PALEOSURFACES AND BAUXITE PROFILES IN THE POÇOS DE CALDAS PLATEAU, SÃO PAULO / MINAS GERAIS, BRAZIL

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ABSTRACT – This work has the objective of correlating altitude with the bauxite profiles in the Poços de Caldas Plateau in order to identify paleosurfaces. Then, bauxite profiles found in the Plateau have been classified and mapped through DEM. Three different types of bauxite profiles are highlighted in the area: (1) Rim Profiles which are well-developed and thick and are located in the areas of highest altitude in the Plateau; (2) Plateau Profiles which are not very thick and very clayey, normally appear in the lower portion of the landscape; (3) Reworked Profiles, characterized by bauxite reworked fragments composed by similar materials found in the tops of Rim and Plateau Profiles. After relating altitude to the constituting materials of the bauxite profiles, it is noticed that there are occurrences of Rim Bauxite Profiles located in altitudes of Plateau Profiles and Reworked Profiles located over Rim Profiles, above 1,400 meters of altitude. In the opposite direction, tops of the same elevation are found, where there should be Rim Profiles, there are rocky outcrops observed in field, without any evidence of laterite profiles. It is concluded, therefore, that the elevation rates by themselves, at least in this area, are not good enough references to determine the existence and distribution of paleosurfaces.
Keywords: Paleosurface, Bauxite Profiles, Poços de Caldas, São Paulo, Minas Gerais, Brazil.

RESUMO – *F.A. Leonardi, F.S.B. Ladeira, M. dos Santos - Paleosuperfícies e Perfis Bauxíticos no Planalto de Poços de Caldas, São Paulo/Minas Gerais, Brasil*. Este trabalho tem como objetivo correlacionar altimetria com os perfis bauxíticos no Planalto de Poços de Caldas para identificar paleosuperfícies. Para tanto, classificaram-se e mapearam-se os perfis bauxíticos encontrados no Planalto sobre o MDE. Destacam-se na área três diferentes tipos de perfis bauxíticos: (1) os Perfis de Serra que são perfis bem evoluídos e espessos e estão localizados nas áreas de maiores altitudes do Planalto; (2) os Perfis de Campo que são pouco espessos e muito argilosos, normalmente aparecem nas porções mais baixas da paisagem; (3) os Perfis Retrabalhados caracterizados por fragmentos retrabalhados de bauxita compostos por materiais semelhantes aos encontrados nos topos dos Perfis de Serra e no de Campo. Depois de relacionados altimetria e os materiais constituintes dos perfis bauxíticos notam-se que há ocorrências de Perfis Bauxíticos de Serra posicionados em altimetrias de Perfis de Campo e Perfis retrabalhados posicionados sobre Perfis de Serra, acima dos 1.400 metros de altitude. No sentido oposto encontram-se topos de mesma altimetria, onde se acharia Perfis de Serra e o observado em campo são afloramentos rochosos, sem qualquer evidência de perfis lateríticos. Conclui-se, portanto, que as cotas altimétricas, ao menos nesta área, não são, por si só, bons referenciais para determinar paleosuperfícies.
Palavras-chave: Paleosuperfície, Perfis Bauxíticos, Poços de Caldas, São Paulo, Minas Gerais, Brasil.

INTRODUCTION

The main objective of this work is to correlate altitude with the distribution of bauxite profiles mapped in the area of the Poços de Caldas Plateau in order to identify possible paleosurfaces. The bauxite profiles usually work as stratigraphical markers, because they allow this correlation as show by Ladeira and Santos (2006).

To achieve this main objective, the laterite-bauxite profiles in the Poços de Caldas Plateau have been mapped and described. In total, 99 points were observed and in 44 of them bauxite profiles were found.

After mapping and describing the bauxite profiles, with the aid and support of the bibliography, they have been classified in: (1) Rim Bauxite Profile, (2) Plateau

Bauxite Profile, and (3) Reworked Bauxite Profile.

To obtain the topography of the Poços de Caldas Plateau, a Digital Elevation Model (DEM) has been created through a SRTM radar image.

For a complete analysis, and with the same objective of locating the paleosurfaces, a graphic highlighting the amount of points of Reworked, Plateau and Rim Bauxite Profiles of each 100 meters of altitude has been made, showing the distinct levels in which these profiles stand. Finally, the altitude has been correlated with the bauxite profiles distribution.

EROSION SURFACES IN BRAZIL

The first studies about erosion surfaces in Brazil come from the *Davisian* model, in which summit accordance or similar elevation tops are used to define erosion levels.

De Martonne´s work (1943) was one of the first to be highlighted. In his work about the Atlantic Tropical Brazilian morphological problems, the author distinguishes three erosion surfaces, being four with the Pre-Permian Surface (Figure 1), this one located under Paleozoic sediments of the Paraná basin. The first is the Neogenic Surface – in Pouso Alegre region; the second, Cristas Médias Surface, of a Tertiary age; the third, Campos Surface, in Campos do Jordão, Campos de Paraíso and Campos de Ribeirão Fundo.

> "The most recent, whose Neogenic age is well determined, has its bigger development in the Parnaíba basin and Alto Tietê, where it has been slightly upwarped ("gauche") and moreover notably reduced by the erosion that has made the ocean reach the base of the tectonic slope of Serra do Mar. The level of the wavy hills that cut the pre-Permian surface can be related to it, to the west and north, and it does not seem to have suffered noticeable perturbations. The Appalachian crests that dominate it are witnesses of an older surface that seems to be in accordance to the Botucatu cuesta; this would be due to a Paleogene erosion cycle. When cutting the ideal extension of the pre-Permian surface, it seems to have suffered a total uplifting to the southeast and dislocations oriented to SO-NE or E-O. It is impossible not to distinguish it from the high surface of the fields, violently fractured in Mantiqueira, certainly older, but whose age is still doubtful" (De Martonne, 1943).

