Cretaceous biota of the Triângulo Mineiro region (Brazil): A review of recent finds

*Biota cretácica de la región del Triângulo Mineiro (Brasil):
Revisión de hallazgos recientes*

C. R. A. Candeiro¹

ABSTRACT

The Bauru Group (Adamantina, Uberaba, and Marília Formations) crop out in the Triângulo Mineiro region, Minas Gerais State, Brazil, and yield a rich continental biota. Invertebrate and vertebrate taxa from underlying and overlying strata, as well as biostratigraphical correlations with other fossil sites in Argentina, suggest an Upper Cretaceous age for this biota. The diversity of the fossil assemblage recorded in these formations is summarized here and includes: frogs, lizards, crocodiles, titanosaurs, abelisaurid and carcharodontosaurid dinosaurs. This fossil assemblage provides important clues to understand faunas from other southern landmasses, particularly those from the Cretaceous of the African continent.

Key-words: Upper Cretaceous, Triângulo Mineiro, Adamantina, Uberaba, and Marília Formations, biota, Brazil.

RESUMEN

Los afloramientos del Grupo Bauru (formaciones Adamantina, Uberaba y Marília) en la región del Triângulo Mineiro, Provincia de Minas Gerais, Brasil, posee un rico contenido de biota continental. Los taxa de invertebrados y vertebrados de estos estratos, así como las correlaciones bioestratigráficas con otros yacimientos fósiles de Argentina, sugieren una edad del Cretácico Tardío. La diversidad de la asociación fósil registrada en las formaciones del Triângulo Mineiro se resume en el presente trabajo e incluye: sapos, lagartos, tortugas, cocodrilianos, titanosaurideos, dinosaurios abelisaurideos y carcharodontosaurideos. Esta asociación es importante para la comprensión de las faunas del sur de América y también de las del Cretácico de África.

Palabras-clave: Cretácico superior, Triângulo Mineiro, formaciones Adamantina, Uberaba y Marília, biota, Brasil.

Introduction

The Triângulo Mineiro region (19° 11'-10" and 19°-49' 59"S, 47° 30' and 48° 19' 24" W) occupies approximately 3.265 km², and is located in western Minas Gerais State, Brazil (fig. 1). The region contains one of the richest Upper Cretaceous continental biota known in the country (see table 1). Fossil bearing strata of fluvial, eolian and lacustrine sediments, are exposed in the Triângulo Mineiro region, which includes Campina Verde, Monte Alegre, Prata, Uberaba, and Uberlândia municipalities.

Vertebrate bones were first discovered in late 1940 near Uberaba Town; during the following

decade, Llewellyn Ivor Price re-studied the vertebrate-bearing deposits of the Triângulo Mineiro region focusing on the Adamantina and Marília Formations. The Adamantina, Uberaba, and Marília Formations from Triângulo Mineiro have yielded abundant dinosaur bones, including partial skeletons, eggs, and teeth associated with remains of other macro and microvertebrate assemblages (Bertini *et al.*, 1993; Dias-Brito *et al.*, 2001).

The most common taxa is reptilian, and occurs in the Adamantina and Marília formations of Campina Verde, Monte Alegre, Prata, and Uberlândia municipalities. The Uberaba Formation, restricted to the Triângulo Mineiro region, includes only a few vertebrate taxa. In the Uberaba Formation scarce

¹ Laboratório de Macrofósseis, Departamento de Geologia, Universidade Federal do Rio de Janeiro (UFRJ), Av. Brig. Trompsky, S/N, Cidade Universitária, Rio de Janeiro, RJ, Brazil. E-mail: candeiro@ras.ufu.br.

Fig. 1.—Map of the Triângulo Mineiro municipalities (Minas Gerais State, Brazil) illustrating location of the more important biota-bearing Bauru Group regions. 1, Campina Verde; 2, Monte Alegre de Minas; 3, Prata; 4, Uberlândia; 5, Uberaba.

records of dinosaurs are represented mainly by eggs and isolated bones.

The intention of this work is to summarize the current knowledge of the stratigraphy of the Upper Cretaceous fossil-bearing units of the Bauru Group from Triângulo Mineiro, and the composition of fauna and flora inferred from their assemblages.

