

STRATIGRAPHY, VERTEBRATE FAUNA AND ENVIRONMENTS OF THE UPPER CRETACEOUS OF THE NORTHWESTERN BAURU GROUP, BRAZIL WITH SOUTH AMERICAN PALEOBIOGEOGRAPHICAL IMPLICATIONS

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Resumo - as formações Adamantina e Marília são as únicas unidades do Grupo Bauru do Cretáceo Superior expostas na região sul do estado de Goiás na região central do Brasil. Elas são compostas por siltitos arenosos e arenitos cinzentos muito finos. Essas unidades registram a sedimentação lacustre que prevaleceu nos primeiros estágios da evolução do Grupo Bauru. Com base em dados de superfície, foi realizada uma análise estratigráfica regional para estabelecer a composição faunística e a distribuição paleogeográfica do ambiente deposicional que atuou na fase final de sedimentação da unidade geológica. Dada a escassez e o pouco conhecimento da fauna terrestre cretácea do norte do Grupo Bauru, essa porção do sul do estado de Goiás, no Brasil, apresenta grande potencial para fornecer novos dados paleontológicos. Isso contribuirá para o aumento do conhecimento e o refinamento das hipóteses biogeográficas da fauna de vertebrados que ajudam a explicar a distribuição de numerosos clados na América do Sul pós-Campaniana.

Palavras-chave: Grupo Bauru – Cretáceo Superior – Brasil Central – Implicações paleogeográficas.

Abstract - The Adamantina and Marília formations are the only units of the Upper Cretaceous Bauru Group exposed in the southern region of the state of Goiás, Central Brazil. They are made up of sandy siltstones and very fine gray sandstones. These units record the lacustrine sedimentation that prevailed in the first stages of Bauru Group evolution. Based on surface data, a regional stratigraphic analysis was carried out to establish the faunistic composition and paleogeographical distribution of the depositional environment that acted in the final phase of the geological unit sedimentation. Given the scarcity and little knowledge of the Cretaceous terrestrial fauna of the north of the Bauru Group, this portion of the southern state of Goiás in Brazil holds great promise for providing new paleontological data. This will contribute to increasing knowledge and refining biogeographic hypotheses of the vertebrate fauna that help to explain the distributions of numerous clades in post-Campanian South America.

Keywords: Bauru Group – Upper Cretaceous – Central Brazil – Paleogeographical implications

1. INTRODUCTION

The Bauru Group in the Paraná Basin, in the central region of Brazil, is spread over an area of nearly 230,000 km². It outcrops in the states of Goiás, Mato Grosso, Mato Grosso do Sul, Paraná and São Paulo (Soares et al. 1980). Much of the published data about this geological unit and its paleontological record come from the Triângulo Mineiro region and the western of São Paulo State (see Brusatte et al. 2017 for a review). In contrast, there are few studies regarding the Bauru Group in southern Goiás State, a region known as its western edge.

The Cretaceous rocks of southern Goiás State occur along an extensive SW-NE belt, delimited by the coordinates 10° – 12°S and 51° – 00°W. The first mention of Cretaceous beds from Goiás was made by Derby (1895) who described fossil bone fragments found in Mato Grosso State

and mentioned the rocks known today as the Bauru Group. The rocks of the Marília Formation in Goiás were interpreted as the result of the deposition of alluvial fans and of ephemeral lake systems (Barcelos 1984, Fulfaro et al. 1994, Batezelli 2003, Batezelli et al. 2006). Basilici et al. (2009) and Basilici & Dal' Bo (2010) reviewed these rocks and reinterpreted them as an ancient aeolian sand-sheet characterized by a cyclical vertical interchange of aeolian deposits and paleosols.

This paper provides a brief description of the Cretaceous continental units exposed in southern Goiás State, and discusses their main vertebrate faunal record, environments and potential paleontological exploration with paleobiogeographical correlation with other post-Campanian areas from South America.

2. STUDY AREA

In Goiás State, rocks of the Bauru Group are restricted to the southern portion, part of the northwestern portion of the Bauru sequence. In this region, a small area of the Santo Anastácio Formation is exposed — which is part of the Caiuá Group (Fernandes and Coimbra, 1994) — and the outcrops of the Adamantina and Marília (Barcelos 1984) formations are more expressive (Fig. 1), representing part of the Bauru Group

(Fernandes & Coimbra 1994). The Marília Formation in western São Paulo State was first described by Almeida & Barbosa (1953), Barcelos (1984) and, later, by Barcelos & Suguio (1987). These last authors studied the range of the Bauru Group units beyond São Paulo State and showed that this formation extended to southern Goiás State and northeastern Mato Grosso do Sul State.

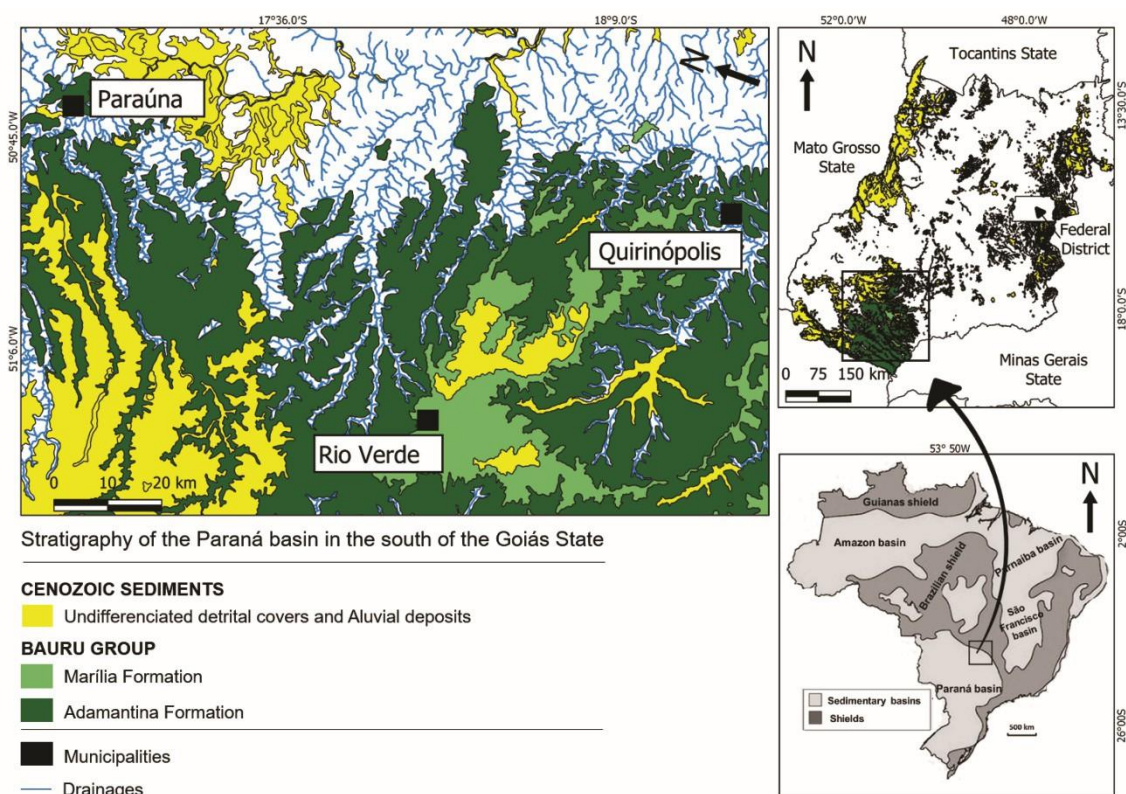


Fig. 1 Details of the study area. Location of the main vertebrate-bearing areas of the Bauru Group in southern Goiás State, Brazil (adapted from SIEG, 2023).

