

DINOTURBATION IN THE CRETACEOUS AREADO GROUP, SANFRANCISCANA BASIN (BRAZIL)

BERNARDO DE CAMPOS PIMENTA E MARQUES PEIXOTO 

Instituto de Geociências, Universidade Estadual de Campinas, Rua Carlos Gomes, 250, 13083-855, Cidade Universitária “Zeferino Vaz”, Campinas, SP, Brazil.
b.peixoto@protonmail.com (Corresponding author)

LUCIANO ALESSANDRETTI , CAIO CÉSAR RANGEL 

Laboratório de Paleontologia Estratigráfica, Instituto de Geografia, Geociências e Saúde Coletiva, Universidade Federal de Uberlândia, Campus Monte Carmelo, Av. XV de Novembro, 501, 38.500-000, Bairro Boa Vista, Monte Carmelo, MG, Brasil.
luciano.geors@gmail.com, caiocrangel@ufu.br

LUCAS WARREN 

Departamento de Geologia, Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista “Júlio de Mesquita Filho”, Avenida 24-A, Bela Vista, 178, 13506-900, Rio Claro, SP, Brazil.
lucas.warren@unesp.br

DANIEL SEDORKO 

Museu Nacional/UFRJ, Departamento de Geologia e Paleontologia, Campus de Pesquisa e Ensino, Av. Bartolomeu de Gusmão, 875, 20941-160, Bairro São Cristóvão, Rio de Janeiro, RJ, Brazil.
sedorko@mn.ufrj.br

ABSTRACT – Soft-sediment deformation structures (SSDS) can be produced by abiotic factors, invertebrate bioturbation, or trampling by large tetrapods. Differentiating between these origins is crucial for ichnological interpretation, particularly in stratigraphic units where body fossils are rare or bedding-plane exposures are limited. In this study, we describe new occurrences of SSDS interpreted as dinoturbations, cross-sectional tracks formed by heavy tetrapods, in the Três Barras Formation (Areado Group, Abaeté Sub-Basin, Sanfranciscana Basin), in Minas Gerais State, Brazil. These structures occur in fine- to medium-grained, cross-bedded sandstones, and preserve downward deformation, faulting, and local compaction. Their features, along with their stratigraphic position, support interpretation as tetrapod trampling traces, possibly produced by dinosaurs. These ichnological findings are significant within the context of the marine incursions into the Sanfranciscana Basin, as the dinoturbations indicate that, at the time of their formation, the environment was continental. This highlights the potential of ichnological data to refine paleoenvironmental reconstructions and to identify stratigraphic intervals in which the depositional system was predominantly continental during episodic marine incursions in intracratonic basins.

Keywords: soft-sediment deformation structures (SSDS), Três Barras Formation, tetrapod ichnology, continental, eolian.

INTRODUCTION

Deformation structures in soft sediments can result from abiogenic processes, invertebrate bioturbation, or trampling by large tetrapods (Christofoletti *et al.*, 2021). Differentiating among these agents has become an increasingly relevant topic in ichnology, as it provides a valuable tool for inferring the presence of tetrapod paleofauna, especially in stratigraphic units lacking body fossils or with limited bedding-plane exposures (Peixoto *et al.*, 2020, 2025). This is particularly relevant for the Três Barras Formation, which contrasts with the underlying Quiricó Formation known for its rich body fossil record (Amaral *et al.*, 2019; Bittencourt *et al.*, 2020; Zaher *et al.*, 2011, 2020; Fragoso *et al.*, 2021; de Carvalho & Santucci, 2021, 2024). Moreover, soft-sediment deformation structures (SSDS) attributed to tetrapod trampling can help

stratigraphically constrain intervals with higher potential for track preservation. This allows for more efficient prospecting for bedding-plane tracks, which often provide clearer insights into trackmaker identity. In cases where SSDS are large and occur in Middle to Late Mesozoic rocks, they are frequently referred to as “dinoturbations,” reflecting the dominant presence and size of dinosaurs during that time, making them the most probable producers (see Zaher *et al.*, 2011; de Carvalho & Santucci, 2018).

Here, we describe new occurrences of dinoturbations in the Early Cretaceous Três Barras Formation (Areado Group, Abaeté Sub-Basin, Sanfranciscana Basin), located in Minas Gerais State, Brazil. We interpret their triggering mechanisms and analyze their morphological characteristics to enhance the accuracy of their identification and interpretation in the sedimentary record. Finally, we discuss their significance in the context of the marine incursions that occurred in Sanfranciscana Basin at the time.



GEOLOGICAL SETTING

The Sanfranciscana Basin is located in central Brazil, spanning approximately 350,000 km² (Sgarbi *et al.*, 2001; Zalán and Romeiro-Silva, 2007) (Figure 1A). This basin consists of two primary sub-basins: Abaeté in the south and Urucuia in the north (Campos & Dardenne, 1997a; Sgarbi, 2000). The last bears an important Brazilian aquifer, the Urucuia Aquifer System (Gonçalves *et al.*, 2020). The basin's geological sequences from the Phanerozoic include a glaciogenic Carboniferous–Permian sequence (Santa Fé Group) and two Cretaceous groups (Areado and Urucuia/Mata da Corda) (Campos & Dardenne, 1997a, b; de Barros *et al.*, 2025). The Areado Group, part of the Lower Cretaceous, includes the Abaeté, Quiricó, and Três Barras formations, in ascending stratigraphic order (Campos & Dardenne, 1997a; Sgarbi, 2000; Mescolotti *et al.*, 2019).

This study examines the basal Três Barras Formation within the southern portion of the Abaeté sub-basin (Figure 1).

The underlying Quiricó Formation is composed of fine-grained siliciclastic rocks, such as shales and siltstones, with local interlayers of cross-bedded sandstones and very thin pseudomorphic salt deposits (Cardoso *et al.*, 2022, 2024). It is interpreted as formed in lacustrine and playa-lake settings (Campos & Dardenne, 1997a; Sgarbi *et al.*, 2001; Mescolotti, 2015; Simplicio *et al.*, 2016). The marine microfossils are in shale and chert (Kattah & Koutsoukos, 1992; Pessagno Junior & Dias-Brito, 1996; Dias-Brito *et al.*, 1999; Fauth *et al.*, 2024).

