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Geoarchaeology and Landscape Evolution: Geochemical Approaches in the Semi-Arid Environments of Northeastern Brazil

Geoarqueologia e Evolução da Paisagem: Abordagens Geoquímicas em Contextos Semiáridos do Nordeste Brasileiro

Ana Cristina de Lima Pedrozo Cardouzo[1]; Bruno de Azevedo Cavalcanti Tavares[2]

[1] Federal University of Pernambuco, Brazil. Email: anacristina.cardouzo@ufpe.cbr
ORCID: https://orcid.org/0009-0000-4927-2742

[2] Federal University of Pernambuco, Brazil. Email: bruno.tavares@ufpe.br
ORCID: https://orcid.org/0000-0003-1823-3016

Abstract: Geoarchaeology focuses on the interactions between humans and their physical-natural environment. Among these, geochemical analyses stand out for investigating the chemical components of crustal rocks, soil profile alterations, sedimentary deposits, and landscape evolution. This study explores the applications of such approaches in archaeology, particularly in paleoenvironmental reconstructions and landscape formation models. Two archaeological areas were examined: Morro do Chapéu (Bahia) and the Carnaúba River Watershed (Rio Grande do Norte/Paraíba), through colluvial and fluvial vertical sections. At Morro do Chapéu, the results enabled the proposition of evolutionary models influenced by climatic, geomorphological, and sedimentological factors, revealing intense chemical alteration, deposition of mature sediments, and pedogenetic stabilization. In contrast, deposits from the Carnaúba River indicate a semi-arid regime with seasonal high-energy pulses and a braided-channel system, reflecting climatic seasonality and variable transport conditions. Multidisciplinary integration thus provides valuable insights into the evolution of semi-arid landscapes and their connections with human occupations. These results highlight the relevance of geochemical approaches in reconstructing past climatic and environmental dynamics, especially in tropical settings where such processes strongly influenced cultural trajectories.

Keywords: Geoarchaeology; Geochemistry; Carnaúba Watershed; Morro do Chapéu.

Resumo: A Geoarqueologia dedica-se ao estudo das interações entre o ser humano e o meio físico-natural. Entre elas, destacam-se as análises geoquímicas, voltadas à investigação dos componentes químicos das rochas da crosta, das alterações em perfis de solos e depósitos sedimentares, bem como da evolução da paisagem. Este trabalho apresenta aplicações desse enfoque na Arqueologia, especialmente em reconstruções paleoambientais e na proposição de modelos formativos da paisagem. Para isso, foram analisadas duas áreas arqueológicas: Morro do Chapéu (BA) e a Bacia do Rio Carnaúba (RN/PB), a partir de seções verticais coluvionar e fluvial. Em Morro do Chapéu, os resultados permitiram propor modelos evolutivos influenciados por fatores climáticos, geomorfológicos e sedimentológicos, indicando intensa alteração química, deposição de sedimentos maduros e estabilização pedogenética. Já os depósitos do rio Carnaúba revelam regime semiárido marcado por pulsos sazonais de alta energia e canais entrelaçados, refletindo a sazonalidade climática. A integração multidisciplinar, portanto, contribui para compreender a evolução de paisagens semiáridas e suas relações com ocupações humanas em contextos tropicais

Palavras-chave: Geoarqueologia; Geoquímica; Bacia do rio Carnaúba; Morro do Chapéu.

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1. Introduction

Geoarchaeology refers to the field of archaeology that examines human environment interactions by applying Earth science methods to archaeological questions. This approach provides insights into how past human groups engaged with their surroundings and how environmental factors may have influenced their social and cultural dynamics (Rapp & Hill, 2006; Cardouzo & Tavares, 2024). In Northeastern Brazil, geoarchaeological studies have focused on understanding how natural formation processes shape the archaeological record (Mützenberg et al., 2013; Moraes, 2015; Galvão, 2019; Macedo, 2023). Researchers have also worked to reconstruct the natural environments of archaeological areas in the region, particularly by examining how paleoclimatic and paleoenvironmental dynamics correlate with human occupations in the semi-arid Northeast (Macedo, Felice & Corrêa, 2025).

From this perspective, researchers can draw on a wide range of analytical approaches to reconstruct past environments and better understand ancient human contexts. These approaches draw on environmental proxies commonly used to interpret past contexts, including biological, lithological, and geomorphological evidence derived from Quaternary deposits (Bradley, 2015; Lowe & Walker, 2015; Karkanas & Goldberg, 2019). Among these possibilities, geochemistry emerges as a key approach; although widely applied in the geosciences, it is still used only incipiently in archaeology.

Authors such as Renfrew and Bahn (2005), when discussing analytical and interpretive methods in archaeology, address geochemistry only in the limited context of phosphate geochemical prospection. This technique aims to identify organic evidence within stratigraphic profiles by detecting elevated phosphorus concentrations in sediments, which can indicate probable human presence at specific levels. Beyond this type of analysis, geochemical approaches become essential in contexts where depositional layers are homogeneous and macroscopic observations, such as discontinuities, sedimentary structures, or distinct lithofacies, are not clearly expressed in the stratigraphic section.

In this context, identifying the chemical components of the vertical section allows researchers to detect discontinuities along the deposit through their geochemical signatures. This approach has been applied in significant studies in the Upper Uruguay River region by Lordeau et al. (2025) and Pereira Santos et al. (2024), who used it in archaeological contexts to identify colluvial deposits with interspersed episodes of human occupation throughout the Holocene. From this perspective, the present research applies this approach to Northeastern Brazil by identifying depositional layers and soil formation processes in contexts of intense archaeological occupation, with chronologies spanning the Late Pleistocene through the Holocene.

Accordingly, this article presents a methodological review of geochemical applications in archaeological contexts of Northeastern Brazil, aiming to demonstrate how these analyses can support the interpretation of depositional layers and soil formation in settings of intensive human occupation. For this purpose, we selected two areas located in distinct semi-arid contexts, the setentrional northeast and the central region of Bahia, where geomorphological and environmental processes, as well as the formation of deposits and archaeological records, occur in different ways.

2. Methodology

This research comprises four main stages. The first involves a bibliographic review to characterize the study areas, described in the following section, and to establish the conceptual basis of Landscape Geochemistry and its applications in archaeological studies within Geoarchaeology. The second consists of field sampling carried out in 2023 and 2024.

The third stage involves applying geochemical signature indices to the collected samples. Finally, the fourth stage compares the two study areas and evaluates how the use of these indexes contributes to comprehend different archaeological environments.

The geochemical indexes employed in this study (Cruz, 2006; Fonsêca et al., 2024; Santos, 2024) are based on the resistance of minerals to chemical weathering and on the concentration of elemental components in the samples. As a result of climatic and geomorphological conditions, these indices vary from one environment to another. Each context presents distinct mineralogical and climatic characteristics, resulting in sediments with different geochemical signatures (Taylor & Eggleton, 2001). Water acts as the primary agent of these transformations, altering saprolites and regolith and promoting the formation of new minerals, especially clays and iron–aluminum oxyhydroxides (Birkeland, 1999; Fonsêca, 2018).

