Variation of the kaolinite and gibbsite content at regional and local scale in Latosols of the Brazilian Central Plateau Variabilité à l'échelle régionale et locale de la teneur en kaolinite et gibbsite des latosols du plateau central brésilien.

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C.R Geoscience
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Variation of the kaolinite and gibbsite content at regional and local scale in Latosols of the Brazilian Central Plateau

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Abstract

Mineralogy of the Latosols of the Brazilian Central Plateau remains under discussion in the absence of clear relationship with their age according to their geomorphic location. The aim of this study was thus to clarify the origin the kaolinite and gibbsite content variation by studying a regional toposequence and using data from the literature. Chemical composition and soil color were used to discuss mineralogy. The mineralogy of the clay fraction was also

discussed by using X-ray diagrams. Our results showed, that the large variation of kaolinite and gibbsite content can be explained by taken into account both their local and regional location, the variation of the hematite and goethite content remaining limited. The model that is proposed to explain such a variation combines a regional component which is mainly associated to the age of the geomorphic surface and a local component which is mainly associated to the hydraulic conditions along the toposequence.

Keywords: Oxisol, Ferralsol, mineralogy, iron oxyhydroxide, soil color, biome Cerrado

Résumé

Variabilité à l'échelle régionale et locale de la teneur en kaolinite et gibbsite des Latosols du Plateau Central Brésilien

La minéralogie des Latosols du Plateau Central Brésilien reste discutée en l'absence de relation clairement établie avec leur âge qui est fonction de leur position géomorphologique. L'objectif de cette étude est par conséquent de clarifier l'origine de la variation de teneur en kaolinite et gibbsite en étudiant une toposéquence régionale et les données de la littérature. La minéralogie a été discutée à partir de la composition chimique et de la couleur du sol. Elle a aussi été discutée à l'aide des données de la diffraction des rayons X. Les résultats montrent que la variation élevée de la proportion de kaolinite et de gibbsite des Latosols peut être expliquée en prenant en compte à la fois leur localisation régionale et locale. Le modèle proposé combine en effet une composante régionale qui est principalement liée à l'âge de la surface géomorphologique et une composante locale qui est elle principalement liée aux conditions hydriques le long de la toposéquence.

Mots-clés : Oxisol, Ferralsol, oxy-hydroxyde de fer, couleur du sol, biome Cerrado

1. Introduction

The Latosols of the Brazilian Soil Taxonomy [8], which are Oxisols in the Soil Taxonomy [33] and Ferralsols in the World Reference Base [12] cover approximately 40% of the Brazilian Central Plateau [24]. This region that corresponds to 24% of Brazilian territory is composed of two main geomorphic surfaces developed during the Cretaceous Superior and Tertiary: (i) the South American Surface (SAS) which is the oldest and mainly made up of tablelands called chapadas with smoothly convex plane portions with an elevation ranging from 900 to 1,200 m, (ii) and the Velhas Surface (VS) characterized by moderate and convex slopes at an elevation below 900 m [23].

In the Central Plateau, the Latosols are Red Latosols (~28%) where the hematite is the main iron oxyhydroxide, Yellow Red Latosols (~10%) where hematite and goethite are present in similar proportion and Yellow Latosols (~2%) where goethite is the main iron oxyhydroxide. Besides iron oxyhydroxides, gibbsite and kaolinite were shown to be the main associated minerals in Latosols of the SAS and VS, respectively [39]. However, several studies showed high proportions of kaolinite in Latosols of the SAS and high proportions of gibbsite in Latosols of the VS. Indeed, Resende [27] studied a topolithosequence 67 km-long across the SAS and VS and showed high proportion of kaolinite in Red Latosols and Yellow Red Latosols developed in clay sediments on the SAS. Curi and Franzmeier [6] studied a toposequence 200 m-long on the VS with Latosols developed in weathered basalts and found Red Latosols upslope with a high proportion of gibbsite. Macedo and Bryant [14] studied a hydrosequence 3 km-long on the SAS and found Yellow Red Latosols downslope with similar proportion of kaolinite and gibbsite. Several authors [10, 11, 15, 16, 20] studied Latosols located on the two geomorphic surfaces and recorded a variable proportion of gibbsite and kaolinite for Latosols developed on the same surface. Thus, the mineralogy of the Latosols of the Brazilian Central Plateau remains under discussion because it appears weakly related to their age according to their location on the two main geomorphic surfaces. In this

context, the aim of this study is (i) to analyze the mineralogy of these Latosols by studying Latosols along a regional toposequence and using data from the literature, (ii) and to show that a model consistent with our data and those from the literature can be proposed.

