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Surface slope effects for ripple orientation on sand dunes in López crater, Terra Tyrrhena region of Mars

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ABSTRACT

Ripple orientations on small sand dunes (dunes lacking substantial slip faces) at widely distributed sites across Mars have been documented using High Resolution Imaging Science Experiment (HiRISE) images, in an effort to determine the last formative aeolian sediment transport direction experienced at these locations. Howard (1977) used field measurements and first principles to derive an expression for determining how much the surface slope on a sand dune deflects the orientation of sand ripples with respect to the formative wind direction. A Digital Terrain Model derived from stereo HiRISE images was used to assess the potential deflection of ripples on sand dunes on the floor of López crater on Mars. Three-quarters of the area covered by sand dunes within the DTM has a surface slope <10°, where deflection angles are expected to be <17° (a value that should not pose a major issue for comparison to model-derived winds); such surface slopes are typical of small sand dunes on Mars that lack large slip faces. Sand ripples therefore should be good indicators of the most recent sand-transporting winds that have blown across sand dunes on Mars, as long as areas on or very near to slip faces are avoided.

1. Introduction

Ripple orientations on small sand dunes (e.g., dunes lacking substantial slip faces) at 40 widely distributed sites across Mars have been documented using High Resolution Imaging Science Experiment (HiRISE) images (McEwen et al., 2007), in an effort to determine the most recent sand transporting surface wind directions experienced at these locations (Johnson and Zimbelman, 2015; Zimbelman and Johnson, 2016). At a presentation of the early stages of this work, the question was raised as to how well the observed ripple orientations correspond to the actual direction followed by the surface winds. Howard (1977) used both field measurements and first principles to derive an expression for determining how much the surface slope of a sand dune deflects the ripple orientation with respect to the formative wind direction. Sand dunes on the floor of López crater (14.55°S, 97.77°E) on Mars provide the opportunity to assess the magnitude of ripple deflection on small sand dunes with slip faces present on only a limited portion of the dunes. A Digital Terrain Model (DTM) of the sand dunes in López crater derived from stereo HiRISE images provides an excellent data set of the topography of the López dunes, with which the orientations of wind ripples can be compared to the surface slope magnitude and orientation obtained from the DTM (Zimbelman and Johnson, 2015). The Howard (1977) equation was used to determine the magnitude of ripple deflection expected to have taken place on these sand dunes. The results of this analysis indicate that ripple deflection is not significant when areas either on or near to slip faces are avoided, so that documented ripple patterns for small sand dunes on Mars can provide useful information about the surface winds that have recently blown across the area.

2. Background

Sand dunes were first identified on Mars in images taken by Mariner 9, the first spacecraft to go into orbit around Mars (McCauley et al., 1972). Subsequent missions to the Red Planet documented sand dune deposits across much of the planet (Cutts et al., 1976; Breed et al., 1979; Tsoar et al., 1979; Hayward et al., 2007, 2014; Lorenz and Zimbelman, 2014, pp 135–155). Orbiter images have revealed a wide variety of dune types on Mars, including most types common on Earth (except those directly associated with vegetation), as well as some distinctive dune shapes that appear to result from unique wind patterns present at a few locations (Breed et al., 1979; Hayward et al., 2007, 2014).

The HiRISE camera (McEwen et al., 2007) has brought about an entirely new perspective for examining sand dunes on Mars

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(Bridges et al., 2007). In particular, HiRISE reveals previously unseen complex surface textures on dunes and ripples (Bridges et al., 2007), including the nearly ubiquitous presence of wind ripples on the surface of sand dunes imaged across the planet. The Martian wind ripples observed with HiRISE have wavelengths of a few meters, substantially larger than their counterparts here on Earth. The continuous monitoring of dunes with HIRISE has provided widespread documentation of the movement of both ripples and dune margins under current Martian atmospheric conditions (Silvestro et al., 2010; Bridges et al., 2012a,b; 2013), a situation not widely anticipated prior to the HiRISE observations. The orientation of wind ripples on sand dunes has been used to infer trends for the last formative aeolian sediment transport directions that have occurred at some Martian sand dunes (Ewing et al., 2010; Liu and Zimbelman, 2015), including the importance of recognizing both short-term and long-term influences on the formation of ripples and dunes (Liu and Zimbelman, 2015; Liu et al., 2016). In the current investigation we specifically exclude consideration of mega-ripples with surface coatings of coarse grains, features that are more appropriate to be considered under the general term of 'Transverse Aeolian Ridges' (e.g., Zimbelman, 2010).

Jackson et al. (2015) recently made the important inference that ripple movement on Mars likely reflects a 'steered' wind direction for certain dune ridges' shapes, when the shape of the dune itself can affect the path of the wind (this result was clearly illustrated using computational fluid dynamics code applied to HiRISE DTM data of sand dunes in Proctor crater). However, the results of Jackson et al. (2015) were obtained for large sand dunes with well-developed slip faces; such dunes are large enough to induce complex wind patterns downwind of the crests of the slip faces. The question remained as to whether ripple orientation on small dunes lacking substantial slip faces was significantly altered by dune topography, or whether ripple orientation on small dunes accurately recorded the most recent wind direction.

