LETTER

Reply to Grosch and McLoughlin: Glass bioalteration trace fossils can be preserved by titanite in Paleoarchean greenstones

Before debating the criticism that Grosch and McLoughlin (1) extend toward our paper (2), we point out that we agree on important issues, such as the difficulty of interpreting titanite textures in greenstones with complex metamorphic histories. We further agree with them that their images are too ambiguous to be certain of the presence of any biotextures.

We welcome Grosch and McLoughlin's (1) clarification of their textural continuum of titanite textures in figure 1 of ref. 1, even though we are missing a genetic interpretation. We distinguish two types of titanite textures: (*i*) well-crystallized blade-like titanite crystals that have no resemblance to Cenozoic glass bioalteration and (*ii*) some "filamentous" textures that indeed closely resemble candidate biotextures. Lumping two visually distinct texture types into one group does not automatically give license to infer one process for their formation. Furthermore, we suggest here that none of the images conjure any simple metamorphic or biotic interpretations. In particular the candidate biotextures lack any obvious connections to glass surfaces or cracks in the glass, prohibiting a direct morphological comparison with Cenozoic biotextures.

Grosch and McLoughlin (1) defend most of their key views (3) in unsubstantiated statements while ignoring arguments we made in our paper (2), including, for example, the following.

Grosch and McLoughlin (1) make a plea against titanite as a replacement mineral without taking note of the arguments we provide in explanation of the process. Instead, they refer to the lack of evidence from microbial experiments and geological observations. We did provide geological evidence, and note that their concern about missing evidence from microbial experiments is not surprising as biotextures are formed on time scales that are not reproducible in the laboratory (4). The latter is relevant to biotextures of all ages, even the Cenozoic ones that they accept (3).

Grosch and McLoughlin (1) ignore the fact that the presence of biomarkers in biotexture cavities proves only occupation of a cavity unless a causal relationship can be established.

Grosch and McLoughlin (1) try to diffuse our texture size argument by affirming the quality of their texture measurements (that we never questioned) while ignoring the fact that their perceived size data discrepancy is rooted in their misrepresentation of the literature data.

Grosch and McLoughlin (1) ignore the similarity between images of their assumed purely abiotic titanite textures (3) with an example of biotextures interacting with varioles in Cenozoic glass bioalteration (2). This convincing comparison remains unrefuted.

Grosch and McLoughlin (1) do not give any consideration to our finding that their samples were likely reheated above the closure temperature, whereas Fliegel et al.'s (5) samples are too far away from the dike to be sufficiently reheated. Not considering this possibility has been a shortcoming in Grosch and McLoughlin's paper (3) and ignoring this in their comment (1) does not bring us any further.

Although we appreciate the opportunity to further clarify our points of view, the comment by Grosch and McLoughlin (1) lacks the rigor and conviction that should be expected in this discussion and, consequently, does little to refute the issues raised in our paper (2).

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1 Grosch EG, McLoughlin N (2015) Questioning the biogenicity of titanite mineral trace fossils in Archean pillow lavas. *Proc Natl Acad Sci USA* 112:E3090–E3091.

2 Staudigel H, Furnes H, DeWit M (2015) Paleoarchean trace fossils in altered volcanic glass. *Proc Natl Acad Sci USA* 112(22): 6892–6897.

3 Grosch EG, McLoughlin N (2014) Reassessing the biogenicity of Earth's oldest trace fossil with implications for biosignatures in the search for early life. *Proc Natl Acad Sci USA* 111(23): 8380–8385.

4 Staudigel H, Furnes H, Smits M (2014) Deep biosphere record of in situ oceanic lithosphere and ophiolites. *Elements* 10(2): 121–126.

5 Fliegel D, et al. (2010) In-situ dating of the Earth's oldest trace fossils at 3.4 Ga. *Earth Planet Sci Lett* 299(3-4): 290–298.

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The authors declare no conflict of interest.

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