

# Deciphering the origin of dubiofossils from the Pennsylvanian of the Paraná Basin, Brazil

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## Author's response

First and foremost, we would like to emphasize how interesting the open review process conducted by the journal has been. None of the authors had prior experience with this type of review, and we consider it highly beneficial to have received the valuable questions and suggestions from the referees. In response to the reviewers' comments, we have already made the necessary modifications to the manuscript. As such, many of the revised points below are part of the responses we provided to the reviewers. We are pleased to report that all the issues raised were accepted and significantly improved the contribution of this work.

Regarding the main concerns emphasized by all three reviewers, we focused primarily on revising the abstract, introduction and conclusion: 1) We clarified the reasons why the initial proposal of the material being a sponge skeleton was not sustainable and discussed the motivations that led us to treat the material as a dubiofossil from the outset. This approach allowed for a more comprehensive examination of its characteristics and facilitated a broader comparison with both abiotic and biotic materials. 2) We extensively modified the conclusion to explicitly state that our evidence and discussions have enabled us to suggest a complex history but prevent us from drawing a more robust conclusion regarding the origin of the material. As a result, it remains classified as a dubiofossil. We acknowledge that future investigations, particularly the application of other analytical techniques, may provide new insights in this regard. Nevertheless, we believe this contribution holds significant value in assisting similar research involving challenging material associations, particularly with the proposed descriptive and interpretative protocol derived from our comprehensive literature review.

As suggested by Reviewer 1, we endeavored to reduce the length of the introduction by eliminating paragraphs and making the sentences more concise and assertive. Nevertheless, we also incorporated other relevant points proposed by all three reviewers, which is why the introduction may not appear significantly shorter, but it has been enhanced and now holds important aspects for the rest of the article.

We want to emphasize the modifications made in the discussions section, where we included new hypotheses for the material, as suggested by the reviewers. These hypotheses were carefully examined in light of the evidence presented in the original manuscript. The reviewers' suggestions greatly enriched our discussion, expanding the proposals for the material.

However, despite these valuable contributions, robust evidence regarding the origin of the material remains elusive. This limitation somewhat influences the subsequent discussion about the diagenetic and metamorphic history, which significantly altered the material and prevents a narrower classification of the original product.

Below, we present the modifications made to the manuscript, indicated in the Author's track-changes file, the lines and pages quoted below in our comments refer to the archive of the resubmitted manuscript.. We have used section divisions in the article to facilitate the editors' review process. Likewise, we have color-coded the questions/suggestions from the reviewers, using dark green for Reviewer 1 (R1), indigo blue for Reviewer 2 (R2), and light green for Reviewer 3 (R3). Modifications suggested as "Remarks from the preceding review file validation" are highlighted in yellow and have been duly addressed. Additionally, any changes made by the authors are indicated in gray.

### **Abstract.**

**Line 13: The meaning of the threshold between abiotic and biotic minerals sounds vague without some examples. I suggest drawing attention to at least one example of a mineral dubiofossil and the implication of its interpretation:**

We rewrite the sentence to exclude the vagueness of the “threshold between abiotic and biotic”, replacing by: “Mineral dubiofossils, being potential outcomes of both abiotic and biotic environments, emerge as valuable entities that can contribute significantly to the understanding of this issue, facilitating the testing and refinement of biogenicity criteria.” (line 13-15)

**Lines 13-14: Although this manuscript may contribute to the investigation of general mineral dubiofossils described in the literature, I suggest to include the geological unit and age, following the sentence “The aim of this contribution is to decipher the origin and history of branched mineralized structures that were previously considered mineral dubiofossils.” In this way, the text makes it clear that the aim of this manuscript is to understand the taphonomic patchways in this specific case (Rio do Sul Formation, Pennsylvanian of the Paraná Basin).**

As recommended, at line 15, we added the age and unit to specify our object as: “mineral dubiofossils from Pennsylvanian of the Paraná Basin, Brazil”.

