# EVALUATING WIND STRENGTHS REQUIRED TO MOBILIZE MARTIAN COARSE-GRAINED RIPPLES: GUSEV, MERIDIANI PLANUM, AND GALE.

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**Introduction:** Three Mars rover missions have encountered aeolian dunes, drifts, impact ripples, and coarse-grained ripples (aka "megaripples" a term used here for brevity) [1-9]. Megaripples are large ripples commonly surfaced with grains too coarse to saltate, but having finer-grained interiors [e.g., 10]. They are common features encountered along all three rover traverses. Megaripple surfaces are slightly indurated and/or dust mantled, indicating mobilization is rare and unlikely to be measureable during brief rover encounters. From these circumstances we propose a method to estimate wind conditions prevailing when megaripples were last active. We apply this method to megaripples at Gusev, Meridiani Planum, and Gale.

**Background:** Megaripples develop during strong wind events when a wide range of grain sizes is present. Coarse grains too large to saltate are driven in creep by impacts from finer, saltating grains. Our fieldwork and wind tunnel experiments indicate: (1) Saltation-driven creep of coarse grains is an effective sorting process; the coarsest mobile grains concentrate rapidly at megaripple crests (even coarser grains are left behind, upwind) and represent a limiting combination of impacting and target grain characteristics, and wind-driven impact speed. (2) The coarsest mobile grains can sustain many saltating grain impacts before finally responding by being nudged downwind. Apparently, moving one of the largest mobile grains downwind in creep occurs only when one of the largest, most energetic grains available from the saltating population strikes an optimal location on the target grain.

**Method:** Points (1-2) above suggest an approach for estimating minimal saltation conditions (wind strength + saltating grain characteristics) required to move a specified target grain in creep. In the limiting case of maximum impact efficiency, assume all kinetic energy from the saltating/impacting grain is converted to energy just sufficient to move the target grain up and over the lip of its resting place socket. One form of the derived relationship is:

$$v = \frac{(M+m)}{2m} R \sqrt{\frac{2g}{R - \frac{1}{4}h}} \tag{1}$$

which gives the required incoming velocity $v$ for a saltating grain of mass $m$ to move a resting, larger target grain with mass $M$ and radius $R$ to a height $h$ posed by an obstacle in front of it that would otherwise prevent "escape" of $M$. The value of $h$ depends on many factors. In a 2D idealized scenario of identical spherical target grains, the target grain $M$ would be cradled by other $M$ grains yielding $h = 0.134R$ and a potential escape angle ~30° from horizontal. This is highly idealized, however: (1) for 3D, $h$ would be somewhat less than $0.134R$; (2) none of grain(s) $M$—either the target grain or the supposedly "identical" grains it is resting on—will be spherical, or of identical mass; (3) there will be extremely local-scale (grain-to-grain) "uphills" and "downhills" in arrangements of grains $M$; etc.

The saltating grain impact speed $v$ from eq. (1) is then compared with grain impact speeds from a library of numerical saltation trajectory experiments to identify the particular wind+grain combination that delivers saltating grains $m$ with the desired grain impact speed $v$, and thereby identifying conditions prevailing when the megaripple was last mobilized. The numerical trajectory calculation series was performed for grain sizes 0.03-0.90 mm, and wind friction speeds $u_* = 0.5$, 1.0, 1.5, and 2.0 m/s. For all experiments, T=293°K, P=6.7 mb, and grain density=3000 kg/m$^3$. Megaripples encountered by rovers generally are not on cohesionless sand sheets, but on relatively hard ground of exposed rock or indurated soil scattered with lags of stony debris. To represent these conditions in a generalized way and facilitate comparisons, all numerical trajectory calculations used a bounce coefficient of 0.8 with a semi-log wind profile having $z_0$=0.0001 m.

The proposed method was compared against parameters specified by a previous experiment [3] involving megaripples at White Sands, NM: target grain ~2 mm; $u_*$=0.41 m/s; $z_0$=0.0001 m; saltating grain and target grain densities $\rho$=2380 and 2630 kg/m$^3$, respectively. Figure 1 shows the results, where the pale green curve of grain impact speeds exceeds the blue curve of eq. (1), predicting that an impacting grain ≥0.5 mm was required under the measured wind conditions; this size is consistent with the coarse tail of the measured saltating population (see Fig. 10 in [3]).

**Results:** Figure 1 summarizes how eq. (1) and the numerical trajectory results can be combined to determine wind conditions prevailing when megaripples were last mobilized. (This is different from future reactivation, which would require additional saltation energies to overcome surface induration.) Megaripple cross-sections examined during fieldwork in UT, NM, and CA indicate that megaripple interiors incorporate the finer saltating fraction. Megaripple interiors on Mars exposed by rover wheel scuffs or trenches can therefore reveal the saltating size fraction when the bedforms were active.

