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A NEW SPECIMEN OF WHIP SCORPION (ARACHNIDA; THELYPHONIDA) FROM THE CRATO FORMATION, LOWER CRETACEOUS OF BRAZIL

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ABSTRACT – Fossil whip scorpions (Thelyphonida) are extremely rare in the Crato Formation strata, Araripe Basin, Lower Cretaceous (Aptian) of Brazil. Only four specimens of whip scorpions have been described in this unit so far. All specimens have been assigned to the genus *Mesoproctus* Dunlop and only one species has been formally proposed, *M. rowlandi* Dunlop. For Mesozoic times, apart from Crato Formation, whip scorpions are only documented by two species in the amber deposits of the Hukawng Valley, northern Myanmar. In this scenario, each new discovery of Mesozoic whip scorpion is highly important. In addition, we present the first documented example of book lungs from a fossil whip scorpion. Here, we present and illustrate a new specimen of whip scorpion found in the Crato strata.

Keywords: Crato arachnofauna, Uropypi, *Mesoproctus*, Aptian, *Lagerstätten*.

RESUMO – Os fósseis de escorpiões-vinagre (Thelyphonida) são extremamente raros nos estratos da Formação Crato, Bacia do Araripe, Cretáceo Inferior (Aptiano) do Brasil. Apenas quatro espécimes de escorpiões-vinagre foram descritos nesta unidade até agora. Todos os indivíduos foram atribuídos ao gênero *Mesoproctus* Dunlop e apenas uma espécie foi formalmente proposta, *M. rowlandi* Dunlop. Durante a Era Mesozoica, além da Formação Crato, os escorpiões-vinagre são documentados apenas por dois espécies nos depósitos de âmbar do Vale Hukawng, norte de Mianmar. Neste cenário, cada nova descoberta de escorpião-chicote de idade mesozoica é significamente relevante. Além disso, apresenta-se, pela primeira vez, a preservação de pulmões folíaceos em um espécime fóssil de escorpião-chicote. Neste estudo, descreve-se e ilustra-se um novo espécime de escorpião-vinagre encontrado nos estratos da Formação Crato.

Palavras-chave: Aracnofauna Crato, Uropypi, *Mesoproctus*, Aptiano, *Lagerstätten*.

INTRODUCTION

Thelyphonida is an order comprising scorpion-like arachnids known as whip scorpions or vinegaroons (Figure 1). Despite the similarity to scorpions, whip scorpions are more closely related to spiders (Tetlie & Dunlop, 2008). Overall, whip scorpions can be recognized by their robust pedipalps, first pair of tactile appendages and a long, slender, whip-like flagellum (Haupt, 2000; Selden *et al*., 2016). Thelyphonida are carnivorous, preying mostly on insects, millipedes, scorpions, and terrestrial isopods (Cai & Huang, 2017). They are nocturnal hunters able to survive in the litter, under rocky outcrops, or in rotten wood. The diversity of Thelyphonida comprises one family, four subfamilies, 18 genera and 128 species, including the fossils (World Arachnid Catalog, 2023). Whip scorpions can be found in tropical and subtropical regions of Asia, the Americas and Africa (Harvey, 2003).

The fossil record of whip scorpions is scarce and only ten valid species are known to date. Seven species date back to Late Carboniferous and four are representatives of the Cretaceous. After a careful revision by Tetlie & Dunlop (2008), six Paleozoic species included in four genera were recognized as valid: *Geralinura carbonaria* Scudder, 1884; *G. britannica* Pocock, 1911; *Parageralinura naufraga* Brauckmann & Koch, 1983; *P. neerlandica* Laurentiaux-Viera & Laurentiaux, 1961; *Prothelyphonus bohemicus* Kušta, 1884; and *Proschizomus petrunkevitchi* Dunlop & Horrocks, 1996. Recently, Garwood & Dunlop (2023) recognized *P. petrunkevitchi* within Thelyphonida based on the presence of petellar and tibial apophyses. Eight years earlier, Selden

Figure 1. A recent representative of the whip-scorpion *Mastigoproctus maximus* (Tartani, 1899) collected at the Federal University of Mato Grosso. The specimen is exposed respectively in ventral (**A**) and dorsal (**B**) views. Scale bar = 10 mm.

