Neutral pH water on early Ceres

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Ceres would provide a clue for understanding planetary formation processes in our solar system, as it is considered as one of a few proto-planets remaining today [1]. Ceres' surface spectra show a unique absorption band at 3.06 μm, which is recently found to be due to the presence of NH_4-bearing hydrous silicates (e.g., mica) [2]. This suggests that a large amount of annmonia/annmonium should have been contained in the interior ocean of early Ceres, and that Ceres' building materials would have been originated from the outer solar system beyond the NH_3 snowline [2]. However, the formation of NH_4-bearing hydrous silicates would depend on not only the presence of NH_3 in the interior ocean but also its chemical compositions and solution pH where the hydrous silicates were formed.

Here, we performed hydrothermal experiments to constrain water pH on early Ceres [3,4], simulating the reactions between the oceanic water and rock components [1]. We synthesize phlogopite (mica) in NH_3-rich solutions at pressure of 300 bars and temperature of 200 or 300 deg. C. Based on chemical analysis of the fluid and solid samples and infrared analysis of the produced phlogopites, we show that NH_4^+ ions in the solutions are not incorporated into hydrous silicates effectively at high pH, which is typically achieved in NH_3-rich solutions equilibriated with chondrites. Together with the presence of carbonates on Ceres [5], we show that oceanic pH on early Ceres is highly likely to have been near neutral. To achieve neutral pH, the rock compositions of Ceres would be different from that of carbonaceous chondrites. As sulfate salts were found on Ceres [6], sulfate ions may have been a major anion to keep the water pH neutral. This further implies that sulfur in the core could have been oxidized by geological processes, e.g. igneous activity, on earlt Ceres, or that H_2S in the solar nebula could have been oxidied by water vapor at around the H_2O snowline.

[1] Castillo-Rogez & McCord (2010) *Icarus* **205**, 443-459. [2] De Sanctis et al. (2015) *Nature* **528**, 241-244. [3] Hsu et al. (2015) *Nature* **519**, 207-210. [4] Sekine et al. (2015) *Nat. Comms.* **6**:8604, 1-8. [5] Rivkin et al. (2007) *Icarus* **185**, 563-567. [6] Nathues et al. (2015) *Nature* **528**, 237-240.