> "A mais recente, cuja idade neogênica é bem determinada, tem o seu maior desenvolvimento na bacia do Parnaíba e no Alto Tietê, onde ela foi ligeiramente empenada ("gauche") e sobretudo notavelmente reduzida pelo desabamento que fez chegar o oceano ao pé do degrau tectônico da Serra do Mar. A ela pode-se ligar, a oeste e ao norte, o nível das colinas onduladas que recorta a superfície pré-permiana, e não parece ter sofrido perturbações notáveis. As cristas apalachianas que a dominam são as testemunhas de uma superfície mais antiga, que parece poder concordar-se com a cuesta de Botucatu e seria devida a um ciclo de erosão paleogênica. Recortando o prolongamento ideal da superfície pré-permiana, ela parece ter sofrido um levantamento geral para o sudeste e deslocações orientadas para SO-NE ou E-O. É impossível não distingui-la da alta superfície de campos, violentamente fraturada na Mantiqueira, certamente mais antiga, cuja idade é ainda duvidosa" (De Martonne, 1943).

FIGURE 1. Relation among the different surfaces. Ideal cut W-E (Serra da Mantiqueira to Cuesta de Botucatu). P – Pre-Permian surface; C – Campos Surface; E - Cristas Médias Surface (Eocenic); N – Neogenic Surface. Adapted from De Martonne (1943).

In terms of the paleogeography of the Brazilian Shield old planation surfaces, following Ab´Sáber (1955), it is easy to recognize that the great Serra do Mar faults started right after the formation and the uplift of the Cristas Médias Surface, dividing the whole erosion surface produced in that time, as well as part of the other one, older and more uplifted, corresponding to the Campos Surface, whose well-conserved remains survive in the Mantiqueira and Bocaina ranges.

Freitas (1951) emphasized on the existence of three erosion cycles. The oldest one was during the Mesozoic period, when it would have been preceded by epirogenic uplift; it would have to finished in the Cretaceous, thus resulting in the Cretaceous peneplain, *level B* (level of peneplain crests, between 1,200 and 1,400 meters of altitude; for instance, the Serra do Japí in São Paulo). After a new positive epirogenic movement, resulting in the fragmentation of the Brazilian Shield (Escudo Brasileiro), the main tectonic accidents of the relief in the country would have started in the Tertiary period. Thus, the Tertiary peneplain has been developed, corresponding to *level A*, which the third cycle follows, in other words, the Q*uaternary cycle* or *post-deposition cycle* of the São Paulo and Curitiba layers (Ponçano and Almeida, 1993).

Freitas also pointed out that the two highest levels of the old planation surfaces in Brazil correspond to the last Gondwana peneplains, which were developed in the main outcropping parts of the Brazilian Shield during the Mesozoic. At the same time, the regional continental masses extended a lot to the East, but in a lower tectonic level (Ab'Saber, 1955).

King (1956) identified Erosion Surfaces in Brazil in the following order: Fossil Surface (Carboniferous Period); Desert Surface (Triassic); Post-Gondwana Surface or Gondwana Surface (Cretaceous); South American Planation (Paleocene-Eocene) followed by an uplift (Oligocene); Velhas Cycle (Miocene-Pliocene) and Paraguaçu Cycle (Pleistocene-Holocene).

In the explanation of these Erosion Surfaces, King (1956) emphasized that:

> [...] the fundamental element of the Brazilian scenery was a vast plain produced by the denudation, between the early Cretaceous and the middle Tertiary, when it was uplifted and after being reduced to a plateau dissected by polyciclic erosion (polyciclic stream incision) which has digged valleys in almost all the surface, or locally, a set of according summit elevations upon the crests [...]. This vast peneplanation that grades to the deposition surfaces in the Andean mountain range and underneath the Argentine pampas is named the South American peneplanation (p. 149). The erosion cycles that have taken place after the South American surface and have acted during the Late Tertiary and Quaternary, after the Middle Tertiary epirogenetic uplifting and the following ones are marked by the carving and openings of valleys that destroyed most part of the plateau produced by the South American cycle and nowadays include almost all the landscape [...] only locally these later cycles have reached an advanced level of planation. The erosion cycle named Velhas that developed immediately after the South American and reached a base level in the Late Tertiary, for instance, it is typically present in the form of valleys that have dissected the plateau produced by the South American cycle [...] (1956).

> [...] o elemento fundamental do cenário brasileiro foi uma vasta planície, produzida pela desnudação, entre o Cretáceo inferior e o Terciário-médio, quando foi soerguida, sendo mais tarde reduzida a um planalto dissecado pela erosão policíclica (polyciclic stream incision) que escavou vales em quase toda superfície, ou, localmente, uma série de elevações de topo coincidente, sobre as cristas [...]. Esta vasta pene-planação, que concorda com superfícies de deposição nos contrafortes andinos e abaixo dos pampas argentinos, é denominada peneplanação Sul-Americana (p.149). Os ciclos de erosão que sucederam ao ciclo Sul-Americano e que atuaram durante o Terciário superior e o Quaternário, após os soerguimentos epirogenéticos do Terciário médio, e posteriores, são marcados pelo entalhamento e abertura de vales que destruíam a maior parte do planalto produzido pelo ciclo Sul-Americano e que ocupam agora quase toda a paisagem [...] só localmente, todavia, esses ciclos posteriores atingiram uma fase avançada de aplainamento. O ciclo de erosão denominado Velhas, que sucedeu imediatamente o Sul-Americano e atingiu um nível de base no Terciário superior, por exemplo, acha-se presente, tipicamente, sob a forma de vales que dissecaram o planalto produzido pelo ciclo Sul-Americano [...] (1956).

Following, the author stated (King, 1956):

> "The Quaternary cyclical erosion is represented in the adjacent coastal area (the Paraguaçu cycle) where sometimes it destroys all the previous topographies. The cycle shows two phases, but it has not reached the generalized planation phase anywhere [...]. It is essentially a cycle of recent valleys that involve the whole continent".

