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THE GENESIS AND EVOLUTION OF THE PORTO TROMBETAS BAUXITE DEPOSITS IN THE AMAZON BASIN, PARA, BRAZIL

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The Porto Trombetas bauxite deposits, located in the Amazon Basin, have a very important reserve, estimated in more than one thousand million tons. These deposits occur on high dissected plateaux with altitudes varying between 160 and 190 m. The very homogeneous profile shows the following sequence of layers, from the top to the bottom: a kaolinitic layer, a nodular bauxitic layer, a ferruginous nodular layer, a bauxitic layer and a clay layer. The origin of the kaolinitic upper layer (named »Belterra clay«) and the bauxite parent rock are the two problems treated in this study. 1) The kaolinitic upper layer would be a result of the degradation of an older bauxitic ferralitic profile with the leached alumina accumulating in the underlying nodular bauxite. 2) It appears to be reasonable to consider that the bauxites were developed from the »Alter do Chão« formation which age is Upper Cretaceous, may be Aptian-Turonian

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GENEZA I EVOLUCIJA BOKSITA PODRUČJA PORTO TROMBETAS U AMAZONSKOM BAZENU U DRŽAVI PARA U BRAZILU

Boksiti područja Porto Trombetas u amazonskom bazenu predstavljaju veoma značajne rezerve koje se procjenjuju na više od jedne milijarde tona. Ležišta se nalaze na jako raščlanjenim platoima s nadmorskim visinama između 160 i 190 m. Izrazito homogeni profil ima slijedeći slijed naslaga odozgo naniže: kaolinitski sloj, sloj nodularnog boksita, sloj boksita te sloj gline. Porijeklo kaolinitskog gornjeg sloja (tzv. »Belterra-gline«) i ishodišne boksitne stijene dva su pitanja o kojima je riječ u ovoj studiji.

1. Kaolinitski gornji sloj mogao bi biti rezultat degradacije nekog starijeg boksitnog feralitskog profila, s akumuliranjem izlužene glinice u narednom donjem nodularnom boksitu.

2. Čini se da je opravdano mišljenje kako su boksiti nastali od formacije »Alter do Chão« koja je gornjokredne starosti, možda apt-turonske.

(R. M.)

INTRODUCTION

The Brazilian reserves of bauxite are estimated at 3 200 millions tons and the Amazonic bauxites account for 97 % of them. The main deposits are located in the low Amazon Basin (Porto Trombetas, Nhamudá, Juruti, Almeirim) and on the edges of the Marajó Basin (Paragominas, Mazagão) (Fig. 1).

