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A POSSIBLE LUNGFISH BURROW IN THE UPPER CRETACEOUS ADAMANTINA FORMATION (BAURU BASIN, BRAZIL) AND ITS PALEOECOLOGICAL AND PALEOENVIRONMENTAL SIGNIFICANCE

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ABSTRACT – Vertebrates produce a variety of trace fossils, mostly tracks and trackways, coprolites, and burrows resulting from fossorial and subterranean habits. Burrows, particularly, tend to represent temporary or permanent shelter. Vertebrate burrows are relatively understudied in the Brazilian Mesozoic units, as well as in Cretaceous rocks worldwide. This study aims to analyze a paleoburrow in the Upper Cretaceous Adamantina Formation and to discuss its paleobiological and paleoenvironmental implications. A descriptive study was carried out on the paleoburrow morphology, following aspects such as orientation, architecture, and dimensions, and facies association analysis provided the interpretation of the paleoenvironment in which the tracemaker lived. The origin of the paleoburrow was highlighted, as well as the size of its possible producer, besides inferring the exposure time of the paleoburrow from taphonomic interpretations, which contains allochthonous bone remains. The results suggest long periods of dry conditions, as previously suggested for the much-debated Adamantina Formation, interrupted by flooding events as evidenced by facies analysis and suggested by the lungfish burrow. The possibility of a lungfish record also expands the presence of these animals to Adamantina Formation, even though more data are needed to understand the paleoecology of these formation.

Keywords: lungfish, paleoburrow, floodplain, Adamantina Formation.

RESUMO – Os vertebrados produzem uma variedade de traços fósseis vestigiais, na sua maioria pistas e caminhos de rolamento, coprólitos e tocas resultantes de hábitos fossoriais e subterrâneos. As paleotocas, particularmente, tendem a representar abrigo temporário ou permanente. As paleotocas de vertebrados são relativamente pouco estudadas nas unidades mesozoicas brasileiras, bem como nas rochas cretácicas de todo o mundo. Este estudo visa analisar o registro de uma paleotoca no Cretáceo Superior da Formação Adamantina e discutir as suas implicações paleobiológicas e paleoambientais. Foi realizado um estudo descritivo sobre a morfologia da paleotoca, seguindo aspectos como orientação, arquitetura, e dimensões, e a análise de associação de fácies forneceu a interpretação do paleoambiente em que o produtor viveu. Foi destacada a origem da paleotoca, bem como o tamanho do seu possível produtor, além de inferir o tempo de exposição da paleotoca a partir de interpretações tafonômicas, que contém restos ósseos alóctones. Os resultados sugerem longos períodos de condições secas, como sugerido anteriormente para a tão debatida Formação Adamantina, interrompida por eventos de inundação como evidenciado pela análise de fácies e sugerido pela toca do peixe pulmonado. A possibilidade de um registo de peixe pulmonado também expande a presença destes animais à Formação de Adamantina, embora sejam necessários mais dados para compreender a paleoecologia destas formações.

Palavras-chave: peixe pulmonado, paleotoca, planície de inundação, Formação Adamantina.

INTRODUCTION

The interactions between macroorganisms and sedimentary substrates produce different biogenic structures that are good indicators of paleoenvironmental conditions (*e.g.*, Pemberton & Frey, 1982; Bromley, 1990; Genise, 2004; Bromley & Heinberg, 2006; Melchor *et al.*, 2010; Buatois & Mángano, 2011, 2018; Sedorko *et al.*, 2020). Vertebrate trace fossils usually result from locomotion (tracks and trackways), excretion (coprolites), and fossorial habits (burrows) (Voorhies, 1975), providing relevant paleoecological and paleoenvironmental information (*e.g.*, Reichman & Smith, 1990; Groenewald *et al.*, 2001; Hasiotis *et al.*, 2004, 2007; Hembree, 2010; Dentzien-Dias & Figueiredo, 2015; Mukherjee *et al.*, 2017; Martinelli *et al.*, 2019).

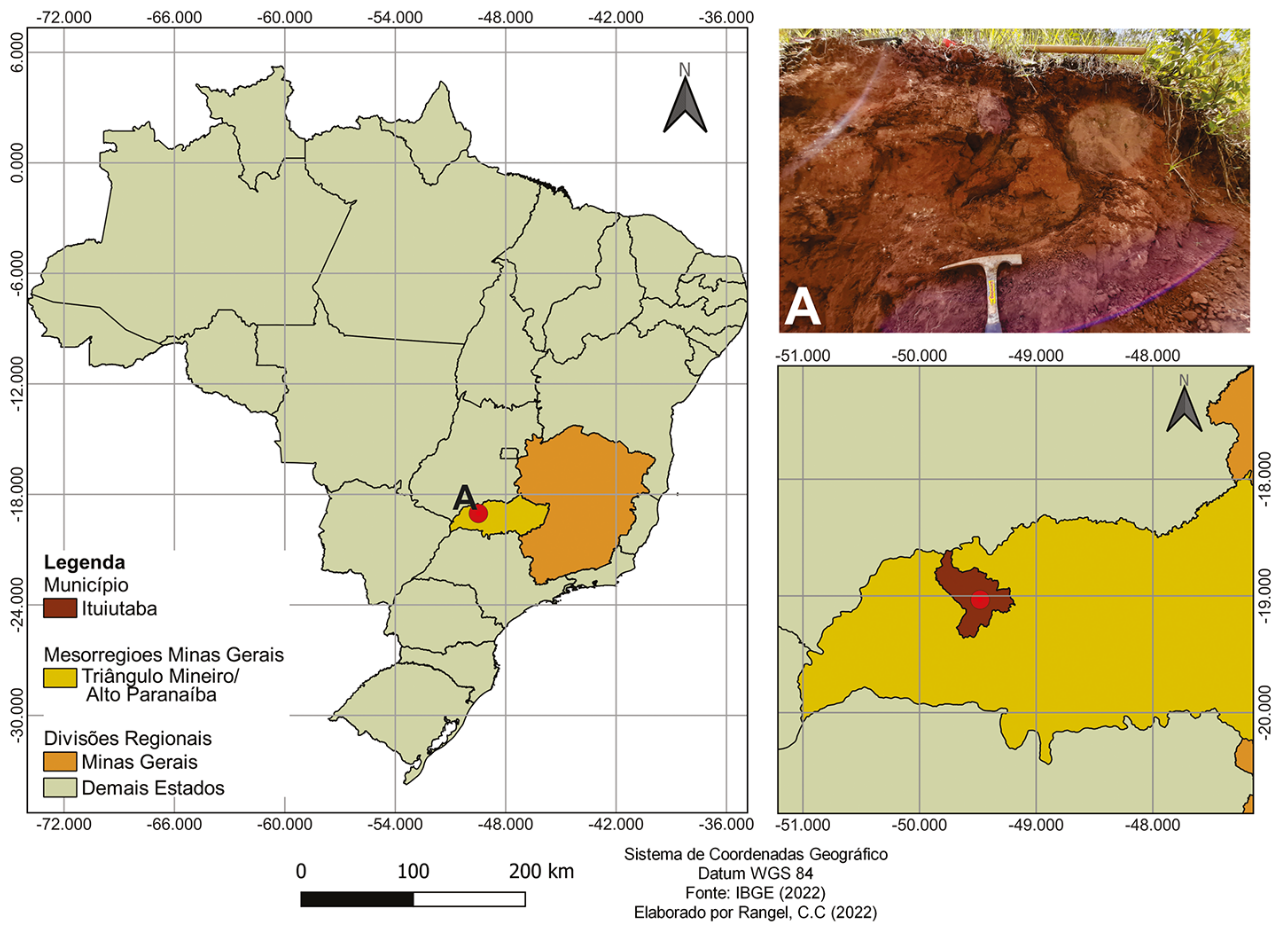
Paleoburrows are mostly associated with paleosol horizons, cross-cutting stratigraphic levels, and evidence specific zoological groups. These structures may provide a relative age for an ichnoassemblage due to their inferred producer and its stratigraphic relationships (Ponomarenko & Ponomarenko, 2019). Mammals are among the main present-day fossorial vertebrates, constructing complex burrows with several tunnels, branches, entrances, and chambers (Kinlaw, 1999). However, the fossil record is plenty of other examples of fossorial lineages: Paleozoic fishes and tetrapods (Hembree *et al.*, 2004; Francischini *et al.*, 2018); Permian–Triassic reptiles and synapsids (Modesto & Botha-Brink, 2010); Jurassic–Cretaceous ornithopod dinosaurs (Martin, 2009; Krumenacker *et al.*, 2019), synapsids (Dentzien-Dias *et al.*, 2008; Riese *et al.*, 2011), and possibly crocodylomorphs (Martinelli *et al.*, 2019).

