Papéis Avulsos de Zoologia
Museu de Zoologia da Universidade de São Paulo

ARTICLE

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 Cretacous; 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 paleontological 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

Pap. Avulsos Zool., 2021; v.61: e20216175
http://doi.org/10.11606/1807-0205/2021.61.75
http://www.revistas.usp.br/paz
http://www.scielo.br/paz
Edited by: Luís Fábio Silveira
Received: 01/12/2019
Accepted: 17/06/2021
Published: 04/09/2021

ISSN On-Line: 1807-0205
ISSN Printed: 0031-1049
ISNI: 0000-0004-0384-1825

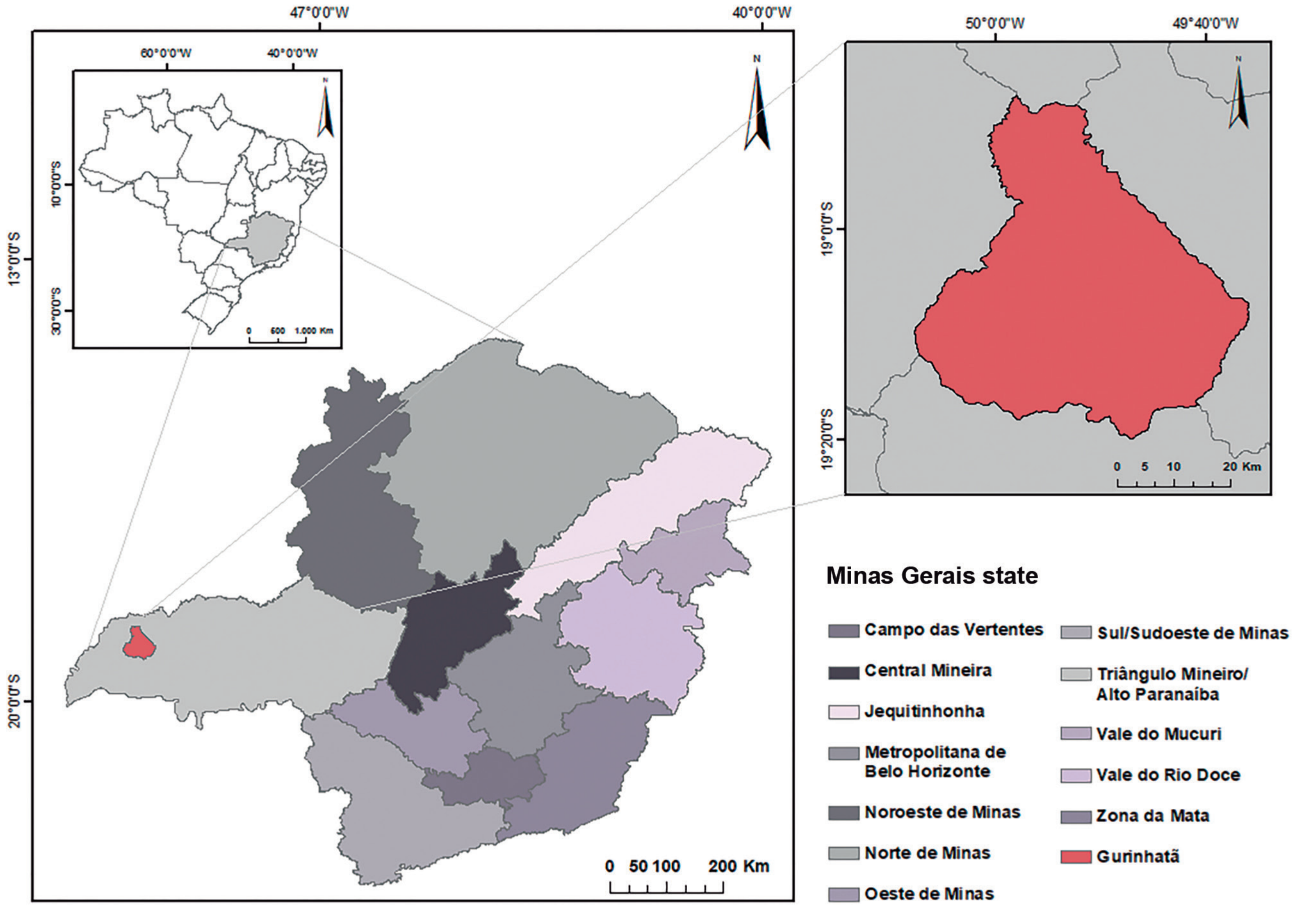

Figure 1. Location map of the municipality of Gurinhatã, Minas Gerais state. Geographic coordinate system: SIRGAS 2000. Source: IBGE/April 2019.

