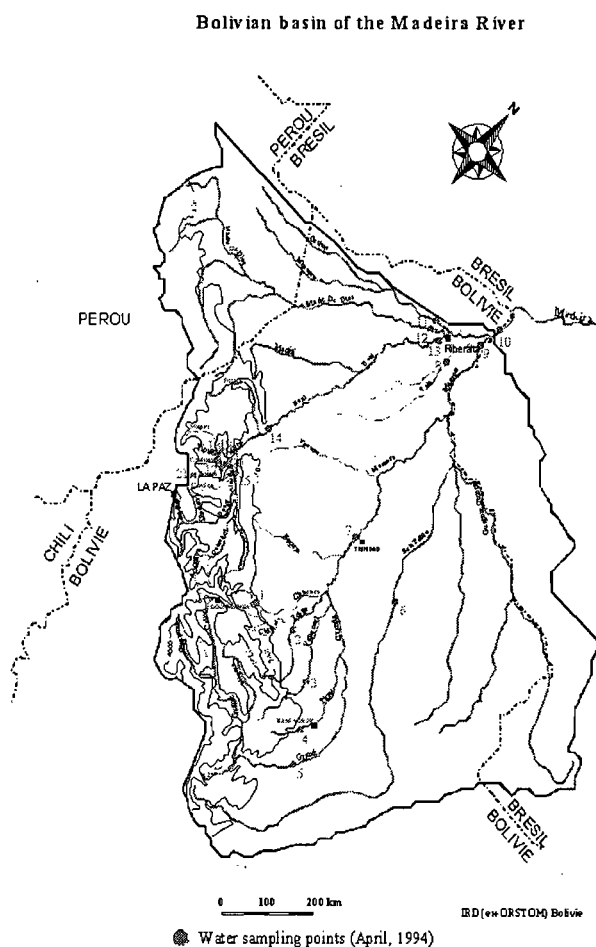


Fig. 1; Map of the Beni and Mamore subbasins showing sampling stations

waters is generally low (< 2) indicating either a low contribution from weathering of silicate phases or formation of cation rich clays (Stallard, 1985) (Fig. 3)

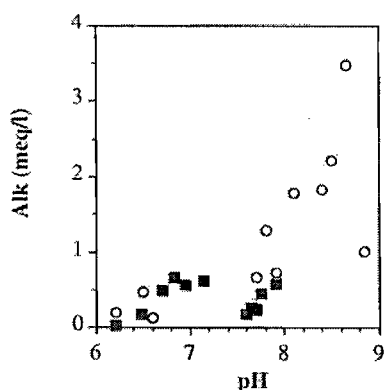


Fig. 2. Plot of Alkalinity vs. pH. Full squares: Beni subbasin; open circles: Mamore subbasin.

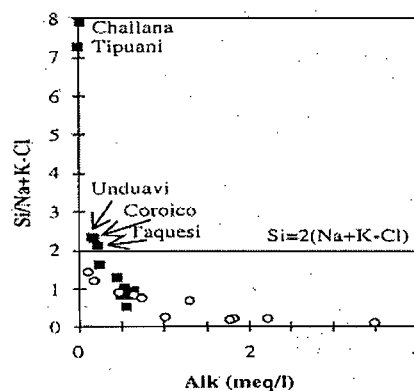


Fig 3 Si/Na+K+Cl vs. Alkalinity. Symbols as in Fig. 2

The plot of R versus Alkalinity displays an asymptotic trend and suggests a predominant role of carbonate as source for major dissolved cations.

The geochemistry of trace elements in the Andean tributaries of the Mamore River are characterized by high concentrations of Mn (55 to 4290 nM), Sr (894 to 1943 nM), Mo (2.5 to 20.3 nM), Ba (99 to 399 nM) and U (0.3 to 3.9 nM) while high concentrations of As (1.9 to 310.6 nM), Zn (3.8 to 218.5 nM), Cd (0.03 to 1.66 nM) and Cs (0.06 to 2.57 nM) characterize Andean tributaries of the Beni River with maximum values measured in the Taquesi R. The geochemistry of trace elements can be divided into two groups according to their relationships with major elements and pH: (1) those which are correlated with major ions (Mo, Rb, Ba, U and to a lesser extent Zn and Cd) are controlled by their abundance in the most weatherable lithologies (carbonate rocks, evaporates and sulfides contained in shales), while silicate rocks have only a limited influence; (2) those which are not correlated with major ions (Mn, Ni, Cu) are controlled by adsorption processes and/or complexation. Regarding to the anthropogenic influence, the high Zn, As, and Cd concentrations measured in the Taquesi river can be explained by important mining activities. High values of V measured at the end of the dry season in plain rivers ('black waters') can be correlated with the decreasing of the phytoplankton biomass.

Suspended Particulate Material (SPM)

Detailed evaluation of the mineralogy and major element chemistry of SPM have been already undertaken (Guyot, 1993). SPM is made up of clays (57 to 76%) and quartz (15 to 33%) with subordinate amounts of plagioclase and K-feldspar. Illite (53%), kaolinite (20%), chlorite (18%) and smectite (9%) are the main clay minerals in the Madeira basin. There is a high degree of correlation among the trace metals in SPM (Fig. 4). No obvious difference has been detected between the Beni and Mamore sub-basins. The fractionation of trace elements in the solid load results mainly from a binary mixing between quartz and

muscovite+illite. These minerals which are amongst the most resistant to chemical weathering have been introduced in river waters by physical erosion

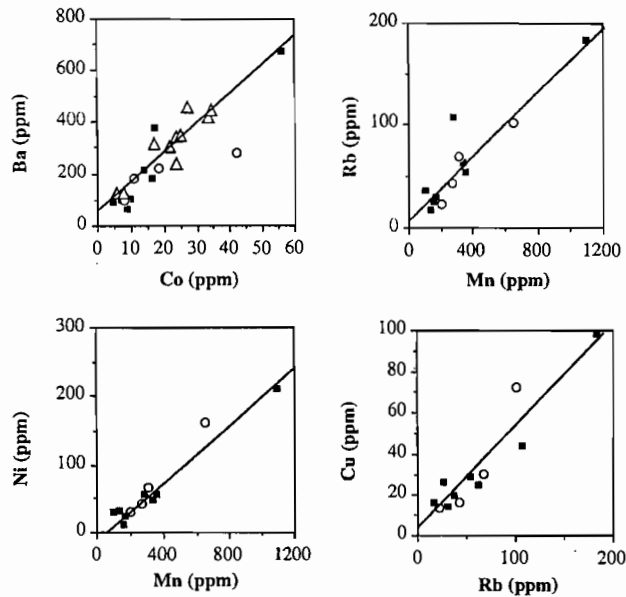


Fig. 4. Ba vs Co, Rb vs Mn, Ni vs Mn and Cu vs Rb in SPM; Full squares: Beni subbasin; open circles Mamore subbasin, triangles: Congo basin

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