CRATER-LAKE HABITABILITY AND DIVERSITY: RE-INTERPRETING EARLY DEPOSITIONAL ENVIRONMENTS AT THE RIES IMPACT STRUCTURE, GERMANY M. J. O. Svensson[1,2], G. R. Osinski[2], F. J. Longstaffe[2], T. A. Goudge[3], [1]Institute for Earth and Space Exploration, [2]Dept. Earth Sciences, The University of Western Ontario, 1151 Richmond Street N. London, Ontario, Canada, N6A 5B7 (msvenss@uwo.ca), [3]Jackson School of Geosciences, The University of Texas at Austin, Austin, TX.

Introduction: As possible host environments for microbial life and as high-resolution record keepers of climate change and aqueous history over time, lake deposits in meteorite impact craters have been the subject of significant interest both on Earth and on Mars [1,2]. During the early stages of the lake's life cycle, the interaction between water and latent heat from melt-bearing impactites can generate hydrothermal systems capable of creating habitats for microbial life [2]. These conditions, however, have yet to be studied in detail. At the Ries impact structure, Germany, impact-generated hydrothermal deposits are well documented and spatially variable [e.g., 3], and multiple styles of post-impact lacustrine deposits have been studied [e.g., 4]. Environmental diversity is fundamentally linked with biodiversity, and so the spatial variability of these hydrothermal and lacustrine environments provides a key for understanding the role of impact events and post-impact modification in the origins of life on Earth and potentially Mars.

Here, we provide details of hydrothermal activity and crater-lake deposition in the central basin and outer basin lake deposits at the Ries impact structure, sampled by the Nördlingen 1973 (FBN73) and Wörnitzostheim drill cores, respectively (Figs. 1A, B). We reconcile early post-impact sedimentary and hydrothermal processes within the central and outer basins to elucidate the environmental conditions of early post-impact crater lake deposits, highlighting implications for habitability.

Background: The ~24 km diameter, ~14.8 Ma [5] Ries impact structure in southern Germany is a complex impact structure hosted in gneissic crystalline rocks overlain by Jurassic limestones and Triassic siltstones, sandstones and conglomerates [6]. The Ries structure has a tectonic outer rim and a central basin bound by a ~12 km diameter "inner ring" (Fig. 1B). Hydrothermal deposits are most common in the ~270 m thick sequence of melt-rich crater-fill impactites present within the central basin [3] (Fig. 1B). Hydrothermal mineralization has also been documented in the region of the inner ring [8], and in spatially discontinuous melt-bearing ejecta beyond the inner ring where it is more limited to fracture linings and pore-fillings [3]. Lake deposits have been well-documented within the central basin [4, 7], near the inner ring [e.g., 8], and in outer basins overlying melt-bearing ejecta [9–11].

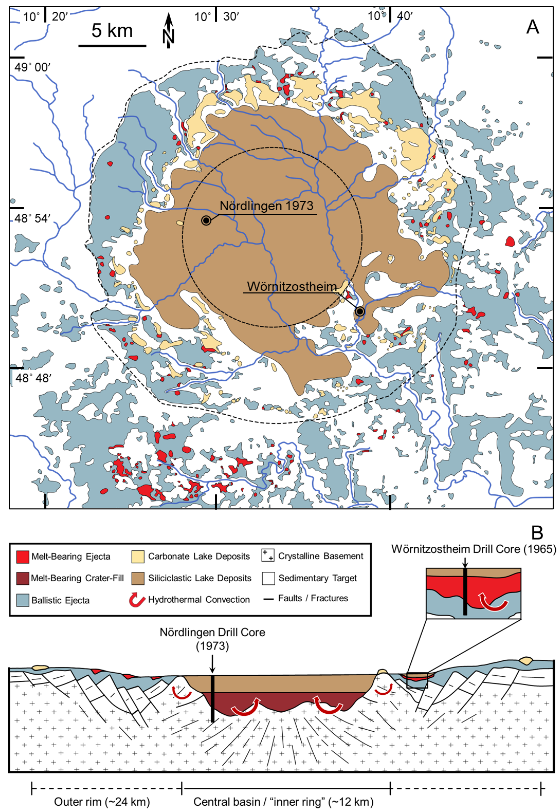

Fig. 1: (A) A simplified geological map and (B) a cross section of the Ries impact structure highlighting the location of the Nördlingen drill core (FBN73), the Wörnitzostheim drill core, the approximate bounds of the central basin, and key lithologies [after, 12].

