



Ichnofossils associated with lingulide shells from the Lower Permian of Brazil

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Abstract: Lingulides from Lower Permian of Brazil (24% substrates) showed signs of bioerosion in form of multiple small shallow pits that resemble incomplete *Oichnus paraboloides* borings. A single lingulide valve showed a centrally located large circular predatory *Oichnus simplex* boring. Several lingulide shells (c. 21%) show small *Arachnostega* traces in their interior. The diameter of *Arachnostega* burrows is relatively constant. These burrows are more similar to juvenile stages of *Arachnostega gastrochaena* and do not form well-developed meshwork of tunnels. This is the first record of *Arachnostega* from the interior of lingulide shells and indicates that even very small lingulide shells were suitable substrates for cryptic organisms.

Key-words:

- Brachiopods;
- borings;
- burrows;
- Campo Mourão Formation;
- Paraná Basin;
- Brazil

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Résumé : *Ichnofossiles associés à des coquilles de lingulides du Permien inférieur du Brésil.*- Les lingulides du Permien inférieur du Brésil (24% des substrats) portent des traces de bio-érosion sous forme de nombreux petits trous peu profonds qui ressemblent à des perforations incomplètes d'*Oichnus paraboloides*. Une seule coquille de lingulide montre une grande perforation prédatrice circulaire d'*Oichnus simplex* localisée en son centre. Plusieurs coquilles de lingulides (environ 21%) présentent des traces d'*Arachnostega* à l'intérieur. Le diamètre des terriers d'*Arachnostega* est relativement constant. Ces terriers sont très semblables aux stades juvéniles d'*Arachnostega gastrochaena* et ne forment pas de réseaux de tunnels bien développés. C'est la première mention d'*Arachnostega* à l'intérieur de coquilles de lingulides et ce qui prouve que des coquilles de lingulides, même très petites, pouvaient constituer un substrat convenable pour des organismes cryptiques.

Mots-clefs :

- Brachiopodes ;
- perforations ;
- terriers ;
- Formation de Campo Mourão ;
- Bassin de Paraná ;
- Brésil

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1. Introduction

The Lingulidae Family is part of the Lingulida Order (HOLMER & POPOV, 2000). The lingulide brachiopods have chitino phosphatic shells (HOLMER & POPOV, 2000). They have a stratigraphic range from the early Cambrian to Recent (HOLMER & POPOV, 2000). The data on soft body anatomy of Early Cambrian lingulides from the Chengjiang Fauna (ZHANG *et al.*, 2003) include preservation of a pedicle, schizolophous lophophore, as well as a recurved, U-shaped digestive tract with a functional anus showing that major features of soft body anatomy characteristic of Recent lingulites were already present in early Cambrian. Sometimes fossil lingulide shells contain borings.

The earliest predatory borings have been described in *Cloudina* from the Ediacaran (BENGTSON & ZHAO, 1992). The Paleozoic record of predation is mostly based on drillings known from the shells of both lingulate and rhynchonellate brachiopods, and a lesser amount from mollusks (BRETT & WALKER, 2002; BRETT, 2003; HARPER, 2003; HUNTLEY &

KOWALEWSKI, 2007). VERMEIJ (1977) has shown that predation was an important evolutionary factor since the early Cambrian. It is well known that predation intensities have increased from the Cambrian to the Recent (VERMEIJ, 1977, 1987; VERMEIJ *et al.*, 1981). This increase in predation intensities is mirrored by the morphological evolution of the gastropod shell (VERMEIJ, 1977, 1987; VERMEIJ *et al.*, 1981).

Often fossilized shells of various invertebrates contain burrows of the other invertebrates. The ichnofossil *Arachnostega* was first systematically described and named by BERGLING (1992) accommodating irregular, branching burrows on the surface of internal moulds of various shelly fossils (*e.g.*, VINN *et al.*, 2014). *Arachnostega* presumably belongs to the category fodichnia (BERGLING, 1992), but it is equally possible that it in fact represents a dwelling burrow (domichnion) (FATKA *et al.*, 2011). The exact zoological affinities of the tracemakers that produced *Arachnostega* and their paleoecology are not yet fully understood (VINN *et al.*, 2018).

