# FORMATION OF RECURRENT SLOPE LINEAE (RSL) BY FRESHWATER DISCHARGE OF MELTED COLD TRAPS.

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**Introduction:** Southern mid-latitude (31º–52º) RSL are narrow (0.5–5 m) low-albedo features that appear just before southern summer, typically from outcropping bedrock, and on steep slopes that preferentially face the equator [1]. They grow incrementally, apparently transporting no material, before beginning to fade in southern fall [1]. *McEwen et al.* [1] suggested four RSL formation mechanisms: brine flow in the shallow subsurface, briny surface flow, wet debris flow, and dry dust avalanche or grain flow. *Levy* [2] showed that the incremental growth of RSL was consistent with a subsurface hydraulic conductivity of silty sand to well-sorted sand and gravel. *Chevrier and Rivera-Valentin* [3] suggested formation via melting of brine at least 20 cm deep with a freezing temperature of ~223 K. While these inferences are plausible, two large questions remain. What is the role of salts and what is the source of the water?

**Observations:** We examined all archived High Resolution Imaging Science Experiment (HiRISE) images of RSL and their framing Context Camera (CTX) images, along with ground surface temperatures from Thermal Emission Spectrometer (TES) and Thermal Emission Imaging System (THEMIS). *McEwen et al.* [1] suggested that RSL are visible between solar longitude ($L_s$) 260° and 10°, with a dark or faded albedo suggesting active or inactive RSL, respectively. From our observations of 30 known and candidate southern mid-latitude RSL sites, however, we found that RSL can be dark but not lengthening, and therefore RSL go through four phases each year (**Fig. 1**). (i) RSL are dark and lengthen from $L_s$ 252º±7º to 314º±12º (97±31 sols). (ii) RSL then transition to being dark but not lengthening until $L_s$ 16º±14º. (iii). Then they fade until $L_s$ 118º±1º. (iv) The background/substrate albedo is then observed until $L_s$ 252º±7º. The ranges given for phases iii and iv are for RSL sites poleward of 39ºS. More equatorward sites fade faster, probably because they are warmer, sublimation would increase (**Fig. 1**).

TES seasonal near-maximum (14:00 Local Solar Time or LST) surface temperatures indicate that RSL start lengthening when temperatures reach 297±5 K, and they stop lengthening at 289±9 K (**Fig. 2**). THEMIS seasonal afternoon (14:24 – 17:36 LST) surface temperatures indicate that RSL only lengthen if this temperature is above 273 K. Indeed, water-saturated soil can be expected to be above 273 K to a depth of ~10 cm for several hours per day.

We also find that immediately after the planet-encircling dust storm of Mars Year (MY) 28, RSL are more numerous, flow for much longer distances, and emanate from more sources (including non-bedrock sources). These new non-bedrock sources emanate from small divides in the drainage pattern, presumably from bedrock covered with a thin veneer of regolith. This increase in activity was likely caused by the greenhouse effect of dust, which raised the subsurface temperatures.

**Formation and Recharge Mechanism:** Mid-latitude RSL are largely associated with surficial features indicating buried metastable ice (e.g. mantled units, pedestal craters, concentric crater fill, etc.). This ice is >400 ka old and would likely maintain a saturated subsurface atmosphere.

We suggest that the reason RSL emanate from bedrock outcrops is because bedrock has a thermal conductivity ~40x larger than regolith, which allows the annual thermal wave to penetrate to depths of several meters. During the winter, the subsurface temperature of outcropping bedrock will be below the frost point of the subsurface atmosphere. Consequently, water vapor will condense into the bedrock unit throughout the winter. In the spring, subsurface temperatures begin to rise above the mean annual temperature causing the cold trapped ice to sublimate away. This water vapor ultimately travels toward the surface until it reaches the diurnal skin depth. Here, temperature inversion can re-trap the water vapor.

The lengthening phase of RSL (phase i) begins when near-maximum surface temperatures reach 297±5 K. Quickly rising subsurface temperatures and subsurface temperatures >273.15 K allow ice to melt. Once melted, this water drains through the bedrock and enters the regolith. This water would have a low salt content, but would dissolve any salts left in the regolith. However, previous large RSL flows would have washed much salt away. While salt would increase water stability, it is difficult to suggest a way that salt at 10s wt% as suggested by *Chevrier and Rivera-Valentin* [3] could be recharged annually. Indeed, RSL only flow when afternoon surface temperature are above 273 K (**Fig 2**), which leads us to conclude the water in RSL does not have a significant salt content.

This liquid water remains metastable because it is protected by the low-gas diffusivity of the regolith, which can lower its evaporation rate by up to two orders of magnitude [4]. However, water is still wicked to the surface via capillary forces. This adsorbed water has been shown to darken high surface area materials similar to the martian regolith [5]. When the afternoon surface temperature drops below 273 K, RSL stop growing (phase ii) and sublimate (phase ii and iii) until all the ice is lost (phase iv).

**Conclusions:** RSL lengthen for ~97 ± 31 sols (**Fig. 1**) when surface near-maximum (TES derived) and afternoon (THEMIS derived) temperatures are 299 ± 4 K and >273 K, respectively (**Fig. 2**). This suggests high concentrations of brine are not necessary to generate RSL. Immediately after the MY 28 dust storm, RSL are longer and emanate from more sources (**Fig. 3**). Our proposed flow mechanism explains the repeatability of RSL and allows vapor-deposited ice to recharge bedrock even at topographic highs (e.g., crater central peaks).

