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PHYSICAL PROPERTIES OF CRYOVOLCANIC BRINES: APPLICATIONS TO THE EVOLUTION OF GANYMEDE;

J.S. Kargel, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

Introduction. Carbonaceous chondrites contain abundant veins of water-soluble salts, including carbonates and hydrated sulfates of Mg, Ca, Na, Ni, and Fe. These constitute over one-fourth of the mass of the meteorite Orgueil. Magnesium sulfate is the most abundant salt, constituting nearly half the mass of all salt components combined (anhydrous), and 73% of the highly water-soluble salts [1]. The common assumption that icy satellites and asteroids contain rock compositionally similar to carbonaceous chondrites suggests that salts may be important in the cryoigneous evolution of icy satellites and asteroids. Ordinary chondrites, an alternative rock component of icy satellites, lack abundant salts, although their anhydrous silicate assemblages are unstable with respect to water and would react to produce salts upon initial melting of ice. In any case salts would ultimately be involved in any melting and differentiation processes.

Here, I review some basic physicochemical properties of likely cryovolcanic brines and consider how the existence of soluble salts in Ganymede might affect its structure and evolution. Ganymede is selected for applications since it is very likely composed of relatively "simple" mixtures of water ice and rock (thus, ammonia may not be important in its evolution), because Ganymede displays photogeologic evidence consistent with brine volcanism, and since the Galileo mission will soon allow observational tests of the concepts presented here. These models are based on data appropriate to low pressures, and thus are not strictly valid for Ganymede, but should suffice to illustrate the importance of salts in icy satellite evolution, and the necessity of exploring the properties of salt-water systems at high pressures. Initial results of high-pressure experiments in the magnesium sulfate-water system are presented in another abstract [2].

Physicochemical properties of brines. The dominance of $MgSO_4$ in chondrite salts is a sufficient basis (but not the sole objective rationale) for concentrating attention on the magnesium sulfate-water system in this brief report. This system has a eutectic near 17% $MgSO_4$ (by mass) and -3.9° C [2]. The eutectic liquid coexists with water ice and $MgSO_4.12H_2O$. The addition of other major salt components somewhat complicates matters, but $MgSO_4$ remains the most important solute in chondrite-equilibrated brines under most circumstances.

Figures 1 and 2 show the density and viscosity, respectively, of the $MgSO_4$-H_2O eutectic liquid in the context of data for other volcanically important liquids and solids; for consistency and simplicity, these data all represent the crystal-free state at the liquidus. Real lavas commonly are erupted with ten percent or more crystals, which would have a small effect on lava density but a large effect on viscosity. Thus, Figure 2 qualitatively indicates the **relative** differences in the lava viscosities, and quantitatively provides **minimum** viscosity estimates at eruption. The $MgSO_4$-H_2O eutectic is about six times more viscous than pure water. However, as shown in Figure 3, even the gravity-scaled rheology of magnesium sulfate eutectic would be "runnier" on Ganymede than the least viscous silicate lavas on Earth (komatiite). Thus, aqueous brines on Ganymede would produce sub-meter flow thicknesses except where ponded. This is at least consistent with the lack of observed flow edges in Voyager images (but image resolutions would require flow thicknesses of 50 meters or more to be resolved, thus allowing substances substantially more viscous than magnesium sulfate-water).

Models of a sulfate-rich Ganymede. Consider as a special case Ganymede Model #1 whose rocky component very closely resembles C1 chondrites, and the ice fraction is solely water ice. Like C1 chondrites, Model #1 has 38% of its S in the form of magnesium sulfate. It is trivial to calculate the total quantity of ice, salt, and rock ("rock" now refers to involatile minerals minus highly soluble salt), based on the specific gravity of Ganymede (1.93), of pressure-averaged ice (1.25), and of carbonaceous chondrite rock (2.6), and the chondritic abundance of S (6%). In this special case the H_2O:$MgSO_4$ ratio is equal to the eutectic composition (17 wt.% $MgSO_4$). Complete melting and melt extraction of the ice-salt eutectic fraction would leave the rocky interior barren of both ice and sulfate and would produce a crust about 600 km thick composed of about equal weight fractions of ice and $MgSO_4.12H_2O$. Since the eutectic liquid is denser than the frozen ice-salt eutectic mixture, early brine volcanism would have given way to later intrusive activity. If differentiation was early enough the eutectic-composition crust could become heavily cratered during later stages of heavy bombardment.

Consider in Model #2 a Ganymede where the fraction of oxidized S is greater than 38%. Complete melting and melt extraction of the eutectic fraction would leave residual amounts of sulfate in the rocky core. Residual sulfate would melt incongruently in a series of stages (consult Fig. 1 of [2]). Each liquid would be denser than the eutectic-composition crust and would be unable to contribute to late-stage volcanism. On the other hand, in Model #3 the fraction of oxidized S is less than 38%, and excess water ice would exist in the rocky core after eutectic melting; melting of water ice in the core would produce more-or-less pure liquid water, which is substantially less dense than the frozen eutectic crust, and may result in late-stage water volcanism.

