

EXPERIMENTAL STUDY OF SALT AND WATER MIGRATION IN PERMAFROST AND APPLICATIONS TO MARS. J. L. Miller¹, M. T. Mellon², H. G. Sizemore³, and C. A. Hibbitts⁴, ¹Johns Hopkins University Department of Earth & Planetary Sciences (jmill250@jhu.edu), ²Cornell Center for Astrophysics & Planetary Science, ³Planetary Science Institute, ⁴Johns Hopkins University Applied Physics Laboratory

Introduction: Modern Mars is cold and dry, such that liquid water is unstable at the surface. However, water ice has been observed at shallow depths in trenches dug by the Mars Scout Lander Phoenix, inferred from global leakage-neutron and gamma-ray-emission measurements, and in seen fresh high-latitude impact craters¹⁻³. Sulfate and chloride minerals, which have been identified by remote sensing and in situ chemical analysis⁴⁻⁶, may stabilize liquid water in the near surface at subfreezing temperatures as thin briny films capable of moving through the regolith and transporting salts. We experimentally investigate salt effects on ice formation beginning with condensation of atmospheric water vapor through migration of thin liquid films of salty water.

Experiments: We focus on chloride and sulfate salts, such as those found at the Viking and Phoenix sites⁴⁻⁶. $MgCl_2$, $MgSO_4$, and $CaSO_4$ were uniformly added to Mars soil simulant (Birch Hill loess from Alaska, a silt-dominated soil with minimal organic, clay, and native salt contents) at concentrations consistent with those measured on Mars (1 wt%, 10 wt%, and 10 wt% respectively). A fourth sample contained all three salts at these same concentrations. The salt-doped soils were subjected to temperature gradients: 0 °C at the surface extending to -5, -10, or -15 °C at the base of a 2 cm column. Soils were initially dry. A continuous flow of humidified nitrogen (frost point -1°C) was delivered to the soil headspace, allowing water to migrate through and condense within the soil column. After ~10, 20, or 40 days, we sectioned the soil samples, observed textural changes and gravimetrically measured ice content. Salt concentration profiles were also determined by measuring the electrical conductivity of sectioned samples in solution. These concentrations are considered to be significantly different from starting concentrations when plotting outside of the percent error (9.35% for $MgCl_2$, 4.85% for $MgSO_4$, 1.19% for $CaSO_4$).

Salt Migration: $MgCl_2$ was observed to migrate toward the warm surface of the soil column, at the smallest temperature gradients (0 to -5 and -10 °C), but not at the largest temperature gradient (0 to -15 °C) (Fig. 1). In contrast, $MgSO_4$ was found to migrate toward the warm surface at the largest temperature gradients (0 to -10 and -15 °C), but not at the smallest one (0 to -5 °C) (Fig. 2). $CaSO_4$ (Fig. 3) and the mixed salt experiments do not considerably migrate.

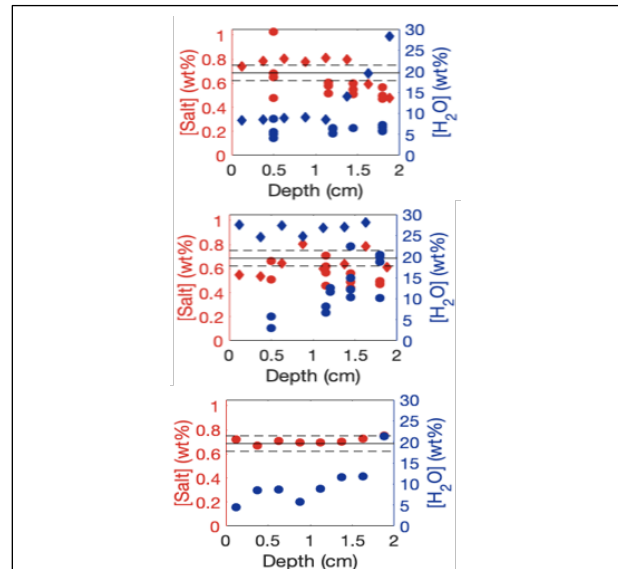


Figure 1. $MgCl_2$ migration. Temperature gradients are 0 to -5 °C (top), 0 to -10 °C (middle), and 0 to -15 °C (bottom). Water concentrations (blue) are plotted along salt concentrations (red). Experiments were run over 20 days (circles) or 40 days (diamonds). Salt concentration change is significantly different from the starting concentration measurements (solid line) when lying outside of the standard error (dashed lines).

