First Record of Sauropod Remains from the Maastrichtian Marília Formation (Bauru Group) of Monte Alegre de Minas Since Friderich von Huene’s Description in 1931
Os Primeiros Registros de Saurópodes Provenientes do Maastrichtiano da Formação Marília (Grupo Bauru) de Monte Alegre de Minas Desde a Descrição de Friderich von Huene em 1931

Carlos Roberto A. Candeiro¹,²; Diego Sullivan J. Alves³; Lívia M. Gil¹,² & Silvia Fernanda M. Figueirôa⁴

¹Universidade Federal de Goiás, Campus Aparecida de Goiânia, Curso de Geologia, Laboratório de Paleontologia e Evolução, Rua Mucuri, s/n, Area 03, St. Conde dos Arcos, 74968-755, Aparecida de Goiânia, GO, Brazil
²Universidade Federal de Goiás, Instituto de Ciências Biológicas, Programa de Pós-Graduação em Biodiversidade Animal, Alameda Palmeiras, s/n, Chácara Califórnia, 74710-310, Goiânia, GO, Brazil
³Universidade Estadual de Campinas, Instituto de Geociências, Departamento de Geografia, Cidade Universitária Zeferino Vaz, Barão Geraldo, 13083-870, Campinas, SP, Brazil
⁴Universidade Estadual de Campinas, Faculdade de Educação, Cidade Universitária Zeferino Vaz, Barão Geraldo, 13083-870, Campinas, SP, Brazil
E-mails: candeiro@ufg.br; diego_sullivan@hotmail.com; sfigueiroa@fe.unicamp.br

Recebido em: 25/02/2019      Aprovado em: 27/05/2019
DOI: http://dx.doi.org/10.11137/2019_2_325_332

Abstract

After 86 years since the historical work by von Huene describing dinosaur remains from the Marília Formation (Bauru Group) from the Monte Alegre de Minas municipality, new bone fragments from the same locality are presented here. The materials were identified as a part of a prezygapophysis and the margin of a robust bone. The fragmentary condition of these specimens did not allow a more specific assignment, but it was possible to identify characters that are present both in titanosaurids and sauropods.

Keywords: Sauropod; biodiversity; Triângulo Mineiro region; Late Cretaceous

Resumo

Após 86 anos, do trabalho histórico de von Huene que descreveu restos de dinossauros da Formação Marília (Grupo Bauru) de município de Monte Alegre de Minas, aqui se reportam fragmentos de ossos tentativamente atribuídos como uma parte de pré-zigapófise e borda de um osso robusto. O estado muito fragmentário de preservação destes materiais dificulta uma atribuição mais específica, mas estes apresentam características respectivas de dinossauros titanosaurídeos e saurópodes.

Palavras-chave: Saurópode; biodiversidade; região do Triângulo Mineiro; Neocretáceo
First Record of Sauropod Remains from the Maastrichtian Marilia Formation (Bauru Group) of Monte Alegre de Minas Since Frederich von Huene’s Description in 1931
Carlos Roberto A. Candeiro; Diego Sullivan J. Alves; Lívia M. Gil & Silvia Fernanda M. Figueirôa

1 Introduction

The dinosaur remains from the Monte Alegre de Minas municipality were identified by Frederich von Huene in 1931 when he first discovered fossil remains in the rocks of the Maastrichtian of Marília Formation (Bauru Group) in the Triângulo Mineiro region (Fernandes & Coimbra, 1996). After a long period without new paleontological findings from the same region, this contribution confirms the paleontological potential of these rocks as dinosaur remain-bearing levels. New field works were conducted in the same area where von Huene made his findings, and two more specimens were discovered: the articular facet of a prezygapophysis and the margin of an unidentified sinuous and robust bone. Although fragmentary, this new material adds, for the first time since 1931, new dinosaur specimens to the records of western Minas Gerais State.

The goal of the present study is to describe and compare these two new dinosaur specimens. These findings add new dinosaur materials to the records of this region.