Vertebrate burrows often represent temporary or permanent shelter for survival, reproduction and protection of cubs, and social organization (*e.g.*, Kinlaw, 1999; Varricchio *et al.*, 2007; Voigt *et al.*, 2011). These subterranean systems can reveal how the structure was dug, depending on the substrate in question, and when abandoned, they might become an empty space in the environment to be occupied or even be filled by one or more events (Kent & Snell, 1994; Kinlaw, 1999; Voigt *et al.*, 2011; Kinlaw & Grasmueck 2012; Cardonatto & Melchor, 2021).

Vertebrate burrows are relatively understudied in the Brazilian Mesozoic units, and in Cretaceous rocks worldwide. In Brazil, they occur in the Permian–Triassic Buena Vista Formation (formerly the "Piramboia Formation", Francischini *et al.*, 2018), the Norian Caturrita Formation (Silva & Dominato, 2010), the Upper Jurassic Guará Formation (Dentzien-Dias *et al.*, 2008), the Lower Cretaceous Botucatu Formation (Manes *et al.*, 2021), and in the Upper Cretaceous Marília and Adamantina formations (Martinelli *et al.*, 2019; Silva *et al.*, 2022). In other hand, Cretaceous burrows attributed to lungfishes are common worldwide (Surlyk *et al.*, 2008; Marshall & Rogers, 2012; Fanti *et al.*, 2016), associated to its aestivation behavior that generated chambers with variable morphologies. Lungfishes' fossils were previously reported for Bauru Group (Alves *et al.*, 2013, 2021). In this sense, this study aims to describe a new record of a paleoburrow in the Late Cretaceous deposits of the Adamantina Formation and to discuss its paleobiological and paleoenvironmental implications.

GEOLOGICAL SETTING

The intracratonic Bauru Basin (Campanian–Maastrichtian) covers an area of approximately 330,000 km² and was originated by flexural process related to the Alto Paranaíba Uplift event, after the fragmentation of the Gondwana (Fernandes, 1998; Batezelli, 2017). The basin filling can reach 300 m and records continental paleoenvironments that characterize the Bauru Group. The Araçatuba Formation represents the basal unit of the Bauru Group. It is composed of mudstones and very fine-grained sandstones, superimposed by the fine- to medium-grained sandstones from Adamantina and Uberaba formations. These strata are covered by fine- to coarse-grained, locally conglomeratic sandstones of the Marília Formation (Batezelli, 2017). The Adamantina, Uberaba and Marília formations were interpreted as distributive fluvial systems with a northeast source area and a basinward progradational pattern (Fernandes, 1998; Batezelli & Ladeira, 2016; Batezelli *et al.*, 2019). This study focuses on the Adamantina Formation (Turonian–Santonian) in the Ituiutaba municipality (Minas Gerais State, Figure 1), from where the paleoburrow described herein comes. A diversity of sauropod and few theropods dinosaurs, squamata, testudines, anurans, fish, and crocodylomorpha somatofossils have already been reported in the sedimentary beds of the Adamantine Formation. Crocodylomorpha is the highest



Sistema de Coordenadas Geográfico
Datum WGS 84
Fonte: IBGE (2022)
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Figure 1. The paleoburrow from Brazilian Mesozoic. The green star represents the found Cretaceous paleoburrow. **A**, the Serra do Corpo Seco Hill from the Municipality of Ituiutaba, Triângulo Mineiro region, Minas Gerais State.

diverse group in this unit, with about 20 taxa (see Matinelli & Teixeira, 2015, Darlim *et al*., 2021).

MATERIAL AND METHODS

The paleoburrow was found in the Serra do Corpo Seco (outcrop coordinates: 19º01’55.1”S 49º28’51.1”W), Ituiutaba Municipality, Minas Gerais State (SE Brazil). The lower part of this structure is oriented towards on the east side and the upper is perpendicular to the depositional plane. The three-dimensional paleoburrow morphology was accessed by successive excavations. Macroscopic observation, measurements with measuring tape and scale, photographs, and sketches were made during the fieldwork to carry out the paleoburrow description. The sediment fill was collected for textural characterization. The descriptive criteria followed Bordy *et al*. (2017) and Cardonatto & Melchor (2021).

The burrow was destroyed during this study, but its filling was collected. The measurements were taken on both burrow axis, the longest and shortest. Bone fragments were found inside the paleoburrow filling and are housed at the scientific collection of the Laboratório de Paleontologia Estratigráfica-LAPE/UFU, under the number V-0126 (Figure 2). The analysis of the taphonomic aspects of these fragments considered its weathering stage, following Behrensmeyer (1978). The sedimentologic description considered the rock texture, geometry, primary sedimentary structures, and fossil content (*e.g*., Reading, 1996).

RESULTS

Sedimentary facies

The sedimentary succession exposed in the study area comprises sandy to conglomerate beds (Figure 3), characterized as clast supported conglomerate (Cg), gravel to coarse-grained sandstone (Sg), and very fine- to fine grained sandstone (Sh) facies (see more in Table 1; Figures 4A–B). Most of the succession is represented by paleosols (facies P)

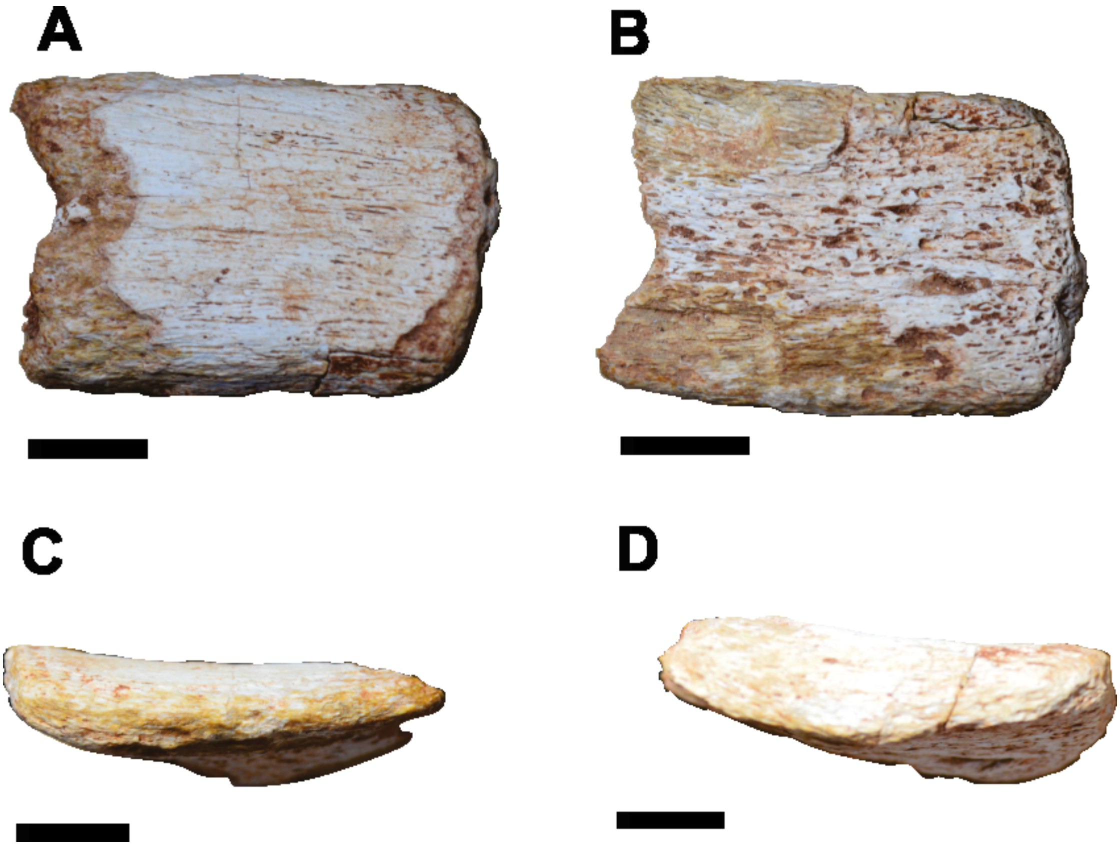

Figure 2. V-0126, a bone remain collected inside the paleoburrow. **A**, smooth surface view. **B**, trabecular surface view. **C–D**, weathered bone edge in lateral views.

Table 1. Sedimentary facies and architectural elements description.

Facies code	Description	Trace fossils	Architectural element
Cg	Clast supported conglomerate, polymictic, with pebbles up to 6 cm in finning upward trend	—	Channels (CH)
Sg	Gravel to coarse-grained sandstone with isolated pebbles in the matrix up to 5 cm in finning upward trend	—	Channels (CH)
Sh	Very fine- to fine grained sandstone with incipient horizontal stratification, locally with low angle cross-stratification	—	Amalgamated sandbars (SB)
Sm	Fine- to coarse-grained sandstone, massive, with carbonated cement, locally with carbonate nodules and irregular basal contact	Rhizoliths	Floodplain fines (OF)
P	Paleosoil with sandy composition and carbonated matrix, with block or massive structures	Rhizoliths, paleoburrow	Floodplain fines (OF)
Fm	Massive siltstone to poorly laminated mudstones	—	Floodplain fines (OF)

associated with sandstone and mudstone (Sm and Fm facies; Figures 4C–D; Table 1). The paleoburrow is preserved in a sandy matrix with pedogenetic signatures (facies P; Figure 4F), associated with rhizoliths mostly represented by root casts and rhizocretions (Figure 4E).

