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**Continental Upper Cretaceous red, green and white beds from the Bauru Group (Triângulo Mineiro region, Minas Gerais State, Brazil) and their vertebrate fauna**

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ABSTRACT

Vertebrate remains have been found in the Upper Cretaceous Bauru Group in Triângulo Mineiro region (western Minas Gerais State, Brazil) since 1940. Excellent outcrops of an exclusively continental Cretaceous in red, green and white beds are exposed in northern Bauru Basin. The oldest unit is the Turonian-Santonian Adamantina Formation, followed by Coniacian-Santonian Uberaba and late Maastrichtian Marília formations. Geological and palaeogeographical observations indicate that the Bauru Group sediments in Triângulo Mineiro were deposited in arid and semi-arid terrestrial environments with an anastomosing river in the Adamantina Formation. Thus, the vertebrates recorded within dwelled arid and semi-arid

environments. The Triângulo Mineiro vertebrate fauna is closely related to the Neuquenian, Coloradoan and Allenian assemblages from Argentina.

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**PALAVRAS CHAVE:**

Triângulo Mineiro  
Grupo Bauru  
Vertebrados  
Neocretáceo  
Brasil

**RESUMO** – CAMADAS CONTINENTAIS VERMELHAS, VERDES E BRANCAS DO CRETÁCEO SUPERIOR DO GRUPO BAURU (REGIÃO DO TRIÂNGULO MINEIRO, ESTADO DE MINAS GERAIS, BRASIL) E SUA FAUNA DE VERTEBRADOS. Desde 1940 os restos de vertebrados fósseis têm sido encontrados nos sedimentos do Cretáceo Superior do Grupo Bauru na região do Triângulo Mineiro (oeste do estado de Minas Gerais, Brasil). Excelentes afloramentos continentais de cor vermelha, verde e branca se encontram expostos na porção norte da Bacia Bauru. A unidade mais antiga é a Formação Adamantina (Turoniano-Santoniano), seguida pelas formações Uberaba (Coniaciano-Santoniano) e Marília (Maastrichtiano). Observações geológicas indicam que os sedimentos do Grupo Bauru no Triângulo Mineiro foram depositados em um ambiente terrestre árido e semi-árido com a presença de rios anostomosados na Formação Adamantina. Os vertebrados reportados neste grupo viveram em um ambiente árido a semi-árido. A fauna de vertebrados do Triângulo Mineiro é proximamente relacionada com as assembléias Neuqueniana, Coloradiana e Alleniana reportadas na Patagônia Argentina.

