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GEOMORPHOLOGICAL CHARACTERIZATION OF COLLUVIUM AT MATA GRANDE MASSIF, STATE OF ALAGOAS: A COMPARISON OF MONTANE ENVIRONMENTS IN THE NORTHEAST OF BRAZIL

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Abstract

The study of geomorphological dynamics demands the identification of surface processes. From a systemic perspective, the elements of the landscape and the energy inputs acting on them are reflected in the sedimentation environments and their deposits. In this context, the humid exception areas circumscribed by the semi-arid environment of Northeastern Brazil make up a unique environmental set, whose records of past denudational events, in the form of hillslope deposits, represent a high-quality regional proxy for the reconstruction of their temporal evolution. Therefore, this work sought to identify the markers of the geomorphological dynamics of the sub-humid massif of Mata Grande, State of Alagoas, expressed in their surface coverings, comparing them with those of other similar areas on the Borborema Province. The research started from the description of colluviums in the area, by means of grain-size and morphoscopical analysis, in order to draw comparisons with similar materials from other sub-humid montane areas. It was observed that the colluviums of Mata Grande are composed mostly of muddy sand, with debris flows incorporating from pebbles to boulders. The materials revealed to be similar to those of other environments of sub-humid hillslopes of the Northeast, corroborating the existence of a specific dynamic to these environments.

Keywords: Hillslope sediments; Exception areas; Accommodation space.

CARACTERIZAÇÃO SEDIMENTOLÓGICA DOS COLÚVIOS DO MACIÇO DE MATA GRANDE – AL: UMA COMPARAÇÃO ENTRE BREJOS DE ALTITUDE DO NORDESTE DO BRASIL

Resumo

O estudo da dinâmica geomorfológica demanda o reconhecimento dos processos superficiais. A partir de uma visão sistêmica, os elementos da paisagem e os *inputs* de energia atuando sobre eles se refletem nos ambientes de sedimentação e seus depósitos. Neste contexto, as áreas de exceção úmida circunscritas pelo ambiente semiárido do Nordeste do Brasil compõem um conjunto ambiental único, cujos registros de eventos denudacionais pretéritos, sob a forma de depósitos de encosta representam um *proxy* regional de grande qualidade para a reconstrução de sua evolução temporal. Diante disso, este trabalho buscou identificar os marcadores da dinâmica geomorfológica do maciço sub-úmido de Mata Grande, Alagoas, expressos em suas coberturas superficiais, comparando-os com os de outras áreas congêneres sobre a Província Borborema. A pesquisa partiu da descrição dos colúvios da área, por meio da análise de sua granulometria e morfoscopia, no intuito de proceder comparações com materiais semelhantes oriundos de outros brejos de altitude. Observou-se que os colúvios de Mata Grande são compostos em sua maior parte por areia lamosa, ocorrendo ainda fluxos de detritos, incorporando de seixos a matacões. Os materiais mostraram-se semelhantes aos dos outros ambientes de encostas sub-úmidas do NE, corroborando a existência de uma dinâmica própria a esses ambientes.

Palavras-chave: Sedimentos de encosta; Áreas de exceção; Espaço de acomodação.

CARACTERIZACIÓN SEDIMENTOLÓGICA DE LOS COLUVIOS DEL MACIZO DE MATA GRANDE, ESTADO DE ALAGOAS: UNA COMPARACIÓN ENTRE AMBIENTES MONTANOS EN EL NORESTE DE BRASIL

Resumen

El estudio de la dinámica geomorfológica exige el reconocimiento de los procesos superficiales. Desde una perspectiva sistémica, los elementos del paisaje y las entradas de energía que actúan sobre ellos se reflejan en los ambientes de sedimentación y sus depósitos. En este contexto, las áreas de excepción húmedas circunscritas por el medio ambiente semiárido del noreste de Brasil constituyen un conjunto ambiental único, cuyos registros de eventos denudacionales pasados, en forma de depósitos coluviales, representan un *proxy* regional de alta calidad para la reconstrucción de su evolución temporal. . Por lo tanto, este trabajo buscó identificar los marcadores de la dinámica geomorfológica del macizo subhúmedo de Mata Grande, estado de Alagoas, expresados en sus revestimientos de superficie, comparándolos con los de otras áreas similares en la Provincia Borborema. La investigación comenzó a partir de la descripción de coluvios en el área, por medio del análisis de su granulometría y morfoscopia, con fines de hacer comparaciones con materiales similares de otros ambientes de altitud. Se observó que los coluvios de Mata Grande están compuestos principalmente de arena fangosa, con flujos de escombros que todavia se incorporan de cantos a bloques. Los materiales mostraron ser similares a los de los otros ambientes de laderas subhúmedas en el Noreste, corroborando la existencia de una dinámica específica para estos ambientes.

Palabras-clave: Sedimentos de ladera; Áreas de excepción; Espacio de acomodación.

1. INTRODUCTION

The study of past semi-arid environmental dynamics contributes to the understanding of contemporary and future behavior of the landscape of the Northeast of Brazil. Currently, according to research conducted in the region it became a consensus that the Quaternary climatic variability is indispensable for addressing this issue.

The environmental changes that occurred in the Pleistocene and Holocene transformed the sculpturing of tropical landscapes, with still poorly studied repercussions in the dry Northeast, since even the contemporary climate of the region has peculiar characteristics which are distinct from the rest of the country.

This peculiarity is expressed in different elements of the northeastern landscape, which constitute a set of tools for paleoenvironmental reconstruction. With regard to geomorphology, studies of residual and remobilized surface coverings represent one of the main contributions to the reconstruction of surface dynamics, since, according to Corrêa (2001), there is consensus among researchers that the processes that operate on the surface of the crust generate sets of relief forms and correlative deposits that maintain direct affinity with the mechanisms that originated them.

Sediments are the result of the interaction of the elements of the environment. When a change occurs that disturbs the balance between these elements, a response is triggered in the balance of matter and energy of the geomorphological system and, based on the idea of the process-response model, the erosion-accumulation system changes, leading to responses in the landforms. The slopes are particularly sensitive to these changes in energy input and adjust to a new state of equilibrium (HACK, 1972). Nevertheless, Mabesoone (1982) concludes that sediments preserve the characteristics of the original environment and the processes that produced them. Melo et al (2014) add that the responses to the processes are observed in the different geometries of the sedimentary deposits, their composition and spatial distribution, also stating that in the case of recent deposits, the contemporary surface of the land can be directly affected, as a response to the depositional system.

