RHEOLOGICAL EVOLUTION OF BRINE LIQUIDS AND SUSPENSIONS: CHLORIDE AND SULFATE BRINES AS ANALOGS TO CRYOFLOWS ON EUROPA. A. A. Morrison[1,2], A. G. Whittington[2], F. Zhong[3], K. L. Mitchell[3], and E. M. Carey[3], [1]University of Missouri, Columbia, MO, [2]University of Texas San Antonio, San Antonio, TX (aaron.morrison@utsa.edu), [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: Cryovolcanism has been implicated on many icy bodies in the outer solar system to explain many of the observable surface features. Europa has many features (e.g. domes [1], flows [2], smooth terranes [3]) that have been suggested to be a result of effusive cryovolcanism. Many of these features have also been argued to have tectonic or otherwise non-volcanic origins. To better understand the cryovolcanic process we conduct rheological experiments of brine liquids (and crystal suspensions) that may be analogs to erupted products on Europa. Chloride and sulfate systems are suggested to be major components of the surface and ocean compositions. Therefore, having an understanding of the rheological evolution of these compositions will allow us to link material properties to possible morphologies. This will allow us to better model the emplacement of observed features and suggest whether cryovolcanism would be an appropriate genesis.

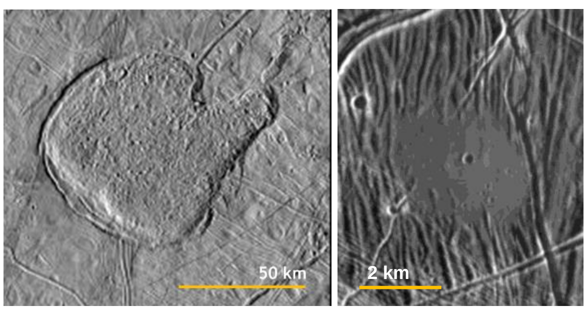

Figure 1. *Possible cryolava dome (Murias Chaos ~100 x 77 km across, 230 m/pixel) on Europa imaged by Galileo SSI (observation E15REGMAP02, ASU ipf 1242). Smooth feature (~3.2 km across, 26 m/pixel), possible cryolava flow filling existing topography, imaged by Galileo SSI (PIA00592, NASA/JPL/ASU).*

Rheological properties of potential cryovolcanic products are fundamental in determining how features are emplaced and the morphologies that result. Few experimental studies [4,5] have been conducted of the rheology over relevant composition and temperature space. Supporting data that covers the liquid and subliquidus (partially crystallized) regimes exists for only a narrow range of compositions relevant to cryovolcanism. Defining the rheology of these materials allows inferences about possible compositions based on the observed morphology. Understanding how these materials move, deform, and evolve upon crystallizing will help constrain what morphological features can form by various compositions. This will also allow comparisons to terrestrial silicates and determinations of how similarly the two kinds of materials behave. If they are, in fact, analogous to silicate systems (in terms of viscosity, flow index, yield strength, etc.), are they formed and emplaced by the same mechanisms and processes? And if not, what factors are contributing to the differences? Determining rheological properties of these cryogenic materials should allow us to answer these questions.

Methods: The H_2O-XCl (X = Na,K,NH_4) and H_2O-YSO_4 (Y = K_2,Mg,$(NH_4)_2$) binary systems were chosen for their simplicity, well characterized phase diagrams, and eutectic temperatures that are easily achieved. These systems also contain many of the major components relevant to proposed cryovolcanism on Europa [6,7,8]. Solutions of three different concentrations were synthesized from reagent grade powders and deionized water for each composition (2, 5, and 6 wt% K_2SO_4; 5, 10, and 15 wt% for all others). An Anton Paar MCR302 rheometer was used to measure viscosity with a cone-and-plate configuration, utilizing a Peltier plate temperature control system. Disequilibrium cooling experiments were conducted at rates of 2, 1, and 0.5 K/min under a constant shear rate of 50 s^{-1}. Isothermal measurements were made at intervals between room temperature and the freezing point (1 – 600 s^{-1}) representing the equilibrium case or effectively the 0 K/min cooling experiment.

Preliminary Results: Figure 2 shows the results of the cooling experiments for NaCl and $MgSO_4$ solutions. The non-linear evolution of viscosity as a function of temperature and concentration are clearly seen. These two compositions have the strongest influence on viscosity. Data for the other compositions have been omitted here for brevity but do not show as much variation in viscosity as either composition in Figure 2. The empirical model of Laliberté [9] works well at predicting the viscosity of these and many other solute bearing solutions at ambient and elevated temperatures. However, the model did not include data at much lower temperatures than ~0°C. Thus, the lower temperatures relevant to cryovolcanism are not in the range of calibration for the model, resulting in viscosity extrapolations that are not always reliable. The model does seem to extrapolate well for some compositions but does particularly poorly for the $MgSO_4$ and K-bearing compounds (Figure 2).