> "A erosão cíclica quaternária acha-se representada na área adjacente à costa (ciclo Paraguaçu), onde algumas vezes destrói todas as topografias anteriores. O ciclo apresenta duas fases, mas em nenhum local atingiu a fase de aplainamento generalizado [...]. Trata-se, essencialmente, de um ciclo de vales recentes que marginam o continente".

According to Almeida (1964), a sharp flattening of the tops between 1050 m and 1300 m of altitude takes place in the Atlantic Plateau. As a witness of this surface, the Serra do Japí occurs (1200-1220 m of altitude), named by De Martonne as the "Cristas Médias Surface". Concerning the age of this surface, it is accepted that it is older than the Pliocene sedimentation in the Paraíba and São Paulo basins. It is agreed with Freitas (1951) that De Martonne´s (1943) Japí Surface and Campos Surface are just one unit. About the evolution of the relief after the Japí event, there is evidence in São Paulo of advanced erosion cycles, earlier than the Japí Planation Surface, which are rather visible in the valleys of some important streams of the Atlantic Plateau, in altitudes between 800 and 1000 m.

Moraes Rêgo (1946), while interpreting the formation process and the morphology of the São Paulo state emphasizes that the shape of the current São Paulo relief is dated from the erosive period which appears as a consequence of the Pliocene uplift. Evidence about the influence of the earlier topographies has been recorded, mainly that one created by the uplift in the end of the Cretaceous period. Therefore, it marks the existence of the Post-Cretaceous planation in Brazil, earlier than the Pliocene, between the Eocene and the Miocene stages, pointing to phenomena of the same kind as observed in other areas of South America.

A review made by Ponçano and Almeida (1993) points the main erosive surfaces in the Crystalline Plateaus of Eastern São Paulo and adjacent lands (Table 1). When performing a correlation among the erosion surfaces, as emphasized by Moraes Rêgo (1946), De Martonne (1943), Freitas (1951), King (1956), Almeida (1964), Ab´Sáber (1955) and based on the review made by Ponçano and Almeida (1993; Table 1), the Japí Surface has been highlighted, an erosion surface which Almeida (1964) claims to be the same one found in the Poços de Caldas Plateau of São Paulo and Minas Gerais.

TABLE 1. Schematic distribution of the main regional erosion phases, following several authors.

	MORAES RÊGO (1932)	DE MARTONNE (1943)	FREITAS (1951)	KING (1956)	ALMEIDA (1964)	BIGARELLA, ANDRADE (1965)	AB'SÁBER (1969, 1972)
Holocene			Quaternary Cycle	Paraguaçu Cycle			
Pleistocene	Uplift					Paleopavements Pediments P2, P1 Pediplain Pd1	Paleopavements
Pliocene	Peneplanation Lowering	↑	Uplift	↑	Several Surfaces along valleys originated by erosion of slopes, without side planation		Several Intermountain Surfaces originated predominantly by pediplanation
Miocene	↑	Neogenic Surface	Tertiary Peneplain at the *level A*	Velhas Cycle ↑		↑	
Oligocene	Uplift	↑		Uplift	↑ Fault	Pediplain Pd2	
Eocene	Peneplanation	Cristas Médias Surface	Uplift and Fault	↑	↑ Japi Surface	↓ ↑	↑
Paleocene		Campos Surface		South American Peneplanation	↓	Pediplain Pd3	Summit Surface
Cretaceous		↓	Cretaceous Peneplain or *level B*. Uplift	Post-gondwana Surface Gondwana Surface			↓
Jurassic							
Triassic				Desert Surface			
Permian							
Carboniferous		Pre-permian Surface		Fossil Surface	Itagua Surface		
Devonian					Itapeva Surface		

Source: Ponçano and Almeida (1993).

Ponçano and Almeida (1993) showed that the Japí Surface (Almeida, 1964) dates back to the Eocene period, and it has possibly extended since the Permian until the Oligocene. It can correspond to the Moraes Rêgo´s (1932) Planation Period, De Martonne´s (1943) Cristas Médias Surface, King´s (1956) Gondwana Surface and Bigarella & Andrade´s (1965) Pd_3 Surface.

THE STUDY AREA

The Poços de Caldas Plateau (Figure 2) is located in the western border of the Serra do Mantiqueira and in contact with the eastern end of the Paraná sedimentary basin. It is located between longitudes 46º and 47º W and latitudes 21º and 22º S. It extends over an area of 800 km^2 and portrays an example of domic structural model with ring dykes (due to circular fissures and the rising of nephelitic magma in the massif periphery). It appears as an individualized area (bounded by an almost perfect ring), forming an effusive and intrusive complex of rocks that represents the biggest alkaline occurrence in Brazil (Christofoletti, 1973).

According to Björneberg (1959), the geological structure in the Poços de Caldas Plateau, mapped and described by Ellert (1959) (Figure 3), corresponds to a round-shaped chimney of alkaline intrusions that measures 33 km in diameter. Surrounding the city of Águas da Prata and in isolated areas inner the plateau, there are sandstones which have been affected by the intrusions.

For Almeida (1964), the relief of the plateau has been evolving from an erosion surface that flattens its summits in altitudes between 1550 to 1600 m. This surface extends to the gneissic region to the northwest of the eruptive area, in São Paulo, flattening Serra do Mirante, Forquilha and Boqueirão, where the elevation decreases westwards. Almeida (1964) believed it to be the Japí Planation Surface, uplifted in the same way as the Campos do Ribeirão Fundo region. The surface has been destroyed in the gneissic rock areas, where the relief is 300 to 400 meters lower. According to the author, the biggest resistance of the eruptive rocks allows the relief to persist in elevation in the high basins of the Antas and Verde rivers.

