LATE CRETACEOUS TETRAPODS DIVERSITY OF THE TRIÂNGULO MINEIRO REGION (MINAS GERAIS STATE, BRAZIL)

Diversidade de Tetrápodes do Cretáceo Superior na região do triângulo mineiro (Estado de Minas Gerais, BRASIL)

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Abstract
The Turonian-late Maastrichtian Adamantina, Uberaba and Marília Formations crop out at the Triângulo Mineiro region, Minas Gerais State, Brazil, yielding 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 biota recorded from the Adamantina, Uberaba and Marília Formations of Triângulo Mineiro region is summarized here and includes; frogs, lizards, turtles, crocodiliforms, titanosaurs, abelisaurids and carcharodontosaurids dinosaurs and aves. This tetrapod content provides important clues to help understand fauna from elsewhere, such as those from the Cretaceous of Gondwana.

Key words: Upper Cretaceous. Triângulo Mineiro. Adamantina. Uberaba and Marília Formations. Tetrapods.

Resumo
As formações Adamantina, Uberaba e Marília (Turoniano-Neomaastrichtiano) afloram na região do Triângulo Mineiro, Estado de Minas Gerais, Brasil são representadas por uma abundante e diversa biota do Neocretáceo. Os taxa de invertebrados e vértebrados se constituem de um importante registro de correlação biostratigrafica com os registros encontrados na Argentina. Esse conteúdo sugere uma idade referente ao Cretáceo Superior a essa biota. A diversidade dessa biota registrada nas formações Adamantina, Uberaba e Marília da região do Triângulo Mineiro inclui; restos de sapos, lagartos, tartarugas, crocodilos, além de dinossauros titanossaurídeos, abelisaurídeos e carcarodontosaurídeos e aves. Esse registro

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de tetrápodes confere um importante entendimento da relação dessa fauna com a encontrada no Cretáceo do Gondwana.

Palavras-chave: Cretáceo Superior. Triângulo Mineiro. Formações Adamantina. Uberaba e Marília. Tetrápodes.

Introduction

The Triângulo Mineiro region (19° 11'-10" and 19° 49' 59"S, 47° 30' and 48° 19' 24" W) is 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 in the country (Appendix). 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 1940 decade near Uberaba Town. During the nineteen-forties, Llewellyn Ivor Price studied the vertebrate-bearing deposits of the Triângulo Mineiro region, in the Adamantina and Marília Formations. These sites were revisited after an interruption of more than 20 years. 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 vertebrates and microvertebrate assemblages (Bertini et al., 1993; Dias-Brito et al., 2001).

The best-known taxa occur 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 invertebrate vertebrate taxa. In the Uberaba Formation scarce 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 biota-bearing lithostratigraphic units of Bauru Group from Triângulo Mineiro region, and the composition of faunal and floral assemblages within them.

Historical setting

The fossil bearing strata of Triangulo Mineiro region are also exposed in the vicinity of Prata and Uberaba towns where the Brazilian paleontologist Llewellyn Ivor Price collected material in 1940 (Kellner, 1996; Candeiro et al., 2008). More recently the Centro de Pesquisas Paleontologicas, Museu Nacional, Laboratório de Macrofosseis/Universidade Federal do Rio

de Janeiro, and Laboratório de Geologia/Campus Pontal/Universidade Federal de Uberlandia teams have re-examined the stratigraphy and paleontological content of these region, and re-newed collecting efforts are summarized by Candeiro et al., (2008).