**References:** [1] McEwen, A. et al., (2011) *Science*, 333, 740-743. [2] Levy, J. (2012) *Icarus*, *219*, 1-4. [3] Chevrier, V. and E. Rivera-Valentin (2012) *GRL*, *39*, L21202. [4] Altheide, T. et al. (2009) *E. Plant. Sci. Lett.*, *282*, 69-78. [5] Pommerol et al. (2009) *Icarus*, *204*, 114-136.

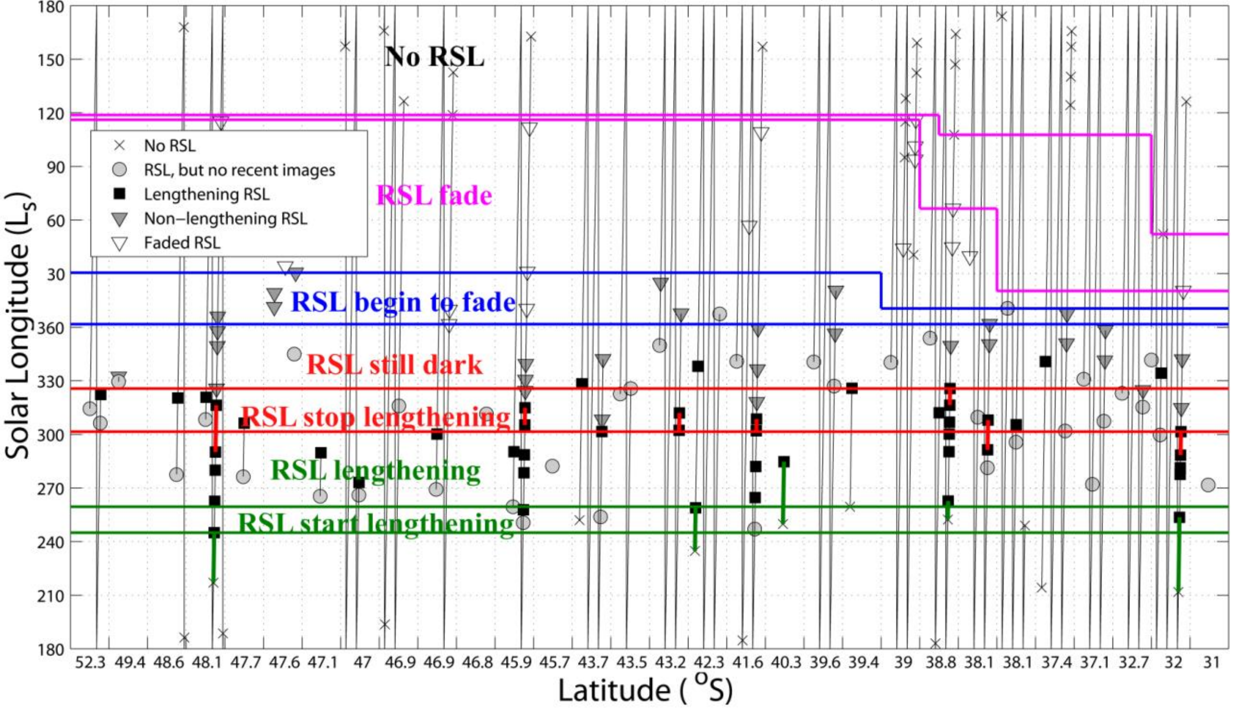

**Fig. 1.** RSL seasonality is displayed by plotting the Ls against 30 known and candidate RSL sites poleward of 31ºS. Note x-axis is not linear, where each labeled latitude value represents an RSL location that corresponds to known and candidate RSL sites. The data symbols indicate the four phases of RSL activity along with a fifth phase if lengthening cannot be determined due to lack of a recent image. The lines that connect the symbols divide a site into multiple MY. Horizontal green and red lines were used to determine the duration of RSL lengthening indicated by the corresponding color.

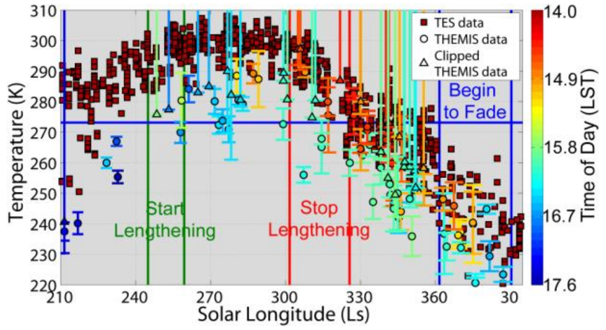

**Fig. 2.** TES and THEMIS derived temperatures at RSL sites show afternoon temperature are only > 273.15 K (horizontal blue line) when the RSL are lengthening. The error bars on the THEMIS data indicate the minimum and maximum temperature measured at the RSL site, many of their upper bounds are unconstrained due to data clipping.

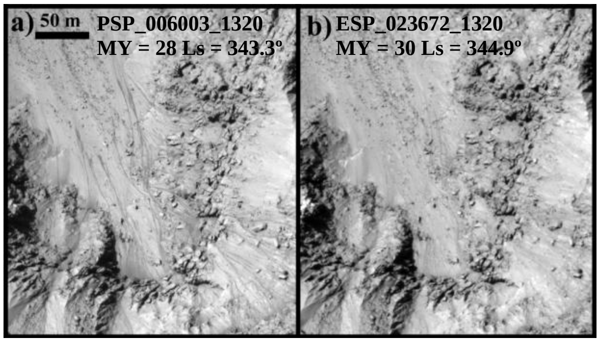

**Fig. 3.** RSL flow longer distances and are more numerous after the MY 28 dust storm **(a)** than in typical years **(b)**. Here we show the differences in the SW part of Asimov crater 47.6ºS, 4.6ºE with images taken almost exactly 2 MY apart.