Overlying the Quiricó Formation, and interfingering with it, there is the Três Barras Formation, which consists of eolian sandstones with paleodunes and wet interdune facies, and subordinate fluvial deposits (Sgarbi, 1991; Campos & Dardenne, 1997a, b; Mescolotti *et al.*, 2019). This unit also contains records of structures of bioturbation, such as *Taenidium*, and the chert-bearing marine microfossils (Kattah & Koutsoukos, 1992; Pessagno Junior & Dias-Brito, 1996; Carvalho & Kattah, 1998; Dias-Brito *et al.*, 1999; Mescolotti *et al.*, 2019; Fauth *et al.*, 2024).

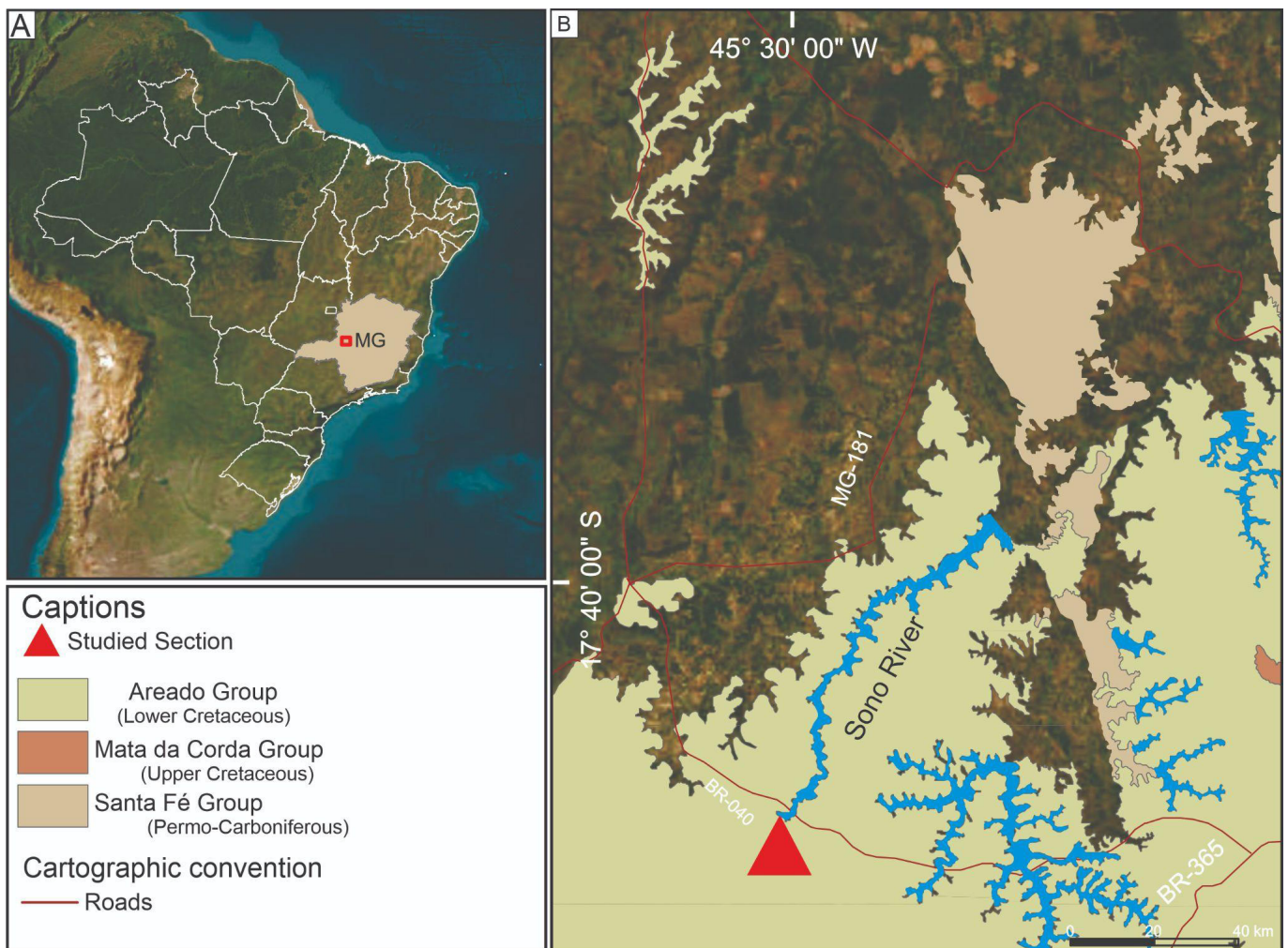


Figure 1. Localization of the area studied. **A**, studied locality within Brazil and Minas Gerais State (MG). **B**, geological map of area around the studied outcrop (-17.968494, -45.983100) near Rio do Sono bridge in João Pinheiro County. Modified from Cambria *et al.* (2025).

Concerning the age of the Areado Group, this should be from Barremian–Aptian based on the identification of *Globigerinelloides* (Dias-Brito *et al.*, 1999), with studies of radiolarians from chert microfacies of the Três Barras Formation indicating a Barremian age (Dias-Brito *et al.*, 1999). The Quiricó Formation has been proposed to range from Valanginian–Albian based on ostracods (Do Carmo *et al.*, 2004; Leite *et al.*, 2018), with more recent studies suggesting a narrow age range from Berriasian to possibly Albian (Leite *et al.*, 2024). However, there is an ongoing discussion about the taxonomical assignment of these ostracods (Coimbra, 2020; Leite & Do Carmo, 2021), which precludes a more precise age assignment. The SSDS described here are in the Rio do Sono outcrop (-17.968494 S, -45.983100 W) of Três Barras Formation, in the João Pinheiro County, Minas Gerais State, and probable molds of *Pattersonocypris* recovered from the heterolithic layers overlying the dinoturbations (Figure 2) allow correlation with the Alagoas Stage of Aptian age.

MATERIAL AND METHODS

The studied outcrop is located near the Rio do Sono bridge in João Pinheiro County, Minas Gerais State, Brazil (coordinates: -17.968494 S, -45.983100 W), and corresponds to exposures of the Três Barras Formation (Areado Group, Abaeté Sub-Basin, Sanfranciscana Basin) interfingering with the Quiricó Formation. Fieldwork focused on documenting soft-sediment deformation structures (SSDS) within fine- to medium-grained sandstones and adjacent heterolithic deposits. Sedimentological logging was conducted at the outcrop scale, with attention to lithofacies, sedimentary structures, bed geometry, and stratigraphic relationships, using traditional methods of facies analysis (*sensu* Walker, 1992), in which the genetically related lithofacies define facies associations corresponding to sub-environments in a depositional system. The lithofacies code follows Miall (1977).

