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Article

BIOSTRATINOMY OF QUATERNARY VERTEBRATE FOSSILS FROM LAJEDO DE SOLEDADE, RIO GRANDE DO NORTE, BRAZIL: INFERENCES REGARDING THE PROCESSES OF ACCUMULATION AND DEPOSITION

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ABSTRACT – Lajedo de Soledade is a large outcrop of carbonate rock whose ravines contain abundant fossil material. This work presents the biostratinomic analysis of 896 specimens of vertebrate remains from two such ravines, namely Ravina das Araras and Ravina do Leon. The material from Ravina das Araras was collected from three different layers with stratigraphic control, whereas the Ravina do Leon material consists of a single deposit. The assemblages consist of disarticulated, microfossil elements, and are dominated by Anurans, small- and medium-sized mammals. Comparison between ravines leads to the conclusion that Lajedo de Soledade preserves elements with varied biostratinomic history that were at least partly accumulated by the action of birds of prey, and that the main factor controlling the observed patterns in the assemblages is variation in availability of water over Lajedo's history. Comparison with other kinds of deposits in the BIR places the ravines apart from both caves and natural tanks in terms of biostratinomic patterns. It is unlikely that Lajedo de Soledade is reliable in terms of original species abundance and its use for paleoecology is limited.

Keywords: biostratinomy, vertebrate taphonomy, Lajedo de Soledade, BIR, Quaternary.

INTRODUCTION

Lajedo de Soledade is a 3 km^2 outcrop of carbonate rock located in Rio Grande do Norte state, northeast of Brazil. It consists of the largest section of exposed rocks of the Jandaíra Formation, Potiguar Basin (Bagnoli, 1994; Maia & Bezerra, 2020), and is well-known for its archaeological and paleontological content, as well as its scenic beauty and local economic importance (Porpino *et al*., 2009).

Most of the material thus collected stemmed from a site known as Ravina do Leon ("Leon's Ravine"), and most of what is known regarding the paleofauna of the Lajedo de Soledade derives from this site (Santos *et al*., 2002b; Porpino *et al*., 2004, 2009). Santos *et al*. (2002a, b) did the first important work dealing with these remains, followed by Porpino *et al*. (2004). These works identified many of the mammalian material down to the family level (Santos *et al*., 2002b) and down to the genus and, where possible, species (Porpino *et al*., 2004) and made some preliminary taphonomic analysis of the mammalian fossil fauna of the Lajedo through both macroscopic examination and analysis of thin sections (Santos *et al*., 2002a).

In 2007, Porpino *et al*. (2009) produced a synthesis of the Lajedo de Soledade site for the 'Sítios Geológicos e Paleontológicos do Brasil' (SIGEP) program, bringing together the state-of-the-art knowledge on the geology, paleontology, and archeology of the Lajedo, along with a brief history of the conservation efforts related to the site.

The Lajedo is also well-known for its archeological significance, featuring a wealth of rock art, including engravings and paintings, as well as ceramic and lithic materials (Miller, 2009; Porpino *et al*., 2009). These artifacts have been the subject of extensive study and speculation regarding their origin and connections to the groups of natives that inhabit the surrounding areas. While some have posited its importance as a religious location (Spencer, 2005; Miller, 2009; Porpino *et al*., 2009) for the Paleoindians of the region, no secure link could be suggested in terms of material tradition or dating for the anthropogenic features of the site.

The Lajedo de Soledade vertebrate fossil assemblage is composed mainly of assorted postcranial material, fragmentary and isolated teeth, and osteoderms, representing a fauna that is unusually diverse for the Rio Grande do Norte, including a representative of Ursidae, relatively uncommon for the Quaternary of Brazil (Santos, 2001; Santos *et al*., 2002b; Porpino *et al*., 2004, 2009).

Though preliminary taphonomic analysis and tentative preliminary interpretations of the genesis of the assemblage have been undertaken (Santos *et al*., 2002a; Porpino *et al*., 2009), no systematic investigation of the biostratinomy of the site has been made. Furthermore, most of the material studied came from a single place, the Ravina do Leon, without proper stratigraphic control. Those factors, combined with the time elapsed since the last systematic investigation of Lajedo from a paleontological standpoint, warrant a stratigraphically careful study of the biostratinomy of the site.

This paper describes and interprets the fossil assemblages of Ravina das Araras and Ravina do Leon in terms of their biostratinomic parameters to shed light on the processes responsible for the formation of the Quaternary Vertebrate assemblage of Lajedo de Soledade.

GEOLOGICAL SETTING

Lajedo de Soledade is an outcrop of the Jandaíra Formation, which is part of the Apodi Group of the Potiguar Basin (Galindo *et al*., 2016; Rodrigues, 2019). The Lajedo (05º35' S, 37º48' W) is located entirely within Apodi county, west of the Rio Grande do Norte state, Northeast of Brazil (CPRM, 2005) (Figure 1).

Galindo *et al*. (2016) determined that most of the record of the Jandaíra Formation is made up of calcarenites and bioclastic calcilutites, with the occasional presence of clastic and evaporitic rocks. These rocks were subjected to extensive uplift, exposition, and erosion, resulting in karstification through the dissolution of the soluble carbonate rocks of the Jandaíra unit. This process led to the karstic features we can observe nowadays through the extensive Jandaíra outcrops that pepper the western Rio Grande do Norte (Sallun Filho & Karmann, 2012; Galindo *et al*., 2016; Maia & Bezerra, 2020). These karstic features include but are not limited to caves, sinkholes, and extensive pavements.

The Lajedo de Soledade results from karstification processes on the rocks of the Jandaíra Formation. It was shaped over time as the carbonate rocks were dissolved by water, sculpting the initially thin and shallow grooves into ravines that can reach a few meters across and up to 6 m deep, with some being over 800 m long (Bagnoli, 1994; Galindo *et al*., 2016; Maia & Bezerra, 2020).

The development of karstic features on the Jandaíra Formation is strongly controlled by the system of faults and fractures that affect the whole basin, influencing the genesis and development of small valleys and ravines in a preferentially NE/SW or NW/SE trend (Maia & Bezerra, 2020; Porpino *et al*., 2009). The ravines display a range of developmental stages, some incipient, others well developed. The processes have led to the formation of small canyons and channels within the Lajedo, where the bulk of Quaternary sediment accumulation has occurred.

Within the Lajedo, as is the rule for the sections of the Jandaíra that have undergone intense karstification (Maia *et al*., 2013; Maia & Bezerra, 2020), the primary sedimentary deposits along the faults, ravines, and canyons are of two types: (i) breccias, originating from collapse of ceilings and walls during the karstification process; (ii) alluvial sediments deposited from suspension or traction.

MATERIAL AND METHODS

Material

The paleontological material consists of skeletal elements collected during excavations undertaken by members of the Paleontology Laboratory of the Universidade do Estado do Rio de Janeiro (**LABPALEO/UERJ**) and other researchers. The Ravina das Araras material was collected during excavations undertaken under rigorous stratigraphic control (Figure 2). Part of the material was collected *in situ*, and removed sediment was sieved, which allowed further recovery of elements that would otherwise have been missed. These materials are currently in the care of the LABPALEO at the Universidade do Estado do Rio de Janeiro (**UERJ**). Material from Ravina do Leon was collected without such stratigraphic control, however all specimens come from a single sedimentary layer. These materials are housed partly at the Museu do Lajedo de Soledade (**MLS**), Apodi, Rio Grande do Norte State, Brazil, and partly at the Museu Câmara Cascudo of the Universidade Federal do Rio Grande do Norte (**MCC/UFRN**), Natal, Rio Grande do Norte State, Brazil.

Methods

The paleontological material was analyzed based on data relating to both the assemblage as a whole and the modifications observed on individual elements. This approach largely follows the methodology outlined by Behrensmeyer (1991). Not all parameters from that study are used here, in line with the author's recommendation to adapt the methodology to specific sites. However, its basic structure and key parameters have been preserved, with additional guidance drawn from other sources.

The parameters used in the analysis of the vertebrate assemblages featured in this work were: (**A**) sample size; (**B**) number of individuals; (**C**) taxonomic diversity (Eberth *et al*., 2007); (**D**) degree of articulation (Behrensmeyer, 1991); (**E**) element representation (Dodson, 1973; Behrensmeyer, 1975; Shipman & Walker, 1980); (**F**) weathering (Fiorillo, 1988); abrasion (Fiorillo, 1988); (**G**) breakage (Villa & Mahieu, 1991); (**H**) surface marks (Fiorillo, 1988; Fernandez-Jalvo & Andrews, 2016).

In the present work, "specimen" means an identifiable specimen that may or may not be ascribed to any given taxon, and the sample size is the number of identifiable specimens in the assemblage (**NISP**). The number of individuals is an estimate of the minimum number of individuals (**MNI**). 'Linear Marks' and 'Pits and Perforations' here are the same as in Fernández-Jalvo & Andrews (2016). Trampling' is a more interpretive description, meaning 'shallow, roughly linear, subparallel sets of scratches' (Fiorillo, 1988). 'Root marks' is another interpretive description, meaning a set of intercrossing etching marks. Surface marks are noted as either absent (0) or present (1).

