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BAUXITIZATION OF ALKALINE ROCKS IN SOUTHERN BRAZIL

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ABSTRACT

The present paper is a preliminary inventory of the bauxitization of alkaline rocks in southern Brazil. Two different alteration profiles associated with two distinct topographic compartments were recognized. In the Ridge Profiles bauxite lies directly over the fresh rock, while in the Plateau Profiles an intermediate clayey horizon appears. In the former, bauxitization is still an active process, while in the latter, kaolinization is the present phenomenon. In a topographic sequence the kaolinization starts in the lower part of the topography and migrates upwards affecting the base of the previous bauxitic alteration profile.

It was also shown that the rock type is an essential factor controlling bauxitization together with the topographic factor, which controls internal drainage.

I. INTRODUCTION

The Brazilian bauxite deposits, with an estimated reserve of 4 billion metric tons, are all of lateritic origin and formed by the weathering of different rocks. Nearly 97% of the deposits are situated in the Amazon region and are developed on clastic sediments of Tertiary age (Barreiras Formation). The other 3% are originated by the weathering of different lithologies in particular, alkaline rocks.

Alkaline rocks are widespread in Brazil, mainly in the central and southern regions. Despite their adverse climatic conditions (subtropical to temperate climate), these rocks, with a particular chemical composition (low silica and high alumina content), give rise to important bauxite deposits rather than to kaolinite material as might be expected.

A great deal of work has been done on the geological, petrological and tectonic aspects (ELLERT,1959; PENALVA,1967; RIBEIRO FILHO,1967; ULBRICH and GOMES,1981) but very little attention has been paid to the supergenic alteration of the alkaline rocks, with the exception of the mining company reports and the works of WEBER,1959; MONIZ,1969; ALMEIDA,1977; SIGOLO,1979 and GROKE,1981.

The present paper represents a preliminary inventory of the bauxitization process in the southern Brazil, where it is more closely associated with the alteration of alkaline rocks. On the other hand it was possible, through this study, to propose certain indications concerning the genesis of the deposits and the equilibrium conditions of the bauxitic material in the subtropical environment.

II. GEOLOGICAL CONDITIONS

In southern Brazil during the Upper Mesozoic and Lower Tertiary, the Pre-Cambrian basement was intensely cut by alkaline intrusions of different shape, size and importance. Their geographical distribution, associated with other characteristics (age, chemical composition, etc.), suggests a clear genetic relationship with the volcanic rocks of the Paranã Basin, related to the opening of the southern Atlantic.

Based on available geological, petrological and geochronological data, ULBRICH and GOMES (1981) have proposed a preliminary classification of Brazilian alkaline rocks into eight different rock associations grouped into 10 alkaline provinces. Three of these provinces exhibiting bauxitization occur in southern Brazil: the Anitãpolis, Poços de Caldas and Coastal provinces (Fig.1).

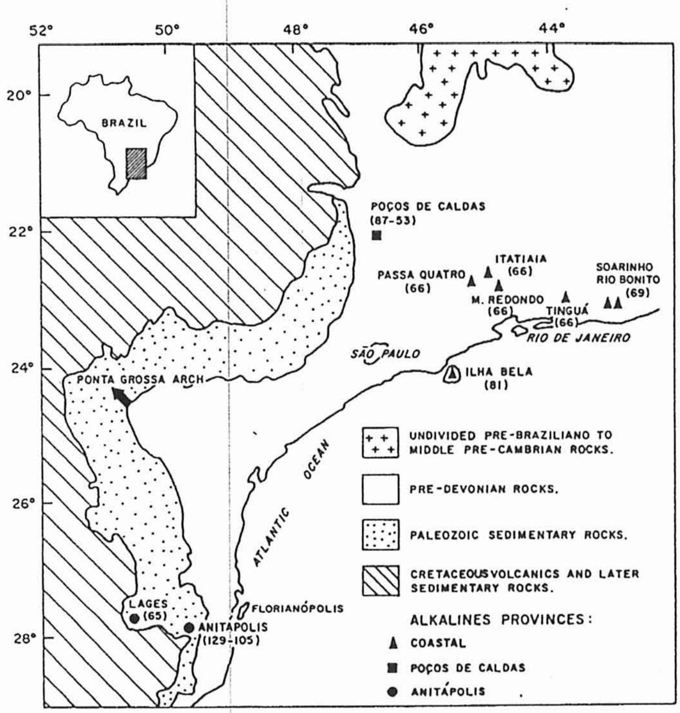

Fig.1. Map of alkaline massifs southern Brazil.

