https://rbgeomorfologia.org.br/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 27, nº 3 (2026)

http://dx.doi.org/10.20502/rbg.v27i3.2771

Research article

Interactions between biogenetic and morphogenetic forces on slopes: termite mounds and murundus

Interações entre as forças biogenéticas e morfogenéticas nas vertentes: termiteiros e murundus

Roberto Marques Neto [1], Henrique Carvalho de Oliveira [2], Lara Pereira Loures [3] e Luísa Costa Coimbra[4]

[1] Universidade Federal de Juiz de Fora, Department of Geosciences, Juiz de Fora, Brazil. E-mail: roberto.marques@ufjf.br
ORCID: https://orcid.org/0000-0002-6496-789X

[2] Universidade Federal do Rio de Janeiro, Post-Graduate Program in Geography, Rio de Janeiro, Brazil.
E-mail: henriquecarvalho123.o@gmail.com
ORCID: https://orcid.org/0000-0000-0000-0000

[3] Universidade Federal de Juiz de Fora, Department of Geosciences, Juiz de Fora, Brazil. E-mail: laraploures@gmail.com
ORCID: https://orcid.org/0009-0000-3461-1764

[4] Universidade Federal de Juiz de Fora, Department of Geosciences, Juiz de Fora, Brazil.
E-mail: luisacoimbra2022@gmail.com
ORCID: https://orcid.org/0009-0001-3964-3383

Received: 14/11/2025; Accepted: 02/06/2026; Published: 09/09/2026.

Abstract: The evolution and dynamics of slopes are essentially investigated from the intrinsic morphogenetic and pedogenetic perspectives. This article proposes an additional focus on the operative biogenetic aspects, seeking to discuss dialogically the biotic and erosive influences on the generation of microreliefs (*murundus* and termite mounds). To this end, morphometric, biological, and pedological aspects of these morphologies were addressed, aiming to investigate their genesis, evolution, and morphometric aspects. Results obtained in two latosolic catenas in the municipality of Carrancas, Minas Gerais, are presented in an area of *cerrado strictu sensu* and *campo cerrado*. The results demonstrated overlapping cycles of vertical uplift caused by invertebrates (primarily termites) combined with differential erosion in the catena under *cerrado strictu sensu*, and essentially biogenic evidence in the catena over *campo cerrado*. In both cases, greater soil aggregation and a significantly higher concentration of nutrients and organic matter were observed in the *murundus*, suggesting a role for endopedonic organisms in nutrient cycling. Furthermore, it was found that bioturbation processes engender irregularities on slopes through cycles of uplift, occupation, and abandonment, interfering with morphological aspects and erosional and depositional organization.

Keywords: vertical uplift; differential erosion; latosolic catena; *cerrado*.

Resumo: A evolução e dinâmica de vertentes são essencialmente investigadas a partir dos aspectos morfogenéticos e pedogenéticos intrínsecos, e o presente artigo propõe um enfoque adicional centrado nos aspectos biogenéticos operantes, procurando discutir dialogicamente as influências bióticas e erosivas na geração de microrrelevos (murundus e termiteiros). Para tal, foram abordados aspectos morfométricos, biológicos e pedológicos concernentes a tais morfologias com vistas na investigação acerca de sua gênese, evolução e aspectos morfométricos, apresentando resultados obtidos em duas catenas latossólicas no município de Carrancas (MG) em área de cerrado strictu sensu e campo sujo de cerrado. Os resultados demonstraram ciclos sobrepostos de remonte vertical levados a efeito por invertebrados (essencialmente cupins) consorciados à erosão diferencial na catena sob cerrado strictu sensu, e evidências essencialmente biogênicas na catena sobre campo cerrado.

Em ambos os casos, foi verificada uma maior agregação do solo e uma concentração de nutrientes e matéria orgânica sensivelmente maior nos murundus, sugerindo papel dos organismos endopedônicos na ciclagem de nutrientes. Além disso, foi constatado que os processos de bioturbação engendram irregularidades sobre as vertentes a partir de ciclos de remonte, ocupação e abandono, interferindo nos aspectos morfológicos e nas organizações erosivas e deposicionais.

Palavras-chave: remonte vertical; erosão diferencial; catena latossólica; cerrado.

---

1. Introduction

The ongoing processes in the evolution and dynamics of slopes involve chemical forces (given by weathering and mineral neoformation), physical forces (given by the action of tectonism and by the external dynamics promoted by surface runoff), and biological forces, driven by fossorial fauna through their excavations and the formation of ducts and galleries, as well as by trampling promoted at the surface. The biota inhabiting the interior of the soil promotes chemical and physical alterations as a function of its metabolism and the bioturbation processes exerted on surface covers, directly affecting slope morphology and surface processes, thus interfering in their evolution and dynamics (Penteado-Orellana, 1980; Miklos, 2012; Lima et al., 2018).

Among the main results of the action of organisms in the soil are termite mounds or *murundus*, circular to elliptical microreliefs formed by biogenic and\or erosive activity, carried out mainly by termites and ants, organisms that perform vertical uplift of surface covers, including soils, resulting in landforms that are often copious on slopes and valley bottoms. Such morphologies figure among the most expressive surface biogeomorphological facts in tropical environments, being recurrent in different geoenvironments and soil types, and often assuming a profusion capable of significantly interfering in the structure and dynamics of the landscape. According to Bignell (2019), the complex mutualisms occurring between isopteran invertebrates and the soil microbiota also influence the physical and chemical aspects of pedological cover, given their ability to open ducts and galleries and digest organic components and consequently interfere in soil mineralogy. The high ecological potential prevailing in warm and humid tropical zones favors the presence of a large quantity of endopedonic organisms, which consequently begin to interfere in the geomorphological organizations in which they are inserted. Despite the recurrence and importance of the role of organisms in slope morphology and dynamics, this remains a problem that is still insufficiently investigated.

The lack of systematic studies and more conclusive results is symptomatic in the divergences surrounding interpretations regarding the origin and evolution of *murundus* and their relationships with relief and landscape. Some authors support the biological hypothesis (Furley, 1986; Miklós, 2012; Lima et al., 2025), according to which *murundus* are features resulting from termite activity, especially termite mounds, in addition to ants, earthworms, and giant earthworms. Other authors, in contrast, attribute the origin of *murundus* to differential erosion (Penteado-Orellana, 1980; Resende et al. 2002; Sales, 2021). In any case, both origins are not strictly mutually exclusive, and there may be convergence between biogenetic and morphogenetic processes in the formation of these landforms (Ponce; Cunha, 1993; Antunes et al. 2012).

Furley (1986) emphatically highlights the recurrence of *murundus* in tropical landscapes, where they form true "*murundu* fields," found in two particular situations: (1) areas semi-permanently affected by groundwater and infiltration, forming discrete islands of woody *cerrado* with Red-Yellow Latosol; (2) areas affected by seasonal rainfall and runoff that maintain little contact with groundwater, forming less perceptible mounds and having a more linear shape in accordance with the decline of the slopes on which they occur. In both situations described, *murundus* present a wide variety in terms of size, orientation, type and diversity of vegetation cover, as well as with regard to their associations with surface flows and groundwater.

Delving deeper into this interesting field of contradictions, Miklós (2012) asserts that, due to the magnitude, population density, biomass, and transforming action of the environment by soil-dwelling invertebrates, such organisms inevitably figure as fundamental agents in the organization and dynamics of soils in intertropical

landscapes. Furthermore, the author emphasizes the role of vertical uplift in the generation of Latosols and latosolic B horizons, the main pedological transformations of the tropical environment, shaping microaggregates, cementing material on the surface where erosive processes dominate, and feeding back soil functionality with the organic matter derived from their waste and withering. Throughout this epigeal movement, Lima et al. (2025) demonstrate the preference of invertebrates for clayey materials to the detriment of sandy ones, which tends to figure as the dominant granulometric fraction in the mounds.

The vertical uplift activity that results in the formation of *murundus* also has a strong relationship with vegetation. Resende et al. (2004) demonstrated, in a research conducted in the *Cerrado* of the *Triângulo Mineiro* region, that larger landforms proved themselves favorable for the occurrence of woody species, especially in hydromorphic environments, which are not tolerated by many species; in these cases, *murundus* function as "islands" for the occurrence of such species and therefore act in maintaining regional biodiversity. In direct dialogue with this support function for vegetation, it was found that the sorting work performed by fossorial fauna to build *murundus* results in an increase in organic matter and clay minerals relative to the surrounding soils (Oliveira et al. 2012), as well as in the microbial biomass present in the soil (Pinheiro et al. 2013).

In light of the arguments presented, the expansion of studies regarding the role of biota in the surface structuring of the landscape is of great value, since they permeate fields of knowledge that are still not very consensual, accessing specific areas of geomorphology, biogeography, pedology, and geoecology. Consequently, such studies require appropriate methodological strategies to better understand the important geoecological functions that occur at the relief-soil-biota interface.

Tropical landscapes are replete with termites, and even the most general observations reveal how extensive the spatial distribution of vertical uplift is. Occurring in all Brazilian morphoclimatic domains, such geomorphic features are distributed across different geomorphological and geochemical compartments, appearing in varied dimensions along interfluvial zones, slopes, and valley bottoms, thus permeating oxidizing and reducing landscape environments. In addition to the classic termite mounds predominantly built and occupied by termites, there are also the *murundus* typical of hydromorphic environments distributed throughout the Brazilian *Cerrado*.