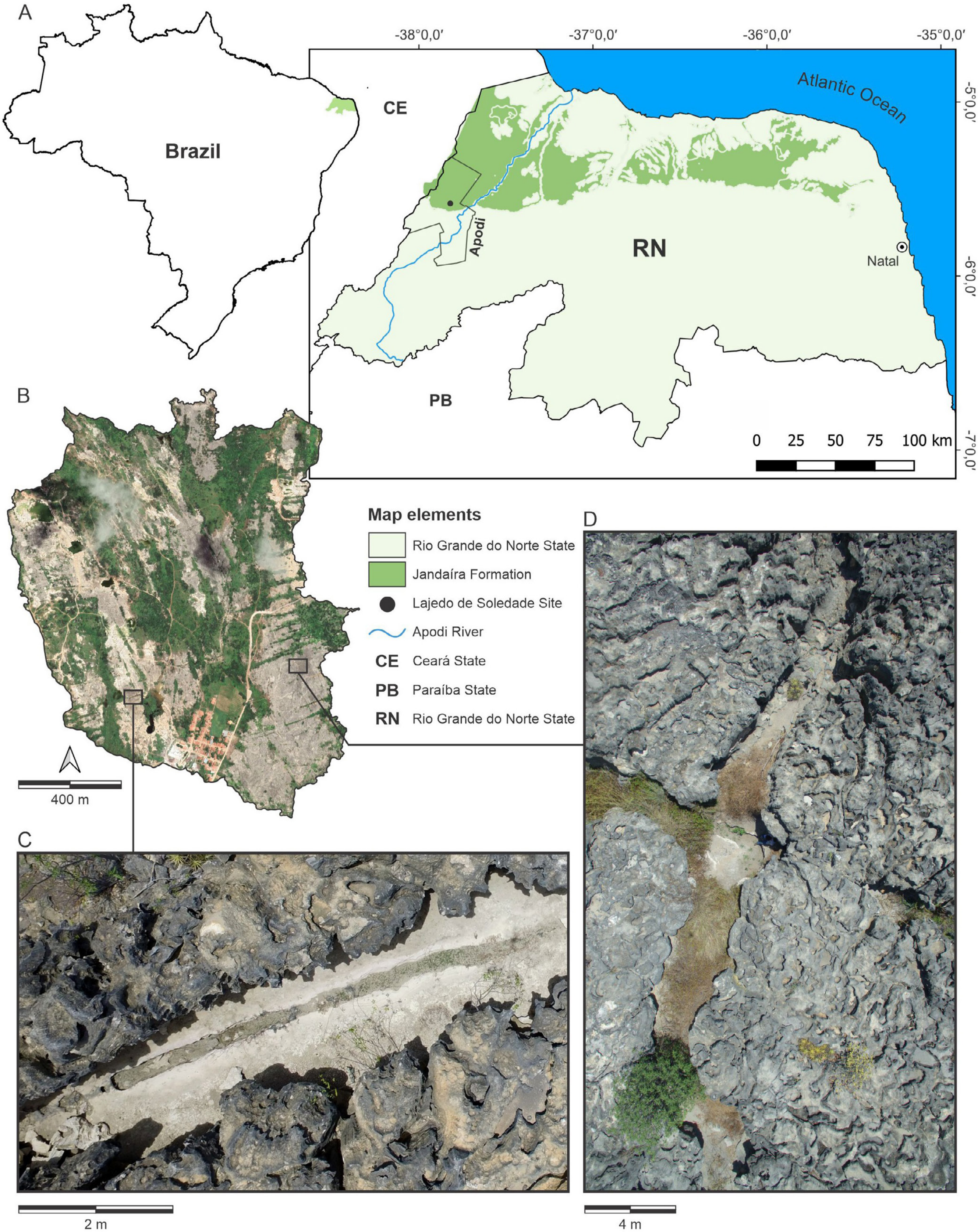

Figure 1. Location map of Ravina das Araras and Ravina do Leon, Lajedo de Soledade; **A**, map of Brazil showing the location of Rio Grande do Norte with an inset map of Rio Grande do Norte showing Apodi County and Lajedo de Soledade. **B**, aerial view of Lajedo de Soledade. **C**, aerial view of Ravina do Leon. **D**, aerial view of Ravina das Araras. Adapted from Costa *et al.* (2024).

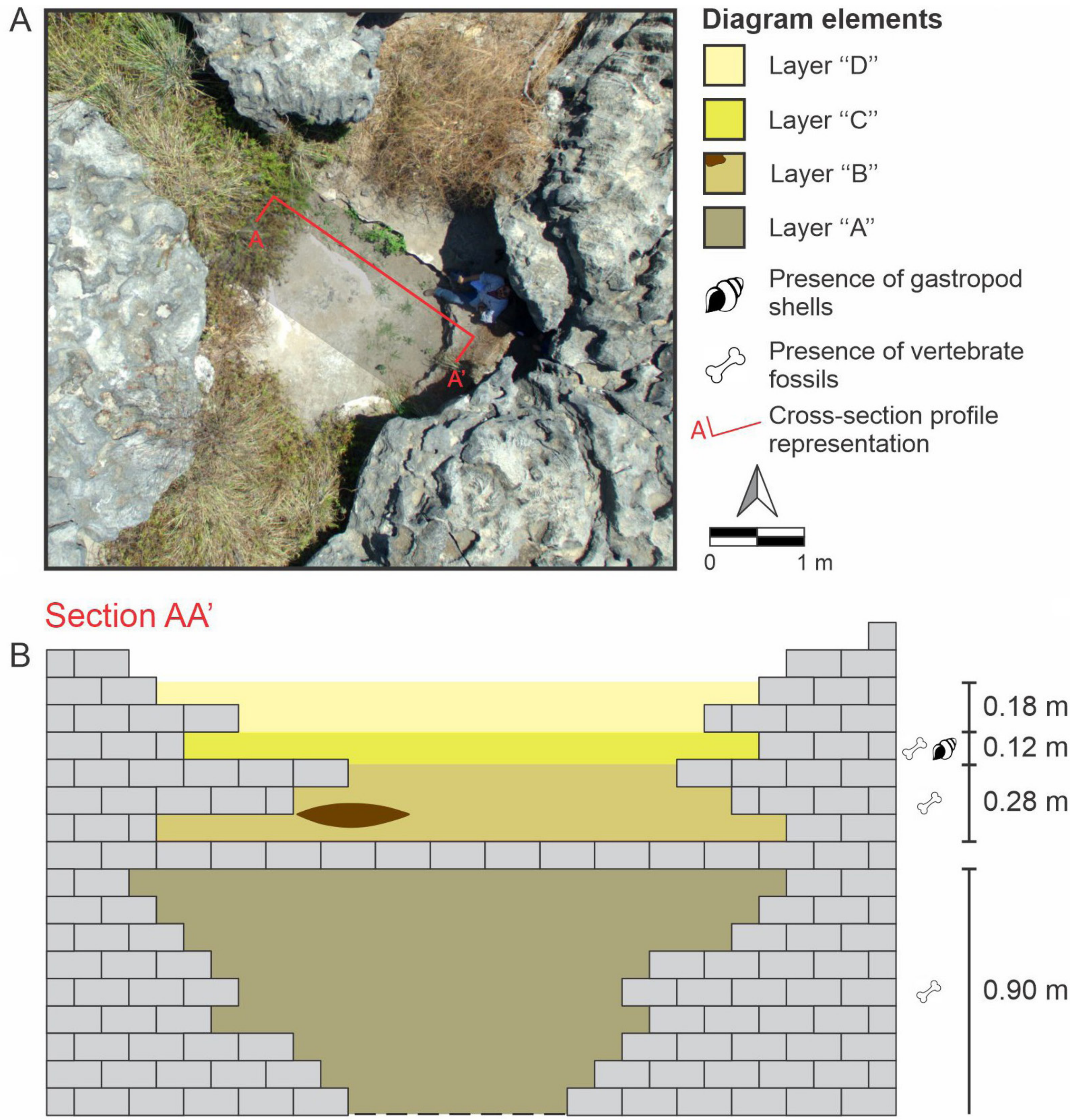

Figure 2. Overview and stratigraphic section of Ravina das Araras. **A**, aerial view of Ravina das Araras. **B**, section diagram of Ravina das Araras. Modified from Costa *et al.* (2024).

RESULTS AND DISCUSSION

Ravina das Araras

The number of identifiable specimens for the Ravina das Araras was 582: 84 in Layer A, 361 in Layer B, and 137 in Layer C. At least 87 individuals are represented in the assemblage: 21 in Layer A, 41 in Layer B, and 25 in Layer C. In terms of taxa, Ravina das Araras is dominated by Rodentia and Anura, with a considerable amount also of Felidae, Canidae, Equidae and Camelidae. Layer A, Layer B, and Layer C are all multitaxic, and have high-diversity assemblages.

Layer A

The most abundant element represented (Figure 3) in Layer A of Ravina das Araras is vertebrae (approximately 30% of the assemblage), one of the most numerous elements in the vertebrate body (Korth, 1979; Andrews, 1990; Lyman, 1994a).

