Geochemistry and mineral formation in the Earth surface
Int. Meet. "Processe of mineral formation" Granada. Spain
R. Rodrigue Clemente Y, Tardy Y ed. 16.22 March 1986

PROCESSES OF ALUMINIUM AND IRON ACCUMULATION IN LATOSOLS DEVELOPED ON QUARTZ-RICH SEDIMENTS FROM CENTRAL AMAZONIA (MANAUS, BRAZIL)

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ABSTRACT

The profile studied consists of three main layers: (1) a sandy -loam parent material, which consists of quartz, kaolinite and a little amount of hematite; (2) a gibbsitic and hematitic nodule layer; (3) a soft kaolinitic clay cover. Progressive sequences of facies were identified from the base to the top of the profile. They form a succession of mineralogical constituents, with a progressive decrease of the cristallinity of the kaolinite. These sequences indicates that the clay cover, which can be more than 5 m thick, derives from the parent material by an in situ transformation. The profile is in a dynamic equilibrium: it is destroyed at the top by biochemical and physical alteration, and deepens at the base by dissolution of quartz and leaching of silica, and by authigenesis of kaolinite, gibbsite and hematite. These constituents are in a dissolution-generation equilibrium at each level of the profile. This equilibrium gives the different cristalline forms of the kaolinite at each level. These processes lead to a relative accumulation of Al and Fe with regard to Si.

INTRODUCTION

The formations described in this paper are developed on low plateaux located 60 km north of Manaus, Amazonia (fig. 1). The soil profile found on the plateaux consists of three main layers, which are from the base to the top:

- <u>the parent material</u>. It is a sandy-loam, clastic, poorly consolidated sediment from the Barreiras Group (Sombroek, 1966; Brasil, 1978). This sediment, previously placed in the tertiary (Brasil, 1978) is now considered as Cretaceous (Putzer, 1984);
- <u>a nodular layer</u> (-16 to -17m);
- <u>a soft clay layer</u> (-7m to topsoil). This layer, called Belterra Clay, was considered by various authors (Sombroek, 1966; Tricart, 1978; Putzer, 1984) as a tertiary lake sediment. Some others (Truckenbrodt & Kotschoubey, 1981) consider the clay as a tertiary sediment deposited in semi-arid climatic conditions. Others (Chauvel et al., 1982; Irion, 1984; Lucas et al., 1984) conclude that the clay is an in situ lateritic formation developed by weathering from the Barreiras Sediment.

The origin of the lateritic formations and the processes of lateritization have been the subject of a considerable number of works and interpreta-

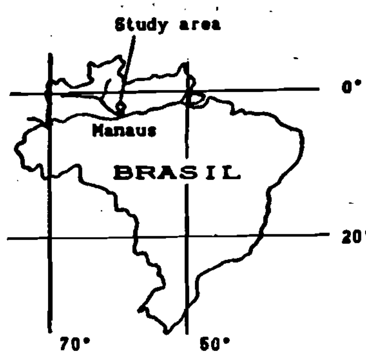

Figure 1. Location of the study area.

tions (Pedro and Melfi, 1983). The purpose of this paper is to study the genesis of a lateritic profile developed from a simple parent material, which consists of quartz, kaolinite, and iron oxi-hydroxides in small amount.

MATERIAL AND METHODS

The study area is located 2°33'N and 60°02'E. The climate is equatorial of Amazonian type, with 2100 mm of annual precipitation and a poorly defined dry season. The vegetation is a dense, humid, evergreen forest. The profile was studied by macroscopic and microscopic (thin section and SEM) investigations. The plasmic fabrice were described according to Brewer (1976). The Munsell colors of the plasmas are given in plain light.

The mineral constituents were identified by X-rays diffractometry, and thermogravimetric analysis on global samples. Kaolinites are the only clay minerals observed. Since the works of Bailey (1963), Plançon and Tchoubar (1977), it has been well established that kaolinite cristals show various crystallinity. Many classifications or index of crystallinity have been proposed (Hinckley, 1963; Parker, 1969; Van den Marel and Khroner, 1969; Lietard, 1977; Cases et al., 1982; Cruz et al., 1982; Mestdagh et al., 1982). Two common methods were used in this study:

- from the X-ray spectra, the Hinckley index calculated from the 4.46, 4,36 and 4,18 Å bands (Hinckley, 1963);
- from IR spectra, the study of the OH-stretching vibrations in the 3700-3600 cm^{-1} region by infrared spectrometry (Giese and Data, 1973; Farmer, 1974; Hlaway et al., 1977): when the crystallinity decreases, there is a progressive inversion of the minima between the 3650-3700 cm^{-1} bands and a disappearance of the 3670 cm^{-1} band.