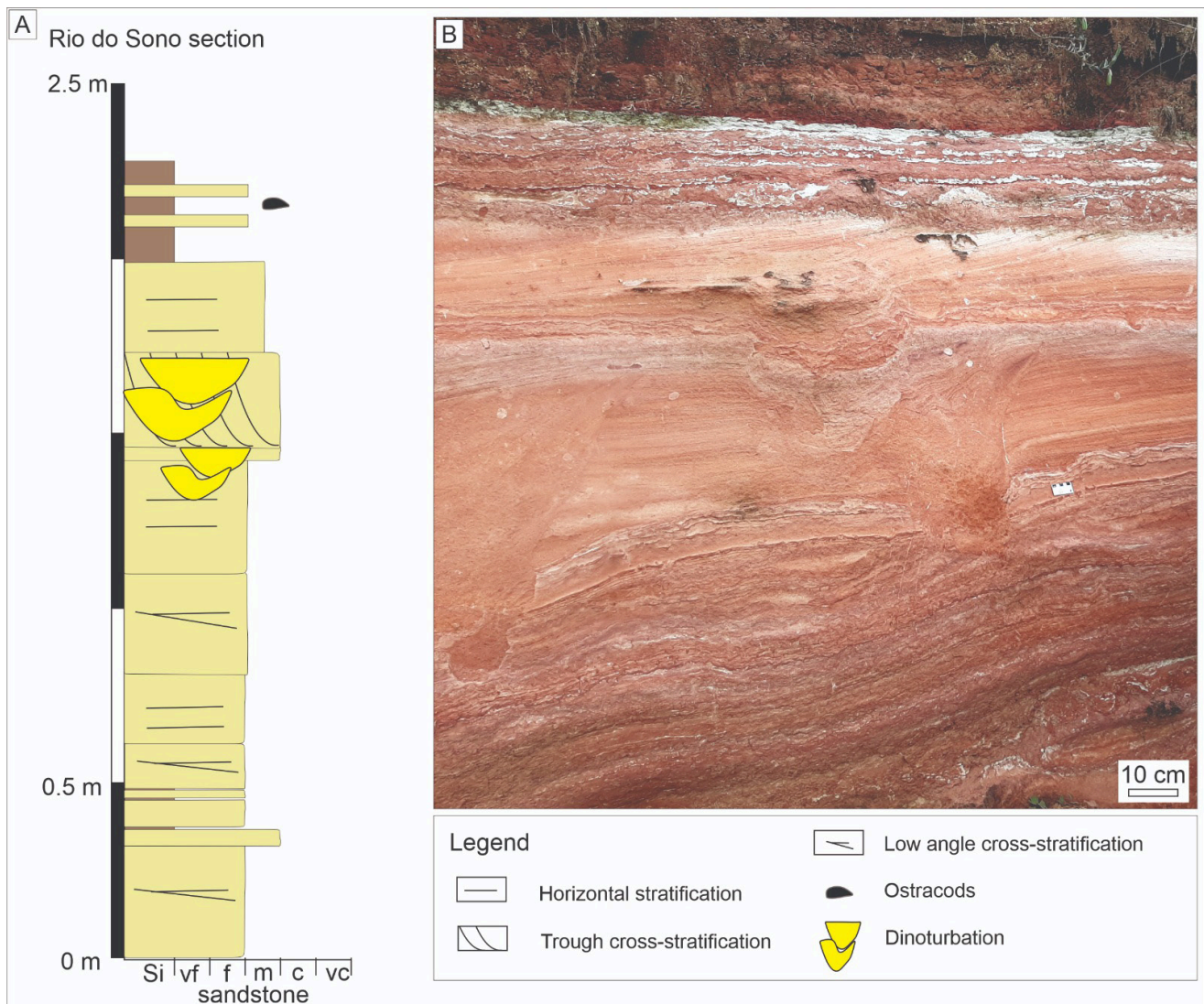


Figure 2. Stratigraphic log and position of the dinoturbation in the studied section. **A**, sedimentological log of the studied section at “Rio do Sono bridge”. **B**, detail of the dinoturbation in the St facies.

SSDS were mapped, measured, and photographed in situ, with their orientation, geometry, and deformation style carefully described. Structures were analyzed using ichnological criteria for cross-sectional tracks, based on diagnostic features proposed by Loope (1986), Melchor (2015), and Christofolletti *et al.* (2021). Specific attention was given to downward deformations, localized faulting, folding, and associated compaction features.

RESULTS

Stratigraphical section

The SSDS are in sandstone with trough cross-stratification (St facies), characterized as well sorted fine- to medium-grained sandstone (Figure 2), interpreted as the dune toe (Mountney, 2006).

Underlying the St facies there are beds with moderately sorted fine- to medium-grained sandstone with horizontal stratification (Sh facies), which also bear smaller SSDS (Figure 2). The outcrop also presents low-angle cross-stratified, fine- to medium-grained sandstone and heterolithic siltstone with thin lenses of very fine-grained sandstone (see detailed description of the outcrop in Cambria *et al.*, 2025), where some ostracods were recovered.

Soft-sediment deformations in Três Barras Formation

The structures (Figure 3A) are deformations of sedimentary layers downward, with a concave-upward general morphology, down-folding the underlying strata and producing normal faults (Figure 3B), all evidence of a descending force vector restricted to a small area, like the foot of the animal when stepping.