1.1 Brief History of the Geology and Paleontology of Monte Alegre de Minas

Titanosauria is the only sauropod clade with records from the Bauru Group of Central Brazil. Many isolated remains from the Triângulo Mineiro region have been described thus far (e.g., von Huene, 1931; Kellner & Campos, 2000; Bertini et al., 2001; Santucci & Bertini, 2001; Almeida et al., 2004; Marinho & Candeiro, 2005; Lopes & Buchmann, 2008; Santucci, 2008; Candeiro, 2010; Bittencourt & Langer, 2011). The following taxa have been formally described to this geological unit: *Maxakalisaurus topai* Kellner, Campos, Azevedo, Trotta, Henriques, Graik & Silva 2006, from the Adamantina Formation of the municipality of Prata; *Baurutitan britoi* Kellner, Campos & Trotta 2005, *Trigonosaurus pricei* Campos, Kellner, Bertini & Santucci 2005, and *Uberabatitan ribeiroi* Salgado & Carvalho, 2008, from the Marília Formation of the municipality of Uberaba.

The first fossils from the Triângulo Mineiro region described by *Friedrich* von Huene (1931) were found in the municipality of Monte Alegre de Minas at the beginning of the last century. This region showed a great potential for the exploration of limestone surface deposits and, until today, limestone mining operations are still active. Von Huene (1931) has briefly mentioned the femur of a titanosaur dinosaur found by the Comissão Geográfica e Geológica de São Paulo (Geographic and Geologic Commission of São Paulo), however, the author does not give a detailed description of the specimen. This material has been used as reference by many historical studies on fossils from the Bauru Group of the Triângulo Mineiro region (e.g. Kellner & Campos, 2000; Candeiro et al., 2004; Candeiro, 2005, 2007; Peyerl et al., 2015).

The first verified mention of fossil materials from the Late Cretaceous of the Triângulo Mineiro region was made by the paleontologist Frederich von Huene in 1931, who reported the herbivorous titanosaurid dinosaur fossils found in the region of Monte Alegre de Minas. During the 1940s and 1950s, many important studies (e.g., Price, 1945, 1950a, b, 1951, 1955) were published about the fossils from the Uberaba and the Marília formations. These works comprise the most important systematic studies about the reptile fauna from Peirópolis/Uberaba, in the Triângulo Mineiro region.

According to Figueirôa (1997), the first geological surveys to the Triângulo Mineiro region were based on three main lines of action: territorial demarcation, exploration of minerals for industrial use, and offering of general services. Moreover, important studies were made during this period in order to delimit the frontiers between the states of São Paulo and Minas Gerais. The southern border of the Triângulo Mineiro region is limitrophe with the São Paulo State, and it was part of an important area of mineral resources and of significant interest to the surveys made by the Comissão Geográfica e Geológica de São Paulo (Figueirôa, 1997; Candeiro et al., 2014).

Milward (1935) was the first to mention the great extension of the outcrops in the Triângulo Mineiro region. These outcrops are characterized by elevated lowlands and steep slopes. The geological unit was formed by fluvial systems that eroded and
exposed the outcrops throughout a large area across the geographical boundaries of the Triângulo Mineiro region that are delimited by the rivers Rio Grande, Rio Paranáiba, and Rio Araguaia.

Hasui (1969) described the western portion of the Marília Formation in the Triângulo Mineiro region where rocks composed of clay were predominant, indicating the past occurrence of short periods of erosive phases that could be interpreted as alternate floods and sedimentation. This author was the first to systematically describe the stratigraphic units that outcrop in the Triângulo Mineiro region, and characterized these rocks as the Bauru and Ubra formations.

