FEEDING THE MARS DUST CYCLE; SURFACE DUST STORAGE AND DUST DEVIL ENTRAINMENT. S. M. Metzger, Department of Geological Sciences; MS – 172, University of Nevada, Reno, Reno NV 89557 (metzger@scs.unr.edu).

Introduction: The wind-blown transport of fine-grained particulate material is the dominant geomorphic process currently producing erosion, transport and deposition on Mars. This is evidenced by the pervasive occurrence of globally-distributed seasonal wind streaks and regional albedo changes as well as close-up examination of dust drape changes on rocks at the Viking Lander sites [1]. Furthermore, dust and the mechanisms that loft it from the surface link the surficial geology and its interaction with the atmosphere.

The Martian dust cycle has significant relevance to that planet's current and past climates because airborne dust alters atmospheric thermal structure and circulation dynamics [2]. Insolation bearing upon airborne dust motes will heat them and the air with which they come into contact. This may lead to greater instability of the dusty layers of the atmosphere and induce convective mixing. When dust concentrations overtake the point where they block a significant amount of sunlight from reaching the lower atmospheric layers or surface, however, those layers will cool and possibly shut down vertical convection. The challenge stems from the difficulty of explainig how dust is entrained into the tenuous Martian atmosphere. Also, we have yet to understand whether the surface provides newly-developed dust, recycles existing dust or traps airfall dust in such a manner as to effectively remove it from the cycle.

Because silt- and clay-sized particles are so small relative to sand grains and the microtopography of natural surfaces, it is very difficult for wind to successfully impart sufficient shear stress to erode them. Given the low air pressure at the Martian surface (6 - 12 mbar), high wind speeds are required to loft dust (defined in [3] as particulates less than 25 μm) on Mars via turbulent wind shear (2 m/s surface friction shear velocity [4], or greater than 30 m/s measured approximately 1.5 m above the surface [3]). In contrast, in an equally dry but much thicker Earth atmosphere, dust entrainment typically occurs at a surface friction shear velocity of 0.3 m/s [3][5].

Clearly, some mechanism(s) besides turbulent wind shear must be at work to loft dust into the Martian sky. [1] summarize the models presented to address this dilemma. These include (a) dust fountaining when CO_2 or H_2O vapor is desorbed from soil and vented through constricted surface ruptures, (b) dust devils or tornadoes, (c) the ejection "splash" from the impact of saltating sand grains (because sand-sized grains are the easiest particles to achieve transport thresholds), (d) the development of dust and silt particles into sand-sized aggregates, and (e) the turbulent buffeting of the surface in bursts and sweeps at such time as the atmosphere may become highly unstable. Until the work herein had been reported [Metzger et al., 1999a], no direct surface observations were able to rule out (or in most cases *confirm*) any entrainment mechanism nor determine their relative effectiveness.

Furthermore, dust that is lofted will eventually settle. [2] indicate a Mars dust settling rate of 0.0017 m/s (based on a 1.6 μm platety clay particle taking 6 x 10^5 seconds to fall 1 km). [6] calculate that dust throughout the 13 km scale height of the Martian atmosphere should fully settle out within 100 days (therefore a rate of 0.0015 m/s). Thus some means must be at work on Mars to frequently replenish atmospheric dust, even when large dust storms are not evident.

Dust Devil Vortices: Dust devils have been cited as a trigger for the free-convection model of planet-encircling dust storms [2]. [7] interpreted Viking Lander data to infer the passage across the meteorology instruments of at least 4 vortices that should have been strong enough to develop dust devils. The slow-scanning Viking Lander cameras, however, were not appropriate for imaging such transient events.

