WINDY MARS: A RECORD OF BEDFORM MIGRATION AND SAND ACTIVITY

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Introduction

Mars contains abundant dunes and ripples (collectively termed ''bedforms''), attesting to processes associated with prodigious sand production and aeolian transport. Until very recently, the extent of movement by winds in the low density Martian atmosphere was unknown, a limitation induced by the relatively low resolution and temporal baseline of previous optical instruments and platforms. Analysis of images from the High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) over the last ~4 Martian years (since Nov. of 2006) shows that many ripples and dunes on Mars are moving, some with rates and fluxes comparable to those on Earth. These results show that significant particle mobility and landscape modification occurs under present conditions. Here we summarize these discoveries and offer perspectives on their significance for landscape modification and Mars exploration.

Methods

HiRISE is the best system for studying Martian bedforms remotely due to its superior resolution and high signal-to-noise [1]. Beginning in 2008, targets were selected for repeated imaging based on coverage obtained at a similar season (L_s), one to four Martian years earlier. Two types of techniques have been used: 1) Overlaying of image pairs, with rocks and other fixed features used as tie points. This is the most common method, as it can be done relatively quickly and does not require a stereopair-derived digital elevation model (DEM) that is available for only a limited number of HiRISE targets. From these data, local studies have been conducted [2-12] and global statistics have been compiled, comparing migration rate to such variables as elevation, latitude, albedo, and predicted winds [13-15]. For this abstract, 148 locations on Mars were studied in this way. 2) Orthorectified images from a DEM, from which very precise changes and volumetric sand flux can be measured. Using such data, sophisticated techniques such as COSI-Corr have been used to measure changes down to sub-pixel precision [6].

Results

The main overarching observations are that:

(1) All images of dune fields and ripple patches in the north polar erg show migrating bedforms (Fig. 1).

(2) There are dark bedforms on Mars that show no evidence of movement, consistent with low inferred erosion rates in some areas, including the region of *Opportunity*'s traverse [16].

(2) The location of mobile bedforms shows no correlation to the frequency of high speed winds as predicted by the Ames General Circulation Model (GCM) [13]. This is likely due to two factors. The first is that GCMs are inherently low in spatial and temporal resolution, and therefore insensitive to localized gusts and topographic effects [17]. The second is that these gusts are only needed to initiate saltation, with sand transport maintained by the much lower impact threshold speeds on Mars [18].

(3) Where motion occurs, the ripples and dunes have low albedo (Fig. 2), with crisp textures. Transverse Aeolian Ridges (TARs) are generally brighter and consistently immobile.

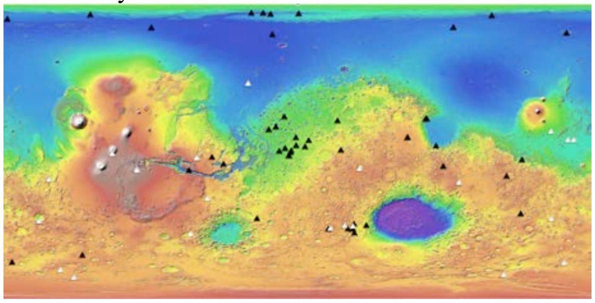

Figure 1: Map of bedform movement overlaid on Mars Orbiter Laser Altimeter topography. Black and white triangles represent mobile and immobile bedforms, respectively. TARs are not included.

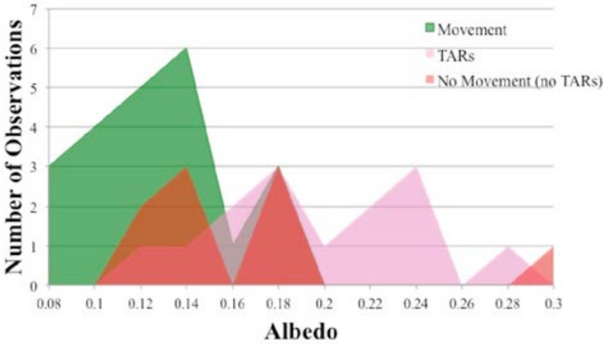

Figure 2: Number of HiRISE image pairs vs. albedo (I/F divided by the cosine of the incidence angle).

(4) The fraction of bedforms that are mobile, along with their rates of migration, increases with decreasing elevation (Fig. 3), a fact that is particularly apparent when dunes in the polar erg (where rates may be high due to katabatic winds) are removed.

(5) Martian bedform migration rates range from 0.2 to 12 m per Earth year (Fig. 4). All data, except for the Meridiani example, plot between the resolution

obtainable with MOC and HiRISE, indicating that MOC was just at the cusp of bedform migration detection. This is consistent with pre-MRO findings that were indicative of dune motion, although did not show it directly, such as lee slope avalanches, brink rounding, and dome dune changes [19-21].

(6) Over all of Mars, there is a rough negative correlation between dune migration rate and height, and within a single dune field (in this case Nili Patera), a tighter relationship (Fig. 5). This is an expected trend given how dunes behave on Earth [22].

(7) Sand flux can be estimated by combining bedform migration rate and topography. Flux has been measured at Nili Patera, with an average value of 2.3 m^3 m^{-1} yr^{-1} in the dune field, implying basalt abrasion rates of 1–50 μm yr^{-1} [6]. From the ripple and dune data, the contribution of flux from reptation and saltation is estimated at 4:1, within the span of 1.5-9:1 on Earth [23]. Extensive HiRISE imaging of Nili shows that the flux varies seasonally and is consistent with an effective threshold between that required for fluid and impact (splash) detachment [24]. Fluxes have also been measured in Herschel Crater [11].