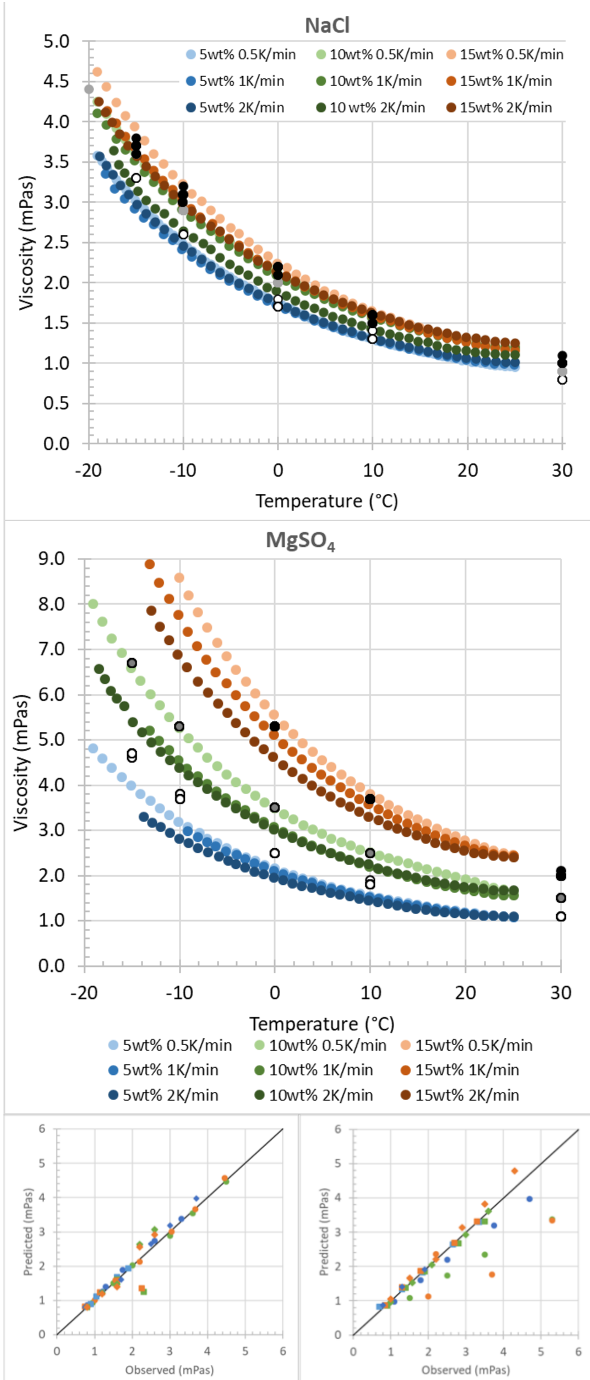

Figure 2. *Experimental viscosity data (in mPas) as a function of temperature for 5wt% (blue), 10wt% (green), and 15wt% solutions (orange) at cooling rates of 0.5 (light), 1 (medium), and 2 K/min (dark). (top) NaCl experimental data: colored points are from cooling experiments and grayscale points are from isothermal experiments. (middle) $MgSO_4$ experimental data: colored points are from cooling experiments and grayscale points are from isothermal experiments. (bottom) Observed vs. predicted values of viscosity from our data and model extrapolations [9] with chlorides on the left and sulfates on the right. Color is the same as above.*

Discussion: Of the solutes studied thus far, $MgSO_4$ and NaCl are the two that have the strongest effect on viscosity. These two components are coincidently also considered to be major constituents of the surface ices and potentially the subsurface ocean on Europa [6,8]. Thus, the H_2O-NaCl-$MgSO_4$ ternary system will be the focus of further experimental work. With the liquids characterized, work can begin on understanding the viscosity evolution during crystallization. However, since this ternary system is actually a quinary system (i.e. a reciprocal salt pair), crystallization must be carefully monitored. Additional work in the reciprocal binary systems of H_2O-Na_2SO_4 and H_2O-$MgCl_2$ may be required. Further investigation of the mixed-cation and mixed-anion effects will also need to be considered.

Understanding the microphysics of how viscosity changes during cooling and crystallization will help to inform the macrophysics and the morphologies we would expect to find. Data from upcoming JUICE and Europa Clipper missions should provide much higher resolution imagery that may reveal smaller scale flow features from low viscosity material that in not resolvable by the current available data.

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