SEASONAL SLOPE HYDRATION CYCLES COULD EXPLAIN THE FORMATION OF RECURRING SLOPE LINEAE.

A. O. Shumway[1], J. D. Toner[1], and S. C. King[1], [1]Department of Earth and Space Sciences, University of Washington (shumway@uw.edu)

Introduction: Understanding water on Mars is essential for assessing the potential for past/extant life, planetary protection risks, and for understanding the chemical and physical evolution of the planet's surface. In the frigid, dry conditions of present day Mars, only extremely salty water or water adsorbed onto soil can remain liquid [1]. Despite generally unfavorable conditions, water is strongly linked to enigmatic surface features known as recurring slope lineae (RSL). RSL are dark streaks that seasonally propagate down warm Martian slopes [2]. They are active during warm seasons and fade during cold seasons, which strongly suggests some role for water, but their formation mechanism remains strongly debated.

RSL activity during warm conditions suggests that they are brine flows, possibly upwelling from deep groundwater aquifers [3]. Alternatively, the morphology of RSL suggests that they are sand avalanches because they terminate at slope angles similar to other sandy dunes on Mars [4]; however, even sand avalanche hypotheses posit some as-of-yet-unknown role for water to explain the seasonal occurrence of RSL.

To explain how sand avalanches could occur seasonally, we are conducting experiments to test the hypothesis that relative humidity (RH) cycles cause RSL slopes to fail/stabilize by altering the critical angle of repose.

Mechanism for RSL Formation: Granular materials form steeper slopes in humid conditions than when the air is dry [5]. At high RH, the water content of soil increases as more water adsorbs onto grains. Adsorbed water forms thin films on surfaces, which strengthen cohesive forces between grains and raise the angle of repose. Conversely, if a wet slope dries out, the angle of repose will decrease because the cohesive force between grains is less. When the angle of repose falls below the actual steepness of the slope, the sediment destabilizes and mass wasting occurs.

On Mars, slope destabilization caused by dehydration of soils during warm seasonal conditions could cause sand avalanches that explain RSL. In this model, slopes fail when soils release adsorbed water during warm, low-RH conditions in the summer, and stabilize during periods of cold, high-RH conditions in the winter. This research addresses a fundamental problem in dry hypotheses: namely, how dry flows could occur seasonally. This mechanism for RSL formation was first proposed when RSL were discovered [2], but at the time there was no known explanation for the association of RSL with rocky slopes.

However, recent analyses of wind patterns near RSL sites indicate that windblown deposition of sediment onto the lee faces of outcrops could serve as the source of sediment for RSL flows. Studies of RSL in Garni Crater find a connection between RSL location and patterns of wind deposition and erosion [6, 7]. In Garni, the majority of RSL occur on the leeward side, where sediment has been deposited; inversely, almost no RSL occur on the wind-scoured side, where erosive processes dominate. In this model, RSL are associated with rocky outcrops because steep, rocky slopes create a lee effect that traps sediment and resupplies RSL.

RSL sites are also often located downwind of large dune fields. Such dunes likely act as the original source of wind-blown material to RSL, and the correlation between dunes and RSL supports wind-blown sand hypotheses. Together, these evidence point towards a dry mechanism for RSL formation.

Angle of Repose Experiments: To determine the effect of RH and adsorbed water on slope stability, we are measuring the angle of repose in simulated Martian sediment (Mars Mojave Simulant [8]) at RH conditions between 0 and 100%. We equilibrate sediment simulant at fixed temperature in an evacuated chamber where a reference salt solution controls the RH. By measuring the mass before and after equilibration, we determine the amount of water adsorbed to the soil and the RH of the chamber.

Using this method, soil samples (both with and without added salts) are equilibrated to a desired RH in the transparent cylinder shown in Fig. 1. Then, the cylinder is set horizontally and rotated slowly by a motor (~4 rotations per hour). We film the chamber as it spins, recording the profile of the sediment as it gradually increases until the angle of repose is reached and the slope fails. We then analyze the videos using Mathematica to record statistics on hundreds of slope failure events and calculate the angles of repose profile. Each slope is a complex profile that cannot be defined by a single angle, so we calculate steepness across the length of the slope and plot a distribution of static and dynamic angles of repose (Fig. 2).