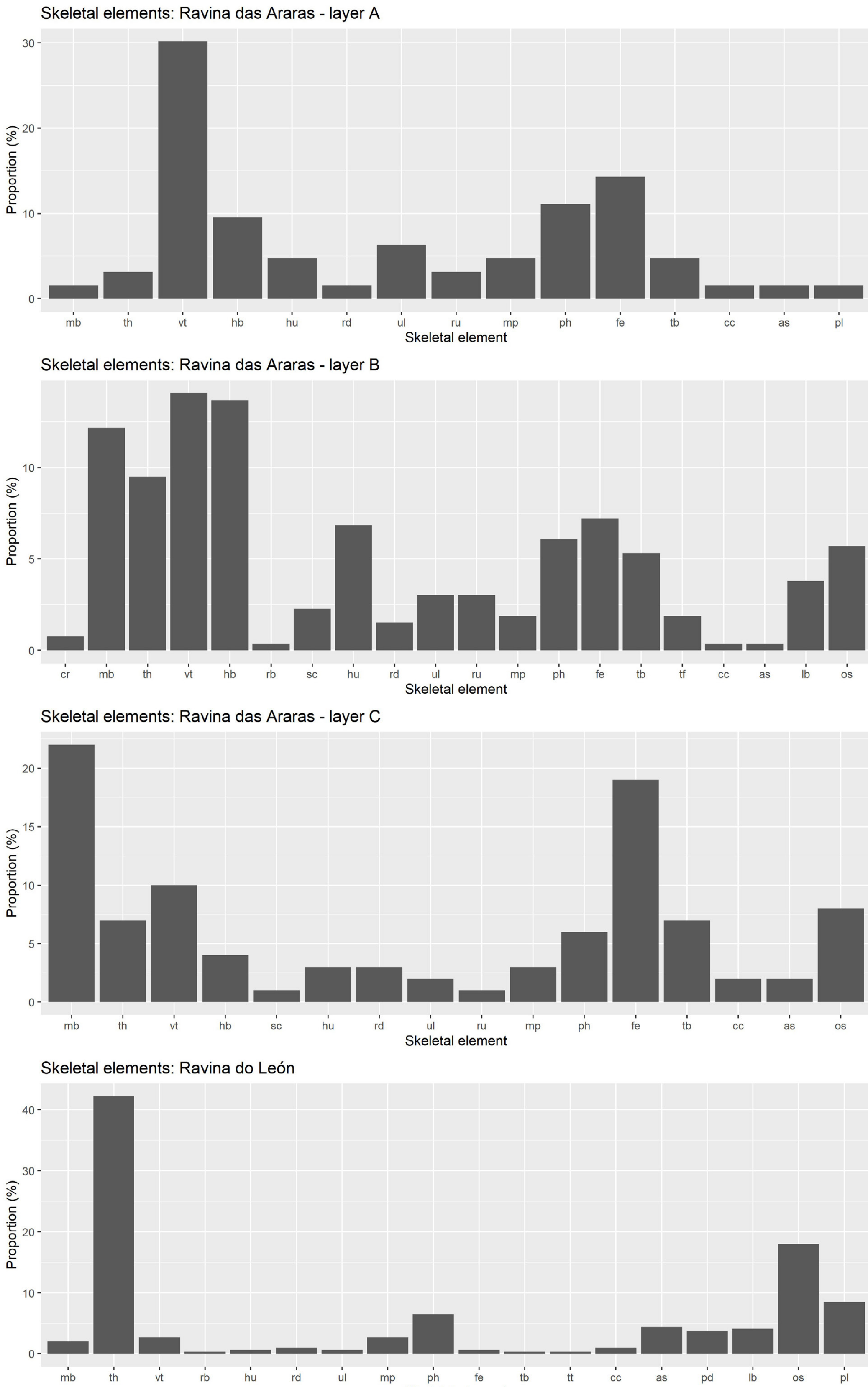

Figure 3. Skeletal representation in Lajedo de Soledade. **Abbreviations: cr**, cranial element; **mb**, mandible; **th**, isolated tooth; **vt**, vertebra; **hb**, hip bone; **rb**, rib; **sc**, scapula; **hu**, humerus; **rd**, radius; **ul**, ulna; **ru**, radioulna; **mp**, metapodial; **ph**, phalanx; **fe**, femur; **tb**, tibia; **tf**, tibiofibula; **cc**, calcaneus; **as**, astragalus; **pl**, plastron; **os**, osteoderm; **lb**, long bone.

Also important is the contribution of phalanges, femora, and hip bones, each comprising around 10% of the assemblage. While phalanges are also very common in the skeletal body, their contribution in this assemblage is markedly inferior to that of vertebrae. Furthermore, they are equivalent in number to the femora and hip bones, elements with smaller participation in the skeleton. The remainder of the assemblage is made up of, in descending order of representation, ulnae, metapodials, tibiae, humeri, isolated teeth, radioulnae, mandibles, radii, calcanei, astragali, and plastrons. Thus, around 40% of the assemblage belongs to elements of the axial skeleton. The most common elements of the appendicular skeleton are posterior long bones, represented mainly by femora.

Isolated teeth, another most common skeletal part, are notably scarce in Layer A. Their contribution is on par with less numerically important elements such as tibiae. The relative abundance or scarcity of numerically relevant elements of the skeleton points to the possibility of sorting during the genesis of this accumulation. This is corroborated by the scarcity of elements associated with the late and intermediate stages of sorting of small bones (Dodson, 1973): mandible, calcanei, humeri, and cranial elements. Most of the assemblage consists of elements belonging to the early stages of transport groups, with some important contributions of intermediate elements. This points to an assemblage that has undergone at least a moderate degree of sorting.

Elements in Layer A cluster around 2.0 cm, with progressively fewer elements belonging to larger sizes (Figure 4). The curve trails off before reaching 5.0 cm, and very few elements reach past 5.0 cm. Regarding size classes, almost 100% of elements of Layer A belong to the "micro" class, being smaller than 5.0 cm (Figure 4).

When considering element representation, examining the destructive processes that may have influenced the assemblage and contributed to its observed characteristics is crucial. Most of the Layer A assemblage consists of fragmented elements, approximately 70% (Figure 5). A highly fragmented and disarticulated assemblage, devoid of associated specimens as seen here, shows the lack of rapid burial following death (Hill, 1979; Hill & Behrensmeyer, 1984; Weigelt, 1989).

The 'curved' morphology of breakage outline predominates, with around 70% of the breaks displaying that morphology. In terms of breakage angle (Figure 6), the oblique morphology is more common, with some 40% of the breaks in the assemblage. Elements displaying a 'right' angle break represent around 35% of the assemblage. It is essential to recognize that the morphology of breaks correlates with the timing and manner of breakage; its significance stems from a statistical, assemblage-level perspective, rather than being applicable to individual specimens (Villa & Mahieu, 1991). This means that breakage morphology serves as a valuable tool for identifying trends within a collection of skeletal elements. For Layer A, the dominance of curved outline breaks and the prominence of oblique angle breaks suggest a notable presence of "green" and "fresh" breaks within the assemblage. This indicates that many elements were fractured soon after death when the bone tissue still possessed considerable resistance to force (Andrews, 1990; Villa & Mahieu, 1991; Lyman, 1994b; Fernandez-Jalvo & Andrews, 2016). Significant force is required to break apart still-fresh bones, a characteristic often associated with the actions of predators, impacts from coarse-grained sediment influenced by gravity, or trampling (Andrews, 1990; Behrensmeyer, 1991; Fernandez-Jalvo & Andrews, 2016).

The pattern of weathering of Layer A shows a predominance of unweathered or slightly weathered elements (stages 0 and 1 make up more than 70% of the assemblage) (Figures 7 and 8). Furthermore, the third most significant category is that of stage 2, meaning that heavily abraded specimens are the clear minority in this assemblage. The low level of weathering present in this assemblage is an indication of the relatively low levels of subaerial exposure undergone by the specimens of Layer A (Behrensmeyer, 1975, 1991). Estimation of duration of exposure in terms of years before burial by use of weathering is a practice that should in general be disregarded (Lyman, 1994b, 2008), and all that can be reliably inferred from this data is that the assemblage consists mostly of elements that have reached the point of collection having undergone relatively little exposure during the biostratinomic cycle. The presence of elements with higher degrees of weathering suggests that at least part of the elements in the assemblage underwent relatively strenuous weathering processes, and, therefore, the possibility must be entertained that a number of elements have been destroyed prior to collection and study.

The pattern of abrasion in Layer A shows (Figure 9) a predominance of unabraded specimens, which make up more than 75% of the assemblage. Low levels of abrasion are due to the lack of processes responsible for abrasion, polishing, or rounding of elements. This obvious statement leads us to infer the lack of influence of these processes, namely the prolonged influence of running water, wind, or trampling (Fernandez-Jalvo & Andrews, 2016). When water is suspected of being the main agent behind abrasion, this does not necessarily entail long transportation distances (Fiorillo, 1988; Behrensmeyer, 1991). However, the near absence of abrasion when the sediment displays signs of its influence lends support to the notion that little to no transport took place.

Some 30% of elements of this layer display skeletal modification in their surface in the form of pits and/or perforations of some manner (Figure 10). That value is similar to that of linear marks found in the assemblage. In contrast, both modifications related to roots and trampling are scarce.

The scarcity of trampling marks in the layer further supports our observations regarding the reduced significance of processes capable of abrading bones. Overall, surficial marks offer insights into the quantity, severity, and timing of element modification under both subaerial conditions and non-definitive burial environments (Fiorillo, 1988; Andrews, 1990; Behrensmeyer, 1991; Lyman, 1994b). Pits and linear marks are the most prevalent forms of surficial modification in this layer, yet they are present on only one in five elements. The sedimentological evidence bolsters the notion of an accumulation area that experienced

