Revista Ciência Agronômica, v. 50, n. 2, p. 177-187, abr-jun, 2019
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Pedogenesis in a topo-climosequence in the Agreste region of Pernambuco[1]

Pedogênese em uma topoclimossequência no agreste de Pernambuco

Carlos Roberto Pinheiro Junior[2], Marcos Gervasio Pereira[3]*, Ademir Fontana[4], Lucia Raquel Queiroz Pereira da Luz[5] and Thaís de Andrade Corrêa Neto[6]

ABSTRACT - The Borborema Plateau is characterized by different stages of relief evolution, which modify the climate and vegetation, and where high-altitude tropical forests can be seen surrounded by caatinga. The aim of this study was to characterize the soils of a topo-climosequence in the Agreste region of the State of Pernambuco, and evaluate the influence of the relief and climate on the pedogenesis. A topo-climosequence was selected, and trenches were opened in the geomorphological features of high-altitude forest (P1), between forest and pediplane (P2) and on a pediplanation surface (P3 and P4). A morphological description and a physical, chemical and micromorphological characterization were carried out. In general, the soils are sandy, with the predominance of a single-grain structure or weak aggregation. Higher values for pH, S, V% and assimilable P were found on the lower parts of the landscape. From the micromorphological analysis, the incipient development of pedogenic structures was detected in the C horizon in P1 and P3, clay translocation in P2 and the degradation of iron micronodules in P4. The P1 and P3 profiles were classified as *Neossolos Regolíticos Distróficos espessarênicos* (Regolsols), the P2 profile as a *Argissolo Amarelo Distrófico típico* (Alisol), and P4 as an *Planossolo Háplico Eutrófico arênico* (Planosol). Soil variation in the landscape was determined by climate, relief and parent material. Micromorphology was efficient in detecting attributes not seen in the field, such as incipient aggregation in the Neossolos Regolíticos (Regosols) and the degradation of iron micronodules in the Planossolo Háplico (Planosol).

Key words: Relief. Micromorphology. Sandy soils.

RESUMO - O Planalto da Borborema é caracterizado pelos diferentes estágios de evolução do relevo, modificando o clima e a vegetação, sendo observadas florestas tropicais, (brejos de altitude), circundado por caatinga. O objetivo deste trabalho foi caracterizar os solos de uma topoclimossequência no agreste pernambucano, avaliandoa influência do relevo e do clima na pedogênese. Foi selecionada uma topoclimossequência e abertas trincheiras nas feições geomorfológicas de brejo de altitude (P1), entre brejo de altitude e pediplano (P2) e em superfície de pediplanação (P3 e P4). Foi realizada a descrição morfológica e a caracterização física, química e micromorfológica. De maneira geral, os solos são arenosos, com predomínio da estrutura grão simples ou fraca agregação. Maiores valores de pH, S, V% e P assimilável foram quantificados nas partes mais baixas da paisagem. Na análise micromorfológica detectou-se o desenvolvimento pedogenético incipiente de estrutura nos horizontes C de P1 e P3; translocação de argila em P2; e degradação de micronódulos de ferro em P4. Os perfis P1 e P3 foram classificados como Neossolos Regolíticos Distróficos espessarênicos (Regosols); P2 como Argissolo Amarelo Distrófico típico (Alisol); P4 como Planossolo Háplico Eutrófico arênico (Planosol). A variação dos solos na paisagem foi determinada pelo clima, relevo e material de origem. A micromorfológica foi eficiente na detecção de atributos não observados em campo, como agregação incipiente nos Neossolos Regolíticos e degradação de micronódulos de ferro no Planossolo Háplico.

Palavras-chave: Relevo. Micromorfologia. Solos arenosos.

DOI: 10.5935/1806-6690.20190021

*Author for correspondence

Received for publication in 13/08/2017; approved in 15/05/2018

[1] Pesquisa financiada pela CAPES Proex

[2] Programa de Pós-Graduação em Agronomia-Ciência do Solo, Universidade Federal Rural do Rio de Janeiro/UFRRJ, Seropédica-RJ, Brasil, robertojrpinheiro@gmail.com (ORCID ID 0000-0002-2721-6704)

[3] Departamento de Solos, Universidade Federal Rural do Rio de Janeiro/UFRRJ, Seropédica- RJ, Brasil, mgervasiopereira01@gmail.com (ORCID ID 0000-0002-1402-3612)

[4] Centro Nacional de Pesquisa de Solos, Embrapa Solos, Rio de Janeiro-RJ, Brasil, ademir.fontana@embrapa.br (ORCID ID 0000-0001-7624-8676)

[5] Centro Nacional de Pesquisa de Solos, Embrapa Solos, Recife- PE, Brasil, lucia.luz@embrapa.br (ORCID ID 0000-0002-3988-5729)

[6] Pós-doutoranda do Programa de Pós-Graduação em Agronomia- Ciência do Solo, Universidade Federal Rural do Rio de Janeiro/UFRRJ, Seropédica-RJ, Brasil, tacneto@gmail.com (ORCID ID 0000-0003-1752-1526)

INTRODUCTION

Among the factors that influence soil formation, relief and climate are most often considered the main determinants of pedogenesis due to their influence on water flow and chemical weathering. Variations in relief are responsible for a number of changes in the characteristics and attributes of the soil, as they govern both the water dynamics of the landscape and drainage, controlling the intensity of formation processes. Variations in relief determine climatic change, especially in the water regime, which in turn intensifies reactions and processes in the soil (PEDRON; AZEVEDO; DALMOLIN, 2012). As a result, the degree of soil development, as well as the dynamics of exchangeable cations and the rate of weathering, are directly related to the position of the soil in the landscape (MEIRELES *et al*., 2012).

The district of Jurema, located in the Agreste region of Pernambuco, is inserted in the Borborema Plateau, characterized by different stages of relief evolution, which is reflected in the variations in climate, plant cover and predominant lithostructure (GURGEL *et al*., 2013; RODAL; BARBOSA; THOMAS, 2008). The topographic variations in the region promote changes in the climate and the occurrence of orographic rainfall with indices greater than 1,000 mm year^{-1} in the highest parts of the landscape, where the altitude can reach 900 m. Such conditions are responsible for the formation of pockets of moisture where ombrophilous, evergreen, and semi-evergreen forests, known as high-altitude tropical forests, can be seen, surrounded by caatinga vegetation with a semi-arid climate (RODAL; BARBOSA; THOMAS, 2008).