et al. (2016) described *Parageralinura marsiglioi* from the Later Westphalian of Italy. Mesozoic whip scorpions are even rarer, and the bulk of the species come from the amber of Myanmar. Wunderlich (2015) proposed *Burmathelyphonus prima*, the first whip scorpion formerly described there. *Burmathelyphonus parvus* was proposed by Cai & Huang (2017). Dunlop (1998) described the first Mesozoic whip scorpion, *Mesoproctus rowlandi*, from the Lower Cretaceous Crato Formation of Brazil. Although Crato strata are famous for their outstanding arachnofauna, only four whip scorpions have been recovered from this unit (Dunlop, 1998; Dunlop & Martill, 2002). When described by Dunlop (1998), *Mesoproctus rowlandi* was placed in an uncertain family, later Dunlop & Martill (2002) maintained this condition. Harvey (2003) places the genus in the family Thelyphonidae but as an uncertain subfamily, this position was maintained in the World Arachnid Catalog (2023). Crato whip scorpions are well-known for their large size compared to the other fossil representatives and all are assigned to a single genus, still with an uncertain subfamilial position.

Here, we describe a new exemplar of a whip scorpion from the Crato Formation of the Araripe Basin. Our fossil is probably assignable to the previously proposed species, *Mesoproctus rowlandi*. The specimen appears incomplete but is larger in overall size than the other whip scorpions formerly reported for this unit. Despite the incompleteness of the specimen described here, we report for the first time the presence of book lungs in fossil whip spcorpions.

GEOLOGICAL SETTING

The Araripe Basin is one of the largest basins in the interior of the Brazilian northeast (Figure 2). This basin displays five depositional tectonic-sedimentary sequences: a Paleozoic Sequence; Pre-Rift; Rift; Post-Rift I; and Post Rift II (Assine, 2007). The Crato Formation is embedded in the Post Rift I sequence and comprises a 70-m thick succession composed of carbonate layers interbedded with siliciclastic sediments such as shales, claystones and sandstones (Assine *et al*., 2014).

The Crato Formation strata are attributed to transgressive-regressive events associated with the expansion and contraction of a lacustrine system (Neumann, 1999). Recently, Varejão *et al*. (2021) suggested that the Crato Fm. represents a shallow and hypersaline lacustrine system (Downen *et al*., 2016). The Crato carbonates record the second lacustrine phase of the Araripe Basin (Assine *et al*., 2014). The origin of the Crato limestones has been attributed to biological precipitation under microbial influence (Catto *et al*., 2016). The carbonates facies are characterized by micritic calcite composition with low magnesium content (Catto *et al*., 2016).

The Crato limestones host abundant high-quality fossils. This excellent preservation of Crato fossils have made it known worldwide as a *Fossil Lagerstätte* (Heimhofer & Martill, 2007). The Crato Fm. is part of the *Sergipe variverrucata* palynozone, which implies a late Aptian-early Albian age for this unit (Coimbra *et al*., 2002; Coimbra

Figure 2. Location and geological setting of the Araripe Basin. **A**, position of the Araripe Basin in the territory of Brazil. **B**, position of the Araripe Basin in northwestern Brazil. **C**, simplified map of the Araripe Basin, Crato Formation outcrops associated with the Santana Group.

& Freire, 2021). Most of the Crato limestone outcrops are exposed due to the commercial extraction of Pedra Cariri slabs in small quarries.

MATERIAL AND METHODS

The whip scorpion described here is assigned to the Crato Formation, upper Aptian (circa 115 Ma), Lower Cretaceous. The specimen is part of the collection of the Laboratório de Paleontologia (**LP**), Universidade Federal do Ceará (**UFC**), Fortaleza, Ceará state, with the collection number LP/UFC CRT 2798. This specimen was collected from the Três irmãos quarry located in Nova Olinda, Ceará, northeastern Brazil. This fossil material was prepared using a fine needle to gently remove pieces of the carbonate matrix overlying details of the body.

Photographs were taken with a Nikon D7100 digital camera. The specimen was drawn with the aid of a *camera lucida* attached to an Olympus C011 microscope. Morphological nomenclature is based on Shultz (1993), Dunlop (1998) and Dunlop & Martill (2002). All measurements are given in millimeters. Morphological structures are identified by the following abbreviations: **ap**, tergal muscle apodeme; **cx**, coxa; **fe**, femur; **fg**, flagellum; **pc**, pedipalpal coxae; **pp**, pedipalp; **pt**, patela; **py**, pygidium; **st**, sternite; **ti**, tibia; **tr**, trochanter; **ts**, tarsus. Legs numbered from I–IV.