2. Material and Methods

Ten Latosols (L) developed in different parent materials were selected for study along a 350 km-long toposequence across the SAS (L1 to L4) and VS (L5 to L10). Location and basic properties of these Latosols can be found in [26] and Table 1. The Latosols L5 and L6 were located on the upper VS, L7 and L8 on the intermediate VS, and L9 and L10 on the lower VS. The Latosols L7 and L8 are those also studied by Volland *et al.* [37, 38] and similar to those studied by Balbino *et al*. [1, 2, 3]. A set of 25 samples was collected in the diagnostic horizons Bw_1, Bw_2 and when possible Bw_3 of the Latosols selected. The SiO_2, Al_2O_3, and Fe_2O_3 contents were determined on the <2-mm material after dissolution in 1:1 H_2SO_4 [5, 7, 15, 30, 35]. This acid attack enables dissolution of the clays, Fe oxyhydroxides and Al hydroxides [22, 28, 31].

The SiO_2 and Al_2O_3 extracted with sulfuric acid were used to compute the kaolinite (*K*) and gibbsite (*Gb*) content as following [4, 28]:

$$K = S_{SiO_2} / K_{SiO_2} \qquad (1)$$

where *K* is the kaolinite content (%) of the sample, S_{SiO_2} the SiO_2 content of the sample recorded with sulphuric acid extraction (%), K_{SiO_2} the specific proportion of SiO_2 of the kaolinite and equaled to 0.465.

The goethite (*Gt*) and hematite (*Hm*) contents were computed by combining two equations relating *Gt* and *Hm* as following:

$$S_{Fe_2O_3} = Gt_{Fe_2O_3} \times Gt + Hm_{Fe_2O_3} \times Hm \qquad (2)$$

$$Hm/(Hm+Gt) = (RI - 3.50)/8.33 \qquad (3)$$

where $S_{Fe_2O_3}$ is the Fe_2O_3 content (%) of the sample recorded with sulphuric acid extraction, $Gt_{Fe_2O_3}$ is the specific proportion of Fe_2O_3 in the goethite and equaled to 0.899 for a non Al-substituted goethite and to 0.675 for a 33% Al-substituted goethite [32], $Hm_{Fe_2O_3}$ is the specific proportion of Fe_2O_3 in the hematite and equaled to 1 for a non Al-substituted hematite and to 0.890 for a 16% Al-substituted hematite [32], *RI* is the red index [9, 21, 30] and equaled to:

$$RI = \left(M + C/V\right) \qquad (4)$$

with M a parameter related to the hue (M was 10 for 10R, 7.5 for 2.5YR, 5 for 5YR, 2.5 for 7.5YR and 0 for 10YR), *C* the chroma and *V* the value of the Munsell notation [9, 21, 30].

The gibbsite content of the sample was computed as following:

$$Gb = \left\{\left[\left(S_{Al_2O_3} - (Gt \times Gt_{Al_2O_3}) - (Hm \times Hm_{Al_2O_3}) - (K \times K_{Al_2O_3})\right]/Gb_{Al_2O_3}\right\} \qquad (5)$$

where *Gb* is the gibbsite content (%) of the sample, $S_{Al_2O_3}$ the Al_2O_3 content of the sample recorded with sulphuric acid extraction (%), $K_{Al_2O_3}$ the specific proportion of Al_2O_3 of the kaolinite and equaled to 0.395, $Gb_{Al_2O_3}$ the specific proportion of Al_2O_3 of the gibbsite and equaled to 0.654. Equation (1) and (5) assumed kaolinite and gibbsite without any substitution.

The mineralogy of the < 2 µm fraction of the Bw_2 horizons was determined by using X-ray diffraction on powder samples by using a Thermo Electron ARL`XTRA diffractometer [29]. The SiO_2, Al_2O_3, and Fe_2O_3 contents of the < 2 mm material of 162 Bw horizons collected in Latosols of the Central Plateau and earlier published [25] were also used to discuss the mineralogy of Latosols.

