

ON MANIRAPTORAN MATERIAL (DINOSAURIA: THEROPODA) FROM VALE DO RIO DO PEIXE FORMATION, BAURU GROUP, BRAZIL

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ABSTRACT – Non avian theropod remains are scarce in Brazil and few specimens were referred to Maniraptora. Remains of a non-avian theropod dinosaur (DGM 930-R) from Vale do Rio do Peixe Formation, Bauru Group, found near the Santo Anastácio municipality, São Paulo State are described. DGM 930-R is represented by two partial caudal vertebra centra, a partial diaphysis of the right femur with marked lines of arrested development (indicatives of a habitat with marked seasonality), a partial dorsal rib and other rib fragments, a partial bone that possibly represents the proximal portion of the ischium, and some unidentifiable elements. DGM 930-R is referred as a Maniraptoran *incertae sedis*, possibly related to Deinonychosauria because of the box-like anterior vertebral centrum with quadrangular-shaped posterior articulation. The circumference of the femur of DGM 930-R suggests it was a medium-sized dinosaur (about 3 m long) that shared the same geographic space with other theropods (megaraptorans, abelisauroids, and carcharodontosaurids) and mesoeucrocodylians.

Key words: Theropoda, Maniraptora, Bauru Group, Brazil.

RESUMO – Terópodes não avianos são raros no Brasil e apenas alguns espécimes foram referidos a Maniraptora. No presente trabalho são descritos restos de um terópode não aviano (DGM 930-R) da Formação Vale do Rio do Peixe, Grupo Bauru, encontrados próximos ao município de Santo Anastácio, São Paulo. DGM 930-R é representado por dois centros vertebrais parciais, parte de uma diáfise do fêmur esquerdo com linhas de parada de crescimento bem delimitadas (indicativos de habitat com sazonalidade marcada), parte de costela dorsal e outros fragmentos de costelas, uma possível parte proximal do isquio e alguns elementos não identificáveis. DGM 930-R é referido como Maniraptora *incertae sedis*, possivelmente relatado a Deinonychosauria, pois o centro vertebral mais anterior, com formato de caixa, apresenta a forma da articulação posterior quadrangular. A circunferência do fêmur de DGM 930-R sugere que se tratava de um dinossauro de porte médio (aproximadamente 3 m de comprimento) que compartilhou o mesmo espaço geográfico com outros terópodes (megaraptores, abelissauroides e carcarodontossaurídeos) e mesoeucrocodilianos.

Palavras-chave: Theropoda, Maniraptora, Grupo Bauru, Brasil.

INTRODUCTION

For almost two centuries, non-avian theropod dinosaurs have been treated as icons by the society and by the scientific community. Although the Brazilian dinosaur fossil record is fairly good for sauropodomorphs, both theropods and ornithischian remain are poorly known. Currently, different theropod taxa have been described for some geological basins in Brazil, especially the Bauru Basin (Novas *et al.*, 2005, 2008; Machado *et al.*, 2008, 2013; Bittencourt & Langer, 2011; Candeiro *et al.*, 2012a; Martinelli *et al.*, 2013; Méndez *et al.*, 2012, 2014) increasing our knowledge about the dinosaurian diversity in Brazil. In the Bauru Basin of Brazil, the occurrence of Maniraptora is based upon isolated teeth

(Bertini *et al.*, 1997; Bertini & Franco-Rosas, 2001; Franco-Rosas, 2002), a scapula (Machado *et al.*, 2008), a manual ungual phalanx (Novas *et al.*, 2005) and a dorsal vertebra (Candeiro *et al.*, 2012a).

A new specimen (DGM 930-R) that was collected in 1950 in a quarry to the west of Santo Anastácio city, São Paulo State (Vale do Rio do Peixe Formation; Bauru Basin) is presented, which is referred to Maniraptora. The material is fragmentary, without signs of deformation and bone surfaces are well preserved with some visible muscle scars. DGM 930-R includes two partial vertebral centra, a partial diaphysis of the left femur, partial ungual, partial ribs, an unidentified partial bone that possibly represents the proximal portion of the ischium, and some non-diagnosable elements.

Institutional abbreviations. DGBU, Department of Geology, Pusan (Busan) National University, Pusan, Korea; DGM, Museu de Ciências da Terra, Departamento Nacional de Produção Mineral, Rio de Janeiro, Brazil; IGM, Mongolian Institute of Geology, Ulan Baatar, Mongolia.

SYSTEMATIC PALEONTOLOGY

Superorder DINOSAURIA Owen, 1842

Suborder THEROPODA Marsh, 1881

MANIRAPTORA *incertae sedis* Gauthier, 1986

(Figures 2-4)

Material. DGM 930-R, fragmentary postcranial elements including two caudal vertebra centra, a partial diaphysis of

the right femur, a partial ungual, a partial dorsal rib and other rib fragments, a partial bone that possibly correspond to the proximal portion of the ischium, and some unidentifiable elements.