In order to investigate the use of wind ripples as records of the last formative aeolian sediment transport directions on Mars, a systematic mapping of ripple orientations in HiRISE images was instituted by a project supported by the Mars Data Analysis Program (MDAP) of NASA, focusing on mapping ripple orientations on 'small' sand dunes (those lacking evidence of substantial slip faces) at locations widely distributed across the planet (Johnson and Zimbelman, 2015; Zimbelman and Johnson, 2016). Early in this investigation, the question was raised regarding how well the ripples visible on Martian dunes preserve the orientation of the most recent sand-driving winds, motivated in large part by a remarkable study undertaken to investigate precisely this question. Howard (1977) used first principles and field documentation of both ripple orientation and surface wind conditions on a barchan in the Salton Sea area of California to derive an expression for how sand grains move at an angle to the surface wind on a sloping surface: $\sin\beta = \tan\theta \sin\gamma/\tan\alpha$, where β is the angle between the direction of fluid and gravitational stresses (the deflection angle), θ is the surface slope, γ is the angle between the wind and the surface gradient directions, and α is the angle of repose for loose sand. Howard (1977) used a value of 30.5° for the angle of repose, but here we use a value of 32°, which is closer to the value for fine dry sand that typifies most active dunes. The value of the angle of repose has only a limited effect on the computed deflection angle; deflection angles decreased by <0.5°, <1.0°, <1.6° and <2.5° for slopes of 5°, 10°, 15°, and 20°, respectively, when 32° is used rather than 30.5°. With good topographic information obtainable from a DTM derived from a HiRISE stereo pair, the parameters needed to apply the Howard equation can be obtained.

Of the forty sites at which ripple orientation have been measured for the MDAP project, the low relief sand dunes on the nearly level floor of López crater (centered at 14.57° S, 98.04° E) in the Terra Tyrrhena region of the southern cratered highlands were chosen for investigation of the possible effects of surface slope on ripple orientation. This 85-km-diameter crater is named after Epidio López, a Mexican astronomer and author who lived from 1879 to 1965 (IAU Nomenclature web page at planetarynames.wr.usgs.gov). The dunes in this crater are typical of the majority of sand dune fields on Mars that are found on crater floors in the southern highlands (Hayward et al., 2014). More importantly, an excellent HiRISE stereo pair was produced for a portion of the dune field in López crater (described next).

3. Methodology

A DTM with one meter posting (Figs. 1 and 2) was produced by the authors in June of 2014 for a portion of the sand dune field on the floor of López crater using SOCET SET software and hardware located at the Astrogeology Branch of the U. S. Geological Survey in Flagstaff (Zimbelman and Johnson, 2015). Stereo HiRISE images

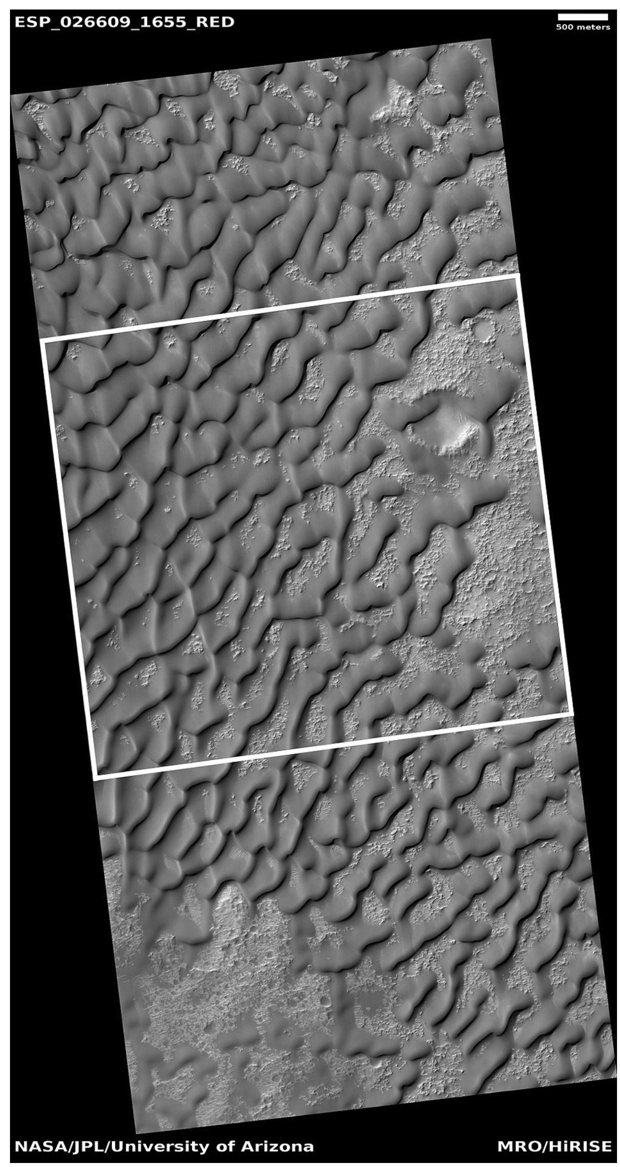

Fig. 1. Browse version of HiRISE image ESP_026609_1655, showing a portion of the dune field on the floor of López crater. The box indicates the location of the area shown in Figs. 2 and 3. This image makes a stereo pair with HiRISE image ESP_026675_1655.