The Anitãpolis Province is situated in the State of Santa Catarina and consists of the Lages and Anitãpolis massifs, only the first of which has associated bauxitic deposits. The alkaline rocks crop out sparsely in the interior of a domic structure and occur either as large bodies of coarse texture forming the main regional ridges or as small dikes of fine and medium texture.

The Poços de Caldas Province in the State of Minas Gerais comprises a nearly circular massif.

The Coastal Province, covering the States of São Paulo and Rio de Janeiro, exhibits a large number of alkaline rock occurrences, most of them associated with bauxitic deposits. Itatiaia and Passa Quatro are the most important massifs.

These provinces consist mainly of unsaturated to saturated syenitic sequences made up essentially of syenites, phonolites, trachytes, foyaites, tinguaites and other alkaline rocks. These rocks present nearly the same mineralogical composition, the main differences between them being their textures and structural aspects. The most frequent mineralogical composition includes K-feldspar, nepheline, aegirine-augite, sodalite, cancrinite and other feldspathoids. In the Itatiaia massif supersaturated sequences are also present, and the mineralogical assemblage includes, besides nearly 30% quartz, microperthite and biotite. In the Poços de Caldas massif the alkaline rocks were locally affected by hydrothermal processes that formed sericite, 1:1 clay minerals, kalsilite, etc.

Erosive action is quite intense in the alkaline massifs and removes most of the formed alterites; thus bauxitic accumulation is restricted to particular zones (Fig.2).

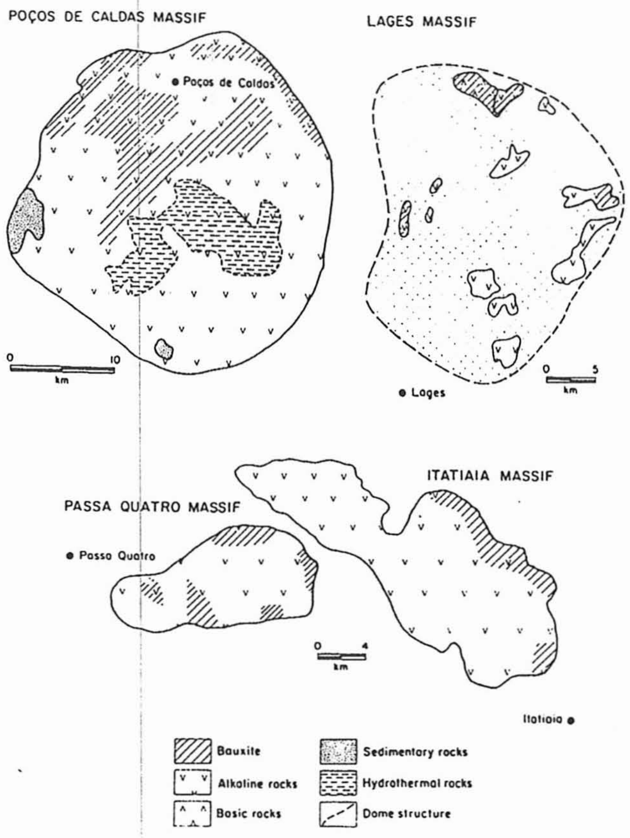

FIGURE 2

Distribution of bauxite in the studied alkaline massifs.

III.MORPHOLOGICAL AND BIOCLIMATIC CONDITIONS

A.Climate and vegetation

Tha alkaline provinces in southern Brazil are associated with high altitudes that directly influence the climatic condition. In this region climate is mainly mesothermic (NIMER,1977) of temperate type in the higher altitudes or latitudes and of tropical type in the lower altitudes and latitudes. The average annual temperature varies from 12-13^{0}C in Lages and the higher zoner (> 1600 m) of Itatiaia and Passa Quatro massifs to 18^{0}C in Poços de Caldas. In the lower zones (> 800 m) of Passa Quatro and Itatiaia, the climate is humid and sub-warm with an average annual temperature of 22^{0}C.

The climate is always wet having 1300 to 2000 m of precipitation and either with rainfall well distributed throughout the whole year in Lages or with 2 dry months (July and August) in the other regions.

The dominant vegetation cover is the grassland associated either with Araucaria subtropical forest in the southern most region or with dense tropical forest in the other regions.