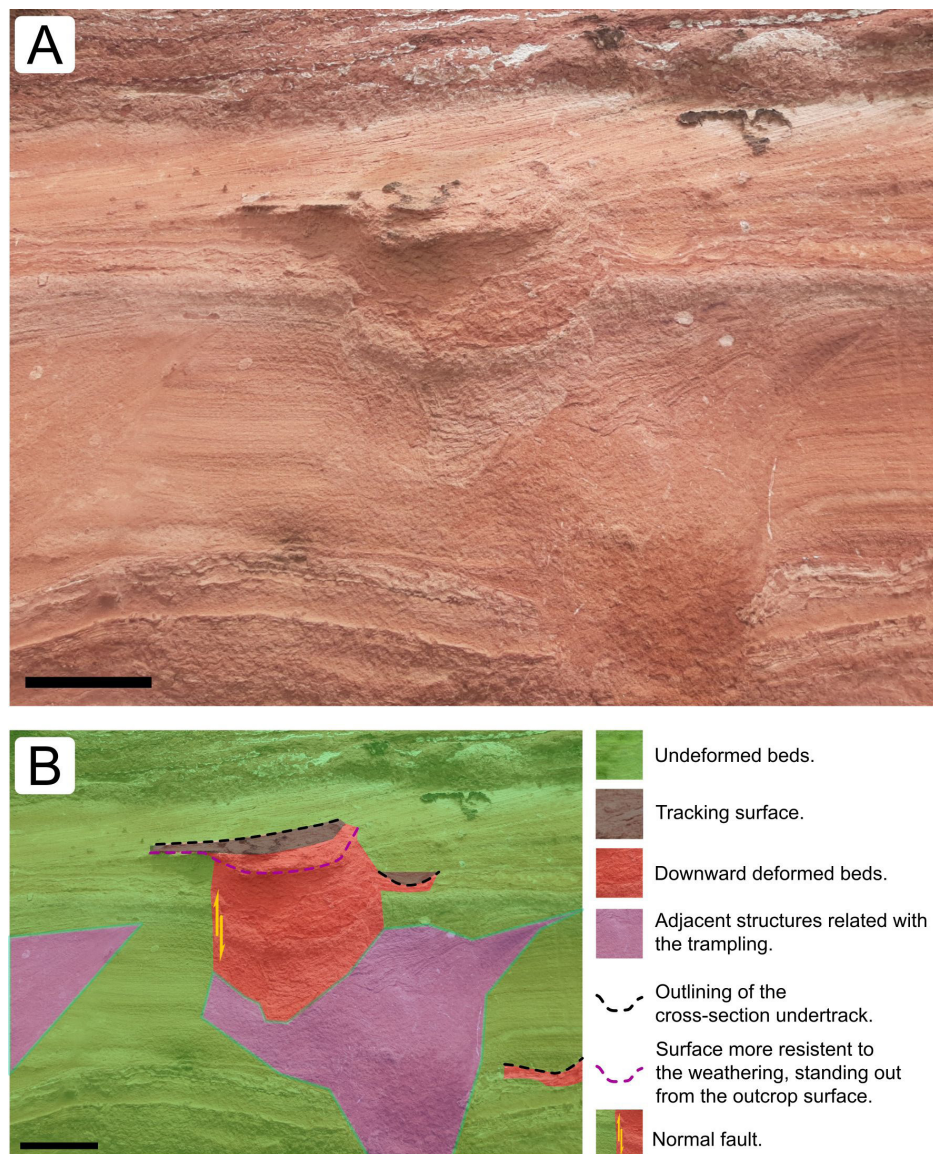


Figure 3. Cross-section tracks of heavy tetrapods in Três Barras Formation. **A**, general view of the cross-section tracks in the trough cross-stratification sandstone (St facies). **B**, indication of the sedimentary structures related to the production of the cross-section tracks. Areado Group, Sanfranciscana Basin, Minas Gerais State, Brazil. Scale bars = 20 cm.

The SSDS in the St facies also propagate to the underlying low-angle cross-stratified sandstone (Sh facies) because of the descending force. Sh facies also bears smaller SSDS (Figure 2). No casts are evident, so the feet that produced the deformations do not enter deep in the substrate, and the layers overlying the structures are plain upward. The uppermost portion of the largest deformation can be part of the plain view track (tracking surface). It seems that the differential compaction of the trampled sediment in this part, and the layers immediately below, make this more resistant to weathering, so the deformed section endures and stands out from the outcrop (Figure 3B), this can also have influenced the degree of cementation in these parts. There are other adjacent sedimentary structures (Figure 2B) related to the downward propagation of the deformation by trampling in the soft sediment and could be marginal parts of other cross-section tracks or deformations induced by them.

DISCUSSION

Soft-sediment deformation structures (SSDS) can be produced by abiogenic agents or biogenic agents like bioturbation by invertebrates or trampling by heavy tetrapods (Christofoletti *et al.*, 2021; Varejão *et al.*, 2022). Based on Christofoletti *et al.* (2021) and Melchor (2015), we interpret the SSDS reported there as produced by tetrapods, therefore, being cross-section tracks of animals trampling on the dune toe (St facies), and in interdune areas (Sh facies) (Cambria *et al.*, 2025). Other occurrences of similar structures were already reported in other outcrops of Três Barras Formation (Mescolotti *et al.*, 2019, fig. 8). There are similar examples of cross-section tracks in interdunes from other units (Christofoletti *et al.*, 2021; Dentzien-Dias *et al.*, 2007, fig. 5; Díaz-Martínez *et al.*, 2018, fig. 3G–J; Paz *et al.*, 2014, figs. 5B and 6A), in dunes (Francischini *et al.*, 2018, figs. 6C–D; Helm *et al.*, 2018; Hsieh *et al.*, 2023; Loope, 1986), and also examples in other continental depositional settings in Brazil (Carvalho *et al.*, 2021; Carvalho & Leonardi, 2021, fig. 10C–D; Varejão *et al.*, 2022).

It is not possible to identify the tetrapod group that produced these cross-section tracks as fine anatomical characteristics are not accessible in the described structures. Dinosaurs and Crocodyliformes are feasible producers since they were the largest tetrapods inhabiting the terrestrial realm during the Cretaceous (Sookias *et al.*, 2012; Turner & Nesbitt, 2013; Vermeij, 2016; Smith *et al.*, 2016; Godoy & Turner, 2020; Otero *et al.*, 2022; Jannel *et al.*, 2022; Dempsey *et al.*, 2025). In Brazil, they had high diversity and a broad range of body sizes (Bandeira *et al.*, 2018; Bittencourt and Langer, 2011; Langer *et al.*, 2022; Leonardi & Carvalho, 2021). Corroborating with dinosaurs as producers, there are records of dinosaur tracks in plain view in the Três Barras Formation (Carvalho & Kattah, 1998, 2024) and other body fossils in the Quiricó Formation (Navarro, 2019; Zaher *et al.*, 2011, 2020). However, it is not possible to rule out Crocodyliformes, at least as producers of the smaller SSDS, since there were large species in Brazil during the Cretaceous (Bandeira *et al.*, 2018, 2025; Godoy & Turner, 2020; Langer *et al.*, 2022).

