

THE EVOLUTION OF OCEANS IN LARGE ICY SATELLITES. O. Bollengier¹, B. Journaux¹, J.M. Brown¹ and S.D. Vance², ¹Department of Earth and Space Sciences, University of Washington, Seattle (WA), United States (corresponding author: obollengier@gmail.com), ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena (CA), United States.

Introduction: The largest icy satellites of Jupiter (Europa, Ganymede, Callisto) and Saturn (Titan) harbor the most extensive bodies of liquid water currently known in the solar system. With their rich chemistry, stability through time, and expected thermo-chemical exchanges at their silicate interface, the hydrospheres of these moons currently appear as the most favorable places for life in our stellar neighborhood [1].

Among these moons, Europa is seen as standing in a class of its own. Owing to its lower water fraction (~10 wt%), its hydrosphere is limited to the pressure range of the low-density ice Ih (< 0.2 GPa). Its ocean is thus expected to be in contact with its rocky interior, a configuration favoring the input of energy and chemicals required for life [2]. Meanwhile, the higher pressures found in the thicker hydrospheres of Ganymede, Callisto and Titan (up to ~2 GPa for Ganymede [3]) imply the formation of the high-pressure ices III, V and VI. These denser ices would form layer isolating the ocean from the silicate mantle [3]. For this reason, the astrobiological potential of the largest icy worlds is not considered on par with that of Europa.

In this work, by considering the presence of salts in the hydrospheres of the largest icy satellites, we argue that the downward migration of any subsurface ocean eventually down to the silicate interface is a necessary consequence of their cooling over time. Our conclusion invites to reconsider in a more favorable light the range of habitats that may be found in large icy worlds.

Approach: Understanding the evolution of aqueous fluids in hydrospheres requires a knowledge of their density (to assess their gravitational stability) and PTX equilibrium with H₂O ices (to assess their crystallization or the melting of ices). MgSO₄, one of the main salt expected in the aqueous chemistry of the outer solar system, is also the only one for which accurate densities have been reported for the fluids in the GPa range pertaining to the largest icy worlds [4]. However, in this pressure range, the H₂O-MgSO₄ phase diagram was only explored up to 0.2 GPa [5].

We carried anvil cell experiments to provide the missing liquidus and eutectic determination in the 0.2 – 1.2 GPa pressure range. In parallel, we coupled the thermodynamic model for MgSO₄(aq) [4] with one available for H₂O ices Ih, III, V and VI [6] to provide an independent construction of the water-rich side of the H₂O-MgSO₄ phase diagram agreeing with our experimental constraints.

Combining the density and equilibrium knowledge in the H₂O-MgSO₄ system, we show that MgSO₄-bearing brines can reach higher densities than any H₂O ice phase with which they could be in equilibrium in Ganymede's hydrosphere. Building on this conclusion, and adopting for a framework the general cooling of icy moons, we show that a crystallizing salt-bearing subsurface ocean will eventually progressively migrate downward to the silicate interface (fig.1). The consideration of the ice liquidus allows the construction of plausible structures with thermal gradients in each liquid and ice layer similar to those currently existing in the literature [7].

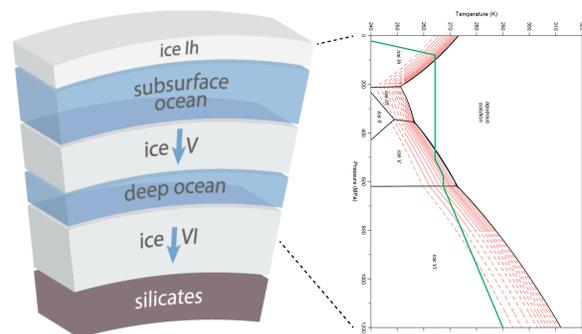


Fig. 1. Evolution of the ocean in a high-pressure hydrosphere and associated thermal gradient.

Perspectives: Recent work has demonstrated the ability of strains of *E. Coli* to thrive at pressures up to 2 GPa [8], encompassing the whole pressure range of Ganymede's hydrosphere. The perspective of deep oceans as a natural evolution of large icy worlds thus invites to reconsider their habitability more favorably. Though based on the H₂O-MgSO₄ system, our conclusions are expected to pertain to other chemistries as well. Our group is currently undertaking the study of the H₂O-NaCl and H₂O-NaCl-MgSO₄ systems to test this hypothesis further.

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