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DERIVATION OF ENCELADUS' OCEAN COMPOSITION FROM THE LAST CASSINI MEASUREMENTS

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Abstract. The last Cassini measurements over Enceladus' south pole have redefined our understanding of its plumes' composition. These measurements provide important information about the internal ocean's composition since the source of the geysers is likely connected to it. Here, we applied a thermodynamic statistical model allowing the quantification of the effect of volatiles trapping into clathrates on the resulting internal ocean's composition, to reproduce the observed plumes measurements. Two end-members were considered for the plumes composition. In both cases, a gas input made predominantly of 80–90% CO_2 is required to enable the convergence of the CO_2/CH_4 ratio in the ocean towards the plumes' measured value.

Keywords: Enceladus, ocean's composition, clathrate, astrobiology, Cassini

1 Introduction

The Cassini spacecraft has greatly improved our knowledge of the Saturnian system, especially in the case of Enceladus, one of the most intriguing moons orbiting the ringed planet. Enceladus is expected to harbor an internal ocean (Iess et al. 2014; Soucek et al. 2017). One of the major discoveries of the Cassini spacecraft is the gas and ice emission creating plumes over the south pole of Enceladus. Thanks to the presence of the Ion and Neutral Mass Spectrometer (INMS) aboard Cassini, the chemical composition of these plumes has been measured. The goal of our work is to quantify the chemical evolution of the Enceladus' ocean, considering a gas input into the ocean and clathrate production. At the end of our calculations, we aim at obtaining the same chemical abundance ratios in the ocean as those detected in the plumes, assuming the plumes composition is representative of the ocean's.

2 Model

Our thermodynamic statistical model gives the abundances of species dissolved in the ocean, and the proportion of guests trapped in clathrate, produced at each time step (Mousis et al. 2013; Bouquet et al. 2015). We assume that Enceladus' ocean is in a steady state, implying a gas input to balance the expulsion of volatiles with the plumes. Clathrate formation is triggered when a significant amount of a chemical species is reached in the ocean and exceeds the solubility limit. As different species are more or less prone to be trapped into clathrates, this process leads to a chemical evolution of the ocean. The ocean reaches an equilibrium when the clathrate formed contains the same gas mixture as the one provided to the ocean. Table 1 shows the abundances of the main volatiles detected in the plumes. H_2 does not form clathrate at the considered pressure conditions, and NH_3 forms a stoichiometric hydrate. We finally obtain two end-members ratios for the plumes composition, i.e. $CO_2/CH_4 = 8$ and 1. Different ice shell thicknesses have been considered, with densities of 940 kg/m^3 for the ice and 1040 kg/m^3 for the ocean (Soucek et al. 2017). Gravity is set to 0.113 m/s^2 (Olgin et al. 2011; Iess et al. 2014). This conducts to pressures of ∼80 bar and 108 bar for 3 km and 40 km ice thicknesses, respectively.

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Table 1. Cassini measurements in Enceladus' plumes (Waite et al. 2017).

Chemical species	H_2O	CO_2	CH_4	NH_3	H_2
Ratio (%)	96–99	0.3–0.8	0.1–0.3	0.4–1.3	0.4–1.4

3 Results

Figure 1 showss the time evolution of Enceladus ocean's composition. The amount of gas injected into the ocean is modeled after estimates Cassini measurements, leading to a value of (1-5)$\times 10^9$ mol/yr (Waite et al. 2017). Left panel shows that steady state is reached after $\sim$200 millions years of evolution for enabling the convergence of the CO_2/CH_4 ratio to 1 and requires the adding of 3.1 times more CO_2 than CH_4 to the ocean at each time step. Right panel shows that steady state is reached after 3 billion years of evolution for enabling the convergence of the CO_2/CH_4 ratio to 8. Here, 34 times more CO_2 than CH_4 must added to the ocean at each time step.

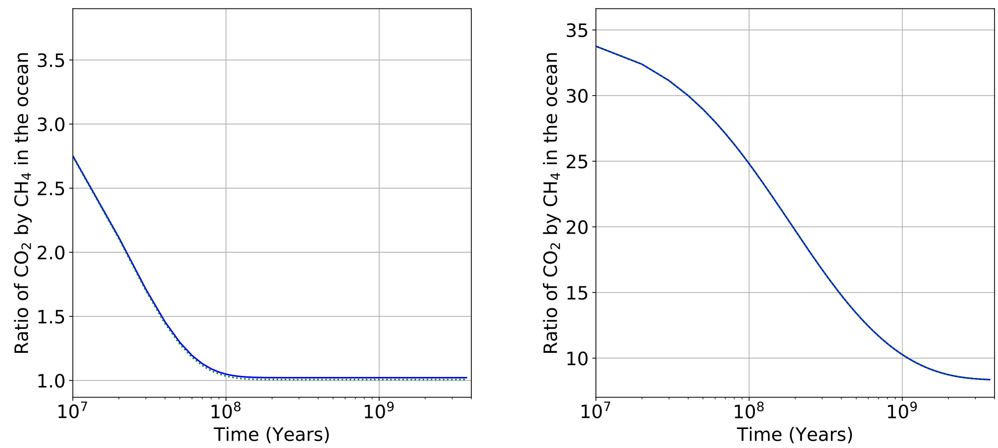

Fig. 1. Composition of Enceladus' ocean over time, assuming convergence of its CO_2/CH_4 ratio toward 1 (left panel) and 8 (right panel).

4 Conclusions and perspectives

Our calculations indicate that Enceladus' ocean could need a time of evolution as long as the Solar System lifetime to reach equilibrium. Further investigation is needed to support this preliminary conclusion. Future studies will be also devoted to the consideration of the ocean's pH. In Enceladus' alkaline ocean, the speciation of CO_2 is expected to be shifted towards HCO_3^- ions (Glein et al. 2015), reducing the amount of CO_2 available to form clathrates. Moreover, we will consider a possible variation over time of the flux of volatiles into the ocean, to account for possibly more intense initial hydrothermal activity.

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