THE BAUXITES OF THE PASSA QUATRO ALKALINE MASSIF

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Introduction

The Passa Quatro massif, as well as the Itatiaia massif, is located in the limits of Minas Gerais and São Paulo States. It is a part of the Mantiqueira Mountains and corresponds to alkaline intrusions (nepheline syenites, microsyenites, tinguaites and phonolites) in a Precambrian basement constituted mainly of gneisses, migmatites, schists and quartzites (Fig. IX.1). The minimum age for the alkaline rocks is 70 million years (Ulbrich & Gomes, 1981). The up throwing of the massif is

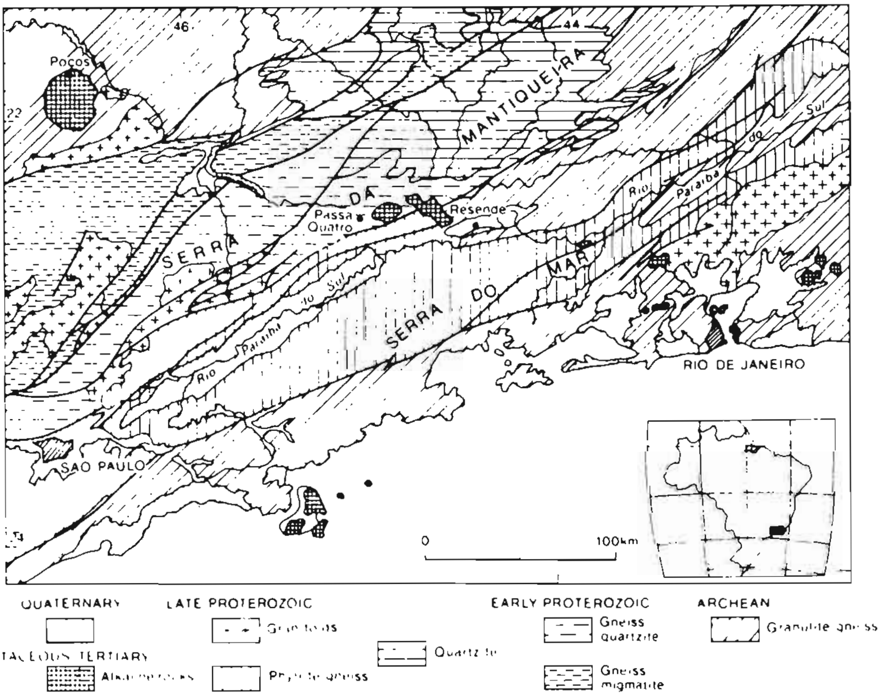

Figure IX.1 - Geological map of the East São Paulo and the South Minas Gerais states (after Fonseca et al., 1979 and Almeida et al., 1984) and localization of Passa Quatro alkaline massif.

contemporaneous to the opening of the Paraíba Rift (Upper Cretaceous to Miocene) (Almeida, 1976, 1980).

Following this tectonic phase, three main geomorphologic units werw developed in the region: a mountainous zone, with altitudes ranging from 2,770 to 1,300 m; a zone of slopes and hills with altitudes comprised between 1,300 and 600 m, and a zone of low valley extending till the sedimentary continental basins, distributed within the rift bottom (Volta Redonda, Resende and Taubaté basins).

The rocks of the Passa Quatro massif werw submitted to an important bauxitization, originating two types of bauxite deposits, related to the upper geomorphologic units. The summit bauxites, in the mountainous zone, is characterized by an "in situ" preservation of the weathering profiles. The piedmont bauxites, within the slope zone, are colluvial accumulations related to pediments. The global reserves of these deposits have been estimated at about 15 million tons of which 5.5 million tons correspond to the piedmont deposits.

The mountainous zone is submitted to a humid tropical climate of altitude, with an annual average rainfall of 2,400 mm, a mean temperature of 11°C, the minimum attaining -6°C (Nimer, 1979).

The slope zone presents a humid tropical climate with contrasting seasons, having an annual rainfall of 1,500 mm and mean temperature of 18°C. The winter months (May to August), with a precipitation lower than 50 mm, are the driest months.

I. The Summital Bauxites

The summital bauxite deposits of the Passa Quatro massif were prospected in 1974 (CBA) and 1981 (CORIMBABA). One of these deposits, Alto das Posses, was selected for a detailed study. The deposit is constituted of a group of hills, with 2,200 m of altitude, surrounding a central depression with 2,000 m of altitude. The external slopes form a large rocky escarpment. The bauxite outcrops on the internal convex steep slopes (40°).

In one of these slopes, a serie of shafts were established (Fig. IX.2). In the upper and the middle part of the slope, the bauxite lies directly on the parent rock, while in the lower part, a clayey horizon is intercalated between the bauxite and the parent rock (Melfi & Carvalho, 1983).