Locality and horizon. An old quarry to the west of Santo Anastácio city, São Paulo State, Brazil; Campanian-Maastrichtian Vale do Rio do Peixe Formation, Bauru Basin (Figure 1; Fernandes & Coimbra, 2000). The Bauru Basin corresponds mainly of sandstones deposited during semi-arid to arid climate, between the Coniacian and Maastrichtian; it extends over an area of 370,000 km² in the Brazilian states of São Paulo, Paraná, Mato Grosso do Sul, Minas Gerais and Goiás. The Vale do Rio do Peixe Formation is composed of sandstones intercalated with siltstones and sandy mudstones; the sandstones consist mainly in aeolian deposits while the

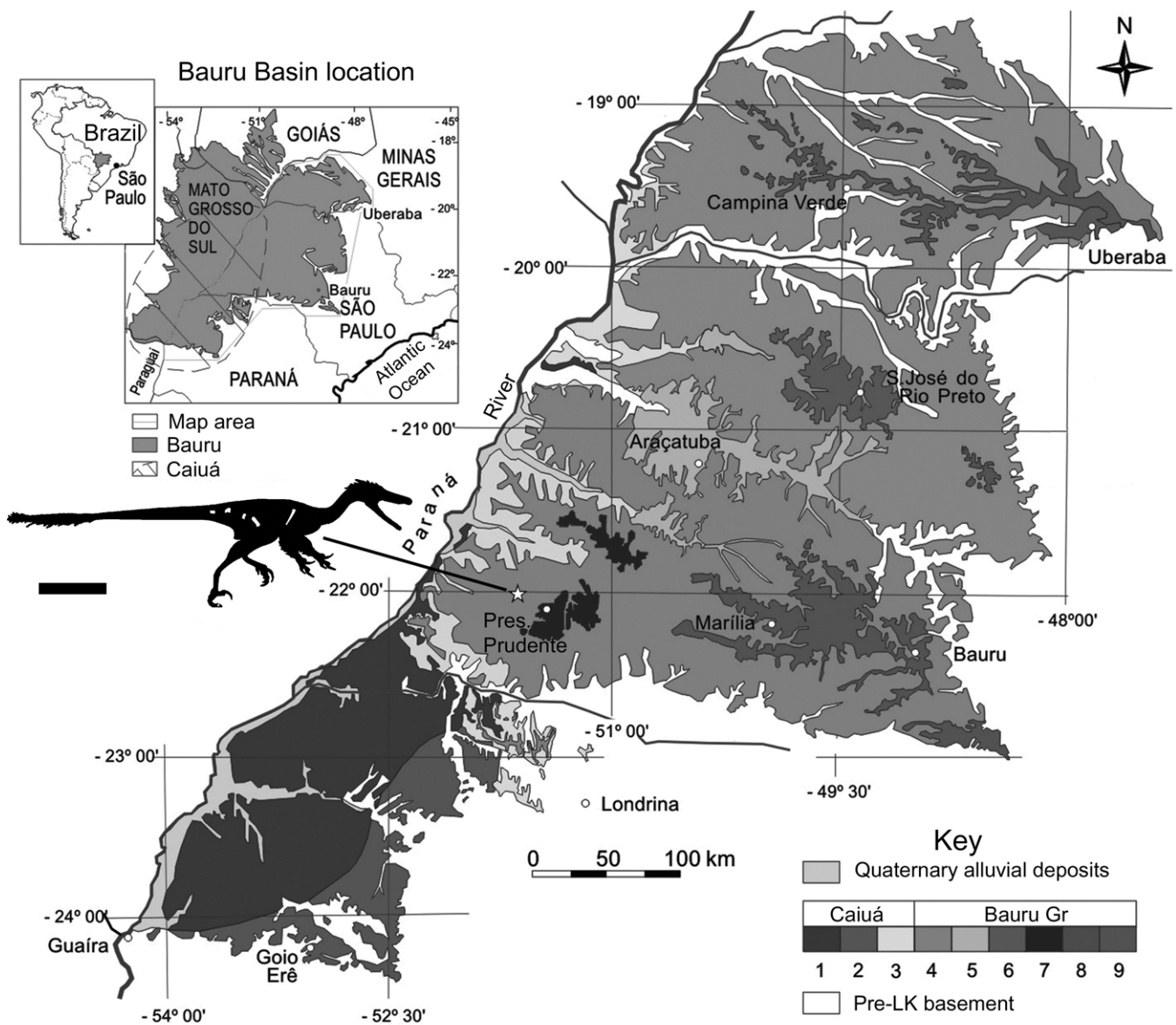


Figure 1. Geological map of the Bauru Basin showing the location of the old quarry to the west of the Santo Anastácio municipality (white star) in southwestern São Paulo State (modified from Fernandes *et al.*, 2007). 1, Rio Paraná Formation; 2, Goio Erê Formation; 3, Santo Anastácio Formation (Caiuá Group); 4, Vale do Rio do Peixe Formation; 5, Araçatuba Formation; 6, São José do Rio Preto Formation; 7, Presidente Prudente Formation; 8, Uberaba Formation; 9, Marília Formation (Bauru Group). Silhouette modified from Porfiri *et al.* (2011). Scale bar = 50 km.

mudstones were probably deposited in depressions in shallow and ephemeral aqueous bodies, created during periods of higher water level (see Fernandes & Coimbra, 2000 for detailed review of the Bauru Basin).