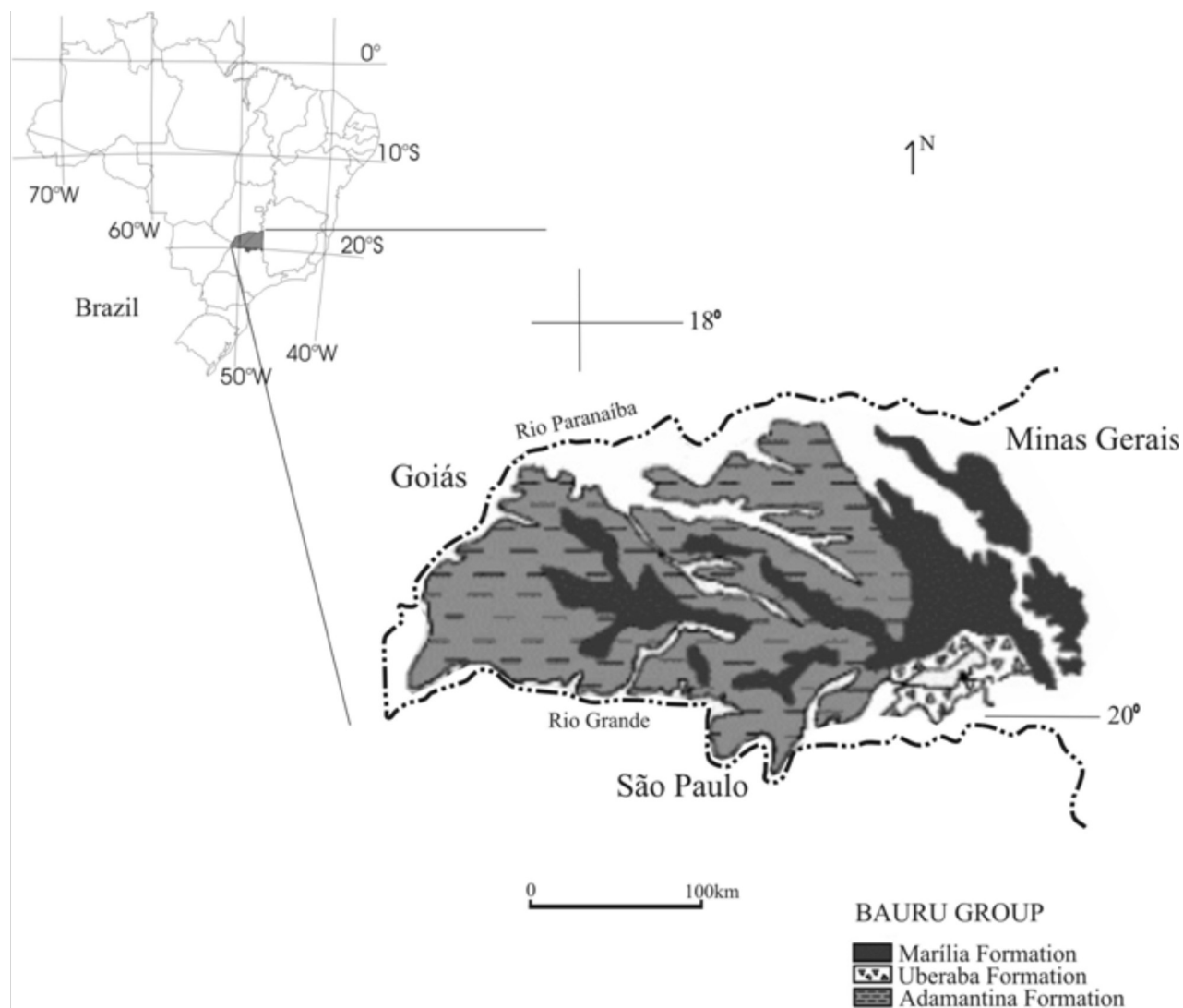
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## 1. Introduction

The Bauru Group is the best-known sedimentary unit of the Triângulo Mineiro region (BARCELOS, 1993; CANDEIRO, 2005). Its Upper Cretaceous continental beds are some of the most fossiliferous and best stratigraphically documented in Brazil (Fig. 1). Since 1940 and the first Late Cretaceous vertebrate remains from Minas Gerais State, their calcareous and fossiliferous contents have received special attention in the last decades, the abundance of Late Cretaceous taxa has legitimated the ever increasing and continuous attention to these beds.

Recent geological investigations by Barcelos (1993) in Triângulo Mineiro of the Bauru Group (Figs. 1-3), between 19° 11' 10"/19° 49' 59" S and 47° 30'/48° 19' 24" W, evidenced/documentated the regional distribution of several Upper Cretaceous bed units at the formation level. The present paper aims to present/provide an updated summary account of the continental Bauru Group

units from Triângulo Mineiro region, focusing on their environment and ages, as well as on their mutual palaeogeographical and stratigraphical relationships. The continental vertebrate content from each unit is also briefly commented. The stratigraphic chart of the Cretaceous System of the Triângulo Mineiro Bauru Group is shown in Figures 2 and 3.



**Figure 1.** Geological map of the Triângulo Mineiro region, Minas Gerais State, Brazil (modified from Fernandes and Coimbra, 1996).

## **2. The Upper Cretaceous Bauru Group beds in the Triângulo Mineiro region**

The Bauru Group (Fig. 1) was erected/defined by Soares *et al.*, (1980). It is widely exposed in the northern-central part of the Bauru Basin. Excellent outcrops are visible in the Triângulo Mineiro region around the Uberaba and Prata municipalities (Minas Gerais State). They are exposed in the Veadinho (Uberaba Municipality) and Boa Vista (Prata municipality) hills. The Adamantina Formation interdigitates with Uberaba Formation near Frutal municipality, both overlain by the Marília Formation. The age of this group can be regarded as Turonian (Adamantina Formation) to late Maastrichtian (Marília Formation).

