NUMERICAL MODELING OF WIND-DRIVEN EVOLUTION OF MARTIAN FINES.

R. Sullivan[1], B. Hallet[2], K. Herkenhoff[3], G. Kocurek[4], J. Kok[5], and the MSL Science Team. [1]CRSR, Cornell Univ., Ithaca, NY, USA (rjs33@cornell.edu), [2]Univ. of Washington, Seattle, WA, USA, [3]USGS, Flagstaff, AZ, [4]Univ. Texas-Austin, Austin, TX, USA, [5]Univ. Calif.-Los Angeles, Los Angeles, CA, USA.

Introduction: *Saltation* is the wind-driven bouncing of sand along the ground. Higher wind energies and/or smaller grains can lead to *suspension*, when turbulent eddies can loft grains for much longer distance. Both processes (the distinction is gradational) occur on Mars, even simultaneously at the same location. Work reported here combines numerical modeling of grain trajectories with grain size-frequency analyses of rover hand lens-resolution images. Results address these issues: (1) initiation of sand bed movement on Mars at modest wind speeds; (2) near-subsurface materials comprised of grains <300 μm with the same basalt-like elemental abundances at widely separated landing sites (not to be confused with much finer global air fall dust); (3) a potential source of sediment contributing to very fine-grained sedimentary rocks of basalt-like composition; (4) the potential for slow erosion of bedrock surfaces over long periods of time far from active dune fields.

Numerical Modeling: Numerical experiments [e.g., 1-3] have modeled the process of saltation, in which wind energy is transferred continuously via saltating grains to a bed of loose particles until an equilibrium "saturation" sand flux rate is achieved. When a saltating grain re-impacts the sand bed it loses energy by "splashing" other grains before rebounding with 50-60% of its original momentum [e.g., 4] back up into the boundary layer, where the energy that was lost to the bed is recovered as the grain is re-accelerated along its trajectory by the wind.

Work reported here involves conditions different from the sandy beds relevant to dunes and ripple fields. Instead, motivated by the observation of singular sand grains perched on rocks seen in MER MI images, we model grain trajectories of dispersed, isolated saltating grains mobilized across hard ground (e.g., rock surfaces, or crusted, cohesive regolith covered with rocky debris). These settings occur in numerous Mars lander and rover panoramas. Individual grains perched on exposed rock/clast surfaces should be more susceptible to being drawn into rolling, then bouncing motion directly by wind than if clustered together with other, mutually shielding grains on a sandy bed. Hard surfaces should yield higher elastic impact efficiencies than for loose sand beds. Wind speeds well *below* minimum for initiating grain motion on sandy beds are included in the experiment matrix. This is motivated by modest wind speeds indicated by meso-scale modeling of various landing sites [e.g., 5], measurements of typical winds by Viking, Pathfinder, and Phoenix [6-8], as well as HiRISE analyses revealing bedform motions without any obvious correlation to extreme wind storm events [9-14].

The code used here calculates the trajectory of a single grain under specified environmental conditions, but also evaluates, at each point along the trajectory, the grain response time to the local flow and the duration of the dominant local turbulent eddy size, all for the purpose of evaluating the grain's susceptibility to suspension throughout its trajectory. The code was verified for Earth conditions by calculating trajectories of silt- to coarse sand-sized grains at a range of wind speeds and confirming the expected saltation/suspension transition quartz grain size near 70 μm at wind friction speeds just above those needed to initiate grain motion on Earth. For Mars, we used 6.7 mb, 250°K, 3000 kg/m^3 grain density, and wind friction speeds u_* = 0.5, 1, 2, and 3 m/s. (For reference, u_* near 2 m/s is required to initiate grain motion on a sand bed on Mars [15].) The lowest friction speed of 0.5 m/s represents winds of 10-15 m/s at heights of 1-2 meters—modest breezes not very different from typical measurements by Viking, Pathfinder, and Phoenix [6-8]. Stronger wind friction speeds of 1, 2, and 3 m/s represent atypical wind strengths more likely associated with the passage of large storms. Grain size range was 30-900 μm. Bounce restitution coefficient for hard ground was 90%. In reality this is likely to be closer to 100% much of the time, but nevertheless could be highly variable, along with launch angle. Therefore results reported here are only representative. Each experiment ran 20-70 bounces (with the same launch angle), sufficient for developing a characteristic hop height and hop length for comparison with other experiments using different u_* and/or grain size.

Results and Discussion: Figure 1 illustrates how grain kinetic energy (KE) at impact with hard ground varies with grain size. Notable is the steep, three orders-of-magnitude decline of KE at grain sizes smaller than 150 μm. This represents a substantial decline in the potential for grain damage and, therefore, further grain size reduction. Additionally, the transition to suspension begins to affect grains smaller than 300 μm. This is significant because suspension behavior limits the number of hops (therefore, the number of potentially grain-damaging impacts) per storm. The three order-of-magnitude reduction in impact KE from 150 to 30 μm, combined with the transition to suspension over this same size range, should effectively arrest attrition-driven grain size evolution. These results support a previously proposed concept for wind-driven evolution of the martian regolith in which <300 μm regolith fines at the MER-A, MER-B, Phoenix, and MSL sites can be interpreted as representing the end-state of aeolian mechanical weathering of originally coarser material [16, 17].