3. Results and Discussion

3.1. Composition and mineralogy of the Latosols along the regional sequence studied

In the Bw horizons studied, the Fe_2O_3 content ranged from 15 to 33%, the Al_2O_3 content from 43 to 68% and the SiO_2 content from 11 to 36% (Fig. 1a). For those belonging to Latosols developed on the SAS, the Fe_2O_3 content ranged from 15 to 33%, the Al_2O_3 content from 54 to 68% and the SiO_2 content from 11 to 24%. On the other hand, for those belonging to Latosols developed on the VS, the Fe_2O_3 content ranged from 18 to 24%, the Al_2O_3 content from 43 to 52% and the SiO_2 content from 22 to 36%, (Fig. 1a). The range of Fe_2O_3 content is consistent with the one recorded by Melfi and Pédro [19] for Latosols of the Central Plateau.

The results showed a relatively small variation of the iron oxyhydroxide content between the Latosols studied whatever the Al-substitution rate since *Gt+Hm* ranged from 13 to 27% in the absence of Al-substitution and from 15 to 29% when the goethite and hematite were 33% and 16% Al-substituted, respectively (Fig. 2 a and b). On the other hand, there was a large variation of the kaolinite and gibbsite content with *K* ranging from 17 to 67% and *Gb* from 15 to 65% with non Al-substituted goethite and hematite and *K* ranging from 18 to 69% and *Gb* from 13 to 62% when the goethite and hematite were 33% and 16% Al-substituted, respectively (Fig. 2 a and b). Thus, the Latosols sampled along the regional toposequence studied were gibbsitic Latosols on the SAS (L1 to L4) and kaolinitic Latosols on the VS (L5 to L10) (Fig. 2a). The mineralogy obtained with data from sulfuric acid extraction was consistent with the X-ray diagrams recorded for the < 2 µm fraction of the Bw_2 horizons studied (Fig. 3). X-ray diagrams showed also a greater kaolinite content in the L3 than in L10 and a close gibbsite content between the latter, thus indicating again no sharp variation of mineralogy between the Latosols developed on the SAS and VS (Fig. 3).

3.2. Mineralogy of Latosols located in the Brazilian Central Plateau

Results from sulphuric extractions earlier published [25] were used to describe the mineralogy of <2-mm material of Latosols as done above for the Latosols of the regional

toposequence studied. The Fe_2O_3 contents ranged from 9 to 34%, the Al_2O_3 content from 36 to 78% and the SiO_2 content 9 to 42% (Fig. 1b). For the Bw horizons of Latosols developed on the SAS, the Fe_2O_3 content ranged from 9 to 34%, the Al_2O_3 content from 39 to 78% and the SiO_2 content from 9 to 39%. On the other hand, for the Bw horizons of Latosols developed on the VS, the Fe_2O_3 content ranged from 18 to 33%, the Al_2O_3 content from 36 to 60% and the SiO_2 content from 13 to 42%, (Fig. 1b).

The Fe_2O_3, Al_2O_3 and SiO_2 contents were used to compute *K*, *Gb* and *Gt+Hm* as done for the Bw horizons of the regional toposequence studied. In the absence of Al-substitution in goethite and hematite, results showed that *K* and *Gb* ranged from 11 to 78% and from 1 to 77%, respectively (Fig. 2c). On the other hand, with 33% Al-substituted goethite and 16% Al-substituted hematite, results showed that *K* and *Gb* ranged from 12 to 79% and from 0 to 75%, respectively (Fig. 2c). Results showed also a large overlapping of the mineralogical composition range between Latosols developed on the SAS and those developed on the VS (Fig. 2c). Indeed, for the Bw horizons of Latosols developed on the SAS, *K* ranged from 11 to 75% and *Gb* from 3 to 77% with non Al-substituted goethite and hematite, and *K* ranged from 12 to 78% and *Gb* ranged from 0 to 75% with 33% Al-substituted goethite and 16% Al-substituted hematite. On the other hand, for the Bw horizons of Latosols developed on the VS, *K* ranged from 21 to 78% and *Gb* from 1 to 57% with non Al-substituted goethite and hematite, and *K* ranged from 22 to 79% and *Gb* ranged from 0 to 55% with 33% Al-substituted goethite and 16% Al-substituted hematite. Results showed also that *Gt+Hm* from 9 to 31% in the absence of Al-substitution and from 9 to 35% when the goethite and hematite were 33% and 16% Al-substituted respectively (Fig. 2 c and d) without any relationship with the location of Latosols on the two main geomorphic surfaces.