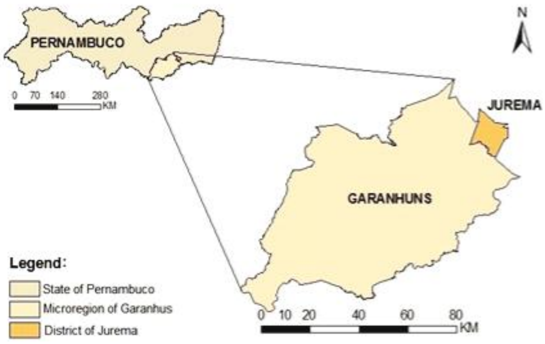
With the exception of the study by Souza *et al*. (2010), little is known about the high-altitude forest environments in the State of Pernambuco. Given the importance of conserving these environments due to the special conditions of humidity, temperature and vegetation, characterization of the physical, chemical and macro- and micromorphological attributes of the soil, with the aim of understanding the factors and processes active in its genesis, is an important tool for adopting management practices and maintaining the functions of the soil and organisms.

To this effect, the aim of this study was to evaluate soil genesis under the influence of relief and climate in a topo-climosequence in the Agreste region of the State of Pernambuco, Brazil.

MATERIAL AND METHODS

The study area is located in the district of Jurema, in the Agreste region of Pernambuco, inserted in the microregion of Garanhuns (Figure 1). The geomorphological unit is known as the Borborema Plateau, with altitudes ranging from 200 to 900 meters. These present different stages of relief evolution, the result of tectonic influences combined with changes in climate, followed by folding and fracturing, and associated with successive leveling (BRASIL, 1983).

Figure 1 - Location of the study area in the Agreste region of Pernambuco



The geology of the region is included in the Garanhuns Group, in which the quartzites, granites and gneisses of the Proterozoic period predominate. These rocks are characterized by their coloration, which varies from whitish and yellowish to pale pink, of phanerocrystalline structure, and a mineralogy predominantly composed of quartz, feldspar and biotite. A topo-climosequence was selected for the study, and four trenches were opened in different geomorphological features: high-altitude forest (P1), between forest and pediplane (P2) and on a pediplanation surface (P3 and P4). General information on the areas whose profiles were described is shown in Table 1. The morphological description of the soil profiles was carried out as per Santos *et al*. (2015), and disturbed and undisturbed soil samples were collected for laboratory analysis.

The air-dried fine-earth fraction (ADFE) was obtained from the collected samples, after drying, declumping and sieving (2 mm mesh), on which the physical and chemical analysis was carried out. Granulometry was quantified by the pipette method. Values were determined for the pH in H_2O, and the Ca, Mg, Al, Na, K, assimilable P and H+Al content (DONAGEMMA *et al*., 2011). The assimilable P content was also extracted with a 0.5 mol L^{-1} Na_2CO_3 solution at pH 8.5 and quantified by colorimetry from the color intensity of the phosphomolybdic complex as per Olsen *et al*. (1954). To quantify the levels of total organic carbon (TOC), $K_2Cr_2O_7$ was used as an oxidizing agent in an acid medium (H_2SO_4), titrating with ammonium ferrous sulfate (YEOMANS; BREMNER,

Table 1 - General information on the topo-climosequence in the district of Jurema in the State of Pernambuco

Profile	Coord. (UTM)	Type of landscape/ altitude	Local relief/slope	Parent material	Primary vegetation/ Current use	Rainfall (mm)	Drainage
P1	0815893/9033276	High-altitude forest/753 m	Gently rolling and rolling/5-20%	Granite	Semi-deciduous tropical forest/Pasture	1500	Well-drained
P2	0813595/9033764	Between forest and pediplane/723 m	Gently rolling/5-8%	Granite	Deciduous tropical forest/Annual crops	1000-1300	Well to mod. drained
P3	0814013/9032123	Pediplanation surface/658 m	Gently rolling and flat/5%	Granite	Hyper-xerophylic caatinga/Pasture	500-800	Imperf. drained
P4	0811552/9037289	Pediplanation surface/625 m	Gently rolling and flat/2-5%	Granitic sandy-clay colluvial material	Hyper-xerophylic caatinga/Pasture	500-800	Imperf. drained

Legend: Coord: coordinates; Mod: moderately; Sharp: sharply; Imp: imperfectly

1988). The total Fe, Al, Ti and Si content was determined by sulfuric attack (DONAGEMMA *et al*., 2011), where the samples of ADFE were solubilized in 1:1 H_2SO_4, heated and then filtered. From the filtered extract, Fe_2O_3 and Al_2O_3 were quantified by complexometry with EDTA and CDTA respectively, and TiO_2 by the peroxidation of titanium sulfate to persulfate with H_2O_2, determined by spectrophotometry. The SiO_2 content was obtained by solubilization of the residue in NaOH and quantified by colorimetry from the color intensity of the silicomolybdic complex. From the results, the ki and kr indices were calculated. The micromorphological characterization was performed on undisturbed samples, impregnated with polyester resin to make up thin slides. The slides were then observed under a petrographic microscope, and a micropedological description made as per Bullock (1985). From the morphological, physical and chemical attributes, the profiles were classified according to the Brazilian System of Soil Classification (SANTOS *et al*., 2013).

RESULTS AND DISCUSSION

In general, each profile along the topo-climosequence shows a sandy texture and a poorly developed structure. The profiles at the highest points in the landscape, under the influence of a climate with greater rainfall, show low base saturation, whereas on the pediplanation surface, the semi-arid climate favors greater base saturation in P4, determined by the lower leaching rate. The profiles presented a sequence of horizons: Ap1, Ap2, C1 and C2, in the profile located in the high-altitude forest (P1); Ap, BA, Bt1 and 2Bt2 in the profile between forest and pediplane (P2); and on the pediplanation surface: Ap, C1, C2 and C3 in P3, and Ap, E, Bt1, Bt2 and Bt3 in P4.