SYSTEMATIC PALEONTOLOGY

Order THELYPHONIDA Latreille, 1804
Family THELYPHONIDAE Blanchard, 1852

Mesoproctus Dunlop, 1998

Mesoproctus rowlandi Dunlop, 1998
(Figures 3–5)

Fossil material. LP/UFC CRT 2798 is preserved in a pale yellowish limestone slab. The fossil appears not well preserved where the legs, chelicerae and the entire prosoma occur as a two-dimensional impression (Figures 3–4). However, most of the opisthosoma is well preserved displaying structures in detail. Overall, our specimen consists of a fossiliferous compression composed of a friable orange-brown material, probably iron oxide-hydroxides (Bezerra *et al*., 2020). These characteristics indicate that the fossil studied here experienced moderate to high weathering during post-diagenesis, which resulted in its poor preservation. Considering the preservational status of the fossil material, the specimen probably came from the uppermost part of the interval II proposed by Varejão *et al*. (2019). This interval consists of yellow to red-colored laminites and corresponds to an interval informally named by Corecco *et al*. (2022) as

Figure 3. Photomicrograph of LP/UFC CRT 2798, *Mesoproctus rowlandi*. Scale bar = 5 mm.

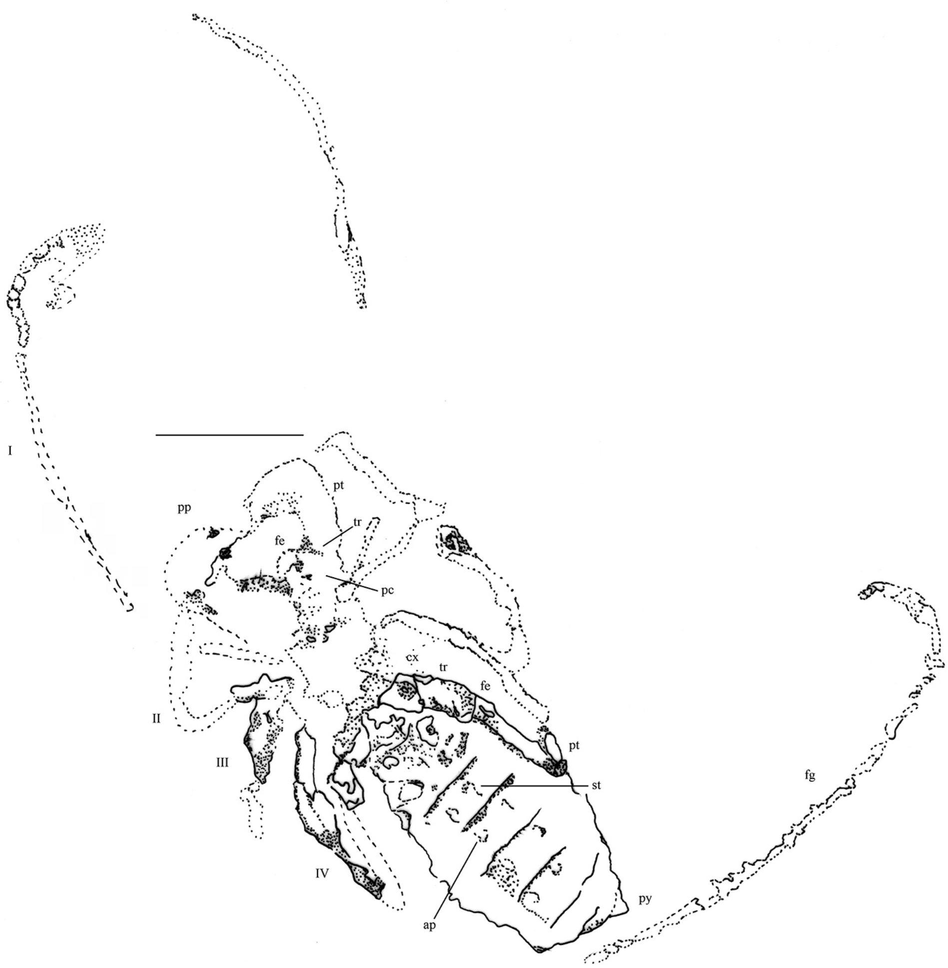

Figure 4. Camera lucida drawings of LP/UFC CRT 2798, *Mesoproctus rowlandi*. Scale bar = 10 mm.

'veio do besouro', from which most Crato mineralized insects are recovered.

