SALTY SOLUTION TO SLIPPING SOILS ON MARTIAN SLOPES.

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Introduction: Surface flows on Mars such as RSL and gullies could be related to reactions of Ca sulfates and Cl salts. On Earth, collapse features have been observed in environments where gypsum ($CaSO_4 \cdot 2H_2O$) and halite (NaCl) are found together including the Dead Sea in Israel [1], the Sorbas karst network in Spain [2], and stratovolcanoes in Mexico [3]. Despite the cold and arid conditions in the Antarctic Wright Valley [4], elevated salt and moisture levels exist a few cm below the surface at many sites. This could be similar to Mars, where near-surface water ice is present [5]. Recent observations of martian surface features note that RSL and gullies have both occurred in equatorial regions of Mars [6,7], where CRISM has detected hydrated sulfates on the surface [8]. Lab experiments and geochemical modeling are combined here with martian observations to produce a new theory explaining surface flows related to salty soils on Mars.

Earth Observations: Gypsum reactions with halite on Earth are associated with sinkholes in evaporite deposits [e.g. 1]. As liquid water comes in contact with halite, it dissolves and forms a brine system. Dissolution of gypsum adjacent to these brines occurs and then cracks, faults, and porous features form. Disintegration of extensive gypsum deposits can form large caves, such as those at Carlsbad caverns, NM. Formation and collapse of karst systems in Spain has occurred through dissolution of halite, gypsum, and glauberite ($Na_2Ca(SO_4)_2$) [2]. Collapse sinkholes up to 100 m in diameter are observed due to gradual dissolution of sulfates and Cl salts. Further, gypsum veins in stratovolcanoes have been associated with edifice collapse and debris flow [3]. Gypsum is present in all of these systems where instability and mobility of surface materials is observed.

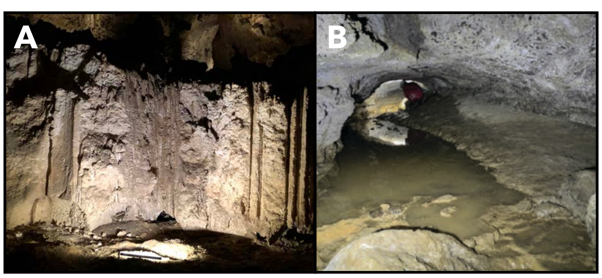

Fig. 1. A) 4 m thick gypsum slab with drip holes from acidic water, Carlsbad Caverns, NM, and B) gypsum ceiling at Borro Cave, Spain [2].

Near surface gypsum and halite are found in the Antarctic Dry Valleys where liquid water is mobile a few cm below the cold and arid surface [e.g. 4]. Wright Valley sediments 4-6 cm below the surface near Don Juan Pond, Don Quixote Pond and other evaporative settings contain elevated gypsum abundance. In some locations the highest gypsum abundance is correlated with high halite content as well.

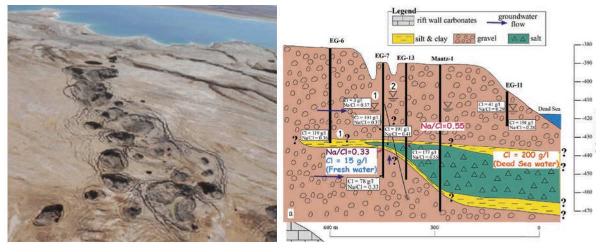

Fig. 2. A) sinkhole features adjacent to the Dead Sea, Israel, and B) diagram illustrating subsurface salts [1].

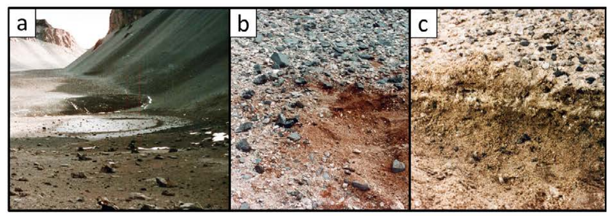

Fig. 3. A) Don Juan Pond, Wright Valley, Antarctica, B) red altered soil 1-4 cm below sediment surface, and C) bright layers down 3-4 cm at Don Quixote Pond.

Mars Observations: Ice has been identified just below the surface in HiRISE images (Fig. 4) at several sites on Mars [5]. Shallow ice may have formed at high obliquity events. Melting of this near-surface ice on sun-facing slopes could be providing a small amount of liquid water that is gradually absorbed by Cl salts in the soil until a saturation point is reached and dissolution occurs. This Cl-brine could then further dissolve Ca sulfates in the regolith, releasing more debris and facilitating downslope flow of dry material as the liquid water sublimates when exposed to the surface.

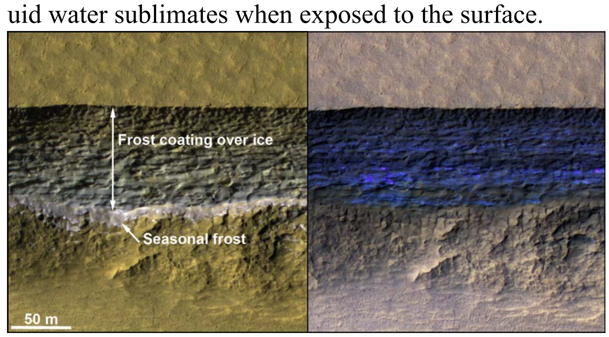

Fig. 4. HiRISE view of near-surface ice on Mars [5].