Dealing with the characteristics of the semi-arid “sedimentation environment” of the Northeast of Brazil, Mabesoone (1988) warns that the term refers to a geographically restricted complex, characterized by its geomorphic aspects. Thus, the environment reflects a set of physical, chemical and biological variables that can change from one place to another, within the limits of the geomorphic unit. In these terms, the author proceeded to characterize the fluvial environments and surface geochemical alteration of the region. In line with this type of approach, the present research sought, through sedimentological analysis, to describe the hillside deposits that occur in a montane area in the semiarid region of the state of Alagoas, Northeast of Brazil, and to propose a comparison between deposits from ecologically similar areas within the region.

Ab'Sáber (2003) characterizes the northeastern "brejos" (sub-humid montane enclaves) as morphoclimatic, geopedological and hydrological spaces, which despite being circumscribed by the semi-arid environment are capable of supporting semi-deciduous forest conditions, having the moister climate as the main element of landscape differentiation due to the greater elevation and hillslope exposure to moisture laden winds. Thus, from the analysis of the unconsolidated surface coverings of one of these areas, aggregating sedimentological and geomorphological data, it was sought to characterize aspects of the local surficial dynamics in relation to their surroundings, and compare them to other montane enclaves (brejos) within the region. The area chosen for this comparison is the "brejo" of Mata Grande, a sub-humid enclave inserted in the semiarid context of the state of Alagoas.

2. CHARACTERIZATION OF THE STUDY AREA

The study area, the Mata Grande massif and its surroundings, lies in the municipality of Mata Grande, located in the extreme NW of the State of Alagoas, limited to the north with the municipalities of Manari and Inajá (State of Pernambuco), to the south with Inhapi and Água Branca, to the east with Canapi and to the west with Tacaratu (State of Pernambuco) and Água Branca (Figure 1).

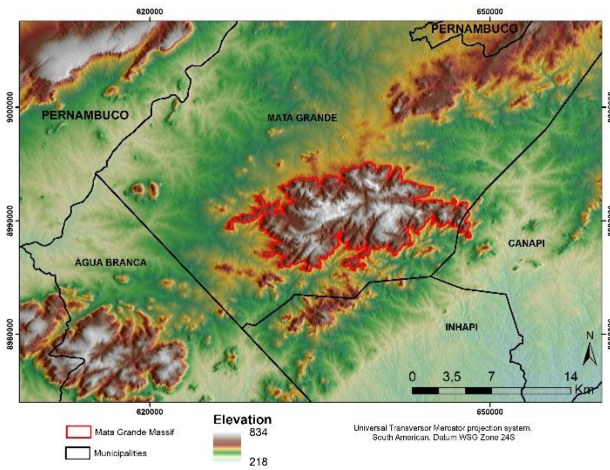

Figure 1 – Locations of the Mata Grande massif.

Regarding its geological context, the area lies within the Borborema Province, represented locally by the lithotypes of the Cabrobó, Belém do São Francisco and Riacho da Barreira complexes (Chorrochó Suite), Salgueiro/Terra Nova Intrusive Shoshonitic Suite, Tacaratu and Inajá formations and colluvium-eluvial deposits. These units range in age from the mesoproterozoic, Neoproterozoic and paleozoic to the upper cenozoic (CPRM, 2005).

Geomorphologically, according to the classification proposed by Cavalcanti (2010), the municipality of Mata Grande is located in the Southern Sertaneja Depression, characterized by pediments with or without detritic cover, occurrence of inselbergs and a residual massif, associated to a Neoproterozoic pluton, whose mesological characteristics define it as “brejo de altitude” (highland sub-humid enclave), physiographically differentiated from its surroundings. In the area, the paleo-Mesozoic sediments from the Jatobá basin also outcrop, giving rise to a landscape dominated by a cuestiform topography and residual landforms such as buttes and mesas.

The rainy season in Mata Grande begins in mid-January and ends in May, which does not differ much from the rest of the semi-arid Northeast, with the Intertropical Convergence Zone (ZCIT), being the main meteorological system that causes rain in this period. The role played by the El Niño-Southern Oscilation (ENSO) phenomenon as a modulator of the effects of ZCIT in the region is also noteworthy. ENSO establishes a pattern of teleconnection with the rains in the region, reinforcing them in the years of La Niña and provoking droughts in the years of El Niño (SANTOS et al, 2019; MARRAFON & REBOITA, 2020). In the fall-winter the area also suffers the influence of dissipating cold fronts, which can bring rain to the region, in addition to Upper Levels Cyclonic Vortexes (ULCV) which, operating from spring onwards, can trigger torrential rains or periods of drought, depending on their position over the continent (ALVES, 2016; ALVES et al, 2017).

When comparing the monthly distribution of rainfall in Mata Grande, located at an elevation of 650 m over the residual massif, with that of Delmiro Gouveia, at 220 m altitude over the pediplains of the Sertaneja Surface (Figure 2), it appears that the distribution of dry and rainy periods does not differ as to their length and temporal occurrence along the year, but as to their intensity. In February, the rainiest month in the region, Mata Grande receives approximately 55% more rainfall than Delmiro Gouveia. The climatic aspects that differentiate the residual massif from its surroundings are the total accumulated rainfall and average monthly temperatures. In February, the wettest month, the average monthly precipitation reaches 140 mm in Mata Grande, under an average temperature of 26 °C, while on the adjacent semi-arid pediplains these values reach 91 mm and 28 °C, respectively.

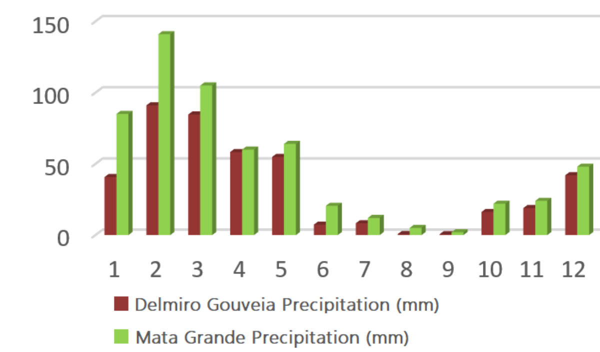

Figure 2 - Monthly precipitation (mm) comparison between Mata Grande and Delmiro Gouveia, State of Alagoas

Pedological covers in the area display associations of Leptsols and Planosols in the semi-arid lowlands, whereas over the residual massif, where the weathering characteristics differ substantially from the surrounding depressions, Cambisols and Alisols associations prevail. In general, due to the hydrological conditions on the highlands, the soil covers are thicker and present well-developed clay-rich horizons (EMBRAPA, 2016).

