MARTIAN AND TERRESTRIAL ROCK ABRASION FROM WIND TUNNEL AND FIELD STUDIES

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Introduction:

Earth and Mars exhibit ventifacts, rocks that have been abraded by saltating sand [1-5]. Previous theoretical and laboratory studies have determined abrasion susceptibilities of rocks as a function of sand type and impact angle [6] and rock material strengths [7]. For the last two years we have been engaged in wind tunnel and field studies to better understand the fundamental factors which control and influence rock abrasion and ventifact formation on Earth and Mars. In particular, we are examining: 1) What types of rocks (composition, texture, and shape) preferentially erode and what are the relative rates of one type vs. another? 2) What are the controlling factors of the aeolian sand cloud (flux, particle speed, surface roughness, etc) which favor rock abrasion?, 3) How do specific ventifact characteristics tie into their mode of formation and rock properties?

We find several important factors: 1) Initial rock shape controls the rate of abrasion, with steeper faces abrading faster than shallower ones. The relationship is partly dependent on angle-dependent flux (proportional to sin[□]) but exhibits additional non-linear effects from momentum transfer efficiency and rebound effects that vary with incidence angle. 2) Irregular targets with pits or grooves abrade at greater rates than targets with smooth surfaces, with indentations generally enlarging with time. Surfaces become rougher with time. 3) Targets also abrade via slope retreat, which is roughly dependent on the slope of the front face. The formation of basal sills is common, as observed on terrestrial and Martian ventifacts [5].

Methods

Abrasion target casts were made from an ABS-type plastic or wood and produced using computer numerically controlled machining at Ames Research Center. Each ventifact model is oriented at a constant angle to the wind (as seen from the side; either 15, 30, 45, 60, or 90°), with three different incidence angles (angle relative to wind as seen from above) per model (0°, 45°, and 60°). Molds of the casts were then made out of a polymer at JPL. These molds serve as shapes to produce models of analog rock materials made of our soft sandstone stimulant. The simulant was made from a mixture either 150 µm or 550 µm mean sand in a matrix composed of sheet rock paste and water. The material is strong enough to resist breaking yet friable enough to lose mass and form ventifact-like features when subjected to impacting sand (Figure 1). We also cut angled facets of various foams to test other types of abrading materials. Some foams were found to abrade rapidly and were used to assess rates of abrasion as function of facet angle without regard to roughness factors present in the sandstone simulant targets.

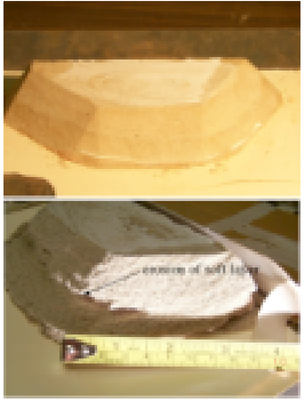

Figure 1: Sandstone simulant prior (left) and after (right) abrasion.

All experiments used the Mars Surface Wind Tunnel (MARSWIT) run by Arizona State University's Department of Geological Sciences and based at NASA's Ames Research Center, Moffett Field, CA. An open-circuit boundary-layer wind tunnel [8], it has dimensions of 13 m (length) x 1.2 m (width) x 0.9 m (height) and is contained within a 4000 m^3 pressure chamber. Instrumentation associated with the wind tunnel includes pressure and temperature sensors, wind velocity probes, piezoelectric sensors, humidity monitors, and photographic equipment. Both terrestrial and Martian pressures can be maintained. Low (Martian) atmospheric pressures down to 3.5 mb are achieved via a five-stage steam ejection plant. At Earth standard pressures (~ 1 bar), winds up to 11 m s^{-1} are achieved using a fan and motor system. Sand is fed through an adjustable, motorized hopper mounted on the top tunnel downwind. The hopper has a volume of ~ 0.03 m^3 and can hold about 1 standard bag of sand. The sand used had a mean size of ~550 µm (30 mesh or grit). Sand flux was controlled by the size of the opening at the bottom of the hopper and the speed of the motor and can be accurately adjusted in real time. Large fluxes of sand effectively produce a sand cloud similar to that found in nature.

Not including calibration runs, 123 experiments at Earth pressure have been conducted. Martian runs, which are much more difficult to do, are ongoing. During each experiment the mass loss, sand flux, and morphological changes of the target as a function of the first two parameters are noted. In most cases, targets were abraded in three runs, with the weight and dimensions recorded before and after each one. Wooden block targets were also used to assess sand impact physics analyzed from high speed video.

