Serpentinization and habitability in the Enceladus’ subsurface ocean

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Saturn’s moon, Enceladus, is presently discharging water-vapor plume from its south pole. The discovery of silica nanoparticles in the plume strongly suggested the presence of ongoing hydrothermal activities at the bottom of the subsurface ocean (Hsu et al., 2015). In this work, to estimate the composition of hydrothermal fluids, we conducted thermodynamic modeling of chondrite-seawater reactions at 100 to 300 degrees C and 100 bars with four representative initial seawater compositions; pH = 5.6-13.2 and DIC = 70-320 mmolal (Marion et al., 2012; Postberg et al., 2009; Hsu et al., 2015; Sekine et al., 2015; Glein et al., 2015).

The results show that the chondritic core is serpentinized by the interaction with seawater, generating chemically-varied hydrothermal fluid in all cases. Although SiO2 concentration in the hydrothermal fluid partially depends on the initial seawater composition, it generally increases with increasing temperature of chondrite-seawater reactions. However, the SiO2 concentration in hydrothermal fluids even at 300 degrees C does not exceed the solubility of silica in seawater in the cases with seawater pH values higher than 9.0 because NaHSiO3(aq) increases with increasing pH when Na is the primary cation in seawater (e.g., silica solubility is 1.8 mmolal at pH = 8.5 and 216 mmolal at pH = 10.5). Therefore, pH of seawater is estimated to be less than 9.0 to keep the silica-saturated seawater by subseafloor hydrothermal activities. Taking into account the observation of Na2CO2 in the plume (Postberg et al., 2009), the most reasonable pH of Enceladus’ seawater would be fall within the range between 8.5 and 9.0.

Molecular hydrogen (H2) concentration in the hydrothermal fluid also changes with the initial seawater composition and the temperature of chondrite-seawater reactions. Based on the modeling of the mixing between seawater and hydrothermal fluid, we calculated the Gibbs free energies of hydrogenotrophic methanogenesis and acetogenesis in the mixing zone at the seafloor. As a result, it was revealed that these redox reactions are endergonic under all assumed conditions. Especially, H2 concentration in hydrothermal fluid exceeds 50 mmolal at 300 degrees C, which can generate relatively high energies comparable to those of O2-respirating microbial metabolic reactions (e.g., aerobic sulfide oxidation and hydrogen oxidation) in terrestrial seafloor hydrothermal systems. The results suggest that these hydrogen-based redox reactions can assure the energetic habitability of potential living forms in the hydrothermal systems within Enceladus.

Keywords: Enceladus, hydrothermal system, serpentinization, habitability