Similar to terrestrial experience [e.g., 18], results here indicate grain trajectories over hard ground are longer and higher than for saturated saltation conditions on active sand beds. For example, representative hop lengths for 300 μm grains over hard ground on Mars are ~30 m and ~100 m at $u_* = 0.5$ and 1.0 m/s, respectively. Hop length for the same grain at $u_* = 2$ m/s would be ~400 m, except results show the trajectory would be modified by buffeting from turbulent eddies and could actually be longer. Grains smaller than 300 μm are even more susceptible to suspension while bouncing over hard ground at $u_* = 2$ m/s (wind speed ~50 m/s at 1.5 m). These results explain how <300 μm regolith (the end-state of aeolian mechanical weathering) encountered at four widely-dispersed landing sites could have become widespread via a long history of occasional wind storms across the martian surface, as well as become compositionally homogenized, according to APXS results from the MER sites and MSL [19-21]. (This material should not be confused with dust-sized particles, e.g., 4 μm, which are also globally distributed, but by routine suspension directly into the atmosphere for much longer periods.)

Kinetic Energies in Fig. 1 that cause grain attrition will also cause damage to target material. Long grain trajectories associated with these KEs suggest that slow erosion and ventifaction of exposed rock and rubble might continue over long periods even when deposits of abundant loose sand are not immediately upwind of targets.

Analysis of HiRISE images has revealed ripple and dune motion at several locations on Mars [9-14], but association with corresponding strong wind events is uncertain. Results reported here suggest a process by which ripple and dune sands can be stimulated into saturated saltation flux without requiring initiation by an unusual, strong wind event on the actual dune. Even under modest wind conditions of $u_* = 0.5$ m/s, or $u_* = 1.0$ m/s (around half the strength required to initiate sand movement on dunes), dispersed, isolated sand grains saltating across hard ground from upwind of dunes and ripple fields can impact these deposits with sufficient KE to start a saltation cascade, which is sustainable under modest wind conditions due to the relatively low impact saltation threshold on Mars for beds of loose sands [1, 2, 22]. Dispersed sand grains might be expected on the surface for several hundred meters beyond the margins of dune fields. If some of these grains are set into motion from exposed perches on rocky material and blown back across hard ground toward nearby dune fields under even just moderate wind conditions, the stage is set for initiation of sustained saltation on the dunes when these grains arrive.

The wind-driven production and distribution of <300 μm material could be an important component of the sedimentary rock cycle on Mars. This material represents a potential source of sediment that in the past could have contributed to very fine-grained sedimentary rocks of basalt-like composition, examples of which have been encountered by MSL at Gale crater [23-25].

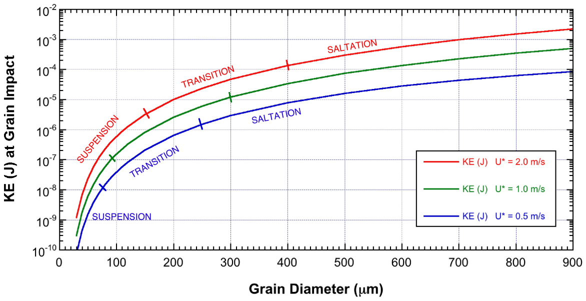

Fig. 1. Representative impact kinetic energies predicted for grains saltating across hard ground on Mars.

References: [1] Claudin, P. and Andreotti B. (2006) *EPSL*, *252*, 30-44. [2] Almeida, M. P. et al. (2008) *PNAS USA*, *105*, 6222-6226. [3] Kok, J. and Renno N. (2009) *JGR.*, *114*, D17204. [4] Rice, M. et al. (1995) *Sedimentol.*, *42*, 695-706. [5] Rafkin, S. and Michaels, T. (2003) *JGR*, *108*, E12, 8091. [6] Tillman, J. et al. (1994) *JAS*, *51*, 1709-1727. [7] Sullivan, R. et al. (2000) *JGR*, *105*, 24547-24562. [8] Holstein-Rathlou, C. et al. (2010) *JGR*, *115*, E00E18. [9] Bourke, M. et al. (2008) *Geomorph.*, *94*, 247-255. [10] Silvestro, S. et al. (2010) *GRL*, *37*, L20203. [11] Chojnacki, M. et al. (2011) *JGR*, *116*, E00F19. [12] Silvestro, S. et al. (2011) *GRL.*, *38*, L20201. [13] Bridges, N. et al. (2012) *Nature*, *485*, 339-342. [14] Bridges, N. et al. (2012) *Geol.*, *40*, 31-34. [15] Iversen, J. and White, B. (1982) *Sedimentol.*, *29*, 111-119. [16] Sullivan, R. et al (2010) *EOS Trans. AGU*, P53A-1489. [17] Sullivan, R. et al. (2013) *LPS XLIV*, #2198. [18] Bagnold, R. (1954) *Physics of Blown Sand and Desert Dunes*, pp. 35-37. [19] Ming, D. et al. (2006) *JGR*, *113*, E12S39. [20] Morris, R. V. et al. (2006) *JGR*, *111*, E12S15. [21] Blake, D. F. et al. (2013) *Science*, *341*, 1239505. [22] Kok, J. (2010) *GRL*, *37*, L12202. [23] Grotzinger, J. et al. (2013) *Science*, 1242777. [24] McLennan, S. et al. (2013) *Science*, 1244734. [25] Vaniman, D. et al. (2013) *Science*, 1243480.