The Lower Cretaceous deposits of the Sanfranciscana Basin are classical expressions of continental depositional settings, deposited by rivers, lakes, deltas, playa lakes, and eolian dune fields (Sgarbi & Dardenne, 1997; Zalán & Romeiro-Silva, 2007; Fragoso, 2011; Mescolotti *et al.*, 2019; Cardoso *et al.*, 2022), but fossil findings of marine organisms preserved in thin chert layers, including radiolarians, foraminifera, bivalves, sponge spicules, and dinoflagellate cysts (Kattah, 1991; Kattah & Koutsoukos, 1992; Pessagno Junior & Dias-Brito, 1996; Dias-Brito *et al.*, 1999; Fauth *et al.*, 2024), raised the idea that marine incursions were able to reach deep inside the craton, but without leaving a broad geological record in-line with its dimension. The evidence is concentrated in the chert layers interpreted as radiolarites and shale (Fauth *et al.*, 2024). Several hypotheses were raised to explain the marine fossil occurrences, from remobilization through hurricanes (Sgarbi, 2011); A large marine incursion coming from the Pacific (Pessagno Junior & Dias-Brito, 1996; Dias-Brito *et al.*, 1999), and more recently proposed, at least three episodic marine incursions facilitated by faults (Fauth *et al.*, 2024).

The fact that several marine incursions with such magnitude were able to occur without broad geological record is a phenomenon that needs to be studied since this raises the possibility that other marine incursions in the South America continent, and even elsewhere, took place without any elusive evidence. The dinoturbations reported here indicate that at the time of their production, the area represents a continental depositional setting.

CONCLUSIONS

The soft-sediment deformation structures (SSDS) reported here are interpreted as cross-section tracks produced by large tetrapods. It is not possible to identify the tetrapod group of the producer, but since the section is from the Early Cretaceous (Aptian), large dinosaurs are the most probable the tracemakers, having been the heaviest animals of the time on the continents, but Crocodyliformes remain an alternative tracemakers, at least for the smaller SSDS. The relevance of the rigorous study of such occurrences relies on the fact that there is evidence that marine incursions were able to reach deep inside the craton, flooding the Sanfranciscana Basin. In this context, and in an attempt to find ichnological signals of these marine incursions, the dinoturbation reported here indicates a continental setting at least at the moment of the production of the dinoturbation (within the Aptian).

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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AUTHOR CONTRIBUTIONS

Bernardo de Campos Pimenta e Marques Peixoto: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Original Draft, Visualization. Luciano Alessandretti, Caio César Rangel, Lucas Warren: Writing - Review and Editing, Visualization. Daniel Sedorko: Review and Editing, Visualization, Resources, Project administration, Funding acquisition.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

DECLARATION OF AI USE

We have not used AI-assisted technologies to create, review, or any part of this article.

ETHICS

This work did not require ethical approval, collecting licenses, or previous authorizations.

CONFLICT OF 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.

REFERENCES

- Amaral, C.R.L.; Machado, M.S.; Brito, P.M. & Pereira, E., 2019. The paleobiota of the Sanfranciscana Basin in the lower cretaceous and the paleodrainage of the São Francisco River. *Journal of South American Earth Sciences*, **96**:102360. doi:10.1016/j.jsames.2019.102360
- Bandeira, K.L.; Brum, A.S.; Pêgas, R.V.; Cidade, G.M.; Holgado, B.; Cidade, A. & de Souza, R. G. 2018. The Baurusuchidae vs Theropoda record in the Bauru Group (Upper Cretaceous, Brazil): a taphonomic perspective. *Journal of Iberian Geology*, **44**:25–54. doi:10.1007/s41513-018-0048-4
- Bandeira, K.L.N.; Navarro, B.A.; Pêgas, R.V.; Brilhante, N.S.; Brum, A.S.; de Souza, L.G.; da Silva, R.C. & Gallo, V. 2025. A reassessment of the historical fossil findings from Bahia State (Northeast Brazil) reveals a diversified dinosaur fauna in the Lower Cretaceous of South America. *Historical Biology*, **37**:548–589. doi:10.1080/08912963.2024.2318406
- Bittencourt, J.S. & Langer, M.C. 2011. Mesozoic dinosaurs from Brazil and their biogeographic implications. *Anais da Academia Brasileira de Ciências*, **83**:23–60. doi:10.1590/S0001-37652011000100003
- Bittencourt, J.S.; Simões, T.R.; Caldwell, M.W. & Langer, M.C. 2020. Discovery of the oldest South American fossil lizard illustrates the cosmopolitanism of early South American squamates. *Communications Biology*, **3**:201. doi:10.1038/s42003-020-0926-0
- Cambria, V.; Nascimento, D.L.; Alessandretti, L.; Rangel, C.C. & Sedorko, D. 2025. Paleoenvironmental controls on *Skolithos serratus*: a case study from the Lower Cretaceous of the Sanfranciscana Basin. *Boletim Paranaense de Geociências*, **83**:1–11. doi:10.5380/bpg.v83i1.100082
- Campos, J.E.G. & Dardenne, M.A. 1997a. Estratigrafia e sedimentação da Bacia Sanfranciscana: Uma revisão. *Revista Brasileira de Geociências*, **27**:269–282. doi:10.25249/0375-7536.1997269282
- Campos, J.E.G. & Dardenne, M.A. 1997b. Origem e evolução tectônica da Bacia Sanfranciscana. *Revista Brasileira de Geociências*, **27**:283–294. doi:10.25249/0375-7536.1997283294
- Cardoso, A.R., Basilici, G.; Silva, P.A.S. 2022. Early diagenetic calcite replacement of evaporites in playa lakes of the Quiricó Formation (Lower Cretaceous, SE Brazil). *Sedimentary Geology*, **438**:106212. doi:10.1016/j.sedgeo.2022.106212
- Cardoso A.R.; Basilici G. & Mesquita A.F. 2024. The Cretaceous palaeodesert of the Sanfranciscana Basin (SE Brazil): A key record to track dissolved evaporites in the West Gondwana. *Cretaceous Research*, **155**:10578. doi:10.1016/j.cretres.2023.105788
- Carvalho, I.S. & Kattah, S.S. 1998. As pegadas fósseis do paleodeserto da Bacia Sanfranciscana (Jurássico Superior-Cretáceo Inferior, Minas Gerais). *Anais da Academia Brasileira de Ciências*, **70**:53–67.
- Carvalho, I.S., & Kattah, S. 2024. The dinosaur footprints in the Cretaceous Aeolian Deposits of Sanfranciscana Basin. In: I.S. Carvalho & G. Leonardi (eds.) *Dinosaur tracks of Mesozoic Basins in Brazil: impact of paleoenvironmental and paleoclimatic changes*. Cham, Springer Nature Switzerland, p. 123–145. doi:10.1007/978-3-031-56355-3_5
- Carvalho, I.S. & Leonardi, G. 2021. Fossil footprints as biosedimentary structures for paleoenvironmental interpretation: examples from Gondwana. *Journal of South American Earth Sciences*, **106**:102936. doi:10.1016/j.jsames.2020.102936
- Carvalho, I.S.; Leonardi, G.; Rios-Netto, A.M.; Borghi, L.; Freitas, A.P.; Andrade, J.A. & Freitas, F.I. 2021. Dinosaur trampling from the Aptian of Araripe Basin, NE Brazil, as tools for paleoenvironmental interpretation. *Cretaceous Research*, **117**:104626. doi:10.1016/j.cretres.2020.104626
- Christofoletti, B.; Peixoto, B.C.P.M.; Warren, L.V.; Inglez, L.; Fernandes, M.A.; Alessandretti, L.; Perinotto, J.A.J., Simões, M.G. & Assine, M.L. 2021. Dinos among the dunes: Dinoturbation in the Pirambóia Formation (Paraná Basin), São Paulo State and comments on cross-section tracks. *Journal of South American Earth Sciences*, **109**:103252. doi:10.1016/j.jsames.2021.103252
- Coimbra, J.C. 2020. The genus *Cypridea* (Crustacea, Ostracoda) and the age of the Quiricó Formation, SE Brazil: a critical review. *Revista Brasileira de Paleontologia*, **23**:90–97. doi:10.4072/rbp.2020.2.02
- de Barros, G.E.B.; do Carmo, D.A.; Andrade, L.S.; Assine, M.L. & Sedorko, D. 2025. Expanding the ichnological record of the Late Paleozoic Ice Age: Evidence from the Santa Fé Group, São Francisco Basin (Brazil). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **680**:113337. doi:10.1016/j.palaeo.2025.113337
- de Carvalho, J.C. & Santucci, R.M. 2018. New dinosaur remains from the Quiricó Formation, Sanfranciscana Basin (Lower Cretaceous), Southwestern Brazil. *Cretaceous Research*, **85**:20–27. doi:10.1016/j.cretres.2017.12.017
- de Carvalho, J.C. & Santucci, R.M. 2021. New fish remains from the Quiricó Formation (lower cretaceous, Sanfranciscana Basin),