Forests are usually restricted to the main river valleys and steepest slopes.

B.Topography

The alkaline massifs of southern Brazil form generally high plateau with altitudes above 1200 m which can attain 2500 m. They often are subcircular massifs with a rugged topographic rim which can be higher or lower than the central plateau (Figs.3 and 4).

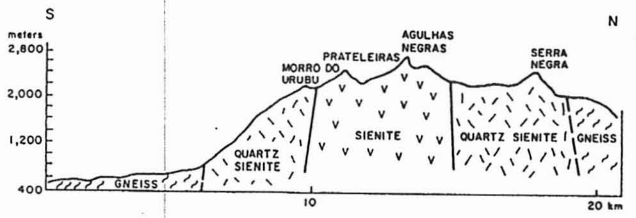

FIGURE 3

Schematic cross-section of the Poços de Caldas alkaline massif (after ALMEIDA,1977).

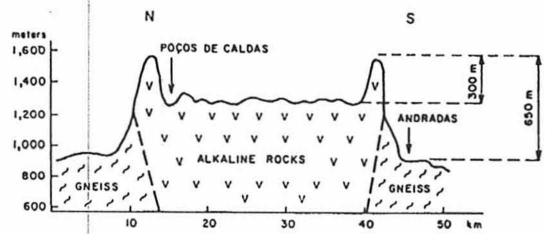

FIGURE 4

Schematic cross-section of the Itatiaia alkaline massif.

In most alkaline massifs, two very different topographic compartments are thus distinguished:

1.Ridge topography with or without flat tops

This topographic feature is quite common at the border of the massifs, and accompanying the steepest slopes of hills found sometimes in the central plateau (Fig.5). Here alkaline rock crops out alternate with a thin bauxitic alteration cover. This topographic compartment is represented in all the studied massifs, and is specially well developed in the Poços de Caldas and the Passa Quatro massifs.

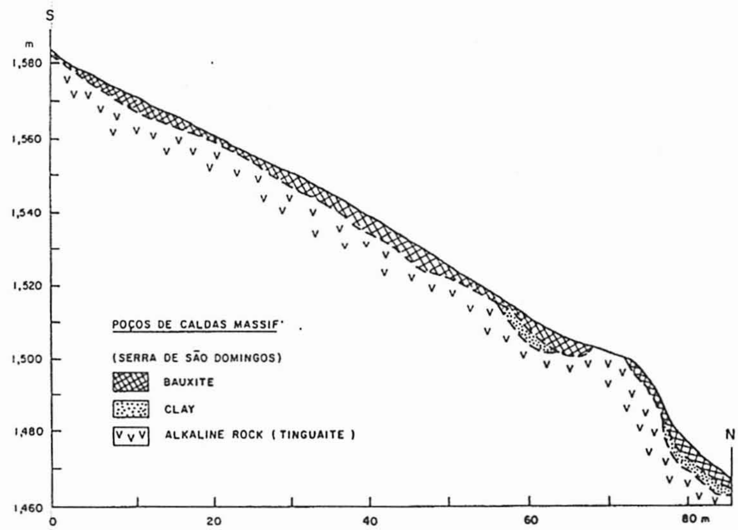

Fig.5. Ridge topography of the Poços de Caldas alkaline massif.

2. Undulated topography of high plateau

This is the more relevant topographic expression related to the internal portion of the massifs. The topography is moderately to strongly undulated and is associated with a rather continuous alteration layer of bauxitic and clayey composition. This feature is observed in all the studies massifs (Fig.6).

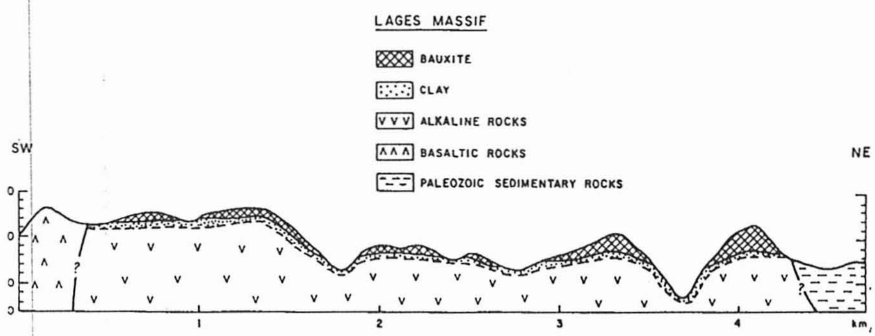

Fig. 6. Undulated topography of the high plateau of the Lages alkaline massif.

