Comparative geochemistry analysis between the ocean of Enceladus and the aqueous ocean on Earth during the Snowball Period and its interaction with the atmosphere in a hypothetical destabilization of the ice crust.

Katherine Villavicencio Valero[1] and Emilio Ramirez Juidias[2]

[1]International Research School of Planetary Sciences
[2]Universidad de Sevilla

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Abstract

Enceladus is one of the moons of Saturn that has caught the attention of scientists due to the potential for harboring life. It has a stratified internal structure, below its ice shell has been detected an ocean layer which material is expelled through the jets from the plumes located in the south pole. The ice layer could limit the exchange of material between the ocean and the atmosphere. We present a model of the thermal atmospheric evolution with the presence of clouds, in order to understand, what would happen in the ice crust if the atmosphere has a small greenhouse effect. That change in the atmosphere was present during the Snowball period on Earth, where some molecules from the primitive ocean were liberated into the atmosphere. Those molecules probably are present in the ocean on Enceladus. We also present a comparative geochemical analysis of the molecules present in the ocean of Enceladus and the ones which were present in the ocean of Earth during the Snowball period in order to predict if Enceladus is in a primitive evolutionary stage and if these molecules could interact with the atmosphere if the ice crust has a destabilization.

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K. Villavicencio[1,2] and E. Ramírez-Juidías[3], katherine.villavicencio@unich.it
[1]International Research School of Planetary Sciences, Viale Pindaro 42, 65127, Pescara, Italy
[2]Université Claude Bernard Lyon 1, 2 Rue Raphaël Dubois, Villeurbanne Cedex, 69622, Lyon, France
[3]University of Seville, Graphic Engineering Department, ETSI, Av. de los Descubrimientos, 41092, Seville, Spain.

Introduction: Enceladus has a subsurface ocean beneath the ice shell. This might be the origin of the water vapor expelled through jets in the south pole, that is a component of the atmosphere. The atmosphere composition could change if the interaction with the material from the ocean does not be limited by the ice crust. What would happen if the atmosphere of Enceladus slightly changes with the presence of clouds? This work presents a comparative analysis of the chemical reactions in the ocean of Enceladus with the aqueous geochemistry oceans on Earth during the Snowball event. We also present a simulation of the atmosphere with a slightly greenhouse effect and how this process could destabilize the ice crust.

Data about the composition of primitive and ancient oceans on Earth can be obtained through geochemical simulations of the interaction of oceanic water with atmosphere biosphere and lithosphere (Glein et al. (2014) and Ray et al. (2021)). In order to compare the composition of the ocean of Enceladus and the terrestrial oceans during the Snowball event, it has been used the data of concentration of molecules in the ocean during the Snowball event on Earth. The data of the concentration of species in the ocean of Enceladus has been calculated from the spectral lines of the plumes of Enceladus using the available information from the PDS: The Planetary Atmosphere Node database from the Cassini mission. Table 1 shows a few key species that are present in both oceans:

Table 1. Concentration of species of molecules.

Species	Enceladus (g/kg)	Earth (g/kg)
Na^+	7.3429	10.7838
Cl^-	7.0764	19.3531
${CO_3}^{2-}$	2.8666	0.0162
${HCO_3}^-$	0.0311	0.1068
${SO_4}^{2-}$	0.01 – 0.1	2.713

The ocean on Earth is a bit saltier than the one on Enceladus, and the most common ions in both oceans are the Na^+ and the Cl^-. These oceans have a different pH level, around 8.1 on Earth and more basic in Enceladus, around 12.2 (Zolotov 2007). The ocean on Enceladus contains more dissolved inorganic carbon (${CO_3}^{2-}$) than on Earth (${HCO_3}^-$). This could be due to the serpentinization of H_2 in Enceladus.

Sulphate species appear to be scarcer in Enceladus but the role of electron acceptor could be taken by other elements such as iron, the same way it happened on Earth. In the lower concentration (0.01) of ${SO_4}^{2-}$ only aqueous reductants (HS^-) react with the oxidants, while in the larger concentration (0.1) the minerals are considered as a source for reductants. The quantity of sulphate is below the amount that is present on Earth, but it is almost similar to the concentration of molecules during the Snowball event.

Simulation of the global temperature if Enceladus would have clouds: if the concentration of water in the atmosphere were higher and the formation of clouds were possible, the temperature would rise and stabilize due to the greenhouse effect. In order to predict a possible melting of the ice shell that allows for the emergence of the ocean of Enceladus, this model considers the concentration of molecules present in the plumes of Enceladus detected by the Cassini mission. By applying the Navier Stokes Equations for the greenhouse effect, the result we obtained says that, the stabilization of the temperature is reached with the 5% of clouds and tends to stabilize after roughly 1000 years at 0°C, indicating that, a possible greenhouse effect could be provoked into the atmosphere of Enceladus and the molecules analyzed could interact with the atmosphere changing the global composition and a possible melting of the ice crust.

The thermal evolution of the atmosphere with a small percentage of clouds could allow for a destabilization of the ice crust through time, provoking a greenhouse effect as it happened during the Snowball event on Earth, leading to the appearance of material from the ocean. The dynamic between the material from the ocean and the atmosphere could produce a change in the chemical composition into the atmosphere giving as a result that, the aminoacids present in the ocean of Enceladus (Guzman et al. 2019) could start building the chains of life.

References: [1] Glein et al. (2014) Geochimica et Cosmochimica Acta, 1-64. [2] Ray et al. (2021) Icarus, 364, 114248. [3] Zolotov (2007) GRL, 34, 1-5.