

Phase diagram of the binary H₂O-NaCl and salty ice VII at pressure and temperature conditions of exoplanets and large icy moons

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Abstract

We present here the first experimental data for the phase diagram of the H₂O-NaCl system at high. Our results show a significant influence of NaCl on the phase diagram. A lot of NaCl is directly dissolved into the dense ice phase. This would increase the depth of the solid phase transition inside large icy moons or super-earth exoplanets. These results may have major implication for astrophysical, geophysical and geodynamical modelisations of this water-rich planetary bodies.

1. Introduction

Water ice is a major molecule in the Universe. It is present in most of the large moons around Jupiter and Saturn as well as in exoplanetary systems. H₂O is expected to be found deep in planetary interiors as high density ice such as ice VII. The possible mixing with other common species such as ammonia or methane has been extensively studied (rev. Sohl 2010 [4]). However, there is no data available yet for the H₂O-NaCl system although it is predicted as a major constituent of planetary oceans [4]. In the present study, we investigated experimentally the influence of the salt on the phase diagram of H₂O-NaCl, and on the properties of dense ice VII which presence is proposed in large icy moons and Ocean exoplanets

2. Methods

The experiments have been performed in a gas-membrane diamond-anvil cell (DAC) equipped with ultralow-fluorescence diamonds. The high-pressure cell was loaded by placing a 80 μ m thick Pt-lined gasket drilled with a 200 μ m diameter hole on one of the diamond culets. At least two ruby spheres were added and ambient pressure and temperature R1 ruby

measured systematically before loading the high-pressure chamber with the salty solutions, 1 and 4 molal NaCl, respectively. The cell was closed immediately after, ensuring no H₂O loss by evaporation.

The DAC was externally heated and temperature was continuously read from a thermocouple glued on one diamond anvil. The estimated precision on temperature is better than 1 K.

Pressure (P) in the cell was calculated using the ruby R1 frequency shift [2]. The estimated uncertainty is ± 0.07 GPa.

Phase identification was made by optical microscopy combined with Raman spectroscopy. Raman spectra were collected in the backscattered geometry using the 514.5nm line of an Ar⁺ laser (Spectra PhysicsTM) as the incident energy (100 mW) a LabRam HR 800 Raman spectrometer (Jobin Yvon HoribaTM) equipped with a 600 g/mm grating and a MitutoyoTM long-working-distance 50x objective.

Experiments were performed between 330 and 570 K, up to 7 GPa. We first isolated a single crystal of ice VII and then took P-T measurements when only very few drops of liquids were still visible for the solidus and when only a very small rounded crystal remained for the liquidus. The solidus was determined by a isothermal pressure increase, and the liquidus by a isobaric temperature increase. Raman spectra of the liquid and the ice were measured at each steps.

3. Results

The solidus and liquidus of ice VII were determined for 1 and 4 molal NaCl and compared to the melting curve of pure H₂O. They have been measured in the stable and the meta-stable domains. For instance, the Simon equation fitted to our data for 1 molal NaCl is

$$P \text{ (GPa)} = 2.196 + 1.619 \times \left(\left(\frac{T \text{ (K)}}{350} \right)^{2.84} - 1 \right) \quad (1)$$

It shows a significant influence on the melting curves up to 0.8 GPa on the liquidus in comparison with the melting curve of pure ice VII [2] (figure 1). The solidus curve shows fractional crystallization below 390 K while crystallization occurs at equilibrium at higher temperature.

At low temperature, we see an important pressure difference (0.5 GPa) between the solidus and the liquidus. The growing crystals display cubic habitus in accordance with the Ice VII crystal symmetry ($Pn3m$). The Raman spectrum of a single crystal of Ice VII is inhomogeneous. A Raman spectroscopic profile taken perpendicular to the crystallization front shows a progressive depolymerization of ice VII as the ice crystallizes. This can be interpreted as a progressive increase in the amount of NaCl dissolved in the ice VII structure.

At high temperature the solidus and the liquidus curves overlay. The growing crystals have a rounded shape suggesting permanent equilibration with the brine during crystallization. The Raman spectra show no difference between the core and the rim, indicating that important amount of salt is trapped inside the ice VII directly during crystallization.

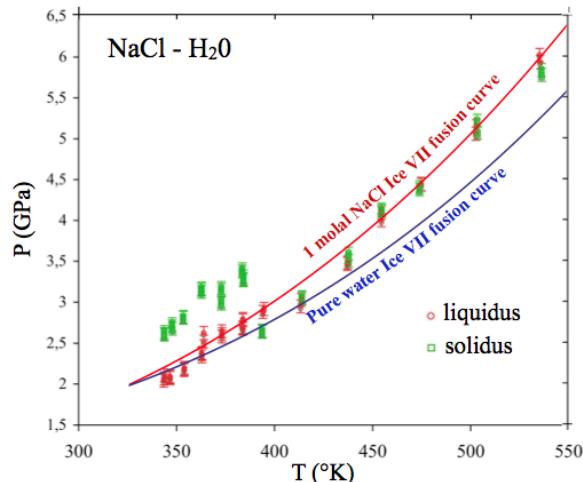


Figure 1 Melting curve of a NaCl solution of 1 molal of Na-Cl. Green square are the solidus measurement, and the red circles are the liquidus ones. They are plotted with their error bars. The solid red curve is the Simon's equation fit for the liquidus presented in the equation 1. The solid blue line is the Simon's equation fit given by Datchi[1] for pure water Ice VII.

4. Discussion

This first series of experiments show that significant amount of NaCl can be incorporated into the Ice VII. We also quantified the influence of this salt on the melting curve of ice VII. Both aspects have major consequences on the interior and the possible oceans of big icy bodies. The incorporation of salt in the ice VII structure could greatly change its conductivity properties and then be a major agent of the icy bodies intrinsic magnetic field. We also expect significant changes in the viscosity of ice VII due to depolymerization as salt is incorporated in ice VII. As the melting curves are changed, possible buried ocean inside icy bodies could perpetuate at much greater depth than their pure water equivalent. This may promote extensive metamorphism of the silicate interiors due to interaction with mobile fluids. Such fluids would strip salts more efficiently from the silicates and transport them to fluid and ice reservoirs. A deep ocean in contact with the silicate substrate is also a key parameter for sustaining a suitable environment for potential life as class III habitats[3].

4. References

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