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OCURRENCE OF *LINGULAPHOLIS* (CRANIOPSIDAE, BRACHIOPODA) IN THE PIMENTEIRA FORMATION (DEVONIAN, PARNAÍBA BASIN)

REGISTRO DE LINGULAPHOLIS (CRANIOPSIDAE, BRACHIOPODA) NA FORMAÇÃO PIMENTEIRA (DEVONIANO, BACIA DE PARNAÍBA)

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RESUMO - - O gênero *Lingulapholis* teve restrições temporais e espaciais durante o Devoniano, sendo encontrado apenas na Colômbia e nos Estados Unidos. No Brasil, seu táxon relacionado *Craniops* é comum nas bacias do Amazonas, Paraná e Parnaíba. Novos dados das cidades de Picos e Itainópolis, flanco leste da Bacia do Parnaíba, levaram à descoberta de um gênero de braquiópode ainda não descrito para esta região do Gondwana. O braquiópode *Lingulapholis* foi encontrado associado a fragmentos de plantas em condições de moderada a baixa energia hidrodinâmica, conforme indicado pela assembleia icnológica, em expressões próximas de icnofácies *Cruziana* alternadas a icnofácies *Skolithos*. A presença de *Lingulapholis* sugere que a Bacia do Parnaíba esteve inserida na zona de mistura faunística difusa durante o Devoniano Médio.
Palavras-chave: *Lingulapholis*. Craniopsidae. Devoniano. Gondwana. Icnologia.

ABSTRACT - The genus *Lingulapholis* had temporal and spatial restrictions during the Devonian, being found only in Colombia and the United States. In Brazil, its related taxa *Craniops* is common in the Amazonas, Paraná, and Parnaíba basins. New data from the cities of Picos and Itainópolis, east flank of Parnaíba Basin, led to the discovery of a yet previously undescribed brachiopod genus for this region of Gondwana. The *Lingulapholis* brachiopod was found associated with plant fragments under conditions of moderate to low hydrodynamic energy as indicated by ichnological assemblage, in proximal expressions of *Cruziana* ichnofacies alternated to *Skolithos* ichnofacies. The presence of *Lingulapholis* suggests that the Parnaíba Basin was inserted in the zone of diffuse faunal mixing during the Middle Devonian.
Keywords: *Lingulapholis*. Craniopsidae. Devonian. Gondwana. Ichnology.

INTRODUCTION

The genus *Lingulapholis* Schuchert, 1913 is inserted in the family Craniopsidae Williams, 1963, which also includes *Craniops* Hall & Clarke, 1892, ?*Discinopsis* Hall & Clarke, 1892, ?*Heliomedusa* Sun & Hou, 1987, *Paracraniops* Williams, 1963, *Pseudopholidops* Bekker, 1921, and *Wrightiops* Popov & Cocks, 2014. The family occurs from the Lower Cambrian (Epoch 2) to the Lower Carboniferous (Tournaisian) in many localities around the world. (Raasch, 1958; Skovsted & Holmer, 2005; Popov & Holmer, 2009).

During the Devonian, the family was represented just by two genera: *Craniops*, with records in Argentina, Australia, Brazil, Canada, China, Colombia, and the United States; and *Lingulapholis*, from Colombia and the United States. In Brazil, the family was only represented by *Craniops* in Amazonas (Grahn, 1992), Paraná (Quadros, 1987) and Parnaíba (Melo, 1988) basins. This study aims to present new paleontological data from the Parnaíba Basin confirming the occurrence of the genus *Lingulapholis* in the Brazilian Devonian.