Geological and paleontological setting

The Bauru Group is an important fossil-bearing unit in the Triângulo Mineiro region that ranges in age from Turonian to late Maastrichtian (fig. 2). According to Fernandes & Coimbra (1996) the group comprises a southeastward-thinning succession of continental rocks nowadays exposed in modern drainages throughout South-Central Brazil, which conformably overlies magmatic rocks of the Jurassic-Cretaceous Serra Geral Formation (São Bento Group, Paraná Basin). The Bauru Group has been a source of dinosaur and other fossil vertebrates (figs. 3A-K), invertebrates, and plants that have been discovered and collected since the early part of the 20th century.

Fernandes & Coimbra (1996) included the Adamantina, Uberaba, and Marília formations (ascending order) in the Bauru Group; this stratigraphic arrangement is widely accepted and used in this study.

Adamantina Formation

This unit was established by Soares *et al.* (1980) referring to the continental deposits which unconformably overlie the Serra Geral Formation (São Bento Group, Paraná Basin). The Adamantina Formation crops in the States of Goiás, São Paulo and in the Triângulo Mineiro region, Minas Gerais State. Sediments are fluvial-lacustrine reddish clays and sands, deposited during warm and humid climatic events (Suguio & Barcelos, 1983). Based primarily on its vertebrate fossil contents, it is assumed that the Adamantina sediments were deposited during the Turonian-Santonian (Dias-Brito *et al.*, 2001). The geology of the Adamantina Formation in Triângulo Mineiro region has been studied by several authors (Barcelos, 1984; Ferreira-Júnior, 1996; Goldenberg & Garcia, 2000). The formation's maximum thickness is close to 200m.; it is composed of medium-grained sandstones, shales, and conglomerates that are purple, dark red and brownish in color, deposited in a fluvial environment under braided regime (Barcelos, 1984).

Fossil content

The Adamantina Formation has a remarkable faunal record of essentially vertebrate taxa. Dinosaur remains are the most representative record. Among sauropods, specimens recovered include the eutitanosaurian *Aeolosaurus* (Almeida *et al.*, 2004), isolated caudal vertebrae, and ribs of Titanosauria from the Prata area (Marinho, 2003; fig. 3J). Recently at the Prata Site was described a new titanosaur *Maxakalisaurus topai* by Kellner *et al.* (2006). Abelisaurid, carcharodontosaurid, and theropod indet. isolated attributed to teeth were reported by Marinho (2003), and Candeiro *et al.* (2003, 2006), from this unit near the Boa Vista Hill (Prata Town). The fossil-bearing horizons of the Adamantina Formation at Boa Vista Hill have yielded freshwater taxa including turtles and crocodyliforms (Marinho, 2003; Candeiro *et al.*, 2003).

Uberaba Formation

This unit, defined by Barbosa (1934), is one of the most homogeneous and characteristic units of the Bauru Group. The formation has restricted exposures in Triângulo Mineiro region where interdigitates with the Adamantina Formation. Litholog-

Table 1.—List of biota content from the Late Cretaceous Triângulo Mineiro region (Minas Gerais State, Brazil). Localities are shown in figure 1

