INVESTIGATING THE COARSEST GRAVEL RIPPLES ON EARTH – FIELD RELATIONSHIPS, SEDIMENTOLOGICAL CHARACTER AND IMPLICATIONS FOR MARS. S. L. de Silva[1], N. T. Bridges[2], J. R. Zimbelman[3], M.G. Spagnuolo[4], D.M. Burr[5]; S.Scheidt[3], A. Ortiz[6] [1]Oregon State University, Corvallis, OR 97331 (desilvas@geo.oregonstate.edu), [2]CEPS/NASM MRC 315, Smithsonian Institution, Washington D.C. 20013-7012. [3] JHUAPL, Laurel, MD 20723, [4]University of Buenos Aires, Argentina, [5]University of Tennessee Knoxville, Knoxville, TN 37919, [6]Universidad de Salta, Salta, Argentina

Introduction: Coarse gravel megaripples in the Puna of Argentina represent some of the most extreme aeolian bedforms on Earth in terms of particle properties and formation conditions [1, 2]. These gravel ripples are built on a bedrock of ignimbrites and composed of a bimodal association of dense (>2 g cm^{-3}) lava and metamorphic clasts up to 2.5cm in diameter and pumice clasts (<1.5 g cm^{-3}) up to 5 cm in diameter, making these the coarsest grained ripples yet described on Earth (Figure 1). While the mechanisms of origin and formation are debated [1,2,3], it is clear that these ripples must represent extreme conditions that define an end member of the spectrum of granule ripples on Earth. The relevance to Mars is threefold: First, these aeolian gravel bedforms consist of materials that have similar equivalent weight to those composing the granule ripples at Meridiani Planum, Mars. Second, the spatial relationships among these Puna megaripples, topography, and bedrock are analogous to relationships among Transverse Aeolian Ridges (TARs), topography, and bedrock on Mars. Third, the gravels are locally derived and may point to an alternative source to globally transported dark dune sediments on Mars [4,5]. We report here the progress we have made studying these megaripples, conducted under the auspices of NASA MFRP grant NNX10AP79G. We dedicate this work to the memory of our collaborator Ron Greeley.

Geologic Background: The gravel megaripple fields of Catamarca, Argentina are located in one of the windiest parts of the Argentinean Puna. The gravel ripples are distributed in five distinct fields in close proximity to each other, centered around 26°45'S 67°45'W. The fields vary in areal extent from 300 km^2 to 50 km^2, representing the largest areas of coarse gravel ripples yet described on Earth [1,2]. Each field is located in a separate "basin" demarked by bounding volcanic and basement (metamorphic) highlands and is distinct in componentry and macroscopic appearance, reflecting variable sources of the lithic clasts. The largest of the fields is Campo Piedra Pomez that is built on the bedrock of the 70 ka Campo Piedra Pomez ignimbrite (CPP). Here dark megaripples prevail [4,5]. The largest and coarsest megaripples are found in the Purulla and White Lake fields, while the White Barchan field hosts the smallest quartz-dominated megaripples.

Observations and Interpretations. The megaripple fields display amplitudes up to 2m and wavelengths of up to 30m (Figure 1). Common to all the fields is that the bedrock rhyolitic ignimbrites are weakly to moderately indurated and have been abraded by wind-blown sediment to produce prominent yardangs and demoiselles. Yardang development in the Purulla field is limited by the poor induration of the ignimbrite.

Figure 1. Large lithic dominated gravel megaripple bedforms of the Purulla field. Wind from bottom right. Note concentration of large pumice on the lee side of the bedform and person for scale. Amplitude of the topography is ~2m and the wavelength is almost 30m.

Figure 2. Detail of the gravel bedforms at Purulla. Wind direction is out of the page. The crest is dominated by lithic clasts up to 2cm and the lee-side (bottom left) is dominated by pumice up to 5 cm.

In some fields, the gravel bedforms consist of lithics derived exclusively from erosion of the bedrock ignimbrite. In others, the source is a mixture of local bedrock ignimbrite and surrounding highlands. Pumice is derived from the local ignimbrite exclusively. Profiles of the ripples made using laser profiling and Brunton measurements show significant variability, with ripples in the Purulla area showing more symmetry between lee and stoss slopes than those in the Campo Piedra Pomez.