Only one of the summital shaft (PQA) was studied in detail. This profile, 9 m deep, presents, from the fresh rock up to the surface, four main facies: a friable saprolite, a massive saprolitic bauxite, a fragmented

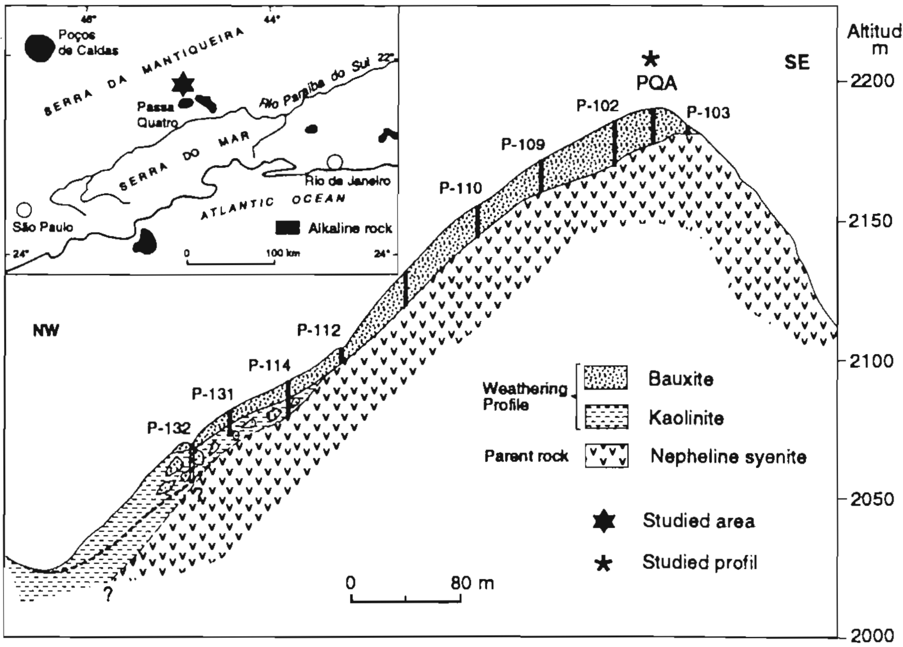

Figure IX.2 - Geographic setting of the Passa Quatro alkaline massif and cross-section of the studied ridge (Sigolo, 1988).

saprolitic bauxite and a surface nodular bauxite (Fig. IX.3) (Sigolo, 1988). The density and porosity values, as well as the volumetric changes, based on the iso-zirconium reasoning (Brimhall & Dietrich, 1987; Colin et al., 1988) are given in Table IX.1. As a matter of fact, the high and constant zirconium content throughout the alteration profile are related with the presence of unaltered euhedral zircons of small size. (<50 μm) (Boulangé & Colin, 1994).

The chemical analysis for the profile PQA, as well as the alteration balance calculated on the basis of constant zirconium are given for major elements and rare earth elements in Table IX.2.

II. Profile Description

1. The parent rock, as spherical blocks of metric size, was found between 8 and 9 m of depth (sample 17c). It is a nepheline syenite with granular structure. The normative mineralogical composition, calculated from 5 analysis, shows 58% potassic feldspar (microperthitic orthose, sanidine), 31% nepheline, 8% ferrous-magnesian minerals (biotite 1.9%,

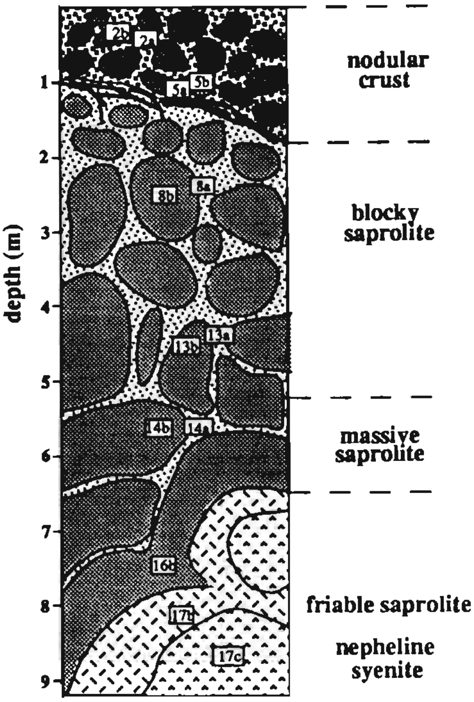

Figure IX.3 - Sketch of the PQA pit and sample location. The member indicates the sample, the index indicate the matrix (a), the bauxite fragments (b) and the syenite (c).

hornblende 0.9%, ægerine-augite 5.1%) and zircon (0.085), sphene (0.74%), magnetite (1%), apatite (0.56%) and pirochlore as accessory minerals. The bulk density (2.57), lower than the real density (2.70), shows a weak porosity (<5%) for the rock, due probably to a slight alteration.

2. *The friable saprolite (sample 17b)* forms a thick white cortex (15 to 20 cm), with granular texture, around the parent rock. The transition from fresh syenite to friable saprolite is quite sharp. The mineral transformation is observed at the rock contact within few millimeters. The nepheline and feldspar crystals are replaced by gibbsite, while the pyroxene and the amphiboles have been dissolved and partially replaced by goethite, crystallized in the cleavage plans and grains border. The X ray diffraction analysis shows that gibbsite and goethite, forming a porous network, are well crystallized. The bulk density is week (1,46) and its relation with the real density (2,58) (Table IX.1) shows the development of a strong porosity (42%), associated to the dissolution of primary

Table IX.1 - Physical properties of the PQA samples for the matrices (a), the bauxitic fragments (b) and the nepheline syenite (c): bulk density ($_{\rho w}$), grain densit ($_{\rho g}$), porosity ($_{\phi}$) and volumetric change (ε_{Zr}).