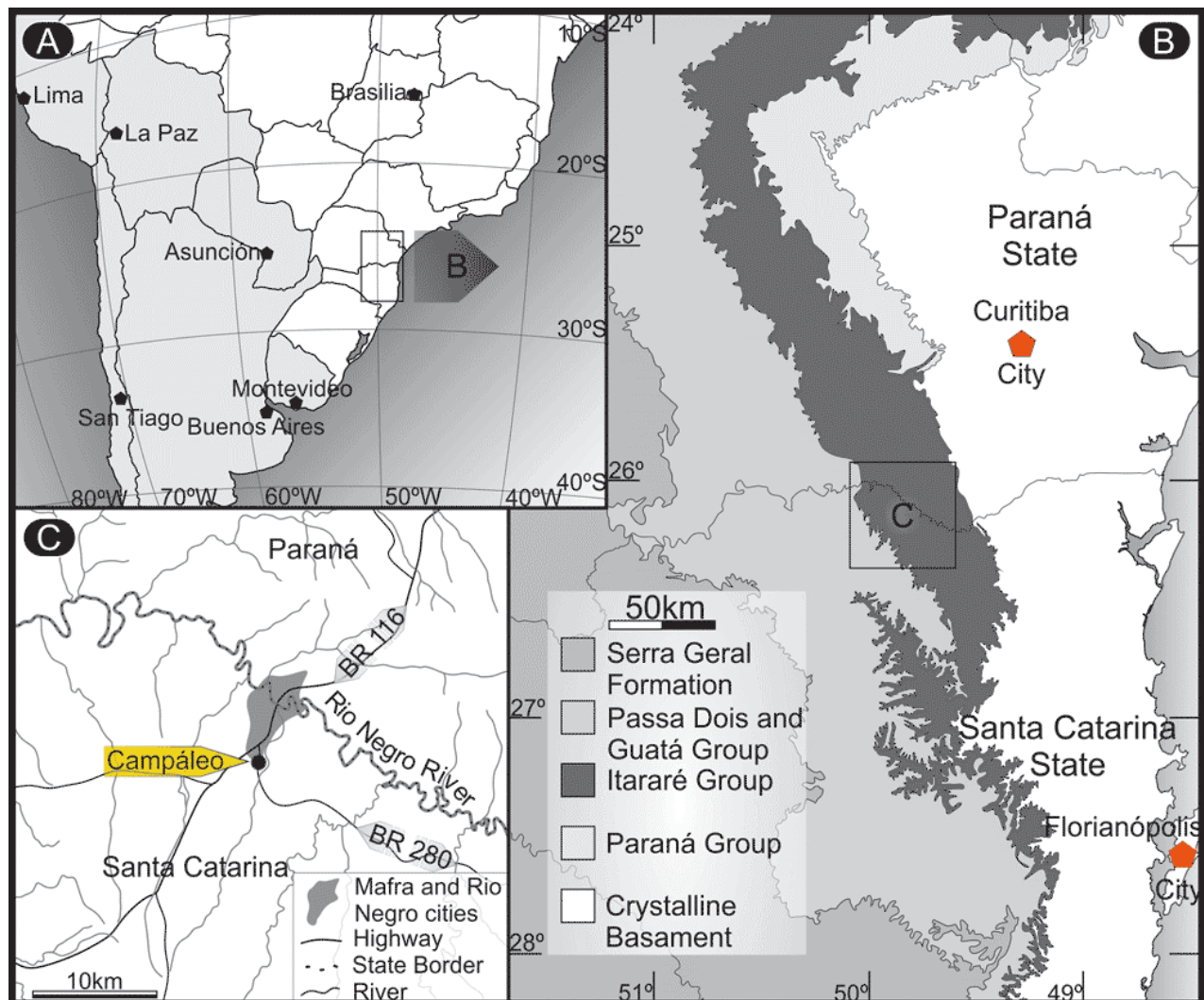


Figure 1: Localty map (modified after RICETTI *et al.*, 2016).



