YARDANG SHAPES REVEAL SUBSTRATE LITHOLOGY AND MATERIAL PROPERTIES IN THE ARGENTINIAN PUNA.

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Introduction: Yardangs are eolian erosional landforms with regular spacing and long, streamlined profiles [1, 2] (Fig. 1). While found primarily in deserts on Earth, they are also prominent on Mars and other planetary bodies [1, 2]. Yardang dimensions are thought to vary with the intensity, direction, and sediment load of the wind [1], and initial work into the effects of substrate properties on yardang shape reveals that larger yardangs form in more indurated materials [2]. However, detailed relationships between yardang shape, wind, and substrate properties have not been established. This study seeks to quantify these associations.

Field Area: The 70 ka Campo de Piedra Pomez (CPP) ignimbrite in the hyperarid Puna region of Argentina (Fig. 2) hosts spectacular yardangs, making it an ideal analog to yardangs in the martian Medusae Fossae Formation [1-3]. The small size of the CPP "mesoyardangs" (1-20 m long and up to 10 m tall) contrasts greatly with the larger "megayardangs" (tens of meters tall and hundreds of meters long) in other ignimbrites found throughout the region (Fig. 1).

During December 2018 and 2019, we visited several localities in the CPP to assess material properties (Fig. 2). The CPP ignimbrite includes at least three facies of sintered, unwelded pyroclastic flow deposits with gently sloping surfaces (<7°) that are eroding to form mesoyardangs. The nearby Rosada and Cerro Galan ignimbrites host megayardangs with larger dimensions thought to result from their welded lithologies [2-4]. Field observations of the materials are described below.

White Yardangs (cppi/w, lcpw): The largest area of the CPP ignimbrite is a zone of porous white material. Any slight welding textures have been destroyed by the replacement of ash shards with vapor-phase deposited crystals (devitrification), made evident in the field by pumice clasts eroded into negative relief against the matrix. In contrast, lithic clasts in this zone are more resistant than the matrix such that they protrude in finger-like "dedos" pointing into the dominant wind direction for that point on the yardang [5,6].

Orange Yardangs (cpp*o, lcpo): The white zone is mantled in many areas by orange material corresponding to a thin, low temperature zone on the margins of the pyroclastic flow [7]. Although slight compression and sintering of ash shards is noted in thin section, the lack of devitrification is evident in the field where the still glassy pumice clasts are intact and resistant.

Tan Yardangs (tan): Yardangs also occur in an adjacent valley where the CPP ignimbrite occurs as a tan-

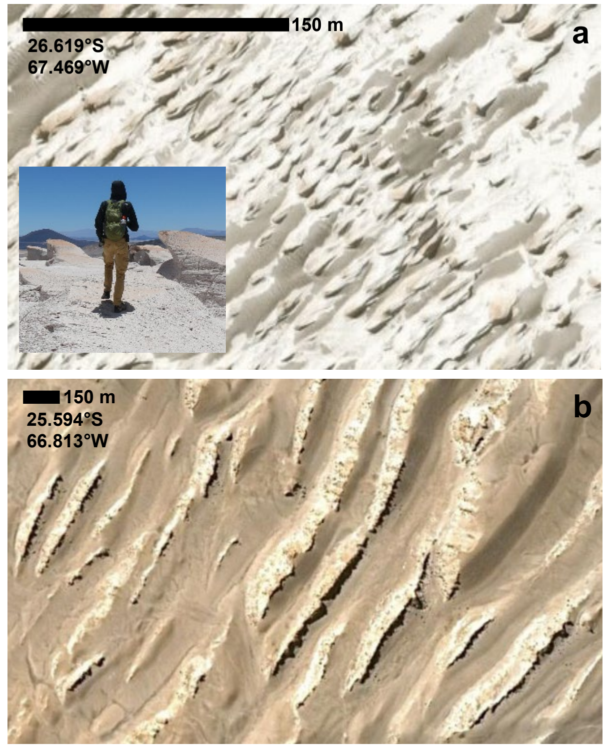

Fig. 1. (a) Mesoyardangs in the Campo de Piedra Pomez and (b) megayardangs in the Cerro Galan Ignimbrite. North to the right. Sources: Google Earth

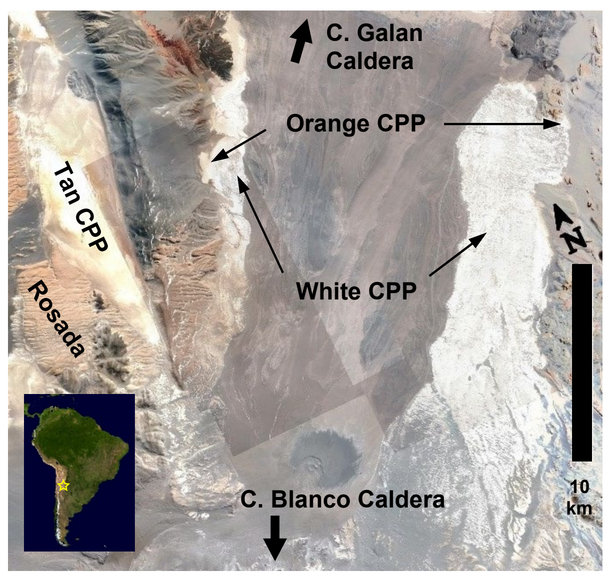

Fig. 2. Map of yardang-bearing ignimbrites in the southern Puna. Cerro Galan and Cerro Blanco are outside the map area in the directions indicated by thick arrows. Sources: Google Earth, Wikimedia

colored facies. Here, the pumice clasts form dedos due to being more resistant than the ash matrix, in contrast to the opposite condition in the white yardangs.