Conclusions. Observations indicate late-stage (post-heavy bombardment and post-tectonic) volcanism on Ganymede; on this basis Model #3 is preferred. The highly fluid character of Ganymedian volcanism is consistent with extrusions of either water or salt-water brines. Callisto, however, may have had more than 38%

of its S as sulfate, offering an explanation for the absence of late-stage volcanism there. The occurrence of abundant elemental S on Io suggests that the jovian system may exhibit a radial increase in oxidation, possibly related to mixing between the jovian and solar nebulae, or related to chemical processing in the deep, warmest portions of the jovian nebula. In any case, if magnesium sulfate is an important constituent of certain icy satellites it certainly would have been important in their geological evolution. The occurrence of sulfates in the observable surfaces of these satellites might be detected by Galileo. However, the harsh radiation environment in the jovian system may have caused the decomposition of sulfates and the production of refractory substances such as MgO.

References. [1] Fredriksson, K. and J.F. Kerridge, 1988, Meteoritics 23, 35-44. [2] Hogenboom, D.L., J.S. Kargel, J.P. Ganasan, and J.S. Lewis, 1991, (ABSTRACT), this volume.

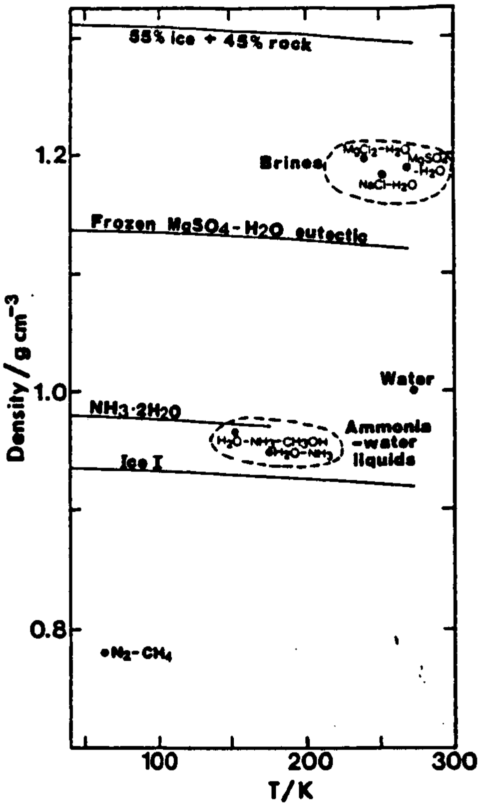

Figure 1.

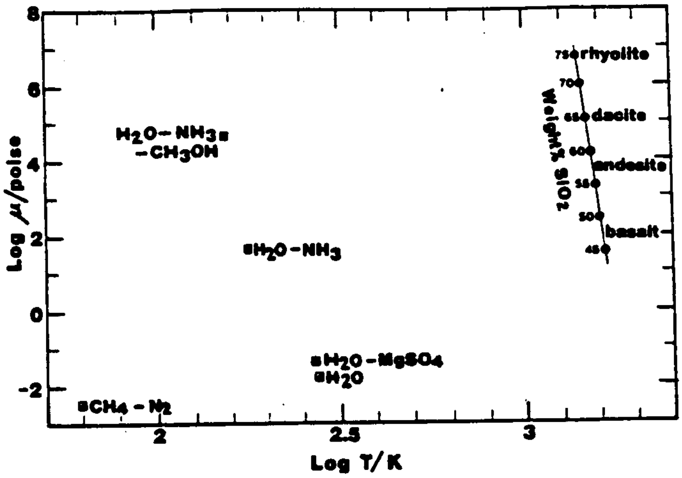

Figure 2.

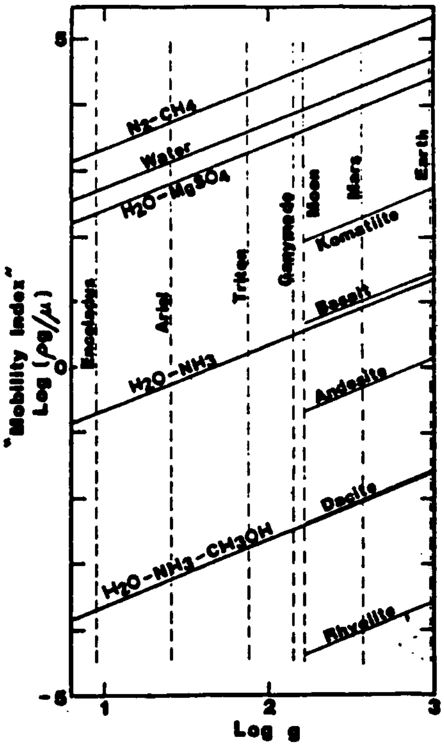

Figure 3.