**DOES THERMAL FATIGUE PLAY A ROLE IN LUNAR REGOLITH FORMATION?**

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**Introduction:** The lunar regolith contains a record of 4.6 billion years of solar system history, and it is continuously formed and overturned by impacts of objects over many orders of size magnitude. Understanding the nature and evolution of the lunar regolith is a key element of the quest to understand the evolution of the Moon as a whole, as well as the Earth-Moon system.

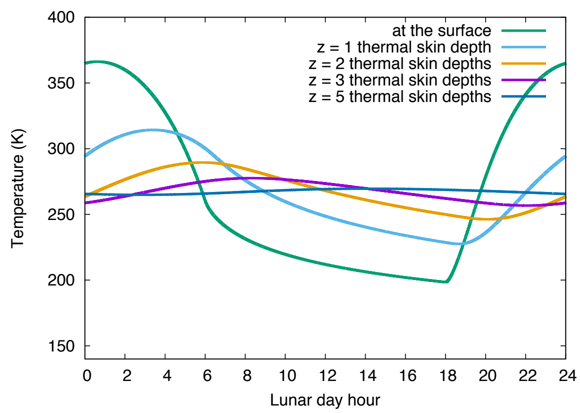
Recently, Ghent et al. (2014) [1] have shown that there is an inverse relationship between the rockiness of craters' ejecta and their age. This provides insight into the rate of lunar impact flux in the past billion years [2].

Traditionally, micrometeorite impacts have been thought to be mainly responsible for the breakup of boulders and regolith formation. However, recent studies have shown that thermal fatigue is the leading factor in regolith formation on small asteroids [3]. Thermal fatigue is primarily caused by temperature variations between day and night, and is a mechanism for rock weathering and fragmentation without involving subsequent ejection. Here, we use thermomechanical models to understand whether diurnal thermal variations cause enough stress on boulders on the surface of the Moon to break them down, and if so, how much time is required for pre-existing cracks to grow enough to break the rocks.

**Modeling and Preliminary Results:** To understand the effect of thermal fatigue on lunar rocks, we use models that are based on thermal diffusion, linear elastic fracture mechanics, and fatigue crack growth law [3].

*Temperature Profiles:* The diurnal lunar temperature profiles are calculated using a thermophysical model with the assumption of a single equatorial facet at a distance of 1 AU from the Sun. Since the Moon has two main rock types, basalt (in the Maria) and anorthosite (in the highlands), the thermal model is applied for a general case of basalt, as well as anorthosite gabbro. For simplicity, a constant albedo of 0.15 and emissivity of 0.95 are assumed for both [4]. Therefore, the difference between the two temperature profiles is due to the different bulk thermal inertia values: 1570 $Jm^{-2}K^{-1}s^{-1/2}$ for basalt and 515 $Jm^{-2}K^{-1}s^{-1/2}$ for anorthosite gabbro. Figure 1 shows the lunar temperature profiles at the surface, as well as at different thermal skin depths ($l_s$) for basalt ($l_s$ = 0.6m) and anorthosite gabbro ($l_s$ = 0.22m). It is evident that a lower thermal inertia causes a higher temperature variation.

a)




b)

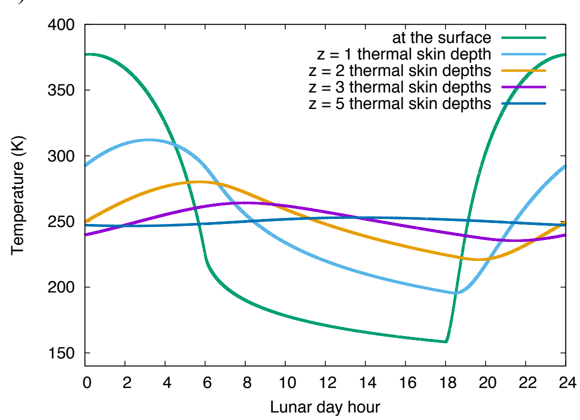
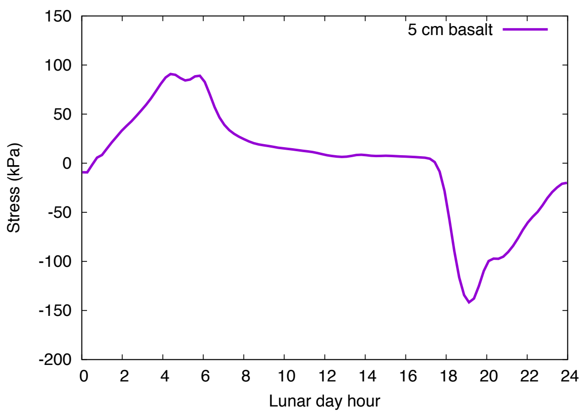



