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Surface-based 3D measurements of small aeolian bedforms on Mars and implications for estimating ExoMars rover traversability hazards

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ABSTRACT

Recent aeolian bedforms comprising loose sand are common on the martian surface and provide a mobility hazard to Mars rovers. The ExoMars rover will launch in 2020 to one of two candidate sites: Mawrth Vallis or Oxia Planum. Both sites contain numerous aeolian bedforms with simple ripple-like morphologies. The larger examples are ‘Transverse Aeolian Ridges’ (TARs), which stereo imaging analyses have shown to be a few metres high and up to a few tens of metres across. Where they occur, TARs therefore present a serious, but recognized and avoidable, rover mobility hazard. There also exists a population of smaller bedforms of similar morphology, but it is unknown whether these bedforms will be traversable by the ExoMars rover. We informally refer to these bedforms as “mini-TARs”, as they are about an order of magnitude smaller than most TARs observed to date. They are more abundant than TARs in the Oxia Planum site, and can be pervasive in areas. The aim of this paper is to estimate the heights of these features, which are too small to measured using High Resolution Imaging Science Experiment (HiRISE) Digital Elevation Models (DEMs), from orbital data alone. Thereby, we aim to increase our knowledge of the hazards in the proposed ExoMars landing sites. We propose a methodology to infer the height of these mini-TARs based on comparisons with similar features observed by previous Mars rovers. We use rover-based stereo imaging from the NASA Mars Exploration Rover (MER) Opportunity and PRo3D software, a 3D visualisation and analysis tool, to measure the size and height of mini-TARs in the Meridiani Planum region of Mars. These are good analogues for the smaller bedforms at the ExoMars rover candidate landing sites. We show that bedform height scales linearly with length (as measured across the bedform, perpendicular to the crest ridge) with a ratio of about 1:15. We also measured the lengths of many of the smaller aeolian bedforms in the ExoMars rover Oxia Planum candidate landing site, and find that they are similar to those of the Meridiani Planum mini-TARs. Assuming that the Oxia Planum bedforms have the same length/height ratio as the MER Opportunity mini-TARs, we combine these data to provide a probabilistic method of inferring the heights of bedforms at the Oxia Planum site. These data can then be used to explore the likely traversability of this site. For example, our method suggests that most of the bedforms studied in Oxia Planum have ridge crests higher than 15 cm, but lower than 25 cm. Hence, if the tallest bedforms the ExoMars rover will be able to safely cross are only 15 cm high, then the Oxia Planum sites studied here contain mostly impassable bedforms. However, if the rover can safely traverse 25 cm high bedforms, then most bedforms here will be smaller than this threshold. As an additional outcome, our results show that the mini-TARs have length/height ratios similar to TARs in general. Hence, these bedforms could probably be classified simply as “small TARs”, rather than forming a discrete population or sub-type of aeolian bedforms.

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1. Introduction

The surface of Mars hosts various types of aeolian bedforms (Fig. 1), from small wind-ripples of centimetre-scale wavelength (e.g., Sharp and Malin, 1984; Sullivan et al., 2005), through larger decametre-scale "Transverse Aeolian Ridges" (TARs; e.g., Bourke et al., 2003; Balme et al., 2008; Berman et al., 2011) to kilometre-scale dunes (e.g., Cutts and Smith, 1973; Hayward et al., 2007). To date, all mobile Mars surface-missions have encountered recent aeolian bedforms of one kind or another, despite being located in very different ancient environments: the Sojourner rover (Rover Team, 1997) explored a megaflood outwash plain, the Mars Exploration Rovers (MERs) "Spirit" and the ongoing "Opportunity" (Squyres et al., 2004) investigated the interior of Gusev Crater and the sedimentary Meridiani plains respectively, and the Mars Science Laboratory (MSL) "Curiosity" rover (Grotzinger et al., 2012) is studying fluviolacustrine and other sediments within Gale Crater. Hereafter, when we refer to aeolian bedforms and deposits, we refer to recent bedforms consisting of loose sediments (although we do not specify if they are currently active or not), rather than lithified or indurated bedforms, or bedforms preserved in outcrop.

Aeolian deposits consisting of loose unconsolidated material can constitute hazards to surface mobility of rovers: sinkage into the aeolian material and enhanced slippage can hamper traction and hence prevent forward progress, forcing the rover to backtrack (e.g., MER Opportunity, Arvidson et al., 2011) or, in the worst case, leading to permanent entrapment and end of mission (e.g., MER Spirit, Arvidson et al., 2010). Being able to estimate the depth of loose aeolian material (or the height of aeolian bedforms) before a rover drives over them is therefore clearly of great advantage. Although measurement of bedform heights can be performed *in situ*, this provides no scope for forward planning, nor for assessing the traversability of a candidate landing location prior to final site selection. What is needed is a way to estimate aeolian hazard severity in a given area using remote sensing data alone. The aim of this paper is to find a way to estimate the heights of aeolian bedforms that are too small to be measured using HiRISE (High Resolution Imaging Science Experiment; McEwen et al., 2007) DEMs, in order to increase our knowledge of the hazards they pose to rovers.

In 2020, the European Space Agency, in partnership with the Russian Roscosmos, will launch the ExoMars rover to Mars (Vago et al., 2015, 2017). The rover has the explicit goal of looking for signs of past life. The ExoMars rover will be equipped with a drill capable of collecting material both from outcrops and the subsurface, with a maximum reach of 2 m. This subsurface sampling capability will provide the best chance yet to gain access to well preserved chemical biosignatures for analysis. However, drilling on a planetary surface is difficult, time-consuming and not without risk. Hence, selecting scientifically interesting drilling sites, and being able to reach them, is vital for the mission; the ExoMars mission was conceived as a mobile platform to ensure that the drill can be deployed at the best possible locations.