Description. The specimen displays massive pedipalps folded in on themselves as in extant Thelyphonida. The pedipalp coxae, 6.1 mm in length, are also massive but they are preserved only in outline, without displaying any fine detail. Overall, the prosoma (Figure 5A) appears barely preserved, 13 mm in length and 8 mm in width, the characteristic Y-shaped sternum between the second pair of leg coxa is not visible. The posterior sternum is also not clearly preserved. The legs are preserved laterally with the legs I extended anteriorly. The legs are mostly flattened and distally deteriorated. Legs II+IV are shorter and stout. The opisthosoma can be divided into eleven visible segments, where the first opisthosomal segment corresponds to the triangular-shaped sternite between the coxae of legs IV. The four book lungs are visible (Figure 5B). As they are preserved, it was not possible to clearly detail any individual tissue (*i.e*., lamellae or bridging trabeculae) in the book lungs. Most of the opisthosoma is compressed, favoring the observation of characters from the ventral surface. Tergites V–VIII are particularly well-preserved showing lengths and widths: 3 mm, 9.1 mm; 3.0 mm, 9.1 mm; 3.1 mm, 9 mm; and 3.0 mm, 8.9 mm, respectively. They preserve the paired circular apodomes along the length of each tergite. The flagellum is clearly visible, 49 mm in length, and comprises at least 30 individual articles. The articles are broader than long at the base and narrow distally. All measurements are shown in Table 1.

Remarks. Although our fossil is incomplete, LP/CRT UFC 2798 preserves the body, the large, robust, and well-developed pedipalps, and narrow and elongated legs where leg I is remarkably antenniform. The prosoma and opisthosoma are substantially elongated. A well-developed pygidium is followed by a characteristic flagellum composed of multiple articles. This combination of characters allows us to assign LP/CRT UFC 2798 to *Mesoproctus* sp., most likely a representative of *M. rowlandi*.

