HIGH RESOLUTION LASER SCANNNING TECHNIQUES FOR ROCK ABRASION AND TEXTURE ANALYSES ON MARS AND EARTH

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Introduction: Aeolian abrasion is operative in many arid locations on Earth and is probably the dominant rock erosion process in the current Martian environment. Therefore, understanding the controlling parameters and rates of aeolian abrasion provides 1) insight into the stability of rocks on planetary surfaces and the environments under which the rocks abrade, and 2) a link between ventifact (a rock abraded by windblown particles) morphology and: a) abrasion conditions, b) possible ancient environments under which the rocks were abraded, and c) rock properties.

Research on ventifacts includes terrestrial field studies [1-8] and analyses of Martian lander images [8-10]. Rock abrasion susceptibility has been quantified from laboratory investigations [11-12]. Recent wind tunnel experiments to produce analog ventifacts, combined with theoretical and field comparisons, have been ongoing under present NASA funding [8,13].

Because the abrasion susceptibility of natural rocks is so low, monitoring any shape or roughness changes under controlled wind tunnel conditions is difficult or impossible on reasonable time scales. This has necessitated the use of analog materials, such as those in the current PG&G study [13]. However, it is difficult to quantitatively assess the change in shape and roughness. Because of the limitations of current measurement techniques, harder, and therefore more rock-like, analog materials have been avoided.

Abrasion of natural ventifacts occurs at rates of ~30-500 µm yr^{-1} based on mass loss measurements [3,5], but any shape changes over the period of a standard investigation (a few years) cannot be measured using standard measuring schemes. It takes several years [5] or even a couple of decades [3] of integrated abrasion to produce mass losses of sufficient magnitude to allow extrapolation of annual abrasion rates. Finally, the lack of quantitative data on the shapes and roughnesses of ventifacts prevents more than a qualitative, visual identification of them in images, the sole morphological data set for Mars rocks.

To make progress on these present limitations, we are incorporating a laser scanning and shape analysis technique that can determine changes caused by abrasion at the sub-mm scale. The results are very promising and we plan further investigations in the wind tunnel and field. Our intent here is to discuss the basic technique, initial results, and upcoming plans.

Methods: The accurate modeling of three-dimensional (3D) structures is essential to many scientific endeavors, especially those that exhibit shape changes with time, such as abrasion studies. A fruitful method for recording 3-D shapes is laser scanning [14]. The laser scanned 3D data consist of points (x_i, y_i, z_i;, i = 1, …, n) known to lie on or near a surface of interest. The 3D surface data points are less than 300 microns apart, providing the capability of distinguishing among small, subtle differences regardless of lighting or orientation during the original scan, as well as preserving the shape file for any future analysis. The resulting data are representative of the surface being scanned. Using analytical algorithms, it is possible to convert the ~200,000 3-D points into surfaces whose characteristics can be used to mathematically compare with other surfaces and 3-D objects. Segment slope and slope direction, curvature fits over several segments, and other mathematical treatments can be applied to the data.

Results: To verify the applicability and utility of the laser scanning technique, we analyzed abrasion simulants in the MARSWIT wind tunnel as well as natural rocks using a PRISM LDI model 200 (a.k.a. PS3300) 6.7 mW laser scanner. Initial results show that abrasion of analog targets can be monitored very precisely (Figure 1). Changes in front slope angle and volume of less than 0.1° and 1% are apparent. Roughness changes seen visually seem to correlate to roughness variations measured by taking the area of segments divided by the area of a plane fit to those segments. The roughness of front faces increases with time, as expected for a surface being sandblasted. The decrease in roughness of the top face may be caused by initial smoothing by sand impacting at nearly flat trajectory angles. Three-dimensional images of the targets show fine details not easily seen in images or with the naked eye (Figure 2).