*Gusev crater and Meridiani Planum.* At Gusev and Meridiani Planum, explored by the two Mars Exploration Rover (MER) vehicles, dominant megaripple surface grain sizes are ~1.0-1.8 mm [11,12]. Megaripple interior materials are poorly sorted, <0.3 mm. Figure 1 shows that saltating grains from the coarse tail of this size-frequency, 0.15-0.2 mm, could have mobilized Gusev megaripples with winds of $u_*$=1 m/s (wind speeds ~20-35 m/s at height of 1 m). Meridiani Planum megaripples required somewhat stronger winds or coarser saltating grains due to assumed hematite density of target grains.

*Gale crater.* Grain size-frequencies of megaripple surfaces, megaripple interiors, and other sandy deposits show more variation at Gale crater, explored by the Mars Science Laboratory (MSL) rover, than at the MER sites. Figure 1 reflects some of this diversity (red curves). The very large Dingo Gap megaripple (sol 534) was last mobilized with stronger winds and coarser saltating grains than the MER features.

The bedforms flooring Hidden Valley (sol 707), which proved impassable to MSL, could have been activated by only modest winds $u_* \leq 1$ m/s driving relatively fine ~0.1 mm sand as found in drifts among outcrops along MSL's traverse. If the strongest wind events are the most rare, the Hidden Valley megaripples, with relatively small ~0.7 mm surface grains, might have been mobilized more recently than other megaripples at Gale with coarser surface grains.

Several megaripples encountered by MSL have crests with surface grains 3-9 mm, implying the availability in the past of correspondingly coarser saltating grains (and wind events strong enough to drive them) when last mobilized. Chain reactions that mobilized a downwind succession of increasing grain sizes during a given wind event might have been involved. For example, ~0.6 mm grains (slightly finer than those of the Hidden Valley ripples), if impacted by 0.2 mm grains driven by $u_*$ = 1.0 m/s winds, would receive far more energy than required to simply rotate downwind out of their sockets; numerical experiments suggest ejection speeds would be enough for 0.6 mm grains to increase hop size into sustained saltation, which could then drive 4 mm grains in creep. The 9 and 7 mm crest grains of gravel ripples from sols 924 and 931, respectively, are still challenging to explain, but these gravel ripples may be the products of the chain reaction process suggested here. These ripples are located at one end of a small canyon whose floor includes several other megaripples, consistent with a scenario that grains driven from one megaripple to another by canyon-funneled winds culminated with conditions conducive to creep migration of very large grains at the downwind end of the canyon.

Initial analysis of the larger bedforms covering the Bagnold Dunes at Gale indicates that, despite megaripple-like heights and crest separations, coarse grains at crests (~0.5 mm, sol 1182) should be driven easily by saltating trough/interior grains, so crest grains likely saltate to some extent, too. This argues against these features migrating as megaripples when last active. This same interpretation previously was applied to the similar bedforms at El Dorado at Gusev [4].

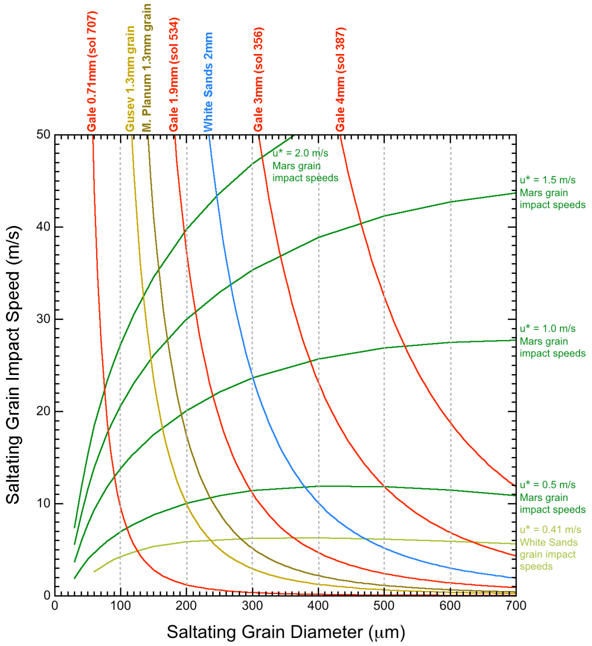

*Figure 1. Green curves show grain impact speeds from numerical trajectory experiments for five $u_*$ values: four Mars conditions and one for White Sands. Concave-up curves define the minimum grain impact speeds to dislodge seven target grain sizes on megaripples: White Sands (blue); Gusev average (tan); Meridiani Planum average (brown); and four examples from Gale crater (red).*

**References:** [1] Greeley R. et al. (2004) *Science*, 305, 810. [2] Sullivan R. et al. (2005) *Nature*, *436*, 58-61. [3] Jerolmack D. et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002544. [4] Sullivan R. et al. (2008) *JGR*, *113*, doi:10.1029/2008JE003101. [5] Blake D. et al. (2013) *Science*, *341*, 1239505. [6] Minitti M. et al. (2013) *JGR*, *118*, doi:10.1002/2013JE004426. [7] Bridges N. et al. (this meeting). [8] Ewing R. et al. (this meeting). [9] Lapotre M. et al. (this meeting). [10] Fryberger S. et al. (1992) *Sedimentol.*, *39*, 319-331. [11] Weitz C. et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002541. [12] Cabrol N. et al. (2014) *JGR*, *111*, doi:10.1002/2013JE004535.