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Fe, Al and Si species and organic matter leached off a ferrallitic and podzolic soil system from Central Amazonia

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Abstract

The geochemistry of soil formation in central Amazonia, Brasil, was investigated by studying the waters draining off small podzolic, ferrallitic or mixed catchment areas. Dissolved, colloidal and particulate fractions were obtained by cascade filtration and tangential-flow filtration. The organic carbon, Fe, Si, Al concentrations and the complexing capacity with regard to Cu^{2+} were determined for each fraction. In the waters draining podzolic areas, bulk concentrations were in the range 25.0–38.1 mg L^{-1} for organic carbon, 240–280 μg L^{-1} for Fe, 130–630 μg L^{-1} for Al and around 0.9 mg L^{-1} for Si. Fe mainly migrates as organo-metallic complexes, while Al migrates roughly half as inorganics in the particulate fraction and half as small species likely inorganic in the dissolved fraction. The result is the leaching of all elements and the relative accumulation of residual quartz. In the waters draining ferrallitic areas, bulk concentrations were in the range 1.2–1.9 mg L^{-1} for organic carbon, 45–55 μg L^{-1} for Fe, 106–220 μg L^{-1} for Al and around 1.9 mg L^{-1} for Si, this later concentration remaining below saturation with quartz. Most elements were transported in the dissolved fraction, except 10% of Si which was in the particulate fraction, likely as quartz, and 40–45% of Al which was in the colloidal fractions, likely as Al-hydroxides. The result is a relative enrichment of the soil in Si with regard to Al. The soils strongly control the physico-chemical characteristics of the forest stream waters, and their transport capacity with regard to complexable metals. Moreover, our results showed that the behaviour of Al with regard to organic matter was different from the behaviour of Fe.

Keywords: Amazon basin; Ferrallitic soils; Leaching; Podzols; Soil organic matter; Soil water

1. Introduction

Podzols, also called spodosols, broadly occur in cool humid regions (McKeague et al., 1983; Lundström et al., 2000; Sommer et al., 2001), or in tropical warm humid regions (Klinge, 1965; Brabant, 1987; Schwartz, 1988). In both regions, they are characterized by the following horizons: a surface A horizon with slightly decomposed vegetative material, an eluviated E horizon mainly formed by relic quartz sand or poorly weatherable minerals, and spodic horizons enriched with humic compounds (Bhs), or with Fe and Al oxides or poorly crystallized alumino-silicates, allophane or imogolite (Bs). A specificity of the podzols is the complete leaching of all elements from the eluviated E horizon, including Al and Fe. Those elements are poorly soluble in the soil solution conditions, and the organic matter is supposed to play a key role in their transport.

Many hypotheses and theories have been proposed to explain the formation of podzols (Deb, 1949; Stobbe and Wrigh, 1959; De Coninck, 1980; Anderson et al., 1982; Buurman, 1984; Wang et al., 1986; Ugolini and Dahlgren, 1987; Taylor, 1988). Most of them were developed from the geochemical properties of the solid phase. Only a few considered the role of the soluble mobile phase (Ugolini and Dahlgren, 1987; Lucas et al., 1996; Lundström et al., 2000; Lucas, 2001). The currently used theories are the fulvate theory and the proto-imogolite theory.

The fulvate theory involves the formation of soluble organo-metallic complexes, especially with fulvic acids (FA) (Ugolini

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and Dahlgren, 1987; Lundström, 1993). Fe and Al complexes migrate in depth through the E and the Bhs horizons and stop to the top of the Bs horizon, where they decompose. Released Al and Fe interact in the Bs horizon with dissolved Si to precipitate imogolite and allophane. The proto-imogolite theory involves the formation of positively charged, small sized proto-imogolite in the eluviated horizon (E) (Farmer et al., 1980; Farmer and Fraser, 1982). Proto-imogolite migrates through E and Bhs horizons, and accumulates in the Bs horizon, forming imogolite. The FA released in topsoil migrate through E horizon, and precipitate on the imogolite surfaces to form the Bhs horizon. Basically, in the fulvate theory Al migrates through E horizons as a fulvic acid complex, while in the proto-imogolite theory Al migrates as inorganic proto-imogolite.

