

SALT AND WATER MIGRATION IN MARS-LIKE PERMAFROST SOILS. J. L. MILLER^{1,2}, C. A. HIBBITTS², M. T. MELLON³, H. G. SIZEMORE⁴. ¹Johns Hopkins University, Department of Earth and Planetary Sciences (3400 N Charles Street, Baltimore, MD 21218, Jamie.Miller@jhuapl.edu), ²Johns Hopkins University, Applied Physics Laboratory (11100 Johns Hopkins Road, Laurel, Maryland 20723), ³Cornell University, Cornell Center for Astrophysics and Planetary Science (104 Space Sciences Building, Ithaca, New York 14853), ⁴Planetary Science Institute (Tucson, AZ).

Introduction: Evidence of water and salt is apparent in the abundant duricrusts (weakly-cemented soils) observed on Mars. These duricrusts, and the soluble salts that cement them, are observed at every landing site on Mars, and remote sensing reveals that salts and duricrusts are globally widespread¹⁻³. Given that modern Mars is cold and dry, the origin and hydrological history of duricrust is not presently understood. Despite instability of liquid water on the surface of Mars, salts may help to stabilize water in thin films of liquid-like water which can persist below freezing^{4,5}. Thin films move throughout the soil column, transporting salts into layers where they can cement loose soil grains into cohesive duricrust⁵. Here, we investigate a possible mechanism of duricrust formation by migration of thin liquid films and salts. We also examine salt effects on water mobility and ice formation. Water and salts may migrate via desiccation (water leaving a wet soil) to form duricrusts. We experimentally investigate this process.

Experiments: We selected sulfate and chloride salts similar to those found at the Viking and Phoenix sites. We doped a Mars simulant soil with solutions of individual salts. MgCl_2 (1 wt%), MgSO_4 (10 wt%), and CaSO_4 (1 wt%) were individually added to Birch Hill loess from Alaska, a Mars-analog that is silt-dominated soil with minimal organic and native salt contents, at concentrations consistent with those measured on Mars. We performed two sets of experiments. The first explored drying at the surface only and the second explored transport of salt due to migration during drying.

Desiccation at the Surface. A small amount (~0.5 g) of moist, salt-doped soils were spread into a thin, even layer (~2 cm diameter) on a sheet of aluminum foil and subjected to a constant temperature (-196 °C, -20 °C, 20 °C, 80 °C, 150 °C) and then desiccated. Subfreezing samples were either flash frozen (liquid nitrogen for -196 °C) or slowly frozen (-20 °C) before being desiccated in a vacuum chamber at -20 °C for one week. Ambient samples (20 °C) were desiccated by nitrogen purge. Heated samples (80 °C and 150 °C) were desiccated in an oven (2 to 4 hours, respectively). After desiccation, samples were analyzed for reflectance spectra.

Desiccation at Depth. Moist, salt-doped soils were packed into a 2-cm acrylic tube and subjected to a constant temperature (-196 °C, -20 °C, 20 °C, 80 °C, 150 °C) and then desiccated (Fig. 1). Subfreezing samples were either flash frozen (liquid nitrogen for -196 °C) or slowly frozen (-20 °C) before being desiccated in a vacuum chamber at -20 °C for one week. Ambient samples (20

°C) were desiccated by nitrogen purge. Heated samples (80 °C and 150 °C) were desiccated in an oven (2 to 4 hours, respectively). After desiccation, samples were sectioned into 4 segments (each ~50 mm thick) and their surfaces were analyzed

via visible and infrared reflectance spectroscopy for brightness changes and for signatures of hydrated salts, both of which are sensitive to changes in salt abundance.

Desiccation

Effects: In surface desiccation experiments, MgCl_2 and CaSO_4 reflectance spectra do not show a notable change in spectral slope with change in desiccation temperature. In contrast, MgSO_4

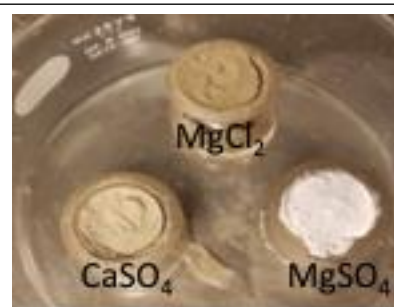


Figure 1. Desiccation experiments at depth.