The Bauru Group has been deposited during nearly 45 Ma from the Turonian through to the Late Cretaceous. This series of mostly continental beds consists of conglomerates, sandstones and claystones corresponding to fluvial, fluvio-lacustrine and braided environments. They are generally arranged in recurrent fining-upward sequences. The Bauru Group comprises the Adamantina, Uberaba and Marília formations with its respective vertebrate fauna (Fig. 3).

#### *Adamantina Formation*

This unit, defined by Soares *et al.* (1980), is with the Uberaba Formation, one of the most uniform and characteristic units of the Bauru Group. It crops out from the Uberlândia to Iturama municipalities area pitchy in the Triângulo Mineiro region. It is unconformably overlain by the volcanic Serra Geral Formation and interdigitates with Uberaba Formation. This unit also spreads to the east over the States of Goiás and São Paulo. It consists of coarse-grained, light violet and pink sandstones of fluvial origin with well developed paleosols. Thin beds of siltstones and claystones, reddish in color, between layers of hard sandstone may indicate swamp conditions. The Adamantina Formation can be up to 100m thick. According to Dias-Brito *et al.* (2001), its age is Turonian-Santonian. From the Prata site, Huene (1933) and Powell (2003) reported dinosaur bones of “*Titanosaurus*”. However, according to Wilson and Upchurch (2003), their characteristics do not fit in with those of genuine “*Titanosaurus*” and lead these authors to assign this material to Titanosauria. The most remarkable theropod dinosaur discovery in

this unit corresponds to Abelisauridae and Carcharodontosauridae (Marinho, 2003 and Candeiro *et al.* 2008), all specimens housed in the Museu de Minerais e Rochas of Uberlândia City (Minas Gerais State). From the Prata site, turtles, crocodiles and new sauropods (ongoing studies) were recovered in association with the eutitanosaurian *Aeolosaurus* (ALMEIDA *et al.*, 2004; CANDEIRO *et al.*, 2006) and *Maxakalisaurus topai* (KELLNER *et al.* 2006). Only a crocodylian specimen from the Adamantina Formation of the Triângulo Mineiro region (Iturama Municipality), regarded to as *Sphagesaurus huenei* Price, 1945, is reported in a short abstract by Kellner *et al.* (1997).

### *Uberaba Formation*

The Uberaba Formation was defined by Hasui (1969), its type locality being the Uberaba road north of Uberaba City in the Triângulo Mineiro region. Its regional context was studied by many outstanding geologists: Barcelos (1984, 1993), Soares *et al.* (1979), Ferreira-Junior (1996), and Fernandes and Coimbra (1996). It is mainly composed of green freshwater limestones, sandstones, and based in conglomerate, all cemented by carbonate (CaCO<sub>3</sub>) together with volcanoclastic sediments (BARCELOS, 1984). Paleosoils are frequent, whereas red-brownish siltstones and claystones are occurring in thin packages, some of them evidencing/documenting swamp conditions. The Uberaba Formation is up to 140m thick (FERNANDES and COIMBRA, 1996). According to Dias-Brito *et al.* (2001), this Formation is Coniacian-Santonian in age. These sediments provided microfossils which ones turtles, titanosaurids, eggshells, indeterminate dinosaur remains and ichnofossils.

