

DISCOVERY OF LUNAR SUBSURFACE CAVITIES USING THERMAL INERTIA R. A. Slank¹ and J. M. Hurtado Jr.², ¹The University of Texas at El Paso, El Paso, TX 79968 (raslank@miners.utep.edu), ²The University of Texas at El Paso, El Paso, TX 79968 (jhurtado@utep.edu).

Introduction: Previous studies have revealed a small number of subsurface cavities, including lava tubes, lava flow pits, and impact melt pits on the Moon [1-4]. The interiors of such cavities would have been protected from micrometeorite bombardment, solar radiation, space weathering, and extreme diurnal temperature swings over long periods of geologic time. As a result, these subsurface features can provide access to pristine crustal samples and stratigraphy. These cavities would also provide protection of important volatiles, such as water ice, that would enable future exploration missions by relieving many operational constraints, including the supply of propellants and life support. In addition, subsurface cavities could serve as the sites of protective habitats for future lunar explorers.

The goal of this research is to establish a methodology using thermal inertia and numerical modeling to detect and characterize lava tubes and other subsurface cavities in the lunar subsurface. Numerical modeling (both forward and inverse methods) will be used to predict the thermal inertia signatures expected for subsurface cavities and will be used to constrain characteristics such as the depth and size of the subsurface cavities from those datasets.

Background: Thermal inertia (P) describes the resistance of a material to changes in temperature [5]. It is defined as:

$$P = \sqrt{K\rho c} \quad (1)$$

where K is thermal conductivity, ρ is density, and c is specific heat. Unfortunately, these parameters cannot be directly measured using remote sensing techniques, so thermal inertia is typically estimated from other directly measured data or it is modeled. One way to approximate thermal inertia is by calculating apparent thermal inertia (ATI), which is defined as [5]:

$$ATI = \frac{1-a}{\Delta T} \quad (2)$$

where a is albedo and ΔT is the difference in temperature over a diurnal cycle. A more sophisticated treatment allows the determination of thermal inertia from ATI [6]:

$$P = ATI \left(\frac{S_0 C_t}{\sqrt{\omega}} \right) \left\{ \frac{A_1 [\cos(\omega t_2 - \delta_1) - \cos(\omega t_1 - \delta_1)]}{\sqrt{1 + \frac{1}{b} + \frac{1}{2b^2}}} + \frac{A_2 [\cos(\omega t_2 - \delta_2) - \cos(\omega t_1 - \delta_2)]}{\sqrt{2 + \frac{\sqrt{2}}{b} + \frac{1}{2b^2}}} \right\} \quad (3)$$

where S_0 is the solar constant ($1,366 \text{ W/m}^2$ at 1 AU) C_t is the atmospheric transmittance (1 for the Moon), δ_1 is solar declination at time t_1 , δ_2 is solar declination at time t_2 , A_1 and A_2 are Fourier coefficients, and b is a parameter dependent on the time of maximum daytime temperature:

$$b = \frac{\tan(\omega t_{max})}{1 - \tan(\omega t_{max})} \quad (4).$$

If a subsurface cavity is present, the subsurface cavity should have a greater ATI or thermal inertia than the surrounding area since there is a smaller temperature change from day to night compared to the surrounding rock. This is because there is a void space below the rock as well above. The void space will help regulate the temperature of the surface above the subsurface cavity, causing the temperature difference to be less than the surrounding solid rock.

Methods: To locate subsurface cavities, DIVINER global surface brightness temperature and visual albedo maps are used to calculate temperature difference, apparent thermal inertia, and thermal inertia maps [5] of the Moon for a complete diurnal cycle. Temperature maps for day and night were integrated with time maps for day and night to calculate a maximum temperature and minimum temperature maps. Those two maps were used to calculate the maximum temperature difference, which was then applied to calculate ATI and the log of ATI . Once ATI was calculated, the data was used to calculate thermal inertia and the log of thermal inertia.