Unfortunately there is no information about the exact locality where DGM 930-R was found. These materials were kept unstudied for more than 50 years without more information. Because in the Santo Anastácio municipality there are several outcrop of the Vale do Rio do Peixe Formation, we are confident that the specimen DGM 930-R comes from this unit.

Description. The largest preserved vertebral centrum (Figures 2A-E; see Table 1 for measurements). The presence of an articular surface for a chevron (Figure 2E, *ch*) and its format (box-like) indicate it is an anterior caudal. The vertebra is broken dorsal to the level of the neurocentral suture, and the dorsal portion of the neural arch including the transverse process is missing (Figure 2C), suggesting the centrum was completely fused to the neural arch. Just the ventral portion of the transverse process and neural canal are preserved. The vertebra is amphicoelous, with the articular surfaces slightly concave and the borders thick and rounded. It has a box-like shape in anterior view; the lateral margins are flat, and the ventral margin is slightly curved (Figure 2C) and the posterior articular face is quadrangular-shaped (*i.e.* the posterior edge are straight and sub-parallel and the ventral edge is also straight) (Figure 2B). The borders of the anterior articulation are damaged, so it is not clear if it was also quadrangular-shaped as the posterior articular face. The ventral surface does not present any groove. The left lateral surface has a shallow depression in the anterior part, but it is not a pleurocoel, which was not present in any of the preserved vertebrae of this specimen. In both lateral surfaces there are tuberosities that were interpreted as the origin of the muscle *caudofemoralis longus* (*sensu* Romer, 1923). Beyond the tuberosities, there are also several small foramina spread on both lateral sides of the centrum and

at the base of the transverse processes (Figures 2A, C).

The second preserved vertebral centrum (Figures 2F-H) is cranio-caudally elongated and subcircular in posterior view (Figure 2F; see Table 1 for dimensions). The size and proportions of this centrum compared to the largest one (Table 1) suggests a posterior position in the caudal series. It has two large foramina on the right side (Figure 2G) and a large one on the left side along with other smaller foramina. Different to the more anterior caudal centrum, this one is broken at the suture of the neural arch. It is also amphicoelous and also bears muscle scars for the muscle *caudofemoralis longus* below the sutures. The ventral surface does not bear any groove or keel, so the centrum is spool-shaped.

The preserved part of the diaphysis of the right femur is subcircular in cross section (Figure 3; Table 1). The measured circumference (Table 1) suggests the total length of the femur was about 273 mm based on equations provided by Christiansen (1999). The mid-shaft of the femur is slightly curved and hollow (Figures 3E-F) and bears three distinctive muscle scars. The first one is interpreted as the adductor ridge (Figure 3C, *ar*), because it has the shape of an oval concavity (Hutchinson, 2001) located on the medioposterior surface of the diaphysis (Figure 3C). The surface, where this scar is located, is flatter than the surface of the more proximal part of the shaft of the femur. The second preserved scar was interpreted as the *linea intermuscularis cranialis* (Figure 3B), a ridge that extends from the proximal anteromedial surface to the distal medial surface of the femur (Hutchinson, 2001). The last scar possibly corresponds to the *linea intermuscularis caudalis* (Figure 3C). The shape and orientation of the preserved portion of these structures suggest this material correspond to the distal half of the diaphysis.

The fragment of the diaphysis of the femur also shows marked lines of arrested growth (LAGs; Figure 3G), suggesting its growth was periodically interrupted or reduced by environmental cyclical events (Chinsamy & Rubidge,

Table 1. Measurements (mm) of preserved elements of DGM 930-R. **Symbol:** * estimated values.

Measurement	caudal centrum 1	caudal centrum 2	femur	ischium?	pedal ungual
Length (preserved portion)	42	37	70	40	21
Total length	42	41*	273*	?	?
Width of anterior articular surface	34*	?	–	–	–
Height of anterior articular surface	31	?	–	–	–
Width of posterior articular surface	36	27	–	–	–
Height of posterior articular surface	25*	23	–	–	–
Midshaft anteroposterior diameter	–	–	22	–	–
Midshaft mediolateral diameter	–	–	27	~22	–
Midshaft circumference	–	–	79	–	–
Width of proximal articulation	–	–	–	28	16*
Height of proximal articulation	–	–	–	?	17*

