HIGH-PRESSURE WATER ICE AND SALTS THERMODYNAMICS: HOW CAN PHYSICAL CHEMISTRY CONSTRAIN THE HABITABILITY OF DEEP OCEANS?

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Introduction: Discoveries and investigations of deep oceans in the solar system, at Europa, Ganymede, Callisto, Enceladus, Titan, and possibly in Dione, Triton, Pluto and hypothetical water-rich exoplanets, have brought greater attention from the planetary science and astrobiology communities to the high-pressure behavior of water-rich chemical systems. NASA's Europa Mission [1] and ESA's JUICE mission [2] are promising to return even greater details about these deep ocean worlds. The pressures and temperatures of water rich environments predicted in such planetary bodies reach beyond any conditions found in Earth's natural habitats, and therefore are outside the range of most thermodynamic datasets. If we want to constrain the conditions where life might have appeared and thrived, we need to better understand the primitive chemical conditions in deep oceans in icy worlds, most probably controlled by abiotic geochemical reactions (e.g. hydrothermalism, chondritic material aqueous alteration, silicate dehydration). We chose to focus on NaCl and $MgSO_4$ aqueous chemistry as they are suggested by space probe results, remote sensing obser-vaions and geochemical modeling, to be dominant species in icy moons deep oceans [3,4].

Approach: Recently our own experimental and simulation work on H_2O-NaCl and H_2O-$MgSO_4$ systems densities suggests the existence of various possible liquid aqueous habitat sandwiched between high pressure ice layers and possibly the silicate bedrock [5-7]. The next step towards more realistic oceanic composition is to quantify the combine influence of these systems (H_2O+NaCl+$MgSO_4$). Furthermore, salts have been observed to incorporate high-pressure water ice polymorphs, but large uncerntaities remains on how much this would change their physical properties compared to a pure H_2O counterpart [8,9].

We present our latest experimental results conducted in diamond anvil cells on the stability fields of high pressure ice VI and ice VII (<10 GPa) in equilibrium with NaCl+$MgSO_4$ aqueous solutions. We were also able to make *in-situ* observations of relative densities between the ices and the aqueous solutions that can be compared to fluid densities in H_2O-NaCl and H_2O-$MgSO_4$ systems separately [5,6].

We also describe recent findings from high pressure X-Ray diffraction and X-Ray Fluorescence synchrotron experiments on salt incorporation in high-pressure ices VI and VII and the resulting effects on their volume, density and composition [10]. The incorporation of salts species is observed to change significantly all of these properties and can imply major effects on solute distribution and transport in thick hydrospheres with high pressure ices that will be discussed. The combination of all these experimental results enables us to infer a more complex story about habitability in water-rich planetary bodies where liquid habitats can be located below dense high-pressure ices and solutes can be transported by high-pressure ice convection.

Perspectives: These results should inspire the astrobiology and organic chemistry communities to explore new sets of habitable environment chemical and physical conditions that could be present deep in icy moons and water-rich exoplanets.

These studies are conducted with the goal of constructing a comprehensive thermodynamical model of water solution up to high pressure (< 10GPa) useful for the earth science, planetary science and astrobiology communities. This comprehensive model based on derivatives of Gibbs energy surfaces for each phase is able to provide all major thermodynamical properties (e.g. density, bulk modulus, heat capacity, sound speed) [11].

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