LOW THERMAL INERTIA AND HIGH ELEVATION BEDFORMS AS SEEN BY THE HIRISE CAMERA

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Introduction The High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) provides unprecedented detail of geologic features on Mars [1]. One of HiRISE's chief objectives is to provide a better understanding of aeolian (wind) features and processes. A summary paper of initial results was recently published [2]. Here we report in greater detail on the finding that much of the low thermal inertia mantle is organized into small "reticulate" ridges, which we interpret as bedforms. We show that the bedforms' morphology and distribution are consistent with windblown (saltated) material, although the thermophysical properties indicating that these materials are dust-rich are difficult to reconcile with this hypothesis. Some yardangs have a texture similar to the reticulate forms, suggesting cementation over time.

Background Viking IRTM observations showed that the summit regions of the Tharsis and Elysium volcanoes have low thermal inertias, consistent with a surface coated by fine (~2-40 µm), bright (albedo > 0.27) dust [3,4]. Later images from MOC showed a mantle that in many places partly or completely obscured details of the volcanic landforms, with wind tails and aeolian grooves common [5]. The general hypothesis for the formation of this mantle is that the high elevation volcanoes act as sinks for Martian dust that settles onto the surface following major dust storms [4]. Presumably the low pressures (<1 to ~2 mb) and therefore lack of sufficient shear stress to liberate significant dust off the surface allows it to accumulate over time. However, the formation of dark (albedo 0.2-0.3) collars within brighter annuli in the upper 10-20 km of the volcanoes, and the presence of downslope wind streaks at the base of the collars [6], indicates downslope winds that are probably induced by nighttime cooling [7]. Therefore, at least the upper surface in some regions is subject to aeolian transport. This may account for the wind tails and grooves described by [5]. The thermal inertia of high elevation materials does not have a unique signature [8], and there is evidence from the seasonal variability and diurnal differences in apparent inertia on the volcanoes of a heterogeneous surface [9], such that the interpretation of a pure dust surface may be overly simplistic.

At HiRISE resolution, most mantled areas of the volcanoes are composed of networks of "reticulate" ridges down to scales of a few meters or less [2] (Fig. 1-2). Similar morphologies have also been seen in Valles Marineris, the equatorial lowlands, and other locations [10], although the distribution in these areas is not as pervasive.

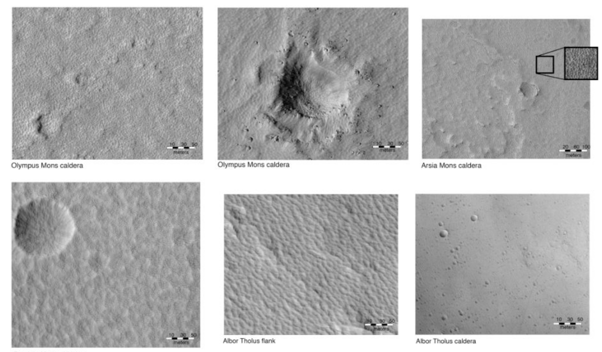

Figure 1: "Reticulate" bedforms in the Tharsis and Elysium Montes. The Arsia image shows a sub-frame enlarged 2x and stretched. Only Albor Tholus lacks bedforms (Arsia: PSP_002157_1715; Pavonis: PSP_002249_1805; PSP_001920_1990; Albor Tholis: PSP_003492_1995).

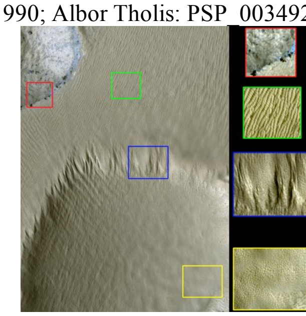

Figure 2: Portion of HiRISE image PSP_005836_1735 of Arsia Mons. Colored boxes are enlarged and stretched at right, with the reticulate bedform morphology clearly apparent.

Methods Seventy HiRISE images in the Tharsis and Elysium regions were studied, both on the volcano flanks and in the intervening plains. For each image, the bedforms' presence, areal coverage, shape, and size were measured. The MOLA elevation and THEMIS thermal inertia corresponding to the HiRISE image center was recorded. Using Google Earth software applied to Mars, HiRISE and CTX footprints were overlaid onto THEMIS VIS and thermal inertia maps to provide qualitative relationships among bedform attributes, location, and thermophysical properties.

Results Of the 70 images studied, 30 contain reticulate bedforms. Most of these are located on the volcano flanks and summit calderas, with the intervening plains generally lacking the reticulate morphology. The reticulate texture is expressed at three scales (Figure 3). The smallest is composed of intersecting sets of ridges

~1-2 m across. There are organized into larger clusters ~15-20 m which are, in turn, within ridge sets that are about ~50-200 m across. The latter looks like impact craters in many cases and therefore may simply be underlying topography that is draped by the mantle. The symmetry of the smallest reticulate bedforms is variable. In some cases, they have a very symmetrical "honeycomb" texture (e.g., yellow box in Fig. 2). In other examples, long sets of ridges of constrained azimuth are linked by shorter ridges with orthogonal azimuths, an "accordion" morphology, bearing a close resemblance to the 1st and 2nd order, respectively, bedforms seen elsewhere on Mars [2] (e.g., green box in Fig. 2).

