ELEVATION DEPENDENCE OF BEDFORM WAVELENGTH ON THARSIS MONTES, MARS

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Abstract

We measure the wavelength of aeolian bedforms on the surface of Martian volcanos, spanning a 23km range in elevation, or nearly an order of magnitude in atmospheric pressure and density. We find that the bedform wavelength varies as the reciprocal of density. We discuss theoretical models that predict such a dependence.

1. Introduction

The unprecedented high resolution of the HiRISE experiment on Mars Reconnaissance Orbiter allows new insights into aeolian features and processes on Mars. HiRISE images of Mars with ground sampling down to 25 cm/pixel show that the dust-rich mantle covering the surfaces of the Tharsis Montes is organized into reticulate ridges whose form and distribution are consistent with formation by aeolian processes. Previous analysis[1] has indicated that dust aggregates are the most likely material composing these bedforms, since the area has low thermal inertia, and the low atmospheric density at these high elevation sites would make difficult the transport of solid materials.

It might be expected (see later) that certain characteristics of aeolian bedforms might have a dependence on atmospheric density. The high imaging resolution, and the range of elevations spanned by the slopes of Martian volcanos, allow us to investigate this question.

2. Observations

We measured the wavelength of reticulate bedforms in 13 HiRISE images on or near the Tharsis Montes over an elevation range of -0.8 to 22.8 km, the largest elevation range readily available on Mars with what can be assumed to be a relatively uniform bedform composition. This exposes elevation (and thus pressure or density - we assume an isothermal atmosphere and thus density is proportional to pressure) as the likely only variable and thus allows us to critically examine any wavelength dependence on pressure.

Within each image, 4 sub-regions were selected. In each of these sub-regions, 10 traverses were made in which the wavelengths of 4-7 ripple sets were measured, each along a parallel line. This resulted in 200-234 'ripple' wavelength measurements per image.

Example images are shown in figure 1 – the difference in wavelength at different elevations is striking.

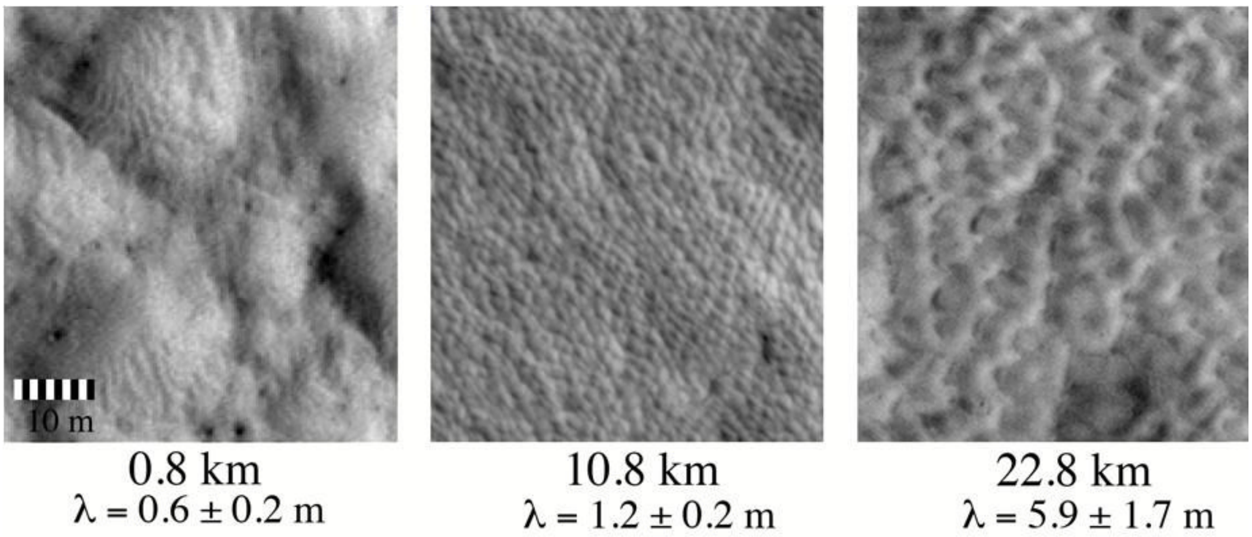

Figure 1. HiRISE imagery of Tharis bedforms. Even with the high resolution, the smallest bedforms (at lowest elevation) are barely resolved. The dependence at higher elevations is very clear, however.

3. Results

Converting elevation to pressure using a scale height of 11.2km, we display the relationship of wavelength with pressure and 1/density in figures 2 and 3.

