Doc. 268

LATERITISATION PROCESSES

Proceedings of the II International Seminar on Lateritisation Processes held in São Paulo, Brazil, July 4-12, 1982, organized by the Working Group of Lateritisation Processes (IGCP-129) and Laterites and Lateritisation (IAGC)

Edited by

A. J. MELFI

Instituto Astronômico e Geofísico - University of São Paulo, Brazil

and

A. CARVALHO

Instituto de Geociências - University of São Paulo, Brazil

IUGS
UNESCO
IGCP

PROJECT 129
International Working Group
Lateritisation Processes

IAGC
Working Group
Laterites and Lateritisation

Printed in the Instituto Astronômico e Geofísico
University of São Paulo - Brazil

1983

sysno = 1504726

237-

BAUXITIC ALTERATION ON BASIC AND ALKALINE ROCKS IN THE STATE OF SÃO PAULO, BRAZIL, UNDER TROPICAL HUMID CLIMATE

Mario C. Motta [illegible]

~~M.C.T.~~ GROKE[1], A.J. MELFI[2] AND A. CARVALHO[1]

1 - Instituto de Geociências - USP, Brazil
2 - Instituto Astronômico e Geofísico - USP, Brazil

ABSTRACT

Geochemical, mineralogical and micromorphological analysis were carried out on samples of bauxitic alteration of basic and alkaline rocks from the regions of Curucutu and Lavrinhas, both situated in São Paulo State, Brazil. The analysis of the different alteration facies showed out the importance of the mineralogical type and the chemical system of alteration in the evolution of the primary minerals.

The three different microsystem of alteration, as defined by Proust (1976) and Meunier (1977), were recognized in the studied material: contact, fissured and plasmic microsystem. These systems are characterized by different physico-chemical conditions with direct influence in the alteration evolution within each system. Thus, it was possible to observe and analyse the mineralogical filiations and the mechanisms of bauxitization processes in the studied material.

INTRODUCTION

The present study was carried out on bauxitic materials occurring in two different regions of São Paulo State: a ferruginous bauxite from Serra de Cubatão in Curucutu and a bauxite ore from Serra da Mantiqueira in Lavrinhas (Fig. 1).

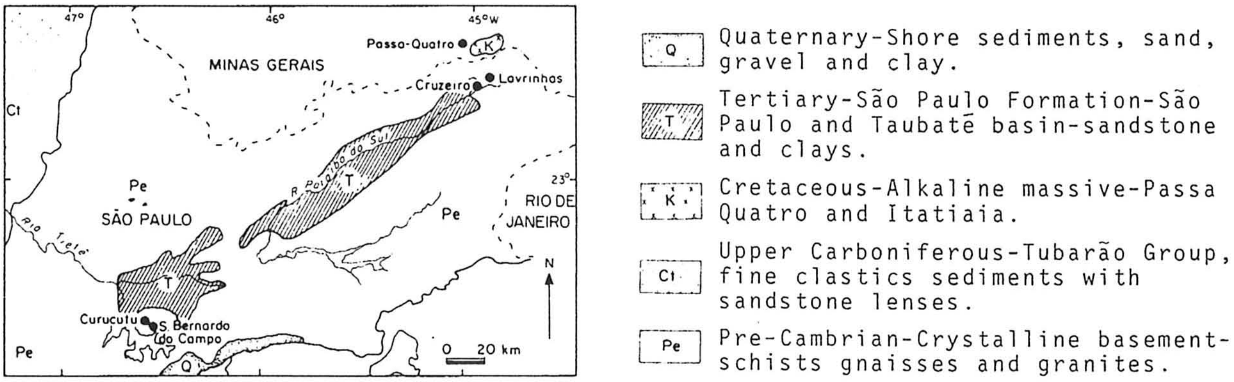


FIG. 1. Regional Geological Map of the Northern of São Paulo State. (cf. Geological Map of the State of São Paulo IGG, 1963).

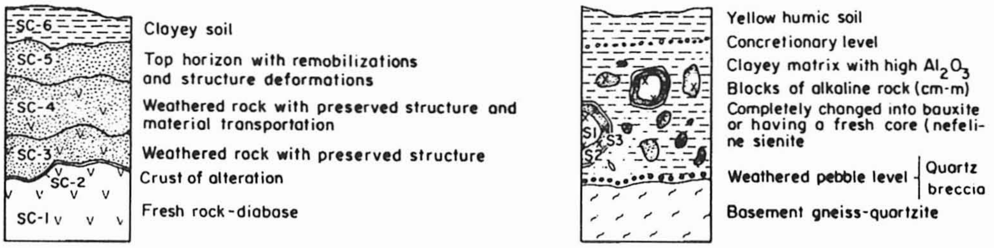
The region of Curucutu is formed by schists and gneisses of the precambrian basement, cut by a large amount of basic and ultrabasic rocks, most of which have evolved into bauxitic material (Felicissimo & Franco, 1956 and Gomes, 1956). In the study area the bauxitic parent rock is a diabase, described as an olivine-gabbro by Gomes (1956).