### *Marília Formation*

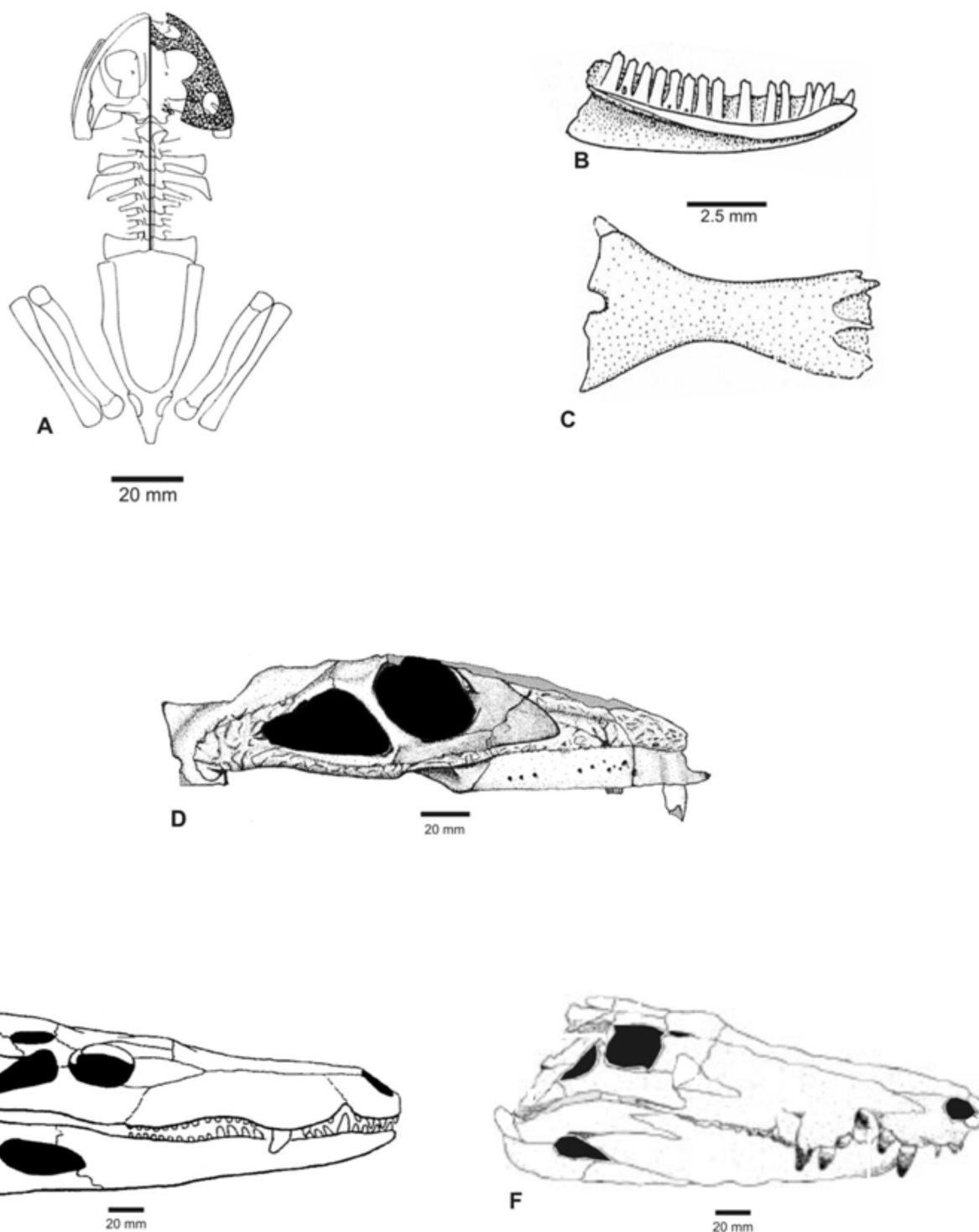
The Marília Formation sediments display an uneven distribution in the Triângulo Mineiro, as well as in the west of São Paulo state. According to Barcelos and Suguio (1987), this unit was deposited by alluvial coalescent fans, later re-processed and finally deposited by a fluvial anastomosing system, in association with calcretes and calcareous lacustrine deposits. Barcelos (1984) subdivided the Marília Formation into members as follows:

Echaporã, Ponte Alta and Serra da Galga, given that the last two lithological units are restricted to the Triângulo Mineiro region. These sediments display the following respective characteristics (GARRIDO *et al.*, 1992): *Ponte Alta* – a basal “ calcareous white member”, characterized by thin and medium calcareous carbonates/limestones with pebbles and calcareous nodules (“beach-lake”–type: alkaline waters oversaturated with calcium bicarbonates); *Serra da Galga* – upper “member of white limestone and conglomerate”, composed by conglomerate and thin-to-medium grain-size limestone of feldspar-bleached colour. These sediments formed in coalescent alluvial fan regime were re-processed by braided rivers within “beach-lake” sediments according to Suguio (1973, 1980), both members were elaborated under a partially dry climate favourable to the fossil preservation.