2 Geological Setting

The Marília Formation (Bauru Group) (Fig. 1) is subdivided in the Ponte Alta, Serra da Galga and Echaporã members (Figure 1) (Barcelos, 1984). According to Batezelli (2003), this geological unit is composed of calciferous sandstones (Ponte Alta Member), conglomerates, conglomerate sandstones, claystones, and siltstones, associated with calcretes and silcretes (Serra da Galga Member), as well as of sandstones and conglomerates cemented by calcium carbonate (Echaporã Member). The deposition of the Marília Formation occurred by the association of alluvial fan, fluvial, and ephemeral lake systems (Barcelos, 1984; Fernandes & Coimbra, 2000; Goldberg & Garcia, 2000). Aeolian sand sheet deposits indicate the periodicity of the sedimentation episodes and soil development (Dal’ Bó, 2009 Basilici et al., 2009), and the presence of an alluvial braided river (Batezelli & Ladeira, 2016). Dias-Brito et al. (2001) suggest that the Marília Formation is of Maastrichtian age.
In this region, the Marília Formation outcrops reach 3 m in thickness (Fig. 2) and are characterized by massive sandstone facies (Sm) (Miall, 1996). These sandstones are reddish in color, fine to medium-grained, poorly-sorted, showing dispersed clasts, and cemented by calcium carbonate (CaCO₃) with two levels of powdery calcrite. The sedimentary structures were completely obliterated by the pedogenic paleoprocesses and the cementation by CaCO₃. The fossil remains are located in the lower levels of the deposit.

3 Material

Institutional abbreviation – All fossil material were collected during a field work carried out in 2013 and are from the outcrops of the Marília Formation in the municipality of Monte Alegre de Minas. The specimens are permanently deposited in the collection “Paleontologia Universidade Federal de Goiás – Coleção de Vertebrados / Paleo-UFG/V” of the laboratory Laboratório de Paleontologia e Evolução of the Universidade Federal de Goiás. The specimens described here are labeled as Paleo-UFG/V-0020 and Paleo-UFG/V-0021.

Locality – Both specimens described here were recovered from a carbonate-cemented sandy deposit of the Marília Formation (Alves & Candeiro, 2013), located approximately 30 km west of the urban area of Monte Alegre de Minas.

4 Systematic Palaeontology

Dinosauria Owen, 1842
Saurischia Seeley, 1888
Sauropoda Marsh, 1878
Titanosauria Bonaparte & Coria, 1993
Titanosauria indet.
Specimen – Paleo-UFG/V-0020 consists of a part of a prezygapophysis (Fig. 3A).

Description. Paleo-UFG/V-0020 is a poorly preserved fragment of bone – the preservation state is similar to the one seen on *Rocasaurus muniozi* Salgado & Azpilicueta, 2000, *Gondwanatitan faustoi* Kellner & Azevedo, 1999, *Baurutitan britoi* Kellner, Campos & Trotta, 2005, and *Trigonosaurus pricei* Campos, Kellner, Bertini & Santucci, 2005 – and corresponds to the articular portion of a prezygapophysis anterodorsally projected, with its extremity dorsally oriented as seen on the caudal vertebrae of titanosaurs (Salgado et al., 1997; Powell, 2003; Campos et al., 2005). The edge of the body of the prezygapophysis is slightly inclined forward. The partially preserved prezygapophysis is relatively long (110 mm). The articular facet of the prezygapophysis has a suboval shape, being slightly larger on its anteroposterior dorsoventral diameter. The comparisons between this specimen and the prezygapophyses of other titanosaurs, such as *Aeolosaurus rionegrinus* Powell, 1987, *Gondwanatitan faustoi* Kellner & Azevedo, 1999, *Baurutitan britoi* Kellner et al., 2005, *Rocasaurus muniozi* Salgado & Azpilicueta, 2000, and *Trigonosaurus pricei* Campos et al., 2005, indicate that the material described here is part of a caudal vertebra, possibly fitting in the interval among the seventh and the tenth caudal vertebrae (Salgado & Azpilicueta, 2000; Campos et al., 2005).

?? Sauropoda indet.

Specimen – Paleo-UFG/V-0021 is the margin of a robust bone (Fig. 3B).

Description – Paleo-UFG/V-0021 is tentatively interpreted as the distal portion of a robust bone (e.g. pubis, humerus, coracoid) of an unidentified dinosaur. The caudal portion of the material is poorly preserved and the original compact trabecular bone surface observed along the whole specimen is very common in bones of saurischian dinosaurs. The well-structured spongy and trabecular structure seen on the lateral aspect of the material is similar to the specimens of *Sauropoda* studied by Wilson & Sereno (1998), Wedel (2007), Company (2011), and Wilson et al. (2011). The specimen is slightly curved and lateromedially compressed. The medial margin of the bone is better preserved than the lateral margin. The medial margin extends about 84 mm more distally than the lateral margin. The maximum length (proximodistal) of the specimen is 64 mm. The distal surface is irregular in cross-section view and the long axis is transversely oriented (62 mm mediolaterally and 75 mm craniocaudally). Although distally incomplete, it is noticeable that this dinosaur bone is robust and sinuous, especially along its distal margin.

