Revista Brasileira de Ciência do Solo
ISSN: 0100-0683
editor-rbcs@sbcs.org.br
Sociedade Brasileira de Ciência do Solo
Brasil

Fontana, Ademir; da Silva Chagas, Cesar; Kangussu Donagemma, Guilherme; Rosas de Menezes, Andressa; Calderano Filho, Braz

Soils Developed on Geomorphic Surfaces in the Mountain Region of the State of Rio de Janeiro

Revista Brasileira de Ciência do Solo, vol. 41, 2017, pp. 1-17
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

Revista Brasileira de Ciência do Solo

Division - Soil in Space and Time | Commission - Soil Genesis and Morphology

Soils Developed on Geomorphic Surfaces in the Mountain Region of the State of Rio de Janeiro

Ademir Fontana[(1)*], Cesar da Silva Chagas[(1)], Guilherme Kangussu Donagemma[(1)], Andressa Rosas de Menezes[(2)] and Braz Calderano Filho[(1)]

[(1)] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Solos, Rio de Janeiro, Rio de Janeiro, Brasil.
[(2)] Universidade Federal Rural do Rio de Janeiro, Departamento de Solos, Programa de Pós-Graduação em Agronomia, Seropédica, Rio de Janeiro, Brasil.

*** Corresponding author:**
E-mail: ademir.fontana@embrapa.br

Received: January 9, 2017

Approved: May 22, 2017

How to cite: Fontana A, Chagas CS, Donagemma GK, Menezes AR, Calderano Filho B. Soils developed on geomorphic surfaces in the mountain region of the State of Rio de Janeiro. Rev Bras Cienc Solo. 2017;41:e0160574.
https://doi.org/10.1590/18069657rbcs20160574

ABSTRACT: The evaluation of soils in representative landscapes constitutes an opportunity to evaluate spatial distribution, discuss formation processes, and apply this knowledge to land use and management. In this sense, from the perspective of an environmentally diversified region, the aim of the present study is to evaluate the occurrence and understand the formation of soils in different geomorphic surfaces of a landscape from a mountain region in the state of Rio de Janeiro. The study was developed in the Pito Aceso microbasin in the municipality of Bom Jardim, composed of narrow valleys and a rugged mountain domain, with elevation between 640 and 1,270 m. In a representative landscape, the geomorphic surfaces were obtained from the slope segments and flow lines. On the geomorphic surfaces, soil profiles were described by their morphological properties, collected, and analyzed to describe the chemical and physical properties of each horizon. Geomorphological aspects and possible variations of the parent material directly affected pedogenesis and led to distinct soil classes in the landscape. Variation in the geomorphic surfaces directs the processes for soil formation under current conditions, as well as the preservation of polygenetic soils. Soils of lower development and with greater participation of the exchangeable cations were identified at the summit (talus deposit) *(Neossolo Litólico* and *Cambissolo Húmico)* and toeslope (colluvial-alluvial) (*Neossolo Flúvico*), whereas more developed soils with lower nutrient content occur in the concave (*Argissolos Vermelho* and *Amarelo*) and convex (*Latossolo Amarelo*) backslope, except for the *Argissolo Vermelho-Amarelo* in the shoulder, which had high exchangeable cations contents.

Keywords: soil classes, soil-landscape relationship, pedogenetic development.

INTRODUCTION

Agriculture in the mountainous region of the state of Rio de Janeiro is developed in all parts of the landscape, where the topographical features of mountainous relief associated with intense rainfall impel erosive processes, intensifying soil losses and sediment transport to water courses (Mendes, 2006). In this region, technological levels and cropping intensity vary substantially, promoting different ways to evaluate soil and different implications for conservation or degradation.

Knowledge of soil at different levels of detail and soil dynamics is necessary due to the importance of soil in the environment as a provider of services in water quantity and quality, carbon storage, nutrient cycling, biodiversity, vegetation support, or as an agricultural production factor for land use and management planning. The basic unit of study is the soil genesis environment, the pedoenvironment, which provides for analysis of soil formation and dynamics, as well as landscape evolution. In addition, these evaluations can be related to soil surveys, allowing the lack of information and mapping in various scales of detail to be improved.

The examination of soil profiles and characterization in a representative landscape are taken as a unit for making inferences regarding soil genesis, which can be carried out by evaluation of the soil-landscape relationship. In this evaluation, the occurrence of soils is the basis of landscape segmentation into geomorphic surfaces, which is obtained mainly by the combination of the slope elements and form, characterizing the pedoenvironment. Daniels et al. (1971) refer to geomorphic surfaces as a landscape portion defined in time and space, containing geographical limits modeled by environmental components. According to the conceptual model proposed by Ruhe (1956), the interaction of slope segments and the environment explains soil diversity. Additionally, Hugget (1975) shows that the relief forms from water flow models make for variations in soil characteristics and properties in different landscape segments.

Basically, pedogenetic models and theories express the influence of the processes involved in soil differentiation, which can be observed in the morphology, chemical, physical, and mineralogical properties. Regarding processes, they denote the arrangement and extent of the formation factors, such as relief, parent material, climate, and biota, all acting in a certain period of time. The first concept of formation factors was made by Vasilii Vasilevich Dokuchaev (Dokuchaev, 1967) and complemented by Hans Jenny (Jenny, 1941) in proposing the equation model for soil formation, which is known as the factorial-functional or mental-theoretical model (Lepsch, 2010; Kämpf and Curi, 2012a).

The application of the concepts presented is reported in the studies of Silva and Vidal-Torrado (1999), Cooper and Vidal-Torrado (2000), Nunes et al. (2001), Figueiredo et al. (2004), Lima et al. (2006), Moreau et al. (2006), Silva et al. (2007), Corrêa et al. (2008), Almeida et al. (2009), Clemente et al. (2009), Campos et al. (2007, 2010, 2011, 2012), Cooper et al. (2010), Pereira et al. (2013), Martins and Rosolen (2014), Rodolfo Júnior et al. (2015), aiming to elucidate the occurrence and formation of soil based on evaluation of the soil-landscape relationship in Brazil. Notably, there are few studies concerning the soil-landscape relationship in the mountain region of the state of Rio de Janeiro, such as the study of Calderano Filho et al. (2010).

In this context, the hypothesis is that the soils genesis would be differentiated along of the geomorphic surfaces and landscape positions. In order to increase the knowledge of the soil distribution and soils genesis in an environmentally diversified region, the aim of the present study is to evaluate the occurrence and understand the formation of soil on different geomorphic surfaces of a landscape in a mountainous region of the state of Rio de Janeiro.

MATERIALS AND METHODS

The study was conducted in the Pito Aceso microbasin in the municipality of Bom Jardim, a mountainous region in the state of Rio de Janeiro (RJ) (Figure 1). The regional geomorphology comprises the coastal massifs of the Serra dos Órgãos Plateau, with the predominance of high hills, mountains, and small mountain alignments (Matos et al., 1980; Dantas, 2001). In the Pito Aceso microbasin, the topography is marked by narrow valleys, slopes of differentiated altitudes, and rugged relief, with elevation between 640 and 1,270 m.

The lithology consists of rocks from the Rio Negro complex (orthogneisses and migmatites) (Matos et al., 1980). The parent material comprises the product of alteration of the rocks mentioned, as well as colluviums transported in different phases (Calderano Filho et al., 2010). In the lowland, the material is composed of sandy clay sediments, comprising different alluvial and colluvial deposits.

The climate of the region, according to Köppen classification system, is Cwa, which means dry winter and rainy summer, defined as subtropical, with winter temperatures below 18 °C and summer temperatures above 22 °C. Average annual temperature is 20.3 °C and average annual rainfall is about 1,350 mm (Carvalho Júnior et al., 2013). The primary vegetation is Overgreen Rainforest, equivalent to Dense Ombrophylous Forest, with large tree species and dense formation (Dantas, 2001).

The selected landscape was compartmentalized by the slope segments (Ruhe, 1960) and flow lines - curvature and profile (Hugget, 1975). From this combination, points were established for opening pits for soil profiles and then morphology was described and each horizon was sampled (Santos et al., 2013a). Based on morphological properties and chemical and physical properties, the soils were classified according to the Brazilian Soil Classification System (Santos et al., 2013b).