Dias-Brito *et al.* (2001) assigned a Late Maastrichtian age to the Marília Formation. This lithological unit yielded invertebrates, plants and mainly vertebrates remains. The vertebrate fauna from the Marília Formation consists of some fishes (Characiform, Perciform and Siluriform), frogs (*Baurubatrachus pricei*, Fig. 3A), turtles (*Cambaremys langertoni*), lizards (*Pristiguana brasiliensis*, Fig. 3B), crocodylians (*Itasuchus jesuinoi*, *Peirosaurus torminni*, *Uberabasuchus terrificus*, Fig. 3C), turtles and dinosaurs (Abelisauridae, Carcharodontosauridae, Maniraptora and eutitanosaurians *Baurutitan britoi*, *Uberabatitan ribeiroi*, *Aeolosaurus*). The most comprehensive vertebrate records from the Marília Formation are the dinosaur remains recently recovered from the Uberaba and Prata area and described by Novas *et al.* (2005, 2008), Salgado *et al.* (2008) and Kellner *et al.* (2005).

SYSTEM	STAGES (Age boundary in Ma)	BAURU GROUP	
LATE CRETACEOUS	65.0±0.1	Marília Formation	
	MAASTRICHTIAN		
	71.3±0.5		
	CAMPANIAN		
	83.5±0.3		
	SANTONIAN	Adamantina Formation	Uberaba Formation
	85.8±0.5		
	CONIACIAN		
	89.0±0.5		
TURONIAN			
93.5±0.2			
CENOMANIAN			
98.9±0.6			

**Figure 2.** Stratigraphic scheme of the Bauru Group (absolute ages from Remane, 2000).



**Figure 3.** *Baurubatrachus pricei* (modified from BAEZ and PERI, 1989); *Pristiguana brasiliensis* B, left dentary, C, (Modified from ESTES, 1983); Crocodyliform skulls in lateral view, D, *Sphagesaurus huenei* (modified from POL, 2003), E, *Itasuchus jesuinoi* (modified from RASMUSSEN, 2002), and F, *Uberabasuchus terrificus* (modified from CARVALHO *et al.*, 2004).



### 3. Discussion

The fossil vertebrate diversity of the Bauru Group in the Triângulo Mineiro region has been acknowledged since the 1940s. Beside the wealth and diversity of dinosaurians in the Bauru Group, these formations also yielded an impressive range of vertebrate taxa (Tab. 1), as well as of microfossils, trace fossils and invertebrates. So far ornithischian dinosaurs have not been documented in the Late Cretaceous Triângulo Mineiro. Whereas the taxonomical literature on the Triângulo Mineiro fossils thrives, palaeoecological studies are still scarce (PRICE, 1950; ESTES and PRICE, 1973; BAEZ and PERI, 1989; GOLDBERG and GARCIA, 2000; CARVALHO *et al.*, 2004; CANDEIRO *et al.*, 2008).

The most interesting and productive fossil horizon from the Triângulo Mineiro region is the late Maastrichtian Marília Formation. At Peirópolis, a thick horizon consisting of white sandstones delivered abundant bone and tooth fragments. Field works and continuous excavations retrieved a large number of vertebrate remains. Since Price (1951) described dinosaur eggshells, further field work and screening of the horizon just above the Ponte Alta Member around Peirópolis delimited a vast field scattered with vertebrate remains (CANDEIRO *et al.* 2006).

**Table 1.** Faunal communities in the Triângulo Mineiro beds

<b>Continental community</b>	<b>Freshwater community</b>
<b>Frogs</b>	<b>Fishes</b>
“Leptodactylidae” <i>Baurubatrachus pricei</i>	Characiform
<b>Lizards</b>	Siluriform
Iguana <i>Pristiguana brasiliensis</i>	Perciform
<b>Crocodylomorpha</b>	Osteichytes indet.
<i>Itasuchus jesuinoi</i>	<b>Turtles</b>
<i>Peirosaurus tormini</i> , <i>Crocodylia</i> indet., <i>Crocodylomorpha</i> indet., <i>Sphagesaurus</i> <i>huenei</i>	<i>Cambaremys langertoni</i>
<b>Dinosaurs</b>	Podocnemidae
<i>Baurutitan britoi</i>	Chelonia indet
<i>Uberabatitan ribeiroi</i>	

*Aeolosaurus, Maxakalisaurus topai*

Titanosauria indet.

