QUANTIFYING ABRASION MATURITY USING HIGH RESOLUTION LASER SCANNING: PRELIMINARY QUANTITATIVE RESULTS AND APPLICATIONS TO TERRESTRIAL AND MARTIAN STUDIES

N.T. Bridges[1], R. Kushunapally[2], A. Razdan[2], A. Stone[3], J. Laity[4], R. Greeley[5], D. Addleman[6] ; [1]Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109 (nathan.bridges@jpl.nasa.gov); [2]PRISM, Arizona State University, Tempe, AZ 85287; [3]Hartwick College, Oneonta, NY 13820 ASU; [4]Department of Geography, California State University, Northridge; [5]Department of Geological Sciences, Arizona State University, Tempe, AZ 85287-1404; [6]Cyberware, Inc., Monterey, CA 93940.

Introduction

Whereas planetary topography has been measured using air- and space-borne laser altimeters, the ability to quantify surfaces at a finer scale, over large surface areas, has only recently been accomplished. Laser scanners measure surfaces down to 100s of microns [1], offering promise to geologic and planetary problems that require quantitative textural information at these scales. In this abstract we report on advances in using algorithms to digest these data that have improved our understanding of rock abrasion processes. We show that abraded analog targets undergo an evolution in textural form that can be quantified using simple parameters. These results can be extended to constrain the abrasion maturity of ventifacts on Earth and Mars.

Background On Laser Scanning

Three-dimensional laser scanners measure a physical surface by making a dense array of non-contact range measurements. The instruments are manipulated much like conventional photographic cameras in that they view the subject surface from a distance of several centimeters to meters. Laser triangulation devices, as used here, incorporate a visible to near-infrared laser diode to generate a static plane of light which illuminates a single profile of the subject surface. The laser beam is spread into a plane of light in the *y-z* axis, producing a light profile at the subject surface along the range (*z*) axis. The third axis, sampling pitch (*x*) is obtained by physical movement of the scanner. A digital imaging camera, called the range image sensor, is located a short distance away from and at a small angle to the side of the laser along a fixed baseline. The angle between the laser light plane and the camera-viewing axis varies between 15 and 30 degrees and is a compromise between resolution and the ability to see into crevices. The camera, properly focused, views the object and laser profile, with a line filter used to maximize the sensitivity near the laser wavelength and reduce the contribution of ambient light. When a significant response from the profile is detected by the CCD or CMOS array in the camera, the profile shape is recorded, along with the position data.

Image processing and geometric computations convert the image of the profile into 2D object-space coordinates. Because both the laser light source and the range image sensor are panned, as a unit, across the subject surface in a direction normal to the laser plane, a series of adjacent 2D profiles are transformed into 3D points, or vertices, that model the surface.

Methods

Scanned Objects: Two types of objects were scanned using a LDI laser scanner for this work: plaster analog ventifacts and abraded rocks at desert sites in the Mojave Desert, California. The analog targets were abraded in the Arizona State University wind tunnel at 30 m/s freestream wind speed with 30 mesh quartz sand at ~STP. They consisted of 3 types: 1) homogeneous targets that were isotropic, 2) heterogeneous targets with harder plaster nodule inclusions, and 3) targets with alternating hard and soft plaster layers. These targets different than the sandstone simulants used in previous work [2,3], but have the same dimensions, with each front and side face 40 cm^2 and the top 92 cm^2. Abrasion of the heterogeneous model, front and side faces angled 45°, showed pitting and fluting, similar to that seen in the field (Figure 1).

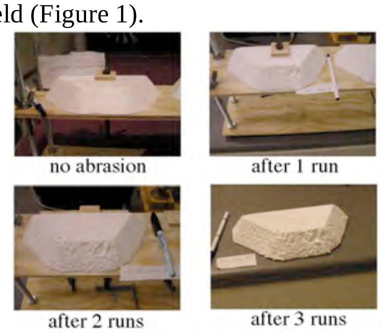


Figure 1: Heterogeneous plaster targets at different states of abrasion.

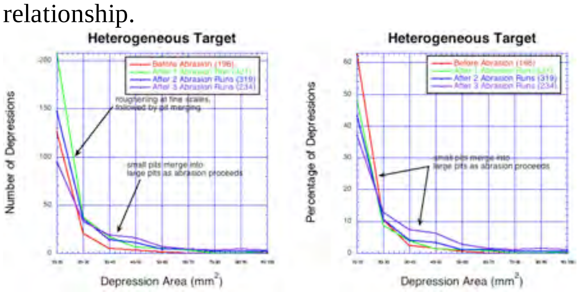
Rocks of several lithologies were scanned in the field: limestone-marbles in the Little Cowhole Mountains (9 rocks; visited 4/04, 11/04, and 5/05), basalts in the Cady Mountains (5 rocks; visited 11/04), and basalts and diorites in hills just east of Silver Lake (5 rocks; visited 5/05). Rocks in the Little Cowholes were scanned on two or all three visits with the intent of monitoring abrasion textural changes over times.

