First dinosaur record from the Marília Formation (Maastrichtian) in the Gurinhatã municipality, Minas Gerais state, Brazil

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Abstract. Titanosaurs are one of the most common dinosaurs found in Cretaceous outcrops, especially in Brazil. In this article we describe a proximal portion of an ulna (Paleo-UFG/V-0039) which was found isolated Paleo-UFG/V-0039 comes from a sandstone outcrop, with fine to medium granulation, of the Marília Formation (Bauru Group) that appears irregularly in the municipality of Gurinhatã, state of Minas Gerais, Brazil. The occurrence described here is the first dinosaur osteological remains documented in this municipality. Although incomplete, Paleo-UFG/V-0039 could be identified as an indeterminate lithostrotian titanosaur whose morphology is similar to some appendicular elements of European species than South American ones. However, the incompleteness of the specimen has difficult complex interpretations. Finally, Paleo-UFG/V-0039 highlights the importance of the Gurinhatã outcrops and other sites in this region for future discoveries.

Keywords. Sauropod; Triângulo Mineiro region; Late Cretaceous; Brazil; Appendicular bones; Lithostrotian.

INTRODUCTION

In Brazil, records of dinosaurs are widely known from the Bauru Group (Late Cretaceous), mostly from the Triângulo Mineiro region, in the state of Minas Gerais (e.g., Kellner & Campos, 2000; Campos et al., 2005; Faria et al., 2015; Bandeira et al., 2018; González-Riga et al., 2019) and from western São Paulo state (Santucci & Arruda-Campos, 2011; Bandeira et al., 2016; Delcourt & Iori, 2018). More recently, some new findings are known from the other poorly explored regions, such as the outcrops in Goiás (Candeiro et al., 2018, 2020). However, due to the historical and highly fossiliferous nature of the units, especially the Triângulo Mineiro area, several contributions discuss the geological and palaeontological research performed by geoscientists in this region (e.g., Candeiro, 2007; Peyerl et al., 2015; Candeiro & Figueiroa, 2017).

The Triângulo Mineiro region has yielded several dinosaur bones from the municipalities of Campina Verde, Uberaba, Monte Alegre de Minas, Prata and Verissimo (Fig. 1). The naturalist von Huene described the first record of sauropods from the Pontal of Triângulo Mineiro, specifically from Monte Alegre of Minas (Candeiro et al., 2019). However, those specimens collected by von Huene are nowadays lost (e.g., Kellner & Campos, 2000). Most of these findings are isolated vertebrae attributed to sauropods (Candeiro, 2007), but mainly lithostrotian remains (Titanosauria: Neosauropoda). Although belonging to the Triângulo Mineiro region and...
Figure 1. Location map of the municipality of Gurinhã, Minas Gerais state. Geographic coordinate system: SIRGAS 2000. Source: IBGE/April 2019.

Figure 2. Geological map of the Gurinhã, Detached formations that outcrops in the municipality. Geographic coordinate system: SIRGAS 2000. Source: IBGE/April 2019.
being regionally close to these cited fossiliferous areas, Gurinhatã had not yet yielded any record of dinosaur remains. In 2018, a team of the Laboratory of Paleontology and Evolution of the Geology Course of the Universidade Federal de Goiás (Labpaleoevo-UFG) began a series of prospecting works (2018-2019) of fossils in Gurinhatã. This fieldwork resulted in the discovery of a new outcrop, found approximately 8 km from the urban area (Fig. 1), where a dinosaur bone was recovered. The specimen (Paleo-UFG/V-0039) consists of a single bone, a quite incomplete ulna. Paleo-UFG/V-0039 was founded isolated, being the first dinosaur record in this locality.

As in other municipalities of the Triangulo Mineiro region, in the region of Gurinhatã, the outcrops are rock expositions of the Bauru Group (Bauru Group, Late Cretaceous, sensu Fernandes & Coimbra, 1996), a geological unit deposited on the strata of the Paraná Basin (Soares et al., 1980; Fernandes & Coimbra, 2000; Brusatte et al., 2017). This unit was developed during the Late Cretaceous, deposited during the Gondwana breaking-up (Fernandes & Coimbra, 2000). The Bauru Group crops out in parts of various Brazilian states, and a detailed stratigraphic review can be seen in some more recent works (e.g., Pinheiro et al., 2018).