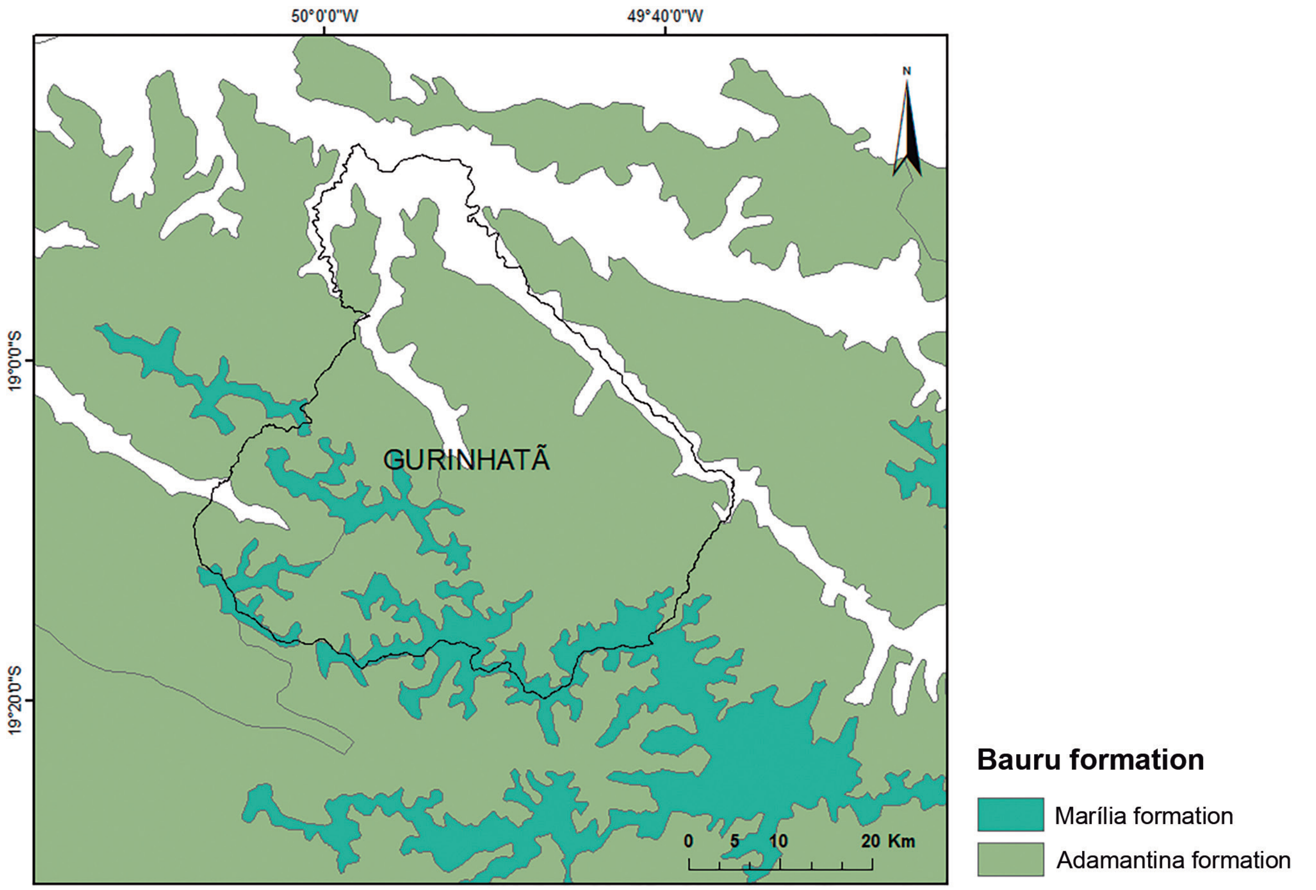

Figure 2. Geological map of the Gurinhatã, Detached formations that outcrops in the municipality. Geographic coordinate system: SIRGAS 2000. Source: IBGE/April 2019.

