Freezing-induced fractionation in simulated Enceladus ocean brines

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The Saturnian moon Enceladus exhibits large cryovolcanic plumes sourced from a subsurface liquid water reservoir that contains evidence of hydrothermal activity and indigenous organics [1,2]. Because of these factors, Enceladus is viewed as one of the most promising bodies in the solar system to harbour extant extraterrestrial life. Particles in the plumes have been observed to contain ice, salts, silica and macromolecular organics [2,3,4], and thus provide the opportunity to probe the composition and habitability of the subsurface ocean. However, our understanding of how fluids evolve as they are transported upwards through the icy shell is rudimentary. Constraints on plume particle composition provided by the *Cassini* mission now permit detailed experiments exploring pathways of formation for Enceladus cryo-salts. We investigated freezing-induced mineral fractionation in simulated Enceladus ocean fluids spanning a range of pH estimates, under both flash-freezing (at approx. 80 K) and gradual-freezing (at approx. 240 K) regimes.

We show that mineral phase partitioning occurs at both freezing rates, and that ice crystal templating of cryo-precipitated minerals (including Na-chlorides, carbonates and silica) ensues even when fluids are flash-frozen. Crystal habits and phase partitioning at the sub-10 micron scale are diagnostic of freezing rate, whilst mineral abundances record parent fluid pH. Current models based on equilibrium thermodynamics do not fully predict mineral assemblages, particularly for lower pH fluids, where freezing kinetics control mineral formation. Our results demonstrate that both the composition and physical partitioning of cryogenic salts in ice are key to understanding their origins, thus their potential for understanding the geochemistry and habitability of Enceladus's ocean. In light of these findings, we urge the development of future missions capable of capturing plume particles whole, and performing microscopic analysis *in situ*, or, preferably, returning them to Earth.

[1] Waite, J. H., et al. (2018) Science, 356, 155–159 [2] Postberg, F., et al. (2018) Nature, 558, 564–568 [3] Hsu, H. et al. (2015) Nature, 519, 207-210 [4] Postberg, F., et al. (2011) Nature, 474, 620–622