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Key Points:

- Temperature and relative humidity conditions at Martian recurring slope lineae locations were modeled and experimentally simulated
- When surface conditions at an RSL location were simulated, Mars-relevant salts only completely dehydrated during the RSL active season
- RSL on Mars may be a dry grain flow triggered by seasonal changes in water content and resulting changes in soil cohesion

Supporting Information:

- Supporting Information S1

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Changes in Soil Cohesion Due to Water Vapor Exchange: A Proposed Dry-Flow Trigger Mechanism for Recurring Slope Lineae on Mars

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Abstract Recurring slope lineae (RSL) are seasonal flows on steep slopes on Mars. Their formation mechanism is unknown, but dry granular flows are a likely explanation. Any proposed trigger for these flows must be consistent with the observed temperature dependence of RSL: more active in warmer months or when sun-facing. Here, we use atmospheric modeling and laboratory experiments to explore a potential mechanism that involves both wet and dry processes at Hale Crater, a known RSL location. We propose that dry flows are triggered by changes in soil cohesion due to the loss of water. When surface temperature and humidity were experimentally simulated, salts likely found in the soil only completely dehydrated during the active season for RSL. We propose that the loss of water from soil in warmer months (or when illuminated) lowers soil cohesion and maximum stability angle. Slope failure may occur, exposing darker underlying material and creating RSL.

Plain Language Summary Some steep hillsides on Mars have dark streaks that appear in warm months and disappear in cold months, year after year. These “recurring slope lineae,” or RSL, could be flowing liquid but are most likely dust avalanching. RSL appear in warmer months, which could be a clue as to what causes the features. In this study, we use an atmospheric model to predict relative humidity and temperature at the surface at one RSL location, Hale Crater. We then simulate these conditions in the laboratory. We find that a type of salt found on Mars can take up and release water from the atmosphere every day, but the salt only loses all of its water when the RSL active season was simulated. We propose that the dry grain flows are triggered in the summer when the soil loses water and becomes less “sticky.” When this happens, dust and sand may slide downhill, exposing the darker material underneath, and create RSL.

1. Introduction

Recurring slope lineae (RSL) are dark flow-like features that have been observed on steep slopes on Mars (McEwen et al., 2011; Stillman et al., 2017). RSL recur annually, typically originating near bedrock outcrops during warm times of the year and incrementally growing for several months before fading. Any individual RSL is observed only intermittently, and so details of initiation and growth are difficult to obtain. The features are widespread on Mars, with most occurrences of RSL activity reported in southern midlatitude (Ojha et al., 2014; Stillman et al., 2014) and equatorial regions (McEwen et al., 2014; Stillman et al., 2017).

The formation mechanism (or mechanisms) of RSL is unknown and the subject of much recent debate and hypotheses (Huber et al., 2020; Stillman et al., 2020). Dry debris flows have been proposed (Dundas, 2020; Dundas et al., 2017; McEwen et al., 2019; Schmidt et al., 2017; Vincendon et al., 2019) and may seem most likely given the current dry Martian climate. Consistent with a dry mechanism, RSL appear to be found primarily on slopes at the angle of repose for unconsolidated Martian sand (Dundas et al., 2017). Additionally, the temporal relationship between RSL lengthening and seasonal dust storms suggest that RSL may involve the progressive removal of bright dust from underlying dark terrain (Vincendon et al., 2019). Possible triggers for a dry flow may be oversteepening of slopes due to dust fallout (McEwen et al., 2019) or to subsurface flows of atmospheric gas caused by temperature gradients found in shadowed terrain (Schmidt et al., 2017). A recent study by Dundas (2020) suggests that dry flows occur due to converging factors of wind, topography, and seasonal dust cover.

Other proposed mechanisms for RSL formation involve liquid water, either freshwater or brine. Water is often invoked because the features visually resemble a flow with fluid-like behavior. Additionally, the apparent temperature-dependence of RSL formation suggests the role of a volatile (Grimm et al., 2014; Ojha et al., 2014; Stillman et al., 2014). Water could be a large-scale seep or flow (Grimm et al., 2014) or just a dampening of the surface that results in darkening (Heinz et al., 2016). The likely lack of shallow aquifers and the small amount of water vapor in the Martian atmosphere argues against the generation of a primarily liquid flow (streamflow) from either a subsurface or atmospheric source, respectively.