Moist, salt-doped soils were packed into a 2-cm acrylic tube and desiccated at a constant temperature until water was removed. A white salt crust formed on the surfaces of the MgSO_4 samples after desiccation. This surface crust appears to correspond with the increased band depth observed in the reflectance spectra at 1.9 μm .

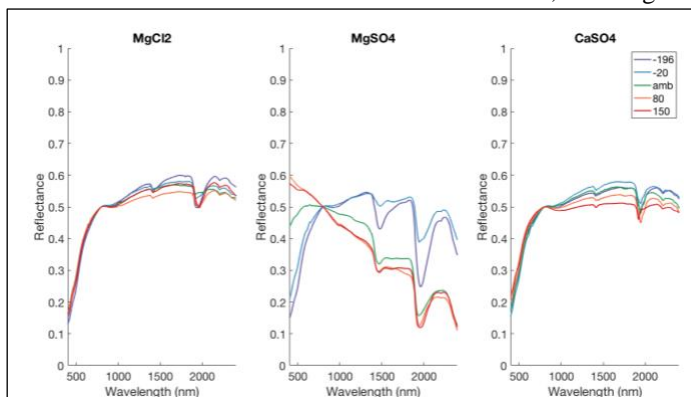


Figure 2. Reflectance spectra of surface desiccation experiments. MgCl_2 (left) and CaSO_4 (right) show no notable change in spectral slope while MgSO_4 (center) shows an increased slope as a function of temperature. Salt and water migration increase due to elevated temperatures, and increase in cation size. The 1.9 μm band deepens at colder temperatures, where salt and water migration are low, and is attributed to either molecular water in the salts or adsorbed onto the matrix.

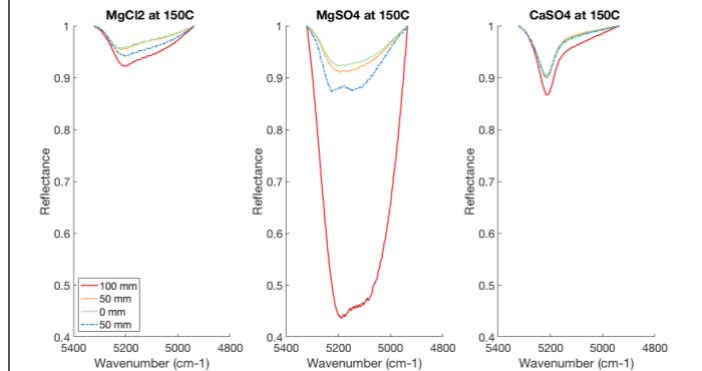


Figure 3. Reflectance spectra of desiccation experiments at depth. Reflectance spectra were obtained for the three desiccated salt-doped soils. Spectral band depth at the 1.9 μm did not appear to change for MgCl_2 (left) and CaSO_4 (right) across depths; however, the band deepened at the surface, caused by an upward migration of salt to the surface as water was removed from the soil.

shows a changing slope as a function of temperature: warmer temperatures have a steeper slope. This indicates a change in salt abundance possibly due to increased migration rate of the salt upward through the soil, compared to the soil at colder temperatures (Fig. 2).

An increased migration rate for Mg^{2+} compared to Ca^{2+} is expected due to increased solvation of the larger cation. Additionally, band depth at 1.9 μm in all the samples appears to be deeper at colder temperatures, where salt migration, and therefore water migration, are low. This spectral feature in the subfreezing MgSO_4 doped soils is deeper due to either molecular water in the salts or adsorbed onto the matrix.

In desiccation experiments at depth, reflectance spectra were obtained for the three salt-doped soils at the five desiccation temperatures. Spectra were plotted after normalizing at the 1.9 μm band (5200 cm^{-1}), such as depicted at 150 $^{\circ}\text{C}$ (Fig. 3). MgCl_2 and CaSO_4 did not show a notable change in band depth with desiccation temperature, especially compared to MgSO_4 which deepened at the surface. This increase in band depth correlates to

an upward migration of salt and a visible salt crust at the surface (Fig. 1).