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 & Suguio, 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.

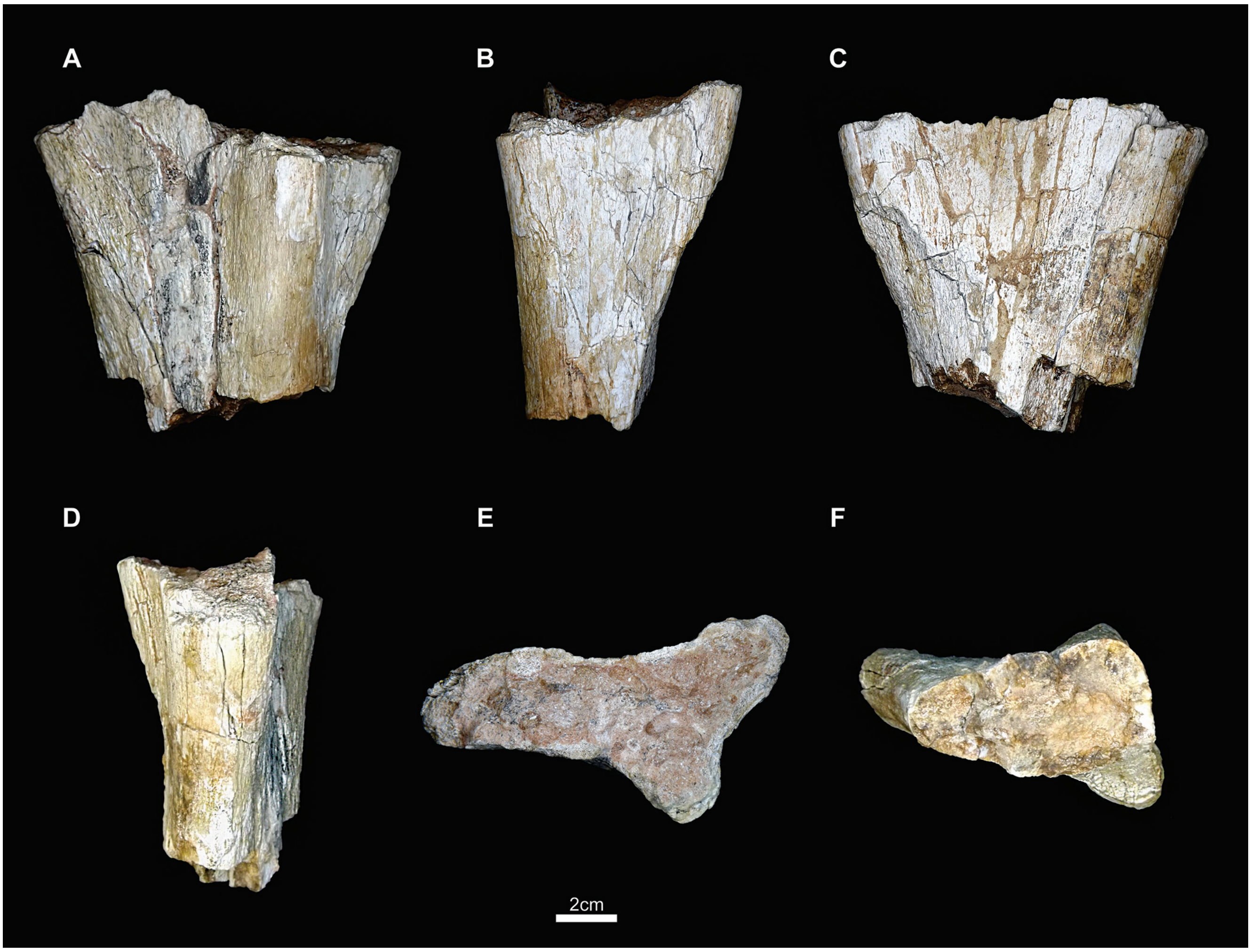

Figure 3. An indeterminate lithostrotian sauropod partial right ulna, Paleo-UFG/V-0039, in (A) Anterior View; (B) Medial View; (C) Posterior View; (D) Lateral View; (E) Proximal View; (F) Distal view.