- Minas Gerais, Brazil. *Journal of South American Earth Sciences* **111**:103430. doi:10.1016/j.jsames.2021.103430
- de Carvalho, J.C. & Santucci, R.M. 2024. A new fossil squamata from Quirico Formation (lower cretaceous), Sanfranciscana Basin, Minas Gerais, Brazil. *Cretaceous Research*, **154**:105717. doi:10.1016/j.cretres.2023.105717
- Dempsey, M.; Cross, S.R.R.; Maidment, S.C.R.; Hutchinson, J.R. & Bates, K.T. 2025. New perspectives on body size and shape evolution in dinosaurs. *Biological Reviews*, **100**:1829–1860. doi:10.1111/brv.70026
- Dentzien-Dias, P.; Schultz, C.L.; Scherer, C.M.S. & Lavina, E.L. 2007. The trace fossil record from the Guar Formation (Upper Jurassic?), Southern Brazil. *Arquivos do Museu Nacional*, **65**:585–600.
- Dias-Brito, D., Pessagno Junior, E.A., & Castro, J.C. 1999. Novas consideraes cronoestratigrficas sobre o silexito a radiolrios do sul da bacia Sanfranciscana, Brasil, e a ocorrncia de foraminferos plantnicos nesses depsitos: In: SIMPSIO SOBRE O CRETCIO DO BRASIL, 5, 1999. Boletim, Rio Claro, UNESP, p. 567–575.
- Daz-Martnez, I.; Cnsole-Gonella, C.; de Valais, S. & Salgado, L. 2018. Vertebrate tracks from the Paso Crdoba fossiliferous site (Anacleto and Allen formations, Upper Cretaceous), Northern Patagonia, Argentina: Preservational, environmental and palaeobiological implications. *Cretaceous Research*, **83**:207–220. doi:10.1016/j.cretres.2017.07.008
- Do Carmo, D.A.; Tomassi, H.Z. & De Oliveira, S.B.S.G. 2004. Taxonomia e distribuio estratigrfica dos ostracodes da Formao Quiric, Grupo Areado (Cretceo inferior), Bacia Sanfranciscana, Brasil. *Revista Brasileira de Paleontologia*, **7**:139–149. doi:10.4072/rbp.2004.2.06
- Fauth, G.; Strohschoen, O.; Baecker-Fauth, S.; Luft-Souza, F.; Santos Filho, M.A.B.; Santos, A.; Bruno, M.D.R.; Mescolotti, P.; Krahl, G.; Arai, M.; Lima, F.H.O. & Assine, M.L. 2024. Multiple short-lived marine incursions into the interior of Southwest Gondwana during the Aptian, Marine *Micropaleontology*, **191**:102389. doi:10.1016/j.marmicro.2024.102389
- Fragoso, D.G.C. 2011. Geologia da regio de Presidente Olegrio e evoluo tectono-sedimentar do Grupo Areado, Eocretceo da Bacia Sanfranciscana, Minas Gerais. Universidade Federal de Minas Gerais, M.Sc. Thesis, 133 p.
- Fragoso, L.G.C.; Bittencourt, J.S.; Mateus, A.L.D.; Cozzuol, M.A. & Richter, M. 2021. Shark (Chondrichthyes) microremains from the Lower Cretaceous Quiric Formation, Sanfranciscana Basin, Southeast Brazil. *Historical Biology*, **33**:1308–1316. doi:10.1080/08912963.2019.1692830
- Francischini, H.; Sales, M.A.; Dentzien-Dias, P. & Schultz, C.L. 2018. The presence of ankylosaur tracks in the Guar Formation (Brazil) and remarks on the spatial and temporal distribution of Late Jurassic Dinosaurs. *Ichnos*, **25**:177–191. doi:10.1080/10420940.2017.1337573
- Godoy, P.L., & Turner, A.H. 2020. Body size evolution in crocodylians and their extinct relatives. In: *Encyclopedia of Life Sciences*. Hoboken, John Wiley & Sons. doi:10.1002/9780470015902.a0029089
- Gonalves, R.D.; Stollberg, R.; Weiss, H. & Chang, H.K. 2020. Using GRACE to quantify the depletion of terrestrial water storage in Northeastern Brazil: The Urucuia Aquifer System. *Science of the Total Environment*, **705**:135845. doi:10.1016/j.scitotenv.2019.135845
- Helm, C.W.; McCrea, R.T.; Lockley, M.G.; Cawthra, H.C.; Thesen, G.H. & Mwankunda, J.M. 2018. Late Pleistocene vertebrate trace fossils in the Goukamma Nature Reserve, Cape south coast, South Africa. *Paleontologia Africana*, **52**:89–101.
- Hsieh, S.; Ninard, K.; Uchman, A.; Łaska, W. & Łapcik, P. 2023. Mammal tracks record anthropogenic environmental influence in late-Holocene inland dunes of the European Sand Belt, Poland. *The Holocene*, **33**:61–80. doi:10.1177/09596836221126130
- Jannel, A.; Salisbury, S.W. & Panagiotopoulou, O. 2022. Softening the steps to gigantism in sauropod dinosaurs through the evolution of a pedal pad. *Science Advances*, **8**:eabm8280. doi:10.1126/sciadv.abm8280