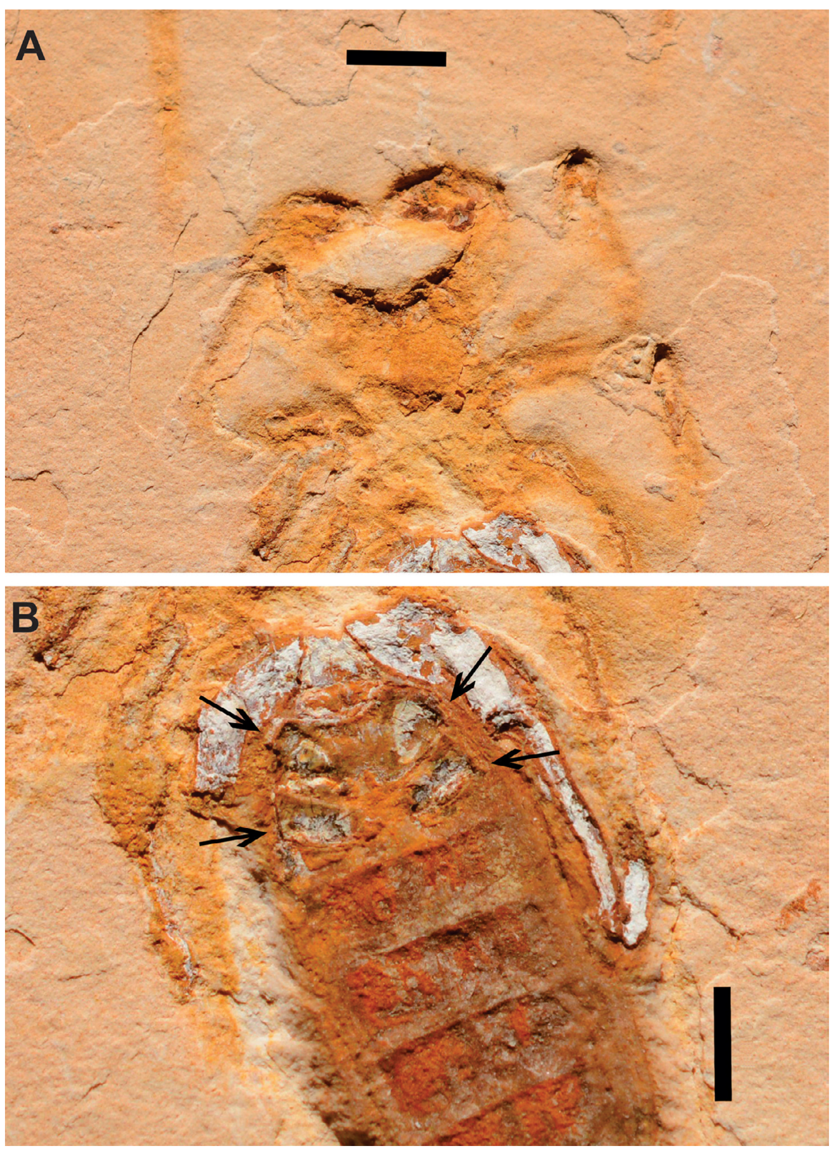

Figura 5. LP/UFC CRT 2798, *Mesoproctus rowlandi*. **A**, magnification of the prosoma in a ventral view where it is possible to visualize pedipalps and prosoma. **B**, ventral view of the abdomen showing the book lungs, sternites and IV legs. Scale bars = 5 mm.

Table 1. *Mesoproctus rowland* measurements (in mm).

Chronym of specimen	Structures	SMNS 64331	MB.A 1041	CRT 2798	MB.A 975	K28006
Body without flagellum	–	16.8	32.5(as preserved)	49	17,1	23,5
Prosoma length/width	–	–	32.5/ 16	13/ 8	–	11
Opisthosoma length/width	–	9/ 4.2	–	23.2/ 9.1	12/3.5	8.5/6.8
Flagellum	–	28	–	49	15.5	–
Post-opistosomic individual articles	–	70	–	30	18	–
Pedipalp length/width	Total	–	32	12.8/ 4	–	–
	Coxa	–	-	6,1	–	–
	Trochanter	–	3	4	–	2.5
	Femur	–	19	8	–	4.
	Patella	–	–	2	–	2.6
	Tibia	–	–	4	–	4.9
	Tarsus	–	–	–	–	8.5
	Apophysis	–	–	4	–	–
Leg I	Total	20	–	48	–	–
	Coxa	–	–	–	–	–
	Trochanter	–	–	2	–	–
	Femur	–	–	–	–	6.7
	Patella	–	–	3	–	8.9
	Tibia	–	–	10	–	9.2
	Metatarsus	–	–	–	–	–
	Tarsus	–	–	0.4	–	3.0
	Apófise	–	–	–	–	–
Leg II	Total	–	–	21	8.2 mm	–
	Coxa	–	–	–	–	–
	Trochanter	–	–	2.7	–	–
	Femur	–	–	6	–	5.7
	Patella	–	–	–	–	2.2
	Tibia	–	–	6.2	–	4.5
	Metatarsus	–	–	–	–	1.2
	Tarsus	–	–	–	–	1.3
	Apophysis	–	–	–	–	–
Leg III Leg IV	Total	–	–	13.3	8.5 mm	–
	Coxa	–	–	–	–	–
	Trochanter	1	–	3	–	–
	Femur	3.3	–	7.3	–	6.0
	Patella	1	–	–	–	2.0
	Tibia	2.5	–	5	–	3.8
	tarsus	–	–	–	–	1.5
	Metatarsus	–	–	–	–	1.2
	Apophysis	–	–	–	–	–
Leg III	Total	–	–	29.9	10.7 mm	–
	Coxa	–	–	4	–	–
	Trochanter	–	–	3	–	–
	Femur	–	–	9	–	7.0
	Patella	–	–	3	–	2.5
	Tibia	–	–	8	–	4.9
	tarsus	–	–	1	–	–
	Metatarsus	–	–	–	–	–
	Apophysis	–	–	–	–	–

DISCUSSION

Considering Mesozoic whip scorpions, LP/UFC CRT 2798 is morphologically close to extant whip scorpions based on the following characters: legs narrowly elongate; leg I clearly antenniform; pedipalps massive and well developed; and a slender and long flagellum. Among all Cretaceous thelyphonid taxa, LP/UFC CRT 2798 is easily separated from those described in Cenomanian Myanmar amber by its much larger body size (total body length over 45 mm). Unfortunately, few specimens have been discovered and they often preserve only the gross morphology. The preservation condition of Crato whip scorpions makes a rigorous comparison with the extant families difficult. Nonetheless, Crato whip scorpions have been assigned to the genus *Mesoproctus* by previous authors. Due to the body proportions and geographical distribution, *Mesoproctus* was suggested to be closely related to the extant *Mastigoproctus* Pocock, 1894, a group in the subfamily Mastigoproctinae.

