**THE SUBSURFACE COHERENT ROCK CONTENT OF THE MOON AS REVEALED BY COLD-SPOT CRATERS.** C. M. Elder[1], B. Douglass[2], R.R. Ghent[3,4], P.O. Hayne[2], J.-P. Williams[5], E. Costello[6], [1]Jet Propulsion Laboratory, California Institute of Technology, [2]University of Colorado Boulder, [3]Planetary Science Institute, [4]University of Toronto, [5]University of California, Los Angeles, [6]University of Hawai'i at Manoa.

**Introduction:** The lunar surface has been bombarded over billions of years, resulting in a subsurface structure nominally comprised of fragmented lunar crust [e.g. 1] underlying impact basin ejecta, often called `megaregolith', [e.g. 2] underlying a layer of fragmental debris, known as regolith [e.g. 3] which likely also contains buried rocks [e.g. 4]. Many different methods have been employed to constrain the exact subsurface structure of the Moon (see summary in [5]), but each method is sensitive to a different combination of depth, block size, volume fraction of blocks etc. Moreover, the exact subsurface profile is unique to the geologic history at any given location. Therefore, there is no consensus on the details of the Moon's subsurface structure or its spatial variability.

Here we provide an additional constraint on the subsurface of the Moon by applying the classic method of using crater ejecta to probe the subsurface [e.g. 6] to a recently discovered class of lunar impact craters, cold-spot craters. Cold-spot craters are surrounded by low thermal inertia material (cold at night) extending ~10-100 crater radii (Figure 1; [8]). This low thermal inertia signature fades within ~0.5-1 Myr after the impact [9], which is several orders of magnitude faster than rock disappearance (breakdown and burial) on the Moon [10]. Therefore any rocks in the ejecta of a cold-spot crater have not yet had time to breakdown or become buried. The abundance of rocks in cold-spot crater ejecta depends only on the subsurface rock content and the excavation depth of the crater. Here we describe our recent work [5] probing the subsurface rock content on the Moon by measuring the rock abundance in cold-spot crater ejecta and suggesting a new model for the subsurface structure of the Moon.

**Methods:** We measured the average Diviner rock abundance [11] in an annulus extending from the crater rim to 1 crater radius away from the rim for all cold-spot craters larger than 250 m in diameter (1 Diviner pixel is ~240 m at the equator). Larger craters excavate deeper into the subsurface, so to compare the rock abundance in the ejecta blankets of different sized craters we assume that the volume fraction of rock, $f$, increases exponentially with depth, $z$:

$$f = 1 - e^{-z/H_{rock}}$$

where $H_{rock}$ is the "e-folding" depth over which the volume fraction of rock increases (Figure 2). We integrate over this profile from the surface to the excavation depth

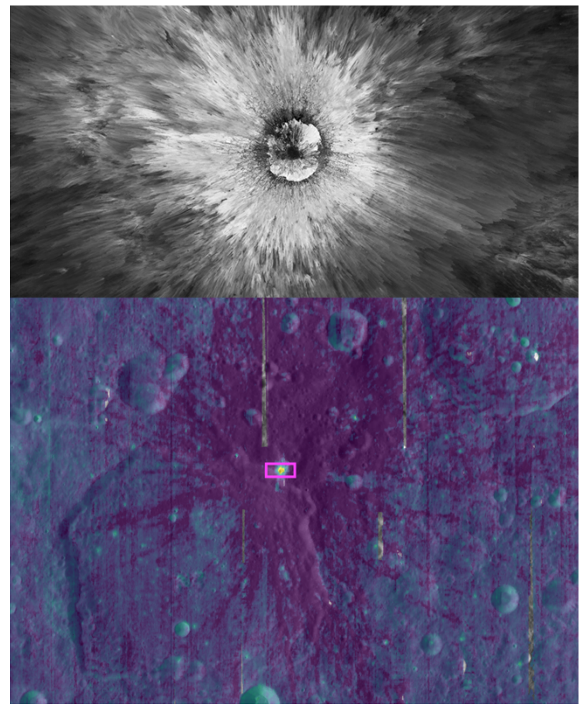

Figure 1: The H-map [7] of a ~1.5 km diameter unnamed cold-spot crater at 151.7°E and 4.1°S where blue indicates low thermal inertia and yellow indicates high thermal inertia (bottom). The magenta box indicates the approximate region shown in a LROC NAC mosaic (top; image credit: lroc.sese.asu.edu/posts/899).

(estimated from the crater diameter using scaling laws in [12]), assume that the volume fraction of rock excavated is equal to the measured Diviner rock abundance,

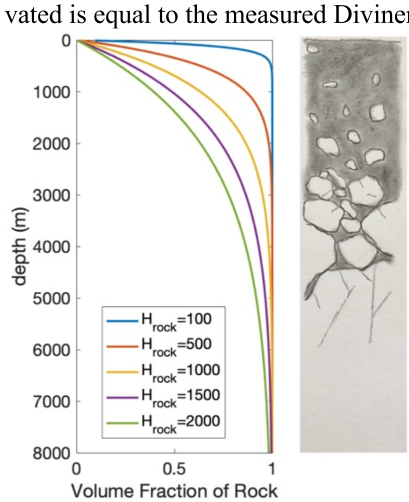


Figure 2: Model volume fraction of rock v. depth for several values of $H_{rock}$ (left). A schematic diagram of the lunar subsurface (right).