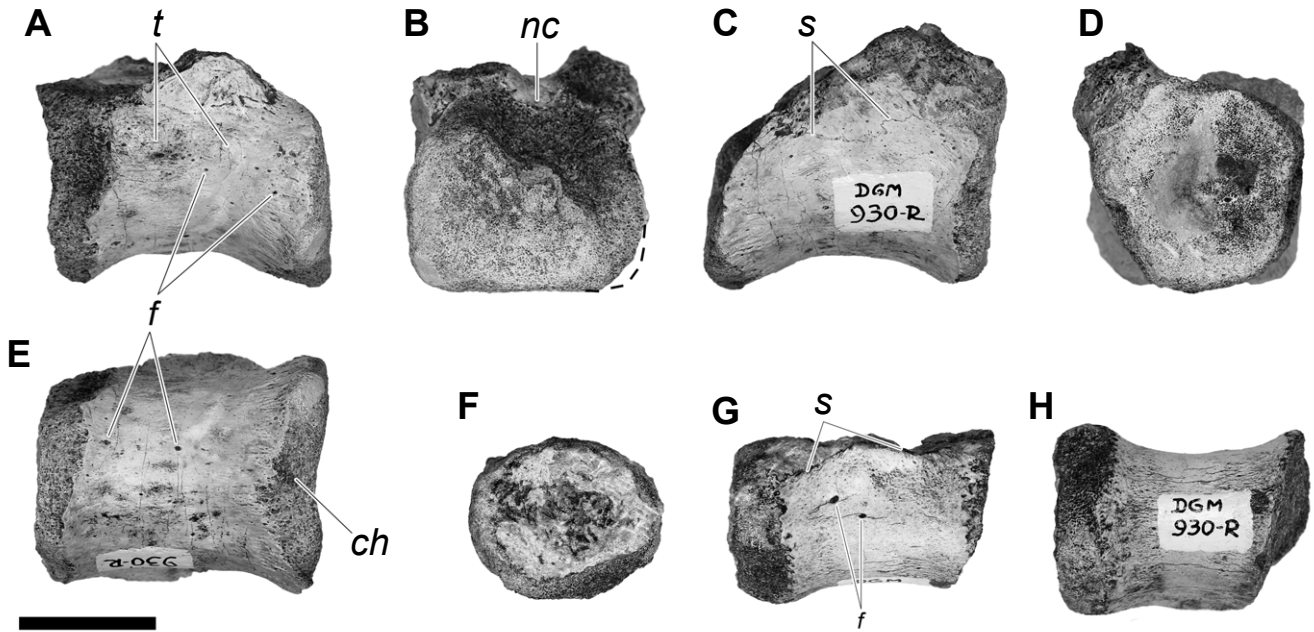


Figure 2. DGM 930-R first preserved caudal vertebra (A-E) in left lateral (A), posterior (B), right lateral (C), anterior (D), and ventral (E) views; second preserved caudal vertebra (F-H) in posterior (F), right lateral (G) and ventral (H) views. Both vertebrae are broken above the suture (s) of the transverse process, but the ventral portion of the neural canal (nc) is preserved. Several small foramina (f) are visible as well as tuberosities (t) for the origin of muscle *caudofemorales longus*. In the first centrum, the region of chevron articulation (ch) is also present. Scale bar = 20 mm.