The municipality of Carrancas (MG) is located in the southern portion of the state of Minas Gerais in a transitional zone between the domain of the Atlantic tropical forests and the *Cerrado*, comprising *cerrado stricto sensu* and *campo cerrado* phytophysiognomies strongly threatened by the more massive expansion of agribusiness from the second decade of the 21st century onward. Beneath the *Cerrado* vegetation, sequences of mounds of varying size were observed in different geochemical environments, from eluvial zones to valley bottoms, with morphology similar to the *murundu* fields typical of hydromorphic environments. Based on this observation, procedures were initiated to interpret, through investigation in two latosolic catenas, the morphological, morphometric, pedological, physicochemical, and genetic-evolutionary aspects of the geoforms under consideration.

2. Methodology

The theoretical foundations of this work consider the dialectics of nature (*sensu* Engels, 1979) existing in the relationships between biogenesis and morphogenesis, conjugated in dynamic processes that may or may not function as conditions for state changes (evolution). Thus, a tensioning inherent to complex systems (*sensu* Morin, 1977) is substantiated, in which forms and processes are mediated by the organic.

Along two latosolic catenas, one covered by *cerrado stricto sensu* and the other by *cerrado campo sujo*, pedological, morphological, morphometric, and biological data surveys were carried out on the targeted features occurring along the slopes, using the quadrat technique (Martins, 1993; Furlan, 2005), with three quadrats sampled for each catena. In 20 m x 20 m plots, the width, length, height, and perimeter of each feature were measured using a measuring tape, accompanied by morphological classifications (convex, conical, or columnar), identification of the state (active,

inactive, degrading), the type of biological exploitation (ants, termites, or both), and vegetation occupation (herbaceous, shrubby, arboreal, or composite). Genesis was differentiated according to the biotic or abiotic nature based on field evidence, and evolution considering the dominant processes: aggradational (vertical uplift, accretion over preexisting uplift) and/or degradational (sheet erosion and rill erosion). The primary data collected for each geoform were recorded on a field sheet and subsequently represented in graphs generated in Excel.

In each catena, the plots were selected in different geochemical environments, namely: eluvial (summits and summit surfaces), transeluvial to transaccumulative (slope domain), and accumulative (valley bottoms), in accordance with the model presented by Ballesteros (1991). Subsequently, the connectivity patterns between such plots were established, revealed in representations in the form of geoenvironmental profiles organized in ArcGIS. In addition to slope morphologies and the distribution of *murundus*, the profiles also provide information concerning the geological substrate, soils, vegetation, and anthropic land use, in turn grouped into geosystemic units differentiated according to the physical-geographical facies, in accordance with the hierarchical system proposed by Sochava (1971; 1978).

The authors themselves systematizes the field evaluation routine for the mounds. For each quadrant, soil samples were collected from a sample mound, with auger sampling performed at the top, center, and base for the *cerrado stricto sensu* catena, with depths varying according to the height of the microreliefs. The option for tripartite division was also the same adopted by Lima et al. (2018). For the *campo cerrado* area, due to the distinctly lower height of the mounds, samples were collected only from a superficial portion (0 to 0.5 m) and a subsurface portion (0.5 to 1.0 m). Specifically regarding the base, it should be noted that it was established considering the reference geomorphic surface, which also guided the positioning of the vertical rod used to measure height. Auger efforts were also used to identify variations in soil coloration indicative of possible variations in organic matter content, as well as to verify the presence or absence of bioturbation marks given by small galleries or evidence of soil disturbance and redistribution of organic matter. In addition, surrounding soil samples were collected, encompassing all geochemical environments.

The collected material was sent for physical and chemical analysis at the Soil Laboratory of the Federal University of Lavras (UFLA) (Mehlich protocol). The following parameters were analyzed: *pH* measured in water; organic matter (dag/kg); *exchangeable acidity* (potassium chloride extractor); *potential acidity* (Al3+ + H+, in SMP extractor); *exchangeable bases*, with Ca and Mg also obtained by the KCl extractor and Na and K by the Mehlich extractor. The *cation exchange capacity* (CEC), given by the sum of potential acidity and exchangeable bases, is calculated under pH 7.0 conditions, and *aluminum saturation* (m) is defined by the division of exchangeable aluminum by the sum of this value to that of the bases multiplied by 100, in addition to granulometry.

The morphopedological, morphometric, and biological data obtained in the field and through laboratory tests were treated dialogically for the interpretation of genetic-evolutionary aspects of the studied landforms, having the biological and geomorphological hypotheses surrounding the debate confronted and interacted with each other.

3. Study area

Located on the southern edge of the São Francisco Craton (Figure 1), within the Neoproterozoic fold belts, Carrancas is situated in an interesting transitional zone at the intersection between the Atlantic tropical forest domain and the *Cerrado*. Such a condition defines intercalations between forest fragments and *cerrado* phytophysiognomies in intermontane sectors of the landscape, lithologically composed of paragneisses underlying the latosolic covers, landscapes increasingly homogenized by the expansion of agribusiness, which has taken advantage of the moderate slopes prevailing on the geomorphological surface under consideration. The high-mountain sectors, in turn, are defined by extensive ridges framed in micaceous quartzites and occupied by rupestrian grasslands over immature soils, distinctly sandy and rich in primary minerals.

The aforementioned Neoproterozoic fold belts define metasedimentary terrains corresponding to the Andrelândia Basin (Pacciulo et al. 1993; Ribeiro et al. 1995) or Andrelândia Megasequence (Heilbron et al. 2004), a Mesoproterozoic depositional system with variable-grade metamorphism resulting from Neoproterozoic collage (Almeida, 1992) linked to the thermotectonic events related to the Brasiliano Cycle.

The studied toposequences are restricted to the intermontane domains of the landscape, which comprise hilly morphology and hills with smoothed slopes, forming extensive latosolic ramps that still preserve fragments of *cerrado stricto sensu* and *campo cerrado*, increasingly suppressed by soybean monoculture that has taken advantage of these smoother relief terrains of southern Minas Gerais, upon which it has advanced through intense mechanization.

Contrasting with the domain of mature soils (predominantly Latosols) of the intermontane gneissic terrains, the quartzite ridges support Cambisols and Litholic Neosols with distinct rockiness on the terrain surface. This geoecological texture supports the aforementioned rupestrian grassland, a phytophysiognomy typified by shrubs, subshrubs, grass tussocks, and small sparse trees in which *candeia* (*Eremanthus sp*.) stands out in notable ecological dominance. In fluvial lowlands, hydromorphic soils occur, also traceable by the coloration of the termite mounds built in these geoenvironments.

The climatic type prevailing in Carrancas refers to the tropical highland climate (Cwb, according to the Köppen system), which is responsible for moderating the temperatures of the typical tropical climate in the highlands of Southeastern Brazil.

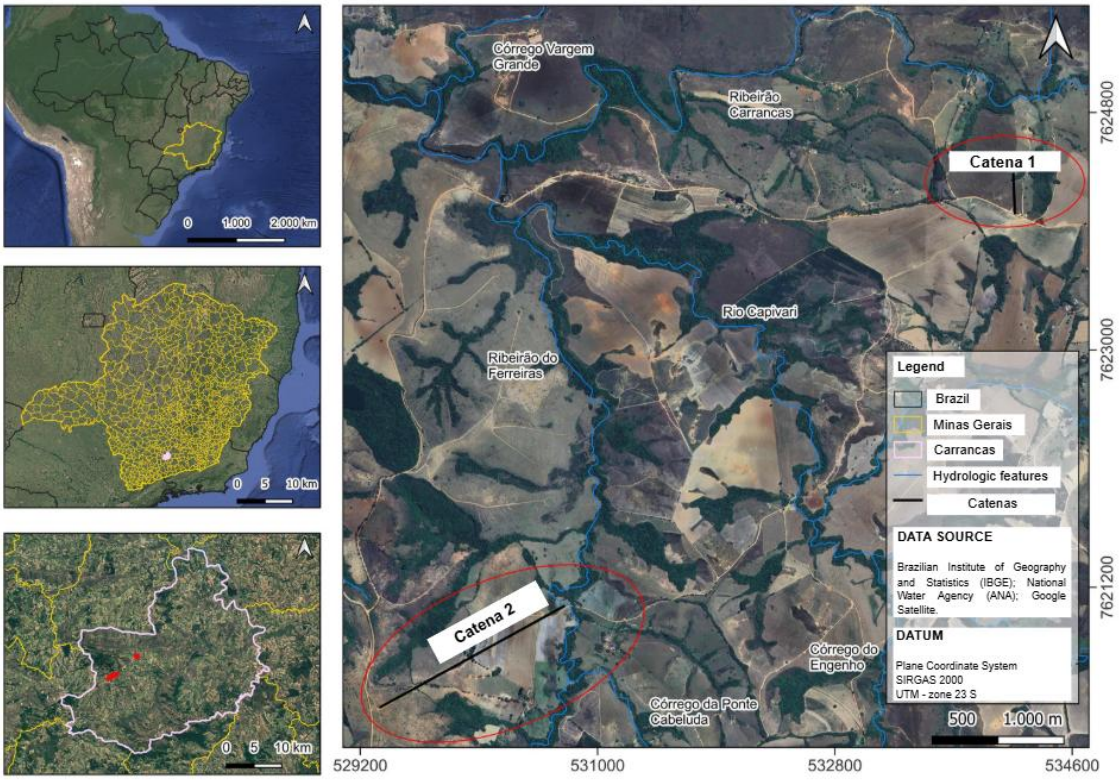

Figure 1. Location of the study area.

