Investigating the Age, Abundance and Origin of Chloride Salt-Bearing Deposits on Mars. E. Das[1], T. D. Glotch[1], K. Mitra[1], C.S. Edwards[2], C. Ye[2], and R. E. Milliken[3] [1]Dept. of Geosciences, Stony Brook University, Stony Brook, NY, eashan.das@stonybrook.edu, [2]Dept. of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, [3]Dept. of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI.

Introduction: Chloride salt-bearing deposits are ubiquitously distributed across the Martian southern highlands [1-4]. These deposits are of particular interest as they likely represent the last instances of stable liquid water on Mars. 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 authors 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]. These hypotheses have largely been based on remote sensing observations. Little work has been done to incorporate geochemical models that could shed light on the formation and evolution of chloride source brines. Our work seeks to bridge this gap by combining remote sensing observations with geochemical models.

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 of Mars. These maps indicate a higher abundance (upwards of 40%) [7,11] of chloride salts than previously estimated from Thermal Emission Imaging System (THEMIS) data (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 (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 ~40% 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.

Here, we present a continuation of these efforts through global scale DTM overlay analyses and geochemical modeling. Abundance data coupled with elevation data and geomorphological context provided from high resolution DTM products are used to place boundary constraints on the brine forming environments from which chloride salts were formed. These constraints can then be used to assess the validity of various proposed formation mechanisms [2,3,4,8,9,10,12] using thermodynamic reaction models.

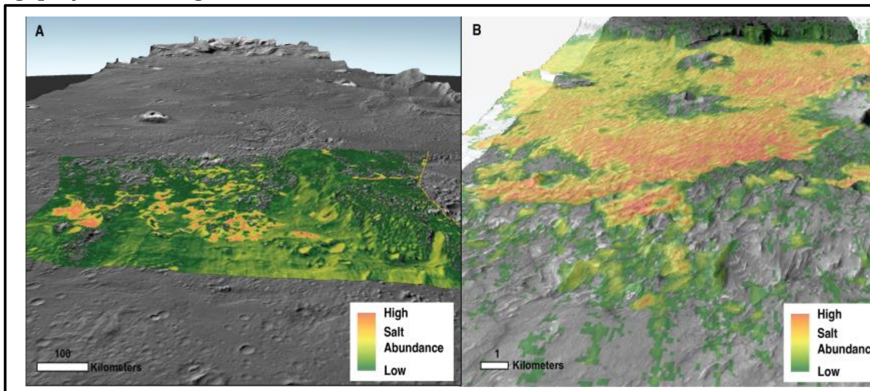

Figure 1: Saltmap/DTM overlay products created form CRISM imagery in Terra Sirenum. DTM in A is created using CTX imagery, while B is using HiRISE.

Methods: *Global Scale Mapping:* Previous mapping has 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]. To capture this variability, it is crucial to create a global inventory of chloride map products.

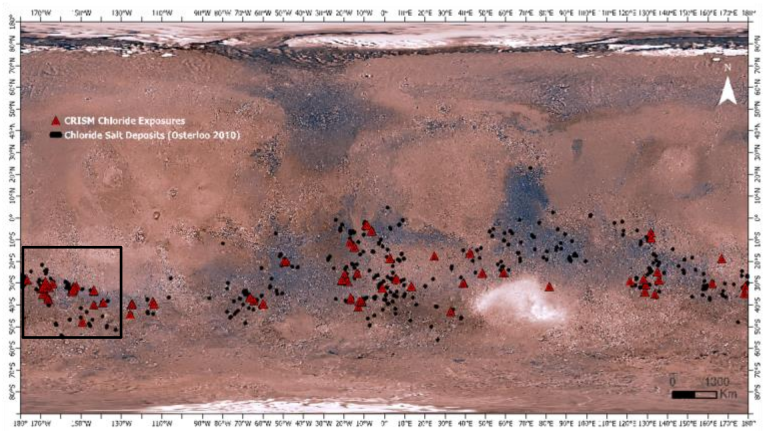

Figure 2: Map showing locations of CRISM data with available CTX/HiRISE data from which Saltmap/DTM overlay products will be made. Terra Sirenum region outlined in black is where most previous work is focused [3,7,11]

All available CRISM data covering chloride salt deposits detected by Osterloo et al. [1-2] (Fig 2.) with overlapping CTX/HiRISE stereo-pairs available were downloaded. The Hapke-based abundance determination model [7] was then applied to obtain abundances.

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 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 will use thermodynamic geochemical models to test the validity of various proposed formation hypotheses (outlined above). Geochemical model input parameters will be informed from volumetric calculations (e.g., salt volumes, precursor pond/lake volumes) and geologic interpretations from DTM overlay analyses and according to the hypothesis being tested. We will track the evolution of chloride-forming systems and place constraints on chloride deposition mechanisms.

To understand the evolution of chloride source brines we will perform thermodynamic reaction modeling using the *React* module in *Geochemist's Workbench* (GWB) using an updated thermodynamic database. We will model basalt-water interactions while varying physicochemical controls that influence the system. These include water to rock ratio (W/R), total water volume (TWV), initial pH, system buffered (open) or unbuffered (closed) by the atmosphere, atmospheric gas concentrations (O_2, CO_2), volcanic degassing inputs, starting water chemistry, and temperature. We will track how basalt composition, fluid chemistry, pH, and basalt alteration products (specifically chlorides) evolve. We will examine the final modeled reaction products and compare chloride quantities to those observed in DTM overlays. Further, certain input parameter values are expected for specific periods in Mars' history. For example, higher relative TWV and temperature values are expected in the Noachian while lower W/R, TWV, and temperatures are expected during the Amazonian. Therefore, model iterations that are not feasible using parameters characteristic of a certain age on Mars will help constrain feasible ages of formation. In addition to testing prior hypotheses, we will run additional iterations informed by geologic interpretations from overlays and prior studies to examine the possibility of alternate mechanisms of formation that have not yet been suggested.

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. Recent work 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. 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 using both remote sensing and geochemical models, we will gain valuable insight into Mars' aqueous history 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.