Among the eight formations that compose the Bauru Group (sensu Pinheiro et al., 2018), in the Gurinhatã municipality outcrops the Adamantina and Marília formations (Fig. 2). The specimen described in this work comes from strata of the Marília Formation, which strata are mainly dated from Maastrichtian (Dias-Brito et al., 2001; Brusatte et al., 2017). This formation is dominated by sandstones and conglomerates, which are often cemented by carbonate (limestone) and some carbonate concretions (Brusatte et al., 2017; Pinheiro et al., 2018) and interpreted as alluvial fan-like (Riccomini, 1997), later reworked by an interlaced system in association with limestone and lacustrine calcareous sediments (Barcelos & Suguió, 1987). Lastly, the Marília Formation is traditionally divided into three subunits (Serra da Galga, Ponte Alta & Echaporã members, sensu Barcelos, 1984). However, more recently, the Serra da Galga and the Ponte Alta members were now part of the Serra da Galga Formation (Soares et al., 2021). Further details on the lithological and stratigraphic aspects of those formations or among the Bauru Group itself can be found in more recent literature (e.g., Brusatte et al., 2017; Pinheiro et al., 2018; Soares et al., 2021) since greater detail is beyond the scope of this work.

Figure 3. An indeterminate lithostrotian sauropod partial right ulna, Paleo-UFG/V-0039, in (A) Anterior View; (B) Medial View; (C) Posterior View; (D) Lateral View; (E) Proximal View; (F) Distal view.
Fractures in the most distal portion indicate a post-diagenetic feature, a taphonomic signature less common for the Marilia Formation titanosaur bones (e.g., Bandeira et al., 2018).

Despite incomplete, this morphology indicates that the bone was genuinely wider at the proximal end and narrowed towards its distal end. The craniomedial and craniolateral processes are prominent (Fig. 4); but, as in other sauropods, the caudal process is much more developed and larger than the former (e.g., Poropat et al., 2015; Upchurch et al., 2015; Ullmann & Lacovara, 2016; González-Riga et al., 2019).

Although this area is not completely preserved, the craniomedial process also is marked by the concave articular surface of the humerus (Fig. 5), while the craniolateral process inclines ventrally, distancing itself from the olecranon, in lateral view (Fig. 3). The caudomedial face exhibits a shallow medial concavity (for insertion of the flexor carpi ulnaris muscle). The ulna shaft is not preserved, but the cross section of the broken distal part of the bone shows that the shaft was subtriangular in this region, due to a caudodistally descending longitudinal crest of the olecranon. The proximal portion of the ascending crest of the olecranon curves slightly medially. In addition, a longitudinal relief ridge defines the medial border of the radial articular face in cranial view.

Comparisons

Among Brazilian titanosaur species, there are few species that have appendicular materials, and even less those that have directly comparable bones (Table 1). Some other titanosaur species have a visible but slight difference between the craniomedial and craniolateral processes are Aeolosaurus sp. (MPCA-Pv 27174; MPCA-Pv 27175 and MPCA-Pv 27180; Garcia & Salgado, 2013), Alamosaurus sanjuanensis Gilmore, 1922 (TMM 43621-1, Lehman & Coulson, 2002), Argyroserus superbus Lydekker, 1893 (Mannion & Otero, 2012), Dreadnoughtus schrani Lacovara & Ullmann, 2014 (Ullmann & Lacovara, 2016), Malawisaurus dixeyi Haughton, 1928 (Gomani, 2005), Mendozaasaurus negueyap González-Riga 2003 (González-Riga et al., 2018), Nambulamtititan patoloemipil Filippi, Garcia & Garrido, 2011 and Patagotitan mayorum Carballido, Pol, Otero, Cerda, Salgado, Garrido, Ramezani, Cúneo & Krause, 2017 (Otero et al., 2020). In Argyrosaurus, Diamantinasaurus, Nambulamtititan, Malawisaurus and Mendozaasaurus, the difference in length between these processes is more linked to the craniomedial process width, which reaches a maximum robustness in Mendozaasaurus. In titanosaur species with stouter appendicular bones, such as Saltasaurus loricatus Bonaparte & Powell, 1980 (Powell, 2003), Neuquensaurus australis (Lydekker, 1893) (Otero, 2010) and Diamantinasaurus matildae Hocknull, White, Tischler, Cook, Galleja, Sloan & Elliott 2009 (Poropat et al., 2015), the olecranon process is extremely proximally elevated (e.g., González-Riga et al., 2019) and the craniomedial and craniolateral processes have almost the development.