The presence of a channel filled by coarse-grained sediments (Cg, Sg, and Sh facies) interspersing facies with pedogenetic features (P, fine- to coarse-grained sandstone massive- Sm, and massive siltstone- Fm facies) suggests a "braided-like" fluvial system consisting of low sinuosity, amalgamated single-story channels (*e.g.*, Miall, 2016). The bedload-dominated transport eroded the floodplain deposits and resulted in conglomerates with finning-upward trends (McKie, 2011). The amalgamated sandbars represent migration along the floodplains generated by unconfined flows (Fielding *et al.*, 2011). The floodplain fines are associated with sandy-dominated floodplain deposits and subordinated fine-grained sediments. The presence of block structures,

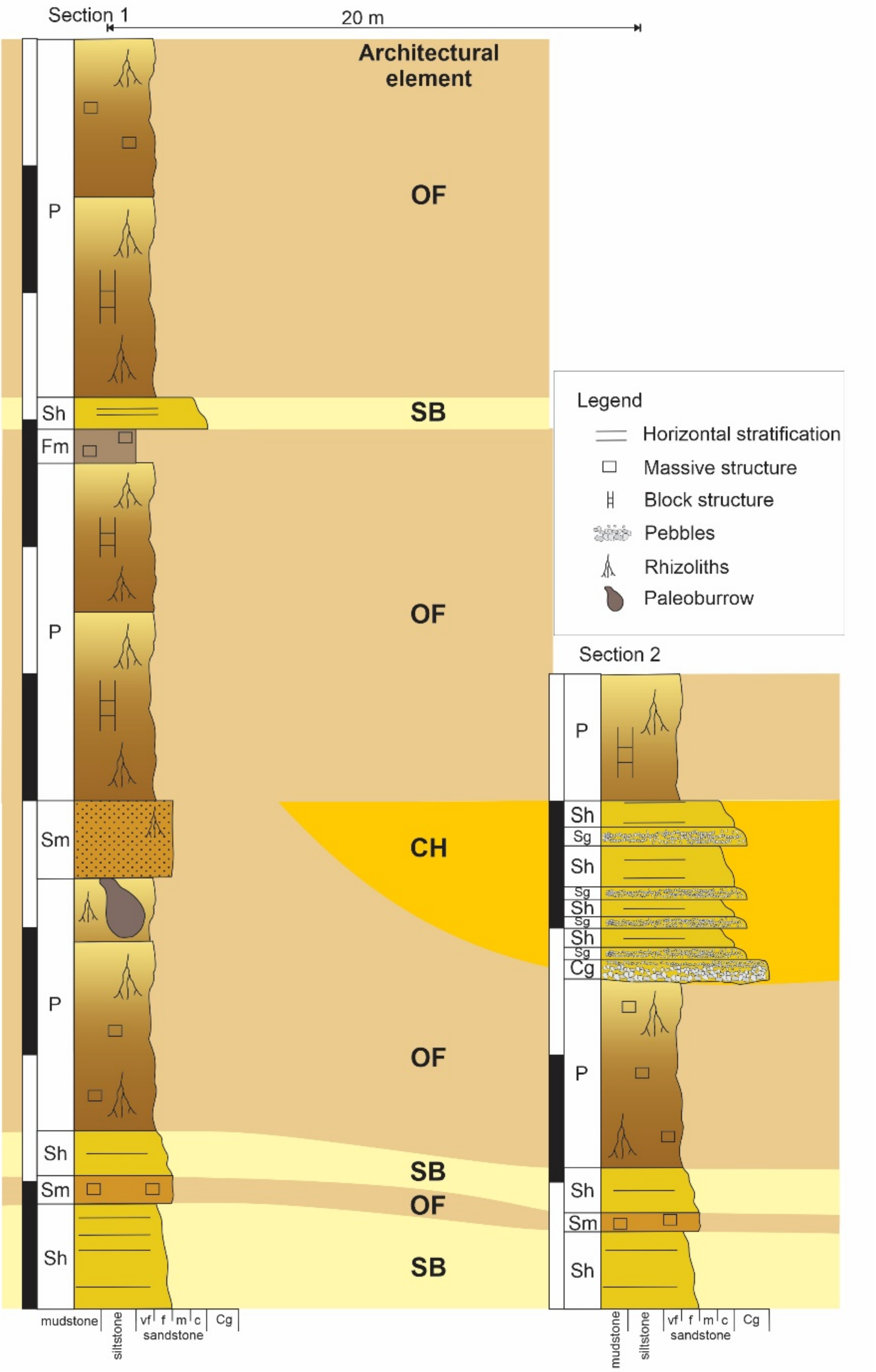

Figure 3. Measured columnar sections with the stratigraphic position of the paleoburrow. Scale bars are in meters.

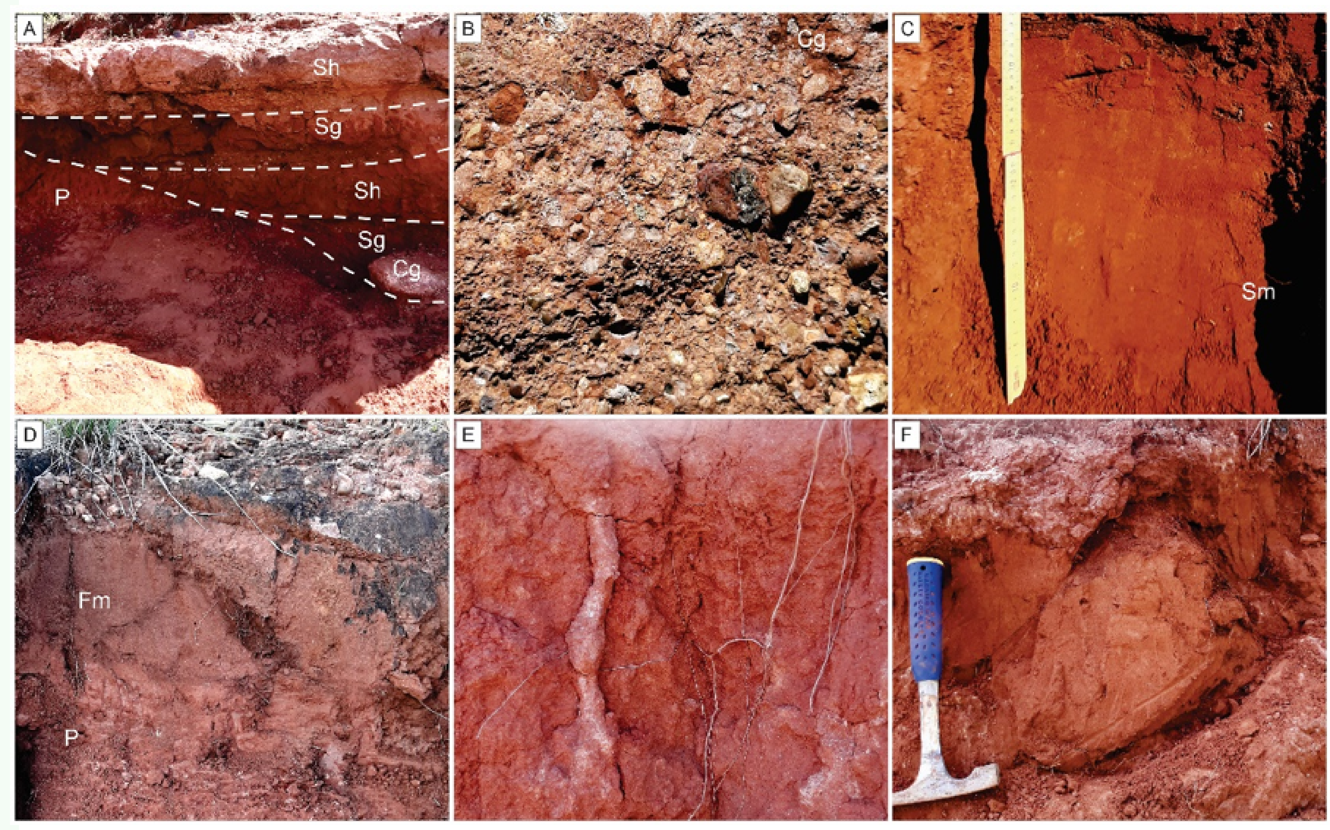

Figure 4. A, the facies are configured as Cg, Sg, and Sh facies, related to a channel filled by coarse-grained sediments and pedogenetic features facies as P, Sm, and Fm. **B**, clast-supported polymictic conglomerate. **C**, fine- to coarse-grained massive sandstone with carbonate cement, locally with carbonate nodules and irregular basal contact with rizoliths. **D**, massive siltstone to poorly laminated mudstone. **E**, rhizoliths represented by filled roots. **F**, the studied paleoburrow filled in by a sandy matrix with pedogenetic signatures.

rhizoliths, and the described paleoburrow are evidence of subaerial exposition (Hajek & Edmonds, 2014). The identified architectural elements (channels, amalgamated sandbars, and floodplain fines) are typical for Adamantina Formation (*e.g.*, Batezelli, 2017).