The potential vegetation cover of the area is characterized by the occurrence of the semi-deciduous tropical forest on the higher elevations of the massif, to the east of the municipality, close to the escarpment of the Borborema Highlands. The presence of remnants of forest vegetation in the area points to a synergic relationship between the arboreal formations and the development of thicker weathering profiles, especially in areas of sediment storage. The remainder vegetation cover of the area is made up of associations of thorn-scrub and dry woodlands under different degrees of xerophytism. There are also barren areas, dominated by rock outcrops such as granitic inselbergs and the summit surface of the massif (www.ima.al.gov.br).

3. METHODOLOGY

3.1. Comparison of the surficial coverings of montane enclaves (brejos de altitude)

To the north of the São Francisco River, the semi-arid core of the Brazilian Northeast is circumscribed by the Borborema geological Province, whose tectonic and lithological characteristics largely affect the spatial distribution and typologies of climatic exception and ecological enclave areas. The Borborema province corresponds to a wide region of branched orogen-type folds, with volcano-sedimentary supracrustals of Late Paleoproterozoic, Mesoproterozoic, but mostly Neoproterozoic age. Its final assemblage occurred between the Neoproterozoic and the Cambrian, under the Brasiliano Orogenic cycle, which was marked by intense plutonism between 730 and 500 Ma, corresponding to more than 30% of the Province surface (Brito Neves et al., 2001).

Among the ecological exception areas, the montane enclaves, in spite of their landscape peculiarities (Gois et al., 2019), constitute a set of geographical spaces sharing similar physical attributes, partly controlled by altitude, in which the arrangements of pedological covers, vegetation, water availability and land uses may come together as parameters for spatial and environmental differentiation.

Aiming at the reconstruction of the geomorphological dynamics on tropical hillslopes, the analysis of colluvial deposits plays a central role. In fact, on unglaciated landscapes colluvial slopes represent the most extensive type of remobilized surface coverings, capable of retaining in their structures valuable information regarding contemporary and past formative processes (Thomas, 2004). In the study area, colluvial sediments occur filling up depositional *loci* along different slope sectors of the massif.

For the initial identification of depositional loci and construction of a digital elevation model (DEM), ALOS satellite images were used, with a spatial resolution of 12.5 m. Geographical coordinates (x, y) and altitude (z) were extracted, followed by the interpolation of data by kriging. For the purposes of this research, kriging proved to be the most adequate method for DEM construction, since it allows a clearer visualization of hillslopes, and enables the treatment of random spatial variables (Valeriano, 2004). By means of the DEM fusion and overlapping of arrows indicative of surface plunge direction, Grid Vector Map function, it was possible to visualize the preferential direction of contemporary overland flow. This tool provides clues concerning sediment storage areas as it permits the identification of preferable storage areas according to the concave or convex terrain morphology. Areas of terminal runoff flow convergence, identified by mathematical altimetry data interpolation, were addressed as potential depositional *loci* (MONTEIRO et al, 2008 apud GOIS & MONTEIRO, 2017).

3.2. Sample collection and treatment

The fieldwork consisted of visiting potential depositional *loci* identified in the first stage of digital processing of topographic data. Each point visited had its coordinates and altitude verified by GPS and at the points where remobilized sediments were found, samples were taken. Before sampling, stratigraphic log sections (profiles) were macroscopically described, aiming at the recognition of depositional structures, lithology and evidence of erosive unconformities such as buried paleo-pavements or *stone-lines*.

Samples were submitted to grain-size analysis, consisting on the assessment of the distribution of soil and sediment forming inorganic particles, which provide the basis for a physical description of the deposits. Such procedure seeks to produce quantitative descriptive data regarding the physical properties of colluvium based on the methodology proposed by Gale & Hoare (1991). Initially, 100g of sediments from each sampling point were separated after being weighted and washed on a 20g to 500 ml solution of sodium hexametaphosphate. During the washing process, the coarse fractions were separated from the finer (< 63µ) residue. Samples were dried in an oven at 60°C. Dry samples were weighted in order to assess the proportion of mud (fine residue) per sample. Finally, the coarser fractions were run through a stack of sieves put together with mesh sizes in decreasing order from top to bottom in order to separate the grains in the following classes gravel (> 2mm), very coarse sand (> 1mm), coarse sand (>0.500 mm), medium sand (>0.250mm), fine sand (>0.125mm) and very fine sand (0.063mm).

The results of the sieving were analyzed with the assistance of the GRADISTAT free license software which applies the Folk (1954) diagram for coarse sediments: gravel, sand and mud (DIAS, 2004). In order to obtain stratigraphic log sections with layers adjusted to their corresponding average grain size fraction, including stone-lines and paleo-pavements, the software SedLog was applied.

Following, sediment sub-samples were submitted to morphoscopic analysis aiming at describing the characteristics of grains' surfaces. Surficial aspects were classified following Tucker (1995) proposal. Firstly, 100 grains at the 0.250mm (medium sand) fraction, per sample, were separated. Grains were described under a binocular magnifier in order to stablish morphological and compositional properties: roundness, sphericity and mineralogy. These properties led to a qualitative and quantitative description of the material, contributing to the identification of the prevailing processes involved in the depositional dynamics.

Tucker (1995) proposed a general model for grain classification according to the following variants: for roundness the values 0.5 (very angular), 1.5 (angular), 2.5 (sub-angular), 3.5 (sub-rounded), 4.5 (rounded) and 5.5 (well rounded) were admitted. For sphericity the following values are accepted: high sphericity (2.5 to 4.5), medium sphericity (2.5) e low sphericity (0.5).