3.3. Variation of the kaolinite and gibbsite content at the regional and local scale

Macedo and Bryant [14] and Motta *et al*. [20] showed that the Latosols distribution on the SAS was closely related to the soil hydraulic regime thus explaining the Red Latosol, Yellow Red Latosols and Yellow Latosol sequence according to local variation of the topography. As a consequence, the Latosols distribution appeared roughly independent of the underlying geological material [20]. Motta *et al*. [20] suggested that more attention should be devoted to geomorphology to explain variation of Latosols characteristics and particularly their mineralogy. Melfi and Pédro [17, 18] showed that Latosols mineralogy should be related to their geochemical functioning that is characterized by an hydrolytic environment according to landscape history at both regional and geological scale. Tardy [34] discussed the kaolinite/gibbsite ratio in tropical soils and showed that the kaolinite–gibbsite equilibrium would be preferentially controlled by variation of the hydraulic conditions along of the toposequences. Finally, Lucas [13] showed that the spatial distribution in equatorial areas of the secondary minerals such as kaolinite, gibbsite and goethite can be related to their stability in aqueous solutions and then to the amount of the water percolating the soils. Thus, as discussed by Lucas [13], the higher the volume of water percolating the profile is, the lower the soil-solution concentrations are.

On the basis of these results, we plotted the altitude at which every Latosols was located on the SAS and VS according to the *Gb*/(*Gb*+*K)* ratio. Figure 4 shows that *Gb*/(*Gb*+*K)* varies according to the local topographic location of every Latosol (Axe 1) and to the regional topographic location of every Latosols (Axe 2). Locally, Latosols located on the slope showed higher *Gb*/(*Gb*+*K)* ratio than those located on the plateau of the same portion of landscape (Fig. 4). At the regional scale, our results showed the *Gb*/(*Gb*+*K)* ratio increased with the altitude thus explaining the trend to an increase in the *Gb*/(*Gb*+*K)* ratio value with the altitude, the age of the surface increasing itself with the altitude. Thus, the Axe 2 shows a regional variability that is mainly related to time. More the topographic surface is old, more the

Latosols are old, higher is the weathering and consequently the hydrolysis processes intensity resulting in a higher gibbsite content in the Bw studied as discussed by Vitte [36] and Melfi and Pédro [17, 18]. On the other hand, the Axe 1 shows a local variability that would be mainly related to the volume of water percolating the soil. Indeed, because of local topographic characteristics, water can percolate more or less easily, maintaining the Fe, Si and Al concentrations that result from mineral hydrolysis at values that are more or less favorable to hydrolysis process continuation. Thus according to the local topographic location, the higher the volume of water percolating the Latosol is, the higher hydrolysis process is, and the higher resulting gibbsite content is.

4. Conclusion

Our results showed that the kaolinite and gibbsite content in the Latosols developed on the South American Surface and Velhas Surface of the Brazilian Central Plateau can be explained by taken into account both their local and regional location. The model proposed combines (i) a regional variation which would be mainly associated to the age of the surface, the more the surface being old, the more SiO_2 removal from the soil being developed and thus the gibbsite content being high compared to the kaolinite content, (ii) and a local variation which would be mainly associated the hydraulic conditions along the toposequence at the scale of several hectometers or a few kilometers, the gibbsite content being the highest where SiO_2 removal is the easiest as upslope and on the plateau border.

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Figures

Fig. 1. SiO_2, Al_2O_3 and Fe_2O_3 relative contents in the Bw horizons of the Latosols of the regional toposequence studied (a) and those of Bw horizons from the literature (b): Latosols located on the South American Surface (+) and Velhas Surface (▲).