The samples used in this study were collected in two distinct depositional environments, colluvial and fluvial, and analyzed using X-ray Fluorescence (XRF). This method detects the characteristic X-rays emitted by the elemental constituents of a sample when it is irradiated with electrons, protons, or X- or gamma rays of appropriate energy (Tavares, 2015). The results, expressed as the percentage of each element, were processed in Origin software, which enabled the application of geochemical indexes and the subsequent visualization of the data in graphic form.

In this study, the following indices were used:

Table 1 – Indices used.

Index	Objective	Fórmula	Descrição dos componentes
CIA – Chemical Index of Alteration	Assess the degree of chemical weathering	CIA = Al_2O_3 / (Al_2O_3 + CaO* + Na_2O + K_2O) × 100	CaO* = CaO in silicates (corrected).
Ruxton Index	Measure the extent of chemical weathering	Ruxton = SiO_2 / Al_2O_3	Lower values indicate greater weathering.
Paleoenvironmental Index	Infer the formative/depositional environment	(SiO_2 + K_2O) / (Al_2O_3 + Na_2O)	Examines relationships between mobile and immobile elements.
Provenance Indexes	Determine the origin of the material	Ex.: Al_2O_3/K_2O; Zr/Ti; Ti/Al	Discriminates sources and the degree of reworking.
Laterization Index	Identify lateritic/weathered sediments	(Fe_2O_3 + Al_2O_3) / SiO_2	Indicates enrichment in Fe and Al and the leaching of silica.

Source: Taylor & Eggleton (2001); Fonsêca (2018); Santos (2024).

The next section presents the results obtained along with a brief discussion of their relevance for analyzing the archaeological context. We also relate the geochemical data to the paleoenvironmental information for each area, highlighting the role of geochemistry in understanding the formative processes of the sites and their environmental settings.

3. Results and Discussion

3.1 Study areas – environmental context

The study regions (Figure 1) are located in Northeastern Brazil, within a semi-arid climate. One area lies in the Seridó Potiguar region (northely northeast), and the other in the state of Bahia, in the municipality of Morro do Chapéu and its surroudings, in the northern sector of the Chapada Diamantina.

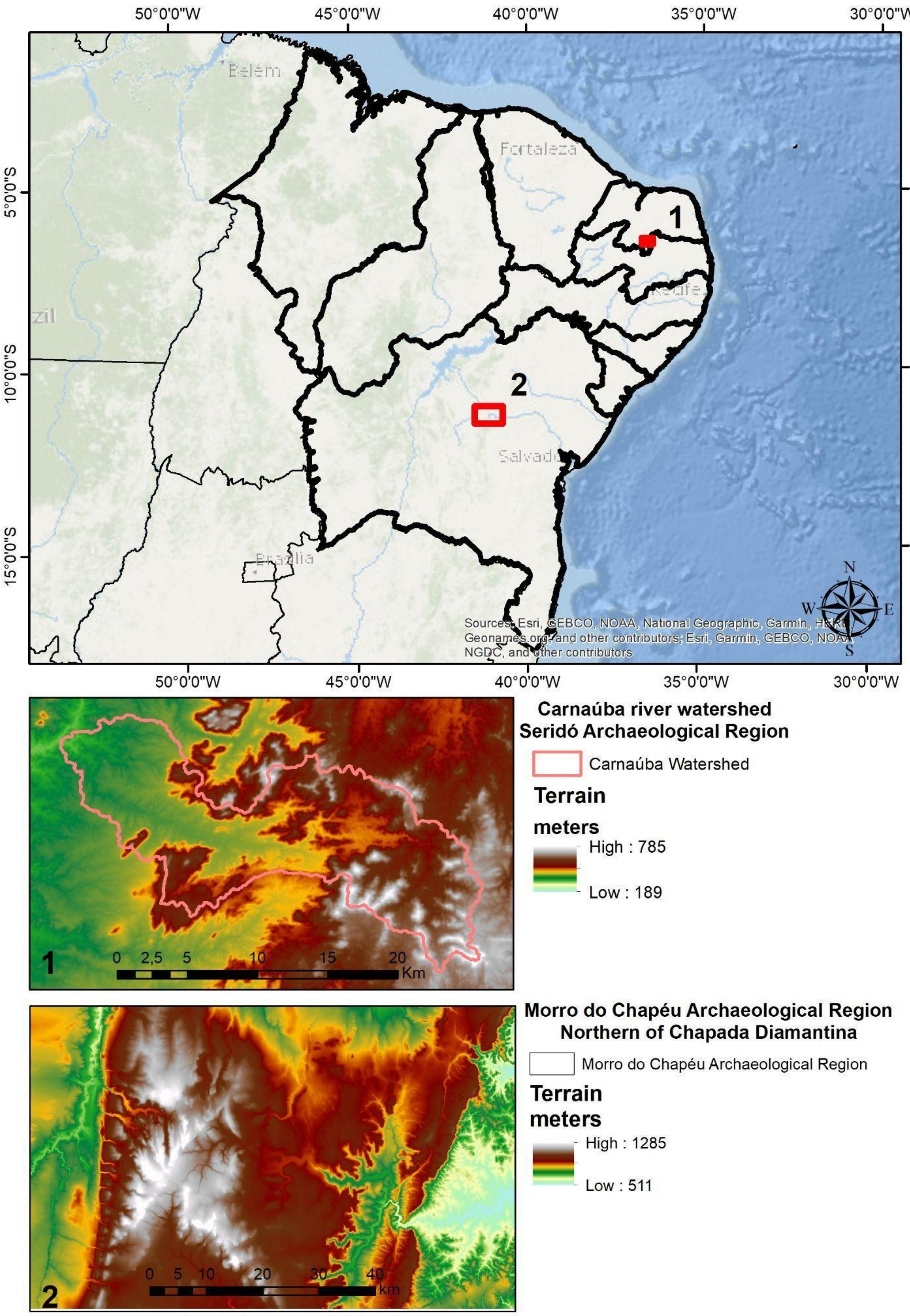

Figure 1 – Location map of the two study regions in Northeastern Brazil.
Source: Authors (2025).

3.2 Morro Do Chapéu - Bahia

The surface deposits analyzed at the Coreia Archaeological Complex are located in the municipality of Morro do Chapéu, Bahia (Figure 2). The area has a high concentration of archaeological sites, notable for the rock art present in rock shelters and caves (Cardouzo & Tavares, 2024).

