Supplementary Material for

"Granular flows at Recurring Slope Lineae on Mars indicate a limited role for liquid water"

Summary

This supplementary material includes additional discussion and references; Supplementary Table 1; Supplementary Figures S1–S4; and caption information for the supplementary animations provided as separate files (Animations S1-S2). The use of trade, product, or firm names is for identification only and does not imply endorsement by the U.S. Government.

Additional Figure Information

In all HiRISE image figures (Figs. 2, 3, S2, and S4) north is up and illumination is from the left. Because of the dusty Martian atmosphere, the contrast in the images is naturally low, so all scenes have been stretched to maximize the contrast in the local scene. The original spacecraft data, as well as map-projected, radiometrically calibrated images, are available via the Planetary Data System at www.hirise.lpl.arizona.edu.

Animations 1–2 were built by taking subsets of the orthoimages stacked in chronological order. Context information includes the Mars date, north direction, and solar azimuth. Martian dates are given using the angular longitude of the Sun (L_S) and the Mars Year calendar[57], where Mars Year 1 began at L_S=0° on April 11, 1955.

Supplementary Text

The granular-flow RSL model has some similarities to sand flows observed by the *Curiosity* rover in Gale crater[58], although larger. Those flows occur on slopes of 31–38°, usually initiate at rock outcrops, and occur in slightly cohesive material (dust-coated sand). The albedo is less than adjacent material due to lack of the dust, but the flows have not been observed to fade over weeks to months like RSL. This behavior is consistent with Gale crater slope lineae observed from orbit, which are likely sand or dust flows[59].

RSL contrast with slope streaks, which are commonly interpreted as dust avalanches[60-62]. Slope streaks generally form in single events (Fig. S4) and can extend onto lower slopes. We attribute this difference in the behavior of two types of granular flow to the formation of slope streaks in dust, which can be cohesive. Cohesion means that the dust can support itself more effectively but will fail more profoundly, producing isolated, larger flows that require a long time to re-set. Additionally, dust can be transported in suspension, which may affect processes allowing resupply of grains for granular flow.

Supplementary References

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58. Dickson, J. L., Head, J. W., Kulowski, M. Active flows at the Mars Science Laboratory landing site: Results from a survey of Mastcam imagery through Sol 971. Lunar Planet. Sci. Conf. 47, abstract #1726 (2016).
59. Dundas, C. M., McEwen, A. S. Slope activity in Gale crater, Mars. *Icarus*, **254,** 213-218 (2015).
60. Sullivan, R., Thomas, P., Veverka, J., Malin, M., Edgett, K. S. Mass movement streaks imaged by the Mars Orbiter Camera. *J. Geophys. Res.*, **106,** 23,607–23,633 (2001).
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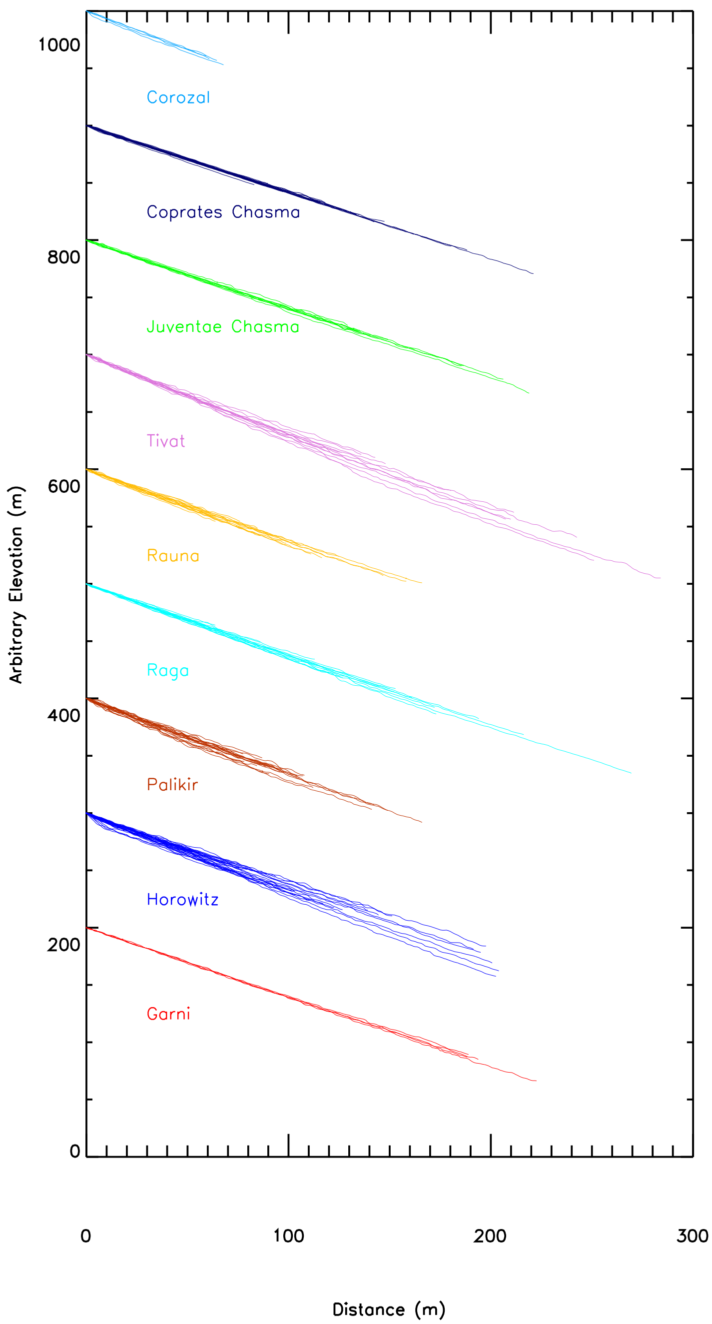
Supplementary Table 1. Slope Measurement Locations