**l.15 Fossil Group does not need to be capitalized**

as suggested by R1 the sentence “fossil group” at line 16 was corrected

**Lines 14-15: Although it may be hard to attribute the dubiofossils reported here with any known biological affinity, I believe that the authors should compare these structures with possible fossil groups, even if it is to rule out the hypothesis. In this case, I suggest briefly mentioning what are the possibilities here, including what features could be interpreted as belonging to any fossil group and why these possibilities are ruled out.**

As suggested by R3 at lines 19-21, we have emphasized the previous proposals biotic and abiotic for the dubiofossils as: “Given the absence of attributes essential for supporting the initial hypotheses proposing the material as a potential set of sponge spicules or a result of contact metamorphism in Pennsylvanian turbidites, the objects are now investigated as mineral dubiofossils” and arguing below (lines 31-33) why it cannot be one of these hypotheses. “The comparative analysis did

allow us to exclude the possibility of the samples being controlled biominerals due to their patternless diversity of morphologies, as well as purely thermometamorphic in origin due to their branched elongated forms.”

Lines 100-101: I suggest including this protocol proposal in the abstract.

The suggestion to put the protocol in the abstract was accepted, as show (lines 21-23): “To address this challenge, we have developed a descriptive protocol for dubiofossils, building upon prior research in the field. This protocol evaluates the following aspects: 1) morphology, texture, and structure; 2) relationship with the matrix; 3) composition; and 4) context. By assessing indigeneity, syngenicity, and comparing the specimens with abiotic and biotic products.”.

Lines 19-22: This sentence is too long and confusing. I m not sure if I got the author's point. If I did, I suggest: "An extensive comparison with abiotic minerals and controlled, induced, and influenced biominerals excluded the possibility of the samples investigated here being a controlled biomineral, due to its patternless diversity of forms and the purely thermometamorphic origin due to the branched elongated form.”

We accepted the suggestion, at lines 27-33 the improved the sentence as: “Extensive comparisons were made between the studied samples and a broad spectrum of abiotic minerals, as well as controlled, induced, and influenced biominerals from similar contexts. These comparative analyses encompassed sponge spicules, sea urchin and algae skeletons, minerals induced or influenced by fungi, bacteria, and microbial mats, as well as inorganic pre- and synsedimentary/eodiagenetic minerals like evaporites, springs, and other precipitates, and mesodiagenetic/metamorphic crystals. Despite this comprehensive analysis, no hypothesis emerged as significantly more likely than others.”.

Lines 24-25: “Mesodiagenesis could have also modified the occurrence ...”. Ok. May the authors explain, in a few words, how these modifications could have occurred during mesodiagenesis?

We added the processes of modification of the dubiofossils during the mesodiagenesis to complete the phrase at lines 37-38, as follow: “Mesodiagenesis could have further modified the occurrence through processes such as mineral stabilization, agglutination, aging, and growth”.

Lines 45-46: What is the conclusion of this manuscript? Are the dubiofossils now interpreted as pseudofossils? Or do they still fit in the “dubiofossils” category? Please, clarify it.

The suggestion was accepted and we emphasized at the abstract what is our conclusion, indicating at lines 41-43 as: “corroborate the origin of the material becomes even more challenging. Consequently, both the hypotheses pertaining to the formation of biotic and abiotic sulfates and carbonates remain plausible explanations, hence sustaining the classification of the material as a dubiofossil.”. That our material remain as dubiofossil.

Line 29: Please, include “a” before “result”

We changed the sentence at line 44 for “dubiofossils can be a result of a complex history”.

## 1 Introduction

l.38 what does this mean? “Ascertaining the biological origin and establishing solid evidence for biogenicity is preponderant”

The sentence " “Ascertaining the biological origin and establishing solid evidence for biogenicity is preponderant” was changed to “Acquiring substantial evidence to establish biogenicity is crucial not only for determining the biological origin but also for comprehending the intricate biosphere-lithosphere interface” which makes the sentence clearer, line 53.

Lines 41-45: The relation of these sentences is confusing. The dot between them suggests that new information it's coming. However, the second sentence appears to be a continuation (without any link) of the first sentence. Please, clarify it.