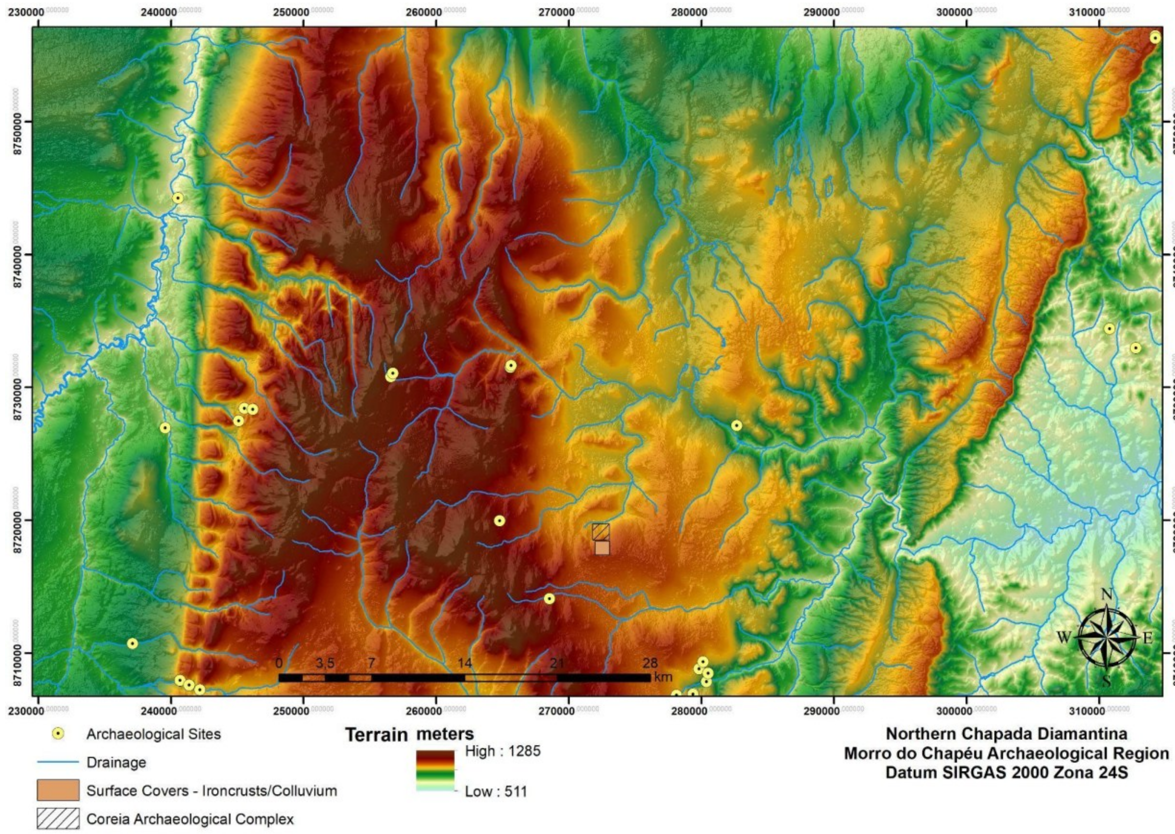

Figure 2 – Hypsometric map of the municipality of Morro do Chapéu.
Source: Authors (2025).

The sampling location (Figure 3) was selected due to the variety of information it can provide about past environments. Understanding the landscape in this sector of the Chapada Diamantina, under the framework of environmental reconstruction, still lacks data obtained through this geoarchaeological approach (Silva, 2025; Cardouzo & Tavares, 2024).

Figure 3 – Surrounding context of the surface deposits in the Morro do Chapéu Archaeological Area (Bahia). Source: Tavares (2024).

The region is situated in the semi-arid climate domain, with average annual rainfall reaching 808 mm in autumn (IBGE, n.d.). The hydrology surrounding the area includes the São Francisco and Paraguaçu river basins (Silva, 2025). Vegetation is typical of the caatinga, predominant in the Northeast, with adaptations to local conditions that play a key role in maintaining the ecosystem.

The lithology consists of deformed sedimentary rocks, in which the stratigraphic succession indicates alternating regressive and transgressive events (Table 2), reflecting the Neoproterozoic marine dynamics of the area (Rocha, 2013).

Table 2 – Formations with their respective lithologies and contexts.

Formation	Lithology	Context
Tombador	Sandstone and metaconglomerate	Marine regression
Caboclo	Limestone and calcarenite	Marine transgression
Morro do Chapéu	Sandstones, meta-sandstones, and quartzites	Marine regression

Source: Authors (2025), based on Rocha (2013).

Finally, the Chapada Diamantina forms a high plateau with folded relief (Corrêa et al., 2019; Silva, 2025), reaching up to 2,038 m in altitude. In the northern sector, where the study area is located, elevations reach approximately 1,100 m (IBGE, n.d.). The relief is diverse and of significant value for ecotourism. Morro do Chapéu, located in the municipality of the same name, is an inselberg that stands out in the landscape, characterized by gentle slopes between escarpments and drainage valleys. The combination of this elevated relief and the semi-arid climate provides favorable conditions for the formation of weathering mantles and laterites, which are the focus of the following analyses.

3.3 Morro do Chapéu archaeological area: analysis of surface deposits

The research began with a bibliographic review to construct the theoretical framework, focusing on the following topics: the regional context (Corrêa et al., 2019; Silva, 2025), the concept of geoarchaeology (Rapp & Hill, 2006; Goldberg & Karkanas, 2019), geochemistry and chemical indices (Eggleton & Taylor, 2001; Santos, 2024), the formation of laterites and ferricretes (Widdowson, 2007), and landscape evolution (Rapp & Hill, 2006).

Following this review, we conducted field sampling in the region (Figure 4), collecting a total of 16 samples from a profile measuring 1.85 m in height and 85 cm in width. The samples were subsequently analyzed using X-ray Fluorescence (Cardouzo & Tavares, 2024).

Figure 4 – Stratigraphic section after sample collection at Morro do Chapéu (Bahia).
Source: Cardouzo (2023).

The first index applied was the Ruxton Index, which evaluates the degree of chemical weathering in rocks based on the relative mobility of silica and aluminum. The analyzed samples generally show a high degree of weathering (Figure 5), which is further confirmed by the CIA graph.

However, the samples from the base of the profile (D1L, D2L, C1L, C2L) show higher silica concentrations than aluminum, despite low Ruxton Index values indicating strong weathering. This elevated silica content may be related to its generally high abundance in the chemical composition; in other words, although these layers exhibit intense chemical alteration, as evidenced by the CIA, this alteration was not sufficient to leach silica (Santos, 2024).

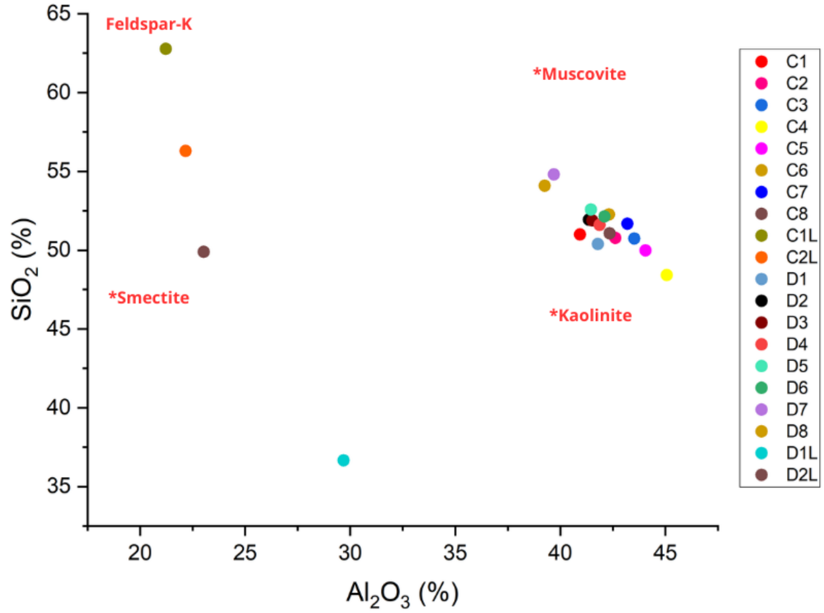

Figure 5 – Ruxton Index for all samples.
Source: Authors (2024).

