**ERODING DUNES? CHARACTERIZATION AND IMPLICATIONS OF MARTIAN SAND SHEETS.** K. D. Runyon[1], N. T. Bridges[1,2], and C. E. Newman[3]. [1]Johns Hopkins University Dept. of Earth & Planetary Sciences, Baltimore, MD (kirby.runyon@gmail.com), [2]Johns Hopkins University Applied Physics Laboratory, Laurel, MD [3]Aeolis Research, Pasadena, CA.

**Introduction:** Aeolian sand transport is the most active agent of landscape modification on Mars today. Sand is concentrated in dunes, ripples, and sand sheets, the latter of which, although common, have received little attention in the Martian literature, though they make up almost half of non-polar aeolian provinces on Mars [1]. Five factors have been proposed to explain why sand sheets form at the expense of dunes [2], yet only one—the presence of a significant coarse-grained population—is relevant to Mars, with the other factors associated with active hydrology and vegetation on Earth.

To address the controlling mechanisms of sand sheets on Mars, and why they are common despite conditions very different from those on Earth, we 1) characterize a Martian sand sheet (Figure 1) and remnant paleo-sheets in Herschel Crater ($D$ = 300 km); 2) model wind shear stresses in a mesoscale GCM; and from their characteristics and GCM modeling we 3) suggest Martian sand sheets episodically form from erosion of upwind dunes (Figure 2) and can indurate.

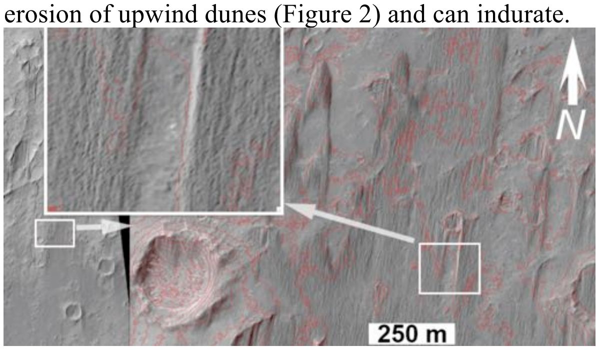


*Figure 1. Sand sheets in Herschel Crater. Red lines are elevation contours at 2 m intervals. The sand sheets are weakly correlated to elevation and most pronounced in the lee of topography. From measurements in a stereo-derived DEM, the edges are <5 m thick with low slopes of 1-4˚. Note the rippled texture. The sand gap in the inset image is ~50 m wide. Image is HiRISE ESP_017417_1655 and the elevation information is from HiRISE DTM DTEEC_017417_1655_016916_1655_A01. Image and DTM credit: NASA/JPL/University of Arizona.*

**Methods:** HiRISE images and derived digital elevation models (DEMs) and ripple displacement maps were used to map the sand sheet extents, edge thicknesses, and dynamics. We used the COSI-Corr method of tracking ripples [3]. A nested mesoscale GCM with 4-5 km resolution predicts atmospheric density and friction speed for a Mars year for Herschel Crater, allowing us to calculate wind shear stress. We also mapped smooth bedrock units on the images interpreted as paleo-sand sheets.

**Results:** *Sheet Characteristics:* Sheets and dunes are inter-related: The co-location of dunes and sandsheets as found in Herschel Crater [4] is common on Mars [e.g., 1,4]. Sheets are downwind of dunes, an arrangement which is the reverse of what is commonly the case for terrestrial aeolian fields with nearly unidirectional sand transport (e.g. [2,5]). Importantly, the vast majority of unidirectional Martian aeolian fields we observe feature sand sheets downwind of sand dunes, implying that the sheets cannot be a dune sand source.

The Herschel sheet case study in Figure 1 is several meters (<5 m) thick, with sloping margins of 1-4˚, similar to western Herschel dome dunes, which lack slip faces, and lower than the 4-8˚ for local barchan stoss slopes in central Herschel [6]. The sheets preferentially fill topographic lows such as craters and occupy areas in the lee of positive topography such as crater rims, knobs, and dunes. Long, thin sand tendrils form in the lee of topography, composing sheet-bounding margins close to 5 m thick. The DEM reveals that elevation contours only weakly correlate with the case study sheet's margins at 2 m contour intervals.

The meter-scale ripples superposing the dunes and sand sheets have a similar braided, "tortured" morphological pattern as some of the "large Martian ripples" described and measured on Gale Crater dunes from both orbit and the ground [7]. Given the similar geomorphology in plan view (Figure 1) to those in Gale, we presume their height is also similar. These active ripples show a Gaussian distribution for ripple migration speeds across the central Herschel sand sheet. The average ripple speed of 1.25 ± 0.36 m/Eyr (Eyr = Earth year) is faster than dune speeds in Herschel, which are 0.2-0.5 m/Eyr. The average azimuth of ripple migration is toward the SSW at 196˚ ± 9˚, which is consistent with the overall orientation of the regional central Herschel barchan dunes.

We estimate total sand flux on the sand sheet by taking the ratio of total flux (measured from regional dune slip face advancements) to the ripple-only flux (measured from ripple fluxes on regional dune stoss slopes). Multiplying that ratio by the measured ripple flux on the sand sheets gives an estimate for total sand sheet flux, which is comparable to dune flux (Figure

3). This implies that saltation operates on sheets but does not build dunes.

*Paleosheets:* The mapped smooth unit (Figure 4) embays low topography in the lee of positive topography, is the same albedo as surrounding bedrock, and features small craters. This suggests it represents indurated paleo-sand sheets with eroded (planed-off) ripples. If they are paleosheets, their presence suggests past epochs of sheet formation and induration.

