First bird remains from the Upper Cretaceous of the Peirópolis site, Minas Gerais state, Brazil

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Candeiro C. R. A., Agnolin F., Martinelli A. G. & Buckup P. A. 2012. — First bird remains from the Upper Cretaceous of the Peirópolis site, Minas Gerais state, Brazil. *Geodiversitas* 34 (3): 617-624. http://dx.doi.org/10.5252/g2012n3a8

ABSTRACT
We report on the first occurrence of Maastrichtian bird material from the Peirópolis locality (Uberaba district), Minas Gerais State (Brazil). The specimens consist of an indeterminate pedal ungual phalanx (CPP 481), a pedal phalanx 1 of left digit II (CPP 470) and an incomplete metatarsal III (CPP 482). The material can be assigned to Aves gen. et sp. indet. (CPP 470 and CPP 481) and to cf. Enantiornithes gen. et sp. indet. (CPP 482). Despite the isolated and incompleteness nature of these specimens, they add to the otherwise poor record of Cretaceous birds from Brazil.

KEY WORDS
Aves,
Enantiornithes,
Bauru Group,
Late Cretaceous,
Minas Gerais,
Brazil.

RÉSUMÉ
Premiers restes aviaires du Crétacé supérieur du site de Peirópolis, État du Minas Gerais, Brésil.
Nous signalons pour la première fois des restes aviaires maastrichtiens provenant des environs de Peirópolis (district d'Uberaba), État du Minas Gerais (Brésil). Les spécimens comportent une phalange unguéale podale indéterminée (CPP 481), une phalange podale 1 de l'orteil gauche II (CPP 470) et un métatarse III incomplet (CPP 482). Ce matériel peut être attribué à Aves gen. et sp. indet. (CPP 470 et CPP 481) et à cf. Enantiornithes gen. et sp. indet. (CPP 482). En dépit de l'isolement et de l'incomplétude de ces spécimens, ils viennent étoffer l'enregistrement fossile, par ailleurs peu documenté, des oiseaux crétacés du Brésil.

MOTS CLÉS
Aves,
Enantiornithes,
Groupe Bauru,
Crétacé supérieur,
Minas Gerais,
Brésil.

INTRODUCTION

Late Cretaceous birds have been collected from fossil faunas worldwide (e.g., Chiappe 1993, 1996; Kurochkin 2000; Hope 2002; Stilwell 2007; Tambussi & Acosta Hospitaleche 2007; Walker *et al.* 2007; Longrich 2008; Ősi 2008). In South America, the Late Cretaceous avian record is dominated by Argentinean discoveries, which include at least eight formally named species (Walker 1981; Brett-Surman & Paul 1985; Chiappe 1991, 1993, 1996; Alvarenga & Bonaparte 1992; Chiappe & Calvo 1994; Clarke & Chiappe 2001; Agnolin & Martinelli 2009). In sharp contrast, there have been only two reports of contemporaneous bird fossils from São Paulo state, Brazil: Enantiornithes indet. remains from the Presidente Prudente locality (Alvarenga & Nava 2005), and Aves indet. material from the Jales locality (Azevedo *et al.* 2007), both coming from the Adamantina Formation (Turonian-Santonian, Bauru Group).

We report here the first record of Late Cretaceous bird remains from the Minas Gerais State (Brazil). The bird specimens were collected during screen washing performed by the Centro de Pesquisas Paleontologias Llewellyn Ivor Price in the site known as "Ponto 1 do Price" (19°43'13.2"S, 47°44'17.9"W), Peirópolis locality (see Candeiro *et al.* 2008: 205, text-fig. 1), Uberaba, Minas Gerais state. The washed sediments belong to the Serra da Galga Member of the Marilia Formation (Bauru Group; Garrido *et al.* 1992; Fernandes & Coimbra 1996; Candeiro 2007), which is considered to be Late Maastrichtian in age (Dias-Brito *et al.* 2001). The Peirópolis area has yielded a rich variety of Late Cretaceous invertebrate and vertebrate fossils, including bivalves, ostracodes, fishes (e.g., characiforms, lepisosteiforms, perciforms, and siluriforms), turtles (podocnemidids), lizards (possible iguanians), mesoeucrocodylians (peirosaurids and possibly trematochamsids), sauropod (titanosaurs) and theropod (abelisaurids, carcharodontosaurids, maniraptorans) dinosaurs (e.g., Brito *et al.* 2006; Candeiro 2007; Candeiro *et al.* 2008 and references therein).