Apart from purely “wet” or “dry” mechanisms, RSL could be a dry flow triggered by the activity of small amounts of water. One example is the proposed boiling of surface or subsurface water that may cause slope destabilization and a dry debris flow on Mars (Massé et al., 2016). Dundas et al. (2017) posit that hydration/dehydration cycles could contribute to volume changes in salts or to changes in grain contact cohesion in soils and, in either case, trigger grain flows. Salts such as perchlorates are widespread on Mars, having been found at several landing sites (Glavin et al., 2013; Hecht et al., 2009; Navarro-González et al., 2010). Chlorine-containing salts may be enhanced at RSL locations (Ojha et al., 2015), although this has been questioned recently (Leask et al., 2018; Vincendon et al., 2019). It has been suggested that salts in the Martian soil may uptake water and then lose water during diurnal or seasonal cycles (Fischer et al., 2014; Gough et al., 2011, 2019; Heinz et al., 2016; Nuding et al., 2014; Primm et al., 2018). This exchange of atmospheric water by salts may be due to deliquescence and efflorescence (solid—aqueous transitions) or hydration and dehydration (solid—solid transitions). It is unknown if these salts play a role in the formation of RSL.

Here, we propose and explore an RSL formation mechanism that involves water loss by salt grains at warm temperatures. We suggest that seasonal dehydration of salts in the upper soil layer can lower the cohesive forces between grains, lowering the maximum stability angle and thus triggering a dry debris flow on steep slopes. This would be expected to occur during the warm months during which RSL are typically active. In order to have water loss, there has to have been previous water uptake by the soil, and so here, we explore both directions of this water vapor exchange between the atmosphere and salts in the regolith at Martian RSL locations. It is not possible to observe this potential water vapor exchange with current orbital observations nor have any previous laboratory or modeling studies examined the potential for surface-atmosphere exchange of water vapor at RSL locations specifically.

In this project, we first use the MarsWRF general circulation model to determine the relevant environmental conditions in the near-surface atmosphere during two different seasons at Hale Crater, Mars. Hale Crater (37°S, 37°W, 125 × 150 km in size) has many confirmed RSL, including some that originate from the central peak of the crater (Stillman & Grimm, 2018). It was chosen for our study because RSL at this location have discrete active and inactive periods that we experimentally simulate to compare and contrast the water uptake and water loss behaviors. Specifically, RSL activity here begins just after $L_s = 180^\circ$ (early spring) and continues until approximately $L_s = 360^\circ$ (the end of summer; Stillman & Grimm, 2018). We then perform laboratory experiments to closely simulate the temperature and humidity conditions modeled during these two seasons. We observe the extent of water uptake and loss by the deliquescent, Mars-relevant salt calcium perchlorate using Raman microscopy. This enables both spectral and visual monitoring of the sample. Finally, we use the results of these experiments to suggest that a dry flow triggered by changes to grain cohesion is a mechanism consistent with the seasonality of RSL.

2. Experiments

2.1. MarsWRF Simulations

The MarsWRF general circulation model was used to simulate the temperature and water vapor concentrations in the near-surface region of Hale Crater. MarsWRF (Toigo et al., 2012) is a numerical Martian atmospheric model that integrates the fully compressible equations of fluid motion on a discrete (“grid-point”) three-dimensional mesh. The model explicitly simulates dynamical processes and parameterizes unresolved processes such as subgrid-scale diffusion, boundary layer eddies and convection, radiative transfer, phase-change processes (including the CO₂ and H₂O cycles), and surface and subsurface heat exchange. The simulations used for experimental input were performed on a global domain, that is, the entire planet mapped in a simple cylindrical projection, with grid-points every 1° of latitude and longitude and 52

uneven vertical levels (thinner near the surface, thicker at higher altitudes) from the surface up to approximately 120 km altitude. The global simulation was run for 1 year (after a further earlier year of model spinup and equilibration), and data from the grid-point at the location of Hale Crater were recorded at intervals of 1 “hour” (i.e., 1/24 of a Martian sol) to fully describe the diurnal changes in temperature and moisture. At $1^\circ \times 1^\circ$ resolution, Hale crater itself is resolved by nine (3×3) grid points. The thermophysical conditions at Hale Crater used in the model simulation are listed in Table S1 in the supporting information.

