Rheological Investigation of Cryovolcanic Slurries: Viscosity of Chloride and Sulfate Brines

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Introduction

Cryovolcanism is a commonly evoked mechanism to explain smooth (resurfaced) terranes and morphologic features analogous to terrestrial volcanic features (Fig 1). Understanding the rheology of erupted material on icy bodies is essential in order to model the emplacement of such features. Many studies assume a simplified rheology but flow behavior can change dramatically with temperature and crystal content. However, with only a few experimental studies providing supporting data over a narrow compositional range [1,2], modeling this complicated process becomes difficult. Having a defined rheology will allow inferences about possible compositions, temperatures, and crystal contents based on observed morphology of flow features/constructs found on many outer solar system bodies.

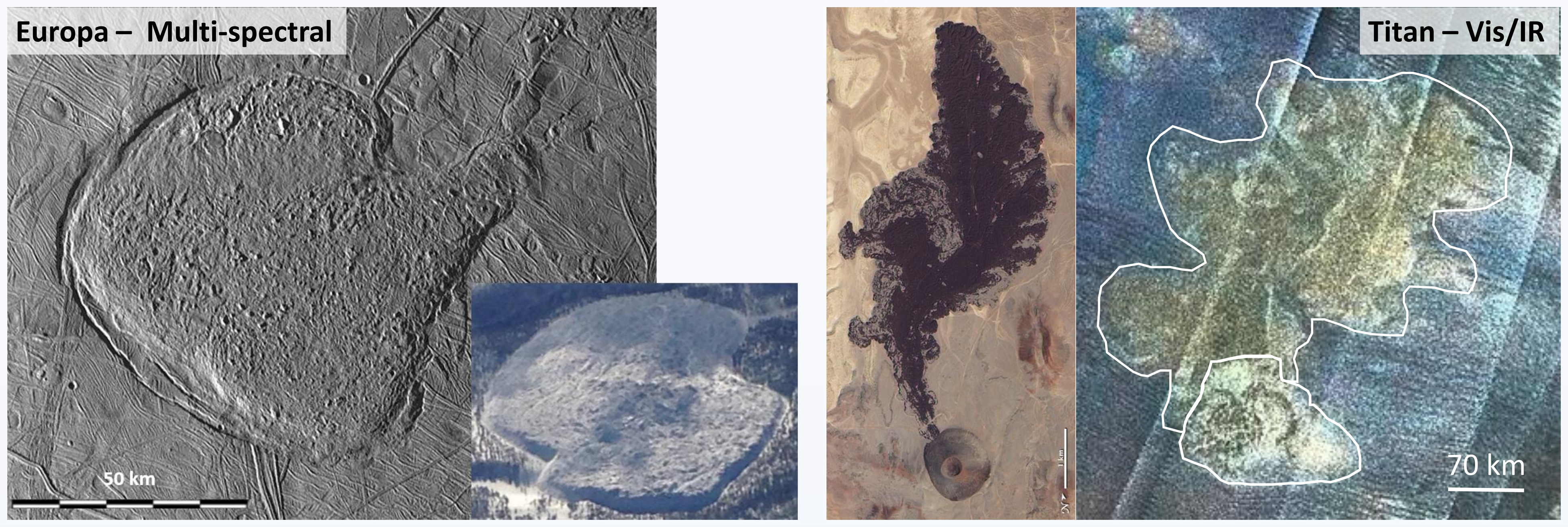

Figure 1 (above): Possible cryovolcanic features on various outer solar system bodies. (left) Cryolava dome (Murias Chaos ~100 x 77 km across, 230 m/pixel) on Europa imaged by Galileo SSI (observation E15REGMAP02, ASU ipf 1242). (middle) Earth analogs of lava dome (Obsidian Dome, CA) and lobate flow (SP Crater, AZ). (right) Possible cryovolcanic construct/edifice (Doom Mons and Sotra Patera ~70 km diameter, 175 m/pixel) on Ceres imaged by Dawn. Image credits: NASA/JHUAPL/SwRI; Alan Whittington; Northern Arizona/NASA Earth Observatory; NASA/JPL-Caltech/ASI/USGS/University of Arizona.

Objectives

To expand the compositional range over which reliable experimental data exists for the rheology of potential cryovolcanic material. Measurements during cooling and crystallization allow parameterization of flow behavior as a function of temperature, composition, crystallinity and strain rate. These results will be used to model how the rheological behavior of icy slurries affects the efficiency of various emplacement mechanisms (e.g., diking, lava tubes, fissure-fed sheet flow).

