Journal of South American Earth Sciences 111 (2021) 103488

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

A segmented wormlike specimen from the Lower Cretaceous lacustrine shales of the Sanfranciscana Basin in southeast Brazil

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ARTICLE INFO

Keywords:
Quiricó formation
Barremian
Protostomia
Limnic paleoenvironment

ABSTRACT

The Quiricó Formation in southeast Brazil has gained relevance in the last few years as a window to Early Cretaceous (Barremian-Aptian) continental ecosystems of Western Gondwana. To its fossil record, we add here the first segmented wormlike specimen. The new fossil was preserved in a lacustrine environment within an arid tropical climate, associated with abundant fishes and plant remains. The incomplete small specimen (size order of 6 mm) has ca. 40 body segments, preserved as compression onto the rock bedding and soft-parts imprints. A combination of characters, such as number of segments, internal and external segmentation and lack of locomotory appendices support annelid affinities. Yet its assignment to a particular taxon is hindered by lack of diagnostic features. The new specimen composes the poorly known benthic stratum within the Quiricó Formation lake system and also adds to a scant fossil record of soft-bodied limnic protostomes in the Early Cretaceous.

1. Introduction

The fossil record of liminic soft-bodied protostomes is scanty throughout the Phanerozoic in comparison with that of their hard-part kin (Newell, 1959; Raup, 1972; Kidwell, 2001). Such record is in general restricted to exceptional *Lagerstätte* deposits (Briggs, 1991; Parry et al., 2018) and render poor fossil diversity of metazoan phyla known to dwell in those environments (e.g., annelids, nematodes, platyhelminths, among others).

Several Lower Cretaceous sedimentary horizons of continental aquatic environments in Western Gondwana (i.e. South America and Africa) are underexplored in paleontological terms (Gallego et al., 2020), and the prospection for fossils in those areas may help to uncover a larger diversity of limnic metazoans than that presently known. Such is the case of the Cretaceous strata of the Sanfranciscana Basin, which have gained relevance in the last few years due to discovery of new ostracods, fishes, lizards and dinosaurs (Zaher et al., 2011; Leite et al., 2018; Bittencourt et al., 2020; Carvalho and Santucci, 2018). Its Lower Cretaceous Quiricó Formation is mainly lacustrine and contains spatially restricted outcrops of carbonatic and organic shales (Bittencourt et al., 2015). Those levels yielded terrestrial and aquatic fossil record which are otherwise inexistent in central Brazil, hence in a large area of central Western Gondwana. To that paleodiversity, we add herein a new segmented wormlike specimen, enriching the fossil record of aquatic soft-body invertebrates for the timeframe delimited by the fossiliferous horizons of the Quiricó Formation.

2. Geological settings

The specimen was recovered from rocks of the Quiricó Formation (Campos and Dardenne, 1997; Sgarbi et al., 2001), cropping out in Fazenda São José, Presidente Olegário municipality, Minas Gerais State (Fig. 1A). The Quiricó Formation constitutes the middle portion of the Areado Group (Lower to Upper Cretaceous), which also comprises the Abaeté and Três Barras formations (Fig. 1B), within the Sanfranciscana Basin (Campos and Dardenne, 1997).

The local stratigraphic section is composed (from the base to top) of carbonate-rich sandstone, siltsone, a quarter meter layer of carbonatic and ferruginous shale (which yield the specimen) and organic shales intercalated with limestone bearing hummocky cross-stratification (Fig. 1C and D). Both lithology and fossil record (see below) suggest a lacustrine environment. Isotopic $\delta^{13}C$ and $\delta^{18}O$ data collected in the lacustrine facies of the Quiricó Formation (with poor stratigraphic control) indicate a lake system with decreasing salinity upwards (Sgarbi et al., 1993). This is in accordance with both the ostracod record (Leite et al., 2018) and the pervasive fluvial input at the top (Campos and

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https://doi.org/10.1016/j.jsames.2021.103488
Received 21 February 2021; Received in revised form 20 July 2021; Accepted 21 July 2021
Available online 24 July 2021

Dardenne, 1997). Climate is interpreted as arid tropical (Lima, 1979; Arai et al., 1995).