Abbreviations

Anatomical abbreviations: cmpr, craniomedial process; lmpr, lateromedial process; popr, caudal process; ol, olecranon; rdfs, radial fossa; mdcc, medial concavity (for *m. flexor carpi ulnaris*).

Institutional abbreviations: CPP, Centro de Pesquisas Paleontológicas Lewellyn Price, Peirópolis, MG, Brazil; **MN**, Museu Nacional/UFRJ, Rio de Janeiro, RJ; **MPCA**, Vertebrate Paleontology collection of the Museo Provincial de Cipolletti "Carlos Ameghino", Río Negro, Argentina; **MPMA** or **MPM**, Museu de Paleontologia de Monte Alto, Monte Alto, SP, Brazil; **MZSP-PV**, Museu de Zoologia da Universidade de São Paulo, São Paulo, SP; **Paleo-UFG**, Laboratory of Paleontology and Evolution of the Geology Course, Universidade Federal de Goiás, Goiás, Brazil; **TMM**, Texas Memorial Museum, University of Texas, Austin, USA; **UFRJ DG-R**, Universidade Federal do Rio de Janeiro, Departamento de Geologia, Rio de Janeiro, RJ, Brazil.

MATERIAL AND METHODS

The material of Minas Gerais state was collected in the municipalities of Gurinhatã, and are housed under the acronyms Paleo-UFG/V-0039 at the collection of the Laboratório de Paleontologia e Evolução, which is part of the Geology Course of the Aparecida de Goiânia Campus, Federal University of Goiás. Here, we followed the stratigraphic scheme proposed by Soares et al. (1980) and the age suggested by Dias-Brito *et al.* (2001) it was possible to make comparison by using bibliographic data and taxonomical proposal from Upchurch, Barret & Dodson (2004).

RESULTS

Systematic Paleontology
Dinosauria Owen, 1842
Saurischia Seeley, 1888
Sauropoda Marsh, 1878
Titanosauriformes Salgado, Coria & Calvo, 1997
Somphospondyli Wilson & Sereno, 1998
Titanosauria Bonaparte & Coria, 1993
Lithostrotia Upchurch, Barrett, & Dodson, 2004
Lithostrotia indet.
(Fig. 3)

Description

Paleo-UFG/V-0039 is recognized as a proximal fragment of the right ulna, based on its morphology. The bone is thin in its central portion and becomes robust proximally. The distalmost part of the fossil is slightly craniocaudally expanded. In a proximal view, the ulna is triradiate and 'V'-shaped, a feature observed in other titanosauriforms (Upchurch *et al.,* 2015). The irregular 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 titanosaurs 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; García & Salgado, 2013), *Alamosaurus sanjuanensis* Gilmore, 1922 (TMM 43621-1, Lehman & Coulson, 2002), *Argyrosaurus superbus* Lydekker, 1893 (Mannion & Otero, 2012), *Dreadnoughtus schrani* Lacovara & Ullmann, 2014 (Ullmann & Lacovara, 2016), *Malawisaurus dixeyi* Haughton, 1928 (Gomani, 2005), *Mendozasaurus neguyelap* González-Riga 2003 (González-Riga *et al.,* 2018), *Narambuenatitan palomoi* Filippi, Garcia & Garrido, 2011 and *Patagotitan mayorum* Carballido, Pol, Otero, Cerda, Salgado, Garrido, Ramezani, Cúneo & Krause, 2017 (Otero *et al.,* 2020). In *Argyrosaurus, Diamantinasaurus, Narambuenatitan, Malawisaurus* and *Mendozasaurus,* the difference in length between these processes is more linked to the craniomedial process width, which reaches a maximum robustness in *Mendozasaurus.* In titanosaurs 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 titanosaurs exhibit a large elongation of the craniomedial process, such as *Atsinganosaurus ve-*