4. Results

The applications carried out and presented in this article focused on two latosolic catenas located in areas of *cerrado stricto sensu* and *cerrado campo sujo*, as previously announced. First, the results for each of the catenas will be presented, to be discussed in the following section.

Catena 1 (C1)

The first analyzed catena, here designated as C1, is covered by *cerrado stricto sensu*, with distinctly denser vegetation during the rainy season. For this slope, plots were studied in eluvial, transeluvial, and transaccumulative/accumulative zones.

The quadrant sampled in the eluvial zone encompasses an oxidizing environment with deep latosolic pedogenesis projecting onto an interfluvial belt typified by hills with smoothed slopes and a flattened surface. In the transeluvial zone, a strongly oxidizing condition still prevails, with similarities in the geochemical signatures typical of tropical Latosols. As for the transaccumulative zone, there is a transition to a hydromorphic domain due to the more intense interaction with the groundwater table that will become established in the accumulative zone, with significant changes in the chemistry of superficial covers. The darkened coloration of the termite mounds in the lower section of the transaccumulative zone indicates that this segment is also affected by the seasonal rise of the groundwater level.

Along C1, both the eluvial and transeluvial belts present sequences of mounds interspersed with depressions quite similar to the *murundu* fields of hydromorphic valley-bottom zones, yet positioned in an oxidizing environment throughout the entire slope. A series of microforms of varying dimensions and with different patterns of biological exploitation occurs. In the transaccumulative and accumulative sectors, however, the mounds assume an appearance much more closely tilted to the classic termite mounds so abundant in pastures and deforested areas.

Figures 2, 3, and 4 show the proportional distribution of the mounds according to the parameters under consideration for the three geochemical compartments analyzed in C1.

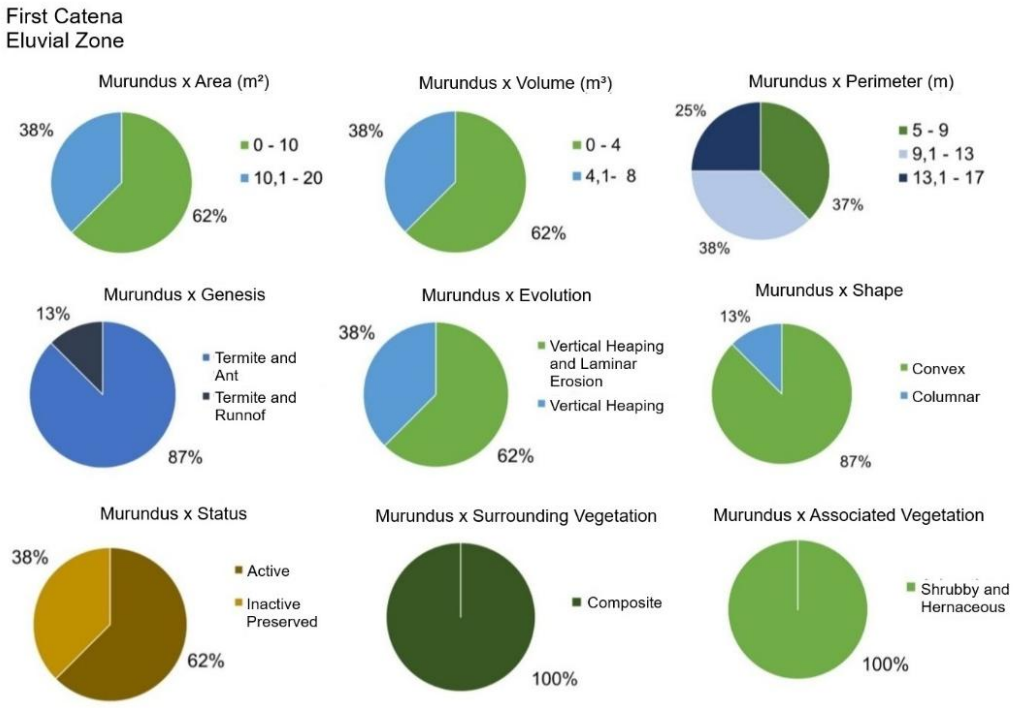

Figure 2. Characteristics of the mounds analyzed in the C1 eluvial zone.

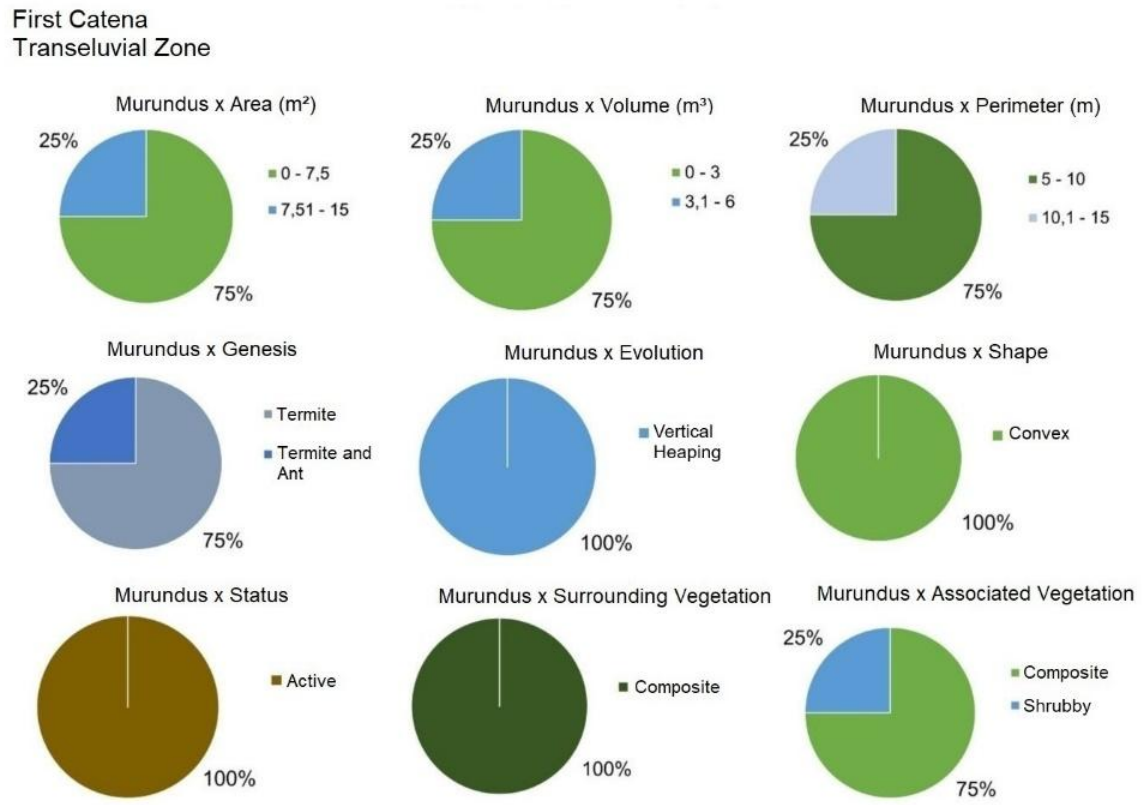

Figure 3. Characteristics of the mounds analyzed in the C1 transeluvial zone.