As for the morphological attributes, each horizon in profile P1 and P3 has a single-grain structure (Table 2), just like the surface horizons of the P2 and P4 profiles. The subsurface horizons of P2 have a subangular blocky structure, while a prismatic structure, composed of angular and subangular blocks, was seen in P4.

The main factor in the occurrence of a single-grain structure, are the high levels of the sand fraction in the soil, as evidenced by the presence of the sand and loamy-sand textural classes, together with a predominance of the coarse-sand fraction and consequently, a low level of mineral colloids, which hinders the formation of soil aggregates. The pattern of a single-grain structure or low degree of development, was also seen by Santos *et al*. (2012) when studying the *Neossolos Regolíticos* (Regosols) of the semi-arid region of Pernambuco, where there was a predominance of the loamy-sand textural class in all of the profiles under study. For blocky and prismatic structures, the principal ratio is due to the higher clay content in the subsurface.

Each horizon of the profiles under study present colors of a yellow hue (10YR), indicating the presence of goethite, whose formation is favored by the low iron content of the parent material (KÄMPF; CURI, 2000; MEDEIROS *et al*., 2013).

The moist color in the surface horizons showed a predominant value of 3. The same pattern was also seen in most of the subsurface horizons, with the exception of the 2Bt2 (P2), C3 (P3) and Bt3 (P4) horizons. The predominance of this darkened color, even in the subsurface, is associated with the presence of goethite, which may present yellowish tones despite low levels of organic carbon.

By analyzing the physical attributes of the soil, a sand content greater than 700 g kg^{-1} was seen in most of the horizons of the profiles under study, except in 2Bt2 in P2, C3 in P3, and Bt1, Bt2 and Bt3 in P4 (Table 3). Low values were seen for the fine sand/coarse sand ratio (FS/CS), indicating the predominance of coarser particles in the sand fraction.

Table 2 - Morphological attributes of soils of a topo-climosequence in the district of Jurema in the State of Pernambuco

Horizon$^{)}$	Depth cm	Color		Structure$^{(1)}$	Textural class
		Dry	Moist		
P1 – Neossolo Regolítico Distrófico espessarênico (Regosol) (High-altitude forest)					
Ap1	0-30	10YR 4/3	10YR 3/3	si. grain	Loamy sand
Ap2	30-75	10YR 4/2	10YR 3/2	si. grain	Loamy sand
C1	75-130	-	10YR 3/3	si. grain	Loamy sand
C2	130-150+	-	10YR 3/2	si. grain	Loamy sand
P2 – Argissolo Amarelo Distrófico típico (Alisol) (Between forest and pediplane)					
Ap	0-30	10YR 5/3	10YR 3/3	si. grain	Sand
BA	30-60	-	10YR 3/3	wk., sm., sab.	Sandy loam
Bt1	60-90	-	10YR 3/3	wk., sm., sab.	Sandy clay loam
2 Bt2	90-160+	-	10YR 5/4	wk., sm., sab.	Clay loam
P3 - Neossolo Regolítico Distrófico espessarênico (Regosol) (Pediplanation surface)					
Ap	0-25	10YR 4/3	10YR 3/3	si. grain	Loamy sand
C1	25-60	-	10YR 3/3	si. grain	Loamy sand
C2	60-100	-	10YR 3/3	si. grain	Loamy sand
C3	100-150+	-	10YR 5/2	si. grain	Sandy clay loam
P4 – Planossolo Háplico Eutrófico arênico (Planosol) (Pediplanation surface)					
Ap	0-20	10YR 5/3	10YR 3/2	si. grain	Loamy sand
E	20-50	10YR 5/2	10YR 4/2	si. grain	Loamy sand
Bt1	50-70	-	10YR 3/2	mo.,me., pri., comp. ab. and mo., me.,sab.	Sandy clay
Bt2	70-100	-	10YR3/2	mo.,me., pri., comp. ab. and mo., me., sab.	Sandy clay
Bt3	100-150+	-	10YR 4/3	st., me. to lg., pri., comp. ab. and mo., me., sab.	Sandy clay

(1) si: single; wk: weak; mo: moderate; st: strong; sm: small; vsm: very small; me: mdium; lg: large; ab: angular blocks; sab: subangular blocks; pri: prismatic; comp: composite

Table 3 - Physical attributes of the soils of a topo-climosequence in the district of Jurema in the State of Pernambuco

Horizon	Depth Cm	Sand			Silt	Clay		DF$^{(1)}$ %	Silt/Clay	FS/CS$^{(2)}$
		Total	Coarse	Fine		Total	Natural			
		g kg^{-1}								
P1 - Neossolo Regolítico Distrófico espessarênico (Regosol) (High-altitude forest)										
Ap1	0-30	747	523	224	121	132	17	87	0.9	0.4
Ap2	30-75	769	533	236	117	114	40	65	1.0	0.4
C1	75-130	755	500	255	130	115	16	86	1.1	0.5
C2	130-150+	774	547	227	116	110	17	85	1.1	0.4
P2 - Argissolo Amarelo Distrófico típico (Alisol) (Between forest and pediplane)										
Ap	0-30	888	655	233	33	79	22	72	0.4	0.4
BA	30-60	776	493	283	63	161	31	81	0.4	0.6
Bt1	60-90	709	467	242	80	211	28	87	0.4	0.5
2Bt2	90-160+	431	209	222	228	341	17	95	0.7	1.1

Continuation Table 3

P3 - Neossolo Regolítico Distrófico espessarênico (Regosol) (Pediplanation surface)										
Ap	0-25	802	496	306	95	103	16	85	0.9	0.6
C1	25-60	706	476	230	153	141	40	72	1.1	0.5
C2	60-100	714	484	230	144	142	12	92	1.0	0.5
C3	100-150+	619	376	243	176	205	22	89	0.9	0.6
P4 - Planossolo Háplico Eutrófico arênico (Planosol) (Pediplanation surface)										
Ap	0-20	820	496	324	130	50	15	70	2.6	0.7
E	20-50	825	523	302	110	65	15	77	1.7	0.6
Bt1	50-70	492	366	126	75	433	36	92	0.2	0.3
Bt2	70-100	500	385	115	61	439	18	96	0.1	0.3
Bt3	100-150+	93	342	151	68	439	30	93	0.2	0.4

(1)DF: degree of flocculation. (2)FS/CS: fine sand/coarse sand

In general, the soils have a sandy texture due to the nature of the parent material, acidic rocks of the Garanhuns Group, with a phanerocrystalline structure and the predominance of the minerals quartz and feldspar. In addition, the low rate of weathering of the alterable primary minerals, which is determined by the climate, does not favor the formation of clay minerals. In the P2 profile, a sharp change can be seen in the FS/CS ratio between the Bt1 and 2Bt2 horizons, suggesting the occurrence of lithological discontinuity (NOVAES FILHO *et al*., 2012). The low values for the silt/clay ratio in the subsurface horizons of P4 may be a reflection of the processes of deposition and accumulation of pre-weathered sediments in the highest parts of the landscape, considering that the current conditions of imperfect drainage and the low rainfall in the area (500-800 mm) are unfavorable to the weathering process.