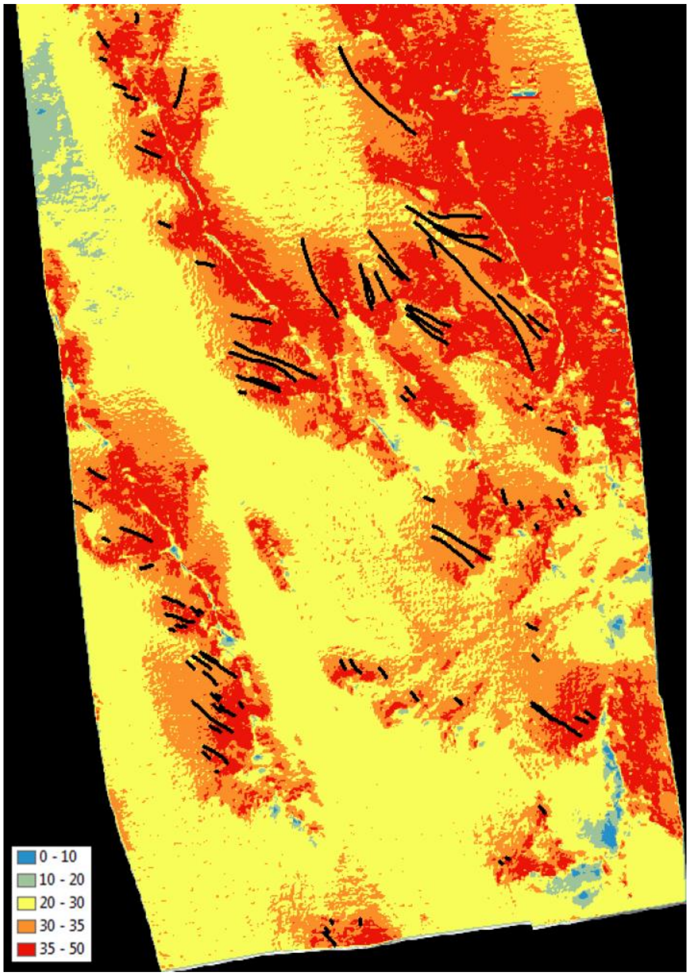
Location	Lat.[a]	Long.[a]	DTM ID and HiRISE Image	L_S	# Lineae
Rauna crater	35.3°	327.9°	DTEEC_034934_2155_034499_2155_A01 ESP_035923_2155	108°	15
Juventae Chasma	-4.7°	298.6°	DTEEC_030373_1755_030795_1755_A01 ESP_030373_1755	327°	9
Garni crater[b]	-11.5°	290.3°	DTEEC_027802_1685_028501_1685_A01 ESP_031059_1685	281°	4
Coprates Chasma	-13.1°	295.2°	DTEEC_034197_1670_033485_1670_A01 ESP_034197_1670	48°	17
Eos Chasma	-15.4º	309.5	DTEEC_039788_1645_039854_1645_A01 ESP_032667_1645	332º	22
Horowitz crater	-31.2°	140.8°	DTEEC_021689_1475_020832_1475_A01 PSP_005787_1475	334°	33
Corozal crater	-38.8°	159.5°	DTEEC_006261_1410_014093_1410_A01 PSP_006261_1410	354°	4
Palikir crater	-41.6°	202.1°	DTEEC_005943_1380_011428_1380_A01 PSP_005943_1380	341°	20
Tivat crater	-45.9°	9.5°	DTEEC_012991_1335_013624_1335_A01 ESP_023184_1335	324°	12
Raga crater	-48.1°	242.4°	DTEEC_014011_1315_014288_1315_A01 ESP_014011_1315	308°	15

