ABUNDANT RECURRING SLOPE LINEAE (RSL) FOLLOWING THE 2018 PLANET-ENCIRCLING DUST EVENT (PEDE).

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Abstract: MRO/HiRISE has been seeing many more candidate RSL than in typical years, following the 2018 dust storm. They have been imaged at 216 unique locations during August-December of 2018, about half of them at locations where RSL have not been seen previously (Fig. 1). They are present on most steep, rocky slopes in the southern middle latitudes in southern summer of Mars Year (MY) 34, rather than ~40% as seen previously [1]. The RSL in late 2018 are present over a wider range of latitudes and slope aspect than in prior years. These RSL sites also show evidence for recent dust deposition: obscuration of relatively dark areas, overall brighter and redder surface than in prior years, and dust devil tracks.

These post-PEDE RSL observations could be explained by flow of freshly-deposited dust down steep slopes [2]. If this is the case, then the otherwise puzzling recurrence and year-to-year variability of RSL activity are now explained.

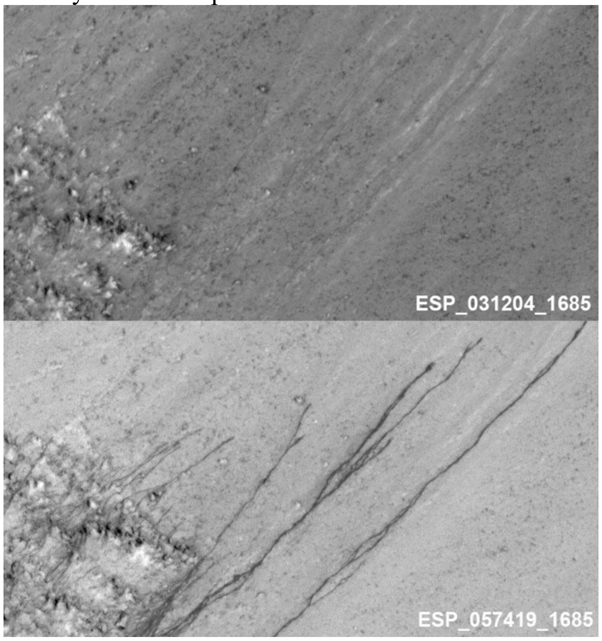

Fig. 1: RSL abundant after 2018 PEDE (bottom) but absent in a prior year at about the same season.

Introduction: Recurring Slope Lineae (RSL) are relatively dark flows on steep slopes with low albedos (minimal dust cover), typically originating at bedrock outcrops [2, 3]. Individual linea are up to a few meters wide and up to 1.5 km long. RSL recur annually (by definition) over the same slopes. The lineae grow incrementally over a period of several months, usually during the warmest time of year for the particular latitude and slope aspect, then fade (and typically disappear) when inactive. This pattern repeats over multiple years, with varying degrees of interannual variability. They are often associated with pristine small gullies or channels that are otherwise rare on equatorial slopes. Hundreds of individual lineae may be present over a local site, and thousands in a single HiRISE image, and there are hundreds of likely RSL sites [1, 4-6].

RSL are common in the southern middle latitudes where they are most active in southern summer on equator-facing slopes, the equatorial regions where activity is usually timed to when the local slope receives the most insolation, and in Acidalia/Chryse Planitia with activity in northern spring and summer [5]. RSL are classified as “fully confirmed” when incremental or gradual growth, fading, and yearly recurrence have all been observed [4]. They are called “partially confirmed” when either incremental growth or recurrence have been observed, or “candidate” sites when they resemble RSL in single images but changes have not been observed or only fading has been seen.

Post-PEDE Observations: Correlations between RSL activity and dust storms has been described by previous workers [3-5, 6-7]. In particular there seemed to be greater RSL activity in 2007 following the MY28 PEDE. However, since the unique temporal behavior of RSL had not been recognized in 2007, the HiRISE images were all targeted for other purposes, and we had no “before” images at any of these locations. The 2018 PEDE provided the opportunity to more systematically monitor RSL. In addition, HiRISE has an ongoing campaign of imaging gullies for changes [8], mostly on pole-facing slopes where RSL are not typically found. But in late 2018 we usually see RSL on the steep east- and west-facing slopes of pole-facing gullies and alcoves. We have also seen new RSL in images targeted for reasons other than monitoring slope processes. As a result, we collected a total of 260 images containing candidate RSL from August 20-December 28 of 2018, in 216 unique locations (plus 44 repeat images) (Fig. 2).

The 2018 PEDE was in its decay phase by August, but dust opacities remained quite high, obscuring small-scale surface features. We did identify some RSL during this decay phase, which provided an important hypothesis test. In a series of experiments, [9] showed that illumination can cause dust to erupt at low atmospheric pressures. For this mechanism to work on Mars, an area must be strongly insolated for some time and then rapidly shadowed, inducing a strong transient temperature profile in the subsurface [10]. However, this mechanism cannot operate during times of high atmospheric opacity, when shadows are only slightly darker than illuminated areas. The presence of active RSL during the decay phase seems to be a challenge for this mechanism.