The primary modeling output used to guide the laboratory simulations were predictions of the ground temperature (T_g) and the partial pressure of water in the lowest vertical layer of air (40 m thick). Savijärvi et al. (2016) modeled conditions over Gale crater incorporating an observation of water vapor at a single height and predicted a decrease in water vapor near the surface due to the adsorption of water vapor by the regolith at certain times of day. This effect was not parameterized in our model simulations as it is this regolith exchange process that we investigate in these laboratory experiments. Thus, we assume that the availability of atmospheric water vapor as expressed by the water partial pressure in the lowest vertical layer is essentially constant down to the surface. The absorption of water by the regolith in the laboratory experiments would then reduce this amount of vapor below the model-predicted values. The relative humidity with respect to liquid water at the temperature of the surface was calculated for use in the experiments. This was done by dividing the vapor pressure of water in the lowest 40 m by the saturation vapor pressure of supercooled water as a function of temperature from Murphy and Koop (2005).

In this paper, all RH values, modeled or experimental, represent the relative humidity with respect to liquid, RH_{liq} , rather than ice, RH_{ice} . The choice was made because current literature discusses the deliquescence and hydration relative humidity thresholds of salts with respect to liquid and constructs phase diagrams using RH_{liq} . It is important to recognize that RH_{liq} and RH_{ice} values are different, especially at low temperatures (Rivera-Valentin et al., 2018) but can be easily interconverted using the different saturation vapor pressures of liquid water vs. ice (Murphy & Koop, 2005).

2.2. Laboratory Experiments

The Raman microscopy system used here to study water uptake and loss by salts has been previously described in detail (Baustian et al., 2010; Gough et al., 2011). Briefly, a Nicolet Almega XR Dispersive Raman spectrometer was outfitted with an environmental cell with automated temperature controller and a chilled-mirror hygrometer at the cell outlet. A platinum resistance sensor within the silver block monitored the sample temperature to ± 0.1 K. To account for any differences in temperature between the sensor and sample, a temperature calibration was performed using sodium chloride deliquescence (Baustian et al., 2010).

The ratio of humidified and dry N_2 gas flow was adjusted to achieve the desired relative humidity. Frost point measurements from the hygrometer and sample temperature measurements from the platinum resistance sensor allowed for real-time monitoring of the relative humidity at the sample. The uncertainty in RH due to the uncertainty in measured dew point was about $\pm 1.5\%$. During the experiments, the H_2O vapor mixing ratio (and thus dew point) was held constant, and the temperature was increased or decreased according to the Martian conditions being simulated. In these experiments, we simulated the modeled Martian temperature and relative humidity values at a rate that was between three and four times faster than real time on Mars. This was chosen to balance experimental practicality with the desire to capture the kinetic effects of phase transitions.

A 1% by weight aqueous solution of calcium perchlorate, $Ca(ClO_4)_2$, prepared using $Ca(ClO_4)_2 \cdot 4H_2O$ (99% pure), was nebulized onto a hydrophobic quartz disk producing particles from 5 to 30 μm in diameter. The sample was placed into the environmental cell, and the relative humidity and temperature conditions were adjusted to the desired conditions for the start of the simulation. In all cases, these conditions were sufficient to recrystallize the salt into a crystalline solid, either anhydrous or hydrated.

For all experiments performed in this study, the 532 nm excitation laser was used to collect Raman spectra (2 cm^{-1} resolution) of salt particles as small as 1 μm in diameter. Using the Raman vibrational spectra, we could observe changes in phase or hydration state. Consistent with past work (Fischer et al., 2016; Nuding et al., 2014), spectral changes were seen in the O–H stretch region ($3,000\text{--}3,600\text{ cm}^{-1}$) and perchlorate stretch region ($900\text{--}1,000\text{ cm}^{-1}$) when humidity was increased around the $Ca(ClO_4)_2$ particles. An optical