For sites with a thermal inertia signature consistent with a subsurface cavity, a 3-D finite element numerical model will be used to determine the length, depth, and diameter of the subsurface cavity. The modeling can help to determine the geometry of the subsurface cavity, specifically whether it is a lava tube or a pit. For pits, thermal inertia signatures may be expected to be circular in map pattern, with relatively small diameters. For lava tubes, the thermal inertia signatures are expected to be more curvilinear and could extend for tens of kilometers. This distinction is important because it will indicate ideal areas for further exploration. A vertical pit may not provide as much protection for explorers and volatiles compared to a lava tube. A pit that has a cavity extension of some kind could serve as better protection than a vertical pit.

Preliminary Results: Figure 1 shows the log thermal inertia map resulting from the night data start-

ing on August 8, 2012 and the day data starting on August 19, 2012. The resulting thermal inertia map is shown in Figure 1.

These results were compared to Rima Sharp where a subsurface cavity has been located by [3] (Figure 2). Although the thermal inertia map shows a high thermal inertia anomaly that spatially corresponds to the known subsurface cavity, the area is much smaller than the known subsurface cavity. This is partially due to missing data. The known cavity at Rima Sharp has a longitudinal span of 4° , whereas Figure 1 indicates a longitudinal span of 2.51° .

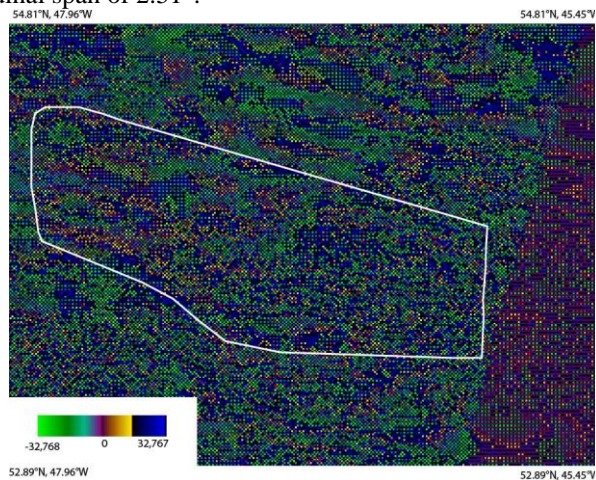


Figure 1: Section of the log of the global thermal inertia map of the Moon at Rima Sharp, from $(54.81^\circ\text{N}, 41.96^\circ\text{W})$ in the upper left hand corner, to $(52.89^\circ\text{N}, 45.45^\circ\text{W})$ in the lower lefthand corner. There is a linear feature trending northwest-southeast where a known lava tube is located [5], where the thermal inertia is higher than the surrounding areas, indicated by yellows and blues.

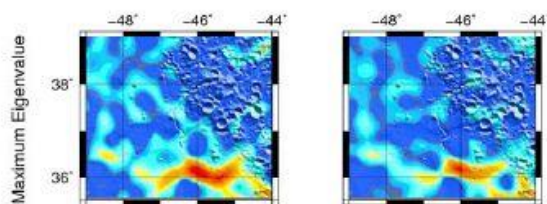


Figure 2: Maximum eigenvalue map in the Rima Sharp region with overlay of the topography indicating a subsurface cavity is present [3].

Continuing work will implent the modeling and apply the method to other sites of interst on the Moon.

References: [1] Ashley, J.W., et al. (2011) *LPSC XLII*, abs.2771. [2] Meyer, J.A. (2012) UTEP M.S. Thesis. [3] Chappaz, L., et al. (2014) *LPSC XLV*, abs. 2019. [4] Wagner, R.V. and Robinson, M.S. (2014) *Icarus*, 237, 52-60. [5] Scheidt, S., et al. (2010) *Journal of Geophysical Research*, vol. 115, F02019. [6]

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