Geological and historical context

The Parnaíba Basin comprises an area of approximately 600,000 km^2 in the north/northeast of Brazil, encompassing the states of Bahia, Ceará, Maranhão, Pará, Piauí and Tocantins (Figure 1.A). On the eastern flank (state of Piauí) and on the western flank (state of Tocantins), crops

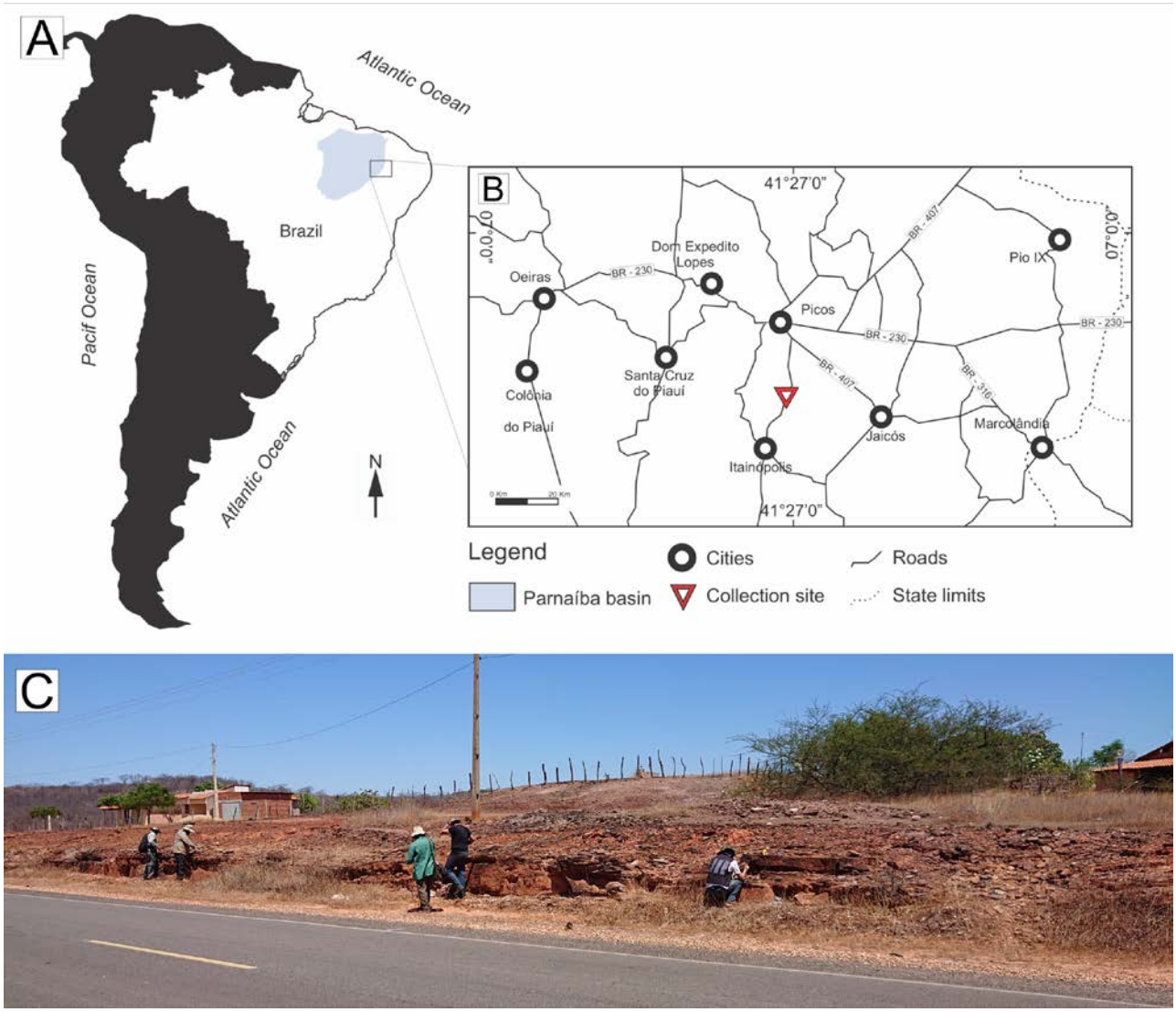

Figure 1- Location map of the explored area with; (A) Parnaíba basin highlighted in South America, (B) study site near the city of Picos, (C) lateral view of the outcrop where the fossil was collected.