However, some titanosaur species exhibit a large elongation of the craniomedial process, such as Atsinganosaurus ve-
Figure 4. Proximal view of different titanosauriforms for comparison. (A) Sonorosaurus (from D’Emic et al., 2016); (B) Wintonotitan (from Poropat et al., 2014); (C) Haestasaurus (from Upchurch et al., 2015); (D) Yongjinglong (from Li et al., 2014); (E) Angolatitan (from Mateus et al., 2011); (F) Atsinganosaurus (from Díez Díaz et al., 2018); (G) Dreadnoughtus (from Ullmann & Lacovara, 2014); (H) Rapetosaurus (from Curry Rogers, 2009); (I) Neuquensaurus (from Otero, 2010); (J) Elaltitan (from Mannion & Otero, 2012); (K) Diamantinasaurus (from Poropat et al., 2015); (L) Malawisaurus (from Gomani, 2005); (M) Lohuecotitan (from Díez Díaz et al., 2016); (N) Mendozasaurus (from González-Riga et al., 2018); (O) Lirainosaurus (from Díez Diaz et al., 2013); and (P) Paleo-UFG/V-0039. Not in scale.

Figure 5. An indeterminate lithostrotian sauropod partial right ulna, paleo-ufg/v-0039, in (A) anterior view; (B) proximal view; (C) explanatory drawing of the right ulna in anterior view.
**Table 1. Brazilian Titanosaur species with appendicular remains.**

| Species + Described by                  | Institution                                                                 | Skeletal remains                                                                 |
|----------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1 Gondwanatitan fausti Kellner & Azevedo, 1999 | Museu Nacional/UIFRJ, Rio de Janeiro, RJ                                   | MM4111-V: 2 incomplete cervical vertebrae; 7 dorsal vertebrae; 6 sacral vertebrae; 8 caudal vertebrae; 4 indeterminate vertebrae; 1 proximal end of the left scapula; 1 incomplete left ilium; 2 fragmentary pubis; 2 incomplete ischium; both umeura, both tubia; several ribs remains and several indeterminate remains. |
| 2 Maxakalisaurus topoip Kellner, Campos, Azevedo, Trota, Henriques, Craik & Silva, 2007 | Museu Nacional/UIFRJ, Rio de Janeiro, RJ                                   | MN 5013-V: 1 right maxilla with teeth; 3 almost complete cervical vertebrae; 9 very fragmentary cervical vertebrae; 1 neural spine of sacral vertebrae; 1 centrum from sacral vertebra; 6 caudal vertebrae; 3 haemal arches; 2 caputulae; 2 sternal plates; 1 distal end from left ilium; 2 humerus; 2 metacarpals; 1 incomplete fibula; 1 left tibia; osteoderm. |
| 3 Ubirabintusinti riberro Silva-Junior et al., 2019 | Centro de Pesquisas Paleontológicas                                   | CPPLIP                                                                            |
| 4 Tapuiasaurus macondoi Zaher, Pol, Carvalho, Nascimento, Riccomini, Larson, Juarez-Valent, Pires-Domingues, da Silva-Jr. & Campos, 2011 | Museu de Zoologia da Universidade de Sao Paulo, Sao Paulo, SP           | MZSP-PV 807: 1 articulated complete skull; 1 mandible; hoidesaparatus; 1 atlas; 1 axis; 5 cervical vertebrae with their respective cervical ribs; 5 dorsal vertebrae; 4 dorsal rib; 1 left sternal plate; 1 right coracoid; 1 right humerus; 1 left radius; 2 ulnae; 2 metacarpals; 2 femora; 1 left fibula; 1 articulated pes almost complete. |
| 5 Arrudatitan maximus Santucci & Arruda-Campos, 2011 | Museu de Paleontologia de Monte Alto, Monte Alto, SP                                               | MPMA 12-0001-97: 2 incomplete posterior cervical vertebrae; 7 incomplete cervical ribs; 1 anterior incomplete dorsal centrum; 1 incomplete neural arch (1) of middle dorsal vertebra; 1 neural arch of posterior dorsal vertebrae; several incomplete diaphysis of dorsal vertebrae; 12 incomplete dorsal ribs; 6 articulated anterior caudal vertebra; 1 mid caudal centrum; 2 posterior caudal vertebrae; 8 haemal arches; 1 fragmentary sacrum; 1 incomplete right humerus; 1 incomplete left humerus; 1 incomplete radius; 1 incomplete right femur; 1 well preserved left femur; 1 left ischium; and several unidentified fragments. |
| 6 Brasilotitan nemophagus Machado, Avilla, Nava, Campos & Kellner, 2013 | Museu de Paleontologia de Marilia, Marilia, SP                                               | MPM 12/3R: 1 right dentarium; 2 midcervical vertebrae (Cv5?Cv6?); 3 incomplete sacral vertebrae; 1 fragmentary ilium; 1 fragmentary ischium; 1 unguis; ? several unidentified fragments. |