We reformulated the second paragraph of the introduction (lines 56-61) in order to clarify the sentences and link the information, as follows: “Thus, in addition to the conventional perspective that organisms are delimited and conditioned to the environment, there is growing evidence of the significant influence of life on natural processes and events (Knoll, 2013; Davies et al., 2020). As a result, it has become increasingly challenging to recognize large-scale physical and chemical cycles on Earth that are unaffected by biosphere activity (Gargaud et al., 2015). Furthermore, accurately measuring the impact of organisms, which are ubiquitous, on erosion, sedimentation, diagenesis, and mineralization has also become a complex task”.

The editors requested the references of the images (circles) in Figure 1.

We opted to replace the images by IA creator in order to reduce the long caption, we use the open AI Bing Image Creator to create the new images. We also make little changes in the caption to clarify the explanation. Please, see page 3.

Lines 55-58: This “narrow threshold between biotic and abiotic environments” is still vague. Could the authors explain better what they understand as a narrow threshold? Could it be information obtained from compositional signals? Crystallographic characters, in the case of biominerals? Are the authors referring to possible changes during superimposition of diagenetic processes during geologic history? What changes and what are the possible implications for the investigation of biominerals? Please, clarify it.

The introductory paragraph (lines 65-73) raises questions regarding the challenging task of identifying biosignatures within the geological record, given the complex overlap of natural cycles, whether biotic or abiotic. The relevance of biominerals to the issue is addressed later in the introduction (after line 91). Even so, as highlighted the sentence “narrow threshold between biotic and abiotic environments” is vague and has been withdrawn, the paragraph has been rephrased to better align with your expectations. The revised text is presented as follows: “These biological and geological processes are integral to the Earth system's natural cycles, exhibiting repetition and overlap across multiple scales (Zhang et al., 2017). The Earth's crust and surface are host to a dynamic interaction of physical, chemical, and biological reactions that shape the geological record (Jacobson et al., 2000; Worden and Burley, 2009; Zhang et al., 2017). Consequently, any geological object, whether abiotic or biotic, must be understood in terms of its formation and original conditions, as well as the subsequent processes that

contribute to its maintenance, modification, or destruction. Due to the complex interplay of these processes and the ongoing changes throughout geological history, it becomes essential to discern specific life signatures”.

Line 58-59: “As they are on the threshold of knowledge between abiotic and biotic, dubiofossils, fossil-like structures formerly related to life with an ambiguous origin (Hofmann, 1972), hold promising potential for enhancing biosignatures.” – Actually, the dubiofossils hold the potential to be or not to be considered a biosignature, once its biogenicity is proven or not. I suggest rephrasing this sentence.

The paragraph between lines 74-78 has been reworded to clarify the explanation of the importance of dubiofossils as shown: “Dubiofossils, fossil like structures formely related to life with and ambiguous origin (Hofmann, 1972), play a crucial role in enhance biosignatures. Through testing and refinement, the biological nature of a dubiofossil can be established, leading to its classification as a genuine fossil; alternatively, if its origin is determined to be the result of abiotic processes, it is categorized as a pseudofossil (Hofmann, 1972; Monroe and Dietrich, 1990; McMahan et al., 2021). Once the biological origin is confirmed, these dubiofossils can be regarded as potential biosignatures or contain distinctive characteristics indicative of past life (McMahan et al., 2021).”

Line 64: Is the biogenecity criteria really an emerging area of science? This has been an extensively debated topic since (at least) Buick (1984). Reference: Carbonaceous filaments from North Pole, Western Australia: Are they fossil bacteria in Archean stromatolites?

We agree that the debates on biogenicity criteria are not recent dating back to the works of Buick and Hoffman and others cited in the text, in paragraph line 64, the term "emerging" was used to emphasize the expansion in the amount of papers published in the last two decades. To avoid misinterpretation, we agree with the reviewer and replace the sentence on line 89 with: “As an area of science that has received significant attention and prominence in recent years, ...”

Line 72: I suggest to change “can be essential for refining...” for “are essential for refining ...”

In Line 72 we change the sentence according to the recommendation, as follows: “are essential for refining ...”.