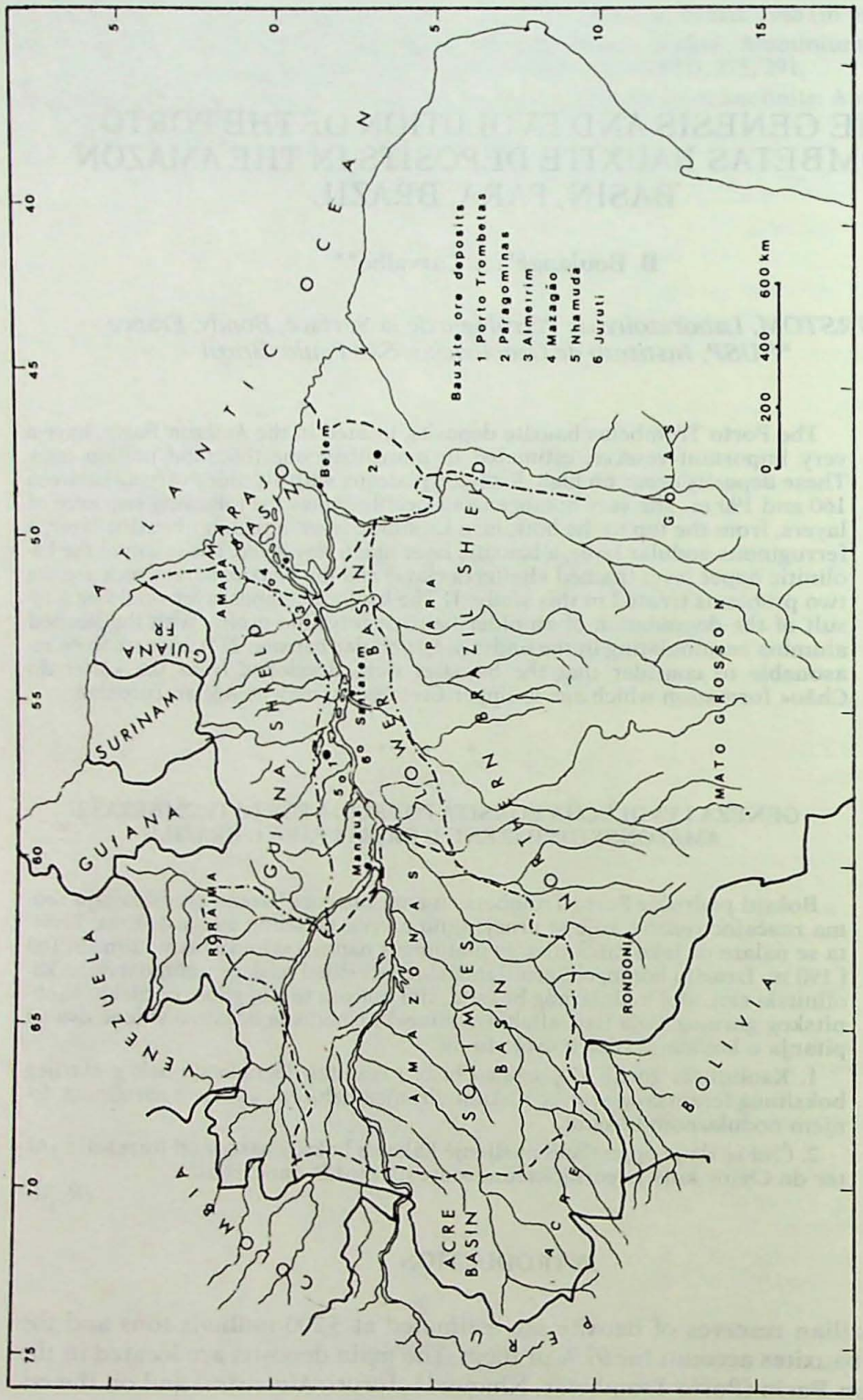

Fig. 1. The Amazon Basin with he localization of the main bauxite deposits

The Porto Trombetas deposits were discovered in 1950, and the open cut began in 1979. As all the Amazonic deposits, the profile shows five layers that are, from the top to the bottom: a kaolinitic layer, a nodular bauxite layer, a ferruginous nodular layer, a bauxitic layer overlying an another kaolinitic layer. These layers previously described in Porto Trombetas [1,8] are the object of a very recent detailed study in Juruti [12]. The main objective of this paper is concentrated only on the two problems related to the origin of the clay upper layer (named »Belterra clay«) and the nature and the age of the parent rock.

THE BAUXITE DEPOSIT

The bauxite deposit of Porto Trombetas is located on the edge of the Rio Trombetas, and about 900 km east of Belém. The climate of this area can be considered as warm (24 °C to 26 °C of average temperature) and humid (1 600 to 2 500 mm/year of rainfall). The vegatation is a hygrophile rain forest (Hiléia Amazônica) on the firm land and an evergreen forest in the valley bottoms.