Taxa	Locality	Stratigraphy	Selected References
INVERTEBRATES			
Gastropoda			
Ostracods			
<i>Llyocypris setembrinopetreei</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Amblyochara</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Llyocypris</i> sp. 1	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Neuquenocypris minor mineira</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Virgatocypris mezzalirai</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Altanicupris australis</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Lycoperocypris angulata</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Candonopsis</i> sp.	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
Gen. et sp. Indet 1	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
Gen. et sp. Indet 1	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
Viviparid			
<i>Viviparus</i> sp. B	Uberaba	Serra da Galga Mb., Marília Fm.	Senra (2002)
<i>Viviparus souzai</i>	Campina Verde	Serra da Galga Mb., Marília Fm.	Senra (2002)
Physidae			
<i>Physa aridi</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Senra (2002)
Bivalvia			
<i>Florencia peiropolensis</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Mezzalira (1974)
<i>Anodontites (Anodontites) pricei</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Mezzalira (1974)
<i>Sphaerium (Musculium) sp.</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Senra (2002)
VERTEBRATES			
Fishies			
Characiform	Uberaba	Serra da Galga Mb., Marília Fm.	Gayet and Brito (1989)
Siluriform	Uberaba	Serra da Galga Mb., Marília Fm.	Gayet and Brito (1989)
Perciform	Uberaba	Serra da Galga Mb., Marília Fm.	Gayet and Brito (1989)
Osteichthyes indet.	Uberlândia, Uberaba	Ponte Alta and Sena da Galga Mbs, Marília Fm.	Bertini <i>et al.</i> (1993), Fernandes (1998)
Frog			
<i>Baurubatrachus pricei</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Baez and Peri (1989)
Turtles			
Chelonia indet.	Uberaba	Serra da Galga Mb., Marília Fm.	Bertini <i>et al.</i> (1993), Marinho (2003)
<i>Cambaremys langertoni</i>	Uberaba	Serra da Galga Mb., Marília Fm.	França and Langer (2005)
Lepidosaur			
<i>Pristiguana brasiliensis</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Estes and Price (1973)
Crocodyles			
<i>Itasuchusjesuinoi</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Price (1955)
<i>Peirosaurus torminii</i>	Uberaba	Serra da Galga Mb., Marília Fm.	Price (1955)
Crocodylia indet.	Uberaba	Serra da Galga Mb., Marília Fm.	Avilla (2002), Candeiro <i>et al.</i> , (2003)
Dinosaurs			
Sauropods			
N. sp. et gen.	Uberaba	Uberaba Fm.	Santucci (2002)
"Megalodontidae"	Uberaba	Uberaba Fm., Sena da Galga Mb., Marília Fm.	Magalhães-Ribeiro (2002a, b)
Titanosauria	Campina Verde, Monte Alegre, Prata, Uberaba	Uberaba Fm., Sena da Galga Mb., Marília Fm.	Powell (1986, 1987, 2003), Marinho (2003)
N. sp. et gen.	Uberaba	Serra da Galga Mb., Marília Fm.	Santucci (2002)
<i>Aeolosaurus</i>	Prata, Uberaba	Serra da Galga Mb., Marília Fm., Adamantina Formation	Santucci (2002), Almeida <i>et al.</i> (2004)
Theropods			
Theropoda indet.	Prata, Uberaba	Serra da Galga Mb., Marília Fm., Adamantina Formation	Kellner (1996), Franco (1999), Candeiro (2002), Marinho (2003)
Abelisauridae	Prata, Uberaba	Serra da Galga Mb., Marília Fm., Adamantina Formation	Candeiro (2002), Marinho (2003)
Carcharodontosauridae	Prata, Uberaba	Serra da Galga Mb., Marília Fm., Adamantina Formation	Candeiro (2002), Marinho (2003)

Table 1.—List of biota content from the Late Cretaceous Triângulo Mineiro region (Minas Gerais State, Brazil). Localities are shown in figure 1 (continued)

Taxa	Locality	Stratigraphy	Selected References
FLORA			
Charophyta			
<i>Feistiella</i> cf. <i>globosa</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Feistiella</i> cf. <i>costata</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Sphaerochara latifasciata</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Nitellopsis</i> ? sp.	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Gobichara</i> (<i>Pseudoharrisichara</i>) <i>groeberi</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Gobichara</i> (<i>Pseudoharrisichara</i>) sp.	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
<i>Chara tomentosa</i>	Uberaba	Ponte Alta Mb., Marília Fm.	Dias-Brito <i>et al.</i> (2001)
Pteridophyta			
<i>Marsilea</i> ?	Uberaba	Serra da Galga Mb., Marília Fm.	Senra and Silva-Silva

ically, these strata are composed of freshwater limestones, sandstones, and basal conglomerate, all cemented by calcium carbonate and vulcanoclastic sediments (Barcelos, 1984); green sandstones with thin layers of light red sandstones are common within the succession. The formation's maximum thickness is close to 140 m (Fernandes & Coimbra, 1996), and is considered Coniacian-Santonian by Dias-Brito *et al.* (2001) in age

Fossil content

The Uberaba Formation has yielded only disarticulated dinosaur specimens. Santucci (2002) noted that sauropod remains from the Uberaba Formation represent possibly basal titanosaurs. One dinosaur nest was reported near the Peirópolis district of the Uberaba Town by Barbosa *et al.* (1970), which Campos & Bertini (1985) attributed to an ornithischian taxon (fig. 3H-I). However, Kellner *et al.* (1998) attributed this record to a theropod dinosaur.