Fig. 1. Contenu relatifs en SiO_2, Al_2O_3 et Fe_2O_3 dans les horizons Bw des Latosols de la toposéquence régionale étudiée (a) et ceux des horizons Bw issus de la littérature (b) : Latosols situés sur la Surface Sud Américaine (+) et sur la Surface Velhas (▲).

Fig. 2. Kaolinite, gibbsite, and (goethite + hematite) relative contents in the Bw horizons of the Latosols of the regional toposequence studied (a, with non Al-substituted goethite and hematite and b, with 33% Al-substituted-goethite and 16% Al-substituted hematite) and in Bw horizons from the literature (c, with non Al-substituted goethite and hematite and d, with 33% Al-substituted-goethite and 16% Al-substituted hematite): Latosols located on the South American Surface (+) and Velhas Surface (▲).

Fig. 2. Contenus relatifs en kaolinite, gibbsite, and (goethite + hematite) dans les horizons Bw des Latosols de la toposéquence régionale étudiée (a, calculé avec une goethite et une hématite sans substitution par Al et b, calculé avec une goethite substituée par Al à 33% et une hématite substituée par Al à 16%) et dans les horizons Bw issus de la littérature (c, calculé avec une goethite et une hématite sans substitution par Al et d, calcul avec une goethite substituée par Al à 33% et une hématite substituée par Al à 16%) : Latosols situés sur la Surface Sud Américaine (+) et ceux situés sur la Surface Velhas (▲).

Fig. 3. X-ray diagrams of the oriented <2 μm fraction (powder) of horizons Bw of the Latosols studied.

Fig. 3. Diagrammes de rayons-X de la fraction <2 μm (poudre) des horizons Bw des Latosols étudiés.

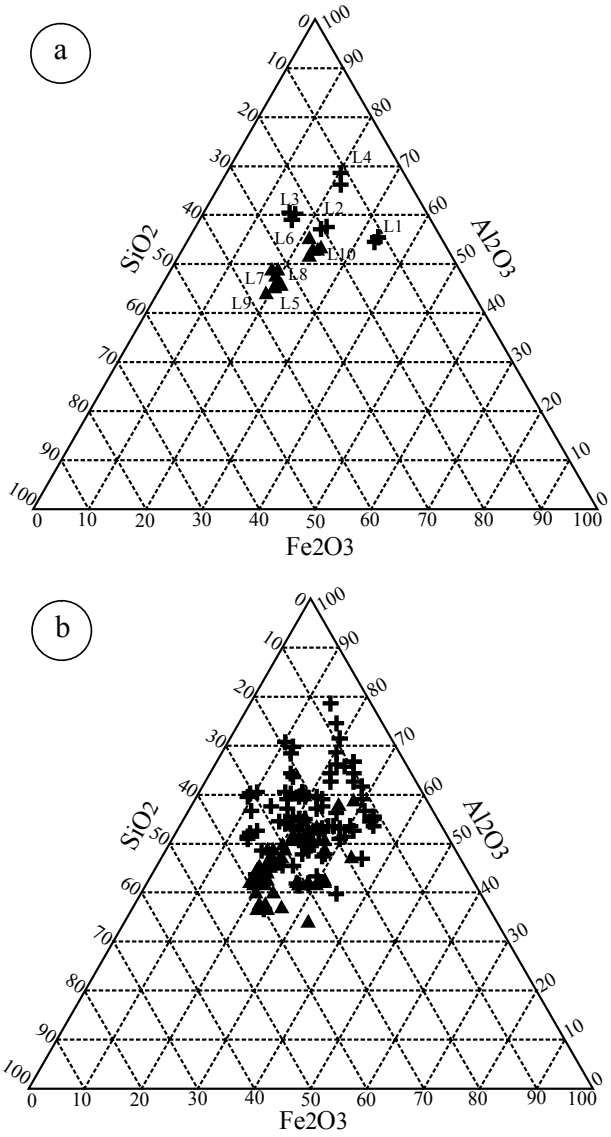
Fig. 4. Altitude of every Latosol (L) according to the gibbsite/(gibbsite + kaolinite) ratio computed with non Al-substituted goethite and hematite (♦) and both 33% Al-substituted goethite and 16% Al-substituted hematite (▲). Every Latosols was also located on its portion of landscape according to the local topography (Axe 1: local variation associated to the hydraulic condition along the toposequence and Axe 2: regional variability according to the age of the surface). SAS: South American Surface, VS: Velhas Surface (VS – I: Upper level, VS – II: Intermediate level, VS – III: Lower level).