[8] identified ~100 dust devils, primarily in Arcadia Planitia, using Viking Orbiter images. Dust column heights reached 1 to 6 km above the Martian surface with maximum reported widths of 1 km, typical widths of 250 m. The necessary high resolution images (60 to 80 m per pixel) taken at mid-day were acquired on only 5 days over Arcadia Planitia and dust devils were present on 3 of those days. They calculated that the average dust devil was lofting 3 x 10^3 kg of dust (10 μm in size). [9] observed hundreds of subparallel surface lineations that did not survive the year that they held to be tornado or dust devil tracks across fine loose material. A survey of Martian dust devils recorded in Viking Orbiter imagery has tallied over 200 examples [10]

During the 43 daytime sessions when ASI-Met was in the appropriate high resolution data collection mode to detect short-duration phenomena, 20 thermal vortex "pressure events" were detected crossing the lander [11]. From an ambient pressure of typically 6.7 mbar, these events consisted of 10 to 50 μbar drops (= 0.7% below ambient pressure) which usually lasted less than a minute. Simultaneously, the wind shifted direction abruptly and wind speed increased. Contrary to expectations, however, the general response of the temperature sensor was to drop as the vortex began to cross the mast. The sensor then recorded a brief maximum concurrent with the pressure drop. Subsequently the temperature again dropped before rising back to the ambient condition.

The vortices detected by ASI-Met may not have had sufficient erosive power to become true dust devils, although one such event resulted in a momentary drop in solar power panel output to suggest that it was indeed dust-charged [11]. Assuming the occurrence of such vortices to be a Poisson process, [12] consider that any given m^2 of landscape around the lander will be crossed by a well structured thermal vortex every two days.

To date, at least five dust plume features have been identified in 16 IMP camera images and interpreted as dust devil vortices [13]. All of the dust devils have been found in portions of the Gallery Panorama sequence taken during the mid-day period of maximum surface heating. [12] estimates total transport by two of the vortices observed by IMP. Given that most terrestrial dust devils have (1) a dust-free core equal to roughly half their outer diameter, and (2) an average vertical velocity (or "lift") of 7 m/s [14], the average vertical flux of vortices near MPF would be 0.5 $g/m^2/s$, consistent with terrestrial results [14]. Speculating further, the South Twin Peak dust devil would loft over 2 kg of material during the 35 seconds it was imaged and the larger plume on Big Crater would loft 740 kg during its observed 400 second duration. In both cases the dust plumes rose over 250 m before extending out of view.

Using the Mars Observer Camera, the Mars Global Surveyor spacecraft has imaged parallel tracks on presumably loose, fine-grained material at 15.4° N, 311.6° W in eastern Arabia Terra. These have been interpreted to be the tracks of 2 dust devils. The longer east-west feature is over 7.7 km long before leaving the frame and averages 2.5 pixels (35 m) in width. [12] speculate that regional winds must have been steady and of moderate intensity (ex. 5 m/s) to produce such near-straight tracks. Therefore, the track would represent a dust devil that lasted at least 24 minutes. Using [12]'s dust loading estimate of 7×10^{-5} kg/m^3, (and the 50% clear core, 18m, and 7 m/s lift assumptions of above) the flux would exceed 0.5 $g/m^2/s$, removing 3.5 g/m^2 from the surface (as the dust devil base takes 7 seconds to cross a given spot), with total particulate transport exceeding 500 kg. [8] estimated the total sediment load in large dust devils (up to 1 km in width and 6 km in height) in Arcadia Planitia to be 3000 kg. These numbers are significant in light of the high frequency of strong thermals predicted to act across much of the Martian surface.

The concentration of soil particles in terrestrial dust devils as measured by [14] is on average 3.3×10^4 $\mu g/m^3$ total suspended particles (total suspended particle, TSP, measured 2 m above ground). In comparison, ambient atmospheric TSP concentrations on Earth (2 m above ground) average 35 $\mu g/m^3$ and may reach 718 $\mu g/m^3$ in such arid environments as Mali, West Africa. Dust haze events on Earth have ranged from 1.1×10^3 $\mu g/m^3$ to 1.4×10^4 $\mu g/m^3$.

