AN EXAMINATION OF ATMOSPHERIC WATER VAPOR AS A SOURCE FOR RECURRING SLOPE LINEAE ON MARS.

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Introduction: Recurring slope lineae (RSL) are seasonally albedo-changing linear features found on valley walls, crater rims slopes, and central peaks of craters on Mars (*1*). The linear features, whose formation mechanism has yet to be explained, extend incrementally and reappear and fade annually. RSL may represent recently flowing liquid water, although dry (or mostly dry) flows have also been proposed (*2*). If an active liquid flow is present, it is most likely in the form of a brine due to the instability of pure liquid water under Martian conditions; however, the source of water and its formation is currently a point of disagreement.

Perchlorate salts, present globally on Mars, are perhaps enhanced at RSL locations (*3*), though this is controversial (*4*). Perchlorate (and other salts) are of interest due to their hygroscopic nature and low eutectic temperature. Salts in RSL could potentially form liquid brine via deliquescence if environmental conditions (temperature, water vapor) are suitable on the surface of Mars today (Fig. 1).

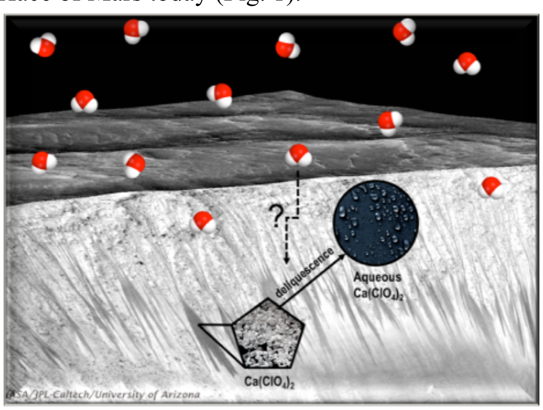

Figure 1. Schematic representation of potential deliquescence of salts in RSL.

Here we present the results of laboratory experiments on calcium perchlorate that utilized atmospheric model outputs to examine the plausibility of atmospheric water vapor as source and possible trigger for RSL formation at Valles Marineris. We aim to address two main questions by combining model simulations and laboratory experiments:

- **Can atmospheric water vapor be a plausible source for RSL?**
- **Is deliquescence (or other water uptake) observed in experiments that simulate modeled conditions at RSL locations?**

Experimental Methods: MarsWRF atmospheric simulations were used to define the experimental parameters (surface temperature, water vapor atmospheric concentration) at observed RSL locations to enable more accurate simulation of Martian conditions than has previously been attempted. MarsWRF (*5*) is a numerical Martian atmospheric model explicitly simulating dynamical processes and parameterizing unresolved processes (e.g., radiative transfer, atmospheric phase changes, etc.). The simulations used for experimental input were 5-domain "nested" simulations, with the largest (lowest resolution) domain being of global extent at a resolution of 2 degrees of latitude and longitude and 52 staggered vertical levels from the surface up to approximately 120 km altitude. Simulations were run for several years at the global scale, with the higher resolution nests being active for 10 days in the final year during the seasons of interest with each successive nest being at 3 times higher resolution and also 3 times smaller linear extent (1/9 area of parent domain) than their parent domain.

To understand the water uptake properties of calcium perchlorate at RSL locations, we have used a Raman microscope equipped with an environmental cell. Details of the setup have been described previously (*6*). Briefly, a Raman microscope is equipped with an environmental cell able to achieve temperatures as low as ~190 K. The Raman microscopy technique enables us to determine the phase of a salt (anhydrous solid, hydrated solid, aqueous solution, or in a mixture with water ice) at a given temperature and relative humidity using both Raman spectroscopy and optical microscopy.

We are able to closely simulate both temperature and relative humidity at a Valles Marineris RSL location. Figure 2 shows a comparison of temperature and relative humidity cycles of the lab simulations vs model outputs at Valles Marineris. The lab simulations were run 4x faster than Mars time (to simulate two Mars days in one ~12 hr day in lab).

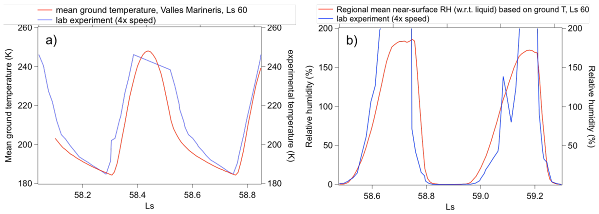

Figure 2. Comparison of (a) temperature and (b) relative humidity between our laboratory experiment (blue) and the model output (red).

Calcium perchlorate particles were spectrally and visually tracked for two back to back simulated diurnal cycles. In Fig. 2, the typical experimental conditions and model simulations are plotted on the calcium perchlorate phase diagram. It appears that aqueous solution may be stable for brief periods throughout the diurnal cycle at Valles Marineris at $L_s = 120$.