Marília Formation

This is the youngest unit of the Bauru Group and was first named by Almeida & Barbosa (1953). The Marília Formation is exposed in the Goiás and São Paulo States and in the Triângulo Mineiro region. The Marília Formation consists in fine to medium sandstones intercalated by conglomerate levels. The sandstones are cemented and contain concretions of calcium carbonate (Fúlfaro & Barcelos, 1991). The formation thickness is estimated to be 180m in Minas Gerais State (Fernandes & Coimbra, 1996). Dias-Brito *et al.* (2001) suggested an Upper Maastichtian age for the Marília Formation.

Barcelos (1984) subdivided the Marília Formation into three members: two restricted in the Triângulo Mineiro region, the Ponte Alta & Serra da Galga Members, and the Echaporã Member that crops in the Goiás and São Paulo States. The Ponte Alta Member is characterized sedimentologically as a "calcareous white member" composed of thin and medium calcareous horizons with pebbles and calcareous nodules deposited in alkaline lakes ("playa-lake" type) oversaturated with calcium bicarbonate (Garrido *et al.*, 1992). The upper Serra da Galga Member is characterized as a "member of white limestone and conglomerate" composed of conglomerate and thin to medium limestones, with a bleached coloration in a feldspar matrix (Garrido *et al.*, 1992). According to Suguio (1973, 1980), both members were formed in a moderately dry climate that would have favored fossil preservation.

Fossil content

Among the aquatic vertebrate taxa are: Lepisosteiformes, Characiformes, Siluriformes, Perciformes and Osteichthyes indet. "Leptodactylidae" species are represented only by *Baurubatrachus pricei* (Baez & Peri, 1989), and represents the only known anuran from the Bauru Group in Triângulo Mineiro region. From the Peirópolis Site (Uberaba) crocodyliform species referred to as peirosaurids such as *Peirosaurus tormini* and *Itasuchus jesuinoi* (Price, 1955), and *Uberabasuchus terrificus* (Carvalho *et al.*, 2004) are known (sense Avilla, 2002; Carvalho *et al.*, 2004; fig. 3A-G). Podocnemine turtles were recorded by Bertini *et al.* (1993). A new turtle *Cambaremys langertoni* was recently described by França & Langer (2005) from Peirópolis Site. Dinosaurs comprise the largest,

most abundant and diverse vertebrates found at the Peirópolis Site (Kellner & Campos, 2000; Marinho *et al.*, 2003; fig. 3K). Teeth remains of titanosaurs, abelisaurid and carcharodontosaurid occur frequently at Uberaba. Recently, Novas *et al.* (2005) reported the first maniraptoran dinosaur remain of the Bauru Group from Peirópolis area. Titanosaurs include *Baurutitan britoi* and *Aeolosaurus* sp. (Bertini *et al.*, 2000; Kellner *et al.*, 2005). One dinosaur nest was reported near the Mangabeira district of the Uberaba Town (Price 1951), which was attributed as “*Hypselosaurus*” sp. (Bertini *et al.*, 1993). Recently, “*Megalolithidae*” egg shells were reported from the Peirópolis area (Magalhães-Ribeiro 2002a, b).

Freshwater invertebrates have been reported from the Marília Formation (see table 1). Mollusks are well represented in the Uberaba municipality and include: *Llyocypris setembrinopetreei*, *Llyocypris* sp. 1, *Neuquenocypris minor mineira*, *Virgatocypris mezzalirai*, *Altanicupris australis*, *Lycocypris angulata*, *Candonopsis* sp., and two new species. *Llyocypris argentinensis*, *I. wichmanni*, and *Neuquenocypris minor* correlate this biota to that from the Neuquen Basin, Argentina (Dias Brito *et al.*, 2001) and support the temporal assignment (see table 1). The charophyte assemblage represented by *Feistiella* cf. *globosa*, *Feistiella* cf. *costata*, *Sphaerochara latifasciata*, *Nitellopsis* ? sp., *Gobichara* (*Pseudoharrisichara*) *groeberi*, *Gobichara* (*Pseudoharrisichara*) sp., and *Chara tomentosa*, has a broad distribution in the Bauru Group (Dias Brito *et al.*, 2001).