4. RESULTS AND DISCUSSION

Four areas (Figure 3) of climatic exception were identified, within the montane enclave typology, in the Borborema Province. They all bear similar morphostructural characteristics as residual massifs deriving from the action differential erosion upon Neoproterozoic plutons and the surrounding metamorphic complexes. The chosen areas have been the object of previous studies concerning quaternary hillslope deposits; the Baixa Verde massif (CORRÊA, 2001), the district of Tabocas in the Caruaru-Arcoverde pluton (MELO, 2008), the Pereiro massif (GURGEL, 2012; GURGEL et al, 2013) and the Água Branca massif (MELO, 2014, 2019; SILVA, 2019).

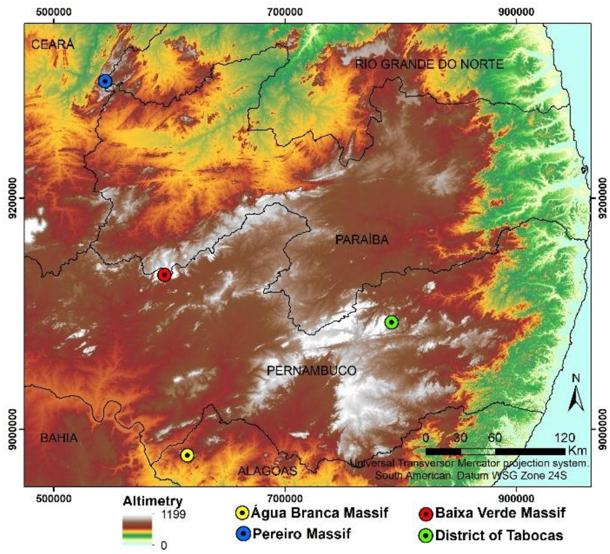

Figure 3 - Montane enclaves of the Borborema Province.

In the Serra da Baixa Verde Massif, state of Pernambuco, Correa (2001) identified two distinct climatic sectors, one being the montane sub-humid enclave with silty-clayey surficial coverings and the other the semi-arid sector with occurrence of sandy and gravelly surface coverings.

In the hillslope environment, most sediments showed a sandy-clay character with coarse grains concentration, consistent with the formation of sandy colluvia under semi-arid conditions by clay-fraction evacuation under the effect of laminar erosion. The most recent depositional units result from the erosion caused by land use practices and still exhibit primary sedimentary structures. On the oldest deposits, with the exception of the gravel layers, significant pedogenesis took place, thus impairing the subdivision of homogeneous hillslope deposits into discrete colluvial units based solely on field observation. Following grain-size and mineralogical analyzes the author concluded that the material displayed little granulometric distribution variation, especially under the sandy fractions, which suggests that surface transport processes had been similar in all sampled areas, dominated by sheet- and gravitational flows.

In the district of Tabocas, municipality of Brejo da Madre de Deus, on the Caruaru-Arcoverde massif, grain-size analyzes of colluvial material filling concave catchments were carried out. According to Melo (2008), the sediment originated from local eluvial covers that were mobilized and stored into catchment hollows, as poorly sorted colluvium, whose average grain-size varied from coarse to medium sand, with the presence of stone-lines derived from debris-flows intercalating the prevailing mud-flow deposits.

By their turn, Gurgel (2012) and Gurgel et al (2013) carried out studies in the Pereiro Massif, state of Rio Grande do Norte. The authors identified the occurrence of hillslope deposition from the last glacial maximum (LGM) to the mid-Holocene, the oldest sediments being located upslope at the massif's higher elevations. Colluvial deposits at the Pereiro Massif derive from debris flows and rock-fall and are stored in depositional loci separated by rock outcrops, staggered levels and topographic shoulders of morphotectonic origins. The sediments fill up hollows, in an incomplete cascade transference sequence (Fryirs et al., 2007) which results from the pulsatile character of the deposition, commanded by infrequent erosion/deposition hillslope events instead of the channelized drainage.

Sedimentation in the Pereiro massif was classified as "mixed", being conditioned both by the inability of contemporary climates to evacuate the hillslope deposits, and by the gradual disconnection of the base level. The authors concluded that the quaternary sedimentation at the Pereiro massif was controlled by tectonics that conditioned the formation of depositional *loci* on the slopes.

The Água Branca massif has been the target of a research aimed at describing its surface coverings. Melo (2014, 2019) classified the area's deposits as a result of debris flows and mud flows, characterizing a very high hydrodynamics. The texture of the colluvial material varies between sand, silty sand and sandy silt, with the predominance of silty sand and sandy silt facies. As it happens in most colluvial deposits, the material is poorly sorted, and the degree of roundness of the grains seems to be more related to the weathering levels suffered by the bedrock than to superimposed changes during transport.

Still in Água Branca, Silva (2019) corroborates the results pointed out by Melo (2014; 2019), identifying poorly selected colluviums, formed from debris flows and mud flows, predominantly consisting of sand in apparently very homogeneous layers.

From a comparison with colluvial sediments from other montane enclaves, it was found that most sediments originating in these areas have a sandy-clay character with a post-depositional concentration of coarse grains in the surface, consistent with the formation of sandy colluvia in semiarid environment by evacuation of fines by laminar erosion. More recent forms of erosion caused by changes in land use such as those found by Corrêa (2001) in Serra da Baixa Verde have also been highlighted.

Most studies show that in older sediments, with the exception of gravel layers, the pedogenetic alteration has obliterated the depositional structures discernible at outcrop scale. The results of previous studies also suggest that the climate controls weathering as well as changes in surficial transport. In addition, the weathering mantle has direct control over the amount of material available for erosion. On the Pereiro massif, in the west of the state of Rio Grande do Norte, research also pointed to a greater tectonic control over the spatial distribution of depositional loci.

The comparison between the types of hillslope sediments in the montane enclaves points to a predominance of certain granulometric and morphoscopic characteristics, which suggests a similarity in the type of transport (Chart 1). A notable exception occurs in the Pereiro massif, in which part of the transport is characterized by the occurrence of rock-falls, this situation is probably due to the tectonic conditions of the area (Gurgel, et al., 2013).