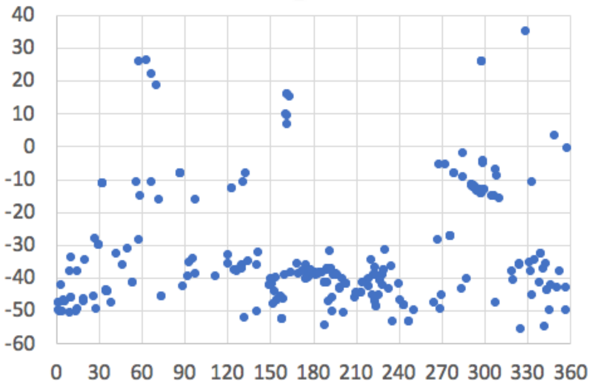

Fig. 2: Map of post-PEDE candidate RSL locations in 2018, MY34, Ls 234-314°. It is unusual to see RSL activity north of 20°N in this season.

The PEDE provided another hypothesis test. The increased RSL activity after the MY28 PEDE could be explained either as an effect of dust deposition on the ground, or from the environmental effects of the dusty air, especially colder days and warmer nights. We re-imaged locations where RSL were unusually abundant in MY28, and found that some had abundant RSL in 2018 and some did not. The distinction seems to be surface dust. Active sites show evidence for dust deposition (reduced albedo contrast, dust devil tracks, higher reflectivity and redder color than in prior years with similar illumination). This indicates that dust on the surface is they key variable, since atmospheric dust opacity was high over all of these sites.

About half of the 216 unique locations with RSL in late 2018, are at locations where RSL have not been seen previously. About 20% of these new sites had HiRISE coverage in previous years during southern summer, yet no RSL were seen. They are present on most steep, rocky slopes in the southern middle latitudes in southern summer of Mars Year (MY) 34, rather than ~40% as seen previously [1]. Note that there is evidence for fresh dust deposition over most of the southern mid-latitudes in 2018, whereas equatorial deposition is patchy. This may resolve the mystery of why RSL occur on some slopes but not others that share the same characteristics (steep, rocky, warm). Rather than requiring some unseen variable such as groundwater, the activity may be a function of whether or not sufficient dust is deposited over a slope in each year.

How Do RSL form? Melting of shallow ice is unlikely, because the ice should be long gone from these warm locations. Groundwater seepage is problematic at many locations where RSL originate at topographic high points. Deliquescence likely happens on Mars, but produces tiny amounts of liquid. A dry granular flow model [11] avoids the problem of explaining the origin of significant water, but the incremental or gradual growth, rapid fading, and yearly recurrence are not easily explained. The annual recurrence of RSL has been difficult to explain in all of the models discussed above. RSL activity is depleting something, either water, salt, or small grains, which must be replenished for recurrence. If RSL are flows of recently deposited dust, then the problem is solved: Dust fallout from the atmosphere replenishes the flowing material.

How can dust flow? Tiny particles should be highly cohesive. However, atmospheric transport and suspension of dust causes electrification [12], which in turn creates clumps of dust [13]. These clumps might behave like granular flows on sufficiently steep slopes. However, it is difficult to believe that dust clumps can erode small gullies. Perhaps the gullies have a different origin and RSL merely follow the topography. If so, then the exact match between RSL maximum lengths and the extent of small-gully fans may be a coincidence, or governed by the same physics of granular flows.

Standard LPSC conclusion: More research is needed.

References: [1] Ojha, L. et al. (2014) *Icarus* 231, 365-376. [2] Schaefer, E. et al. (2019) *Icarus* 317, 621-648. [3] McEwen, A. S., et al. (2011) *Science*, 333(6043), 740–3. [4] McEwen, A. S., et al. (2014) *Nat. Geosci*., 7(1), 53–58. [5] Stillman, D.E., et al. (2016) *Icarus* 265, 125–138. [6] Chojnacki M. et al. (2016) *J. Geophys. Res. Planets* 121, 1204-1231. [7] Stillman [8] Dundas, C. M., et al., (2012) *Icarus* [9] Wurm, G. and O. Krauss (2006) *Phys. Rev. Lett*. 96, 1–4. [10] Kocifaj, M., et al. (2011) *Icarus* 211, 832–838. [11] Dundas, C.M. et al. (2017) *Nature Geoscience* 10, 903-907. [12] Harrison, R.G. et al. (2016) *Space Sci Rev* 203, 299-345. [13] Marshall, J. et al. (2011) *PSS* 59, 1744-1748.