The Chemical Index of Alteration (CIA) is used to assess the degree of chemical weathering in sediments, reflecting variations along a profile. Values above 80 indicate moderate weathering, while values above 90 indicate intense weathering. This degree of alteration is directly related to the environmental conditions of the source area, particularly in humid tropical regions, demonstrating that the origin of the deposit significantly influences the level of weathering.

Figure 6 confirms the hypothesis that the materials are strongly weathered, clustering within the high weathering range. High CIA values indicate an elevated degree of chemical alteration, generally associated with high precipitation and, consequently, greater chemical maturity of the sediments (Nesbitt & Young, 1982). Thus, even in samples where some fractions lack aluminum, it is likely that their formation occurred under conditions of high precipitation. However, considering the region's geomorphology and topography, factors that directly influence sedimentation and chemical weathering, these precipitation levels may correspond to periods of milder semi-arid conditions (Nash & McLaren, 2007).

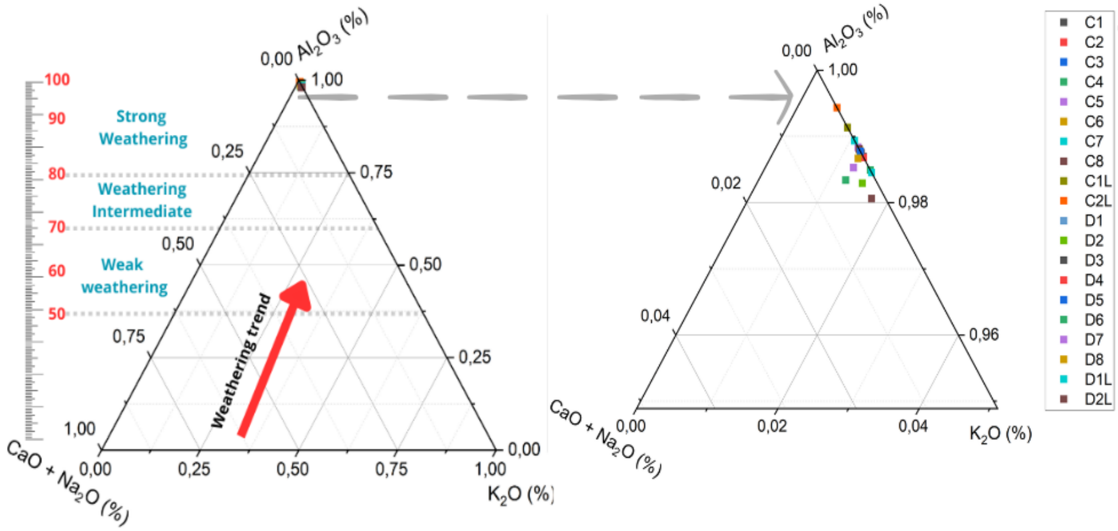

Figure 6 – CIA Index of the samples.
Source: Authors (2024).

The relationship between aluminum and potassium is linked to the origin of the material. In Figure 7, a kaolinitic trend is observed. This does not necessarily indicate that the original material was rich in kaolinite, but rather that intense chemical weathering, favored by factors such as precipitation and topography, promoted the formation of aluminosilicate minerals like kaolinite. This process aligns with the high CIA values observed.

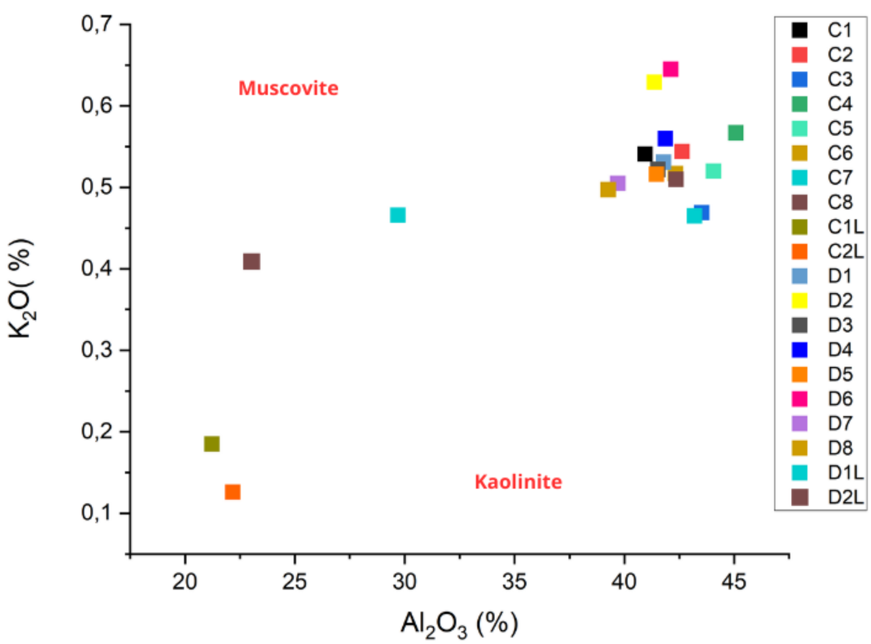

Figure 7 – Aluminum–Potassium relationship of the samples.
Source: Authors (2024).

The relationship between silica, aluminum, potassium, and sodium allows inferences about the formation and depositional environment of the sediments. As shown in Figure 8, the laterites indicate a humid to subhumid environment, distinct from the current semi-arid conditions but consistent with the high degree of chemical weathering (CIA). The other samples, associated with a semi-arid climate similar to the present, suggest sediments that were previously weathered in a different environment and later transported, reflecting a distinct depositional context (Fonsêca, 2024; Santos, 2024).