3. MATERIALS AND METHODS

Facies and association of facies are described following Mial (1996) and Arche (2000). The ages used here are based on studies published by Batezelli (2017) and are in accordance with the proposal of the Cretaceous Subcommittee of the International Commission on Stratigraphy (ICS). The Cretaceous terrestrial stratigraphic chart follows that given by Soares et al. (1980)

and Fernandes & Coimbra (1996). Brusatte et al. (2017) provides a review of the evidence for the ages of these units.

Vertical variation and the spatial relationship between fluvial and aeolian deposits in southern Goiás State were investigated by recording four vertical sections in a reconstruction.

4. PREVIOUS WORKS

4.1. Bauru Sequence

Soares et al. (1980) formalized the most accepted proposal for the lithostratigraphic arrangement of the Bauru Group, which was described from base to the top as: Caiuá, Santo Anastácio, Adamantina and Marília formations. Later, many

other interpretations were made by Fernandes & Coimbra (1996), namely: Caiuá Group - Santo Anastácio, Rio Paraná and Goio Erê; Bauru Group - Adamantina, Uberaba and Marília. Fúl-faro & Barcelos (1993) also suggested that the Caiuá Formation should be differentiated from the Bauru Group, alleging that this lithostrati-

graphic unit predates the deposition of the Bauru sequence as a different tectonic-sedimentary event, as reflected by its cratonic interior of the rift phase of the reactivation of the South Atlantic (Fernandes & Coimbra 1994, Barcelos et al. 1995, Brod et al. 2005).

4.2. Magmatic events in the northern region of southern Goiás State

During the Cretaceous, a period of extensive alkaline magmatism occurred at the borders of the Paraná Basin (Fig. 2) (Hasui & Haralyi 1991, Riccomini et al. 2005). This magmatism was associated with an extensional event named the Waldenian reactivation, which is considered as being the continental expression of the South Atlantic Ocean opening (Almeida 1983, 1986, Cesero & Ponte 1997, Ribeiro 2006). During its first stage (Lower Cretaceous), this event induced the formation of alkaline rocks coeval with the continental basalt flows of the Serra Geral Group (Rossetti et al. 2018). In the second stage, the Upper Cretaceous alkaline provinces were formed.

Through seismic data, Ribeiro et al. (2018) showed that the Cretaceous magmatism of the Paraná Basin borders is related to the Tristão da Cunha plume, which impacted the region during the Lower Cretaceous. These authors consider

that the alkaline rocks that formed at the borders of the basin during the Upper Cretaceous represent an extent of the Lower Cretaceous magmatism. These results were based on evidence that appeared with the expansion of the original study area, which comprises the Midwest region of Brazil. Assumpção et al. (2002) reinterpreted them and showed the existence of the Trindade plume under the Iporá region during the Upper Cretaceous, as previously proposed by Gibson et al. (1995a, 1997).

4.3. Goiás Alkaline Province

In southern Goiás State, near the municipality of Rio Verde, many alkaline bodies outcrop along an elongated area of approximately 250 km in length and 70 km in width (Fig. 2). The direction of this area to northeast to southwest corresponds with the occurrence of a basement faults trend. The main Precambrian structures related to the ascension of alkaline magma during the Upper Cretaceous are the Bom Jardim de Goiás arch, a regional anticlinal structure with an axis dip of S80W (Pena 1974); and the Transbrazilian Lineament, a fault system with a general NE direction (Schobbenhaus Filho et al. 1975). A rift tectonic setting affected the north-central portion of the region during the Upper Cretaceous (Almeida, 1983) and originated the Caiapó Graben.