Sauropoda indet.

Abelisauridae

Carcharodontosauridae

Maniraptora

Theropoda indet.

### **Dinosaur eggshell oospecies**

“Megaloolithidae”

Gen. indet. sp.

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### *Palaeogeography and palaeoenvironmental approach*

The occurrence of vertebrate remains supports the interpretation that the Triângulo Mineiro, including the western part of São Paulo State, was part of the same Patagonian assemblages (Neuquenian, Coloradoan and Allenian, LEANZA *et al.*, 2004) during the Late Cretaceous. This is shown by the occurrence of common Gondwanan vertebrate evidence.

The vertebrate assemblage from the Triângulo Mineiro exists regarding Triângulo Mineiro's paleontological dates based on the vertebrate faunas from Triângulo Mineiro Late Cretaceous. For instance, the crocodylian *Peirosaurus torminni* and the eutitanosaurian *Aeolosaurus* (found also found in the same lithostratigraphic unit in Argentina - Bajo de la Carpa, Santonian - ) are thought to have interchanged with Argentina via a southern route, thus demonstrating a South American connection. The Triângulo Mineiro tetrapods show a clear Gondwanan affinity.

Among the Late Cretaceous terrestrial and freshwater vertebrates recorded from the Triângulo Mineiro, these appear to share the greatest affinities with those from the Neuquén, Malargüe and Chubut Groups of Argentina. In the light of the Triângulo Mineiro specimens, within the context of connected realms, the distribution of southern South American Late Cretaceous vertebrates supports the palaeogeographic inferences recently postulated by Candeiro *et al.* (2004); that is a terrestrial connection between central Brazil

and Argentina that occurred after the Serra Geral volcanism ceased in the Early Cretaceous. This connection area permitted northern Argentina to serve as an exchange corridor for terrestrial biotas between central Brazil and Patagonia.

The composition of the continental derived tetrapods may contribute to the palaeogeographical interpretation. A Patagonian influence is suggested for the studied sequence, based on the occurrence of frogs, lizards, turtles, the peirosaurid, the abelisaurid and the eutitanosaur. Their presence is noteworthy in the Adamantina and Marília Formations as/since they also occur in the Upper Cretaceous of Patagonia (Neuquén and San Jorge Groups). The abundance of continental reptiles, such as the meoseucrocilian (*Peirosaurus tormini*) and the dinosaurs (abelisaurids and carcharodontosaurid), is related to fluvio-lacustre conditions (GOLDBERG and GARCIA, 2000). Meanwhile the crocodyliform (*Peirosaurus*, *Uberabasuchus* and *Itasuchus*) and the frog (*Baurubatrachus pricei*) document lacustrine environments (GOLDBERG and GARCIA, 2000).

Based on the chronostratigraphic dates of Dias-Brito *et al.* (2001) and the present stratigraphical and palaeontological data from the Triângulo Mineiro region, major hiatuses were observed (absence of Cenomanian sediments; Fig. 2). Another important gap concerns Campanian sediments (Fig. 2). No marked palaeontological difference was observed between the Turonian-Santonian Adamantina and the late Maastrichtian Marília Formations. Some taxa were recovered from both the Adamantina and Marília Formations (*e.g.* *Aeolosaurus*, abelisaurids and carcharodontosaurs). The widespread eutitanosaur (*Aeolosaurus*) can be found in this unit and also in the Late Cretaceous Patagonian unit.