Chart 1 - Types of transport and materials in the montane enclaves

Author (s)	Study area	Type of transport	Dominant grain size fraction
CORRÊA (2001)	Serra da Baixa Verde Massif – State of Pernambuco	Debris flow; Mud flow	Medium sand Fine sand
MELO (2008)	Tabocas district - State of Pernambuco	Debris flow; Mud flow	Coarse sand, medium sand, medium clayey sand
GURGEL (2012); GURGEL et al (2013)	Pereiro Massif – State of Rio Grande do Norte	Debris flow; Mud flow Rock-fall	-
MELO (2014; 2019)	Água Branca Massif – State of Alagoas	Debris flow; Mud flow	Silty sand and sandy silt
SILVA (2019); MELO (2019)	Água Branca Massif – State of Alagoas	Debris flow; Mud flow	Sand

For Mata Grande, results did not differ much from the other montane enclaves, with deposition controlled mostly by the climate. According to the location of the deposits, the massif was divided into 4 sectors (Figure 4) sharing common characteristics regarding the recent deposition environments, such as the colluvium ramps that are characterized by Bigarella et al (2003) and Bigarella & Mousinho (1965) as depositional structures formed by the movement of poorly selected and fluid material over an already stabilized surface. In some contexts, colluvial sediments fill up the elevated hollows which characterize 0 order catchments located on the upper slopes (PAISANI et al, 2006).

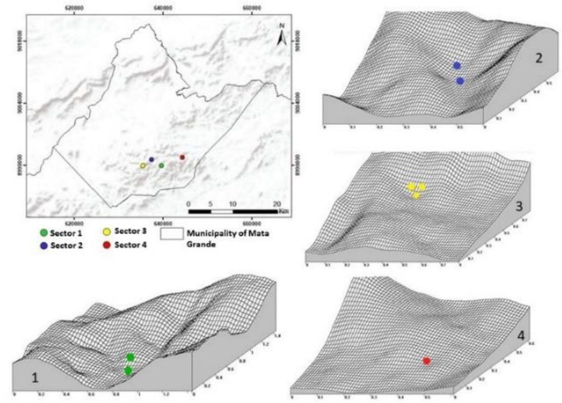

Figure 4 - Location of sampling areas

4.1. Sector 1

In this sector, the sampling was carried out on an 11° ramp, located on the slopes of a wide valley, in the form of a colluvial apron in the southern portion of the massif, at 732m altitude. In the higher sections of the ramp there is a layer of colluvium 30 centimeters thick that is more pedogenetically mature than the material located downstream. Land use in this sector is dominated by the occurrence of pastures.

In this ramp, samples were collected at two points (Figure 5), the first MT1, on the middle slope, is 41 cm thick from bottom to top, divided into two layers (MT1A and MT1B). In the basal layer it is possible to observe the contact with the weathered syenite. The deposit has a laminated structure, and the layers are differentiated by color. The two depositional units have a muddy sand texture with little grain size difference. The concentration of the mud fraction is the most variable property; the upper layer present 9% less mud, and both have a small number of clasts forming a supported matrix structure. The most basal MT1B sample was collected 11 cm above the contact with the alterite, and the most superficial MT1A at 30 cm.

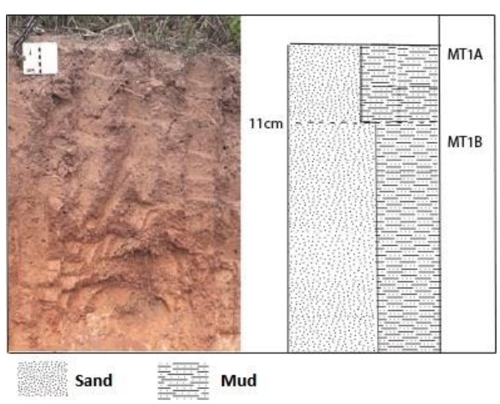

Figure 5 - Sampling profile MT1.

The second point lies downstream from the first, at the foot of the ramp. In this it is observed the occurrence of superficial rill erosion. The color of the material is greyish, and the layers are interspersed with clayey laminae. The surface is covered by a herbaceous layer with shrubs, and land use is characterized by pastoral activities. Colluvial material mixes with alluvial and the deposit can be classified as a colluvium-alluvium ramp. The AL1 profile (Figure 6) displays alternating muddy sand and slightly gravelly muddy sand layers (AL1A and AL1B), indicating variations in transport energy. The lower layer, AL1B, was sampled at 70 cm from the base of the profile and the upper layer, AL1A, at 40 cm. The profile measures 1.13m from base to top, but it was not possible to observe the contact with the bedrock.

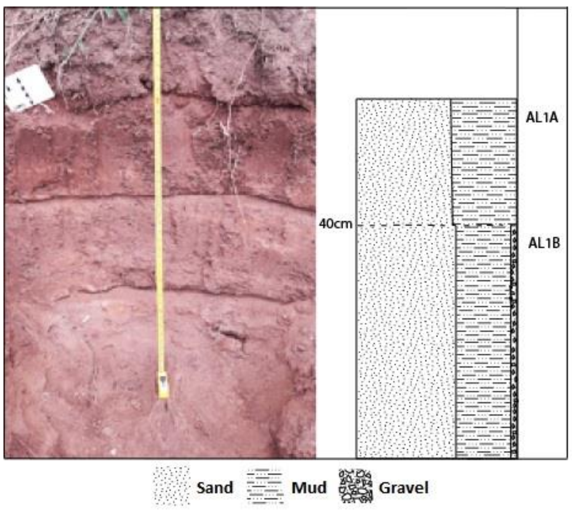

Figure 6 - Sampling profile AL1.

4.1.1. Morphoscopy

The morphoscopic analysis revealed that the layers of the MT1 sampling profile differ in sphericity and degree of roundness. The MT1B sample has mostly subprismal and sub-angular grains, whereas the upper layer displays grains with prismal and angular morphology indicating that those in the basal layer suffered less transport. The first layer sample (MT1B) was collected at 30 cm from the base of the profile, while the second layer sample (MT1A) was collected at 11 cm. The occurrence of bioturbation of the profile was observed, under shrub-tree vegetation and pastoral activities.

In the AL1 profile there is a small variation in grain morphology. The AL1A layer showed a predominance of subprismal sphericity and a matte texture with high grain opacity. The basal layer AL1B showed prismal sphericity and a shiny texture with transparent opacity.

Despite having been remobilized along the slope, the deposits of area 1 lie close to their source areas, being located between the upper and middle slopes. The results of the granulometric analyzes indicate that the transport and the weathering levels did lead to a greater wearing of the grains.