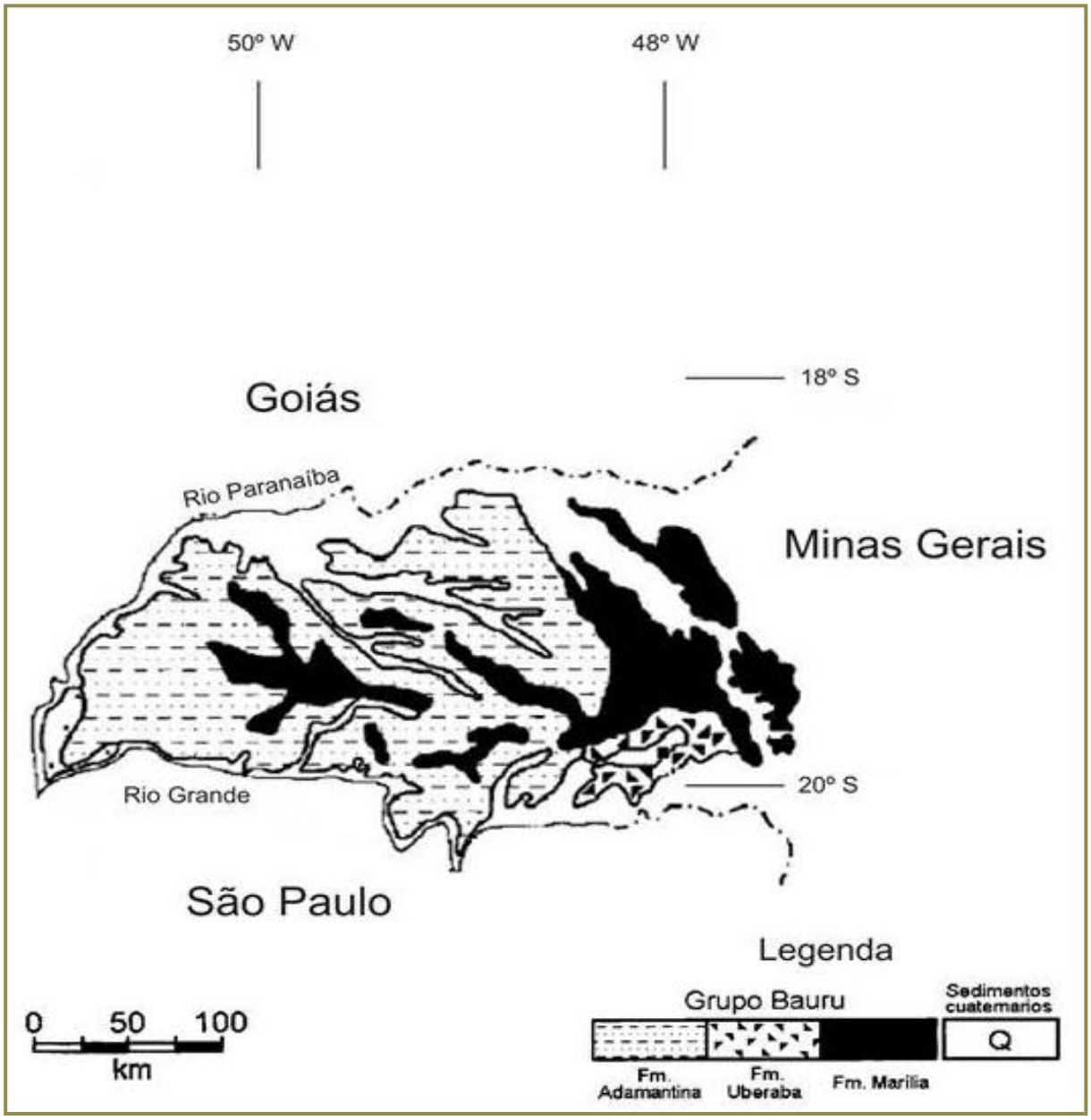

Figure 1. Bauru Group geological map (from Fernandes & Coimbra, 1996).

The first detailed paleontological study of the region around Prata and Peiropolis were conducted by Price (1940, 1945), while the first fossil vertebrates were found in 1940. 33 years later Estes and Price (1973) included in his study of fossils some lizards from Uberaba area. Since 1986 to 1995 field excursions were organized by the Departamento Nacional da Produção Mineral (Rio de Janeiro) and Museu Nacional in cooperation with the

Centro de Pesquisas Paleontologicas Llewllyn Ivor Price, and many vertebrates remains were recovered in Peiropolis (Uberaba) area which Báez and Peri (1989) and Campos and Kellner (1999) described frog and titanosaurs then housed in the Departamento Nacional da Produção Mineral (actual Museu da Ciências da Terra). Additional notes on the fossil theropods dinosaurs, crocodiles and turtles were reported by Bertini et al. (1993).

