A new mechanism for the transverse instability of megaripples and implication for Martian bedforms.

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Introduction: Observations of normal sand ripples indicate that they are almost two-dimensional bedforms, displaying only small modulations in the direction transverse to the wind. In contrast, most megaripples exhibit a clear transverse instability [1] (Fig.1).

Figure 1. Large wavy megaripples near Torra bay, Namibia. The prevailing wind is from right to left. The mean wavelength and height are 3m and 0.4 m respectively. The mean diameter of the coarse particles at the crest is 3 mm.

The transverse instability can be related to variations in bedform height, which do not diminish over time, and to the inverse dependence of the ripple drift velocity on the height. Thus, the higher regions of the bedforms will move more slowly than the lower regions, which promotes further growth of the perturbations [2]. Based on the height difference mechanism, one can denote four basic curved sections relating to crest height and wind direction, which are shown schematically in Fig. 2. Two of them are transverse stable (c and d) because of the different migration speed of the center compared to the vertex. Two are transverse unstable (a and b), with the (a) configuration being the most common in the field .

Based on field measurements and wind tunnel experiments, we suggest a new mechanism that drives the instability: the positive feedback between the ripple height and accumulation of coarse grains along the crest. We show that small irregularities in the distribution of coarse particles along the crest correlate with irregularities in ripple height during the megaripple's growth, which further enhances the concentration of coarse particles. The outcome of this positive feedback is that the thickness of the armoring layer along the crest is nonuniform and correlates with the crest height. The resulting differences in height drive the transverse instability in the regular way: higher portions of the ripple migrate slower than the lower sections, creating a typical wavy form. This positive feedback works until the crest at those specific locations becomes too high, causing an enhancement of wind shear stress at the crest, which can then entrain surface particles. This process controls the ripple height and eventually suppresses further growth of these sites [3]. We also investigated a sample of Martian ripples which show variations in the sinuosity index, suggesting that this parameter can be useful in distinguishing between normal ripples and megaripples on Mars.

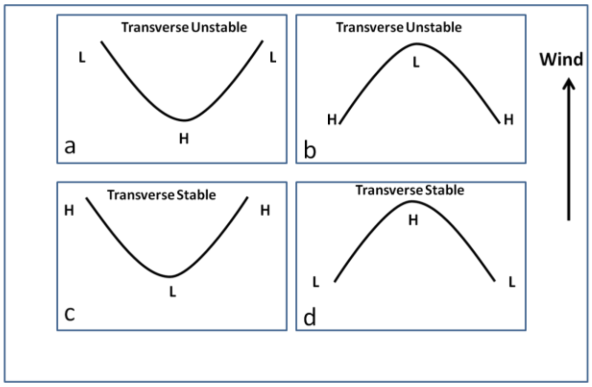

Figure 2. The four suggested basic dynamics of the isolated curved section of the ripple (top view) under the action of unidirectional wind. H is for high points and L for low points. In cases (a) and (b) the initial perturbation will grow as the lower parts move downwind faster than the higher points. In contrast in (c) and (d), initial perturbations will diminish.

Materials and Methdes: The study includes grain size analysis of samples taken from megaripple crests from different locations and controlled wind tunnel experiments with perturbed artificial ripples. Both methods allowed us to confirm the new suggested mechanism.

Wind tunnel experiments were carried out to study the feedback between ripple sinuosity and the surface concentration of coarse particles by investigating the development of initial perturbations of different heights and different grain size along a small artificial ripple.

In addition, we investigate the sinuosity index of martian normal ripples and megaripples to check whether the variation of this parameter can be used to distinguish among these two ripple classes.

We focused on two areas which have been previously investigated in situ by the NASA Martian Exploration Rovers (MERs) Spirit and Opportunity, Gusev Crater and Meridiani Planum [4-5]. In Gusev Crater we mapped the crestlines of three dark ripple fields lying in topographic lows including the bedforms visited by the MER Spirit in El Dorado which were interpreted as normal ripples [4]. In Meridiani Planum, we focused our attention on the plain ripples traversed by the MER Opportunity which were interpreted as megaripples due to their bimodal grain size arrangement [5]. In the study sites we manually digitized the ripple’s crestlines and we computed the sinuosity in ArcGIS.

Results: Field measurments show that the thickness of the armouring layer along the crests correlates with ripple height. This non-uniform grain size distribution along the crest causes the differences in heights along the crest to remain for longer times. These differences may even become more evident, since more coarse particles driven by the impinging saltating grains accumulate at these points of the ripple, which migrate more slowly. Thus, under the influence of unidirectional winds, the basic mechanism of the transverse instability is differential migration along the crest, which will increase the megaripple. The wind tunnel experiments confirm that perturbations of coarse grains at the crest grow in time and increase ripple sinuosity, whereas perturbations of fine particles diminish in time. A quantitative analysis of sinuosity of megaripples and ripples at two sites on Mars shows that the sinuosity index can help in distinguishing among normal ripples and megaripples (Fig. 3).

Conclusions: The new mechanism is based on a feedback between accumulation of coarse particles at the crest and ripple height. The higher portions along the crest are related to a thicker armoring layer. Thus, the differences in height along the crest can grow in time and lead to differential migrating rates of segments along the crest, which enhance the instability. As a result, megaripples are 3D. In contrast, normal ripples composed of fine particles are 2D bedforms since perturbations in height along the crest quickly diminish by lateral sand flux and by excess of shear stress with height. We tested this mechanism by field measurements of grain-size distribution along megaripple crests and by wind tunnel experiments of the evolution of artificial perturbations along the ripple crests.

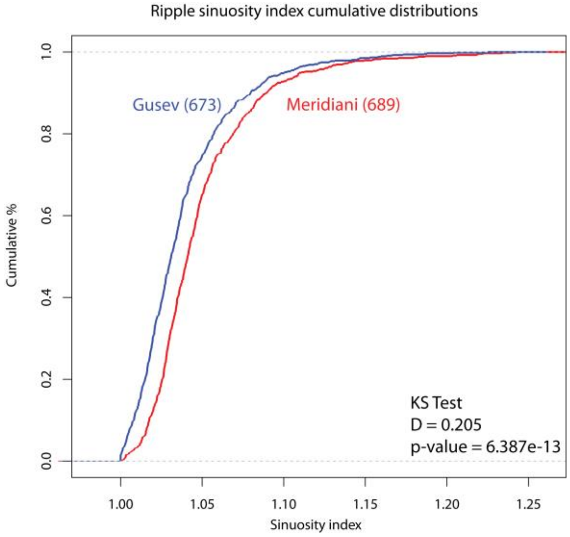

Figure 3. Cumulative distributions of the sinuosity index for the sampled ripples in Gusev Crater and Meridiani Planum. Note that more than 90% of the Gusev ripples show smaller sinuosity values compared to Meridiani. The result of the two-sample Kolmogorov-Smirnov test (low p-value) also indicates that the two distributions are statistically different.

Further analysis will help to better discriminate between different ripple classes both on Earth and on Mars. For example, the distinction between TARs (Transverse Aeolian Ridges, [6-7]), megaripples, and large normal ripples on Mars can be done on the basis of their plain sinuosity when the underlying mechanism are uncovered. Full understanding of this instability will become possible only with a 3D sand transport model, which presently does not exist. This new look at aeolian bedforms on Mars can help in a better classification of them and improve the understanding of the aeolian processes involved in their formation.

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