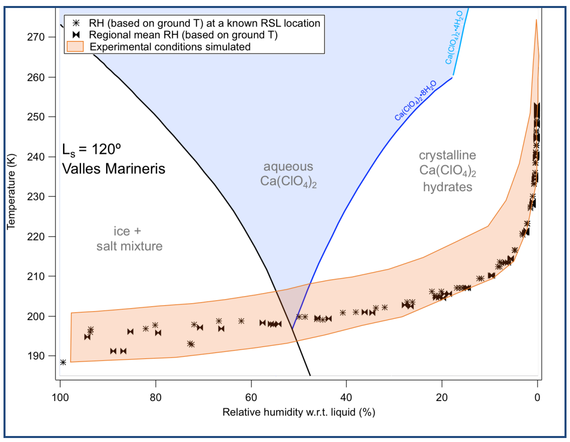

Figure 3. The phase diagram for calcium perchlorate with the typical experimental conditions (orange) and model output values (black symbols).

Results: Throughout the Mars simulated diurnal cycles, the Raman spectra indicate that water uptake is occurring as relative humidity is increased. Fig. 4 demonstrates the peak growth in the O-H stretch, indicating the uptake of water, while the ClO_4^- stretch shifts to signify the solvation of the ion.

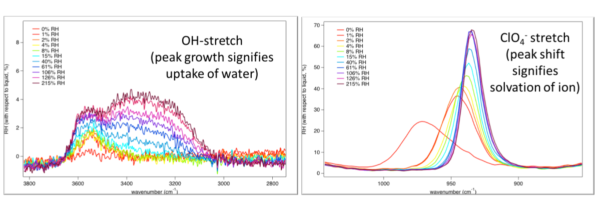

Figure 4. Raman spectra of calcium perchlorate as relative humidity is increased: (a) O-H stretch increases and (b) perchlorate stretch shifts, both indicating uptake of water by the salt.

Additionally, the calcium perchlorate particles undergo visual transformations as the relative humidity is increased and the presence of water uptake is confirmed by Raman spectroscopy. Figure 5 is a microscopic image of calcium perchlorate particles as the temperature and relative humidity are cycled. Visual growth and darkening are observed as the relative humidity increases. When the relative humidity is decreased, the particles decrease in size and become brighter. The diurnal volume changes are interesting and should be considered as a potential trigger mechanism for RSL.

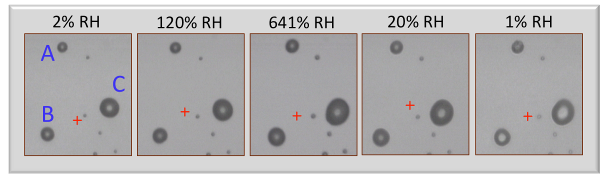

Figure 5. Changes in the appearance of calcium perchlorate particles as RH is increased and then dereased along the experimental trajectory shown in Fig. 3.

Conclusion: We have experimentally examined the behavior of calcium perchlorate for RSL relevant locations based on model simulations. Calcium perchlorate particles demonstrate water uptake and loss, via visual and spectral changes throughout the changes in relative humidity. The water uptake of salts likely has impacts to the atmospheric water cycle and may be associated with RSL formation. The particle size changes (i.e. swelling/decrease throughout the cycle) may be a potential trigger mechanism of RSL. RSL may be initiated via water uptake of salts, causing particle growth, and thus trigger a dry flow.

References:

[1] A. S. McEwen et al., Seasonal Flows on Warm Mar-tian Slopes. Science. 333, 740–743 (2011). [2] C. M. Dundas et al., Granular flows at recurring slope lineae on Mars indicate a limited role for liq-uid water. Nature Geosci. 10, 903–907 (2017). [3] L. Ojha et al., Spectral evidence for hydrated salts in recurring slope lineae on Mars. Nat. Geosci. 8, 829–832 (2015). [4] E. K. Leask, B. L. Ehlmann, M. M. Dundar, S. L. Murchie, F. P. Seelos, Challenges in the Search for Perchlorate and Other Hydrated Minerals With 2.1-μm Absorptions on Mars. GRL. 321, 830–10 (2018). [5] A. D. Toigo, C. Lee, C. E. Newman, M. I. Richardson, The impact of resolution on the dynamics of the martian global atmosphere: Varying resolution studies with the MarsWRF GCM. Icarus. 221, 276–288 (2012). [6] K. J. Baustian, M. E. Wise, M. A. Tolbert, Deposi-tional ice nucleation on solid ammonium sulfate and glutaric acid particles. Atmos. Chem. Phys. 10, 2307–2317 (2010).