

A FRAGMENTARY DINOSAUR FEMUR AND THE PRESENCE OF NEOTHEROPODA IN THE UPPER TRIASSIC OF BRAZIL

FELIPE L. PINHEIRO

Laboratório de Paleobiologia, Universidade Federal do Pampa, Campus São Gabriel, R. Aluizio Barros Macedo,
BR 290, km 423, CEP 97300-000, São Gabriel, RS, Brazil. felipepinheiro@unipampa.edu.br

ABSTRACT – Although already widespread in Laurasia, the Gondwanan Norian record of Neotheropoda (Dinosauria) is scarce, with a single taxon reported for the Los Colorados Formation of Argentina. Here the distal end of a dinosaur left femur from the *Riograndia* Assemblage Zone of Brazil (Norian, Candelária Sequence, Paraná Basin) is described and compared. Although fragmentary, the specimen has a morphology compatible with its attribution to Neotheropoda, being this the first record of the clade from the Brazilian Triassic. The new specimen supports a cosmopolitan distribution of Neotheropoda during the Late Triassic and highlights the potential for the discovery of additional dinosaur clades in Norian rocks of southern Brazil.

Key words: Dinosauria, Gondwana, Norian, Theropoda.

RESUMO – Apesar de já bem distribuído no Laurásia, o registro gondwânico dos Neotheropoda (Dinosauria) é escasso no Noriano, com apenas um táxon reportado para a Formação Los Colorados da Argentina. Aqui é descrito um fragmento distal de um fêmur esquerdo de dinossauro, proveniente da Zona de Assembleia de *Riograndia* (Noriano, Sequência Candelária, Bacia do Paraná, Brasil). Embora fragmentário, o espécime apresenta morfologia compatível com sua atribuição a Neotheropoda, sendo este o primeiro registro deste táxon para o Triássico brasileiro. O novo espécime suporta uma distribuição cosmopolita dos Neotheropoda durante o Neotriássico, além de evidenciar o potencial de rochas do Noriano brasileiro para a descoberta de uma diversidade ainda oculta de dinossauros.

Palavras-chave: Dinosauria, Gondwana, Noriano, Theropoda.

INTRODUCTION

The Upper Triassic sedimentary record of Western Pangaea, especially as represented by the Chañares, Ischigualasto and Los Colorados formations of Argentina and the Candelária Sequence of Brazil (*sensu* Horn *et al.*, 2014), provides rich and unique insights into the origins and early diversification of dinosaurs (*e.g.* Arcucci *et al.*, 2004; Langer *et al.*, 2010b; Marsicano *et al.*, 2016). Compared with the well-sampled coeval deposits of Argentina, dinosaur diversity in Brazilian Late Triassic is still low, with only a few taxa known from the *Hyperodapedon* Assemblage Zone (AZ) and the younger *Riograndia* AZ (Norian) of the Candelária Sequence (Paraná Basin, *e.g.* Langer *et al.*, 2010b) (Figure 1). Although neotheropod dinosaurs were relatively widespread during the Norian, this clade has not been previously reported from the *Riograndia* AZ of Brazil. As a matter of fact, even though neotheropod remains have been recovered from a number of mainly Laurasian norian fossil sites, representatives of this clade were rare during the Late Triassic. Only one neotheropod taxon is known for South American Upper Triassic, despite the fact that rocks of this series are well represented

in that continent (Arcucci & Coria, 2003; Ezcurra & Novas, 2007).

Here, the distal end of a dinosaur left femur from a classic locality of the *Riograndia* AZ is described. The specimen is unlike the other taxa so far recorded for the Candelária Sequence and has a morphology compatible with Neotheropoda, indicating the presence of this clade in the Upper Triassic of Brazil.

Institutional abbreviations. **MMACR**, Museu Municipal Aristides Carlos Rodrigues, Candelária, RS, Brazil; **NMMNH**, New Mexico Museum of Natural History & Science, Albuquerque, New Mexico, USA; **SMNS**, Staatliches Museum für Naturkunde, Stuttgart, Germany.

SYSTEMATIC PALAEOLOGY

Clade DINOSAURIA Owen, 1842
Suborder THEROPODA Marsh, 1881
Clade NEOTHEROPODA Bakker, 1986
(Figures 2A-J)

Material. MMACR 039 T, distal portion of a left femur (Figures 2A-J).