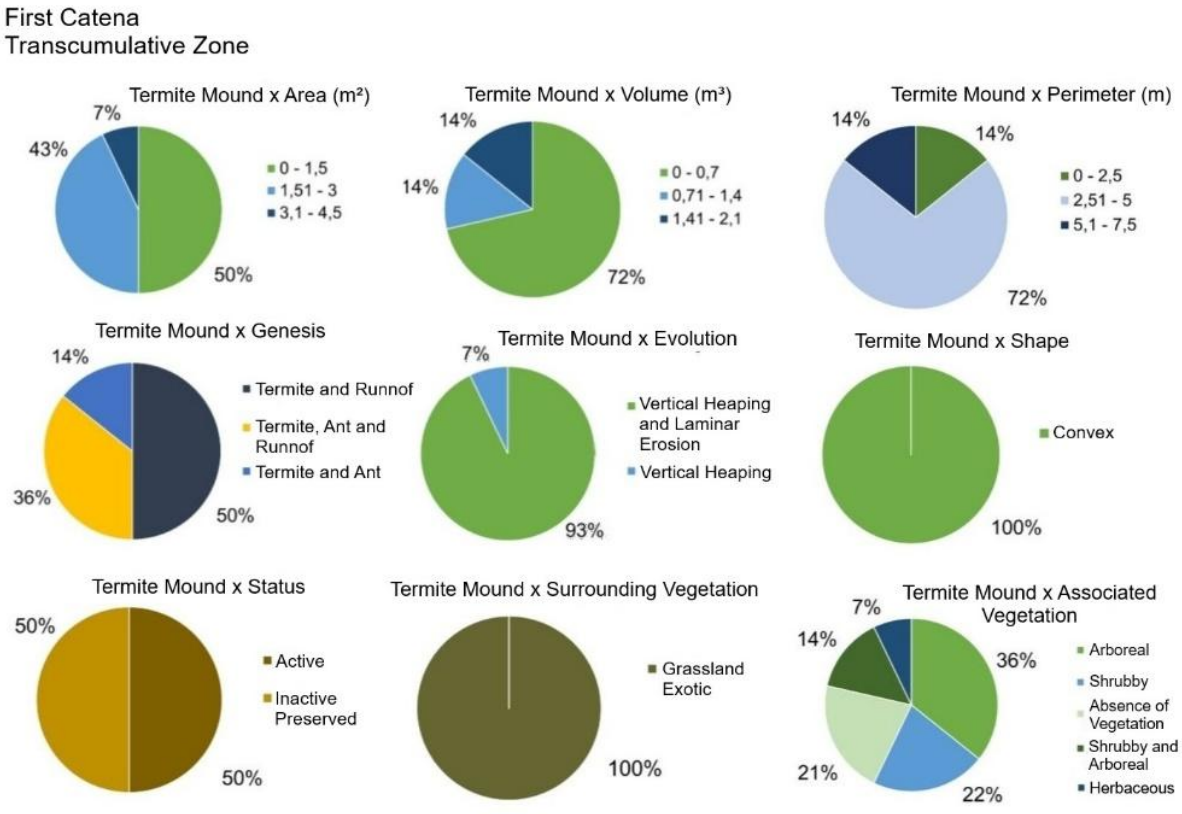

Figure 4. Characteristics of the mounds analyzed in the C1 transaccumulative/accumulative zone.

The dimensions of the mounds tend to decrease from upstream to downstream, as can be verified fundamentally by area and perimeter. Along the catena, features of considerable size prevail, standing out on the slope, with significant lateral development possibly linked to polycyclic evolutionary processes characterized by more than one phase of occupation by builder isopterans that coexisted and coexist with surface water erosion. In the valley bottom the more common termite mounds generated by vertical uplift predominantly by termites occur, thus assuming smaller dimensions, especially in length and width.

Polycyclic evolution can be defended due to the presence of different phases of occupation, carried out by termites, ants, or a consortium of both, with construction of materials over older excrescences, whose basal portions showed no signs of bioturbation in the samples removed by auger. Such a configuration is suggestive, at first, of a fundamental role of differential erosion, characterized by a recurrent and partial incidence of laminar erosive water tables associated with poorly defined rill flows that spread between the hummocks, in a typical configuration of prominences and depressions described for *murundu* fields. Some of the prominences do not present active colonies, with active and inactive murundus coexisting throughout the entire connectivity between the eluvial and transeluvial sections. In the transaccumulative/accumulative section, an area of occurrence of more typical termite mounds, biological activity was verified in all samplings.

In the catena under consideration, a pattern was also noted whereby the evidence of vertical uplift increases downstream, with the entirety of the genetic linkage of the valley-bottom prominences being dominantly active in the form of termite mounds built by termites. In the eluvial and transeluvial domains, the evidence observed in the field suggests a more intense interaction between surface erosion and vertical uplift, predominantly carried out by termites, although mutual occupations are conspicuous.

The full interaction between morphogenetic and biogenetic processes operates in superficial covers with a strong tropical signature, with latosols tending toward acidity, saturated in aluminum, and restricted in exchangeable bases, as can be observed in Table 1.

Table 1. Physical-chemical aspects of soils related to the mounds in C1.

Sector	pH	K	P	Na	Ca	Mg	Al	m%	OM	CEC	Texture
		——————mg/dm³——————						%	dag/kg	%	
Eluvial Zone											
Apical	4.2	91.83	0.1	2.0	0.85	0.76	0.28	13.15	3.49	7.95	clayey
Central	4.6	31.16	0.02	1.0	0.36	0.35	0.19	19.39	2.70	4.89	clayey
Basal	5.1	36.34	0.0	1.0	0.49	0.52	0.23	13.15	3.49	7.95	clayey
Surroundings	4.9	7.94	0.01	1.0	0.23	0.35	0.22	26.83	2.05	7.40	clayey
Transeluvial Zone											
Apical	4.7	33.86	0.47	0.0	0.44	0.35	0.55	38.43	3.60	3.38	clayey
Central	4.7	40.70	0.61	0.0	0.53	0.35	0.56	36.36	3.27	4.88	clayey
Basal	5.0	43.98	0.64	0.0	0.94	0.57	0.40	19.80	3.87	5.92	clayey
Surroundings	4.9	29.52	0.58	0.0	0.60	0.31	0.43	30.28	3.16	4.49	clayey
Accumulative/Transaccumulative Zone											
Apical	4.4	13.80	6.81	1.10	0.94	0.88	1.43	8.30	3.21	10.46	medium
Central	4.8	75.19	3.26	7.0	1.97	1.91	0.53	11.52	3.84	10.87	medium
Basal	4.4	91.09	7.11	5.0	1.87	1.31	0.74	17.83	3.40	10.51	medium
Surroundings	5.0	46.46	3.46	2.0	0.35	0.47	0.62	39.74	1.42	4.64	medium

Along the catena, a tendency of increasing concentration of chemical elements from upstream to downstream was measured, with higher levels concentrated in the transaccumulative zone for K, P, Ca, Na, and Mg, resulting in a higher sum of bases value. The organic matter content does not undergo considerable modifications, but it is also slightly higher in the transaccumulative zone.

The results obtained for the eluvial zone showed a higher concentration of nutrients and organic matter in the *murundu* compared to the surroundings, with a decreasing concentration bias from top to base, and the values found at the base being the most similar to what was found for the geomorphic surface defined in the surroundings.

In the transaccumulative zone of the valley bottoms, a greater concentration of alkaline cations was verified, including K, P in the organic phase, Na, Ca, and Mg, also slightly increasing the concentration of Al. Such a pattern indicates the receiving functionality and the condition of a geochemical barrier, differing geochemically in the intensely leached eluvial and transeluvial zones.

Looking specifically at the transaccumulative zone mounds, the concentrations decrease from microreliefs top to base, although the concentrations of organic matter are relatively uniform, thus showing no relationship between the top of the microreliefs and ancient A horizons preserved from differential erosion.

Figure 5 consists of a geoecological profile of Catena 1, in order to show relationships between the microrelief occurrence pattern, the geochemical compartments, and the horizontal and vertical structure of the landscape.

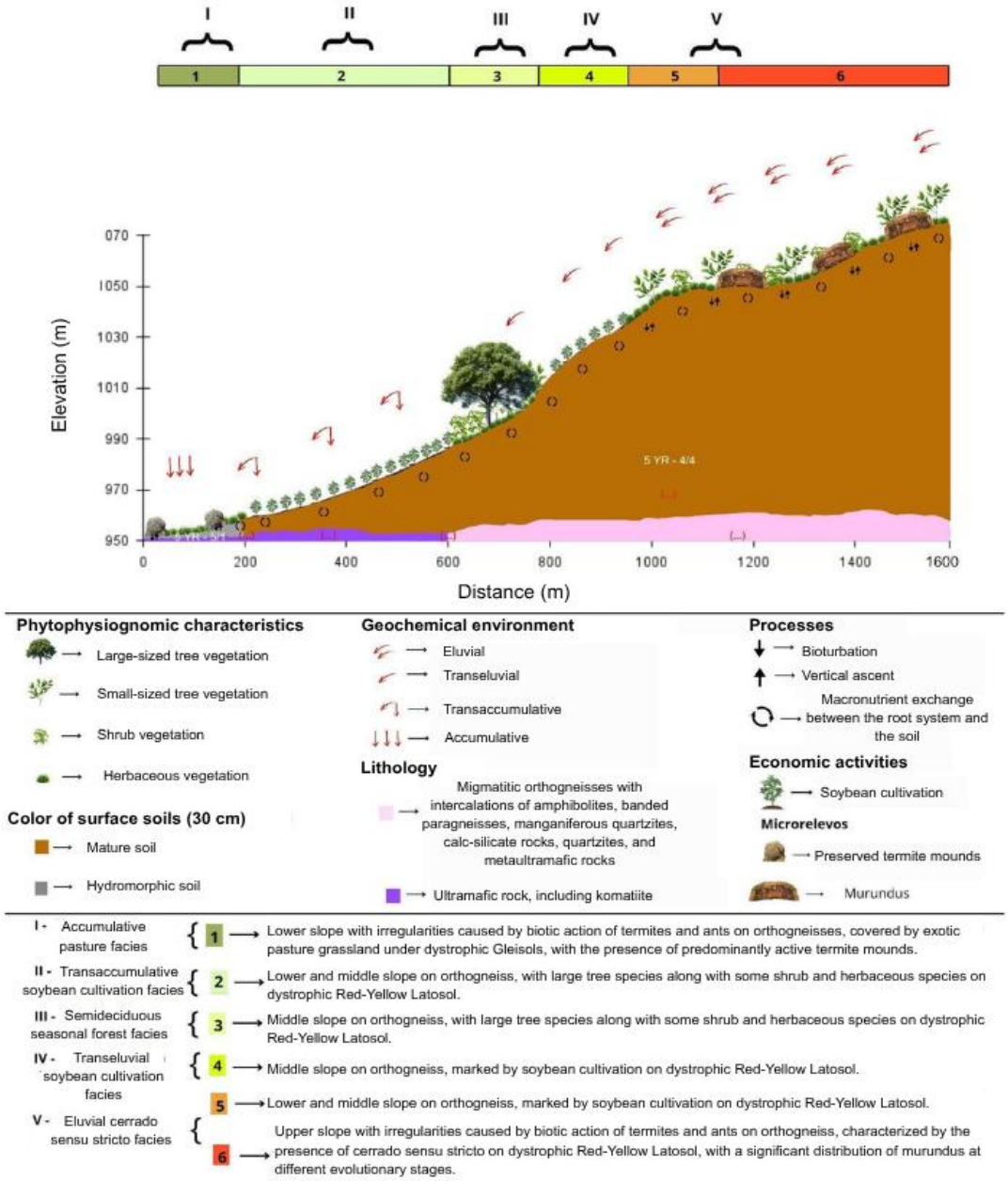

Figure 5. Geoenvironmental profile of Catena 1.