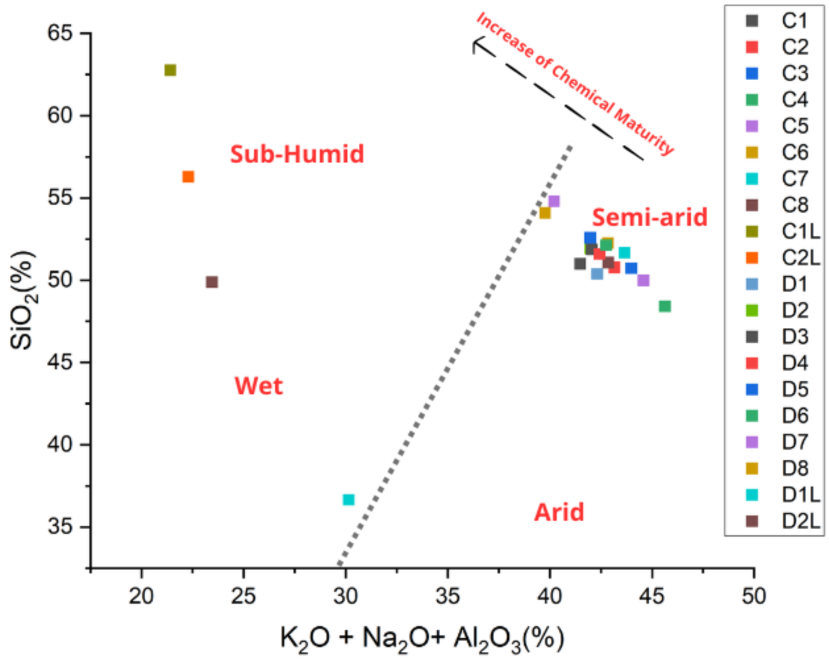

Figure 8 – Paleoenvironmental Index of all samples.
Source: Authors (2024).

The Laterization Index (Figure 9) indicates sediments with greater geochemical weathering and distinguishes those that were reworked rather than formed in situ. Most samples show weak laterization, except for the base of the profile, which exhibits moderate laterization. Three of these samples (C1L, C2L, D2L) are classified as ferruginous laterites, with D2L positioned at the boundary between ferruginous, lateritic, and kaolinitic domains. Sample D1L is classified as a kaolinitic laterite. These data suggest that the laterites at the base of the profile represent older and more stable stages in landscape formation.

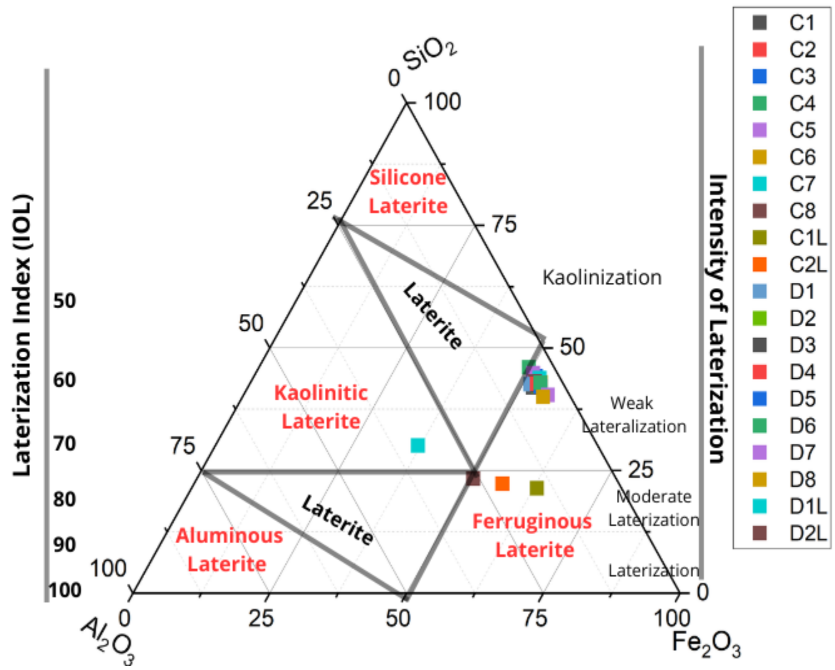

Figure 9 – Laterization Index of all samples.
Source: Authors (2024).

3.4 Rio Carnaúba - Seridó Potiguar

The study area is located between the Borborema Plateau and the Sertaneja Depression, within the Central Potiguar Mesoregion and the Seridó Oriental Microregion, between the municipalities of Carnaúba dos Dantas and Acari. Situated within the Seridó Belt domain, it intersects the Neoproterozoic lithostratigraphic units of the Itaporanga Medium- to High-Potassium Suite of the Seridó Group. The region cuts perpendicularly across the Dextral Carnaúba dos Dantas Strike-Slip Shear Zone and the Sinistral E–W Transcurrent Fault, where the Equador, Seridó, and Serra dos Martins Formations are exposed (Mutzenberg, 2007; Tavares et al., 2025).

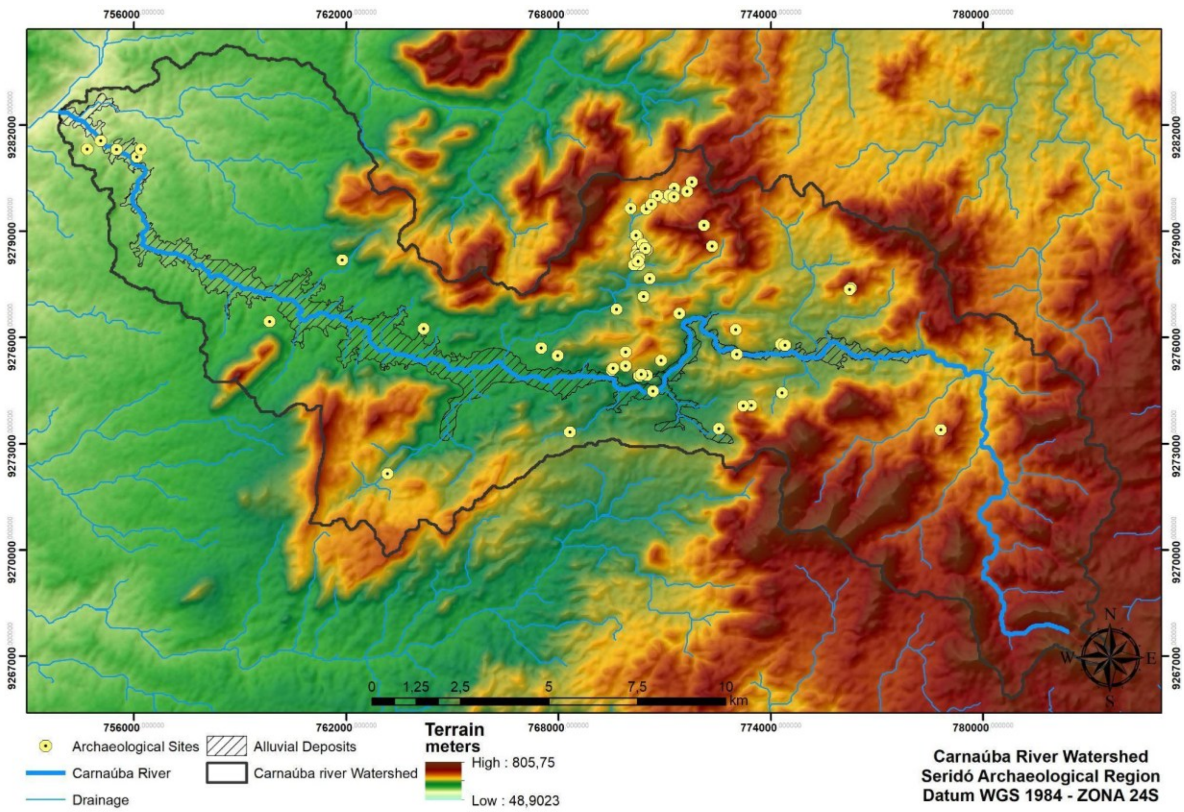

Figure 10 – Hypsometric map of the Carnaúba watershed in the Seridó region.
Source: Authors (2025).