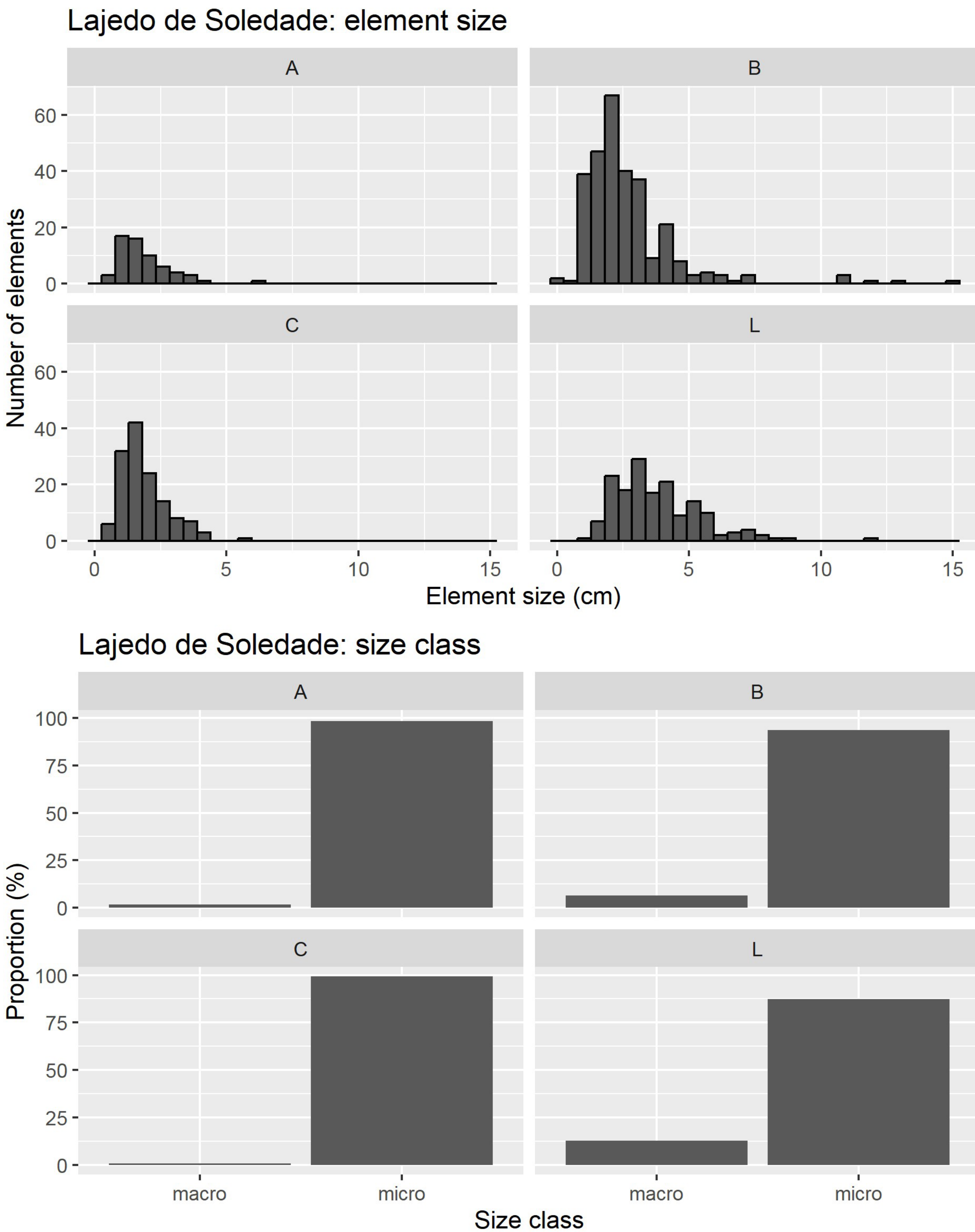

Figure 4. Dimensions of the fossil specimens (element size and size class) in Ravina das Araras and Ravina do Leon. **A**, layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras. **L**, Ravina do Leon.

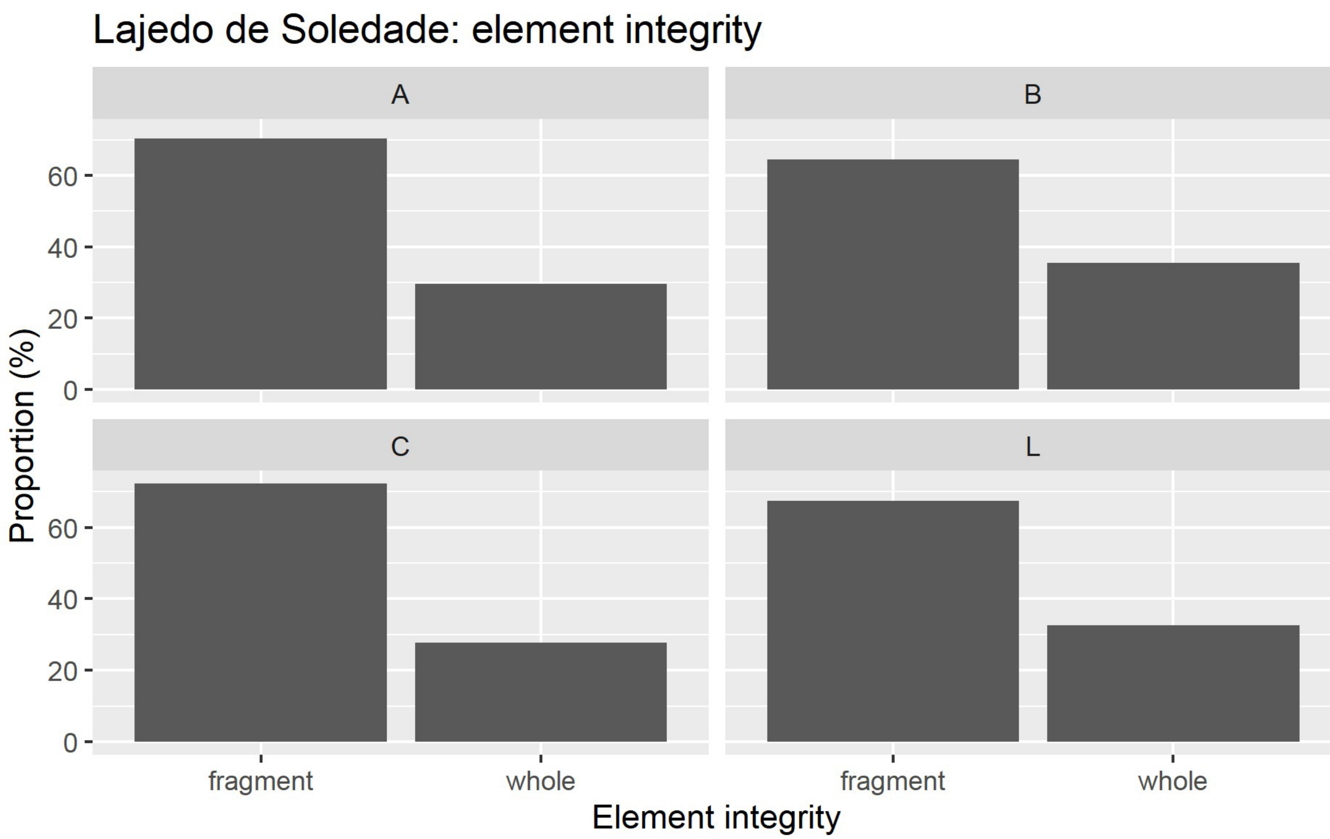

Figure 5. Degree of fragmentation of fossil assemblages of Lajedo de Soledade. **A,** layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras. **L,** Ravina do Leon.

alternating dry and humid periods (Maia & Bezerra 2020; Martins, 2024), suggesting that elements were gradually incorporated into the assemblage and had significant subaerial exposure prior to burial. The relative lack of alteration, in contrast to what might typically be anticipated (Behrensmeyer, 1991), can be interpreted as evidence of the selective removal of heavily damaged elements before the final burial.

Trampling marks are not very common in Layer A, however. The absence of trampling marks is not enough to entirely discard trampling as an important agent, but it does weaken this hypothesis. We said above that Layer A's weathering profile indicates that at least some elements underwent a great deal of subaerial exposure and may have been destroyed in the process. This hypothesis is strengthened by our inference that representation of elements was significantly affected by destructive processes and not only sorting. Elements that are naturally more fragile, and elements that suffered longer exposure may have been initially concentrated but subsequently destroyed, leaving us with the observed taphocoenosis of Layer A.

Given that Layer A has undergone at least a moderate degree of sorting, we could have expected a greater representation of cranial elements. The fact that they are scarce, and nowhere near as common as other elements belonging to intermediate stages of sorting suggests that the origin of such difference may lie in the different robustness of these elements: mandibles, calcanei, and humeri are more robust and durable, and found in small numbers. Given the considerably fragmented nature of Layer A assemblage, with many bones broken while still fresh, we infer that preservation was shaped by sorting and the element's resistance to breakage, particularly during the early stages of the biostratinomic cycle. Fresh bone is hard to break, and mostly associated with trampling, gravity-induced impact by sediment, or predation (Andrews, 1990; Behrensmeyer, 1991; Villa & Mahieu, 1991; Lyman, 1994a; Fernandez-Jalvo & Andrews, 2016).

Layer B

The most common elements (Figure 3) in Layer B are vertebrae, hip bones, mandibles, and isolated teeth. This group represents around 50% of the assemblage. Humeri and femora are also very relevant numerically, each with approximately even distributions, around 7.0% of the assemblage, followed closely by phalanges, tibiae, osteoderms, and long bones. Calcanei, astragali, ribs, and cranial elements are particularly underrepresented. Approximately half of the assemblage is thus made up of elements of the axial skeleton. In contrast with Layer A, however, both anterior and posterior portions of the appendicular skeleton are well represented here.