IV. DIFFERENT TYPES OF ALTERATION PROFILES

The alkaline rocks in southern Brazil, present two distinct types of bauxitic alteration profiles associated with the above topographic compartments.

A. RIDGE ALTERATION PROFILES

Ridge alteration profiles are characteristic of deposits related to a more rugged topography or higher regions with flat top. They are dominant in the northern part of the Poços de Caldas massif associated with the external topographic high ring (Rim deposits of ALMEIDA, 1977) and in the northern and central-northern parts of the Passa Quatro massif. It also occurs more rarely in Lages and in the internal plateau of Poços de Caldas, found on the steep slopes of some small hills.

In these areas the profiles are well drained and a deep alteration was expected. Nevertheless the alteration layer is normally thin due to erosive action. These profiles are homogeneous, with high alumina content and small amount of clay and/or ferruginous contamination.

All alkaline rocks, when completely altered, form always the same alteration profile, characterized by a direct contact of the bauxitic layer with the parent rock, and by the occurrence of 3 main horizons.

A typical profile from Poços de Caldas shows the following morphology:

a. Friable horizon with preserved structure

The alteration of the alkaline rock is rather complete within a few millimeters and gives origin, by intense leaching, to a homogeneous bauxitic horizon of light yellow colour, highly porous, friable and with low density (Friable ore of ALMEIDA, 1977). The thickness varies from 2 to 6 m with average value of 3 m. The density values are around 1 g/cm^3 and the porosity can reach 60%. Joints, fractures or concentric structures of spheroidal alteration may persist in this horizon as relict structures.

b. Coherent dense horizon

Another bauxitic horizon occurs above the friable ore or directly over fresh rock, as in some profiles of Lages and Passa Quatro. This horizon is more coherent, harder and with a higher density than the previous one. It has a yellow reddish colour and a spongy or compact structure, with densities varying from 1.2 to 2.0 g/cm^3 and porosity between 10 to 50%. The thickness ranges from 2 to 10m. In spite of compactness phenomenon, relict rock structures may sometimes be preserved.

c. Nodular horizon

This horizon, when present, is rather thin, rarely attaining 1 m. The structure is nodular, fragmentary and concretionary, with the structural elements embedded in a reddish brown clay matrix or reddish yellow friable bauxitic matrix. The bauxitic blocks are irregular in size, varying from few millimeters to some decimeters. Concentric structures, developed around roots, or rocks fragments are common.

Profiles chemical and mineralogical composition

The chemical and mineralogical composition of the profiles is shown in Figure 7.

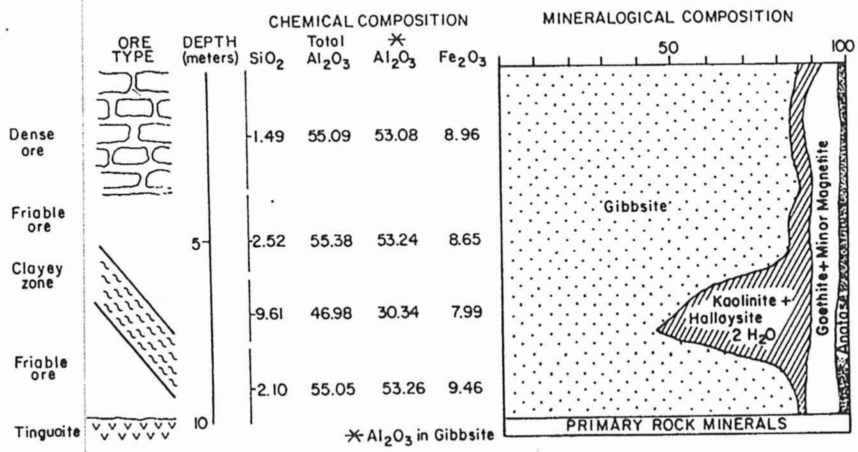

Fig.7. Chemical and mineralogical composition along the ridge alteration profiles, Poços de Caldas (after ALMEIDA,1977).

In can be observed that the limits between fresh rock and the alteration horizon is quite sharp, with no transitional zone (saprolite). The primary minerals are rapidly altered, undergoing a nearly complete loss of silica and alkalis, forming gibbsite, goethite, halloysite and kaolinite associated with small amounts of boehmite, lithiophorite and aluminous gel.