X-ray diffractometry and IR spectrometry were then carried out on microsamples corresponding to the different facies observed. Each sample were collected by microdrilling, and the quartz grains removed by manual separation.

RESULTS

The profile and the different facies observed are shown fig. 2. The quantitative mineralogical data from thermogravimetric analysis are given in

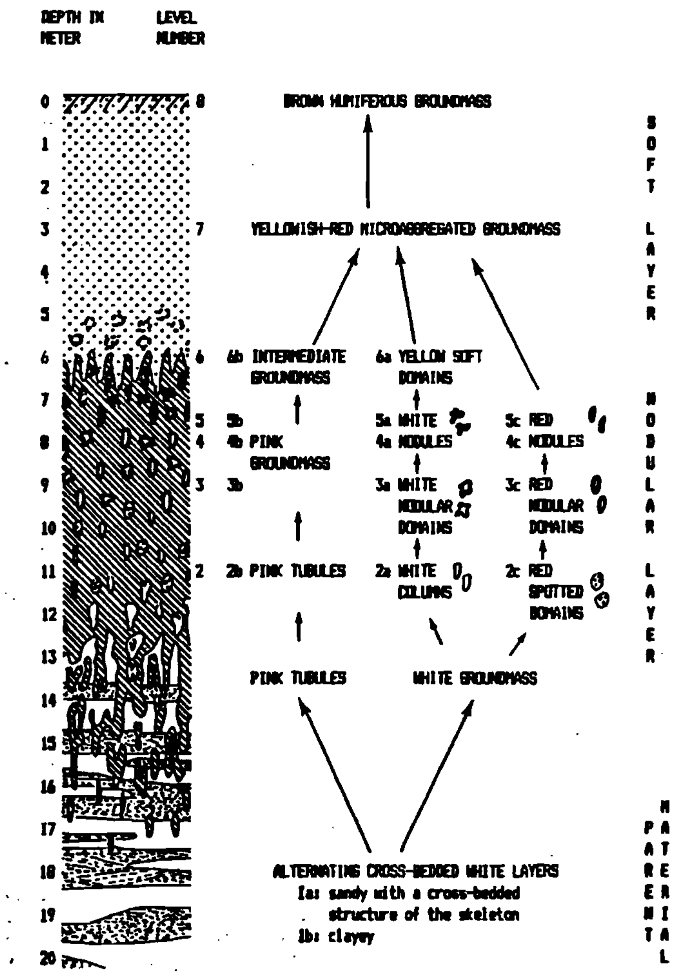

Figure 2: The profile studied and the different facies observed. Sample numbers indicate the level and the genetic sequence of facies: the groundmass sequence (1-2b-3b-4b-5b-6b-7-8); the gibbsitic nodules sequence (2a-3a-4a-5a-6a); the hematitic nodules sequence (2c-3c-4c-5c).

fig. 3. Table 1 present semi-quantitative mineralogical data and fig. 4 gives IR spectroscopy data from the microsamples. These results will be explained and discussed starting from the parent material right up to the topsoil.

The parent material (I)

White coloured, with a few horizontal ferruginous tracks, it is soft with a compact massive structure. It is made of alternating cross-bedded sandy layers (Ia) and clay layers (Ib), varying in thickness from a few centimeters to one meter. The contact between these layers is locally discordant to the fine cross-bedded structure of the sandy layers. Microscopic data show in both layers slightly corroded quartz grains and a few zircon and anatase grains in a pale brown insepic kaolinitic plasma. The clay layers differ from the sandy layers by the presence of numerous 300-400µm patches of cristic kaolinitic plasma (fig. 5a) without quartz grains. The length of kaolinite booklets in this plasma may exceed 100µm.

The IR data show a well cristallized kaolinite, and X-ray data give a Hinckley index of 1.6 both in sandy (Ia) or clayey (Ib) materials despite the two different habitus (pale brown, insepic; uncoloured, cristic).