In 1998, Dunlop presented *Mesoproctus rowlandi*, the only species proposed for the Crato Fm. to date. Dunlop & Martill (2002) published three further specimens of whip scorpions from the Crato strata: MB.A. 1041, MB.A. 975 and SMNS 64331. MB.A. 1041 is relatively incomplete, essentially showing prosoma and pedipalps only in non-detailed morphology, while MB.A. 975 and SMNS 64331 appear better preserved. MB.A. 975 and SMNS 64331 match in overall body size with the holotype (K28006) presented by Dunlop (1998), therefore the authors referred them to *M. rowlandi*. However, MB.A. 1041 displays significantly larger body proportions than the other specimens described. Considering the ontogeny of whip scorpions, the anteriormost prosomal sternite is relatively wide in juveniles, where it tapers and becomes more elongated as the whip scorpion ages (Yoshikura, 1965; Weygoldt, 1971). Dunlop & Martill (2002) compared the anterior sternite preserved in the Crato fossils with both adult and juvenile of the extant *Mastigoproctus giganteus* (Lucas, 1835), concluding that MB.A. 975 and SMNS 64331 are more similar to the juvenile forms, and MB.A. 1041 is an adult form of *M. rowlandi* or even a new species within *Mesoproctus* sp.

The flagellum of LP/UFC CRT 2798 extends to slightly more than half the body length whereas in SMNS 64331, the flagellum reaches almost twice the body length. The flagellum of MB.A. 975 is about the same as the body. On the other hand, the shape of the flagellum's individual articles in LP/UFC CRT 2798 is similar to the articles of SMNS 64331. While the individual articles in MB.A. 975 are longer than wide, which differs from our fossil. The flagella of the specimens are clearly distinct, but the length and the proportions of individual articles can vary intraspecifically (Dunlop & Martill, 2002). Despite resting in ventral view, the fossil studied here preserves the prosoma just as a faint impression, so the anterior sternite is not visible. However, the overall prosoma of LP/UFC CRT 2798 appears to be wider than other Crato whip scorpions, but its poor preservation precludes more advanced inferences. Although body size is not a reliable feature, there are no characters clearly attesting against LP/UFC CRT 2798 being an adult. Our specimen exhibits a bulge at the end of the leg I, there is nothing similar in the biology of extant Thelyphonida. Therefore, this character may be related to poor preservation status of the fossil. Furthermore, such a structure would be too large and heavy for a clearly antenniform leg to bear. Finally, the presence of book lungs in our incomplete specimen was a pleasant surprise. Although Downen (2014) have already documented book lungs in arachnids (spiders) from the Crato Formation, we are the first to report these internal organs in fossil whip scorpions. The lungs observed here contain little detail, but they are similar in size and position to those of modern whip scorpions (Scholtz & Kamenz, 2006).

CONCLUSIONS

In this study, we presented a new specimen of whip scorpion (LP/UFC CRT 2798) from the Crato Formation, Aptian of the Araripe Basin, Brazil. Overall, characteristics such as pedipalps large and well developed, legs narrowly elongated, leg I antenniform, and flagellum slender place our fossil morphologically close to the extant whip scorpions. Unfortunately, Crato whip scorpions are commonly poorly preserved, which hinders a more accurate taxonomic classification. Numerous key features remain unknown for Crato whip scorpions; for example, detailed morphology of the patellar apophysis of the pedipalps and abdominal ommatoids. Due to the incompleteness of the Crato whip scorpions, only one species, *Mesoproctus rowlandi*, has been proposed to date. Although the whip scorpion studied here is also insufficiently preserved, it is larger in overall body size than other Crato specimens. This raises questions about the taxonomic placement of whip scorpions described in the Crato fauna. Dunlop & Martill (2002) presented a large whip scorpion (MB.A. 1041) that is a presumed new species or an adult of *M. rowlandi*, while the others (MB.A. 975, SMNS 64331, K28006) would be juvenile forms of the same species. The prosoma of our specimen is preserved only as an outline which prevents a faithful comparison with Dunlop's (1998) holotype. However, the prosoma dimensions and telson proportions of LP/UFC CRT 2798 match with individuals designated as *M. rowlandi*. Unfortunately, it is difficult to rely on telson length and proportions of individual articles within the flagellum since they are unreliable characters for taxonomic proposes. Even so, we cannot rule out the possibility that LP/UFC CRT 2798 is the adult form of the *M. rowlandi*, while MB.A. 1041 is indeed a new species. We chose to place the studied specimen in *M. rowlandi* for two reasons. The first reason is directly related to the preservation state of the fossil, which does not allow us to identify any morphological differences compared to *M. rowlandi*. The second reason is that *M. rowlandi* is already known from the same unit, so we thought that the most parsimonious approach was to adopt it.

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