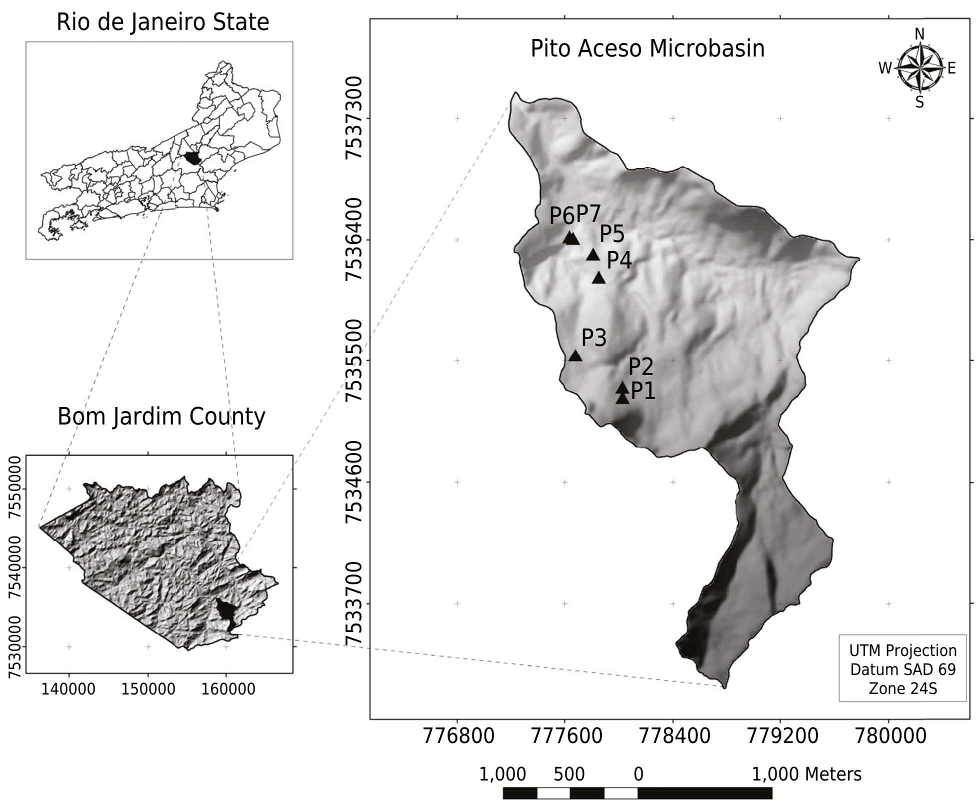

Figure 1. Location of the area studied in the Pito Aceso microbasin, Municipality of Bom Jardim, State of Rio de Janeiro (RJ).

For laboratory analyses, the samples of each horizon were dried in an oven at 50 °C and sieved in a 2 mm mesh, obtaining fine soil. Physical analyses (particle size analysis - coarse sand, fine sand, silt, and clay) and chemical analyses (pH, sorption complex - Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, and H^+, organic carbon, sulfuric acid digestion, and selective extraction of iron by ammonium oxalate acid and dithionite-citrate-bicarbonate) were performed in the fine earth according to the methods described in Donagema et al. (2011). Chemical fractionation of the organic matter was carried out by the technique of differential solubility in basic and acidic solutions, obtaining the organic carbon content in the humic fractions: fulvic acids, humic acids, and humin (Benites et al., 2003).

RESULTS AND DISCUSSION

Evaluation of the landscape by its structural components shows significant variations as to slope segments, flow lines, relief forms, declivity, and altitude, which were jointly defined as distinct pedoenvironments (Table 1, Figure 2). In general, in each soil profile expressive differences are highlighted mainly by the depth, thickness, and color of the surface and subsurface horizons (Figure 2), which causes the occurrence of different diagnostic horizons, the surface *A húmico* (P1, P2, and P5), *A prominant* (P3, P4, and P7), and *A moderado* (P6) horizons, whereas the subsurface horizons were B incipient, B textural, and *B latossólico* (Table 1). From these variations in diagnostic horizons and other characteristics, and the properties of each profile, the soil classes were *Neossolos*, *Cambissolos*, *Argissolos*, and *Latossolos* (Table 1), which correspond to the Entisols, Inceptisols, Ultisols, and Oxisols, respectively, according to Soil Taxonomy (Soil Survey Staff, 2014).

The soils with more pedogenetic evolution were identified by the sequence of horizons A-Bt or A-Bt-Bw (*Argissolos* - P3, P4, and P6), and they occupy the shoulder and concave backslope, whereas in the A-Bw sequence (*Latossolo* - P5) they are in the convex backslope (Table 1, Figure 2). In contrary conditions, soils with the lowest pedogenetic evolution occur at the summit (talus deposit), with the sequence of horizons A-R (*Neossolo Litólico* - P1) or A-Bi (*Cambissolo* - P2), and toeslope, with the horizon sequence A-C-Cg (*Neossolo Flúvico* - P7) (Table 2).

The curvature considerably influences the lateral distribution of the pedological, hydrological, and geomorphic processes and, therefore, the soils that result from interactions among

Table 1. Soil classification and landscape characterization in the Pito Aceso basin, municipality of Bom Jardim (RJ)

Profile	Soil classification[(1)]	Diagnostic horizon	Slope segment[(2)]	Flow lines[(3)]	Slope	Altitude
					%	m
P1	*Neossolo Litólico Húmico típico*	*A húmico*	Summit (talus deposit)	Convex/Linear	65	1,042
P2	*Cambissolo Húmico Distrófico típico*	*A húmico* *B incipiente*	Summit (talus deposit)	Convex/Linear	43	1,010
P3	*Argissolo Vermelho-Amarelo Eutrófico* úmbrico	*A proeminente* *B textural*	Shoulder	Concave/Linear	26	917
P4	*Argissolo Vermelho Distrófico* úmbrico	*A proeminente* *B textural*	Backslope	Concave/Linear	42	780
P5	*Latossolo Amarelo Distrófico húmico*	*A húmico* *B latossólico*	Backslope	Convex/Convex	30	745
P6	*Argissolo Amarelo Distrófico abrúptico*	*A moderado* *B textural*	Backslope	Concave/Linear	34	693
P7	*Neossolo Flúvico Tb Distroúmbrico gleissólico*	*A proeminente*	Toeslope (colluvial-alluvial)	Linear/ Linear	3	686

(1) Santos et al. (2013b). (2) Ruhe (1960). (3) Hugget (1975).

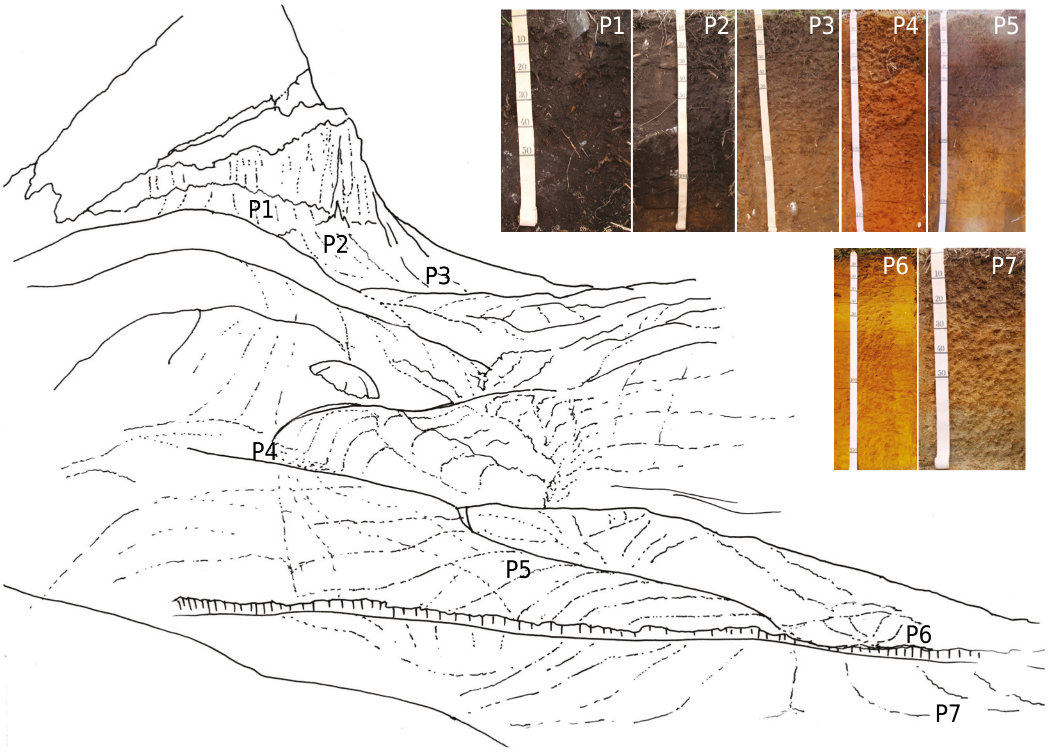

Figure 2. Schematic drawing of landscape and arrangement of soil profiles. Flow of the slope represented by dotted lines and landscape structure by solid lines. P1: *Neossolo Litólico*; P2: *Cambissolo* Húmico; P3: *Argissolo Vermelho-Amarelo*; P4: *Argissolo Vermelho*; P5: *Latossolo Amarelo*; P6: *Argissolo Amarelo*; and P7: *Neossolo Flúvico*.

