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Thermoelastic stresses on airless bodies and implications for rock breakdown

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Thermomechanical breakdown of rocks is thought to be an active process in the solar system, especially on airless bodies that experience large diurnal temperature changes and/or have high thermal cycling rates. Researchers have suggested it may operate on (among others) the Earth, Moon, Mercury, Eros, and Phaethon, however the extent of the damage produced as a result is unknown. Propagation of microcracks occurs due to stresses from expansion/contraction caused by changes in temperature, and mismatches in elastic behavior of adjacent mineral grains. Here we link surface temperatures to actual stresses near rock surfaces in order to better judge the efficacy of thermal weathering on different planetary bodies.

Modeling of grain scale thermoelastic behavior on airless bodies provides insight into the magnitude and distribution of stresses produced. In this study, we imposed solar and conductive fluxes on a microstructure over one solar day, and solved the heat and displacement equations. The microstructures are grids of hexagonal grains that are assigned properties of plagioclase and pyroxene. Results indicate that lunar surfaces experience a diurnal maximum stress of 150 MPa while under tension. Examination of the microstructures during this state reveals that maximum stresses are concentrated along surface-parallel boundaries between mineral types, suggesting that temperature and rock heterogeneity dominate thermoelastic behavior. Examination of microstructures over time reveals an anti-correlation between high stresses and large spatiotemporal temperature gradients, indicating that they are not an effective proxy for grain scale stress. Model runs done for arbitrary solar system bodies with varying rotation period and solar distance indicate that bodies that rotate slowly and/or are close to the sun are subjected to the highest stresses. This suggests that certain groups of asteroids, particularly NEAs, may be highly susceptible to thermal breakdown. For example, our calculations shows that (3200) Phaethon experiences a peak diurnal stress of at least $\sim$300 MPa during perihelion.

This model simulates stresses induced in a flat surface, however there are a variety of effects that will impact the thermoelastic behavior of more unique topographic features. For example, the size and surface curvature of a boulder will impact how quickly it heats and cools, and to what extent stress is relieved by expansion of the boulder edges. Additionally, temporal and directional thermal loading of boulders will set up macroscopic temperature gradients that will interact with grain scale processes. Coupling the microstructure modeling with 3D modeling of boulder scale stresses will provide a way to investigate the relationship between macro- and micro-scale thermoelastic processes on these surfaces.

We will present results of thermoelastic stresses induced in microstructures and boulders on a variety of airless bodies. This work represents the first step in quantifying the contribution of thermal stress weathering to regolith production rates on these bodies.