Catena 2 (C2)

C2 is defined on an extensive and smoothed latosolic slope, with a morphometric pattern quite similar to C1, but covered by *cerrado campo sujo*, with continuous Poaceae cover punctuated by mesophanerophytic trees and sparse shrubs, unlike the dense *cerrado* aspect occurring in the previously listed toposequence. The granulometric analyses applied in C2 invariably fell into the medium textural class, with expressive concentrations of sandy fraction varying between 61 and 72 dag/kg in both surface and subsurface levels, contrasting with the clayey texture of C1. In addition, the soils of the catena in question are chemically poorer and present more modest organic matter contents.

The most latent evidence was a significant decrease in the microrelief occurrence compared to C1, in addition to metric dissimilarities, fundamentally height (Figures 6 and 7). Thus, graphical results reflect much more regular behaviors in a significantly lower occurrence density per quadrant. In C2, the occurrences are more uniform in terms of size and shape, with only convex morphologies having been found.

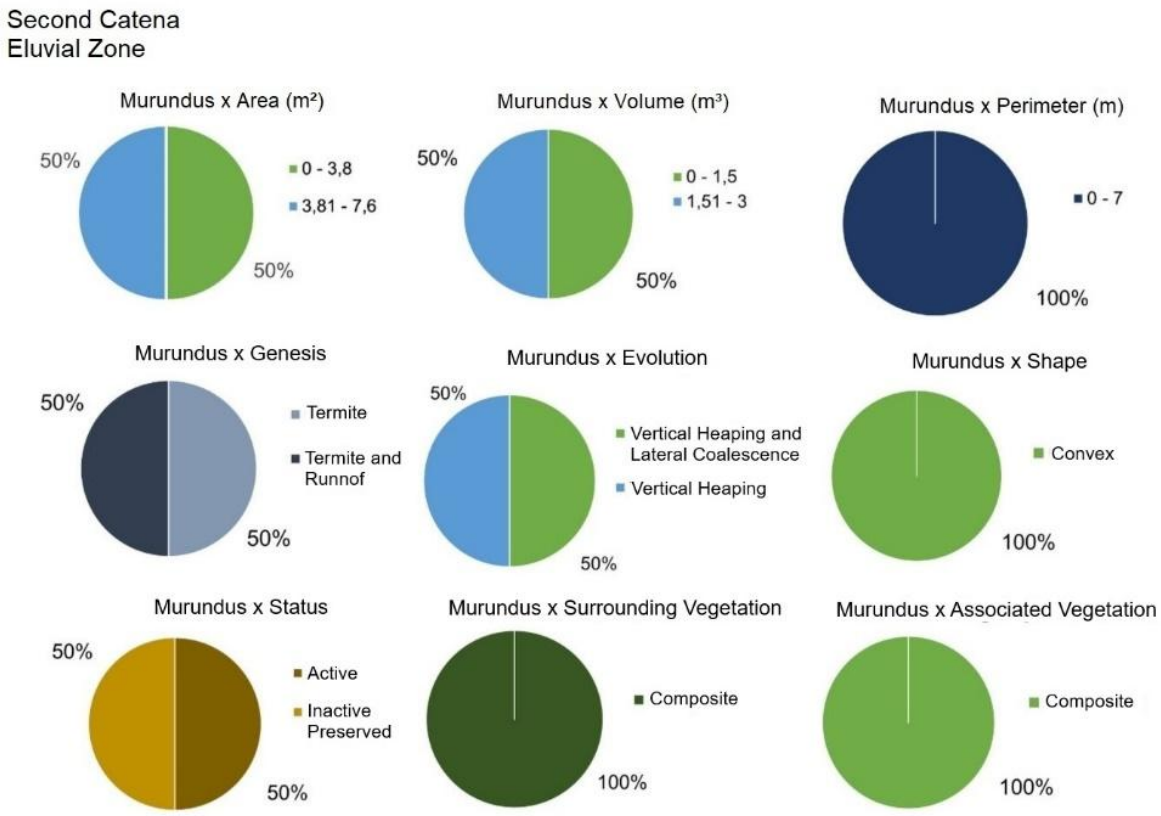

Figure 6. Characteristics of the mounds analyzed in the C1 eluvial zone.

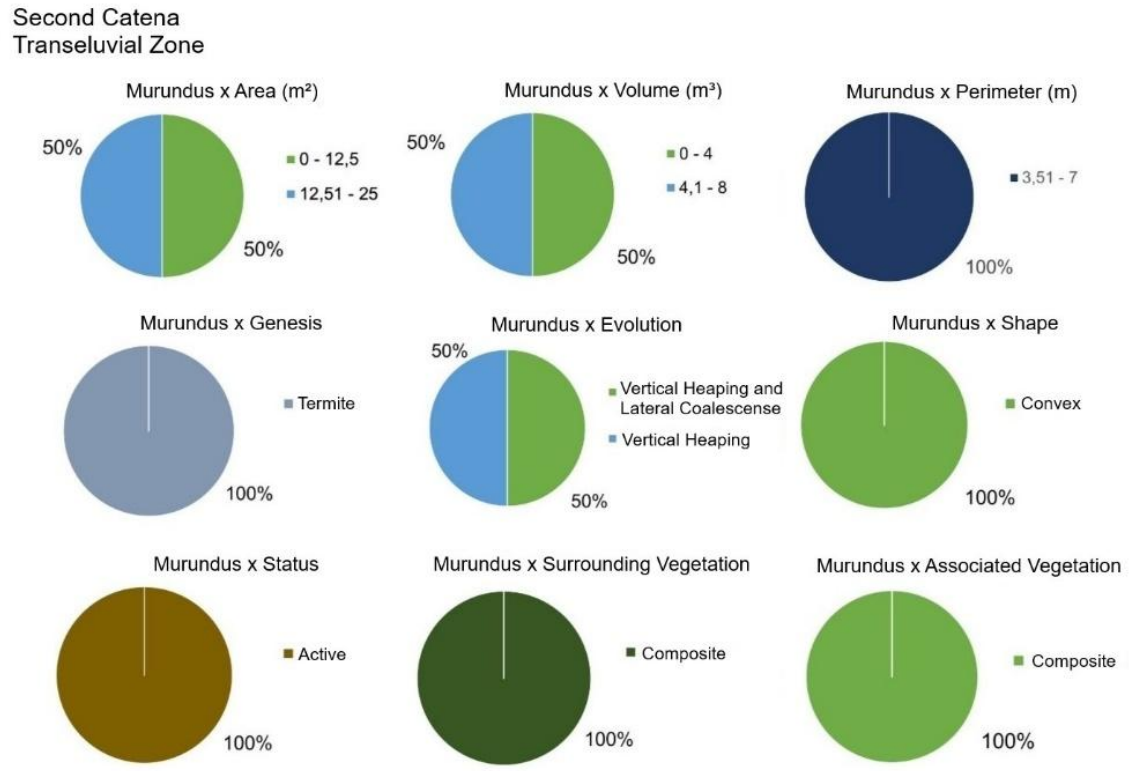

Figure 7. Characteristics of the mounds analyzed in the C1 transeluvial zone.

The biogenic influence increases from the eluvial zone to the transeluvial zone, with increased occurrence of termite mounds toward the valley bottom. Distinctly, what is seen under *cerrado campo sujo* is not a sequence of mounds and depressions, but small prominences that stand out more punctually over the slope, which makes a division into upper, middle, and central sections in the manner carried out in C1 difficult.

Augerings were performed in active and inactive structures in order to establish some comparison parameters. In inactive structures, higher concentrations of organic matter were found from 0.5 m depth onward, a range from which the soil presents a distinctly darker coloration, although the contents were low. Such a characteristic may also be due to root decomposition, presumed from the marks and remains of root material present in the collections. Woody plants such as the wolf apple (*Solanum lycocarpum*), nance (*Byrsonima crassifolia*), and the *açoita-cavalo* (*Luehea divaricata*) are quite conspicuous on the microreliefs.