5 Discussion

Although fragmentary, the material described here show anatomical information that allows
an approximate taxonomic identification. The prezygapophysis (Paleo-UFG/V-0020) presents the following characters used by Powell (2003) to the diagnosis of Titanosauria: enlarged prezygapophyses in the anterior caudal vertebrae and prezygapophyses with anteroposteriorly elongated articular facets. This is in agreement with the proposals made by Powell (2003) and Salgado & Coria (1993) regarding the characteristics of the prezygapophyses of this taxon. By considering the anterodorsal projection of the prezygapophysis with a dorsally oriented apex observed in the specimen Paleo-UFG/V-0020, it was possible to make a preliminary identification of this material as a Titanosauria. The record of the sauropod fauna known from the Triângulo Mineiro region is exclusively formed by species and isolated, fragmentary specimens of titanosaurids (see Candeiro, 2007; Gil & Candeiro, 2014; Martinelli & Teixeira, 2015). Therefore, it would be reasonable to assign Paleo-UFG/V-0020 to this taxon. Besides, most of saurischian dinosaurs have presacral vertebrae with well developed spongy structure (Wilson & Sereno, 1998; Wedel, 2007; Company, 2011; Wilson et al., 2011). Paleo-UFG/V-0021 presents this same characteristic and, although it is very fragmentary, we believe that it is more parsimonious to preliminary consider this specimen as an indeterminate Sauropoda due its compressed camellate structure than to assign it to a more inclusive taxonomic level.

The taxonomy of Paleo-UFG/V-0020 and Paleo-UFG/V-0021 supports the presence of dinosaurs in the region of Monte Alegre de Minas and, together with the previous records from the rocks of the Bauru Group reported by von Huene (1931), it shows the importance of this classic palaeontological area of the Triângulo Mineiro region. In addition, we emphasize that the municipality of Monte Alegre was the first locality where the occurrence of dinosaurs in the Triângulo Mineiro region was first discovered in 1930, and only 14 years later Price (1945) published his discoveries made on the municipality of Uberaba.

6 Conclusion

The specimen Paleo-UFG/V-0020 consists of an incomplete prezygapophysis assigned to Titanosauria while the specimen Paleo-UFG/V-0021 was assigned to ?Sauropoda indet. The presence of these taxa in the Marília Formation, in Monte Alegre de Minas, provides new faunal data to this paleontological unit after 86 years. The dinosaur fauna from this region is known for consisting of sauropod remains, and the Monte Alegre de Minas municipality outcrops have been showing the same sauropod elements than other areas of the Triângulo Mineiro region. Moreover, these records are from one of the few localities where dinosaur remains are found in the conglomerate levels from the Marília Formation in the Triângulo Mineiro region.

In summary, as previously mentioned, the fragments of sauropod remains from the Maastrichtian faunal assemblage of Monte Alegre municipality are very inconsistent and biased. However, despite the fragmentary condition of the two specimens described here, it was possible to acquire new information about the Late Cretaceous dinosaurs of the Marília Formation from the Monte Alegre locality, providing further data on the sauropod fauna of Minas Gerais State.

7 Acknowledgments

We are much indebted to Silvina de Valais (Universidad Nacional de Río Negro/Argentina), for comments on the early manuscript and Gabriela de Souza Santos for academic support. This contribution was partially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo a Pesquisa de Goiás (FAPEG). R. Candeiro is also grateful to CNPq for the Produtividade em Pesquisa fellowship, and D. Alves of Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for supporting and funding (Doctor scholarships).

References

Almeida, E.B.; Avilla, L.S. & Candeiro, C.R.A. 2004. Restos caudais de Titanosauriidae da Formação Adamantina (Turoniano-Santoniano), sítio do Prata, estado de Minas Gerais, Brasil. Revista Brasileira de Paleontologia, 7: 239-244.