Gibbsite is the predominant mineral, accounting for more than 80% of the bauxitic material bulk composition. Boehmite is rare and distributed in the whole profile. Halloysite and kaolinite are frequent, but found in smaller amounts, except in zones of clayey veins which cut the bauxitic ore. Goethite is the main iron compound, followed by haematite, which is common in Lages, anatase and residual magnetite.

With respect to the chemical composition, this material corresponds to the righ grade bauxite (BÁRDOSSY,1982) with high alumina content (55%) and low silica and iron.

B. PLATEAU ALTERATION PROFILE

The most important bauxite reserves associated with alkaline rocks present this type of profile. It occurs in all the studied massifs, related to a smoother topography and more gentle slopes. In the Poços de Caldas massif it occurs in the internal plateau area ("Plateau Deposits", ALMEIDA,1977) and is formed from all the different lithologies except those previously affected by hydrothermal processes. It is also frequently observed in Lages and in the western part of the Passa Quatro massif ("campo" deposits).

In these areas the internal drainage is rather poor, leaching phenomena are thus inhibited and, originate a more heterogeneous material with contaminations particularly of clay. These profiles are nevertheless quite thick since they are protected against erosion. They are characterized by two different materials, the first one being rather thick, of clay nature and lying directly over fresh rock; and the other one, of bauxitic nature covering the first material. The bauxitic material is quite thin and is of lower quality.

The profiles show three main horizons, as follows:

a. Clayey horizon without preserved structure

This horizon lies directly over fresh rock and the thickness varying from a few centimeters to 4 meters. It presents a reddish colour, clay texture and massive structure.

This horizon is thicker in the lower parts of the topography where it may be the only existing material.

b. Bauxitic material with preserved structure

Above the clay layer a bauxitic horizon can occur. This horizon is rather coherent and dense, showing normally a spongy or compact structure, and thickness varying from 2 to 7 m. Its colour is light yellow or reddish yellow. The density ranges from 1.6 to 2.0 g/cm^3 and the porosity from 16 to 55%.

The friable horizon with preserved structure, which is dominant in the ridge deposits, appears scarcely in the plateau deposits.

c. Nodular horizon

This horizon, very rare in the ridge profiles, is common in the plateau deposits, where it can reach up to 2 m. The characteristics are essentially the same as the one in the Ridge profiles, but here the nodular elements can attain diameters over 25 cm.

Profiles and mineralogical composition

The chemical and mineralogical composition of the described profiles is shown in Figure 8.

It is noteworthy that the mineralogical composition is here quite similar to that of the Ridge profiles, the only difference being the presence of a micaceous illitic mineral, in the clay horizon of the Plateau profile. This clay horizon is made up predominantly of kaolinite, with subordinate halloysite-2H_2O, illite (sericite) and traces of gibbsite.

In the bauxitic horizon gibbsite is predominant (50-70%) but less abundant here as compared to the Ridge profiles. Contents of kaolinite and halloysite-2H_2O are rather important, and can reach 30%. The other minerals present are boehmite, goethite, magnetite, cliakite and anatase.

These deposits are less homogeneous than the Ridge profiles, and clay intercalations are frequent. The average content of Al_2O_3 is around 51%, SiO_2 6% and Fe_2O_3 10%.

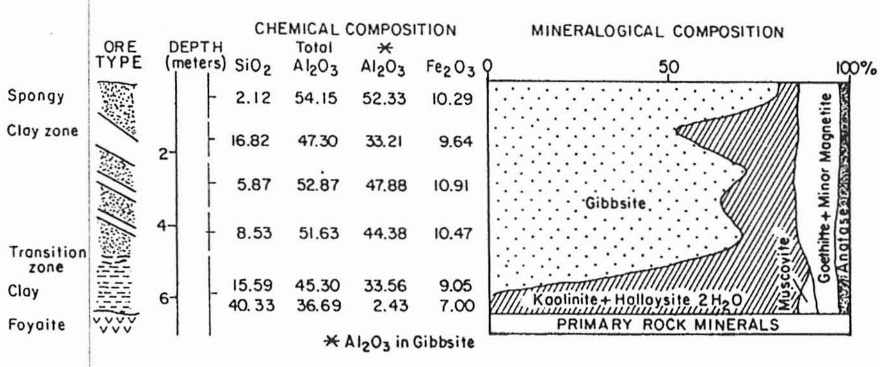

Fig.8. Chemical and mineralogical composition along the high plateau alteration profiles, Poços de Caldas (after ALMEIDA,1977).

