LITHOLOGY AND YARDANG SIZE IN THE PUNA AND MEDUSAE FOSSAE FORMATION: DOES DENSITY MAKE THE DIFFERENCE?
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Introduction: Yardangs are streamlined landforms that erode from consolidated materials exposed to eolian abrasion and near-unimodal wind regimes in desert regions on Earth, Mars [1], Titan [2], and Venus [3]. The hydrodynamic and erosional processes contributing to yardang formation are complex and the subject of ongoing research. [4-6] Therefore, the methods and conclusions of a given yardang study may only be applicable to an individual system.

Anderson (1986) [7] described four inputs factoring into eolian abrasion: kinetic energy of windblown sediment, surface interactions, frequency of wind events, and material properties of substrates. Other studies [5,6] have made progress on the first three factors, but material properties are often rolled into a single parameter fitted to derive their influence empirically. This is problematic for understanding the role of material properties in extraterrestrial yardangs where the variability of geological materials is usually not observed *in situ*. Since the magnitude of erosion depends on material properties [7,9], our work seeks to model their influence so that we can derive analytical solutions for planetary yardang sizes such as the martian Medusae Fossae Formation (MFF). Here yardangs can be hundreds of meters in size while having very low density for its proposed ignimbrite lithology [8] unlike the largest, densest terrestrial yardangs [9].

For a terrestrial analog to the MFF, examined the Campo de Piedra Pomez (CPP) in the Puna region of Argentina (Fig. 1), where the unwelded ignimbrite has a density close to the MFF and the yardangs are meters to tens of meters in scale [9]. During field work to the Puna in December 2019, we collected drone imagery and ignimbrite samples, including along a leeward-to-windward transect. We collected 11 samples and images to construct a 10 km^2, 2.5 cm resolution Digital Terrain Model (DTM) from which we extracted yardang features. We also extracted yardangs from a 1 m resolution HiRISE DTM of the MFF [10] using identical methods.

Yardang Characterization: In addition to measuring density, porosity, and compressive strength in CPP rocks, we have developed a semi-automated method to extract yardang features (Fig. 2) and measure length, width, height, and spacing to compare to the normative yardang morphologies from the literature [6].
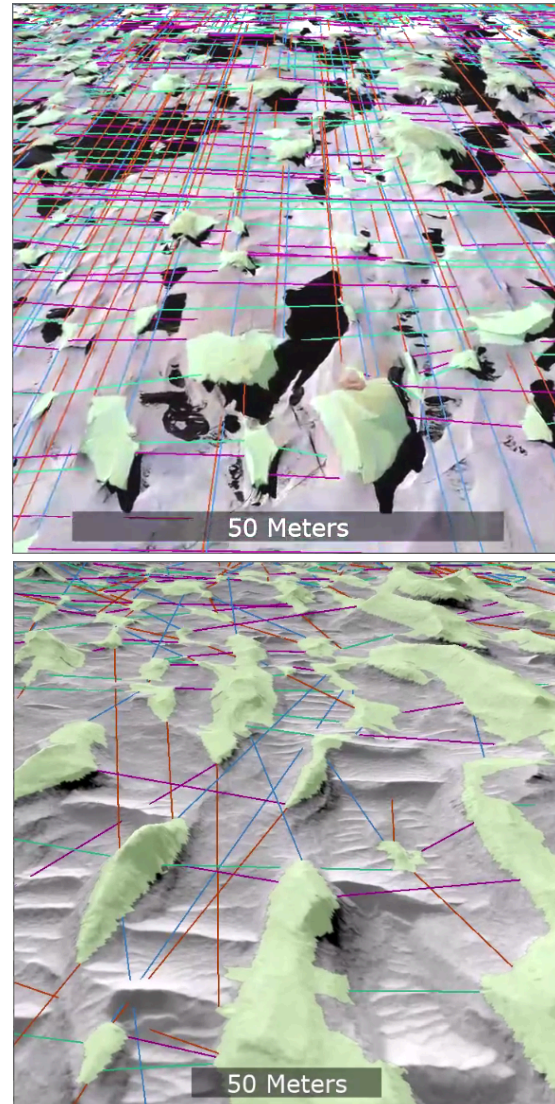

Fig. 1. Yardang outlines and measurements in the Campo de Piedra Pomez (CPP), Argentina (top) and the Medusae Fossae Formation (MFF), Mars
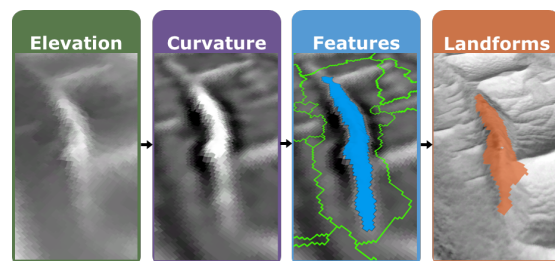

Fig. 2. Demonstration of the yardang extraction method for an MFF yardang in a HiRISE DTM

The yardang extraction method (Fig. 2) uses a generalized definition of yardang boundaries adapted from [6] that accepts DTMs as input. Since all yardangs are positive-relief features bounded by steep sides, we define the yardang outline as an elevation contour approximating the zone where curvature inflects from negative (concave) values near the base to positive (convex) values on the yardang. Yardangs are also bounded by topographic saddles where they interact with each other or surrounding topography. After extracting features with their width, height, and length, automatic spacing measurements are made parallel and orthogonal to yardang orientations or wind directions, depending on which is more consistent (Fig. 1). ArcGIS toolboxes and Python scripts for the algorithm are in a GitHub repo, "YardangTools" [11].