Albeit diverse, the biota of the Sanfranciscana Basin is not well known, even with an extensive area of outcrop. The macrofossils found in the same level of the new fossil comprise leaves of conifers, terrestrial and aquatic angiosperms (Duarte, 1997), as well as abundant and well preserved gonorhynchiform fish *Dastilbe moraesi* Silva Santos (in Scorza and Silva Santos, 1955) (Fig. 1D) and rare osteoglossomorph *Laeliichthys ancestralis* Silva Santos (1985). In contrast to the fishes, which are frequently preserved as articulated skeletons and soft tissue imprints, the external components of the macrofossil assemblage (basically gymnosperms) are much rarer and in general poorly preserved and disarticulated. This taphonomic pattern suggests that the new specimen, which is delicate and also preserved as soft tissue, is also endogenous to the lake or lived under influence of the variation of water volume. In the overlying organic shales, spores, pollen grains and aquatic insect larvae (Heteroptera) have been recovered with the same fishes and plants recorded in the carbonatic levels (Santos, 1971; Lima, 1979; Arai et al., 1995; Martins-Neto, 1996). Charophytes, conchostracans, chondrichthyans, other actinopterygians, coelacanthiforms, lizards and dinosaurs have been collected from other localities and levels of the Quiricó Formation (Carvalho and Maisey, 2008; Zaher et al., 2011; Bittencourt et al., 2015, 2018, 2020, 2018; Carvalho and Santucci, 2018; Fragoso et al., 2019).

The age of the Quiricó Formation is poorly constrained. The carbonatic-organic succession at the fossil locality represents the middle levels of that formation. Palynological surveys of the organic shales (Arai et al., 1995; Lima, 1979) support a Barremian age, which is partially in accordance with age indicated by ostracods recovered in distinct levels and localities of the Quiricó Formation (do Carmo et al.,