these processes (Pennock et al., 1987). The influence on soil properties has mainly been related to the concave and convex flow lines that control the distribution of water and soluble materials from the highest to the lowest part of the landscape. Thus, there is a close relationship between curvature and the occurrence of soil classes. In this case, the deepest soils have small variance in morphological properties and physical and chemical properties along the soil profile, such as the *Latossolos* that occupy the convex shape, whereas, in the contrary situation, the *Cambissolos* and *Argissolos* occur in the concave shape. For the *Argissolos*, occurrence in these conditions is related to high slope and the convergent water flow on these geomorphic surfaces, which favors morphogenesis (Chagas, 2006).

Variations in soil genesis were evidenced by morphological properties. The thickness of the surface horizons ranged from 0.25 m (P7) to 1.25 m (P2). In the subsurface horizons, the limit is due to the presence of the ground water level in the *Neossolo Flúvico* (1.00 m) (Table 2). In color expression, a marked characteristic in the surface horizons is the predominance of dark colors, registered by the value and chroma from 1 to 3, except for lighter colors in the P6 profile, value 4 and chroma 4 to 6 (Table 2). For the surface horizons, dark colors mainly reflect the influence of a higher amount of organic matter, and for many horizons this is associated with soil quality. In this context, the smaller thickness and relatively clear color of the Ap and A horizon in the *Argissolo Amarelo* can be attributed to losses of mineral and organic colloidal material by lateral removal, due to the higher water flow in the lower position of the landscape. In this same soil, in the AB horizon, lighter color can be attributed to the intense translocation of colloidal material, which is corroborated by the lower contents of organic carbon (OC) and clay compared to the Bt1 horizon (Tables 2 and 4).

A decrease in the value and chroma in the A2 horizon in relation to the overlying (A1) and underlying (AB) horizons was observed in the profile with the *A húmico* horizon, especially in the *Latossolo Amarelo* (Table 2). This darkening can be attributed in part to

Table 2. Morphological properties and organic carbon of the soils from the Pito Aceso basin, municipality of Bom Jardim (RJ)

Hor[(1)]	Depth	Texture	Structure	Color	OC
	m			moist	g kg^{-1}
			P1 - *Neossolo Litólico* Húmico típico		
Ap	0.00-0.40	sandy loam lr.	st. sm. and vsm. gra.	10YR 2/1	76.2
R	0.40^{+}				
			P2 - *Cambissolo* Húmico Distrófico típico		
Ap	0.00-0.33	clay loam	st. vsm. and sm. gra.	10YR 2/1	37.6
A1	0.33-1.00	sand clay	st. vsm. and sm. gra.	10YR 2/1	28.4
A2	1.00-1.10	sand clay	st. vsm. and sm. gra.	10YR 2/2	18.3
AB	1.10-1.25	sand clay	wk. sm. and med. sab.	7.5YR 3/2	13.5
Bi	1.25-1.50^{+}	clay loam	wk. sm. and med. sab.	5YR 4/4	8.8
			P3 - *Argissolo Vermelho-Amarelo Eutrófico* úmbrico		
Ap	0.00-0.27	sandy clay loam	mo. med. and lg. gra.	5YR 3/1	16.8
AB	0.27-0.43	sandy clay loam	mo. med. sab.	5YR 3/2	12.9
BA	0.43-0.63	sand clay	mo. med. sab.	5YR 3/4	9.2
Bt1	0.63-0.80	sand clay	mo. sm. and med. sab. and ab.	5YR 3/4	7.0
Bt2	0.80-1.20	clay	mo. med. sab. and ab.	5YR 4/4	4.9
BC	1.20-1.50^{+}	sand clay	wk. sm. and med. sab. and ab.	5YR 3/4	4.3
			P4 - *Argissolo Vermelho Distrófico* úmbrico		
Ap	0.00-0.48	sandy clay loam	mo. sm. and med. gra.	5YR 3/3	11.8
BA	0.48-0.75	sand clay	mo. med. sab.	3.5YR 3/4	7.0
Bt1	0.75-0.95	clay	mo. med. sab.	2.5YR 3/3	10.1
Bt2	0.95-1.10	clay	mo. med. sab.	2.5YR 3/4	8.4
Bt3	1.10-1.33	very clayey	mo. med. sab.	2.5YR 4/5	6.4
Bw	1.33-1.80^{+}	clay	wk. sm. and med. sab.	2.5YR 4/7	5.4
			P5 - *Latossolo Amarelo Distrófico húmico*		
Ap	0.00-0.20	clay	mo. sm. and med. gra.	7.5YR 3/2	17.2
A1	0.20-0.38	clay	mod. sm. and med. gra.	7.5YR 3/3	15.8
A2	0.38-0.61	clay	st. sm. gra.	7.5YR 2.5/2	17.2
AB	0.61-0.85	clay	wk. med. sab.	10YR 3/3	10.9
BA	0.85-1.05	clay	wk. med. sab.	10YR 4/6	7.3
Bw1	1.05-1.47	clay	wk. med. sab.	10YR 5/8	4.9
Bw2	1.47-1.80^{+}	clay	wk. med. sab. that is undone st. vsm. gra.	8.5YR 6/8	3.5
			P6 - *Argissolo Amarelo Distrófico abrúptico*		
Ap	0.00-0.26	sandy clay loam	mo. sm. and med. gra. and wk. sm. and med. sab.	7.5YR 4/4	9.9
A	0.26-0.40	sandy loam	wk. sm. and med. sab.	10YR 4/4	7.3
AB	0.40-0.62	sandy loam	wk. sm. and med. sab.	10YR 4/6	3.7
Bt1	0.62-1.04	clay	mo. med. sab.	7.5YR 4/4	6.0
Bt2	1.04-1.60^{+}	clay	mo. sm. and med. sab.	7.5YR 5/8	4.5
			P7 - *Neossolo Flúvico Tb Distroúmbrico gleissólico*		
Ap	0.00-0.25	sandy clay loam	mo. med. and gr gra.	10YR 3/3	11.5
C	0.25-0.63	sandy clay loam	wk. sm. and med. sab.	10YR 5/6	3.5
Cg	0.63-1.00^{+}	sandy clay loam	massive	7.5YR 6/2	3.6

[(1)] Horizon. wk.: weak; mo.: moderate; st.: strong; vsm.: very small; sm.: small; med.: medium; lg.: large; gra.: granular; ab.: angular blocky; sab.: subangular blocky; lr.: little rubble; OC: organic carbon. Other conventions: p = tillage or other disturbance (disturbance by mechanical means, pasturing, or other modifications by human uses); t = accumulation of clay (clay formed within a horizon and subsequently translocated within the horizon or that has been moved into the horizon by illuviation, or both); w = intensive alteration (designation for the mineral material with an advanced stage of weathering, low clay activity, granular structure, or moderately blocky, and no clay or organic matter accumulation); g = gleying (iron reduced and removed during soil formation or that saturation through stagnant water that could be observed by gray, bluish, greenish or mottling colors resulting from the mobilization of iron or manganese with or without segregation). All designations are according to Brazilian recommendations from the Field Soil Description and Sampling Manual (Santos et al., 2013b).

the increase in OC contents in this horizon (Table 2) and the higher participation of fulvic and humic acid fractions, which represent 50 % of OC, with predominance of humic acids (26 %) (Table 3). Humic acids impart a dark color to soil due to their intense black color. For the other surface horizons, the influence of these two fractions was lower (<38 %), with humic acid values lower than 15 % (Table 3).