A key feature of these fields is that the eroded surface of the ignimbrite bedrock on which the gravels develop is distinctively wavy and scalloped at the 1 to 2m vertical and 10m horizontal scale. Gravels appear to collect on the erosional surface in the swales or troughs between yardangs and vary from areally extensive sheets through diffuse lenses to distinct bedforms. The best developed bedforms appear to nucleate and develop on the crest of the surface topography. This relationship is confirmed by trenching into the bedforms, which reveals that the largest gravel bedforms make up only 30cm of the 2m amplitude of the megripple topography. The upper 20cm is dominated by crudely bedded coarse gravels, while the lower portion contains significantly more sandy material. The coarsest particles are concentrated at the surface and peak of the ripple. Large pumice, up to 2.5x the size of associated lithic fragments, is loosely concentrated on the lee of the bedform. No evidence of slip faces were found in the sections we made, confirming that these bedforms are indeed ripples and not dunes. Rare internal sandy beds suggest ephemeral sand sheets swept through the area.

A model for the origin of the Coarse Gravel Megaripples in the Puna of Argentina: Componentry supports the macro- and mesoscale observations that the origin of the gravels is from erosion of the bedrock ignimbrite augmented locally by input from surrounding highlands [5]. Locally there is abundant evidence that the gravels that constitute the megaripples are a lag material that developed on the eroded bedrock ignimbrite surface. The strong association of the discrete megaripple bedforms with local topographic “highs” and pumice with the gravels suggests that organization of the gravels into bedforms was influenced by these two factors. The concentration of pumice on the lee side of the bedforms implies a symbiotic relationship between gravel bedform and pumice. We suggest that saltation of pumice (and sand) results in reptation of gravel through impact energy transfer. Undulose topography on the bedrock surface may set up local turbulence and Bernoulli effects that might promote accumulation of gravel on crests. Bedforms start to nucleate and stabilize on highs, setting up a feedback between the bedform, airflow, and lee-side accumulation of saltating pumice. Once the bedform stabilizes it produces a lee-side wind shadow zone that allows pumice to concentrate. As the bedform stabilizes, flow separation results in formation of vortices that deepen the troughs. This stabilized bedform is an equilibrium surface that is only modified if the bedforms are disrupted during rare extreme conditions. Thus we envisage an evolution of the surface from bedrock => yardangs => gravel sheets => gravel bedforms => stable megaripples that cap bedrock ridges.

Implications for Mars: The predominance of aeolian (wind-driven) activity as a surface-modifying agent on Mars has been recognized throughout the history of telescopic, satellite, and robotic investigation of the planet. The most obvious expressions of aeolian processes are manifested in dunes, yardangs (aerodynamic ridges in bedrock) [6,7], sand ripples [8,9], and Transverse Aeolian Ridges (TARs) [10].

Granule ripples on Earth have been suggested as potential analogs for ripple-like TARs on Mars [11]. Moreover, dark dunes on Mars have been hypothesized as volcaniclastic sediments [12], including those of the western Medusae Fossae Formation (MFF) [e.g., 4]. Thus, comparison between TARs and western MFF on Mars and terrestrial volcaniclastic bedform-forming sediments allows us to offer insight into aeolian processes on Mars and the origin of TARs.

Beyond helping understand the bimodal granule ripples imaged by rovers at Meridiani [13], our observations in the Puna may help reconcile current models of TARs with the recognition that some periodic bedrock ridges (PBR) may be produced by erosion [14]. The flow separation model presented for PBRs is not unlike that which we envisage for the Puna megaripples.

Moreover, if the Martian dark gravel/sand is locally derived, as we suggest for dark megaripples in the CPP of the Puna, this derivation would obviate the need for large scale atmospheric transport of dark sediment [4,5]. It may be that much dark sand elsewhere on Mars, prior to transport to its present location, could have been derived from ancient volcanoclastic mantles that have subsequently been stripped away.

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