We follow the phylogenetic relationships within Aves proposed by Zhou *et al.* (2009), and the taxonomy employed by Chiappe *et al.* (1999).

INSTITUTIONAL ABBREVIATIONS

CPP	Centro de Pesquisas Paleontologias Llewellyn Ivor Price, Peirópolis, Minas Gerais State;
MACN	Museo Argentino de Ciencias Naturales "Bernadino Rivadavia", Buenos Aires;
PV	Paleovertebrate Collection;
RN	Río Negro Province, Buenos Aires.

SYSTEMATICS

Class AVES Linnaeus, 1758

Genus and species indet.

REFERRED MATERIAL. — CPP 481, isolated pedal ungual phalanx lacking its proximal end (Fig. 1A). — CPP 470, isolated pedal phalanx 1 of left digit II (Fig. 1B).

PROVENANCE. — "Ponto 1 do Price" (see Candeiro *et al.* 2008), Peirópolis locality, Uberaba, Minas Gerais State, Brazil. Serra da Galga Member; Marilia Formation; Bauru Group (Fernandes & Coimbra 1996).

DESCRIPTION

CPP 481 is a small pedal ungual of unknown position on the pes (Fig. 1A). The ungual is laterally compressed and dorsoventrally deep. The lateral sulcus is notorious and well defined, and is both dorsally and plantarly delimited by thin bony rims; regrettably, the eroded nature of bone surface precludes a detailed description of lateral sulci. Close to the plantar margin of the ungual there are small nutrient foramina. The proximal articular surface is dorsoventrally deep and laterally compressed, with well defined articular cotylae that are separated by a vertical and well defined ridge. The flexor tubercle is a low, rounded protuberance.

CPP 470 consists of a complete, robust pedal phalanx 1 of left digit II (Fig. 1B). It is dorsoventrally flat and transversely wide, and lacks a marked constriction of the shaft. It bears a well developed proximomedial process. In medial view, the process has a broad, circular surface for ligament attachment. The proximal articular surface is round and bordered by a small, proximodorsal rim. The distal trochlea is prominent, with the trochlear edges diverging ventrally. The trochlear rings are acute and tall, especially in the medial portion. The distal articular sulcus is deep and has a "V"-shaped section. The distal flexor pits are deep and bordered caudodorsally by an osseous rim.

REMARKS

CPP 481 is identified as a possible pedal ungual because it shows a poorly curved blade, symmetrically arranged lateral sulci, and its proximal articular surface ellipsoidal with a well-defined median keel (see Agnolin & Martinelli 2009). Regrettably, the incomplete nature of CPP 481 does not allow to identify to which digit it belongs. CPP 481 may be identified as a bird because it differs from derived coelurosaurian dinosaurs (i.e. Dromaeosauridae Matthew & Brown, 1922, Troodontidae Gilmore, 1924, *Rahonavis*; Paul 2002), and resembles basal Aves in having greatly reduced flexor tubercle, such as most members of the Enanthiornithes (e.g., *Soroavisaurus australis* Chiappe, 1993, *Neuquenornis volans* Chiappe & Calvo, 1994, *Sinornis santensis* Sereno & Rao, 1992; Chiappe 1993; Chiappe & Calvo 1994; Sereno *et al.* 2002), *Archaeopteryx* Meyer, 1861 (Mayr *et al.* 2007), *Zhongornis* Gao *et al.*, 2008 (Gao *et al.* 2008), *Jeholornis* Zhou & Zhang, 2002 (Zhou & Zhang 2003) and *Zhongjianornis* Zhou, Zhang & Li, 2010 (Zhou *et al.* 2009), among others. Moreover, CPP 481 also resembles birds and differs from derived coelurosaurian dinosaurs in having a relatively un-curved ungual blade. In fact, in basal birds most pedal unguals (with the single exception of the second one) show a nearly straight blade, as can be observed in some Enantiornithes and basal ornithurines (e.g., *Sinornis santensis* Sereno & Rao, 1992; Sereno *et al.* 2002), *Archaeopteryx* (Mayr *et al.* 2007), *Zhongornis* (Gao *et al.* 2008), *Jeholornis* (Zhou & Zhang 2002), and *Zhongjianornis* (Zhou *et al.* 2009). On the other hand, in derived deinonychosaurian coelurosaurian dinosaurs (e.g., *Buitreraptor* Makovicky, Apesteguía & Agnolín, 2005, *Rahonavis* Forster, Sampson, Chiappe & Krause, 1998, *Deinonychus* Ostrom, 1969, *Microraptor* Xu, Zhou & Wang, 2000, Troodontidae; Ostrom 1969; Rauhut & Werner 1995; Xu 2002; Makovicky *et al.* 2005) the ungual blade is extremely curved (Zheng *et al.* 2009). Both features in combination may be employed to assign CPP 481 to Aves. Within this clade, a more precise referral of the available specimen is not possible due to the poorly informative and incomplete nature of the available material.