The Carnaúba River watershed features a sedimentary cap in its headwaters, formed by the sandstones of the Serra dos Martins Formation. Beneath these sandstones lies the biotite schists of the Seridó Formation and the igneous intrusions of the Dona Inês Suite. In the upper course, the Itaporanga Suite is also present, controlling the main drainage axis along with several extensional fault segments. In the middle course, the biotite schists of the Seridó Formation are more extensive. This area contains multiple rock shelters that host archaeological sites. In addition to the Seridó Formation, the muscovite quartzite of the Equador Formation occurs in elevated sectors, primarily concentrated in the central portion of the basin. This lithology also appears at archaeological sites in the central river area. In this portion, there is a considerable accumulation of alluvial material, resulting from reworking by the Carnaúba River, forming an extensive fluvial valley filled with unconsolidated Quaternary deposits (Mützenberg, 2007; Tavares et al., 2025). In the lower course, granites are prominent, belonging either to the Itaporanga Suite or the São João do Sabugi Suite. Archaeological sites in this sector are distributed on large boulders and granitic dissolution morphologies.

Finally, the sedimentation in the Carnaúba River valley, occurring as the alluvial plain and its fluvial terraces, exhibits a sandy character typical of a semi-arid environment, with a braided morphology channel. It reflects alternating phases associated with the sedimentary cycle of a braided channel under semi-arid conditions, where variations in bedload and suspended load respond to the high climatic irregularity of the region. Thus, the sedimentary sequence observed in the stratigraphy of the middle course of the Carnaúba River indicates phases of active channels, bedload deposition, flood events, and the formation of gravelly and sandy bars, including evidence of their migration. This sequence aligns with Miall's (1995) principles for sedimentation regimes in braided and anastomosed drainage systems.

3.5 Fluvial dynamics from geochemistry in semi-arid environments: the Carnaúba River, Seridó Potiguar

Unlike the Morro do Chapéu context, where sampling occurred on elevated sectors of the plateau in a morphology of slopes and pediments associated with colluvial deposits, the Seridó stratigraphic profile lies in a fluvial environment. The profile was taken from the terraces that make up the middle course of the 48 km-long Carnaúba River, which originates in the Borborema Plateau and drains into the Acauã River, within the Sertaneja Depression domain (Figure 11). In its middle course, the river features a valley filled with fluvial sediments, reaching depths of up to 10 meters (Tavares et al., 2025).

Figure 11 – Geomorphological setting of the Carnaúba River in the Seridó region (RN) in its middle course. Source: Bruno Tavares (2024).

The profile in question (Figure 12) has a thickness of 2.50 m, indicating multiple sedimentation cycles associated with a braided channel under semi-arid conditions. We selected this profile because it exhibits characteristics linked to variations in sediment load in response to the irregular semi-arid climate of the Carnaúba River valley.

Figure 12 – Stratigraphic section of alluvial deposits at the Carnaúba River (RN).
Source: Bruno Tavares (2024).

In contrast to Morro do Chapéu, the Carnaúba River samples exhibit a low degree of weathering, as indicated by the Ruxton and CIA indices. However, the Si/Al ratio shows that these samples underwent weathering processes, with the high silica content likely resulting from provenance or the presence of silica-rich lithologies in the study landscape. Graphical analysis confirms this elevated silica concentration, which tends to decrease due to progressive mineralogical transformation caused by weathering, as exemplified by sample 11_RC, which plots within the kaolinitic domain. For more robust inferences, it is essential to consider the sample's stratigraphic position within the profile and its relationship with the surrounding geomorphological context.

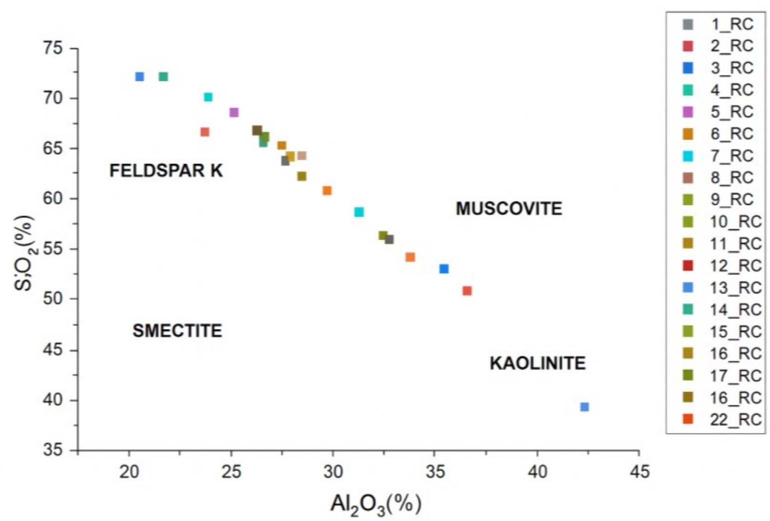

Figure 13 – Ruxton Index of the Carnaúba watershed samples.
Source: Authors (2025).

Consistent with the Ruxton graph, the CIA values indicate that the analyzed samples exhibit a low degree of chemical alteration. However, in this context, the provenance of the deposits may have influenced the observed chemical maturity, given that the study area is characterized by silica-rich mineralogies and lithologies.

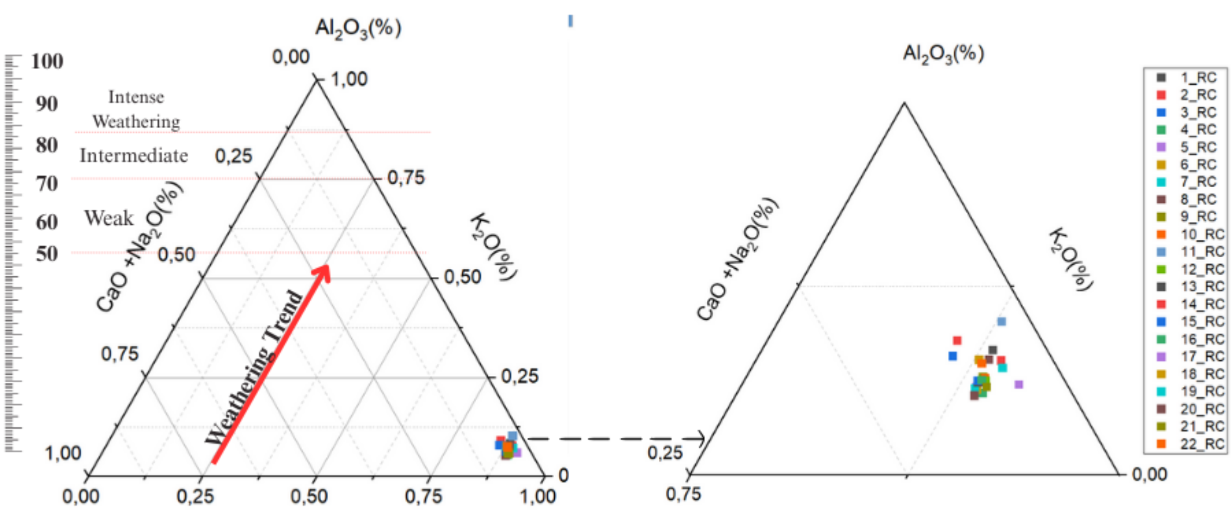

Figure 14 – CIA Index of the Carnaúba watershed samples.
Source: Authors (2025).