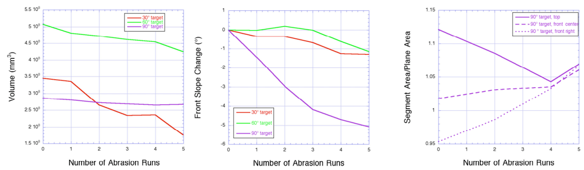

Figure 1: Results from the initial scanning of ventifact analog targets abraded in MARSWIT.

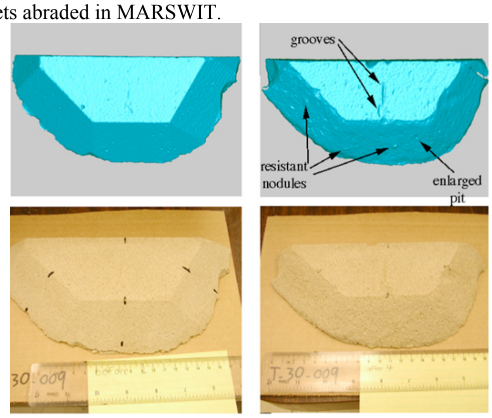

Figure 2: Textures seen in 3-D models produced from laser scanned targets that are not easily discernable visually.

Images of natural rocks are also promising (Figure 3). Comparing a rock with solution pits and a ventifact shows significant textural differences, with the former having fairly shallow pits and a lack of fluting whereas the ventifact exhibits fine-scale flutes and deeper, rounded pits. The fact that the laser scanned images looks so much like the actual rocks gives confidence that mathematical representations of shape and textural features relevant to geology are possible.

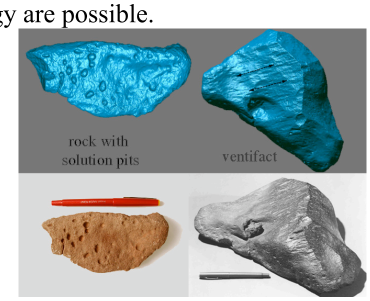

Figure 3: Rock with solution pits (left) and a ventifact (right) reproduced from a laser-scanned 3-D shape file (top) and seen in photographs (bottom). The arrows on the ventifact scanned image show rilling produced by wind abrasion.

Discussion/Upcoming Investigations: *Laboratory Studies* Wind tunnel tests will use abradable targets under terrestrial and Martian conditions as described in [13]. As a substantial improvement over the current investigation, all samples will be laser scanned prior to and after each abrasion run, with the intent of measuring volume, shape, and texture changes to a high accuracy and precision (linear dimensions up to 100 μm). We will assess roughness elements (pits, flutes, grooves, etc.) using mathematical algorithms previously employed by PRISM for other studies. Individual pits can be located by searching for segments that are depressed below the mean surface, after which their sizes and shapes can be mathematically determined. Dimensional changes will be easily determined by mathematically determining the distance between fitted plane boundaries.

Field Studies: We will utilize an established Mojave Desert field site that has been utilized previously [13,15]. We will use this site to quantitatively measure roughness and shape changes of our abrasion targets via the methods just described. Natural ventifacts will be studied at the field site. We will use the laser scanner to quantitatively measure the shapes, dimensions, and roughnesses of fossil and actively-forming ventifacts, thereby providing a comparison to the analog experiments. It is envisioned that 20-30 samples will be measured with the laser scanner. Potentially more exciting is using the laser scanning system to measure changes in the shapes, textures, and abrasion rates of the ventifacts over the two field seasons. Because the laser scanning technique has the ability to measure changes on the 100 μm scale (or possibly finer using certain techniques), we propose to study natural ventifacts at the field site and see if any observable changes occur over two years.

Integrating Results: We will use our experimental and field results to better understand the rock abrasion and ventifact formation process on Earth and Mars. We will determine relative abrasion rates as a function of microscale roughness, shape, and target properties at both terrestrial and Martian conditions. From this, we will model how the abrasion of natural rocks proceeds with time. If we are able to measure abrasion rates of natural ventifacts, we will be able to extrapolate such results to our experiments and conditions on Mars.

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