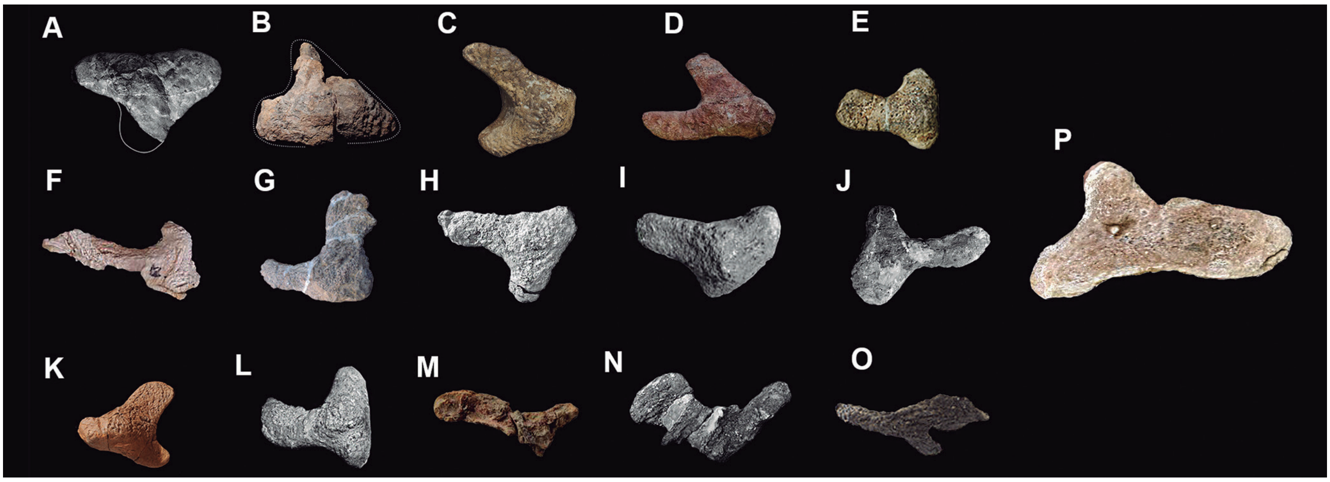

Figure 4. Proximal view of different titanosauriforms for comparison. (A) Sonorosaurus (from D'Emic *et al.,* 2016); (B) Wintonotitan (from Poropat *et al.,* 2014); (C) Haestasaurus (from Upchurch *et al.,* 2015); (D) Yongjinglong (from Li *et al.,* 2014); (E) Angolatitan (from Mateus *et al.,* 2011); (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 Díaz *et al.,* 2013); and (P) Paleo-UFG/V-0039. Not in scale.

