

Investigating the Age, Abundance and Origin of Chloride Salt-Bearing Deposits on Mars. E. Das¹, T. D. Glotch¹, C.S. Edwards², C. Ye², R.E. Milliken³ and K. Mitra¹,¹Dept. 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: Hundreds of chloride salt-bearing deposits have been identified on the surface of Mars from remote sensing observations [1-4]. Various mechanisms and ages have been suggested for their formation, yet no broad consensus has been reached and many questions remain. [2] suggested formation of chloride salt-bearing deposits in ancient playa like environments from surface water runoff. Meanwhile, various theories have suggested formation of chloride in shallow lacustrine environments. [3,4,8,9,12]. [8] suggested Noachian-Hesperian aged formation with chloride sourced from volcanically degassed Cl deposition and/or dissolution of igneous chlorapatite. Water for this process would have been sourced from shallow groundwater transport and surface water runoff. [9] suggested late-Hesperian to Early Amazonian formation from shallow ponding related to episodic meltwater-related surface water runoff. Recent work has suggested the reduction of chlorate to chloride by redox-sensitive elements like iron and manganese in surface-water or groundwater systems. The subsequent evaporation or freezing of the chloride-containing solution could produce chloride deposits [10].

Recent work using a Hapke radiative transfer model-based water abundance estimation approach [5-6] applied to Compact Reconnaissance Imaging Spectrometer on Mars (CRISM) data covering these deposits provides new constraints on the salt abundances and hydration states of these deposits [7]. This work created water and salt abundance maps from ~40 CRISM images in the Terra Sirenum region in the southern highlands of Mars. These maps indicate a higher abundance (upwards of 40%) [7,11] of chloride salts than previously estimated (between 20-30%) [3-4]. These abundance maps were overlaid onto digital terrain models (DTMs) created from higher resolution imaging datasets (from Mars Reconnaissance Orbiter (MRO) Context & Camera (CTX) and High-Resolution Imaging Science Experiment (HIRISE)). The resulting overlay products provide crucial geologic context from which we can infer how and when these deposits formed.

Overlay products created for CRISM images in Terra Sirenum alone (example shown in Fig. 1) show significant variation in salt deposit morphology. These range from smaller, localized, perched deposits within regional topographic lows (Fig. 1A) to extensive, flat, indurated deposits (Fig 1B). Preliminary analysis also shows variation in salt abundances between locations. Maximum abundances vary from ~30% in some deposits to as high as ~70% in others [7,11]. This observed diversity in salt abundances, and depositional environment likely indicates disparate formation scenarios. We use salt map/DTM overlay products to decipher possible salt deposition mechanisms, which are currently poorly constrained.

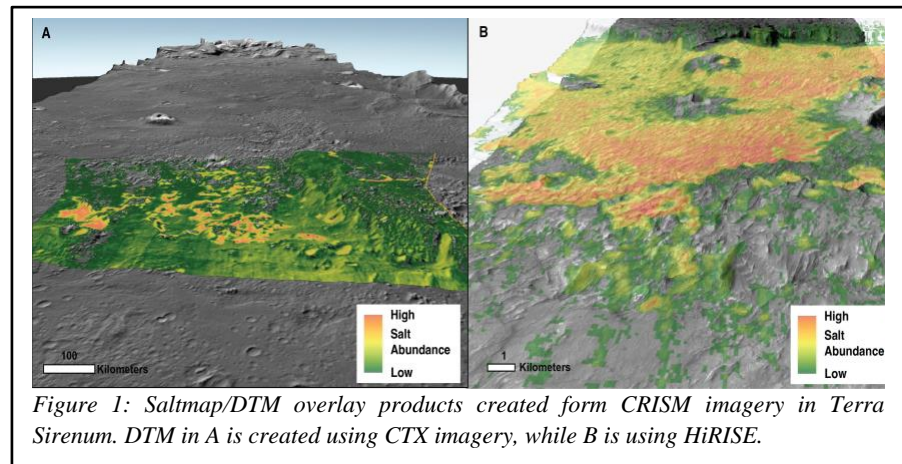


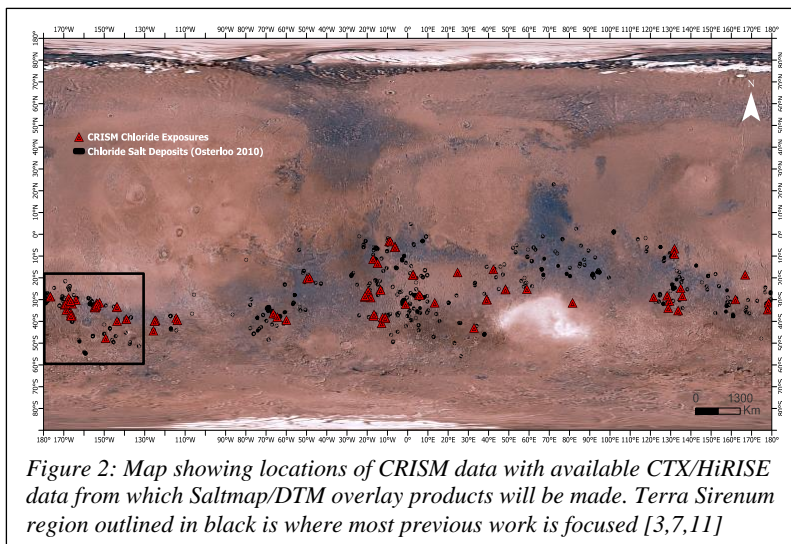
Figure 1: Saltmap/DTM overlay products created from CRISM imagery in Terra Sirenum. DTM in A is created using CTX imagery, while B is using HiRISE.

