Basaltic sand ripples in Eagle crater as indirect evidence for the hysteresis effect in Martian saltation.

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Introduction: Aeolian ripples, which form regular patterns on sand beaches and desert floors and also on Mars, indicate the instability of flat sand surfaces under the wind-induced transport of sand grains. The opportunity rover documented small normal basaltic sand ripples at the bottom of Eagle crater [1]. These ripples are composed of fine sand (100 micron) and their average wavelength and height are 10 cm and 1 cm respectively. Such light particles are thought to be easily suspended by turbulence at the fluid threshold, such that the wind speed at which these bedforms develop must be substantially below the fluid threshold. The occurrence of these bedforms on the Martian surface thus requires the impact threshold to be substantially smaller than the fluid threshold. Recently [2], it was suggested that saltation on Mars can be maintained at much lower wind speeds than the fluid threshold which is needed to initiate it. We used the COMSALT model for saltation [3] together with a dynamic model for sand ripples [4] to show that the small basaltic ripples can develop under wind speeds below the threshold for suspension.

COMSALT includes many of the advances of previous models [e.g., 5], and in addition it includes: (1) a physically based parameterization of the splashing of surface particles that agrees with experimental and numerical studies [3], (2) a generalization of this splashing process to beds of mixed particle sizes, and (3) a detailed treatment of the influence of turbulence on particle trajectories, which agrees with laboratory measurements. Because of these and other advances, COMSALT is the first physically-based numerical saltation model to reproduce a wide range of experimental data. The model has also been recently used to show that saltation can be maintained on Mars by wind speeds an order of magnitude less than those required to initiate it [2].

We used COMSALT to give the basic values of the parameters used by the ripple model for saltation on Mars, specifically the average number of reptating grains per impact of one saltating grain, the number density of saltator impact on a flat surface, and the probability distribution of reptation length.

The ripple model is based on the classic approach of Anderson (1987) [6] and includes a correction to the reptation flux that depends on the local bed slope [4]. According to Anderson's model, the sole role of saltating grains is to bring energy into the system, extracting it from the wind that blows above the surface of the sand. In this view, ripple formation is due entirely to spatial changes in the reptation flux. We thus built a one dimensional heuristic model of sand transport based on the Exner equation [4]:

$$(1-\lambda_p)\rho_p \frac{\partial h}{\partial t} = -\frac{\partial Q}{\partial x}, \qquad (1)$$

where $h(x,t)$ is the local height of the sand surface at point x and time t, λ_p is the porosity of the bed, ρ_p is the grain density and $Q(x,t)$ is the sand flux, which includes both saltation and reptation flux. Here, we assume that saltation flux can be taken as constant and we do not take it into consideration in the Exner equation. Thus, in Eq. 1 we take into account only reptation flux of fine particles, Q_{rf}. The reptation flux at a certain point and time is obtained by the sum of all the grains that pass that point at that time. The grains have a probability distribution of reptation lengths $p_f(\alpha)$. Following Anderson (1987), we derive the explicit expression for reptation flux on a flat surface:

$$Q_{rf}^0 = m_f n_f \int_0^\infty d\alpha\, p_f(\alpha) \int_{x-\alpha}^{x} N_{im}(x')dx', \qquad (2)$$

where the subscript f denotes fine grains, m_f is the mass of each particle, n_f is the average numbers of reptating grains ejected by the impact of one saltating grain, and p_f is the probability distribution of reptating grains. Because saltation flux is uniform and the fixed angle ϕ at which the grains descend back to the ground is assumed to be constant, the number density of impacting grains changes only because of variations in bed slope. Based on geometrical considerations, we obtain,

$$N_{im}(x) = N_{im}^0 \frac{1+h_x \cot\phi}{\sqrt{1+h_x^2}}, \qquad (3)$$

where h_x is the local slope and N_{im}^0 is the number density of impacting grains on a flat surface. We further modify Eq. (2) to take into account correction of the reptation length on an inclined plane [4]. This correction leads to a mean reptation length that is shorter on the windward slope and longer on the leeward slope of the bedform. The full model can be written as:

$$h_t = -Q_0 \partial_x \left[(1-\mu_f)Q_{rf}^0\right], \qquad (4)$$

where the parameter μ_f heuristically includes the correction to reptation flux discussed above, and $Q_0 = m_f n_{rf} N_{im}^0 \cot\phi / \rho_b(1-\lambda_p)$. The basic parameters used in the model ($N^0_{im}, n_f, p_f(\alpha)$) will be given by COMSALT (see Figure 1), which simulates Martian conditions.

