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# Invertebrate traces in pseudo–coprolites from the upper Cretaceous Marília Formation (Bauru Group), Minas Gerais State, Brazil

Heitor Francischini [a, *], Voltaire D. Paes Neto [a], Agustín G. Martinelli [a, b], Vitor P. Pereira [a], Thiago S. Marinho [b, c], Vicente P.A. Teixeira [b], Mara L.F. Ferraz [b], Marina B. Soares [a], Cesar L. Schultz [a]

[a] Instituto de Geociências, Universidade Federal do Rio Grande do Sul (UFRGS), Avenida Bento Gonçalves 9500, Agronomia, 91540–000 Porto Alegre, RS, Brazil
[b] Centro de Pesquisas Paleontológicas L. I. Price, Complexo Cultural e Científico Peirópolis (CCCP), Universidade Federal do Triângulo Mineiro (UFTM), BR–262, Km 784, Bairro Peirópolis, 38039–755 Uberaba, MG, Brazil
[c] Instituto de Ciências Exatas, Naturais e Educação (ICENE), UFTM, Av. Randolfo Borges Jr. 1700, Univerdecidade, 38064–200 Uberaba, Minas Gerais, Brazil

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ABSTRACT

Pseudo–coprolites are inorganic structures often confused with fossil faeces. The absence of some diagnostic features, such as inclusions, coprofabrics, grain adhesion, and defined shape, suffices to disregard these structures as coprolites. Herein we revise the so–called "coprolites" from the Serra da Galga Member of the Marília Formation (Maastrichtian of Bauru Group, Paraná Basin), at "Ponto 1 do Price" locality near the town of Peirópolis (Uberaba municipality, Minas Gerais State, Brazil) and conclude that they are, in fact, pseudo–coprolites related to calcretes. These data also agree with the geological setting of "Ponto 1 do Price", composed mainly of coarse sandstones and conglomerates, in which these pseudo–coprolites were found. In addition, some of these specimens exhibit superficial traces, here described as a new boring ichnospecies, *Asthenopodichnium fallax* isp. nov., produced by invertebrates in Late Cretaceous fresh–water settings of Brazil.



## 1. Introduction

Coprolites are fossilized faeces of ancient animals. The studies on coprolites began with the classic work of William Buckland (1829), who coined the term coprolite (literally "dungstone"). Since then, hundreds of contributions on the subject have appeared all around the world; for a historical overview, reference is made to Duffin (2009) and Hunt, Lucas, Milàn, & Spielmann (2012).

The distinction between coprolites and structures of inorganic origin is difficult, because usually faeces fossilize without any definite shape. Therefore, other features such as the presence of marks on the surface, inclusions of undigested remains (e.g., bones, scales, plants), and texture are important to determine their real nature (Dentzien–Dias et al., 2013; Fiorelli et al., 2013; Hunt, Chin, & Lockley, 1994; Northwood, 2005; Sharma, Kar, Agarwal & Kar, 2005; Thulborn, 1991).

Taking this problem into consideration, some authors have reviewed the authenticity of several fossilized faeces. Spencer (1993) and Mustoe (2001) analyzed the sideritic, spindle–shaped, coiled and concretionary structures of the Upper Cretaceous Whitemud and Wilkes formations of North America, diagnosed as coprolites by Roberts (1958). Due to their ferruginous composition, absence of internal inclusions and scarcity of vertebrate remains at this locality, the authors proposed that these excrement–shaped structures are in fact pseudo–coprolites produced by the methanogenesis–related deformation of the organic–rich silt and clay, forcing the sediment injects into hollow logs. Seilacher Marshall, Skinner, and Tsuihiji (2001) reviewed the sideritic "coprolites" from fluvial deposits of various ages and localities of Canada, China, Madagascar, and the United States (Dake, 1960; Danner, 1994; Major, 1939; Spencer, 1993), and concluded that these structures

*Abbreviations:* CPPLIP, Centro de Pesquisas Paleontológicas Llewellyn Ivor Price, Complexo Cultural e Científico de Peirópolis, UFTM, Peirópolis, Uberaba, MG, Brazil; UFRGS, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil; USNM, United States National Museum of Natural History, Washington, D.C., USA.