The lateritic bauxite deposits occur on various plateaux in an area of more than 2 200 sq. km. These high plateaux are deeply downcut, with altitudes varying from 160 to 190 m (Fig. 2) With a gentle dip (1 to 5 °) toward the Amazon river, they present convex slopes that can attain 30 °. They overlook a large morphological unit, with altitudes varying from 100 m at the foot of the plateaux to 70 m near the Amazon river wich has its water level at 40 m. Presently the open pit is on the large plateau Saraca. Despite being flat, the summit present ondulations with altitudes varying from 175 m to 185 m. Locally one can observe also small depressions attaining more than 10 m of diameter and from 2 to 5 m deep. The profile is very homogeneous in the whole plateau (Fig. 3) and presents the following sequence from the top to the bottom:

— a kaolinitic layer, homogeneous, yellow to reddish yellow downwards, without any apparent stratification and with thickness varying from 8 to 10 m on the plateaux and 0 to 5 m on the edges of the plateaux:

— a nodular bauxite layer (1 to 3 m) having in the upper part a great number of pale yellow porcellaneous gibbsite nodules with violet spots and a few ferruginous nodules. In the lower part these ferruginous nodules become gradually coarser, forming by anastomosis larger fragments of irregular shape, vertically elongated, enveloping the ferruginous round spots that increase in diameter downwards. Finally, this layer changes into the underlying layer through a transitional zone (10 cm);

— a ferruginous nodular layer (1 m), with nodules, in the upper part (30 cm), cemented by a hard pinkish gibbsitic matrix and the middle part (60 cm) embedded in a brownish yellow argilomorphous matrix. In the lower part, the ferruginous nodules are again cemented by a pinkish gibbsitic matrix forming a true crust;

— a bauxitic layer (1 to 6 m) whose upper part (1 m) is alumino-ferruginous, compact, massive and which is locally capped by a very ferruginous crust with alumina rich pale zones, and iron rich dark zones. The lower part (5 m) of this bauxitic layer which is the main mined level, is formed by a porous and friable bauxite, presenting a saccharoid facies, different degrees of ferruginization and pale to dark red colours. The transition to the underlying layer is quite gradual. This bau-