In the area of Lavrinhas the bauxite is formed on a colluvial material originated from the alkaline massive of Passa Quatro, constituted mainly of nefeline-sienite. A large number of economic bauxitic deposits are in exploration in this region (Penalva, 1967 and Sigolo, 1979). In the colluvial material nefeline-sienite, foyaites and tinguaites are found. The sampled material was a nefeline-sienite and its weathering products which occur as blocks of different sizes mixed with a gibbsitic-kaolinitic matrix. The material which forms the bauxite in the region is allocthonous but the alteration has started after the stabilization of the talus (Groke, 1981).

The regional rocks in Lavrinhas are mainly biotite-gneisses and granites together with small outcrops of quartzite and pegmatites with muscovite and tourmaline.

Concerning the climate, the region is subtropical with an annual rainfall of 1300 mm, with maximum temperature average of 25°C and minimum of 14°C.

In Figure 2 it is shown the typical profile of the different deposits.



CURUCUTU LAVRINHAS

FIG. 2. Typical profiles.

The purpose of this research was to study the geochemical, mineralogical and micromorphological aspects of the evolution of bauxitic materials starting from the fresh rock. Another aim was to study the role of the alteration microsystems. This was possible through the study of the material microstructure organization and the occurred mineral transformation, during the weathering process.

Having these objectives in mind the sampling material was selected according to the nature of the deposit: in Curucutu the material was collected in profiles in side pits and trenches, while in Lavrinhas it was collected from basaltic blocks having a fresh core enveloped by bauxite at different stages of evolution.

RESULTS

For the study of the evolution the profiles were divided into alteration facies, each one characterized by its structure, chemical composition and different properties such as colour, cohesion and density. These facies have been studied by geochemical, mineralogical and micromorphological methods. The geochemical characterization has been performed only on samples having an isovolumetric alteration, i.e., with the structure preserved.

Geochemical Characterization

The selected samples were submitted to total chemical analysis for determination of the major elements and some of the minor elements (Table 1). The content of the major elements, expressed in percentage of oxides in weight, were recalculated in percentage of volume allowing the calculation of the geochemical balance (Table 2). It was then possible to evaluate the gains and losses of the elements during the alteration, which can be better visualized in Figures 3 and 4 that show the variation of absolute content of various oxides as a function of the bulk density, considered as an alteration index.

TABLE 1. AVERAGE CHEMICAL COMPOSITION (% IN WEIGHT) OF DIABASE AND ITS ALTERATION PRODUCTS (A) AND NEFELINE-SIENITE AND ITS ALTERATION PRODUCTS (B).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O	TiO_2	H_2O
(A)									
Diabase SC-1	50.94	11.90	9.81	12.96	1.65	9.62	0.15	1.00	1.04
SC-2	15.86	27.97	23.11	0.11	0.08	0.30	0	2.25	29.46
Bauxite SC-3	12.84	31.90	22.25	0.23	0.03	0.14	0.01	1.64	29.81
(B)									
Nefeline-Sienite S-1	55.87	19.92	1.86	1.07	13.65	0.13	6.63	0.45	1.75
S-2	14.21	37.61	6.85	0.29	1.83	0.08	3.59	0.74	29.55
Bauxite S-3	9.19	44.47	7.71	0.06	1.19	0.07	2.76	1.11	31.65

Mineralogical and micromorphological characterization

A. Region of Curucutu - basic rock

Fresh Rock

The parent rock of bauxite at Curucutu is a metadiabase formed mainly of plagioclase, diopside and hornblende. Secondarily it occurs augite, hypersthene, enstatite, tremolite and olivine, and more rarely (less than 1%) magnetite, chlorite and biotite. The olivine grains show frequently a pyroxene reaction border when included in the