At the turn of the 1940 began the industrial exploitation of the calcareous rocks at the Uberaba near the Peiropolis region (Candeiro et al., 2008). Most of the fossils found were sent to the Departamento Nacional da Produção Mineral. This material found on the Veadinho Hill (Peiropolis) allowed Price (1940) to produce an extensive study in which he published two crocodiliformes species (*Peirosaurus torminni* and *Itasuchus jesuinoi*) and dinosaurs remains (eggs and bones). In 1940th F. Huene reported some titanosaurs remains in Monte Alegre and Prata vicinity.

Since 1990 the Museu de Minerais e Rochas in Uberlandia and Museu Nacional have purchased a collection of invertebrates and vertebrates, originating from Prata and Monte Alegre areas. Some of the collection specimens originate from the outcrops of Prata. A recent examination of the Senra (2002) and Candeiro (2004) revealed that it also contains specimens of invertebrates.

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 and Coimbra (1996) the group comprises a southeast ward-thinning, continental rock exposed in modern drainages throughout South-Central Brazil, and conformably overlies magmatic rocks of the Jurassic-Cretaceous Serra Geral Formation (São Bento Group, Paraná Basin). The Bauru Group has been a source of important dinosaur and other fossil vertebrates (Figs. 3A-K), invertebrates, and plant discoveries since the early part of the 20th century.

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

Adamantina Formation

This unit was established by Soares et al., (1980) for the continental deposits which unconformably overlie the Serra Geral Formation (São Bento Group, Paraná Basin). The Adamantina Formation is exposed in the States of Goiás, São Paulo and in the Triângulo

Mineiro region, Minas Gerais State. The formation's sediments are fluvial-lacustrine reddish clays and sands, deposited during warm and humid climatic events (Suguio and Barcelos, 1983). Based primarily on its vertebrate fossil contents, the Adamantina sediments were deposited during the Turonian-Santonian (Dias-Brito et al., 2001). Based on calcium carbonate cemented conglomerate there is a succession of very fine sandstones. The geology of the Adamantina Formation in Triângulo Mineiro region has been studied extensively (Barcelos, 1984; Ferreira-Júnior, 1996; Goldenberg and Garcia, 2000). The formation's maximum thickness is nearly 200 m.; 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 brainded regime (Barcelos, 1984).

Tetrapod content. The Adamantina Formation has a remarkable faunal record, of essentially vertebrate taxa. Dinosaur remains are most representative record. The eutitanosaurian *Maxakalisaurus topai* was discovered in Prata region by Kellner et al. (2006) and represents one of the largest dinosaurs that ever lived in Cretaceous of Brasil. Among other sauropods the remains include the eutitanosaurian *Aeolosaurus* (Almeida et al., 2004), and isolated caudal vertebrae and ribs of Titanosauria from the Prata area (Marinho, 2003; Fig. 3J). Other Titanosauria has been described by (Henriques et al., 2002). Abelisaurid, carcharodontosaurid and theropod indet. teeth were reported by Marinho (2003), and Candeiro et al., (2003), 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; Oliveira et al., 2004). The Campina Verde area have recorded *Campinasuchus dinizi* (Carvalho et al., 2011) and *Pissarrachampsa sera* (Montefeltro et al., 2011) and from Iturama *Sphagesaurus* sp. (Kellner et al, 1995)

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 and interdigitates with the Adamantina Formation. Lithologically these strata are composed of freshwater limestones, sandstones, and based conglomerate, all cemented by carbonate ($CaCO_3$) and vulcanoclastic sediments (Barcelos, 1984); it is also composed of green sandstones with thin layers of light red sandstones. The formation's maximum

thickness is nearly 140 m (Fernandes and Coimbra, 1996), and is regarded as Coniacian-Santonian by Dias-Brito et al., (2001).

Tetrapod content. Few fossils have been recorded from this unit. The Uberaba Formation has yielded disarticulated dinosaur specimens. Santucci (2002) has noted sauropods remains of the Uberaba Formation that are possible basal titanosaurs. One dinosaur nest was reported near the Peirópolis district of the Uberaba Town by Barbosa et al., (1970), which Campos and Bertini (1985) attributed to an ornithischian taxon (Fig. 3H-I). 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 and Barbosa (1953). The Marília Formation is exposed in the Goiás and São Paulo States and in the Triângulo Mineiro region. The Marília Formation consists of fine to medium sandstones intercalated by conglomerate levels. The sandstones are cemented and contain concretions of calcium carbonate (Fúlfaro and Barcelos, 1991). The formation thickness is estimated to be 180m in Minas Gerais State (Fernandes and Coimbra, 1996). Dias-Brito et al., (2001) suggested an Upper Maastrichtian age for the Marília Formation.

