Aqueous Geochemistry in Icy World Interiors: Fate of Antifreezes and Radionuclides, and Application to Ceres

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Introduction

The geophysical evolution of many icy moons and dwarf planets seems to have provided opportunities for interaction between liquid water and rock (silicate and organic solids) [1-3]. Here, we explore two ways by which water-rock interaction can feed back on geophysical evolution: the production or consumption of antifreeze compounds, which affect the persistence and abundance of cold liquid, and the potential leaching into the fluid of radionuclides, affecting the distribution of a long-term heat source.

Methods

We use the PHREEQC code [4] to model equilibrium rock and fluid compositions resulting from the interaction of chondritic rock with either pure water or C, N, S-bearing cometary fluid, thought to be the materials initially accreted by icy worlds. We estimate solution freezing temperatures from their compositions.

Results

Our findings suggest that water-rock interaction can strongly alter the nature and amount of antifreezes, resulting in solutions rich in reduced nitrogen and oxidized or reduced carbon that can remain partially liquid down to around 176 or perhaps even 157 K, the respective eutectic temperatures of the NH_3-H_2O and CH_3OH-H_2O systems [5,6]. The prominence of Cl in solution seems to hinge on its primordial supply in ices. Equilibrium assemblages, rich in serpentine and saponite clays, retain thorium and, at low temperatures (T < 50ºC), low water:rock ratios ($W:R$ < 5), and conditions more reducing than the hematite-magnetite buffer, uranium radionuclides. However, the radionuclide ^{40}K can be leached at high pH > 10 and/or high $W:R$ > 5.

Discussion and Application to Ceres

We recommend the inclusion of these effects in future models of the geophysical evolution of ocean-bearing icy worlds. Our simulations suggest that Ceres' unusual surface mineralogy comprising NH_4-phyllosilicates, carbonates, serpentine, and a dark absorber (magnetite, sulfides, and/or carbon black) [7] may result from alteration of chondritic material by cold fluids.

[1] Neveu et al. (2015) *JGR* **120**, 123-154. [2] Hsu et al. (2015) *Nature* **519**, 207-210. [3] Neveu & Desch (2015) *GRL* **42**, 10197-10206. [4] Parkhurst & Appelo (2013) *USGS Tech. Rep.* **6**, A43. [5] Croft et al. (1988) *Icarus* **73**, 279-293. [6] Miller & Carpenter (1964) *J Chem Eng Data* **9**, 371-373. [7] De Sanctis et al. (2015) *Nature* **528**, 241-244.