4.2. Sector 2

The area constitutes an elevated *hollow* at approximately 675m in altitude with 7° gradient slopes, forming a concave zero order catchment filled by a complex of colluvial ramps. Across the *hollow* two sampling profiles were described, one on the proximal sector of the colluvial deposit and another at the distal sector. The material lies close to the source area. According to Corrêa (2001), in the elevated hollows of the crystalline highlands within the Borborema Province a concentration of colluviums may occur due to shallow translational slides and gravitational flows. The fact that the studied hollows are unchanneled result in the longer storage times of the deposits in spite of the vicinity to the source area.

The first profile, MT2 (Figure 7), presents 1.70m from the base to the top and was subdivided into 3 layers, resulting in samples MT2A, MT2B and MT2C. The profile is lithologically heterogeneous, the basal layer (MT2C) is composed of slightly gravelly muddy sand. The sample at this level was collected at 1.25m from the surface, being composed of 40.72% of muddy material. The intermediate layer (MT2B), collected at 83cm from the surface, is formed by muddy gravel with a clast-supported structure with blocks, indicating a deposit of talus that filled the longitudinal axis of the hollow. The superficial layer (MT2A) collected at 35 cm from the top, as well as the basal layer, has a texture of muddy sand with gravel and about 41.9% of mud in its composition, indicating a deposition dominated by mud flows.

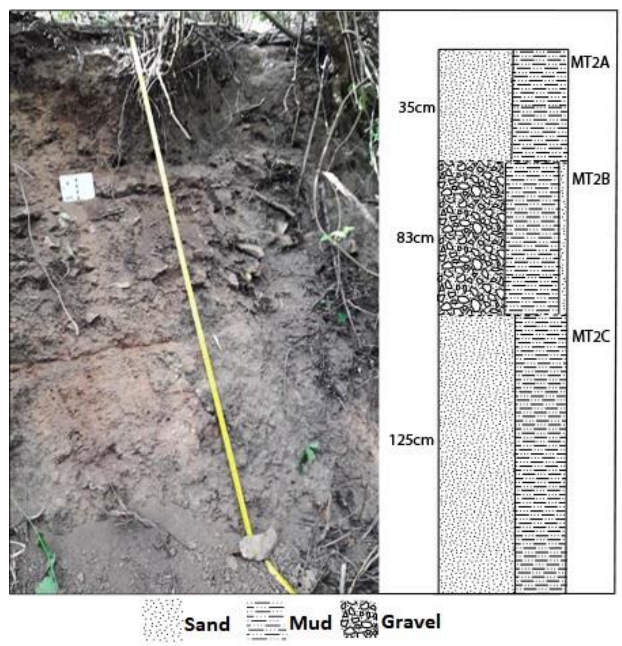

Figure 7 - MT2 sampling profile

The second profile, MT3 (Figure 8), on the distal sector of the colluvial deposit, has similar characteristics to the previous one. The 1.40 m thick profile was divided into 3 layers, the most basal (MT3C), sampled at a depth of 1.20 m, consists of gravelly muddy sand, with only 27% of mud in its composition. The intermediate layer (MT3B), sampled at 85 cm, presents a texture of muddy gravel, with smaller clasts than those of the previous one (MT2), thus indicating a decrease in the deposition energy along the hollow. The most superficial layer (MT3A) was sampled at 40 cm from the top, it is composed of sandy mud with gravel, with 40% mud in its composition, indicating a thicker mud flow than that of the basal layer and that of the upper layer of the previous profile, located upstream, which points to a greater transport of fines to this section of the slope.

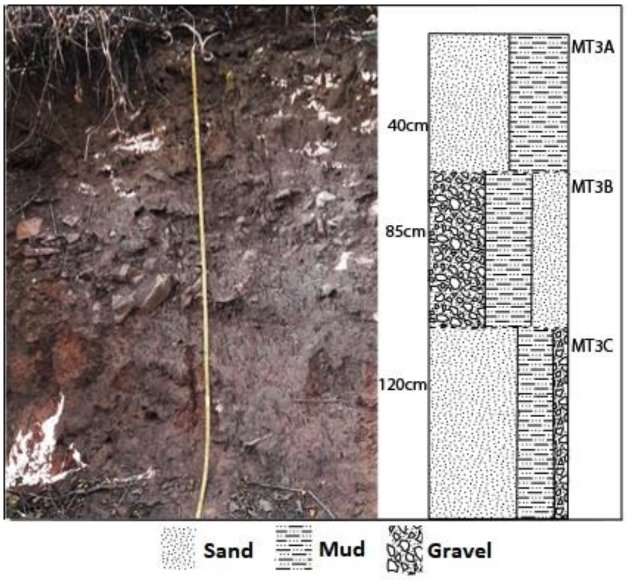

Figure 8 - MT3 sampling profile

In this unit, there was a lateral continuity of the layers that fill the hollow, from the distal sector to the headlands. Such a depositional situation without disruptions in the sequence of layers that fill the hollow was observed by Silva (2019) for the holocenic colluviums of the Água Branca massif located 36km from the study area. In this way, it is possible to propose the hypothesis that on the residual massifs of the semiarid region of the state of Alagoas, holocenic depositional events were capable of mobilizing coarse and muddy material to the axis of the hollows located on the slopes, but in sequence there were no events with enough energy to remove them from the upper slopes or dissect them.

On sector 2 springs outcrop along the hillsides and are used by the population as a source of drinking water, whereas the slopes of the hollow are used for growing vegetables, which makes them prone to surface erosion. Downstream, the groundwater is exploited with the installation of wells on the colluvium ramp, which in that sector is up to 6 meters thick. It cannot be ruled out that part of the downstream sediment remobilization arises from anthropic action in historical times as observed by Corrêa (2001), at Serra da Baixa Verde Massif in the state of Pernambuco.

4.2.1. Morphoscopy

The morphoscopic analysis of the samples of the MT2 profile revealed that there are no major differences between the sampled material. The grains showed a spherical pattern - samples MT2A and MT2B - with sub-angular roundness, shiny and transparent texture. The MT2C sample has angular roundness, opaque and matte texture, indicating less water in the transport.