Results: Running COMSALT [2] for the unique Martian conditions (air pressure 700 Pa, air temperature 220 K, gravitational acceleration 3.72 m/s^2, and particle density 3000 kg /m^3) will give us the essential parameters that will then be used in the normal ripple evolution model. We will simulate the ripples for two cases, without any kind of cohesion and with cohesion [7].

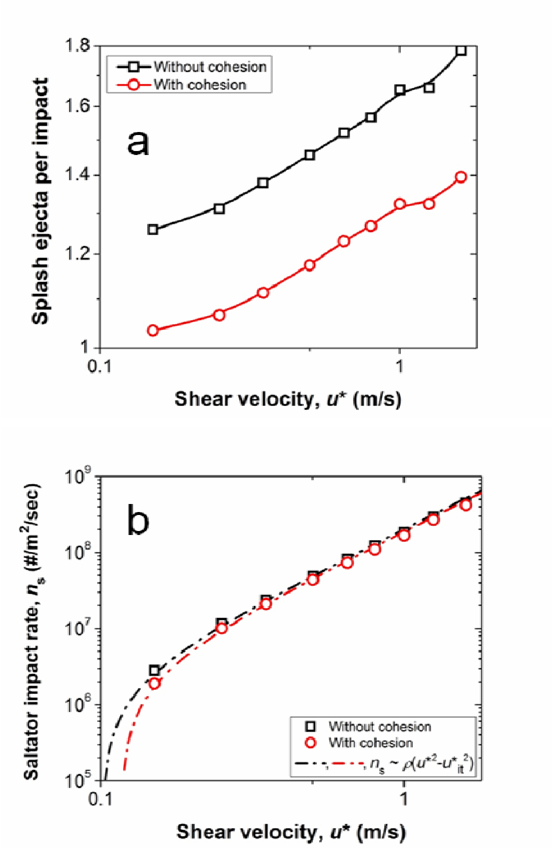

Figure 1: COMSALT simulation results for n_f (panel a) and N^0_{im} (panel b) for 100 micron under Martian conditions.

Together with the computed probability distribution of reptation length given by $p_f(\alpha) = s(1-\exp(-\sqrt{x/a}))(b/x)\exp(-\sqrt{x/b})$ where s, a, b are numerical constants.

Figure 1 shows the results of COMSALT simulations for two of the model parameters (Eq. 1): n_f, the average number of reptating particles per impact of saltation impactor (a) and N^0_{im}, the average impact number of saltation particles on a flat bed (diameter 100 micron) as a function of shear velocity under Martian conditions with and without cohesion between sand grains.

Figure 2 shows results of the one hour ripples simulations on Mars using the input from COMSALT (Figure 1) for different shear velocities. It looks that the observed basaltic ripples at Eagle crater (height 1 cm and wavelength of 10 cm) can be formed under the action of winds with shear velocities ($0.35 < u^* < 0.8$ m/s) which is much below the fluid threshold on Mars for this grain size which $u^*_{th} \sim 1.6$ m/s. This result is indirect evidence which supports the hysteresis effect in saltation on Mars [2].

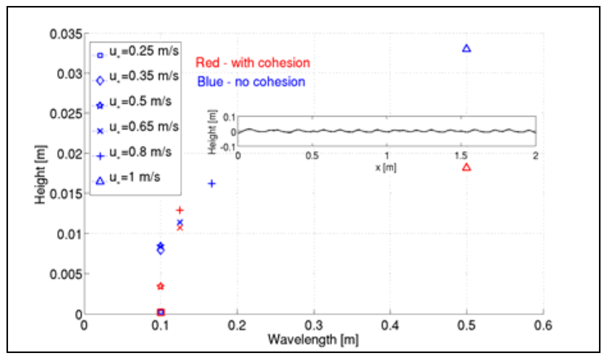

Figure 2: Model simulations (Eq. 1) of normal ripples on Mars with parameters computed by COMSALT for different shear velocities after one hour. The inset shows the final ripples profile for $u^* = 0.65$ m/s. Note that for higher values of shear velocity, the ripples become quite large .

Conclusion: Numerical simulations show that ripples like the basaltic ripples on Eagle crater can be developed by shear velocity of 0.5 m/s, much below the fluid threshold for 100 micron grain on Mars. These findings can be regarded as indirect evidence of the unique saltation mechanism on Mars and support recently observed migration of dunes and ripples [8] .

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