Regarding the Paleoenvironmental Index, the samples cluster within the semi-arid domain, supporting the data indicating low chemical weathering and, therefore, a low degree of chemical maturity. This pattern aligns with the current morphoclimatic context of the region, which falls within the semi-arid domain.

Thus, the data indicate a persistently semi-arid environment that likely restricted the formation of secondary minerals. However, two samples (11_RC and 14_RC) fall within the subhumid morphoclimatic domain, distinct from the current conditions. These data suggest a wetter episode during the formation of these sediments. Therefore, for more robust inferences, it is necessary to consider the samples' position within the collected profile and their location within the surrounding landscape.

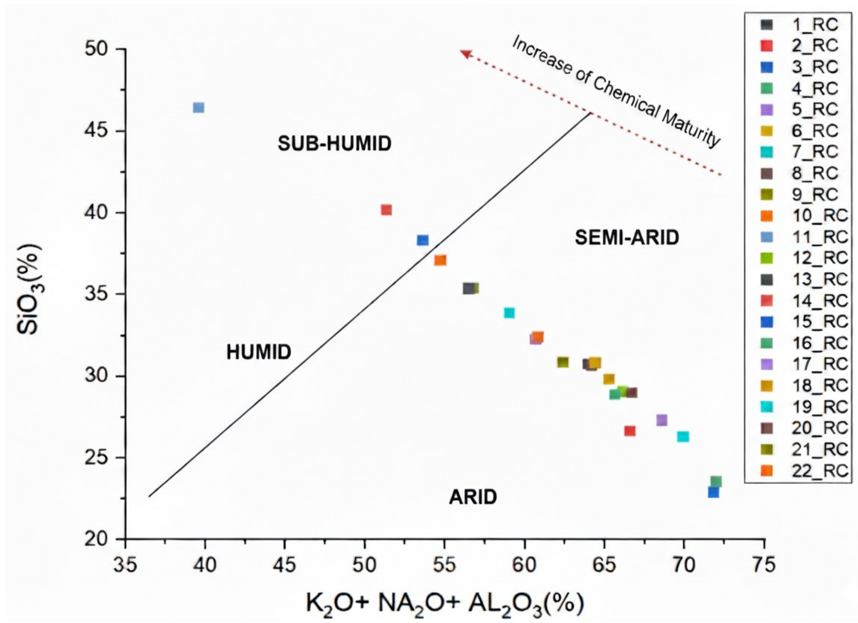

Figure 15 – Paleoenvironmental Index of the samples in the Carnaúba watershed.
Source: Authors (2025).

Finally, unlike the context observed in Bahia, the laterites here are incipient, with the analyzed samples presenting and decreasing of Chemical maturiry within a weakly lateritized context, reflecting semi-arid conditions. However, some samples begin to show moderate laterization, suggesting a period of stability in the formation of lateritic features. Notably, sample 11_RC, unlike the others, falls within a lateritic context, supporting its high chemical maturity and probable formation under more humid conditions. Considering this sample's position within the collected profile and the surrounding landscape, it is possible that a wetter period contributed to the formation of this more geochemically mature lateritic feature, or alternatively, the sample may have been reworked from a more humid area and subsequently deposited in the study site.

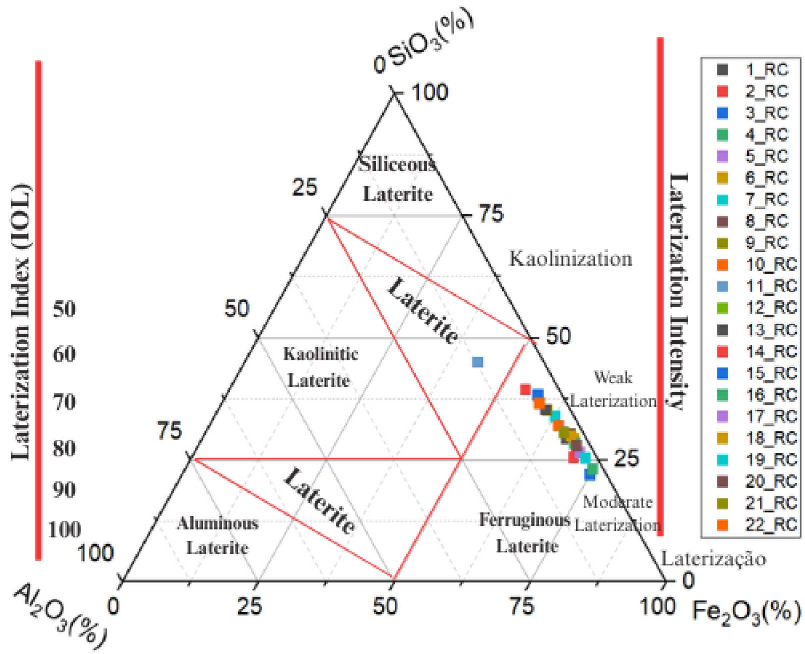

Figure 16 – Laterization Index of the samples from the Carnaúba watershed.
Source: Authors (2025).

The aluminum–potassium relationship reflects the material's origin. For our samples, values range from the illite to the muscovite domain, reflecting the characteristics of the surrounding landscape.

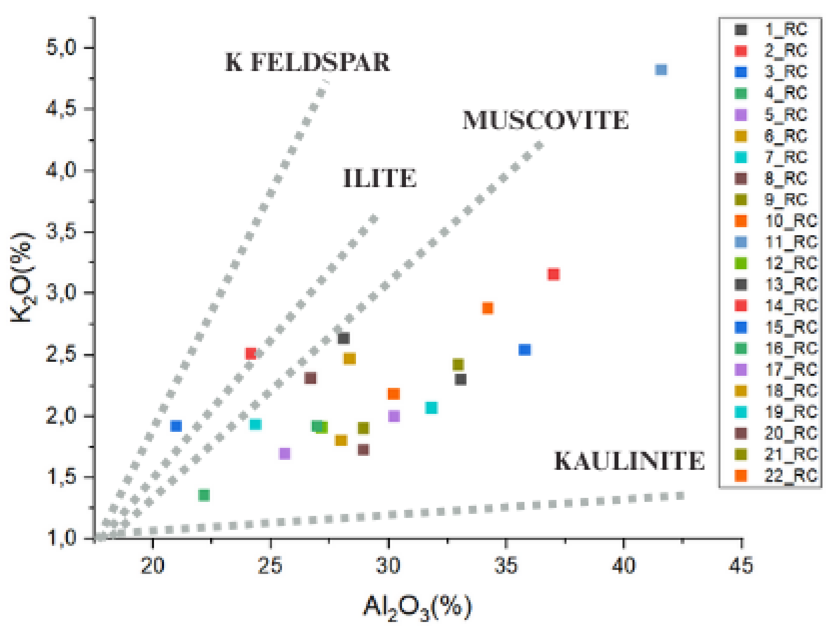

Figure 17 – Potassium–Aluminum relationship in the Carnaúba watershed samples.
Source: Authors (2025).