[a]Planetocentric latitude, east longitude.

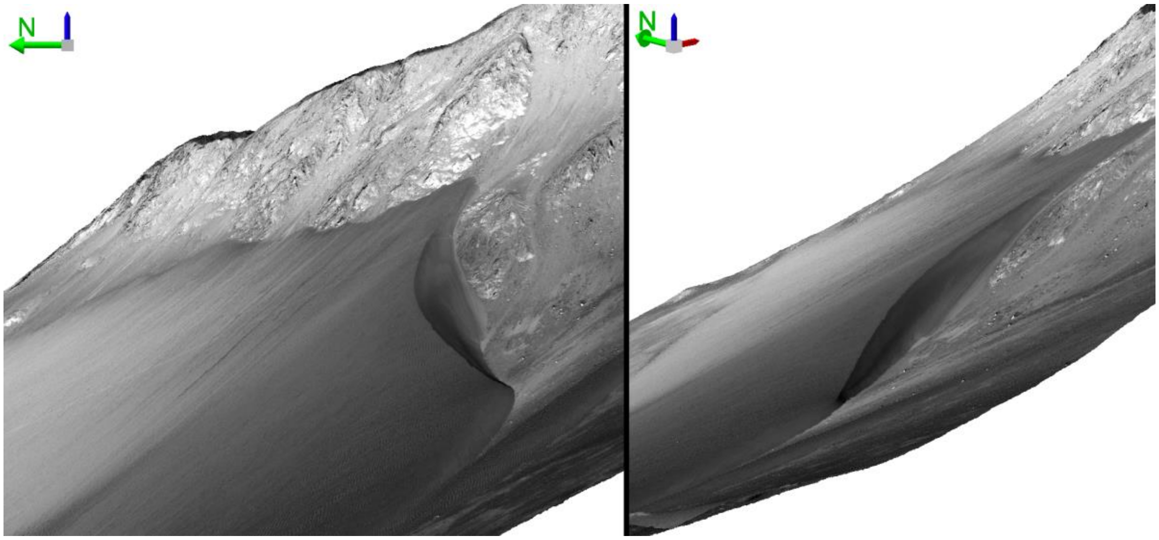
[b]South-facing lineae.



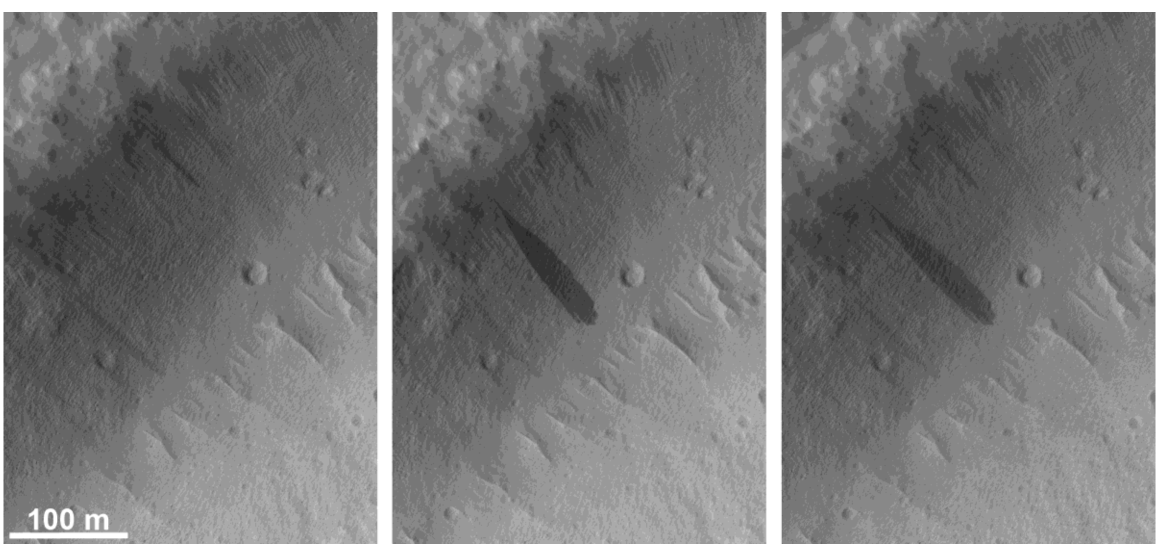
Supplementary Figure 1: Slope profiles for RSL at nine of the ten locations examined. (Eos Chasma (Fig. S2) omitted due to greater range in length.) Elevations are arbitrarily offset to place the start of all the lineae from a particular location at a single reference elevation. Lineae range from straight to very slightly concave.