Fig. 4. Altitude de chaque Latosol (L) en fonction du rapport gibbsite/(gibbsite + kaolinite) calculé avec une goethite et une hématite non substitute par Al (♦) et avec à la fois une goethite substituée par Al à 33% et une hématite substitué par Al à 16% (▲). Chaque Latosol est localisé sur sa portion de paysage (Axe 1: variabilité locale liée aux conditions hydriques le long de la toposéquence et Axe 2: variabilité régionale en fonction de l'âge de la surfaces. SAS: Surface Sud Américaine, VS: Surface Velhas (VS - I: Niveau Supérieur, VS - II: Niveau Intermédiaire, VS – III: Niveau Inférieur).

Tables

Table 1 – General characteristics of the Latosols studied.

Tableau 1 - Caractéristiques générales des Latosols études.



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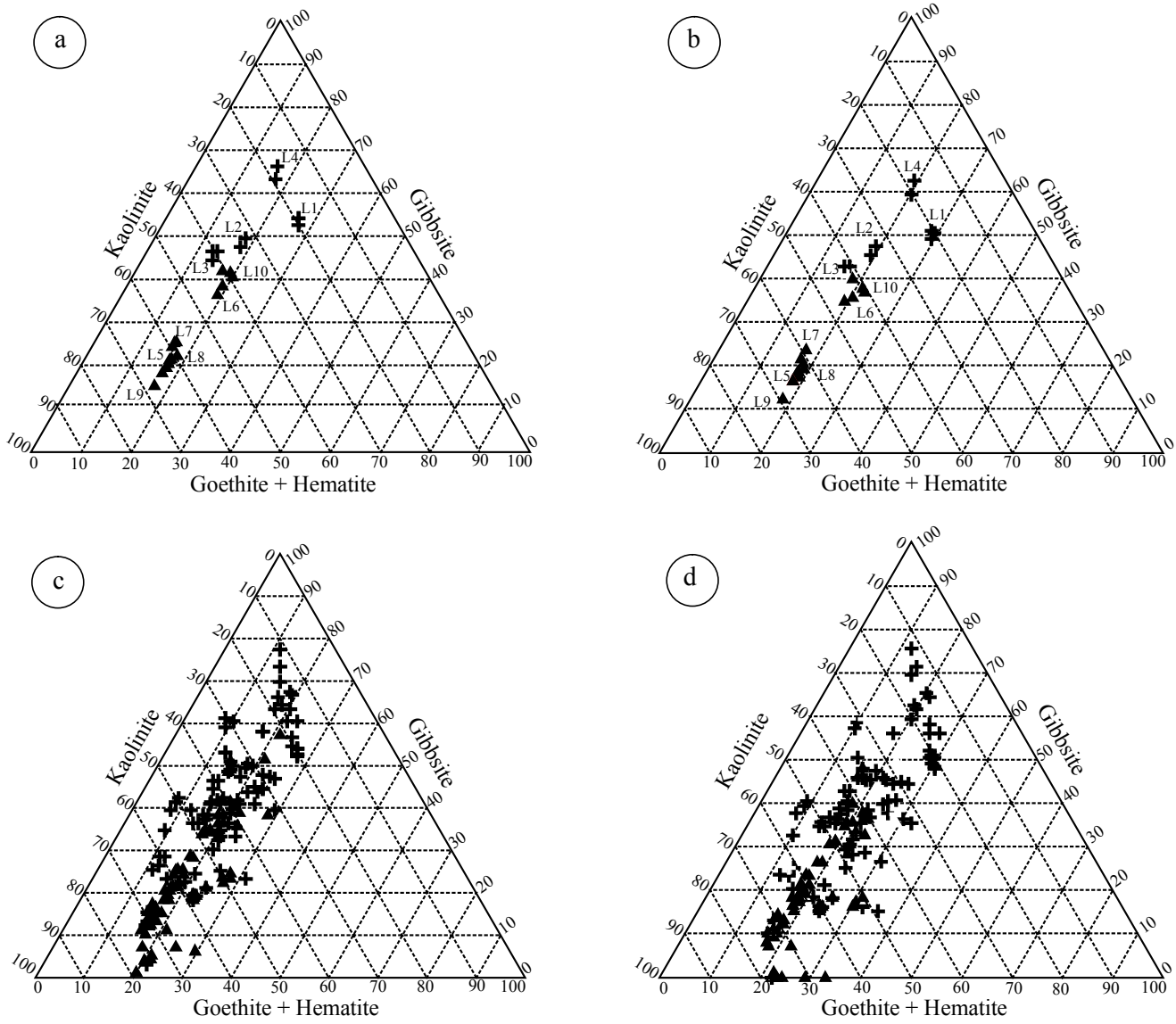