* Corresponding author.
*E-mail address:* heitorfrancischini@hotmail.com (H. Francischini).

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were in fact cololites (i.e., natural intestinal casts), formed after the pre–mineralization of the vertebrate gut contents. As such, these studies have highlighted the problem of considering coprolites only on the basis of external shape.

Coprolites are commonly reported from the Upper Cretaceous Bauru Group deposits in southeastern Brazil, mainly coming from the Presidente Prudente (Campanian–Maastrichtian), Adamantina (Campanian–Maastrichtian), and Marília (Maastrichtian) formations (e.g., Nobre, Carvalho, Vasconcellos & Souto, 2008; Souto & Nava, 2007). Nevertheless, there are only few contributions that address these specimens in detail. In the Presidente Prudente Formation, only three coprolites were described by Souto and Nava (2007) and their contents included fish scales. Several specimens from the Adamantina and Marília formations were figured by Souto (2008), but their internal and external morphology were not described in detail. In addition, Nobre et al. (2008) described cylindrical, isopolar and coiled coprolites from the Adamantina Formation, assigning them to notosuchian crocodyliforms. Souto (2010) recorded cylindrical, coiled and concave–ended coprolites from the Adamantina Formation. The author proposed that crocodyliforms were the producers, due to the high levels of calcium and phosphate in the samples, the liquefied consistency of some of them, and their association with eggshells in the same outcrop. Teeth of newborn crocodiles, fish scales and indeterminate bone fragments were recorded from inside these coprolites, in addition to gas vesicles, ostracod valves, and protozoan cysts (Souto, 2010). Iori and Marinho (2014) noted the presence of three flat, ornamented crocodyliform osteoderms inside a shapeless coprolite from the Adamantina Formation. According to these authors, the coprolite could be related to theropods, because bone structures of the prey are completely destroyed in the digestive tract of extant crocodiles. Ribeiro et al. (2012) figured one specimen from the Marília Formation as a coprolite, but there is no mention of the nature of the material. Recently, the taphonomy of coprolites of "Ponto 1 do Price", one of the main fossiliferous outcrops of the Marília Formation in Minas Gerais State, has been discussed in an unpublished undergraduate thesis (Oliveira, 2013). Oliveira (2013) described 211 specimens but failed to list diagnostic features (such as inclusions, texture and defined morphology) of the excremental nature of these specimens. Most recently, Souto and Fernandes (2015) presented brief descriptions of two ovoid and anisopolar coprolites from the same outcrop. Finally, we presented preliminary observations, in an abstract meeting (Francischini et al., 2014), of structures that were described as coprolites, bearing external traces originally interpreted as pupal chambers of dung flies. However, further analyses of these specimens shed new light onto the matter, resulting in positive evidence that they are in fact pseudo–coprolites.

In this contribution, we analyze the specimens traditionally referred as "coprolites" collected from the palaeontological site "Ponto 1 do Price" (near Peirópolis town, Uberaba municipality, Minas Gerais State, southeastern Brazil), from the Late Cretaceous Serra da Galga Member of the Marília Formation (Bauru Group). Some of the specimens have regular traces on the outer surface, which were analyzed and compared in order to interpret the nature of these marks. For the same purpose, we analyze the sedimentary environment in which such structures were deposited.

