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Degradation and dismantling of iron crusts under climatic changes in Central Africa

A. Beauvais[a,α] and Y. Tardy[a,b]

[a]*Institut Français de Recherche Scientifique pour le Développement en Coopération, (ORSTOM), 213 rue La Fayette, F-75480 Paris Cedex 10, France*
[b]*Centro de Energia Nuclear na Agricultura (CENA), av. Centenario, s/n, Caixa Postal 96, 13400 Piracicaba, S.P., Brazil*

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1. Introduction

In Africa, under contrasted tropical climate influences, the lateritic weathering profiles are often capped with an iron crust (Maignien, 1958). However, three main geographical domains can be distinguished: (1) a northern Sahelian domain under tropical arid climate where iron crusts are dismantled under the effect of mechanical erosion processes (Leprun, 1977); (2) a southern forest domain under tropical humid climate, where the iron crust dismantling (Nahon et al., 1989) results from chemical mechanisms identified by Beauvais (1991) and Tardy (1993); and (3) a transitional domain widespread between the former two domains, where iron crusts are developing under contrasted influences of tropical climate with an annual rainfall ranging from 1200 to 1800 mm (Tardy, 1993). This is the case in the Haut-Mbomou area in southeastern Central African Republic, where the climate is humid tropical with 3 months of dry season and 9 months of wet season. On average, the rainfall is 1600 mm yr^{-1}, the temperature is close to 25°C and the relative humidity of the air is ~80%. A long-term tectonic steady state has led to the development of horizontally and vertically extended iron crust systems in this area. However, the lateritic landscape shows some areas of dismantling iron crust under forest (Beauvais, 1991). Hence, Haut-Mbomou, situated between the southern equatorial rainforest and the northern tropical dry savannahs, provides an ideal site to study evolutional paths of laterites under the influence of climatic changes.

The landscape consists of three iron crust systems (Beauvais, 1991), which present domains of iron crust degradation. One distinguishes: (1) high plateaus at altitudes of 650 m above mean sea level (a.s.l.); (2) slopes between 640 and 610 m a.s.l.; and (3) low plateaus at an altitude of 600 m a.s.l. Patches of forest develop in the core of the plateaus and rings of forest develop at the edges of the high plateaus and the uppermost part of the slopes, and in the valleys. In the forest area, the iron crusts are destroyed and replaced by soft micronodular red soils.

2. Petrological features of iron crust dismantling

Iron crust dismantling profiles consist of: (1) a humic layer containing hematitic nodules surrounded by a goethitic perinodular rim; and (2) an iron crust layer which is chemically degraded and physically dismantled into blocks,

[α]*Present address:* Department of Geological Sciences, University of Washington, Seattle, WA 98195, USA.

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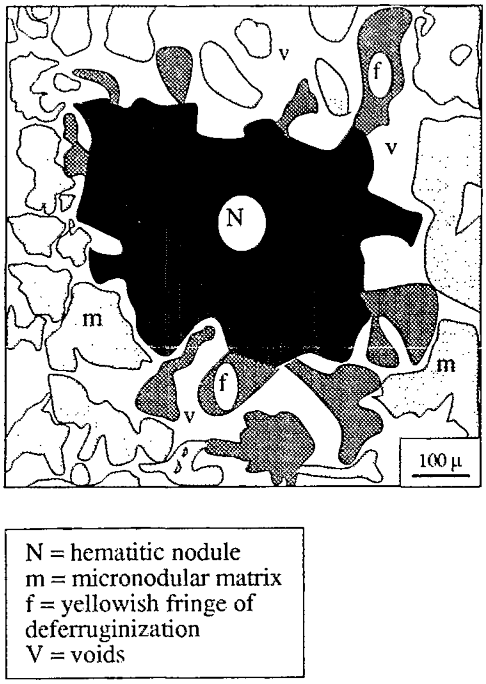

Fig. 1. Petrographical features of the deferruginization of hematitic nodules within the dismantling layer of iron crust of a Haut-Mbomou profile.

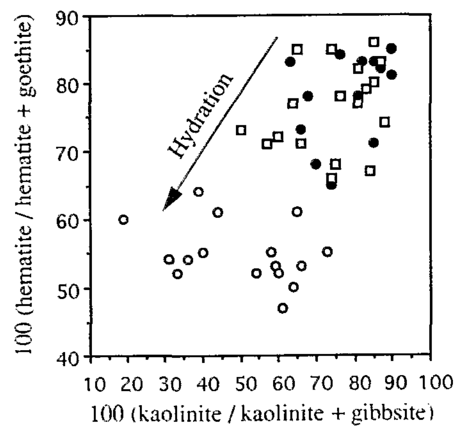

Fig. 2. Simultaneous increase of goethite and gibbsite in the dismantling facies of iron crust consisting of hematite and kaolinite as a function of the hydration increase.