Studies of soils with variations in color in surface horizons and darkening with depth was highlighted in a *Latossolo Amarelo* with an A humic horizon at the 1st Soil Classification and Correlation Meeting (Embrapa, 1979), as well as observed in other soil profiles with the A horizon described in the same region (Calderano Filho, 2012). In this respect, Calegari (2008) highlights the occurrence of soil profiles with this same pattern of color variation in an *A húmico* horizon developed in *Latossolos* from different regions of Brazil.

In the subsurface horizons, the colors ranged from 2.5YR (red) to 10YR (yellow), with values from 3 to 6 and chrome from 4 to 8 (Table 2). The soil color variation can be attributed in part to the chemical and mineralogical composition of the rock, such as varied sources of iron, and/or attributed to the dynamics of iron oxide formation and expression. For free drainage environments, the gradient between the yellow and red color is attributed to the differentiated formation and expression of goethite and hematite. The yellowish color indicates greater expression of goethite, while the reddish color denotes the presence of hematite (Sposito, 1989; Inda Jr et al., 2012; Ribeiro et al., 2012).

The relationship between different parent materials, mainly in regard to their mineralogical composition, and color in the subsurface was highlighted by Santos (2009) in soil profiles from three toposequences in the Paraíba do Sul region, state of Rio de Janeiro. In that

Table 3. Humic fraction contribution to the organic carbon of the soils from the Pito Aceso basin, municipality of Bom Jardim (RJ)

Horizon	C-FAF	C-FAH	C-HUM	C-FAF + C-FAH
	%			
P4 - *Argissolo Vermelho Distrófico* úmbrico				
Ap	22.0	28.8	40.7	50.8
BA	37.1	14.3	74.3	51.4
Bt1	29.7	22.8	53.5	52.5
Bt2	31.0	21.4	75.0	52.4
Bt3	37.5	6.3	68.8	43.8
Bw	33.3	9.3	40.7	42.6
P5 - *Latossolo Amarelo Distrófico húmico*				
Ap	12.8	12.8	30.8	25.6
A1	14.6	14.6	29.1	29.2
A2	23.8	25.6	11.0	49.4
AB	14.7	22.9	43.1	37.6
BA	13.7	16.4	61.6	30.1
Bw1	34.7	12.2	34.7	46.9
Bw2	34.3	2.9	71.4	37.2
P6 - *Argissolo Amarelo Distrófico abrúptico*				
Ap	28.3	17.2	37.4	45.5
A	27.4	17.8	37.0	45.2
AB	27.0	16.2	83.8	43.2
Bt1	41.7	10.0	45.0	51.7
Bt2	33.3	4.4	93.3	37.7

C-FAF: carbon of the fluvic acid fraction; C-FAF: carbon of the humic acid fraction; C-HUM: carbon of the humin. The organic carbon content in the humic fractions was obtained according Benites et al. (2003).

study, soils developed from basic materials (basalt and gabbro) had 5YR color in the intermediate part of the profile and 7.5YR in the underground. In contrast, along the toposequence, acidic rocks (muscovite-biotite gneiss) with lower iron contents had a varied color, reddish in the upper and middle thirds (2.5YR, 5YR, and 7.5YR) becoming yellowish in the lower third, where the 7.5YR and 10YR become more evident.

In hydromorphic environments, such as that observed in the Cg2 horizon (*Neossolo Flúvico*), iron is reduced and, for that reason, the grayish color expresses mixing of predominantly kaolinite mineral and organic matter. The occurrence of mottled indicates iron oxidation in the aeration zones, according to the seasonality of hydromorphism by fluctuation in the ground water level. In the Bt1 and Bt2 horizons in *Argissolo Vermelho* and *Amarelo*, a decrease in value and chroma was observed in relation to the overlying horizons, characterizing a slight darkening in soil color. As a differential pattern, these horizons have colloidal organic matter in their morphology as films deposited on the surface of soil aggregates. Meanwhile, in the *Argissolo Vermelho*, the effect of the substantial humic acid increase in these horizons (black color) is added, around 22 % of the OC, whereas in the *Argissolo Amarelo* the increase was in fulvic acids (yellow-brown) and about 42 % of OC (Table 3).

In this same line of observation, Oenning (2001), Almeida et al. (2009), Botelho (2011), and Lunardi Neto (2012) report an expressive degree of darkening for the AB, BA, and Bt horizons in soils from the states of Santa Catarina and Rio Grande do Sul. The authors highlight the dark horizons related to the occurrence of organic material on the peds surface and the increase in OC, which was attributed to illuviation of colloidal organic matter. In addition, Oenning (2001), Botelho (2011), and Lunardi Neto (2012) discuss the greater participation of humic acids in several soil profiles, thus emphasizing the participation of the humic fraction in the dark color in the subsurface horizons. For the same soils, Almeida et al. (2009) and Botelho (2011) reject the occurrence of a buried A horizon, which was defined by the similarity of sand fractions between the horizons along the soil profile. Regarding deposition of colloidal organic matter, the authors suggest that the organic compounds associated with aluminum and iron may have accumulated as clay-humic complexes during events after the development of the B textural horizon. This darkening concurs with the maximum accumulation of fine clay in the AB and BA subsurface horizons and not with the horizons that exhibit clay accumulation in the profile.

The OC contents in the surface horizons have a large amplitude, from 3.7 to 76.2 g kg^{-1}, whereas the amplitude in the subsurface horizons is from 3.5 to 10.1 g kg^{-1} (Table 2). The observation of a wide range of OC contents along the landscape may be associated with different soil formation conditions, especially for the surface horizons. Considering that the current conditions of humid climate and mountainous relief favor decomposition of the organic material and higher erosion due to surface runoff, the surface horizons with high OC contents have characteristics of "Relictual Soils - Paleosols'' (Queiroz Neto and Castro, 1974; Lepsch and Buol, 1988; Buol and Eswaram, 1999; Calegari, 2008). These authors associate relictual soils with a stable landscape, where the cold climate propitious the accumulation of organic matter by the significant decrease in biogeochemical processes, thus the organic matter is preserved through the formation of organomineral complexes. According to Schaetzl and Anderson (2005), under relictual soil conditions, accumulation of large amounts of organic matter on the surface occurred in the past climate, where grass species predominated and a drier climate in the late Pleistocene to medium Holocene (Calegari, 2008).

In association with the previous conditions, the influence of the microclimate with a lower temperature at higher elevations (>1000 m) and the physical protection provided by rock fragments increase preservation of organic matter in the surface horizon of *Neossolo Litólico* and *Cambissolos Húmico* through a significant decrease in organic matter decomposition rates. In the case of *Neossolo Flúvico*, the presence of the A prominent horizon and seasonal hydromorphism lead to a decrease in the decomposition rates of organic matter by biogeochemical processes.

For the other chemical properties, the pH values in water and KCl varied slightly within each soil profile, and the pH in water was higher than 5.4 in all the horizons of *Cambissolo* and *Argissolos Vermelho-Amarelo* and *Amarelo* (Table 4). The lower values for pH in KCl compared to pH in water give a negative ΔpH and express the predominance of negative charges, giving the soils cation exchange capacity. Together with this observation, there is a gradient in the soil profile and through the landscape of the exchangeable cations. The sum of exchangeable bases (SB) decreases from the summit to the toeslope, as well as at depth; it varies from 3.5 to 12.3 $cmol_c$ kg^{-1} at the summit and shoulder, while in the other positions it does not exceed 2.3 $cmol_c$ kg^{-1} (Table 4).

The SB gradient along the landscape may be related to rochosity at the summit and shoulder, where the weathering of the primary minerals serves as a constant source of calcium and magnesium. Along the slope, the leaching of the elements is attributed to removal of bases from pedogenic evolution, or to the colluvial nature of reworked and weathered material. In further analysis, the variation of the parent material along the landscape contributes differentiated as source of primary minerals, and consequently in the contribution of these in the soils.