Discussion: the large size of the kaolinite booklets in the clay layers attest their in situ generation. Moreover, the discordance between sandy and clay layers indicates an in situ transformation of the sandy material into the clayey material. So the parent material appears already transformed in comparison with a sediment: this transformation consists of the dissolution of quartz and the generation of well-cristallized kaolinite.

The nodular layer (II)

From parent material to level 2 (12 m deep): at a depth of around 16 m pale pink tubules appear in the sandy material as well as in the clayey material. These 0.5 to 1 cm thick tubules are vertically oriented, and become progressively more coloured and numerous at higher level, until they form a network (facies 2b) surrounding 2-3 cm thick columns of white material (facies 2a). Simultaneously, the amount of quartz in the sandy material progressively decreases. The layered structure of the parent material ceases to be perceptible at level 2, where the whole groundmass acquires a clay texture. A few domains, 3-5 cm in size, remain without pink tubules but show contrasted red spots (facies 2c).

Microscopic data show, from level 1 to level 2, the disappearance of the cristic kaolinitic plasma and of the main part of the quartz grains which become more and more corroded (fig. 5b) and are replaced in situ by an insepic kaolinitic plasma. No difference were observed between facies 2a and 2b except in the colour of the plasma. In facies 2c, a red ferruginous plasma bordering the voids corresponds to the red spots.

As seen in fig. 3 and table 1, these morphological changes correspond to an important increase in the amount of kaolinite at the expense of the quartz content. The appearance of small amounts of gibbsite is noticed in pink tubules and white columns, and hematite corresponds to the red spots.

As seen in fig. 4, the crystallinity of the kaolinite decreases in comparison with the parent material, slightly in the white columns (2a), even more in the red spotted domains (2c) and more again in the pink tubules (2b).

From level 2 to the top of the nodular layer (7 m deep): the morphological transformations already observed up to level 2 progressively increase. The quartz amount of global samples varies from an average of 80% in the parent material, to less than 10% at the top of the nodular layer. The pink tubules lead to a pink groundmass of compact polyedric structure. The white columns are reduced at level 3 to white nodular domains, which further up become white indurated gibbsitic nodules. The red plasma in the red spotted domains spreads out to fill nearly the totality of the domains,

giving vertically lengthened red ferruginous nodules.

Microscopic data indicate an increase in the corrosion of quartz grains. Small hard patches of dense gibbsitic cristic plasma appear from level 3 up in the white nodular domains. At a higher level, these patches increase in size, forming white nodules (fig. 5c). Around level 4, a diffuse impregnation by little gibbsite crystals (size<4µm) appears in the

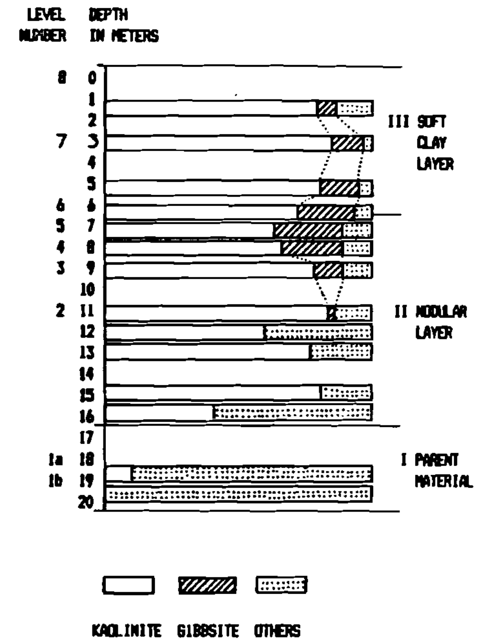

Figure 3. Quantitative mineralogical constitution of global samples (data from thermogravimetric analysis)

kaolinitic plasma of the pink groundmass. At level 5, this impregnation also occurs in the red ferruginous nodules, as small white areas replacing the hematitic plasma. As seen in fig. 3 and table 1, these changes correspond to a progressive increase of the gibbsite amount in each facies. This increase appears at a lower level and is more intense in the white nodules.

As seen in fig. 4, the decrease in the crystallinity of the kaolinite is more important in the pink groundmass (the 3670 cm^{-1} band disappears completely from 2b to 5b), than in the white nodules (2a, 3a, 4a, 5a) and in the red nodules (2c, 3c, 5c) where the 3670 cm^{-1} band is still present.