To investigate the possibility of an analytical solution to explain the relationship between yardang size and substrate properties, we take the strongest linear relationships between yardang morphometry and material properties (Fig. 3) and suggest how they can be integrated in future analytical and numerical models.

Results: Using 1269 yardangs in the MFF and 4102 in the CPP, we tested the normative dimensions described by [6]. Our results agree that the ratio of width/spacing has a mean near 1 (Fig. 4) but found length/width to be ~2-3 rather than 5-10. Further, heights ≠ √widths, but instead heights were scaled by a factor of ~0.25 (Fig. 5). These values diverge from [6] and require further comparison between models.

Yardang orientations in the MFF have greater variability due to a small number of very large (km-scale) yardangs around which small yardangs are reoriented by local wind directions. This autogenic effect deviates from the notion that yardang directions are always aligned with the regional wind.

By correlating material properties with dimensions for individual yardangs in the CPP (Fig. 3), we find that the largest yardangs are both strong and low density. [7] shows analytically that abrasion scales with the ratio of strength/density, but this is not represented in numerical models of yardangs. Density would also play an important role in the [5] model, where dense substrates would drive mass wasting and inhibit removal of denuded material from interyardangs. Future models should include these parameters under Mars conditions.

References: [1] Kerber [2] Greeley (1999) Technical Report, ASU. [3] Paillou et al. (2016) *Icarus 270*. [4] Rabinovitch, LPSC 50 (2019), #2250 [5] Barchyn and Hugenholtz (2015) *GRL 42*, 14 [6] Pelletier et al. (2018) *JGR:ES 123*, 4 [7] Anderson
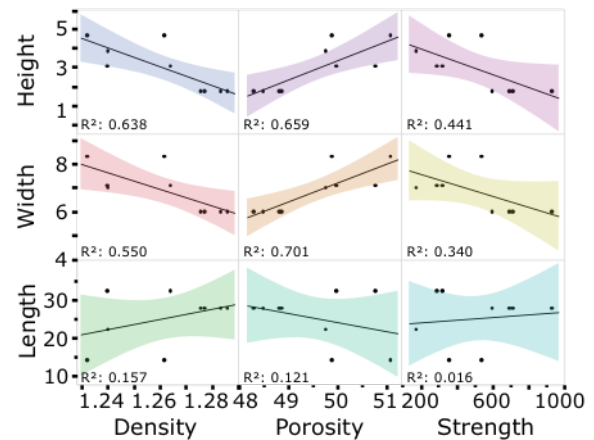

Fig. 3. Correlations of dimensions and material properties for individual yardangs in the CPP
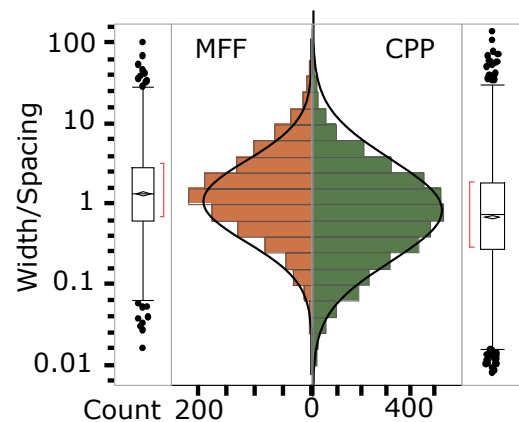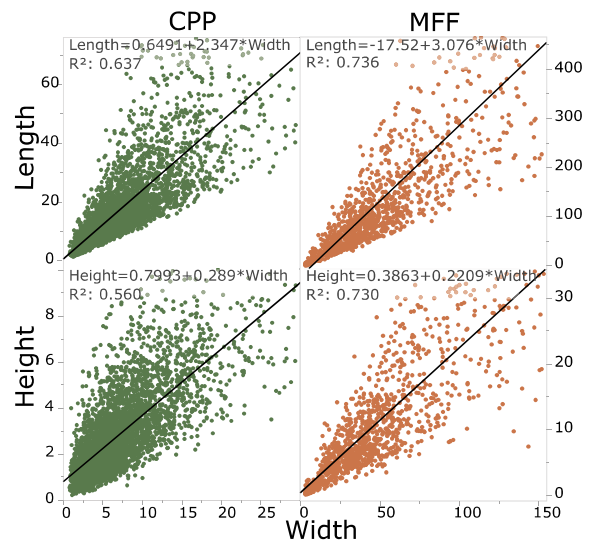

Fig. 4. Yardang width:spacing in the CPP and MFF

Fig. 5. Yardang width vs. length and height in the CPP and MFF. Note differences in scales.

(1986) *GSA Bull. 97*, 10 [8] Ojha and Lewis (2018) *JGRP 123*, 6 [9] de Silva et al. (2010) *PSS 58*, 4 [10] https://www.uahirise.org/dtm/dtm.php?ID=PSP_009175_1810 [11] http://github.com/dmcdoug/YardangTools