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RESEARCH ARTICLE

Late Paleozoic, Late Cretaceous and Pleistocene-Holocene reptiles and mammals fauna: a review from Goiás State, Brazil

Fauna de reptiles y mamíferos del Paleozoico Superior, Cretácico Superior y Pleistoceno-Holoceno: una revisión del Estado de Goiás, Brasil

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ABSTRACT

The territory of Goiás State in Central Brazil has yielded reptile fossils from the Permian, Cretaceous and fossil mammals from the Pleistocene-Holocene. Many new fossils have been found during the last years, allowing a better understanding of community structure and faunal evolution during these time intervals. In this study we present an updated synthesis of the reptilian and mammal faunas of Goiás. Tetrapod fossils have been found in the Paraná Basin rocks (Permian Passa Dois and Upper Cretaceous Bauru groups) in the Southern Goiás State since 1935. Goiás state fossils have been recorded in eight municipalities, and include mollusks, turtles, mesosaurids, crocodiliforms, dinosaurs, and mammals. This paleofauna is exclusively comprised of classic South American taxa that are also found in other former parts of Gondwana.

Key points

Paleozoic and Mesozoic fauna from Goiás state (Brazil) were common to abundant in gondwanan areas of Central Brazil

Reptiles with predominantly Gondwanan distribution became present across the Permian and Cretaceous periods

The Paraná Basin and Cenozoic sediments bear diverse reptilian and mammalian faunal content

Keywords: Central Brazil; Fossil record; Goiás; Megafauna; Tetrapods.

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RESUMEN

El territorio del estado de Goiás en el centro de Brasil ha producido fósiles de reptiles del Pérmico, de Cretácico y de mamíferos del Pleistoceno-Holoceno. Se han encontrado muchos fósiles nuevos durante los últimos años, lo que permite una mejor comprensión de la estructura de la comunidad y la evolución de la fauna durante estos intervalos de tiempo. En este estudio presentamos una síntesis actualizada de las faunas de reptiles y mamíferos de Goiás, basada particularmente en el registro de mesosaurios, tortugas, crocodiliformes, dinosaurios y mamíferos. Se han encontrado fósiles de tetrápodos en las rocas de la cuenca del Paraná (grupos Pérmico Passa Dois y Cretácico Superior Bauru) en el sur del estado de Goiás desde 1935. Los fósiles del estado de Goiás se han registrado en ocho municipios e incluyen moluscos, tortugas, mesosáuridos, cocodrilos, dinosaurios, y mamíferos. Esta paleofauna se compone exclusivamente de taxones sudamericanos clásicos que también se encuentran en otras partes anteriores de Gondwana.

Puntos clave

La fauna del Paleozoico y Mesozoico del estado de Goiás (Brasil) fue común en las áreas gondwánicas de Brasil Central

Reptiles con distribución predominantemente gondwánica comenzaron a estar presentes a lo largo de periodo Pérmico y Cretácico

La cuenca del Paraná y los sedimentos Cenozoicos contienen restos de fauna diversa, tanto reptiliana como de mamíferos

Palabras clave: Brasil central; Goiás; Megafauna; Registro fósil; Tetrápodos.

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1. Introduction

Knowledge of tetrapods fossils of Goiás State, Central Brazil, has been improved considerably over the past 15 years thanks to the work of several Brazilian researchers who study the reptiles and mammals of this region. As with some other groups of fossil organisms, much of the data about these taxa has been sparsely and sparingly reported in a few scientific publications, mostly in short communications in local or regional journals or conferences, although, most recently, some reports have been published in the annals of national and international societies, and in Brazilian scientific journals.

The first known record of fossil tetrapods in Goiás State was presented by Milward (1935), who reported the presence of mesosaurid (aquatic reptile) remains in southwestern regions of Goiás. Other groups of Cenozoic tetrapods are relatively well represented in Goiás State (Fracasso and Salles, 2005; Paulo, 2009, 2014), and include fossils of major mammalian groups such as Artiodactyla, Carnivora, Chiroptera, Didelphimorphia, Perissodactyla, Primates, Proboscidea, Rodentia, and Xenarthra. Over the last 80 years, however, research stalled. There were few publications of fossil discoveries made in Goiás, compared to the scientific production from similar areas (Triângulo Mineiro, western São Paulo State, and Mato Grosso State) (see Gil, 2019). This has started to change. For example, recently, new discoveries of Cretaceous fossils have been made in the rocks of the Bauru Group (Upper Cretaceous) in Goiás, including remains of turtles, crocodyliforms, and dinosaurs (Candeiro *et al.,* 2018a, 2020a, b). There has also been reports of small mammals and megafauna from the Pleistocene, and Permian reptiles (Fracasso and Salles, 2005; Paulo, 2014; Oliveira *et al.,* 2020).

Most of the published descriptions of Goiás fossils are from the last 16 years. In short, despite the fossiliferous potential of the region, research in the state of Goiás is still incipient and sparse, but it has great potential for fossil prospecting and scientific production.

This contribution provides an up-to-date summary of the fossil record of Late Permian, Late Cretaceous and Pleistocene-Holocene reptiles and mammals of Goiás State. These records offer an excellent opportunity for the future development of paleontology in the region, which should help to decipher the complex paleobiologic history of Central Brazil over the past ca. 300 million years. The review of existing literature and reptiles and mammals specimens currently stored in collections also allows us to roadmap the most promising lines of paleontological studies to be developed in the forthcoming years.

2. Material and Methods

2.1. Material

A survey of the main fossiliferous localities and paleontological materials in Goiás State was carried out, based on thorough review of the literature. According to these works, four clades of reptiles and mammals from the state have been found so far. In addition, a review of our bibliography and the collection of the Laboratório de Paleontologia e Evolução /Course of Geology/Universidade Federal de Goiás (UFG) indicates that such fossils have been found in eight municipalities.

2.2. Methods

A compilation of the available bibliography was made on the fossil reptiles and mammals of the Permian, Cretaceous and Pleistocene-Holocene of Goiás State. Based on these literature sources, we performed a detailed review of the fossil fauna of turtles, mesosaurids, crocodyliforms, dinosaurs, and mammals. In order to simplify information searching, the main bibliographic source of each particular taxon is indicated here. Taxa were separated into three geological time spans: 1, Paleozoic (Permian); 2, Mesozoic (Cretaceous); 3, Cenozoic (Pleistocene and Holocene) (Figure 1). The geological periods were based on the Gradstein *et al.* (2004).

For this review, we organize Goiás State into five geographical zones: 1) north (Minaçu); 2) central (Goiânia); 3) south-central (Paraúna); 4) south (Paranaíguara and Quirinópolis); 5) southwest (Jataí, Mineiros, Montividiu, Perolândia, Rio Verde, and Serranópolis) and west (Piranhas) (Figure 1). This arrangement is consistent with the geographic organization for Goiás State proposed by the IBGE (2017).