The rover (Fig. 2) has a mass of 310 kg and is expected to travel a few km during its seven-month primary mission. The rover's locomotion system is based on a passive 3-bogie system with deformable wheels (Patel et al., 2010). Lander accommodation constraints have imposed the use of relatively small wheels (28.5 cm diameter without grousers, 12.0-cm width). In order to reduce the traction performance disadvantages of small wheels, flexible wheels have been adopted. However, the average wheel ground pressure is still ~10 kPa (higher than that of the NASA MER rovers, which is ~5.7 kPa; Heverly et al., 2013). This is a concern for traversing unconsolidated terrains. To mitigate this risk the ExoMars team is considering the use of 'wheel walking', a coordinated roto-translational wheel gait in which the wheels are raised and lowered in sequence, that can improve dynamic stability and provide better traction for negotiating loose soils. The plan would be to engage wheel walking in case a certain predetermined wheel slip ratio limit is

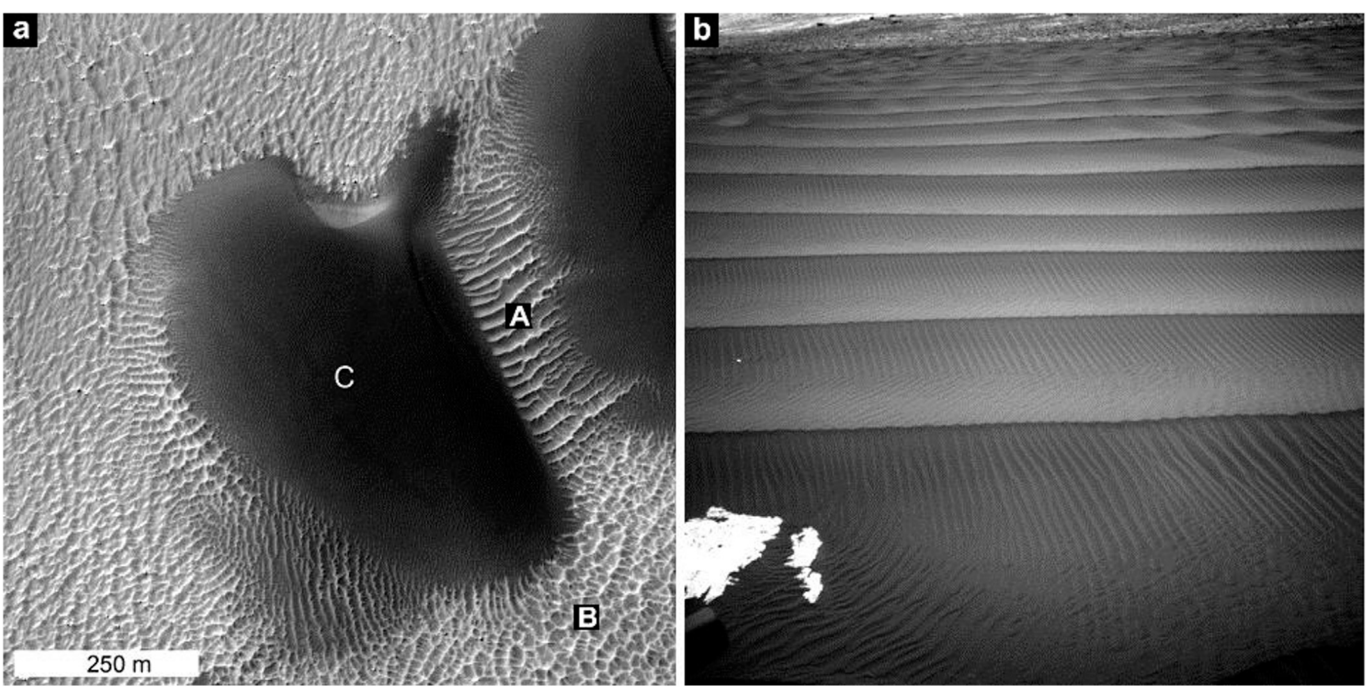

Fig. 1. Examples of aeolian bedforms on Mars. North is up and illumination is either from the left or bottom left in this and all following orbital images. a) An example of large aeolian bedforms on Mars. "A" shows a field of transverse aeolian ridges (TARs) with simple to branching crest-ridge morphology. "B" shows TARs with reticulate crest-ridge patterns. TARs usually have crest-to-crest lengths of up to a few tens of metres. "C" indicates the presence of a large dark dune. These martian dunes often have superposed metre-scale ripple-like bedforms on their upper surfaces, but can themselves be hundreds of metres or greater in length. Note the small, arcuate slip face at the northern edge of the large dark dune. Part of HiRISE image ESP_042040_1275 located at ~ −53.05°N, 33.27°E. Image credit: NASA/JPL/UofA. b) An instance of smaller aeolian bedforms, as observed by NASA's Curiosity rover. The image shows a population of simple, ripple-like bedforms with metre-scale wavelength stretching to the middle-distance. Superposed on these bedforms, and with crest-ridges perpendicular to them, is a population of smaller ripples with 5–10 cm wavelength. Similar subsidiary ridge crests can even be seen in orbital images (Bridges et al., 2007). Note: white patch in bottom left is exposed rocky material. This is an MSL NavCam (right) image from Sol 1601 (a 'sol' is a martian day) of the mission and has image ID NRB_539621449EDR_F0603162NCAM00260M. Image credit: NASA/JPL-Caltech.