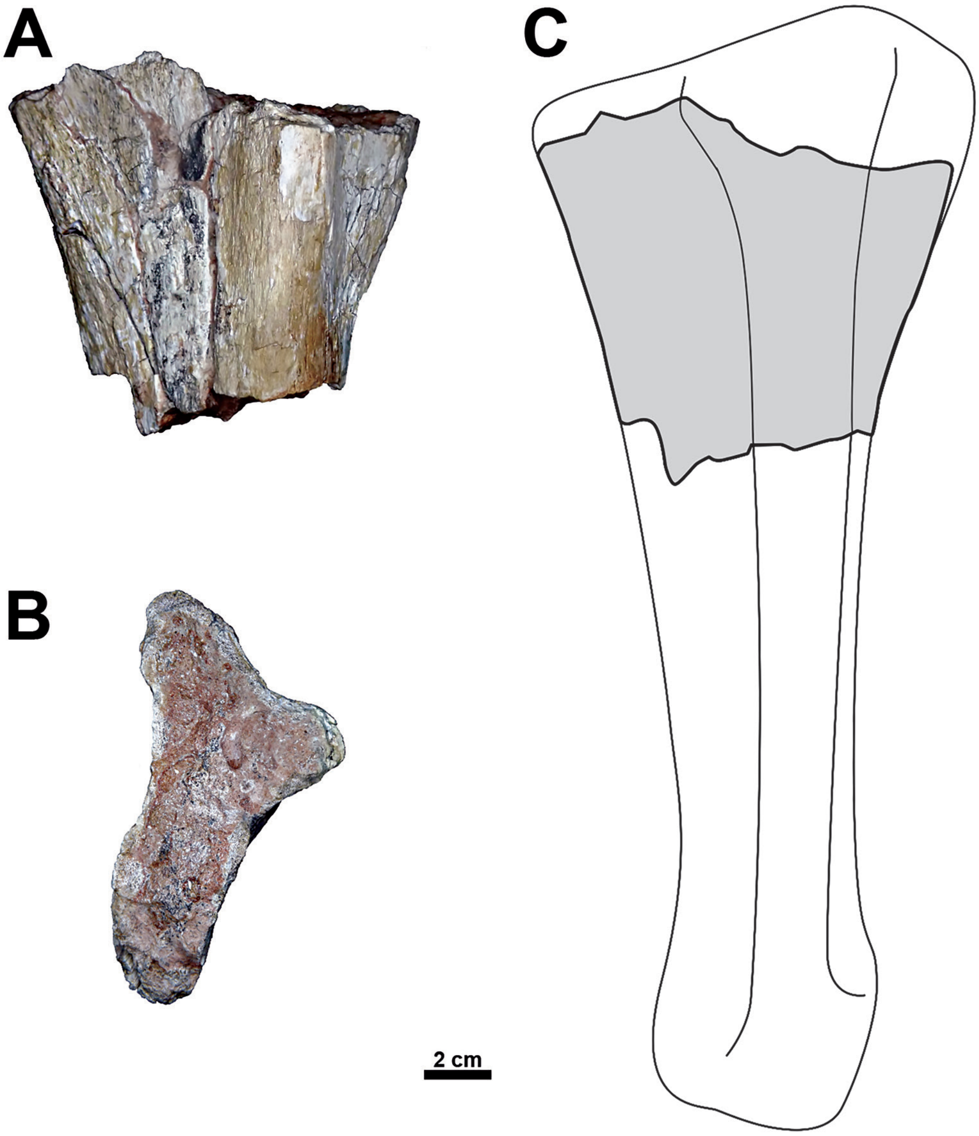

Figure 5. An indeterminate lithostrotian sauropod partial right ulna, paleo-ufg/v-0039, in (A) anterior view; (B) proximal view; (C) explanatory drawning of the right ulna in anterior view.

Table 1. Brazilian Titanosaur species with appendicular remains.

	Species + Described by	Instituition	Skeletal remains
1	*Gondwanatitan faustoi* Kellner & Azevedo, 1999	Museu Nacional/UFRJ, Rio de Janeiro, RJ	MN4111-V: 2 incomplete cervical vertebrae; 7 dorsal vertebrae; 6 sacral vertebrae; 24 caudal vertebrae; 4 indeterminate vertebrae; 1 proximal end of the left scapula; 1 incomplete left ilium; 2 fragmentary pubis; 2 incomplete ischia; both umera, both tibia; several ribs remains and several indeterminate remains.
2	*Maxakalisaurus topai* Kellner, Campos, Azevedo, Trotta, Henriques, Craik & Silva, 2007	Museu Nacional/UFRJ, 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 vertebra; 1 centrum from sacral vertebra; 6 caudal vertebrae; 3 haemal arches; 2 scapulae; 2 sternal plates; 1 distal end from left ischium; 2 humeri; 2 metacarpals; 1 incomplete fibula; 1 left tibia; osteoderm. MN 7048-V: 1 distal end of right scapula. MN 7049-V: 1 sternal plate. MN 7050-V: 1 sternal plate. MN 7051-V: 1 caudal vertebra.
3	*Uberabatintan riberoi* Silva-Júnior *et al.,* 2019	Centro de Pesquisas Paleontológicas Lewellyn Price, Peirópolis, MG	CPPLIP
4	*Tapuiasaurus macedoi* Zaher, Pol, Carvalho, Nascimento, Riccomini, Larson, Juarez-Valieri, Pires-Domingues, da Silva-Jr. & Campos, 2011	Museu de Zoologia da Universidade de São Paulo, São Paulo, SP	MZSP-PV 807: 1 articulated complete skull; 1 mandible; hioidesaparatus; 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; metarcapals; 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 (?) of middle dorsal vertebra; 1 neural arch of posterior dorsal vertebrae; several incomplete diapophysis of dorsal vertebrae; 12 incomplete dorsal ribs; 6 articulated anterior caudal vertebrae; 1 mid caudal centrum; 2 posterior caudal vertebrae; 8 haemal arches; 1 fragmentary scapula; 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 Marília, Marília, SP	MPM 125R: 1 right dentarium; 2 midcervical vertebrae (Cv5?Cv6?); 3 incomplete sacral vertebrae; 1 fragmentary ilium; 1 fragmentary ischium; 1 ungueal; ? several unidentified fragments.

