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Modelling the Rock-Water Interface on Enceladus

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Abstract

Understanding the potential reactions occurring at the rock-water interface within Enceladus is crucial for establishing that environment's viability as habitable. We are developing methodology to both model and simulate this environment and present preliminary results from this work.

1. Introduction

The detection of plumes emerging from the South Polar Region (SPR) on Enceladus [1] and a high heat flux in the same location [2] have provided evidence of a sub-surface ocean and potential ongoing hydrothermal activity [3, 4]. This, coupled with the presence of bio-essential elements (such as carbon, nitrogen and hydrogen) within the plumes [5], raises the possibility that Enceladus' sub-surface could be a potentially habitable environment.

To understand this environment fully, and to ascertain if it can support life, the biogeochemical cycles occurring at the rock-water interface need to be constrained. Using the data provided by Cassini [6, 7], we aim to model the processes occurring at the rock-water interface. This modelling requires a definition of both silicate and ocean chemistry and an understanding of the physical parameters anticipated to occur at this interface.

Our initial focus will be to model the internal environment at the rock-water interface, then using the results from this, we will simulate these conditions in a laboratory, using a high temperature high pressure reactor. We will present preliminary results of the modelling and its implications for the experimental work.

2. Defining Silicate Chemistry

Cassini detected SiO_2 nanoparticles within the plumes [4], most likely produced through rock-water interactions. This infers Enceladus has a silicate interior [4], but its precise composition is not yet confirmed.

Analysis of the plumes has provided identification of carbon species, including methane, short chain hydrocarbons and carbon dioxide [6, 7]. In addition, nitrogen species were detected in the form of ammonia, molecular nitrogen and hydrogen cyanide [6, 7]. Analysis of the particles within Saturn's E-ring by the Cassini Dust Analyzer [7, 8] suggests that the silicate contains Mg-rich, Al-poor minerals. The inferred composition is one equivalent to a carbonaceous chondrite [3].

For our experiments, we have devised a simulant, basing the silicate on the average composition of a CI chondrite. An average elemental composition was calculated using data available from the Alais, Orgueil and Ivuna meteorites. Using minerals that have been detected previously within CI chondrites, the same chemistry was replicated as closely as possible (Table 1). In addition to the silica component, we will also incorporate the organic components that have been detected in CI chondrites.

Table 1: Initial mineralogy for the silicate interior of Enceladus

Mineral	Weight %
Olivine (9:1 Fo:Fa)	15
Magnetite	15
Serpentine	15
Almandine	10
Diopside	5
Talc	5
Quartz	5
Pyrite	3
Anhydrite	1
Apatite	1
Dolomite	1
Magnesite	0.15
Calcite	0.02

3. Ocean Chemistry

We will be using a theoretical starting composition for the 'initial' sub-surface ocean, based upon the chemistry of the ice shell, assuming the ocean originated from the melting of this. The composition will be based upon previous research by Neveu et al., [9] using C, N, S-bearing cometary fluids, proposed to be the materials initially accreted by icy worlds [9].

4. Modelling

The modelling will focus on the interaction of the 'initial' ocean chemistry with the defined silicate simulant – mimicking the interaction of the sub-surface ocean with the silicate interior, specifically focusing on the movement of carbon species.

We will initially use CHIM-XPT [10], used previously to model martian water-rock interaction [11-13], at a temperature range of 273-373 K [4]. These temperatures were chosen based on the assumption that the concentration of salt and ammonia is insufficient to have an effect on the freezing/melting point of water. We will explore a pressure range suggested by Hsu et al., of 10-80 bar [4], which will allow us to better constrain the pressure to be used for the simulation experiments. Based upon the plume chemistry, the expected pH of the sub-surface ocean would be alkaline, with an estimated range from 8.5-12 [14]. This would also be consistent with our martian models that contain many of the same minerals [12,13]. We expect phyllosilicates and oxides to form, potentially zeolites [13].

The CHIM-XPT database contains hydrocarbons (e.g. CH_4, C_2H_6, C_3H_8), ammonia, and C-N-S-bearing compounds. This will allow us to establish a baseline mineralogy before incorporating the full set of organics into the models. The modelling will lead to a theoretical 'modern' ocean composition, which can be compared to the composition of the plumes, analysed by Cassini [6, 7]. Since these plumes are expected to originate from the sub-surface ocean, it can be considered that the plume composition reflects that of the ocean.

5. Summary

We plan to model the rock-water interface on Enceladus using the chemistry of a CI chondrite to represent the silicate interior. Using both Cassini data and preliminary modelling of an early sub-surface ocean, we will acquire a theoretical composition for the current sub-surface ocean. Subsequently, modelling the interaction between the ocean and silicate we aim to acquire a better knowledge of what reactions are occurring at their interface. We plan to use the results of this modelling work to underpin laboratory simulations of the rock-water interface.

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