Burrow description

The burrow was exposed in a longitudinal section at the outcrop (Figure 4F). It presents a simple, flask morphology, with a narrow upper shaft connecting a lower, wider chamber. The paleoburrow is 35.39 cm deep and 32 cm wide in its widest axis, thus the depth/width ratio is 1.1. It has a subvertical orientation and a simple architecture, lacking adjacent chambers or branches. The burrow neck is almost perpendicular to the sediment layers, while the chamber is directed ~ 40°, with its final portion not very wide (Figures 5A–B). The contact between the burrow and the host rock is sharp, but lacks ornamentation (*e.g.*, claw- or tooth-made scratches). The burrow is passively filled by the sediments that compose the overlying bed (Sm facies). Additionally, scattered fragments of tetrapod bones were found within the filling, more precisely above the level in which the burrow reaches its wider diameter. The larger bioclast fragment is 4 cm long, 2.7 cm wide, and 0.9 cm thick (code LAPE-V-0126). The cracks parallel to the main axis in LAPE-V-0126 indicate the Weathering Stage 1 of Behrensmeyer (1978), while smaller fragments probably fall into advanced stages. No secondary bioturbation was found within the burrow filling.

DISCUSSION

On the origin of the structure

As presented in the results, the studied material is an incomplete burrow, showing a simple architecture, with a flask shape and a narrow upper shaft connecting a lower, wider expansion. The burrow lacks diagnostic features (such as the presence of surface ornamentation or bilobate floor (Cardonatto & Melchor, 2021) that allows recognizing a particular producer. Thus, phenetic and coincident correlations (following Carrano & Wilson, 2001) are necessary to tentatively infer a tracemaker among the vertebrate groups present in the Adamantina Formation (mainly crocodylians and dinosaurs) and the Late Cretaceous units of the Bauru Group, such as lungfishes and turtles (see Alves *et al.*, 2013, Martinelli & Teixeira, 2015; Silva *et al.*, 2022). Anurans, lepidosaurs, and mammals were excluded *a priori* from

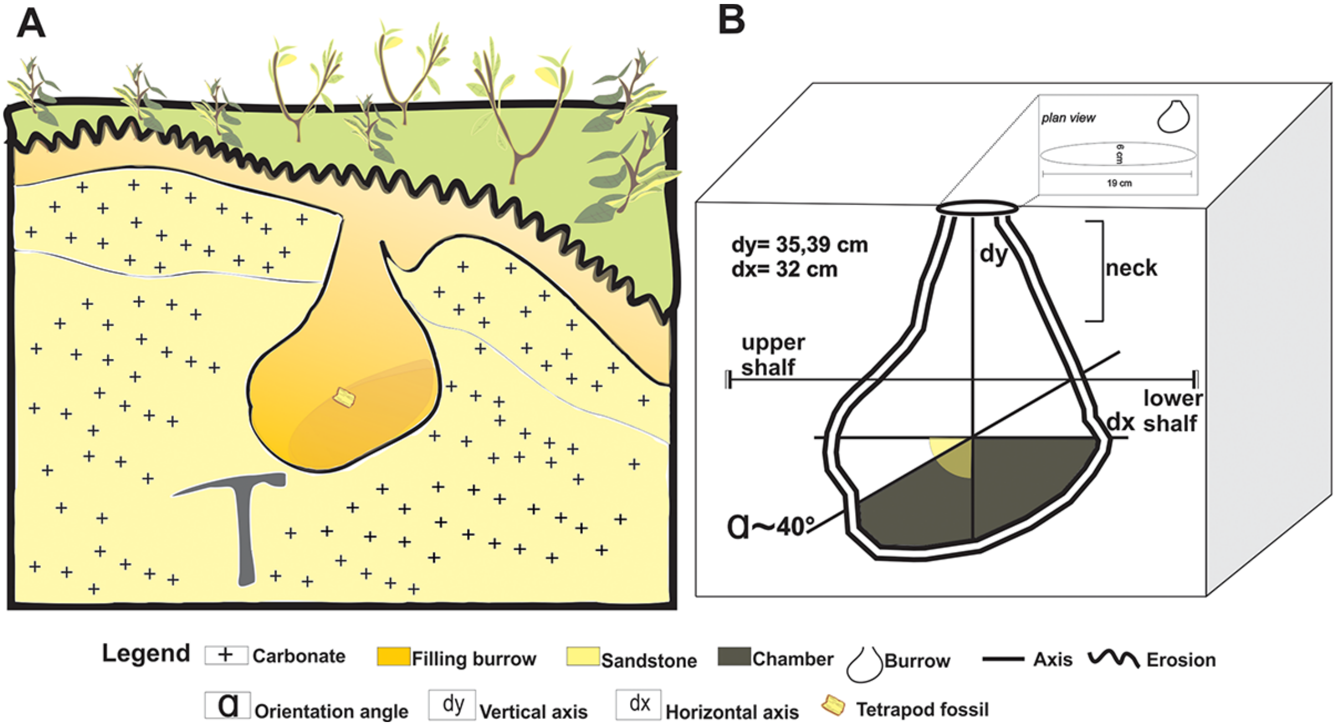

Figure 5. A, sketch of the paleoburrow found and demonstrating the delimitation of the structure, as well as the layers with carbonate nodules, with hammer as 13 cm scale. **B**, the measurements of the paleoburrow and its orientation angle.

the comparison due the lack of sufficient data regarding potential fossorial habits on the Bauru Group specimens, the controversial taxonomy of some materials, and on the fact that the species known from the Bauru Group are too small to fit the producer of the burrow described here.

The tetrapod burrow record is very scarce in Jurassic and Cretaceous deposits. Therefore, we compiled some information regarding the taxa present on the Marília and Adamantina formations, as well as in other Cretaceous units, to discuss the potential tracemakers. A diverse vertebrate fauna dominated by tetrapods has been described for the Adamantina Formation (see Martinelli *et al*., 2019). Among them, Mesoeucrocodylia is the most diverse group, comprising sphagesaurid, baurusuchid, and other notosuchian species. Martinelli *et al*. (2019) described a filled terminal burrow in the Campanian–Maastrichtian deposits of the Serra da Galga Formation (formerly Serra da Galga Member of the Marília Formation), assigning it to a tetrapod, possibly to an advanced notosuchian. This burrow is circa 86 cm longer than the one described herein and presents an expanded terminal chamber with an oblique floor (~30°), which is not observed in the described paleoburrow.

Even though these structures are likely different in architecture, both are relatively incomplete, hampering deeper comparisons. Other fossil crocodylomorph burrows are unknown so far, precluding a proper comparison. However, some potential fossorial species occur in the crocodylomorphs preserved in the Bauru Group (*e.g*., Marinho & Carvalho, 2009; Martinelli *et al*., 2019). Thus, they cannot be ruled out as potential producers of the described paleoburrow.

A simple and sinuous tunnel with a terminal chamber preserved in Cenomanian deposits in the USA was attributed to the euornithopod *Oryctodromeus cubicularis* due to skeletal remains preserved within the burrow filling (Varricchio *et al*., 2007; Fearon & Varricchio, 2016). Similar material was described from the Albian Otway Group of Australia (Martin, 2009). Despite the burrow architecture and the presence of skeletal remains in the burrow filling being comparable with the paleoburrow found in the Adamantina Formation, the morphology, orientation, and diameter of both burrows are not similar. Moreover, ornithischians were not found in the Adamantina Formation yet, and none of the dinosaur taxa known in this unit (sauropods and theropods) present osteological anatomy that suggest adaptation for deep excavation or fossorial life (Martinelli & Teixeira, 2015; Martinelli *et al*., 2019).

Silva *et al*. (2022) described several burrows from the Adamantina Formation in São Paulo State, assigning them to terrapins, mainly Podocnemididae. They differ from the burrow described herein by being simple tunnels, with flat floors, low inclination (22°) and lack of chambers or expansions (Silva *et al*., 2022).