Sample *	**Depth** (m)	ρ_w g/cm^3	ρ_g g/cm^3	Φ %	**Zr** (ppm)	ε_{Zr}
2 b	-0.50	1.77	2.45	28	2083.26	-0.52
2 a	-0.60	2.10	2.58	19	2816.36	-0.70
5 b	-1.10	1.62	2.44	34	2288.92	-0.53
5 a	-1.20	2.13	2.57	17	2509.10	-0.67
8 b	-2.50	1.64	2.53	35	2463.41	-0.52
8 a	-2.60	2.02	2.52	21	2241.48	-0.65
13 b	-4.50	1.93	2.55	24	2777.92	-0.57
13 a	-4.60	2.05	2.58	21	2102.54	-0.69
14 b	-5.50	1.49	2.57	42	2344.99	-0.43
14 a	-5.60	2.00	2.59	23	2056.55	-0.53
16 b	-7.50	1.43	2.52	43	2539.69	-0.52
17 b	-8.20	1.46	2.58	43	2641.26	-0.54
17 c	-9.00	2.57	2.70	1	684.31	0.00

(*)sample numbers are keyed to numbers in Fig. IX.2.

minerals. In the saprolite, the volume change attain 54%, a nearly constant value up to the surface.

3. *The massive saprolite or massive bauxite* (sample 16b) presents a thickness varying from 1 to 3 meters. It is formed by large rounded blocks, separated by fissures of 1 to 5 cm width. As a continuation of the alteration cortex, it preserves the granular texture and the friability. The blocks are constituted essentially by gibbsite (90%), associated with small amount of goethite, hematite and anatase. The bulk density (1,43) and the real density (2,52) reflects a strong porosity (43%). Except for the zircon, all the minerals of the parent rock are altered, with a pseudomorphic texture. The fissures are the preferential way of water circulation and they are partially filled by a matrix constituted by cryptocrystalline gibbsite, goethite and small amounts of kaolinite.

4. *The fragmented saprolite or fragmented bauxite,* 4 meter thick, is formed by bauxite blocks (samples 8b, 13b and 14b) with 40 to 80 cm of diameter, enveloped by a fine matrix (samples 8a, 13a and 14a). The blocks present a friable nucleus with hard borders and the structures are preserved. The bulk density varies from 1,49 to 1,90, the real density is

Table IX.2 - Major elements (wt%) and rare earth elements (ppm) of the samples from PQA profile. The gains ($\tau>0$) and the losses ($\tau<0$) based on the Zr constant in relation to the syenite.

	nodular crust				blocky saprolite						massive saprolite	friable saprolite	syenite
Sample	2b	2a	5b	5a	8b	8a	13b	13a	14b	14a	16 b	17b	17c
SiO_2	1.78	1.76	1.67	3.02	1.96	4.76	1.12	1.78	0.51	0.53	0.52	0.64	54.20
Al_2O_3	59.86	59.00	57.50	56.10	59.13	55.65	60.00	57.00	59.00	58.20	59.00	58.00	21.00
Fe_2O_3	4.80	5.90	5.60	8.22	5.59	6.69	5.67	7.51	8.14	7.84	7.60	5.85	2.06
MgO	0	0	0	0	0	0	0	0	0	0	0	0	0
CaO	0.03	0.05	0.35	0.14	0.06	0.01	0.37	0.21	0.17	0.09	0.04	0.01	1.61
Na_2O	0	0	0	0	0	0	0	0	0	0	0	0	7.30
K_2O	0.18	0.20	0.14	0.36	0.39	0.73	0.16	0.31	0	0	0.22	0.05	7.90
TiO_2	0.83	1.18	1.07	1.49	1.21	1.29	0.97	1.66	1.30	1.87	2.09	1.37	0.62
MnO	0.19	0.24	0.20	0.30	0.10	0.20	0.13	0.22	0.22	0.20	0.22	2.79	0.13
H_2O	31.50	31.42	31.40	29.25	31.20	29.12	31.65	30.61	31.05	30.57	31.02	30.88	1.87
Total	99.17	99.75	97.93	98.88	99.64	98.45	100.07	99.30	100.39	99.30	100.71	99.59	97.03
La	125.57	113.32	105.68	88.28	96.46	75.29	121.27	104.41	78.63	60.22	52.96	68.40	176.23
Ce	1033.32	1152.84	1051.00	1127.68	870.9	1146.59	843.12	1114	694.32	2048.21	461.90	310.92	368.30
Nd	50.71	65.60	63.58	46.25	43.83	33.62	55.03	43.28	41.06	35.72	23.96	37.08	134.03
Sm	6.90	9.61	9.21	6.65	6.11	4.90	7.82	6.07	5.96	5.14	3.45	5.36	18.51
Eu	0.94	1.23	1.19	1.02	0.87	0.77	0.95	0.91	0.78	1.02	0.58	0.64	1.77
Gd	6.93	9.93	9.71	7.20	5.22	5.22	6.31	6.31	6.04	6.04	3.73	5.25	16.48
Dy	5.82	8.78	8.90	6.89	5.53	4.87	6.33	5.65	5.89	6.5	3.57	4.18	10.35
Er	3.60	5.97	5.79	4.69	3.83	3.26	4.52	3.79	3.98	3.73	2.66	3.55	5.40
Yb	4.41	8.01	7.13	5.71	4.75	3.85	5.42	4.73	4.50	4.22	3.54	4.23	4.27
Lu	0.84	1.34	1.19	1.02	0.86	0.66	0.99	0.83	0.79	0.74	0.60	0.77	0.72
ΣREE	1239.04	1376.63	1263.38	1295.39	1038.36	1279.03	1051.76	1289.98	841.95	2171.54	556.95	440.38	736.06
τSi	-0.99	-0.99	-0.99	-0.98	-0.99	-0.97	-0.99	-0.99	-1.00	-1.00	-1.00	-1.00	0
τAl	-0.06	-0.31	-0.18	-0.27	-0.21	-0.19	-0.29	-0.11	-0.18	-0.07	-0.24	-0.28	0
τFe	-0.23	-0.30	-0.19	0.09	-0.24	-0.01	-0.32	0.19	0.16	0.27	0.00	-0.26	0
τTi	-0.56	-0.54	-0.48	-0.34	-0.45	-0.36	-0.61	-0.12	-0.38	0.04	-0.09	-0.42	0
τLa	-0.77	-0.84	-0.82	-0.86	-0.85	-0.87	-0.83	-0.81	-0.87	-0.89	-0.92	-0.90	0
τCe	-0.08	-0.24	-0.15	-0.16	-0.34	-0.05	-0.44	-0.02	-0.45	0.85	-0.66	-0.78	0
τNd	-0.88	-0.88	-0.86	-0.91	-0.91	-0.92	-0.90	-0.89	-0.91	-0.91	-0.95	-0.93	0
τSm	-0.88	-0.87	-0.85	-0.90	-0.91	-0.92	-0.90	-0.89	-0.91	-0.91	-0.95	-0.92	0
τEu	-0.83	-0.83	-0.80	-0.84	-0.86	-0.87	-0.87	-0.83	-0.87	-0.81	-0.91	-0.91	0
τGd	-0.86	-0.85	-0.82	-0.88	-0.89	-0.90	-0.88	-0.88	-0.89	-0.88	-0.94	-0.92	0
τDy	-0.82	-0.79	-0.74	-0.82	-0.85	-0.86	-0.85	-0.82	-0.83	-0.79	-0.91	-0.90	0
τEr	-0.78	-0.73	-0.68	-0.76	-0.80	-0.82	-0.79	-0.77	-0.78	-0.77	-0.87	-0.83	0
τYb	-0.66	-0.54	-0.50	-0.64	-0.69	-0.72	-0.69	-0.64	-0.69	-0.67	-0.78	-0.74	0
τLu	-0.62	-0.55	-0.51	-0.61	-0.67	-0.72	-0.66	-0.62	-0.68	-0.66	-0.78	-0.72	0
τZr	0	0	0	0	0	0	0	0	0	0	0	0	0