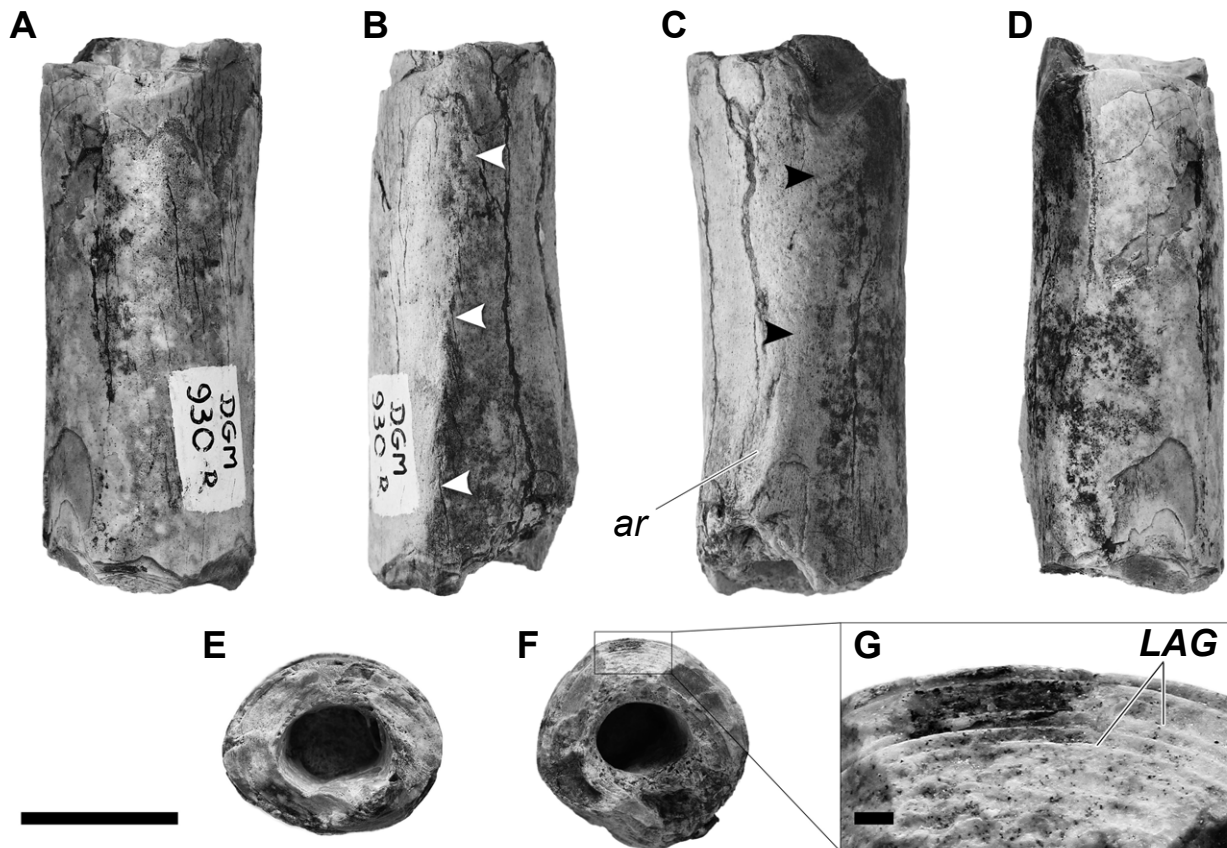


Figure 3. DGM 930-R right femur in anterior (A), medial (B), posterior (C), lateral (D), proximal (E) and distal (F) views; G, detail of the lines of arrested growth (LAG). The preserved muscle insertion scars are interpreted as the *linea intermuscularis cranialis* (white arrowheads) and *caudalis* (black arrowheads) and the adductor ridge (ar). Scale bars: A-F = 20 mm; G = 1 mm.

1993; Chinsamy *et al.*, 1995; Padian *et al.*, 2001), which is congruent with the proposed arid to semiarid paleoambient with occasional periods of higher water level, proposed for the Santo Anastácio Formation (Fernandes & Coimbra, 2000). Applying the circumference of the femur in regression analyses of other dinosaurian taxa (Christiansen & Fariña, 2004; Therrien & Henderson, 2007; Benson *et al.*, 2014), it was estimated a total body weight of about 34–40 kg and a total body length of about 3 m for DGM 930-R.

A fragment of bone was interpreted as the proximal portion of the ischium (Figures 4D–I) because it has a general shape that resembles the proximal ischium of *Saurornithoides mongoliensis* (Norell *et al.*, 2009). It has an internal cavity, as is indicated by bone surfaces that are partially preserved (Figures 4G, I). The proximal end is highly porous and expanded with a marked flat articular surface (the preserved portion supposedly correspondent to the iliac articulation surface). In the distal end (in distal view; Figure 4I), a ventral expansion (partially broken) possibly corresponds to the most

proximal portion of the obturator process. Unfortunately, the poor preservation of this bone fragment makes this diagnosis highly uncertain.

This specimen also includes a partial ungual phalanx, but only the proximal portion is preserved and yet poorly preserved (Figure 4A; Table 1). The ventral surface is flat but inclined and the dorsal surface is slightly concave. The ratio between the width of the ventral and dorsal articular surfaces suggest it is a pedal ungual, as seen in other theropod dinosaurs, such as *Deinonychus antirrhopus* (Ostrom, 1969, fig. 75), *Raptorex kriegsteini*, *Aucasaurus garridoi* and *Santanaraptor placidus* (pers. obs.). It is not possible to determine to which pedal it corresponds, but, proportions suggest it was from the toes I or IV.

Several rib fragments are preserved (Figure 4A). The biggest one is 120.5 mm long (proximal and distal ends are lacking). It is triangular in cross section, and has marked muscle scars. Other rib fragments are triangular to sub-circular in cross section.