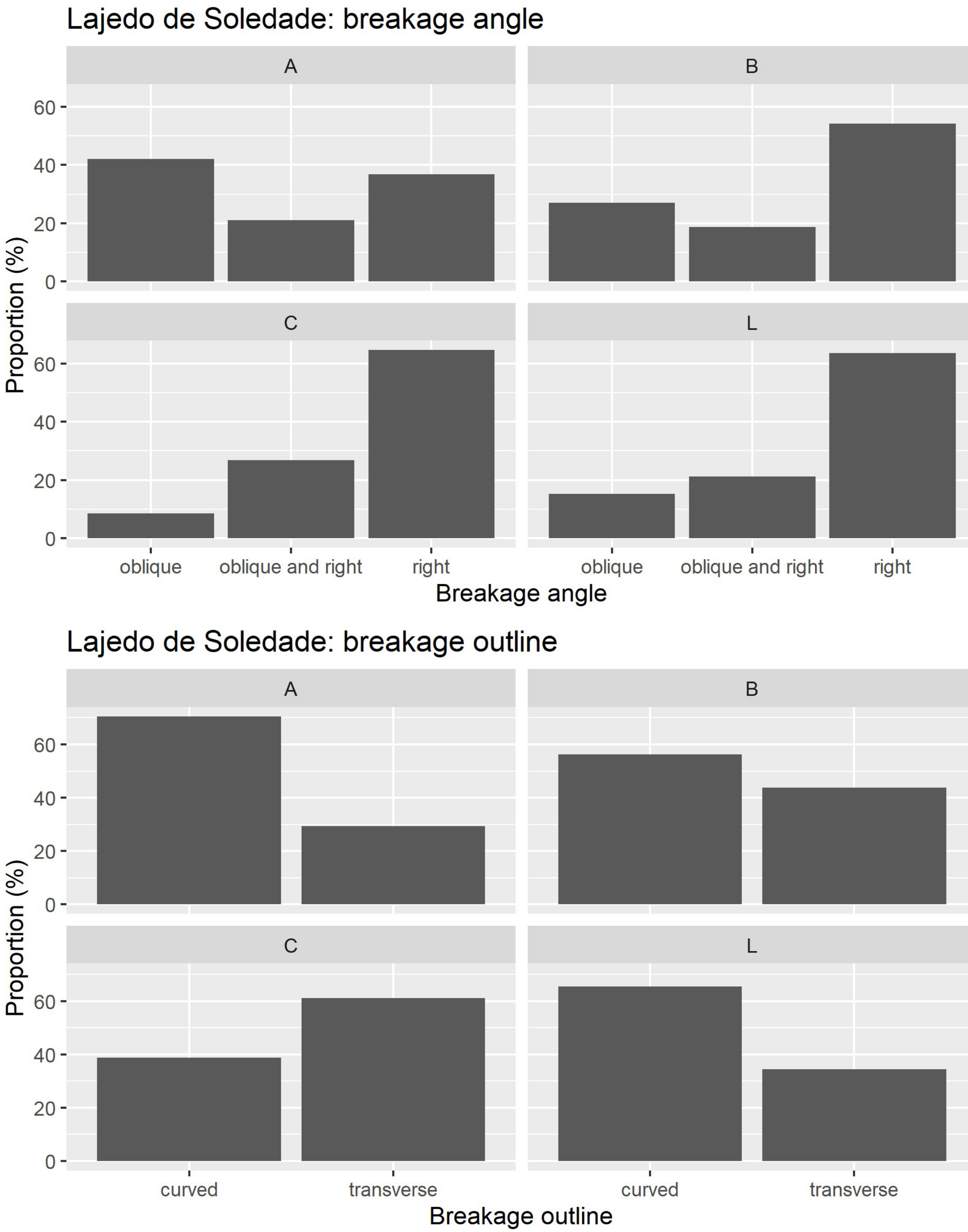

Figure 6. Breakage Angle and Breakage Outline for Ravina das Araras and Ravina do Leon. **A**, layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras; **L**, Ravina do Leon.

Figure 7. Bone modification in the fossil assemblages of Lajedo de Soledade. **A**, weathering stage 0. **B**, weathering stage 1. **C**, weathering stage 2 (MLS-62, dorsal view). **D**, weathering stage 3. **E**, abrasion stage 1 (MLS-362, anterior view). **F**, breakage outline ‘curved’. **G**, breakage angle ‘right’ and breakage outline ‘transverse’ (anterior view). **H**, breakage angle ‘oblique’. **I,** surface mark ‘trampling’. **J**, surface mark ‘pit’ (MLS-75,). **K**, surface mark ‘root’ (MLS-11, lateral view). **L**, surface mark ‘linear’ (MLS-99, lateral view). Scale bars: A–K = 1 cm; L = 1 mm.

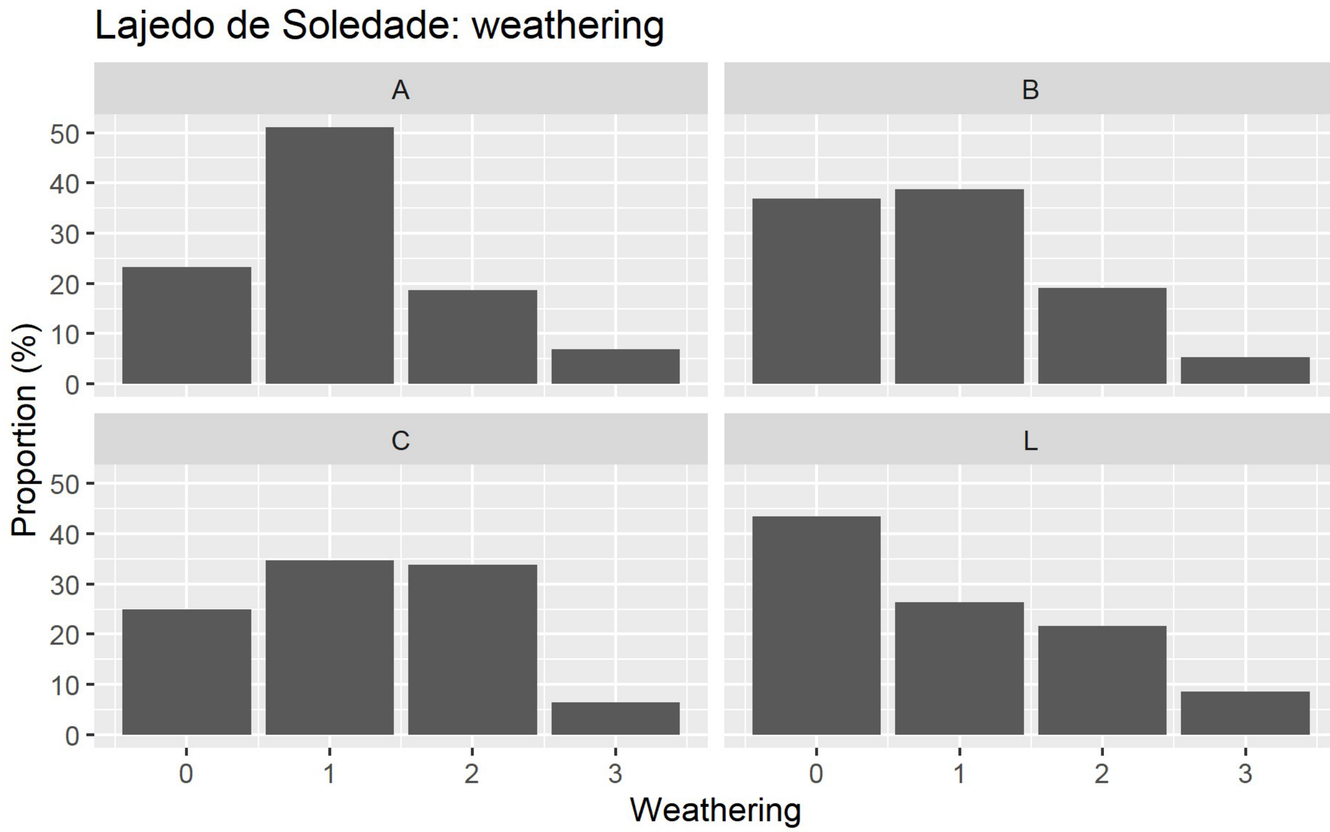

Figure 8. Degrees of weathering of Ravina das Araras and Ravina do Leon. **A**, layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras. **L**, Ravina do Leon.

The two most common elements in Layer B (vertebrae and isolated teeth), are some of the most numerous components of the vertebrate skeleton. Hip bones and mandibles, however, are just as common in this assemblage, appearing in higher numbers than would otherwise be expected if their original numerical skeletal proportions were maintained (Korth, 1979; Andrews, 1990; Lyman, 1994b). In Layer B, there is an important contribution of elements belonging to all stages of Dodson transport groups, a possible indication of a lack of sorting of elements. The scarcity of less transportable elements, such as cranial elements, could suggest a preservation bias for more transportable items. Conversely, the paucity of immediately movable elements like calcanei and astragali contradicts this hypothesis.

Layer B also displays elements belonging preferentially to smaller sizes (Figure 4) but is more varied than Layer A. Its elements are more evenly distributed between 1.5 cm and 4.0 cm, and a considerable number of elements are slightly larger than 5.0 cm. Some elements even reach as far as 15.0 cm, the largest specimen in Ravina das Araras. In terms of size class, Layer B is the only layer of Ravina das Araras with a relevant presence of elements larger than 5.0 cm (Figure 4), which make up around 5% of the assemblage.

The pattern for Layer B is like that observed in Layer A (Figure 5), with most material in various states of fragmentation. The amount of whole material is slightly larger than observed for Layer A (around 35%). In Layer B the curved morphology of breakage outline (Figure 6) is more common, with some 55% of the breaks displaying that morphology. In terms of breakage angle (Figure 6), more than 50% of breaks display a 'right' angle type of morphology, with the oblique morphology being responsible for just under 25% of elements.

Once again, considerations of element representation cannot be divorced from evidence of the destructive processes that are acting on the assemblage. Layer B is made up mostly of broken elements and is wholly disarticulated, indicating a lack of rapid burial after death (Hill, 1979; Hill & Behrensmeyer, 1984; Weigelt, 1989). The preponderance of breakage angle of type 'right' can be associated, at the level of assemblage (again, not at the level of individual elements), with specimens that were no longer fresh at the time of breakage. However, the relatively even distribution of breakage outlines between 'curved' and 'transverse' contradicts this hypothesis (Villa & Mahieu, 1991). The answer to this conundrum may lie in the pattern of destructive processes prevalent during the formation of Layer B: elements may have been originally broken while fresh and later suffered further breakage, leading to this mixed pattern. If the pattern of bone modification supports the idea of extensive alteration of the taphocoenosis, the hypotheses of different timing of breakage will

Figure 9. Degree of abrasion of Ravina das Araras and Ravina do Leon. **A**, layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras. **L**, Ravina do Leon.

have been bolstered. Breakage of fresh bones is usually associated with trampling, carnivore action, or sediment impact, whereas breakage of dry bone is usually associated (at the assemblage level) with post-depositional processes (Behrensmeyer, 1991; Villa & Mahieu, 1991; Fernandez-Jalvo & Andrews, 2016). The importance of dry and green breaks indicates the mixed nature of processes responsible for the breakage and destruction of elements in Layer B.

The pattern here is similar to Layer A but with a higher influence of stage 0 elements (Figure 7 and 8). Both stage 0 and stage 1 are similar in their contribution to this assemblage, indicative of minor exposure to subaerial conditions (Behrensmeyer, 1975; Fiorillo, 1988; Fernandez-Jalvo & Andrews, 2016). The proportion of stage 2 and stage 3 elements is similar to layer A, which is under 30% of the assemblage. Again, estimation of years exposed before final burial should be avoided by using weather alone (Lyman, 1994b, 2008), and all that can be reliably inferred is that most surviving elements remained for relatively little time under exposure. The presence of elements with higher degrees of weathering indicates that at least part of the assemblage underwent prolonged periods of exposure and, therefore, a varied taphonomic history of the taphocoenosis. It must be kept in mind that at least some elements will have been destroyed before the final burial.