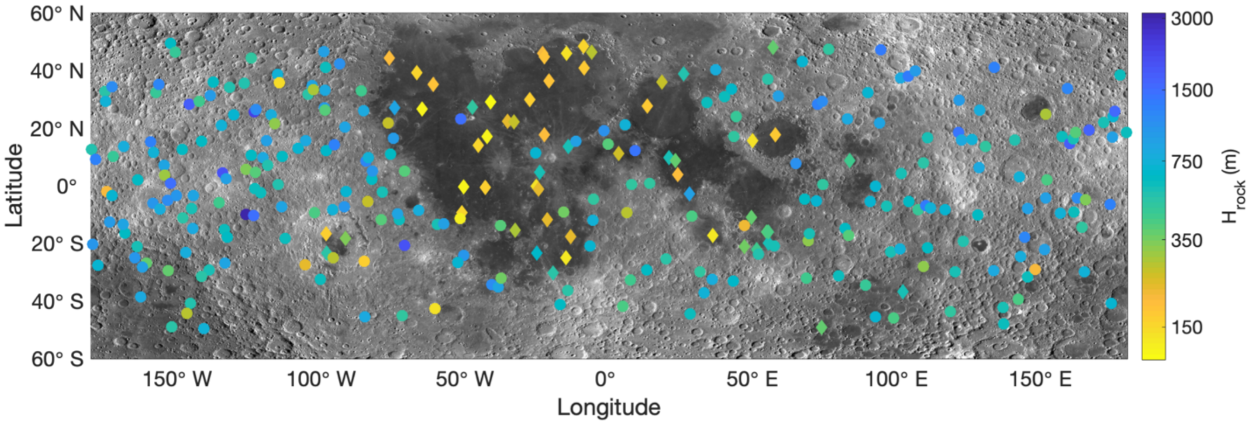


Figure 3: The value for $H_{rock}$ at each large cold-spot on the Moon, where yellow indicates a lower $H_{rock}$ and a higher subsurface rock content and blue indicates a higher $H_{rock}$ and a lower subsurface rock content. Maria bounds mapped by [13] are used to distinguish cold-spot craters in the maria (diamonds) and from those in the highlands (circles).

and solve for $H_{rock}$ for each cold-spot crater larger than 250 m in diameter.

**Results:** We find that cold-spot craters in the maria generally have a lower $H_{rock}$ (higher subsurface rock content) than craters in the highlands (Figures 3 and 4). This is consistent with the more recent resurfacing of the maria compared to the highlands. However, $H_{rock}$ values in the highlands span a wider range of values and substantially overlap those in the maria (Figure 4). Some of the anomalously low $H_{rock}$ values in the highlands may be associated with cryptomaria deposits and the Orientale basin [5].

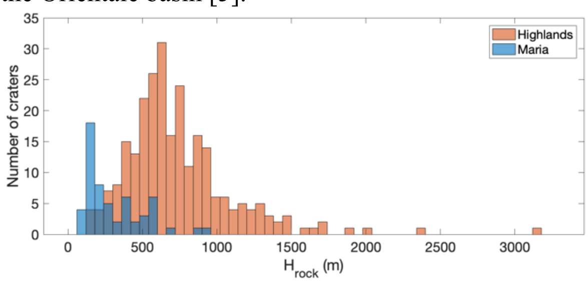


Figure 4: The distribution of $H_{rock}$ values in the maria (blue) and the highlands (red).

**Discussion:** In addition to the exponential model of subsurface rock content, we also tested a simple two-layer model of fine-grained material with a thickness $d_{reg}$ overlying bedrock, but we found that it did not provide a good fit to the observed Diviner rock abundance values [5]. In the two-layer model, we assumed that all rocks in the ejecta blanket came from the underlying bedrock layer and that the volume rock fraction in the ejecta blanket is proportional to $\frac{d_e - d_{reg}}{d_e}$ where $d_e$ is the crater excavation depth. We assumed that the Diviner rock abundance is equal to the volume fraction of rock ejected and solved for $d_{reg}$, but this resulted in a $d_{reg}$ that is strongly dependent on crater diameter. This is a non-physical result since the regolith structure pre-dates the formation of the cold-spot crater which suggests that the transition between fine-grained regolith and coherent rock is not abrupt over the depths probed by cold-spot craters [5]. However, it is possible that the signature of a thin layer of "rock-free regolith" could be overwhelmed by an underlying exponential increase in volume fraction of rock.

**Conclusions:** Cold-spot crater ejecta provide an opportunity to probe the lunar subsurface, because the craters formed within the past million years. We find that the subsurface rock content is higher in the maria than in the highlands which is consistent with a more recent resurfacing in the maria. However the subsurface rock content within the highlands spans a wider range of values and overlaps those of the maria. We also found that a simple two-layer model of fine-grained regolith overlying coherent rock cannot explain the observed variability in rock abundance of cold-spot crater ejecta suggesting that the transition between regolith and rock is not abrupt.

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