Morphoscopy showed more variations between layers of the MT3 profile. The MT3C sample was spherical, with angular roundness and matte and opaque texture, while the MT3B sample showed sub-discoid sphericity, roundness at the sub-rounded level and opaque and matte texture. For MT3A sample, the sphericity was spherical, the rounding was very angular and the texture was shiny and transparent. The MT3 profile lies at a greater distance from the source area and it is possible to assume that the materials that compose it have undergone greater reworking.

4.3. Sector 3

Sector 3 is located at 635m above sea level on a 28° slope, also on an elevated hollow, which has been cut into two sections for the construction of highways. In the rainy season, mass movements are observed. The area presents a colluvium package at different weathering stages, with the limits between deposition and the underlying weathered bedrock its visible along the hillsides of the hollow. In this sector, three profiles were analyzed, the first two along the upper road cut and the third on the lower road cut. The first, MT4 (Figure 9), constitutes a 1.46m thick deposit close to the lateral limit of the hollow. It was observed that the profile is composed of two layers, the most basal (MT4B) with a texture of lightly gravely sandy mud. The first sample was collected in this layer at a depth of 45 cm. Above, lies the most superficial layer (MT4A), also characterized as a slightly gravely sandy mud. At this level, the sampling took place at a depth of 20 cm. No bioturbation was observed.

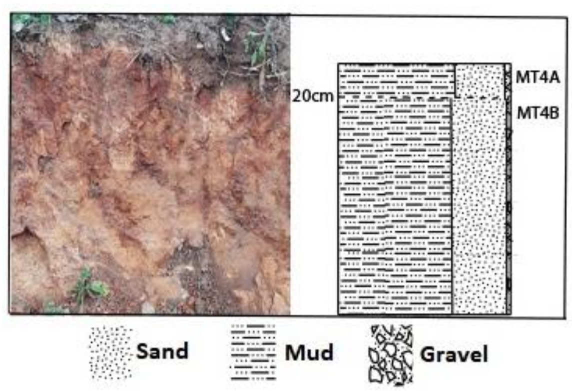

Figure 9 - MT4 sampling profile

The second profile, MT5 (Figure 10), was observed at the same altitude as the previous one, but on a more central position of the deposit. The profile has a thickness of 2.35m, the material is presented in two layers, the basal (MT5B) being yellowish in color. In this layer, the sampling was carried out at a depth of 83 cm. The surface layer (MT5A) is more hardened and darker. At this level, the sampling took place at a depth of 20 cm. The most basal layer has a gravely mud texture whereas the superficial layer is a lightly gravely sandy mud.

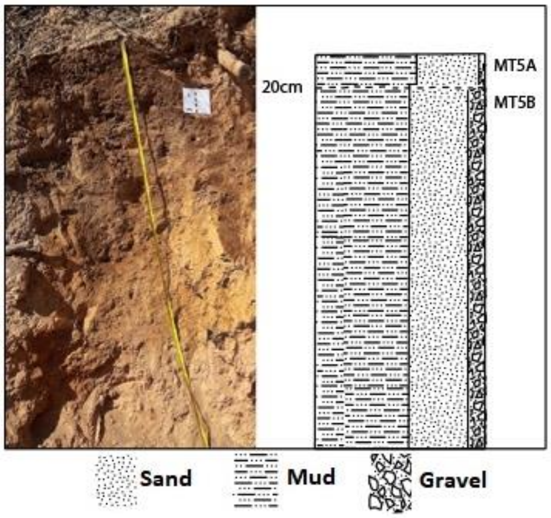

Figure 10 - MT5 sampling profile

The study area is similar to the areas of montane enclaves described in the works of Silva (2019) and Corrêa (2001), located on upper slopes, with colluvial sediments arranged in abrupt contact over the bedrock, with no surface drainage or dissection. The deposits present different textures in the same profile, as observed in sector 2, the same occurs in other hillslope contexts in the semiarid, such as the Água Branca massif, in the state of Alagoas and the Serra da Baixa Verde, in the state of Pernambuco.

The third and final sampling of sector 3 took place along the road that cuts through the lower portion of the hollow. The MT8 profile (Figure 11) is 12m thick, and the finer colluvial material is sectioned by three stone-lines with clasts in the pebble fraction. Samples were taken from the layers between the stone lines. The first layer (MT8C) was sampled at a depth of 11.20m at the top of the stone-line closest to the base of the profile. Below this, at a depth of 12m, lies the contact with the weathered bedrock. At 9.50m from the top, another stone-line occurs, with the second sampling (MT8B) being carried out between 9.50m and 11.20m in depth. The third stone line is located at a depth of 8m from the top, with the sample (MT8A) being taken between 8m and 9.50m. All layers had a slightly gravelly sandy mud texture (Figure 8).

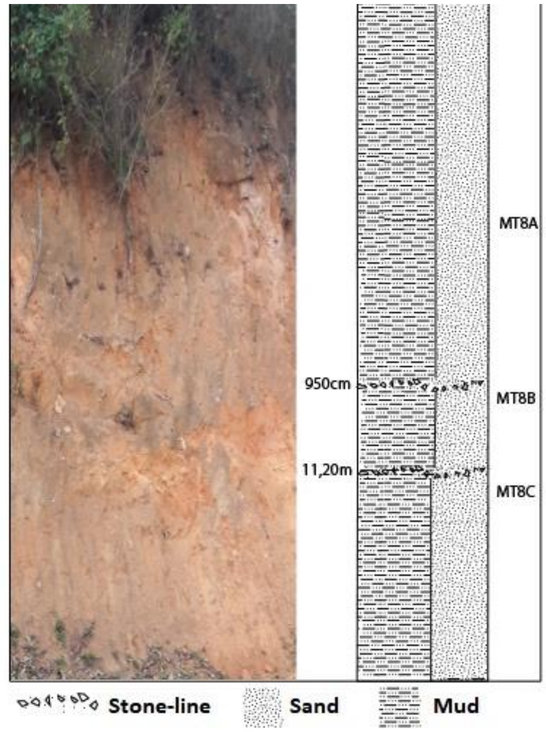

Figure 11 - MT8 sampling profile

The MT8 profile, despite being located further downstream from the hollow than the previous ones, presents a higher concentration of the muddy fraction, which may indicate that the parent material was more weathered, so the climatic condition at the time of pedogenesis was probably more humid than that during the deposition of MT4 and MT5 levels.