Locality, unit and age. The specimen comes from the ‘Botucarai Hill’, a well-known *Riogradia* AZ site (Norian, Candelária Sequence, Paraná Basin) located in a road cut 6 km west of Candelária city, Rio Grande do Sul, Brazil (29°40’53’’S; 52°50’28’’W). The outcrop exposes sandstones intercalated with mudstone lenses. Remains of sauropodomorphs from the ‘Botucarai Hill’ site were reported by Bittencourt *et al.* (2013). The Norian age of ‘Botucarai Hill’ site is based on the presence of the dicynodont genus *Jachaleria*, also known from the lower levels of the Los Colorados Formation (Soares *et al.*, 2011).

Comparative description. MMACR 039 T (Figures 2A-J) is well preserved, lacking strong diagenetic alterations. The proximal end and most of the shaft are missing, and there is a superficial breakage that partially excavates the anterior surface of the bone. The preserved fragment is 37 mm long and 21 mm in lateromedial width, and measures 15 mm between its anterior margin and the posterior most extension of the medial (tibial) condyle.

The distal end is only slightly expanded lateromedially in relation to the shaft, a condition not observed in most Triassic dinosaurs, such as herrerasaurids (e.g. Novas, 1993), sauropodomorphs (e.g. Langer, 2003; Müller *et al.*, 2015), *Guaibasaurus* (Bonaparte *et al.*, 1999; Langer *et al.*, 2010a) and ornithischians (e.g. Butler, 2010).

The distal anterior surface bears a faint extensor groove that is connected distally with a very discrete sulcus intercondylaris (Figures 2A,B). An extensor groove is regarded as a derived character, present in some abelisauroids and tetanurans (Ezcurra & Novas, 2007), but absent in herrerasaurids, basal sauropodomorphs such as *Saturnalia*, basal ornithischians, such as *Lesothosaurus* and *Eocursor*, as well as some early theropods, such as *Liliensternus*, *Coelophysis*, *Tawa* and *Zupaysaurus* (e.g. Langer, 2003; Ezcurra & Novas, 2007; Butler, 2010). The distal femur of herrerasaurids, *Saturnalia*, *Eocursor* and *Tawa* has a distinctly convex anterior surface. *Guaibasaurus*, *Pampadromaeus*, *Eoraptor* and *Coelophysis* (NMMNH 42351), although