Also the introduction is more long-winded than necessary (10% reduction would not hurt), and does not address the difference between biologically induced and organic matrix mediated biotic structures. Biologically induced seems more plausible, but the idea that these are actually biological structures seems to be what the text implies. This is explained later on, but be sure to clarify this distinction from the outset.

the R1 argued that the intro was too long. For that, we decided to eliminate the paragraph reviewing the type of artifacts and its biogenicity criteria (around line 110), because it was only a review and does not change our introduction.

The introduction was reduced as recommended, including the differentiation of induced and influenced biominerals as suggested. Now in lines 96-103 is included the sentences: "Essentially, controlled biominerals are minerals that are directly produced and regulated by living organisms that exercise a high level of control over their formation and composition. Induced biominerals are indirectly formed by living organisms, these play an active role in triggering or influencing their formation, producing certain organic compounds or creating specific environmental conditions. Often an indirect result of the metabolic action. In influenced biominerals, there is a passive role in mineral formation or modification caused by the

presence of living or dead organisms (see Dupraz et al. 2009 for a broader review), by exclusion abiotic minerals are the result of physical-chemical reactions, without any biological interference.”

Line 81 to 86: I believe it is important to emphasize here also the limitations in separating minerals purely products of inorganic (abiotic) processes from a wide range of biologically induced minerals. This difficulty is recognized in the literature, since this category of biominerals does not present intrinsic characteristics (such as crystallographic properties) different from biotic ones. This is one of the main challenges inherent to this issue of mineral biogenicity.

To complement the introduction, emphasizing the difficulty of differentiating abiotic minerals from biotic ones as indicated in lines 103 to 104, we chose to include the sentence below, which we hope resolves the issue: “In practice, it is challenging to differentiate each of these products in the geological record due to the lack of diagnostic characteristics, such as specific shapes or crystallographic properties and compositional signatures that resist modifications over time (see Weiner and Dove, 2003; Dupraz et al., 2009).”

Practical issue: in order to better present the problem to the readers, I recommend to increase the reasons of why the presented structures are considered dubiofossils in the Introduction; in the line 94 it is saying that they were previously interpreted as sponge spicules. Is there some reference for this? Why? It's because of the morphology, paleoenvironmental context? I suggest to explore more and encourage readers to start questioning right here.

As suggested, we added a paragraph to explain the first association with sponge spicules and why the needles cannot be sponge. And it is positioned at the end of the penultimate paragraph (110-116) as follows: “This material was previously proposed as sponge spicules from the Paraná Basin (Mouro and Saldanha, 2022), since some formats resemble spicules, the distribution of structures could delimit circular and ellipsoidal features such as flattened bodies, in moreover, close to the outcrop, an earlier stratigraphic unit of similar context contains well-preserved fossil sponges in abundance (see Mouro and Saldanha, 2022). However, the diversity of formats and the absence of specular net prevented the classification of this material as porifera, remaining as a mineral dubiofossil.”

Lines 95-96: This information was already mentioned in lines 66-67. I suggest removing this sentence (from here, or from lines 66-67) to avoid repetition of information.

We decided to remove the repeated text from the last paragraph of the introduction as recommended (lines 95-96), replacing it with: “these elongated tubes will be examined across the four classes of biogenicity criteria, (1 to 4) explained above”.

Line 101-103: “Suspendisse a elit ut leo pharetra cursus sed quis diam. Nullam dapibus, ante vitae congue egestas, sem ex semper orci, vel sodales sapien nibh sed lectus. Etiam vehicula lectus quis orci ultricies dapibus. In sit amet lorem egestas, pretium sem sed, tempus lorem.” Is there a purpose for this sentence or was it a mistake?

The erroneous excerpt at the end of the introduction is automatic Latin text coming from the journal's template, the excerpt has now been removed completely.

Line 97-99: “We endeavor to unravel the intricate history of unique mineral occurrence, which has been shaped by the overlapping effects of geologic processes and the omnipresence of life.”. But in the end (in the conclusions) this not happen. I suggest rewrite here.

