FORMATION CONDITIONS FOR COARSE-GRAINED MEGARIPPLES ON EARTH AND MARS: LESSONS FROM THE ARGENTINEAN PUNA AND WIND TUNNEL EXPERIMENTS

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Introduction

The Martian surface contains a diversity of aeolian landforms, attesting to the effectiveness of wind as a major geomorphic agent despite the lower atmospheric pressure, gravity, and frequency of threshold winds compared to Earth. Rover observations have documented sand mobility at the field scale [1,2] and HiRISE has shown many dunes and ripples undergoing active migration [3]. The understanding of the formation mechanisms, rates, and particle fluxes of Martian aeolian bedforms is informed by terrestrial analog field work, commonly augmented with wind tunnel and modeling studies. Martian dunes and ripples have fairly close terrestrial morphometric analogs, emphasizing the role of saltation and impact splash in both environments. However, “Transverse Aeolian Ridges” (TARs) are a class of Martian bedform for which a viable terrestrial analog is much harder to find. With sizes and morphometric properties intermediate between dunes and ripples, TARs have been proposed as large megaripples formed via impact splash and creep, reversing dunes, or both [4-6].

Gravel megaripple fields of Catamarca, Argentina [7-9] are located in one of the windiest parts of the Argentinean Puna and may be the best terrestrial analog for TARs. In the region of the Cerro-Blanco caldera complex, late Pleistocene ignimbrites ranging in age from 13,000 to 70,000 years dominate the landscape [8,10]. These rhyolitic ignimbrites are weakly to moderately indurated and have been wind eroded to produce prominent yardangs and demoiselles. They contain about 5% by volume of lithic clasts with densities ranging from 2.6 to 3 g/cm^3, and up to 10% crystal-poor pumice clasts with densities of ~0.8 to 1.3 g/cm^3. Erosion liberates these clasts and the crystals from the matrix ash. The ash is quickly elutriated away, leaving a lag of crystals and clasts dominated by older ignimbrites, lavas, basement metamorphic-rich lithics, and pumice fragments.

We have been studying the Puna gravel megaripples and local wind conditions in an attempt to better understand potential TAR formation on Mars. Here we describe preliminary results from in situ wind profile measurement, time-lapse imaging, and simple wind tunnel studies.

Methods and Initial Results

Wind Profile Measurements

Wind profile measurements were conducted in December, 2010. Three anemometers were set up on at logarithmic spacings up to 1.6 meters. A semi-log fit to the profile data shows a roughness height (z_0) of a few centimeters for a range of freestream wind speeds and field conditions. The derived roughness heights are similar to typical gravel sizes at the ripple crests, indicating that at least some grains can be saltated if wind speeds are high enough. Friction speeds (u*) were below that needed to move pumice. This is consistent with our qualitative observations that local sand was saltating, but no clasts were moving, indicating conditions were below threshold for the major megaripple components. However, in the winter, winds are probably more active, consistent with changes seen in our time-lapse imaging (below).

Time-lapse imaging

Time-lapse cameras were placed at three locations. However, only one camera, anchored on a coarse-grained ripple at “White Lake Field,” worked over a long enough time span to return interesting data. It took pictures every 2.875 (-50%, +100%) hours over ~9-10 months (image time-tagging was not automatic, but will be reconstructed later) Comparison of images acquired in December, 2010 and ~July, 2011 show displacement, removal, and addition of clasts up to several centimeters in size. Most of these look like pumice [Fig. 1].

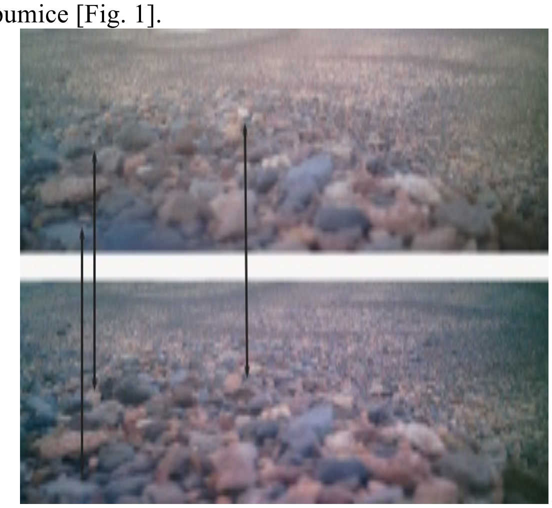

Fig. 1: Removal and addition of large pumice fragments as seen in time lapse images acquired in December 2010 (top) and ~July 2011 (bottom) at the “White Lake Field” site (S26°30.865’, W67°42.053’). Arrows point to some changes in clasts between the two images.