- Kattah, S.S. 1991. *Anlise faciolgica e estratigrfica do Jurssico Superior/Cretceo Inferior na poro meridional da Bacia Sanfranciscana, Oeste de Minas Gerais*. Universidade Federal de Ouro Preto. M.Sc. Thesis, 227 p.
- Kattah, S.S. & Koutsoukos, E.A.M. 1992. A ocorrncia de radiolrios em fcies sedimentares de origem marinha no Mesozoico da Bacia Sanfranciscana. *Revista Escola de Minas*, **45**:214.
- Langer, M.C.; Delcourt, R.; Montefeltro, F.C.; Silva Junior, J.C.; Soler, M.G.; Ferreira, G.S.; Ruiz, J.V.; Barcelos, L.A.; Onary, S.; Marsola, J.C.A.; Castro, M.C.; Cidade, G.M. & Batezelli, A. 2022. The Bauru basin in So Paulo and its tetrapods. *Derbyana*, **43**:e776. doi:10.14295/derb.v43.776
- Leite, A.M.; Do Carmo, D.A.; Ress, C.B.; Pessoa, M.; Caixeta, G.M.; Denezine, M.; Adorno, R.R. & Antonietto, L.S. 2018. Taxonomy of limnic Ostracoda (Crustacea) from the Quiric Formation, Lower Cretaceous, So Francisco basin, Minas Gerais State, Southeast Brazil. *Journal of Paleontology*, **92**:661–680. doi:10.1017/jpa.2018.1
- Leite, A.M. & Do Carmo, D.A.D. 2021. Description of the stratotype section and proposal of hypostratotype section of the Lower Cretaceous Quiric formation, So Francisco Basin, Brazil. *Anais da Academia Brasileira de Cincias*, **93**:e20201296. doi:10.1590/0001-3765202120201296
- Leite, A.M.; Do Carmo, D.A.; Gonalves, L.R. & Xi, D. 2024. Biostratigraphy of Limnic Ostracoda (Crustacea) from the Quiric Formation, Lower Cretaceous of the So Francisco Basin, Minas Gerais State, Brazil: An approach on paleozoogeographic evolution of Gondwana. *Cretaceous Research*, **158**:105816. doi:10.1016/j.cretres.2023.105816
- Leonardi, G. & Carvalho, I.S. 2021. Review of the early Mammal *Brasilichnium* and *Brasilichnium*-like tracks from the Lower Cretaceous of South America. *Journal of South American Earth Sciences*, **106**:102940. doi:10.1016/j.jsames.2020.102940
- Loope, D.B. 1986. Recognizing and Utilizing Vertebrate Tracks in Cross Section: Cenozoic Hoofprints from Nebraska. *Palaaios*, **1**:141–151. doi:10.2307/3514507
- Melchor R.N. 2015. Application of vertebrate trace fossils to palaeoenvironmental analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **439**:79–96. doi:10.1016/j.palaeo.2015.03.028
- Mescolotti, P.C. 2015. Paleocorrentes e paleogeografia do Grupo Areado, cretceo inferior da Bacia Sanfranciscana. Universidade Estadual Paulista, M.Sc. Thesis, 60 p.
- Mescolotti, P.C.; Varejo, F.G.; Warren L.V.; Ladeira, F.S.B.; Gianinni, P.C.F. & Assine, M.L. 2019. The sedimentary record of wet and dry eolian systems in the Cretaceous of Southeast Brazil: stratigraphic and paleogeographic significance. *Brazilian Journal of Geology*, **49**:e20190057. doi:10.1590/2317-4889201920190057
- Miall, A.D. 1977. A review of the braided-river depositional environment. *Earth Sciences Review* **13**:1–62. doi:10.1016/0012-8252(77)90055-1
- Mountney, N.P. 2006. Eolian facies models. In: H.W. Postmaster & R.G. Walker (eds.) *Facies Models Revisited*. Society for Sedimentary Geology, p. 19–83.
- Navarro, B.A. 2019. Osteologia ps-craniana e relaes filogenticas do titanossauro do Cretceo Inferior Tapuiasaurus macedoi Zaher *et al.* 2011. Universidade de So Paulo, M.Sc. Thesis, 123 p.
- Otero, A., Carballido, J.L., & Pol, D., 2022. *South American Sauropodomorph Dinosaurs: Record, Diversity and Evolution*. Springer Earth System Sciences. Cham, Springer International Publishing. doi:10.1007/978-3-030-95959-3
- Paz, M.; Baez, A.D.; Pino, D.A.; Yunes, Y.S.; Garat, L.M.; Ponce, J.J. & Tunik, M.A. 2014. Anlisis sedimentolgico de depsitos lacustres y elicos del Cretceo Tardo en la localidad Paso Crdoba, Cuenca Neuquina. *Revista de la Asociacin Geolgica Argentina*, **71**:459–741
- Pessagno Junior, E.A., & Dias-Brito, D., 1996. O silexito a radiolrios ao sul da Bacia Sanfranciscana, Brasil. Idade, origem, significado. In: SIMPSIO SOBRE O CRETCIO DO BRASIL, 4, 1996. *Boletim*, guas de So Pedro, UNESP, p. 213–221.