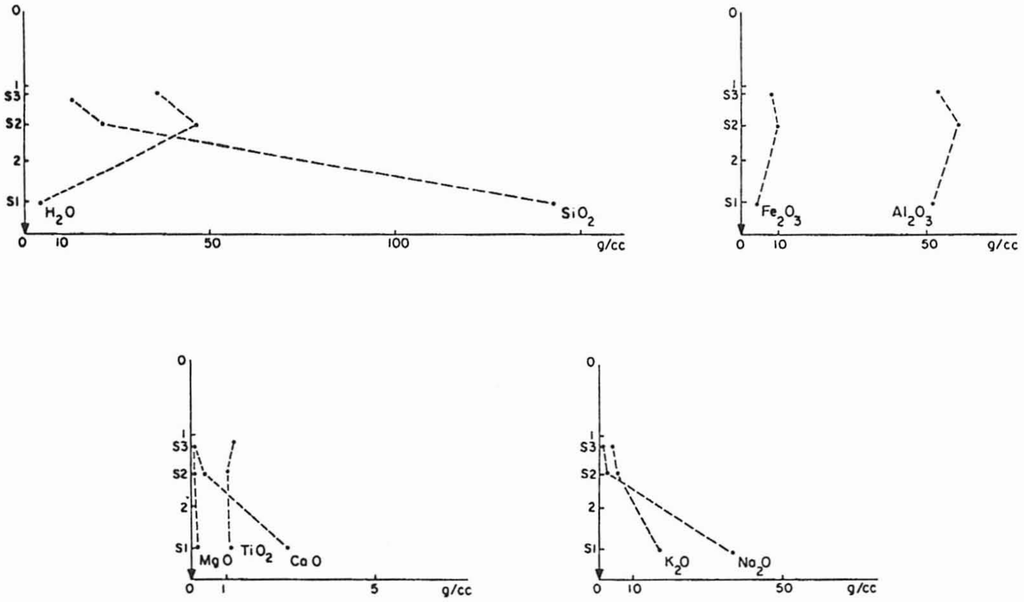


FIG. 3. Variation of the absolute content of several oxides (g/100 cc) as function of the bulk density (g/cc) for nefeline sienite and its alteration products.

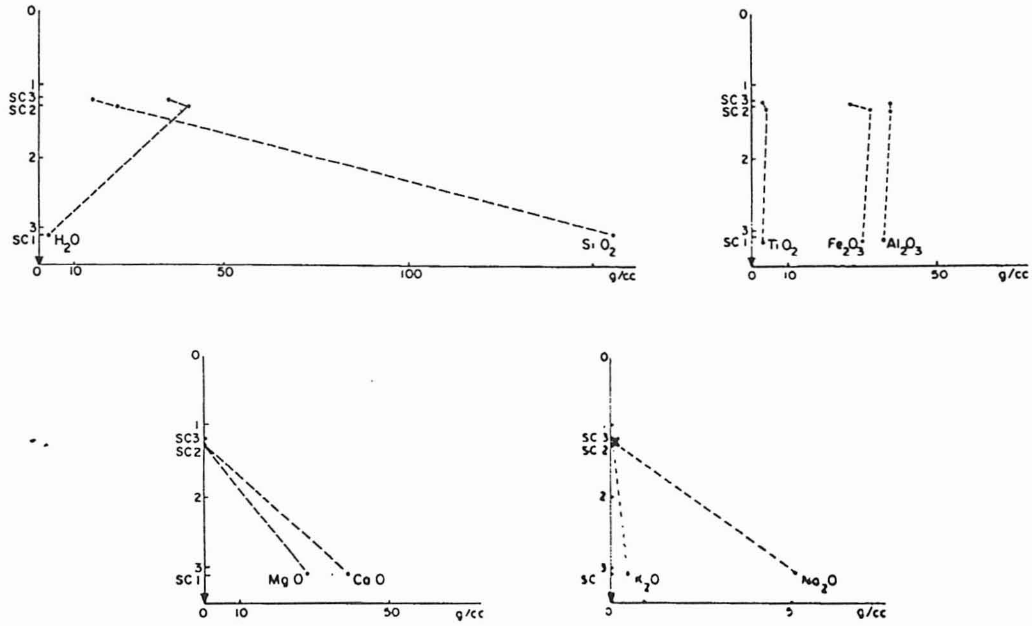


FIG. 4. Variation of the absolute content of several oxides (g/100 cc) as a function of the bulk density (g/cc) for diabase and its alteration products.

TABLE 2. GEOCHEMICAL BALANCE

a) GEOCHEMICAL BALANCE FOR NEFELINE-SIENITE ALTERATION

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	H_2O
S-2	-121.4	+6.7	+5.7	-2.30	-32.1	-0.2	-11.9	-0.1	+40.9
S-3	-132.8	+2.0	+3.9	-2.67	-33.6	-0.2	-14.0	0	+31.0

LOSSES	SiO_2	CaO	Na_2O	MgO	K_2O	TiO_2
S-1 → S-2	85.0%	83.9%	92.0%	66.7%	70.0%	20.0%
S-1 → S-3	93.0%	97.4%	96.3%	66.7%	82.4%	0

GAINS	Al_2O_3	Fe_2O_3	H_2O
S-1 → S-2	0.1%	118.8%	908.9%
S-1 → S-3	0.1%	81.3%	688.9%

b) GEOCHEMICAL BALANCE FOR DIABASE ALTERATION

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	H_2O
SC-2	-135.3	+0.7	+0.6	-39.7	-5.0	-0.5	-29.1	-0.1	+36.0
SC-3	-141.4	+0.8	-4.1	-39.5	-5.1	-0.5	-29.3	-1.2	+31.7

LOSSES	SiO_2	Fe_2O_3	CaO	Na_2O	MgO	K_2O	TiO_2
SC-1 → SC-2	86.5%	(GAIN)	98.0%	98.0%	98.6%	100%	3.2%
SC-1 SC-3	90.4%	13.6%	99.3%	99.2%	99.3%	100%	38.7%

GAINS	Al_2O_3	Fe_2O_3	H_2O
SC-1 → SC-2	1.9%	2.0%	1,125%
SC-1 → SC-3	2.2%	(LOSS)	990.6%

plagioclase or pyroxene grains.