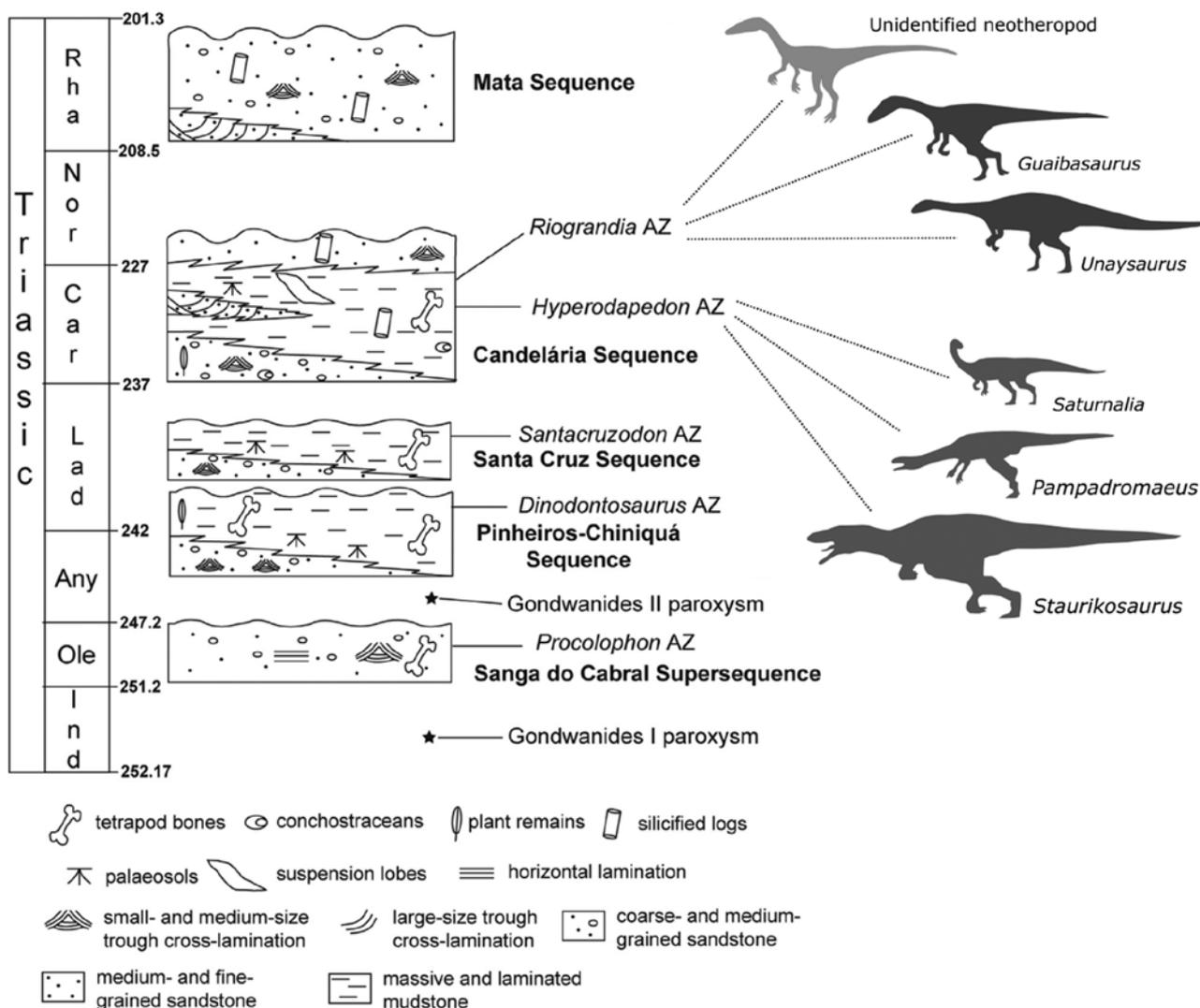


Figure 1. Southern Brazil Triassic chronostratigraphy, depicting vertebrate biozones and recovered dinosaur taxa. Modified from Zeffass *et al.* (2003) and Horn *et al.* (2014). *Saturnalia*, *Pampadromaeus* and *Staurikosaurus* silhouettes modified from Pretto *et al.* (2015).

having a flat femoral anterior surface, lack an extensor groove (Bonaparte *et al.*, 1999; Ezcurra & Novas, 2007; Sereno *et al.*, 2013; Müller *et al.*, 2015).

A U-shaped popliteal fossa excavates the posterior surface of the specimen (Figures 2I,J). The depth of this fossa resembles the condition observed in *Saturnalia*, *Pampadromaeus*, *Eoraptor* and neotheropods, and is deeper than in herrerasaurids (Novas, 1993; Langer, 2003; Bittencourt & Kellner, 2009; Alcober & Martínez, 2010; Sereno *et al.*, 2013; Müller *et al.*, 2015).

The medial condyle is anteroposteriorly oriented, forming an angle of a little less than 90° with the femoral anterior

surface (Figures 2I,J). This contrasts with the obtuse-angled distal anteromedial corner developed in a number of basal dinosaurs. This character, however, is considerably variable among early dinosaurs, and may be influenced by size. An anteromedial corner forming an acute angle is more widespread among neotheropods, being present, for example, in *Dilophosaurus*, *Streptospondylus* (Welles, 1984; Allain, 2001) and *Liliensternus* (based on a replica of the syntype, deposited at the SMNS). On its posterior surface, the medial condyle of MMACR 039 ends in a small prominence, flanked ventromedially by a deep sulcus. This unusual structure is here interpreted as an epicondyle (Figures 2C,D).