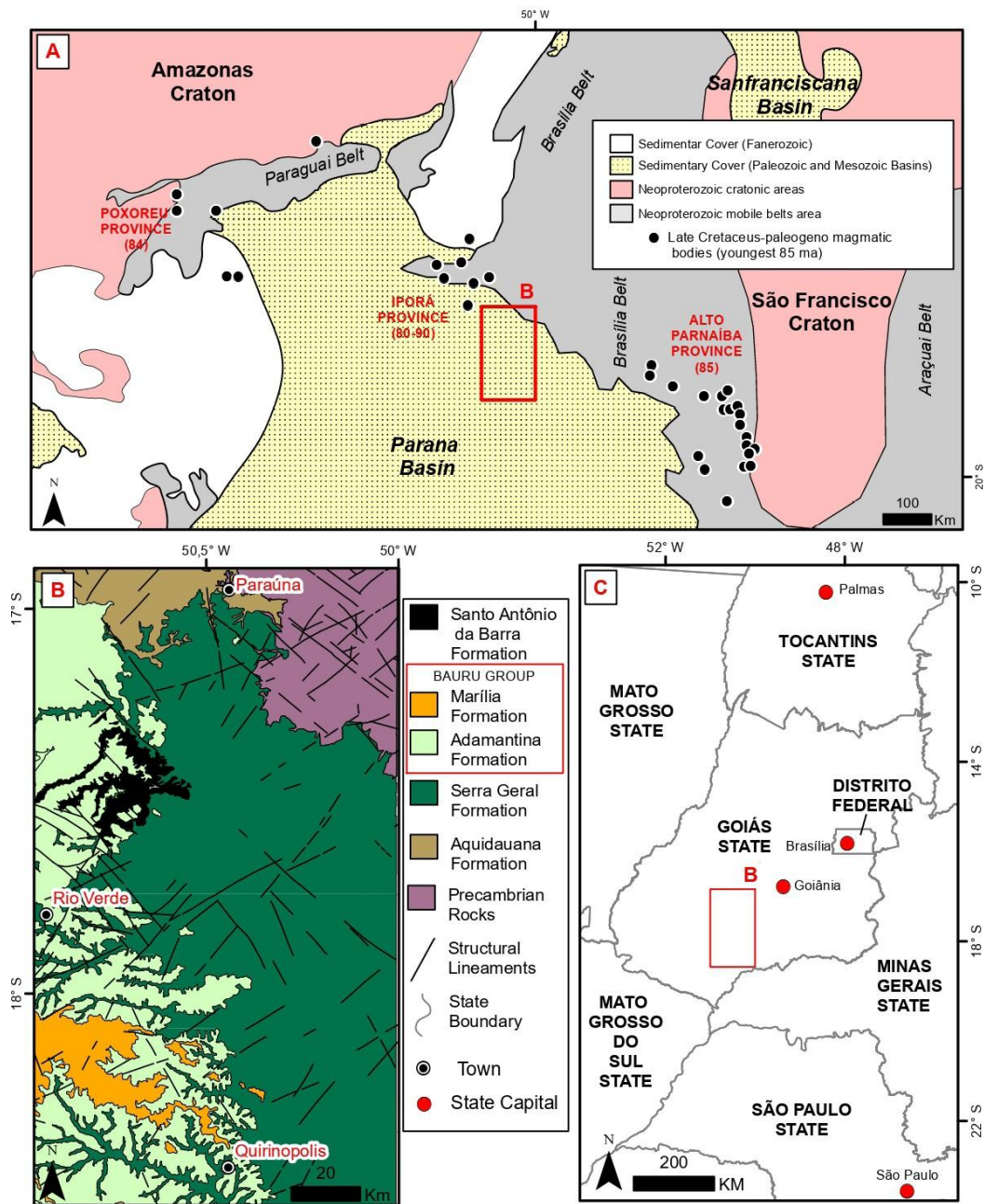


Fig. 2. Geological map of the main area of the Goiás Alkaline Province- GAP (adapted from Santos *et al.*, 2021).

The Cretaceous alkaline rocks from the northern portion (Fig. 2) were initially assigned by Guimarães et al. (1968) as the Iporá Group. Bez et al. (1971) added the volcanic alkaline rocks from Santo Antônio da Barra to this group, naming the set as the Rio Verde Volcanic District. In a more regional study, Almeida (1983) grouped the occurrences of alkaline rocks at the borders of the Paraná Basin in different provinces and named the rocks from Goiás State as the Rio Verde-Iporá Igneous Province. This proposal has since been widely used by many authors (e.g., Danni et al. 1992, Junqueira-Brod et al. 1999a,b,c, 2000a, b, Carlson et al. 2007). Yet Lacerda Filho et al. (2000) suggested the name Alkaline Province of Southern Goiás.

Sgarbi & Gaspar (2002) grouped the Alto Paranaíba and Rio Verde-Iporá Igneous provinces (Almeida 1983, Gibson et al. 1995a) under the name Minas-Goiás Alkaline Province and divided it into four subprovinces: Mata da Corda, Alto Paranaíba, Iporá and Santo Antônio da Barra. However, based on recent isotopic data returns to the former classification of two distinct provinces, retaining the former name Alto Paranaíba Igneous Province to designate the rocks that outcrop in western Minas Gerais State and close to the town of Catalão (Goiás State), and classifying the rocks from Iporá and Rio Verde as the Goiás Alkaline Province (GAP).

The Goiás Alkaline Province (*sensu* Lacerda Filho et al. 2000) occurs from the rocks of Santo Antônio da Barra, in the south, to the Santa Fé region, in the north (Fig. 2). This province has a large variety of petrographic types with volcanic, subvolcanic, and intrusive products. While there is a profusion of volcanic rocks in the southern

portion of the province, intrusive bodies are more abundant in the northern portion (Gaspar & Danni 1981, Danni & Gaspar 1992, Danni et al. 1992, Carlson et al. 2007). In southern Goiás State, the alkaline magma intrudes both Precambrian rocks and Phanerozoic sediments of the Paraná Basin. Complementarily, other area of interest in this work is the region of the Rio Verde hydrographic basin. It is located within the Parana Basin, in rock formations of the Bauru Group. Therefore, this region presents ages compatible with those of the Marília and Adamantina formations (see next section).

4.4. Geo- and thermochronologic ages

The Bauru Group (Bauru Basin) has provided one of the richest and most diverse assemblages of continental vertebrates from the Late Cretaceous of the Central Brazil. The ages of the formations in this group have been controversial. In general, their deposits are interpreted as post-Coniacian rocks based on stratigraphic, radiometric and paleontological data (e.g., Gobbo-Rodrigues et al. 1999a,b: Campanian-Maastrichtian/Fm. Adamantina-Araçatuba, Campanian/Fm. Uberaba and Maastrichtian/Fm. Marília; Dias-Brito et al. 2001: Turonian-Santonian /Fm. Adamantina, Coniacian-Santonian/Fm. Uberaba and Late Maastrichtian/Fm. Fm. Marília). Langer et al. (2022) carried out the most detailed study, compiling, integrating and suggesting ages for tetrapod faunas of Coniacian-Santonian (Araçatuba Formation), Campanian-Early Maastrichtian (Adamantina and Uberaba formations), and Maastrichtian (Marília Formation). The stratigraphic and chronostratigraphic arrangement proposed by Batezelli (2017) and Langer et al. (2022) are used here.

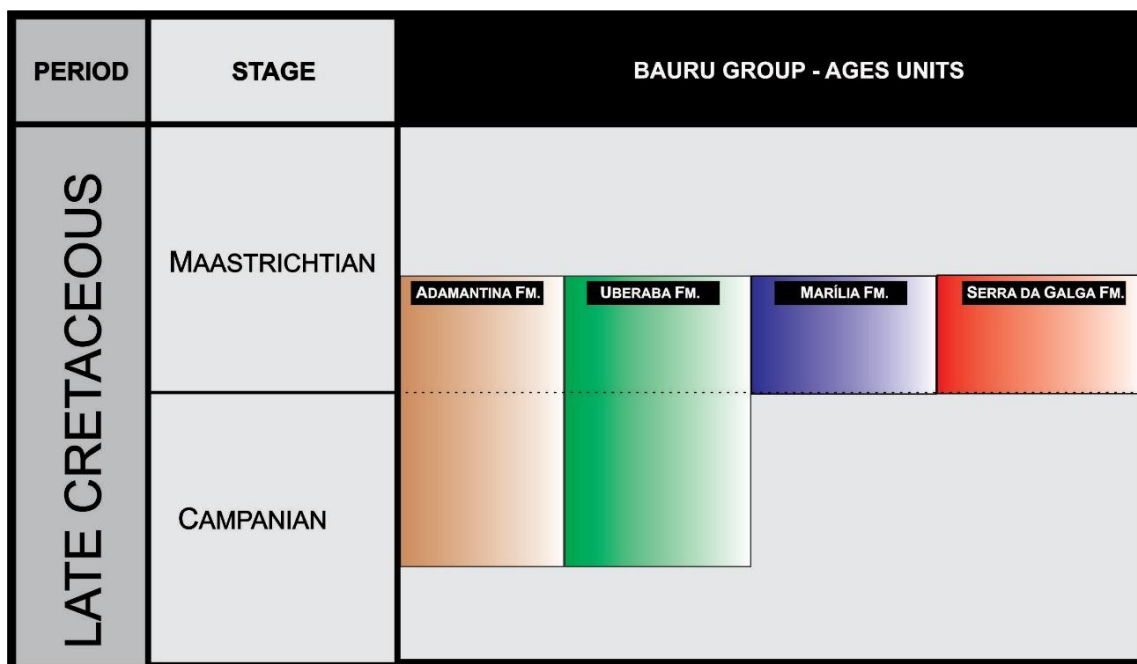


Fig. 3. Geological and geochronological chart of the Bauru Group in southern Goiás State, Brazil (adapted from Batezelli, 2017 and Langer *et al.*, 2022).