Geochronology			Lithostratigraphy				
Permian	Lopingian	Changhsingian —254.14±0.07—	Passa Dois Supergroup	Rio do Rasto Fm.	Morro Pelado Mb.		
		Wuchiapingian —259.8±0.4—			Serrinha Mb.		
	Guadalupian	Capitanian —265.1±0.4—			Teresina Fm.		
		Wordian —268.8±0.5—			Serra Alta Fm.		
		Roadian —272.3±0.5—		Irati Fm.	Assistência Mb.		
	Kungurian —283.5±0.6—	Taquaral Mb.					
	Cisuralian	Artinskian —290.1±0.26—		Guatá Group	Tatuí Fm.	Palermo Fm.	
		Sakmarian —295.0±0.18—				Rio Bonito Fm.	Siderópolis Mb.
							Paraguaçu Mb.
							Triunfo Mb.
Asselian —298.9±0.15—	Tubarão Supergroup	Itararé Group	Taciba Fm.				
Gzhelian —303.7±0.1—			Lontras Shale				
			Kasimovian —307.0±0.1—	Campo Mourão Fm.			
Moscovian —315.2±0.2—			Lagoa Azul Fm.				
Bashkirian							
Carboniferous	Pennsylvanian						

Figure 2: Stratigraphic position of Lontras Shale in the Lower Permian of Paraná Basin (modified after RICETTI *et al.*, 2016).

The aims of the present note are threefold; firstly, to describe bioerosion of early Permian lingulide shells; secondly, to describe predatory borings in early Permian lingulides and, thirdly, to document the ichnogenus *Arachnostega* from Lower Permian strata in Brazil for the first time.

2. Geological background and outcrop

Lingulide shells were collected from the Campáleo outcrop, which is located in the city of Mafra in the State of Santa Catarina, Brazil (Fig. 1). The outcrop is positioned in the Lontras Shale (Fig. 2), upper part of Campo Mourão Formation and eastern border of Paraná Basin. The Campáleo outcrop (UTM 22J 0.618.473, 7.106.243) comprises the first 10 m of the Lontras Member (MOURO *et al.*, 2017). At the base of outcrop there is a 1-m-thick silty bioturbated argillite bed (*i.e.*, the *Glossifungites* suite) and is overlain by a fossiliferous, 1.10-m-thick black shale layer (*i.e.*, the Lontras Shale), followed by a non-fossiliferous, 7-m-thick shelly rhythmite layer (MOURO *et al.*, 2017). Lontras Shale can be informally divided into four levels, including sublevels, distinguished on the bases of rock features, fossil content, and pyrite concentration (MOURO *et al.*, 2016, 2017). Based on the quantity and preservation of the fossils that have been recovered in the Lontras Shale and are exposed at the Campáleo outcrop, this site has been identified as an important lower Permian (Cisuralian, 299 myr to 275 myr) Fossil-Lagerstätte (RICETTI *et al.*, 2016; MOURO *et al.*, 2016, 2017). Lontras Shale is interpreted as a deglaciation phase. The paleoenvironment is interpreted as a restricted marine area, very close to the coast (RICETTI *et al.*, 2016; MOURO *et al.*, 2016, 2017).

3. Material and methods

A small collection of 58 lingulide shells was searched for associated ichnofossils. Shells with signs of bioerosion, predatory borings and cryptic burrows were selected for photographing. Photographing was carried out using a Zeiss digital camera. Dimensions of ichnofossils were measured from calibrated photos.



4. Results

About 24% of 58 lingulides studied showed signs of bioerosion in form of multiple small shallow pits (Fig. 3). This type of pits resemble incomplete *Oichnus paraboloides* borings. Their diameters of aperture have a range from 0.03 mm to 0.17 mm. The diameter of pits in a single lingulid valve is largely variable. Also, some shells are completely covered with small pits; borings do not show preference for special shell regions.