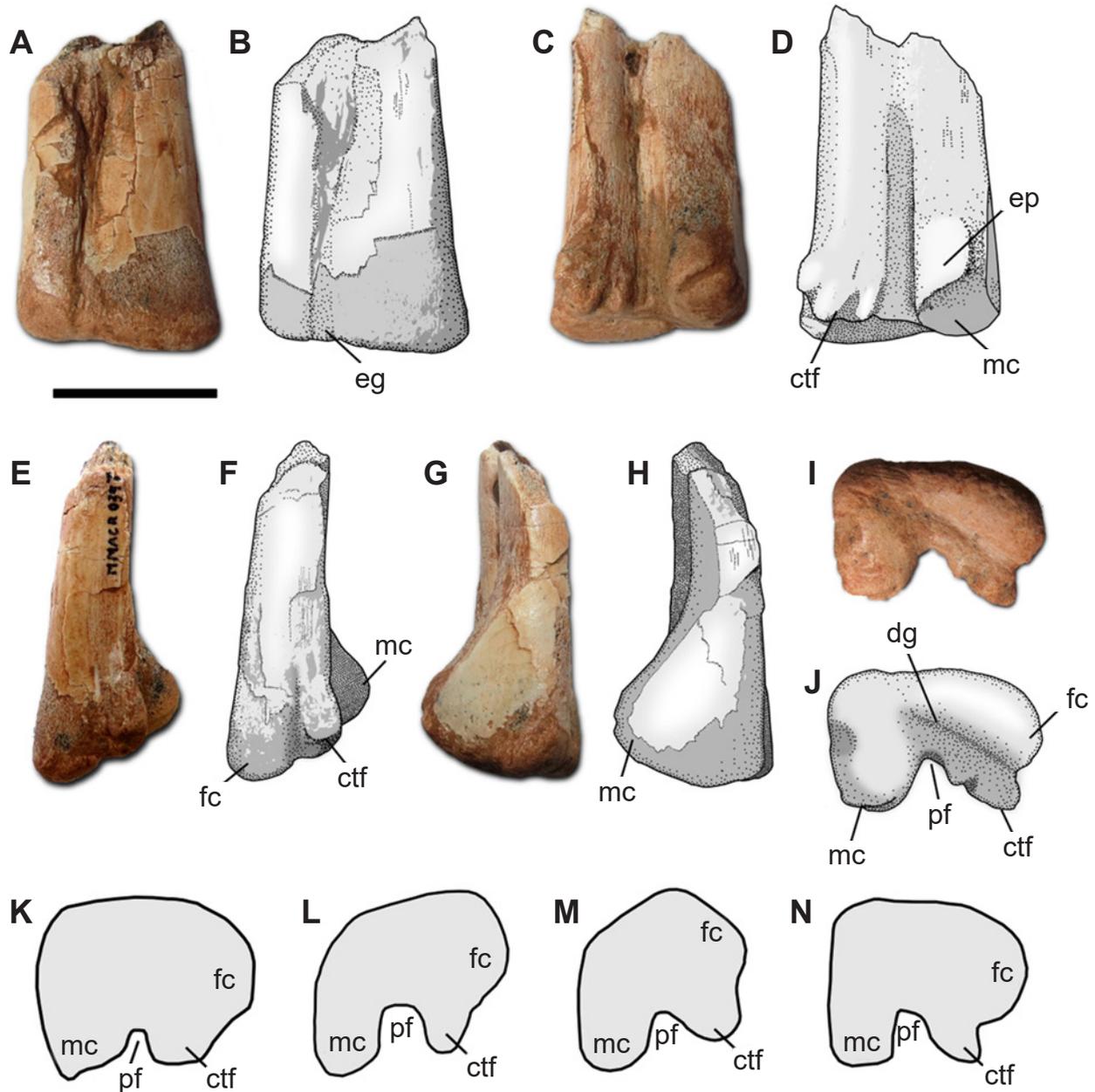


Figure 2. A–J, specimen MMACR 039 T, photographs and interpretative drawings in A–B, anterior; C–D, posterior; E–F, lateral; G–H, medial and I–J distal views. K–N, selected Triassic dinosaur femora in distal view. K, *Herrerasaurus* (redrawn from Novas, 1993, mirrored). L, *Pampadromaeus* (redrawn from Müller *et al.*, 2015). M, *Eocursor* (redrawn from Butler, 2010, mirrored). N, *Liliensternus*. **Abbreviations:** ct, crista tibiofibularis; dg, distal groove; eg, extensor groove; ep, epicondyle; fc, fibular condyle; mc, medial condyle; pf, popliteal fossa. Scale bar: A–J = 20 mm; K–N = not to scale.

The crista tibiofibularis is deflected laterally, tapering posterolaterally into a pointed tip (Figures 2I,J), being separated from the rounded fibular condyle by a well-developed lateral groove, a distinctive feature of neotheropods. A laterally deflected crista tibiofibularis is widespread among neotheropods (e.g. Welles, 1984; Allain, 2001), but is also present in Sauropodomorpha (e.g. *Saturnalia*, *Plateosaurus*) and silesaurids (e.g. *Sacisaurus*), although generally to a lesser degree than represented in MMACR 039 T (Langer, 2003, fig. 4; Langer & Ferigolo, 2013, fig. 17). The crista tibiofibularis of *Eoraptor*, albeit laterally deflected, has a rounded outline (Serenó *et al.*, 2013).

In distal view, MMACR 039 T displays a deep, mostly straight, distal groove (Figures 2I,J), anterior to which the distal surface expands to form the distal corpus of the fibular condyle. A posterior expansion is absent (Figures 2E,F), contrasting with the condition of basal sauropodomorphs, such as *Saturnalia* and *Pampadromaeus*, where the distal surface is also elevated posteriorly, contributing to the crista tibiofibularis (Langer, 2003; Müller *et al.*, 2015).