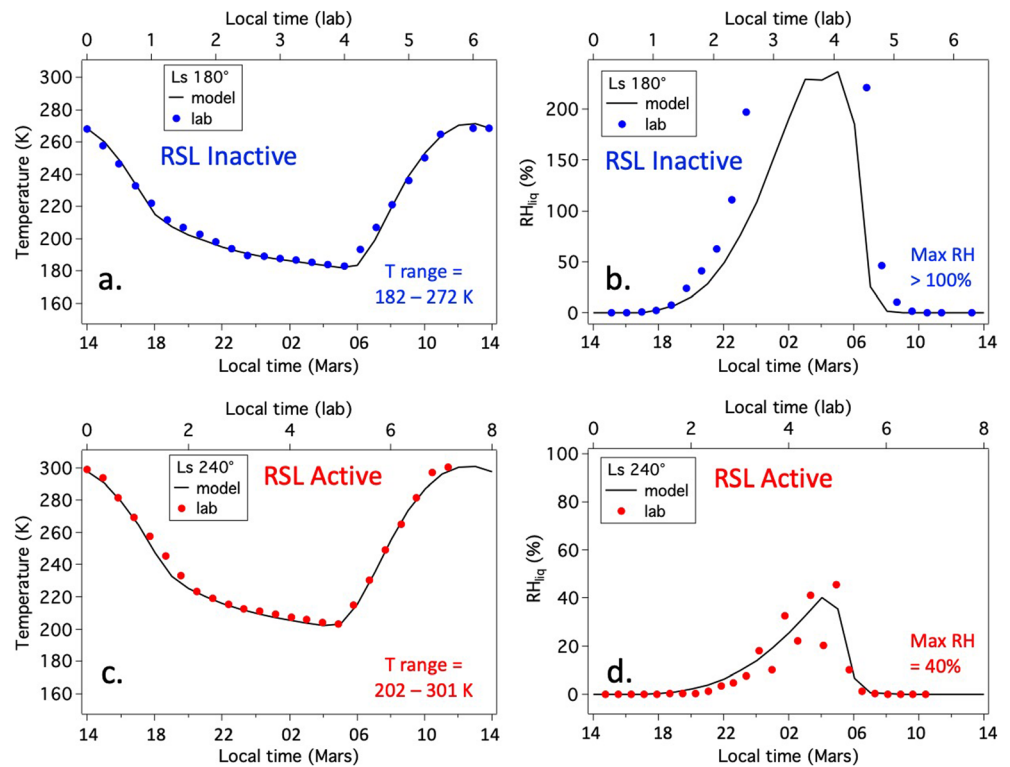


Figure 1. A representative laboratory simulation of diurnal model output at Hale Crater for temperature (a) and relative humidity (RH_{liq}) (b) at L_s = 180°, and temperature (c) and relative humidity (d) at L_s = 240°.

microscope (Olympus BX51) with 10, 20, 50, and 100× magnification capabilities was also used to directly observe changes in appearance (color, size) as salt particles underwent phase transitions. Spectra and microscope images were collected every 15 min during an experiment. All spectra and images collected during the experiments are available in the data repository listed in the Acknowledgements.

3. Results

3.1. Simulation of Modeled Environmental Conditions

Two seasons at Hale Crater were simulated in the lab for this study: one before RSL activity begins (L_s = 180°) and one during the lengthening of RSL at this location (L_s = 240°; Stillman & Grimm, 2018). A summary of the modeled surface conditions at the Hale Crater RSL location is shown in Table S1. In this paper, we refer to L_s = 240° as the “RSL active period” and L_s = 180° as the “RSL inactive period”. A representative lab simulation of a diurnal cycle for each season is shown in Figure 1, with temperature in the left panels and relative humidity with respect to liquid on the right. For each figure, the lower x-axis spans 14:00–14:00 local Mars time, with midnight towards the middle. Time is shown in this manner because the lab simulations began at the warmest and driest time of day. (Here, as elsewhere, we report Mars local times in units of 1/24 of a sol, and not as terrestrial hours.) Lab time for the approximately 6–8 hr experiments is shown on the upper x-axis. The temperature cycle is well simulated in both seasons. The relative humidity cycle is also reasonably well simulated, with the largest deviations occurring during the periods of highest RH. The model and experiment both permit the relative humidity at the ground, using the ground temperature rather than the near-surface air temperature, to surpass 100%. The L_s = 180° simulations were much colder and wetter than the L_s = 240° simulations. However, the modeled water vapor pressures were between 2 and 4 times larger for L_s = 240° (0.156–0.168 Pa) compared to L_s = 180° (0.040–0.086 Pa). Temperature changes in the shallow subsurface for L_s = 180° and 240° were also calculated by the MarsWRF model (Figure S1), but were not part of the experiments.