In regard to potential acidity, the Al^{3+} contents vary greatly between and within the profiles, especially in the *Argissolo Vermelho-Amarelo*, with absence of this element throughout the soil profile, and for the surface horizons of the *Latossolo Amarelo*, in which the contents are around 2.2 $cmol_c$ kg^{-1} (Table 4). In the Bt1 and Bt2 horizons of the *Argissolo Vermelho* and in the A2 and AB horizons of the *Latossolo Amarelo*, the Al^{3+} contents are higher than the overlying and underlying horizons. That pattern is attributed an increase in the OC contents and the predominance of humic fractions with higher reactivity, such as fulvic and humic acids (Tables 2 and 3).

The values of cation exchange capacity (CEC) in the soil profiles decreased with depth, except for the gley horizon. The values ranged from 3.7 to 35.1 $cmol_c$ kg^{-1} in the surface horizons and from 5.1 to 11.4 $cmol_c$ kg^{-1} in the subsurface horizons (Table 4). The high values of CEC in the surface horizons are related to the high organic matter content, observed mainly in the *A húmico* and *A proeminente* horizons. According to Calderano Filho (2012), the predominant mineralogy of the clay in the soil of the same region is kaolinite and iron and aluminum oxides, with very low CEC participation. Thus, by the chemical dynamics and large participation of potential acidity, the soils have base saturation from 7 to 47 % in the surface horizons. Values of base saturation from 10 to 41 % in the sub-surface horizons, except for the *Argissolo Vermelho-Amarelo* with values above 53 % throughout the profile (Table 4). In contrast, the *Latossolo Amarelo* stands out through aluminum saturation higher than 50 % practically throughout the profile.

For particle size composition, predominance of coarse sand (251 to 528 g kg^{-1}) and clay (125 to 619 g kg^{-1}) fractions was observed, except for the *Neossolo Litólico*, in which the coarse sand content is followed by silt (Table 4). The clay increases in depth for the shoulder and backslope, where the water flow facilitates lateral removal of the colloidal material from the surface horizons. However, the colluvial-alluvial soil has erratic distribution of the particle size fractions and greater participation of the silt fraction occurs in the summit with talus deposition, which reflects the low degree of pedogenetic development.

In morphology, the occurrence of cutans (common and strong, common and moderate) in the Bt1 and Bt2 horizons, corroborating the increase in clay contents in depth for the *Argissolos*. The values of the textural gradient in the *Argissolos Vermelho-Amarelo*, *Vermelho* and *Amarelo* (1.44, 1.91, and 2.37, respectively) are highlighted, and in the *Argissolo Amarelo*, abrupt variation in the texture was observed according to the clay contents, which were 181 and 447 g kg^{-1} in the AB and Bt1 horizons, respectively

Table 4. Chemical and physical properties of the soils from the Pito Aceso basin, municipality of Bom Jardim (RJ)

Horizon	pH		SB	Al^{3+}	CEC	V	m	CS	FS	Silt	Clay	CS/FS
	H_2O	KCl		$cmol_c\ kg^{-1}$			%		$g\ kg^{-1}$			
					P1 - *Neossolo Litólico* Húmico típico							
Ap	5.3	4.1	8.8	0.9	34.2	26	9	488	159	228	125	3.07
R												
					P2 - *Cambissolo* Húmico Distrófico típico							
Ap	6.1	4.8	12.3	0.1	35.1	35	1	298	121	248	333	2.46
A1	6.0	4.4	9.7	0.2	20.8	47	2	338	113	194	355	2.99
A2	5.7	4.1	4.2	1.2	14.2	30	22	321	144	181	354	2.23
AB	5.7	4.1	3.5	1.2	11.6	30	26	341	149	170	340	2.28
Bi	5.6	4.0	4.0	1.5	10.7	37	27	251	130	284	335	1.93
					P3 - *Argissolo Vermelho-Amarelo Eutrófico* úmbrico							
Ap	6.2	5.1	6.9	0	10.1	68	0	377	177	181	265	2.13
AB	6.3	4.9	7.0	0	9.7	72	0	332	164	156	348	2.02
BA	6.4	4.6	6.2	0	9.1	68	0	312	154	144	390	2.03
Bt1	6.3	4.9	5.5	0	8.2	67	0	320	120	120	440	2.70
Bt2	6.2	4.9	4.8	0	9.0	53	0	258	145	101	496	1.78
BC	6.1	4.8	4.4	0	6.6	67	0	294	161	48	497	1.83
					P4 - *Argissolo Vermelho Distrófico* úmbrico							
Ap	4.9	3.9	2.3	0.7	9.0	26	23	528	102	86	284	5.18
BA	4.9	3.9	1.7	0.8	7.9	22	32	428	110	75	387	3.89
Bt1	4.8	3.9	1.6	1.6	11.4	14	50	313	78	74	535	4.01
Bt2	4.9	3.9	1.5	1.2	10.3	15	44	295	72	36	597	4.1
Bt3	5.0	4.1	1.1	0.9	7.9	14	45	272	68	41	619	4.0
Bw	5.0	4.2	0.9	0.6	6.4	14	40	315	72	36	577	4.38
					P5 - *Latossolo Amarelo Distrófico húmico*							
Ap	4.5	3.9	1.9	1.7	13.9	14	47	343	105	100	452	3.27
A1	4.5	4.0	1.1	2.2	14.0	8	67	335	91	101	473	3.68
A2	4.6	4.0	1.1	2.2	15.0	7	67	333	103	91	473	3.23
AB	4.9	4.0	0.9	2.1	11.6	8	70	341	103	63	493	3.31
BA	5.0	4.1	0.8	1.4	8.4	10	64	326	113	48	513	2.88
Bw1	4.7	4.1	0.6	1.0	6.0	10	62	322	117	49	512	2.75
Bw2	4.8	4.2	0.6	0.7	5.2	12	54	326	119	42	513	2.74
					P6 - *Argissolo Amarelo Distrófico abrúptico*							
Ap	5.6	4.1	1.5	0.4	5.8	26	21	413	166	178	243	2.49
A	5.4	4.0	0.8	0.5	4.3	19	38	474	166	178	182	2.66
AB	5.6	4.0	0.9	0.3	3.7	24	25	493	135	191	181	2.58
Bt1	5.4	4.0	1.1	0.7	5.8	19	39	311	112	130	447	2.78
Bt2	5.4	4.2	0.7	0.4	4.9	14	36	275	98	118	509	2.33
					P7 - *Neossolo Flúvico Tb Distroúmbrico gleissólico*							
Ap	4.3	3.7	1.1	1.8	10.7	10	62	353	173	188	286	2.04
C	4.6	3.8	0.8	1.1	5.1	16	58	479	200	119	202	2.40
Cg	5.3	3.9	2.6	0.5	6.3	41	16	364	218	174	244	1.67

SB: sum of exchangeable bases; CEC: cation exchange capacity at pH 7.0; V: base saturation; m: aluminum saturation; CS: coarse sand; FS: fine sand. These analyses were performed in the air-dried fine earth according to the methods described in Donagema et al. (2011).

(Table 4). In this context, occurrence of the translocation and removal process is conducted by soil relief in favor of the relative and/or absolute increase in clay contents. In this sense, the position and curvature of the geomorphic surface become significant in the differentiated formation along the landscape, as in the formation of the textural gradient in the *Argissolos*.

As regards the composition obtained by sulfuric acid digestion of the subsurface horizons, SiO_2 and Al_2O_3 are predominantly present, with contents from 94 to 232 g kg^{-1}, most of them greater than 150 g kg^{-1}. However, the Fe_2O_3 were approximately half of the previous oxides (43 to 92 g kg^{-1}) (Table 5). In this context, similar results were obtained by Pereira and Anjos (1999) in soils developed in different rocks and sediments, and Chagas et al. (2013) in *Argissolos* developed from noritic granulites in the northwest region of the state of Rio de Janeiro. Santos (2009), in the Ribeirão do Cachimbal microbasin in the Paraíba do Sul region, highlights equitable distribution between SiO_2, Al_2O_3, and Fe_2O_3 in basic rocks, while for acid rock, Fe_2O_3 was approximately 1/3 in comparison to SiO_2 and Al_2O_3. The Ki and Kr values also had a similar pattern to the study under discussion.

