OBSERVATIONS OF ROCK-POOR MATERIAL AT LUNAR RED SPOTS: INSIGHTS FROM THERMAL INFRARED AND RADAR DATA SETS.

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Introduction: There are a number of features on the Moon (predominantly in the Procellarum KREEP terrain) proposed to be the result of non-mare volcanism, called lunar red spots due to their strong ultraviolet absorption [1]. These features have low FeO content, low TiO_2 content, and in many cases high thorium content [2]. Studies using mid-infrared data from the Lunar Reconnaissance Orbiter (LRO) Diviner Lunar Radiometer Experiment (Diviner) additionally found evidence for silicic material such as quartz, silica-rich glass, or alkali feldspar associated with at least four red spots, indicating that they originate from an evolved magma source [3]. Further study of red spots is necessary to support future missions such as the Commercial Lunar Payload Services Lunar-VISE mission scheduled to land at the Gruithuisen Domes in 2026 [4].

An investigation of gravity data from the Gravity Recovery and Interior Laboratory (GRAIL) mission found that the Gruithuisen Domes have low crustal density, consistent with an abundance of felsic material with high porosity due to vesicularity or pyroclastics [5]. Other studies have also found evidence for pyroclastic material at a number of red spots in the form of high reflectance fine-grained material with low radar backscatter [6,7]. In this work, we present additional evidence for pyroclastics at a number of red spots, and suggest alternative hypotheses for the low thermal inertia that we observe at red spots. We do this by investigating the thermophysical properties of a number of red spots using Diviner thermal infrared data, and comparing these results with radar data from LRO and Arecibo.

Methods: Using the Diviner nighttime data, we derived rock abundance (RA) and H-parameter for a number of red spots (Gruithuisen Domes, Mairan Domes, Compton-Belkovich Volcanic Complex (CBVC), Lassell Massif, Mons Hansteen, Helmet, and Darney) using the methods of [8] and [9]. RA describes the abundance of large (> 1 m) rocks within each Diviner pixel, and H-parameter describes how the density and conductivity of the rock-free regolith component increase with depth. H-parameter can be considered analogous to thermal inertia of the fines component, and on the Moon is often related to the abundance of small rocks mixed in with the regolith [9].

Albedo is an important factor in the H-parameter derivation, because high albedo surfaces reflect more sunlight during the day resulting in colder nighttime temperatures (and H-parameter is derived by fitting a model to nighttime temperatures). Inaccuracies in the assumed albedo can lead to errors in derived H-parameter. We utilized Diviner solar reflectance data to create maps of Lambert albedo for each red spot in order to match the same spatial resolution of the infrared observations. Lunar red spots are relatively small and have a high albedo compared with surrounding maria.

We additionally utilized radar datasets to compare with the Diviner thermal infrared data. We analyzed S-band (12.6 cm) radar return and circular polarization ratio (CPR) data from the Mini-RF instrument [10] on LRO and from Earth-based Arecibo observations [11], revealing the sub-surface rock content of the red spots.

Results: The red spots we investigated generally have low RA and contain localized regions of high H-parameter (low thermal inertia). They also generally have low radar backscatter and low CPR. Selected regions within a number of red spots have H-parameter values up to ~40% higher than surrounding maria.

Discussion: Each red spot exists in a slightly different geologic context from the others (i.e., domes, smooth plains, or rugged highlands material) and a combination of factors likely contributes to the thermophysical properties that we observe. For example, Lassell Massif (Figure 1; top) shows signs of pyroclastic material in a diffuse area surrounding two irregular craters (Lassell G and K) in the southern part of the feature. This diffuse area has low RA, high H-parameter, and low CPR, indicating an abundance of fine-grained material interpreted as pyroclastic mantling that may have originated, explosively, from vents on the massif. The red spots CBVC and Mons Hansteen show similar evidence for pyroclastics in visible images, and the low RA, high H-parameter, and low CPR values that we observe indicate a lack of cm- to m-scale blocks, consistent with fine-grained pyroclastic material.

The Helmet feature (Figure 1; middle) has low RA and low CPR across much of the feature, but only shows high H-parameter in certain locations (e.g., the northeastern part). Because both H-parameter and CPR are affected by the presence of small rocks in the regolith, this result is somewhat unexpected. It is possible that differences between the Diviner and Mini-RF datasets result from the different sensing depths of the instruments and their sensitivity to different sized rocks. Diviner is sensitive to the top ~10 cm for regolith, while S-band signals from Mini-RF can penetrate >1 m into the surface. Additionally, S-band radar signals are scattered by ~0.1–1.25 m rocks, while H-parameter can be affected by rocks <1 m but larger than typical regolith fines.

