CRACKING THE YARDANG CLASSIFICATION CODE: UNVEILING HOW IMAGE RESOLUTION DIFFERENCES IN THE PUNA, ARGENTINA CAN REVEAL ASPECTS OF YARDangs ON MARS AND TITAN.


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Introduction: The Puna Plateau, located in the Central Andes Mountains of Argentina, is known for its arid environment, fast wind speeds and high elevation. Within the volcanic ash deposits of the Puna are several fields of yardangs, erosional landforms of varying sizes created by aeolian processes of deflation and abrasion [1, 2, 3]. Yardangs are highly parallel and have a regular width and spacing across the field, revealing regional communication of wind speed and direction [4, 5]. Yet many questions remain about yardangs, including the details of the stages of progression from incipient to mature [6]. Yardangs are found on Mars [7, 8], Saturn’s moon Titan [9], and potentially other planetary bodies, and field studies on Earth could reveal more about how they form extraterrestrially [10]. Careful examination of their shapes, sizes, and relationship to other surrounding materials, such as gravel ripples common among yardangs, may answer some of these questions about their formation.

Data: The features under study are the mesoyardangs in the Campo de Piedra Pomez, each several meters in size. We examined drone and satellite imagery to identify features and establish a classification scheme. These data sets were all in visible wavelengths and of different resolutions (Fig. 1). Drone images were obtained during field studies in the Puna in 2019, across a 5 km, 2.5 km$^2$, swath spanning from the front to the back of the field (Fig. 2). 8 separate image passes were done using a Mavic2 Pro and Mavic 2 drone, out of which orthomosaics, at 3 cm resolution, and digital elevation models (DEM$s$) were created [11]. The orthomosaics and DEM$s$ were classified based on the individual pixel values according to color or elevation using ArcGIS Pro software. This process identified landscapes classified as yardangs, gravel, and bedrock for the orthomosaics, and yardangs vs other surrounding material for the DEM$s$ (Fig. 2).

Figure 2, A: 3 cm resolution drone imagery. B: Classification results of the drone imagery. Blue indicates yardang tops, white is bedrock, and grey is gravels.
We also obtained 25 km$^2$ of 15 cm resolution satellite imagery (Fig. 3). We used this imagery to do similar classification on the surface to the drone region to see if similar results could be obtained. We also computed further classifications outside the area covered by our drone imagery to see how the results of drone vs. satellite imagery compare.

**Results:** Our classification model successfully identified yardang tops (being distinctly orange from weathering) white substrate and grey intervening gravels as three separate units. Because of the stark contrast between the desert varnish (orange tops) on the yardangs, dark gravels and light color substrate the classification was successful. We compared these results to a small study area where each unit was traced by hand to obtain an accuracy of about 82%. The accuracy of the satellite imagery has not been calculated yet but some initial observations show that the imagery might pick out the gravels and bedrock better than the yardangs. This could be due to the lower resolution and overall brighter image making it harder to pick out the weathered yardang tops. It also might help to simplify the shapes of the units as the satellite imagery does not have a high enough resolution to see small pockets of gravels or the cracks throughout the bedrock.

Concerns remain that the classification mainly identifies altered yardang tops and may miss some lower portions of the yardangs, which are in the active salination zone and are scoured white like the substrate.

We also performed image ratioing to compare the results of the three units and their areas. For each segment of our drone imagery we compared the areas of yardangs, bedrock and gravel to the overall area to calculate the percentage that each unit occupied within the image segment. Our analysis shows a consistent pattern of increasing yardang and bedrock area and decreasing gravel area from southeast (downwind) to northwest (upwind) (Fig. 4).

**Discussion:** The patterns revealed in our study suggest landscapes in yardang regions may be controlled by their positions upwind or downwind relative to the dominant wind direction. Furthermore, each of the regions may represent yardangs in a different stage of formation, with the earliest stage in the northwest and latest in the southeast. This is consistent with a model in which bare bedrock first forms ridges, followed by deepening into yardangs, all perhaps aided by gravel movement across the field. This spatial organization suggests a dynamic interplay between wind-driven processes and the evolving stages of yardang development.

**Conclusion:** The findings from our field studies on the mesoyardangs of the Campo de Piedra Pomez in the Puna Plateau offer valuable insights into the formation and evolution of yardangs in arid environments. Our study, utilizing drone imagery and satellite data, aimed to shed light on the details of yardang progression and their spatial distribution, has potential implications for understanding similar landforms on other planetary bodies.

The integration of satellite imagery into our analysis allowed for a broader perspective, extending beyond the area covered by drone imagery. The comparison of classification results between the two datasets can reinforce the reliability of our findings and provide additional context for interpreting the yardang landscape.

**Future Work:** Further work includes obtaining an additional 100 km$^2$ of 15 cm satellite imagery, acquiring new 3 cm drone imagery from field work in Argentina and classifying these images to see what further mysteries this yardang field has yet to unearth.

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