V.GENETIC CONSIDERATIONS

A.Bauxitization processes in southern Brazil

The great aluminium accumulation on the earth surface are the result of the interaction of various factors, of morphological, bioclimatic and lithological nature.

With respect to the morphologic and bioclimatic factors, the southern Brazilian alkaline provinces are characterized by a strongly undulated topography with steep slopes and marked erosion, a high plateau vegetation and a mesothermic subtropical to temperate climate with well distributed rainfall. These conditions are not favourable for bauxite formation. Consequently, only the rock composition, i.e., high feldspar and feldspathoids content, with no quartz and very few ferro-magnesian minerals, can account for that evolution. A clear evidence favouring this interpretation is the fact that other rock types do not form bauxite deposits, as for example, basic rocks in Lages, or kaolinitic sediments and hydrothermally altered alkaline rocks in Poços de Caldas or surrounding gneissic or granitic rocks in the different massifs.

The deposits formed on alkaline rocks are not very thick since topographic conditions favour quick erosion.

B.The formation of the different profiles

The studied profiles showed an evolution towards direct bauxitization associated with hydrolitic processes. This fact is supported by the preservation of the original rock structure and the direct contact bauxite and fresh rock.

The mineralogical evolution, under this particular condition can be followed by microscopic analysis. It can be observed that feldspathoids are the first minerals to be affected by weathering. The processes starts at the border and discontinuities of the crystals, giving origin to a gibbsitic network preserving the original rock structure (Photo 1). The feldspar follows the same pattern of alteration. Later on, the nucleii of both minerals are dissolved and partially leached, forming amorphous or poorly crystallized compounds of cliakite type which can evolve into gibbsite or can be eliminated leaving empty cavities (Photo 2). The result is an extremely porous material with low density and preserved structure. This material, initially friable, changes into a hard and spongy one as a result of partial recrystallization of gibbsite.

The gibbsitic material originated from feldspar and from feldspathoids present different pattern thus making it possible to recognize the primary mineral (Photo 3).

The pyroxenes, which alter almost simultaneously with the feldspar, are completely dissolved leaving behind a ferruginous residue that rapidly crystallizes into goethite. Haematite can also occur associated with goethite.

In the upper part of the bauxitic profile the physico-chemical conditions promote the partial dissolution and migration of gibbsite and precipitation of a secondary gibbsite in the cavities, forming a compact and dense bauxite (Photo 4).

Thus, three generations of gibbsite can be recognized in the bauxitic horizon, two of which are associated with relative accumulation processes. The first one is formed at the beginning of the weathering process and is related to the alteration microsystem. The second one is associated with the evolution of amorphous gels of aluminous and siliceous aluminous composition. Finally, the last generation is formed by aluminium absolute accumulation through ionic or gel migration and precipitation.

In most of the profiles, the occurrence of a clay layer between fresh rock and the bauxitic material may suggest an indirect origin for the bauxite. Nevertheless, even in this case, the analytical data and field observations seem to favour a direct origin. The preservation of the original rock structure in the bauxitic layer though not in the clay layer seems to be a clear evidence for a direct process. On the other hand, micaceous clay-minerals are present in the clay layer, but not in the above bauxitic layer. These micaceous minerals are stable and resist to the weathering processes, consequently they are expected to be present also in the bauxitic zone, if it was formed through indirect processes, from the clayey horizon.

The relationship between the two profile types can be studied in various profiles occurring in a topographic sequence (Fig.9), allowing a better understanding of their genesis.