The soft clay layer (III)

At the top of the nodular layer, the pink groundmass becomes yellowishred and more porous, resulting in a microaggregated structure. This transformation occurs in a one meter thick glossic transition. The red hematitic nodules disappear in the top 20 cm of the nodular layer, showing features of dissolution and replacement by the microaggregated groundmass. The white gibbsitic nodules remain at a higher level, up to 1 or 2 m above

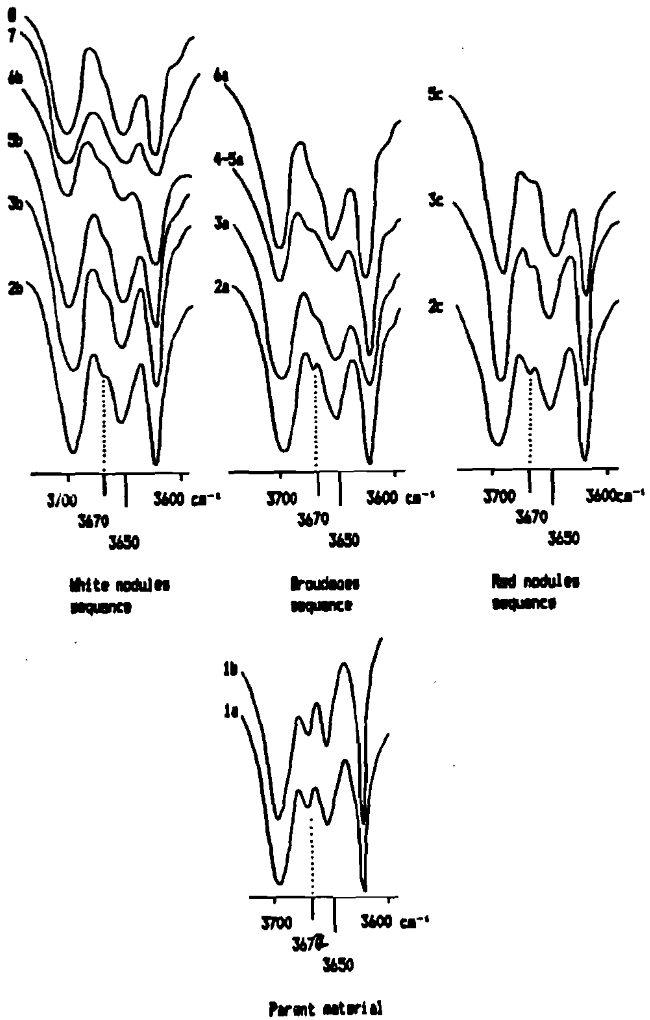

Figure 4: Infrared spectra of the OH-stretching area of the kaolinite of selected samples from the different facies (same sample numbers as in fig. 2 and table 1).

the disappearance of hematitic nodules. They are progressively replaced by yellow soft domains, themselves replaced by the microaggregated groundmass.

Within the top meter of the profile, the amount of quartz grains progressively increases, as a result of the destabilization of the kaolinite, which is linked to the increase in the amount of organic matter (Scatolini et al., 1985). Gibbsite is still present (see fig. 3).

In this layer, the IR spectra of the kaolinite between 3700 and 3600 cm^{-1} (fig.4, samples 6a, 6b, 7, 8) consist only of three OH-stretching vibrations, which characterize a high disorder of kaolinite related to a high proportion of dickite-like OH orientations (Giese and Data, 1973; Mestdagh et al., 1982; Cruz et al., 1982). The Hinckley index of kaolinite in level 7 is 0.6, indicating a low crystallinity, which is in accordance with the IR results.

Level 8	8	Brown humiferous groundmass	K, g
Level 7	7	Yellowish-red microaggregated groundmass	K, g
Level 6	6a	Yellow soft domains	G, k
	6b	Pink intermediaite groudmass	K, G
Level 5	5a	White nodules	G, k
	5b	Pink groudmass	K, G
	5c	Red nodules	H, k, g
Level 4	4a	White nodules	G, k
	4b	Pink groudmass	K, G
	4c	Red nodules	H, k
Level 3	3a	White nodular domains	K, G
	3b	Pink groundmass	K, g
	3c	Red nodular domains	K, H
Level 2	2a	White columns	K, g
	2b	Pink tubules	K, g
	2c	Red spotted domains	K, H
Level 1	1a	Sandy parent material	K, q
	1b	Clay parent material	K, q

K, K, k: kaolinite
G, G, g: gibbsite
H, H, h: hematite
q: quartz

The size of the letters indicates semi-quantitative amount of minerals in each sample. Quartz grains were removed from the samples.