Crust of Alteration

The transition from fresh rock to alteration cortex is abrupt; 1 to 2 cm far from the fresh rock the material is already completely altered, but the structure is still preserved.

The plagioclase is completely transformed into gibbsite. This gibbsite preserves the descontinuity network that isolates plagioclase fragments, normally leached, contributing to increase the porosity and decrease the bulk density, as compared to the fresh rock (Photo micrograph 1).

The alteration of pyroxenes and amphiboles follows the same pattern as the plagioclase, with goethite forming instead of gibbsite.

The olivine alteration also forms goethite in the whole space previously occupied by the primary mineral. This goethite has a better crystallization than the one originated from pyroxenes and amphiboles (shows simultaneous total extintion in the whole crystal). Magnetite formed previously in the crystal fissures is preserved during the alteration. The reaction cortex of the olivines, formed of pyroxene is altered the same way as the pyroxene (Photo micrograph 2). Clay mineral of 2/1 type (vermiculite) has been rarely observed coating the pore walls, forming geodes and argillans.

Weathered Rock with Preserved Structure

The material corresponding to this alteration facies is similar to alteration crust. It can be observed, in the microscope, a gibbsitic skeleton, replacing the previous plagioclases, a ferruginous and more porous one substituting the pyroxenes and amphiboles and also olivine relicts.

The vermiculite formed in the previous stage does not exist in this alteration facies, being replaced by gibbsite and iron oxide.

Weathered Rock with Preserved Structure and Transport of Material

The main difference as compared to the previous facies is the nearly complete destruction of the opaque minerals and the importation of gibbsitic material. This material comes from the higher profile levels and fill in the pores of both ferruginous and gibbsitic skeleton. In this case an absolute aluminum accumulation occurs, decreasing the porosity and increasing the bulk density (Photo micrograph 3).

The structure of the ferromagnesiam minerals, underlined by the iron oxides and hydroxides, is formed by the gibbsite crystallization in their interior (Photo micrograph 4).

Remobilized Horizons

In this alteration facies the primary structure is still visible in some parts of the sample, but as a whole, this structure is completely destroyed by the remobilization, particularly of the gibbsite. The gibbsite leaving the previous places destroys the traces of the plagioclase and accumulates in the form of geodes or gibbsans. These accumulations are identified in the microscope as thin crusts (1 - 2 mm thick) coating fissures walls (Photo micrograph 5).

In some places hematite is observed in the pores of the goethite skeleton, suggesting transformation of goethite into hematite proceeded or not of remobilization. Some ferri-gibbsans can occur formed by iron oxide (goethite or hematite) in the interior and gibbsite in the outer band or vice-versa. Relicts of olivine are also present. Remobilization of iron is locally observed by the deformation of the ferruginous skeleton.

B. Region of Lavrinhas - alkaline rock

Fresh Rock

The main minerals present in the nefeline-sienite are nefeline, leucite, plagioclase and orthose; and as accessory titanite, green hornblende and opaque minerals (magnetite and ilmenite).

Tha plagioclase (mainly albite) show single twinning and inclusions of nefeline and hornblende. The hornblende crystals are also included in the leucite or in the contact leucite and plagioclase. The opaque minerals can be found included in any of the other minerals.

Crust of Alteration

The feldspathoids are the first minerals to be attacked in the alteration, starting from the discontinuities and mineral contour. This alteration gives origin to a gibbsitic network with high porosity, preserving the cleavage and fissure traces and the crystal limits. The nefeline and leucite fragments isolated within the gibbsite suffer either dissolution and total leaching or are transformed into a silico-aluminous amorphous material, and further into gibbsite by loss of silica.

In this case some fresh plagioclase fragments still exist (Photo micrograph 6). But most of them are almost completely altered, resulting in a porous gibbsitic skeleton (Photo micrograph 7). *It is possible to distinguish between the gibbsitic network* formed from the feldspathoids and the one originated from the plagioclases, on the basis of its discontinuity patterns (Photo micrograph 8).

The hornblende is altered leaving a ferruginous residue of goethite or hematite.

Vermiculite can also be observed in the crystal outer band.

Weathered Rock with Preserved Structure

In this facies, the feldspathoids and the plagioclases are completely altered, resulting in a gibbsitic skeleton. The same happens to the amphiboles, that form ferruginous (goethite or hematite) skeleton. When the alteration of the horneblendes gives origin to goethite, the structure is better preserved.

The titanites are rather resistant and some fresh fragments are still found. Their alteration produces a leucoxene amorphous or cryptocrystalline phase that after leaching evolve to gibbsite.