around 2,55 and the porosity decreases from 42% to 25% (Table IX.1). The porosity decrease corresponds to the formation of gibbsitic and/or goethitic cutans in the dissolution voids. The mineralogical constituents are gibbsite (90%), hematite (6%), goethite (1%), kaolinite (2%) and anatase (1%). The matrix is light red to rose, with argillomorphic textures with small bauxite grains. The bulk density goes up to 2 and the porosity is 20%. This matrix is constituted of gibbsite (86%, kaolinite (6%), goethite (6%) and anatase (2%).

5. *The nodular crust or nodular* ***bauxite***, 1 to 2 m thick, forms the surface horizon. It is constituted of bauxite blocks with 10 to 15 cm diameter, enveloped in a humic matrix with gray color in the surface and brown yellow in depth. Blocks and matrix are formed mainly by gibbsite (90%). But the initial gibbsite, pseudomorphic on primary minerals, is partially replaced by a second generation gibbsite that mask the inherited textures. The lower part of this surface horizon is marked in the presence of sub-horizontal small veins rich in magnesium (lithiophorite). These veins,

together with the decreases of bauxite blocks size, mark a clear structural discontinuity between this crust and the underlying fragmented bauxite.

On the slope of this hill (Fig. IX.3), the bauxitic facies are similar to those described in the higher shaft (PQA). Nevertheless, under the massive bauxite, the contact with the fresh rock is not direct, but through a clay horizon having fragments of bauxite with preserved structure. The clay matrix is constituted essentially by kaolinite (>70%). The bauxite fragments (30% of the material) present variable sizes from centimeters to some decimeters. On the larger fragments one can observe, from the exterior towards the center, all the terms of the gradation from the pure kaolinite, with no preserved structure, to a bauxite with granular and preserved texture, like the one observed in the higher shafts. The observation with the SEM and the analysis with the electronic microprobe showed that the internal gibbsite of the blocks is submitted to a resilication process (Sigolo, 1988).

III. The Geochemical Variations

The main geochemical changes occur during the transformation of the nepheline syenite into friable saprolite. It is noteworthy the extreme thinness (2 to 3 mm) of this transformation zone. All the parent minerals are altered during this step. The alkaline and earth alkaline elements are totally leached. The aluminum, iron and titanium are partially leached and the rest precipitates in situ, forming mainly gibbsite associated with a small amount of goethite, hematite and anatase.

Globally the chemical composition keeps constant toward the top of the profile. The volume reduction varies from 50 to 70%, with higher values for the matrix as compared to the bauxite blocks. On the other hand, the transformation of massive saprolite into fragmentary saprolite is followed by a slight iron increase (Fe between 16 and 27%) and a relatively low aluminum loss (Al between 7 and 18%). This differentiation occurs together with the deposition of gibbsitic and goethitic cutans, that are observed at this level in the minerals dissolution voids, and underlines an absolute accumulation of these elements (Boulangé et al., 1975; Bocquier et al., 1985). The structural discontinuity observed at a microscopic scale, between the fragmentary saprolite and the nodular crust is expressed chemically as well as mineralogically.