3. Geological setting

The Paraná Basin comprises an intracratonic unit located in the central east of South America. This basin contains a package of volcano-sedi-

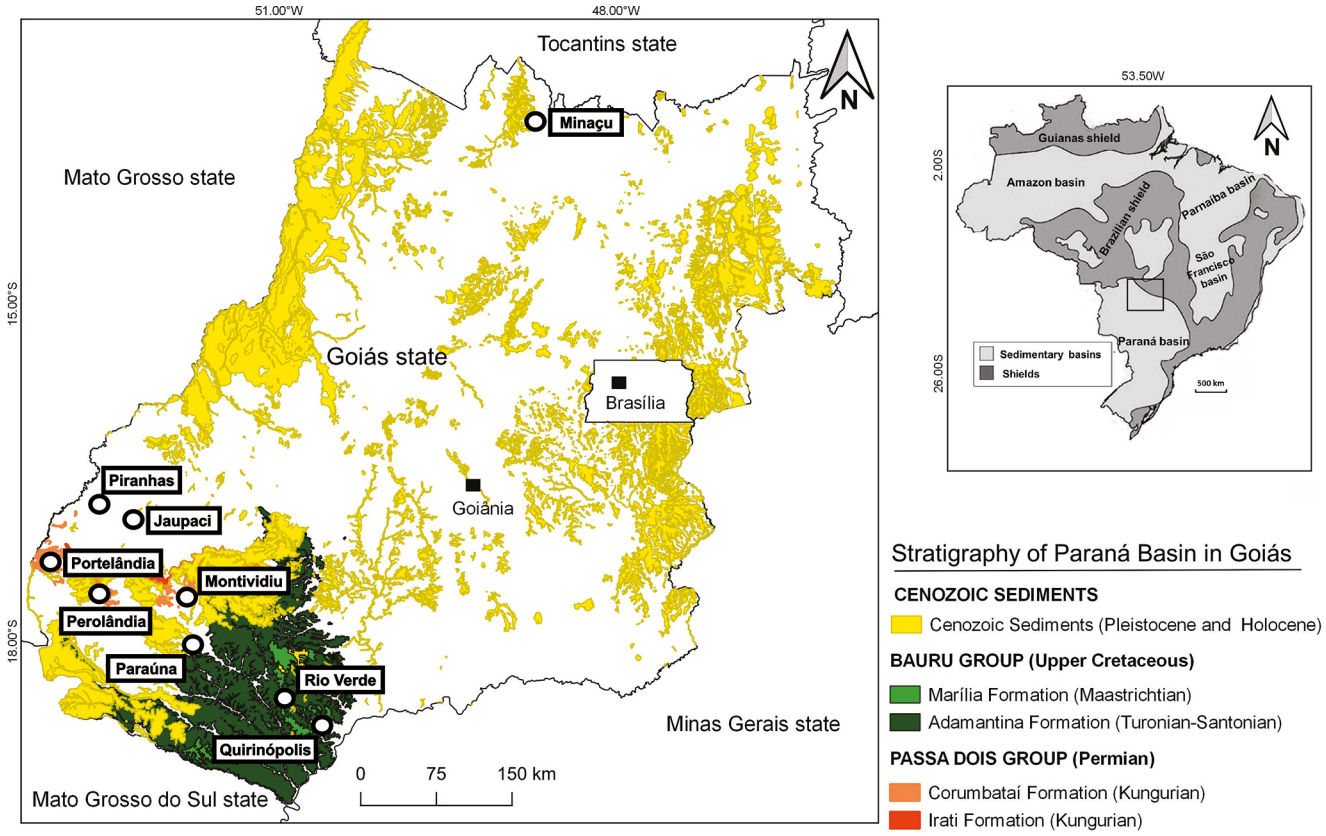


Figure 1. Geological map of the Paraná Basin with emphasis on the Goiás State (adapted from Limarino and Spalletti, 2006).
Figura 1. Mapa geológico de la Cuenca del Paraná con énfasis en el Estado de Goiás (adaptado de Limarino and Spalletti, 2006).

mentary strata deposited between the Ordovician and the Cretaceous (Milani *et al.,* 2007). Its covers parts of Argentina, Brazil, Paraguay, and Uruguay, with an approximate area of 1,400,000 km^2. According to Milani *et al*. (2007), this geological unit has a superposition of packages deposited in three different tectonic environments or basins. Zalán *et al*. (1990) point out that the dynamics of the tectonic plates that led to the evolution of Gondwana from the Permian to the Cretaceous contributed to the formation of this basin.

According to Milani (1997) and Milani *et al*. (2007), the stratigraphic framework of the Paraná Basin consists of six depositional supersequences, each comprising the geological record corresponding to a few tens of millions of years in length. The supersequences that correspond to the volcano-sedimentary package are: Rio Ivaí (Ordovician–Silurian), Paraná (Devonian), and Gondwana I (Upper Carboniferous–Lower Triassic), representing sediments deposited by Paleozoic transgressive-regressive cycles. The Gondwana II, Gondwana III, and Bauru supersequences comprise Mesozoic continental sedimentary successions and associated igneous rocks.

In Goiás State, the sedimentary rocks of the Paraná Basin (Figure 1) are present on the southwestern border of the state, comprising an area of approximately 92,500 km^2 (Milani *et al.,* 2007). The Late Permian geological units of the Goiás State that contain fossil vertebrates belong to the Irati Formation (Passa Dois Group), where mesosaurid remains have been reported. Reptilian remains from the Late Cretaceous are known from the Adamantina and Marília Formations (Bauru Group) (Soares *et al.,* 1980; Paulo, 2009, 2014; Candeiro *et al.,* 2018a) (Fig. 2). From the Cenozoic covers of Goiás State, mammal remains have been reported since the 1930s.

3.1. Paleozoic (Upper Permian): Passa Dois Group

The Passa Dois Group is subdivided into the Irati, Serra Alta, Teresina, and Rio do Rasto formations that emerge in the southern portion of the Paraná Basin (Schneider *et al.,* 1974). In the state of São Paulo, the sedimentary package called Corumbataí Formation is the equivalent of the rocks from the Teresina Formation (Milani *et al.,*

2007). In Goiás State, this group is represented by the Irati Formation dated as Kungurian (278.4 ± 2.2 Ma, Santos *et al*., 2006) and Corumbataí Formation (Figure 2) dated as Wuchiapingian (257.5 ± 2.2 Ma, Rocha-Campos *et al.,* 2019), both ages obtained from zircons from ash fall beds. According to Milani *et al*. (1994), the Irati Formation would have been deposited under conditions compatible with a restricted sea which was progressively more saline from the seabed to the surface. The Irati Formation contains claystones, dark shales, limestones, and sandstones with horizontal lamination, cross-lamination, oolites, ripple marks, and intraformational conglomerates (Schneider *et al.,* 1974). This unit was deposited in a wide epicontinental sea in southern Gondwana (Lavina *et al*., 1991; Milani *et al.,* 1994, 2007). In southwestern Goiás State, dolomitic limestones from the Irati Formation are commercially extracted, as they are useful as fertilizer to buffer acidic soils. The main municipalities in which this unit is exposed are Caiapônia, Jataí, Mineiros and Montevidiu.

3.2. Mesozoic (Upper Cretaceous)

The southern region of Goiás State is geologically located in the Bauru supersequence (Bauru Group), one of the four supersequences into which the Paraná Basin is divided (*sensu* Milani y Zalán, 1999; Milani *et al.,* 2007). There is a considerable Upper Cretaceous sedimentary record in this region which is formed by the Adamantina and Marília formations (*sensu* Soares *et al.,* 1980).

Soares *et al*. (1980) proposed updated stratigraphic arrangements that are still used for the Bauru Group unit and include, in ascending order, the Adamantina, Uberaba, and Marília. The age of the Adamantina Formation has been attributed as Turonian-Santonian in age; it is considered by several authors as chronologically correlated to the Uberaba Formation, Coniacian-Santonian in age (Barcelos, 1984; Goldberg and Garcia, 2000; Dias-Brito *et al.,* 2001; Candeiro and Rich, 2010).