out Devonian rocks from the Canindé Group. The Canindé Group comprises the Itaim (Emsian-Eifelian), Pimenteira (Eifelian-Frasnian), Cabeças (Eifelian-Famenian) and Longá (Famenian-Carboniferous) formations (Góes & Feijó 1994, Vaz *et al.* 2007). The Pimenteira Formation was deposited in a proximal shelf marine environment, being influenced by tides and storms (Vaz *et al.*, 2007). It presents intercalations of fine sandstones with hummocky cross stratification and dark gray to black shales, siltstones, bioturbated claystones, with rare conglomeratic levels (Della Fávera 1990). The outcrops of the Pimenteira Formation in the state of Piauí have been explored by several researchers (Kegel 1953 1966, Brito & Santos 1965, Brito 1977, Castro 1968, Campanha & Mabesoone 1974, Melo 1985, Campos 1985, Fonseca & Melo 1987, Lima Filho & Caldas 1987, Carvalho 1995, Fonseca 2004 2015, Ponciano *et al.* 2012, Franco-Neto et al., 2023) for their paleontological diversity of invertebrates, such as trilobites, brachiopods, bivalves, conulariids, tentaculitis, gastropods, and trace fossils.

Around the city of Itainópolis, *Tropidoleptus carinatus* Conrad, 1839 was recorded by Kegel (1953), while in Pedro II city, Ponciano et al. (2012) reported Terebratulida. In the city of Picos, there are records of *Australocoelia*? sp., *Cranaena* sp., *Derbyina smithi*, linguids, *Montsenetes* cf. *M. boliviensis* Rachebouef, 1992, Mutationellinae indet., *Orbiculoidea* sp., "*Paranaia*" sp., *Scaphiocoelia*? sp., and *Tropidoleptus carinatus* (Melo, 1985; Fonseca & Melo, 1987; Carvalho, 1995; Fonseca, 2004, 2015; Ponciano *et al.*, 2012). The fossils from the cities of Oitis and Pimenteiras are quite similar to this area, sharing the taxa*Cranaena* sp., *Derbyina smithi*, *Montsenetes* cf. *M. boliviensis*, *Orbiculoidea* sp., and *Tropidoleptus carinatus*. "*Paranaia*" sp. has

been exclusively reported in Oitis, whereas lingulids and Terebratulida are restricted to the city of Pimenteiras (Kegel, 1966; Krausel & Dolianiti, 1957; Santos, 1961; Brito & Santos, 1965; Brito, 1977; Castro, 1968; Campos, 1985; Fonseca & Melo, 1987; Lima Filho & Caldas, 1987; Carvalho, 1995; Fonseca, 2004, 2015; Ponciano *et al.*, 2012). In São Miguel do Tapuio, *Derbyina smithi* and *Orbiculoidea* sp. have been reported in the sandstones of the Pimenteira Formation (Campanha & Mabesoone, 1974; Oliveira & Barros, 1976; Lima & Leite, 1978; Muniz, 1988; Melo, 1988).