There was great variation in the chemical attributes of the profiles under study (Table 4). In general, an increase can be seen in the values for pH, sum of bases (S), and assimilable P on the downward slope.

The values for pH ranged from 3.44 in the P1 profile (high-altitude forest), to 7.26 in P4 (pediplanation surface), being directly related to the increase in the value of S for the same direction in the landscape, which varied from 1.33 (P1) to 13.25 (P4). In each profile, the values for Mg were higher than for Ca. This pattern was also seen in other profiles in the State of Pernambuco, formed from gneiss with a coating of quartz (JACOMINE *et al*., 1972).

The P1, P2 and P3 profiles had a base saturation of less than 50%, a result of their dystrophic character (SANTOS *et al*., 2013), followed by the S values, which ranged from 0.77 to 3.11, and the aluminum content of 0.4 at 1.1 cmol$_c$.kg^{-1}. The P4 profile had a base saturation of more than 50%, resulting from its eutrophic character (SANTOS *et al*., 2013), associated with higher values for Ca, Mg and K when compared to the other profiles. The predominantly sandy texture, which determines a low capacity for cation retention, together with the greater runoff favored by the relief in the higher parts of the landscape, intensifies base leaching, which explains the low Ca, Mg and K content of P1, P2 and P3. The occurrence of dystrophic soils at the highest points, and eutrophic soils at the lowest, was also seen by several authors (CAMPOS *et al*., 2010, 2011, MEIRELES *et al*., 2012), when studying the soil to landscape relationship. According to Anjos *et al*. (1998), this pattern of a greater sum of bases at the lowest points is defined by the soil to landscape relationship, which controls the behavior of the water flow, as well as the processes for the removal and accumulation of cations.

Higher values for Na were found in the subsurface horizons of P4, where the semi-arid climate conditions favor the addition of Na to the soil by capillary rise from the groundwater, with the desorption of other cations in the sortive complex and the consequent increase in Na values (GONÇALVES; MARTINS; RAMOS, 2015).

The levels of assimilable P vary from 0 to 88 mg kg^{-1}, with the highest values in P4 compared to the other profiles. However, due to the high pH values in this profile, quantifying the P values by the Olsen method is recommended, where the levels varied from 3 to 52 mg kg^{-1}. In this case, the use of Mehlich-1 solution may overestimate the assimilable P content, considering that the dilute acid solution dissociates the little-soluble forms of phosphate (CORRÊA *et al*, 2008).

The total organic carbon content (TOC) is influenced by the low deposition of organic material

Table 4 - Chemical attributes of the soils of a topo-climosequence in the district of Jurema in State of Pernambuco

H(1)	Depth cm	pH$_{H2O}$	Al	Ca	Mg	H+Al	Na	K	P Meh(2)	P Ols(3)	S	T	V	m	Na%	TOC	T clay
			cmol$_c$ kg^{-1}						mg kg^{-3}		cmol$_c$ kg^{-1}		%			g kg^{-1}	cmol$_c$ kg^{-1}
P1 - Neossolo Regolítico Distrófico espessarênico (Regosol) (High-altitude forest)																	
Ap1	0-30	3.5	1.0	0.5	1.0	6.0	0.01	0.02	9	6	1.53	7.52	20	40	0.1	9.7	-
Ap2	30-75	3.4	1.0	0.3	1.0	5.2	0.01	0.02	6	4	1.33	6.51	20	42	0.2	7.5	-
C1	75-130	3.4	0.9	0.4	1.0	5.5	0.01	0.02	6	5	1.43	6.96	21	39	0.1	7.8	-
C2	130-150+	3.9	0.6	0.7	1.0	5.3	0.01	0.02	10	7	1.68	7.03	24	26	0.1	10.4	-
P2 - Argissolo Amarelo Distrófico típico (Alisol) (Between forest and pediplane)																	
Ap	0-30	4.5	0.1	0.8	1.9	3.1	0.02	0.02	7	5	2.66	5.71	47	2	0.4	7.3	-
BA	30-60	4.5	0.1	0.8	1.9	3.8	0.02	0.04	6	3	2.66	6.47	41	3	0.3	5.9	24.9
Bt1	60-90	4.1	0.4	0.4	2.1	4.3	0.04	0.02	3	1	2.56	6.83	37	12	0.6	5.7	30.9
2Bt2	90-160+	3.8	0.6	0.4	2.7	3.7	0.04	0.01	0	0	3.17	6.84	46	15	0.6	2.6	49.9
P3 - Neossolo Regolítico Distrófico espessarênico (Regosol) (Pediplanation surface)																	
Ap	0-25	3.9	0.7	0.1	0.7	3.1	0.01	0.02	4	3	0.83	3.90	21	46	0.3	4.2	-
C1	25-60	3.9	1.1	0.1	0.6	3.8	0.01	0.01	3	1	0.77	4.57	17	58	0.2	4.2	-
C2	60-100	4.0	1.0	0.1	0.6	4.0	0.01	0.01	3	1	0.77	4.73	16	57	0.2	2.0	-
C3	100-150+	3.6	1.0	0.1	0.6	3.8	0.04	0.02	4	1	0.78	4.62	17	56	0.9	2.0	44.4
P4 - Planossolo Háplico Eutrófico arênico (Planosol) (Pediplanation surface)																	
Ap	0-20	6.6	0.0	2.2	1.6	0.6	0.01	0.09	78	37	3.91	4.47	87	0	0.2	3.2	-
E	20-50	6.9	0.0	1.8	1.3	0.5	0.01	0.09	88	52	3.20	3.66	87	0	0.3	2.0	-
Bt1	50-70	7.3	0.0	4.2	8.4	0.4	0.15	0.30	41	33	12.96	13.39	97	0	1.1	3.0	32.3
Bt2	70-100	6.1	0.0	3.4	9.3	1.3	0.40	0.25	7	2	13.25	14.59	91	0	2.7	3.0	30.1
Bt3	100-150+	6.1	0.0	2.4	9.9	0.9	0.50	0.24	15	3	13.04	13.95	93	0	3.6	0.7	31.5