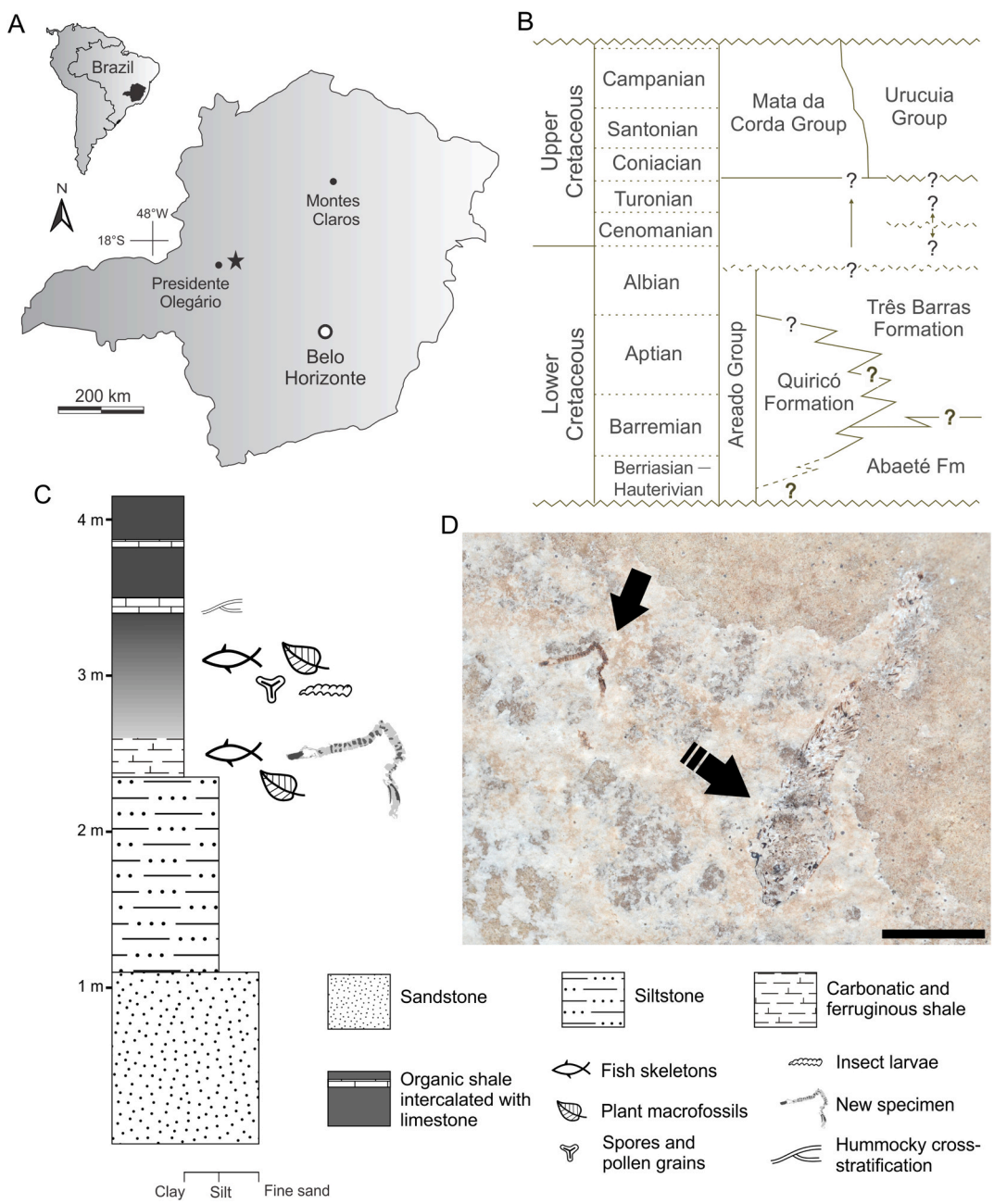

Fig. 1. A, Map of Minas Gerais State, showing the fossil locality (star). B, Partial lithostratigraphy of the Sanfranciscana Basin (modified from Campos and Dardenne, 1997), with its Cretaceous strata. C, Stratigraphic section of the fossil locality (fossil symbols from U.S. Geological Survey, 2006). D, Photograph of the fossil-bearing rock showing the new specimen (normal arrow), associated with a *Dastilbe* fish (dashed arrow). Scale bar: 5 mm.

2004; Leite et al., 2018). Older than Berremian age for its lower levels (Carvalho and Maisey, 2008; Machado et al., 2017; Leite et al., 2018) has been recently disputed (Coimbra, 2020) and is open to scrutiny. Uppermost levels are probably lower Aptian (Arai et al., 1995; Leite et al., 2018).

3. Material and methods

The material is a single specimen compressed onto the rock bedding. It is housed in the Instituto de Geociências, Federal University of Minas Gerais (IGC-P).

The mechanical preparation was performed with small needles and brushes, in order to expose body parts which were partially covered with sediment. A camera Leica DFC 295 coupled to a stereomicroscope Leica M205C was used for producing photographs of the uncoated material. Image processing was performed with the software Leica Application suite LAS v.3.8.

The scanning electron microscope (SEM) images were produced in a JEOL JSM-6510 equipment (after coating the specimen with carbon), using both secondary electrons (SE) and backscattered electrons (BSE) detectors. BSE improved the contrast between fossil and sedimentary matrix, due to differences in their chemical composition. This approach allowed tracing the exact location and shape of the organic remains. We used JEOL SEM Control User Interface v.3.1 for image processing. To improve visualization, enhanced contrast was applied with Adobe® Photoshop® to SEM images.

4. Systematic paleontology

Metazoa Haeckel (1874).
Protostomia Grobben (1908)
Cf. Annelida Lamarck (1802)
Gen. et sp. indet.