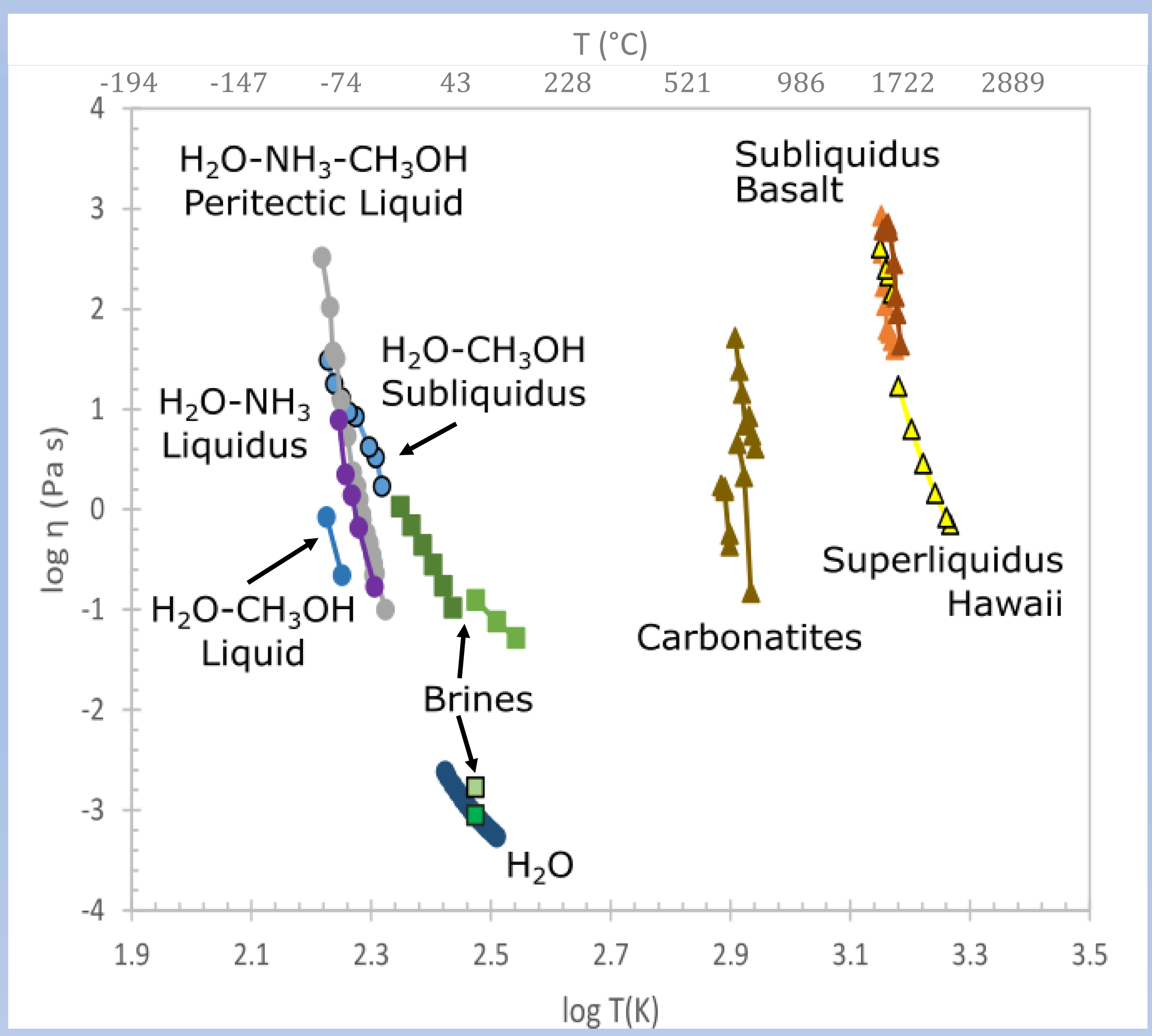

Figure 2: Viscosity data for water [3] (thick blue line), brines [4] (green squares), ammonia-water (purple circles) [1], methanol-water (blue circles) [2], ammonia-methanol-water (gray circles) [1], East Africa Rift basalts (red/orange triangles), Oldoinyo Lengai carbonatite [5] (brown triangles), and Hawaiian basalt [6] (yellow triangles). Ranges of potential cryovolcanic compositions overlap with terrestrial lavas.

Results & Discussion

Using an Anton Paar MCR302 rheometer, with rotational parallel-plate and cone-and-plate geometries, liquid viscosities were measured from 25° C down to -20° C for multiple concentrations of chloride and sulfate solutions. Each solution was also cooled at 2 K/min, 1 K/min, and 0.5 K/min. Viscosity does not appreciably change with respect to concentration on the water rich side of the eutectic and thus the temperature dependence is the main controlling factor. $MgSO_4$ shows slightly more variability at lower temperatures. Viscosity models of aqueous solutions typically cover the liquid range and predict the viscosity well. However, when attempting to extrapolate to sub-ambient conditions the models begin to break down. They also do not account for the effect of crystals once solidification begins. Thus far in these experiments, crystallization has been so rapid that a very narrow temperature range exists where the solution is partially crystallized. Further experiments will be run to characterize the physical effect of crystals on the viscosity of these aqueous slurries.