Methodology: This study contributes new drill core observations and new data from optical microscopy, back-scattered and secondary electron imagery (BSE & SE, respectively), powder X-ray diffraction (*p*XRD) of bulk size-fractions, <2 μm, 2–0.2 μm and <0.2 μm size-fractions, and isotope ratio mass-spectrometry (IRMS) for hydrogen and oxygen isotopes of each size-fraction.

Results: The Wörnitzostheim drill core samples sedimentary rocks at 20.1–2.0 m depth. A group of matrix-supported conglomerates with rounded glass and crystalline clasts occur at 20.1–13.1 m, which is overlain by a normally graded series of sandstone units at 13.1–10.7 m. Chaotically and finely laminated marlstones, interbedded with occasional mud crack-bearing marlstones and dolomite packstones with tube structures occur at 10.7–2.0 m.

The pores and fractures in the Wörnitzostheim basal conglomerates host rare skeletal feldspars, which possess bow-tie spherulitic textures. These feldspars occur in contact with euhedral dolomite rhomboids that line the pores of the voids, and with honeycomb textured smectitic clay minerals. The matrix of the conglomerates, which mainly comprises smectites, with illite and kaolinite occurring as minor additional phases, have $\delta^{18}O$ ranging from +9.8 to +23.4 ‰ and $\delta^{2}H$ ranging from –129 to –61 ‰ across all analyzed size-fractions.

Similar to the Wörnitzostheim drill core, the basal conglomerates and gravelstones from the graded unit in FBN73 hosts feldspar spherulites, but this latter variety typically occur in radial patterns. These feldspar spherulites occur in association with other void-filling minerals documented previously [13], and with smectitic and illitic clay mineralization. The basal conglomerates and gravelstones of FBN73 are also matrix supported and clasts are typically sub-rounded.

Discussion: *Depositional Environments:* The coarse, rounded glass clasts and smectite-dominated matrix of the conglomerates in the Wörnitzostheim drill core likely indicate formation from eroded local melt-bearing ejecta in a high energy environment. These deposits are interpreted here as deposition from a subaerial water-laden debris flow, potentially during alluvial fan formation. The overlying normally graded sandstone units likely indicates a reduction in the amount of energy of the system and possibly alluvial fan back-stepping. The fine laminations in the marlstones indicate deposition from a lake system, with chaotic lamination triggered by soft sediment deformation. Ephemeral, playa lake conditions are indicated by mudcracks. The tube structures in the dolomite packstones could represent either cladophorite tubes or root traces in a shallow eulittoral environment. The occurrences of finely laminated marlstones overlying the dolomite packstone likely indicate landward shoreline progression.

The Ries graded unit likely has subaqueous origins (cf., 14). Given the sub-rounding of the clasts and the normal grading, we re-interpret the graded unit here as likely a debris flow deposit that formed during alluvial fan deposition, similar to the conglomerates and sandstone units in the Wörnitzostheim drill core.

Hydrothermal & Meteoric Water Temperatures: The skeletal feldspars in the voids of the conglomerates in the Wörnitzostheim drill core suggest temperatures of 40–100 ˚C [15]. Hydrogen and oxygen isotope data for the <0.2 μm size-fraction indicate clay mineral formation primarily at ~20 ˚C from local meteoric water. Isotopic analysis of the <2 μm and 2–0.2 μm size-fractions indicate the presence of higher temperature phases that could potentially be detrital [9]. The radial feldspars from the FBN73 graded unit likely indicate formation at ~100–200 ˚C [15], which is consistent with the ~100 ˚C estimate based on bladed calcite and likely associated with pervasive alteration to the base of the graded unit [13]. Hydrothermal mineralization was therefore pervasive and warmer in the early crater-lake deposits of the Ries central basin sampled by FBN73 but was cooler and limited to pores and fractures in the outer basin setting of the Wörnitzostheim drill core. In both cores, hydrothermal mineral deposits are concentrated in the basal conglomerates. The common formation of illite in addition to smectite in both drill cores likely represents relatively high K_2O activity, suggesting that the associated fluids were weakly alkaline.

Conclusions & Implications for Habitability: This study has shown that the sandstones, gravelstones and conglomerates that record early crater-lake depositional processes provided sufficient porosity and permeability to enable the flow of likely weakly alkaline fluids. These fluids have temperatures that are spatially variable: from 40–100 ˚C in the periphery of the lake to 100–200 ˚C closer to the lake center. These fluids could be ideal for the transport of metabolically important compounds for biological communities [16].

The basal conglomerates of early post-impact debris flows can create spatially diverse environments, with varying amounts of water and at varying temperatures, creating greater opportunities for microbial organisms to gain a foothold and diversify. These basal lacustrine deposits are therefore ideal candidates to explore potential pathways for life's emergence on Earth and potentially on Mars.

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