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Thermophysical Properties of the Lunar Surface from Diviner Observations

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Orbital thermal infrared measurements are sensitive to a variety of properties of the Moon's surface layer, including rock abundance, regolith cover and porosity, and small-scale surface roughness. With its multiple spectral channels and large dynamic temperature range, the Diviner Lunar Radiometer [1] on NASA's LRO spacecraft has enabled the first global, high-resolution maps of these important thermophysical properties. Here we present a summary of the results of Diviner's thermophysical investigation thus far.

Maps of surface rock abundance show low typical values of <1% with higher abundances for recent craters and their blocky ejecta, as well as mass wasting on crater walls, rilles, and impact melt features [2]. The extent and abundance of surface rocks decrease systematically with crater age, and rocky surfaces are only preserved on the youngest craters (<1 Ga). We used nighttime regolith surface temperatures and eclipse cooling observations to constrain profiles of density and conductivity in the upper $\sim$1 m, revealing a remarkably homogeneous subsurface structure [3]. Geographic variations in upper regolith density are nonetheless apparent. For example, buried rocks are suggested within young impact ejecta showing strong radar backscatter, high subsurface density, and a lack of surface rocks [2,4]. Rock fragmentation and regolith accumulation rates can be quantified by comparison of the Diviner data with published crater ages, yielding typical erosion rates which rapidly decrease from $\sim$10 kg m-2 yr-1 for crater ages of $\sim$1 Ma to $\sim$1 mg m-2 yr-1 at $\sim$1 Ga [4]. Variations in upper regolith density correlate with the ages of individual mare basalt units, suggesting this layer is actively processed by impacts on geologically short timescales, which may reveal age relationships previously unseen [5].

Vast cold regions surrounding fresh impact craters during lunar night (termed "cold spots") are only apparent in thermal infrared data [2]. These features cannot be explained by the emplacement of ejecta, and instead are well modeled by the in situ decompression of the top $\sim$1–10 cm of regolith. Among a variety of explanations for this phenomenon, a model of grain lifting and turbulent mixing within an expanding vapor cloud best matches observations. The Diviner observations suggest impact vaporization leads to prominent yet ephemeral scars in the upper regolith that may be common on airless bodies in the Solar System.

Surface roughness at scales smaller than the $\sim$250 m Diviner footprint affects the measured spectral slope in brightness temperatures. We used Diviner brightness temperature spectra measured at a variety of solar illumination and viewing geometries to constrain and map the RMS slopes of the Moon's surface [6]. Due to the general increase in roughness at smaller scales, the RMS slopes of $\sim$20-30° derived from Diviner data are likely dominated by the smallest scales where strong temperature gradients can exist, which are of order millimeters for typical lunar regolith [7,8]. Thus, these measurements complement those acquired by other techniques, such as laser altimetry [9], which typically measure surface roughness at scales larger than one meter.

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