GRAIN-SCALE THERMOELASTIC STRESSES ON PHOBOS AND IMPLICATIONS FOR ROCK BREAKDOWN.

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Introduction: Thermal stress weathering is the mechanical breakdown of rock from expansion and contraction caused by changes in temperature. Microcracks may form or propagate due to temperature gradients set up by a thermal cycle or shock [1, 2]. This process may play an important role in the evolution of airless landscapes by contributing to regolith production and crater degradation [3, 4, 5].

Traditionally the effectiveness of this process has been assessed by rates of surface temperature change, with a threshold of 2K/min required for permanent damage [6, 7, 4]. Rock surfaces on bodies that lack atmospheres experience dramatic temperature changes that may induce high thermoelastic stresses in the near sub-surface. The thermoelastic behavior of each surface is primarily controlled by its distance to the sun and its solar day length, providing a unique experience on each body [3]. For example, slowly rotating bodies that are close to the sun (such as Mercury) experience a wide diurnal temperature range. Bodies further from the sun (such as asteroids) have a much smaller temperature range, but rotate quickly and thus experience a more rapid thermal cycling rate.

Phobos is a unique case because it experiences a solar eclipse of 54 minutes at midday each rotation near martian equinoxes (no eclipses occur near solstices). These eclipses allow fast surface cooling during the hottest period of the day. This may induce a more rapid change in the stress state of a rock surface than a traditional sunrise and sunset. If stresses are high enough to cause microfractures to propagate, it may also increase the thermal cycling rate because it will experience two sunsets and thus two peaks in tensile stress each day for much of the martian year.

While many studies suggest stresses induced by these temperature changes may cause rock breakdown, the extent of the damage produced as a result is unknown. Here we link surface temperatures and temperature gradients to actual stresses near rock surfaces in order to better judge the efficacy of thermal weathering on different planetary bodies. This work will help to place Phobos and Deimos in context within the inner solar system by examining how their surface processes may differ from Earth's moon and near-earth objects.

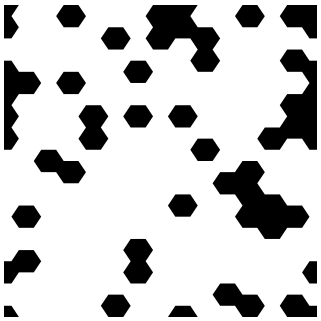

Figure 1. Microstructure 5mm across used for OOF2 modeling. Each hexagon represents a mineral grain with unique material properties.

Model: In this study, we modeled grain-scale thermoelastic stresses produced on airless surfaces using Finite Element Analysis of Microstructures (OOF2) [8]. OOF2 is a 2-D finite-element modeling program developed at NIST and designed to help scientists simulate the behavior of microstructures. We used OOF2 to model the thermal behavior of microstructures with varying grain sizes and thermophysical properties, and to explore the relationship between the induced spatial and temporal temperature gradients and stress.

Using OOF2, we imposed the solar and conductive fluxes calculated by a simple 1-D thermal model at the surface and at 5 mm depth on a microstructure. The microstructure (Figure 1) has bulk properties typical of a basalt, and a grain size of ~0.3 mm. We assigned 25% and 75% of the grains properties typical of plagioclase and pyroxene minerals, respectively. The heat and displacement equations are solved over a solar day on an equatorial surface on Phobos.

The stress parameter presented in these results is the effective stress, or von Mises stress. This parameter is calculated from the second invariant of the stress tensor and is commonly used in materials science studies. A material is said to fail when the effective stress reaches some critical yield strength of the material. While the effective stress is always positive, a sign correction has been applied to the data (Figure 2, 3) to