- Peixoto, B.C.P.M.; Mángano, M.G.; Minter, N.J.; Reis Fernandes, L.B. & Fernandes, M.A. 2020. A new insect trackway from the Upper Jurassic–lower Cretaceous eolian sandstones of São Paulo State, Brazil: implications for reconstructing desert paleoecology. *PeerJ*, **8**:e8880. doi:10.7717/peerj.8880
- Peixoto, B.C.P.M.; Sedorko, D.; Barros, G.E.B.; Francischini, H.; Ghilardi, R.P. & Fernandes, M.A. 2025. Pulses of life: Wet events in Botucatu Paleodesert evidenced by trace fossils analysis (earliest Cretaceous, Paraná Basin, Brazil). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **658**:112608. doi:10.1016/j.palaeo.2024.112608
- Sgarbi, G.N.C. 1991. Arenitos eólicos da Formação Areado (Bacia do São Francisco): Caracterização, diagenese e aspectos químicos. *Revista Brasileira de Geociências*, **21**:342–354. doi:10.25249/0375-7536.1991324354
- Sgarbi, G.N.C. 2000. The Cretaceous Sanfranciscan basin, eastern plateau of Brazil. *Revista Brasileira de Geociências*, **30**:450–452. doi:10.25249/0375-7536.2000303450452
- Sgarbi, P.B.A. 2011. Magmatismo do Cretáceo na região sudoeste da Bacia Sanfranciscana: o Grupo Mata da Corda. In: A.C. Pedrosa-Soares, C.M. Noce, E. Voll, M. Kuchenbecker, H.L.S. Reis & D.G.C. Fragoso (eds.). *Projeto Alto Paranaíba*. Belo Horizonte, CODEMIG-UFMG, p. 56-64.
- Sgarbi, G.N.C. & Dardenne, M.A. 1997. Evolução climática do Gondwana nas regiões centro-sul do Brasil e seus registros geológicos continentais durante o Mesozoico, enfatizando o Arco do Alto Paranaíba, a Borda NNE da Bacia do Paraná e a porção meridional da Bacia Sanfranciscana, no oeste do estado de Minas Gerais. *Geonomos*, **4**:21–49.
- Sgarbi, G.N.C., Sgarbi, P.D.A., Campos, J.E.G., Dardenne, M.A., & Penha, U.C., 2001. Bacia Sanfranciscana: o registro fanerozoico da Bacia do São Francisco. In: C.P. Pinto, M.A. Martins-Neto (eds.) *Bacia do São Francisco: Geologia e Recursos Naturais*, Sociedade Brasileira de Geologia, p. 93–138.
- Simplicio, F.; Basilici, G.; Fernandes, L.R.M. & Sgarbi, G.N.C. 2016. Temporal evolution of playa lake: the sedimentary record of Quiricó and Três Barras Formation (Sanfranciscana Basin, southeastern Brazil). *Terrae*, **13**:3–13.
- Smith, F.A.; Payne, J.L.; Heim, N.A.; Balk, M.A.; Finnegan, S.; Kowalewski, M.; Lyons, S.K.; McClain, C.R.; McShea, D.W.; Novack-Gottshall, P.M.; Anich, P.S. & Wang, S.C. 2016. Body Size Evolution Across the Geozoic. *Annual Review of Earth and Planetary Sciences*, **44**:523–553. doi:10.1146/annurev-earth-060115-012147
- Sookias, R.B.; Benson, R.B.J. & Butler, R.J. 2012. Biology, not environment, drives major patterns in maximum tetrapod body size through time. *Biology Letters*, **8**:674–677. doi:10.1098/rsbl.2012.0060
- Turner, A.H., & Nesbitt, S.J. 2013. Body size evolution during the Triassic archosauriform radiation. *Geological Society Special Publications*, **379**:573–597. doi:10.1144/SP379.15
- Varejão, F.G.; Warren, L.V.; Simões, M.G.; Cerri, R.I.; Alessandretti, L.; Santos, M.G.M. & Assine, M.L. 2022. Evaluation of distinct soft-sediment deformation triggers in mixed carbonate-siliciclastic systems: Lessons from the Brazilian Pre-Salt analogue Crato Formation (Araripe Basin, NE Brazil). *Marine and Petroleum Geology*, **140**:105673. doi:10.1016/j.marpetgeo.2022.105673
- Vermeij, G.J. 2016. Gigantism and its implications for the history of life. *PLoS ONE*, **11**:e0146092. doi:10.1371/journal.pone.0146092
- Walker, R.G. 1992. Facies, facies models and modern stratigraphic concepts. In: R.G. Walker & N.P. James (eds.) *Facies Models: in Response to Sea Level Change*. St. John's, Newfoundland and Labrador, Geological Association of Canada, p. 1–14.
- Zaher, H.; Pol, D.; Carvalho, A.B.; Nascimento, P.M.; Riccomini, C.; Larson, P.; Juarez-Valieri, R.; Pires-Domingues, R.; Junior, N.J.S. & Campos, D.A. 2011. A Complete Skull of an Early Cretaceous Sauropod and the Evolution of Advanced Titanosaurians. *PLoS ONE*, **6**:e16663. doi:10.1371/journal.pone.0016663
- Zaher, H.; Pol, D.; Navarro, B.A.; Delcourt, R. & Carvalho, A.B. 2020. An Early Cretaceous theropod dinosaur from Brazil sheds light on the cranial evolution of the Abelisauridae. *Comptes Rendus Palevol*, **19**:101–115.
- Zalán, P.V. & Romeiro-Silva, P.C. 2007. Bacia do São Francisco. *Boletim de Geociências da Petrobras*, **15**:561–571.

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