lauciensis Garcia, Amico, Fournier, Thouand & Valentin, 2010 (Díez Díaz *et al.,* 2018); *Lohuecotitan pandafilandi* Díez-Díaz, Mocho, Páramo, Escaso, Marcos-Fernández, Sans & Ortega, 2016; *Lirainosaurus astibiae* Sanz, Powell, le Loeuff, Martinez & Pereda, 1999 (Díez Díaz *et al.,* 2013); *Elaltitan lilloi* Mannion & Otero, 2012 and *Rapetosaurus krausei* Curry Rogers & Forster, 2001 (Curry Rogers, 2009). This elongation is well-marked in *Atsinganosaurus, Lohuecotitan, Elaltitan* and in Paleo-UFG/V-0039, where it becomes almost twice the length of the lateromedial process. This development leads to a more compressed morphology craniocaudally, when compared to the ulnae of other titanosaurs.

The medial depression on the shallow descending olecranon crest in Paleo-UFG/V-0039 is similar to that in *Rapetosaurus* (Curry Rogers, 2009), *Saltasaurus* (Powell, 2003), *Atsinganosaurus* (Díez Díaz *et al.,* 2018), *Lirainosaurus* (Díez Díaz *et al.,* 2013), *Lohuecotitan* (Díez Díaz *et al.,* 2016), and *Neuquensaurus* (Otero, 2010). The expression of this concavity as a distinct structure in the proximal region of the ulna is shared only between the new specimen studied here, *Elaltitan* (Mannion & Otero, 2012) and *Lohuecotitan* (Díez Díaz *et al.,* 2016). The clear presence of a high muscular scar on the cranial face of the ulnar axis is shared by Paleo-UFG/V-0039, *Dreadnoughtus, Neuquensaurus,* and the *Aeolosaurus* sp. MPCA-Pv 27174; MPCA-Pv 27175 and MPCA-Pv 27180 (Otero, 2010; García & Salgado, 2013; Ullmann & Lacovara, 2016). According to Ullmann & Lacovara (2016), countless titanosaurs as *Dreadnoughtus, Neuquensaurus, Isisaurus, Jainosaurus, Narambuenatitan* and *Aegyptosaurus,* have a low longitudinal crest along the cranial ulna denoting the medial limit of the articulation of the radius. Finally, transverse expansion of the distal ulna is a characteristic only observed in opisthocoelicaudiines (Filippi & Garrido, 2008), which makes it unlikely that the new specimen is within this clade.

DISCUSSION AND CONCLUSION

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 later have not been described yet nor properly figured. In this way, although quite incomplete, Paleo-UFG/V-0039 is is important because it is one of the few records of a titanosaur ulna in the Marília 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 craniomedial process that is longer than the craniolateral process, a large elongation of the craniomedial process is restricted to a few taxa (*Atsinganosaurus, Lohuecotitan* 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 Gurinhatã 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).

ACKNOWLEDGMENTS

The authors gratefully acknowledge Emerson Oliveira by collection support. This paper was improved by the thoughtful comments from two anonymous reviewers. Our collaborative project was funded by a grant from the Fundação de Amparo à Pesquisa do Estado de Goiás and the Newton Fund, which supported SLB's visit to Brazil to work with CRAC. CRAC was partially supported by the Conselho Nacional de Ciência e Tecnologia by Produtividade e Pesquisa fellow. SLB is also supported by a Marie Curie Career Integration Grants (CIG 630652).

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 aquisition, 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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Published with the financial support of the "Programa de Apoio às Publicações Científicas Periódicas da USP"