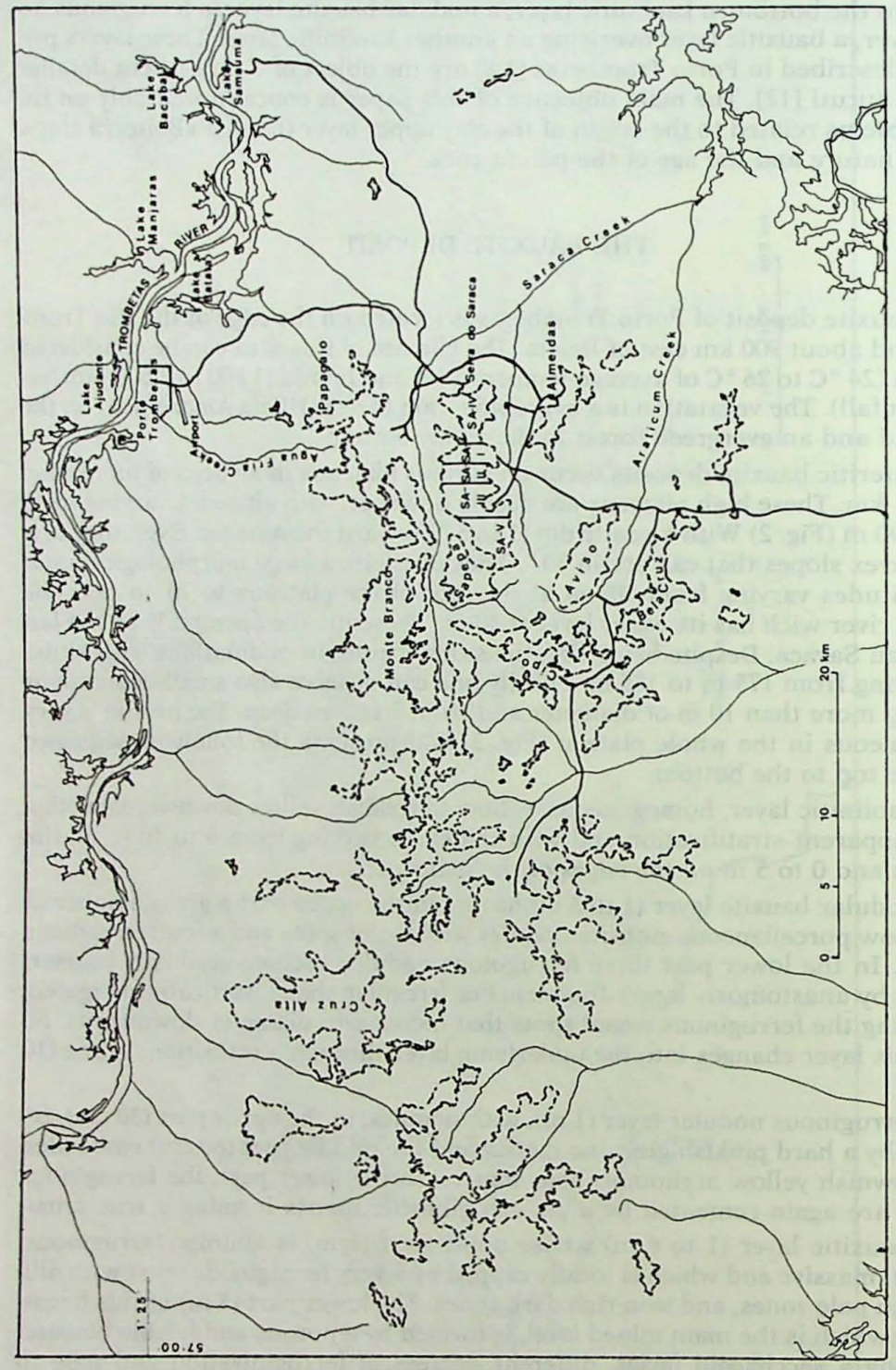

Fig. 2. The bauxitic plateaux of Porto Trombetas (Pará)