(1)H: horizon (2)PMeh: phosphorous determinad by Mehlich 1. (3)POls: phosphorous determinad by Olsen (1954)

on the surface of P3 and P4; however for P1 and P2, the forest results in a greater contribution; despite this, TOC levels were lower than 10 g kg^{-1} in each profile, decreasing with depth, except for horizon C2 in P1, which displayed an increase in TOC content. This result for C2 in P1 can be explained by the loamy-sand texture throughout the profile, which helps the plant root system to develop to greater depths, with the translocation of organic material.

As for the weathering complex, all the profiles displayed a low Fe_2O_3 content (Table 5), due to the nature of the parent material that has low levels of this element. Despite the silt/clay ratio indicating an advanced stage of weathering, values for the ki index (silica/aluminum ratio) were greater than 2.25, even reaching 3.89 in P4; however, this is due to the nature of the parent material and the low weathering determined by the climate factor, which favors the highest levels of SiO_2 through the weathering of the feldspars present in the sand fraction and the lesser removal of silica. The greater values for SiO_2 present in the solution after weathering of the primary minerals explain why high activity clay was seen in all the profiles. Furthermore, the quartz present in the parent material gives it greater structural stability and resistance to weathering, with a consequently lower dissolution rate, thereby influencing the Si/Al ratio (LIU *et al*., 2016).

According to the SiBCS [Brazilian System of Soil Classification] (SANTOS *et al*., 2013), the P1 and P3 profiles present a moderate surface A horizon with the absence of subsurface diagnostic horizons, characterized by the weak action of pedogenic processes. They have a base saturation (V%) of less than 50% and a predominantly sandy texture down to a depth of over 100 cm, basically composed of quartz and feldspar. Together, these attributes classify the profiles as *Neossolos Regolítico Distrófico típico* (Regosols).

The P2 profile has a B/A textural ratio equal to 2.35, characterizing a significant increase in the clay content in the subsurface, giving rise to the subsurface textural diagnostic B horizon. The surface horizon was classified as moderate A; in addition, the profile displays a predominant yellowish color (hue 10 YR) and low base saturation. Despite the presence of high-activity clay in the Bt horizon, the dystrophic character allows it to be classified as a *Argissolo Amarelo Distrófico típico* (Alisol).

Table 5 - Total silicon, iron, aluminum and titanium content by sulfuric attack

Horizon	Depth cm	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ki	Kr	Al_2O_3/ Fe_2O_3
		g kg^{-1}						
P1 - Neossolo Regolítico Distrófico espessarênico (Regosol) (High-altitude forest)								
Ap1	0-30	41.0	24.0	6.0	3.8	2.90	2.50	6.28
Ap2	30-75	45.0	26.0	6.0	4.5	2.94	2.56	6.80
C1	75-130	49.0	29.0	8.0	5.8	2.87	2.44	5.69
C2	130-150+	45.0	27.0	8.0	4.6	2.83	2.38	5.30
P2 - Argissolo Amarelo Distrófico típico (Alisol) (Between forest and pediplane)								
Ap	0-30	33.0	1.07	4.0	1.3	3.30	2.87	6.67
BA	30-60	62.0	42.0	9.0	2.7	2.51	2.21	7.33
Bt1	60-90	82.0	62.0	12.0	3.2	2.25	2.00	8.11
2Bt2	90-160+	162.0	117.0	27.0	4.4	2.35	2.05	6.80
P3 - Neossolo Regolítico Distrófico espessarênico (Regosol) (Pediplanation surface)								
Ap	0-25	46.0	25.0	6.0	3.8	3.13	2.71	6.54
C1	25-60	64.0	33.0	9.0	4.0	3.30	2.81	5.76
C2	60-100	63.0	43.0	9.0	4.4	2.49	2.20	7.50
C3	100-150+	78.0	57.0	10.0	5.2	2.33	2.09	8.95
P4 - Planossolo Háplico Eutrófico arênico (Planosol) (Pediplanation surface)								
Ap	0-20	34.0	15.0	6.0	1.7	3.85	3.07	3.92
E	20-50	32.0	14.0	7.0	1.8	3.89	2.94	3.14
Bt1	50-70	163.0	92.0	39.0	4.4	3.01	2.37	3.70
Bt2	70-100	171.0	106.0	40.0	4.4	2.74	2.21	4.16
Bt3	100-150+	160.0	96.0	37.0	4.1	2.83	2.27	4.07

The P4 profile showed abrupt textural change and yellowish colors with low subsurface saturation, reflecting its low permeability due to the imperfect drainage, thereby characterizing the planic subsurface diagnostic B horizon. This horizon presents high-activity clay, indicating the presence of type 2:1 clay minerals. In addition, the profile shows a high base saturation and a sandy texture from the surface to the start of the planic B horizon, which occurs at a depth of 50 cm. These attributes together classify the profile as an *Planossolo Háplico Eutrófico arênico* (Planosol).

With the micromorphological analysis, it was possible to find typical features from the action of different pedogenic processes. In general, there was a predominance of quartz grains in the coarse fraction, coated in clay and organic matter. Alteration of the mineral feldspar was also found (Figure 2), in its turn, releasing silica, which explains the higher SiO_2 content of the weathering complex and consequently the high values of the ki index.

The *Neossolos Regolíticos* (Regosols) (P1 and P3), in spite of the non-aggregated single-grain structure seen in the field evaluation, show evidence of the incipient action of pedality in the micromorphological analysis, where a granular microstructure with the development of a few blocks was seen. In both profiles, organization of the subsurface pores was of the impacted type with a few fissures.