Modern turtles can dig a wide range of burrow morphologies. The most striking example is the Gopher tortoise (*Gopherus polyphemus*) burrows, which comprise simple, unbranched tunnels, with a low-angle ramp (Kinlaw & Grasmueck, 2012), a distinct architecture from that described herein. Regarding modern turtle nests, they are actively filled by the female after the oviposition (also differing from our material) (Landers *et al*., 1980), and no exception for that is known from the fossil record so far. Based on these data, we also exclude turtles as the potential producers of the burrow found at Serra do Corpo Seco.

Lungfishes are known for producing vertical aestivation burrows since the Devonian (Hasiotis *et al*., 1993; Friedman & Daeschler, 2006; Gobetz & Andallanjlerner, 2006; Jones & Hasiotis, 2018). Although Paleozoic lungfish burrows show simple, nearly vertical, unbranched architectures and relatively smooth surficial morphologies, the Mesozoic and Cenozoic record often present terminal and wider chambers, where the individual remains coiled inside a mucous cocoon during aestivation period (Hasiotis *et al*., 1993, 2007). The aestivation burrows of modern lungfishes generally present vertical shafts and slight angle (Greenwood, 1986). Thus, due to the simple morphology, absence of ornamentation, passive filling, and preservation in a flooding plain close to the main channel, we tentatively attributed our burrow to a lungfish excavation.

In summary, the burrow described here present an ambiguous morphology, making it difficult to assign it to a precise tracemaker. Therefore, for the moment, we assign it to a lungfish, and exclude most of the vertebrate taxa known from the Adamantina Formation because of (i) their size (sauropod and theropod dinosaurs and some crocodilian taxa); and (ii) the lack of evidence based on corporal or ichnological/taphonomic data of the group (crocodilians and turtles). New discoveries on the region are necessary to attest this attribution. Besides the inaccurate assignment, it is important to notice that the material described here enlarges the knowledge on the scarce Cretaceous record of paleoburrows in continental settings.

Paleoenvironmental inferences

A vertebrate filled burrow can not only be associated to biological aspects of its producer, but also to the paleoenvironmental conditions in which it was produced and filled, being a very useful tool for paleoenvironmental and paleoecological interpretations. Some burrows can be produced by primary diggers, that are organisms that modify the excavation in secondary way, and the organism just dwelling the burrow (Kinlaw, 1999). These excavations can be made by claws, teeth, and horns of organism in action on substrate (Hopkins, 2005; Hasiotis *et al*., 2007; Becerra *et al*., 2013; Hildebrand, 2013). This burrow does not preserve excavation marks caused by claws, teeth, or horns on the inner wall, possibly due to excessive exposure of the structure to environmental conditions, a fact suggested by concretions in the surrounding host rock, showing an exposure time before and during the sediment deposition. The erosive contact influences the overall preservation of the paleoburrow, due to the impossibility of visualizing the continuity of the structure towards the surface or even into the host rock.

The open burrow worked as a trap for the deposition of sediments transported by energy flows of different intensities. The trap is configured by various ways of filling by sediments that vary according to flow velocities, sediment supply, dry or water-filled conditions, and initial placement and weight of fossil/bones or grains, resulting in homogeneous or stratified filling (Woodruff & Varricchio, 2011; Gallois, 2013; Mcloughlin *et al*., 2020). The fill flow previously carried the fossil fragments into the burrow. The presence of carbonate fills in some cracks and carbonate cement inside some burrows is used to establish further stratigraphic controls on their genesis (Jäger & Heinrich, 1975). These are closely associated with paleosol formation and, therefore, alter the microstructure and ancient edaphic zones (Sycheva *et al*., 2019). The krotovinas can be filled with ferromagnetic minerals, which are used to paleomagnetic measurements, such as clayey paleosol (Rico & Bidegain, 2013). These structures also indicate a significant biological activity, since it can be filled not only by sediments, but also by coprolite and the remains of other organisms (Pietsch, 2013; Popova, 2015; Barczi *et al*., 2020). Some digs serve as a natural source of habitat and heterogeneity for the ecosystem, altering the topography, the availability of nutrients for vegetation or even the habitat for aquatic organisms, such as what happens with the extant alligator holes in the region of the Everglades (Palmer & Mazzotti, 2004). Therefore, the capability of a krotovina or burrow to record temporal information or even condition small living environments for animals and plants is relevant, as evidenced in this outcrop, where nodules are found scattered throughout the area that borders the burrow or even the rhizotubules that meet its external wall, not entering the filled part, anchoring a plant on substrate.

Eventually, bone remains found inside a burrow can be associated to its probable producer. However, in our case, the bone remains found within the burrow filling are highly fragmented and somewhat weathered (Figure 6D), the larger bone presenting cracking lines parallel to its main axis (falling into the Weathering Stage 1 of Behrensmeyer, 1978), while the smaller fragments are millimetric and highly decayed. The fragments were found in the middle part of the chamber (Figures 6B–C) surrounded by the homogenous structureless reddish sandstone, indicating a passive burrow filling. The evidence for abrasion and weathering suggests that they had significant residence time outside the burrow previously to the transportation to within the burrow (at least 0–3 years, considering the Weathering Stage 1 of Behrensmeyer, 1978).

In general, bone remains found inside a burrow can be considered as belonging to its producer or occupant only if they are nearly complete, articulated or disarticulated, but with elements still closely associated (*e.g*., Smith, 1987; Groenewald *et al*., 2001; Damiani *et al*., 2003). Therefore, it is unlike that the bone fragments found inside the burrow belong to the producer and denotes an allochthonous origin. Thus, the burrow and the bones had a time of subaerial exposure, a fact suggested by the Behrensmayer stage, by the erosive contact, by the concretions in host rock and by the non-preservation of excavation marks on the inner wall of the paleoburrow. Paleoburrows help in the interpretation of paleosols, and geologic studies should focus on the linkage between trace fossils and paleosols, and how they can be used to interpret the paleoenvironmental parameters under which those paleosols were formed (Hasiotis & Halfen, 2010).

Figure 6. A-B, burrow chamber filled with massive sandstone. **C**, chamber delimitation. **D**, bone fragment found in the middle of the chamber.

Some burrows are passively filled, in the manner of sediment traps, simply by gravity-induced deposition; the fillings may be virtually identical to the host matrix or may be more akin to an overlying layer of sediment (Frey & Pemberton, 1985). The filling of the chamber is a continuation of the top layer; therefore, it exposes lithological composition and similar sedimentary structures, with no evidence of apparent carbonate concretions (Figures 6A–B).

In pedogenic calcretes, carbonate precipitation occurs mainly in the vadose zone above the water table, specifically in cavities in the host rock, similar to what occurs in underground calcretes (Alonso-Zarza *et al*., 2012). The water table level can be evidenced by burrows, which indicate a markedly ephemeral deposition at the central point of an active sedimentary basin, an important tool for the reconstruction of hydrological and climatic conditions (Voigt *et al*., 2011). Therefore, a pedogenic origin is suggested for these calcretes dispersed in the host rock, a phenomenon related to an arid or semi-arid environment (Figure 7). The formation of pedogenic calcretes maintains a close relationship with the vegetation of the area, indicated by the distribution of rhizohaloes and rhizocretions, and which typify the paleosol (Catena *et al*., 2017; Nascimento *et al*., 2021). Deep and abundant rhizohalos and red matrix indicate good drainage and low water table; yellow rizohaloes suggest relatively high soil moisture and organic matter content (Kraus & Hasiotis, 2006; Smith *et al*., 2008). The yellow rhizohaloes are seen on the host rock, visible 15–20 cm from the surface. Limestone rhizotubules are also seen, which are usually found in soils that undergo periodic drying (Kraus & Hasiotis, 2006).

CONCLUDING REMARKS

The paleoburrow reported herein is referred to a lungfish as a potential producer according to the evidence presented. This interpretation is supported by its simple architecture and sub-vertical orientation with expansion of a chamber at the end of the structure. Those results also evidence long periods of dry conditions, as previously suggested for the much-debated Adamantina Formation, interrupted by flooding events as suggested by facies analysis and the presence of a lungfish burrow.

