EPSC Abstracts
Vol. 10, EPSC2015-644, 2015
European Planetary Science Congress 2015

On the possibility of Serpentinization on Enceladus

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Abstract

This work studies the possibility of serpentinization at the water/rock boundary of Enceladus (pH 7–9, 25–50 bars, and 0–50 °C), and further estimates the hydrogen production rates. Thermodynamic databases were created with the DBCreate program [10], and geochemical modeling was applied with the EQ3/6 software package [2]. The chemical composition of the subsurface aquifer is assumed to be similar to the plumes. Nine scenarios were tested to specify the core composition. It is shown that serpentinization seems to be possible at the water/rock boundary on Enceladus if an iron-rich end-member is present in the core.

1. Introduction

Enceladus, an icy moon of Saturn, is considered a potential place for a second genesis of life in a rather easy accessible environment for future space missions[5]. Plumes erupting material out to Saturn's E ring have been detected[6]. This and the latest gravity data received by NASA's Cassini probe highly suggest a regional subsurface water reservoir to exist[1]. The Cassini mission has detected most of the necessary elements for life (C,H,N,O,P,S) in these plumes[9], and three ecosystems known from the Earth could in theory exist in the subsurface environment [4]. These ecosystems rely on a sufficient hydrogen source. On Earth, this molecule is known to be produced when the oceans interact with silicates in the mantle through a geochemical process called serpentinization. The aim of this work is first of all to examine whether serpentinization is possible on Enceladus at an assumed pressure of 25-50 bars [7] and a temperature of 0-50°C. If it is possible, then the second aim is to estimate the hydrogen production rate.

2. Methods

Geochemical modeling with the EQ3/6 software package has been applied [10], and thermodynamic databases have been created with the DBCreate program [2]. Due to the present lack of data on the chemical composition of the subsurface sea, it is assumed to equal the chemical composition of the plumes. Nine scenarios based on Enceladus being a captured comet or consisting of aggregated ring material are used to specify the core composition. These are different combinations of pyroxenes and olivines or no silicates, respectively. As an example the chemical evolution for the model with 1.0 mol fayalite is shown in Figure 1.

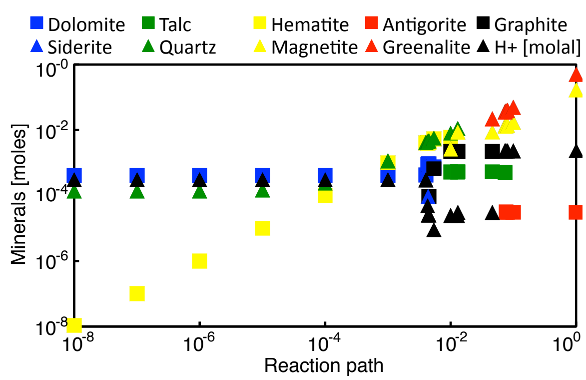

Figure 1: Moles of product minerals as a function of the reaction path for the model with 1.0 mol fayalite at 25 bars, 0 °C and pH 9. Carbonate minerals are blue, silicate minerals are green, oxide minerals are yellow, minerals in the serpentine group are red, graphite (C) and hydrogen are black. Notice: The hydrogen concentration is given in molality on the same scale.

3. Results

Minerals in the serpentine group are produced in the end of the reaction with antigorite and greenalite produced simultaneously. The hydrogen production rate decreases in the central part and increases towards the end. Serpentines were only produced in the presence of an iron-rich end-member. In this case the hydrogen production increases in the end. To calculate the hydrogen production rates, numerical integration of hydrogen to the entire reaction in the different scenarios was applied. The results of the nine scenarios in the four different environments can be found in Table 1.

Table 1: Hydrogen production rates [mg H_2 / kg solution] for nine scenarios tested for four set of parameters.

pH	9	7	9	9
Pressure [bars]	25	25	50	25
Temperature [°C]	0	0	0	50
All five minerals[a]	1.9	1.9	1.8	1.9
All three pyroxenes[a]	2.1	2.1	2.1	2.2
Both olivines[a]	2.4	2.4	2.4	2.4
1.0 mol diopside	0.0	0.0	0.0	0.0
0.9 mol enstatite	0.0	0.0	0.0	0.02
2.8 mol ferrosilite	0.03	0.03	0.03	0.56
3.9 mol forsterite	0.0	0.0	0.0	0.0
1.0 mol fayalite	2.2	2.2	2.2	2.2
None minerals[b]	-	-	-	-

[a]The distribution of the minerals is equivalent to the distribution found in the nucleus of comet 9P/Tempel 1[3]. [b]Serpentinization did not occur in the model with no minerals.

4. Discussion

The complex aqueous solution assumed (based on the composition of the plumes) affects the serpentinization process on Enceladus. In addition, the pressure and temperature ranges might be too small to make a significant change on the hydrogen concentration. To improve the estimate of the hydrogen production rate, measurements for the silicate ions in the aqueous solution on Enceladus are needed.

5. Conclusions

This work shows that serpentinization seems to be possible at the low pressure and temperature likely found at the water/rock boundary on Enceladus. Hydrogen is only produced in the presence of an iron-rich end-member. In these scenarios, the hydrogen concentration is estimated to be around 2.0 mg/kg solution. Hence, the resulting available amount of hydrogen in the subsurface aquifer could be sufficient to serve as a substrate for hydrogenotrophic methanogenic life on Enceladus [8].

Acknowledgements

We would like to thank Wolfgang Bach from the Research Group "Petrology of the Ocean Crust" (University of Bremen) for his very helpful support on applying the geochemical modeling software.

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