In the state of Tocantins, western flank of the Parnaíba Basin, *Australocoelia*, *Spirifer*, *Orbiculoidea*, Spiriferacea indet. and brachiopods without specific identification were reported (Ramos & Barbosa, 1967; Barbosa *et al.*, 1966; Campos & Campos, 1975; Lima & Leite, 1978; Sundaram & Cunha, 1982; Melo, 1988). In the area of the Mangues river, a tributary of the Tocantins river, there are reports of *Derbyina* sp., *Orbiculoidea* sp., and Spiriferacea indet. (Melo, 1985, 1988). In the city of Santa Teresa, Queiroz *et al.* (2013) recorded *Australocoelia palmata* Morris & Sharpe, 1846, *Australospirifer iheringi* and *Tropidoleptus carinatus*. In Turiritins, the brachiopods are represented by *Chonetes* sp., Chonetacea indet., infaunal lingulids, *Orbiculoidea* sp., Spiriferacea indet., and *Spirifer* (Barbosa et al., 1966; Lima & Leite, 1978; Quadros, 1982; Melo, 1985, 1988). In Santo Antoninho, the specimens of *Australocoelia* sp., Chonetacea indet., Spiriferacea indet. were described by Barbosa *et al.* (1966) and Melo (1985, 1988). Gama Jr. (2008) and Ribeiro *et al.* (2021) point to the occurrence of *Amphigenia* cf. *A. elongata* Vanuxem, 1842, *Australocoelia palmata*, *Delthyridoidea*, *Montsenetes carolinae* Fonseca, 2004, *Mucrospirifer pedroanus* Rathbun, 1874, and *Tropidoleptus carinatus* in the vicinity of Palmas. Near Novo Acordo, there are *Australocoelia* sp., *Australospirifer*? sp., *Schuchertella*?, *Derbyina*? sp., lingulids, and *Orbiculoidea* sp. (Ribeiro *et al.*, 2021).

In Maranhão state, there are reports of brachiopods in the Devonian of the Pimenteira formation from a borehole acquired in the city of Carolina. For the same unit, there are records of *Amphigenia* sp, Chonetacea indet., *Derbyina smithi*, *Eodevonaria* sp., lingulids, and Spiriferacea indet. (Kegel, 1953; Melo, 1985, 1988; Caputo & Crowell, 1985).

Collection site

The fieldwork was conducted around the cities of Picos and Itainópolis, Piauí State. The outcrop is located on the road BR-020 (S 07º 18' 38,1", W 41º 25' 14,3"), approximately 27 km south from the city of Picos (Figure 1B). The outcrop (Figure 1C) is approximately two meters high and has a lithology predominantly composed of sandstones with hummocky cross-stratification. This location was previously studied by Silva *et al.* (2012) and Ponciano *et al.* (2012) and was informally referred to as "Riachão".

Fossils occur well-distributed in the outcrop, with a predominance of *Spongiophyton* fragments and trace fossils. The collected fossils are housed in the scientific collection of the LAPALMA - Laboratório de Paleontologia de Macroinvertebrados, from the Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Campus of Bauru, under registration numbers CCLP1421.A and CCLP1421. B.

RESULTS

Facies analysis

The outcrop is on the edge of BR-020 road and is about 2 meters high. It contains a cyclical succession of sandstones (very fine and fine-grained) with hummocky cross-stratification and siltstones. Fragments of *Spongiophyton* and ichnofossils were found at the base of the section. The *Lingulapholis* reported here occurs at 0.9m from the base of the outcrop. Trace fossils are well distributed in the section and were grouped into two suites. The *Skolithos* suite was represented by the predominance of vertical trace fossils, such as *Skolithos* and *Arenicolites* associated with *Palaeophycus* in low degree of bioturbation (1-2 on a scale of 0 to 6; *sensu* Reineck, 1967). The *Rusophycus* suite had a predominance of resting structures, identified as *Rusophycus*, associated with *Cruziana*, *Diplichnites*, *Palaeophycus*, and *Planolites* (Figure 2).