Following the morphogenetic analysis, altitude and dissection level, Moraes and Jiménez-Rueda (2008) showed a classification of the physiography in the Poços de Caldas Plateau region, dividing them into plateau and alluvial landscapes. When considering the plateau landscapes, the following areas may be highlighted: (a) very low Plateau (800 - 900 m), (b) low Plateau (900 - 1000 m), (c) medium Plateau (1000 - 1200 m), (d) high Plateau (1200 - 1400 m), (e) very high Plateaus and residual surfaces (above 1400 m), as well as escarpments and coalescing fans. About the alluvial landscapes, the occurrence of current flood plains and flood paleoplains can be emphasized.

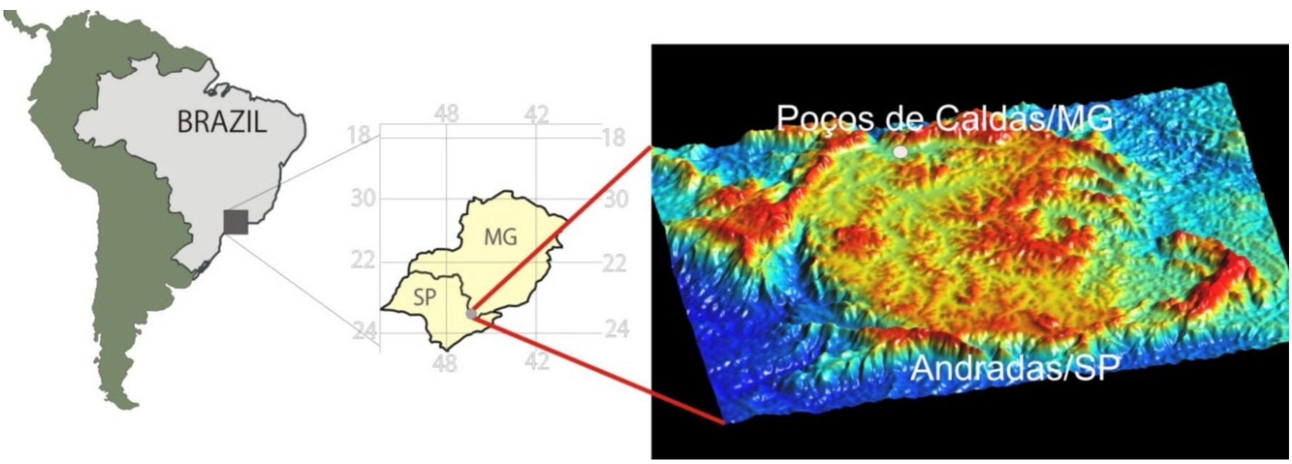


FIGURE 2. Location of the study area.

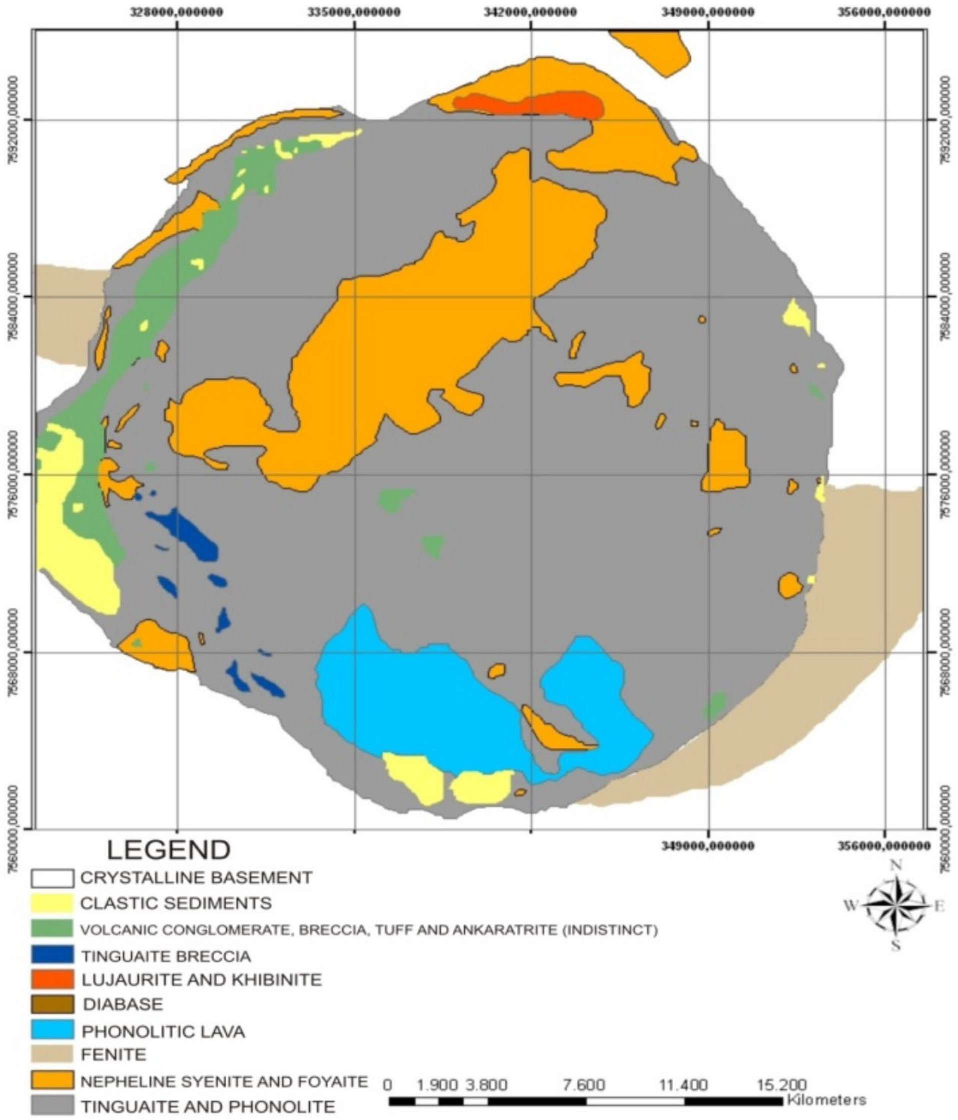


FIGURE 3. Geological Map of the Poços de Caldas Plateau, São Paulo/Minas Gerais, Brazil. Adapted from Ellert (1959).