In the P1 profile, coating of the coarse fraction by clay particles and organic colloids was seen (Figure 3), which in turn act by uniting the primary particles, explaining the occurrence of an incipient blocky structure. In addition, these coatings of organic material in the subsurface may explain the increase in the TOC content of the subsurface relative to the overlying horizons, where its mobilization may have been facilitated by the predominantly thick texture.

The C2 horizon in the P3 profile displayed features similar to P1, with incipient development of a blocky structure (Figure 4), which is due to the presence of biological features (Figure 5) that aid in cementing and arranging the particles on a microscopic scale.

Figure 2 - Photomicrograph of a gefuric weave with porphyric zones (A). Mineral feldspar under alteration (B). Horizon C1, profile P1

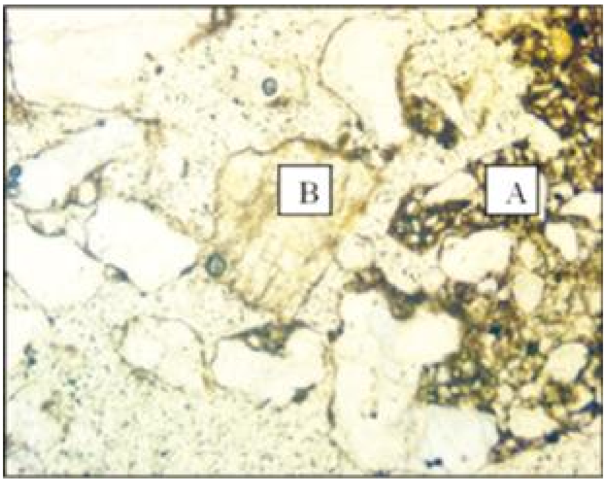


Figure 3 - Textural pedological crust feature in the coarse parent material (quartz), organic material and clay. Horizon C1, profile P1

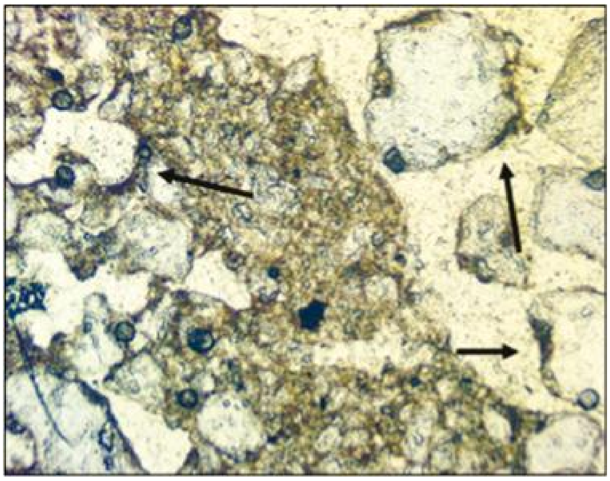


Figure 4 - Photomicrograph of an open porphyric zone forming blocks (C). Horizon C2, profile P3

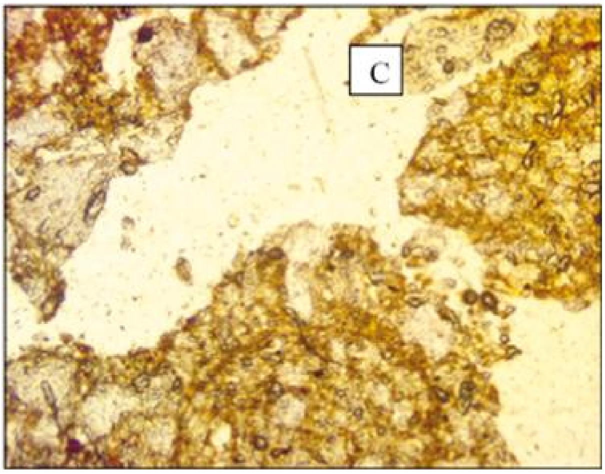
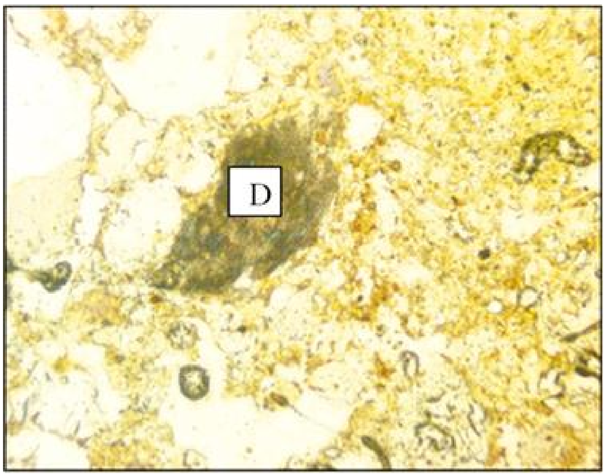


Figure 5 - Photomicrograph of a biological pedological feature (D). Horizon C2, profile P3



In the 2Bt2 horizon of the P2 profile, there is a predominance of quartz grains, distributed in a dense mass of fine material (porphyritic pattern) and organized in a granular microstructure and in blocks. The main pedofeatures seen were the abundant clay coating and dense clay filling of the cavitary porosity (waxiness) (Figure 6 and Figure 7).

In Bt3 in the P4 profile, there was also the dominance of quartz grains with a porphyric distribution pattern. In this horizon, the formation of angular and subangular blocks can be seen between the macropores, while microporosity is responsible for the formation of microfissures that give rise to the prismatic structure (Figure 8). Alterations in the quartz can be seen with coating and filling by the organic matter. Another pedofeature was the occurrence of degraded iron micronodules (Figure 9), which is associated with the drainage conditions of the profile.