In some structures with ongoing biological activity, the auger removals revealed a soil with darker coloration due to the enrichment of organic matter still retained and well distributed throughout the profile. In other cases, the typical mineral horizon of Red-Yellow Latosol proved uniform beyond 1 m depth.

As in C1, structures with mutual occupation by ants and termites were found, with termite mounds occurring in different stages. Field observations found a dominance of worker and accessory larval forms, with soldiers being scarcely recurrent in the observed structures. Mutual occupation by ants also proved common, with recurrent predation exerted upon the termites.

Bioturbation structures were also not found in C2. Despite the intense biological activity found in the field, augerings allowed to verify that the ongoing biogenic action is superficial, and also suggest recent colonization over a preexisting structure.

Catena 2 presents soils with distinctly greater quantities of sand fraction, as mentioned. Thus, the chemical parameters found were also reduced more than in C1, given the substantial decrease in the active charge of the soil. Table 2 presents the results obtained for C2 for the pertinent individual and comparative analyses.

Table 2. Physical-chemical aspects of soils related to the mounds in C2.

Sector	pH	K	P	Na	Ca	Mg	Al	m%	OM	CEC	Texture
				mg/dm³				%	dag/kg	%	
Eluvial Zone											
Apical - 1	4.3	14.57	0.18	0.0	0.05	0.04	1.47	91.88	0.73	3.03	medium
Basal - 1	4.1	10.97	0.27	0.0	0.08	0.06	0.98	85.52	1.11	3.27	clayey
Apical - 2	3.8	25.62	0.70	0.0	0.06	0.05	1.23	87.23	1.91	5.48	medium
Basal - 2	4.4	41.46	0.91	0.0	0.07	0.07	1.28	83.66	1.11	5.25	clayey
Surroundings	4.8	14.67	0.89	0.0	0.41	0.16	0.98	61.64	1.74	3.11	medium
Transeluvial Zone											
Apical - 1	5.1	12.36	0.85	0.0	0.05	0.04	0.60	83.33	1.17	2.52	medium
Basal - 1	5.2	9.78	0.12	0.0	0.06	0.05	0.33	7.21	1.03	2.34	medium
Apical - 2	4.8	18.25	0.50	0.0	0.09	0.06	0.97	84.35	2.70	5.18	medium
Basal - 2	4.5	13.37	0.50	0.0	0.09	0.08	0.92	82.14	2.23	3.80	medium
Surroundings	4.4	40.70	0.78	0.0	0.44	0.23	1.35	63.68	3.53	6.87	medium

In the eluvial zone, for the two sampled microreliefs, a decrease in the macronutrient content from the apical part to the basal segment was verified, although they are quite reduced in all ranges, which makes such variations insignificant. From the apical to the basal part, aluminum saturation also decreases. On the other hand, an increase in organic matter content was verified, although in very low quantities. With the exception of K, the variation of the other elements between the two sampled mounds is low.

Regarding the granulometry measured for the eluvial zone, a relatively uniform distribution was verified, without significant variations from the surface to deeper levels.

The geochemical behavior of the transeluvial zone bears strong similarities to the upstream eluvial zone: decrease in nutrient content and aluminum saturation. The variation among the chemical elements between the samples is also negligible, with the exception of K, as occurs in the eluvial zone. The difference found refers to the decrease in organic matter content.

The granulometry and the distribution of proportions among granulometric fractions also sustain the pattern of the eluvial zone, without major variations between the sections of the microreliefs, as well as among them. However, in the transeluvial zone, a small decrease in the sandy fraction accompanied by an increase in clay content was verified.

As presented for C1, Figure 8 consists of a geoenvironmental profile designed for C2, which allows the visualization of elements of the relationships between microreliefs and the superficial and subsuperficial structure of the landscape.

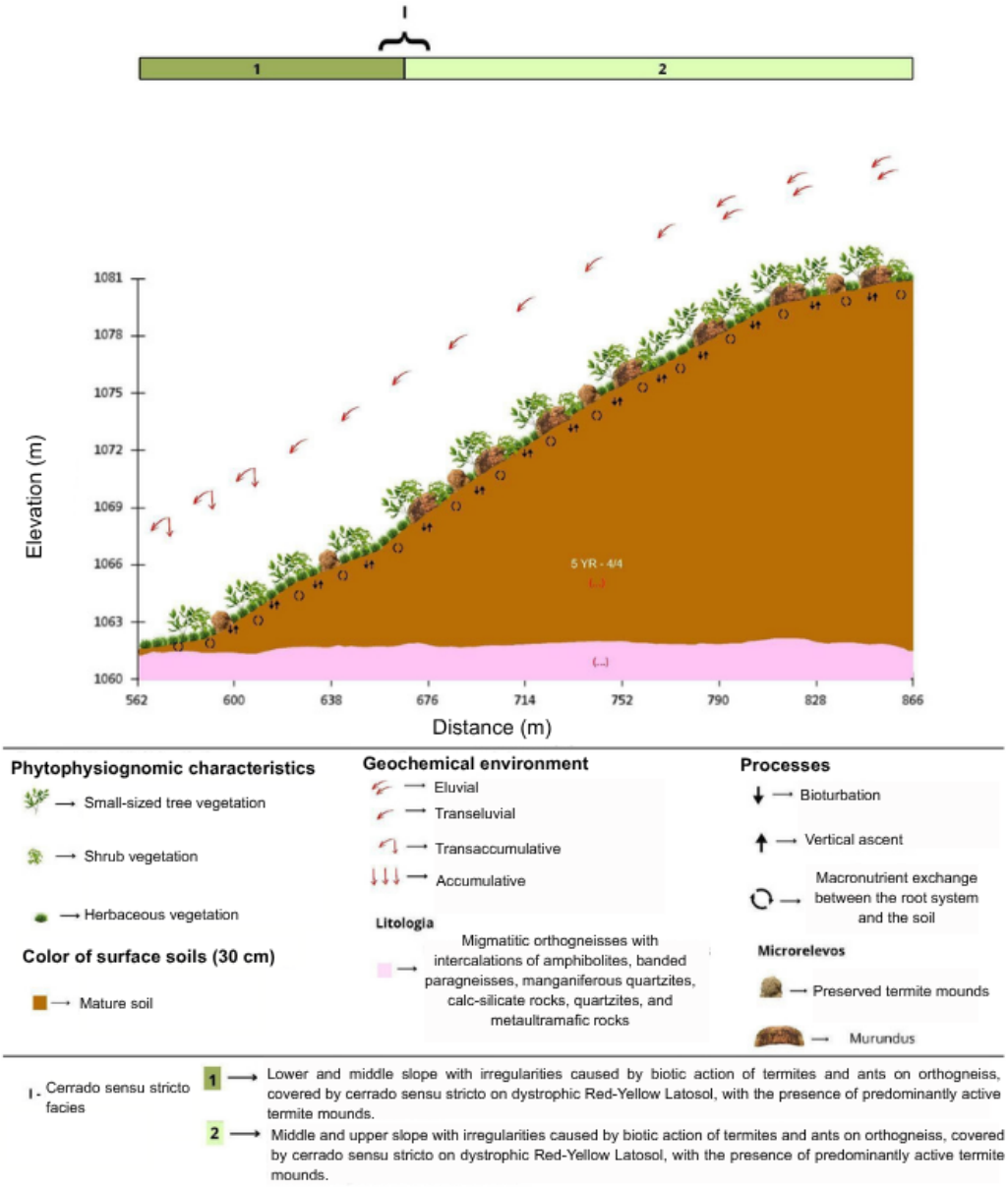

Figure 8. Geoenvironmental profile of Toposequence 2.

5. Discussion

The soils concerning the two studied latosolic catenas differed significantly in their physical-chemical aspects, as previously presented. Although C1 presents relatively low concentrations of macronutrients and organic matter content, in C2 the availabilities are even lower, aggravated by the predominance of the sandy fraction and consequent reduction of the active charge of the soil. Such a configuration suggests a significant edaphic influence

on the phytophysiognomic variations, differentiating more open *cerrado campo sujo* physiognomies on sandier soils and *cerrado stricto sensu* with greater arboreal density on clay-textured soils, with reflections on the biogeomorphological aspects of the slopes. The better structuring prevailing in clayey soils seems to directly influence the density of *murundus* in the landscape, as well as their stability, since the microreliefs of C1 are distinctly more aggregated and substantially more difficult to prospect with the auger. Figure 9 illustrates, by way of sampling, the general aspects of the two catenas under consideration.