In Layer B, unabraded elements (Figure 9) are even more common than in Layer A, with over 80% of these indicating a lack of processes such as polishing or rounding. Once again, the pattern indicates the lack of influence of these processes, namely the prolonged influence of running water, wind, or trampling (Fernandez-Jalvo & Andrews, 2016). The near absence of abrasion suggests minimal to no transport of the elements. This is because moderate abrasion can result from hydraulic transport over moderate to long distances or over a moderate time interval, even within a short distance. Furthermore, it implies that these bones were not stationary on the substrate or surface while exposed to sediment flows (Fernández-Jalvo & Andrews, 2016).

This layer also shows a predominance of pits, perforations, and linear marks in the assemblage (Figure 10). Much like what is observed in Layer A, pits and perforations are slightly more common than linear marks. Here, however, they are more common than in Layer A, hovering around 50% to 60%. Root marks are also more common, appearing in around 15% of the material. Similarly to Layer A, it displays little signs of trampling, which further corroborates our remarks on the diminished importance of processes that could abrade bones. Surficial marks indicate the amount, severity, and timing of element modification under subaerial and non-definitive burial conditions (Fiorillo, 1988; Andrews, 1990; Behrensmeyer, 1991; Lyman, 1994b).

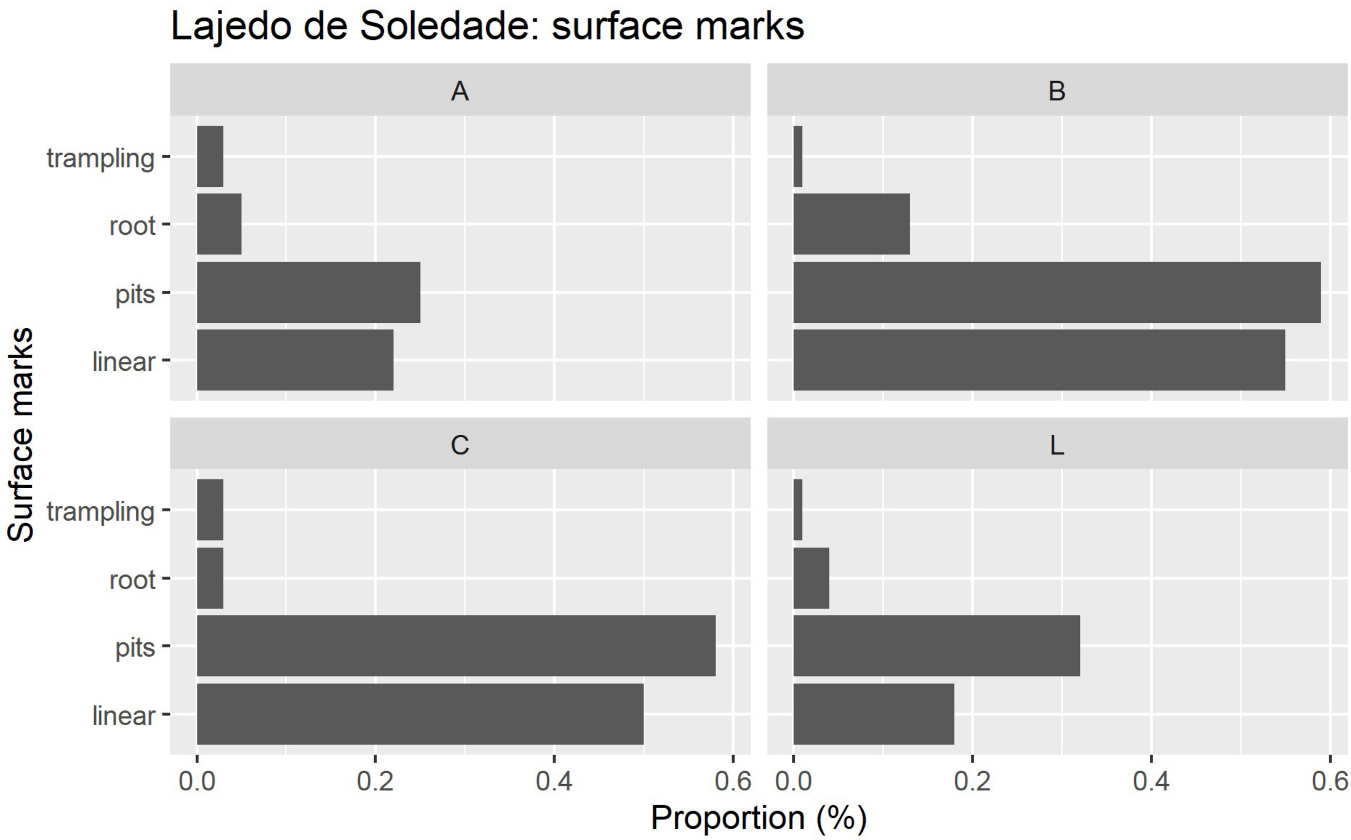

Figure 10. Surface marks of Ravina das Araras and Ravina do Leon. **A**, layer A of Ravina das Araras. **B**, layer B of Ravina das Araras. **C**, layer C of Ravina das Araras. **L**, Ravina do Leon.

Pits and linear marks are very common in Layer B, both of which are reliable indicators of the intensity of modifying agents and processes, likely scavengers and carnivores (Andrews, 1990; Behrensmeyer, 1991). Also relevant here are the marks related to rooting processes, which are usually associated with at least incipient vegetation and shallow burial (Behrensmeyer, 1991; Lyman, 1994b; Fernandez-Jalvo & Andrews, 2016).

Layer B differs from Layer A in at least two aspects: the diminished evidence of sorting and the increased evidence for elements with different taphonomic histories. Both surface marks and breakage patterns in Layer B support the idea of skeletal elements that were subject to processes and agents of different intensity. The ubiquity of isolated teeth and vertebrae may be ascribed to their original proportions in the skeleton, but the abundance of mandibles and hip bones begs a different explanation. Predators are commonly cited agents of concentration and alteration of bones, and birds of prey in particular for assemblages dominated by microfossils, as is the case here (Korth, 1979; Shipman & Walker, 1980; Lyman, 1994b; Andrews, 1990; Pinto Llona & Andrews, 1999). Actuotaphonomic evidence suggests that predation by owls tends to preferentially preserve mandibles (Korth, 1979; Serrano *et al*., 2022), which could account for their overrepresentation here. This does not imply, however, that predation played no part in the formation of Layer A (as evidenced by the predominance of types of breaks associated with 'fresh' breakage). Sedimentological evidence suggests (Martins, 2024) higher water availability during the formation of Layer B compared to the conditions of formation of Layer A, with a more pronounced seasonality (as opposed to a longer dry period, as would be the case for Layer A). Destructive processes and agents would severely affect elements concentrated and exposed for a long period before final burial (Shipman & Walker, 1980). While it is commonplace to associate larger elements with higher resistance to destruction, there is evidence that small elements are more readily preserved under certain conditions, namely, when water arrives in sufficient quantities to cover and protect small elements but otherwise leaves larger elements exposed (Behrensmeyer, 1991). Given the more frequent dry-wet alternating periods in Layer B, this seems to account for the differences in the observed taphocoenoses.

Layer C

The most common elements (Figure 3) in Layer C are mandibles (over 20% of the assemblage) and femora (just short of 20% of the assemblage), a fact that would not be expected given their relative abundance in the vertebrate skeleton. Elements that would be expected to feature heavily and appear less frequently are vertebrae and osteoderms. Just behind come vertebrae, isolated teeth, osteoderms, phalanges, tibiae, and hip bones. Scapulae and radio-ulnae are the scarcest elements in this assemblage. In common with Layers A and B, elements of the axial skeleton are numerically very relevant in this Layer. Elements of the appendicular skeleton are better represented in this layer, though, mainly by femora.

Mandibles belong to later stages of transport, according to Dodson (1973), and their overrepresentation in the assemblage is a possible indication of at least a moderate degree of sorting by water. This hypothesis is weakened somewhat by the scarcity of late to intermediate-stage elements such as calcanei, radii, and ulnae. Calcanei are particularly sturdy and robust bones, compact and resistant to destruction, and their absence is noteworthy. The layer is also rich in elements belonging to intermediate stages (mainly femora) and some early-stage elements. Also remarkable is the paucity of isolated teeth, very numerous in the vertebrate skeleton. The evidence suggests, at most, a very weak sorting with no apparent tendency to winnow out the assemblage and leads us to look elsewhere for the pattern of observed element representation.

Layer C follows the pattern of distribution (Figure 4) of Layer A, with elements clustering around 2.0 cm and an overall decline in numbers around 5.0 cm, with the occasional element larger than 5.0 cm. In terms of size class, Layer C is similar (Figure 4) to Layer A in having almost no elements larger than 5.0 cm.

Regarding the physical integrity of the bones, Layer C follows the pattern observed for the other two Ravina das Araras assemblages, consisting of mostly fragmented material. Layer C boasts the highest proportion of incomplete material (Figure 5), over 70%. As far as breakage outline is concerned, Layer C has mostly elements (Figure 6) with a ‘transverse’ morphology (a shade over 60%). When dealing with breakage angle (Figure 6) there is clear dominance of the ‘right’ morphology, with more than 60% of breaks.

Layer C is also a highly fragmented, isolated, and disarticulated assemblage, typical of an assemblage that did not undergo rapid burial after death (Hill, 1979; Hill & Behrensmeyer, 1984; Weigelt, 1989). The predominance of transverse and right breaks is usually associated with non-fresh breakage of elements (Villa & Mahieu, 1991; Lyman, 1994b; Fernandez-Jalvo & Andrews, 2016), that is, breaks that did not take place soon after or around the time of death. Worthy of note is the scarcity of oblique morphology in this layer, which is usually associated with fresh breaks. From an assemblage level, it is possible to infer that there was a significant influence of post-depositional breakage in the elements, possibly trampling, sediment compaction, or falling blocks (Fernandez-Jalvo & Andrews, 2016). While considerable force is required to break fresh bone, dry or mineralized bone is more easily damaged.