## 2. Material and methods

The pseudo–coprolites have been discovered during fieldworks conducted by the staff of the CPPLIP of the Universidade Federal do Triângulo Mineiro (UFTM), based in Peirópolis town, Uberaba municipality (Minas Gerais State, Brazil) since the beginning of systematic prospections and excavations in 1994. Several specimens were found *ex situ* at the base of a vertical outcrop. However, others with the same features were collected *in situ* from sandstone and conglomerate lenses facies. In this sample, some specimens have superficial traces that are described below. Previous contributions have mentioned and/or figured specimens from the same locality at Peirópolis (i.e., "Ponto 1 do Price"), that were referred to as "coprolites" (e.g., Carvalho, Ribeiro & Avilla, 2004; Francischini et al., 2014; Oliveira, 2013; Ribeiro, Carvalho, & Neto 2014; Ribeiro et al., 2012; Salgado & Carvalho, 2008; Souto, 2008; Souto & Fernandes, 2015), but with exception of Francischini et al. (2014), none of these authors mentioned external traces. Selections of these earlier records, together with recent finds, are here studied in detail and are referred to as pseudo–coprolites (see below).

The analyzed material includes nine specimens (CPPLIP–0101, CPPLIP–0232, CPPLIP–0443, CPPLIP–0460, CPPLIP–0460H, CPPLIP–0611, CPPLIP–1083, CPPLIP–1214 and CPPLIP–1440), which possess superficial traces (Fig. 1), and seven specimens without such marks (Fig. 2; CPPLIP–0409, CPPLIP–0410, CPPLIP–0658, CPPLIP–0460A, CPPLIP–0460I, CPPLIP–1205 and CPPLIP–1211).

A set of techniques demonstrates that these traditionally considered "coprolites" are non–biogenic structures. These include macroscopic description, thin sections, computerized tomography (CT) scan, and X–Ray diffractometry (XRD). Two specimens (CPPLIP–0101 and CPPLIP–0443) were cut, following standard petrographic techniques. Thin sections were obtained using the methodology proposed by Chin (2002, 2007), analyzed under a Zeiss Axio Scope A1® optic microscope and photographed using the software Axio Vision® LE 64.

The remaining fragments of the specimens CPPLIP–0101 and CPPLIP–0443 were submitted to XRD analysis in the Laboratório de Difratometria de Raios–X from the UFRGS (Porto Alegre, Brazil), using a Siemens® D–500 x–ray diffractometer.

The largest specimen, CPPLIP–1083, was subjected to Aquilion® CT scan, at the Hospital de Clínicas of the Universidade Federal do Triângulo Mineiro (UFTM; Uberaba, Minas Gerais State, Brazil). The scan produced 106 "longitudinal" slices and 46 "coronal" slices, with 512 × 512 pixels. From the scanned data (DICOM format), the 3D–images were visualized in high resolution and processed with the free software InVesalius 3.0 beta 4.

Despite the fact that the geology of Marília Formation is reasonably well known, we raised a new stratigraphic log for "Ponto 1 do Price", positioning the pseudo–coprolite–bearing layers to reassess local geology.

The superficial traces in some pseudo–coprolites were counted, measured and compared with other similar ichnospecies, such as *Asthenopodichnium xylobiontum* Thenius, 1979, *A. ossibiontum* Thenius, 1988, *A. lithuanicum* Uchman, Gaigalas, Melešytė and Kazakauskas, 2007, *A. lignorum* Genise, et al., 2012, *Petroxestes pera* Wilson and Palmer, 1988, *P. altera* Jagt, Neumann and Donovan, 2009 and *Cubiculum ornatus* Roberts, Rogers and Foreman, 2007.

## 3. Locality and horizon

The material studied comes from the site "Ponto 1 do Price" (GPS coordinates 19°43′24.6″ S/47°44′45.4″ W), also known as the "Caieira quarry", located in the region named Serra do Veadinho, near Peirópolis town, Uberaba municipality (Minas Gerais State, southeastern Brazil), from the Serra da Galga Member of Marília Formation outcrops (Fig. 3; Fernandes & Coimbra, 1996; Barcelos, 1984). This outcrop is composed of fine– to coarse–grained sandstones, associated with conglomerates in fining–upwards cycles (Salgado & Carvalho, 2008; Soares, Landim, Fulfaro & Sobreiro Neto, 1980). The invertebrate burrows *Skolithos* and *Arenicolites* occur in both sandstone and conglomerate facies (Carvalho et al., 2004). The