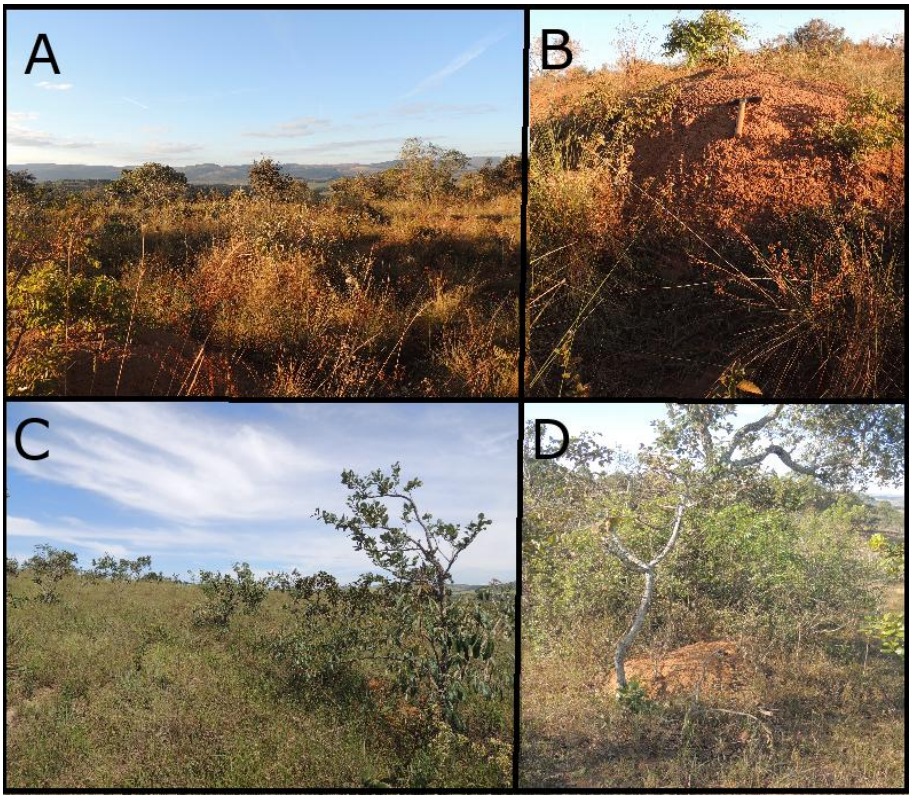

Figure 9. A) General aspect of *cerrado stricto sensu* in C1. B) Typical occurrence mound in C1. C) General aspect of *cerrado campo sujo* in C2. D) Typical occurrence mound in C2.

From this broader differentiation, the interpretation of some similarities and dissimilarities between the studied catenas allows some findings, as well as it raises new questions regarding the role of biogenesis in slope sculpting and the genetic-evolutionary meaning of the associated microreliefs.

For the two catenas under consideration, it was found that the mounds appear in all geochemical environments, from summits to valley bottoms, showing the plasticity of the builder isopterans in altering the superficial structure of the landscape in different sectors and geochemical environments. However, differences were found between the mounds built in the eluvial and transeluvial zones and those occurring in the reducing environments of the transaccumulative zones, projecting a biosequence whereby biological activity varies along the slope regarding its intensity and its surface results.

The biologically active state of the microreliefs was dominant in the two catenas, generally presenting more profuse biological activity in the outermost envelope, sometimes involving the entire microrelief from top to base, sometimes restricted to some sections revealing partial occupation. For both catenas, the dominant insects are termites, often sharing the same structure with ants, persistent invaders and predators of the former.

For the two catenas, no direct evidence of biological activity was found at subsurface levels, but in some samples an increase in organic matter in the soil was measured from 40 cm onward, mainly (which may be related to root decomposition). However, some active termite mounds are structured in soils that are darker due to the

concentration of organic matter, even contrasting with intensely mineralized Latosols positioned a few dozen meters away and at the same altimetric range.

In the catena related to *cerrado stricto sensu* (C1), the microreliefs proved larger, more numerous, and more concentrated, being distinctly smaller and distant from each other in the context of *cerrado campo sujo* (C2). In both, however, it was found that the biological exploitation took advantage of preformed structures. The forces and processes responsible for the generation of such structures fall within one of the cores of the issue debated and evoked at the beginning of the present exposition: the tension between biogenetic and morphogenetic forces involved over time. Evidently, a dialectical relationship emerges between a constructive/aggregating biogenesis and a destructive/erosive morphogenesis that reinforces the nature of complex systems on surfaces covered by *murundus* and termite mounds.

In C1, the microreliefs present the same morphological aspect as the classic *murundus* cited in the literature and related to hydromorphic environments, yet occurring in oxidizing and intensely leached sectors. In this case, the slope is distinctly irregular, intercalating elevations and depressions dissected by erosive rill flows, and it is precisely in the hydromorphic sectors of the accumulative zone, in permanent to semipermanent interaction with the groundwater table, that the typicality of the classic *murundus* is lost to give way to the typical termite mounds of deforested areas and pastures.

Although associated with hydromorphic environments, the interpretations directed toward C1 indicate that *murundu*-type features may also be found in other relief compartments, both in eluvial zones and in eminently transeluvial slopes, where the environment is distinctly oxidizing and the interaction with the groundwater table is, at most, seasonal. As emphasized by Bignell (2019), such soils where the mounds are abundant are characterized by good drainage and stability provided by the aggregation enhanced by biological activity.

The configuration in C2, however, is distinct, since the microreliefs are generally lower, have less abrupt emergence, and the occurrence density is lower. The result in the landscape can be seen in the extensively rectilinear slopes, without significant irregularities or local variations in gradients, as made explicit in the geoenvironmental profile of Figure 8. Although they do not present such a marked similarity with the classic *murundus* as verified for C1, neither do they have the same aspect as the termite mounds that so commonly punctuate slopes and valley bottoms in deforested areas used for grazing. In contrast, the *cerrado campo sujo* in which they are found establishes adherence with the parkland savanna phytophysiognomy discriminated in the classification of the Brazilian Institute of Geography and Statistics (IBGE, 2012), normally nesting discrete islands of woody vegetation with species that are also abundant in the valley-bottom *murundu* fields, such as locustberries (*Byrsonima sp*.), as occurs in the study area.

The differences found between the morphological patterns and occurrence density patterns between C1 and C2 correspond when the regional arrangements beyond the sampled sequences are observed. It is therefore credible to suggest that differential erosion figures as the dominant force in C1 and related catenas/toposequences, thus indicating that such a genetic linkage would not apply only to valley-bottom *murundu* fields, since very similar configurations occur in geochemically oxidizing environments. In C2, on the other hand, no arrangement intercalating mounds and depressions was found, which suggests an essentially biological genesis.

In both catenas it was possible to perceive, under the different density conditions, that biological activity directly interferes with slope morphology, engendering irregularities generated by the different cycles of vertical uplift often superimposed, followed either by abandonment and progressive erosive degradation or by a new occupation. The result is the occurrence of irregular slopes, with undulations, local depressions, and small steps formed in the direction of the gradient by the polycyclic constructions, in an arrangement similar to that found by Oliveira et al. (2025) in toposequences in the Atlantic tropical domain. Such an arrangement proved more expressive in C1, where clayey soils provided with more intense chemical reactions enable a more significant biological activity than that prevailing on the more inert covers of C2, predominantly sandy. In both cases,

however, a coevolutionary nexus is visualized, expressed by the convergence between morphogenesis, pedogenesis, and biogenesis.

There still remains doubt regarding the possible existence of past biological activity similar to the current one, which, although not verified through bioturbation marks, also cannot be discarded, since the passage of gravitational water through the soil may obliterate such marks. In any case, whether the evolution is given by vertical uplift or by differential erosion, the recurrent occupation by isopterans points to a polycyclic evolution that superimposes phases of biological exploitation associated with the physical processes occurring on the slopes.

In this field, the analysis of the literature associated with the case studies presented here indicates that the understanding regarding the genesis and evolution of *murundus* is still highly incomplete. The geomorphological hypotheses linking *murundu* fields to differential erosion have gained strength, despite the frequently found evidence of biological activity, suggestive of a biogenetic influence in the origin of these forms in the landscape. On the African continent, where such features have been systematically studied for a longer time, their genesis is frequently associated with termite activity, as shown by the compilation of studies listed by Pullan (1979), which differentiates smaller features (termite mounds) and larger geoforms designated as termite hills, emphasizing their conspicuousness throughout sub-Saharan Africa, occupying areas with semideciduous forests and savannas, morphologies that may be quite ancient (Moore; Picker, 1991; Erens et al., 2015).

The murundus found in the tropical belts of South America do not present the dimensions of those found in Africa, which commonly exhibit heights greater than 2 m. However, they occur in phytogeographical and geomorphological contexts similar to those described for the African continent, underlining the trait of tropicality inherent to the geoforms under study, still insufficiently understood in their biogeomorphological significance.

6. Conclusion

Some of the results found in the present study dialogue with several other case studies on *murundus* and termite mounds, such as the occurrence in different sectors of the landscape, the greater concentration of macronutrients and organic matter compared to the surroundings, and the presence of predominantly active biological activity. In addition to reaffirming such patterns, what can the present study additionally state?

The analyzed catenas, although they presented distinctions in the occurrence patterns of termite mounds and *murundus* under *cerrado stricto sensu* and *cerrado campo sujo* covers, can hardly have their results established as a pattern. The assumptions concerning complex systems (*sensu* Edgar Morin) provide support by assuming that particularities may be interpreted according to a unity, causing each case to present its particular elements, whatever the sample universe may be. From this theoretical perspective, suggestive general patterns should be viewed with caution even in numerous samplings since certain phenomena may present significant variability.

It is credible to consider that genetic and evolutionary variabilities of such magnitude explain the specific case of *murundus*. As discussed, different studies are not only based on different hypotheses, but have also produced distinct results, both due to the considered hypothesis and because of what the empirical data suggest, sometimes pointing to biogenesis, sometimes leaning toward morphogenetic merits. The very results presented here pointed to a more forceful role of erosion in C1, evidence that was not found in C2, where the microreliefs presented an eminently biogenetic linkage. In theory, this is what can be affirmed, and which may not be affirmative for other cases. However, the laboratory and field methodological routines may be replicated in other studies devoted to this thematic field, contributing to a refinement in understanding.