The alteration conditions, leading to the direct bauxitization of a parent rock, gives origin to a fractionation and an important leaching of the REE, that is lower for Ce and HREE (Fig. IX.4)(Sigolo et al., 1987). In the parent rock, the REE are mainly concentrated in the apatite and sphene. Cerium and HREE are also present in the zircon (Gromet & Silver, 1983). As for the transition from the friable saprolite into the massive saprolite, one observes that the REE leaching, as compared to the major elements, shows a slight delay, which is manifested by an increase of all REE losses. This delay is associated with the differential alteration of the parent minerals. As a matter of fact, the apatite is altered at the same time as the nepheline and feldspar, while for the sphene, more resistant, the alteration goes up to the massive saprolite. The cerium has a peculiar behavior. One observes (Fig. IX. 4B), from the friable saprolite to the massive saprolite, a strong positive Ce anomaly. Cerium can precipitate as Ce^{3+} and form locally florencite $(La,Ce)Al_3(PO_4)_2(OH)_6$ (Sigolo, 1988).

However, this Ce anomaly is not only due to its liberation from the alteration of apatite and sphene, but also to the stability of the zircons. As a matter of fact, the zircons, with size lower than 50 μm, are frequently associated with the sphene in the parent rock and liberated during the alteration. The zircons preserve their euhedral shape and present no traces of alteration. The REE distribution in the zircon shows a strong HREE concentration, and a positive Ce anomaly (Murali et al., 1983;

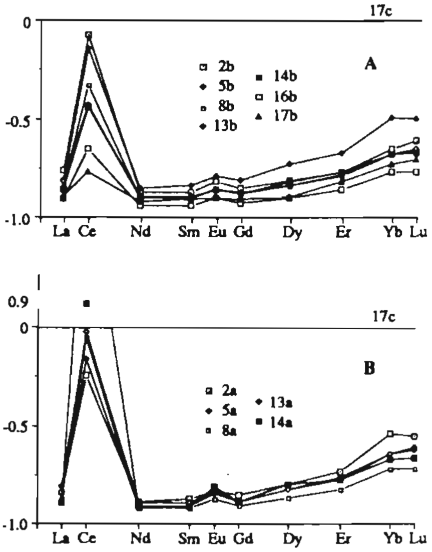

Figure IX.4 - REE net mass transport fonction patterns (τ). A is related to bauxite fragments, B is related to matrices.

Hinton & Upton, 1991). The ratio (Ce/ HREE)ch ,relatively constant (around 8) in the bauxite fragments (16b to 8b), show clearly that the positive Ce anomaly is partially associated with the zircon stability and its concentration in the saprolite. On the other hand, the strong variation of this ratio (10 to 24) in the matrix (14a to 8a) shows a mobilization of Ce in the circulation zone. The utilization of iso-zirconium reasoning allows to make evident an intensive leaching of all REE and a relation between Ce and residual HREE in the zircons (Boulangé & Colin, 1994).

As considering the low REE content, the results for fragmentary and nodular bauxites has to be taken carefully and only the global variation has some signification. The values obtained for $(\tau_{j,w})$ (Table IX.2) are always lower in this upper facies. It means that the mass balance, as referred to the underlying saprolite, shows a gain in REE. In the nodular crust in the surface, only Ce is leached (-79 g/m^3 as referred to the massive saprolite). Consequently, as except for CE, it seems that no particular chemical variation marks the existing discontinuity between the two upper facies.

IV. Genesis of the Bauxitic Profile

This summit profile results from a direct bauxitization (Millot, 1964; Boulangé & Millot, 1988) of the nepheline syenite. The alteration is rather intensive and the individualization of aluminum and iron oxihydroxides as gibbsite and goethite, occurs even in the contact of the parent minerals. All the petrologic and geochemical characteristics confirm the direct evolution from the parent rock. The large amount of dissolved elements gives origin to an important porosity. This porosity represents about 70% of the feldspars volume and 40% of the nephelines volume. Considering the dominance of these minerals in the parent syenite, it is observed that, despite the structure being preserved, a volume reduction of approximately 50% occurs. Under the microscopy, considering a bidimensional scale, this reduction is about 20%, which is not easily observed.

Apart of some small variation between the bauxite fragments and the matrix, the chemical composition keeps rather constant within the profile. Nevertheless, a discontinuity under the upper horizon of nodular crust is observed. However, the mass balance shows that there is no particular variation of the elements and that the nodular crust is originated from the same parent rock as the underlying facies. Consequently, the discontinuity, only structural, could be considered as a limit between an ancient alteration profile and the recent one, represented by the saprolite underlying facies. Thus, the geologic history of this profile would involve two bauxitization period, which duration is not possible to stablish.

In the slopes, the presence of a kaolinitic horizon with residual bauxite balls would be an evidence of the succession of the two episodes. The first episode would be an intense bauxitization and the second one a partial resilication. This resilication could correspond to an accumulation of silica coming from the alteration of the summit profile, during the second bauxitization period.