According to Resende and Santana (1988), the qualitative composition of the clay mineralogy can be inferred by the molecular relations of the Ki and Kr index. The Ki values in the profiles ranged from 1.44 to 2.14, with most less than 1.8, and the Kr ranged from 1.13 to 1.64. The values of both indexes >0.75 indicate the predominance of kaolinite in the clay fraction. This evidence was also reported by Calderano Filho (2012). Thus, kaolinite was often accompanied by goethite and gibbsite.

In fact, the iron oxide contents obtained by selective extraction show wide variation among the soil profiles. Highest values were observed in the C horizon of the *Neossolo Flúvico*, both for the Feo (1.0 to 5.1 g kg^{-1}) and Fed contents (34.6 to 51.8 g kg^{-1}) (Table 5). The lowest Feo contents were found in the backslope soil profiles, while, for the Fed, there was a tendency to increase from the summit to the toeslope. The predominance of high crystallinity forms of iron was detected by the Feo/Fed ratio and contents ranged from 0.03 to 0.14. In the slope profiles, contents were less than 0.05, which are lower than those found in the summit soil profiles (talus deposit) and toeslope (Table 5). In soils developed from different parent materials, Pereira and Anjos (1999) reported the variation among the subsurface horizons. These authors observed predominance of Fed,

Table 5. Oxides obtained by sulfuric acid digestion and selective extraction of the soils from the Pito Aceso basin, municipality of Bom Jardim (RJ)

Soil Class	Horizon	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ki	Kr	Feo	Fed	Feo/Fed
		g kg^{-1}						g kg^{-1}		
P2 - *Cambissolo Húmico*	Bi	232	184	88	12.0	2.14	1.64	4.8	36.3	0.13
P3 - *Argissolo Vermelho-Amarelo*	Bt1	159	188	81	10.6	1.44	1.13	4.7	34.6	0.14
	Bt2	205	164	92	10.9	2.13	1.56			
P4 - *Argissolo Vermelho*	Bt1	173	166	84	9.2	1.77	1.34	2.2	40.8	0.05
	Bt2	175	188	83	9.6	1.58	1.23			
	Bt3	185	195	91	10.3	1.61	1.24			
	Bw	173	191	78	9.5	1.54	1.22			
P5 - *Latossolo Amarelo*	Bw1	158	163	74	8.6	1.65	1.28	1.0	40.0	0.03
	Bw2	152	164	71	8.2	1.58	1.23			
P6 - *Argissolo Amarelo*	Bt1	203	197	72	13.9	1.75	1.42	1.6	45.0	0.04
	Bt2	226	215	86	15.5	1.79	1.42			
P7 - *Neossolo Flúvico*	C	99	94	43	5.2	1.79	1.38	5.1	51.8	0.10
	Cg	133	113	48	6.6	2.00	1.57			

Ki = $(SiO_2/Al_2O_3) \times 1.7$; Kr = $(SiO_2 \times 1.7)/(Al_2O_3 + (0.64 \times Fe_2O_3))$; Feo: iron extracted by oxalate ammonium acid; and Fed: iron extracted by dithionite-citrate-bicarbonate. These analyses were performed in the air-dried fine earth according to the methods described in Donagema et al. (2011).

and greater Feo participation in the Cg horizons, which resulted in Feo/Fed ratios similar to those of this study. Santos (2009) observed wide variation in these oxides among the soil classes and among the horizons of each soil profile; the Feo/Fed ratio was slightly lower in the soils formed on the slope (backslope).

The differentiated formation of the soils is revealed by the application of theories and models that include the factors, mechanisms, and processes of soil formation. These will be approached clearly by variations in the degree of pedogenetic development, depending on the morphological, physical, chemical, and mineralogical properties of the profiles studied. The *Neossolo Litólico* and *Cambissolo Húmico* have the lowest degree of development, which is attributed to rejuvenation (morphogenesis > pedogenesis) through constant deposition of rock fragments as a talus deposit. In the *Neossolo Flúvico*, the constant accumulation of sediments is mainly due to the deposition of alluvial materials with different particle sizes and chemical compositions. Furthermore, for the *Neossolo Flúvico* with seasonal hydromorphism, expression of the great majority of pedogenetic processes is limited by its lowland position and proximity to the watercourse. As a reflection of seasonal hydromorphism, the anaerobic condition leads to reduction of Fe^{3+} to Fe^{2+} and, thus, the colorlessness of the iron oxides. In this process, the grayish colors stand out as a consequence of the mixture of kaolinite and organic matter, resulting in the gleization process (reduction/oxidation) (Kämpf and Curi, 2012b).

Nevertheless, *Argissolos* occur mainly where the flow lines lead to water convergence (concave curvature), providing greater water infiltration in the soil profile and surface runoff. The greater internal water flow in the profile contributes to expression of downward translocation of dispersed colloidal organic and mineral materials, as observed by the textural gradient and increase in OC contents in the subsurface. In this soil, the absolute increase in the clay content in the subsurface horizon is caused by the pedogenetic process of argilluviation (eluviation/illuviation), which was observed through the relative increase in the clay content and by the cutans in the Bt1 and Bt2 horizons. In association with the previous process, surface runoff promotes selective removal of the mineral and organic colloidal particles by the elutriation process (Kämpf and Curi, 2012b). The argilluviation or elutriation processes occurring in an isolated or combined manner direct the formation of the B textural horizon.

In the *Latossolo Amarelo* and *Argissolo Vermelho*, the presence of the Bw horizon suggests considerable evolution of soils due to lower participation of silicate minerals in the clay fraction and consequent relative increase in oxides, attributed to the process of ferralitization (desilication and oxidation) (Kämpf and Curi, 2012b), which is favored by the combination of free drainage in the soil profile and high rainfall. In addition to the action of pedogenetic processes, possible variations in the chemical and mineralogical composition of the parent material lead to differences in the sorption complex and color variation in the subsurface. However, the presence of colluvium is considered possible since variations in the relationship between coarse sand and fine sand were found, as in *Argissolo Vermelho-Amarelo* from the significant change between the Bt1 and Bt2 horizons, in the *Argissolo Vermelho* between the Ap and BA horizons, and the *Latossolo Amarelo* between the AB and BA horizons (Table 4).

Reflections on the formation of *Latossolos* with the *A húmico* horizon have been made based on polygenetic development and are thus considered relictual. Calegari (2008) concluded that the *A húmico* horizons were developed under drier and colder conditions in the lower and middle Holocene when the accumulation of organic matter and the melanization process would have begun, along with active soil fauna contributing to redistribution and homogenization of the material along the profile. In that study, the author refers to colluvial material, based on bibliographical reviews, as well as the morphological, particle size, and geochemical data of the study itself, which almost always indicate lithological discontinuity between the A and B horizons. The reworked material deposited from summit surfaces provides *latossólicas* porperties, especially microaggregates, kaolinite mineralogy, and oxides.

In the present landscape, the occurrence of *Latossolos* demarcates the resilience of these soils and their strong association with accentuated development of the surface horizons and the structure of the profile as a whole. In the surface of occurrence, the convex relief form is highlighted, as a factor that influences divergence of the lines of water flow, minimizing the erosive action of the surface water. The study by Chagas (2006) showed the influence of curvature on the degree of weathering of soils, with the most developed soils always occupying the slopes with convex curvature, similar to that verified in this study.

The occurrence of the Bt horizon over Bw in the *Argissolo Vermelho* suggests the occurrence of differentiated pedogenic processes, indicating possible polygenetic formation. According to Bocquier (1973), it is possible that transformations from one soil to another are not complete, especially in the deeper layers or horizons of the soil profile, since accumulations and transformations make them more superficial. Coltrinari et al. (1978) indicate the possibility of significant clay accumulation at the top of a *B latossólico* horizon because of translocation of the clay fraction, mainly as a result of the water percolation through the profiles. In the landscape of the present study, this would be controlled by climatic variation throughout the Pleistocene/Holocene, as highlighted by Lepsch and Buol (1986), Pessenda et al. (2005), and Calegari (2008).

CONCLUSIONS

Local geomorphological features are associated with possible variations in the chemical and mineralogical composition of the parent material, directly influencing pedogenesis and conditioning the occurrence of distinct soil classes in the landscape. Variation in the geomorphic surfaces conditions soil formation processes under current conditions and preservation of polygenetic soils.