We understood R2 recommendation and decided to delete the last part of the sentence in lines 120-121, in fact the discussion of the ubiquitous presence of life was less explored in our results and therefore we chose to leave the sentence as below: “We endeavor to unravel the intricate history of unique mineral occurrence, which has been shaped by the overlapping effects of abiotic and biotic geologic processes.”.

## 1.1 Geological settings

Figure 2: There are some dark grey colored areas in this figure, it is quite difficult to read what is inside. I suggest to increase the contrast of the background colors and the letters inside the figure.

The editors asked about the references of the maps in figure 2.

At the Figure 2 (page 6) we improved the contrast and put a white buffer around the captions, thank you to improve the visualization of this image. We also modified the caption putting the respective references for each map.

Lines 123-125: I suggest including the last sentence of this topic (“The detailed outcrop description with sedimentary structures and biotic elements is presented at the Sect. 3.1.4”), following this sentence. Additionally, could it be possible to include the position where the dubiofossils occur in Figure 8?

We change the placement of the last sentence of Geological settings, including it just after the sentence, lines 145-146, in the middle of the paragraph. We emphasize that the position of the dubiofossils in Figure 8 is indicated in the lateral geological section of Figure 8A (page 20), marked by the circular icon that indicates our material and a box with its vertical coverage area close to the contact with the sill.

## 2 Materials and methods

Line 144: I do not think that the information about the ichnofossil occurrence fits in this topic.

We agreed that the information on trace fossils was isolated in the materials and methods paragraph, and we decided to include it in the text as follows: “(5) indigeneity and syngenicity, we used field-collected data, including some ichnofossils, which were also collected and observed under a stereomicroscope in the laboratory.” (lines 165-164 )

Line 147: How many morphologies were described? Additionally, here is an appropriate place to include the number collection of these thin sections.

Line 147: Does this sample have a number collection? Same question for lines 157, 161 and 168.

We rewrite the sentence of different morphologies as follows: “The morphologies were described, and length, width, and relative angles of the branches were measured.” (line 170)

As for the collection numbers, the samples are included in the collection of the Laboratory of Paleontology at UFSC as indicated, their collection number was included as follows: "under the numbers: UFSCLP 395-418, 877-971, 993-1029 totaling 153 samples, the other 100 samples are not included in the collection to avoid redundancy. UFSCLP numbers 1023a and b, 1024-1029 have petrographic slides, stored in the same collection under the number of the respective hand sample."

(lines 170-174) the following topics explain which samples went through the other analyses, some of which were destroyed for Micro CT and XRD.

**Additional details** of the descriptive methods and statistical analyses were added by the authors to improve the methodology. Explained as follows: “through photos using Corel Draw software.” (lines 169-170); “Additional statistical analyzes, as mean, median and histograms, were performed using Excel tools” (line 171) and “, and 0.7  $\mu\text{m}$  maximum spatial resolution resulting in optical magnification 3.982500, and pixel size 4.519758. Treated in FIJI open software (<https://imagej.net/software/fiji/>), using simple processing, adjusting brightness, contrast, intensity, stacking 2d slices and the volume viewer tool.” (line 180-182); and “For the mineralogical XRD analysis, one siltstone slab (not storage in the collection), containing at the same level a portion with distributed elongated material and the other only with matrix, was prepared through mechanical scraping of surfaces containing matrix and needles and only matrix.” In lines 189-191.

**Line 168: “One horizontal thin-section...”. Remove “horizontal”.**

At line 197: the word “horizontal” has been removed.

### 3 Results and discussion

#### 3.1 Description

**l.184 et seq. “sticks” is not the right word here. These appear to be acicular crystals, so “needles” would also work..**

**In all discussion text: maybe replace “sticks” by needles, or acicular structures.**

The term stick or stick-shape (at l.184 and seq) was chosen due to the length-width ratio not being so intense, even varying between the morphotypes described, in addition to the fact that sometimes the thickness is not fixed along the specimen or does not have tapered ends that would characterize a needle -shape sensu stricto. The use of the term stick in the article by Baucon et al. (2020) cited and compared with the samples also contributed to this choice. However, reviewing the definitions in crystallography, many times both terms are used as synonyms, therefore, whenever possible, it was chosen to use the terms needle and needle-shape as suggested. Several changes in the manuscript.