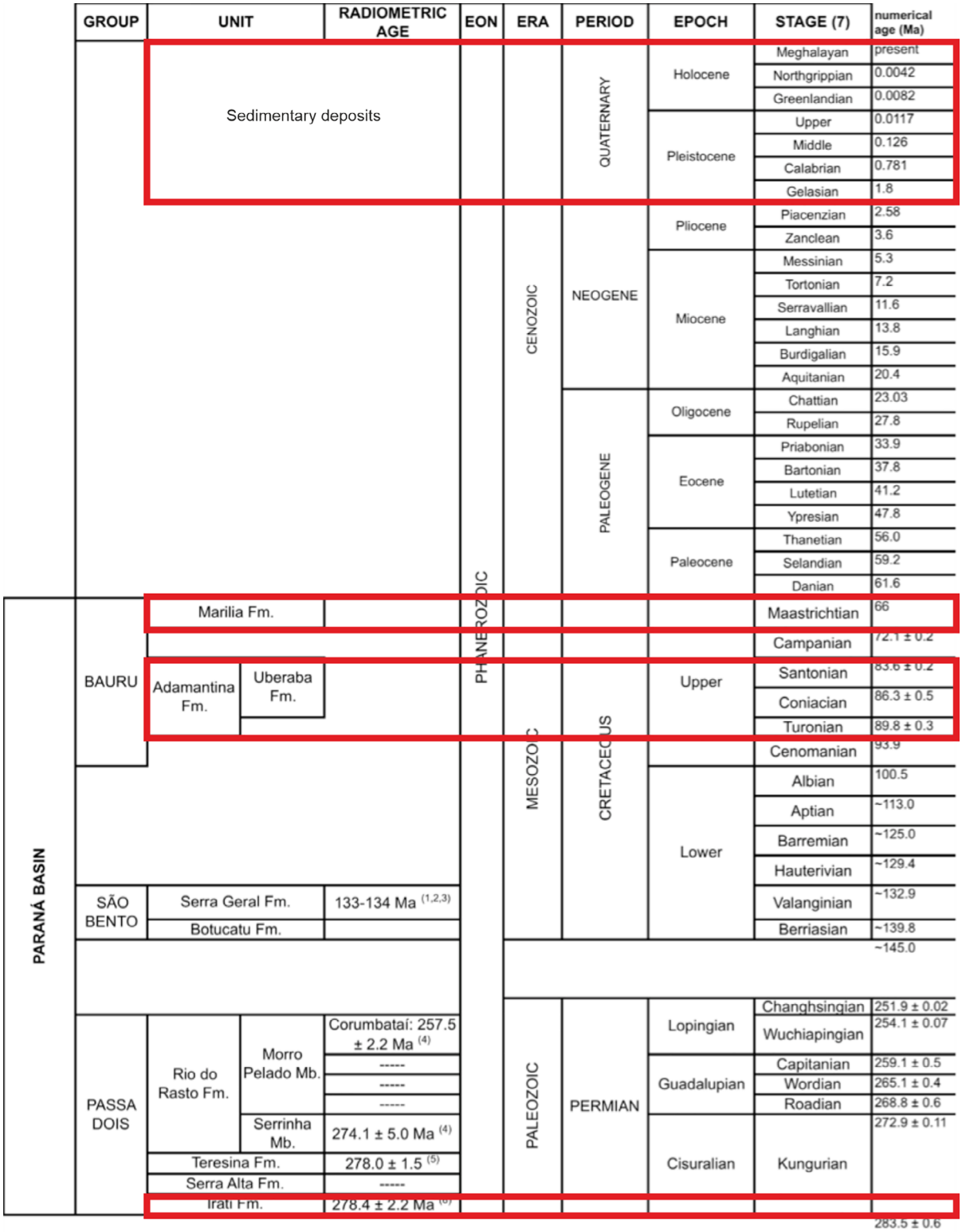
The Bauru Group outcrops are exposed in southern Goiás State. The most representative outcrops of this geological unit are in the southern municipalities of Goiás (*e.g.*; Caçu, Cachoeira Alta, Itajá, Itarumã, Mineiros, Paranaiguara, Paraúna, Quirinópolis, Rio Verde, and Turvelândia) where the rocks of the Adamantina Formation overlap the Cretaceous basalts of the Serra Geral Formation (Serra Geral Group, Paraná Basin) (*sensu* CPRM, 2004), which is dated at ~134 Ma by several authors and techniques (Ar-Ar step-heating, U-Pb in baddeleyite and zircon) (Renne *et al.,* 1992; Thiede and Vasconcelos, 2010; Janasi *et al.,* 2011).

The Adamantina Formation was deposited during the Turonian-Santonian stage (Dias-Brito *et al.,* 2001). This unit, defined by Soares *et al*. (1980), is exposed in the municipalities of Itajá, Itarumã, Quirinópolis, Paraúna, Paranaiguara, and Rio Verde, in southern Goiás State. The overlaps the volcanic rocks of the Serra Geral Formation (Serra Geral Group, Paraná Basin; Rosetti *et al.,* 2018). The strata of the Adamantina Formation consist of reddish fluvial-lacustrine sandstones deposited during hot and humid climatic events (Soares *et al.,* 1980; Barcelos, 1984; Barcelos and Suguio, 1987; Fúlfaro *et al.,* 1994; Candeiro *et al.,* 2018a). So far, the fossil record from the region consists mainly of vertebrate remains (Simbras *et al.,* 2013; Resende *et al.,* 2014; Candeiro *et al.,* 2016, 2018a, 2018b).

Dias-Brito *et al*. (2001) assigned the Marília Formation to the Late Maastrichtian based on its ostracod record, from studies conducted in western São Paulo State and in the Triângulo Mineiro. The Marília Formation was described by Almeida and Barbosa (1953) in the western region of São Paulo State and, later, in the southern areas of Goiás State (Soares *et al.,* 1980; Barcelos, 1984; Barcelos and Suguio, 1987; Fúlfaro *et al.,* 1994). This geological unit consists of fine to medium sandstones interspersed by conglomerate levels. The sandstones are cemented and contain calcium carbonate concretions (Fúlfaro and Barcelos, 1991). According to Barcelos and Suguio (1987), the Marília Formation was deposited in an anastomosed river system, in association with fine to medium sandstones and lacustrine limestone deposits. In the southern region of Goiás, the Marília Formation is the most fossiliferous, as ichnofossils and invertebrate and vertebrate remains have been found (Soares *et al.,* 1980; Barcelos and Suguio, 1987; Fúlfaro *et al.,* 1994; Dal´Bo and Basilici, 2010, 2011).

3.3. Cenozoic (Pleistocene-Holocene)

The work of Brasil (1983) indicate that the geomorphological units present in Goiás State had their genesis during the Pleistocene (Figure 2). These areas correspond to extensive peneplaned



1,2- Ar-Ar (Renne et al., 1992; Thiede and Vasconcelos, 2010).
3- U-Pb in baddeleyte and zircon (Janasi et al., 2011).
4- U-Pb in zircons from volcanic ash (Rocha-Campos et al., 2019).
5- U-Pb in zircons from volcanic ash (Rocha-Campos et al., 2006).
6- U-Pb in zircons from volcanic ash (Santos et al., 2006).
7- Stages limits according to the International Cronostratigraphic Chart-2018.

Figure 2. Geochronological chart of Goiás State units bearing reptiles and mammals (unit/age in red; geological age from Grandstein *et al.* 2005).

Figura 2. Cuadro geocronológico de las unidades del estado de Goiás con reptiles y mamíferos (unidad/edad en rojo; edad geológica de Grandstein *et al.* 2005).

surfaces that are often interrupted by drainage networks. Studies performed by the Pena *et al.* (1975) present these structures as "chapadas" (plain-topped morphologies) or "chapadões" (extensive *chapadas*) covered by a thin layer of partially lateralized detrital deposits of sandy-clay nature that date to the Pleistocene. The alluvial deposits are distributed along watercourse channels which are usually short and consist of pebbles associated with clays and sands (Pena *et al.*, 1975).