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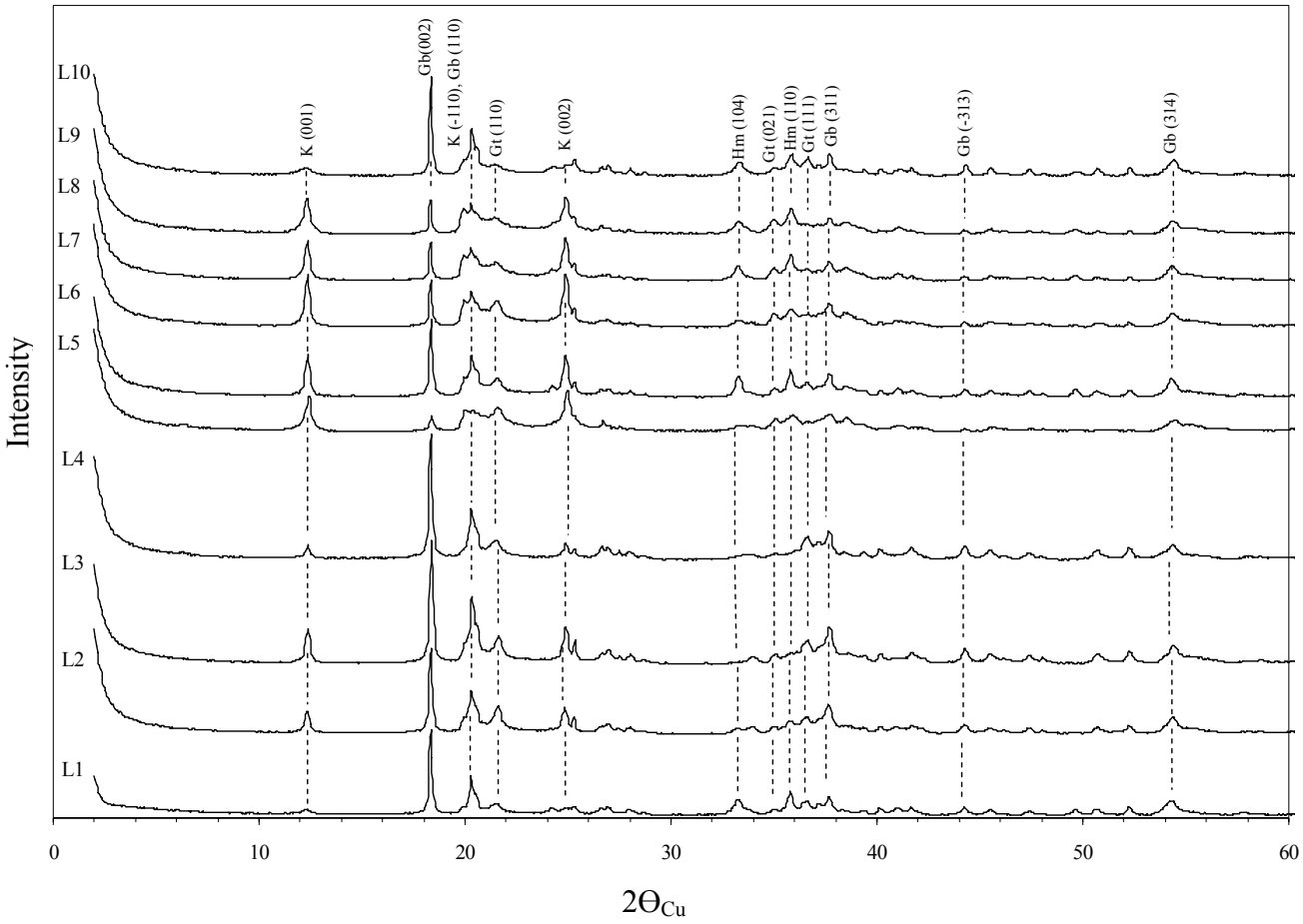