Systematic paleontology

Phylum Brachiopoda Duméril, 1806
Subphylum Craniiformea Popov et al. 1993
Class Craniata Williams, 1963
Order Craniopsida Gorjansky & Popov, 1985
Superfamily Craniopsoidea Williams, 1963
Family Craniopsidae Williams, 1963
Genus ***Lingulapholis*** Schuchert, 1913

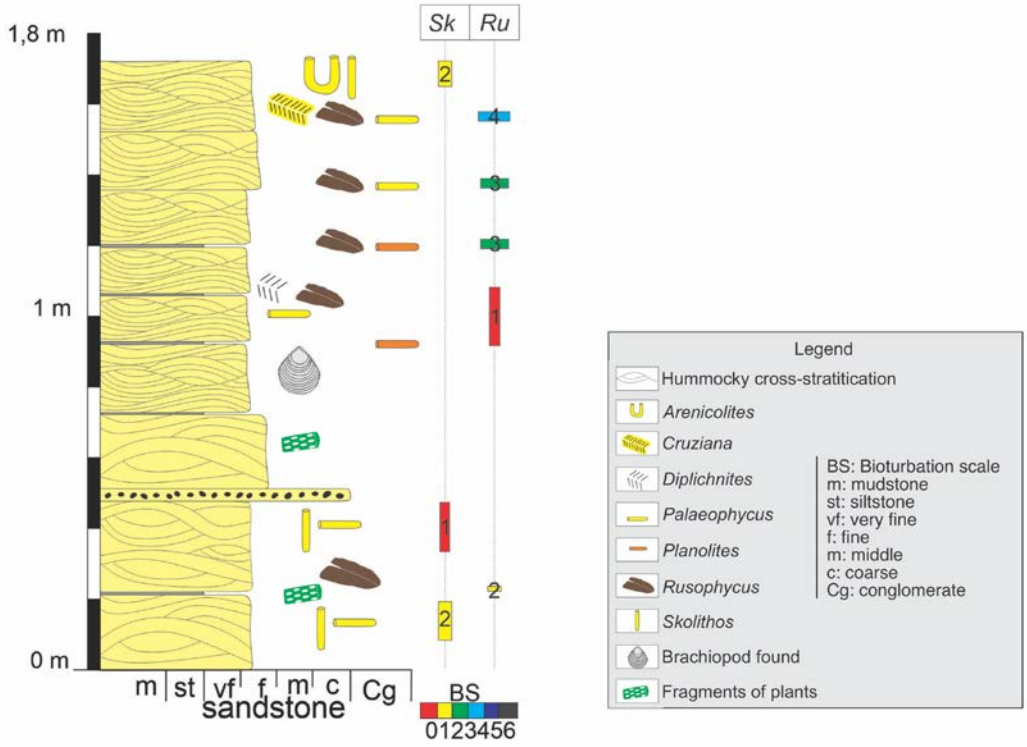

Figure 2- Lithological profile from Riachão locality, Piauí, Brazil.