The Gruithuisen Domes have generally low RA, and we see high H-parameter at the south-facing slope of the Delta dome (Figure 1; bottom). Low RA is consistent with the older age of the red spots relative to surrounding maria. We do see low CPR values at some locations on the domes, however, it must be noted that CPR can be affected by slopes. Work is underway to better understand these slope effects. It is possible that the Domes contain buried pyroclastic material (as suggested by [12]) that has been exposed in some areas by impact cratering, resulting in the high H-parameter seen only in certain locations. It is also possible that the high H-parameter of the south-facing slope of the Delta dome is related to the porosity of the top layers of regolith or to the relative effectiveness of the silicic target rocks being comminuted into fine-grained and rock-poor regolith. It is likely that some combination of factors contributes to the material properties that we see here at the Gruithuisen Domes, and at each red spot.

References: [1] Whitaker (1972), *The Moon*, *4*(3), 348-355. [2] Hagerty et al. (2006) *JGR Planets*, 111(E6). [3] Glotch et al. (2010) *Science*, 329, 1510-1513. [4] https://www.nasa.gov/press-release/nasa-selects-new-instruments-for-priority-artemis-science-on-moon [5] Kiefer et al. (2016) *LPSC XXXXVI*, Abs. 1722. [6] Clegg-Watkins et al. (2017) *Icarus*, 285, 169-184. [7] Bhattacharya, et al. (2013). *Current Science*, *105*, 685-691. [8] Bandfield et al. (2011) *JGR Planets*, 116 (E12). [9] Hayne et al. (2017) *JGR Planets*, 122 (12). [10] Cahill et al. (2014) *Icarus*, *243*, 173-190. [11] Campbell et al. (2010) *Icarus*, *208*, 565–573. [12] Ivanov et al. (2016). *Icarus*, *273*, 262–283.

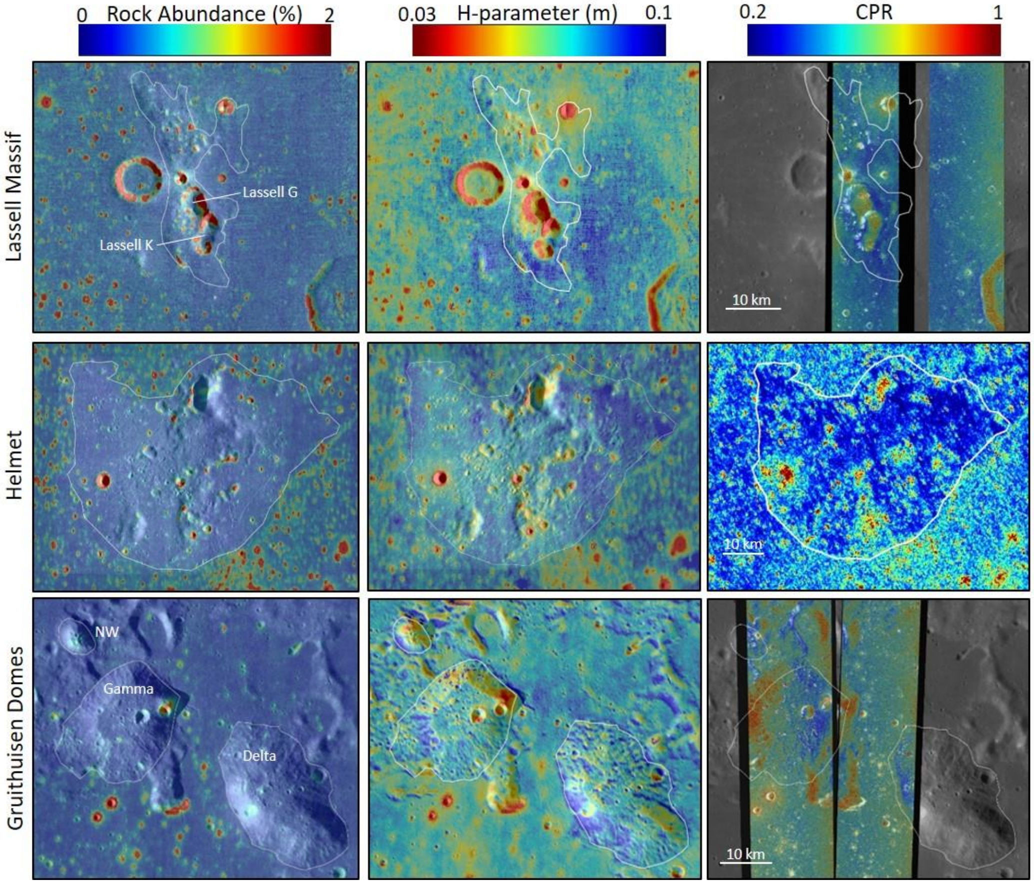

Figure 1: *Rock Abundance (left), H-parameter (center), and CPR (right) maps for three lunar red spots. (top) Lassell Massif is surrounded by a diffuse area with low RA, high H-parameter, and low CPR that is likely due to pyroclastics. (middle) The Helmet red spot is rock-poor (with low RA and CPR) compared with its surroundings and has high H-parameter in its northeast section. (bottom) The Gruithuisen Domes have low RA and we see high H-parameter on the south-facing slope of the eastern Delta dome.*