Rosada Yardangs (rosada): The 6.3 Ma Rosada ignimbrite [3] is the most indurated yardang-forming material we studied. Intense welding is evidenced by flat pumice fiamme and alignment of phyllosilicates, indicating high depositional temperatures.

Cerro Galan Yardangs (galan): 100 km north of the CPP, the large volume and low porosity of the 2.2 Ma Cerro Galan ignimbrite contrasts greatly with that of the CPP ignimbrite and the degree of induration approaches that of the Rosada. The Cerro Galan ignimbrite contains abundant phenocrysts and shards but no fiamme [4].

Yardang Morphology vs Hardness: Initial evaluation of yardang morphology was conducted using the approximately 30 cm resolution color imagery in ArcGIS Pro. Yardangs shapes were outlined to compute their length, width, and aspect ratios (length:width). In each locality, yardangs with a median aspect ratio were targeted for in-situ measurements. The compressive strength (a proxy for erosion resistance [8]) of yardang materials was measured using a Proceq Silverschmidt rebound hammer. The measured results varied greatly, from 14 MPa for the tan yardangs to 56 MPa for the Rosada ignimbrite. Yardangs in the white and orange ignimbrite zones had values from 25-30 MPa while the Cerro Galan ignimbrite was 39 MPa. When plotted against the median aspect ratio of yardangs in each area, a rough positive correlation is evident (Fig. 3).

The aspect ratio also correlates with other yardang material properties. The CPP ignimbrite has been previously characterized as having 50% porosity and a density of 1.25 g/cm^3 while welded ignimbrites have lower porosity and higher densities, such as 15% and 2.19 g/cm^3 for the Rosada [9]. Hence, higher porosity and lower density are associated with lower strengths and shorter aspect ratios.

Discussion: Even with the limited number of characterized areas, the trend in Fig. 3 is useful for placing each yardang area on a continuum. High median aspect ratios could be related to unusual stratigraphy in the tan yardangs and possibly to fluvial activity in the Galan yardangs.

Several factors besides substrate properties affect yardang morphology. High aspect ratio yardangs positioned on the upwind margin of the field are likely protected from minor winds by yardangs in the interior of the field, which have lower aspect ratios due to erosion from multiple wind directions [9]. The configuration of strata within a yardang is also seen to have an effect on yardang morphology. Some large yardangs (e.g. in the tan area) are underlain by a soft, thick layer of large pumice clasts which is preferentially eroded by the saltation load in winds from the downslope direction but protected by harder surfaces facing winds from upslope directions. Also, fine ash beds can have variable effects on a yardang vertical profile, depending on the bed's induration and position relative to the saltation load.

These findings can be used to infer the properties of extraterrestrial yardangs with similar morphologies after applying scaling laws for differences in eolian abrasive forces. Yardangs in volcanic tuffs of the Medusae Fossae Formation on Mars have been proposed as human landing sites due to their potential for in-situ resource utilization as habitations and building materials [11]. This work helps with targeting specific yardang areas for these purposes.

Conclusions: Yardang morphology is affected by the hardness and lithology of a substrate according to its abrasion resistance, among other factors. This establishes a firm basis for further studies of yardang morphologies and substrate properties.

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References: [1] Greeley R. (1999) Technical Report, ASU. [2] de Silva S. et al. (2010) *PSS* 58, 459-471. [3] Báez, W., et al. (2015) *Revista Mexicana de Ciencias Geológicas* 32.1 29-49. [4] Francis P., et al. (1983) *Nature* [5] Breed C., et al. (1989) *Arid Zone Geomorph.* 284-307 [6] Rabinovitch J., et al. (2019) *LPSC 50* #2250 [7] Smith. R. (1960) USGS PP #354-F [8] Witte L., and Backstrom, J. (1951) *Proc. Am. Soc. for Testing and Materials* [9] Ahern, A., et al. (2019) *9th Int. Conf. on Mars* #6337 [10] Kerber, L., et al., this meeting [11] Kerber, L., et al. (2015) LS/EZ W. #1043

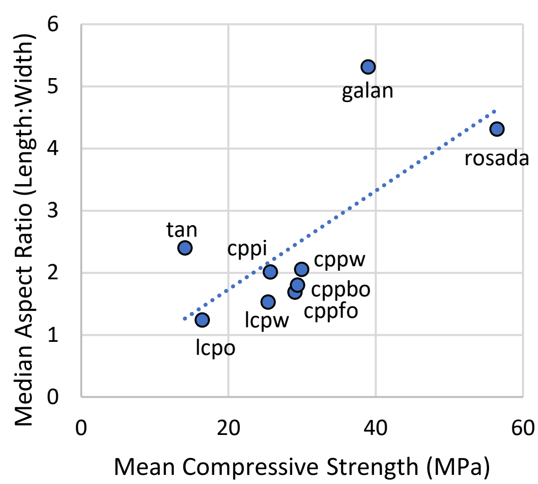

Fig. 3. Aspect ratio plotted against compressive strength for various yardang areas. Linear trendline is dotted in blue. See text for data label descriptions.