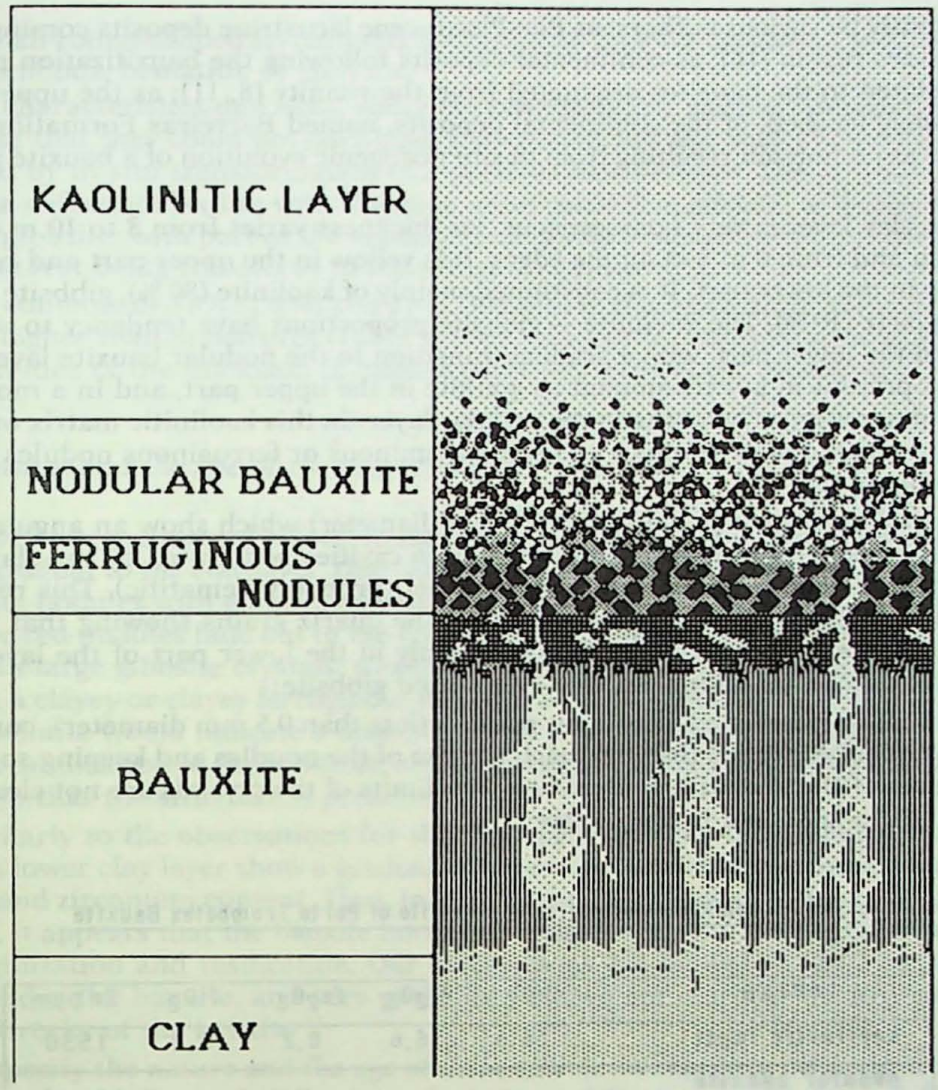

Fig. 3. The bauxitic profile of Porto Trombetas

xitic layer is cut by large vertical pockets containing residual blocks and fragments of bauxite and a yellowish red clay material;

— a clay layer with yellow to brown colour embedding aluminous and ferruginous nodules.

DISCUSSION

The kaolinitic clay upper layer

The kaolinitic upper layer with no evident sedimentary structure, named Belterra Clay [11], covers completely the bauxitic layer. Its origin has been interpreted

differently by various authors: as Plio-Pleistocene lacustrine deposits coming from the Andes region [16]; as continental deposits following the bauxitization period, but related to the bauxites originated from the vicinity [8, 11]; as the upper part, extremely leached, of the continental deposits, named Barreiras Formation [1, 7, 10], or as an horizon resulting from in situ pedogenic evolution of a bauxite profile [17].

This clay layer is very homogeneous. Its thickness varies from 8 to 10 m on the plateau and from 0 to 5 m on the edges. It is yellow in the upper part and reddish yellow in the lower part. It is constituted mainly of kaolinite (80 %), gibbsite (10 %) and quartz (10 %). The kaolinite — gibbsite proportions have tendency to reverse toward the lower part, with a gradual transition to the nodular bauxite layer. The iron is present in a little amount as gœthite in the upper part, and in a more important quantity as hematite in the nodular layer. In this kaolinitic matrix one can observe small quartz granules and small aluminous or ferruginous nodules in the following form:

— small quartz grains (less than 0.8 mm diameter) which show an angular and irregular shape, with fissures and dissolution cavities penetrated by the clay matrix or sometimes filled up with a red product (probably hematitic). This red product is totally enclosed within the limit of the quartz grains showing that it was formed before the matrix. Sometimes, mainly in the lower part of the layer, the quartz grains are coated with well-crystallized gibbsite;

— small round-shaped aluminous nodules (less than 0.5 mm diameter), constituted by gibbsite crystals that can reach the size of the noudles and keeping some local traces of the hematitic red product. The limits of the crystals are not clear and the gibbsite fades out in the matrix;

Table I - Chemical composition of a profile of Porto Trombetas Bauxite

LAYERS	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Zr ppm
kaolinitic layer	36,6	36,6	8,2	2,8	1530
nodular bauxite					
matrix	26,2	43,3	8,3	2,2	1400
aluminous nodules	4,3	61,2	2,2	1,1	640
ferruginous nodules	18,8	19,1	50,3	0,7	640
ferruginous nodules	6,9	26,3	45,6	1,0	780
bauxite					
upper pale zone	2,1	60,2	5,0	0,7	440
dark zone	0,6	47,4	25,5	0,8	420
lower zone	3,9	57,9	6,6	1,4	552
clay layer	29,4	40,8	8,0	4,0	1580
	31,2	35,6	15,4	2,0	800
	25,3	44,7	7,2	1,6	720

— small round-shaped ferruginous nodules (less than 0.5 mm diameter), red, argilomorphous, hematitic or gœthitic.