DISCUSSION

MMACR 039 T can be distinguished from known herrerasaurids (Figure 2K) by the presence of a deep popliteal fossa, an incipient extensor groove on its anterior surface and a laterally deflected, pointed, tibiofibular crest, separated from the fibular condyle by a sharp groove (Novas, 1993; Alcober & Martínez, 2010; Bittencourt & Kellner, 2009). An extensor groove and a tibiofibular crest separated from the fibular condyle by a deep sulcus are also absent in most silesaurids (e.g. *Sacisaurus*, but see below), sauropodomorphs (Figure 2L) and early ornithischians (Figure 2M), from which MMACR 039 T can also be distinguished by the anterior margin of the distal femur forming an angle close to 90° with the medial one. Moreover, basal ornithischians, such as *Eocursor*, have a markedly convex anterior surface on their distal femur, formed mainly by an anterolateral projection of the fibular condyle (e.g. Butler, 2010, fig. 15). A similar condition is also present in silesaurids such as *Sacisaurus* (Langer & Ferigolo, 2013).

Several features are consistent with the attribution of MMACR 039 T to Neotheropoda (Figure 2N). An acute angle formed between the medial margin of the medial condyle and the anterior surface of the distal femur, although also present in some herrerasaurids is common among neotheropods (see above). This is also true for a laterally deflected, pointed tibiofibular crest, albeit this feature also seems to be widespread among basal sauropodomorphs (e.g. Langer, 2003) and silesaurids (e.g. Langer & Ferigolo, 2013). In addition, the presence of a small epicondyle on the posterior surface of the medial condyle was regarded by Ezcurra & Novas (2007) as a potential synapomorphy of Neotheropoda, even though this feature is not thoroughly discussed by these authors and its distribution among basal theropods needs further clarification. Furthermore, Langer (2003) observed that the

lack of an elevation posterior to the distal groove (as is the condition in MMACR 039 T) is characteristic of basal theropods, such as *Liliensternus*. Of particular relevance is the presence of an extensor groove on the anterior surface of the femur, a character that, although better developed in more derived tetanurans, is also present in some abelisauroids (Ezcurra & Novas, 2007; Carrano *et al.*, 2012). The distribution of this character among basal neotheropods, however, needs further investigation.

A yet undescribed silesaurid from the Carnian of Poland shares with MMACR 039 T a laterally deflected, pointed tibiofibular crest, separated from the fibular condyle by a deep sulcus (G. Niedźwiedzki, personal communication). The femur of the new silesaurid, however, lacks an extensor groove and has a convex anterior margin that forms an obtuse angle with the medial condyle.

Despite its fragmentary condition, the morphology of MMACR 039 T supports a neotheropod affinity for the specimen, at least until further evidence proves otherwise. The presence of a tibiofibular crest that is sharply distinguished from the fibular condyle by a deep sulcus is regarded by Ezcurra & Novas (2007) as a probable synapomorphy of the Coelophysoidea, perhaps indicating the attribution of MMACR 039 T to this clade. *Eoraptor lunensis*, however, also presents a moderately deep groove between the tibiofibular crest and the fibular condyle (Serenó *et al.*, 2013). It is remarkable that the ratio between the lateromedial width and the anteroposterior length of MMACR 039 T closely matches that in *Coelophysus* (NMMNH 42351).

The oldest neotheropods are known from fragmentary bones from the upper Carnian Chinle Formation, Arizona, and Dockun Group, Texas, USA (Hunt *et al.*, 1998; Nesbitt *et al.*, 2007; Nesbitt & Ezcurra, 2015, but see Ramezani *et al.*, 2014). Throughout the Norian, the Neotheropoda became relatively widespread, with several described taxa preserved mainly in Laurasian Upper Triassic deposits (see Langer *et al.*, 2010b; Brusatte *et al.*, 2010; Niedźwiedzki *et al.*, 2014 and references therein for a review). The Gondwanan Norian neotheropod record is still scarce. In the South American Triassic, this clade is represented only by the coelophysoid *Zupaysaurus rougieri* from the upper levels of Los Colorados Formation (Arcucci & Coria, 2003; Ezcurra & Novas, 2007) and fragmentary remains from the Quebrada del Barro Formation, northwestern Argentina (Martínez *et al.*, 2015). Remarkably, the fossil assemblage of 'Botucaraí Hill' probably correlates to the basal level of Los Colorados Formation, what is suggested by the presence of the dicynodont genus *Jachaleria* in both Argentinean and Brazilian deposits (Soares *et al.*, 2011). Therefore, the attribution of MMACR 039 T to Neotheropoda makes it the oldest representative of this clade in South America.

The presence of a neotheropod in Norian strata of Brazil extends the Late Triassic distribution of this group in Western Gondwana. Furthermore, the new specimen draws attention to the still hidden dinosaur diversity in the Upper Triassic of Brazil, a shortcoming that will be addressed by more intensive collection efforts.

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