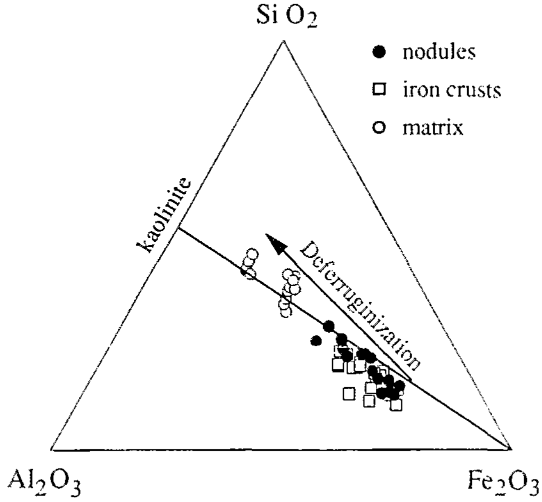

Fig. 3. Preferential leaching of iron with regard to aluminium during the iron crust dismantling.

pebbles and nodules embedded in a micronodular and sandy–clay matrix. Under the polarizing microscope, the hematitic nodules present a yellowish peripheral fringe of deferruginization composed by goethite and kaolinite (Fig. 1). The micronodular matrix is constituted by domains of a kaolinite and goethite mixture which develops at the expense of a previous reddish assemblage consisting of a mixture of kaolinite and hematite.

The dismantling of the iron crust leads to the transformation of hematite into goethite and also to the transformation of kaolinite into gibbsite (Fig. 2). Furthermore, the proportion of kaolinite increases in the micronodular soft matrix but not in the iron crust, so that an important amount of iron is leached out (Fig. 3). Obviously, the transformation of dehydrated or poorly hydrated minerals, hematite and kaolinite, into hydrated minerals, goethite and gibbsite, induces a relative loss of iron.

3. The influence of water activity

Within the lateritic weathering profiles evolving under contrasted influences of tropical climate, the water activity is equal to 1 in the water-table fluctuation area. It is below 1 in the middle part of the profile at the vicinity of a dry area which has been called the "creux hydrique" (Tardy et al., 1988a). At the surface, it is equal to the relative humidity of the air fixed by the climatic environment.

In the Haut-Mbomou profiles, two types of geochemical reactions control the mineralogical differentiations:

$$\underset{\text{(hematite)}}{Fe_2O_3} + \underset{\text{(water)}}{H_2O} \rightleftharpoons \underset{\text{(goethite)}}{2FeOOH}$$

$$\underset{\text{(kaolinite)}}{Al_2Si_2O_5(OH)_4} + \underset{\text{(water)}}{5H_2O} \rightleftharpoons$$

$$\underset{\text{(gibbsite)}}{2Al(OH)_3} + \underset{\text{(dissolved silica)}}{2Si(OH)_4}$$

All the lateritic profiles show a medium indurated layer, rich in hematite and kaolinite. This proves the existence of a permanent "creux hydrique" characterized by a water activity below 1 under contrasted influences of tropical climate (Tardy et al., 1988a). On the other hand, the base and the top of such profiles are often water saturated, and thus, they present preferential sites for goethitic facies development.

When the tropical climate becomes more humid, the "creux hydrique" domain tends to disappear everywhere the water table emerges during the rainy season and everywhere forest growths are present. These pedoclimatic changes are responsible for the geochemical iron crust dismantling.

4. The oxidation/reduction influence

Within most of the lateritic profiles evolving under forest, biological activity provides more reducing conditions. The p_{O_2} decreases whereas p_{CO_2} increases. At the upper part of the profiles, within the humic layer, the weathering solutions are loaded with reducing anions such as SO_4^{2-}, NO_3^-, PO_4^{3-} and Cl^-, which decrease Eh and pH and thus lead to the leaching of iron.

5. Conclusions

Thus, under humid tropical climate, iron crusts are both formed and degraded. In all the lateritic profiles formed under contrasted influences of tropical climate, local hydration involves the formation of a surficial pisolitic layer (Nahon, 1976; Tardy and Nahon, 1985), while local dehydration favours the iron crust regeneration in the deep nodular layer. Under forest, the iron crust dismantling is due to an increase in hydration processes, a decrease in Eh and leaching of iron, as results of forest growth under more humid climatic conditions. In such an environment, the iron crust dismantling results directly from humidity, organic matter decomposition and respiration of roots which provide hydratation and reduction and lead to the transformation of hematite into goethite, kaolinite into gibbsite, and also to preferential leaching of iron relative to aluminium.

In the study area, the high plateaus are nibbled and tend to disappear while the lowermost parts of slopes and the low plateaus are reinforced by lateral accumulations of iron lost from the rings of dismantling processes located above.

Consequently, under contrasted influences of tropical climate, landscapes are covered by savannah, and iron crusts are forming. If the climate becomes more humid, rings and tongues of forest progress, hydration and reduction increase, chemical dismantling accelerates and takes precedence of the iron crust forming. The iron crusts are relayed by soft ferrallitic soils. If the climate becomes more arid, rings and tongues of forest regress, both the chemical dismantling and the lateral development of iron crusts slow down. Surficial hydration and internal dehydration are the dominant mechanisms of the iron crust vertical dynamics (Tardy, 1993).

Thus, iron crust formation appears to be limited towards the arid zone by the formation of montmorillonite soils (Leprun, 1979), and towards the humid zone by the formation of goethite- and gibbsite-rich ferrallitic soils. Finally, the chemical iron crust dismantling reflects more humid climatic conditions. All in all, the variety of iron crust facies results from climatic changes caused by the migration of continental plates during the Tertiary era (Tardy et al., 1988b).

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