Pedogenesis along the topo-climosequence is strongly influenced by the felsic parent material and its interaction with the climate, determining low rates of weathering, which can be evidenced by the high amount of feldspars, contributing to the predominance of a very sandy texture. This texture, in turn, affords a slight capacity for cation retention, which together with the predominance of coarse sand, intensifies the leaching process. Variations in relief are responsible for the drainage conditions and the

Figure 6 - Textural pedological feature of clay filling. (E) (waxiness). 2Bt2 horizon, profile P2

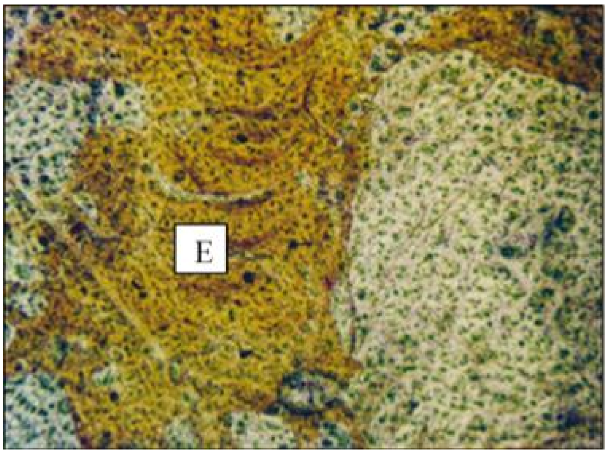


Figure 7 - Textural pedological feature of internal filling of the cavitary pore: (almost a coating) (F). 2Bt2 horizon, profile P2

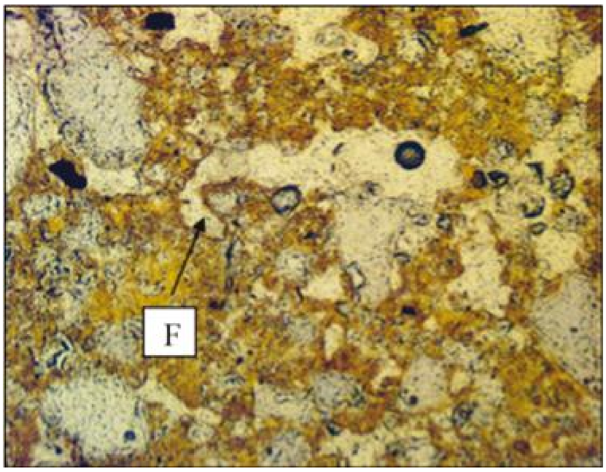


Figure 8 - Photomicrograph of porphyric microfissure porosity forming a prismatic structure. Bt3 horizon, P4 profile

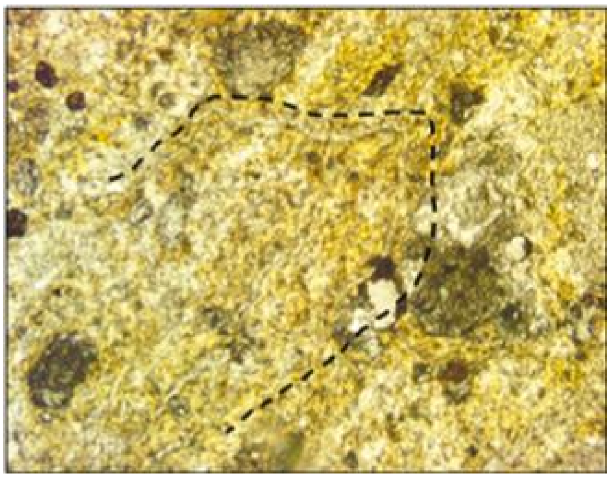
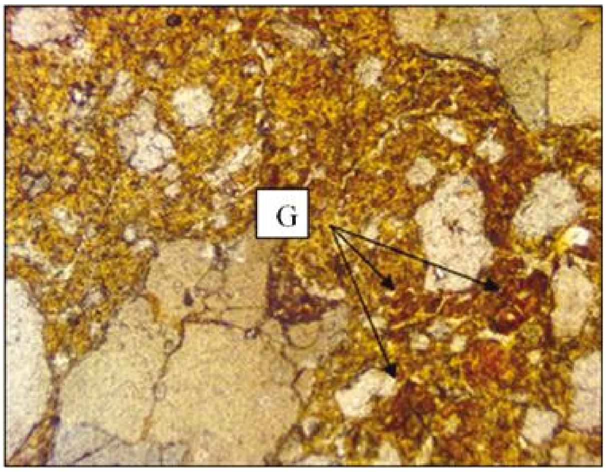


Figure 9 - Textural pedological feature of degraded iron micronodules (G). Bt3 horizon, P4 profile



surface runoff, altering the chemical attributes of the soil and the action of pedogenic processes, favored not only by removal and accumulation but also by cycles of wetting and drying. In addition, the climate factor, which favors the occurrence of greater rainfall in the higher parts of the landscape, intensifies leaching and surface runoff, with subsequent base accumulation in the pediplane.

Among the more active specific pedogenic processes, most important are eluviation/illuviation and elutriation, in the formation of the textural B horizon in P2; lessivage and leucinization, favoring the formation of the E horizon; and ferrolysis in the formation of the planic B horizon and E horizon in P4. The P1 and P3 profiles are characterized by the low-intensity action of the pedogenic processes, showing no subsurface diagnostic horizon; however, as seen in the micromorphological analysis, incipient action of the process of pedality can be seen.

Formation of the P2 profile is due to the action of the pedogenic processes of eluviation/illuviation and elutriation. In the first, translocation of clay particles takes place, with water as the transport agent, a process facilitated by the sandy texture, with the predominance of coarse sand determined by the parent material, and the subsequent accumulation of these clay particles in the subsurface (FANNING; FANNING, 1989). From the micromorphological evaluation of the 2Bt2 horizon, clay coating and filling were found in the pores, confirming the occurrence of translocation. In the second process, a position in the relief with a greater slope and a weak aggregation of the surface horizon facilitates the action of erosive processes in the removal of the finer particles, contributing to a relative increase in the clay content of the subsurface (KÄMPF; CURI, 2012).

The main pedogenic processes involved in the formation of this soil are lessivage, leucinization and ferrolysis (KÄMPF; CURI, 2012). Lessivage is characterized by the intense translocation of clay, which is facilitated by the presence of the E horizon, in turn formed by the process of leucinization, which includes the translocation of organic material, with lighter colors being seen in this horizon. The process of ferrolysis occurs due to the wetting and drying cycles, in which redox reactions involving iron cause destruction of the clay minerals of the surface horizons after the gradual acidification of the soil solution (oxidation reactions release H^+), and consequently a thickening of the E horizon. The action of this process was seen in the micromorphological analysis, in which degraded iron micronodules were found, typical of environments with wetting and drying cycles.