Description. The specimen (IGC-P 0388) is very small (total preserved length: 6.5 mm; average width: 0.30 mm), with a narrow ribbon-like shape (Fig. 2). Under SEM-BSE, the fossil appears as whitish tones highlighted from the greyish rock matrix (Figs. 2B and 3), indicating that body remnants have been partly preserved as organic matter. Darker spots on the segments (Fig. 2A) can be denser preserved tissue or ingested detritus within midgut. The body is roughly homonomous, with ca. 40 preserved segments. The body end where segments are narrower is here interpreted as posterior (Fig. 2), yet due to compressive and distortion effects on the body architecture, we cannot ascertain the actual orientation of the specimen.

Anteriorly, the rectangular black sector is distinct from other body parts by being thicker and not segmented (Figs. 2 and 3A). It is as long as three to four body segments and twice as long as wide. It also shows a decayed texture: 'rugose' aspect, with longitudinal and irregular slit lines (Fig. 3A). It is not compatible with the clitellum of oligochaetes or with the head and proboscis of polychaetes and some cycloneuralians. The lack of diagnostic features hinders the identification of this structure, and in fact, it may represent ingested detritus within the intestine other than any specific organ. The negative space between the black anterior area and the segments is result of damage and separation prior to fossilization. The flanks of those portions display rather elongated tissue remains (Figs. 2 and 3A), which are interpreted herein as damaged longitudinal muscle bundles of the body wall.

In most body parts, the segments are regular in size and shape, and can be distinguished from each other by intersegmental clefts. The space between the segments has evidence of tissue imprints. Those traits are considered herein as expression of true segmentation. The segments have annulated texture, i.e. external segmentation (Fig. 3B), with more than ten annuli over each body segment at the posterior portion of the body. The line that delimits each annuli 'bumps' towards the middle of the segment, suggesting a possible sulcus or fold.

