THE EFFECT OF EXPERIMENTALLY DETERMINED SALT VISCOSITY ON CONVECTIVE PLUMES IN THE SUBSURFACE OF MARS. M. A. McGraw[1], A. S. Light[1], and B. J. Travis[2], [1]University of Montana (Department of Physics and Astronomy, 32 Campus Drive, Missoula, MT 59812; maureen.mcgraw@umontana.edu; agatha.light@umontana.edu), [2]Los Alamos National Laboratory (Earth & Environmental Sciences Division, MS F665, Los Alamos, NM 87545; bjtravis@lanl.gov).

Introduction: There is an extensive body of physical and chemical evidence for the presence of liquid water on the surface of Mars in the past, but little is known about the subsurface hydrology. The most recent unmanned mission, the Mars Exploration Rovers Spirit and Opportunity, which have been exploring the surface of Mars for over two years, continue to collect data supporting the presence of past liquid water. Little doubt now exists that water once flowed across the surface of Mars, carving huge channels billions of years ago. But where has that water gone?

Current surface conditions on Mars render water thermodynamically unstable. However, the presence of relatively young gullies that overlay other young geologic features suggests that water may still play a role in the evolution of the surface [1]. Numerical models can be used to explore varying theories about the subsurface hydrology on Mars. Specifically, we examined the possibility that the radiogenic heat flux from Mars' interior could cause hydrothermal convection to occur and thin the permafrost layer in some regions. Local channeling effects (such as a fissure) could then transport the liquid water to the surface causing a brief upwelling of water which could flow for a short time on the surface.

The Miniature Thermal Emission Spectrometer (Mini-TES) aboard Opportunity collected infrared spectra of surface features at Meridiani Planum to determine Martian mineral abundances. Mini-TES found both crystalline hematite and basalt and determined that 15 to 35% by volume of surface outcrops believed to be of aqueous origin are magnesium and calcium sulfates [2]. The presence of salt in the Martian surface minerals allows the assumption that any liquid present in the subsurface is likely to be in the form of a brine. The presence of salt alters the viscosity of a fluid, which is one of the key parameters in understanding whether or not convection will occur.

Experimental Data: Rather than using an empirical relationship, a set of experiments were conducted that measured the viscosities of varying concentrations of magnesium sulfate and calcium chloride at a range of temperatures. The measurements were made with a Cannon-Ubbelohde viscometer for transparent liquids. The measurements were made in a constant temperature bath of ethyl alcohol, which was stabilized to within ±1 °C. The range of temperatures measured varied for each solution based on the freezing point. The temperature of the bath was monitored every 60 seconds during the viscosity measurement; these values were averaged and used as the solution temperature for the measurement. In general the standard deviation of the temperatures during a measurement was small, with the highest values $\sigma \leq 0.44$ °C. Each measurement was repeated five times.

The viscosity data were then fit using TableCurve 2D to find a simple function that best represented the data and could be used for modeling. The data was best fit by a single equation of the form:

$$y^{-1} = a + bx + cx^2 \qquad (1)$$

The fit values are valid from the freezing point of the solution to around 70 °C. At warmer temperatures, the fitted curves flatten out, which is consistent with what is expected to happen physically. Therefore, it is probably reasonable to use the fits for temperatures as high as 150 °C. The data (symbols) and the fits (line) based on Equation 1 are shown in Figures 1 and 2 for calcium chloride and magnesium sulfate, respectively. Overall the function fit the data well, with R^2 values greater than 0.98. The equations fit to the viscosity data were then incorporated into the numerical model as a direct relationship, which improves the model representation of the brine solutions.