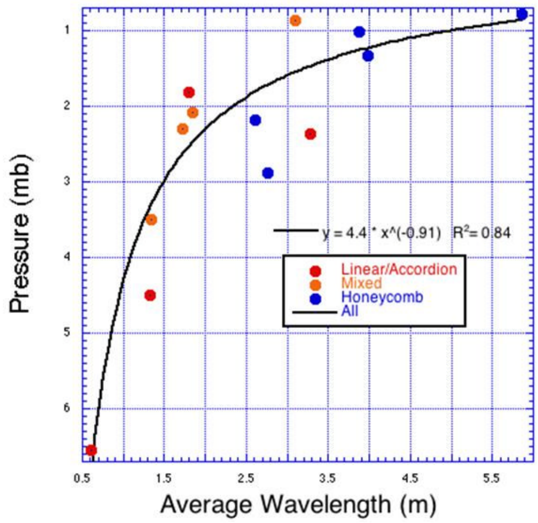

Figure 2. Wavelength variation with pressure. Although a best-fit power law is shown, the fit is statistically indistinguishable from an exponent of (-1).

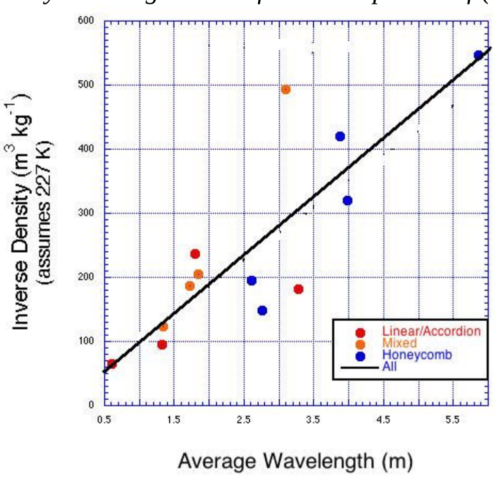

Figure 3. The data of figure 2 replotted as $1/\rho_f$ - a linear fit describes the data well.

4. Theoretical Considerations

We show here that whether these bedforms are considered to be dunes or ripples, the wavelength may be expected to vary as the reciprocal of density in each case.

First, we consider dunes. Recent work[2] suggests that a flat sediment bed will destabilize under shear flow to form 'elemental' dunes with a spacing (the wavelength of the fastest-growing bedform) that relates to the saturation length, or in turn with the 'drag length', the distance scale over which a particle will be accelerated to a large fraction of the freestream speed. The resultant expression is $\sim 53(\rho_s/\rho_f)d$ where d is the particle size and ρ_s is the (solid) particle density and ρ_f the fluid density.

Second, if we consider these bedforms as ripples, we note the assertion of Bagnold[3] that ripples are defined by the saltation length. This perspective, while no longer seen as accurate, does contain a grain of truth. More recent work[4] much more successfully reproduces the phenomenology of real bedforms, and relates to the aerodynamic shear stress variations over a perturbed surface. We mirror Pelletier's analysis as follows.

1)The friction speed (u*) is defined as: $u^* = (\tau/\rho_f)^{0.5}$, where τ is the shear stress and ρ_f is the atmospheric density as before.

2) In order for particles to get raised from the surface by the wind, the friction speed must exceed a threshold value (u_{*t}). The amount of shear stress needed should be constant for a given material and particle size. Therefore, the threshold friction speed should be inversely proportional to the square root of ρ_f .

3) Numerical modeling[4] of ripple wavelength (l) shows that: $l = \sim 3000 z_0$, where z_0 is the aerodynamic roughness height.

4) On an active, flat surface, the heuristic correlation exists that $z_0 \sim d/15 + C_m(u_* - u_{*t})^2/g$, where C_m is a constant.

Now, it is easy to show by numerical experiment that the average value of a windspeed (or friction speed) that follows a statistical distribution (such as the Weibull distribution, which is widely used in terrestrial wind energy work, and provides a satisfactory fit to Viking windspeed data[5]), for those values in the distribution above some threshold, is proportional to that threshold by a factor of order 1~2. It therefore follows that the excess shear velocity ($u_* - u_{*t}$), is proportional to u_{*t}, and squaring, that $l \sim 1/\rho_f$

5. Conclusions

We have measured a strong elevation dependence of bedform wavelength on Martian volcanos, that corresponds to proportionality to the reciprocal of atmospheric density. This relationship agrees with two independent perspectives on theoretical bedform scale length.

References: [1] N. T. Bridges et al., Geophysical Research Letters, 34, L23205, 2007, [2] P. Claudin, and B. Andreotti.. Earth and Planetary Science Letters, 252, 30–44, 2006 [3] Bagnold, R. A., Physics of Blown Sand and Desert Dunes, Methuen, 1941. [4] J. D. Pelletier, Geomorphology, 105, 322–333, 2009 [5] R. D. Lorenz, Journal of Spacecraft and Rockets, 33, 754-756, 1996