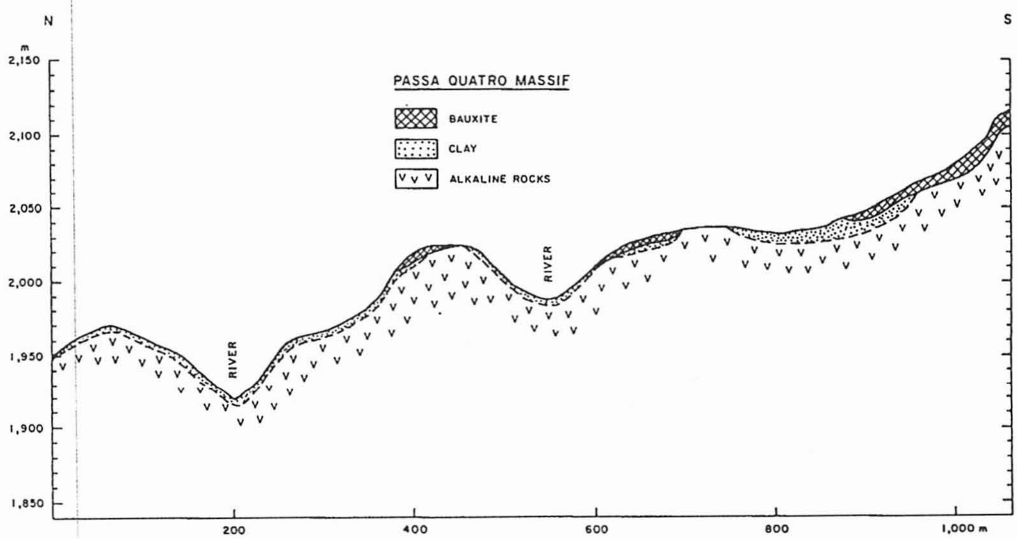

Fig.9. Cross-section of a high plateau deposit, Passa Quatro alkaline massif.

In the upper and steepest part of the topography the excellent internal drainage lead to the formation of a bauxitic layer with no clay intermediate horizon. In the lower part of the topography, where the internal drainage is not as good and where silica lateral migration is active a clay layer, is formed with predominant kaolinite. This material, being impervious, slows down the solution movement, blocking the lateral migration. As the process goes on, the kaolinitic/gibbsitic limit migrates towards the top, leaving behind profiles with kaolinitic material at the base and gibbsitic material at the top. It is evident in this case, that kaolinization is the active evolution process. Consequently, in the plateau situation it is the kaolinitic material which is in equilibrium with the environmental conditions, moving bauxitization back so that it is found only on the steepest zone of the topography.

VI. CONCLUSIONS

The present study allow us to put forward some general considerations about the bauxitization process in southern Brazil.

1. The bauxitic formation from alkaline rocks is a direct process. Initially, gibbsite is formed directly by alteration of the primary silicate minerals, with no intermediate clay material. In the upper part of the profiles under particular conditions (higher acidity, presence of organic matter, etc.), this gibbsite becomes unstable, is dissolved and reprecipitates further down as a new generation of gibbsite (secondary gibbsite).

2. In southern Brazil, the most important factor controlling bauxitization is rock composition followed by, topography and in particular internal drainage conditions.

3. Kaolinization is the general active processes, which means that it is the one in equilibrium with the environmental conditions. Bauxitization corresponds to a past evolution and at present, bauxites are being destroyed. Exceptionally bauxitization is still an active process on the steep slopes.

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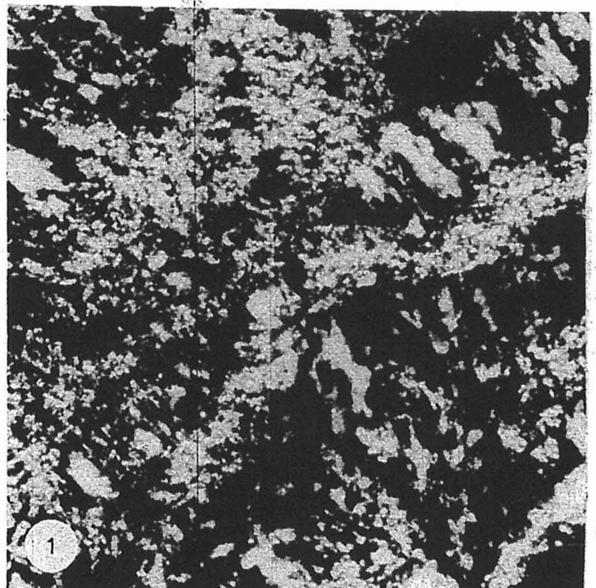

