Role of microbial processes in the functioning (Fe mobilization and redistribution) of a representative tropical soil sequence

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Abstract
Field studies and laboratory experiments have been performed to determine the main processes and the parameters involved in the weathering and soil evolution in a tropical soil sequence from ferralsols to gleysols. The work considers mainly the redox interfaces of a soil sequence located in Brazil, looking at the interactions between minerals – soil organic matter and microorganisms.
Results show that the bacterial activity (mainly of iron reducing bacteria, IRB) located at the redox interfaces of the hill-side sequences and under the dependence of water movement, soil organic matter and iron availability is the major agent of these weathering processes.

Key Words
Tropical soils, microbial soil functioning, critical zone, iron reducing bacteria.

Introduction
In humid tropical countries, strong weathering of soil materials and, in particular of ferric oxyhydroxides (hematite, goethite), occurs on very large areas. It leads to fundamental changes in soil properties, involving yellowing, bleaching and consistency of soils (Schwertmann and Kämpf 1985; Peterschmitt *et al.* 1996; Fritsch *et al.* in press) (e.g. from Ferralsols-Cambisol to Gleysols), and also metal dispersion and redistribution (Quantin *et al.* 2002). The redistribution (solubilization-accumulation) of iron is a major process, strongly dependant on topographic criteria, drainage conditions (Tardy 1993) and microbial activity (Berthelin 1982; Stemmler and Berthelin 2003). It corresponds to the more common process acting in the tropics (Fritsch *et al.* in press). Formerly in such soils, the weathering and evolution were considered as based mainly on geochemical processes. Now biological parameters are recognized through interactions between microbial, chemical, and physical phenomenons (Macedo and Bryant 1987; Stemmler and Berthelin 2003). Very few data exist on the hydrobiogeochemical and geomicrobiological conditions that promote the mobilization and transfer of iron in tropical soil landscapes. To study and better define the role of such biological factors, we have selected a sequence of well drained to poorly-drained soils (Acrisols-Cambisols - Gleysols) of the humid region (2 300 mm per year) representative of the upper Amazon basin. In such sequence, iron mobilization has played and is still supposed to play an important role in the vertical and lateral soil differentiation.

The purpose of the study was (1) to determine in laboratory experimental conditions, close to the field conditions, the iron reducing bacterial (IRB) (Lovley 1997; Bousserrhine *et al.* 1999) activities in different soil profiles and horizons of the soil sequence, and to show their possible involvement in the evolution of soil sequences as observed in the fields (2) to connect the laboratory results with the physico-chemical and geochemical analysis performed on soils and waters.

Material and methods
The soil sequence (100 m long, 3 m depth) was located at Humaita, upper Amazon basin (Brasil) and was equipped of lysimeters from the soil F6 to F1 (Figure 1). Soil samples (F1 to F6) were collected near the lysimeters in horizons of reference profiles of the sequence from the plateau (red-yellow Acrisols) to the depression (Gleysol).