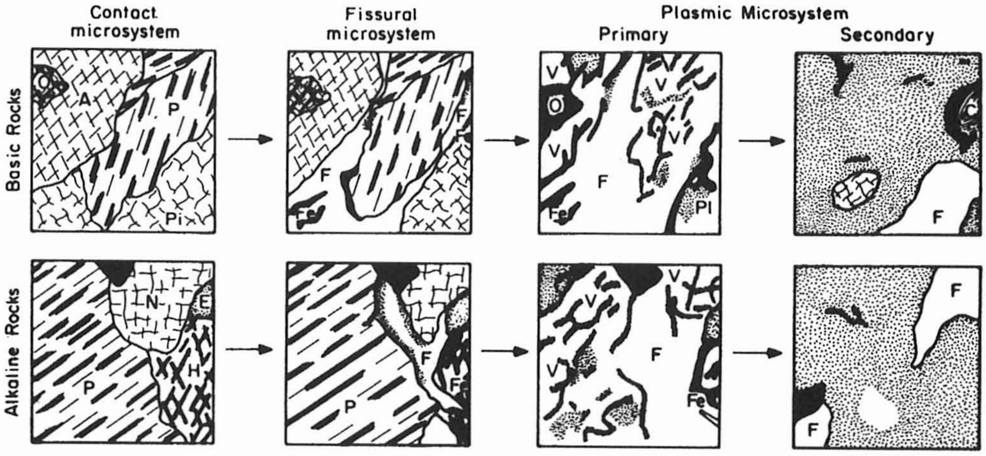
At this stage, there are evidences of intense iron remobilization, that fills in the skeleton pores (previous primary minerals) forming ferrans staining the gibbsitic portions. In both the remobilization iron and the skeleton iron the hematite predominates on gibbsite.

In this facies most of the opaque minerals still subsist.

C. Evolution of the Microsystem

The microscopic and micromorphological characterization of the studied material allowed to confirm the punctual character of the alteration. In this case the microsystem plays a fundamental role in the evolution of the phenomena of dissolution and recrystallization of the primary and secondary minerals (Proust, 1977 and Meunier, 1977).

In Figure 5 it is shown the evolution of the two types of rocks, through the characterization of the microsystem in four stages.



P - Plagioclase
N - Nefeline
T - Titanite
H - Hornblende

M - Magnetite
A - Anfibolite
Pi - Pyroxene
O - Olivine

Fe - Secondary iron oxides
F - Fissural medium
Pl - Plasma
C - Cutans
(O) - Olivine relicts

FIG. 5. Evolution of the alteration microsystem.

In the first stage, corresponding to the fresh rock, it can be observed that the primary minerals are still fresh and interlocked. In this phase, the alteration solution percolates slowly through small sized spaces. The solutions are concentrated and typical of closed medium. These spaces correspond to the contact microsystem and are the original rock porosity and discontinuities. It is exactly in these spaces that the alteration process starts.

The continuous attack of the percolating solution opens progressively the contact microsystem promoting a faster percolation. The solution is then more diluted and this transformation characterizes the evolution from the contact microsystem to the fissural microsystem. Through this fissural system the intense percolation leads to the lateritic alteration of the studied material: silica and soluble elements are removed and gibbsite and iron oxides are formed. This secondary material constitutes the plasmic microsystem. Considering these materials to be formed inside the rock discontinuities, the original rock structure is initially preserved. Micrographs 1, 2, 7 and 8 show the plasmic microsystem.

Under the continuous action of the weathering process in this system, changes can occur with dissolution, reprecipitation or simply recrystallization. These changes destroy the traces of the original structure. A secondary plasmic system is then formed, containing the remobilized plasma with no relationship with the primary structure and the cutans type of deposits.

DISCUSSION

The mineralogical and micromorphological studies together with the geochemical characterization of the studied materials brought out some aspects concerning the processes of bauxite formation.

In both cases, Curucutu and Lavrinhas, the hydrolytic process has removed most of the elements from the structure of the parent rock leaving behind a skeleton of aluminum and iron oxides and hydroxides.

The aluminum as well as the iron content show an increase per unit of volume. This allows to admit that, even with no perturbation of the original structure, both relative and absolute accumulation have happen. Nevertheless, it is not possible to precise how much Al or Fe was accumulated in situ and how much was imported. It must be noticed that the difference between the Al/Fe in the alteration product and the Al/Fe in the fresh rock is not necessarily the gain in these elements, since part of them can be lost in the hydrolytic process.

In any case, it seems clear that the bauxitization of the studied deposits occurred following two different processes. The first one, acting at the beginning of the weathering, was the relative Al (Fe) accumulation, through the loss of all other elements. In this case, the bauxite is an in situ residue of the superficial alteration of the rocks, and the mechanism involved was the desilicification. The loss of silica can be observed by the low values of the molecular ratio SiO_2/Al_2O_3 (Ki) of the final product (0.1 - 0.2). The process in this case corresponds to the alitization or more precisely the ferralitization since iron has a similar behaviour of aluminum. Nevertheless, the bisialitization is present in the initial alteration of hornblendes, when vermiculite is formed. The presence of vermiculite in such an agressive medium put in evidence the importance of the microsystems which can present very peculiar conditions completely different from the global conditions of the medium. Also the local presence of silico-alumina amorphous material in alkaline rocks alteration is an evidence of the presence of punctual conditions different from the global one. The bisialitization, despite its small quantity and short duration, is an intermediate phase to ferralitization (Maignien, 1961 and Chatelin, 1974).