Araújo y Moreton (2008) reported the existence of Holocene-dated covers that have lowered topographic dimensions and were deposited under alternating climatic and phytophysiognomic conditions. This geomorphological unit comprises extensive peneplanized areas that form the "chapadas/chapadões" covered by this thin layer of predominantly sandy-clay, detrital lateritic deposits (Brasil, 1975). These continually unconsolidated sediments are associated with pebble gravels of varying sizes that have often been deposited in diamond mines. Alluvial deposits are present in the beds of the main rivers of Goiás State.

4. Results: faunal distribution by geological period

The following is a brief review of the geological, geographic and reptile and mammal fauna content of known specimens from Goiás State (Table 1).

FOSSIL TETRAPODS OF GOIÁS				
Taxa	**Geological unit**	**Location**	**Age**	**Reference selected**
Stereosternum tumidum	Irati Formation, Passa dois Group	Perolândia municipality	Permian	Vieira *et al.* (1991)
Brazilosaurus sanpauloensis	Irati Formation, Passa dois Group	Montividiu municipality	Permian	Araujo *et al.* (2000)
Mesosauria	Irati Formation, Passa dois Group	Perolândia and Portelândia municipalities	Permian	Sedor and Silva (2004)
Notosuchia	Adamantina Formation, Bauru Group	Quirinópolis municipality	Late Cretaceous	Candeiro *et al. (*2018a)
Crocodyliformes	Adamantina Formation, Bauru Group	Quirinópolis municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Testudinata	Marília Formation Bauru Group	Rio Verde municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Crocodylomorpha indet.	Marília Formation Bauru Group	Rio Verde municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Titanosauriformes indet.	Marília Formation Bauru Group	Rio Verde municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Titanosauria indet.	Marília Formation Bauru Group	Rio Verde municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Theropoda	Adamantina Formation Bauru Group	Paraúna municipality	Late Cretaceous	Candeiro *et al.* (2018a)
Eremotherium laurillardi		Jaupaci and Piranhas municipalities	Cenozoic	Moreira (1973); Paulo and Bertini (2013); Mendes *et al.* (2020); Oliveira *et al.* (2020)

FOSSIL TETRAPODS OF GOIÁS				
Taxa	**Geological unit**	**Location**	**Age**	**Reference selected**
Platygonus		Jaupaci municipality	Cenozoic	Moreira (1973)
Tapirus		Jaupaci municipality	Cenozoic	Moreira (1973)
Notiomastodon platensis		Jaupaci municipality	Cenozoic	Moreira (1973); Paulo and Bertini (2013); Bampi *et al.* (2016)
Anoura geoffroyi		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Artibeus sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Carollia sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Chrotopterus auritus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Desmodus rotundus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Desmodus sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Emballonuridae sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Histiotus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Glossophaga sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Lionycteris spurrelli		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Lonchorhina aurita		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Micronycteris megalotis		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Mimon bennetti		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Mimon crenulatum		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Molossidae indet.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Myotis sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Natalus stramineus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Phylloderma sp. n.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Phyllostomus discolor		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Phyllostomus hastatus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Platyrrhinus sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Pteronotus davyi		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Pteronotus parnelli		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Sturnira sp.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Tonatia sp. n.		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Lophostoma silvícola		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)
Trachops cirrhosus		Minaçu municipality	Cenozoic	Fracasso and Salles (2005)

Table 1. Reptiles and mammals from the Goiás state record (Late Permian, Late Cretaceous and Pleistocene-Holocene).

Tabla 1. Registro de reptiles y mamíferos del estado de Goiás (Pérmico Superior, Cretácico Superior y Pleistoceno-Holoceno).

4.1. Late Permian

In Goiás State, the Paleozoic sedimentary rocks from the Paraná Basin have provided a significant fossil record. Complete and fragmentary specimens of mesosaurs were found in the Permian strata of the shales from the Irati and Corumbataí (Passa Dois Group) (Figure 2). These materials came from the municipalities of Caiapônia, Montividiu, Perolândia, and Portelândia, in southwestern Goiás State (Erichen and Miranda, 1939; Milward, 1935; Pena *et al.,* 1975; Vasconcelos, 1973; Vieira *et al.,* 1991). Vieira *et al*. (1991) reported that Teixeira, in 1932, was the first to mention the occurrence of mesosaurs in the municipality of Montividiu during the geological reconnaissance performed from the Rio Verde region to the Araguaia River. Caster (1947) then reported for the first time the large amount of mesosaur remains in the Irati Formation, Serra do Caiapó region, southwestern Goiás State. We suggest that Mesosauridae played an important role in the food chain in the Upper Permian Paraná Basin, but the possible biases in their fossil record in relation to other vertebrates do not support the conclusion that mesosaurs outnumbered other tetrapods. Instead, taphonomic bias should be considered first, that is, the preservation of these reptiles was privileged, perhaps because of their aquatic or semiaquatic habitats, which fostered burial and preservation.

Vasconcelos (1973) was the first to report mesosaurids in the outcrops of the Irati Formation, in Perolândia. This region, where specimens of *Mesosaurus brasiliensis* (= *Mesosaurus tenuidens*) were found, was identified as one of the most prolific fossil-bearing areas. The author mentions the importance of these records, since their habitat could be related to shallow seas, proven for the first time for Goiás State and, thus, providing important paleobiogeographic, biostratigraphic, and biochronological information.

Moreira *et al*. (1983) disclosed new records of *Mesosaurus*, *Stereosternum*, and *Brazilosaurus* from Jataí and Perolândia, which were used in studies of the cephalic and cervical regions of these animals. Vieira *et al*. (1991) concluded that materials from the Permian of the Irati Formation, in Goiás, should be considered as *Stereosternum tumidum* Cope 1886 instead of *Mesosaurus brasiliensis* (= *Mesosaurus tenuidens*) or, as Rösler's (1985) report, *Brazilosaurus sanpauloensis*. Araújo *et al*. (2000) reported *Brazilosaurus sanpauloensis* in Montividiu (Figure 3).

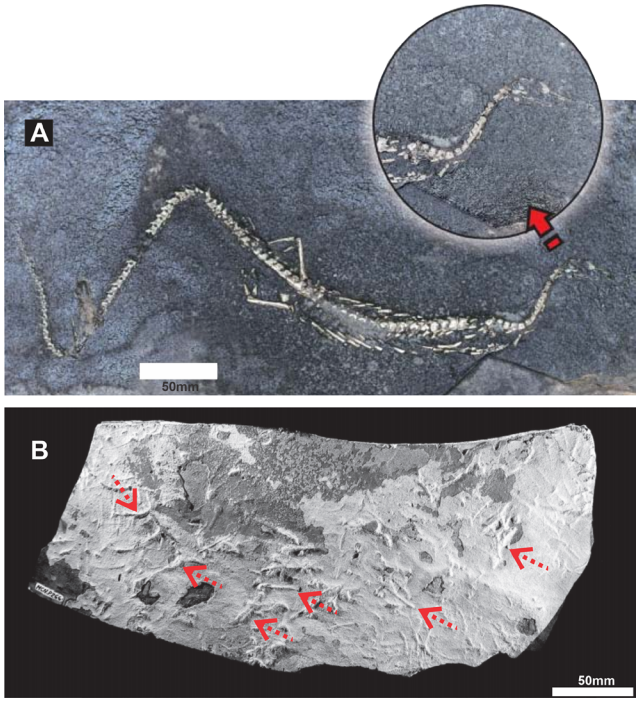


Figure 3. Late Permian reptiles from Goiás State. A, *Brazilosaururs sanpauloensis* from Montividiu municipality – arrow red pointed cranial part (modified from Araújo-Barbarena *et al*., 2000); B, Mesosauridae footprints from Perolândia municipality – arrow red pointed main footprint marks (modified from Sedor and Silva-Costa, 2004). Scale bar: 50 mm.