This layer displays a significantly different pattern from the other two layers. Stages 0,1 and 2 together make up around 90% of the assemblage, and each stage’s contribution is roughly similar (Figure 7 and 8). Like the other layers, stage 3 elements contribute to less than 10% of the assemblage. Elements in Layer C display a more weathered profile, boasting mostly elements belonging primarily to stages 1 and 2. However, stage 0 also contributes significantly. This points to an even distribution of elements in terms of their subaerial exposure. Stage 3 elements are in the clear minority, but that is generally to be expected, given that heavily weathered specimens become more brittle and frailer (due to the process of weathering itself) but also have undergone more time exposed to other destructive agents and processes (Behrensmeyer, 1975; Behrensmeyer, 1991). Their contribution in any assemblage is expected to be lighter than other stages. However, the abundance of relatively weathered elements in Layer C points to a taphonomic history that allowed elements to weather in place and remain relatively safe from further destruction until the final burial.

The abrasion pattern of Layer C is similar (Figure 9) to the one observed for Layer B, with more than 80% of the elements showing no sign of abrasion. Layer C’s pattern for surface marks (Figure 10) is very similar to Layer B’s, with the notable exception that root marks are less prevalent here and appear in approximately the same number of specimens as trampling marks.

Prolonged influence of transport by water or wind, or even trampling, can be discarded for Layer C, given its low level of abrasion (Fernandez-Jalvo & Andrews, 2016). It can be reliably inferred that the surviving elements of Layer C were neither transported over long distances in running water nor were they trapped under conditions of cyclic influence by high energy traction water transport (Fiorillo, 1988; Fernandez-Jalvo & Andrews, 2016).

The abundance of linear and pit marks in Layer C is indicative of severe exposure to destructive agents prior to burial (Behrensmeyer, 1991). Trampling and root marks are uncommon. It is possible that a number of elements would have been destroyed by such processes prior to final burial, *i.e.*, it is not certain that the processes leading to trampling and root marks were negligible during the formation of this layer. All that can be stated for certain is that surviving elements do not, predominantly, exhibit these marks.

The abundance of femora and mandibles in Layer C is a possible indication of at least some sorting, but the scarcity of other expected elements weakens that hypothesis. The abundance of mandibles and femora and corresponding scarcity of astragali and calcanei are expected in concentrations derived from owl predation (Korth, 1979; Shipman & Walker, 1980; Andrews, 1990). Most of the breakage in Layer C is associated with dry or mineralized bones. That evidence is not enough to discard the hypothesis of the importance of concentration by birds of prey, given that predation by owls does not necessarily entail the breakage of a great number of elements (Pinto Llona & Andrews, 1999; Ortiz *et al*., 2025). The pattern of surface marks in Layer C is similar to the one observed in Layer B, suggesting a similar duration and intensity of destructive processes. Their weathering profile, however, differs significantly. Weathered and unweathered elements are approximately equally represented in Layer C. Continuous destructive pressure on an otherwise undisturbed assemblage would yield a stepwise weathering profile, as observed for Ravina do Leon. We interpret the observed pattern in Layer C to indicate an assemblage representing elements with a varied taphonomic history (Behrensmeyer, 1991), which were gradually added, removed, and possibly reworked during the formation of this layer. Sedimentological evidence suggests another increase in water availability, contrasting with the drier conditions for Layer A and an intermediate stage for Layer B (Martins, 2024). Under the more frequent and pronounced influence of water, elements may well have been more frequent and quickly buried than was the case for Layer B, meaning that gradually added bones would have had time to weather but not enough time to be removed from the assemblage.

General considerations about the Ravina das Araras

Fossildiagenetic studies have shown an increase in the influence of water during the evolution of the Ravina das Araras layers, that is, from Layer A to Layer C (Martins, 2024). The biostratinomic evidence presented here supports that hypothesis, given that the increase of water influence in each consecutive layer is consistent with the patterns observed in each taphocoenosis and the changes observed throughout the development of the Ravina das Araras fossil concentrations. Beginning with Layer A, which displays evidence for long periods of exposure before final burial, a paramount importance of destructive processes and a bias towards survival of more robust elements and a moderate degree of sorting, we move to Layer B, which shows increased evidence for a predator-influenced concentration, possibly by birds of prey, and evidence for an assemblage that mixed together elements with varied taphonomic history, to Layer C, which shows even more evidence for predation and varied taphonomic histories.

Given the fact that Lajedo de Soledade is also an archaeological site (Bagnoli, 1994; Gonçalves *et al*., 2020; Miller, 2009; Porpino *et al*., 2009; Spencer, 2005), there remains the possibility that the leading cause of accumulation of vertebrate remains is anthropogenic. In the absence of direct evidence, be it a demonstrable association of artifacts and vertebrate remains, or a demonstrable association of human and non-human remains, human interaction must be inferred from the remains themselves (Lyman, 1994b; Reitz & Wing, 2007; Russell, 2012; Beisaw, 2013; Gifford-Gonzalez, 2018).

None of the linear marks observed in any of the assemblages displayed the characteristic 'v-shaped' trough morphology typically associated with non-organic agents (Fernandez-Jalvo & Andrews, 2016; Gifford-Gonzalez, 2018). Additionally, no specific pattern concerning element representation could be linked to what one would expect from a human-influenced accumulation (Russell, 2012; Gifford-Gonzalez, 2018). Finally, the predominance of small-sized elements at the site suggests that it is highly improbable that the Ravina das Araras fossil site resulted from human activity.

In addition to the above, it must be stated that among the most common findings in butchery deposits are the teeth of large mammals (Hillson, 2005). Given the relatively low number of such findings, the probability that the Ravina das Araras accumulation is primarily anthropogenic is severely weakened. It is not impossible that, in part, the assemblage of Ravina das Araras is a result of the reworking of previous deposits, and among these could be included one or several such butchery deposits.

Fossil concentrations dominated by small vertebrates are frequently ascribed to the action of predators, mainly birds and carnivorous mammals (Korth, 1979; Shipman & Walker (1980); Andrews, 1990; Serrano *et al*., 2022). Actuotaphonomic observation of the present-day conditions of the Lajedo has allowed the authors to identify at least one such potential agent: the Barn Owl (*Tyto alba*). Barn Owls were observed in Ravina do Peninha, another Lajedo de Soledade ravine. The authors observed many pellets, presumably from Barn Owls, one of which was opened and revealed disarticulated elements belonging to Anura.

The skeletal elements from the Barn Owl pellet were mostly unbroken, and only one showed sign of corrosion. This is consistent with actualistic evidence for Barn Owl predation (Korth, 1979; Pinto Llona & Andrews, 1999). No reliable evidence of corrosion was discovered among the elements of Ravina das Araras, which may corroborate the hypothesis that Barn Owls were an important agent of accumulation. Actuotaphonomic evidence indicates that an increase in rainfall and humidity is correlated with an increase in the concentration of carcasses of small vertebrates, presumably killed by owls (Shipman & Walker, 1980).

We conclude that the pattern observed in the taphocoenoses of Ravina das Araras is a product of shifting environmental conditions prevailing in and around the Lajedo de Soledade. The manner and timing of concentration of carcasses before burial were relatively constant throughout the history of Ravina das Araras. The increasing availability and influence of water were the main factors behind the different patterns. Microvertebrate fossil assemblages are often a main source for paleoecological reconstruction, especially as data for faunal abundance estimates (Blob & Fiorillo, 1996). Taphonomists have proved either skeptical (*e.g.*, Dodson, 1973) or mildly optimistic (Eberth, 1990) regarding the usefulness and trustworthiness of microvertebrate assemblages for these ends. The Ravina das Araras assemblage shows that microvertebrate assemblages are highly susceptible to small environmental changes, and their taphonomic imprint is prone to loss and alteration. We therefore side with Dodson in believing that there is "[…] little ground for optimism' that the 'disarticulated remains of small animals' can be used for ecological studies" (Dodson, 1973).

Ravina do Leon

The Ravina do Leon assemblage is comprised mainly of isolated teeth, which account for more than 40% of the assemblage (Figure 3). Next come phalanges, osteoderms, and plastrons. These elements all rank as some of the most numerous in the skeleton (Korth, 1979; Andrews, 1990; Lyman, 1994b). These elements are also robust and highly resistant to destruction. Therefore, being common and resistant to destruction may be the most likely explanation for the observed pattern of bone representation. This is corroborated by the fact that the other numerically relevant elements are calcanei and podials. It is impossible to ascribe these surviving elements to any transport groups and, as observed above, their association is likely to result from both their original abundance and resistance to destruction.

The evidence supports the conclusion that Ravina do Leon was formed under highly destructive circumstances, allowing only the most numerous and most highly resistant to endure. Whether due to short-term conditions (*e.g.*, high-energy transport, boulder collapse) or long-term (*e.g.*, prolonged exposure, trampling, predation).

In terms of size class, Ravina do Leon is, same as Ravina das Araras, predominantly comprised of elements smaller than 5.0 cm (Figure 4). However, here the contribution of "macro" elements is considerably more relevant, reaching over 12.5% of the assemblage. The pattern of physical integrity for Ravina do Leon is similar to the one observed for the Ravina dos Araras as a whole (Figure 5), containing mostly fragmented material. In this case, incomplete elements make up a little over 65% of the assemblage. The pattern of element integrity for Ravina do Leon shows a predominance of fragmented material. This fragmented, dispersed assemblage indicates the absence of rapid burial after death (Hill, 1979; Hill & Behrensmeyer, 1984; Weigelt, 1989).

Ravina do Leon's breakage outline (Figure 6) pattern shows a predominance of the "curved" morphology, with over 60% of breaks. The breakage angle of type "right", which is predominant (approximately 60%; Figure 6), indicates breaks that occurred when the bone was already dry or mineralized (Villa & Mahieu, 1991), that is, not around or soon after death. However, analysis of breakage outline patterns indicates a predominance of fractures associated with green breaks. These two pieces of evidence point to a varied and complex history of accumulation and breakage in Ravina do Leon, with no simple pattern to account for observed phenomena.