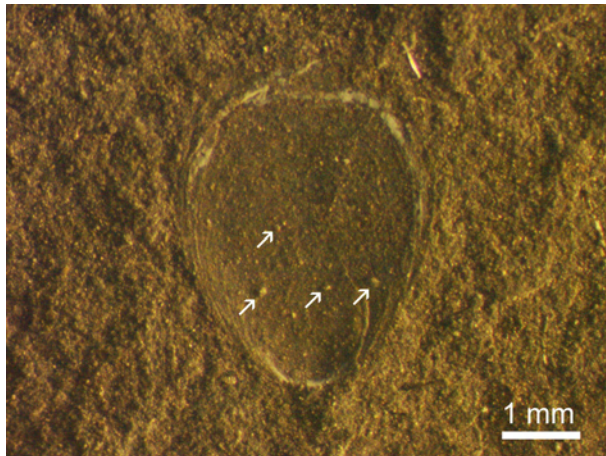


Figure 3: Small rounded pits in the lingulid shell (arrows) indicating the bioerosion.

A single lingulide valve shows a centrally located large circular *Oichnus simplex* boring with 0.67 mm wide (Fig. 4). Same valve also exhibits some traces of bioerosion.

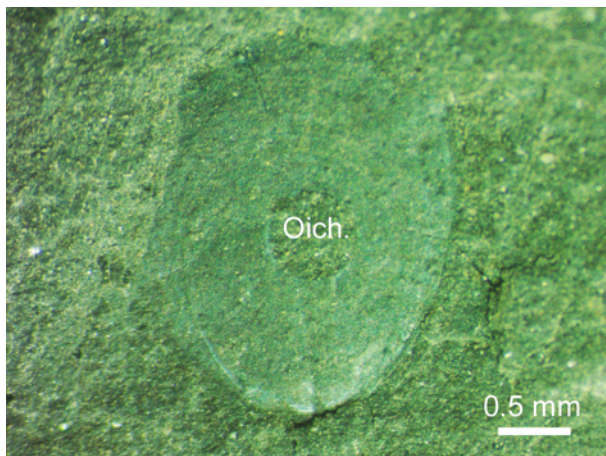


Figure 4: Lingulide valve shows a centrally located large circular *Oichnus simplex* boring (Oich.).

Almost 21% of the lingulide shells show small *Arachnostega* traces in their interior (Fig. 5). *Arachnostega* traces are visible through somewhat translucent shell material as a colour contrast. The diameter of burrows is relatively constant and ranges from 0.08 mm to 0.09 mm. These traces are more similar to juvenile stages of *Arachnostega gastrochaena* and do not form well-developed meshwork of tunnels. The *Arachnostega* burrows are filled with lighter colored sediment than the dark grey rock matrix.

5. Discussion and conclusions

Bioerosion

Dead or/and living lingulide shells were encrusted by phosphate boring organisms that needed a domicile. Considering the shallow depth of the pits in lingulides, it is likely that the soft body of organisms responsible for pit formation were only partially located within their borings. Thus, the function of these pits may have been rather enabling encrusters stronger contact with substrate than providing a shelter against predators for a true endobiont. It is interesting to notice that bioerosion in phosphatic substrates is rare when compared to calcareous ones (VINN & TOOM, 2016), which partially can be explained by study bias, as most of skeletons of marine organisms are calcareous. The earliest boring in phosphatic substrates are known from the early Cambrian (VINN & TOOM, 2016). The domiciles bored by worm-like organisms into calcareous brachiopod shells are common since the Middle Ordovician (VINN, 2004, 2005). They have usually been classified as *Trypanites* or *Vermiforichnus* (VINN, 2005). The latter two are much deeper than shallow pits in studied Permian lingulides and were created by worms that could fully retract to their borings. Thus, in calcareous brachiopods borings were usually created by endobiotic organisms, while in studied lingulides they were made by epibiotic organism. The variable diameter of pits in lingulides indicates that they were made by several generations of encrusters and were not a result of a single colonization event by multiple larvae of boring epibionts. Alternatively, different diameters of borings could result from growing organism which over time produce traces of larger diameter. The biological affinities of organisms responsible for creating the shallow pits in lingulides will remain unresolved without soft body preservation, but the architecture of these pits would fit with sponges as the makers. It is difficult to estimate bioerosion intensities in phosphatic lingulides, because of lack of other comparable records, but most of specimens with small pits show moderate bioerosion intensities.