The specimen CPP 470 resembles basal birds, such as Enantiornithes, in having a subcircular distal trochlear ring, with dorsally displaced and small distal flexor pits that are ellipsoidal in contour, features that allow us to identify

this element as pertaining to a bird (Agnolin & Martinelli 2009). A similar, but larger, element (MACN-PV-RN 1107) was described by Agnolin & Martinelli (2009) from the Upper Cretaceous Los Alamitos Formation of Río Negro Province, Argentina. They noted that the well developed proximomedial process and laterally expanded and dorsoventrally compressed shaft are features present in MACN-PV-RN 1107 and reminiscent of derived neornithine predatorial birds, such as Falconiformes (Agnolin & Martinelli 2009); these features are also present in CPP 470. Nevertheless, given the incomplete nature of CPP 470, we identify it only as Aves indet.

Clade ORNITHOTHORACES Chiappe, 1996
cf. Enantiornithes Walker, 1981

Genus and species indet.

REFERRED MATERIAL. — CPP 482, an incomplete metatarsal III of the left foot missing its proximal end (Fig. 1C).

PROVENANCE. — "Ponto 1 do Price" (see Candeiro *et al.* 2008), Peirópolis locality, Uberaba, Minas Gerais state, Brazil. Serra da Galga Member; Marilia Formation; Bauru Group (Fernandes & Coimbra 1996).

DESCRIPTION

CPP 482 consists of a left metatarsal III lacking its proximal portion (Fig. 1C). The preserved portion of the bone indicates that it was not fused to metatarsals II and IV along most of its length. The distal end of the bone is laterally oriented and exhibits a large lateral crest proximal to the distal articular trochlea. This crest is proximally delimited by a shallow medial concavity (Fig. 1C) as also occurs in some Enantiornithes, such as *Soroavisaurus* Chiappe, 1993 and an indeterminate enantiornithine (Chiappe 1993; Forster *et al.* 2002; O'Connor & Forster 2010). Distally, the lateral crest is delimited by a concavity representing the distal foramen, as typically occurs in Enantiornithes (O'Connor & Forster 2010). The distal articular trochlea is relatively narrow and the trochlear rings are proximodistally low and rounded. The medial ring projects farther distally than the lateral one. The trochlear sulcus is wide and shallow. Circular flexor pits are shallow and slope gradually into the bone. Proximally to the distal articular trochlea there exists a large and shallow extensor pit. In plantar view, the proximal end of the bone exhibits a longitudinal groove, which also occurs in several basal birds (e.g., *Vorona* Forster, Chiappe, Krause & Sampson, 1996, Euenantiornithes Chiappe, 2002, *Confuciusornis* Hou *et al.*, 1995; Chiappe & Walker 2002; Forster *et al.* 2002).