**Line 180: What does simple and complex mean in this case? What characters define the geometry as simple or complex?**

**Lines 187-189: I suggest to include the approximated total number of specimens per category (at least the measured specimens). Do all categories occur at the same stratigraphic level?**

As the description of the various morphologies comes right after the sentence on line 208, we chose to exclude the phrase “Thus, geometry ranges from simple to complex.” and we hope that Thank you for suggesting the inclusion of sample amounts by classes, we have inserted a visual estimate just after the general description of the samples (lines 217-219), as follows: "Of the nearly 250 samples, by visual estimation, approximately 40% belong to class A, 35% to class B, 15% to class C and 10% to class D."

**Figure 3: Replace the second “C” by “D”. Include “yellow” before “curved contours”. Additionally, It is hard to visualize ramifications in B, F and H. Maybe an arrow could help.**



Figure 4: It is hard to visualize ramifications in C-G. Maybe an arrow could help.

For the Figure 3, we change the letter C to D and included the “yellow curved contours” in the caption. We also added more arrows in the plate of Figure 3 and 4 to help to visualize the ramifications. Pages 9 and 11.

L201 Punctually? Wrong word.

The word “Punctually” was changed to “Rarely”, line 230.

Lines 187-189: I suggest to include the approximated total number of specimens per category (at least the measured specimens). Do all categories occur at the same stratigraphic level?

As for the issue of samples and morphologies coming from the same stratigraphic level, we have included a new section once this characteristic of the samples was not explicit. We hope that it is now clear and fulfills your expectations. This new paragraph was inserted right after the description of the classes (lines 245-250) and before table 1, as shown: “Despite the limited stratigraphic control of the collections, the grouping of classes based on different colors/matrix compositions suggests that the morphologies are not consistently present at the same stratigraphic level. It is possible that these forms may occur at various levels with similar compositions. For instance, Class A may or may not be found in the lighter siltstone layers, while Class C may or may not be present in the darker claystone layers. Additionally, it is important to note that there is a possibility of variation within classes occurring at the same stratigraphic level, particularly in the case of Class D. This class exhibits a transition from small needles, similar to the morphotypes of Class A, to dots.”

These are interesting structures, well described and characterized. My main misgiving is that the paper does not come to a conclusion, other than these structures are not organic skeletal hardparts. Even though they are calcite now, they do not show typical calcite crystal form and are presumably pseudomorphous after other minerals. Resolving their crystallography is needed to make a selection and advance a reasonable explanation.

The characteristics of the delicate material and over an undulating surface make it impossible to manufacture thin sections in better quality. Even so, we redescribed all the petrographic slides, carefully evaluating the crystallographic properties and suggesting which minerals are more likely, some characteristics refer to carbonates and others to clay minerals, which are discussed in the composition section: allied to other chemical techniques, they allow inferring the main composition of calcite needle. We hope that now the petrographic description is more complete, as this paragraph has been replaced as follows: “Despite the different external shapes found in a hand sample, [...] however birefringence resembles a possible carbonate (calcite?), see composition discussion in Sect 3.1.3.” the new complete excerpt is on page 13 on the resubmitted manuscript.

Figure 5: "Figure 5" in the figure caption is duplicated. Please, remove one of them. Figure 5A (right) is too dark. Could the authors improve this image?

For the figure 5 (page 14): The second caption was removed and the dark image Figure 5A (right) was improved to facilitate the visualization of the needle structures.

We improved the interpretation of the relationship with the matrix to clear some results from Micro-CT (lines 285 and 288). We added the phrase “(darker, amorphous gray tone on Micro-CT, Fig. 6A-E)”. The term “density differences” was added as one of the characteristics evaluated in the relationship with the matrix. And improved the caption of figure 6, page 16.

Figure 7: legend. Replace “Raman specters” by “Raman spectra”.