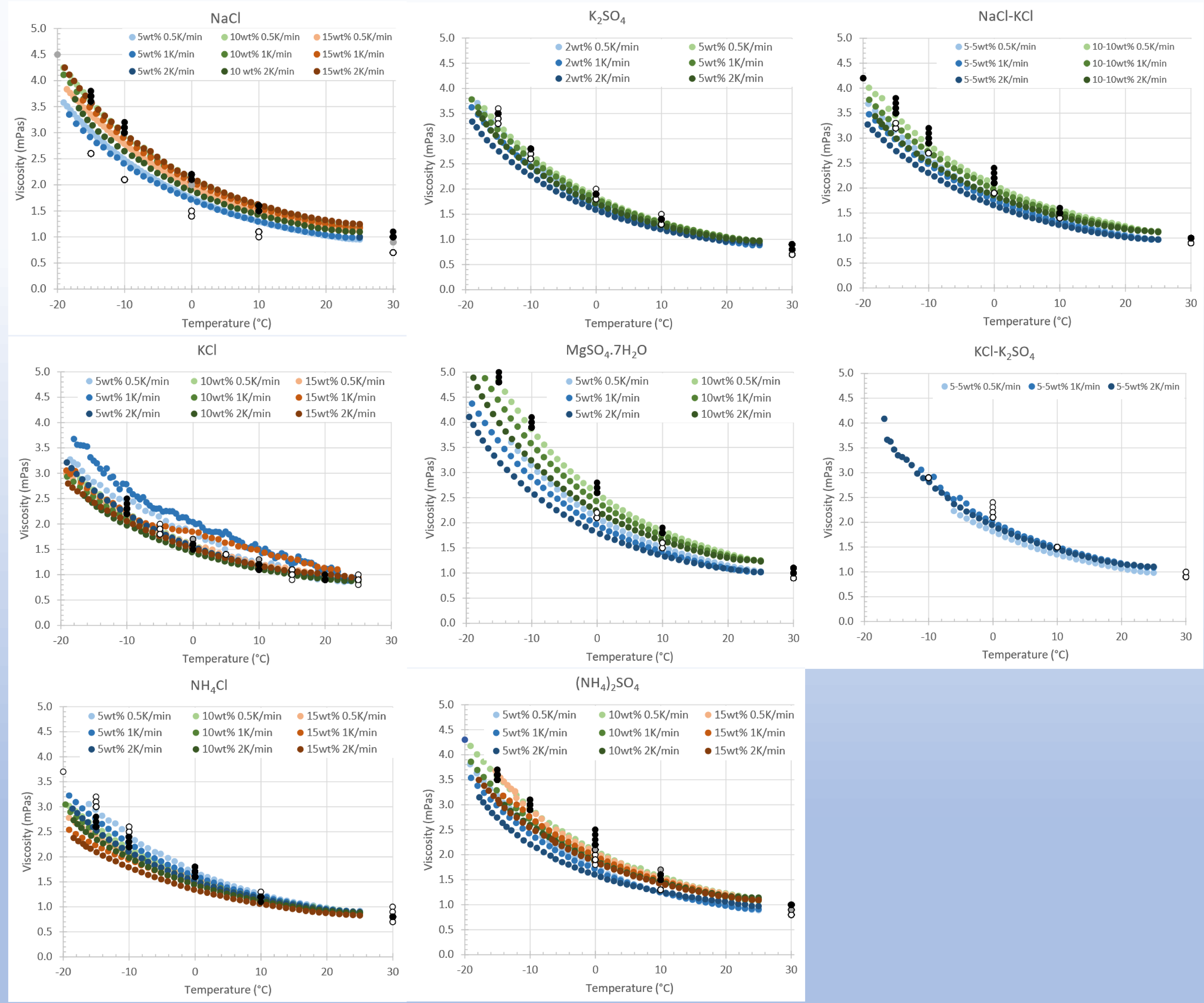

Figure 3: Temperature dependent liquid viscosity for aqueous NaCl, KCl, NH_4Cl, K_2SO_4, $MgSO_4$, $(NH_4)_2SO_4$, NaCl-KCl mixture, and KCl-K_2SO_4 mixture. Isothermal viscosity is shown as grayscale points with the lightest (white) for the lowest concentration and the darkest (black) for the highest concentration. Cooling experiments are grouped by color with the lightest shade indicating 0.5 K/min and the darkest shade indicating 2 K/min.

Anticipated Advances

- Experimental liquid viscosity dataset for briny compositions relevant to icy satellites
- Extend viscosity dataset to crystal-bearing slurries from liquidus to eutectic temperatures, spanning strain-rate conditions from vent to final emplacement
- Test and modify existing rheological models including strain-rate and crystal fraction dependence

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References

[1] Kargel et al. (1991) *Icarus 89*, 93-112. [2] Zhong et al. (2009) *Icarus 202*, 607-619. [3] Kestin et al. (1978) *J. Phys. Chem. Ref. Data*, *7*(3), 941-948. [4] Zhang et al. (1997) *J. Chem. Eng. Data*, *42*, 526-530. [5] Norton and Pinkerton (1997) *Eur. J. Min.*, 351-364. [6] Sehlke et al. (2014) *Bul. Volc.*, *76(11)*, 876.