As a ground truth calibration, we also placed 15 sandstone and foam targets of various shapes at a ventifact site in the Mojave Desert from May 17 to November 3, 2002. The targets were weighed and their dimensions measured before and after placement. A weather station at the site controlled

Results

1. Morphological Changes

Abrasion of sandstone simulant targets in the wind tunnel exhibited several interesting aspects that are directly relevant to understanding rock abrasion. Without exception, the targets became rougher as abrasion progressed, commonly forming incipient flutes which enlarged with time (Fig. 2). Prefabricated flutes enlarged with time.

Many samples formed basal sills. Although commonly interpreted in natural ventifacts to form when burial of soil protects a rock face from abrasion, our experiments also indicate that a lesser degree of abrasion, probably from lower fluxes and kinetic energies of particles near the surface, also comes into play [5]

Figure 2: Example of morphological changes observed for 3 runs of sandstone simulant target under Earth pressure. Pitting becomes more pronounced with time. An incipient sill is seen after final abrasion run.

2. Mass Loss and Slope Retreat

Mass loss and changes of all target faces were measured before and after each experiment. As seen in Figure 4, mass loss is proportional to facet angle, with higher angled surfaces exhibiting both a greater amount of abrasion per amount of sand and a steeper rate (slope) of abrasion. In the limited number of cases where pre-pitted samples were used, they showed the greatest degree of abrasion. The trends are similar, although not quite as regular, when retreat of the front slope is plotted.

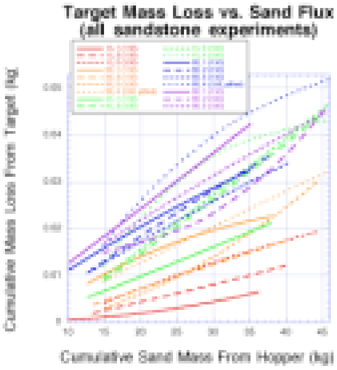

Figure 3: Target mass loss vs. sand mass used (proportional to time). Numbers (150 or 550) refer to the size of sand, in µm, making up the matrix of the sandstone target. "Pitted" indicates that prefabricated pits were carved into the targets.

3. Field Analog Studies

The plot of targets in the Mojave yielded mixed results. On the one hand, the mobility of sand was aptly demonstrated by burying many of the targets. The wind also blew some off of their mounts. Those that survived the summer exhibited significant mass loss, slope retreat, and basal sill formation, similar to the wind tunnel experiments (Figure 4).

Figure 4: Before and after pictures of sandstone simulant target of same composition as targets used in wind tunnel experiments. Sill formation seen on this example. New pits were found in other targets. Target lost 60% of its mass during its 6 months of exposure.

4. Impact Physics and Rebound Effects

We have used high speed video (5000 frames per second) to record the impact of sand particles hitting faceted faces. Analysis of the videos shows that sand hitting targets with faces oriented ≥45° to the wind rebound and re-collide with the targets one or more times (Figure 5). These rebound effects, combined with the efficiency of momentum transfer, may contribute to deviations from what would be expected if abrasion were solely due to the effect of incident sand flux on angled facets, as seen in Figure 3.

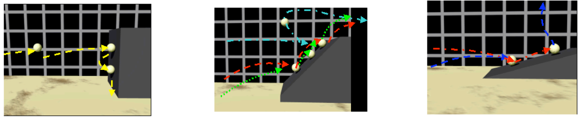

Figure 5: Diagrams based on high speed video analysis of sand particles impacting sloped surfaces. a) Sand that hits a 90° surface commonly falls to the ground and then roles away. b) Particles hitting a 60°-sloped surface can rebound, thereby increasing the effective particle flux. c) Sand hitting a 15°-sloped surface bounce off and do not rebound.

Application to Earth and Mars

The incentive for these experiments is to better understand how rocks abrade on Earth and Mars. We find many similarities between the experiments and ventifacts on Earth and the appearance of what are interpreted as ventifacts on Mars. The susceptibility for a rock to erode is strongly dependent upon its initial shape and texture, with steeper, rougher surfaces abrading at a greater rate. The pitted, faceted appearance of many Martian rocks [3,9-11] is easily attributable to aeolian abrasion. Because many Martian rocks are likely volcanic and therefore should contain vesicles, which, as these experiments show, will abrade more rapidly with time. Given sufficient supplies of sand and the high velocity winds needed for saltation on Mars, ventifact formation should occur.

References:

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