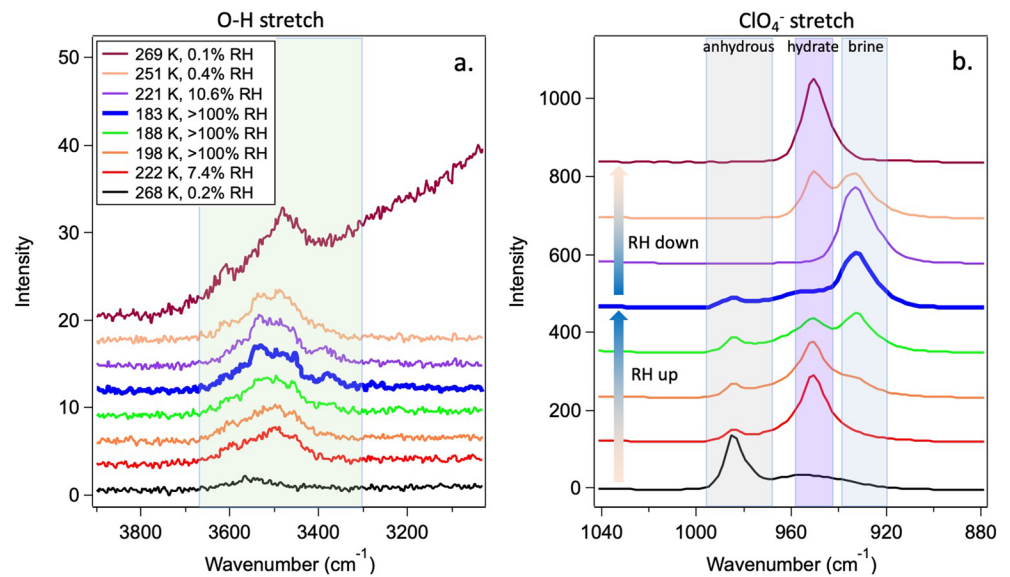


Figure 2. Raman spectra collected during a simulated diurnal cycle representing $L_s = 180^\circ$ at Hale Crater (RSL inactive season). The relative humidity (RH_{liq}) is increased and then decreased over 375 min by lowering and then raising the temperature. Changes in the (a) O–H stretch region and (b) ClO_4^- stretching region are shown. Based on both stretches, there is still H_2O present at the end of the experiment, which represents the warmest time of day on Mars. Spectra are offset for clarity. The legend in (a) applies to (b) as well.

3.2. RSL Inactive Season ($L_s = 180^\circ$)

Figure 2 shows Raman spectra collected during a portion of the $L_s = 180^\circ$ (RSL inactive season) Hale Crater experiment, the temperature, and RH conditions for which are shown in Figures 1a and 1b. These data were collected over 375 min while relative humidity was increased and then decreased around the salt to simulate a full Martian sol. The O–H stretching region (Figure 2a) and ClO_4^- stretching region (Figure 2b) both indicate that while some water was present initially, additional water uptake occurs almost immediately, between 0% and 7% RH. During this small humidity interval, the intensity of the O–H stretch at $\sim 3,500\text{ cm}^{-1}$ increases and the ClO_4^- stretch shifts from 985 cm^{-1} , characteristic of the anhydrous salt, to 950 cm^{-1} , characteristic of a hydrated salt. As the RH continues to increase, components of the ClO_4^- stretch migrate to even lower wavenumbers (933 cm^{-1}), indicating a brine component may be present by the time water vapor saturation is reached. This is consistent with the results of Nuding et al. (2014) who report deliquescence of $Ca(ClO_4)_2$ by $\sim 55\%$ RH. At the highest RH reached during the experiment (thick blue trace, representing $\sim 05:00$ local Mars time), all three components (anhydrous salt, hydrated salt, aqueous brine) appear to be present. This metastable combination may fully transition to brine given sufficient time and/or water vapor. Because our experiments were performed on an accelerated time scale (3–4 \times faster than Mars time), phase transitions of either water uptake or loss would have even more time to occur on Mars.

When the RH is lowered and the temperature raised, the O–H stretch persists and is present even at the end of the experiment, when the warmest and driest period of day ($\sim 14:00$ local Mars time) is simulated. At the same time, the ClO_4^- stretch migrates to higher wavenumbers but only as high as 950 cm^{-1} . This indicates that a hydrated salt was the end product after the diurnal cycle was completed. Temperatures of 269 K and RH values less than 1% were insufficient to dehydrate calcium perchlorate to the anhydrous state. This is consistent with Gough et al. (2019), who found temperatures $\geq 298\text{ K}$ are needed to obtain anhydrous $Ca(ClO_4)_2$ salt.

To summarize this $L_s = 180^\circ$ experiment and two additional $L_s = 180^\circ$ trials (not shown), salts at Hale Crater in early spring are expected to absorb atmospheric water vapor diurnally, forming a brine and/or hydrated phases overnight. By afternoon, warmer and drier conditions will cause the loss of some condensed phase water from the salt, but some H_2O will persist, likely as a crystalline hydrate. The remnant water was observed in all three $L_s = 180^\circ$ trials and is important for our proposed mechanism.