Wind tunnel investigation

Experiments were conducted at the Arizona State University wind tunnel in January, 2012. It operates at standard pressure and temperature, with a fan and motor system able to achieve free stream winds up to 30 m s^{-1}. It has dimensions of 13 (length) x 1.2 (width) x 0.9 m (height). A upwind motorized hopper can drop sand into the windstream. The test sections is coated with fine sand paper (average grain size = 120 µm). Upwind the tunnel is smooth plywood. Initially we had intended to simulate the field z_0 and u^* (adjusted for atmospheric density) determined from the wind profile data and collected samples by coating the tunnel floor with materials of similar sizes to those in the Puna. Because of calibration issues at the tunnel, we were not confident that the wind speed profile could be measured. So, we instead did first order measurements of *relative* threshold wind speeds of various field materials by placing them in the test section. Wind speed was gradually ramped up and threshold stages (vibrating, rolling, saltating) were noted, with simultaneous side-mounted video and overhead time-lapse imaging. Fluid and impact threshold were simulated, with the latter using quartz and scoria sand dropped from the upwind hopper.

Data are scattered (Fig. 2), but, based on our observations, we are confident more trends will result with further analysis (for example, clast size and shape have not been differentiated in Fig. 2). However, clear threshold stages are apparent, with even large pumice grains capable of being saltated. We also documented clear material segregation and clumping into ripple-like forms (Fig. 3).

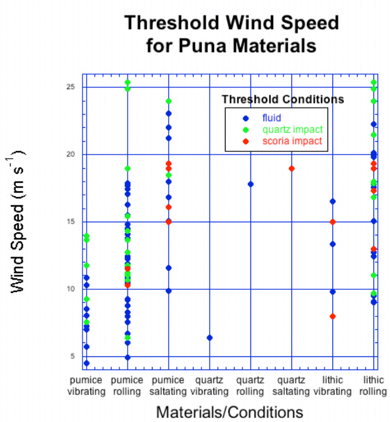

Fig. 2: Freestream threshold speeds for field materials measured in the ASU wind tunnel.

Discussion

More robust field and wind tunnel studies are planned for this project that will provide quantitative measurements of threshold friction speed for various materials and estimates of gravel ripple changes. Our preliminary observations nevertheless provide some important information on megaripple formation conditions in the Puna and insight into Martian processes. Large pumices and lithics can move at wind speeds that clearly occur in the region. If the time-lapse 2010-11 images are representative, ripple material movement is an ongoing process and is probably most effective in the winter.

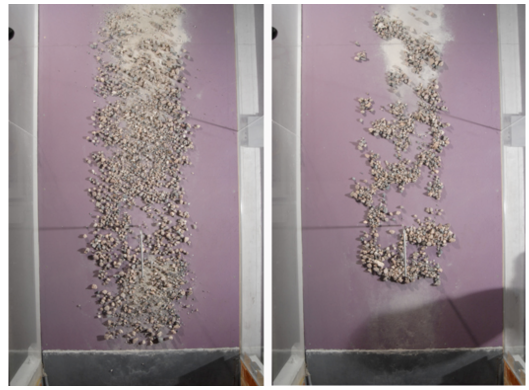

Fig. 3: Initial and final stages of wind tunnel tests to determine freestream threshold of large pumices, lithics, and gravels. Sunset crater ash (> 800 µm) was saltated the length of the wind tunnel to simulate impact threshold conditions of pumice-like materials. Note the clumping of materials into ripple-like forms.

There is strong evidence that the Puna ripples are concentrated at the peaks of swales on the eroded bedrock ignimbrite surface (reflecting differential induration by exsolved gasses that passed through cooling cracks) [11]. The observed clast transport is therefore inconsistent with a model in which 1) ripple materials remain in place, or 2) the ripples gradually migrate across the landscape. Rather, the position of the megaripples may remain relatively constant, with clasts periodically removed from one megaripple and then blown downstream onto another. Such a model for dynamic, yet emplaced, megaripples may be operative on Mars. TARs have not been observed to migrate in contrast to some dunes and ripples [3] and it has been inferred that those distal to large dunes are inactive under present conditions [12], perhaps an unsurprising result if TARs are indeed megaripples armored with coarse grains like those that characterize plains ripples in Terra Meridiani [1]. This may also explain why some Martian large traverse bedforms are aligned on the crests of periodic bedrock ridges that have been hypothesized to have formed from aeolian erosion [13]. Continued studies of the Puna megaripples will provide further insight on these enigmatic Mars landforms.

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