Supplementary Figure 2: Slope map of RSL site near Eos Chasma with selected lineae (from ESP_032667_1645) sketched in black. Lineae ranging from <30 m to >1.5 km long all terminate on slopes of 30–35º, the orange region of the map, mostly reaching to the yellow-orange boundary at 30º. Most such slopes have lineae, but some are not drawn because they are ill-defined and/or are difficult to distinguish from topography on east-facing slopes with stronger topographic shading. Long lineae (hundreds of meters in length) are found only where there is a long angle-of-repose slope available. (Slope map derived from a HiRISE DTM resampled to 10 m post spacing in order to reduce noise. Minor jitter effects are visible as a pattern of left-right trending bars, but are not large enough to affect interpretation of the slopes. The lineae in Table S1 are a subset of those in this figure with the highest-quality topography.)



Supplementary Figure 3: Perspective views of the lineae and climbing dune shown in Fig. 2. Sand is advancing obliquely uphill and to the right. The left panel shows that lineae occur where sand advance is blocked by a steep outcrop, while a slipface occurs where the sand is not obstructed. The right panel shows that both the dark sandy surface below the slipface and the lighter material below the lineae are part of a smooth, continuous sediment body. Large ripples are present across the surface, indicating that the material is sandy. The stoss slope of this sand surface is unusually steep, at 30°, allowing reverse grainflows. Some RSL begin well upslope of the well-defined dune. (Perspective views generated by draping an orthorectified image over a DTM in Esri ArcScene®. Zero vertical exaggeration; blue vectors indicate vertical direction and green indicates north. HiRISE DTM DTEEC_046619_1665_045907_1665_A01.)



Supplementary Figure 4: Formation of a slope streak. These three HiRISE images show that the streak formed within a one-month interval and was subsequently unchanged over 5.5 years. This is consistent with a single slope failure producing the flow, unlike RSL. (HiRISE images PSP_001364_2160 (Nov. 10, 2006), PSP_001760_2160 (Dec. 11, 2006), and ESP_027776_2160 (June 29, 2012). North is up and light from the left in each image. The slight appearance of rotation between panels is due to different viewing geometry.)

Caption for Supplementary Animation 1: Grainflow activity on a sand dune slip face (slope approximately 28°), resembling RSL. Lineae were present at L_S=288º, along with widespread dust devil tracks. They became more extensive through L_S=338º, including some incremental growth or overprinting. The lineae had faded by L_S=50º of the next year, coincident with the disappearance of dust devil tracks. Changes continued on the slipface through L_S=124º, the low-pressure season when aeolian activity is reduced, but did not produce distinct lineae because of a lack of surface dust. New lineae and many dust devil tracks then formed sometime between L_S=209 – 260º. (All image figures are HiRISE cutouts from orthorectified images (credit: NASA/JPL/University of Arizona) with north up and light from the left. The downhill direction on the slipface is towards the bottom of the image.)

Caption for Supplementary Animation 2: Upslope ripple movement observed on an RSL fan in Coprates Chasma. This demonstrates that in at least some locations sand-sized grains can be resupplied by uphill movement. The ripples are of the same scale as the large ripples observed by (*47*) and could be superposed by smaller bedforms. (Same location shown in (*11*), but with extended time series.)