In the right flank of segments 6–7, thin and short projection appears

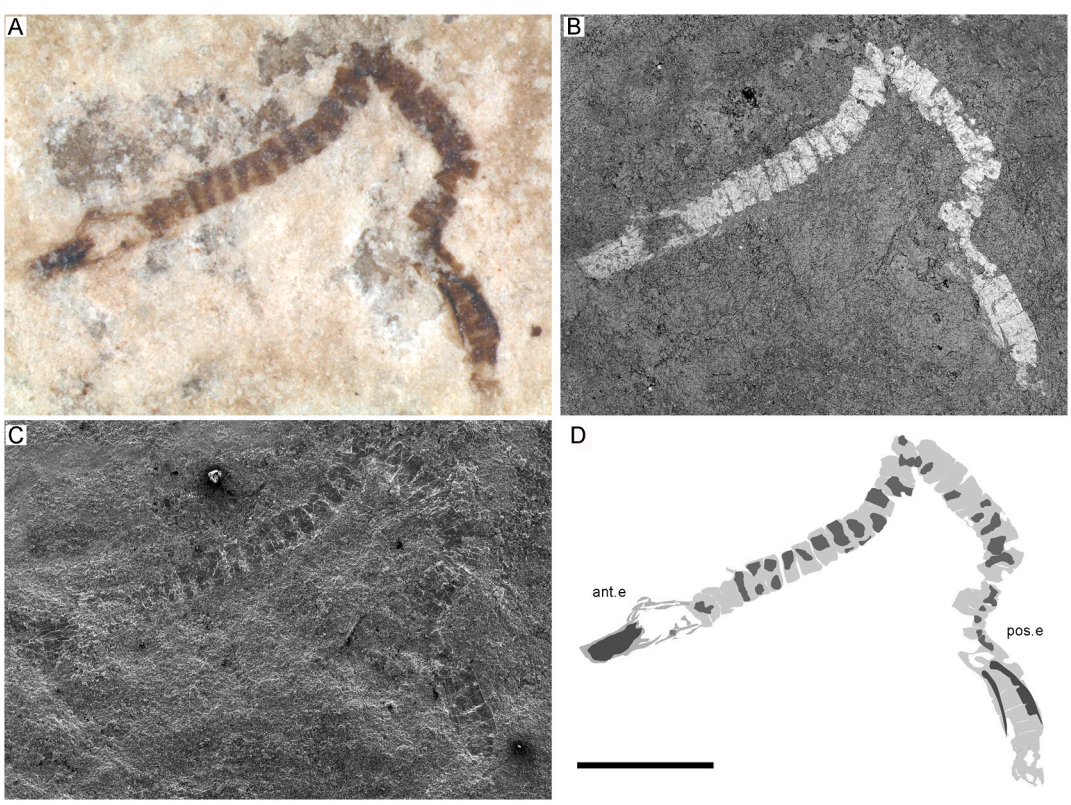

Fig. 2. IGC-P 0388. A, Photograph under stereomicroscope. B, Photograph under SEM-BSE. C, Photograph under SEM−SE. D, Drawing based on information gathered from stereomicroscope and SEM. Abbreviations: ant. e, anterior end; pos. e, posterior end. Scale bar = 1 mm.