Soils with a lower degree of development (*Neossolos* and *Cambissolos*) and with greater participation of the sorption complex were identified at the summit (talus deposit) and toeslope (colluvial-alluvial), whereas the more developed soils with lower nutrient content occurred in the concave (*Argissolos*) and convex (*Latossolo*) backslope, except for the *Argissolo Vermelho-Amarelo* in the shoulder, which had high content of the sorption complex.

The formation of the *A húmico* horizon can be explained by the climate and vegetation conditions, while its current occurrence is due to the condition of greater stability of relief features, as in the *Latossolo*. The influence of the microclimate near the rocky base with lower temperature at higher altitude (>1,000 m) and the physical protection provided by the rock fragments is increased for the *Neossolo Litólico* and *Cambissolo Húmico*.

The development of a textural gradient in the *Argissolos* results from the combination of several processes and, in this study, it was closely related to water activity on the soil surface, whose concave curvature and linear profile condition both water infiltration in the soil profile and surface flow, removing particles of colloidal size and/or water percolation in the profile that facilitates the translocation of the colloidal mineral material.

ACKNOWLEDGMENTS

Our thanks for financial support of the projects: Faperj No. E-26/112.139/2008: Agroecological Zoning with Support of Digital Mapping Techniques of the Bom Jardim County (RJ); Faperj No. E-26/111.934/2011: Dynamics of soils with high organic matter content of the mountainous region of Rio de Janeiro State; Embrapa No. 02.09.01.021.00.00:

Landscape dynamics associated to indicators to subsidize land use planning and the characterization of environmental services. Thanks also to the researcher Fabiano de Carvalho Balieiro from Embrapa Solos for the landscape design presented in figure 2.

REFERENCES

Almeida JA, Cararo DC, Uberti AAA. Genesis of the sombric horizon in Ultisols (Red Argisols) in Southern Santa Catarina, Brazil. Rev Bras Cienc Solo. 2009;33:405-16. https://doi.org/10.1590/S0100-06832009000200018

Benites VM, Madari B, Machado PLOA. Extração e fracionamento quantitativo de substâncias húmicas do solo: um procedimento simplificado de baixo custo. Rio de Janeiro: Embrapa Solos, 2003. (Comunicado técnico, 16).

Bocquier G. Genése et évolution de deux toposéquences de sols tropicaux du Tchad: interprétation biogéodynamique. Paris: Orstom, 1973.

Botelho MR. Gênese de horizontes subsuperficiais escuros de solos em área do Batólito Pelotas, RS [tese]. Pelotas: Universidade Federal de Pelotas; 2011.

Buol SW, Eswaran H. Oxisols. Adv Agron. 1999;68:151-95. https://doi.org/10.1016/S0065-2113(08)60845-7

Campos MCC, Marques Júnior J, Pereira GT, Montanari R, Camargo LA. Relações solo-paisagem em uma litossequência arenito-basalto na região de Pereira Barreto, SP. Rev Bras Cienc Solo. 2007;31:519-29. https://doi.org/10.1590/S0100-06832007000300012

Campos MCC, Ribeiro MR, Souza Júnior VS, Ribeiro Filho MR, Almeida MC. Relações solo-superfície geomórfica em uma topossequência várzea-terra firme na região de Humaitá (AM). Rev Bras Cienc Solo. 2012;36:325-36. https://doi.org/10.1590/S0100-06832012000200002

Campos MCC, Ribeiro MR, Souza Júnior VS, Ribeiro Filho MR, Costa EUC. Segmentos de vertente e atributos do solo de uma topossequência na região de Manicoré, AM. Rev Cienc Agron. 2010;41:501-10. https://doi.org/10.1590/S1806-66902010000400001

Campos MCC, Ribeiro MR, Souza Júnior VS, Ribeiro Filho MR, Souza RVCC. Relações solo-paisagem em uma topossequência sobre substrato granítico em Santo Antônio do Matupi, Manicoré (AM). Rev Bras Cienc Solo. 2011;35:13-23. https://doi.org/10.1590/S0100-06832011000100002

Calegari MR. Ocorrência e significado paleoambiental do Horizonte A húmico em Latossolos [tese]. Piracicaba: Escola Superior de Agricultura "Luiz de Queiroz"; 2008.

Calderano Filho B. Análise geoambiental de paisagens rurais montanhosas da Serra do Mar utilizando redes neurais artificiais. Subsídios a sustentabilidade ambiental de ecossistemas frágeis e fragmentados sob interferência antrópica [tese]. Rio de Janeiro: Universidade Federal do Rio de Janeiro; 2012.

Calderano Filho B, Polivanov H, Guerra AJT, Chagas CS, Carvalho Júnior W, Calderano SB. Estudo geoambiental do município de Bom Jardim - RJ, com suporte de geotecnologias: subsídios ao planejamento de paisagens rurais montanhosas. Sociedade & Natureza. 2010;22:55-73. https://doi.org/10.1590/S1982-45132010000100005

Carvalho Júnior W, Chagas CS, Calderano Filho B, Bhering SB, Donagemma GK, Calderano SB, Araújo FO, Pereira NR. Zoneamento agroecológico do município de Bom Jardim, região serrana do Estado do Rio de Janeiro. Rio de Janeiro: Embrapa Solos; 2013. (Boletim de pesquisa e desenvolvimento, 230).

Clemente EP, Schaefer CEGR, Oliveira FS, Albuquerque Filho MR, Alves RV, Sá MMF, Melo WF, Corrêa GR. Topossequência de solos na Ilha da Trindade, Atlântico Sul. Rev Bras Cienc Solo. 2009;33:1357-71. https://doi.org/10.1590/S0100-06832009000500028

Chagas CS. Mapeamento digital de solos por correlação ambiental e redes neurais em uma bacia hidrográfica no domínio de mar de morros [tese]. Viçosa: Universidade Federal de Viçosa; 2006.

Chagas CS, Fontana A, Carvalho Junior W, Caires SM. Atributos topográficos na diferenciação de Argissolos. Rev Bras Cienc Solo. 2013;37:1441-53. https://doi.org/10.1590/S0100-06832013000600002

Coltrinari L, Coutard JP, Nakashima P. Itinerário de excursão ao Vale do Parateí, SP. In: Colóquio interdisciplinar Franco-Brasileiro “Estudo e cartografia de formações superficiais e suas aplicações em regiões tropicais”; São Paulo. São Paulo: Guias das Excursões; 1978. p.11-28.

Cooper M, Vidal-Torrado P. Gênese de ferri-argilãs em horizontes b texturais de uma sequência de solos sobre diabásio em Piracicaba (SP). Sci Agric. 2000;57:745-50. https://doi.org/10.1590/S0103-90162000000400024

Cooper M, Vidal-Torrado P, Grimaldi M. Soil structure transformations from ferralic to nitic horizons on a toposequence in Southeastern Brazil. Rev Bras Cienc Solo. 2010;34:1685-99. https://doi.org/10.1590/S0100-06832010000500021

Corrêa MM, Ker JC, Barrón V, Torrent J, Curi N, Torres TCP. Caracterização física, química, mineralógica e micromorfológica de horizontes coesos e fragipãs de solos vermelhos e amarelos do ambiente tabuleiros costeiros. Rev Bras Cienc Solo. 2008;32:297-313. https://doi.org/10.1590/S0100-06832008000100028

Daniels RB, Gamble EE, Cady JG. The relation between geomorphology and soil morphology and genesis. Adv Agron. 1971;23:51-88. https://doi.org/10.1016/S0065-2113(08)60150-9

Dantas ME. Geomorfologia do Estado do Rio de Janeiro. In: CPRM. Serviço Geológico do Brasil. Rio de Janeiro: geologia, geomorfologia, geoquímica, geofísica, recursos minerais, economia mineral, hidrogeologia, estudos de chuvas intensas, solos, aptidão agrícola, uso e cobertura do solo, inventário de escorregamentos, diagnóstico geoambiental [CD ROM]. Rio de Janeiro: Embrapa Solos; Niterói: DRM- RJ; 2001.

Dokuchaev VV. Russian Chernozem. Jerusalem: Israel Program of Scientific Translation; 1967.

