

HAPKE-BASED LABORATORY AND REMOTE DETERMINATION OF MARTIAN CHLORIDE SALT ABUNDANCES. E. Das¹, T.D. Glotch¹, C.S. Edwards², C. Ye² and R. E. Milliken³,¹Dept. of Geosciences, Stony Brook University, Stony Brook, NY, eashan.das@stonybrook.edu, ²Dept. of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, ³Dept. of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI.

Introduction: Remote compositional analyses of various orbital spectrometer datasets (Mars Odyssey Thermal Emission Imaging System (THEMIS), Mars Global Surveyor Thermal Emission Spectrometer (TES) and Mars Reconnaissance Orbiter Compact Reconnaissance Imaging Spectrometer on Mars (CRISM)) have identified hundreds of chloride salt-bearing deposits throughout the Martian southern highlands [1, 2]. Identification of chloride salt-bearing deposits has involved an atypical process due to the lack of diagnostic spectral absorption features of anhydrous chlorides in both the visible/near-infrared (VNIR) and mid-infrared (MIR) wavelength regions. Despite diagnostic absorptions, these materials have relatively unique spectral properties that have been used for their identification [3,4].

At NIR (1-2.6 μm) wavelengths, CRISM spectra of chloride-bearing deposits lack narrow vibrational absorptions, exhibit red (positive) spectral slopes relative to surrounding terrain, and exhibit weak or nearly absent 3 μm OH/H₂O feature [3-6]. These properties are consistent with nominally anhydrous chloride salts and/or deposits with lower bulk hydration than that of the surrounding terrain.

MIR orbital and lab spectroscopy and spectral modeling have previously constrained the abundance of chloride salt in typical Martian deposits to ~10-25 wt.% [3]. In our work we attempt to utilize the variability of the 3 μm water band in CRISM data to better constrain both the salt abundance and water content of chloride salt deposits on Mars, which will inform models of the deposition and geochemical evolution of these units. To supplement analyses of orbital data we perform lab experiments to improve on Hapke based approaches [8,9] to constrain the chloride salt and related water abundances.

Methods: *Lab Work:* To observe the relationship between salt content and water abundance we created a suite of binary mixtures of Exolith Labs Mars Global Simulant (MGS-1) [10] and Alfa Aesar spectroscopy-grade halite. Mixes were created with varying proportions of salt abundances by weight percent (90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, 5%, 1%). Once prepared each of the mixtures were placed in an oven (at T~80°C) and allowed to dry for multiple days before collecting spectra.

Spectra of the samples were collected over the 0.35-5.0 μm range. VNIR spectra over the 0.35 – 2.5 μm

wavelength range were collected using an ASD FieldSpec3 Max spectrophotometer and referenced to a calibrated Spectralon plate. We used a Nicolet 6700 Fourier transform infrared (FTIR) spectrometer equipped with a diffuse reflectance accessory to collect spectra in the 1-5 μm range. A CaF₂ beam splitter, DTGS detector, and Globar IR source were used in acquisition of FTIR data. A diffuse gold plate was used as the reference spectrum to obtain diffuse reflectance spectra. A steady flow of extra dry N₂ gas was used to purge the sample chamber and to maintain a dry environment during collection of the spectra. The samples were kept in the chamber for several minutes under the flow of N₂ gas before spectra were collected to allow weakly bound surface adsorbed H₂O to be purged before data collection.

ASD and FTIR reflectance spectra were collected for the entire mixture suite. The FTIR data were corrected using a multiplicative factor in the overlapping wavelength range to match the ASD spectra and the data sets were spliced together to create a continuous spectrum over the 0.35-5 μm range.

Each reflectance spectrum was converted to Single-Scattering Albedo (SSA) using the Hapke radiative transfer model [11], followed by a continuum removal over the 3 μm region. From the continuum removed spectra we calculate the effective single particle absorption thickness (ESPAT) [8,9,11] which we used to estimate water abundance at both 2.9 and 3.0 μm using parameters and linear curve fitting parameters as described in [8,9]. We use the resulting data to revise the fitting parameters that linearly relate salt content to water abundance for halite-bearing soils.

Orbital Data Analysis: We attempt to estimate the water abundance of salt bearing deposits across the Martian southern highlands using 60 CRISM images that were atmospherically corrected and converted to SSA using an updated Discrete Ordinate Radiative Transfer (DISORT)-based atmospheric correction model [12]. Once corrected and converted to SSA we used the same Hapke-based approach described above to estimate water content within each pixel of the CRISM image cube.