At the caption of the Figure 7 (pages 18-19), we changed the terms “Raman specters” by “Raman spectra”, in the text other “specters” words are also substituted.

l.273 I have never seen heterolith as a noun, generally heterolithic bed

Line 273: I suggest replacing “14 m of heterolith (Fig. 8A) defined by tabular centimetric layers...” by “14 m of centimetric heterolithic layers, measuring 0.2 to 4 cm (Fig. 8A)...”

We accept the suggestion for line 324 and modify it to “14 m of centimetric heterolithic layers, measuring 0.2 to 4 cm (Fig. 8A)”.

Figure 8: I suggest replacing “Local geologic features” by “Geological setting and sample features of the Bemara Quarry”. I also suggest replacing the comma between “Serra Geral Group” and “ a schematic section” by “...Serra Geral Group, followed by a schematic section of...”. Figure 8B: Where is the dubiofossils occurrence and the sill, according to the dashed line?

Line 279: Could the authors include MISS in the schematic section from Figure 8A?

Line 302: Same comment for Line 279.

We accepted the suggestions at the Figure 8 (page 20), replacing the caption for “Geological setting and sample features of the Bemara Quarry”, and the subsequent text by “Serra Geral Group, followed by a schematic section...”. We appreciate these appointments. We also indicate at the Figure 8B where the dubiofossils and the sill are located.

The MISS are included in the geological section of Fig. 8A, the icon referring to ichnofossils also represents the microbial mats found, it was just not indicated in the legend. The MISS have been added.

As remarked by the editors, the Figure 8 (page 20), have same photographs without references, these were taken and edited by the authors. We confirm our authorship.

Lines 281-282: Shouldn't the references follow a chronological order?

The Journal's rules are flexible regarding the order of citations in the text, we chose to keep them in chronological order, separating publications by the same author many years apart, keeping them all in chronological order. Therefore, on lines 333-334 it is reordered as: “Balistieri et al., 2002, 2003; Buatois et al., 2006; Gandini et al., 2007; Netto et al., 2009; Lima et al., 2015, 2017; Noll and Netto, 2018; Callefo et al., 2019b; Balistieri et al., 2021; De Barros et al., 2021 Netto et al., 2021”. Other similar list citations were readjusted to this pattern.

Kinneyia (l.303) is a misnomer for wrinkle marks. Stimson, Matt, Andrew MacRae, Randall Miller, Steve Hinds, Nic Minter, Zabrina Prescott, Brad Redden, Margaret MacNeil, Sarah Cron, and Stephanie Foster. "Rugalichnus mclaughlinensis: a new ichnospecies of microbially induced sedimentary structure from the nonmarine Early Carboniferous of New Brunswick, Canada." In Fossil Record 6, pp. 281-297. New Mexico Museum of Natural History & Science, 2018.

Stimson, M.R., Miller, R.F., MacRae, R.A. and Hinds, S.J., 2017. An ichnotaxonomic approach to wrinkled microbially induced sedimentary structures. *Ichnos*, 24(4), pp.291-316.

Due to the inappropriate name of *Kinneyia* discussed in the references indicated by the reviewer, it was decided to exclude the name *Kinneyia*, keeping it only as “wrinkle structures” (in l.358 and in the caption of the Fig. 9, page 22), without major effects for the text or discussion.

Line 310: I suggest mentioning Figure 5I-J to discuss microfabric.

We cited the Fig. 5I-L at line 361 to help to discuss the microfabric.

Lines 327-348: I did not understand the relevance of this discussion for this manuscript. What is the implication of this discussion for the dubiofossils and their origin, once they occur “sometimes” (Line 350) associated with trace fossils and miss?