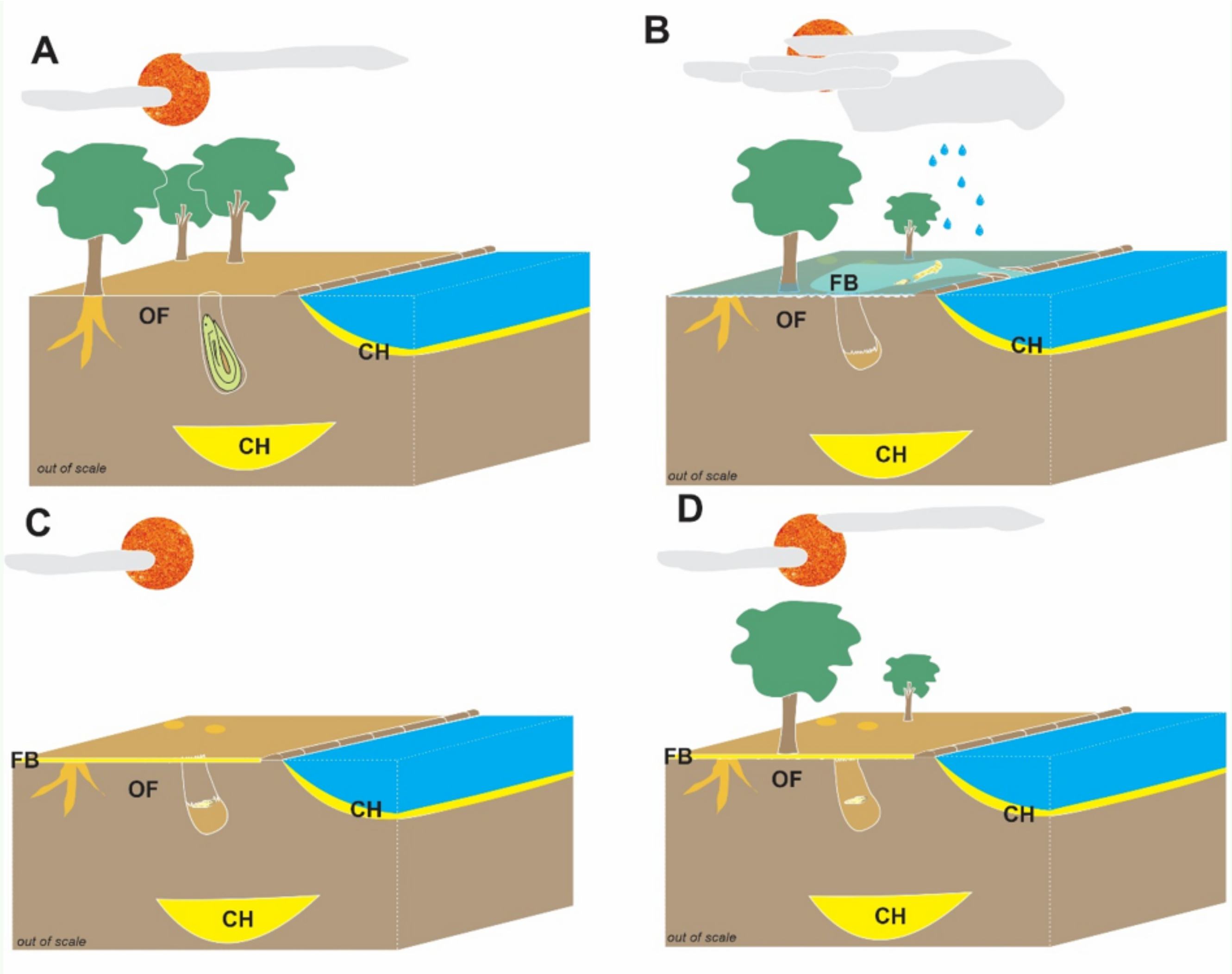

Figure 7. Palaeoenvironmental reconstruction based on paleoburrow, rizhotubules, and depositional model of Adamantina Formation deposits in Serra do Corpo Seco. **A**, construction of a burrow in a flooding plain (overbankfines; **OF**) close to the main channel (CH). **B**, flooding events and deposition of amalgamated sandbars (**SB**). **C**, dry periods and slow filling of the opened burrow. **D**, successive flooding events generating filling of the burrow.

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REFERENCES

Alonso-Zarza, A.M.; Meléndez, A.; Martín-García, R.; Herrero, M.J. & Martín-Pérez, A. 2012. Discriminating between tectonism and climate signatures in palustrine deposits: lessons from the Miocene of the Teruel Graben, NE Spain. *Earth-Science Reviews*, **113**:141–160. *doi:10.1016/j.earscirev.2012.03.011*

Alves, Y.M.; Machado, L.P.; Bergqvist, L.P. & Brito, P.M. 2013. Redescription of two lungfish (Sarcopterygii: Dipnoi) tooth plates from the late Cretaceous Bauru group, Brazil. *Cretaceous Research*, **40**:243–250. *doi:10.1016/j.cretres.2012.07.007*

Alves, Y.M.; Montefeltro, F.C. & Cidade, G.M. 2021. New occurrences of *Atractosteus* (Ginglymodi: Lepisosteoidea: Lepisosteidae) from the Bauru Group (Upper Cretaceous, Brazil) and paleobiogeographic implications. *Cretaceous Research*, **121**:104735. *doi:10.1016/j.cretres.2020.104735*

Barczi, A.; Szalai, D. & Nagy, V. 2020. Exploring soil compaction in the light of recultivation during temporary land use for alternative purposes in Hungary. *Annals of Faculty of Engineering Hunedoara-International Journal of Engineering*, **18**:159–168.

Batezelli, A. 2017. Continental systems tracts of the Brazilian Cretaceous Bauru Basin and their relationship with the tectonic and climatic evolution of South America. *Basin Research*, **29**:1–25. *doi:10.1111/bre.12128*

Batezelli, A. & Ladeira, F.S.B. 2016. Stratigraphic framework and evolution of the Cretaceous continental sequences of the Bauru, Sanfranciscana, and Parecis basins, Brazil. *Journal* *of South American Earth Sciences*, **65**:1–24. *doi:10.1016/j.jsames.2015.11.005*

Batezelli, A.; Ladeira, F.S.B.; Nascimento, D.L.D. & Da Silva, M.L. 2019. Facies and palaeosol analysis in a progradational distributive fluvial system from the Campanian–Maastrichtian Bauru Group, Brazil. *Sedimentology*, **66**:699–735. *doi:10.1111/sed.12507*

Becerra, F.; Casinos, A. & Vassallo, A.I. 2013. Biting performance and skull biomechanics of a chisel tooth digging rodent (*Ctenomys tuconax*; Caviomorpha; Octodontoidea). *Journal of Experimental Zoology Part A: Ecological Genetics and Physiology*, **319**:74–85. *doi:10.1002/jez.1770*

Behrensmeyer, A. 1978. Taphonomic and ecologic information from bone weathering. *Paleobiology*, **4**:150–162. *doi:10.1017/S0094837300005820*

Bordy, E.M.; Sciscio, L.; Abdala, F.; McPhee, B.W. & Choiniere, J.N. 2017. First Lower Jurassic vertebrate burrow from southern Africa (upper Elliot Formation, Karoo Basin, South Africa). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **468**:362–372. *doi:10.1016/j.palaeo.2016.12.024*

Bromley, R. 1990. *Trace Fossils: Biology and Taphonomy*. London, Unwyn Hyman, 310 p.

Bromley, R.G. & Heinberg, C. 2006. Attachment strategies of organisms on hard substrates: A palaeontological view. *Paleogeography, Paleoclimatology, Paleoecology*, **232**:429–453. *doi:10.1016/j.palaeo.2005.07.007*

Buatois, L.A. & Mángano, M.G. 2011. *Ichnology: Organism-Substrate Interactions in Space and Time*. Cambridge, Cambridge University Press, 370 p.

Buatois, L.A. & Mángano, M.G. 2018. The other biodiversity record: Innovations in animal-substrate interactions through geologic time. *GSA Today*, **28**:4–10. *doi:10.1130/GSATG371A.1*

Cardonatto, M.C. & Melchor, R.N. 2021. Tocas de Vertebrados Atuais e Fósseis. *In*: D. Sedorko & H. Francischini (eds) *Icnologia: interações entre organismos e substratos*, Editora CRV, p. 247–277.

Carrano, M.T. & Wilson, J.A. 2001. Taxon distributions and the tetrapod track record. *Paleobiology*, **27**:564–582. *doi:10.1666/0094-8373(2001)027<0564:TDATTT>2.0.CO;2*

Catena, A.M.; Hembree, D.I.; Saylor, B.Z.; Anaya, F. & Croft, D.A. 2017. Paleosol and ichnofossil evidence for significant Neotropical habitat variation during the late middle Miocene (Serravallian). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **487**:381–398. *doi:10.1016/j.palaeo.2017.09.024*

Damiani, R.; Modesto, S.; Yates, A. & Neveling, J. 2003. Earliest evidence of cynodont burrowing. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, **270**:1747–1751. *doi:10.1098/rspb.2003.2427*

Darlim, G.; Carvalho, I.S.; Tavares, S.A.S. & Langer, M.C. 2021. A new Pissarrachampsinae specimen from the Bauru Basin, Brazil, adds data to the understanding of the Baurusuchidae (Mesoeucrocodylia, Notosuchia) distribution in the Late Cretaceous of South America. *Cretaceous Research*, **128**:104969. *doi:10.1016/j.cretres.2021.104969*

Dentzien-Dias, P.C. & Figueiredo, A.E.Q. 2015. Burrow architecture and burrowing dynamics of *Ctenomys* in foredunes and paleoenvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **439**:166–175. *doi:10.1016/j.palaeo.2015.01.023*

Dentzien-Dias, P.C.; Schultz, C.L. & Bertoni-Machado, C. 2008. Taphonomy and paleoecology inferences of vertebrate ichnofossils from Guará Formation (Upper Jurassic), southern Brazil. *Journal of South American Earth Sciences*, **25**:196–202. *doi:10.1016/j.jsames.2007.08.008*

Fanti, F.; Conte, G.L.; Angelicola, L. & Cau, A. 2016. Why so many dipnoans? A multidisciplinary approach on the Lower Cretaceous lungfish record from Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **449**:255–265. *doi:10.1016/j.palaeo.2016.02.024*

Fearon, J.L. & Varricchio, D.J. 2016. Reconstruction of the forelimb musculature of the Cretaceous ornithopod dinosaur *Oryctodromeus cubicularis*: implications for digging. *Journal of Vertebrate Paleontology*, **36**:e1078341. *doi:10.1080/02724634.2016.1078341*

Fernandes, L.A. 1998. *Estratigrafia e evolução geológica da parte oriental da Bacia Bauru (Ks, Brasil)*. Instituto de Geociências, Universidade de São Paulo, São Paulo, Ph.D. Thesis, 216 p.