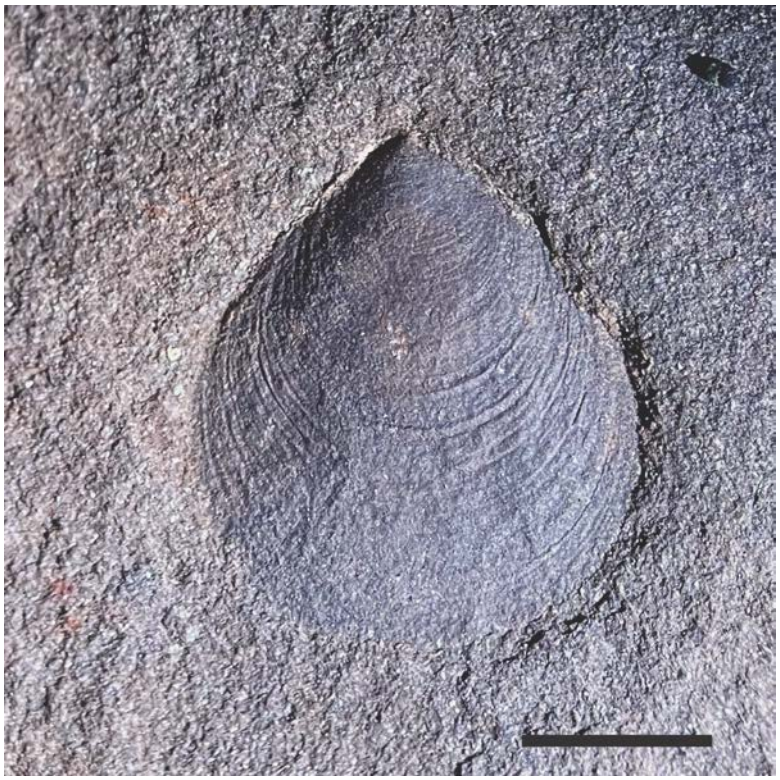

Figure 3- External mold of the dorsal valve of *Lingulapholis* (CCLP1421.A) collected during fieldwork. Scale bar equals 5mm.

Material. External mold of the dorsal valve CCLP1421.A and CCLP1421.B
Location and Horizon. Outcrop on BR-020 road, Riachão locality, Itainópolis, Piauí, Brazil.
Age and Stratigraphy. Eifelian-Frasnian, Pimenteira Formation, Canindé Group, Parnaíba Basin.
Description. The specimen is an external mold of the dorsal valve of *Lingulapholis* sp. It is 12mm wide and 14.5mm long. The shell has a biconvex, triangular shape, slightly elongated with divergent sides, partially curved and rounded anterior margins. The anterior commissure line is rectomarginal and the umbonal region is convex. Growth lines have a mixoperipheral pattern and the ornamentations are concentric, radial, and well-marked.

DISCUSSION

Considering the invertebrate fossils from Devonian strata of the Parnaíba Basin, many taxonomic identifications have been made at the genus or family level. In the state of Piauí, *Australocoelia*? sp., *Scaphiocoelia*? sp., (?) *Lingula*, Terebratulida indet., Mutationellinae indet. and brachiopods indet. were identified (Kegel, 1966; Krausel & Dolianiti, 1957; Santos, 1961; Castro, 1968; Campanha & Mabesoone, 1974; Melo, 1985, 1988; Campos, 1985; Lima Filho & Caldas, 1987; Carvalho, 1995; Ponciano *et al.*, 2012). However, most of these identifycations are dubious. The same happens in Tocantins state, from where "*Australocoelia*" (?), *Australospirifer*? sp., *Derbyina*? sp., (?) *Orbiculoidea*, *Schuchertella*?, Braquiópodos indet., Chonetacea indet., Discinidae, and Spiriferacea indet. need a morphofunctional analysis for species determination (Ramos & Barbosa, 1967; Barbosa *et al.*, 1966; Campos & Campos, 1975; Lima & Leite 1978; Melo, 1985, 1988; Portela *et al.*, 1976; Ribeiro *et al.*, 2021; Sundaram & Cunha, 1982).

Additionally, the taxonomic inaccuracy is evidenced by the recurrent use of quotation marks. During biostratinomic anddiagenetic phases morphofunctional structures necessary for taxonomic detailing can be lost or modified, justifying part of the dubious taxonomic identifycations for brachiopods from the Parnaíba Basin.

In Devonian beds from Parnaíba Basin there is a preferential occurrence of Spiriferida and Terebratulida brachiopods. The order Spiriferida (which includes the genera *Australospirifer*, *Delthyridoidea*, and *Spirifer*) has been only reported to the western edge of the basin, while the order Terebratulida (genera *Amphigenia*, *Cranaena*, *Derbyina*, *Scaphiocoelia*, and *Paranaia*) is more present at eastern border. This contrasting distribution can be derived from asymmetric collection efforts, considering that there are more works in the state of Piauí (see Kegel, 1966; Krausel & Dolianiti, 1957; Santos, 1961; Brito & Santos, 1965; Campanha & Mabesoone, 1974; Oliveira & Barros, 1976; Brito, 1977; Castro, 1968; Campos, 1985; Fonseca & Melo, 1987; Lima Filho & Caldas, 1987; Muniz, 1988; Melo, 1988; Carvalho, 1995; Fonseca, 2004, 2015; Ponciano *et al.*, 2012) than in Tocantins.