Barcelos (1984) subdivided the Marília Formation into three members: two restricted in the Triângulo Mineiro region, the Ponte Alta and Serra da Galga Members, and the Echaporã Member exposed 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; which were deposited in alkaline lakes ("beach-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 partially dry climate that would have favored fossil preservation.

Biota content. Among the tetrapod taxa are the neobatrachian or "advanced frogs" represented by *Baurubatrachus pricei* Báez and Peri, 1989, and *Uberabatrachus carvalhoi* Báez et al.,2012. From the Peirópolis Site (Uberaba) there are crocodyliform species referred to as peirosauridoids such as *Uberabasuchus terrificus*, *Peirosaurus tormini* and *Itasuchus jesuinoi* Price, 1955 (Carvalho et al., 2004; Fig. 3A-G). Podocnemine turtles were recorded by

Bertini et al., (1993). Recently França and Langer (2003) reported a new chelonian assigned to Eupleurodira. Dinosaurs comprise the largest, most abundant and diverse vertebrates found at the Peirópolis Site (Kellner and Campos, 2000; Marinho et al., 2003; Fig. 3K). Remains of titanosaurs, abelisaurid and carcharodontosaurid teeth occur frequently at Uberaba. Lopes and Buchmann (2008) described titanosaurs remains attributed to *Aeolosaurus* sp.. The genus Titanosaurus was first reported in the formation Marília by Powell (1986), since then the occurrence of this genus has been reported several times. The titanosaur *Uberabatitan ribeiroi* was described by Salgado and Carvalho (2008), and represent one of the largest Brazilian dinosaurs. One dinosaur nest was reported near the Mangabeira district of the Uberaba Town (Price 1951), which was identified as "*Hypselosaurus*" sp. (Bertini et al., 1993). Recently, "Megaloolithidae" egg shells were also reported from the Peirópilis area (Magalhães-Ribeiro 2002a, b). Candeiro et al. (2012) described the first avian bones from Peirópolis site which represented widespread Enantiornithes taxa in Central South America.

Table 1. Tetrapod fauna from the Upper Cretaceous of the Triângulo Mineiro region.

Táxon	**Geological unit**	**Selected references**
"Lizards"		
Pristiguana brasiliensis	Marília Formation	Estes and Price (1973)
Turtles		
Cambaremys langertoni	Marília Formation	França and Langer (2005)
Frogs		
Anura indet.	Marília Formation	Bertini et al. (2003)
Uberabatrachus carvalhoi	Marília Formation	Báez et al. (2012)
Baurubatrachus pricei	Marília Formation	Báez and Peri (1989)
Crocodylomorpha		
Crocodylomorpha indet.	Adamantina Formation	Marinho (2003); Candeiro et al. (2003); Oliveira et al. (2004)
Crocodylia indet.	Marília Formation	Candeiro et al. (2003)
Pissarrachampsa sera	Vale do Rio do Peixe Formation	Montefeltro et al. (2011)
Campinasuchus dinizi	Adamantina Formation	Carvalho et al. (2011)
Uberabasuchus terrificus	Marília Formation	Carvalho et al. (2004)
Sphagesaurus sp.	Bauru Group	Kellner et al. (1995)
Peirosaurus tormini	Marília Formation	Price (1955)
Itasuchus jesuinoi	Marília Formation	Price (1955)
Dinosaurs		
Sauropoda indet.	Uberaba Formation	Santucci (2002)
Theropoda indet.	Adamantina Formation	Marinho (2003) Candeiro et al. (2002)
	Marília Formation	Kellner (1996) Candeiro et al. (2004)