Leanza *et al.*, (2004) defined six tetrapod assemblages from for the Cretaceous period in Argentina which displayed mixed faunas from of Gondwana and Laurasia in the Late Cretaceous. *Aeolosaurus* and *Peirosaurus* from the Triângulo Mineiro region are also recorded in the Patagonian fossil assemblages and matches/fits well to the Neuquenan and Allenian assemblages of Leanza *et al.* (2004). As a consequence, they allow cross correlation with the standard southern South America chronostratigraphic time scale. These correlations reinforce Huene's earlier correlation (1931)

indicating a Late Cretaceous age for the Bauru Group and the Patagonian unit (e.g. the Neuquén Group).

Recently, several authors (e.g. CANDEIRO, 2002; MARTINELLI and FORASIEPI, 2004; APESTEGUIA *et al.*, 2004) reported a possible late survival of carcharodontosaurids (Argentina: Portezuelo, Los Alamitos and Allen Formations; Brazil: Adamantina and Marília Formations). Such a late occurrence of carcharodontosaurids could be interpreted as a mere indication of relict or refuge areas in the Triângulo Mineiro region during and after the Late Cretaceous.

According to Leanza *et al.*, (2004), tetrapod remains from the Candeleros, Huincul, Bajo de la Carpa Formations (Neuquén Group) in Argentina are found in fluvio-lacustrine dunes and intermittent lakes and streams; this depositional feature is also found in the Adamantina Formation. In contrast, the Marília Formation that provided the most representative tetrapod assemblage from the Triângulo Mineiro was deposited in a lake and by/within fluvial systems under dry climatic conditions; its tetrapods lived in under climatic conditions very different than those of Patagonian unit and of the Adamantina Formation. The late Maastrichtian fauna from the Marília Formation obviously lived under hot conditions with wet and dry seasons.

The tetrapod assemblage from the Triângulo Mineiro region is represented by a continental palaeocommunity (Table 1). The importance of tetrapod representatives (i.e. frogs, lizards and dinosaurs), clearly support a predominantly continental depositional setting, which developed under semi-arid conditions for the Marília Formation. The Adamantina Formation assemblages of Prata (MARINHO, 2003; CANDEIRO *et al.*, 2006) are also dominated by a similar continental fauna. Lithologically, the Adamantina, Uberaba and Marília formations show a diversity of lithotypes (ranging from siltstones, mudstones, clays, claystones, calcretes, limestones and sandstones) strongly indicating fluctuating lake and river levels (BARCELOS, 1984).

The presence of a continental community, such as frogs lizards and dinosaurs, indicate the existence of fluvio-lacustrine conditions (CANDEIRO *et al.*, submitted). The Adamantina and Marília formations represent the relicts of an ancient soil cover formed on various shield basements ranging in age from the Turonian to the late Maastrichtian. The calcrete horizon from the

Ponte Alta Member (Marília Formation) is 12 m thick. The presence of few vertebrate remains in a single dominant lithology (pedogenetically modified carbonate sand) indicates that the calcretized palaeosoil was deposited in an alluvial environment, comprising overbank, channel and back-swamp environments (GARRIDO *et al.*, 1992). Variation in the depositional conditions within the Ponte Alta Member was due to a semi-arid climate with periodic dry cycles and seasonal rains, which influenced the sedimentation and preservation of organisms (BARCELOS, 1984, 1993; GARRIDO *et al.*, 1992). The vertebrate-bearing Ponte Alta Member shows a number of sedimentological features related to pedogenesis, such as the presence of high sand-and-pebble content like chert and quartz, representing repeated sheetflood events, and different calcrete and features like absence of bedding, pedotubules, desiccation cracks, bioturbation, prismatic and brecciated structures (BARCELOS, 1984).

#### **4. Conclusions**

The Upper Cretaceous Bauru Group beds consist of conglomerates, sandstones and claystones corresponding to fluvial and fluvio-lacustrine environments. They are arranged in recurrent fining-upwards sequences composing the Adamantina (Turonian-Santonian), Uberaba (Coniacian-Santonian) and Marília (late Maastrichtian) formations. Combination of geological and fossil evidence clearly shows that the Bauru Group in the Triângulo Mineiro region was deposited in an arid and semi-arid environment with seasonal influence, by an anastomosing river in the Adamantina Formation. The vertebrate taxa are represented exclusively by Gondwanan representatives that are closely related to Neuquenan, Coloradoan and Allenian assemblages from Argentina.

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