Table 1: Mineralogy of the different facies of the profile.

SYNTHESIS AND DISCUSSION

All the variations observed along this profile are progressive, and there is no sign of sedimentological discontinuity. From the base to the top of the nodular layer, all the steps between a soft groundmass and indurated gibbsitic or hematitic nodules are observed. At the upper part of the nodular layer, the transition to the soft clay layer is progressive, in the following order: (1) appearance of glosses of microaggregated groundmass, (2) disappearance of the hematitic nodules with signs of dissolution, (3) progressive transformation of hard gibbsitic nodules in yellowish-red soft domains, (4) disappearance of these domains, replaced by the microaggregated groundmass. The petrological and mineralogical

5a: Booklets of kaolinite (parent material, level 1)

5b: Corroded quartz grains with micro-crystalline kaolinite (pink tubules, level 2)

5c: Gibbsite crystal with kaolinite (white nodule, level 4)

variations indicate that the different facies derive from each other. They constitute sequences of facies, as shown in fig. 3:

Groundmass sequence: parent material - pink tubules and white columns - pink groundmass - yellowish-red microaggregated groundmass - brown humiferous groundmass.

Hematitic nodules sequence: red spotted domains - red nodular domains - red nodules.

Gibbsitic nodules sequence: white columns - white nodular domains - white nodules - yellow soft domains.

These sequences form a succession of mineralogical constituents, which result from geochemical processes. In order one observes:

(A) From the parent material to the top of the nodular layer, the quartz grains are strongly dissolved. They are replaced in situ by newly generated kaolinite (presence of kaolinitic plasma in all dissolution cavities of the quartz grains).

(B) From the base to the top of the nodular layer, there is (1) generation of hematite, weak in the groundmass sequence, strong in the hematitic nodule sequence. The hematite accumulates around voids; (2) generation of gibbsite, first in the gibbsitic nodule sequence, then in other facies. The gibbsite accumulates by diffuse impregnation of the plasma.

(C) At the top of the nodular layer, hematite dissolves.

(D) In the two meters above the nodular layer, gibbsite dissolves. An important amount of gibbsite remains in the groudmass.

(E) In the topsoil, the amount of quartz grains progressively increases, as a result of the destabilization of the kaolinite, which is linked to the amount of organic matter (Scatolini et al., 1981). Chauvel et al. (1986) show by experimental percolation a signifiant export of Al from the 30 cm. top of the profile (20 to 30 ppm during the ten first days for a 10 mm/day water percolation), attesting the dissolution of aluminous minerals.

The kaolinite varies progressively within these sequences. Its crystallinity is continually decreasing from the base to the top of the profile. The rate of this decrease is faster in the groundmass sequence than in other sequences. Similar variations are also found in iron-crust and bauxitic profiles (Cantinolle, 1982; Didier, 1985; Ambrosi, 1984), in which the decrease in the crystallinity of the kaolinite is correlated with the increase in Fe^{3+} substitution in the lattice of kaolinite. Further studies of this profile (Electron Spin Resonance) will indicate the link between iron substitution and crystallinity in these kaolinites.

CONCLUSION

The coherent and progressive variations along this type of profile are inconsistent with the hypothesis of different sediment deposits. This profile is thus formed by an in situ differentiation under weathering conditions. The main phenomena are (1) in the lower part of the profile the dissolution of the quartz and the generation of kaolinite, hematite and gibbsite, (2) in the upper part of the profile the dissolution of hematite and gibbsite, (3) in the topsoil the dissolution of kaolinite and gibbsite. The balance of these processes is a desilicification of the sediment, a relative accumulation of aluminium as kaolinite and gibbsite, and in a minor amount a relative accumulation of iron as hematite. These accumulations result from the sinking of the lateritic profile down into the sediment: the profile deepens at its base, and is destroyed at its top. From the moment when they are generated, the mineral constituents do not remain inert throughout this process. The crystallinity sequence of kaolinites shows that they are in a dissolution-generation equilibrium at each level in the profile. Therefore, the entire profile is in dynamic equilisolution of kaolinite, gibbsite or hematite) are the result of a constant dissolution-generation equilibrium between all the mineral constituents.

Acknowledgements

This study was realised in the frame of the Instituto Nacional de Pesquisas Amazônicas (INPA), Manaus, Brazil.

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