Thermal Environments and Illumination in Lunar Pits and Lava Tubes.

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Introduction: On the Moon there exist collapse pit features that are known to provide access to subsurface voids of unknown extent [1]. High resolution images (~1 m) from the Lunar Reconnaissance Orbiter (LRO) have shown that some ~100 m diameter pits have exposed stratigraphy from multiple flood volcanism events [2]; analysis of these layers would provide new understanding of the volcanic history of the Moon, making them ideal targets for future observations and exploration. These features have also been hypothesized to trap volatiles and could provide a haven for future human or robotic expeditions due to their shelter from diurnal temperature extremes, harmful radiation, and small impactors. Our research aims to characterize the complex thermal and illumination conditions within these pits to support these future expeditions.

Methods and Results: For this study we have focused on the most pronounced pit, located in Mare Tranquillitatis (8.34°E, 33.22°N). Using Lunar Reconnaissance Orbiter's (LRO) Narrow Angle Camera (NAC) stereo image pairs we were able to create 3D and 2D models of the pit structure with an extrapolation into the unseen reaches of the void space extending from the pit floor. From these models we used COMSOL Multiphysics to conduct a time-dependent thermal analysis, applying known thermophysical properties of the lunar rock and regolith to the geometry [3-4]. Throughout the model's duration we recorded surface and subsurface temperatures, as well as observe the effect of heating by direct and indirect solar and infrared radiation, throughout a lunar day.

Our results show that the pit floor can reach temperatures of >415 K during the day, hotter than any recorded temperature on the lunar surface, and that the floor maintains a warmer temperature throughout the night than the surface due to self-heating by thermal radiation from the pit's structure onto itself. We also found that a cave extending from the pit floor would reach equilibrium at ~290 K, hotter than the mean surface temperature of ~260 K as would be expected. We then analyzed thermal data from LRO's Diviner Lunar Radiometer Experiment to compare with the 2D and 3D thermal models. Although the diameter of the pit is less than the width of a single pixel in the data, we are still able to see a heightened temperature signal at the location of the pit. This gives us confidence that the COMSOL models are accurate, though not many conclusions can be made from the Diviner data alone.

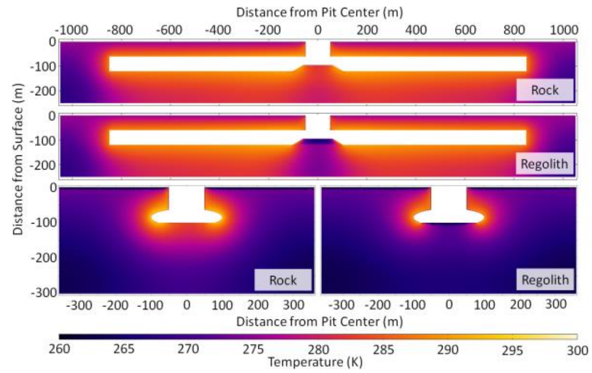

Figure 1: 2D thermal models of the pit with different pit floor compositions and cave geometries. All of the models were run until equilibrium was met. Every model ends with the shadowed regions maintaining a temperature of ~290 K throughout the day with only minimal variation.

We also conducted multiple 2D thermal models as shown in figure one to determine what effects the composition of a pit's collapse material or the size of the subsurface void would have an affect on the temperatures of the floor significantly enough to be measured with Diviner. As seen in Figure 1, the equilibrium conditions for the many different cases are very similar, this is because the pit emulates a blackbody cavity in every case due to its unique geometry. This result means that lunar caves with skylights are perhaps the most safe locations for future exploration and settlements on the Moon.

References:

[1]Haruyama, J., et al. (2009) *GRL* 36, L21206 [2] Robinson, M.S., et al. (2012) *PSS* 69, 18-27. [3] Hayne P.O., et al. (2017) *JGR Plan.* 122, 2371-2400. [4] Bandfield J.L., et al. (2011) *JGR* 116, E00H02