Data Reduction: The raw scanned data, consisting of a 3D point cloud with point-to-point spacings of 100s of μm, were converted to triangle meshes using Raindrop Geomagic software, with each vertex corresponding to an *x-y-z* point. Because, for this study, we are interested in specific features of the abraded rocks, mathematical algorithms were written to automatically extract features of interest and their morphometric parameters. These include pits (depressions), flutes, and grooves and their respective axes, dimensions, areas, volumes, and orientations in 3D space.

The most advanced aspect of our work, reported here, is the quantification of surface depressions (seen to the human eye as pits). It was not possible, with present algorithms, to precisely track each depression from one scan to the next, as the point cloud position relative to the true surface varies for each scan. This paper examines the development of pitting on simulants in heterogeneous plaster models. Other features developed on the models, as well as on rocks in the field, will be discussed at a future date. The abundance of depressions as a function of size, surface area, and volume can be examined on a statistical basis.

Results

The results for the surface area of depressions in heterogeneous targets are shown in Figure 2. Plots are rendered with depression area on the *x*-axis with either number or percentage of depressions within a given size range relative to the total number on the *y*-axis. The number of depressions for the four abrasion stages (before abrasion, after 1 run, after 2 runs, and after 3 runs) was 196, 421, 319, and 234, respectively (Figure 2, left). For depressions 10-20 mm^2 in surface area, there is a clear increase in number after the 1st abrasion run, followed by a decrease after the 2nd and a further reduction after the 3rd. In contrast, at larger scales, the fewest number of depressions occur before abrasion and the most after the 3rd abrasion run. By plotting area to percentage, a relative comparison among depression sizes for a given abrasion stage can be made (Figure 2, right). This plot shows that there is a systematic decrease in the percentage of 10-20 mm^2 depressions as abrasion proceeds. At 20-30 mm^2 there is a cross over of the curves, with larger sizes showing the reverse relationship.



Number of depressions (left) and percentage of depression (right) vs. surface area for heterogeneous target. Values in parentheses are the total number of depressions computed over the whole surface.

Interpretations

These preliminary results have application to understanding abrasion on planetary surfaces for rocks with hardness heterogeneities distributed point-to-point (as opposed to layered hardness heterogeneities) at scales greater than the abrading particles. This includes phaneritic igneous rocks, sandstones, and rocks with primary textures, such as vesicles, where enhanced abrasion probably occurs. In our experiments, pit (depression) abundance increases, then decreases while, simultaneously, the abundance of larger pits increases as smaller ones decrease. This is consistent with textural development that proceeds in stages. It begins with an initial roughening at small scales in which new pits, over and above those present initially, are formed. This evolves into a process in which pits enlarge by either expanding their own dimensions or merging with other pits. In both cases, the size distribution becomes biased to larger values, but the end member of the second case will be distinguished by a decrease in the total number of pits.

Applications and Future Work

This work shows that statistical analysis of surface texture, quantified using precise mathematical algorithms and laser scanning, can provide information on abrasion maturity. In the results shown here, an "immature" abrasion target exhibits a downward sloping curve (from left to right) in a plot of number or percentage of depressions vs. area. As the rock target becomes more abraded, the curve shallows. We are currently applying other algorithms to examine depression shape and direction of semi-major axis with the expectation that pits/flutes/grooves will become more elongated and better aligned in the direction of the wind as abrasion proceeds. We are also evaluating these parameters in the layered and homogeneous targets. The results will be compared to those from the Mojave rocks to see if the latter plot within parameter space predicted by the scanned wind tunnel targets

These results have application to ventifacts on Earth and Mars. By quantifying texture data, as done here, the abrasion maturity of rocks can potentially be assessed. We also expect that other types of rocks not affected by abrasion will have constrained sets of morphometric attributes that can quickly be measured using laser scanned data and proper mathematical algorithms. In the future, we think this will be an excellent tool for determining rock emplacement and modification history.

References

[1] Bridges, N.T., et al., *LPSC XXXV*, 1897, 2004. [2] Bridges, N.T., et al., *Planet. Space Sci.*, *52*, 199-213, 2004. [3] Bridges, N.T. et al., *J. Geophys. Res.*, *110*, E12004, doi:10.1029/2004JE002388, 2005