Alves, D.S.J. & Candeiro, C.R.A. 2013. Levantamento dos afloramentos de arenitos carbonatados da Formação Marília.
lia (Grupo Bauru, Cretácio Superior) no município de Monte Alegre de Minas, Estado de Minas Gerais. *Revisão Georgrafica*, 3: 114-138.

Barcelos, J.H. 1984. Reconstrução paleogeográfica da sedimentação do Grupo Bauru baseada na sua redefinição estratigráfica parcial em território paulista e no estudo preliminar fora do estado de São Paulo. Departamento de Geociências de Rio Claro, Universidade Estadual Paulista de Rio Claro, Tese de Livre Docência, 190p.

Basilici, G.; Dal’Bo, P.F.F.; & Ladeira, F.S.B. 2009. Paleoclimatic interpretations from pedogenic calcretes in a Maastrichtian semi-arid eolian sand-sheet paleoenvironment: Marília Formation (Bauru Basin, southeastern Brazil). *Cretaceous Research*, 30: 659-675.

Batezelli, A. & Ladeira, F.S.B. 2015. Stratigraphic framework of the Bauru Group, Late Cretaceous of Brazil. *Sedimentology*, 56: 1876-1904.

Batezelli, A. 2015. Continental systems tracts of the Brazilian Cretaceous Bauru Basin and their relationship to the tectonic and climatic evolution of South America. *Basin Research*, 29: 1-25.

Batezelli, A.; Saad, A.R.; & Etchebehere, M.L.C. 2003. Análise Estratigráfica Aplicada à Formação Araçatuba (Bacia Bauru - KS) no oeste do Estado de São Paulo. *Geociências*, 20: 05-19.

Batezelli, A. & Ladeira, F.S.B. 2015. 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.

Bertini, R.J.; Santucci, R.M. & Campos, A.C. 2001. Titanosaurs (Sauropoda: Saurischia) in the Cretaceous Superior continental (Formação Marília, Membro Echaporã) of Monte Alto, Estado de São Paulo, and correlation with formations associated with the Triângulo Mineiro. *Geociências*, 20: 93-103.

Bittencourt, J.S. & Langer, M.C. 2011. Mesozoic dinosaurs from Brazil and their biogeographic implications. *Anais da Academia Brasileira de Ciências*, 73: 23-60.

Company, J. 2011. Bone histology of the titanosaur *Titanosaurus* (Titanosauria) from the Late Cretaceous of Brazil. In: Y. TOMIDA; T.H. RICH & P. VICKERS-RICH (Eds.). *Proceedings of the second Gondwanan Dinosaur Symposium*, National Science Museum Monograph 15, Tokyo, p. 111-142.

Candeiro, C. R. A. 2007. Cretaceous biota of the Triângulo Mineiro region: A review of recent finds. *Estudios Geológicos*, 63: 65-73.

Candeiro, C. R. A. 2010. Record of the genus *Aelosaurus* (Sauropoda, Titanosauria) in the Late Cretaceous of South America: Paleogeographic implications. *Estudios Geológicos*, 66: 243-253.

Candeiro, C. R. A.; & Peyerl, D.; Figueirôa, S.F.M. & Castanho, R.B. 2014. History and Paleontology of the Pontal do Triângulo Mineiro: The first fossil discoveries of the Upper Cretaceous of Minas Gerais. *Geographia Opportuno Tempore*, 1: 2-10.

Candeiro, C. R. A. 2005. On a titanosaurid (Dinosauria, Sauropoda) vertebral column from the Bauru Group, Late Cretaceous of Brazil. *Arquivos do Museu Nacional*, 63: 565-593.

Dal’Bo, P. F. F.; Basilici, G.; Angelica, R. S. & Ladeira, F. S. B. 2009. Paleoclimatic interpretations from pedogenic
First Record of Sauropod Remains from the Maastrichtian Marília Formation (Bauru Group) of Monte Alegre de Minas Since Friderich von Huene’s Description in 1931
Carlos Roberto A. Candeiro; Diego Sullivan J. Alves; Lívia M. Gil & Silvia Fernanda M. Figueirôa

Goiás. São Paulo, Escola Profissional Salesianas, 193 p.