Absolute dating techniques using Fission Track Thermochronology- FTT and U-Pb were applied to zircons from Adamantina and Marília formations. The results reported by Dias *et al.* (2018) present a U-Pb age in zircons of 90 ± 22 Ma from samples of the upper Adamantina Formation. FTT dating in zircons of the Adamantina and Marília (and Uberaba) formations, indicate a significant set of dates around Turonian-Santonian ages (Dias *et al.* 2021) — also see Santos *et al.* (2020). These results agree with the ages presented by Menegazzo *et al.* (2016), who report a study associated with other researchers (Hasui & Haralyi 1991, Brod *et al.* 2005, Riccomini *et al.* 2005) indicating latest Late Cretaceous

Regarding Goiás Alkaline Province, Dutra *et al.* (2012) report that published radiometric ages for some of the complexes set them at ages of 75–90 Ma. Earlier, Carlson *et al.* (2007) set an age range of 80–85 Ma. Specifically, K-Ar ages from the Santa Fé complex give an age range of 76–80 Ma. In the Montes Claros area, in Goiás State, the samples present an age range of 89–94 Ma (Sonoki & Garda, 1988). The age range of 83–53 Ma for the Iporá Complex is larger than those for the other complexes (Sonoki & Garda 1988). Some data published by Carlson *et al.* (2007) show whole-rock ages from Santo Antônio da Barra that reach 26 Ma, although these data are inconclusive. Thus, we agree with Dutra *et al.* (2012) that, based on published ages, we can consider GAP to be from the Late Cretaceous.

5. RESULTS

5.1. The Bauru Group in southern Goiás State

The strata of the Bauru Group irregularly outcrop in southern Goiás State. Their northern limit is located at the municipalities of Jataí and Amarinópolis, and their east limit is the Paranaíba river. The most representative outcrops are present in the municipality of Caçu and, mainly, in Quirinópolis municipality, where the rocks are positioned over the Lower Cretaceous basalts of the Serra Geral Formation (São Bento Group, Paraná Basin). The thickness of the Bauru Group here is *circa* 100 meters (Barcelos 1982).

In the studied area a positive relief, sometimes of hills, is formed by the Marília Formation while the lowland areas were mapped and assigned to the Adamantina Formation. The outcrops of the Marília Formation are residual and composed of coarse sandstone facies with successive levels of conglomerates, being interbedded with pelites facies in the outcrops of Quirinópolis. The clastic lithology and architectural elements composed by conglomerates, sands and pelites indicate a subaqueous deposition.

Towards the municipality of Rio Verde, the rocks of the Marília Formation stratigraphically transgress the underlying column. The basalts of the Serra Geral Formation (Lower Cretaceous) — its diffuse substrate — are gradually replaced by older rocks of the Paraná Basin, such as the rocks of the Botucatu and Pirambóia (Jurassic) formations and the Passa Dois Group (Permian).

Towards the Iporá region the Marília Formation transgresses the rocks of the Aquidauana Group (Permian-Carboniferous).

The depositional architecture of the Bauru Group in southern Goiás State has basal layers composed of laminated deposits intercalated with laminitic beds, which represent paleolakes and distal floodplain facies. Therefore, the Bauru sequence during the Upper Cretaceous was regionally controlled by these regional basal layers, indicating a possible endorheism. In southern Goiás State, the Marília Formation shows lagoonal features similar to those present in other regions such as Triângulo Mineiro and western São Paulo State.

5.2. Geosite Serra da Portaria – Paraúna (Adamantina Formation)

Description

In this outcrop, fine massive sandstone (Sm) outcrop as a slab (Fig. 4). In this facies the sedimentary mechanic structures are absent and only are present, on the top, hexagonal desiccation cracks.

Interpretation

The Sm facies may also produce by postdepositional modification, for example, by dewatering and bioturbation. These fine sandstones are well cemented with presence of hematites that give a reddish color as cement.



Fig. 4. Stratigraphic profile (A) and locality (B) for the Adamantina Formation (Bauru Group), exposed at Parque Estadual de Paraúna, southern Goiás State.

5.3. Quirinópolis urban area (Adamantina Formation)

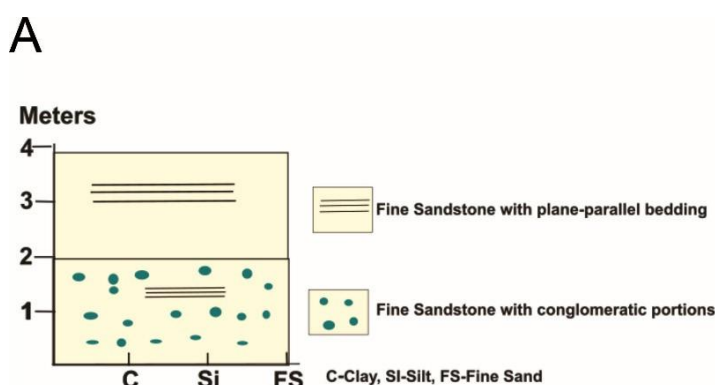
Description

The outcrop has a predominance of horizontally bedded very fine sandstone facies (Sh), which sometimes show low angle cross bedding (Fig. 5). The sandstone presents intercalations of clast-su-

ported gravel (Gh facies) cemented by calcium carbonate. The conglomeratic portions present well-rounded quartz pebbles and clay intraclasts.

Interpretation

The low angle cross bedding is interpreted as an accretion lateral architectural element (LA), which suggests meandering fluvial systems (Miall 1996: 155).



