Isotopic evidence of microbial colonisation of the Lappajärvi impact structure, Finland

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Deeply fractured rocks within meteorite impact structures have been proposed as suitable locations for deep microbial colonisation of Earth's crust (e.g. Osinski et al. 2020), but studies of reporting biosignatures proving such colonisation are still scarce. Modelling shows that habitable conditions for microbial communities in a ~4-km impact structure, can be established tens to a few hundreds of years after the impact in most parts of the crater (Versh et al. 2006). For larger impact structures, the time before habitable conditions is achieved is obviously longer. According to Schmeider & Jourdan (2013), the cooling between roughly 370 and 250 °C of the ~23-km, ~78 Ma Lappajärvi impact structure, took place between ~600 ka and ~1.6 Ma after the impact event. This well-preserved impact structure is a good target for exploration of ancient biosignatures of microbial colonisation. Yet, no proof of microbial colonisation of the Lappajärvi impact crater has been reported.

Here we use secondary-ion mass spectrometry (SIMS) micro-analysis ($\delta^{13}C$ and $\delta^{34}S$, see e.g. Drake et al. 2015a, 2015b) of pyrite and calcite, precipitated in rock fractures and cavities, to detect microbial processes in the crater structure. Recently, SIMS analysis ($\delta^{34}S_{pyrite}$ and $\delta^{13}C_{calcite}$) of deep fractures from Siljan (Drake et al. 2019, 2021) and Lockne (Tillberg et al. 2019) impact structures in Sweden, proved microbial sulfate reduction (MSR), methanogenesis and anaerobic oxidation of methane (AOM). However, U–Pb dating for fracture-hosted calcite at Siljan (Drake et al. 2019) and Rb/Sr for adularia-calcite at Lockne (Tillberg et al. 2019) showed that the microbial activity was > 100 Myr younger than the impact events. This attests to the high level of evidence needed to put forward claims of impact-related colonisation, but also to the potential of using a coupled biosignature-geochronology approach to track colonisation events of meteorite impact structures.

In the present study we present isotopic evidence for microbial colonisation of the Lappajärvi impact structure, in particular $\delta^{13}C_{calcite}$ values diagnostic for methanogenesis and AOM. Radiometric dating of the calcite crystals is in preparation to test the hypothesis of impact-related colonisation. The confirmation of meteorite impact structures as favourable environments for deep biosphere communities substantially enhances our present understanding of the records of colonisation and evolution of microbial life in the deep biosphere. It also enhances our present understanding on deep energy cycling (e.g. gas cycling) of these systems and involve considerable astrobiological implications. Our results show that the Lappajärvi impact will add important input to this discussion.

References

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