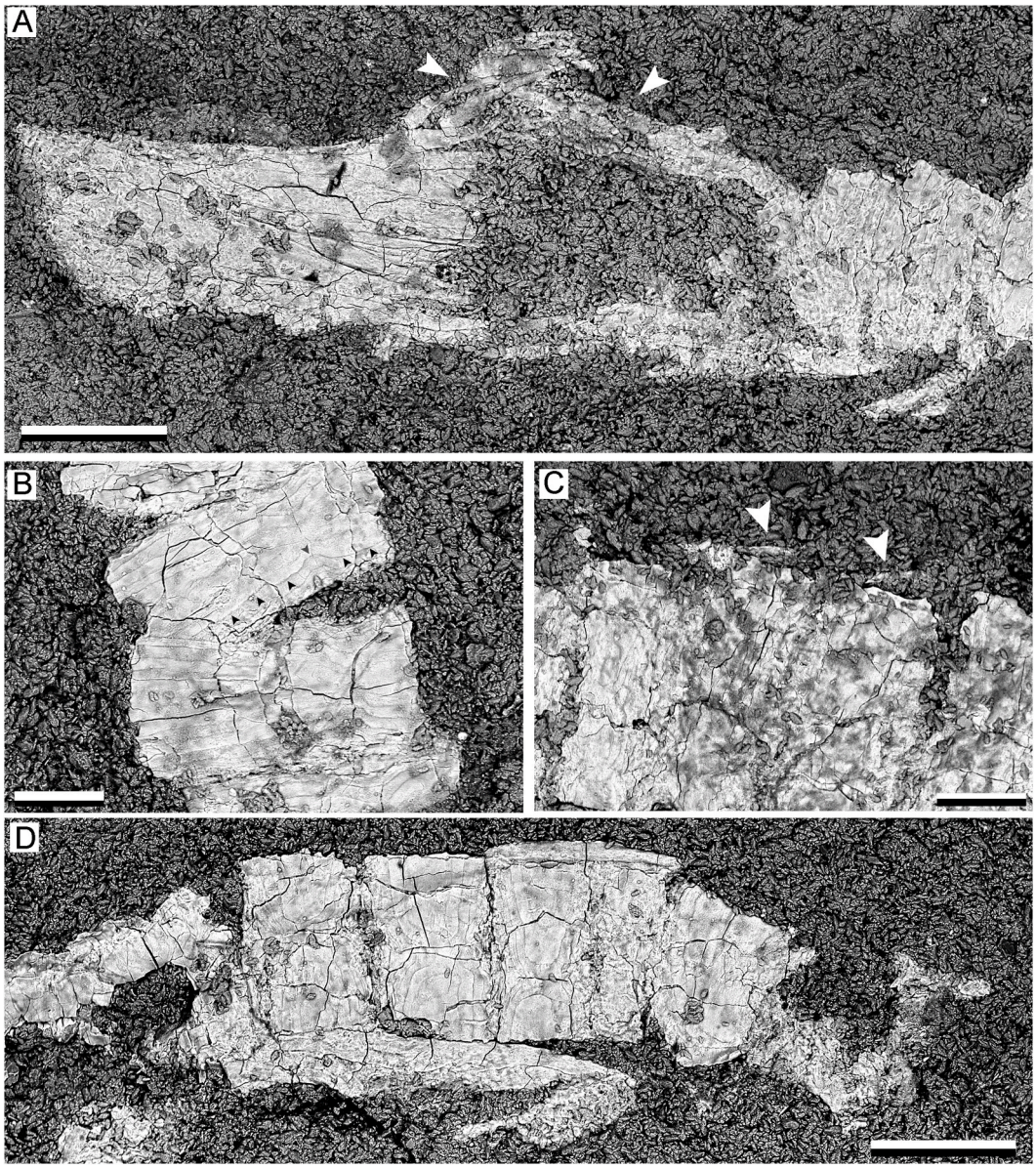

Fig. 3. IGC-P 0388 in SEM-BSE photographs with enhanced contrast. A, Damaged anterior end, showing the rectangular structure and ragged muscle bundles (arrows). B, Surface at segments 18–21, showing external segmentation (white arrows for one of them) with bump (reversed grey arrow). C, Protuberances on the segments 5 and 6 (arrows). D, Terminal portion of the body, depicting the spike-like structures. Scale bars: A, D = 200 μm; B, C = 100 μm.

as whitish tones under SEM-BSE (Fig. 3C) Those may represent appendages or chetae-supported gill remnants, as seen in extant aquatic oligochaetes adapted to low-oxygen environments as *Branchiodrilus* (Glasby et al., 2021). On the other hand, these are restricted to that sector and cannot be confirmed in other body parts.

A pair of large, dense, and recurved spike-like structures (ca 0.60 mm long) is conspicuous in the posterior portion of the body (Figs. 2 and 3D). The structures show evidence of being internal, not an appendage (segmentation is coincident with that of the body). The structures are different from polychaete posterior cirri or locomotor appendages (Glasby et al., 2000; Vinther et al., 2011), and from gill filaments of freshwater oligochaetes (Pinder and Ohtaka, 2004), and its identification remains elusive.

5. Discussion

The new specimen is provisionally referred to Annelida with basis on the general wormlike body architecture combined with both internal and external segmentation (Howell, 1962; Rouse and Fauchald, 1997; Verdonschot, 2015; Timm and Martin, 2015). This identification is also supported by the absence of key features of other segmented protostomes, which include arthropods and possibly onychophorans (Davis and Patel, 1999; Tautz, 2004; Franke and Mayer, 2014). Within arthropods, Myriapoda, branchiopod and branchiuran 'crustaceans' are the only groups with compatible number of body segments (Minelli and Golovatch, 2001; VanHook and Patel, 2008), given that hexapodans and chelicerates have fewer (<20) segments (Dunlop and Lamsdell, 2017; Clark et al., 2019). Yet, the main difference between the new fossil and the aforementioned groups is the absence of locomotory appendages. The lack of well-developed segmental appendages cannot be explained by taphonomic bias, because the specimen is preserved as compression of soft parts within low oxygen environment, and no justification envisages non preservation of similarly composed structures, as legs. Pentastomidans lack such locomotory appendages, but they differ from the specimen described herein in the body shape and presence of sucker mouth and hooks (Riley, 1986).

The presence of compressed remains as organic film, not only a rock imprint of the body, is more common within ecdysozoans due to chitinous cuticle, but annelid specimens can also be preserved in a similar fashion (Parry et al., 2015, 2018). Specimens referred to the eunicidan polychaete *Teruzzia pezzoli* Bracchi and Alessandrello (2005) from the Cenomanian of Lebanon, albeit larger than the specimen described here and deposited in a marine context, have a similar mode of preservation (Bracchi and Alessandrello, 2005).