B



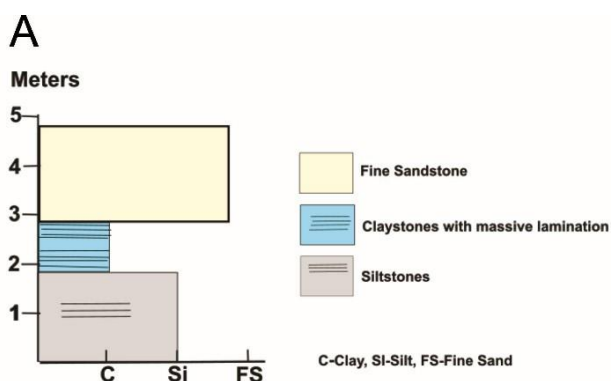
Fig. 5. (A) Stratigraphical profile of urban outcrop; (B) urban outcrop of Adamantina Formation in the municipality of Quirinópolis, southern Goiás State.

5.4. Morro da Antena rural outcrop in Quirinópolis municipality (Marília Formation)

Description

Fine-grained deposits, mainly claystones, siltstones and fine sandstones, form tabular to cuneiform bodies up to 8 m thick and are laterally extensive and intercalated between dune units (fine-grained sandstones with cross bedding)

(Fig. 6). Internally, these units are characterized by massive to laminated claystones from 4 to 22 cm thick and siltstones with abundant rootlets and desiccation cracks. In addition, there are beds from 2 to 17 cm thick, composed of laminated claystones interspersed with fine sandstones, mainly massive or with asymmetrical subcritical climbing ripples. A very striking feature of these deposits is that both the upper and lower contacts are non-erosive abrupt.



B



Fig. 6. (A) stratigraphical profile of Morro da Antena outcrop of the Marília Formation; (B) locality of Morro da Antena

in rural area of the municipality of Quirinópolis, southern Goiás State.

Interpretation

The most expressive level that is located above the layers of pellets constitutes sandstone bodies of approximately 1.8 meters thick showing, from base to top: fine to medium tabular sandstones and fine sandstones with subcritical climbing ripples interspersed with laminated claystones (Fig. 6). In this layer of sandstone occurs tabular fine sandstone with frequent ripple marks and horizontal bedding, which can be interpreted as non-confined flood records. Mud cracks occur on the fine-grained deposits indicating periodic dissection of these areas.

5.5. Pedreira Riocal outcrop in the municipality of Rio Verde (Marília Formation)

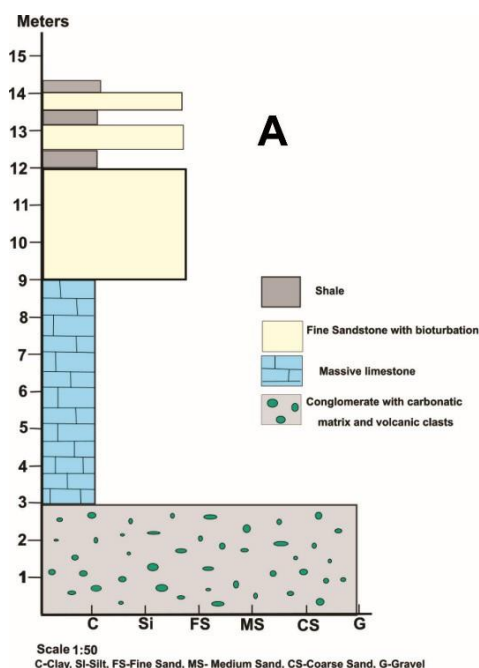
Description

In the Riocal section, the Late Cretaceous se-

quences (total thickness of 16 meters) can be lithologically subdivided into three parts from bottom to top (Fig. 7): (1) 3-meter-thick interval of mixed carbonate-volcanoclastic rocks and white sandy siltstones; (2) 6-meter-thick package consisting of thick, massive-bodied limestones; and (3) 5-meter interval of fine sandstone with thick beds, bioturbated and fractured with shale interbedded in the upper part.

Interpretation

The purer limestone found in the Pedreira Riocal area may have formed within ephemeral playa lakes under a semi-arid climate. This limestone is associated with hardpan calcretes with a total thickness of around 16 m. Except for this occurrence, there is no limestone lacustrine within the Marília Formation. Instead, practically the entire thickness of the Marília Formation can be classified as calcified soils or nodular calcretes.



B



Fig. 7. (A) profile of Morro da Antena outcrop Riocal Quarry of the Marília Formation; (B) Riocal Quarry in the municipality of Rio Verde, southern Goiás State.

5.6. Stratigraphy and paleoenvironments

Records of Cretaceous fossils from the Bauru Group (Paraná Basin) in Goiás are restricted to two geological formations in the southern region of the state — the Adamantina and Marília formations. The fossils from the Adamantina Formation come from the urban area of Quirinópolis and Paraúna municipalities. The thickness of the stratigraphic succession in different localities is variable, although it normally exceeds four meters. The facies bearing the fossils are attributed to fluvial deposits of high to moderate sinuosity with abundant floodplain and sedimentation facies with shallow fluvial-lacustrine deposits (Candeiro et al. 2018, 2020a).

The Adamantina Formation has provided an unprecedented paleontological record in recent years for Goiás State. Among invertebrates, ostracods are represented by the species *Viviparus souzai* Mezzalana, 1974, a taxon also reported from the Turonian-Santonian of São Paulo State. Among vertebrates, undetermined remains of species, including dinosaur-like titanosaurs, have been reported from the Quirinópolis region (Candeiro et al. 2018; 2020, 2022). Among theropod dinosaurs, only isolated teeth have been described from an isolated area in Paraúna (Candeiro et al. 2020b, 2022); remains of cranial and post-cranial bones were also observed in

this area. Additionally, a tooth of a possible large mesoeucrocodylian, Sphagesauria was reported from this Paraúna site (Candeiro et al. 2023).

Paleoenvironment of Adamantina Formation. In southern Goiás State was characterized by Barcelos (1984) as deposits of fluvial systems of low sinuosity of the interlaced sandy and stony sand types. This interpretation mainly includes the deposits of what is here called the upper section. The lower section shows patterns in the conformation of their sedimentary bodies that would correspond to more sinuous river channel systems. In this sense, the descriptions made by Barcelos (1984), Suguio and Barcelos (1983), and Barcelos & Suguio (1987) for the deposits corresponding to these levels in the Quirinópolis area, were interpreted by these authors as sinuous fluvial systems with a muddy load.

Therefore, we consider that the depositional system was aqueous though ephemeral, with the development of fluvial deposits during periods of rain, being a mix of alluvial fans and rivers formed from these fans, with braided dominance, i.e., with a greater coarse sedimentary load, and may also present slightly more meandering characteristics, with a finer sedimentary load, in its more distal portions (Fig. 8). The alluvial fans were formed due to active tectonics during the formation of GAP, which supplied volcanoclastic sediments to the geological unit.