Fielding, C.R.; Allen, J.P.; Alexander, J.; Gibling, M.R.; Rygel, M.C. & Calder, J.H. 2011. Fluvial systems and their deposits in hot, seasonal semiarid and subhumid settings: modern and ancient examples. *In*: S.K. Davidson; S. Leleu & C.P. North (eds.) *From River to Rock Record: The preservation of fluvial sediments and their subsequent interpretation*, Society for Sedimentary Geology, p. 189–214. *doi:10.2110/sepmsp.097.089*

Francischini, H.; Dentzien-Dias, P.; Guerra-Sommer, M.; Menegat, R.; Santos, J.O.S.; Manfroi, J. & Schultz, C.L. 2018. A middle Permian (Roadian) lungfish aestivation burrow from the Rio do Rasto Formation (Paraná Basin, Brazil) and associated U-Pb dating. *Palaios*, **33**:69–84. *doi:10.2110/palo.2017.050*

Frey, R.W. & Pemberton, S.G. 1985. Biogenic structures in outcrops and cores. I. Approaches to ichnology. *Bulletin of Canadian Petroleum Geology*, **33**:72–115. *doi:10.35767/gscpgbull.33.1.072*

Friedman, M. & Daeschler, E.B. 2006. Late Devonian (Famennian) lungfishes from the Catskill formation of Pennsylvania, USA. *Palaeontology*, **49**:1167–1183. *doi:10.1111/j.1475-4983.2006.00594.x*

Gallois, R.W. 2013. Possible tetrapod burrows in the Mid Triassic Otter Sandstone Formation at Sidmouth, Devon, UK. *Geoscience in South-West England*, **13**:208–215.

Genise, J.F. 2004. Ichnotaxonomy and ichnostratigraphy of chambered trace fossils in palaeosols attributed to coleopterans, ants and termites. *Geological Society, London, Special Publications*, **228**:419–453. *doi:10.1144/GSL.SP.2004.228.01.19*

Gobetz, K.E. & Andallanjlerner, S.L. 2006. Lungfish burrows of varying morphology from the upper Triassic. *In*: J.D. Harris; S.G. Lucas; J.A. Speillman; M.G. Lockley; A.R.C. Milner & J.I. Kirkland (eds.) *The Triassic-Jurassic Terrestrial Transition*, New Mexico Museum of Natural History and Science Bulletin, vol. 37, p. 140–146.

Greenwood, P.H. 1986. The natural history of African lungfishes. *Journal of Morphology*, **190**:163–179. *doi:10.1002/jmor.1051900412*

Groenewald, G.H.; Welman, J. & MacEachern, J.A. 2001. Vertebrate burrow complexes from the Early Triassic *Cynognathus* Zone (Driekoppen Formation, Beaufort Group) of the Karoo Basin, South Africa. *Palaios*, **16**:148–160. *doi:10.1669/0883-1351(2001)016<0148:VBCFTE>2.0.CO;2*

Hajek, E.A. & Edmonds, D.A. 2014. Is river avulsion style controlled by floodplain morphodynamics? *Geology*, **42**:199–202. *doi.org/10.1130/G35045.1*

Hasiotis, S.T. & Halfen, A.F. 2010. The Story of O: The dominance of organisms as a soil-forming factor from an integrated geologic perspective and modern field and experimental studies. *In*:

R.J. Gilkes & N. Prakougpek (eds.) *Proceedings of the World Congress of Soil Science*, p. 100–103.

Hasiotis, S.T.; Mitchell, C.E. & Dubiel, R.F. 1993. Application of morphologic burrow interpretations to discern continental burrow architects: lungfish or crayfish? *Ichnos*, **2**:315–333. *doi:10.1080/10420949309380105*

Hasiotis, S.T.; Platt, B.F.; Hembree, D.I. & Everhart, M.J. 2007. The trace-fossil record of vertebrates. *In*: W. Miller III (ed.) *Trace fossils*, Elsevier, p. 196–218.

Hasiotis, S.T.; Wellner, R.W.; Martin, A.J. & Demko, T.M. 2004. Vertebrate burrows from Triassic and Jurassic continental deposits of North America and Antarctica: their paleoenvironmental and paleoecological significance. *Ichnos*, **11**:103–124. *doi:10.1080/10420940490428760*

Hembree, D.I. 2010. Aestivation in the fossil record: evidence from ichnology. *In*: C.A. Navas & J.E. Carvalho (eds.) *Aestivation: Molecular and Physiological Aspects*, Progress in Molecular and Subcellular Biology, p. 245–262.

Hembree, D.I.; Martin, L.D. & Hasiotis, S.T. 2004. Amphibian burrows and ephemeral ponds of the Lower Permian Speiser Shale, Kansas: evidence for seasonality in the midcontinent. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **203**:127–152. *doi:10.1016/S0031-0182(03)00664-3*

Hildebrand, M. 2013. Digging of quadrupeds. *In*: M. Hildebrand; D.M. Bramble; K.F. Liem & D.B. Wake (eds.) *Functional vertebrate morphology*, Harvard University Press, p. 89–109.

Hopkins, S.S.B. 2005. The evolution of fossoriality and the adaptive role of horns in the Mylagaulidae (Mammalia: Rodentia). *Proceedings of the Royal Society B: Biological Sciences*, **272**:1705–1713. *doi:10.1098/rspb.2005.3171*

Jäger, K.D. & Heinrich W. 1975. Altersbeziehungen zwischen Klüftung, Karbonatumsatz und fossilen Tierbauten im Aufschlußprofil Pisede bei Malchin. *Wissenschaftliche Zeitschrift der Humboldt-Universität zu Berlin: Mathematisch-Naturwissenschaftliche Reihe*, **24**:693–699.

Jones, M.F. & Hasiotis, S.T. 2018. Terrestrial behavior and trackway morphology of Neotropical bats. *Acta Chiropterologica*, **20**:229–250. *doi:10.3161/15081109ACC2018.20.1.018*

Kent, D.M. & Snell, E. 1994. Vertebrates associated with Gopher Tortoise burrow in Orange County, Florida. *Florida Field Naturalist*, **22**:8–10.

Kinlaw, A.L. 1999. A review of burrowing by semi-fossorial vertebrates in arid environments. *Journal of Arid Environments*, **41**:127–145. *doi:10.1006/jare.1998.0476*

Kinlaw, A. & Grasmueck, M. 2012. Evidence for and geomorphologic consequences of a reptilian ecosystem engineer: the burrowing cascade initiated by the gopher tortoise. *Geomorphology*, **157**:108–121. *doi:10.1016/j.geomorph.2011.06.030*

Kraus, M.J. & Hasiotis, S.T. 2006. Significance of different modes of rhizolith preservation to interpreting paleoenvironmental and paleohydrologic settings: examples from Paleogene paleosols, Bighorn Basin, Wyoming, USA. *Journal of Sedimentary Research*, **76**:633–646. *doi:10.2110/jsr.2006.052*

Krumenacker, D.J.; Varricchio, J.P.; Wilson, A. & Martin, A.F. 2019. Taphonomy of and new burrows from *Oryctodromeus cubicularis*, a burrowing neornithischian dinosaur, from the mid-Cretaceous (Albian-Cenomanian) of Idaho and Montana, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **530**:300–311. *doi:10.1016/j.palaeo.2019.05.047*

Landers, J.L.; Garner, J.A. & McRae, W.A. 1980. Reproduction of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. *Herpetologica*, **36**:353–361.