We agree that it was long and with few direct implications for our object of study. We had already modified this passage due to a discussion between the authors. We still consider relevant part of the discussion on trace fossils and MISS for two points: 1) both reveal a paleoenvironmental interpretation of the site distinct from lithostratigraphic data and 2) the occurrence, even if infrequent, of biotic traces with dubiofossils is relevant in Sections 3.4. 1 and 3.5.1. On the other hand, we agree that the discussion about which paleoenvironmental interpretation is more correct is less relevant to the origin of the material. We chose, therefore, to modify the text, shortening this part and making it clearer as shown below (lines 390-393):

“Both interpretations are postulated for other outcrops of the Itararé group, and further work must be carried out to resolve the issue. As a more detailed description of the outcrop was not carried out and the paleoenvironmental interpretation is not the main objective of this work, both interpretations were considered in the discussion. Even so, the distribution of sand layers and the number of ichnofossils decreasing towards the top may signify a shallowing pattern in any of the interpretations.”

Line 349: Problematic features and dubiofossils mean the same thing? If so, I suggest replacing “Problematic features” by “These problematic structures...”.

The problematic features were used as a synonym to dubiofossils. As suggested, we changed to: “These problematic structures...”.

### 3.3 Comparison with similar objects

We have added another argument to refute the pure thermometamorphic origin as: “(3) dendrites, as a branched radial growth structure from a point, usually with more than one order of branches (see Jones, 2017).” See line 443.

We also replace the figure 10G to represent the ice cast, another hypothesis suggested by the R1. The caption also changed as: “(G) Ice cast, Voigt et al., (2021);” Page 26.

### 3.4 Evaluating proposals

There are at least 3 alternatives, additional to those discussed, for these small crystal structures which should be addressed somewhere.

A possibility not discussed: aragonite needles are formed in environmental contexts suggested in the text when discussing the possibilities of formation of calcite or dolomite. What happens is that aragonite, a much less stable polymorph, is easily replaced by calcite, which is more stable. This can preserve the original shape of the needles, as if they were replaced relics.

The alternatives suggested by the R1 and R2 was added to the discussion:

- Ice casts; please see lines 520-536;
- other evaporitic minerals, please see lines 555-565;
- aragonite, please see lines 634-647;
- oxalate minerals. please see lines 662-682.

Figure 11 correct spelling is interstitial

The figure 11 the word is now correct spelled (page 36).

We also made some changes in the figure and in the caption to improve our model with the respective processes for each stage of the complex history, nucleation, agglutination, growth, stabilization, replacement, reprecipitation, dissolution, cementation and weathering.

A new paragraph was added at the end of the section 3.5, see lines 784-794, in order to resume and close the discussion about the complex history. To illustrate this paragraph, we added a new figure (Figure 12, page 39) that synthesize the difference between the classes of formats and its processes.

#### 4 Conclusions

These are interesting structures, well described and characterized. My main misgiving is that the paper does not come to a conclusion, other than these structures are not organic skeletal hardparts.

I particularly see no problem with not reaching a more closed conclusion, that is, leaving the discussion open. I believe that the manuscript presented the most in-depth discussions possible about the possibilities, and from my own experience, I believe that it is of great value for approaching the topic of biogenicity of dubiofossils.

The authors' conclusion is not clear. Are these structures dubiofossils or pseudofossils? May this conclusion impossible to reach? Why? These arguments should be clear in the abstract.

The nature of the material and its complex history hindered us from arriving at a more definitive conclusion. However, we concur with the feedback from the three referees regarding the importance of enhancing the clarity of our interpretation. To address this, we have revised the first paragraph of the conclusion (lines 854-863) to emphasize that the diverse morphologies observed are a direct outcome of this intricate history, posing challenges in formulating plausible hypotheses. In addition to elucidating the general steps of the inferred history, we have incorporated two additional paragraphs. The first one, lines 881-888, argues that the observed variations also arise from the distinct characteristics of the substrate and the

varying intensity of the influencing processes. The second paragraph, lines 889-895, highlights two reasons for the lack of more conclusive results, emphasizing the presence of open hypotheses and the classification of the material as a dubiofossil.

We have full confidence that the manuscript has undergone comprehensive discussions, robust arguments, and thorough illustrations, thereby meeting the stringent standards set forth by the Biogeosciences journal, its esteemed editors, and reviewers. Additionally, we conducted meticulous proofreading to ensure the grammar, figures, and reference list are correct. We express our gratitude for the review process, which has proven to be both prompt and constructive throughout.

Kind regards