Clathrate blankets as (in)surmountable barriers for hydrothermal systems in Europa

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November 25, 2022

Abstract

A key question pertaining to Europa's habitability is whether hydrothermal activity could be sustained for long periods of time, enabling redox and nutrient exchange between the ocean and rocky interior [e.g. 1, 2]. Europa's early ocean, if formed during differentiation, could have been infused with gases [3]. A consequence of this initial infusion is that clathrate hydrates may have been stable within the ocean. These clathrates could then rise to the bottom of the ice shell, or blanket the seafloor, depending on their density relative to the ocean. Accumulations of floating and sinking clathrates would affect the geological and thermal evolution of Europa because of their high heat capacity and low thermal conductivity compared to ice Ih, but sinking clathrates could also inhibit chemical exchange between the ocean and the rocky interior. We calculate the stability and density of CH4 and CO2 clathrates, and predict the volumes precipitated at the seafloor or accumulated at the base of the ice shell, for ocean compositions evolved from the interior of Europa during metamorphism on the path towards formation of a metallic core [3]. For a chemically reduced ocean derived from heating a mix of chondritic material near Jupiter [4], plus cometary volatiles, ˜2 x 10ˆ7 kmˆ3 of methane clathrates form. These are less dense than the ocean (Fig. 1), and float to the base of the ice shell. However, for a CO2-rich ocean derived from CI or CM chondrites, ˜3 x 10ˆ8 – 2 x 10ˆ9 kmˆ3 of CO2 clathrates could form, i.e., sufficient feedstock to form a 13–77 km global layer on the seafloor. A salty ocean (e.g. 10 % MgSO4) or a warm seafloor (316 K) may be needed to prevent the accumulation of a CO2 clathrate blanket (Fig. 1), although the blanketing effect would thin the equilibrium thickness of the clathrate layer to ˜500 m for allowable heat fluxes (˜50 mW/mˆ2). [1] Vance, S. et al. (2007). Astrobiology, 7(6), 987–1005. https://doi.org/10.1089/ast.2007.0075 [2] Klimczak, C. et al. (2019). 50th Lunar. Planet Sci. Conf., Abstract #2132, p. 2912. https://ui.adsabs.harvard.edu/abs/2019LPI....50.2912K [3] Melwani Daswani, M. et al. (2021). A metamorphic origin for Europa's ocean (preprint). https://doi.org/10.1002/essoar.10507048.1 [4] Desch, S. J. et al. (2018). Astrophys. J., Suppl. Ser., 238(1), 11. http://dx.doi.org/10.3847/1538-4365/aad95f

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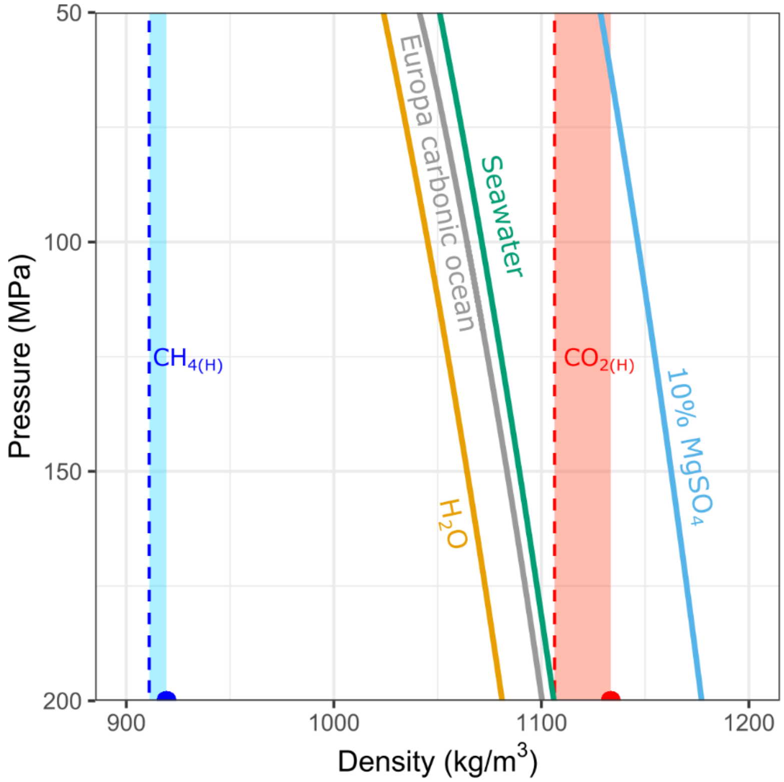
[4] Desch, S. J. et al. (2018). *Astrophys. J., Suppl. Ser.*, **238(1)**, 11. http://dx.doi.org/10.3847/1538-4365/aad95f



Plain-language summary

Whether Europa's ocean is habitable for "life as we know it" could depend on whether hydrothermal activity at the deep seafloor could be sustained for long periods of time, which could be a source of energy and nutrients for potential lifeforms. However, there are a number of impediments to hydrothermal activity, including clathrate hydrates blanketing the seafloor and acting as a barrier between the ocean and the rocky interior. Clathrate hydrates are ice-like crystals of water molecules forming "cages", plus a guest molecule such as carbon dioxide (CO_2) or methane (CH_4) inside the cages. We previously calculated that Europa's early ocean could have been infused with large amounts of CH_4 or CO_2 gas, which could lead to the formation of clathrates. We have now calculated that CH_4 clathrates would be less dense than the ocean, so would float towards Europa's ice shell. However, CO_2 clathrates would tend to be denser than the ocean, sinking to the bottom, and forming a global blanket up to 500 m thick on the seafloor. A very salty ocean (for example, with 10 % magnesium sulfate), or a very warm seafloor (> 313 K), could prevent the accumulation of CO_2 clathrates at the seafloor.