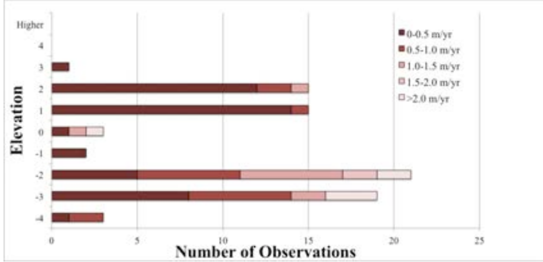

Figure 3: Elevation (km) vs. number of observations as a function of migration rate per Earth year.

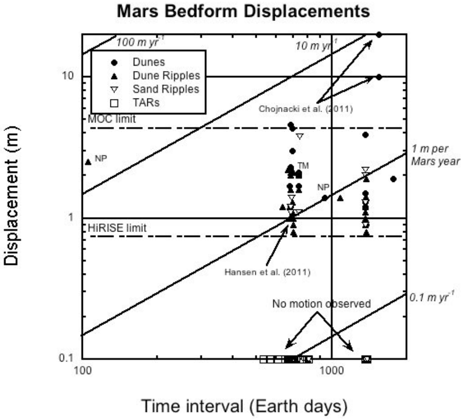

Figure 4: Mars bedform displacement vs. time. ‘‘NP’’ refers to average values for Nili Patera in [6] and TM for Terra Meridian from [8]. Bedforms with no displacement are shown at bottom.

Discussion

Bedform Migration is common, not rare, on Mars, although rates are generally lower for a given size bedform than on Earth (Fig. 5). The mobility may be a result of the low impact threshold on the planet [18], allowing sustained saltation following initiation by infrequent gusts. The fluxes of sand, and the inferred abrasion rates, have terrestrial-like values [6]. Therefore, where winds have a sufficient frequency above threshold and mobile sand is available, landscape modification from infilling and erosion can be significant. This demonstrates that saltation is the most active geomorphic agent in the current Martian environment and is consistent with rapid abrasion rates inferred from MSL cosmogenic dating [25]. Any near-surface organics on Mars are likely preserved in freshly abraded surfaces that have received little exposure to degrading radiation. Therefore, understanding aeolian sand activity on Mars is critical to identifying sites for future in situ study and sample return.

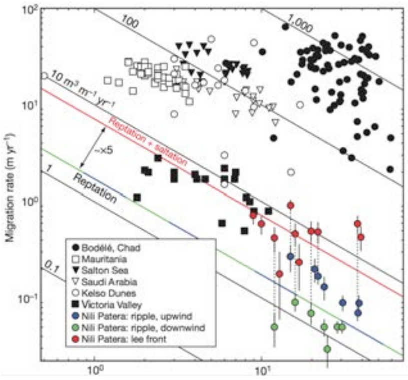

Figure 5: Data for 14 Nili Patera dune migration rates compared to dunes on Earth. Black diagonal lines are isopleths of sand flux. Red and blue/green diagonal lines are mean sand fluxes derived from the lee-front advance and ripple migration measurements, respectively (slightly modified from [6]; acknowledgement to Nature Pub. Group).

References [1] McEwen, A.S. et al. (2007), *JGR, 112*, doi: 10.1029/2005JE002605. [2] Silvestro, S. et al. (2010), *GRL 37*, doi:10.1029/2010GL044743. [3] Ewing, R.C. et al. (2010), *JGR, 115,* doi:1029/2009JE003526. [4] Geissler, P.E. et al. (2010), *JGR, 115*, doi: 10.1029/2010JE003674. [5] Chojnacki, M. et al. (2011), *JGR, 116*, doi:10.1029/2010JE003675. [6] Bridges et al. (2012*b*), *Nature, 485*, 339-342. [7] Hansen, C.J. et al. (2012), *Science, 331*, 575-578. [8] Silvestro et al. (2011), *GRL, 37*, doi: 10.1029/2010GL044743. [9] Geissler, P.E. et al. (2013), *Earth Surf. Proc. Landforms, 38*, 407-412. [10] Silvestro, S. et al. (2013), *Geology, 41*, 483-486. [11] Runyon, K.D. et al. (2014) *LPSC XLV*, 1495. [12] Chojnacki, M. et al. (2014), *Icarus, 230*, 96-142. [13] Bridges et al. (2012*a*), *Geology, 40,* 31-34. [14] Bridges et al. (2013), *Aeolian Res., 9*, doi: 10.1016/j.aeolia.2013.02.004. [15] Banks, M.E. et al. 2014) *LPSC XLV*, 2857 [16] Golombek, M. et al. (2014), *8th Inter. Conf. Mars.* [17] Fenton, L.K. and T.J. Michaels (2010), *Mars 5*, 159-171. [18] Kok, J.F. (2010), *Phys. Rev. Lett,, 104*, doi: 10.1103/PhysRevLett.104.074502. [19] Malin, M.C. and K.S. Edgett (2001), *JGR, 106*, doi: 10.1029/2000JE001455. [20] Fenton, L.K. (2006), *GRL, 33*, doi:10.1029/2006GL027133. [21] Bourke, M.C. et al. (2008), *Geomorph., 94*, 10.1016/j.geomorph.2007.05.012. [22] Greeley, R. and J.D. Iversen (1985), Wind as a geological process on Earth, Mars, Venus and Titan. Cambridge University Press [23] Andreotti, B. (2004), *J. Fluid Mech., 510*, 47-70. [24] Ayoub, F. et al. (2014), *8th Inter. Conf. Mars.* [25] Farley, K.A. et al. (2014), *Science, 343*, 1247166.