SALT DEPOSITS, ICE LENSES AND CONVECTIVE BRINE AQUIFERS ON MARS. B. J. Travis[1] and W. C. Feldman[2], [1]Earth and Environmental Sciences Division, Los Alamos National Laboratory, MS-F665, Los Alamos, NM 87545, bjtravis@lanl.gov, [2]Planetary Science Institute, Tucson, AZ, feldman@psi.edu.

Introduction: A recent study [1], using THEMIS data, has found evidence of chloride salt deposits associated with a number of features on the surface of Mars, primarily in the southern hemisphere. Based on their interpretation of the data, precipitation from briny aquifers and surface ponds is a likely source of those salts. Other studies indicate high hydrogen content (and by inference, water content) at the surface of Mars in certain locales [2], even at the equator. Such ice lenses could be dusty remnants of exchange of H_2O between soil and atmosphere, but they could also represent remnants of frozen brine aquifers.

Could brine aquifers in fact readily transport water and salt to the cold surface? The dominant Cl-containing salts in Martian subsurface aquifers are likely to be $CaCl_2$ and NaCl [3]. Salt depresses a solution's freezing point; the NaCl eutectic point is about -22 ^oC, while for $CaCl_2$, the eutectic point is -52 ^oC. Geothermal gradients on Mars have been estimated to be in the range of 20 to 40 mW/m^2, with considerably higher values earlier in Mars' history, and possibly even now in certain areas such as the Tharsis region. This abstract summarizes results of a numerical study of brine aquifer dynamics in the shallow subsurface subject to geothermal gradients.

Brine Simulations: A previous simulation study of aquifer dynamics in tbe Martian subsurface considered only pure water aquifers [4]. It found that hydrothermal convection develops for a range of geothermal gradients, for reasonable soil properties. A subsequent, combined experimental and numerical study [5] considered both pure water and salty aquifer dynamics in response to a geothermal gradient. Salt not only depresses the freezing point, but can add an unsteady characteristic to hydrothermal convection. Those studies and this one use the MAGHNUM code. MAGHNUM solves the time-dependent governing equations for water and vapor flow, and heat and salt transport in porous, permeable media in 2-D or 3-D geometries. It allows changes between liquid, vapor and ice phases, depending on local thermodynamics.

We consider an aquifer having depth-dependent permeability and porosity and a high initial salt content ($CaCl_2$ at about 1 mole/liter) in the pore water. Surface temperature is set at -60 ^oC, and bottom temperature at -20 ^oC. The aquifer system is 2 km thick and extends right up to the surface. These initial simulations use a 2-D geometry.

Figs. 1 and 2 summarize the structure of flow and transport in this model. Using the values given above, the system starts to convect; that is, the geothermal gradient drives an upward flow of brine through the soil pores. A downward return flow occurs in very narrow channels, "drainage pipes", that are essentially at the eutectic concentration and are completely liquid (see Fig. 1). The narrow "drainage pipes" lead to a non-uniform pattern of ice near the top; there are icy lenses separated by liquid brine regions. The aquifer between the surface and a depth of about 400 m is partially frozen; fluid motion is still possible. The salinity at the top of the aquifer increases and then water begins to freeze out. Water ice fills the pores of the topmost 50 m of the aquifer (Fig. 2), but there are also salt precipitate inclusions in the ice. Inclusion of several salts should result in a vertical stratification of salt precipitates due to the different eutectic points.

The last two figures are for a second simulation in which the aquifer is shallower, with a stronger geothermal gradient sustained by temperatures of -30 ^oC at the aquifer bottom and -55 ^oC at the surface. The Rayleigh number is above critical, and convective motion sets up. The domain modeled is 200 m wide and 200 m deep. Convection starts with a random perturbation to the temperature field. For this simulation, the salt is also $CaCl_2$. As seen in the 1-D profile vs depth (Fig. 4), a low-ice region exists from about 150 m to 30 m below the surface; the topmost 10 m is almost completely frozen. The image of ice fraction (Fig. 3) also shows narrow columns of liquid (i.e., completely liquid, no ice). These are drainage channels, just as in the simulation of the larger, deeper aquifer case. They are thin vertical channels of very salty fluid draining the upper slushy/partially frozen layer.

One feature seen in all the simulations is high ice content in the topmost 10 to 100 m; the ice thickness depends on the geothermal gradient. Also considerable salt precipitates out in the ice layer (about 7.6 cm of pure salt per meter thickness of ice lens, on average for the lower geothermal gradient, and about 15.1 cm per meter for the shallow high heat flux case). If the lens ice evaporates over time, salt deposits will be left behind. Several 3-D geometry simulations have also been made; results are similar to the 2-D cases reported here, but the near-surface pattern of ice is roughly hexagonal.

We are coupling the MAGHNUM code to FREZCHEM, a chemistry package geared to reactions under cold conditions. This will allow us to model complex salt solutions and more accurately determine salt precipitate stratification.