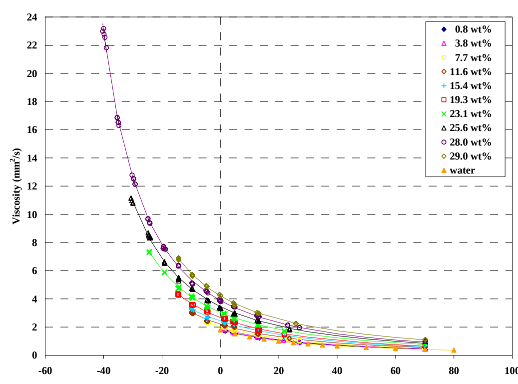

Figure 1: Calcium Chloride viscosity data and fits

Model: The effect of convection in pure water has been evaluated in three dimensions [3], but the impact on the permafrost thickness is conservative and cannot predict episodic thinning that might occur with brine solutions. The computer code MAGHNUM (Mars

Global Hydrology NUmerical Model) was used to investigate the effect of salts on convection in the Martian subsurface. MAGHNUM solves governing equations for conservation of mass and energy transport in a heterogeneous porous medium for cartesian coordinates in one, two, or three dimensions or spherical coordinates. Salt transport and change of phase (water-ice) are included. Radiogenic heating is also an option.

This study considered a two dimensional domain of the near-surface of Mars that was 15 km across and 10 km deep. The top boundary was held constant at –60 ºC, the sides are adiabatic, and the lower boundary was a constant heat flow of 40 mW/m^2 [4]. No fluid left the system. The model used the experimental viscosity data for $CaCl_2$ and $MgSO_4$. Local thermal equilibrium between water and rock was assumed and gravity was set to 3.7 m/s^2.

The permeability and porosity decrease exponentially with depth [5]. For the initial simulations the surface permeability is 500 darcys, which is typical for a gravelly sand or a well-fractured rock. The thermal conductivity of rock was assumed to be 2 W/mºC. Rock heat capacity was taken as 700 J/kgºC and rock grain density was set to 3300 kg/m^3. We assume that fluid flow is described by Darcy's law. Simulations were initiated by either assuming that i) there was a thermal gradient with ice at the top of the domain and the fluid region has a specified initial concentration of salt, or ii) by assuming a constant initial temperature above freezing, an initial salt concentration in the fluid for the entire domain, and cooling the system down to form the ice/permafrost layer.

Simulations: Preliminary results indicate that the two brines considered influence convection differently. The viscosity data indicates that for the same concentration the $MgSO_4$ is more viscous, and therefore convection is expected to be less vigorous than for $CaCl_2$. The viscosity of both salts increases considerably at colder temperatures. Another difference for the brine solutions is that rather than seeing a sharp separation between the ice and fluid regions, as is observed between pure ice and pure water, a partially frozen slush region develops.

The simulations for $CaCl_2$ indicate that relative to a pure water system the formation of a plume is episodic and rolling in nature. What is meant is that a convective plume forms, but it is like the crest of a wave that moves through the subsurface rather than being in a stationary location. This allows the plumes to episodically thin the ice/permafrost over a wider range of locations. This increases the probability of the ice/permafrost being thinned in the area of a fissure or other geologic feature that could transport the fluid to the surface. In general, the fluid viscosity and concentration follows the temperature profile, with lenses of higher concentration forming in the troughs between plumes due to the increase in viscosity. For the $MgSO_4$, the plumes are more stable and the degree of periodicity and rolling occur over a longer time span. Additional simulations will examine how variations in initial concentration affect the results.

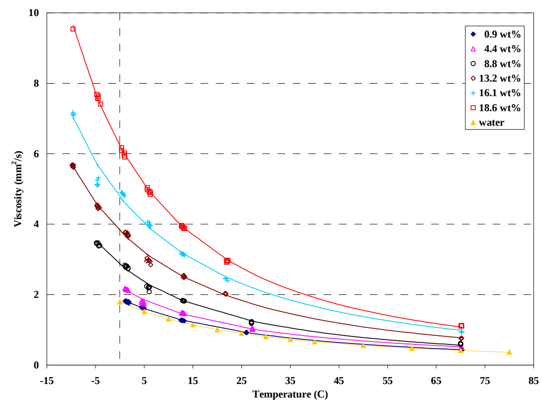

Figure 2: Magnesium Sulfate viscosity data and fits

References:

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