

Enigmatic tubular features in impact glass

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We thank McLoughlin and Grosch (2014) for their Comment, which provides us with the opportunity to expand upon issues surrounding the concept of biogenicity. In our manuscript, "Enigmatic tubular features in impact glass" (Sapers et al., 2014), we present morphological and geochemical evidence suggesting a biogenic origin for tubule features hosted in meteorite impact glass. McLoughlin and Grosch argue that a biogenic origin is unsupported by the data, and that astrobiological implications are unwarranted. In their Comment, they raise three main issues: (1) additional possible abiotic mechanisms; (2) inappropriate comparison between volcanic and impact glasses; and (3) tenuous, or incomplete evidence for endogenicity.

McLoughlin and Grosch suggest the products of shock metamorphism could account for the tubules specifically citing ballen silica presented in Ferrière et al. (2009). Ferrière et al. (2009, their figure 2) present a shocked silica clast containing ballen α -cristobalite with (open) fractures/veinlets of, in part, altered coesite. These features differ from the Ries tubules in (1) appearance—ballen silica are not tubular but approximate spheroidal bodies that interpenetrate each other; and (2) composition—ballen textures occur exclusively in pure silica; the Ries tubular features occur in chemically complex glasses. McLoughlin and Grosch also suggest ambient inclusion trails as a possible abiotic mechanism. This hypothesis can be discounted due to the absence of the main diagnostic criteria (see McLoughlin et al., 2010): terminal inclusions, longitudinal striae, and consistent rhombohedral cross sections. Finally, McLoughlin and Grosch correctly point out that not all of the tubules depicted in our paper are clearly associated with fractures or vesicles. This is expected, as the process of petrographic sectioning commonly truncates the three-dimensional distribution of the tubules, an artifact that is also clearly depicted and addressed by Fisk and McLoughlin (2013, their figure 16a).

Analog studies are fundamental to the study of astrobiology. The biogenicity criteria established by McLoughlin et al. (2007) necessitates proxy comparisons; i.e., to demonstrate homology to biological morphology and behavior. As such, the comparison between volcanic and impact glasses for the purpose of comparing alteration textures is valid. Not only are both amorphous substrates, they are also both produced by the quenching of a super-cooled lithic melt; it is only the process leading to the initial melting that differs. We are surprised by the suggestion that we have misapplied the recommendations from Fisk and McLoughlin (2013), as they explicitly state: "The atlas is intended as an illustrated guide for geologists, microbiologists, and astrobiologists studying glass alteration" (p. 317). Within this atlas, an example of alteration from a terrestrial rhyolitic tuff (Fisk et al., 1998) is discussed in the context of abundance and distribution of submarine volcanic glass alteration features. Considering the precedent in the literature of comparing putative biogenic features in varying lithologies, we think it is an entirely appropriate application to draw comparisons between volcanic acid and impact glass. In addition, based on conductive cooling models, impact-generated hydrothermal activity persists on the same temporal scales as submarine hydrothermal systems. The TAG (Trans-

Atlantic Geotraverse) hydrothermal field has deposits that range in age from tens of thousands to ~140,000 yr (e.g., Rona, 2005). Impact-generated hydrothermal activity can last for tens of thousands of years for a 24-km-diameter crater such as Ries, and to ~1 m.y. for larger, basin-forming impacts.

We fully agree that further high-resolution study is required before the tubular features in the Ries glasses are proven to be of a biological origin. We are currently conducting synchrotron STXM spectroscopic experiments that provide evidence for biological processing. We were very careful to only suggest the possibility of a biogenic origin for these tubules, and purposefully avoided any mention of ichnofossils, or allusion to the ichnogenera proposed by McLoughlin et al. (2009). Our study systematically rules out parsimonious abiotic formation mechanisms, necessitating an alternate origin. As to the FTIR results, we were fortunate to have a negative control, a glass clast lacking the tubular features near the clast containing tubular features. In this respect, our study is the first to incorporate an intrinsic negative control, in which no organic spectra were observed, ameliorating concerns of contamination.

Our hypothesis that endolithic microbes tunnel into impact glasses is thus supported by our observations, and the astrobiological implications are found in the data presented. We do not argue that the tubules themselves are a robust biosignature, and agree that there are more reliable alternatives. We are presenting data to support microbial activity in a novel niche, providing evidence supporting the potential for microbial activity to be preserved in a novel target. The potential for impact glass to host ichnofossils warrants further investigation. We thank McLoughlin and Grosch for continuing this lively discussion and underscoring the importance of consistency in the literature.

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