Titanosaurs are the only records of sauropod dinosaurs known from the strata of the Bauru Group (Gil & Candeiro, 2014; Faria et al., 2015; Brusatte et al., 2017, Bandeira et al., 2018; Candeiro et al., 2018). There is a shortage of recovered titanosaurian appendicular material in the Bauru Group as a whole, however, especially when compared with other axial elements (Bandeira et al., 2018). For example, among the eleven Brazilian titanosaur species, six have associated appendicular elements (Table 1), but only Tapuiasaurus has this bone preserved (Zaher et al., 2011). However, little comparison between the Paleo-UFG/V-0039 and Tapuiasaurus is possible, as the ulnae of the latter have not been described yet nor properly figured. In this way, although quite incomplete, Paleo-UFG/V-0039 is important because it is one of the few records of a titanosaur ulna in the Marilia Formation, and one of the few titanosaurian appendicular elements found in Bauru Group where there are more abundant axial remains, such as ribs and vertebrae (Bandeira et al., 2018). Also, the quality of bone surface preservation is also comparable to other titanosaurs found in the Bauru Group, where many specimens present a superficial loss of bone tissue (e.g., Bandeira et al., 2016, 2018).
The morphology of Paleo-UFG/V-0039 exhibits some important features that help place it within Titanosauria. For example, although most sauropods have a cranio-medial process that is longer than the cranialateral process, a large elongation of the cranio-medial process is restricted to a few taxa (Atingananosaurus, Lohuiecotitan and now Paleo-UFG/V-0039). This finding is important because it may reflect a phylogenetically important character. Many groupings within Titanosauria have been supported chiefly by axial characters, but there may be more appendicular features that provide phylogenetic significance. In the future, more detailed comparative studies focusing on appendicular remains will add useful information for more inclusive phylogenetic analyses.

The specimen Paleo-UFG/V-0039 shows a set of characteristics that allow its attribution to Titanosauria. Adding to this, the fact that to date all records of Late Cretaceous sauropods from the Bauru Group are titanosaurs, it makes sense that the specimen described here belongs to this clade. Moreover, the greater similarity between the morphology of Paleo-UFG/V-0039 and some European species is an illuminating observation, which may speak to phylogenetic links between these sauropods, or perhaps represent convergence between geographically separated species. This and other questions can only be answered by new fossil discoveries in the Gurinhata region, and throughout the Bauru Group sequences in other areas of Brazil. The discovery of this new specimen, although fragmentary, highlights the possibility of future finds in this municipality, which may impact not only anatomical and taxonomic studies, but also biogeographic hypotheses (if more specimens similar to European species are identified).

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**AUTHORS’ CONTRIBUTIONS**

Ramon Cavalcanti: Conceptualization, Project administration, Supervision, Writing – Original draft, Writing – Review & Editing, Investigation, Visualization. Kamila Luisa Nogueira Bandeira: Writing – Review & Editing, Investigation, Validation. Carlos Roberto Candeiro dos Anjos: Funding acquisition, Resource, Writing – Review & Editing. Luciano Vidal: Writing – Review & Editing. Musa Maria: Writing – Review & Editing. Steve Bursatte: Writing – Review & Editing. All the authors actively participated in the discussion of the results, they reviewed and approved the final version of the paper.

**CONFLICTS OF INTEREST**

Authors declare there are no conflicts of interest.

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