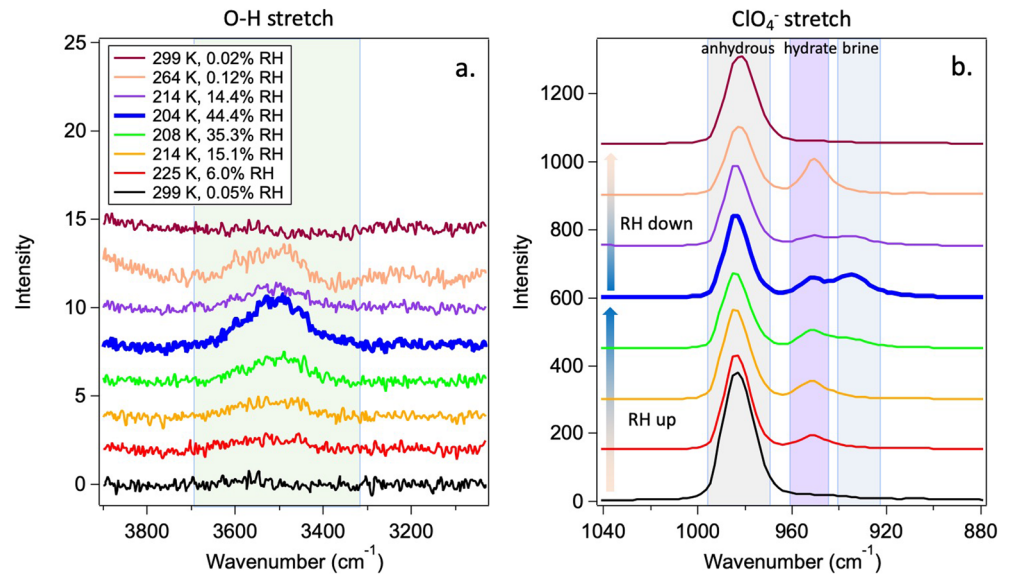


Figure 3. Raman spectra collected during a simulated diurnal cycle representing $L_s = 240^\circ$ at Hale Crater (RSL active season). The relative humidity (RH_{liq}) is increased and then decreased over 345 min by lowering and then raising the temperature. Changes in the (a) O–H stretch region and (b) ClO_4^- stretching region are shown. In this case, based on the absence of an O–H stretch (a) and the location of the perchlorate stretch (b), there is no H_2O present at the end of the experiment, that is, the warmest time of day on Mars. Spectra are offset for clarity. The legend in (a) applies to (b) as well.

3.3. RSL Active Season ($L_s = 240^\circ$)

Figure 3 shows Raman spectra collected during a portion of the $L_s = 240^\circ$ (RSL active season) Hale Crater experiment, the T and RH conditions for which are shown in Figures 1c and 1d. These data were collected over 345 min while relative humidity was increased and then decreased around the salt to simulate a full Martian sol. There are several key differences between this spectral series and that of the RSL inactive season shown above (Figure 2). In this experiment, water is first observed in the O–H stretching region (Figure 3a) at 6% RH. At this point, a small peak at to 950 cm^{-1} representing a hydrated phase appears, and a brine component (933 cm^{-1}) is visible by 44% RH. Even at this maximum RH value reached (thick blue trace); however, the ClO_4^- stretch indicates that the sample is mainly anhydrous perchlorate (990 cm^{-1}) with only minor contributions from hydrate or brine phases. We believe that limited water vapor prevented further phase transitions and that this could be the case on Mars as well.

When the RH is lowered and the temperature raised, the perchlorate salt returns to the completely anhydrous phase by the end of the experiment. There is no O–H stretch at $\sim 3,500\text{ cm}^{-1}$, and the only perchlorate stretch is that of the anhydrous salt (990 cm^{-1}). The spectra present when mid-day ($\sim 14:00$ local time) on Mars is simulated suggests that no water of any phase is present. The maximum temperature reached in this experiment and at Hale Crater at $L_s = 240^\circ$ is 299 K, which is expected to be sufficient to dehydrate calcium perchlorate to the anhydrous phase (Gough et al., 2019).

To summarize this $L_s = 240^\circ$ experiment and two additional $L_s = 240^\circ$ trials (not shown), salts that experience the conditions modeled at Hale Crater in late spring appear to absorb some small amount of atmospheric water vapor diurnally. This absorbed water is sufficient for some portion of the salt, perhaps the outer layer only, to form a brine and/or hydrated phases overnight. By afternoon, warmer and drier conditions will cause the loss of all water from the salt, returning the salt to the anhydrous form. This complete dehydration of the salt was observed in all three $L_s = 240^\circ$ trials and is in contrast to the results of the $L_s = 180^\circ$ experiment. This difference is important for the mechanism we propose.