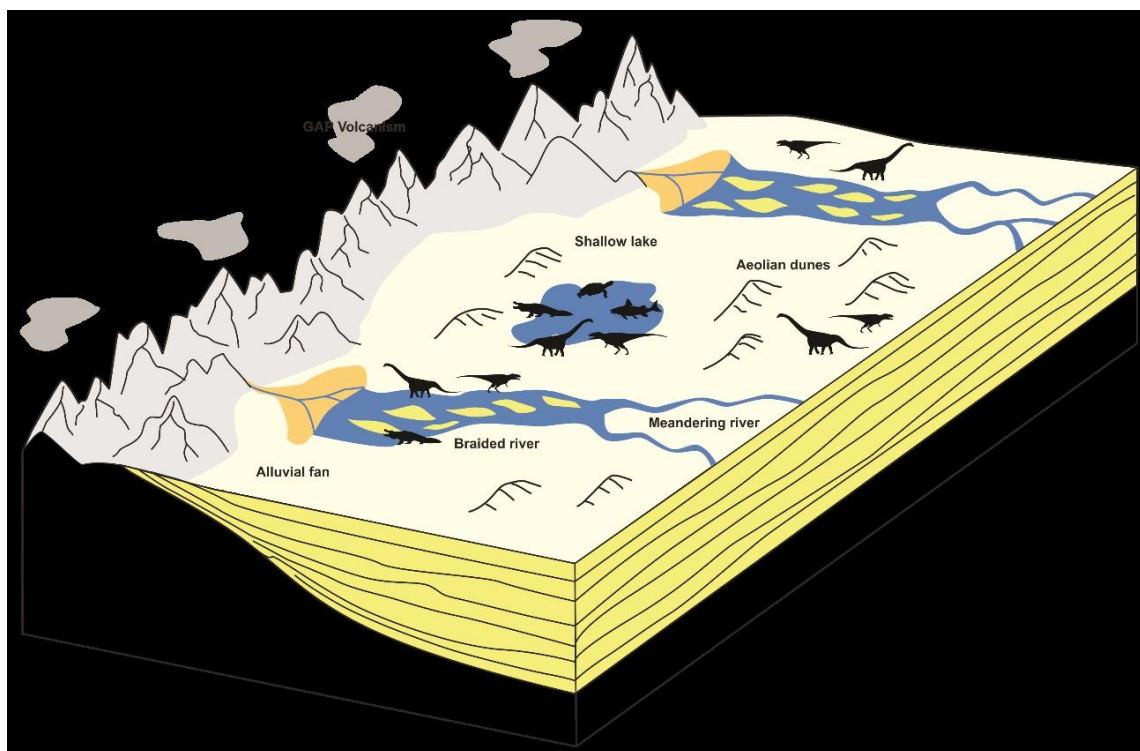


Fig. 8. Paleoreconstruction for the Bauru Group in the studied region, showing the continental environments and influence of the alkali volcanism (GAP) in the sedimentary infill.

The differences observed in the paleoenvironment and sedimentation of the Adamantina Formation are both due to its tectosedimentary evolution described by Batezelli (2003) and to the position occupied by the outcrops in the paleogeographic context of the sedimentary basin. In general terms, the climatic conditions inferred for this unit are hot, with an accentuated seasonal regime (Goldenberg & Garcia 2000, Fernandes & Ribeiro 2015), presenting higher humidity conditions than those inferred for the Adamantina Formation in São Paulo State by Coimbra & Fernandes (1995), Fernandes & Coimbra (1996) and Fernandes & Ribeiro (2015).

The stratigraphical levels of the Marília Formation have produced Maastrichtian fossils in two areas: the thick accumulation of Morro da Antena (Quirinópolis) and Pedreira Riocal (Rio Verde). The record of specimens in this unit is the most abundant of the Bauru Group in Goiás, including the first confirmed occurrences of turtles, cro-

codilians and dinosaurs for the state (Candeiro et al. 2018, 2022, 2024b, c). Here, the Marília Formation was interpreted as eroded surfaces, attributed to wind deflation, an environment that was considered an indicator of important changes in paleoenvironmental conditions. There were periods characterized by greater paleoclimatic aridity that were decisive for the construction of sand sheets, characterized by wind deposition on large unstable morphological surfaces with little vegetation; meanwhile, periods with greater water availability saw the reactivation of ephemeral channels with river transport and deposition (Dal Bó & Basilici 2011). Regionally, interaction between fluvial and aeolian processes in the Marília Formation can be discerned, as evidenced by the gradual transition to wetter conditions and the development of a more permanent fluvial system, and also by intercalations between fluvial and aeolian deposits throughout the entire range. The fluctuation between fluvial and aeolian processes may be

related to the contraction or expansion of the aeolian system reported by Herries (1993) and Mountney & Thompson (2002), conditions that seem to be present for the Upper Cretaceous of Goiás State in the Bauru Group.

Paleoenvironment. The Marília Formation in southern Goiás State presents accentuates lateral variation in facies, which has a gradation from deposits of clear fluvial dominance to levels of the distal floodplain with strong participation of sediments of aeolian origin. In the Quirinópolis sector, for example, this unit has been

interpreted as deposits of a fluvial system of low sinuosity with an abundant load of sandy bed, connected to exceptionally wide and shallow fluvial channels (Barcelos 1984, Barcelos & Suguio 1987). Towards the Itajá sector, the channel deposits show less development. In this sense, the interpretations provided by Basilicci & Dal Bó (2010) is wind deposits attributed by them to the Marília Formation, but the present work indicates the presence of intertwined channels, associated with the development of dunes and wind blankets in the distal sectors of the floodplain.

6. DISCUSSION

The characteristics described for the sedimentary sequence that composes the Bauru Group in Goiás State correspond to the development of a fluvial-lacustrine system. Olariu et al. (2020) and Sherer et al. (2006) defined it as a succession of large-scale basin-filling deposits (on the order of several hundred meters), composed mainly of large channel strip accumulations and extensive floodplain deposits. The evolution of this system responded to the combined action of intrinsic and extrinsic control factors (post-Serra Geral Cretaceous subsidence-tectonism, paleoclimate) (Goldenberg & Garcia 2000, Batezelli 2003). This caused changes in the sedimentary record of variable magnitude that translated mainly into the generation of discontinuities, lithological changes, facial changes and variations in the configuration and architecture of channeled bodies (Fernandes & Ribeiro 2015).

The lithostratigraphy of the Bauru Group described here was based on its lithological compositions. The stratigraphic boundaries that define the Adamantina and Marília formations are materialized by discontinuities of different magnitudes, a factor that in turn allows analyzing them from a sequential point of view (Coimbra & Fernandes 1995, Goldenberg & Garcia 2000). We maintain these units in the lithostratigraphic scheme of the Bauru Group (which differs in part for the states of Minas Gerais and São

Paulo); this number coincides with the number of "depository sequences" identified by Soares et al. (1980), Barcelos (1984) and Fernandes & Coimbra (1996). Conducting a sequence analysis is outside the scope of the current work, but general observations and comparisons can be made in this sense in order to arrive at an approximation to understanding the development of this sequence, and to support the maintenance of this lithostratigraphic scheme.