Manes, M.I.L.; da Silva, R.C. & Scheffler, S.M. 2021. Dinosaurs and rivers on the edge of a desert: A first recognition of fluvial deposits associated to the Botucatu Formation (Jurassic/Cretaceous), Brazil. *Journal of South American Earth Sciences*, **110**:103339. *doi:10.1016/j.jsames.2021.103339*

Marinho, T.S. & Carvalho, I.S. 2009. An armadillo-like sphagesaurid crocodyliform from the Late Cretaceous of Brazil. *Journal of South American Earth Sciences*, **27**:36–41. *doi:10.1016/j.jsames.2008.11.005*

Martin, A.J. 2009. Dinosaur burrows in the Otway Group (Albian) of Victoria, Australia, and their relation to Cretaceous polar environments. *Cretaceous Research*, **30**:1223–1237. *doi:10.1016/j.cretres.2009.06.003*

Marshall, M.S. & Rogers, R.R. 2012. Lungfish burrows from the upper Cretaceous Maevarano formation, Mahajanga Basin, northwestern Madagascar. *Palaios*, **27**:857–866. *doi:10.2110/palo.2012.p12-018r*

Martinelli, A.G. & Teixeira, V.P. 2015. The late Cretaceous vertebrate record from the Bauru group in the Triângulo Mineiro, southeastern Brazil. *Boletín Geológico y Minero*, **126**:129–158.

Martinelli, A.G. *et al.* 2019. Palaeoecological implications of an Upper Cretaceous tetrapod burrow (Bauru Basin; Peirópolis, Minas Gerais, Brazil). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **528**:147–159. *doi:10.1016/j.palaeo.2019.05.015*

McKie, T. 2011. Architecture and behavior of dryland fluvial reservoirs, Triassic Skagerrak Formation, Central North Sea. *In*: S.K. Davidson; S. Leleu & C.P. North (eds.) *From river to rock record: the preservation of fluvial sediments and their subsequent interpretation*, SEPM Society for Sedimentary Geology, p. 189–214.

McLoughlin, S.; Mays, C.; Vajda, V.; Bocking, M.; Frank, T.D. & Fielding, C.R. 2020. Dwelling in the dead zone–vertebrate burrows immediately succeeding the end-Permian extinction event in Australia. *Palaios*, **35**:342–357. *doi:10.2110/palo.2020.007*

Melchor, R.N.; Genise, J.F.; Farina, J.L.; Sánches, M.V.; Sarzetti, L. & Visconti, G. 2010. Large striated burrows from fluvial deposits of the Neogene Vinchina Formation, La Rioja, Argentina: A crab origin suggested by neoichnology and sedimentology. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **291**:400–418. *doi:10.1016/j.palaeo.2010.03.010*

Miall, A.D. 2016. Facies Models. *In*: A.D. Miall (ed.) *Stratigraphy: A Modern Synthesis*, Springer, p. 161–214.

Modesto, S.P. & Botha-Brink, J. 2010. A burrow cast with *Lystrosaurus* skeletal remains from the Lower Triassic of South Africa. *Palaios*, **25**:274–281. *doi:10.2110/palo.2009.p09-077r*

Mukherjee, A.; Pilakandy, R.; Kumara, H.N.; Manchi, S.S. & Bhupathy, S. 2017. Burrow characteristics and its importance in occupancy of burrow dwelling vertebrates in Semiarid area of Keoladeo National Park, Rajasthan, India. *Journal of Arid Environments*, **141**:7–15. *doi:10.1016/j.jaridenv.2017.02.003*

Nascimento, D.L.; Netto, R.G. & Indicatti, R. P. 2021. Neoichnology of mygalomorph spiders: Improving the recognition of spider burrows in the geological record. *Journal of South American Earth Sciences*, **108**:103178. *doi:10.1016/j.jsames.2021.103178*

Palmer, M.L. & Mazzotti, F.J. 2004. Structure of Everglades alligator holes. *Wetlands*, **24**:115–122. *doi:10.1672/0277-5212(2004)024[0115:SOEAH]2.0.CO;2*

Pemberton, G.S. & Frey, R.W. 1982. Trace Fossil Nomenclature and the *Planolites-Palaeophycus* Dilemma. *Journal of Paleontology*, **56**:1–39.

Pietsch, D. 2013. Krotovinas-soil archives of steppe landscape history. *Catena*, **104**:257–264. *doi:10.1016/j.catena.2012.12.003*

Ponomarenko, D. & Ponomarenko, E. 2019. Describing krotovinas: A contribution to methodology and interpretation. *Quaternary International*, **502**:238–245. *doi:10.1016/j.quaint.2018.05.037*

Popova, L.V. 2015. Small mammal fauna as an evidence of environmental dynamics in the Holocene of Ukrainian area. *Quaternary International*, **357**:82–92. *doi:10.1016/j.quaint.2014.08.044*

Reading, H.G. 1996. *Sedimentary Environments: Processes, Facies and Stratigraphy.* 3ª ed. Oxford, Blackwell Science, 688 p.

Reichman, O.J. & Smith, S.C. 1990. Burrows and burrowing behavior by mammals. *Current Mammalogy*, **2**:197–244.

Rico, Y. & Bidegain, J.C. 2013. Magnetostratigraphy and enviromental magnetism in a sedimentary sequence of Miramar, Buenos Aires, Argentina. *Quaternary International*, **317**:53–63. *doi:10.1016/j.quaint.2013.10.044*

Riese, D.J.; Hasiotis, S.T. & Odier, G.P. 2011. Synapsid burrows and associated trace fossils in the Lower Jurassic Navajo Sandstone, southeastern Utah, USA, indicates a diverse community living in a wet desert ecosystem. *Journal of Sedimentary Research*, **81**:299–325. *doi:10.2110/jsr.2011.25*

Sedorko, D.; Alessandretti, L.; Warren, L.V.; Verde, M.; Rangel, C.C.; Ramos, K.S. & Netto, R.G. 2020. Trace fossils from the Upper Cretaceous Capacete Formation, Sanfranciscana Basin, Central Brazil. *Annales Societatis Geologorum Poloniae*, **90**: 247–260. *doi:10.14241/asgp.2020.15*

Silva, G.T.G.; Nascimento, D.L.; Batezelli, A.; Ladeira, F.S.B. & Silva, M.L. 2022. Cretaceous (Maastrichtian) chelonian burrows preserved in floodplain deposits in the Bauru Basin of Brazil: evidence for fossorial origin of turtle shells. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **596**:110994. *doi:10.1016/j.palaeo.2022.110994*

Silva, R.C. & Dominato, V.H. 2010. Tetrapod burrow casts in floodplain deposits from Late Triassic of Southern Brazil. *In*: SIMPOSIO LATINO-AMERICANO DE ICNOLOGÍA, 1, 2010. *Libro de Resúmenes*, São Leopoldo, Universidade Vale do Rio dos Sinos, p. 30.

Smith, J.J.; Hasiotis, S.T.; Kraus, M.J. & Woody, D.T. 2008. *Naktodemasis bowni*: new ichnogenus and ichnospecies for adhesive meniscate burrows (AMB), and paleoenvironmental implications, Paleogene Willwood Formation, Bighorn Basin, Wyoming. *Journal of Paleontology*, **82**:267–278. *doi:10.1666/06-023.1*

Smith, R.M. 1987. Helical burrow casts of therapsid origin from the Beaufort Group (Permian) of South Africa. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **60**:155–169. *doi:10.1016/0031-0182(87)90030-7*

Surlyk, F.; Milàn, J. & Noe-Nygaard, N. 2008. Dinosaur tracks and possible lungfish aestivation burrows in a shallow coastal lake; lowermost Cretaceous, Bornholm, Denmark. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **267**:292–304. *doi:10.1016/j.palaeo.2008.07.004*

Sycheva, O.K.S.; Pushkina, P. & Ukrainsky, P. 2019. Interrelations of the Bryansk paleosol (end of MIS 3) with the Holocene surface soils in micro-depressions of the central forest-steppe within the Russian Upland. *Catena*, **172**:619–633. *doi:10.1016/j.catena.2018.09.021*

Varricchio D.J.; Martin A.J. & Katsura Y. 2007. First trace and body fossil evidence of a burrowing, denning dinosaur. *Proceedings of the Royal Society B: Biological Sciences*, **274**:1361–1368. *doi:10.1098/rspb.2006.0443*

Voigt, S.; Schneider, J.W.; Saber, H.; Hminna. A.; Lagnaoui, A.; Klein, H.; Brosig, A. & Fischer, J. 2011. Complex Tetrapod Burrows from Middle Triassic Red Beds of The Argana Basin (Western High Atlas, Morocco). *Palaios*, **24**:555–566. *doi:10.2110/palo.2011.p11-014r*

Voorhies M.R. 1975. Vertebrate Burrows. *In*: R.W. Frey (ed.) *The Study of Trace Fossils*, Springer, p. 325–350.

Woodruff, D.C. & Varricchio, D.J. 2011. Experimental modeling of a possible *Oryctodromeus cubicularis* (Dinosauria) burrow. *Palaios*, **26**:140–151. *doi:10.2110/palo.2010.p10-001r*

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