Ravina do Leon weathering profile is unlike any of the layers of Ravina das Araras (Figure 7 and 8). The contribution of each stage diminishes gradually, starting at stage 0, the most abundant (around 45%). Then follow stage 1 (around 25%), stage 2 (20%), and finally stage 3 which, in keeping with the pattern for Ravina das Araras, contributes less than 10% to the assemblage. The pattern is interesting: starting from stage 0, the proportion of each stage diminishes in a stepwise fashion. This trend is indicative of a regular process, which tended to preserve less-weathered elements (Behrensmeyer, 1991; Lyman, 1994b). Weathering is a process that weakens an element's resistance to other destructive agents (Behrensmeyer, 1975; Fernandez-Jalvo & Andrews, 2016), meaning that a heavily weathered element is less likely to resist continued destructive conditions. The stepwise pattern observed in Ravina do Leon is what would be expected if continued, semi-regular, destructive agents and processes operated on elements of varied taphonomic history that were gradually added to the death assemblage.

The abrasion pattern is similar to what can be observed for the Ravina das Araras assemblages, with unabraded specimens (Figure 9) dominating the assemblage. The pattern is most similar to Layer A, with around 75% of elements lacking signs of abrasion, indicating mild influence of running water, wind, or trampling (Fernandez-Jalvo & Andrews, 2016). When water is suspected of being the primary agent behind abrasion, this does not necessarily entail long transportation distances (Fiorillo, 1988; Behrensmeyer, 1991). These points to an assemblage that formed under some influence of abrading processes.

The surface marks pattern (Figure 10) is most similar to Layer A of Ravina das Araras: pits and perforations are the most common skeletal surficial modification (around 30%). In Ravina do Leon, however, linear marks are decidedly less common, with less than 20% of elements displaying it.

The scarcity of trampling marks in Ravina do Leon indicates that trampling may not have had much influence on the abrasion of bones. Surficial marks indicate the amount, severity and timing of element modification under subaerial and non-definitive burial conditions (Fiorillo, 1988; Andrews, 1990; Behrensmeyer, 1991; Lyman, 1994b). Pits are the most common surficial modification in Ravina do Leon, but they are absent in most elements. Sedimentological evidence indicates that the area experienced accumulation through alternating dry and humid periods (Maia & Bezerra 2020; Martins, 2024). It is therefore likely that elements were gradually incorporated into the assemblage, with at least some experiencing considerable subaerial exposure before burial. The relative scarcity of alterations, in contrast to what might be anticipated (Behrensmeyer, 1991), suggests that heavily damaged elements may have undergone selective destruction before their final burial.

The elements that make up the bulk of Ravina do Leon assemblage are very common in the vertebrate body, robust and resistant to destruction (Korth, 1979; Andrews, 1990; Lyman, 1994b). The weathering profile indicates an assemblage that underwent continued and regular destructive activity on its elements. Both are consistent with taphocoenosis formed by the gradual addition of elements that were then subjected to destructive processes, making it very difficult for more weathered and modified elements to resist final destruction, biasing the assemblage towards common and robust elements. Breakage pattern indicates a varied history of accumulation, which would be expected in an assemblage derived from continuous modification on gradually accumulated elements, as is the relatively low, but not negligible, pattern of abrasion. If elements suffered such destructive pressure, we may have expected it to bear more extreme values of element modification, which is not the case in Ravina do Leon. However, given how bone modification is correlated with making elements weaker and more prone to destruction, the opposite is probably true: significantly altered remains may have been preferentially destroyed (Behrensmeyer, 1991; Lyman, 1994b). Given all the evidence, we conclude that Ravina do Leon is an assemblage derived from continuous attrition on accumulated material, which allowed only robust and common elements to survive final destruction. Santos *et al.* (2002b) proposed that these features may have been due to the ravines inability to retain larger stages during incipient stages of ravine formation. Our hypothesis holds that retention size was not the primary factor involved in the observed final pattern, but rather continued destructive pressure coupled with original proportion and robustness.

General remarks on the taphonomy of the ravine deposits

The last two decades have witnessed an increase in the number of works on vertebrate taphonomy dealing with assemblages from the Brazilian Intertropical Region (BIR; *sensu* Cartelle, 1999). This directly leads to an increase in the number of basic taphonomic data sets (Fiorillo & Eberth, 2004) available and allows researchers to venture into a comparative approach of inferences on the formation and characteristics of fossil assemblages, as well as their paleoecological possibilities.

The Lajedo de Soledade is unusual in the sense that its depositional environment is not as common in the BIR as caves and natural tanks, the two most common types of fossil sites in the Region (Santos *et al*., 2002a; Auler *et al*., 2006; Araújo-Júnior & Porpino, 2011; Araújo-Júnior *et al*., 2017; Silva *et al*., 2019; Trifilio *et al*., 2024).

Caves can be categorized biostratinomically as nonspecific, meaning that fossil concentrations found within them show no bias toward the size of the skeletal elements; these fossils may be found either in articulation or completely disarticulated and scattered; they can preserve both robust and fragile elements, which may or may not have been transported to their final burial sites. Additionally, these caves occur in environments associated with either low or high-energy events (Santos *et al*., 2002a; Auler *et al*., 2006; Silva *et al*., 2019; Silva, 2024; Trifilio *et al*., 2024). Caves vary tremendously in terms of morphology, geometry, isolation from the surface, climactic conditions, stability, water flow, lighting, and other factors (Shipman & Walker, 1980); Andrews, 1990; Behrensmeyer, 1991). This variability means that caves in the BIR do not show any specific biases and tendencies in terms of biostratinomy. They set themselves apart by occasionally yielding articulated, well-preserved specimens, as well as fragile elements (Silva *et al*., 2019; Silva, 2024; Trifilio *et al*., 2024). This is in direct contrast to both natural tank and Lajedo de Soledade, which preserve predominantly disarticulated elements, usually with a heightened degree of fragmentation (Santos *et al*., 2002a; Silva, 2008; Araújo-Júnior *et al*., 2013, 2015).

When element size is considered, the main contrast is between natural tanks, which tend to preserve larger specimens (*e.g.*, Araújo-Júnior *et al*., 2013), and the ravines of Lajedo de Soledade, which show a unimodal size distribution centered around elements smaller than 5.0 cm. Size is less often reported for studies of cave assemblages, but it is possible to infer that there is no consistent, systematic bias for size operating in caves (*e.g.*, Silva, 2024; Trifilio *et al*., 2024).

Similar to caves, the ravines of Lajedo de Soledade do not exclusively favor robust and common elements. While some assemblages exhibit a predominance of these elements, others do not follow this pattern. The natural tank deposits are, however, characterized by a predominance of robust elements (Santos *et al*., 2002a; Alves, 2007; Silva, 2008; Araújo-Júnior *et al*., 2013, 2015). This is in keeping with taphocoenoses that developed under high-energy conditions and a moderate to high degree of transport, as suggested by the characteristics of "natural tank deposits". In contrast, caves are influenced by a range of conditions and do not favor either high or low energy events. However, the ravines of Lajedo de Soledade predominantly formed under relatively low-energy conditions, resulting in elements that have experienced little to no transport.

Remarks on paleoecological potential of the Lajedo de Soledade fossil assemblages

One of the traditional roles of taphonomy is to offer insight into an assemblage's potential for further studies, especially in paleoecology (Efremov, 1940; Olson *et al*., 1980; Weigelt, 1989; Lyman, 1994b). Relatively few works on vertebrate taphonomy of the Brazilian Intertropical Region attempt to gauge the paleoecological potential of assemblages. Two exceptions are Araújo-Júnior *et al*. (2015) and Araújo-Júnior *et al*. (2013). In both papers, the authors express optimism regarding the assemblages paleoecological potential due to their inferred spatial and temporal fidelity.

We indicated above that the ravines of Lajedo de Soledade offer little hope in terms of their use for paleoecological reconstruction. Specifically, we infer that there is no indication that preservation of original species abundance is to be expected from such deposits. Not only are small elements more susceptible to destruction and transport, but their presence may owe more to predation habits than original proportion in the biocoenosis. The ravines may function as 'traps' (Andrews, 1990; Behrensmeyer, 1991) that preferentially retain elements and carcasses, but there is no reason to believe that biostratinomic processes and agents have not altered the composition and relative abundance of the biocoenosis.

CONCLUSIONS

The Ravina das Araras assemblage consists of three vertebrate fossil-bearing layers, which formed under conditions of increasing water availability. During its evolution, alternating dry and wet periods became more frequent, and these were the main controlling factors of the different patterns observed in its sediments.

From bottom (Layer A) to top (Layer C), the assemblages of Ravina das Araras increasingly display evidence for a predator-influenced concentration, varied taphonomic history, and the influence of water on the deposits. Our interpretation is that the assemblages, dominated by small elements, are highly susceptible to modification of their original composition by biostratinomic processes and agents. It is unlikely that the Ravina das Araras assemblage is the result of human activity given the lack of differential representativeness, direct and indirect marks of interaction, and size of specimens.

Ravina do Leon underwent continued destructive pressure on its accumulated elements, which resulted in a taphocoenosis consisting of the most common and robust elements of the vertebrate skeleton. The main controlling factors responsible for the characteristics of this concentration were the gradual removal of elements and preservation of elements correlated to their original proportion robustness.

In comparison with other fossil-bearing deposits of the Brazilian Intertropical Region, the Lajedo de Soledade assemblages show some similarities with caves, mainly in its variability in terms of robustness of preserved elements; they are also similar to natural tank deposit, in the sense that they preserve disarticulated and dispersed elements. They are, however, unique in their tendency to preferentially preserve microvertebrate specimens under predominantly low-energy conditions. The fossil concentrations of Lajedo de Soledade offer limited potential for paleoecological reconstruction, especially for estimates of relative abundance.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

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AUTHOR CONTRIBUTIONS

André Cidade-da-Silva: writing, initial draft; editing; research. Laís Alves-Silva, Hermínio Ismael de Araújo-Júnior, Rodolfo Dino, Kleberson de Oliveira Porpino: review, investigation, data curation. All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

DECLARATION OF AI USE

We have not used AI-assisted technologies to create, review, or any part of this article.

ETHICS

This work did not require ethical approval, collecting licenses, or previous authorizations.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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