REMARKS

CPP 482 shares with basal birds two plesiomorphic traits that allow to exclude it from the clade Ornithurae: 1) metatarsal III not fused with metatarsals II and IV along most of its length, and showing a large distal lateral foramen; and 2) in plantar view, a longitudinal groove is present along the length of metatarsal III (Clarke & Norell 2002; Forster *et al.* 2002). Among basal birds, CPP 482 resembles basal birds such as *Confuciusornis* and Enantiornithes such as *Soroavisaurus* in that the distal metatarsal III is laterally oriented, with a well-developed lateral crest and a proximal concavity (Chiappe & Calvo 1994; Chiappe *et al.* 1999; Forster *et al.* 2002), as well as very wide distal lateral foramen (O'Connor & Forster 2010). However, CPP 482 differs from *Confuciusornis* and resembles enantiornithine birds in lacking a medial crest above the distal articular surface and in lacking a transverse ridge delimiting the proximal end of the extensor pit (Chiappe *et al.* 1999). Moreover, the medial distal ring of the articular trochlea of CPP 482 extends farther distally than the lateral ring, a condition considered as synapomorphic of Enantiornithes (Sereno 2000). Although proximally incomplete, the preserved portion of shaft of CPP 482 differs from the derived Avisauridae in having a flat, rather than convex, dorsal surface of metatarsal III (Chiappe 1993). However, the medial ring of distal trochlea is more plantarly projected than the lateral one, a condition putatively diagnostic of Avisauridae (Chiappe 1993). Although fragmentary and incomplete, CPP 482 preserves features that suggest it may be assigned to Enantiornithes.