Among annelids, Polychaeta bears parapodia, but they can be reduced in some meiofaunal groups (Fauchald, 1977), and Oligochaeta bears chaetae (Timm and Martin, 2015), which are hardly fossilized. Within clitellatans, IGC-P 0388 cannot be referred to hirundineans with basis on the body architecture and lack of typical characters seen in the group as suckers and conservative number segments (Verdonschot, 2015).

The environmental preferences of extant and extinct annelids are relevant to interpreting their fossil record. The majority, if not all, polychaete fossils have been recovered from marine or coastal deposits (Morris, 1979; Schram, 1979; Wills, 1993; Fitzhugh et al., 1997; Sutton et al., 2001; Bracchi and Alessandrello, 2005; Vinn and Mutvei, 2009; Briggs and Bartels, 2010; Ippolitov et al., 2014; Liu et al., 2015; Clements et al., 2019; Knaust and Desrochers, 2019). Unambiguous oligochaetes are terrestrial or freshwater dwellers (see review of Shcherbakov et al., 2020). Yet, extant polychaetes inhabit freshwater, albeit more rarely than marine environments (Glasby and Timm, 2008), thus fossil findings in lacustrine deposits are not entirely unexpected. The lacustrine environment of the Quiricó Formation favors the identification of the new specimen as an oligochaete, but the lack of diagnostic features hinders a definite assignment. In fact, comparing with Mesozoic oligochaetes, which include tubificids, naiadids and other poorly identified taxa (Dettmann et al., 1992; Manum et al., 1994; Timm et al., 2016; Hethke et al., 2019; Shcherbakov et al., 2020), the new specimen of the Sanfranciscana Basin shows only general morphological similarities and no taxonomic correspondence can be proposed.

The discovery of IGC-P 0388 has a regional relevance, because it is, to our knowledge, the first fossil annelid from Brazil based on soft tissue preservation, i.e. excluding ichnofossils, tubes or scolecodonts (Gobbo-Rodrigues et al., 2014), and the second from South America (Luque et al., 2015). Early Cretaceous records worldwide based on whole-body fossils include poorly preserved oligochaetes (Shcherbakov et al., 2020) and none polychaete, highlighting incompleteness in their fossil record.

Assuming that the new specimen is an aquatic annelid, which is also based on its size (Benbow, 2009), comparisons with extant freshwater annelids which live in lakes or temporarily flooded areas suggest it is a bottom-dwelling taxon (Suriani-Affonso et al., 2011; Gomes et al., 2017). In Quiricó Formation, the new specimen is a rare benthic component of the ecosystem delimited by its carbonatic-organic horizons. Albeit paleoecological inferences are limited, the presence of an ecologically active bottom zone hinted by the new specimen, couple with abundant fishes and aquatic plants, suggests a highly productive lake system.

6. Conclusions

We describe the first segmented wormlike specimen from the lacustrine strata of the Sanfranciscana Basin, referring it provisionally to annelids. A less inclusive classification is hampered by the lack of key features of annelid ingroups. The specimen described herein adds to a poorly known fossil record of annelids in the Cretaceous of Western Gondwana and suggest a productive ecosystem for the Quiricó lake system.

Author statement

Jonathas S. Bittencourt: Conceptualization, Resources, Funding acquisition, Methodology, Investigation, Writing- Reviewing. Natália C. A. Brandão: Investigation, Writing- Reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We are indebted to UFMG colleagues Maria Giovana Parisi, Alexandre Uhlein, Gabriel Uhlein, Alice Fonda, Guilherme Silveira and Adalberto Santos for their support. We also thank Tarmo Timm and two anonymous reviewers for their valuable suggestions. The SEM images were produced in CPMTC-IGC-UFMG. This research was funded by Fundação de Amparo à Pesquisa do Estado de Minas Gerais(FAPEMIG, grant to JSB).

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