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Iron nanoparticles as biogeochemical tracers of hydrothermal activity on icy ocean worlds: Effects of Europa surface-like radiation on particulate chemistry and morphology

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Iron-containing nanoparticles emitted from deep sea hydrothermal vents are increasingly recognized as having long-range transport potential in Earth's oceans. In the context of ocean worlds, nanoparticles expressed at the exterior of an ice shell have the potential to record the (bio-)geochemical conditions at their point of formation and subsequent alteration within the underlying ocean. Here we present work aimed at strengthening our ability to link the characteristics of endogenous particles found on the surface of icy ocean worlds to seafloor conditions under which particles may have formed in putative hydrothermal settings.

We conducted laboratory experiments designed to examine alteration processes in conditions consistent with those on the surface of Europa. First, we identified pyrite (FeS2) and biogenic/short range order iron oxyhydroxides as common iron mineral phases detected in Earth's diverse hydrothermal vent systems. We chose to test minerals with different oxidation states of iron (Fe(II) in pyrite vs. Fe(III) in biogenic iron oxyhydroxides) because the irradiated surface environment on Europa is expected to be oxidizing. We irradiated mineral samples with a 10 keV electron beam at vacuum pressure and cryogenic temperatures in an environmental chamber. Samples are observed using visible through mid-infrared spectroscopy to monitor for spectral alterations arising from the applied radiation. A residual gas analyzer assessed the molecules liberated from the samples during the experiment. Post-irradiation analyses (scanning and transmission electron microscopy, scanning transmission X-ray microscopy, ptychography) reveal coupled textural and chemical effects of irradiation.

Irradiation only slightly affected chemistry and did not affect bulk (micron-scale) morphology of biogenic iron oxyhydroxide particles, suggesting these particles could be a reliable 'fingerprint' for formation conditions. However, at the atomic scale, biogenic iron oxyhydroxides were less ordered after alteration. Similarly, post-alteration pyrite appeared unaltered at the micron scale but oxidation could be detected at the nanoscale. Results could inform models predicting particle transport from vents to the surface of icy ocean moons and be used to prepare for future icy world flyby and landed missions, starting with Europa Clipper.