Modelling Water-Rock Interactions in the Sub-surface Environment of Enceladus.

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Introduction:

Understanding the geochemical cycles occurring at the water-rock interface on Enceladus is crucial for establishing the potential habitability of the sub-surface environment. Using data collected by the Cassini spacecraft (2005-2017) [1, 2] and estimates of the starting composition of the sub-surface ocean on Enceladus, we have modelled how the ocean interacts with a silicate simulant representing the rocky interior. The results from these models define a hypothesized modern ocean chemistry and provide an insight into the geochemical reactions occurring at the water-rock interface. The results from this work support observations made by Cassini, suggesting our chosen starting conditions could provide an insight into the history of Enceladus.

Methodology:

We have used thermochemical modelling (CHIM-XPT) to determine the chemical composition of the sub-surface ocean.

We have defined the chemistry for the silicate interior based upon the chemical composition of a CI carbonaceous chondrite [3]. To test different hypotheses as to the origin of the sub-surface ocean and icy exterior, we have run two models using different starting chemistries for the sub-surface ocean fluid:

Model 1 – Dilute NaCl Solution. This model is based upon the theory that the sub-surface ocean originated as almost pure water [4]. NaCl has been detected in the plumes of Enceladus and E-ring of Saturn and in the model balances the charges of the reactions.

Model 2 – Cometary Ice Fluid. This model assumes that the water originated from a cometary source [4] and uses a cometary fluid composition, based upon data collected from 67P [5]. The dominant species within the starting fluid are therefore H_2O, NaCl, NH_4^+, HCO_3^-, HS^- and SO_4^{2-}.

Physical Conditions. Both models were run at 50, 90 and 120 °C; [6] determined that a temperature of 90 °C or more is required to form the SiO_2 particles that have been measured in the plumes of Enceladus. Pressures were 50 and 80 bar; [6] hypothesized 80 bar pressure at the water-rock interface because of the combined depth of the water ice and ocean fluid, and the gravitational data measurements.

Gravitational measurements imply that the silicate interior of Enceladus is likely to be porous [7], however the extent of this porosity if unknown. We explored this uncertainty by running both models at a high temperature (350 °C) and high pressure (150 bar) to recreate geochemical reactions occurring within the silicate body.

Further assumptions were made based on Cassini data: 1) hydrogen gas (detected in the plumes) is generated in the sub-surface, indicating ongoing hydrothermal activity [8]; 2) high temperature reactions take place in the sub-surface that enable the formation of colloids, detected as solid SiO_2 particles in the plumes [6]; 3) the pH is between 8.5–10.5 based on compositional data [9]; 4) the sub-surface ocean is dominated by salts (NaCl, KCl) [10].

Results:

Sub-surface Ocean. The model outputs mostly generate a range of pHs between 9–10.5 at the water-rock interface. For the higher temperature and pressure runs, the pH is lower and falls between 7–8. The dominant species in the fluid are NaCl, KCl and $NaHCO_3$, which aligns with the Cassini observations. Both models produce aqueous SiO_2, which supports the detection of the solid particles within the plumes.

Gases and Minerals. All the gases at the rock-water interface are dissolved into the aqueous solution. These include H_2O, CO_2, CH_4, NH_3 and H_2, all of which have been detected in the plumes.

Serpentine is the dominant mineral precipitated, accounting for approximately 50 wt.%. This supports the suggestion that serpentinisation reactions are ongoing on Enceladus and are potentially responsible for some of the high heat flux detected on the south polar region.

Conclusion:

Initial analysis of the results from these models, the mineral composition, sub-surface ocean fluid and the gas phase show good agreement with the Cassini data, suggesting the silicate simulant designed may be a good representation for the silicate interior of Enceladus.

References: [1] Waite, J. H., et al., *Nature*, 460, 487-490, 2009. [2] Bouquet, A., et al., *GPR Letters*, 42, 1334-1339, 2015. [3] Hamp et al., *50th LPSC 2019*, Abstract 1091[4] Brown R. H. et al, *Science*, 311, 1425-1428, 2006 [5] Hertier K. H., et al., *RAS monthly notices*, 469, 2017 [6] Hsu H. W., et al., *Nature*, 519, 207-210, 2015 [7] Roberts J. H., *Icarus*. 54-66, 258, 2015 [8] Waite J. H., et al., *Science*, 356, 155-159, 2017 [9] Glein C. R., et al., *Geochem et Cosmochem Acta*, 162, 202-219, 2015 [10] Postberg F., et al., *Nature*, 459, 1098-1101, 2009