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Deep microbial colonization during impact-generated hydrothermal circulation at the Lappajärvi impact structure, Finland

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Deeply fractured rocks within meteorite impact structures have been hypothesized as hot spots for microbial colonization on Earth and other planetary bodies, owing to their characteristic long-term heat flow, impact-generated hydrothermal (IGH) systems with geochemical and thermal gradients, and pore space enabling microbial colonization[1]. Biosignatures of such colonization are rare, however, and most importantly, direct geochronological evidence linking the colonization to the IGH systems are still lacking. U–Pb and Rb/Sr dating of fracture-hosted minerals at Siljan and Lockne impact structures[2,3] showed that the microbial activity was >100 Myr younger than the impact events.

U-Pb dating[4] and $^{40}Ar/^{39}Ar$ based thermal modelling[5] of the 77.85±0.78Ma, 23km diameter Lappajärvi impact structure in Finland, indicate that hydrothermal circulation and post-impact cooling below 250°C lasted ~1–1.6 Ma. This well-preserved impact structure is thus a good target for exploration of ancient biosignatures of microbial colonisation. No evidence of microbial colonisation of the Lappajärvi structure has been reported yet.

Here we provide the first direct evidence for meteorite impact-related microbial colonization on Earth by using microscale secondary-ion mass spectrometry biosignature detection ($\delta^{13}C_{calcite,}$ $\delta^{34}S_{pyrite}$), clumped isotope analysis and U-Pb dating of vug- and fracture-filling mineral assemblages in Lappajärvi impactites. The earliest mineral precipitation at habitable temperatures for life featured substantially ^{34}S-depleted pyrite consistent with microbial sulfate reduction, and occurred in the first few million years after the impact. Later stages of mineral precipitation featured $\delta^{13}C_{calcite}$ values diagnostic for anaerobic microbial consumption and production of methane. Our study provides coupled petrographic-isotopic-temperature-geochronology support for microbial colonization in the waning stages of an IGH system, at a stage when temperatures had dropped to levels where life can sustain. These new insights into microbial colonization of impact structures have implications for the emergence of life on Early Earth and beyond, particularly as deep biosphere habitats in impact structures are considered favorable targets for Mars exploration for extinct life[6].

[1]Osinski, et al. (2020), *Astrobiology* 20, 1121-1149. [2]Drake et al. (2019), *Nat. Commun.* 10, 4736-4714. [3]Tillberg et al. (2019), *Geosciences* 9(5), 202. [4]Kenny, et al. (2019), *GCA* 245, 479-494. [5]Schmieder&Jourdan (2013) *GCA* 112, 321-339. [6]Onstott et al. (2019), *Astrobiology* 19, 1230.