**MICROTUBULES, TRICHITES, AND BIOALTERATION IN IMPACT GLASSES.** A. E. Pickersgill[1], H. M. Sapers[2], M. R. Lee[1], M. Wildman[1], P. Lindgren[3], and L. Hallis[1] [1]School of Geographical & Earth Sciences, University of Glasgow, Gregory Building, Lilybank Gardens, Glasgow, G12 8QQ, UK, (annemarie.pickersgill@glasgow.ac.uk), [2]Department of Earth and Space Science and Engineering, York University, 4700 Keele Street, Toronto, ON, M3J 1P3, Canada; [3]Department of Geology, Lund University, Sölvegatan 12, 223 62 Lund, Sweden.

**Introduction:** Hypervelocity impact cratering is a significant process in the development of solid planetary surfaces and is considered to have played a profound role in the origin of life on Earth and, potentially, on other planets [1–5]. Such events provide heat sources on otherwise cold planetary bodies, creating habitable environments for microorganisms [3]. However, finding direct evidence for microbial colonization within impact structures has proven to be both challenging and contentious [e.g., 6–9]. One approach is to search for evidence of biologically mediated alteration of impact-generated glasses. Microbially mediated bioalteration textures preserve evidence of endolithic microorganisms that ‘bore’ into rocks and minerals. This process is hypothesized to occur in submarine volcanic glass preserved in both modern seafloor basalts [10,11], and in ophiolites and greenstone belts up to ~3.5 Ga old [12,13]. Tubular features with a striking morphological similarity to micro-borings have been recognized in impact glasses from the Ries [7,14] and Boltysh [15] impact structures.

The morphological similarity between putatively biogenic tubular alteration textures and other micro-scale tubular textures makes differentiating biologically mediated alteration from abiotic alteration challenging. Morphology alone is not enough to establish biogenicity of candidate features. Multiple correlated analyses are required to determine biogenicity [16,17]. Here we summarize the main mechanisms, both biogenic and abiotic, suggested to have formed tubular alteration features found in both volcanic and impact glasses, with specific commentary on those features reported in two ~25 km diameter impact structures, the ~14.8 Ma Ries structure, Germany, and the ~65.5 Ma Boltysh structure, Ukraine.

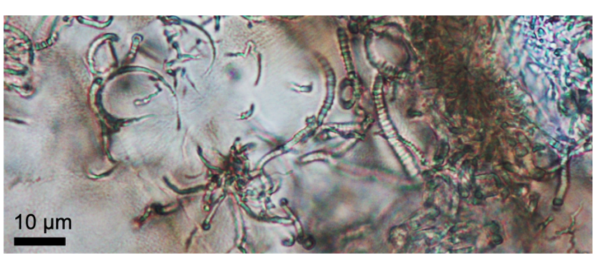


*Figure 1: Putative bioalteration textures in hydrothermally altered impact glass from glass-bearing breccia at the Ries impact structure. Tubules display complex morphologies including bifurcation, branching, and segmentation.*

**Trichites:** Micrometer-scale “hairlike” or “tubular” structures have been described in naturally occurring volcanic glasses since the mid 19th century [18]. At that time the term “trichite” was used to describe these features as they were “of an uncertain mineralogical nature” [18]. Zirkel [18] described “tendril-like forms […] often so much curved and twisted as to resemble knots” as well as “the trichitic hairs are at intervals also grouped radially, and form dark, radiated sphaerolites.” In the subsequent century, some authors were able to identify similar tubular features as pyroxene using a light microscope [19]. Often times, however, such features are simply reported as being present and described in passing as “trichites” or “microlites” because their small size precluded mineralogical identification. The main commonality being the small size (~1 µm diameter, on a par with cells) and the complicated morphologies that are atypical of crystal growth habits.

**Formation mechanisms:** We now have a great many descriptions of micro-tubular structures in volcanic and impact glasses that match the hair-like, knotted, and radiating descriptions of [18] as well as spiral, curvilinear, kinked, and convoluted features that have been ascribed a variety of formation mechanisms:

*Non-canonical quench crystallites*. Some of the larger trichites in volcanic and impact rocks have been identified as pyroxene based on extinction angle [19], and SEM EDS combined with electron backscatter diffraction [15]. Preliminary confocal Raman spectroscopy has also identified some of the tubular structures in Boltysh impact glass to be magnetite and some to be olivine [20]. Despite their convoluted morphologies that are atypical of crystal growth habits, these observations are compelling and encourage further study to understand how crystalline material can grow into such unusual forms (i.e., knotted, spiraled, etc.), though some of these occurrences may be explained by infilled ambient inclusion trails. It is also possible that as of yet undescribed biomineralization processes, either passive or active, could have resulted in the formation of these noncanonical mineral habits.

*Ambient inclusion trails (AITs)*. AITs form when small mineral grains are driven through materials by high fluid pressure, leaving behind a trail that can either remain hollow and tubular or be infilled by a secondary mineral phase [16]. Key characteristics of AITs are the presence of a mineral grain at the end of a tubule; striations along the length of the tube; angular cross-section; crosscutting and branching into smaller tubules (as the mineral grain splits during transport). None of the varieties of tubules at either the Ries or Boltysh impact structures have yet been identified as AITs, though secondary mineralization may be obscuring some of the diagnostic evidence.