The bauxite formed in this process is an isovolumetric alteration product, having a network either gibbsitic, very porous, pseudomorphous on plagioclases and feldspathoids or goethitic (or hematite) also very porous and pseudomorphous on ferruginous primary minerals.

Another existing process is the absolute accumulation affecting the more developed profile levels. The remobilization is facilitated by the high porosity. It consists

PHOTO MICROGRAPHS OF BAUXITE FORMED ON META-DIABASE

Photo 1. Relicts of plagioclase transformed into gibbsite.

Photo 2. Relicts of olivine showing reaction outer band.

Photo 3. Gibbsitic cutans in the ferromagnesian relicts.

Photo 4. Deformation of the ferromagnesian relicts by the deposition of gibbsite.

Photo 5. Gibbsitic deposit.

PHOTO MICROGRAPHS OF BAUXITE FORMED ON NEFELINE-SIENITE

Photo 6. Weathered feldspar.

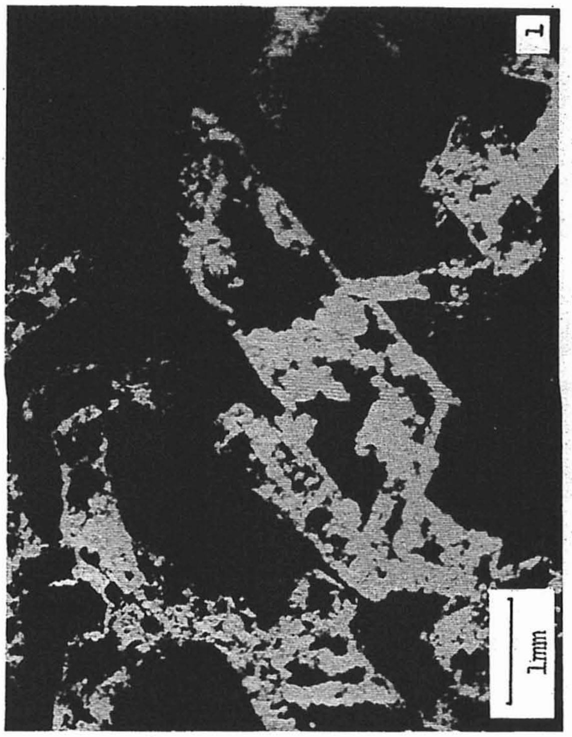
Photo 7. Gibbsite preserving the discontinuities of the previous feldspar.

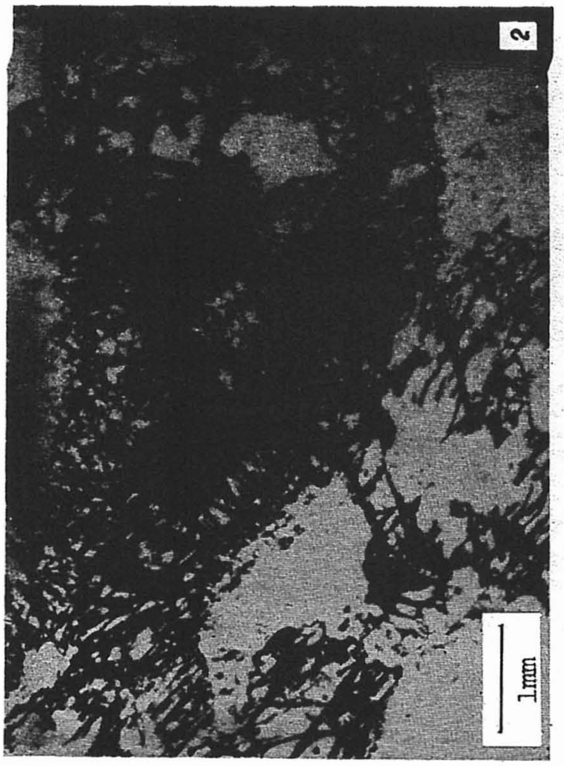
Photo 8. Different forms of gibbsite occurrence:

. on the left - primary gibbsite formed from feldspar;

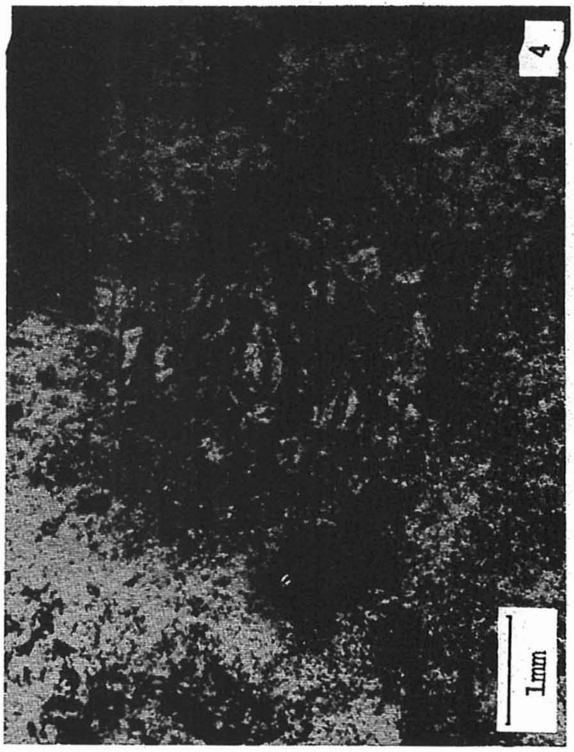
. on the right - primary gibbsite formed from feldspathoids;

. on the left and right corner - secondary remobilized gibbsite.