The existing paleogeographic pattern during the beginning of Bauru Group sedimentation, in the beginning of the Turonian, was strongly controlled by the compressional tectonics of the formation of the Atlantic Ocean. The formation of an important belt of folds and thrusts (limit of the Paramirim Craton), as well as the establishment of a new volcanic arc in the western sector of the unit (Batezelli 2003), were both notable.

The succession of vertebrate assemblages known from southern Goiás State is one of the youngest known for the Upper Cretaceous of continental Brazil. The records contain all major vertebrate groups from terrestrial environments. Figure 9 shows an overview of the vertebrate taxa found in the two geological units in four areas. From the known records, the fauna comprising the beds of the Bauru Group is by far the least diverse when compared to the known strata of the states of Minas Gerais and São Pau-

lo, but it is likely that it actually includes some distinct forms that we were not able to distinguish in our work to date (e.g., the presence of a new taxon of Notosuchia). The richest diversity appears to occur in the Marília Formation, but the vertebrate diversity of the Adamantina Formation is still poorly understood in comparison.

We must acknowledge, however, that paleontological exploration of the Bauru Group units in Goiás has long been neglected, and much work remains to be done to discover new fossils. As more fossils are discovered, the diversity of these units in Goiás may rival that seen in areas of Brazil that have been better explored.

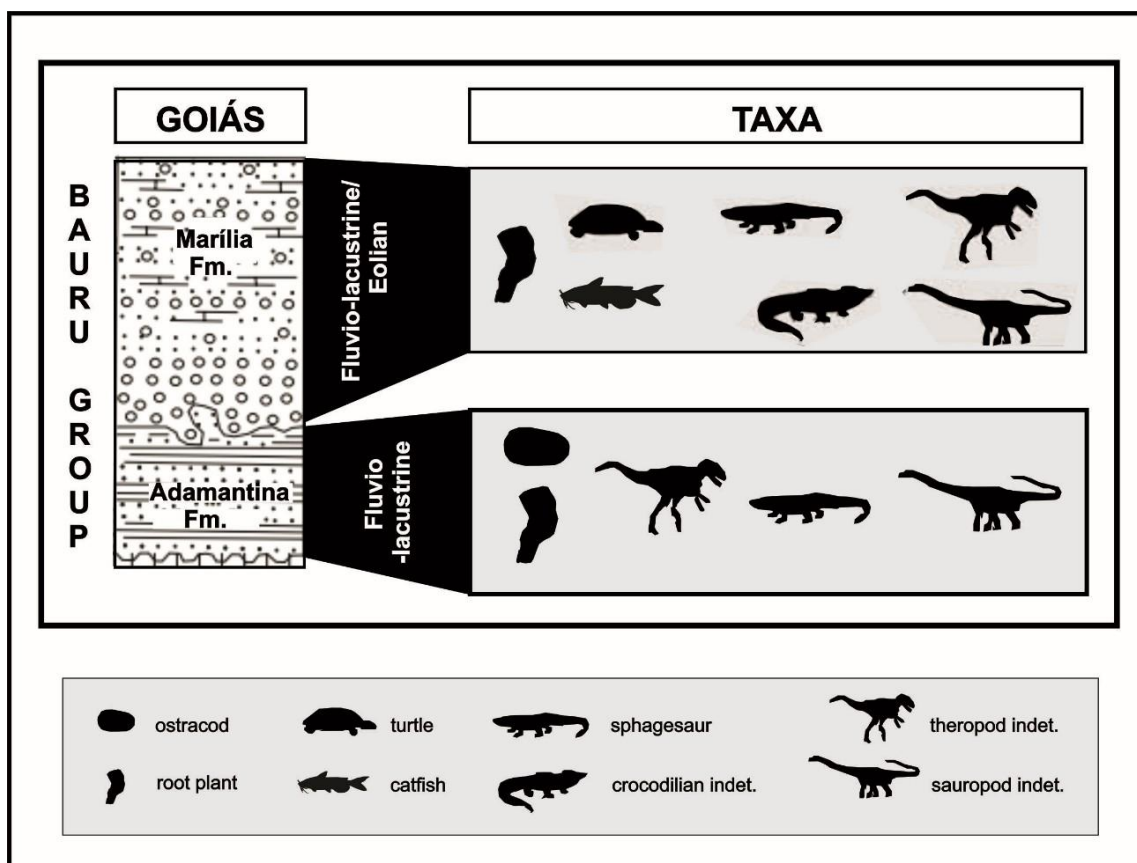


Fig. 9. Distribution of the Upper Cretaceous paleobiota from the Bauru Group of Goiás State, Brazil.

Our review demonstrates that the vertebrate records of the Bauru Group of Goiás State are represented by taxa that cover a large range of compositions and sizes, from turtles (represented by Podocnemididae), to large titanosaurs and theropod dinosaurs, to a possible very large notosuchian (represented by the presence of the largest tooth ever reported for the group). The apparent completeness of the fauna is, on the one hand, very favorable for reconstructing the paleoecosystem of the Bauru Group of Goiás, but it is important to take into account collection bias, such as the proportional differences observed in the collections of vertebrate bones (Candeiro et al. 2018, 2020a,b, 2022, 2024a, b,

c, Maia & Candeiro 2020, Gil et al., 2023). The fossils from the Bauru rocks of Goiás also contain a clear mixture of terrestrial and aquatic components, the latter mainly of freshwater origin, proving the presence of higher volume water regimes. The large size of turtle individuals reported from Rio Verde, together with the peculiar diet of these forms (e.g., planktivores), indicate the occurrence of large water bodies. It was likely that a mosaic of ecosystems was present in this region during the Late Cretaceous, but we cannot distinguish them in detail at this time. Indeed, the records for the Adamantina and Marília formations may represent an example of a localized ecosystem in which turtles

and crocodyliforms appear to be taxonomically (perhaps even ecologically) distinct from those in dinosaur ranges.

The succession of vertebrate assemblages described in the present work covers a time interval of probably less than 28.9 million years (from the Turonian base to the upper Maastrichtian). Therefore, it is interesting to note that few vertebrate lineages can currently be identified among this fauna, and so far, all vertebrate fossils can only be classified at more inclusive taxonomic levels than being diagnosed as new genera or species. This is partly due to the fact that paleontological research in the region has only occurred over the last 10 years, so it is not possible to make detailed comparisons to the fossil taxa and paleoenvironments of the Bauru Group in the better-sampled states of Minas Gerais and São Paulo. Indeed, the paleobiogeographical affinities of the fauna of Goiás, we can say prematurely, could be conditioned by the paleoecological conditions, which allowed connections with other areas of the Bauru Group. In a very preliminary way, it can be stated that a distinct taxon is present in Goiás, and the faunistic composition of these vertebrate records, may also be related to the peculiar regional conditions of that time interval — isolation of the area — which may have favored the biological characteristics of some lineages, in particular the notosuchians (Candeiro et al. 2023). Other groups, such as mesocrocodylians and dinosaurs, also show representative taxonomic diversity in the Adamantina and Marília formations, but additional, more detailed studies are needed to test whether this effect corresponds to a genuine biological event or to sampling bias.