The characteristics described above of both the quartz and the nodules seem to indicate that they could not have been transported and that they should have originated by in situ transformation of a previous bauxite layer. The process would include deferruginization with changing of hematite into gœthite, and dissolution of the gibbsite; with part of the alumina undergoing resilication fo form kaolinite, and the rest being transfered to the subjacent bauxite [12].

The contents of TiO_2 (2.8 %) and Zr (1530 ppm) in this layer being twice or three times higher than in bauxites (Table 1) seem to confirm this hypothesis and could give an idea of the thickness of bauxite necessary to form the clay horizon.

The nature and the age of the parent rock

As we have mentioned before, in the lower part of the bauxite layer the transition is gradual to the clay layer. One can observe the presence of alumino-ferruginous relict nodules with gibbsite and hematite, embedded in the clay matrix. The hematitic red nodules fade out in the goethitic yellow spots. The bauxite relict nodules with large gibbsite crystals, sometimes in association with quartz, are embedded in a clayey or clayey ferruginous matrix. The contact between the gibbsite and the kaolinite would indicate a dissolution and a resilication of the gibbsite rather than a desilication of the kaolinite, and the arrangement of the quartz relict would confirm that the structure is preserved.

Similarly to the observations for the clay upper horizon, the chemical analysis of this lower clay layer show a gradual silication and an important increase of titanium and zirconium content. Thus, in the present conditions of climate and topography, it appears that the bauxite horizon is being submitted to a degradation: deferruginization and resilication. Our observations are limited to the 2 or 3 m of clay under the bauxite, and very probably we have not reached the sedimentary parent rocks of the bauxite.

To specify the nature and the age of these sediments that gave origin to the bauxite, we should discuss briefly about the history of the Amazon Basin [3, 5, 13, 15]. Its fromation began during the paleozoic, at the same time of the separation of the African and American continents. From the Ordovician the Devonian, there was an unic basin submitted to an homogeneous marine sedimentation related to east-west transgression. During the Westphalian, the area was tilted towards the west leading to an inversion of the sedimentation that occured from west to east. The Amazon Basin can be divided into three sub-basins including the Marajó Basin, characterized by three types of sedimentation:

— in the western part in the upper Amazon sub-basin: a marine and purely chemical sedimentation (limestones and evaporites) that went up to the Andes ridge uplifting (Cretaceous-Tertiary) and ended with clay and sands (Mio-Pliocene);

— in the Middle Amazon sub-basin or Solimões Basin: a chemical and continental sedimentation ending with the deposition of the Solimões Formation (100 m of shales, claystones, lignites and sandstones) (Plio-Pleistocene);

— in the Low Amazon Basin and on the emerged parts of the Marajó Basin: a strictly continental and terrigenous sedimentation to which most of the bauxite

deposits are related. These sediments, in discordancy on the paleozoic sediments, show ages up to Pleistocene.

If we accept that the profile results from an in situ evolution, taking into account the concentration of TiO_2 and Zr we can expect the transformation of at least 40 m of a clay sediment. Now considering the balance established in the present conditions of weathering, a period of 30 to 60 millions years would be necessary for the formation of the present profile [12]. Thus, it is uncertain that this bauxitic formation has been developed on the sediments deposited up to the late Tertiary (named generally Barreiras Series of Solimões Formation). In any case these formations do not bear any known bauxite. On the other hand it is likely that these continental and terrigenous sediments belong to the Alter do Chão Formation constituted by: more than 600 m of shales, silts, sandstones and conglomerates [2,9], attributed now to Aptian — Turonian period [4, 6].

Actually, we should say that up to now we have not a well defined hypothesis on the variations of the paleoclimatic and paleotopographic conditions during the bauxitization period. Nevertheless, from the paleoclimatology data [14] we know, that, during the late Cretaceous and the Tertiary, the Amazon Basin was submitted permanently to a very humid climate, and the evolution of the profile would be more dependent of the variations of the water level and surficial pedogenesis conditions. Perhaps it is possible to consider that the deeping of the profile would have two steps with a stop related with the degradation of the bauxite of the upper part.

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