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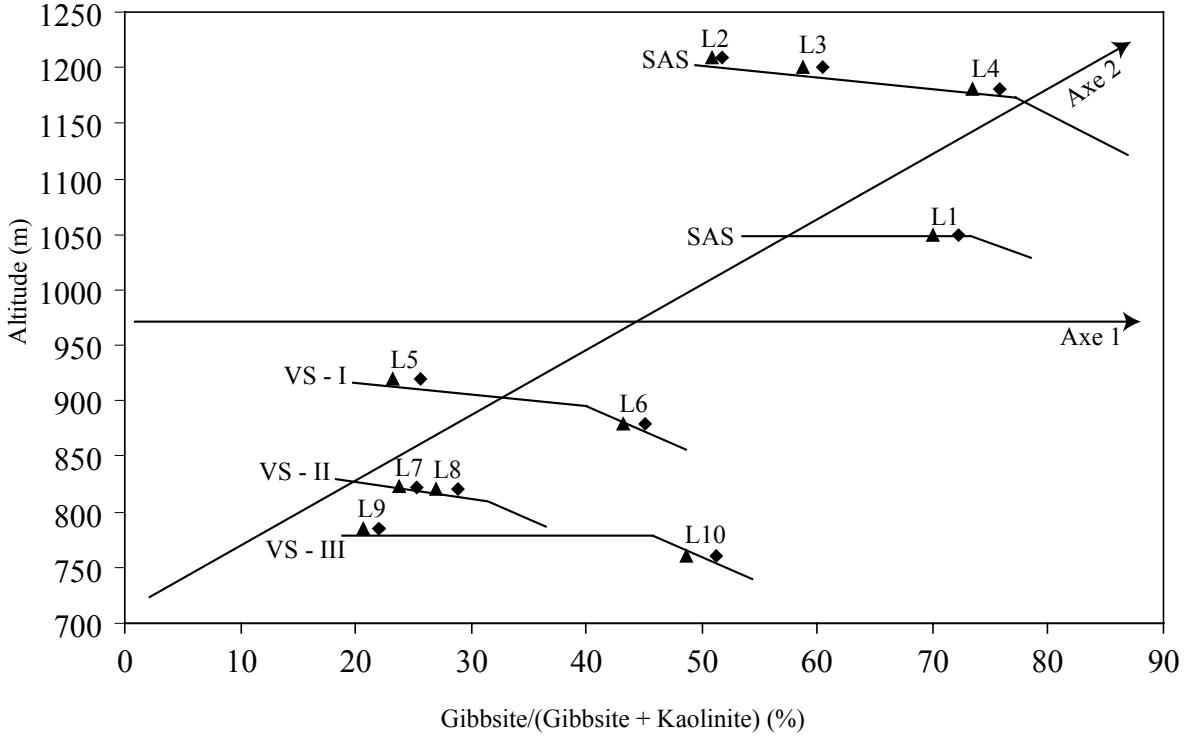

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Table 1 – General characteristics of the Latosols studied.

Tableau 1 - Caractéristiques générales des Latosols étudies.

Latosols	Geomorphic Surface	Altitude (m)	Position along the toposequence	Slope length (km)	Declivity (%)
L1	South American	1050	median	3	< 1
L2	South American	1200	median	5	2
L3	South American	1190	median	5	2
L4	South American	1180	down	12	3
L5	Velhas, Superior Level	920	median-up	12	< 1
L6	Velhas, Superior Level	880	down	20	6
L7	Velhas, Intermediate Level	820	median-up	20	2
L8	Velhas, Intermediate Level	805	median-down	7	2
L9	Velhas, Inferior Level	785	median-up	15	< 1
L10	Velhas, Inferior Level	760	down	15	7