Seasonal flows on steep slopes, or Recurring Slope Lineae (RSL), are observed at equatorial and mid-latitude sites [9]. While Mid-latitude RSL can be explained by processes involving CO_2 frost [10], the origin of equatorial RSL (-25° to +25°) is not yet well defined, and appears to be different from that of mid-latitude RSL [6]. These equatorial RSL (Fig. 5) are associated with small equatorial gullies and are attributed to aqueous processes because temperatures are too warm for CO_2 frost [6]. Morphological studies of several gully sites (e.g. Fig. 6) reveal complex, highly integrated tributary systems at gully source regions, supporting liquid water activity at these sites [11].

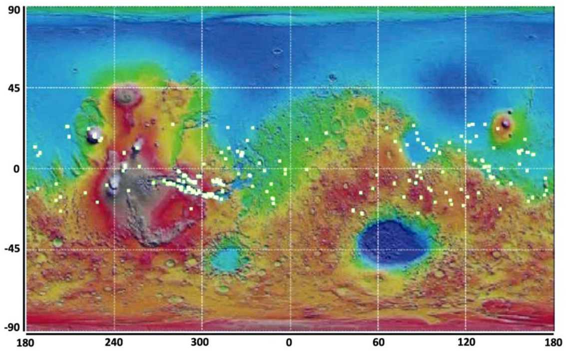

Fig. 5. Equatorial RSL locations [6,7]

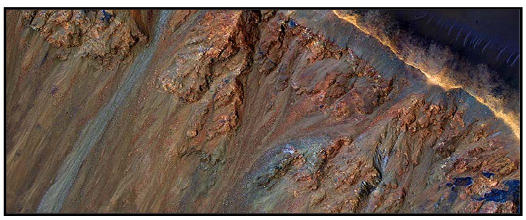

Fig. 6. HiRISE ESP_049488_1720 of Krupac crater (lat -7.8°, lon 86°), image credt: NASA/JPL/UofA.

Lab Experiments: To test hydration of subsurface salts, a lab experiment was performed using altered volcanic material from Mauna Kea (#91-16) [13] as an analog Mars regolith. A 1-cm thick layer of the <2 mm fraction of Mauna Kea soil was placed in a glass dish and covered with ground (<500 µm) anhydrous Drierite (Ca sulfate spiked with Co(II) chloride as a color indicator), anhydrous Drierite pellets, and ground (<500 µm) $CaCl_2 \bullet 2H_2O$ [12] (Fig. 7A), then another 1.5-cm thick layer of Mauna Kea soil was placed on top (Fig. 7B). H_2O was added to the system through a straw inserted through the material to the bottom of the glass dish. The water was absorbed by the dry soil and salts within a few seconds. With the addition of water (10 ml at a time for a total of 70 ml) a hole in the center of the soil/salt system formed and water spread across the bottom of the glass dish. Gradually the salt layer turned pink as it hydrated, cracks formed in the soil (perhaps due to dissolution of the salts), and the salts migrated both up and down through the layers as water was absorbed by the salts. After heating the crust at intervals of 15 minutes at 100 °C for 1 hr, then air

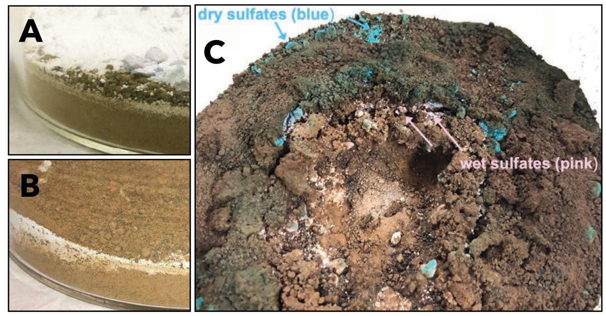

Fig. 7. Views of crust experiment. A) salt layers covering Mauna Kea soil, B) soil-salt-soil layers before hydration experiment, and C) results of crust experiment where dry (blue) sulfates are observed in surface materials and wet (pink) sulfates are observed just below the surface imbedded in hydrated material.

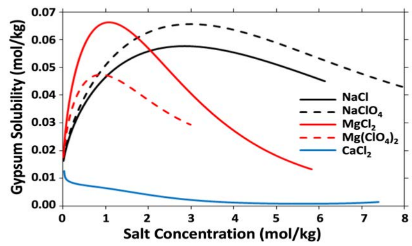

Fig. 8. Modeling reveals that gypsum solubility varies depending on the concentration of halite and other Cl salts.

drying the crust in the lab for a day, the surface material became dry (blue Drierite), while subsurface material stayed slightly hydrated (pink Drierite) (Fig. 7C).

Gypsum and Cl salts affect each other's solubility such that CaCl is more soluble in the presence of gypsum, but gypsum is more soluble in the presence of NaCl [e.g. 14]. Gypsum solubility was modeled with varying concentrations of halite and other Cl salts (Fig. 8), indicating that gypsum becomes more soluble with increasing Na and Mg salt concentrations initially, then less soluble at higher salt levels.

Implications for Mars: Some martian surface flow features, such as RSL and gullies, may have been triggered by dissolution of near surface gypsum and Cl salts. This process would likely have required 100-300 ml of brine to dissolve 1 g of gypsum; thus, it is easier to explain salt dissolution during a wetter epoch on Mars. However, melting ice over time could also produce near surface brine in the martian regolith.

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