Figura 3. Reptiles del Pérmico Tardío del estado de Goiás. A, *Brazilosaururs sanpauloensis* del municipio de Montividiu – parte del cráneo con punta de flecha roja (modificado de Araújo-Barbarena *et al*., 2000); B, Huellas de Mesosauridae del municipio de Perolândia – huellas principales con flechas rojas puntiagudas (modificado de Sedor y Silva-Costa, 2004). Barra de escala: 50 mm.

Sedor and Silva (2004) reported the occurrence of five samples of mesosaurid (Figure 3) footprints in white to gray laminar limestones from the Irati Formation in the municipalities of Perolândia and Portelândia. According to Sedor and Silva (2004), these rare records were interpreted as toe drag marks produced by Mesosauridae while swimming. These records were the first footprint marks of these reptiles reported from Goiás State. In addition, this is the second known locality in the whole Irati-Whitehill System with ichnofossil records assigned to Mesosauridae.

Ferreira *et al*. (2006) considered that the mesosaurs from the Assistência Member strata in southwestern Goiás State correspond to the limestone laminar layers, which represent the deposition in shallow waters, typical of basin borders. The two species reported for Goiás – *Stereosternum tumidum* and *Brazilosaurus sanpauloensis* – correspond to the records found in the strata of

the Karoo System in South Africa (*M. tenuidens* and *S. tumidum*) (Rösler, 1985; Oelofsen and Araújo, 1987; Ferreira *et al.,* 2006). During the Permian Period a large epicontinental sea was formed and occupied an area between South America and South Africa, the so-called Irati-Whitehill Sea (Oelofsen and Araújo, 1987; Lavina *et al*., 1991) (Figure 4). Overall, this complex had shallow, calm waters with restricted circulation and occurred widely in the southern areas of Gondwana during the Permian. Today, these areas correspond to the center-south of Brazil and western South Africa, a large region that once shared similar faunas.

4.2. Late Cretaceous

In southern Goiás State, from the municipalities of Quirinópolis and Rio Verde, there are six known fossiliferous localities that comprise this geological interval and where the first records of reptiles from Goiás State were found. The importance of these deposits and their fossils in stratigraphic context have been previously highlighted in the literature (Resende *et al.,* 2014; Candeiro *et al.,* 2018a, 2018b, 2020a, b; Gil, 2019; Maia *et al.,* 2020). Nevertheless, since the publication of these recent works, the faunal list of southern Goiás State has been expanded and the existence of two fossil-bearing geological units has been confirmed.

Candeiro *et al*. (2018a) described fragmentary Cretaceous records of the Bauru Group (Figures 5 and 6). A specimen of Notosuchia and isolated materials of crocodyliforms were found in the Adamantina Formation of Quirinópolis. A quarry in Rio Verde revealed the most diverse records of the Bauru Group in Goiás State, which include remains of a large turtle, crocodyliforms, titanosauriform dinosaurs, and undetermined Titanosauria. Candeiro *et al*. (2018a) attributed these specimens (tooth and part of a radius) to Titanosauria (as they presented more inclusive diagnostic characteristics), while other fragmentary materials of the postcranium were only attributed to Titanosauriforms for lack of more informative characters. Candeiro *et al*. (2020a) also reported an isolated tooth fragment of a theropod dinosaur from the Paraúna State Park.

The crocodyliforms and dinosaurs that have been described over the last decade from the Late Cretaceous of Goiás have significantly contributed to the understanding of the general panorama of these groups for Brazil, especially for the central region of the country. From this study it is possible to verify that in neighboring regions of southern Goiás there are large areas of concen-

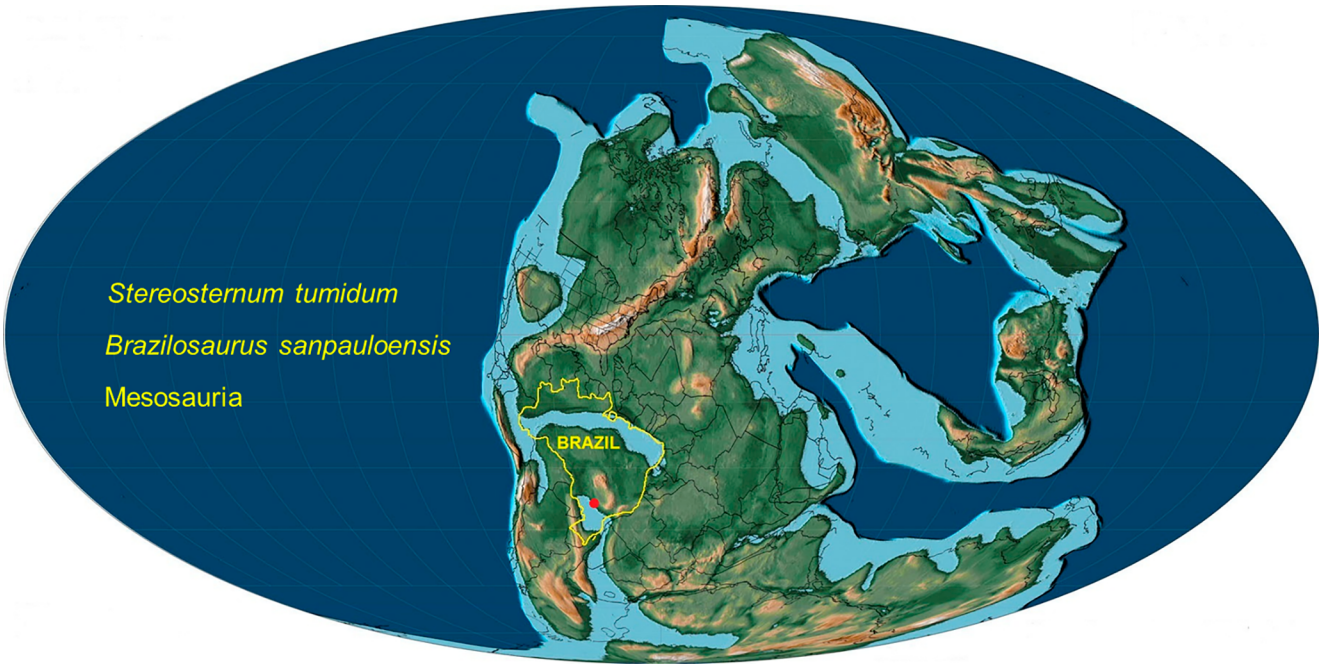


Figure 4. Mesosaurid paleogeographical record distribution in Goiás region during Late Permian Period (paleomap from Scotese, 2014).

Figura 4. Distribución del registro paleogeográfico de mesosáuridos en la región de Goiás durante el Período Pérmico tardío (paleomapa de Scotese, 2014).