Here, we present a continuation of these efforts through global scale mapping for all available CRISM data overlapping deposits identified in [1-2]. We use elevation data from DTM overlay products and updated salt abundance values to perform mass balance calculations. Previous work has shown that volume estimates from these mass balance calculations can be used as inputs in geochemical models to constrain the hydrologic boundary conditions for forming the chlorides [8]. Here, we utilize geochemical models along with DTM overlay products to constrain chloride forming source brines. We examine plausible chloride salt ion sources, water source pathways, lake salinity and depth, chloride precipitation mechanisms, and lake timespans as proposed by previous studies [2,3,4,8,9,10,12].

Methods: Global Scale Mapping: Previous mapping in [7,11] was primarily focused on the Terra Sirenum region of Mars (shown in black outline in Figure 2). However, chloride salts deposits across Mars

vary in regional geology, associated precipitate mineralogy, size, abundance, elevation, and should have variable catchment areas for putative surface runoff/groundwater transport related source brine forming lakes [1,2,3,4,8,9,10,12]. Moreover, previous abundance mapping shows disparate morphology associated with chloride deposits within even a small geographic locale such as Terra Sirenum [11]. Therefore, it is crucial to create a global inventory of chloride map products.

All available CRISM Full Resolution Targeted (FRT) data covering chloride salt deposits detected by Osterloo et al. [1-2] with overlapping CTX/HiRISE imagery available were downloaded, atmospherically corrected, and converted to units of single scattering albedo (SSA) using the Discrete Ordinate Radiative Transfer Model (DISORT) [13]. A map of locations of all Saltmap/DTM products is shown in Figure 2.



DISORT processing was performed at Stony Brook University using the SeaWulf high-performance computing cluster. After processing, the Hapke-Based pipeline outlined in [7] was used to create abundance maps for each CRISM image. For each processed image, associated CTX or HiRISE stereo-pairs were obtained. Where available HiRISE stereo-pairs were used, otherwise CTX stereopairs were selected. The DTMs were created using the MARS-SI online platform, which uses the Ames Stereo Pipeline (ASP). Each abundance map was then resized, co-registered and overlaid on its associated DTM (example shown in Fig. 1)

Geochemical Modeling: We attempt to constrain the paleo-hydrology of chloride salt deposits using a combination of our DTM overlay products and geochemical models. Mass balance calculations along with geomorphology and elevation data from DTMs

will be used to constrain chloride volumes, catchment area, and water transport pathways, which can in turn be used to constrain input parameters for geochemical models to test the feasibility of proposed formation mechanisms mentioned above. We will perform reaction modeling to understand chloride precipitation mechanisms under various conditions and starting compositions relevant to each hypothesis. Reaction modeling will be performed in Geochemist's Workbench (GWB) using the React module. We will also perform 1D reactive transport modeling similar to [8] using updated parameters in agreement with abundances derived from CRISM data. 1D reactive transport modeling will be performed using the X1t module in GWB.

Conclusions, Implications and Future Work:

Chloride salt deposits are widespread across Mars, yet no broad consensus on their ages and formation mechanism(s) has been reached. Our work using higher resolution CRISM data covering these deposits has provided new insights into the hydration state and modal abundance of chloride salt in these deposits. The abundances observed in Terra Sirenum are higher than previously estimated using THEMIS (Thermal Emission Imaging System). We have created a robust new method for obtaining the abundances of these deposits and creating associated DTMs to gather important geologic context for their formation.

Our ongoing work will provide a global scale view of chloride salt abundances, hydration states, and regional geology. Geochemical model outputs, abundance values, and elevation data combined will constrain the duration, size, and composition of salt forming brines and in turn plausible formation mechanisms. By investigating these deposits, we will gain valuable insight into the last time liquid water was stable on the surface of Mars and the processes that formed and sustained them.

References: [1] Osterloo M.M. et al. (2008) *Science*, 319, 1651-1653. [2] Osterloo M.M. et al. (2010) *JGR*, 115, E10012. [3] Glotch T.D. et al. (2010) *GRL*, 37, L16202. [4] Glotch T.D. et al. (2016) *JGR*, 121, 454-471. [5] Milliken R.E. and Mustard J.F. (2005) *JGR*, 110, E12001. [6] Milliken R.E. et al. (2007) *JGR*, 112, E08S07. [7] Das E. et al. (2022) *LPS LIII*, Abstract #2678. [8] Melwani-Daswani M. & Kite E. (2017) *JGR*, 122, 1802-1823. [9] Leask E.K. & Ehlmann B.L. (2022) *AGU Advances*, 3, e2021AV000534 [10] Mitra K. et al. (2022) *Nature GeoSci.* [11] Das E. et al. (2022) *AGU Fall Meeting*, Abstract #1090498. [12] Hynek B. M. et al. (2015) *Geology*, 43 (9), 787-790. [13] Liu Y. et al. (2016) *JGR*, 121, 2004-2036.