**Figure 1: Lunar temperature profiles at different thermal skin depths (ls). a) Basalt (ls = 0.6m), b) Anorthosite Gabbro (ls = 0.22m)**

*Stress Profiles:* The macroscopic stresses of spherical rocks as a function of depth are calculated using an analytical approximation based on a model of a free-plate of given thickness with temperature varying as a function of depth [5]. These stress profiles are based on the temperature profile and different thermomechanical properties of the two main rock types on the Moon: basalt (65% pyroxene, 35% plagioclase) and anorthosite (20% pyroxene, 80% plagioclase).

Stress profiles have been calculated for different rock sizes, bearing in mind the thermal skin depth of ~0.6m for basalt and ~0.22m for anorthosite. Figure 2 shows the stress profiles at the surface of 5 cm basalt and anorthosite rocks.

a)




b)

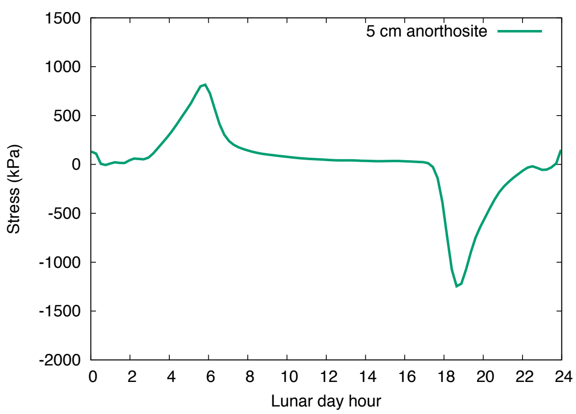



**Figure 2: Lunar stress profiles a) for a 5cm basalt rock, b) for a 5cm anorthosite rock.**

From Figure 2 it is clear that our "anorthositic" rock experiences a higher stress than our "basaltic" rock. This difference arises from the faster temperature changes of anorthosite due to its lower thermal inertia (Figure 1), as well as the different mechanical properties such as bulk and shear modulus.

Next, we use a fatigue crack growth model to predict how long it takes for pre-existing cracks to grow large enough to break the rocks. Paris's law, also known as the fatigue crack growth law, uses the maximum variation of the stress intensity factor calculated from the stress profiles as input. Using only the macroscopic stresses and assuming an initial crack length of 30 microns, very preliminary results predict that a 5 cm basalt rock will break in ~5 x $10^9$ years, whereas a 5 cm anorthosite rock will break in 1 x $10^6$ years.

**Conclusions and Future Work:** Models show that generally stress increases as rock size increases, with the assumption that the rocks are homogenous, leading to the result that larger rocks might be easier to break down by thermal fatigue. Preliminary results show that anorthosite breaks down faster than basalt.

In ongoing work, we are revising our models to include the effect of microscopic stress fields in addition to the macroscopic ones considered here. The microscpoic stresses are caused by the heterogeneities of the material at the microscopic level. Based on [3], this new model will take into account mineral sizes and spacings within each rock type.

**References:** [1] Ghent R. R. et al. (2014) *Geology, 42,* 1059–1062. [2] Mazrouei S. et al. (2015) *LPSC XLVI*, Abstract # 2331. [3] Delbo M. et al. (2014) *Nature*, 508 (7495), 233-236. [4] Bandfield J. et al. (2011) JGR, 116: E12. [5] Bruno A. B. and Weiner J. H. (1997) Theory of Thermal Stresses.

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