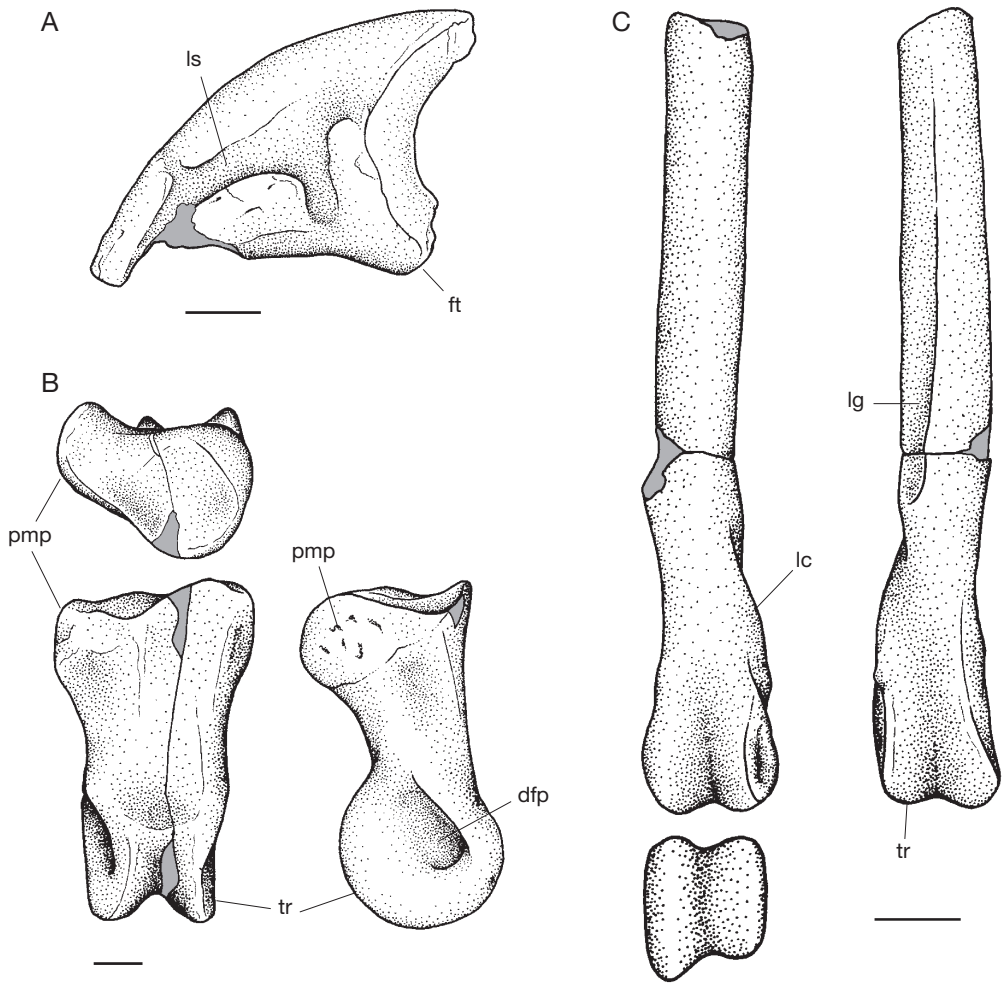

FIG. 1. — **A**, **B**, Aves genera and species indet.: **A**, CPP 481, isolated pedal ungual phalanx in lateral view; **B**, CPP 470, isolated pedal phalanx 1 of left digit II in dorsal (left), lateral (right) and proximal (top) views; **C**, cf. Enantiornithes indet. (CPP 482), incomplete left metatarsal III in dorsal (left), ventral (right), and distal (below) views. Grey areas indicate broken surfaces. Abbreviations: **dfp**, distal flexor pit; **ft**, flexor tubercle; **lc**, lateral crest; **lg**, lateral groove; **ls**, lateral sulcus; **pmp**, proximomedial process; **tr**, trochlear ridge. Scale bars: A, B, 1 mm; C, 2 mm.

CONCLUSIONS

The discovery of avian remains in the Upper Cretaceous Marilia Formation at the Peirópolis locality give unsurprisingly the worldwide, and especially Gondwanan, distribution of birds during the Late Cretaceous. Nevertheless, avian specimens are rare in comparison to other small vertebrate components of the Marilia paleofauna, such as fishes and turtles. Peirópolis is only the third Late Cretaceous locality to produce avian remains in Brazil and the first from the Maastrichtian. The Marilia Formation specimens are similar in degree of incompleteness to the material (i.e. small portion of a distal trochlea) from the Adamantina Formation at the Jales locality in São

Paulo State (Azevedo *et al.* 2007). In contrast, the dozens of well-preserved avian bones collected at the Presidente Prudente locality, also in the Adamantina Formation in São Paulo, allow for the identification of at least three different Enantiornithines (Alvarenga & Nava 2005).

Although the specimens reported here are extremely incomplete and not highly informative, the morphology of the specimen CPP 482 (metatarsal III; Fig. 1C) appears to belong to an enantiornithine taxon. Curiously, in latest Cretaceous contemporaneous avifaunas reported from Patagonia and Antarctica, derived Ornithurae (including stem Neornithes) are the dominant (and probably exclusive) taxa recorded in marine or freshwater deposits (Clarke & Chiappe 2001; Chatterjee 2002; Hope 2002; Agnolin & Martinelli 2009; Agnolin 2010). On the other hand, continental avifaunas appear to be dominated by the extinct Enantiornithes and other basal non-ornithurine birds, a pattern also observed in most Late Cretaceous fossil localities around the world (Feduccia 1995; Chiappe & Walker 2002; but see for example Clarke *et al.* 2006). Present report agrees with this worldwide avifaunal pattern.

Despite the isolated and incomplete nature of the specimens described here, they contribute to the knowledge of the Late Cretaceous biota of the Bauru Group, which constitutes one of the richest in Brazil.

Acknowledgements
We especially thank L. C. Borges Ribeiro for access to the collections of the CPP and for permitting us to study the material here presented, and to A. Kramarz for access to the collection of the MACN. We are much indebted to Dr Jerald Harris, for valuable comments and English corrections on the early manuscript. We thank N. Longrich, J. O'Connor and Annemarie Ohler for their comments on the manuscript. We thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Produtividade em Pesquisa/2009) for financial support for this research provided to R. Candeiro.

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Submitted on 16 April 2010;
accepted on 17 April 2011.