Discussion

The Triângulo Mineiro biota is important for several reasons, principally in terms of stratigraphical interest, because it ranges in age from the Turonian to the late Maastrichtian. It is also historically important because of many early discoveries of Late Cretaceous vertebrates from Central Brazil, including the first dinosaur eggs ever found in Brazil. Crocodiles and dinosaurs are the most common vertebrates found in Triângulo Mineiro region. Titanosaurid dinosaurs are the most abundant, but abelisaurid and carcharodontosaurid theropods are also represented. Our knowledge of Triângulo Mineiro biota has been greatly improved in the last five years through the exploration of a number of rich localities at Uberaba and Prata

Fig. 2.—Geological map of the Triângulo Mineiro region, Minas Gerais State, Brazil (modified from Fernandes and Coimbra, 1996).

municipalities and due to the identification or revision of interesting specimens: 39 taxa have been reported in recent years. New taxa include abelisaurid and carcharodontosaurid theropods, and the eutitanosaurian *Aeolosaurus*, from the Adamantina and Marília Formations. Additional dinosaur specimens have been re-described or revised in detail in recent years (Marinho, 2003; Powell, 2003; Marinho & Candeiro, 2005), including remains from Marília Formation, such as titanosaur osteoderms and caudal vertebrae, and “*Megalolithidae*” eggs. Most of the vertebrate material from Triângulo Mineiro is fragmentary, but specimens of *Peirosaurus*, *Itasuchus*, *Aeolosaurus*, Abelisauridae and Carcharodontosauridae have diagnostic features such as wrinkles on the crown tooth. For the ichnological record, dinosaur eggs of “*Megalolithidae*” are known from the sites of the Uberaba municipality. Finally, the Late Cretaceous mollusk and charophytae records of Uberaba are among the most representative in the Bauru Group and have yielded several species also known from Patagonia (Leanza *et al.*, 2004).

The similarity between the biota contents of the Turonian-Maastrichtian units of the Triângulo Mineiro region to the Patagonian units (Bajo Barreal Formation, middle Cenomanian-Turonian; Angostura Colorada, Late Senonian; Bajo de La Carpa Formation, Santonian; Los Alamitos, Late Campanian; Allen Formation, middle Maastrichtian), suggests

Fig. 3.—A-E, osteoderms and F, premaxilla of left premaxilla of *Peirosaurus tormini*; G, dentary of the *Itasuchus jesuinoi*; H, I, dinosaur eggs from the Uberaba Formation; J, titanosaur caudal vertebra from Prata municipality; K, titanosaur osteoderm from Marília Formation of the Uberaba Municipality. (A-G, from Price, 1955; H, I, from Kellner and Campos, 2000; J, from Marinho, 2003; K, from Marinho and Candeiro 2005). Scale bar in A-F = 2mm; G = 17 mm; H, I = 5 mm; J = 10 mm; K = 20 mm.

that by the early Late Cretaceous there was an interconnection between these realms. This is evidenced from the common presence of Carcharodontosauridae and Abelisauridae. The same geographical spreading pattern is evidenced by the crocodilian *Peirosaurus tormini* found both, in the Marília Formation in Brazil and in the Bajo de la Carpa Formation of Patagonia, where seems to appear as early as the Santonian stage.

It is difficult to determine whether this Brazilian biota is more related to African or Patagonian taxa from the middle Cretaceous. Comparison of the tetrapod assemblages from both areas is heavily biased. Most of the southern Patagonian ones well represented in the Triângulo Mineiro region (e.g. *Aeolosaurus*, *Peirosaurus*, ostracods) are currently considered as endemic. However, the similarity of carcharodontosaurid remains (from the Adamantina Formation, São Paulo State, Brazil) to the African biota may demonstrate their close relationship with African taxa. Another important implication concerns the distribution of the crocodile genus *Itasuchus*, which is found in the Santana Formation (Albian). The frequent occurrences of this genus in the Marília Formation indicate that this taxon was probably also extremely common during Upper Cretaceous.

Conclusions

The evaluation of the Triângulo Mineiro biota has revealed a wide diversity of taxa (e.g. mollusks, crocodilians, dinosaurs) and ostracods. This biota, discovered in the formations of the Bauru Group, spans from Turonian to late Maastrichtian. These sediments were deposited in eolian and fluviolacustrine environments.

The Triângulo Mineiro biota is similar to Argentinean Late Cretaceous faunal assemblages, such as those from Patagonian deposits. The Triângulo Mineiro biota also shares compositional features with Cretaceous continental tetrapod faunas from more distant Gondwanan localities (e.g. continental Africa), indicating a common Gondwanan origin.

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