*Atmospheric Modeling and Dune Erosion:* The GCM may predict occasional sand suspension and therefore dune erosion. The threshold shear stress appropriate for low-resolution modeled winds on Mars is 0.0085-0.0115 $N/m^2$, which is a value appropriate for low-resolution modeled winds [6]. On Earth when the shear stress is ~2.25 times the critical value for movement [8,9], sand becomes suspended. Taking this value, sand begins suspension at shear stresses of at least 0.019 $N/m^2$. The GCM predicts shears stresses higher than this for central Herschel and other locations, but actual shear stresses are likely higher due to local turbulent eddies shed from, e.g., dunes. We thus hypothesize that sand may erode from upwind dunes, travel downwind in suspension, and settle downwind, thus contributing to sheets (Figure 2).

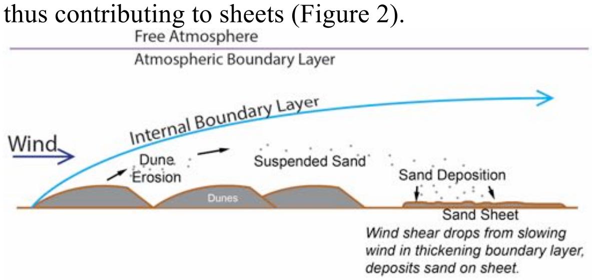


*Figure 2. From our GCM, the wind shear stress is occasionally strong enough to suspend sand. As the wind shear decreases downwind in the thickening boundary layer [4], the sand falls out on the sheet.*

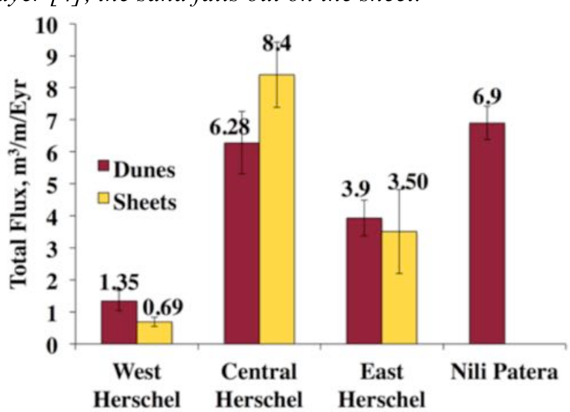


*Figure 3. Total fluxes on dunes measured from slip face advancement rate and crest height (crest flux = rate × height), and total fluxes for sand sheets from multiplying a regionally-derived total-to-ripple flux ratio by the ripple flux. For ripple flux we multiplied the ripple rate by an assumed half-height of 0.15 m [3,7].*

**Conclusions:** At least some current Martian environments are eroding dunes into sand sheets. Deposits interpreted as paleo-sand sheets suggest cycles of sand deposition and mobilization; dune erosion into sand sheets; and sand sheet induration, which is followed by depositional epochs of new dunes, thus repeating the cycle. This appears consistent with other cyclic activities on Mars, such as changes in glacial and fluvial landforms (e.g., [10,11]), that may be modulated by axial obliquity changes [12].

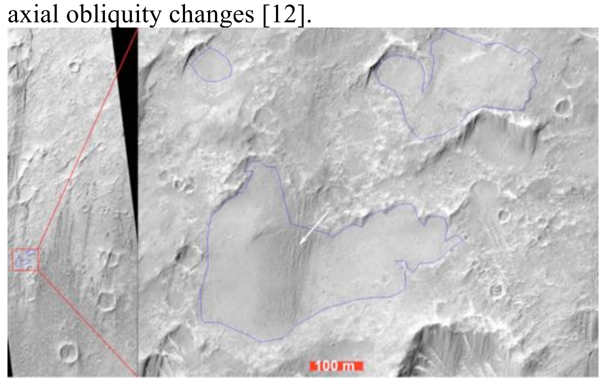


*Figure 4. The blue outlines roughly define the boundaries for a few of the many smooth unit outcrops in central Herschel Crater. Their location downwind of topography (often crater rims) suggests they may be indurated paleosheets. A new "micro" sand sheet appears (white arrow) atop the putative paleo-sand sheet in the lee of topography. HiRISE image ESP_025487_1655. Credit: NASA/University of Arizona.*

**References:** [1] Hayward et al., 2006, http://pubs.usgs.gov/of/2007/1158/. [2] Kocurek, G., and J. Nielson, 1986. Sedimentology, doi:10.1111/j.1365-3091.1986.tb00983.x. [3] Bridges, N.T., et al., 2012. Nature, http:// dx.doi.org/10.1038/nature11022. [4] Runyon, K.D., et al., 2017. EPSL, http://dx.doi.org/10.1016/j.epsl.2016.09.054. [5] Maxwell, T.A., C.V. Haynes Jr., 2001. Quaternary Sci. Rev., doi:10.1016/S0277-3791(01)00009-9. [6] Ayoub, F., et al., 2014. Nature Comm., http://dx.doi.org/ 10.1038/ncomms6096. [7] Lapotre, M.G.A., et al., 2016. Science, doi:10.1126/science.aaf3206. [8] Jerolmack, D.J., Reitz, M.D., Martin, R.L., 2011. J. Geophys. Res., http://dx.doi.org/10.1029/2010JF001821. [9] Nishimura, K., Hunt, J.C.R., 2000, J. Fluid Mech., 417, 77-102, doi:https://doi.org/10.1017/S0022112000001014. [10] Head, J.W., F.J. Mustard, et al., 2003. Nature, doi:10.1038/nature02114. [11] Ehlmann, B.L., et al., 2011. Nature, doi:10.1038/nature10582. [12] Laskar, J., et al., 2004. Icarus, http://dx.doi.org/10.1016/j.icarus.2004.04.005.