Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.28115

Goethite Dissolution in the Extreme Cryosphere: Oxalate, UVA, and Freeze-Thaw Effects

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Acidic cryosphere environments, such as acid mine drainage, permafrost, clouds, and seasonally frozen soils, are extreme environments where freezing concentrates acids, organics, and other impurities into Liquid Intergrain Boundaries (LIBs) within ice. These LIBs become micro-reactors for mineral dissolution, driving iron biogeochemistry and mobilizing this essential nutrient[1-3]. This study investigates the synergistic effects of freeze concentration, UVA irradiation[4], and freeze-thaw cycling on oxalate-mediated goethite dissolution within these icy microenvironments. Batch experiments, coupled with Raman and FTIR spectroscopy, were used to quantify iron release and speciation under both dark and UVA-irradiated conditions, and across a range of salt concentrations and oxalate loadings. Our results demonstrate that this extreme environment enhanced goethite dissolution, with higher relative yields at lower oxalate loadings and ionic strength. Moreover, we highlight that the freeze concentration effect was selective to certain impurities like goethite and salt rather than being universal. UVA irradiation increased the rates and yields significantly and altered the dissolved iron speciation. This integrated approach provides a deeper understanding of iron cycling in the cryosphere, with implications for predicting future iron fluxes under changing climate conditions and potentially informing our understanding of biogeochemical processes on other icy worlds.

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