CONCLUSIONS

1. Soil variation along the topo-climosequence is determined by the factors of climate and relief, favoring the development of specific pedogenic processes that culminated in the formation of a *Argissolo Amarelo* (Alisol) (P2) and *Planossolo Háplico* (Planosol) (P4);
2. The nature of the parent material influences several soil attributes, such as a sandy texture, low capacity for cation retention and a poorly developed structure in all the soils under study, these effects being more marked in the *Neossolos Regolíticos* (Regosols);
3. Micromorphological evaluation was efficient in detecting incipient pedogenic development in the C horizons of the *Neossolos Regolíticos* (Regosols), and in the occurrence of the processes of eluviation/illuviation and ferrolysis, in the Argissolo Amarelo (Alisol) and the *Planossolo Háplico* (Planosol) respectively.

REFERENCES

ANJOS, L. H. C. *et al*. Landscape and pedogenesis of an Oxisol-Inceptisol-Ultisolsequence in Southeastern Brazil. **Soil Science Society of America Journal**, v. 62, n. 6, p. 1651-1658, 1998.

BRASIL. Ministério de Minas e Energia. Secretaria-Geral. **Projeto RADAMBRASIL**. Folhas SC. 24/25 Aracaju/Recife: geologia, geomorfologia, pedologia, vegetação e uso potencial da terra. Rio de Janeiro, 1983. 856 p.

BULLOCK, P. *et al*. **Handbook for soil thin section description**. Woverhampton: Waine Research Publishers, 1985. 152 p.

CAMPOS, M. C. C. *et al.* Relações solo-paisagem em uma topossequência sobre substrato granítico em Santo Antônio do Matupi, Manicoré (AM). **Revista Brasileira de Ciência do Solo**, v. 35, p. 13-23, 2011.

CAMPOS, M. C. C. *et al.* Segmentos de vertente e atributos do solo de uma topossequência na região de Manicoré, AM. **Revista Ciência Agronômica**, v. 41, n. 4, p. 501-510, 2010.

CORRÊA, R. M. *et al*. Disponibilidade e níveis críticos de fósforo em milho e solos fertilizados com fontes fosfatadas. **Revista Brasileira de Ciências Agrárias**, v. 3, n. 3 p. 218-224, 2008.

DONAGEMMA, G. K. *et al*. **Manual de métodos de análise de solos**. Rio de Janeiro: Embrapa Solos, 2011. 230 p.

FANNING, D. S.; FANNING, M. C. B. **Soil genesis, morphology and classification**. Washington, USA, 1989. p. 69-80.

GONÇALVES, M. C.; MARTINS, J. C.; RAMOS, T. B. A salinização do solo em Portugal: causas, extensão e soluções. **Revista de Ciências Agrárias**, v. 38, n. 4, p. 574-586, 2015.

GURGEL, S. P. P. *et al*. Cenozoic uplift and erosion of structural landforms in NE Brazil. **Geomorphology**, v. 186, p. 68–84, 2013.

JACOMINE, P. K. *et al*. **Levantamento exploratório-reconhecimento de solos do Estado de Pernambuco**. Recife: DNPEA. Divisão de Pesquisas Pedológicas, 1972. v. 2.

KÄMPF, N.; CURI, N. Formação e evolução do solo (Pedogênese). *In*: KER, J. C.; SHAEFER, C. E. G. R; VIDAL-TORRADO, P. **Pedologia**: fundamentos. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2012. p. 207-302.

KÄMPF, N.; CURI, N. Óxidos de ferro: indicadores de ambientes pedogênicos. *In*: NOVAIS, R. F. *et al*. **Tópicos em ciência do solo**. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2000. v. 1, p.107-138.

LIU, W. *et al*. Deep weathering along a granite ridgeline in a subtropical climate. **Chemical Geology**, v. 427, p. 17-34, 2016.

MEDEIROS, P. S. C. *et al*. Caracterização e classificação de solos graníticos em topossequência na região Sul do Brasil. **Ciência Rural**, v. 43, n. 7, p. 1210-1217, 2013.

MIREILES, H. *et al*. Relação solo-paisagem em topossequência de origem basáltica. **Pesquisa Agropecuária Tropical**, v. 42, n. 2, p. 129-136, 2012.

NOVAES FILHO, J. P. *et al.* Indicativos de descontinuidade litológica de regolitos derivados de granitos em uma microbacia sob floresta Amazônica, em Juruena-MT. **Revista Brasileira de Ciência do Solo**, v. 36, n. 2, p. 317-324,2012.

OLSEN, S. R. *et al.* **Estimation of available phosphorus in soils by extraction with sodium bicarbonate**. Washington: United States Department of Agriculture, 1954. 19 p. (Circular 939).

PEDRON, F. A.; AZEVEDO, A. C.; DALMOLIN, R. S. D. Alteração mineralógica de Neossolos em uma climo-litossequência no Planalto do Rio Grande do Sul. **Ciência Rural**, v. 42, n. 3, p. 451-458, 2012

RODAL, M. J. M.; BARBOSA, M. R. V., THOMAS, W. W. Do the seasonal forests innortheastern Brazil represent a singlefloristic unit? **Brazilian Journal of Biology**, v. 68, n. 3, p. 467-475, 2008.

SANTOS, H. G. *et al.* **Sistema brasileiro de classificação de solos**. Brasília, DF: Embrapa, 2013. 353 p.

SANTOS, J. C. B. *et al*. Caracterização de Neossolos Regolíticos da região semiárida do estado de Pernambuco. **Revista Brasileira de Ciência do Solo**, v. 36, p. 683-695, 2012.

SANTOS, R. D. *et al*. **Manual de descrição e coleta de solo no campo**. 7. ed. Viçosa,MG: SBCS, 2015. 100 p.

SOUZA, R. V. C. C. *et al*. Caracterização de solos em uma topoclimossequência no Maciço de Triunfo - Sertão de Pernambuco. **Revista Brasileira de Ciência do Solo**, v. 34, p. 1259-1270, 2010.

YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determination of organic carbon in soil. **Communication in Soil Science Plant Analysis**, n. 19, p. 1467-1476, 1988.