The band area, or the area bound within the curve, was calculated for the 1.9 μm band for all reflectance spectra, and plotted to show the relationship between band area and soil depth (0 mm, 50 mm, 100 mm, 150 mm) see Figure 4. The relationship

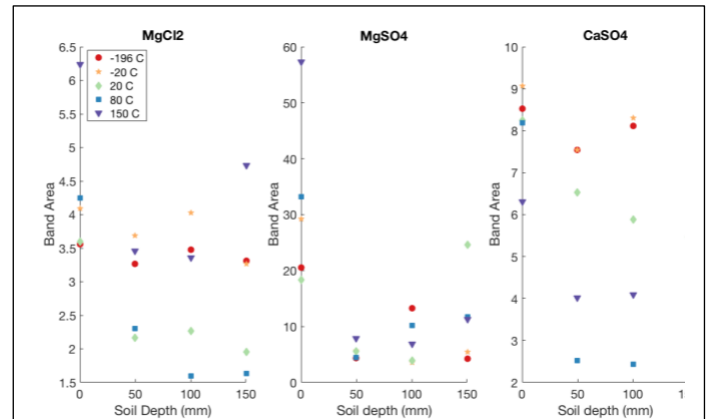


Figure 5. Band area change with temperature. Band areas were calculated for the spectra at 1.9 μm at each desiccation temperature (-196 $^{\circ}\text{C}$, -20 $^{\circ}\text{C}$, 20 $^{\circ}\text{C}$, 80 $^{\circ}\text{C}$, 150 $^{\circ}\text{C}$) for each soil sample depth (0 mm, 50 mm, 100 mm, 150 mm). Change in band area is greatest among MgSO_4 (center) samples, and changes less among MgCl_2 (left) and CaSO_4 (right) samples. These trends show that salt migration is more prominent, as a function of temperature, in MgSO_4 compared to MgCl_2 and CaSO_4 .

between band area and drying temperature (-196 $^{\circ}\text{C}$, -20 $^{\circ}\text{C}$, 20 $^{\circ}\text{C}$, 80 $^{\circ}\text{C}$, 150 $^{\circ}\text{C}$) is explored in Figure 5.

Conclusion: The desiccation experiments presented here may elucidate the processes by which salt and water migrate in the Martian regolith. In general, salt migration appears to be most prominent at elevated temperatures and nearer to the surface. MgSO_4 migrates the most, compared to MgCl_2 and CaSO_4 , which may be expected due to higher solvation of the larger Mg^{2+} cation (its ability to surround itself with more water molecules) and increased mobility in thin films. This mobility effect seems to dominate any solubility effects that the Cl^- anion typically has over the SO_4^- anion in solution. The reason for enhanced MgSO_4 migration compared to MgCl_2 migration is unclear. By gaining a better understanding of salt and water migration processes in an experimental setting, we can more clearly identify the processes that lead to salt migration and duricrust formation on Mars.

References: [1] Moore, H.J. et al. (1987) *USGS Prof. Paper*. [2] Golombek, M.P. et al. (2008) *Cambridge UP*. [3] Jakosky, B.M. & Christensen, P.R. (1986) *JGR*. [4] Anderson, D.M. and Tice, A.R. (1972) *Highway Res. Rec.* [5] Zent, A.P. and Quinn, R.C. (1997) *JGR*.

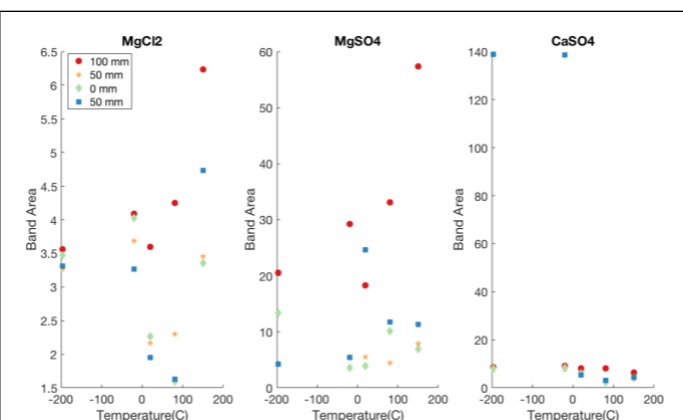


Figure 4. Band area change with soil depths. Band areas were calculated for the spectra at 1.9 μm at each depth (0 mm, 50 mm, 100 mm, 150 mm) for each desiccation temperature (-196 $^{\circ}\text{C}$, -20 $^{\circ}\text{C}$, 20 $^{\circ}\text{C}$, 80 $^{\circ}\text{C}$, 150 $^{\circ}\text{C}$). Change in band area, as a function of depth, is greatest among MgSO_4 (center) samples, which points to the observed upward salt migration. Band area changes less among MgCl_2 (left) and CaSO_4 (right) samples.