FREEZING POINT EXPERIMENTS OF NaCl SOLUTIONS UP TO 70MPa: IMPLICATIONS FOR ICY MOONS AND OCEAN WORLDS

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Introduction: The possibility that subsurface oceans on the icy satellites of the outer planets might host life, or at least potentially habitable environments, has stimulated recent experimental efforts to better define realistic chemical and physical conditions within these water rich bodies. This interest has coincided with rapid developments in high pressure research, including the hydrothermal diamond anvil cell (DAC), which enabled in-situ determinations of phase relations of and other properties of hydrothermal systems (e.g. [1], [2]) These early studies focused on pure water to demonstrate the power and utility of the new techniques, and also to ground discoveries at new conditions in well-established territory (i.e. the well-known phase diagram and equation of state of pure H_2O). More recently, there have been several high pressure, DAC studies aimed at gaining a better understanding of the phase relations salt-water compositions (including NaCl, KCl, and $MgSO_4$) at conditions that are potentially more representative of the deep interiors of icy bodies (e.g. [3], [4], [5], [6], [7]). Currently there exist few experimental studies on these systems with direct relevance to melting near the surface of icy moons such as Europa, Enceladus, and Ganymede. We have performed a preliminary series of high pressure / low temperature measurements of the melting / freezing behavior of a wide range of salt-water solutions that are directly relevant to the compositions and pressure-temperature conditions of icy worlds such as Europa, Enceladus and Ganymede. Knowledge of the melting/freezing behavior will have bearing on our understanding on the structure, temperature, and composition of the icy moons' interiors, and their potential habitability.

Methods: Solutions of varying compositions ranging up to about 20 wt% high purity NaCl were pre-mixed with distilled water by mass. For a single experiment, approximately 100 ml of solution was loaded into a cylindrical stainless steel pressure vessel and sealed with an internal temperature sensor. The entire pressure vessel was immersed in a low temperature circulating bath of anti-freeze fluid at approximately 5 ^{o}C. Once the pressure vessel has thermally equilibrated with the bath, system cooling was initiated. As the bath and the vessel cooled, we tracked the temperature of the sensor. Usually, the solution can be undercooled by several degrees before freezing occurs. Upon the onset of freezing, latent heat is released and the system inside the vessel rapidly heats up to the melting/freezing point, where it plateaus for several seconds until the entire sample has solidified. Once the sample is completely solid, the temperature begins to drop again until the vessel reaches equilibrium with the bath. An example of a time – temperature curve of this process is shown for a 10% NaCl solution in Figure 1.

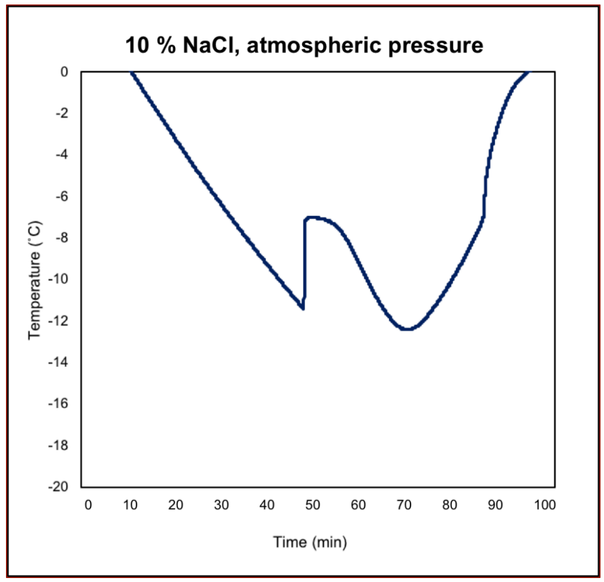

Figure 1*: A typical time - temperature plot for a freezing point experiment. Ice nucleates at around -12^{o}C at which point latent heat is released from the system, and re-equilibrates at the freezing point until the sample is completely solid. The flat plateau that occurs after heating is considered the freezing point. In this sample, freezing occurs at approximately -7^{o}C. There is also a slight kink in the profile upon melting at the same temperature during the warming phase of the experiment.*

Results: A compilation of our preliminary work on NaCl solutions is shown in Figure 2. This plot shows our measurements for the freezing point of solutions up to a concentration of 20 wt% NaCl up to 69 MPa using the methods described above. Overall, these preliminary results are encouraging. The main result, that adding solutes to pure water reduces the freezing point, and that this effect is even more pronounced at higher pressures is qualitatively predicted by theory, and confirmed through these experiments.

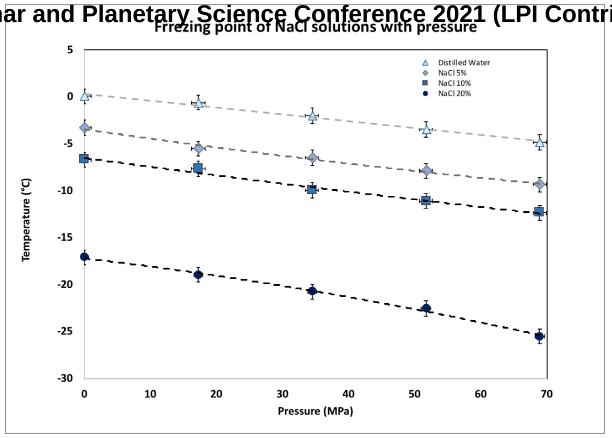

Figure 2: *Preliminary results from these new experiments show that as expected, the addition of NaCl to water depresses the melting point, and that the magnitude of this depression increases at higher pressures.*

We will present these new results in detail, and discuss the implications of these results for the thickness of Europa's crust.

Acknowledgments: We would like to thank John Sheehan and Rob Harlan at Union College for their skilled assistance in building our pressure vessel.

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