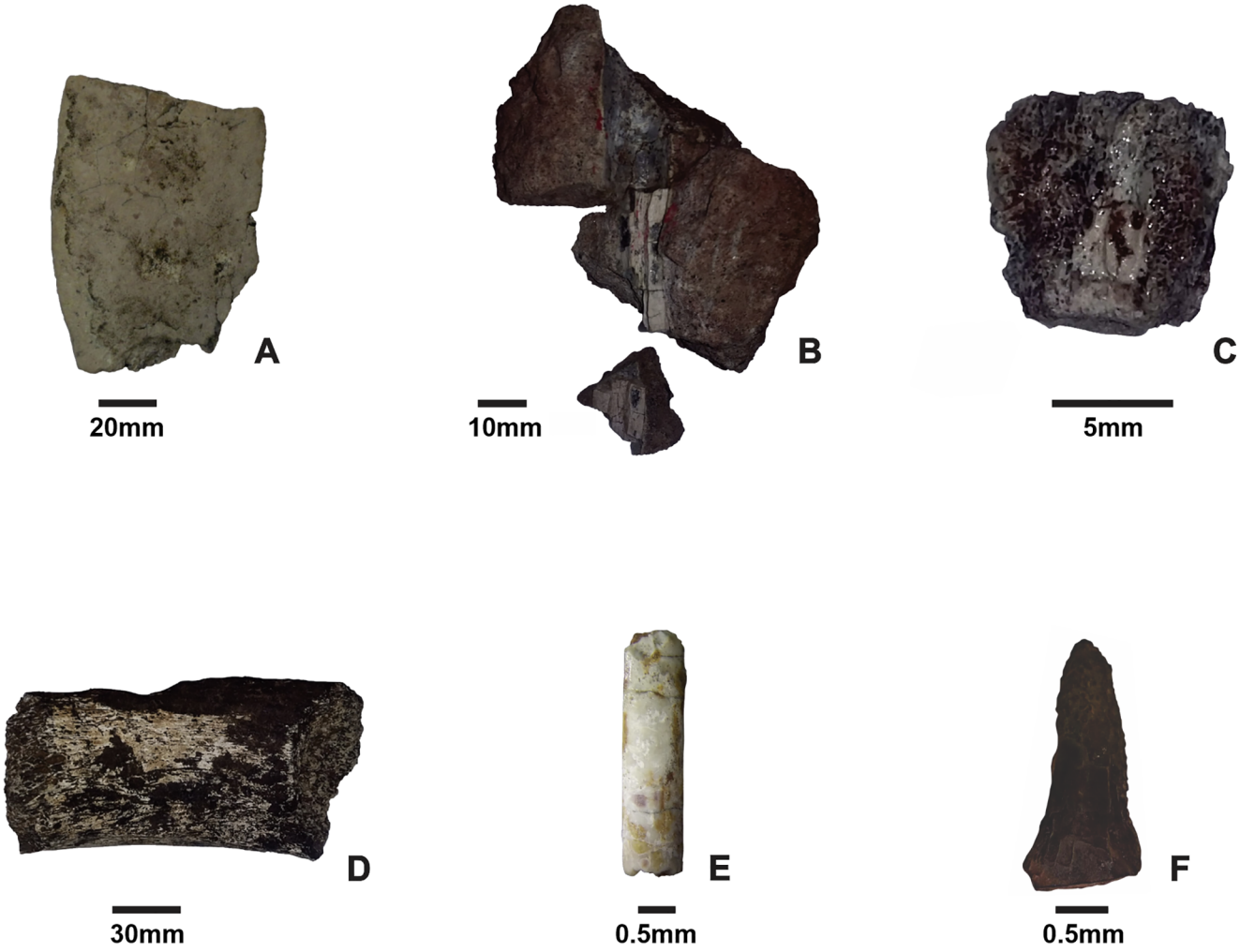


Figure 5. Late Cretaceous reptiles from Goiás State. A, Podocnemidoidae - fragmentary right epiplastron view; B, cf. Notosuchia indet. - proximal half of a femur in lateral view; C, Crocodyliforms indet. - last sacral vertebra view; D, cf. Titanosauria indet. - diaphysis of a right radius; E, Titanosauria indet. – fragmented tooth; F, Theropoda indet. – tooth (A-E from Candeiro *et al.*, 2018a and F from Candeiro *et al.*, 2020a).

Figura 5. Reptiles del Cretácico Superior del estado de Goiás. A, Podocnemidoidae - vista fragmentaria del epiplastrón derecho; B, cf. Notosuchia indet. - mitad proximal de un fémur en vista lateral; C, Crocodyliforms indet. - vista de la última vértebra sacra; D, cf. Titanosauria int. - diáfisis de un radio recto; E, Titanosauria int. – diente fragmentado; F, Theropoda indet. - diente (A-E de Candeiro *et al.*, 2018a y F de Candeiro *et al.*, 2020a).

tration of fossil studies (*e.g.*, Triângulo Mineiro, western São Paulo state) where fossils of titanosaurs have been found, raising the hypothesis that the central region of the country, especially the south of the state of Goiás, may be home to important sites for future paleontological research.

The distribution of these Late Cretaceous records helps to understand the distribution of these reptiles, which fills knowledge gaps for this Brazilian region and may be useful for future studies on paleobiogeography. Although the southern region of the state of Goiás has been neglected and little explored, in recent years it has shown fossiliferous potential (see Simbras *et al.*, 2013; Resende *et al.*, 2014; Candeiro *et al.*, 2018). Fieldwork carried out by the team from the Laboratório de Paleontologia e Evolução/Course of Geology/UFG has been recovering several specimens, which despite their fragmentary nature, have provided information on the fauna of the Bauru Group in this region. The new findings, while not diagnostic for less inclusive levels (e.g., clades within Titanosauria), represent an important sample of the region's faunal diversity during the late Cretaceous. These new materials also help and encourage more expeditions to take place in order to recognize new fossiliferous points in the south of the state of Goiás, which may contribute in the future to the finding of other types of vertebrate fossils, in addition to promoting studies on regional paleontology.

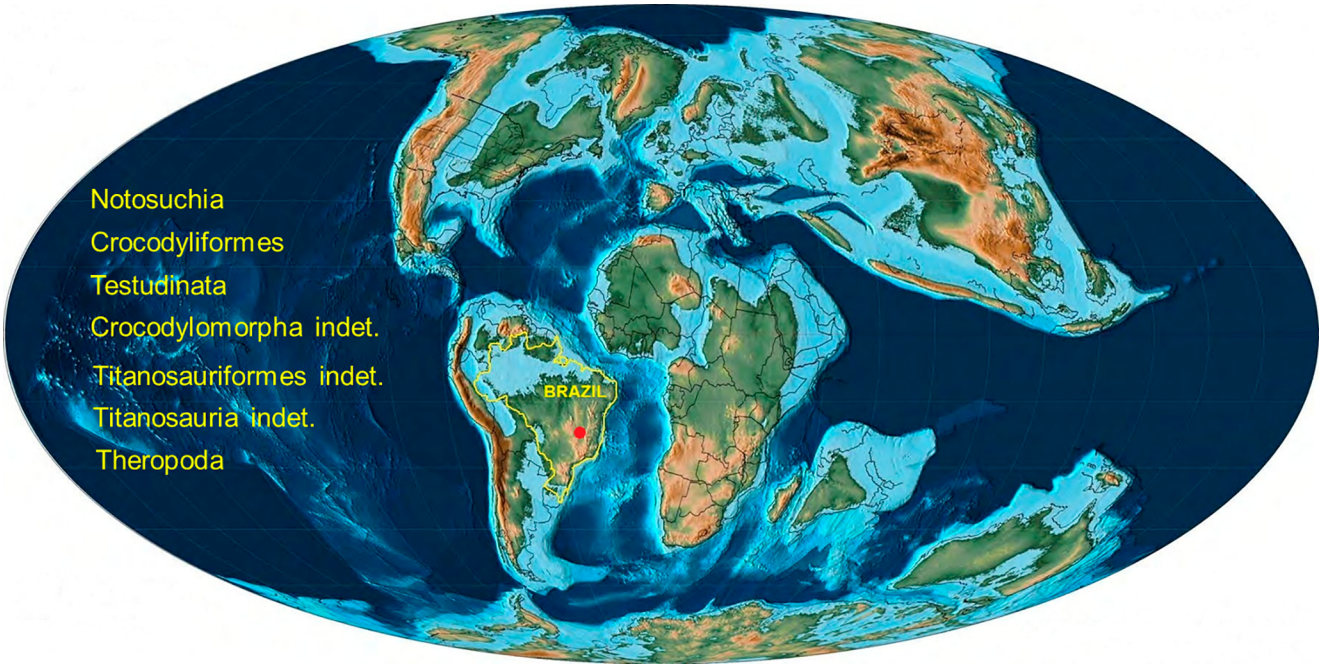


Figure 6. Reptilian paleogeographical record distribution in Goiás region during Late Cretaceous Period (paleomap from Scotese, 2014).