Maniraptora indet.	Marília Formation	Novas et al. (2005)
Enantiornithes indet.	Marília Formation ?	Candeiro et al.(2012)
Titanosauria indet.	Adamantina Formation	Henriques et al. (2002) Marinho (2003)
	Marília Formation	Azevedo and Kellner (1998) Marinho and Candeiro (2005) Trotta et al.(2002) Powell (2003) Santucci and Bertini(2006) Campos and Kellner (1999)
Abelisauridae indet.	Adamantina Formation	Marinho (2003) Candeiro et al., (2002, 2006b)
	Marília Formation	Novas et al. (2008) Candeiro et al. (2004, 2006a)
Carcharodontosauridae indet.	Adamantina Formation	Marinho (2003) Candeiro et al. (2002/2006b)
	Marília Formation	Silva and Kellner (1999) Candeiro et al. (2004)
Aeolosaurini indet.	Adamantina Formation	Almeida et al. (2004) Candeiro et al. (2004b)
Aeolosaurus sp.	Adamantina Formation	Candeiro et al., (2006b)
	Marília Formation	Santucci and Bertini (2001) Lopes and Buchmann (2008)
Titanosaurus sp.	Marília Formation	Bertini et al., (2001), Santucci and Bertini (2001)
Trigonosaurus pricei	Marília Formation	Campos et al. (2005)
Baurutitan brittoi	Marília Formation	Kellner et al.(2005)
Maxakalisaurus topai	Adamantina Formation	Kellner et al. (2006)
Uberabatitan ribeiroi	Marília Formation	Salgado and Carvalho (2008)

Discussion

The Triângulo Mineiro biota is important for several reasons, principally in terms of stratigraphical understanding, because it ranges in age from Turonian to the Late Maastrichtian. It is also important because it includes so many early discoveries of Central Brazil Late Cretaceous vertebrates, including the first dinosaur eggs found in Brazil. The crocodiliform and dinosaur records are the most common vertebrates found in Triângulo Mineiro region. Titanosaur 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 municipalities and due to the identification or revision of interesting specimens. About the 27 taxa have been reported in recent years. The taxa include the abelisaurid and carcharodontosaurid theropods, eutitanosaurian *Aeolosaurus* and Enantiornithes, from the Adamantina and Marília Formations. Recently was reported a complete crocodilian *Uberabasuchus terrificus* by Carvalho et al. (2004). Additional dinosaur specimens have been re-described or revised in detail in recent years (Marinho, 2003; Powell, 2003), 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. For the ichnological record, dinosaur eggs of "Megalolithidae" are known from the Late Maastrichtian sites of the Uberaba municipality. Finally, the Late Cretaceous mollusk and carophytae records of Uberaba are among the most representative in the Bauru Group and have yielded several Patagonian species.

The similarity of the biota content of the Turonian-Maastrichtian *Aeolosaurs*-bearing, *Peirosaurus*-bearing and the Ostracod-bearing units of the Triângulo Mineiro region to the Pagonian 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 that by the early Late Cretaceous there was an interconnection between both biota realms. This is evidenced by the presence of Carcharodontosauridae and Abelisauridae, which seems to be a derivate of the African or Patagonian dinosaurs in a strict sense. The same spreading patterns are evidenced by the *Peirosaurus torminni* crocodilian found in the Bajo de la Carpa Formation of Patagonia, which seems to appear as early as the Santonian stage in Patagonia.

It is difficult to determine whether the tetrapod exchange is marked by the African or Patagonian taxa in the middle Cretaceous. Comparison of the tetrapod assemblages from both areas is heavily biased. The largest southern Patagonian records most representative in the Triângulo Mineiro region (e.g. *Aeolosaurus*, *Peirosaurus*, Enantiornithes) are currently considered endemic. However, the similarity of carcharodontosaurid and spinosaurid remains (from the Adamantina Formation, São Paulo State, Brazil) to the African tetrapod content may demonstrate their close relationship with eastern Gondwanan taxa. Another important implication concerns the range of the crocodile genus *Itasuchus*, which is found in the

Santana Formation (Albian). The frequent occurences of this genus in the Marília Formation indicate that this taxon is the most common crocodiliform in the Late Cretaceous.

Conclusion.

The evaluation of the Triângulo Mineiro tetrapods has revealed a wide diversity of taxa, especially reptiles (e.g. crocodililiforms, dinosaurs) and aves. This tetrapod content, discovered in the formations of the Bauru Group, is from Turonian-late Maastrichtian sediments deposited in eolian and fluviolacustrine environments and is composed of carophytae, ostracods, frogs, lizards, chelonians, crocodilifomrs, dinosaurs and aves..

The Triângulo Mineiro tetrapods are similar to Argentinean records of Late Cretaceous faunal assemblages, such as those from Patagonian sediments. 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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