6.1. Paleontological importance of fossils from the southern Goiás State

Most vertebrate fossils found in the Bauru group come from a few well-explored localities in the states of Mato Grosso, western São Paulo, and Triângulo Mineiro (e.g. Candeiro et al. 2006a, b, Ribeiro et al. 2023). Areas such as those in the

mid-west of the country continue to be little explored and unknown, leading to some relevant work in the area, especially in recent years with the work of our research group. (e.g., Weishampel et al. 2004, Candeiro et al. 2004, 2018, Candeiro & Martinelli 2006).

The Cretaceous fossils recovered from the Bauru Group deposits in the south of the state of Goiás are already beginning to have a direct impact on the national Cretaceous palaeontology of the Central region of Brazil. For example, the mesoeucrocodylian *Sphagesauria* indet. identified (Paleo-UFG/V-112; Candeiro et al. 2023) from the Paraúna Adamantina Formation provides new geographic data for this South American crocodyliform clade, representing the largest tooth occurrence and the northern-most to South America. Before their discovery, sphagesaurids consisting of *Sphagesaurus huenei* Price, 1950, *Armadillosuchus arrudai* Marinho & Carvalho 2009 and *Caryonosuchus pricei* Kellner, Campos, Riff & Brandalise 2011 (all from Adamantina Formation); another group consisting of *Caipirasuchus paulistanus* Iori & Carvalho 2011 (Adamantina Formation), *Caipirasuchus montealtensis* Iori, Marinho, Carvalho & Campos 2013 (Adamantina Formation), *Caipirasuchus stenognathus* Pol, Nascimento, Carvalho, Riccomini, Pires-Domingues & Zaher 2014 (Adamantina Formation), and *Caipirasuchus mineirus* Martinelli, Marinho, Iori & Pinheiro 2018 (Adamantina Formation); *Caipirasuchus attenoroughi* Ruiz, Bronzati, Ferreira, Martins, Langer & Montefeltro 2021 (Santo Anastácio Formation); and a third clade composed of the smallest known sphagesaurid *Adamantiniasuchus navae* Nobre & Carvalho 2006 (Adamantina Formation) and *Yacararani boliviensis* Novas, Pais, Pol, Carvalho, Mones, Scanferla & Riglos 2009 (Cajones Formation). However, the taxonomic assignment of Paleo-UFG/V-112, and temporal ambiguity of the Adamantina Formation strata serve to limit biogeographical inferences currently. If the Goiás deposits of this unit are post-Campanian (for example, if they are actually contemporaneous with the Campanian

reptile beds of São Paulo, Argentina and Bolivia), not only would Paleo-UFG/V-112 represent the only occurrence of a large Sphagesauria in South America (as these are all represented by small animals) but would represent a significant increase in the temporal range of the clade.

Comparison of other fossils from the Marília Formation reported for Quirinópolis and Rio Verde (e.g., siluriformes fishes, turtles, mesoeucrocodylia, sauropod and theropod dinosaurs) with isochronous faunas from Bauru Group (Minas Gerais and São Paulo), Argentina (Neuquén Group), Bolivia (Cajones Formation) and Uruguay (Paysandú Formation) can be useful to infer distributions correlations among these units.

In general, the faunal composition makes southern Goiás taxa similar to other Upper Cretaceous gondwanan continental fossil assemblages in Brazil, Bolivia, Argentina and Uruguay, respectively (e.g., Candeiro et al., 2017, 2018, 2024a, b, c) In particular, they offer insights into whether Late Cretaceous terrestrial vertebrate faunas exhibit continental-level cosmopolitanism or patterns of regional endemism, as proposed by Bonaparte (1996). Here it can be inferred that the deposits of the Bauru de Goiás Group are a unit representing northern extensions of the faunal corridors that dominated western Gondwana during the Late Cretaceous. Given the proximity (200 km from Minas Gerais/São Paulo; 300/km Bolivia, 3,500km Argentina;

and 1,700km Bolivia; and 2,000km) and the potentially contemporary nature of the faunas, an initial hypothesis of 'Regional Biotic Similarity' predicts that the "uniform" set recovered from pre-Campanian geological units found in Argentina (Neuquén Group), Bolivia (Cajones Formation) and Bauru Group in Goiás will present faunal overlap with other areas of South America.

Other important tetrapod group, titanosaurid dinosaurs, are present in both the post-Campanian geological units of Argentina and Bolivia and in deposits of the Bauru Group of Goiás, as evidenced by samples including cylindrical teeth and bones with camellate structures. As such, at least some of the vertebrates from Goiás (e.g., Siluriformes, Podocmenidae, Sphagesauria) represent similar forms found for the Late Cretaceous of Argentina, Bolivia, and Uruguay. Notably, the forms from Goiás may be conspecific with others from the aforementioned countries. In summary, initial comparisons do not refute broad taxonomic overlap between the faunas of Goiás and other post-Campanian areas of South America. However, more fieldworks, more investments in the region and material descriptions efforts are essential for assembling a more reliable picture of the distribution of these vertebrate groups in the Late Cretaceous for Bauru Group, particularly those from central South America. At this perspective, the areas studied in the south of Goiás play a central role in this objective.

7. CONCLUSIONS

Our overview further emphasizes the enormous potential of the vertebrate fossil record of the Upper Cretaceous of southern Goiás State for the study of Bauru Group ecosystems and their evolution over time. In particular, we show that this area, which was often neglected and treated separately from other exposures of the Bauru Group, actually formed a single sedimentary unit. In conclusion, our review leads to two issues that should be addressed in future studies: (1) it will be a challenge to correlate the strata of parts of Goiás and Minas Gerais-São Paulo

with the macrofaunas, bearing in mind that we do not have paleontological and sedimentological evidence of a complete profile covering the entire Turonian-Santonian and Maastrichtian; and (2) systematic area-wide prospecting, combined with systematic excavations in known sites and new areas in southern Goiás, should be conducted to provide a better understanding of lateral variation between records and the composition of fossiliferous localities. This northern portion of the little-known Bauru Group that is in the state of Goiás offers great perspective for

fossils discoveries of new Cretaceous species and groups that could be crucial for faunal comparisons and paleobiogeographical inferences proposed to explain the post-Campanian vertebrates of South America.

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