Figura 6. Distribución del registro paleogeográfico reptiliano en la región de Goiás durante el Cretácico Superior (paleomapa de Scotese, 2014).

4.3. Cenozoic

Moreira and Melo (1971) reported the first occurrences of Pleistocene mammals in mid-west Goiás State; these were molars and molar fragments found in Rio Claro, Jaupaci municipality. Moreira (1973) assigned these materials to *Eremotherium*, *Platygonus*, *Tapirus*, *Notiomastodon,* and other undetermined mammalian taxa.

New fossil specimens have been described from the classic fossiliferous area of Pau Ferrado, Jaupaci municipality, which is a rudimentary diamond mine. Paulo and Bertini (2013) described, for the first time, materials from *Eremotherium laurillardi* and *Stegomastodon waringi* (= *Notiomastodon*) (Figures 7 and 8) found in this site and that were kept for years at the Museum of Natural History of the Instituto do Trópico Sub-Úmido of the Pontifícia Universidade Católica de Goiás, in Goiânia city.

Bampi *et al*. (2016) described a large rib, also from the Pau Ferrado site, as *Notiomastodon platensis*. This specimen shows marks produced by lithic artifacts and is one of the few records of lytic marks in Brazilian fossil mammals. According to Mothé *et al*. (2017), this specimen, together with other South American records, confirms the occurrence of human interaction with Pleistocene megafauna and could corroborate claims that the human species had an important role in the extinction of these large animals during the early Holocene.

Abrantes *et al*. (1998), Abreu *et al*. (1998), Abreu and Salles (2000) and Fracasso and Salles (2005) described a diverse mammal paleofauna that became the most representative of the taxonomic richness of Goiás State (see Table 1). This paleofauna include *Anoura geoffroyi*, *Artibeus* sp.; *Carollia* sp.; *Chrotopterus auritus*, *Desmodus rotundus*, *Desmodus* sp.; Emballonuridae sp. Epígeno/*Histiotus*, *Glossophaga* sp.; *Lionycteris spurrelli*, *Lonchorhina aurita*, *Micronycteris megalotis*, *Mimon bennetti*, *Mimon crenulatum*, Molossidae sp. indet.; *Myotis* sp.; *Natalus stramineus*, *Phylloderma* sp. n.; *Phyllostomus descolor*, *Phyllostomus hastatus*, *Platyrrhinus* sp.; *Pteronotus davyi*, *Pteronotus parnelli*, *Sturnira* sp.; *Tonatia* sp. n.; *Lophostoma silvicola*, and *Trachops cirrhosus*. The authors point out that Phyllostomidae was the family with the highest number of species recorded in the region. These findings affirmed that a population reduction of these taxa occurred in the region and suggest that the climate was warmer and wetter during some intervals of the Upper Pleistocene or Lower Holocene (Figure 8), compared to cooler and drier intervals.

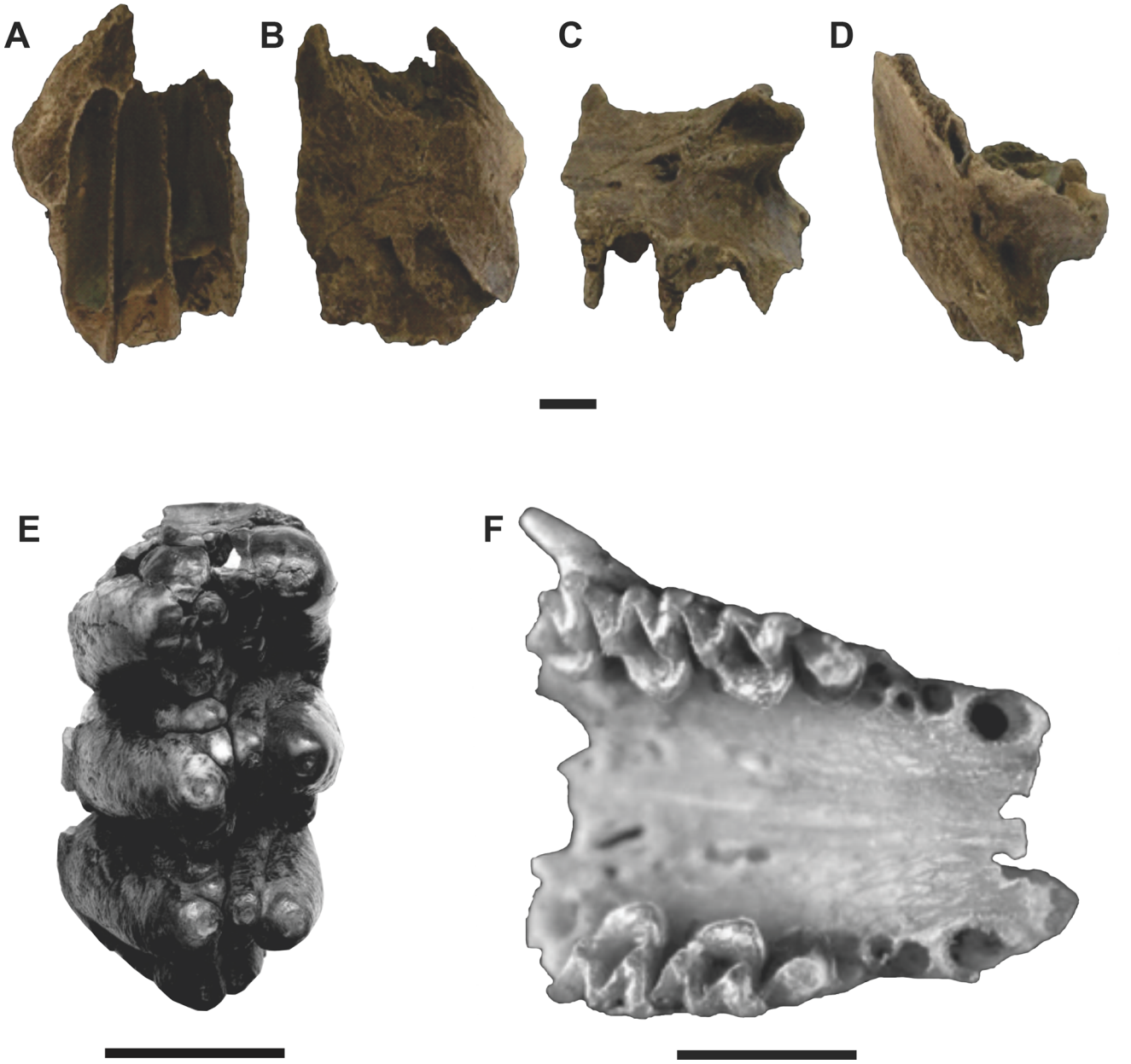


Figure 7. Pleistocene-Holocene mammals from Goiás State. *Eremotherium* A (lingual view), B (lateral view), C (oclusal view), D (detail, infraorbital foramen region) (modified from Mendes *et al*., 2020); *Notiomastodon* E (molar occlusal view) (from Paulo, 2009); *Natalus stramineus* F (palatal view of the rostrum) (Fracasso and Salles, 2005). Scale bar: A-D = 20 mm, F = 50 mm, G = 10mm.