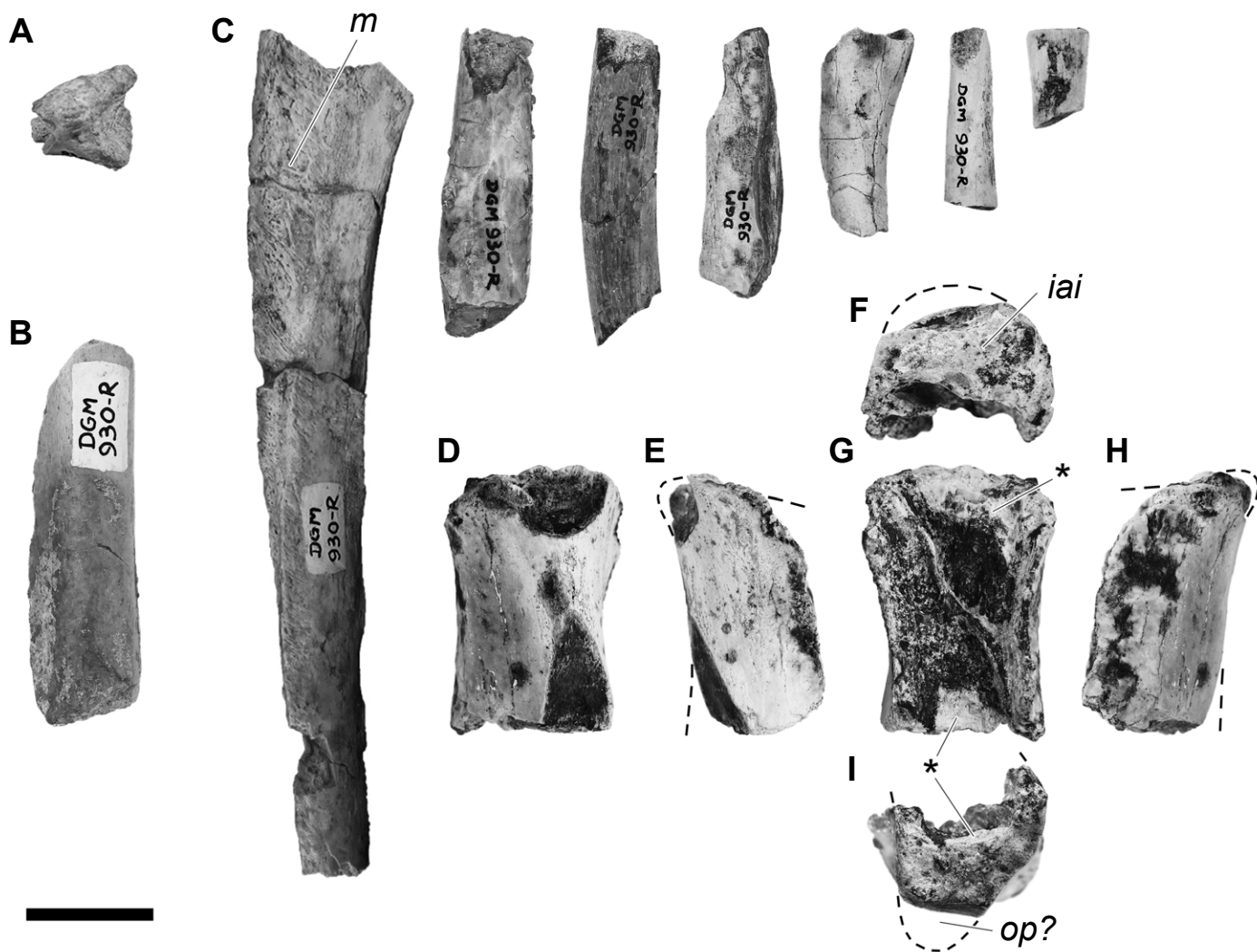


Figure 4. A–I, other preserved bones of DGM 930-R: partial pedal ungual in dorsal view (A), fragment of unidentified long bone (B), rib fragments (C) with indication of muscle scars (m), and fragment interpreted as the proximal portion of the ischium in anterior (D), left lateral (E), proximal (F), posterior (internal), (G), right lateral (H), distal (I) views. This fragment has a hollow internal cavity as internal bone surfaces are preserved (*); the supposed iliac articulation of the ischium (iai), obturator process (op?), and broken parts (dashed lines) are also indicated. Scale bar = 20 mm.

DISCUSSION

As most of the preserved bones of DGM 930-R are fragmented, comparisons to other taxa are difficult. The two caudal vertebral centra are the most diagnostic remains, as the preserved portion of the femur is not informative. Box-like anterior caudal vertebral centrum are characteristic of maniraptorans of the Paraves group (Turner *et al.*, 2012), but were also present in oviraptorosaurs, such as *Conchoraptor gracilis* and *Microvenator celer* (Turner *et al.*, 2012) and in therizinosaur *Falcarius utahensis* (Zanno, 2010). Consequently, DGM 930-R is classified as a maniraptoran. In this work abelisauroids are excluded, a well represented taxa in Brazilian cretaceous strata (*e.g.* Méndez *et al.*, 2014), because they have spool-shaped anterior vertebrae, as seen in *Masiakasaurus knopfleri* (noasaurid), *Carnotaurus sastrei*, *Aucasaurus garridoi* and *Pycnonemosaurus nevesi* (abelisaurids). The presence of maniraptoran dinosaurs in the Southern Hemisphere has been confirmed by several authors (Novas & Pol, 2005; Machado *et al.*, 2008; Agnolín & Novas, 2011; Gianechini & Apesteguía, 2011; Benson *et al.*, 2012; Novas *et al.*, 2005, 2009, 2013; Turner *et al.*, 2012). Therefore comparisons of DGM 930-R to other taxa will be restricted to maniraptorans in which this type of caudal vertebra was observed.