MATERIAL AND METHODS

Initially, survey and bibliographic analysis about the study area were done in order to make its general characterization and updating of the theoretical/ methodological literature. Then, observations and mappings of the bauxite profiles along the roads and in hilltops have been done and, therefore, 99 points have been observed, and in 44 of them bauxite profiles were found. The description and analysis of the materials had the approach of the *alteration profile* methodology proposed by Retallack (1990), applying descriptive processes including: color, structure, horizon thickness and their contact relations, besides using Manual de Coletas de Solo em Campo (Santos et al., 2005). After the description of the materials, the bauxite profiles were classified in: Rim, Plateau and Reworked Bauxite Profiles.

To obtain the topography of the Poços de Caldas Plateau, a Digital Elevation Model (DEM) was prepared through SRTM radar images. Besides altitude data, DEM/SRTM allowed the mapping of the different compartments and geomorphologic aspects of the area, which have been confirmed during field work. The DEM has been made with the ENVI program (Environment for Visualizing Images) using the technical procedures described in the ENVI Guide, published by Sulsoft (2007).

A graphic has been also created to identify the different levels in the Plateau relief and correlate them with the bauxite profiles, aiming to detect possible paleosurfaces. For its accomplishment, the bauxite profiles have been mapped over the topographic maps of 1:50,000 (Caldas, Poços de Caldas, São João da Boa Vista, Pinhal and Santa Rita de Caldas), obtaining the altitude of each point. The amount of Rim, Plateau and Reworked Bauxite Profile points each 100 meters of altitude has been identified.

Finally, bauxite profiles have been correlated with altitude in the Poços de Caldas Plateau.

RESULTS AND DISCUSSIONS

In the Poços de Caldas Plateau, 99 points have been observed, as shown in Table 2.

From these observed points (Figure 4), 44 points in which bauxite profiles may be found were emphasized in this work. Analyzing these profiles, it has possible to classify them in:

1. Rim Bauxite Profiles: they are well-developed, with high rate of aluminum, rather thick and located in areas of higher altitude in the Plateau. An example of this type of profile is Fazenda Recreio Exploration Mine, with apparent total thickness of over 100 meters (Figures 5 and 6).

TABLE 2. Observed points in the field in the Poços de Caldas Plateau.

Points Observed In The Field		
		Amount
Bauxite Profiles	Rim	22
	Field	10
	Reworked	12
Measure - Faults and/or grooves in parent rock and laterite profiles		37
Points – Control points without evidence of bauxite profiles		18
TOTAL		99

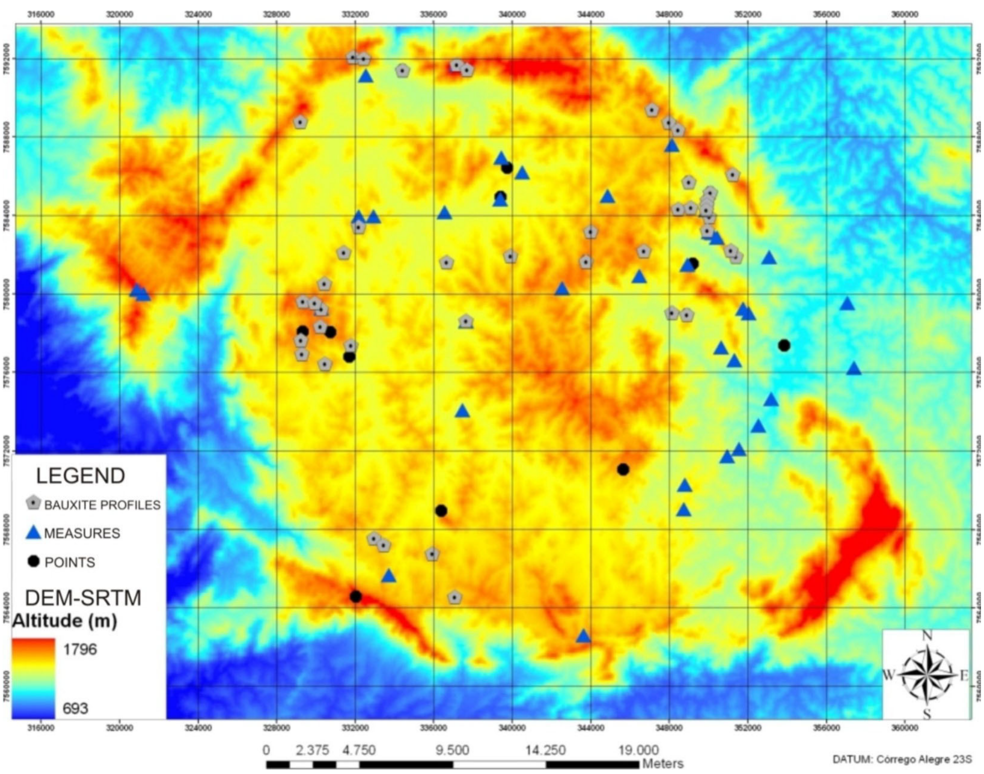


FIGURE 4. Mapping of the observed points in field.

2. Plateau Bauxite Profiles: they are not very thick, very clayey and have lower rate of aluminum than the Rim Profiles, normally appearing in the lower parts of the landscape, although possibly being uplifted (Figure 7).
3. Reworked Bauxite Profiles: characterized by bauxite fragments (gravels). They are similar materials to those ones found in the tops of Rim Profiles and Plateau. These materials, when concentrated, are usually explored, as observed in the base of Morro do Serrote, at the western part of the Plateau (Figure 8).