The identified *Lingulapholis* is somewhat similar to those of the Superfamily Linguloidea, however the growth lines have a different pattern (Williams *et al.*, 2009). In the Superfamily Linguloidea, growth lines reconnect to each other in the umbonal region, differently from the genus *Lingulapholis* (Popov & Holmer, 2009), where the growth lines tend to be interrupted near the commissure line (Figure 3). Another distinguishable character is the median ridges, which can usually be identified in specimens of the Superfamily Linguloidea; these ridges range from the anterior to the posterior region in both shells while they are absent in the specimen studied here.

The genus *Lingulapholis*, restricted to the United States (New York and Tennessee) and Colombia, is here expanded to Parnaíba Basin. Several authors have discussed a mixture of fauna in the Parnaíba Basin, due to the occurrence of *Tropidoleptus carinatus* in Tocantins and Piauí (Carvalho, 1995; Fonseca & Melo, 1987; Gama Jr., 2008; Ponciano *et al.*, 2012; Queiroz *et al.*, 2013; Ribeiro *et al.*, 2021). *Tropidoleptus carinatus* lived in regions near the paleo-equator during the Devonian, and had its center of dispersal in the sedimentary basins of northeastern Canada (Popov & Holmer, 2009). The presence of *Lingulapholis* in the Parnaíba Basin corroborates the entry of equatorial brachiopods into the South American basins during the Devonian. Furthermore, the paleobiogeographical analysis of Penn-Clarke & Harper (2020) suggested that the Parnaíba Basin acted as a faunal mixing area, hosting a diverse biota. The basin was located close to latitude 60ºS, in an area called zone of diffuse mixing, where brachiopods from different bioregions were well adapted. The updated occurrence of *Lingulapholis* sp. in Brazil along with the paleobiogeographical propositions made by Penn-Clarke & Harper (2020), suggest that this taxon was able to occupy the temperate waters of the Parnaíba Basin.

In paleoenvironmental terms, *Lingulapholis* occurs associated with trace fossils which suggests conditions of moderate to low hydrodynamic energy, associated with the *Rusophycus* suite. This suite presents a dominance of horizontal, shallow tier structures, commonly preserved as proximal expressions of *Cruziana* ichnofacies (e.g., MacEarchern et al., 2005; Sedorko et al., 2019, 2021). However, the section also has intervals with a *Skolithos* suite,

generated in higher hydrodynamic energy and representing the *Skolithos* ichnofacies. The trace fossils allowed the identification of conditions influenced by storms in the zone from the lower shoreface to the transitional offshore for the strata with *Lingulapholis*, alternated by strata with high energetic ichnofauna in a storm dominated lower shoreface (e.g. Franco-Netto, 2023).

CONCLUSIONS

Although several studies focusing on Devonian macrofossils have been carried out in the states of Piauí and Tocantins in the Parnaíba Basin, taxonomic data are often insufficient and precarious. The locality of Riachão, near the city of Picos - Piauí, presented cyclic packages of fine-grained to very fine-grained sandstones with hummocky cross stratification interbedded to siltstones. The reported fossils are fragments of plants (*Spongiophyton*) and one brachiopod (*Lingulapholis*). The trace fossils are composed of *Arenicolites*, *Cruziana*, *Diplichnites*, *Palaeophycus*, *Planolites*, *Rusophycus*, and *Skolithos*, grouped in two suites (*Rusophycus* and *Skolithos* suites). The presence of *Lingulapholis* corroborates the hypothesis that the Parnaíba Basin was inserted in a zone of diffuse mixing fauna during the Devonian, when brachiopods from equatorial and polar regions coexisted in that area. Our study expanded the distribution of *Lingulapholis* to Brazil (Parnaíba basin), up to now restricted to the United States (New York and Tennessee) and Colombia.

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