Disequilibrium precipitation of salts during rapid freezing of brine: Implications for cryovolcanisms and formation of sodium carbonate of bright spots on Ceres.

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NASA's Dawn spacecraft has found geological evidence for cryovolcanoes on Ceres, the dwarf planet in the main belt. Erupted materials from Ceres' cryovolcanoes are generally bright and distribute locally over Ceres in association with floor-fractured craters and dome-like features, which have young surface ages (e.g., Buczkowski et al, 2016; Ruesch et al, 2016). The bright materials are considered to be composed mainly of sodium carbonate and ammonium salts, which are different from the average crustal compositions (a mixture of magnesium-calcium carbonates and ammonia phyllosilicates) (De Sanctis, 2016; Zambon et al, 2016). The particular compositions of bright materials could provide unique information on the formation and evolution of liquid reservoirs within Ceres.

Two possible processes have been proposed for the formation of liquid reservoirs that generate Ceres' bright spots: One is remnants of a global subsurface ocean formed in the early history of Ceres (Castillo-Rogez et al, 2018), and the other is impact-induced melting of surface materials in a recent time (Zolotov, 2017). Using thermochemical equilibrium models, Castillo-Rogez et al. (2018) suggest that freezing of an early global ocean on Ceres may not be able to generate salt materials found on bright spots. To account for the abundance and composition of salts on bright spots, Zolotov (2017) suggests extremely high concentrations of dissolved ions in localized liquid reservoirs, possibly generated by re-melting of surface due to a recent impact. These equilibrium models suggest the difficulty to form the salt compositions of the bright spots directly from freezing of an early global ocean. However, Vu et al. (2017) and Thomas et al. (2018) experimentally show the importance of kinetics in salt precipitation from rapidly freezing brine. Thomas et al. (2018) show kinetically preference of precipitation of ammonia-bearing salts upon rapid freezing of Na-NH_4-CO_3-Cl brine despite their thermochemical instability. This implies the disequilibria in salt precipitation may have played a key role to determine the salt composition of bright spots.

In the present study, we compare the results of salt precipitation using thermochemical equilibrium model of FREZCHEM with those formed by rapid freezing in laboratory experiments to evaluate the effects of disequilibria. The starting solutions are prepared based on thermochemical calculations of water-rock reactions within early Ceres. We also measure infrared spectra of the salt precipitates to compare with the observations of bright spots on Ceres.

Keywords: Cryovolcanos, Ceres, Thermochemical equilibrium

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