After mapping the observed points in field, it is clearly noticed the lithological control at the location of these profiles, because they are found inside the boundaries of the Poços de Caldas Alkaline Massif. In the external areas of the Massif the profiles do not appear, not even to the southeast of the area, in Serra da Pedra Branca, the highest elevation of the Plateau (1796 m), where there is no evidence of bauxite profiles.

Most of the bauxite profiles are concentrated in the northern portion of the Plateau. Towards the southern area, these profiles do not appear so frequently, even though the origin of the rock is the same. A hypothesis raised by Almeida (1977) shows that due to hydrothermal activity, which has provided the appearance of some minerals as uranium, it is not possible to create bauxite deposits. For Almeida (1977), among the rocks that occur inside the Massif, Cretaceous sediments, mafic volcanic rocks, and hydrothermally altered rocks do not support bauxite deposit.

FIGURE 5. Fazenda Recreio Exploration Mine Rim Bauxite Profile (Google Earth Image).

FIGURE 6. Picture of Fazenda Recreio Exploration Mine Rim Bauxite Profile.

FIGURE 7. Plateau Bauxite Profile.

FIGURE 8. Reworked Bauxite Profile.

A second hypothesis, following Almeida (1977), is that the bauxite profiles concentrate rather to the north because of the minor incidence of rain at the half southern land in the moment of formation of these profiles (therefore regarded as paleoclimates), while it is known that to form bauxite profiles it is necessary high levels of moisture, besides other factors.

Towards the north, the profiles are in the rims of the Plateau, and to the south, the few existing profiles are rather at the inner part of the Plateau. Specifically, the four profiles are isolated at the base of Pico do Gavião. Around the rims, some faults are observed in laterite profiles, mainly to the north, in Morro do Cristo, in the city of Poços de Caldas, Minas Gerais.

DIGITAL ELEVATION MODEL (DEM) AND GEOMORPHICAL UNITS

The interpretation of the paleosurfaces depends upon the evolution of the landscape, the coalescence and preservation of geomorphological remains. The DEM applied here permits the view of the greater relief units, the observation of the strong relief structural control and the drainage of the area.

Considering the DEM, some geomorphological units are emphasized (Figure 9):

- **Unit 1** – Fault scarps at the Plateau rims (1,500 to 1,700 meters of altitude);
- **Unit 2** – High altitude unit, from 1,200 to 1,500 meters of altitude at the center-eastern and center-western area;
- **Unit 3** – Intermediate plateau relief, being between the rim and the mountainous reliefs of the center-eastern and center-western area;
- **Unit 4** – Areas of rather smooth topographies that characterize Ribeirão das Antas and das Vargens (north of the Plateau).

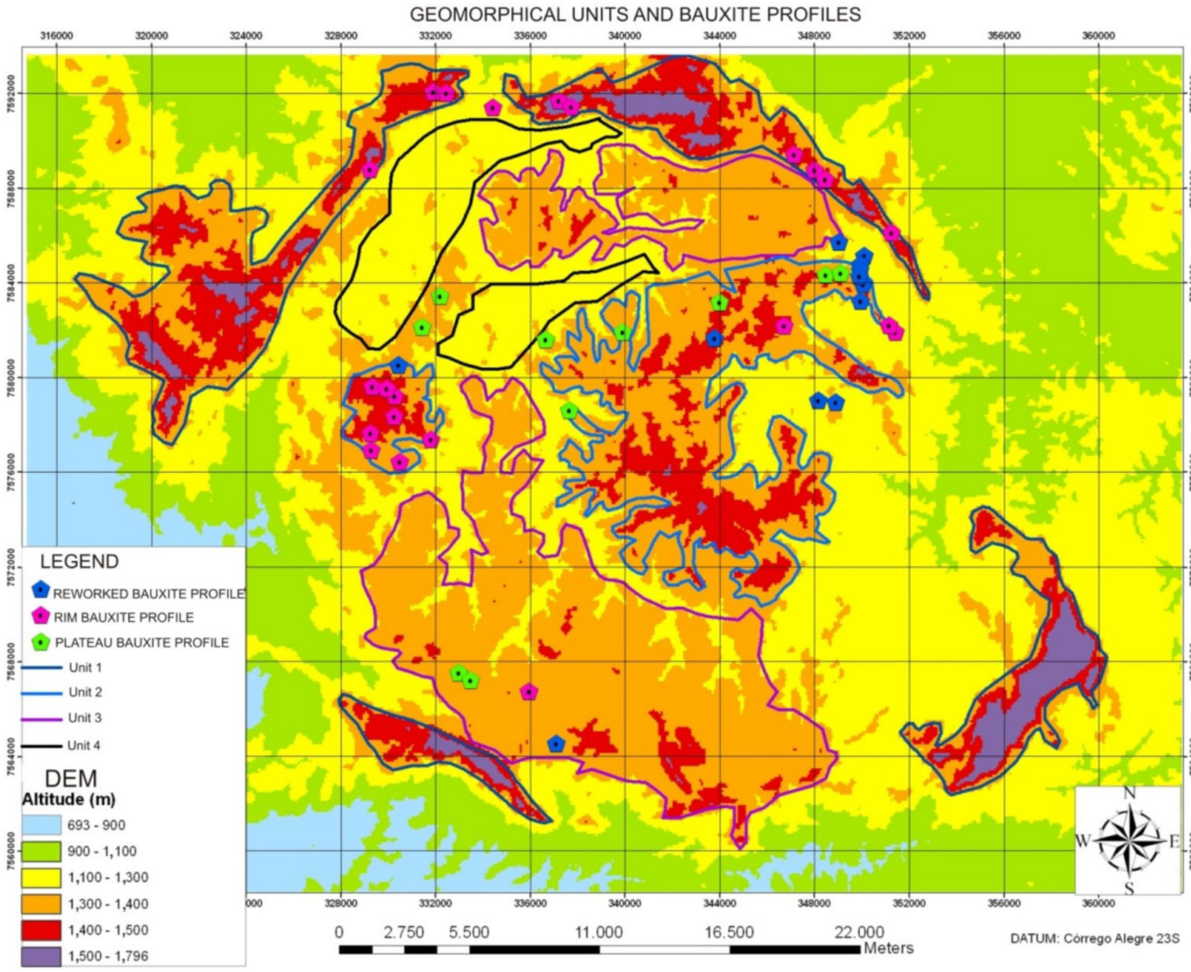


FIGURE 9. Digital Elevation Model.