In equatorial regions, podzol areas are often observed close to ferrallitic soils areas, and may be developed from the same parent material (Lucas et al., 1984). The ferrallitic soils, also called oxisols, are the dominant soil type in tropical warm humid regions. They are characterized by deep weathering of the primary minerals, only the more resistant, as quartz and heavy minerals, remain in the topsoil horizons. The newly generated minerals are mainly kaolinite ($Al_2Si_2O_5$ $(OH)_4$), gibbsite ($Al(OH)_3$), goethite (FeOOH) and hematite (Fe_2O_3). The balance of weathering and soil formation is a relative accumulation of Al, Fe and a loss of Si.

To better understand how clayey ferrallitic soils and sandy podzols can develop under the same climate from the same parent material and to assess the role of the soil solution in the genesis of such a contrasted soil cover, we studied the waters draining off well-known podzolic and ferrallitic soils areas near Manaus, Amazonia, Brazil. We used size fractionation by tangential-flow filtration (TFF) coupled with complexing capacity measurement to gain knowledge about the behaviour of elements. The soils in the studied area being mainly composed of kaolinite, gibbsite, quartz, goethite and hematite (Lucas et al., 1987), Si, Al and Fe are the main elements to consider with regard to the water–minerals interactions, so that we studied their distribution in the size fractions along with organic matter.

2. Materials and methods

2.1. Sampling and sites characterization

The studied area was located 80 km north of Manaus, Brazil (02°34′ S, 60°07′ W) (Fig. 1). The climate is equatorial; average annual rainfall is 2100 mm and a drier season (monthly rainfall around 50–60 mm) lasts three months. A first sampling was realised in October 1992, at the end of the drier season. Because of unsatisfactory results with regard to Al recovery through ultrafiltration, another sampling was realised in October 1999. Landscape consists in dissected plateaux. The soils of the area are kaolinitic, clayey ferrallitic soils (oxisols), sandy quartz podzols (spodosols), and all intermediate soils between these types. The clayey ferrallitic soils are mainly located on the plateaux, while the podzols are located downslope; a typical catena is given on Fig. 2. The soil system in the studied areas was described in detail in previous studies (Lucas et al., 1984; Chauvel et al., 1986; Bravard and Righi, 1991; Lucas et al., 1993). All soils are developed from a continental, tertiary quartzo-kaolinitic sediment. The vegetation on ferrallitic areas is a typical Amazonian rainforest. On podzolic areas and sandier intermediate soils, the forest is lower, called "Campina Rana". On the more extended podzolic areas, the vegetation is a typical low, open forest called "Campina" (Prance and Schubart, 1977).

Two main types of forest streams are found in the area, clear waters and black waters. The clear waters are uncoloured and poor in total organic carbon (TOC), the related catchment area presents no podzols. The black waters are brown-coloured by organic matter (OM), and are characteristic of the presence of podzols in the related catchment area. In podzols areas, the OM released in the topsoil can migrates freely to the stream through the sandy material of the E podzols horizons. In

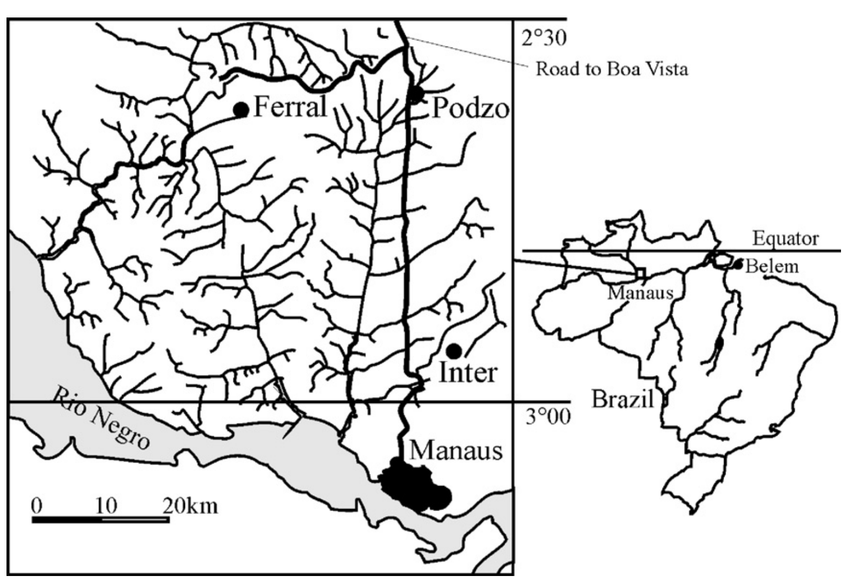

Fig. 1. Geographic map of the studied area and sampling localization.