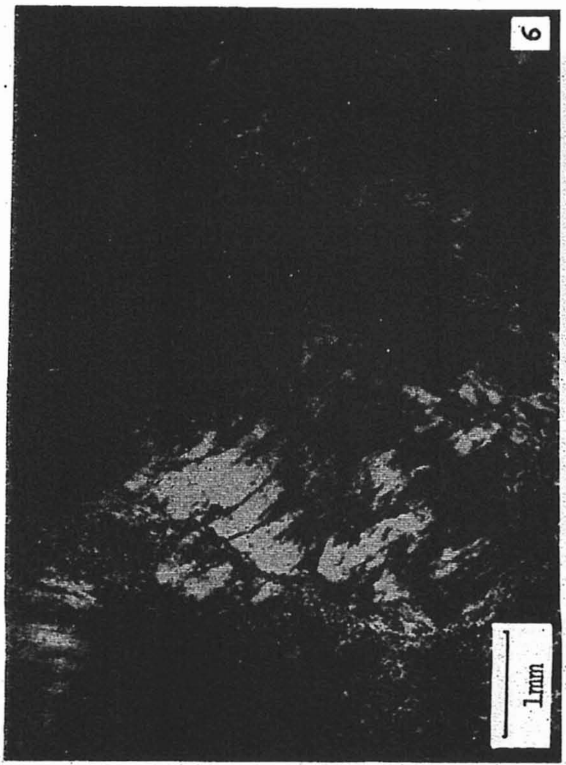

1
1mm

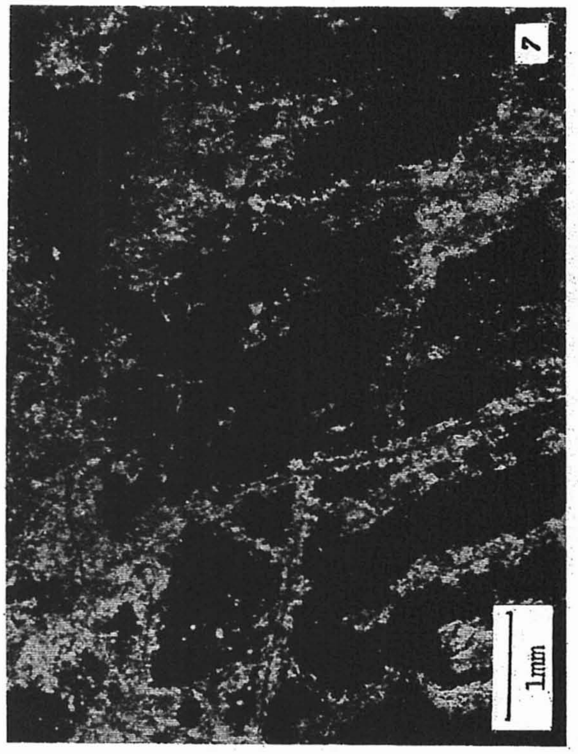

2
1mm

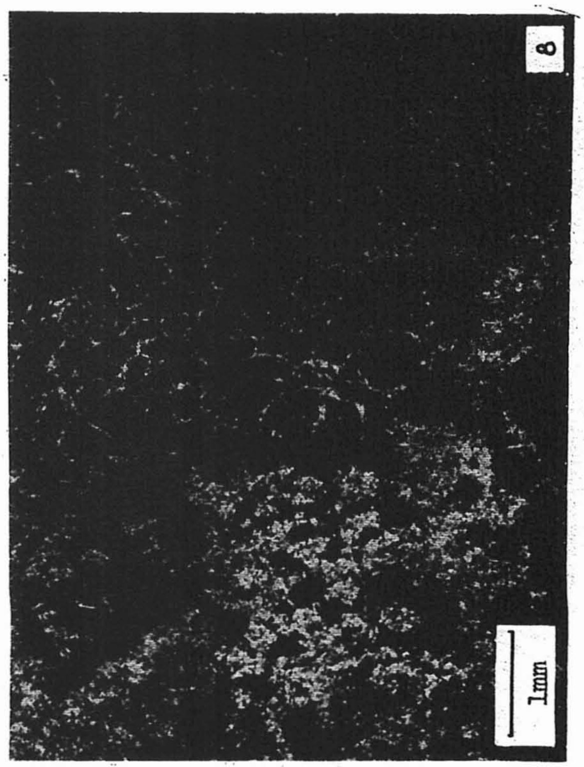

3
1mm


4
1mm


5


6


7


8

of aluminum and iron migration either in suspension or as true solution. It seems that the organic matter plays an important role in this process as it can be observed in Lavrinhas. The abundance of organic matter in the top soil lowers down the pH to levels which can promote the solubilization of the aluminum that migrates and is deposited in the subsoil due to higher pH.