Each one of these units has, besides different altitude levels, distinct characteristics in the relief:

- **Unit 1.** It corresponds to fault scarps in the Plateau rims (1,500 to 1,700 meters of altitude). These scarps show, in their external parts (contact with Depressão Periférica Paulista), difference in levels which not rarely exceed 1,000 m and, in the portions turned to the inner part of the Plateau, these differences are usually lower than 600 m. They show serrated aspects (Figure 10) derived from the drainage axes that cut them.

The landforms are highly dissected, with encased valleys; commonly, falls and wide rocky outcrops are abundant, especially in the Poços de Caldas Plateau southern portion.

Associated to this unit, there are occurrences of Rim Laterite Bauxite Profiles (Figure 11), especially to the north, northwest and northeast, located in the highest parts of the unit, and cut by valleys. To the south, the laterite bauxite profiles do not occur and the rocky outcrops of volcanic rocks predominate at the tops.

In these areas, the slope easily exceeds 100%; therefore, the observation of colluvial materials in the base of the slopes, besides the observation of block falls and usually mass movements, is certainly common.

- **Unit 2.** It appears further inside the Plateau (except to the east) and it shows landforms with high slopes, many times scarped and, commonly with altitude differences (between the top and the base) of 400 meters. Their altitude is a little lower than those which correspond to the Unit 1 and the valleys are not so much encased, although they are characterized by deep valleys as well. In this unit, there are falls and rapids, even though they have lower elevation if compared to those present in Unit 1.

Associated to this unit, as in Unit 1, the occurrences of Rim Laterite Bauxite Profiles, located in the highest parts of the unit, especially in the western portion, where it can also occur Rim Laterite Bauxite Profiles covered by conglomerations of bauxitic materials (reworked bauxite) (Figure 12). In the eastern occurrence of this unit, the tops show predominant outcrops of volcanic rocks and in lower portions the bauxite fragments are common, many times concentrated, forming thick packs characterizing Reworked Bauxites.

The slopes are lower than in Unit 1; however, they exceed 50% in many points and locally (as in Morro do Serrote), they are able to form rectilinear vertical scarps (Figure 13).

- **Unit 3.** It corresponds to the lower altitude, wide hills that do not exceed 1,400 meters; it has much more open valleys (Figure 14), the vertical dissection is rather smaller, rarely reaching 100 meters, but normally it is smaller than this, with tendency to convex slopes.

Associated to this unit, the named Plateau Profiles (Figure 14) are found and also the reworked lateritic materials, occurring in only some Rim Profiles, probably associated to tectonic movements.

The slopes are much gentler than those units, and they do not go over 40%.

- **Unit 4.** It corresponds to positions associated to the biggest channels of the area and in the terminal parts of these valleys inside the Poços de Caldas Plateau. Topography is practically plain (Figure 15) and in a vast area, it has been covered by dams. This area corresponds to recent deposition areas and in some places there is concentration of kaolinite (Figure 16), probably associated to the deposition of materials eroded from the bauxite profiles.

FIGURE 10. Fault Scarps of Serra do Gavião. South of Poços de Caldas Plateau.

FIGURE 11. Rim Bauxite Laterite Profile.

FIGURE 12. Reworked Bauxite covering Rim Profile.

FIGURE 13. Escarpments of Morro do Serrote.

FIGURE 14. Wavy relief with very open valleys, inside the Plateau; to the south, a Plateau Bauxite Profile.

FIGURE 15. Bortolan dam.

FIGURE 16. Kaolinite Exploration Area.

ALTITUDE AND BAUXITE PROFILES

When the association among the surfaces that show bauxite profiles, preserved in the relief, and the altitude of occurrence (DEM and Graphic 1) take place, some unconformities are noticed. The surface of the highest altitude (1,500 - 1,796 m above sea level) does not always fit with the association of Rim Bauxite Profiles, because these profiles are found in the Poços de Caldas Plateau at different altitudes, indicating that the surfaces can be at distinct levels. At the same time, those areas in this unit do not show any evidence of laterite alteration, but just rocky outcrops.

Both Graphic 1 and DEM show that the Rim Bauxite Profiles are, in their major part, in altitudes higher than 1,400 meters, while the largest portion of the Plateau Bauxite Profiles are between 1,300 and 1,400 meters of altitude. But the Reworked Bauxite Profiles are below 1,400 meters instead. Even when the profiles are concentrated at a specific level, there are Plateau Bauxite Profiles in less elevated levels (1,100 to 1,300 meters of altitude).

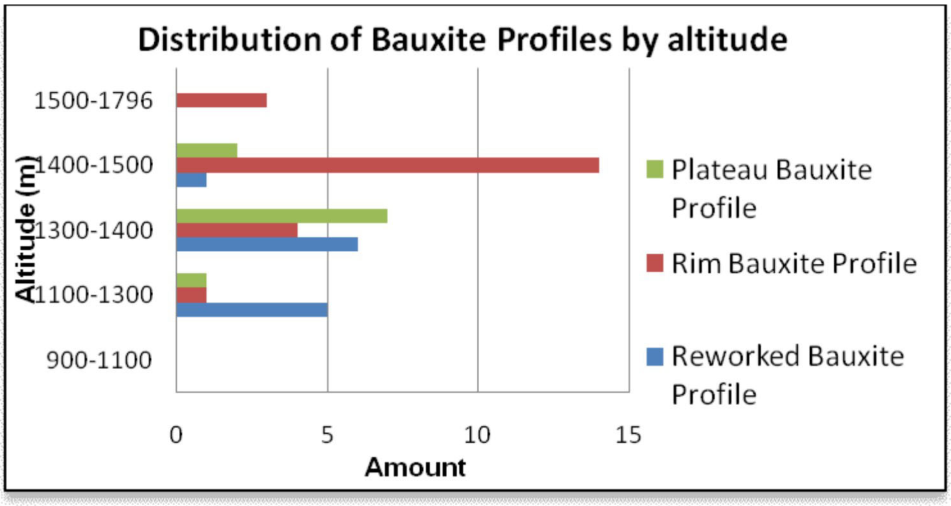
It is noted that some Rim Bauxite Profiles are found at lower elevations (between 1,100 and 1,300 meters and between 1,300 and 1,400 meters) as observed in the south of the Plateau, in Unit 3 of the Digital Elevation Model (Figure 8), being able to give signals of depression on the topographic surface.