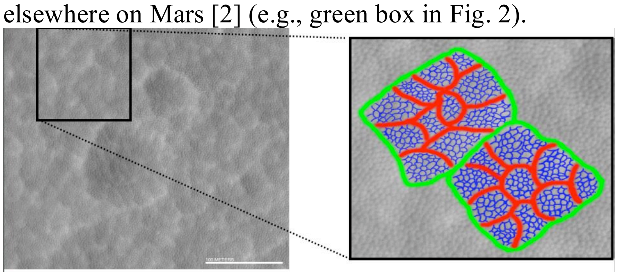

Figure 3: Portion of HiRISE image PSP_002249_1805 of Pavonis Mons. The illustration at right shows three scales of texture. In blue are the smallest reticulate bedforms, about 1-2 m. These, in turn, are organized into clusters, shown in red of size about 15-20 m. Finally, these are clustered at about 50 m scale, shown in green.

The reticulate bedforms are almost exclusively confined to regions of low thermal inertia (Fig. 4). The flanks of the volcanoes span almost 20 km in elevation, with reticulate bedforms found throughout. All images with high thermal inertias, except one outlier, lack reticulate bedforms.

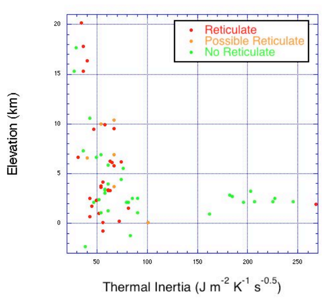

Figure 4: Elevation vs. thermal inertia for the center of HiRISE images in the Tharsis and Elysium regions.

Discussion

The morphology of the reticulate textures is consistent with formation by saltating particles. The honeycomb morphology is analogous to larger size star dunes formed from multiple wind directions. The accordion morphology could be formed from two wind directions, with the longer bedforms forming first, thereby confining subsequent wind flow to orthogonal directions.

The material properties of the bedforms are an enigma. Their general confinement to low thermal inertia areas may be indicative of dust or dust aggregates. There is clearly some current aeolian activity as evidenced by the dark collars [6-7], but any dust lifted off the surface should go into suspension, not saltate to form bedforms [11]. Alternatively, these regions may be heterogeneous, consisting of some coarser material [8,9], perhaps buried by a thin layer of dust where the reticulate bedforms are seen. At least at the highest elevations, the low gas conductivity and atmospheric back radiation, not incorporated into standard thermal inertia models, makes it possible that materials coarser than dust could exist [8]. However, even this interpretation is at odds with our current understanding, given the high threshold speeds at low pressure [12,13] and no surface shear stresses predicted by GCMs able to lift sand at these locations for any point in the obliquity cycle [14]. These bedforms therefore remain a challenge to our understanding of aeolian processes on Mars.

The morphology of the reticulate bedforms is similar to that seen on some Martian yardangs, such as White Rock in Pollack Crater (Fig. 5). It may be that reticulate bedforms can become cemented, at least in some areas, and subsequently be eroded into yardangs. This is consistent with TES results that indicate White Rock is weakly cemented aeolian material [15].

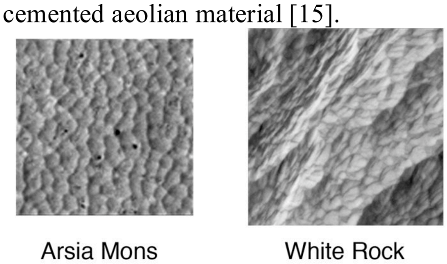

Figure 5: A comparison between the texture of the Arsia Mons reticulate bedforms and White Rock in Pollack Crater (PSP_002099_1720).

Concluding Remarks and Future Plans Reticulate bedforms are a diagnostic feature in low thermal inertia areas of Martian volcanoes. They probably formed via saltation processes from a variety of wind directions, but the details are poorly understood, as are the physical properties of the constituent particles. Future work will be devoted to further image analysis and modeling of aeolian processes where reticulate bedforms are found.

References [1] McEwen, A.S.., et al. (2007), *JGR, 112*, doi:10.1029.2005JE002605.[2] Bridges, N.T. et al. (2007), *GRL, 34*, doi:10.1029/2007GL031445.[3] Zimbelman, J.R. and H.H. Kieffer (1979), *JGR, 84*, 8239-8251.[4] Christensen, P.R. (1986), *JGR, 91*, 3533-3545.[5] Malin, M.C. and K.S. Edgett (2001), *JGR, 106*, 23,429-23,570.[6] Lee, S.W. et al. (1982), *JGR, 87*, 10,025-10,041.[7] Magalhaes, J. and P. Gierasch (1982), *JGR, 87*, 9975-9984.[8] Bridges, N.T. (1994), *GRL, 21*, 785-788 [9] Putzig, N.E. and M.T. Mellon (2007), *Icarus*, doi:10.1016/j/icarus.2007.05.013.[10] Keszthelyi, L. et al. (2008), *JGR*, in press.[11] Greeley, R. and J.D. Iversen (1985), *Wind as a Geological Process*, Cambridge Univ. Press.[12] Greeley, R., et al. (1976), *GRL, 3*, 417-420.[13] Iversen, J.D. and B.R. White (1982), *Sedimentology, 29*, 111-119.[14] Haberle, R.M. et al. (2003), *Icarus, 161*, 66-89.[15] Ruff, S.W. et al. (2001), *JGR, 106*, 23,921-23,927.