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Mineral-assisted co-evolution: Experimental and field constraints on prebiotic reactivity in Icelandic hydrothermal systems

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The co-evolution of life and Earth is rooted in the reciprocal influence between prebiotic chemistry and the inorganic world. While the emergence of life permanently altered Earth's surface, the primitive mineral environment acted as a selective filter, setting the geochemical boundaries for the first metabolic pathways, compartmentalization, and information storage. Among the candidate environments for these transitions, surface hydrothermal systems—such as geysers and solfataras—offer unique physicochemical gradients fostering biochemical reactivity. These systems, while currently active in Iceland, also represent key astrobiological analogs for extinct hydrothermal activity on early Mars.

This study leverages data and samples (solids, fluids, and muds) collected during the PREBIOVIE expeditions (2022, 2025) across Icelandic sites, including the Geysir area and Krýsuvík. We investigate the role of surface hydrothermal systems in facilitating or inhibiting prebiotic reactions and the self-assembly of lipidic structures (liposomes). By coupling detailed geological characterization with experimental chemical reactivity, we demonstrate the potential for mineral-assisted formation of small peptides precursors and key metabolites, illustrating how geology may have catalyzed early metabolic innovations.

Furthermore, we explore the taphonomic capacity of Icelandic geyserites, providing microscopy evidence of their role as high-fidelity microfossil traps. Finally, we evaluate pyrite-rich samples from Krýsuvík and Hveradalir through the lens of biogenicity criteria, discussing the challenges of distinguishing abiotic mineral precipitates from biologically mediated signatures in surface hydrothermal settings. This multi-disciplinary approach provides a holistic view of how microbial-mineral interactions shape the evolution of habitable worlds.