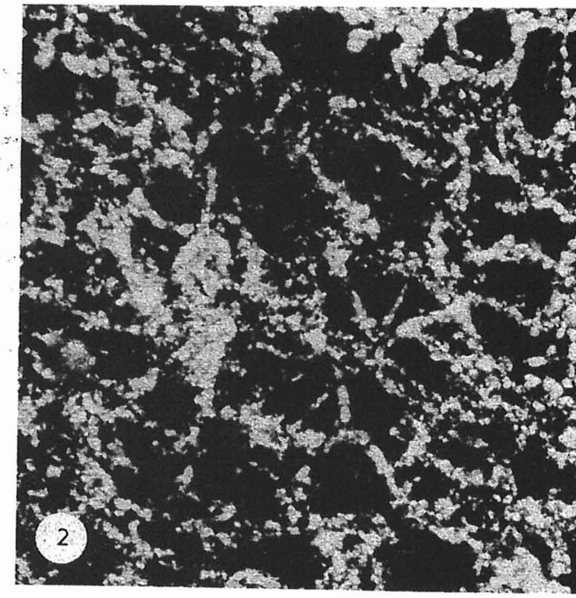

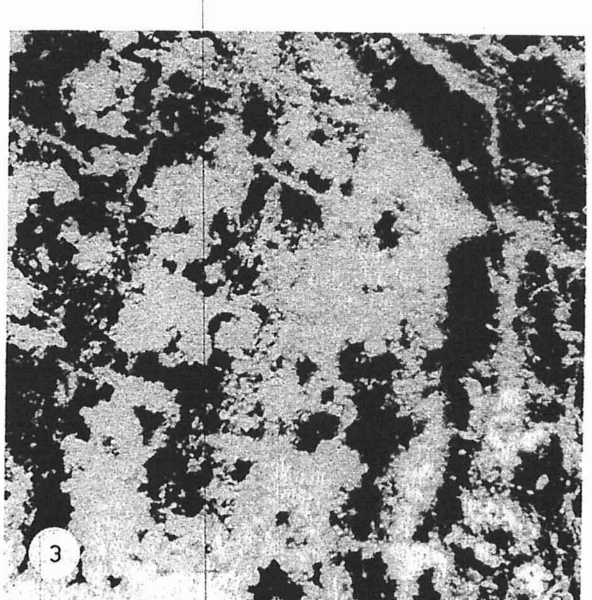

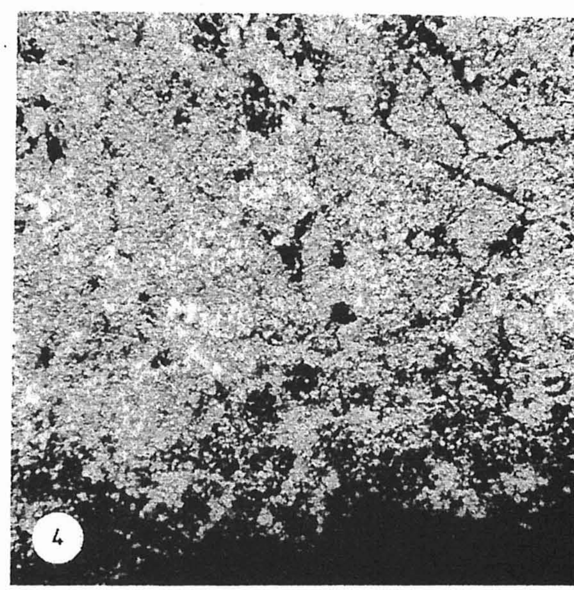

Photo 1 : Thin section micrograph (crossed nichols); gibbsitic network preserving the original rock structure.

Photo 2 : Thin section micrograph (crossed nichols); gibbsite with nucleii of relictual rock, some of which transformed into amorphous material.

Photo 3 : Thin section micrograph (crossed nichols); different pattern of gibbsitic material, corresponding to distinct primary minerals: feldspathoids (Fd) and feldspath (Ft).

Photo 4 : Thin section micrograph (crossed nichols); dense and compact bauxite, with some cavities coated by recrystallized gibbsite.

RESUME :

L' étude des bauxites formées à partir des roches alcalines du sud du Brésil a montré que deux types de profils d'altération s'associent aux deux types de paysages reconnus. Dans les profils de montagne, la bauxite se trouve en contact direct avec la roche mère, tandis que dans les profils de plateau existe une couche argileuse intermédiaire. Dans le premier cas, la bauxitisation est encore un processus fonctionel, tandis que dans le deuxième, la kaolinisation est la processus actuel. Dans les toposéquences, la kaolinisation commence dans les parties basses du paysage et remonte en affectant la base des profils bauxitiques. On a montré que la roche mère est le facteur dominant dans le processus de bauxitisation, mais il est nécessaire aussi que la topographie soit favorable au drainage.