4.3.1. Morphoscopy

As for morphoscopy, the samples showed little variation in all parameters. The MT4B and MT4A samples were spherical with a degree of roundness varying from very angular to angular, with a matte and opaque texture in the lower layer and shiny and transparent in the upper one. For MT5B and MT5A samples, sphericity and roundness are the same, sub-prismoidal and angular. As for texture, the first is shiny and transparent, and the second is opaque and matte. In the samples MT8C, MT8B and MT8A the sphericity varied between sub-prismoidal and sub-discoidal, the degree of roundness between angular and very angular, with the texture being shiny and transparent in the lower layer, and opaque and matte in the upper one. As in the previously discussed areas, the deposits share the same characteristics of those from other montane enclaves of the Brazilian semiarid region.

4.4. Sector 4

The MT6 profile (Figure 12) is located at an altitude of 499m on a 12 ° slope. The area has a hilly topography, covered by shrub vegetation and the presence of incipient linear erosion. The profile is 1.80 m thick, and it is possible to visualize the contact with the underlying weathered bedrock. The deposit lies within a paleo-gully and displays 3 stone-lines separating finer colluvial layers. The samples were taken from the intervals among the stone-lines, in a total of four samples (Figure 9).

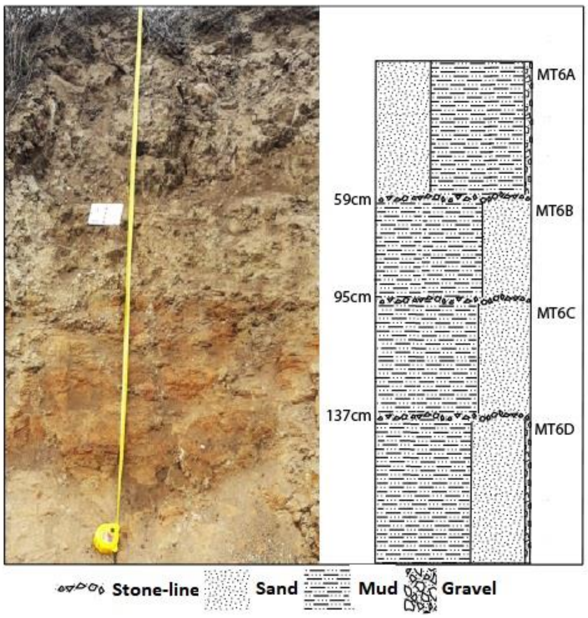

Figure 12 - Profile of the sampling point of sector 4

In the lower layer, MT6D, the material was collected between 1.37m and 1.80m from the top. The sediments have a texture of lightly gravelly muddy sand with small clasts, which suggests a triggering event of moderate energy. Above this, the MT6C layer lies above a stone-line. The sampling was carried out between 95cm and 1.36m in depth, the texture of the material is sandy mud with only 0.5% of gravel. The texture points to a depositional event with less energy than the previous layer and greater availability of weathered material.

The next layer, MT6B, was sampled between 60cm and 95cm deep, the material being a sandy mud, with 0.6% of gravel and a greater percentage of fines than the underlying layer, also indicating less energy during deposition. Above this layer there is another stone-line and the superficial layer MT6A, where the sampling was carried out between 10 cm and 59 cm from the top. The texture of this level proved to be thicker than the previous two, being a slightly gravelly muddy sand, indicating that the energy for transporting this material was greater than in the layers below.

4.4.1. Morphoscopy

As for morphoscopy, the samples did not show great differences in the analysis parameters, the sphericity remained subprismoidal in most grains, the degree of rounding varied between angular in the most basal and in the most superficial, sub-angular in MT6C and sub-rounded on the MT6B. In the latter case, a possible explanation may arise from the association between the degree of roundness and the greater amount of muddy material, which may have prevented the abrasion of the grain surface with the same efficiency as in the previous layers. The sphericity did not vary, all samples are matte and opaque.

The three stone-lines are formed by pebbles, marking alternation between periods of high energy deposition and periods of surface washing by non-channeled flows, resulting in the differential accumulation of the gravel fraction.

In the case of the MT6 deposit, it is possible to propose that each unit between the stone lines corresponds to events of greater climatic energy entry into the hillslope system, and increased torrentiality, followed by dry phases - formation of the stone lines by proportional loss of fines - until a new humidity pulse occurs. Thus, the profile presents characteristics similar to those found by Corrêa (2001) for Serra da Baixa Verde, Melo (2008) in the Tabocas District, and Silva (2019) and Melo (2019) for the Água Branca massif.

5. FINAL CONSIDERATIONS

Montane enclaves are areas peculiar to the landscape of the eastern Northeast of Brazil, being differentiated from their surroundings in relation to various aspects of their physiography, including hillslope sedimentation. It is also observed that throughout the Pleistocene/Holocene these areas were subjected to differentiated environmental dynamics, as it still occurs today.

Due to their physiographic particularities, montane enclaves condition a particular type of slope sedimentation, which occurs in the form of thin colluvium resulting from the accumulation of sediments transported by gravitational flows in varying degrees of water concentration.

The literature survey carried out by this research regarding the quaternary deposits found in various montane enclaves of the Northeast, points to the similarity between their sedimentological properties with the hillslope deposits of the Mata Grande massif, state of Alagoas.

The crystalline areas of the Borborema Province present deposits stored in elevated hollows, with materials whose texture varies from mud to boulders, demonstrating different processes of sediment transfer along the hillslopes, as well as substantial temporal variations as evidenced by the textural differences within the same stratigraphic section.

More regional studies are necessary to typify these montane environments in terms of their depositional characteristics, but in general it can be asserted that regardless of their chronology, surface processes indicate a great variability in the entry of climatic energy into slope systems under the semi-arid regime.

The research revealed that among the montane enclaves of the eastern sector of the Northeast synchronous depositional episodes occurred, but above all the surface dynamics involved were conditioned by peculiar physiographic factors shared between the areas. Nevertheless, local rhythms and controls can lead to greater recurrence/continuity of certain surface processes, as it was seen in the Água Branca Massif. On the other hand, a decrease in slope processes along the Holocene was reported to the Serra da Baixa Verde Massif whereas tectonic-structural controls were recorded in the Pereiro massif.

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