*Natural alpha recoil track (ART) etching.* French and Blake [21] suggested that microborings previously interpreted to be biotic in origin are in fact the result of natural etching by seawater of fission tracks and alpha recoil tracks (effects of radiation damage from samples containing U and Th). Thus far, none of the microtubules in Ries or Boltysh glass conform to the morphology of fission tracks (typically straight and larger in size), but some may be etched alpha recoil tracks as they are often more convoluted and ~1 μm, similar in size to the larger tubules. We are currently investigating the U and Th content of glasses from both sites, to see if there is enough to have reasonably caused radiation damage on the same scale as the volume of tubules.

*Biologically mediated alteration*. Complex morphologies inconsistent with known crystallization mechanisms are highly suggestive of a biotic origin for micro-tubules, however morphology alone is not enough to establish biogenicity. McLoughlin et al. [16] summarize three interdependent lines of evidence for robust claims of biogenicity: "(1) a geological context that demonstrates the syngenicity and antiquity of the putative biosignature; (2) evidence of biogenic morphology and behavior; and (3) geochemical evidence for biological processing." Despite recognition and widespread acceptance of biogenically produced tubular structures in volcanic glasses, these features have not been reproduced in a laboratory setting. That apparent discrepancy is not surprising as many microorganisms cannot be cultured and/or have growth rates that are too slow to be studied in the laboratory.

At both the Ries and Boltysh impact structures, several classes of trichite-like features (i.e., micro tubules) have been identified. At Ries the two most prevalent types were i) features with a constant diameter and complex and convoluted morphologies (bifurcating, spiraling, segmented) and ii) features that radiate from a central point and have variable diameters where fine, dense tubules were found near the centre and wider ones were further out, similar to the spider-like trichites described by [18]. The former are consistent with the biogenicity criteria summarized above, while the latter likely represent non-canonical quench crystallites. At Boltysh, though there are wide variety of tubule morphologies, none have a geologic context consistent with a biological origin, as they appear to be randomly distributed, and not associated with fractures or other pathways for colonization.

**Discussion:** Micro-tubular textures are of interest to planetary science, particularly astrobiology, due to the challenges associated with finding direct evidence for ancient biological activity on Earth, and potentially on other planets. The existence of bioalteration textures in impact glasses could prove to be useful evidence that impact structures create habitable environments and more importantly that those environments were inhabited shortly after their formation. Furthermore, the presence of amorphous phases associated with impact structures on Mars [23] implies that impact-generated glasses are a potential habitat and preservation mechanism on other planets.

Crucially, however, we must be cautious in our interpretations of tubular structures as it is clear that morphologically similar features can be produced by a variety of mechanisms. Both biotic and abiotic production mechanisms are present in impact-generated settings, as demonstrated by the variety of tubules hosted in both the Ries and Boltysh impact glasses.

**Acknowledgments:** We acknowledge funding from the Leverhulme Trust though RPG-2018-061.

**References:** [1] Osinski G.R., et al. (2013) *Icarus*, *224*, 347-363. [2] Farmer J.D. (2000) *GSA Today*, *10*, 1-9. [3] Cockell C.S. and Lee P. (2002) *Biol. Rev. Camb. Philos. Soc.*, *77*, 279-310. [4] Cockell C.S. (2006) *Philos. Trans. R. Soc. B Biol. Sci.*, *361*, 1845-1855. [5] Osinski G.R., et al. September 2020 *Astrobiology*,. [6] Versh E., et al. (2006) *Planet. Space Sci.*, *54*, 1567-1574. [7] Sapers H.M., et al. (2014) *Geology*, *42*, 471-474. [8] McLoughlin N. and Grosch E.G. (2014) *Geology*, *42*, e346-e346. [9] Sapers H.M., et al. (2014) *Geology*, *42*, e348-e348. [10] Benzerara K., et al. (2007) *EPSL*, *260*, 187-200. [11] Fliegel D., et al. (2012) *GCA*, *96*, 80-93. [12] Staudigel H., et al. (2008) *Earth-Sci. Rev.*, *89*, 156-176. [13] Banerjee N.R., et al. (2006) *EPSL*, *241*, 707-722. [14] Sapers H.M., et al. (2015) *EPSL*, *430*, 95-104. [15] Pickersgill A.E. and Lee M.R. 50th LPSC. , 2019; #2675. [16] McLoughlin N., et al. (2007) *Astrobiology*, *7*, 10-26. [17] McLoughlin N., et al. (2010) *Geobiology*, *8*, 245-255. [18] Zirkel F. Microscopical Petrography; 1876. [19] Ross C.S. (1962) *Am. Mineral.*, *47*, 723-740. [20] Pickersgill A.E., et al. 2nd BPSC, 2020. [21] French J.E. and Blake D.F. (2016) *Int. J. Geophys.*, *2016*,. [22] Mason O.U., et al. (2007) *Environ. Microbiol.*, *9*, 2539-2550. [23] Cannon K.M. and Mustard J.F. (2015) *Geology*, *43*, 635-638.