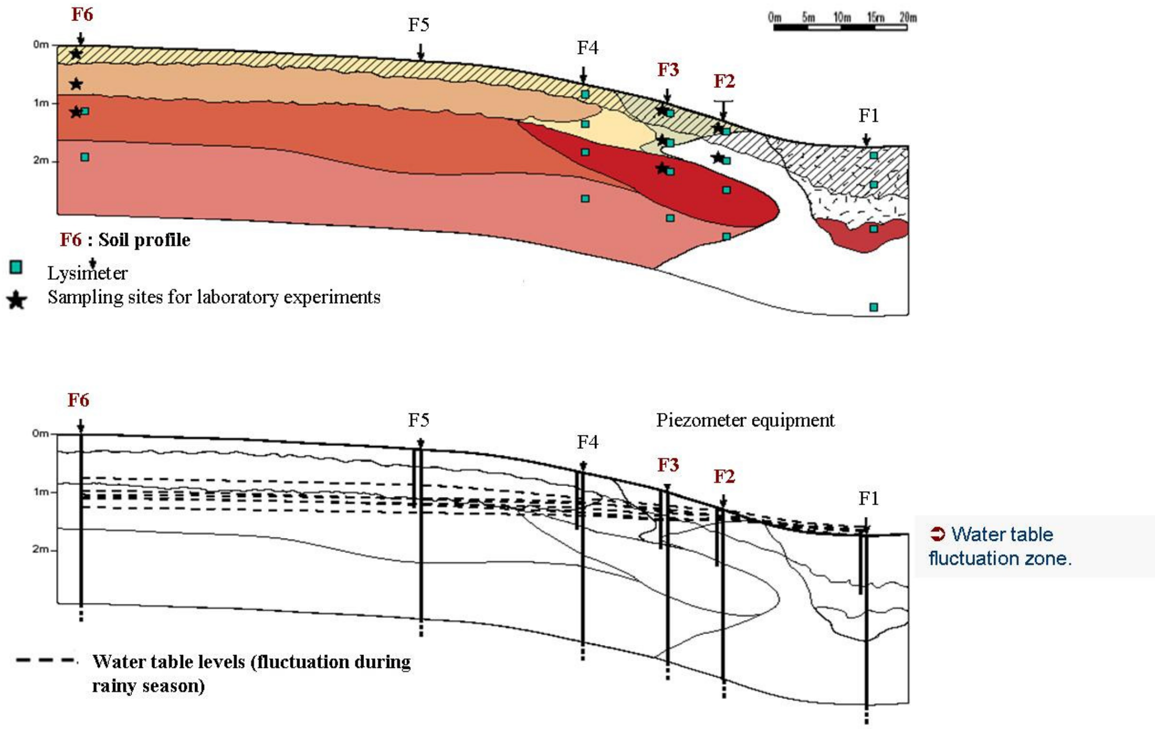

Figure 1. Studied tropical soil sequence of Humaita (Brazil).

The soils were characterized by particle size distribution, elemental analysis, pH, C, N, mineralogy (XRD-TEM). Soil waters were analyzed for Eh, pH, ferrous and total iron, nitrates and ammonia dissolved organic carbon (DOC) in different periods of the year. To determine the bacterial processes, experiments were performed by incubation of soil samples in laboratory devices without addition of nutrients except those from soils. Abiotic controls were also performed. At least 3 replicates were done per treatment Measurements concerned Eh, pH, organic matter biodegradation and mineralization (CO_2, DOC, NO_3^-, NH_4^+, ferrous and total iron, bacterial counting, screening, isolation and identification (biochemical and molecular biology methods: PCR, TGGE).

Results and discussion

Field measurements in soil waters and ground waters (decrease and low values of Eh, production of NH_4^+, decrease and reduction of NO_3^-, high content of Fe^{2+} and of DOC…, screening of microorganims), suggested occurrence of reducing bacterial mediated processes much more in the transition zone of water table and the occurrence of aero-anaerobic and anaerobic bacterial activities involving iron reducing bacteria (IRB). Results of laboratory experiments performed in different devices simulating different environmental conditions and using soil samples originating from different sites and horizons, underline the involvement of iron reducing bacteria both in the biodegradation of soil organic matter (SOM) and the weathering of minerals (mainly ferric oxyhydroxides) which are dissolved as Fe^{2+}. High yields of bacterial iron reduction were observed in aero-anaerobic and anaerobic conditions, but also in nonwaterlogged soils when available organic matter was present to be use by bacteria to develop anoxic conditions and reducing processes. Correlations between mineralization of SOM and solubilization of iron were very significant. Fermentative and non fermentative bacteria appeared to be concerned. Their occurrence was confirmed by molecular biology (PCR-TGGE) indicating Shewanella, Enterobacter, Clostridium, Bacillus). SOM biodegradation and mineralization concerned mainly fulvic compounds. The reduction and dissolution of iron modified also the distribution of iron in their geochemical compartments. A relative decrease of well crystallized ferric iron (Fe_d) and an increase of not well crystallized ferric iron (Fe_0) were observed. Calculation of weathering coefficients has shown that, depending on soils, type of horizons, incubation time… (i.e. bioavailability of SOM and iron) the mineralization of one organic carbon allowed to solubilise from 0.06 to 1.29 iron (Fe). The stronger iron reducing bacterial activities were also located in samples originating from transition zones and fluctuation zones of water table in the surface and subsurface horizons.

Conclusion

The bacterial activity of iron reducing bacteria (IRB) is well correlated with the reduction and dissolution of ferric oxyhydroxides and the release and redistribution of iron in the soil sequence. IRB communities located at the redox interfaces of the hill-side sequences and under the dependence of water movement, organic matter and iron availability are the major agents of the weathering processes and of the redistribution of iron in the soil sequence. However further characterization of bacterial communities and of the factors of control of bioavailability of SOM and of iron is required to aid our understanding of the soil sequence functioning and to better quantify the parameters for modelling.

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