Figura 7. Mamíferos del Pleistoceno-Holoceno del estado de Goiás. *Eremotherium* A (vista lingual), B (vista lateral), C (vista oclusal), D (detalle, región del agujero infraorbitario) (modificado de Mendes *et al*., 2020); *Notiomastodon* E (vista oclusal molar) (de Paulo, 2009); *Natalus stramineus* F (vista palatal del rostro) (Fracasso and Salles, 2005). Barra de escala: A-D = 20 mm, F = 50 mm, G = 10 mm.

5. Final considerations

The territory of Goiás State provides an extensive and informative fossil record of the Late Permian, Late Cretaceous and Pleistocene-Holocene tetrapods from Central Brazil, including, at present, turtles, mesosaurs (two species), crocodyliforms, dinosaurs, and mammals (12 species, three genera). Undoubtedly, the diverse fossil record of reptiles and mammals in Goiás State has contributed to the knowledge of the paleofauna of the Midwest region of Brazil. These sediments have provided, in some important locations such as Minaçu and Jaupaci, several small and

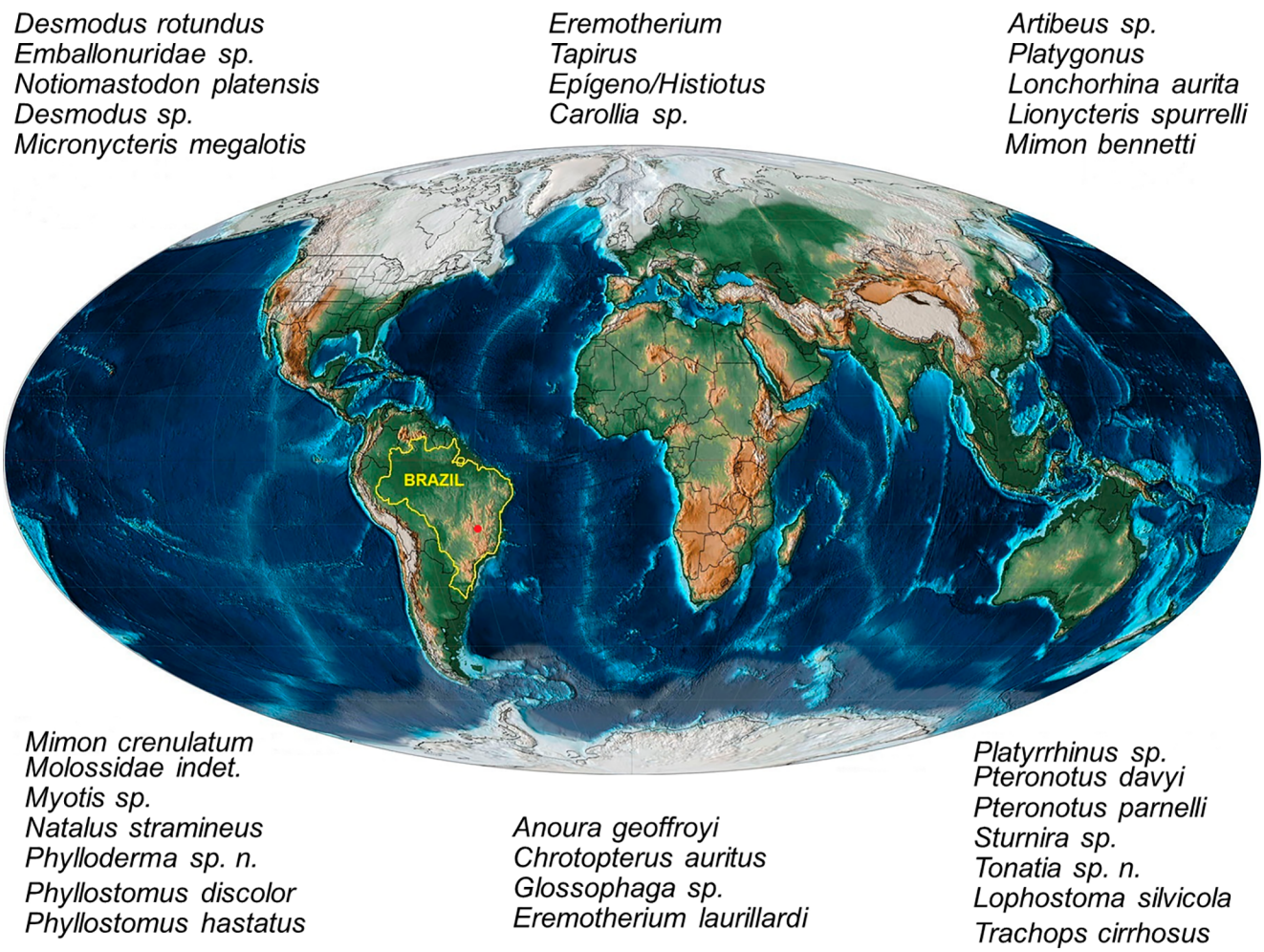


Figure 8. Mammal paleogeographical record distribution in Goiás region during Pleistocene-Holocene epochs (paleomap from Scotese, 2014).

Figura 8. Distribución de registros paleogeográficos de mamíferos en la región de Goiás durante las épocas del Pleistoceno-Holoceno (paleomapa de Scotese, 2014).

large mammal remains, in particular, Artiodactyla, Carnivora, Chiroptera, Didelphimorphia, Perissodactyla, Primates, Proboscidea, Rodentia, and Xenarthra.

The Upper Permian rocks of the Irati Formation have yielded two mesosaurid species, similar to those known from the Karoo System of South Africa (Werner, 2006). The Upper Cretaceous fossils are comparatively less well-known, represented by scarce and fragmentary specimens of turtles, crocodyliforms, and dinosaurs. However, this reality has begun to change in recent years due the discovery of significant new specimens and promising new sites, such as the fossiliferous localities of Quirinópolis and Rio Verde.

During the last 84 years, the increase in knowledge of the Late Permian, Late Cretaceous and Pleistocene-Holocene fossils of Goiás State has allowed some researchers to recognize associations of the Irati-Whitehill System (Oelofsen and Araújo, 1987) or even to identify remains of reptiles that lived during the last stage of the great K-Pg extinction. [Brusatte *et al.*, 2017 (as the Marília Formation in Goiás dates to the very end of the Cretaceous)]. The refinement and further study of these sites and specimens, together with new fieldwork prospecting that might result in new discoveries, are central objectives of the next stage of research in Goiás State.

The paleontological research in Goiás State in the 1970s focused mainly on Late Permian mesosaurids and Pleistocene-Holocene mammalian megafauna, playing an important role in knowledge of taxonomy, and geographical distribution and diffusion of these groups. As the pace of discoveries has changed after the 2000s, future studies should cover different aspects of contemporary paleontological issues (such as paleobiology,

paleoecology, and biogeography), with interdisciplinary approaches and the application of new methodologies.

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