Compared to caudal vertebrae of oviraptorosaurs, DGM 930-R differs in several aspects. Oviraptorosaurs have amphiplatyan caudal centra and the cranial ones are spool-like whereas the caudal ones are box-like, a condition that is opposite to the observed in DGM 930-R in which the anterior caudal is box-like. In DGM 930-R, pleurocoels and a ventral groove are absent on both preserved vertebra; oviraptorosaur vertebrae sometimes have a single pleurocoel close to the base of the neural arch (Osmólska *et al.*, 2004), as in *Heyuannia huangi* (Lü, 2002) and *Gigantoraptor erlianensis* (Xu *et al.*, 2007), and, except for the first proximal centrum, have a ventral wide shallow groove (Osmólska *et al.*, 2004). Also, the distal caudal of DGM 930-R is not as short and dorsoventrally compressed as distal caudals of oviraptorosaurs, in which the mediolateral width exceeds the dorsoventral depth (Osmólska *et al.*, 2004), and does not have ventrally located transverse process, as in *Microvenator celer* (Makovicky & Sues, 1998) and *Gigantoraptor erlianensis* (Xu *et al.*, 2007).

Compared to Alvarezsauridae, there are important differences in the shape of the caudal vertebrae. In most Alvarezsauridae (*Achillesaurus manazzonei*, *Alvarezsaurus calvoi*, *Mononykus olecranus*, *Parvicursor remotus*, *Patagonykus puertai*, *Shuvuuia deserti* and *Xixianykus zhangii*), the caudal vertebrae are procoelous (Chiappe *et al.*, 2002; Martinelli & Vera, 2007; Choiniere *et al.*, 2010; Xu *et al.*, 2010), but in *Achillesaurus* the fourth caudal is amphicoelous (Martinelli & Vera, 2007). Anterior caudal centra of alvarezsaurids are also laterally compressed with a ventral keel in *Achillesaurus*, *Alvarezsaurus*, *Mononykus*, *Shuvuuia* and *Xixianykus* (Martinelli & Vera, 2007; Choiniere *et al.*, 2010; Xu *et al.*, 2010), but there is no ventral keel in the anterior caudal centra of *Patagonykus* (Novas, 1997). DGM

930-R differs from alvarezsaurids in that the anterior caudal centrum is subrectangular, box-like and is amphicoelous. In *Patagonykus* the distal caudal centrum is strongly procoelous and has a ventral sulcus (Novas, 1997). A shallow longitudinal sulcus is also present in the middle caudal of *Achillesaurus* (Martinelli & Vera, 2007). The more distal preserved caudal of DGM 930-R does not have a ventral sulcus, but it is not possible to define if it was amphicoelous or procoelous.

The preserved portion of the femur of DGM 930-R differs from *Linhenykus monodactylus* because the anterior surface near the distal end is slight convex in the lateral surface and concave in medial one (Xu *et al.*, 2013). The muscle scars in the femur of DGM 930-R are more marked than in *Linhenykus*. The mid-shaft of the femur of *Mononykus* has a subtriangular cross section with a flat caudal surface (Altangarel *et al.*, 1994) that differs from the oval cross section of the shaft of the femur of DGM 930-R.

Among deinonychosaurian taxa, dromaeosaurids in general have short and box-shaped anterior caudal centra with a subquadrangular cross-section (Senter *et al.*, 2012). Variably, a mediolaterally narrow and shallow ventral longitudinal groove is present, as is the case of *Deinonychus antirrhopus* (Ostrom, 1969), *Velociraptor mongoliensis* (Norell & Makovicky, 1997, 1999), *Pyroraptor olympius* (Allain & Taquet, 2000), and *Buitreraptor gonzalezorum* (Turner *et al.*, 2007). However, the centra of anterior caudal vertebrae of *Yurgovuchia doellingi* have rounded cranial and caudal articulations and are also round in cross-section, a condition also observed in *Achillobator* (Senter *et al.*, 2012). Box-shaped anterior centra are also observed in the troodontid *Saurornithoides mongoliensis* (Norell *et al.*, 2009). The anterior caudal vertebrae of *Deinonychus* are also characterized by having a quadrangular-shaped posterior articulation and slightly platycoelous articular facets (Ostrom, 1969), while those of *Yurgovuchia* are amphiplatyan (Senter *et al.*, 2012). The posterior caudal vertebrae of dromaeosaurids become longer and lower progressively on about the tenth caudal (Norell & Makovicky, 2004). However in *Buitreraptor gonzalezorum* this shift starts on the third caudal centrum. In troodontids the posterior caudal vertebrae are elongated as in dromaeosaurids (Makovicky & Norell, 2004). DGM 930-R is similar to most dromaeosaurids in that the anterior caudal is box-shaped, with the posterior articulation quadrangular-shaped, but differs in that a ventral groove is absent. The centrum of the posterior caudal of DGM 930-R is also similar to *Velociraptor*, being subcircular in cross section (Norell & Makovicky, 1999), but differs because the ventral groove is absent.