4. Discussion

Here, we present a potential RSL trigger mechanism that is suggested by our experimental results and is consistent with the seasonality of RSL. We focus on Hale Crater because RSL here have well-documented seasonality and also discrete periods of inactivity and activity (Stillman & Grimm, 2018). When the modeled conditions for

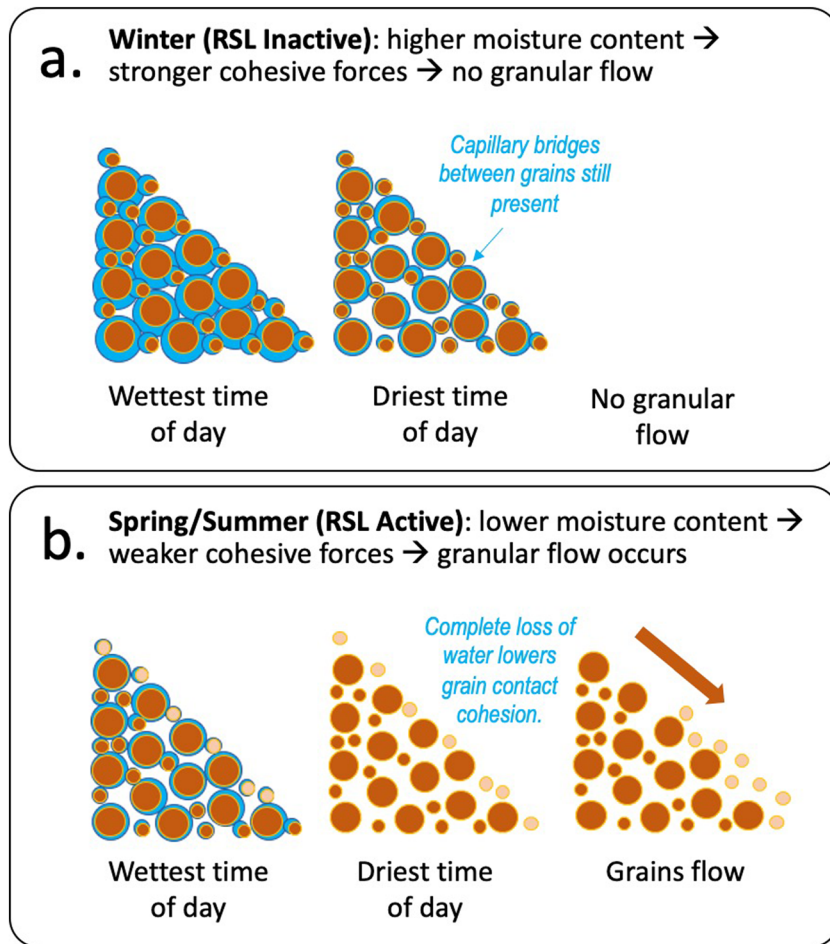


Figure 4. Schematic of the RSL trigger mechanism proposed here and based on our experimental results. There is likely a difference in soil cohesion between the RSL inactive period (cooler and wetter) and the RSL active period (warmer and drier).

the RSL active ($L_s = 240^\circ$) and inactive ($L_s = 180^\circ$) seasons at Hale Crater were experimentally simulated, both sets of conditions were sufficiently cool and wet for water to be absorbed by the salt overnight. Differences in salt behavior between the two seasons arose in midday, however. The surface conditions at $L_s = 180^\circ$ at Hale Crater were cool enough that the salt retained some water even during the warmest time of day. At $L_s = 240^\circ$ at the same location; however, surface conditions were warmer and drier (in terms of relative humidity). Under these conditions, the salt lost all water by the simulated afternoon on Mars.

We propose this dehydration of surface and subsurface salts begins to occur in late spring at Hale Crater as the maximum diurnal temperatures rise. These warm temperatures enable salts like $\text{Ca}(\text{ClO}_4)_2$ to return entirely to the anhydrous phase. This loss of water from the salt is in addition to any loss of adsorbed, thin-film water from soil grains themselves (not studied here). We propose that this loss of water from salty soil reduces the grain cohesion. MarsWRF model results (Figure S1) suggest that the subsurface, to an approximate depth of ~ 6 cm, may be warmed sufficiently to become dehydrated. It is not known what thickness of dust or sand is needed to trigger a flow, and therefore it is not known if our dehydration mechanism can produce sufficient thickness of grains with lower cohesion. However, recent studies suggest eolian dustfall may be the seasonally replenished source material (McEwen et al., 2019) and so the debris flows may be thin. Grain flows as thin as 1 cm have been observed on Mars (Cornwall et al., 2018), and if this movement removed or mixed a thin layer of bright dust, the albedo change would be easily visible from orbit.