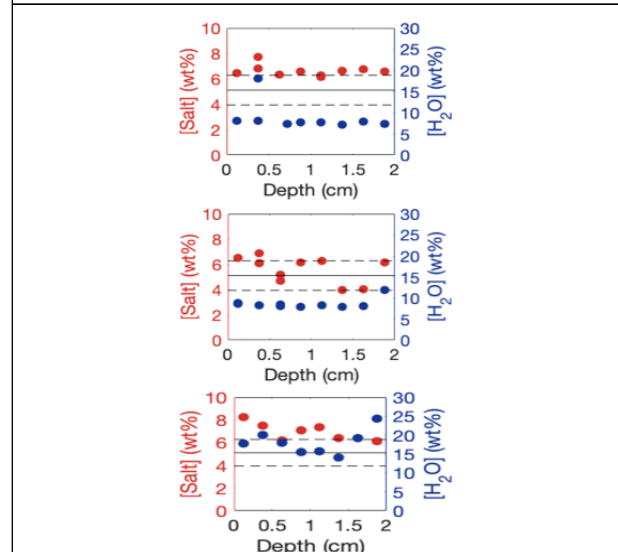
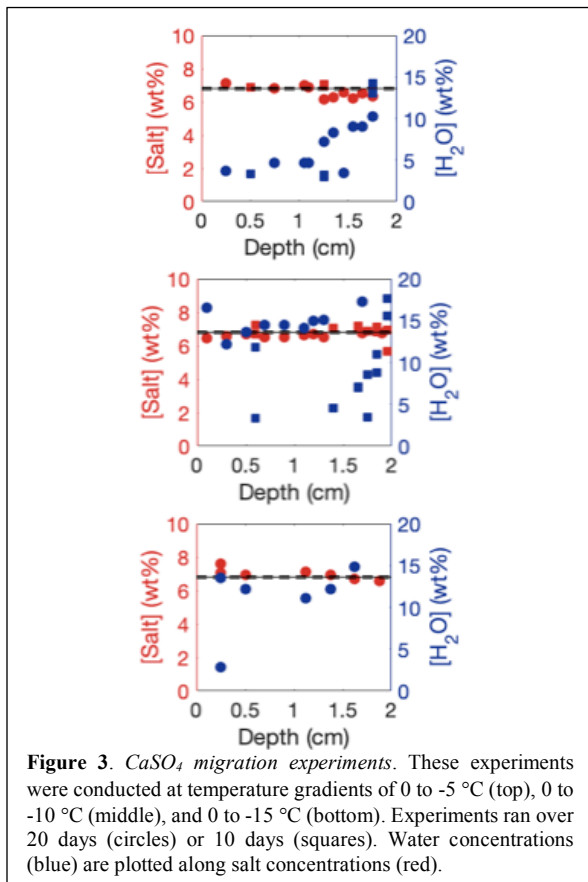


Figure 2. $MgSO_4$ migration. Temperature gradients are 0 to -5 °C (top), 0 to -10 °C (middle), and 0 to -15 °C (bottom). Water concentrations (blue) are plotted along salt concentrations (red). Salt concentration change is significantly different from the starting concentration measurements (solid line) when lying outside of the standard error (dashed lines).



Water Migration: In MgCl_2 experiments, water migrated toward the cold side where it accumulated at the soil's base, especially with longer durations. This migration is in the reverse direction as salt migration (Fig. 1). For MgSO_4 -rich soil water migration is also in the reverse direction as salt migration (Fig. 2), though generally distributed through the column. Although CaSO_4 does not migrate, water does significantly migrate into the soil and accumulate at the cold end of the column. In the three-salt experiments, water accumulated at all soil depths, with greater accumulation at the colder base at the two larger temperature gradients (0 to -10 and -15°C).

Conclusions: The greater total migration of water toward the cold side of the MgCl_2 -rich column may be the result of chloride salts having higher solubility and lower eutectic (as low as -33 °C) compared to sulfate salts (~-3-4 °C), allowing water to remain in a non-frozen state at lower temperatures.

Water and salt migration are often in the opposite directions. This phenomenon may be the result of: 1) vapor diffusion driven by a vapor density gradient, 2) surface diffusion driven by a surface concentration gradient. As the dry porous loess is subjected to water

vapor and increasing water content, water migrates as a vapor phase toward the cold side, driven by lower vapor density in equilibrium with the cold side soil. Vapor phase transport is unable to move salts. As the grain surfaces become covered by water molecules, water begins to migrate toward lower concentrations. Increased water content from an adsorbed phase to thin films and capillary phases begins to dissolve salt and transport it to the warm side.

On Mars, we might expect to see salts assist in driving water toward colder temperatures where ice growth may occur, with salts migrating toward warmer temperatures.

References: [1] Feldman, W. C. et al. (2004) *JGR*, 109, E09006. [2] Byrne, S et al. (2009) *Science*, 325, 1674. [3] Mellon, MT et al. (2009) *JGR*, 114, E00E07. [4] Clark, B. C. & Van Hart, D. C. (1981) *Icarus*, 45(2), 370-78. [5] Hecht, M. H. et al. (2009) *Science*, 325(5936), 64-67. [6] Kounaves, S. P. et al., (2010) *GRL*, 37(9).