It may also be affirmed that the theme treated here should be conveniently must from the perspective of complex systems, in the concatenation of pedogenetic, geomorphological, and biological forces. The evolution of knowledge on *murundus* and the observation of the state of the art reveal that their understanding has always been linked to a lack of consensus due to the existence of different pieces of evidence surrounding the genesis and evolution of these geoforms. It is thus suggested that their study begin from the premise that, since they are

complex systems, the approaches will not always fall into a single explanatory model, while the available explanatory models present varying adherences according to the different conditions of occurrence.

Author Contributions: Conceptualization, Roberto Marques Neto; methodology, Roberto Marques Neto and Henrique Carvalho de Oliveira; software, Henrique Carvalho de Oliveira and Lara Pereira Loures; validation, Roberto Marques Neto and Henrique Carvalho de Oliveira; formal analysis, Roberto Marques Neto; investigation, Roberto Marques Neto, Henrique Carvalho de Oliveira, Lara Pereira Loures, and Luísa Costa Coimbra; resources, Roberto Marques Neto; data preparation, Roberto Marques Neto, Henrique Carvalho de Oliveira, Lara Pereira Loures, and Luisa Costa Coimbra; writing of the article, Roberto Marques Neto; review, Roberto Marques Neto, Henrique Carvalho de Oliveira, Lara Pereira Loures; supervision, Roberto Marques Neto.

Funding: This research received no external funding.

Acknowledgements: To the Dean's Office for Graduate Studies and Research – PROPP of the Federal University of Juiz de Fora for the scholarships granted

Conflict of Interest: The authors declare no conflict of interest.

Declaration on the Use of Artificial Intelligence: The authors declare that no generative artificial intelligence tool was used at any stage in the development of this manuscript.

References

1. ALMEIDA, J. C. H. **Mapeamento geológico da Folha Luminárias (MG 1\50.000) com ênfase na análise estrutural dos metassedimentos do ciclo deposicional Andrelândia**. 1992, 120p. Dissertação (Mestrado em Ciências), Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 1992.
2. ANTUNES, P. D.; FIGUEIREDO, L. H. A.; SILVA, J. F.; KONDO, M. K.; SANTOS NETO, J. A. S.; FIGUEIREDO, M. A. P. Caracterização físico-química de micro relevo de montículos "murundus" na região de Janaúba, norte de Minas Gerais. **Geonomos**, v. 20, n. 1, p. 81-85, 2012. DOI: 10.18285/geonomos.v20i1.30
3. BALLESTEROS, E. M. **Geomorfologia y geoquímica del paisaje**. Salamanca: Edocopmes Universidad de Salamanca, 1991. 145p.
4. BIGNELL, D. E. Termite ecology in the firs two decades of 21st century: a review of reviews. **Insects**, v. 10, n. 60, p. 1-10, 2019. DOI: 10.3390/insects10030060
5. ENGELS, F. **A dialética da Natureza**. 6° Ed. Rio de Janeiro: Paz e Terra, 1979. 238p.
6. ERENS, H.; BOUDIN, M.; MEES, F.; MUJINYA, B. B.; BAERT, G.; STRYDONCK, M. V.; BOECKX, P.; RANST, E. V. The age of large termite-mouds – radiocarbon dating Macrotermis falsiger mounds of the Miombo woodland of Katanga, DR Congo. **Paleogeography, Paleoclimatology, Paleoecology**, v. 435, p. 465-471, 2015.
7. FURLAN, S. A. (2005) Técnicas em Biogeografia. In: VENTURI, L. A. B. (Org.) **Praticando Geografia:** técnicas de campo e laboratório. São Paulo: Oficina de Textos: 99-130
8. FURLEY, P. A. Classification and distribuction of Murundus in the Cerrado of Central Brazil. **Journal of Biogeography**, v. 13, n. 6, p. 265-268, 1986. DOI: 10.2307/2844925
9. HEILBRON, M *et al*. Província Mantiqueira. In: MANTESSO NETO, V. *et al*. (Org.) **Geologia do continente Sul-Americano: evolução da obra de Fernando Flávio Marques de Almeida**. São Paulo: Beca, 2004. 647p.
10. IBGE. **Manual Técnico da Vegetação Brasileira**. 2° ed. Rio de Janeiro: IBGE, 2012. 272p.
11. LIMA, S. S. F.; FEREIRA, M. G.; PEREIRA, R. N.; PONTE, R. M., ROSSI, C. Q. Termite Mounds Effects on Soil Properties in the Atlantic Forest Biome. **Revista Brasileira de Ciência do Solo**, v. 1, n. 14, p. 1-14, 2018. DOI: 10.1590/18069657rbcs20160564
12. LIMA, S. S. F.; FRUETT, T.; BARRÓN, V.; INDIA, A. V. Termite activity in tropical and subtropical Brazilian soils. **Acta Scientiarum**, v. 47, p. 3-9, 2025. DOI: 10.4025/actasciagron.v47i1.71140
13. MARTINS, F. R. **Estrutura de uma floresta mesófila**. Campinas: Editora da UNICAMP, 1993. 246p.
14. MIKLÓS, A. A. W. Biogênese do solo. **Revista do Departamento de Geografia**, v. esp., p. 190-229, 2012. DOI: 10.7154/rdg.v0i2012.384
15. MOORE, J. M.; PICKER, M. D. Helweutjies (earth mounds) in the Clanwillian district, Cape Province, South Africa: 4000-year-old termite nests. Oecologia, v. 83, p. 424-432, 1991.
16. MORIN, E. **O Método 1:** a natureza da natureza. Lisboa: Publicações Europa-América ltda. 1977.
17. OLIVEIRA, H. C.; MARQUES NETO, R.; BARROSO, M. E. O.; COIMBRA, L. N. C. Influências biogênicas na morfologia das vertentes e solos associados: aplicações em duas topossequências latossólico-cambissólicas. **Revista Continentes**, v. 13, n. 27, p. 1-29, 2025. DOI: 10.51308/continentes.v1i27.632

18. OLIVEIRA, L. B. T.; SANTOS, A. C.; SILVA NETO, S. P.; SILVA, J. E. C.; PAIVA, J. A. Alterações físicas e químicas do solo em virtude de construções termíticas no norte de Tocantins. **REVENG**, v. 20, n, 2, p. 118-130, 2012. DOI: 10.13083/1414-3984.v20n02a04
19. PACIULLO, F. V. P.; RIBEIRO, A.; ANDREIS, R. R. Reconstrução de uma bacia fragmentada: o caso do ciclo deposicional Andrelândia. In: SIMPÓSIO SOBRE O CRÁTON DO SÃO FRANCISCO. **Anais...**Salvador, p. 224-226, 1993.
20. PENTEADO–ORELLANA. M. M. Microrrelevos associados a térmitas no Cerrado. **Notícia Geomorfológica**, v. 20, n. 39/40, p. 61-72. 1980.
21. PINHEIRO, L. B. A.; PEREIRA, M. G.; LIMA, E.; CORREA, M. E. F.; SILVA, C. E.; EVELING, A. G. Atributos edáficos e de termiteiros de cupins-de-montículos (Isoptera: Termitidae) em Pinheiral – RJ. **Floresta e Ambiente**, v. 4, n. 5, p. 510-520, 2013. DOI: 10.4322/floram.2013.047
22. PONCE, V. M.; CUNHA, C. N. Vegetated earthmounds in tropical savannas of Central Brazil: with special reference to the Pantanal of Mato Grosso. **Journal of Biogeography**, v. 20, n. 2, p. 219-225, 1993. DOI:10.2307/2845673
23. PULLAN, R. A. Termite hills in Africa: their characteristics and evolution. **Catena**, v. 6, p. 267-291, 1979. DOI: 10.1016/0341-8162(79)90025-0
24. RESENDE, I. L. M.; ARAUJO, G. M.; OLIVEIRA, A. P. A.; OLIVEIRA, A. P.; ÁVILA JUNIOR, R. S. A comunidade vegetal e as características abióticas de um campo de murundu em Uberlândia, MG. **Acta bot. bras**. v. 18, n. 1, p. 9-17, 2004. DOI: 10.1590/S0102-33062004000100002
25. RIBEIRO, A. Evolução de bacias proterozoicas e o termo-tectonismo brasiliano na margem sul do cráton do São Francisco. **Revista Brasileira de Geociências**, v. 25, n. 4, p. 235-248, 1995.
26. SALES, J. C. **Estrutura e funcionamento de um campo de murundus da Savana Brasileira**. 120p Tese (Doutorado em Geografia). Instituto de Estudos Ambientais, Universidade Federal de Goiás, Goiânia, 2021.
27. SOCHAVA, V. B. Geography and ecology. **Soviet Geography: review and translation**. New York, v. 12, n. 5, p. 277-293, 1971.
28. SOCHAVA, V. B. Por uma Teoria de Classificação dos Geossistemas da Vida Terrestre. **Biogeografia,** n. 14, 1978.