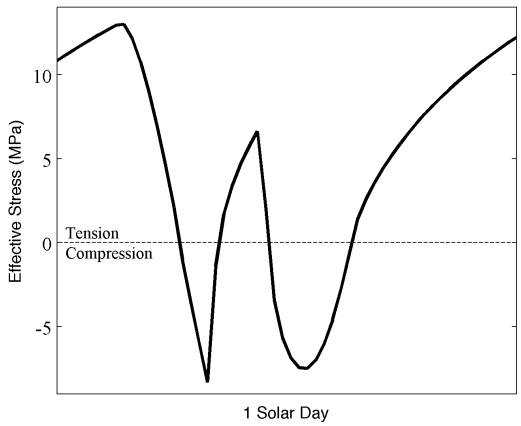

Figure 2. Profile of the maximum effective stress within the microstructure over one solar day (7.7 hours) on Phobos.

visually separate tensile and compressional states. Since tensile strengths are lower, it is tensile stresses that have the highest potential for contributing to rock breakdown. Typical tensile strengths of rocks are on the order of 100 MPa.

Preliminary Conclusions: Preliminary results indicate that flat, equatorial, phobian surfaces experience diurnal maximum effective stresses of 13 MPa while under tension (Figure 2). This peak tensile stress occurs pre-dawn, however there is a second spike at midday during martian equinox seasons, when cooling occurs due to the eclipse. This induces a second period of tensile stress that peaks at 6 MPa. Similar model runs on Vesta and the Moon produce peak tensile stresses of 8 and 150 MPa, respectively.

A snapshot of the microstructure during the time of peak tensile stress (Figure 3) shows that stresses are concentrated along surface-parallel intergrain boundaries, indicating that the heterogeneity of a rock dominates its thermoelastic behavior. This may also have implications for how the rock disaggregates, with cracks propagating parallel to the surface and coalescing where high stress intergrain boundaries are abundant.

These stresses represent the lower limit of what could be expected in a more realistic simulation with naturally shaped, imperfect mineral grains. The existence of microcracks will also concentrate higher stresses at their tips. Comparing these results to typical rock strengths suggests that thermo-mechanical fracturing may be possible on some bodies, such as Earth's Moon, but not on others. Further work is needed to determine how effective this process is on each body, and how much damage may occur as a result.

We will present model results of thermoelastic stresses induced on a variety of microstructures with varying grain properties and distributions for Phobos and Deimos. This works represents the first step in quantifying the contribution of thermal stress weathering to regolith production rates and will allow these moons to be compared to other airless bodies in the inner solar system.

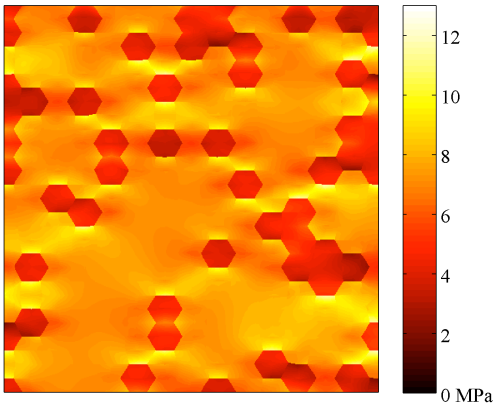

Figure 3. Snapshot of the effective stress over the entire microstructure at the time of peak tension. Stresses are concentrated along intergrain boundaries, with a peak stress of 13 MPa.

References: [1] Siegesmund S. et al. (2008) *Environmental Geology, 56*, 473–494. [2] Lu T. J. and Fleck N. A. (1998) *Acta Materialia, 46,* 4744–68. [3] Molaro J. L. and Byrne S. (2012) *JGR, 117*, E10011. [4] Viles H. et al. (2010) *Geoph. Res. Letters, 37,* L18201. [5] Dombard A. J. et al. (2010) *Icarus, 210,* 713-721. [6] Richter D. and Simmons G. (1974) *Int. Jr. of Rock Mechanics and Mining Sci., 11*, 403-411. [7] Hall K. and Andre M. F. (2001) *Geomorphology, 41*, 23-35. [8] Langer et al. (2001) *Computing in Sci. & Eng., 3*, 15-23.