Once the cohesion of this upper layer of regolith is lowered, slope failure may occur if the slope angle exceeds the static angle of repose for the now-less-consolidated regolith. Granular materials may avalanche, reducing the slope angle until the dynamic angle of repose is reached. If the avalanching grains are coated with light-toned dust, the resulting terrain changes can expose darker material and produce the familiar RSL features. This mechanism is shown schematically in Figure 4.

RSL do not appear everywhere with favorable geologic settings, that is, geomorphologically fresh, equator-facing, steep slopes with good bedrock exposure (Ojha et al., 2014), suggesting that there are other factors required. These authors suggest the presence of salts or other compositional factors as a potential reason for the relative rarity of RSL even on favorable terrain. If dry flows can be triggered by changes in soil cohesion due to salts, then RSL distribution may be correlated to salt distribution or composition or to localized temperature or humidity variations. This cohesion mechanism may also explain the “follow the sun” behavior observed for RSL at locations with near year round RSL (McEwen et al., 2014). Direct illumination of a specific slope may be sufficient to cause localized water loss, lowering of soil cohesion and a subsequent grain avalanche, while nearby slopes with less solar insolation are unaffected.

Even if salts are not enhanced at RSL locations (Leask et al., 2018; Vincendon et al., 2019), they are likely present globally at a low concentration. Their presence may have an important role in the humidity- or temperature-dependent cohesion of steep slopes. On a smaller spatial scale and at a different location, a change in soil cohesion due to change in water content may have been a reason that the “sticky” Phoenix soil would stick to the scoop and inlets but release at a later time of day (Hanley et al., 2014). A similar process could be occurring on steep slopes on Mars. Changes in soil cohesion may only be partially responsible for Martian RSL, but nonetheless should be considered.

The mechanism we propose here does not specifically address the recurring nature of the RSL, which would require an annual (or somewhat periodic) resteepeening of the slopes. McEwen et al. (2019) suggest that RSL recur when sufficient airborne dust is deposited on a slope each year. Dundas (2020) propose that sand deposits are blown uphill to recharge the material needed for RSL. In the case of a periodic resupply of either sand or dust, the influx of material could cause oversteepening of the slope. Our proposed cohesion-change mechanism provides the temperature-dependent, seasonal trigger that may enable a dry debris RSL flow to occur.

5. Conclusions

We have used a combination of modeling and laboratory experiments to show that small amounts of water likely exchange between the atmosphere and salts in the soil at an RSL location, Hale Crater. We modeled the conditions found at the surface with a numerical atmospheric model during both RSL active ($L_s = 240^\circ$) and inactive ($L_s = 180^\circ$) seasons and then simulated these diurnal cycles in the laboratory. This was the first time that environmental conditions specific to RSL locations were experimentally simulated. We found that Mars-relevant calcium perchlorate salt exhibited different water exchange behavior during simulations of RSL active and inactive seasons. Specifically, complete dehydration of the salt only occurred when the warmer RSL active season was simulated. We hypothesize that this complete loss of water in soil only occurs in the warmer seasons and can potentially trigger a dry granular flow by lowering the cohesion of soil grains and thus lowering the angle of repose. Both the purely wet and dry flow hypotheses for Martian RSL have flaws (Dundas et al., 2017; Huber et al., 2020; Stillman & Grimm, 2018; Vincendon et al., 2019); nonetheless, some mechanism is actively forming these features on Mars today. A dry debris flow, favored by many (Dundas et al., 2017; McEwen et al., 2019), must still be consistent with the seasonality and temperature dependence observed and must have some trigger mechanism to activate flows. The mechanism we propose here combines wet and dry processes. Temperature-dependent soil cohesion changes due to salt phase transitions by seasonally variable atmospheric water vapor amounts could explain the seasonality and a potential RSL trigger, at least at Hale Crater. Only small amounts of water are necessary, and the ambient atmosphere is the source.

Data Availability Statement

The model results and laboratory data for this project is available at: <https://doi.org/10.25810/8wbx-mt39>.

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