V. The Piedmont Bauxites

The piedmont bauxites are slope colluvial accumulations. They are constituted of numerous blocks of syenite and bauxite embedded in a clay matrix. They are observed in all the surrounding of the alkaline massifs of Passa Quatro and Itatiaia and it is particularly abundant in the regions of Lavrinhas and Queluz, in the southern part of Passa Quatro (Pinto, 1937; Ribeiro Filho, 1967; Penalva, 1967). These deposits extend from 500 m up to 1,330 m altitudes on large accumulation surfaces (glacis), developed on the basement gneiss (Fig. IX.5) (Sigolo, 1988). These bauxite ores (5.5 million tons) are destined to direct commercialization or treated in place for corindon production (calcination) or aluminum sulfate production.

1. Characteristic of the colluvium deposits

A geomorphological study of the piedmont zone, has shown the presence of three great units named upper surface, middle surface and lower surface (Fig. IX.6). The pediment colluvium deposits are constituted of boulders and blocks of bauxite and alkaline rocks embedded in a clay matrix overlying weathered rocks of the Pre-Cambrian basement. The deposits of each surface present different characteristic.

The upper surface is the most important of Lavrinhas and Queluz sector and its extension can reach 8 km. It presents an altitude of 1,300 m, in the contact of the alkaline massif and the basement gneisses, and 800 m, in its lower part, towards Paraíba do Sul river, forming a 10 to 15° slope. The colluvial deposit , according to the metamorphic basement undulations, can reach 20 m of thickness. The studied profile (Jazida da Sede), with a thickness of 12 m (Fig. IX.6), is constituted, from the top to the bottom, of i) a soil developed on ii) a colluvial deposit, having in its

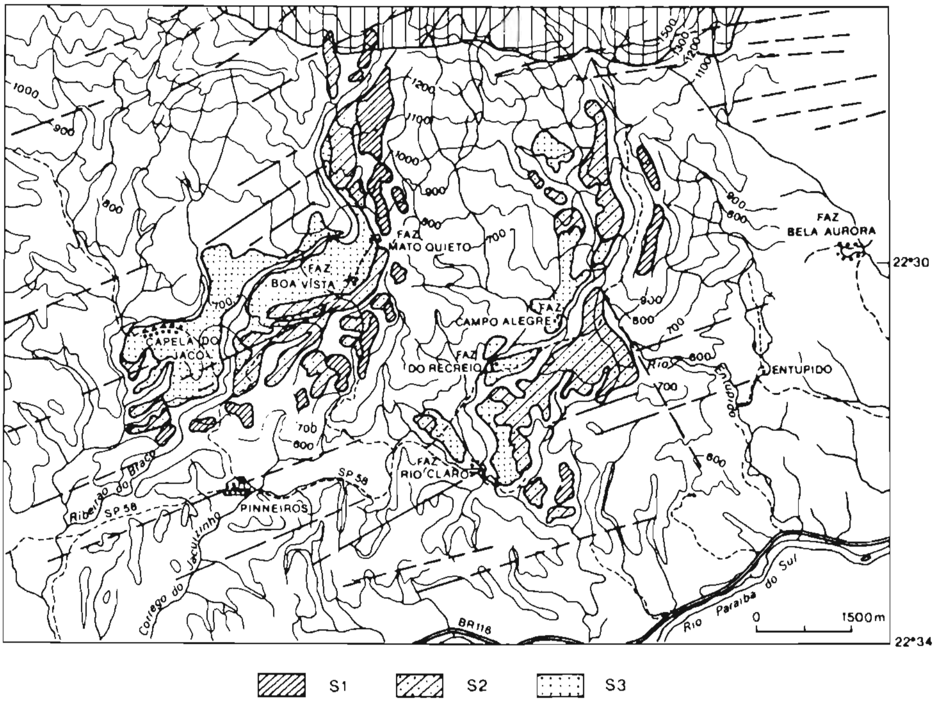

Figure IX.5 - Geomorphological and structural map of the south piedmont of the Passa Quatro alkaline massif (Lavrinhas and Queluz areas).

base iii) a transitional zone in the contact with the basement metamorphic rocks.

The soil or upper barren layer, developed from the colluvial deposits, has a thickness of 2 to 3 m. It is formed of two horizons:

- the upper horizon (1 m), under a thin humic layer, is constituted of gibbsitic nodules, with 2 to 5 cm of diameter, embedded in a matrix formed by kaolinite and quartz. The nodules, normally rounded and sometimes as a tube, are formed by a cryptocrystalline gibbsite and contain always an important amount of silica (20 %),

- the lower horizon with yellow colour is a clay quartzous material, constituted mainly of kaolinite, quartz and gibbsite, concentrated in small whit tubes surrounding roots.

The colluvial middle layer with a thickness of 6 to 7 m, the deposit of economic interest, is constituted of:

- blocks of various rock types (nepheline syenite, microsyenite, hornblende syenite), that can attain 10 m diameter and having or not an alteration cortex;