Implications for RSL: Determining the role of water (if any) in RSL is crucial for our understanding of astrobiology and geomorphology on Mars. Unlike other proposed mechanisms, the desorption model captures the seasonal activity of RSL while requiring only the water vapor present in the atmosphere. The relatively small quantities of water required to increase the angle of repose are consistent with the generally cold and dry conditions on Mars' surface.

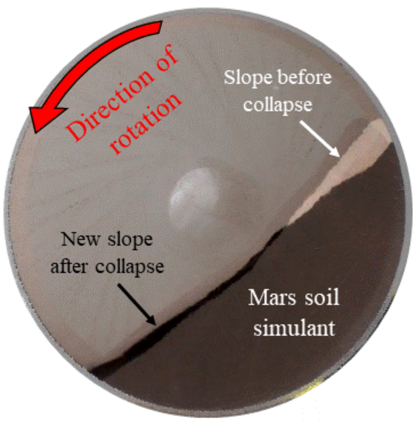

Fig. 1 Apparatus used in slope stability experiment. This figure is a composite of the frames just before and just after slope failure to illustrate the changing slope. Sand from the white shaded area avalanches and is deposited downslope in black shaded area. The static angle of repose is measured in the frame just before collapse and the dynamic angle of repose is measured in the frame following the avalanching of sediment.

In addition to water adsorption, actual Martian soils likely contain salts (such as perchlorates [9]), which wet soils further through deliquescence and further raise the angle of repose. Additional cohesive forces from adsorbed water might explain why a recent study of slope angle at RSL initiation and termination points found significant variation outside of the expected angle of repose for dry sand [10].

Of the many factors that affect angle of repose on RSL slopes, we will discuss the effect of RH on the angle of repose and use it to discern whether the hydration/dehydration cycles sufficiently explain the RSL phenomenon. Future work will include conducting an identical experiment in a cold room to assess how both temperature and RH affect the angle of repose in Martian sediment.

Conclusions: Dry mechanisms of RSL formation are consistent with generally cold and dry conditions on Mars, but struggle to explain the unique seasonality of RSL. We hypothesize that this seasonality is caused by seasonal hydration and dehydration of RSL slopes, resulting in sand avalanches during the summer and slope stability during the winter. To test this hypothesis, we are conducting experiments on the dependence of angle of repose on degree of soil hydration.

It is important to explore the relationship between RH and angle of repose to determine whether RSL are fundamentally wet or dry features. If seasonal RH cycles can explain RSL formation, then the amount (and properties) of water involved would be extremely challenging for possible microbial life.

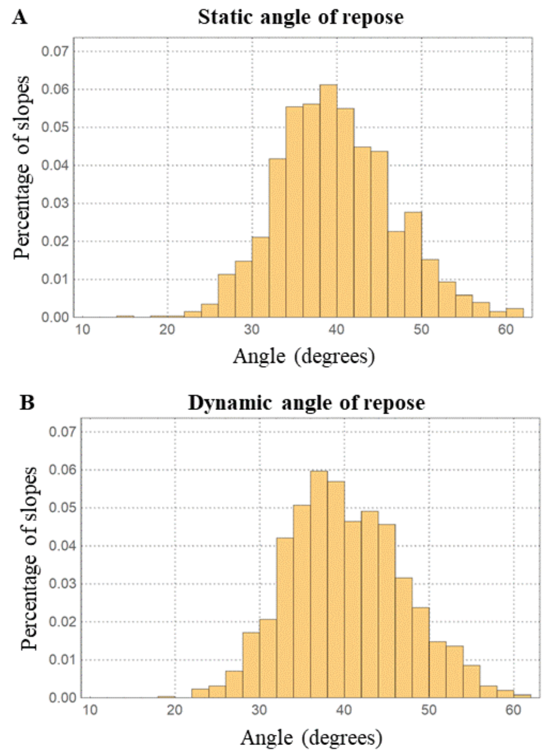

Fig. 2 Histogram showing the distribution of angles of repose measured in dry Martian sediment simulant (i.e. zero adsorbed water). A) The static angle of repose, or the maximum steepness where a slope remains stable, is measured in the frames immediately preceding a slope failure event. B) The dynamic angle of repose, which sediment reaches after slope failure, is measured in frames directly following a slope failure event.

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