During this process, the primary plasma (secondary material neoformed in situ and corresponding to the relative accumulation) loose its stability and is recrystallized forming a secondary plasma where the characteristics inherited from the rocks exist no more. In this case the illuviation is an important phenomena and gibbsitic or ferruginous cutans are formed. This process of aluminum and iron oxide deposit, involving transport in solution, corresponds to the aluminification and ferrification (Erhart, 1973).

Concerning the bauxitization process, the high gibbsite content in the alteration cortex is an evidence of the intense leaching process during a relative short time. This brings out the important role of the high pluviosity, or of the climate as a whole, which is very aggressive. On the other hand it is noticeable the role of the topographic position of the deposits as well as the structure and texture of the parent tock, conditioning the water dynamics, favouring the quick flow of the drainage water.

The mineralogical composition of the nefeline-sienite is highly favourable to the bauxitization. This factor, together with the good drainage and topographic conditions explains the fastness and efficiency of the bauxitization process occurring in these rocks.

Concerning the diabase, the alteration is also quite fast. Nevertheless, due to the great abundance of iron in the primary rock the final product was a highly ferruginous bauxite.

Comparing the alteration of the two different rocks minerals the plagioclase seems to be slightly more resistant than the feldspathoids.

Finally it is worth to notice that in none of the two cases a slowness of the process have been observed and even the kaolinitic intermediate stage, always refered to in literature, was absent.

REFERENCES

- Bisdom, E.B.A., 1967. The role of micro-crack systems in the spheroidal weathering of an intrusive granite in Galicia (NW Spain). Geologie Mijnbouw, 46.
- Bocquier, G., 1979. Importance des microsystems dans les ēvolutions supergēnes. Introduction, Bull. Ass. Franc. pour l'ētude du Sol, nº 2 et 3, Comm. Sem. AFES - Versailles, L'alt. des roches crist. em mil. superf., 1978.
- Boulange, B., Paquet, H. et Bocquier, G., 1975. Le rōle de l'argile dans le migration et l'accumulation de l'alumine de certaines bauxites tropicales. C.R. Acad. Sc. Paris, 280, sērie D, 2183-6.

. Delvigne, J., 1977. Micromorphologie des processes d'altération des roches ultrabasiques de Côte d'Ivoire en vermiculite, montmorillonite et kaolinite. I Reunion Int. Suelos, Granada.

. Eswaran, H., Stoops, G. et Sys, C., 1977. The micromorphology of gibbsite forms in soils. J. Soil Sci., 28.

. Felicissimo Jr., J. & Franco, R.R., 1956. Bauxita no altiplano da Serra de Cubatão. Bol. SBG, Vol. V, nº 2.

. Gomes, J.C.F., 1956. Jazida de bauxita de Curucutu, SP. Rev. Esc. Minas, Ouro Preto, MG, Vol. XX, nº 2.

. Groke, M.C.T., Melfi, A.J. & Wackermann, J.M., 1980. Transformações mineralógicas e estruturais ocorridas durante a bauxitização de rochas cristalinas ácidas. Estudo do depósito bauxítico de Mogi das Cruzes, SP. Anais XXXI Congr. Bras. Geol., Vol. I.

. Groke, M.C.T., 1981. Evolução geoquímica, mineralógica e micromorfológica no processo de bauxitização. Estudo comparativo dos depósitos de Mogi das Cruzes, Curucutu e Lavrinhas, SP, associados a diferentes tipos litológicos. Dissertação de Mestrado, Instituto de Geociências, USP, São Paulo.

. Ildefonse, P., Proust, D., Meunier, A. et Velde, B., 1979. Rôle de la structure dans l'altération des roches cristallines au sein des microsystems. Bull. de l'Assoc. Franc. pour l'étude du Sol, nº 2 et 3, Comm. Sem. AFES, Versailles, L'altération des roches cristallines en milieu superficiel, 1978.

. Meunier, A., 1977. Les mécanismes de l'altération des granites et les rôle des microsystèmes. Thèse Uni. Sci. Poitiers.

. Proust, D., 1976. Étude de l'altération des amphibolites de la roche - l'Abeille. Evolutions chimiques et mineralogiques des plagioclases et des hornblendes. Thèse 3ᵉ cycle, nº 605, Poitiers.

. Sigolo, J.B., 1979. Geologia de depósitos residuais bauxíticos na região de Lavrinhas, SP, e sua viabilidade econômica. Dissertação de Mestrado, Instituto de Geociências, USP, São Paulo.

. Stoopes, G., Altemuller, H.J., Bisdom, E.B.A., Delvigne, J., Dobrovolsky, V.V., Fitzpatrick, E.A., Paneque, P. and Sleeman, J., 1979. Guidelines for the description of mineral alterations in soil micromorphology. Pedologie, XXIX, 1, Ghent.