Peyerl, D.; Candeiro, C.R.A. & Figueirôa, S.F.M. 2015. Trajectory and contribution of geoscientists (1906-1961) to dinosaur research in the Bauru Group (Cretaceous) in the Triângulo Mineiro region of Brazil. Journal of South American Earth Sciences, 1: 64-70.

Powell, J.E. 1987. The Late Cretaceous fauna from Los Almí- tos, Patagonia, Argentina. Part. VI. The titanosaurs. Museo Argentino Ciencias Naturales, 3: 147-153.

Powell, J.E. 2003. Revision of South American Titanosaurid dinosaur: palaeobiological, palaeobiogeographical and phylogenetic aspects. Records of the Queen Victoria Museum, III: 1-173.

Price, L.I. 1950. On a new crocodilian, Sphagesaurus, from the Cretaceous of the state of São Paulo, Brazil. Anais da Academia Brasileira de Ciências, 22: 77-85.

Price, L.I. 1951. Um ovo de dinossaurio na formação Baurú, do Cretáceo do estado de Minas Gerais. Notas Preliminar Divisão de Geologia e Mineralogia, 53: 1-7.

Price, L. 1945. I. A new reptile from the Late Cretaceous of Brazil. Serviço Geológico Mineralógia, 25: 1-8.

Price, L.I. 1950b. Os crocodilideos da fauna da formação Baurú, do Cretáceo terrestre do Brasil Meridional. Anais da Academia Brasileira de Ciências, 22: 473-490.

Price, L.I. 1955. Novos crocodilideos dos Arenitos da Série Bauru, Cretáceo do estado de Minas Gerais. Anais da Academia Brasileira de Ciências, 27: 487-498.

Salgado, L. & Coria, R.A. 1993. El género Aeolosaurus (Sauropoda. Titanosauridae) en la Formación Allen (Campaniano-Maastrichtiano) de la Provincia de Río Negro, Argentina. Ameghiniana, 30: 119-128.

Salgado, L. & Coria, R.A.; Calvo, J.O. 1997. Evolution of titano- nosaurid sauropods. I. Phylogenetic analysis based on the postcranial evidence. Ameghiniana, 34: 3-32.

Salgado, L. & Azpilicueta, C. 2000. Un nuevo saltasaurino (Sauropoda, Titanosauridae) de la provincia de Río Negro (Formacion Allen, Cretáceo Superior), Patagonia, Argentina. Ameghiniana, 37: 259-264.

Salgado, L; Coria, R.A. & Calvo, J.O. 1997. Evolution of titano- nosaurid sauropods. I: Phylogenetic analysis based on postcranial evidence. Ameghiniana, 15: 3-32.

Salgado, L. & Carvalho, I.S. 2008. Uberabatitan ribeiroi, A new titanosaur from the Marília Formation (Bauru Group, Upper Cretaceous), Minas Gerais, Brasil. Palaeonto- logy, 31: 881-901.

Santucci, R.M. & Bertini, R.J. 2001. Paleogeographical and biochronological distributions of the Bauru Group titanosaurids (Saurischia, Sauropoda) Upper Cretaceous of southeastern Brazil. Revista Brasileira de Geociências, 31: 307-314.

Santucci, R.M. 2008. First titanosaur (Saurischia, Sauropoda) axial remains from the Uberaba Formation, Upper Cretaceous, Bauru Group, Brazil. Historical Biology, 20: 165-173.

Wedel, M.J. 2007. Aligerando a los gigantes (Lightening the giants). ¡Fundamental!, 12: 1-84.

Wilson, J.A; D’Emic, M.D; Ikejiri, T; Moacdieh, E.M & Whi- tilock, J.A. 2011. A Nomenclature for Vertebral Fossae in Sauropods and Other Saurischian Dinosaurs. PLOS ONE, 6: e17114

Wilson, J.A & Sereno P.C. 1998. Early evolution and higher-le- vel phylogeny of sauropod dinosaurs. Society of Verte- brate Paleontology Memoir, 5: 1-68.