Once TSP loading is found (in $\mu g/m^3$), the soil flux from the surface is derived by knowing the vertical velocity of the vortex. This involves relating the dust column of the vortex to the upward wind velocity active in that region (interpreted to be approximately 50% less than the maximum vertical velocity found closer to the core [14]). The terrestrial flux rates of [14] are very similar to those estimated by [15], classified by dust devil size, as ranging from 0.2 $g/m^2/s$ to 3.0 $g/m^2/s$. The maximum dust concentration reported by [14] exceeded 8.7×10^4 $\mu g/m^3$, with a vertical flux of 4.4 $g/m^2/s$ for a total aeolian transport of over 2 metric tonnes during its 30 minute lifespan. Even the smallest dust devil sampled is calculated to have eroded 30 kg during a 3 minute period producing an airborne concentration of 2.3×10^4 $\mu g/m^3$ with a flux of 1.5 $g/m^2/s$. This is a substantial amount of particulate matter to place into the atmosphere, often with regional and global wind systems.

The presence of dust devils indicates those surfaces over which they travel include dust, whether as an air-fall drape or bonded within an abraidable crust, and loose sand-sized clasts or aggregates. This may imply that sand, or sand-sized aggregates, if present, is available for use by the vortices as an abrasive mechanism capable of other aeolian processes, such as the development of rock fluting. Whether as particle (clast) roughness or form (topographic) roughness, greater surface relief has several effects on aeolian processes. Large particles absorb or "partition" much of the wind energy that could otherwise be applied to entrain finer surficial material. If a high enough percentage of the surface is armored by rocks, finer clasts between and under them will be thoroughly protected from erosive winds. Behind such obstacles, flow separation of the wind from the clast results in a low pressure zone where finer materials find shelter. Depositional sites become source areas once the wind shifts direction. [16] found that rocky surfaces store more airfall dust than other surfaces but they subsequently lose up to 80% of that dust before it can be stabilized. Any airfall dust that drapes on top of rocks is already placed well up into the wind profile and is going to reach entrainment threshold speeds far sooner than ground level dust.

Topographic relief acts in much the same manner. Wind can be compressed as it squeezes over a mound and is therefore more able to erode loose soil. Conversely, the leeward side of the mound can become a depositional sink, until the wind shifts direction. Depending on orientation to prevailing wind, a wash channel floor might be well sheltered if perpendicular to regional airflow, or provide an aeolian "raceway" if oriented parallel to that flow. Given that dust devil vortices are characterized by abrupt wind shifts that often swing full circle, many localized depositional sinks become dust sources. Thus, over time increased roughness can both inhibit and promote the entrainment of fine material.

Ultimately, dust devil activity can reveal a great deal about the surface geologic and aerodynamic characteristics of the Martian surface, especially far from the view of lander imaging systems. Furthermore, the surface heterogeneity will inhibit and promote dust entrainment over short time scales. Insufficient study exists at present, however, to definitively evaluate the questions of dust generation on the surface nor the likelihood of that surface removing fine particulates from the dust cycle by bonding them into a crust.

References

[1] Greeley et al., in *Mars*, 1992. [2] Kahn et al., in *Mars*, 1992. [3] Greeley and Iversen, *Wind as a Geologic Process,* 1985. [4] White et al., *JGR., 102, E11*, 1997. [5] Pye, Aeolian Dust and Dust Deposits,1989. [6] Smith and Lemmon, *104, JGR*, 1999. [7] Ryan and Lucich, JGR., v. 88, 1983. [8] Thomas and Gierasch, *Sci*, v. 230, 1985. [9] Grant and Schultz, *Science*, v. 237,1987. [10] Wennmacher et al., LPSC 27, 1996. [11] Schofield et al., *Science, 278*, 1997. [12] Metzger et al., in press GRL, 1999. [13] Metzger et al., DPS 30, 1998. [14] Metzger, Ph.D. Diss. UNR, 1999 [15] Gillette and Sinclair, *Atmos. and Envir.,* v. 24A, 1990. [16] Goossens *Sed., 42*, 1995.