Donagema GK, Campos DVB, Calderano SB, Teixeira WG, Viana JHM, organizadores. Manual de métodos de análise do solo. 2a ed rev. Rio de Janeiro: Embrapa Solos; 2011.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Centro Nacional de Pesquisa de Solos. Anais da 1ª. Reunião de Classificação, Correlação e Interpretação de Aptidão Agrícola de Solos; 1979; Rio de Janeiro, SNLCS-SBCS.

Figueiredo MA, Varajão AFDC, Fabris JD, Loutfi IS, Carvalho AP. Alteração superficial e pedogeomorfologia no Sul do Complexo Bação - Quadrilátero Ferrífero (MG). Rev Bras Cienc Solo. 2004;28:713-29. https://doi.org/10.1590/S0100-06832004000400012

Hugget RJ. Soil landscape system: a model of soil genesis. Geoderma. 1975;1:1-22. https://doi.org/10.1016/0016-7061(75)90035-X

Inda Jr AV, Klamt E, Nascimento PC. Composição da fase sólida mineral do solo. In: Meurer EJ, editor. Fundamentos de química do solo. 5a ed. Porto Alegre: Evangraf, 2012. p.29-59.

Jenny H. Factors of soil formation - A system of quantitative pedology. New York: Mac Graw Hill; 1941.

Kämpf N, Curi N. Conceitos de solo e sua evolução histórica. In: Ker JC, Curi N, Schaefer CEGR, Vidal-Torrado P, editores. Pedologia: fundamentos. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2012a. p.1-20.

Kämpf N, Curi N. Formação e evolução do solo (pedogênese). In: Ker JC, Curi N, Schaefer CEGR, Vidal-Torrado P, editores. Pedologia: fundamentos. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2012b. p.207-302.

Lepsch IF. Formação e conservação dos solos. 2a ed. São Paulo: Oficina de Textos; 2010.

Lepsch IF, Buol SW. Oxisol-landscape relationship in Brazil. In: Proceedings of the 8th International Soil Classification Workshop; Campinas; 1986. Rio de Janeiro: Embrapa, SNLCS; University of Puerto Rico; 1988. p.174-89.

Lima HN, Mello JWV, Schaefer CEGR, Ker JC, Lima AMN. Mineralogia e química de três solos de uma topossequência da Bacia Sedimentar do Alto Solimões, Amazônia Ocidental. Rev Bras Cienc Solo. 2006;30:59-68. https://doi.org/10.1590/S0100-06832006000100007

Lunardi Neto A. Gênese de horizontes subsuperficiais escurecidos em Argissolos de Santa Catarina e em Luvissolo da Campanha Gaúcha [tese]. Lages: Universidade do Estado de Santa Catarina; 2012.

Matos GMM, Ferrari PG, Cavalcanti JC. Projeto faixa calcaria Cordeiro/Cantagalo. Belo Horizonte: Departamento Nacional de Produção Mineral, 1980.

Martins FP, Rosolen VS. Caracterização morfológica e física de uma catena (Latossolo- Gleissolo) no campo de murundu do Córrego da Fortaleza, chapada Uberlândia-Uberaba, Uberlândia-MG. Caminhos de Geografia. 2014;15:186-200.

Mendes CAR. Erosão superficial em encosta íngreme sob cultivo perene e com pousio no Município de Bom Jardim - RJ [tese]. Rio de Janeiro: Universidade Federal do Rio de Janeiro; 2006.

Moreau AMSS, Costa LM, Ker JC, Gomes FH. Gênese de horizonte coeso, fragipã e duripã em solos do tabuleiro costeiro do sul da Bahia. Rev Bras Cienc Solo. 2006;30:1021-30. https://doi.org/10.1590/S0100-06832006000600011

Nunes WAGA, Ker JC, Schaefer CEGR, Fernandes Filho EI, Gomes FH. Relação solo-paisagem-material de origem e gênese de alguns solos no domínio do “Mar de Morros”, Minas Gerais. Rev Bras Cienc Solo. 2001;25:341-54. https://doi.org/10.1590/S0100-06832001000200011

Oenning I. Gênese e classificação de solos argilosos com horizonte B escurecido do Sul do Brasil [dissertação]. Viçosa: Universidade Federal de Viçosa; 2001.

Pennock DJ, Zebarth BJ, De Jong E. Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma. 1987;40:297-315. https://doi.org/10.1016/0016-7061(87)90040-1

Pereira MG, Anjos LHC. Formas extraíveis de ferro em solos do Estado do Rio de Janeiro. Rev Bras Cienc Solo. 1999;23:371-82. https://doi.org/10.1590/S0100-06831999000200020

Pereira MG, Schiavo JA, Fontana A, Dias Neto AH, Miranda LPM. Caracterização e classificação de solos em uma topossequência sobre calcário na Serra da Bodoquena, MS. Rev Bras Cienc Solo. 2013;37:25-36. https://doi.org/10.1590/S0100-06832013000100003

Pessenda LCR, Gouveia SEM, Freitas HA, Ribeiro AS, Aravena R, Bendasolli JA, Ledru MP, Siefeddine AF, Scheel-Ybert R. Isótopos do carbono e suas aplicações em estudos paleoambientais. In: Souza CRG, Suguio K, Oliveira AMS, Oliveira PE, editores. Quaternário do Brasil. Ribeirão Preto: Holos Editora; 2005. p.75-93.

Queiroz Neto JP, Castro SS. Formações superficiais e Latossolo Vermelho-Amarelo húmico na área de Bragança Paulista, estado de São Paulo, Brasil. In: Anais 18° Congresso Brasileiro de Geologia; 1974; Porto Alegre. Porto Alegre: Sociedade Brasileira de Geologia; 1974. p.65-83.

Resende M, Santana DP. Uso das relações Ki e Kr na estimativa da mineralogia para classificação dos Latossolos. In: Anais da 3a Reunião de Classificação, Correlação de Solos e Interpretação de Aptidão Agrícola; 1988; Rio de Janeiro. Rio de Janeiro: Embrapa SNLCS; 1988. p.225-32.

Ribeiro MR, Oliveira LB, Araújo Filho JC. Caracterização morfológica do solo. In: Ker JC, Curi N, Schaefer CEGR, Vidal-Torrado P, editores. Pedologia: fundamentos. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2012. p.47-80.

Rodolfo Júnior F, Araújo LG, Souza RQ, Batista FPS, Oliveira DNS, Lacerda MPC. Relações solo-paisagem em topossequências na fazenda Água Limpa, Distrito Federal. Nativa, 2015;03:27-35. https://doi.org/10.14583/2318-7670

Ruhe RV. Geomorphic surfaces and the nature of soils. Soil Sci. 1956;82:441-56.

Ruhe RV. Elements of soil landscape. In: Transactions of the 7th International Congress of Soil Science; 1960. Madison: Soc Soil Sci; 1960. p.165-70.

Santos AC. Pedogênese e alterações geoquímicas em topolitossequência na Bacia do Ribeirão do Cachimbal na região do Médio Vale do Paraíba, RJ [tese]. Seropédica: Universidade Federal Rural do Rio de Janeiro; 2009.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Oliveira JB, Coelho MR, Lumbreras JF, Cunha TJF. Sistema brasileiro de classificação de solos. 3a ed. Rio de Janeiro: Embrapa Solos; 2013b.

Santos RD, Lemos RC, Santos HG, Ker JC, Anjos LHC, Shimizu SH. Manual de descrição e coleta de solo no campo. 6a ed rev ampl. Viçosa, MG: Sociedade Brasileira de Ciência do Solo. 2013a.

Schaetzl R, Anderson S. Soil: genesis and geomorphology. Cambridge: Cambridge University Press; 2005.

Silva AC, Vidal-Torrado P. Gênese dos Latossolos Húmicos e sua relação com a evolução da paisagem numa área cratônica do sul de Minas Gerais. Rev Bras Cienc Solo. 1999;23:329-41. https://doi.org/10.1590/S0100-06831999000200017

Silva AC, Vidal-Torrado P, Pérez MG, Martin Neto L, Vasquez FM. Relações entre matéria orgânica do solo e declividade de vertentes em toposseqüência de Latossolos do Sul de Minas Gerais. Rev Bras Cienc Solo. 2007;31:1059-68. https://doi.org/ 10.1590/S0100-06832007000500022

Soil Survey Staff. Keys to soil taxonomy. 12th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Sposito G. The chemistry of soils. New York: Oxford University Press; 1989.