Using several simplifying assumptions, we then used calculated water abundances to estimate salt content of Martian chloride deposits. We assume (1) that the Martian chloride salt deposits are mixtures of halite and the regional basaltic regolith, (2) that halite

has no water associated with and therefore should not have a 3 μm feature, and (3) that the densities of basalt (2.9 g/cm^3) and halite (2.16 g/cm^3) are representative of the materials present on the Martian surface. The calculation of the salt content from CRISM images relies on the above assumptions and the difference in calculated water abundance between the chloride deposits and the regional basaltic regolith present in the scene. From these assumptions we can calculate the fraction of halite or basalt as:

$$f_{\text{halite}} = 1 - f_{\text{basalt}} = 1 - \frac{H_2O_{\text{Deposit}}}{H_2O_{\text{basalt}}}$$

This provides the areal fractions of halite/basalt derived from orbital measurements at the surface, which are sensitive to the top hundreds of μm of regolith/deposit surface. Therefore, if we can assume that surface areal fractions are representative of volumetric abundances to some depth, we can then calculate the mass fraction of halite as follows:

$$mf_{\text{halite}} = \frac{\rho_{\text{halite}} * vf_{\text{halite}}}{(\rho_{\text{halite}} * vf_{\text{halite}}) + (\rho_{\text{basalt}} * vf_{\text{basalt}})}$$

Where mf_x , vf_x , and ρ_x are the mass fraction, volume fraction, and density of each phase.

Results: Figure 1 shows salt abundance (wt.%) vs water content obtained using the method described above. From this we observe a relative linear trend between calculated water content and salt abundance for our sample suite. Based on this linear fit we then update the fitting terms defined in [8,9] used to estimate water content so that they are optimal for Martian chloride salt-bearing deposits.

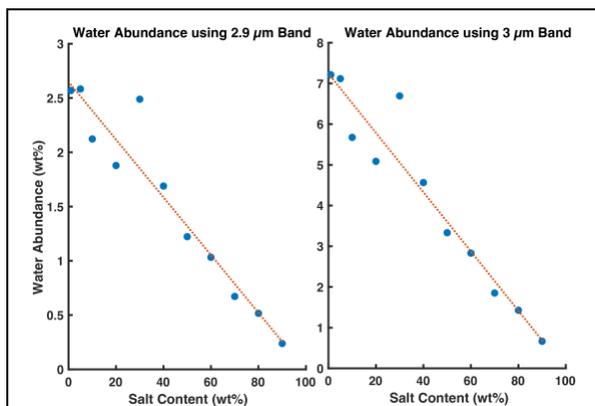


Figure 1: Estimated water abundance (wt%) vs. salt content (wt%) for the sample suite at 2.9 μm (left) and 3.0 μm (right). An overall linear trend is observed at both band positions.

Figure 2 shows a halite abundance map derived from CRISM image FRTA253 for a portion of Terra Sirenum using the approach described above. Derived salt abundances in the region range from ~ 10 wt.% (green) to ~ 30 wt.% (red), which is in line with estimates from [3].

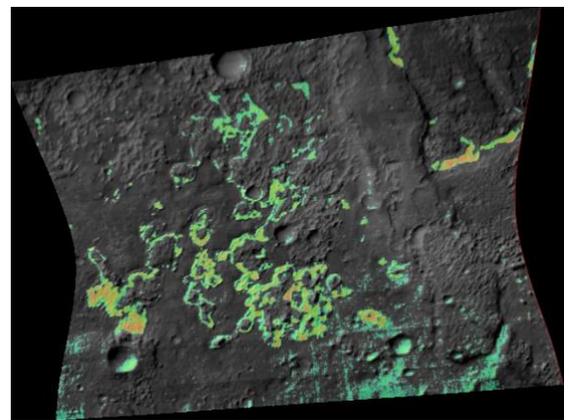


Figure 2: Halite abundance map derived from CRISM image FRTA253 in Terra Sirenum.

Future Work, Conclusions, and Implications:

Repeat measurements of the sample mixture suite with suitable modifications to our procedure are being made to avoid variability in water content for measurements made on different dates. In that vein, we are currently working on constraining the errors in water abundance estimation by performing thermogravimetric analysis (TGA) on our mixture suite to obtain true water abundances which will then be used to compare against the water abundances estimated. This work will help improve Hapke-based abundance estimation methods. A similar lab-based approach could be used for mineral classes that were not measured in [8,9] to improve water-abundance estimation from Hapke model-based approaches.

Alongside follow-up lab work, we are creating salt maps for the entire list of all CRISM FRT data products over identified chloride-salt bearing deposits on Mars. This work will provide critical new tools to further constrain the compositions of Martian chloride salt deposits and provide the first quantitative estimates of the hydration states of these deposits, which in-turn, will inform models of the formation mechanisms of these deposits.

References: [1] Osterloo M.M et al. (2008) *Science*, 319, 1651-1653. [2] Glotch T.D. et al. (2010) *GRL*, 37, L16202. [3] Glotch T.D. et al. (2016) *JGR*, 121, 454-471. [4] Jensen H.B. and Glotch T.D. (2011) *JGR*, 116, E00J03 [5] Murchie S.L. et al. (2009) *JGR*, 114, E00D06. [6] Ruesch O.F. et al. (2012) *JGR*, 117, E00J13 [7] Leask E.K. et al. (2019) *LPS L*, Abstract #2636 [8] Milliken R.E. and Mustard J.F. (2005) *JGR*, 110, E12001. [9] Milliken R.E. et al. (2007) *JGR*, 112, E08S07 [10] Cannon K.M. et al. (2019) *Icarus*, 317, 470-478 [11] Hapke B. (1981) *JGR*, 86, 3039-3054 [12] Liu, Y. et al. (2016), *JGR*, 121, 2004-2036.