References: [1] Osterloo M. M. et al (2008) *Science 319,* 1651–1654. [2] Feldman W. C. et al (2004) *JGR-Planets, 109*, E09006, 1-11 [3] Knauth P. L. and Burt D. M. (2002) *Icarus 158*, 267-271. [4] Travis B. J., Rosenberg N. D. and Cuzzi J. N. (2003) *JGR Planets, 108,* 8040-8054. [5] McGraw M. A., Light A. S., and Travis B. J. (2006) *LPSC XXXVII,* abs. # 2224.

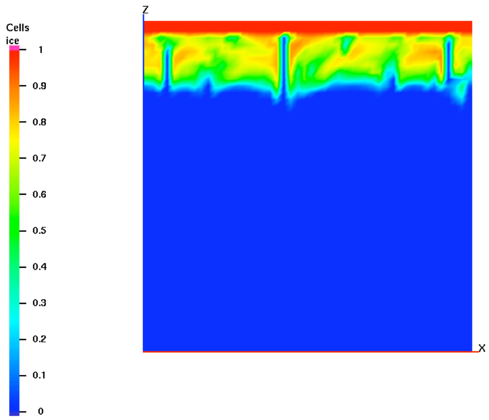

Fig. 1 Ice distribution after quasi-steady state has been established (~3000 yrs). The dimensions of the system shown are 2 km across by 2 km deep. The upper 400 m are partially frozen. A roughly 50-100 m thick ice lens has developed at the surface. Narrow "drain pipes" form, with roughly 1 km spacing, that transport completely liquid brine back to the deeper aquifer.

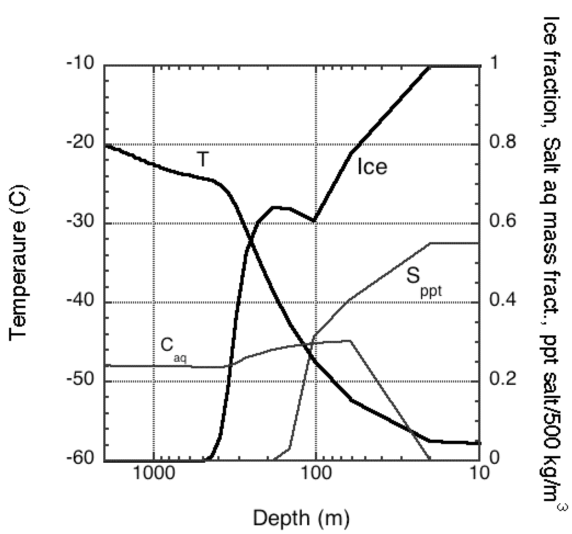

Fig. 2 Averaged profile of temperature (T), ice and aqueous and ppt salt concentration (C, S) vs. depth for the simulation of Fig. 1. Hydrothermal convection driven by the geothermal gradient maintains an almost isothermal brine aquifer until near the surface.

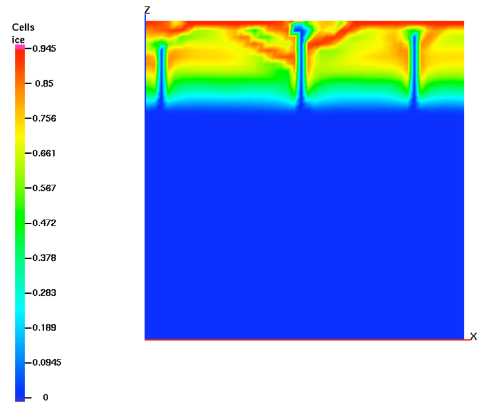

Fig. 3 Ice distribution for a similar simulation to that in Fig. 1, but here the geothermal gradient is higher, and the system considered is shallower, only 200 m in depth. Horizontal dimension shown is also 200 m. Quasi-steady state is reached by about 500 yrs after startup. Because of convection in the brine, the system is mostly liquid up to 30 m below the surface. The region in the upper 50 m is partially frozen and the salt concentration is nearly eutectic. Ice lenses form in the uppermost 10–15 m, interrupted by occasional "drain-age pipes", that transport completely liquid brines back to greater depths.

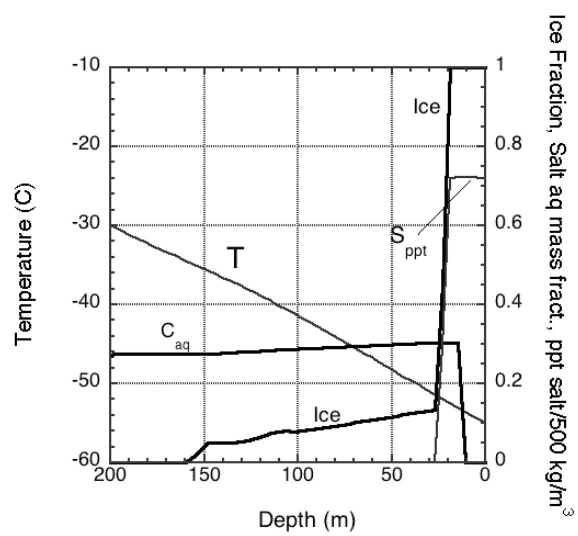

Fig. 4 Averaged profile of temperature (T), ice and aqueous and ppt salt concentration (C, S) vs. depth for the shallow, high geothermal gradient case. The brine solution is very nearly eutectic throughout its depth. An ice lens forms in the topmost 10 - 15 m.