The Physio-Chemical Properties for the Interior of Enceladus

Conference or Workshop Item

THE PHYSIO-CHEMICAL PROPERTIES FOR THE INTERIOR OF ENCELADUS. R. E. Hamp[1], N. K. Ramkissoon[1], K. Olsson-Francis[1], S.P. Schwenzer[1] and V.K. Pearson[1], [1]Faculty of Science, Technology, Engineering and Mathematics, The Open University, Milton Keynes (rachael.hamp@open.ac.uk)

Introduction: Evidence of a sub-surface ocean and potential hydrothermal activity has led to substantial interest in Enceladus as a hypothetically habitable environment [1-3]. Enceladus meets the known requirements for life; there is a supply of water, energy and a source of bio-essential elements, such as nitrogen and carbon [4]. The composition of the sub-surface ocean is a key component in determining the potential existence of life; the current data collected by Cassini could suggest the plausible existence of methanogens, nitrogen fixation bacteria and/or ammonia oxidising bacteria within the sub-surface ocean [3, 5]. However, to understand the real potential of the sub-surface ocean environment to harbour life requires an understanding of the physical and chemical processes operating and their effects on potential life.

Approach: Understanding such processes requires hypotheses to be drawn regarding the present and historic composition of Enceladus' silicate interior, and the (bio)geochemical cycles that may operate/have operated within the moon's sub-surface environment. To this end, a combination of simulation experiments and modelling are planned. Firstly, we plan on modelling the interactions between the silicate and ocean, under the conditions estimated at their interface. Subsequently, we will use the information we obtain from our model, to conduct laboratory experiments to simulate the moon's sub-surface environment, in order to study the reactions between the silicate and ocean. However, definition of the required experimental and modelling parameters is not straightforward since current knowledge of Enceladus is based on limited data [1, 6], existing models [7-9] and previous simulations [2, 10].

Assumptions. Given the paucity of data, some assumptions are required. Firstly, we assume that there is a global salt water sub-surface ocean [11] and that this is an open system [2]. Secondly, we assume the core is silicate and is a porous, unconsolidated body [7, 12] that has not experienced significant melting [2].

The following parameters therefore need definition and justification in order to develop the experimentation further: brine (ocean) composition; silicate composition; temperature; pH; pressure.

Brine composition: Analysis of the plumes indicates that they are predominantly composed of water ice/vapour and the largest non-water constituents are salt grains (NaCl and $NaHCO_3/Na_2CO_3$) [7, 13]. Chemical data from the Ion and Neutral Mass Spectrometer (INMS) confirms the presence of other molecules within the plumes such as, hydrogen, carbon dioxide, methane, ammonia, carbon monoxide and nitrogen [6]. This data will be used to define a plausible brine composition for the current sub-surface ocean. However, there are limitations to this data: molecules may undergo reactions with the changes in pressure and temperature as they ascend through the ice and exit into the vacuum of space, processes such as fractional distillation could also occur [7].

Silicate composition: The detection of SiO_2 nanoparticles within the plumes infers a silicate interior, which could produce these particles through water-rock interactions [2]. The precise composition of this silicate interior is not yet confirmed, but for our model and simulation experiments, this is crucial. Analysis of particles within the E ring suggests that the silicate core contains Mg-rich, Al-poor minerals and organic compounds [1, 6, 14]. The inferred composition from this is one equivalent to a carbonaceous chondrite.

Carbonaceous chondrites exhibit all the characteristics to account for the hydrogen, carbon and nitrogen detected in plume material [2, 7, 9]. The measured hydrogen concentration can be accounted for through serpentinisation reactions occurring between olivine and the sub-surface ocean [15]. The carbonaceous component provide a carbon source for the formation of the various carbon products, which are seen in plumes, and nitrogen containing molecules could be accounted for by the reactions of various amines known to be present in carbonaceous meteorites. Other studies have found that as the subsurface ocean reacts with the silicate core, this produces secondary minerals usually found in carbonaceous chondrites [10].

We will base the initial silicate composition on the chemistry of CI carbonaceous chondrites, this would provide us with an analogue to represent the current composition of Enceladus, where aqueous mineral alteration has occurred. However, when replicating an earlier Enceladus, where a larger proportion of the mineralogy will be (relatively) unaltered, then an alternative chondrite type will be adopted.

The modelling work we propose will aid in defining the brine composition, by modelling the interaction between the proposed silicate and water, under the conditions determined. We will study the changes in the water chemistry, providing an insight into how the silicate controls the brine composition. Using the data from the model and published data, a brine composition will be defined to use in the simulation experiments.

Temperature: Accurately modelling thermodynamically controlled reactions requires the correct temperature to have been initially determined. The estimated temperature at the ocean-ice interface is approximately 273 K [7]. It is assumed that the concentration of salts and ammonia present within the subsurface ocean is insufficient to have an effect on the freezing point of water [13]. The presence of SiO_2 nanoparticles within the plume suggests a minimal temperature of 363 K at the water-rock interface, which is expected to be the minimum temperature required for the formation of the SiO_2 nanoparticles [10], therefore our model and experiments will be using temperatures of 363–373 K at the rock-water interface.

pH: Plume chemistry indicates an alkaline subsurface ocean, with current suggestions for pH ranging from 8.5–10.5 [10]. However, pH can be influenced by temperature meaning there could be a pH gradient within the sub-surface ocean from strongly/moderately alkaline at the water-ice interface to mildly alkaline at the water-silicate boundary [2]. We anticipate for our work the pH will be 8.5–9.5 due to the higher temperature at the rock-ocean interface, however the pH will be predominantly dictated by the brine chemistry. For our simulation experiments the pH will be determined by the results of our modelling work.

Pressure: Pressure, and how it changes with depth in the sub-surface ocean, is not well understood. [10] have provided a conservative range, expecting pressures to vary between 10 and 80 bar, with the pressure increasing with ocean depth [10]. Detailed pressure calculations have suggested that the pressure at the rock-water interface fall within the range of 28 to 45 bar [16] or up to 53 bar [6]. For our work, which focusses on the water-rock interactions, we are intending to invoke a pressure range of 30-50 bar; our experimental procedures are restricted by capabilities of the reaction vessel but the range should be a good representation of the pressure at the rock-water interface.

Summary: We have reviewed the current physical and chemical conditions of the Enceladus sub-surface environment, including the composition, temperature, pH and pressure. Here we have defined some of these parameters and, through the aid of modelling, will define and refine the remaining parameters needed for our experimental work. Simulations of the chemical reactions occurring within Enceladus can then be carried out to advance our understanding of the internal environment of Enceladus and help evaluate its potential habitability. Once a better understanding of the chemical reactions occurring at the rock-water interface has been carried out, then potential analogues on Earth can be evaluated and known microbial life can be tested to see if it could survive the conditions of Enceladus.

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