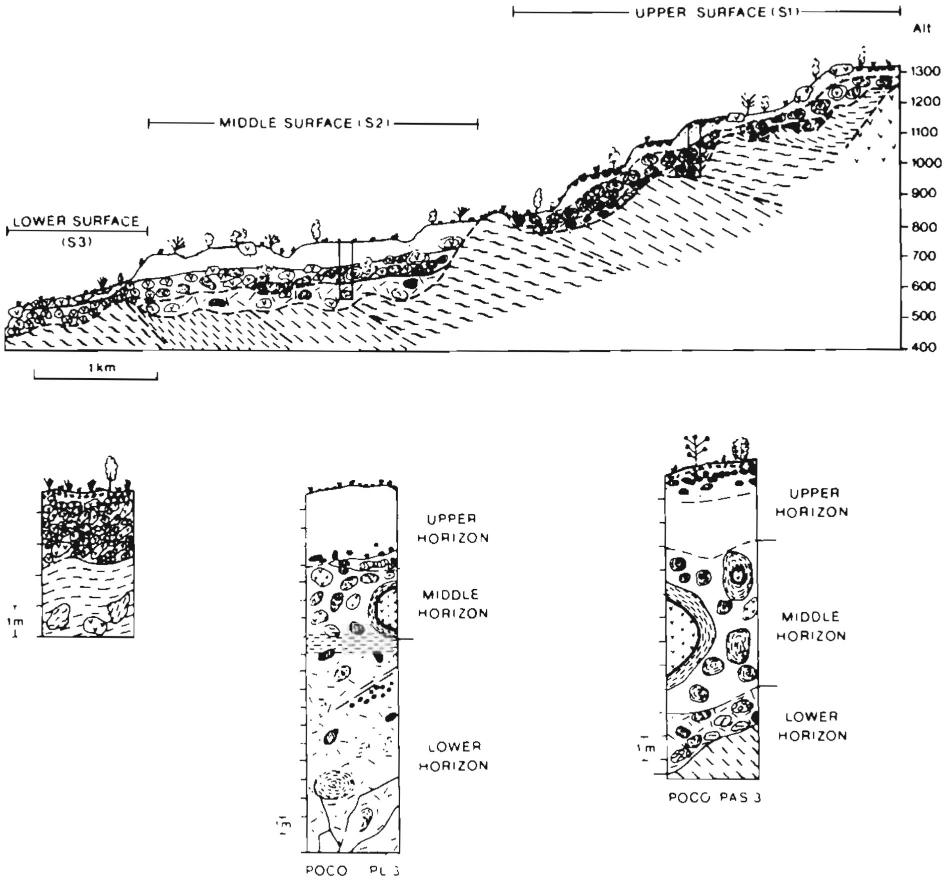

Figure IX.6 - Sketch of the piedmont formation.

- bauxite balls, of decimetric to metric size, with texture and composition close similar to the summit bauxite. These bauxite balls, that could present a rocky core, are affected particularly in its base by a resilication process and its transformation into the kaolinitic matrix is gradual.
- the matrix, of yellow colour, is constituted of kaolinite, gibbsite and quartz.

The lower layer (1 to 2 m), preferentially located in the lower zones of the substratum paleotopography, contains numerous fragments of basement metamorphic rocks (gneiss, quartzites). Certain gneiss fragments are totally altered, some of them into kaolinite and others into gibbsite. The matrix is kaolinitic.

The middle surface extends alongside the recent valleys, down the upper surface. Its altitude ranges from 700 to 800 m, with a gentle slope (lower than 10°). The described profile (Jazida da Sede) presents a thickness of 20 m. The colluvial material of the middle surface presents the same vertical distribution, but the characteristics of each horizon are slightly different as compared with the upper surface horizons.

The soil, with a thickness of 3 to 4 m, is homogeneous and presents only one clay-quartzous horizon. It shows yellow colour, and is overlaid by a very thin humiferous horizon, associated with the herbaceous vegetation presence. Gibbsitic tubular nodules related to a superficial pedogenesis are observed at its base.

The middle layer, with a thickness of about 4m, which also forms the ore deposit presents a lower amount of bauxite boulders, a greater quantity of fresh rock boulders of smaller size. In this case, all the steps of the transition from the bauxite boulders into kaolinite matrix can be observed.

The lower layer can attain here a thickness greater than 10 m. The bauxite blocks are less abundant and sometimes totally resilicated. The fragments of metamorphic rocks, specially those of quartzite, are little abundant. Fissures, coated with manganese appear in the lower part of the profile.

The lower surface presents a small extension with regard to the previous one. It is developed at the foot of the middle surface, some 50 m lower, between 520 and 700 m of altitude, to which is connected through a concave slope. It is in this surface that the last geomorphologic feature, constituted by the present cutting, is impressed

The colluvial material of this surface, with thickness of 4 to 5 m, is constituted of blocks, boulders and pebbles of alkaline rocks and some rare pebbles of bauxite embedded in a little abundant clayey sand matrix. The boulders and pebbles have an average size smaller than those of the upper and middle surface. The recent stream beds have cut in the material of this surface, leaving behind only a pavement of blocks, boulders and pebbles of alkaline rocks.

2. *The evolution of the colluvium deposits*

This piedmont colluvial deposits were submitted, after their placement, to an evolution associated with the new morphoclimatic conditions of the ore deposit.

The upper horizon of sandy clay texture results from a pedogenetic evolution of the upper fine-grained part of the colluvium, locally at the surface. Some gibbsitic nodules indicate an alumina remobilization by roots activity.

In the middle layer, the boulders of alkaline rocks often present a gibbsitic weathering rind, at their upper part. They present as well a kaolinitic fringe, at their base, resulting from a recent differential weathering process, associated with the drainage conditions at the boulder's contact. The bauxitic boulders present resilication features, linked to the present evolution within the profile.