Predation

Most likely large circular *Oichnus simplex* boring was made by some shell drilling predator, probably by a predatory gastropod, though the boring is slightly too small for common gastropod borings (ZONNEVELD & GINGRAS, 2014). The central location of the boring in a lingulide valve is well consistent with the predatory nature of the boring. The boring intensity was relatively low in the studied lingulide community as only one shell with *O. simplex* was found among 58 lingulide specimens. There are no reports on the boring frequency in Permian lingulides (HUNTLEY & KOWALEWSKI, 2007), but some data on boring frequencies on articulate brachiopods are available for the Carboniferous (see HARPER, 2003, and KLOMP-

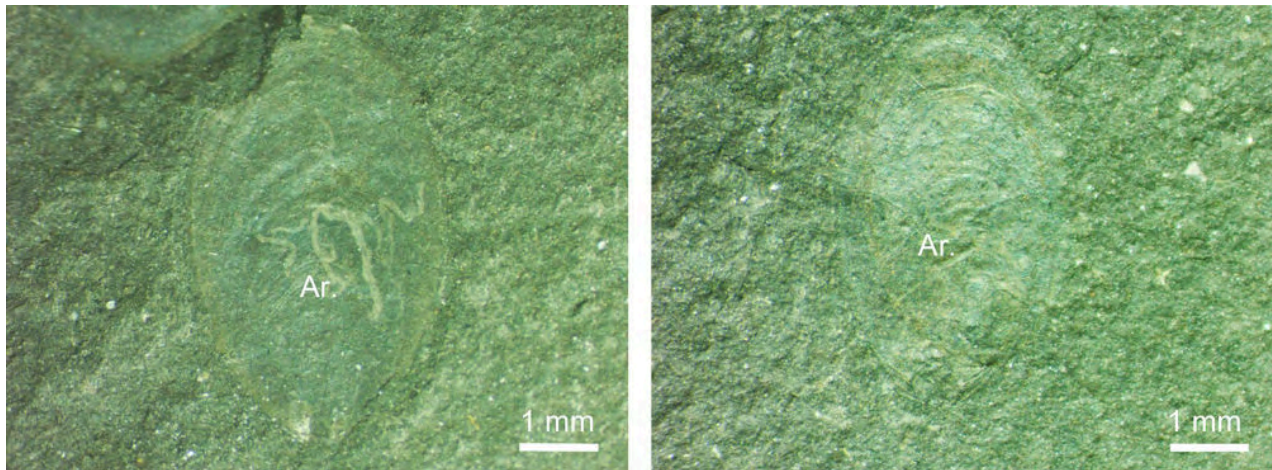


Figure 5: Small *Arachnostega* (Ar.) traces gleaming from the interior of lingulide shells.

MAKER *et al.*, 2019, for review) and Permian (HOFFMEISTER *et al.*, 2004). Carboniferous articulate brachiopods show boring frequencies ranging from 3.3 to 17.1 % (HARPER, 2003), which is much higher than boring frequency of studied Permian lingulides. Therefore, it is very likely that lingulides were not among favorite prey groups in the early Permian of Brazil. In contrast, some Cambrian lingulides exhibit fairly similar boring intensities to the studied lingulides, being <2% of the population (HARPER, 2003). The relatively low boring frequency of studied lingulides may reflect also their infaunal life mode, and their moderate bioerosion intensities could result from post mortem bioerosion.

Cryptic organisms

The earliest examples of *Arachnostega* known to date are of Cambrian age (*e.g.*, FATKA *et al.*, 2011), but the ichnogenus did not achieve global distribution and become common until the Ordovician (*e.g.*, ACEÑOLAZA *et al.*, 2003). This is the first record of *Arachnostega* from the interior of lingulide shells. Dead lingulide shells offered shelter for cryptic organisms that left behind *Arachnostega* traces. *Arachnostega* traces were probably made by small polychaetes that inhabited soft mud filling of the dead lingulide shell. It is interesting to note that even very small lingulide shells were suitable substrates cryptic organisms such as *Arachnostega* trace makers. However, the *Arachnostega* trace makers in Permian of Brazil must have been much smaller than their representatives in the Ordovician of Baltica (VINN *et al.*, 2014) or Miocene of Egypt (VINN *et al.*, 2018).

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