The mid shaft of the femur of dromaeosaurids has a nearly circular cross-section, as observed in *Deinonychus* (Ostrom, 1976), *Velociraptor mongoliensis* (Norell & Makovicky, 1999) and *Unenlagia comahuensis* (pers. obs.). In *Deinonychus*, the ratio between anteroposterior and mediolateral diameters of the midshaft is similar to DGM 930-R. DGM 930-R differs from *Buitreraptor gonzalezorum* and *Mahakala omnogovae* in that they have a flatter distal end

(Turner *et al.*, 2007). The femur of DGM 930-R also differs from DGBU-78, a maniraptoran from Korea, in which the shaft of the femur is anteroposteriorly compressed (Kim *et al.*, 2005). The femur of *Neuquenraptor argentinus* is more robust than that of *Unenlagia comahuensis* (Novas & Pol, 2005) and DGM 930-R.

One of the bone fragments of DGM 930-R was identified as the proximal portion of the ischium (Figures 4D-I) because it has a morphology that is quite similar to the figured by Norell *et al.* (2009) for the troodontid *Saurornithoides mongoliensis*. Unfortunately, the fragmentary nature of this fragment of bone does not allow to confirm that it in fact correspond to the ischium; also, it is not possible to make detailed comparisons to other taxa.

Most of the diagnostic characteristics of DGM 930-R allow to exclude it from Oviraptorosauria and to classify it as a non-Alvarezsauridae maniraptoran dinosaur. Unfortunately, the preserved material does not allow further studies to resolve its phylogenetic position. It is similar to Deinonychosauria in several aspects, but it cannot be undoubtedly attributed to this group because of the lack of a ventral groove on the caudal vertebrae. Consequently, we refer DGM 930-R to the Maniraptora group, tentatively referred to Deinonychosauria. In South America, Deinonychosauria is well represented by the Unenlagiinae (Agnolín & Novas, 2011; Gianechini & Apesteguía, 2011; Candeiro *et al.*, 2012a; Novas *et al.*, 2013), but the presence of Deinonychosauria was also claimed in Brazil based upon isolated teeth (Vilas Bôas *et al.*, 1999; Bertini *et al.*, 1997; Bertini & Franco-Rosas, 2001; Franco-Rosas, 2001, 2002; Elias *et al.*, 2007) and a dorsal vertebra (Candeiro *et al.*, 2012a). Therefore, if DGM 930-R is actually a maniraptoran theropod, it adds more information on this clade in the Late Cretaceous of Brazil.

According to some authors (Candeiro *et al.*, 2006; Martinelli & Pais, 2008; Riff & Kellner, 2011) the top cretaceous predators of the Bauru fauna were the baurusuchid crocodylians. However, the presence of DGM 930-R in the Bauru besides megaraptoran (Méndez *et al.*, 2012; Martinelli *et al.*, 2013;), abelisauroid (Kellner & Campos, 2002; Novas *et al.*, 2008; Candeiro *et al.*, 2012b; Machado *et al.*, 2013; Méndez *et al.*, 2014) and carcharodontosaurid theropods (Candeiro *et al.*, 2012b; Azevedo *et al.*, 2013) indicates the cretaceous fauna of the Bauru also included small/medium sized predatory dinosaurs. We can hypothesize that these theropod taxa occupied a predatory niche as important as the baurusuchids, however this question may be explored with more caution. Despite the fragmentation and incomplete nature of the theropod material from the Bauru Basin, the surfaces of these bones are well preserved. This is particularly enigmatic because in comparison, most mesoeucrocodylian fossils from the Bauru Basin are represented by virtually complete skeletons (Nascimento & Zaher, 2010; Riff & Kellner, 2011). Taphonomic and additional field works are necessary to answer this question.

The material described here contribute to increase the number of occurrences of Maniraptora, especially in Brazil, where most materials are incomplete (Novas *et al.*, 2005;

Elias *et al.*, 2007; Machado *et al.*, 2008; Bittencourt & Langer, 2011; Candeiro *et al.*, 2012a). It also contributes for the knowledge of morphological variations among these theropods, considering that DGM 930-R has caudal vertebrae without a ventral groove, a condition that differs from others taxa.

CONCLUSIONS

DGM 930-R increases the knowledge about the fauna of the Bauru Basin during the Late Cretaceous. Although it is not possible to define to which taxonomic family this specimen belong, some characters allow to infer that DGM 930-R was a medium-size maniraptoran, possibly closely related to Deinonychosauria. Its presence indicates that important predators other than baurusuchids, megaraptorans, abelisauroids and carcharodontosaurids may inhabited this region during the Cretaceous, thus contributing for the record of theropod diversity in the Bauru Group.

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