3.6 Geochemistry of Morro do Chapéu and the Carnaúba river watershed: climatic and landscape contrasts in the Northeastern semi-arid region

Considering the geochemical indices analyzed for the Coreia Complex area (Morro do Chapéu, BA) and the distinction proposed by Widdowson (2007) between laterites and ferricretes, we propose the following evolutionary model. First, an in situ saprolite weathering phase resulted in the formation of laterites, with geochemical indexes indicating that this stage occurred under a more humid climate, favoring intense chemical weathering. Second, a deposition phase of chemically more weathered sediments led to the formation of ferricretes; the data suggest a drier climate, similar to current conditions, and the deposited material exhibits high chemical maturity, indicating that it may have undergone erosion and transport prior to deposition. Finally, the current stability phase promotes the development of pedogenetic processes, with soil formation that, depending on weathering conditions, may evolve into laterites or iron-enriched soils through in situ alteration of previously formed materials.

Although the geochemical indexes support the initially proposed evolutionary model, certain aspects deserve attention. As noted by Nash and McLaren (2007), the geomorphological landscape, particularly topography, can significantly influence local moisture conditions, independent of global climate changes. This factor is especially relevant for the Morro do Chapéu region, located in the northern sector of the Chapada Diamantina within the semi-arid core, but reaching elevations up to 1,260 meters. These elevations enhance the reception of humid winds from the Atlantic atmospheric systems and the South Atlantic Convergence Zone (SACZ), as highlighted by Bigarella et al. (2008). Furthermore, the area's gently sloping topography promotes the development of deeper weathering mantles in specific sectors.

In this context, the laterites identified at the base of the profile may relate to a period of higher humidity, a milder semi-arid environment, or even formation under conditions similar to the present, where local factors such as topography and elevation provided sufficient moisture to enable this type of in situ alteration. Additionally, it is possible that the base of the profile formed at different times for columns C and D, as the laterite from D1L is the only one within the caulinic and humid domain. This may indicate distinct formation phases for sides C and D or a lateral discontinuity between the two sections.

Concurrently, it is also possible that the entire profile, including the laterites, has an allochthonous origin, leading to a second model. First, laterites formed during a humid pulse in an area relatively close to the deposition site. Second, these laterites were transported and deposited. Third, a brief stability phase allowed the development of a weathering mantle. Fourth, chemically mature sediments rich in iron and aluminum were deposited under semi-arid conditions, leading to the formation of ferricrete. Finally, the current stability phase may promote in situ alteration, resulting in laterite formation, or pedogenetic processes.

At the Carnaúba River, the semi-arid climate clearly influences the sedimentation regime. Variations in sediment load indicate seasonal pulses associated with synoptic systems active during the rainy period. Rainfall occurs in summer and autumn, with peak precipitation in February and March, when the accumulated rainfall expected for the entire month can occur in just a few days. These events enable the river to rework its valley, reshaping the braided channels and redistributing sediment along its main axis.

The sediment structure indicates materials of low chemical maturity, consistent with the semi-arid climate of the region, one of the driest areas in northeastern Brazil (Corrêa et al., 2019). This climate produces friable, loosely compacted sediments with low clay formation, except during flood events when normal flow resumes, allowing the deposition of expansive clays as the main channel overflows. This 2:1 clay formation aligns with the sedimentary cycle of an active braided channel, leaving evidence in the landscape of past flood events and the development of floodplains with clay accumulation.

Another characteristic of these deposits is the absence of mantle formation on the slopes, which prevents the reworking of these materials along the drainage axis. Without the development of more chemically mature soils, silt-clay material is scarce throughout the drainage. The higher concentrations of clay observed in the Carnaúba area were discussed by Mützenberg (2007), who reported the presence of kaolinite in colluvial deposits on mid-slopes at the Pedra do Alexandre archaeological site, with chronologies associated with the last interstadial.

Thus, the area presents a semi-arid environment, with the removal of chemically unaltered materials and primary minerals within the composition of the sediments structuring the Carnaúba River deposits. However, it is important to note that the apparent lack of alteration in the graphs may result from the high silica concentration in the landscape surrounding the valley. In other words, even when the index values indicate a certain chemical maturity, the graphical representation tends to be dominated by silica due to its surrounding context.

Therefore, collectively, the results indicate that the colluvial and fluvial environments of the northeastern semi-arid region exhibit distinct but complementary geochemical responses, which are essential for understanding the formation and transformation of archaeological sites.

4. Final Remarks

The results obtained for the Coreia Complex (Morro do Chapéu, BA) allowed us to propose evolutionary models that integrate climatic, sedimentological, and geomorphological variables in the formation of surface deposits. The analysis of geochemical indices revealed a complex evolutionary trajectory, characterized by phases of intense chemical weathering, deposition of chemically mature sediments, and subsequent pedogenetic stabilization. The elevated and gently sloping relief proved crucial in retaining moisture and promoting the development of deep weathering mantles, even under the prevailing semi-arid climate.

The distinction between laterites and ironcrusts (Widdowson, 2007) proved essential for understanding sedimentary and pedogenetic processes. The data suggest that the laterites at the base of the profiles may relate to wetter periods or semi-arid conditions modulated by local relief. The ferricretes reflect a drier context, consistent with current conditions. In contrast to the semi-arid fluvial environments analyzed in the Seridó, we propose the coexistence of two evolutionary models for the plateau: an autochthonous model, with in situ formation of laterites, and an allochthonous model, involving the transport and deposition of previously formed materials, both complementing the regional geomorphological and sedimentary complexity.

In contrast to the wetter conditions of Morro do Chapéu, the Carnaúba River deposits reflect persistent semi-arid conditions. The sedimentary dynamics, driven by seasonal events and high-energy pulses during summer–autumn rains, integrate into the semi-arid sedimentary cycles, corroborating facies described by Miall (1985; 2006) and recent regional studies (Mützenberg, 2007; Tavares et al., 2025; Andrade, 2025; Brandão & Tavares, 2020).

The integration of geochemical, geomorphological, and sedimentological data highlights the importance of multiple factors in the evolution of semi-arid landscapes, providing insights into past and present geological processes. Considering that the studied areas contain archaeological evidence, these results demonstrate the potential of geochemistry to elucidate contexts of prolonged human occupation, offering a basis for models of settlement and past environmental dynamics.

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