An important point in this analysis refers to the Plateau and Reworked Bauxite Profiles that are in the center-east of the Plateau between 1,400 and 1,500 meters, in other words, with difference in level of about 100 meters of altitude from the other points.

The data above suggest the need of certain care about the simple interpretation which deals with relief development in surfaces, agreeing with Corrêa and Mendes (2002) and Ladeira and Santos (2005).

However, through the evidence in the field, it is not possible to correlate the paleosurfaces to the altitude in just a direct manner. The current position of the surfaces has been affected by tectonics that has moved blocks and has defined new altitude levels for the alteration bauxite profiles. Therefore, King's (1956) observation which determined that the high areas in the Plateau, above 1,400 meters, correspond to the Gondwana Surface and Almeida (1964) considered them as the Japí Surface, that has flattened the massif alkaline rocks between 1,550 to 1,600 meters – and need to be interpreted as reserves when it is observed at a more detailed scale.

These discrepancies in the geomorphologic surfaces can be understood if associated to a tectonic event that has provided the uplift or subsidence of these surfaces, later to the formation of bauxite profiles. As an indication of that, there are several faults and grooves found in the bauxite profiles (Figure 17) and prove the existence of alignments before and after the bauxite formation in the area.



GRAPHIC 1. Types of Bauxite Profiles by altitude.

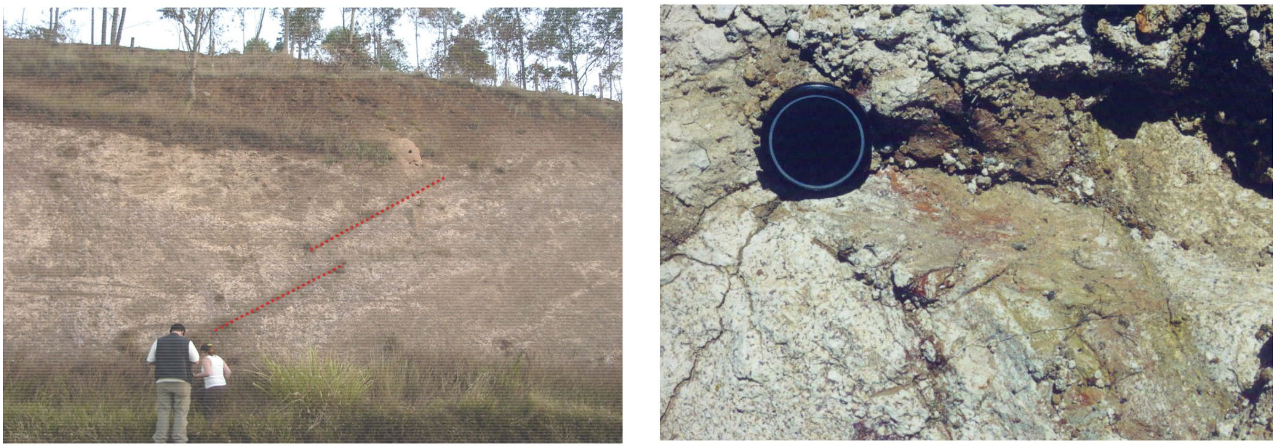


FIGURE 17. Fault dislocating a laterite profile. Road from Poços de Caldas to Caldas, next to Saturnino de Brito dam (at the left) and the fault with grooves in the laterite profile (at the right).

FINAL CONSIDERATIONS

Correlating the Bauxite Profiles as a stratigraphical marker, it is possible to note that:

- Most of the Rim Bauxite Profiles are in altitudes higher than 1,400 meters, in the summits of the Poços de Caldas Plateau;
- Most of the Plateau Bauxite Profiles are found between 1,300 and 1,400 meters of altitude;
- Most of the Reworked Bauxite Profiles are below 1,400 meters;
- However, there are some exceptions which are fundamental, regarding correlation of the profiles and altitude for the identification of paleosurfaces;
- Rim Profiles, that are located in levels where Plateau Profiles are barely found, below 1300 m of altitude;
- Reworked Profiles, located over Rim Profiles, above 1,400 meters of altitude;
- In more elevated areas, above 1,400 m, where normally Rim Profiles occur, rocky outcrops are observed, without any evidence of laterite profiles

in situ. In these cases, thick reworked bauxite deposits are observed at the base of these elevations.

Therefore, in the area it has been observed that, above 1,400 meters, that would correspond to King's (1956) Gondwana Surface, Reworked, Plateau and Rim Bauxite Profiles are found and also rocky outcrops with no evidence of laterite profiles.

With the information raised in the field, the hypothesis that altitude levels – at least in the Poços de Caldas area – cannot be used as unique information to determine paleosurfaces is valid, although most of the profiles are in levels formed by the same material, following the classification proposed here, there are many exceptions because some of profiles are lacking altitude correlation data. The big amount of faults in this area, both observed in the field and based on the reference bibliography, allows to infer that part of the lack of correlation profile/altitude may be associated to tectonic movements after the formation of the bauxite profiles.

For a more extensive analysis, detailed research about tectonics in the area is needed.

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