In the lower part of the colluvial material, it occurs bauxite boulders originated from the alteration of syenite or the basement gneiss. This could be an evidence that, before the pediments formation, rocks of the alkaline massif and the Pre-Cambrian basement were submitted to the same bauxitization process. Most of the rock fragments are altered into kaolinite and the bauxite boulders themselves were completely or partially resilicated and now appear in continuity with the kaolinitic matrix.

Thus, the evolution of the piedmont bauxitic colluvium seems to have been toward the kaolinization, either by weathering of the alkaline rock fragments or by resilication of bauxite fragments. In any case, except locally in the cortex of the syenite blocks at the upper part of the profiles, the transformations indicate a post-deposition "in situ" bauxitization.

VI. Relation between the summital bauxite and the piedmont bauxite

In this area of Passa Quatro massif, two types of bauxite occur. The first one, on the summit, results from an in situ bauxitization of the syenite. The second one is formed of boulders and blocks, with the same structure and the same mineralogical and geochemical compositions that the summital saprolitic bauxite. They are embedded in a kaolinitic matrix, deposited on the basement, at the foot of the alkaline massif. A genetic relation between them seems to be obvious.

There are many arguments showing that the bauxitization has occurred on the syenite before the deposition of the colluvium. As a matter of fact, in this colluvium material one can observe: a mixture of blocks and boulders of fresh alkaline rock and of bauxite; the presence in the lower horizon of bauxite boulders formed from the weathering of gneisses; the resilication of the bauxite boulders in the middle and lower layer of the profiles in this pediment.

These piedmont bauxites were associated with an eventual glaciation of Pleistocene age (de Martone, 1940; Rich, 1953; Odman, 1955). In fact, these deposits could be associated with an important *solifluxion* phenomena (mud-flow or mud stream) of weathered material, coming from the higher zones of the alkaline massif. The phenomena would be caused by the rupture of the equilibrium during the Paraíba rifting (Ebert, 1960; Sigolo, 1988).

It is difficult to accept that the three surfaces were developed at the same time. The topographic situation of the middle and lower surfaces, as compared to the upper surface, seems to indicate that they result from an evolution and redistribution of colluvial materials of the upper surface. A tectonic event, following the formation of the upper surface, is probably responsible for the differentiation of the middle surface. The convex slopes linking these two surfaces would indicate a slow movement during a humid period. The down thrown zones of the middle surface are submitted to a more intense hydromorphy as compared to the deposits of the up thrown surface. This leads to a weathering of the syenite boulders into kaolinite and resilication of the bauxite boulders.

The lateral extension of the colluvial upper surface was certainly more important than it is today and it should be covered the areas where the middle and low surfaces are now observed. Indeed, considering the gentle slopes, mechanical erosion is the only explanation for the presence of very big syenitic boulders within the deposits of the low surface and as far as in the stream beds. This erosion would draw out the fine grained material cleaning the colluvial deposits of the upper and middle surfaces. Thus, locally these fill-in fill pediments were superimposed one into the other.

Considering the age of the alkaline rocks (70 My), the bauxitization would affect simultaneously those rocks and the metamorphic basement rocks during the early Cretaceous and Eocene. The Paraíba rifting could have started at the end of this period, during the Oligocene (Almeida, 1976; Melfi et al., 1976), related to the age of the sediments of Resende and Taubaté basins (Amador, 1975; Lima & Amador, 1983; Melo et al., 1985a and 1985b). This would be also the period of formation of the upper surface. After the cold and dry period of the Oligocene, a new bauxitization period has taken place on the massif. This period would be responsible for the formation of the bauxite profile in the summits and also for the in situ pediment deposits evolution: weathering rind of the rock boulders, resilication of bauxite boulders, alumina remobilization. From the Pliocene up to now, the reworking of the pediment deposits by the rivers was responsible for the shaping of the low surface and its recent incision.

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that the lateritization processes have extended to other rocks such as the diabases and basalts of the Parana Basin.

The Lages bauxite shows many evidences of being an occurrence disconnected with present environmental conditions and it is considered to be a paleoalterite. The presence of clay material surrounding blocks of bauxite identify late processes which might represent an equilibrium with the present environment which is favourable to siallitization processes (Pedro & Melfi, 1982).

Other aspect that dissociate this occurrence from the present time is the relation that was found between the alterite and the local relief preservation conditions.

I. Climate

In Lages, all seasons are well defined and the average temperature tends to be low, around 15°C being usual frost during the winter and, at least, there is snow precipitation three days a year. In general, two principal factors are responsible for the present climate of Lages: geographical position (latitude around 30°S) and altitude (average 900 m). Rainfall is evenly distributed during the year with values higher than 100 mm per month. There is no period of drought, which is common in the Brazilian climate. Thus, the climate is temperate and highly humid. Lages is geographically situated on the limit of the favourable zone (Lelong et al., 1976; Bardossy, 1982) for bauxite formation. At present time, factors like geographical position, climate conditions and field evidences make the processes of podzolization more favourable than lateritization.

II. Regional Aspects

The Lages Region is situated in the eastern border of the intracratonic Paraná Basin which is filled up mainly with detrital sediments and consists of rocks from the Upper Paleozoic to Mesozoic ages. In the geological evolution of the Paraná Basin, the final event consists of extensive basaltic lava flows of Serra Geral Formation with radiometric age of 130 to 135 Ma. (Cordani & Vandoros, 1967). In Lages, the post-basalt alkaline rocks, intrusive in the sedimentary rocks of the Paraná Basin, display a circular structure showed today by differential erosion. The older sedimentary rock extend over the central part of the circular