LOW-THERMAL INERTIA MATERIAL AT LUNAR RED SPOTS: OBSERVATIONS FROM THE LRO DIVINER LUNAR RADIOMETER EXPERIMENT. B. D. Byron[1], C. M. Elder[1], T. D. Glotch[2], P. O. Hayne[3] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (benjamin.d.byron@jpl.nasa.gov), [2]Stony Brook University, Stony Brook, NY, [3]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO

Introduction: Lunar "red spots" are surface features in the nearside maria that are named as such because they have strong absorption in the ultraviolet and are highly reflective at longer wavelengths, and thus appear spectrally red. These red spots take the form of domes, smooth plains, and rugged patches of highlands material surrounded by maria, and are proposed to be associated with non-mare silicic volcanism [1]. Some of the red spots are also associated with elevated thorium content [2], suggesting that they are derived from an evolved magma source.

Investigations of the Christiansen Feature (CF) and concavity index with the Lunar Reconnaissance Orbiter (LRO) Diviner Lunar Radiometer Experiment (Diviner) found evidence of silicic material at a number of lunar red spots [3, 4]. These results, along with photometric results from LRO Camera (LROC) [5] and gravity data from the Gravity Recovery and Interior Laboratory (GRAIL) mission [6], suggested that the red spots are indeed the product of silicic volcanism. Among the more prominent red spots are the Gruithuisen Domes, landing site of a lunar lander and rover mission planned for 2025 as part of NASA's Commercial Lunar Payload Services.

The leading theory for the origin of lunar red spots is basaltic underplating. Basaltic underplating occurs when basaltic magma intrudes into the pre-existing crust and partially melts the country rock forming a silicic magma that, due to its lower density, can ascend and extrude to form rhyolitic lavas [2]. An alternative theory for the origin of the highly silicic material at red spots is fractional crystallization involving silicate liquid immiscibility (SLI). However, [6] note that SLI and underplating are not mutually exclusive, and that the two processes could both contribute to the formation of the red spots. Because red spots are proposed to be composed of low-density felsic material, and regolith temperature over the course of the lunar night is highly dependent on density, Diviner temperature measurements and subsequent derivations of red spot thermophysical properties could help resolve underlying questions about their formation.

Methods: We derive Rock Abundance (RA) and regolith H-parameter maps for seven lunar red spots, including the Gruithuisen Domes and Darney features (Figures 1a and 1c), using the methods described in [7] and [8]. This process involves separating the contributions of large (> 1 m) rocks and fine-grained regolith in the nighttime radiance measurements from Diviner, and then fitting the rock-free regolith temperature with a thermal model in which the density increases exponentially with depth and the e-folding scale (*H*) is the free parameter. This H-parameter is analogous to regolith thermal inertia, with higher H-parameter corresponding to lower thermal inertia.

Because the red spots are relatively small and high albedo features surrounded by low-albedo mare material, this albedo contrast must be accounted for in the H-parameter derivation. Nighttime regolith temperatures on the Moon are affected by the bolometric albedo of the surface, with higher albedo surfaces reflecting more sunlight and thus warming less during the day than lower albedo regions [8]. Previous studies used the LOLA 1064-nm albedo map (scaled to match Diviner reflectance measurements at the equator) in their best-fit H-parameter derivations [8]. The 10 pixels-per-degree (ppd) spatial resolution of the 1064-nm albedo map is too low to fully resolve some features within the lunar red spots, however, and a higher resolution albedo map is necessary. In this work we utilize the LROC Hapke-Normalized 689-nm albedo map [9] due to its higher spatial resolution (76 ppd) compared with the 1064-nm albedo map. We used the same approach as [8] to scale the 689-nm albedo map to match the Diviner equatorial reflectance, and then used these values in our derivation of the best-fit H-parameter for the red spots.

Results: Best-fit H-parameter maps for the Gruithuisen Domes and Darney are shown in Figures 1b and 1d, respectively. Even after accounting for their higher albedo, the red spots have an elevated H-parameter relative to the surrounding maria. The high H-parameter anomaly at Darney corresponds well with the boundaries of the feature. At the Gruithuisen Domes, however, the H-parameter anomaly does not cover the entirety of the domes; only certain regions (such as the southern slope of the delta dome) display high H-parameter. Although we do not show the results here, we note that a number of other red spots that we investigated (including the Mairan Domes, Lassell, Montes Riphaeus, and Helmet) also display higher H-parameter than surrounding maria. The large red spot Hansteen α conversely does not have higher H-parameter than surrounding maria.

In Figure 2a, we see that the average H-parameter of a section of the Darney χ feature (white box in Figure 1d) is ~0.12 m, slightly higher than the average value for nearby maria (red box; ~0.10 m). The average albedo of Darney χ (0.090) is also notably higher than that of the nearby maria (0.055; Figure 2b). In Figure 2c, we plot the nighttime regolith temperature curves for Darney χ (red curve) and the section of nearby maria (blue curve). Darney χ is ~2 K cooler than the nearby maria throughout the night, and those observations are fit well by the model with an H-parameter of 0.12 if we assume the albedo is that of the scaled WAC albedo map (0.09).

The bolometric albedo of the red spots is poorly constrained, so to ensure that the high H-parameter of the red spots is real and not a result of poor fitting due to anomalous albedo, we also run a thermal model in which we assume the H-parameter of Darney χ is equal to the H-parameter of the nearby maria (0.10 m), and instead derive a best-fit albedo using the thermal model of [8]. We find that in order to fit the temperature curve of Darney χ at an H-parameter value of 0.10 m, a broadband solar albedo of 0.15 would be necessary (green line in Figure 2c). This is ~67% higher than the average albedo for Darney χ from our scaled 689-nm WAC albedo map (0.09). We suggest that a modest increase in H-parameter (from 0.10 m to 0.12 m) is more likely than such a large undetected albedo anomaly.

Discussion: Regolith H-parameter is related to thermal inertia, which for lunar regolith is affected primarily by packing density or the presence of small rocks [8]. The presence of low thermal inertia regolith typically suggests that the top ~10 cm of regolith is "fluffier" or that there are fewer small rocks. In the case of the red spots, it could also imply that the rocks have a lower thermal inertia than typical lunar rocks. [6] found that GRAIL gravity measurements indicate the presence of low-density material at the Gruithuisen Domes and Hansteen α and suggested that this would be best explained by a combination of composition and porosity from vesicularity or pyroclastic deposits. Low density, especially due to vesicularity, is expected to correspond to a low thermal inertia. These results, in conjunction with the high silica contents derived through Diviner CF measurements, suggest that the red spots are composed of low-density felsic material (e.g., rhyolite or pumice) likely produced by the basaltic underplating mechanism proposed by [2].

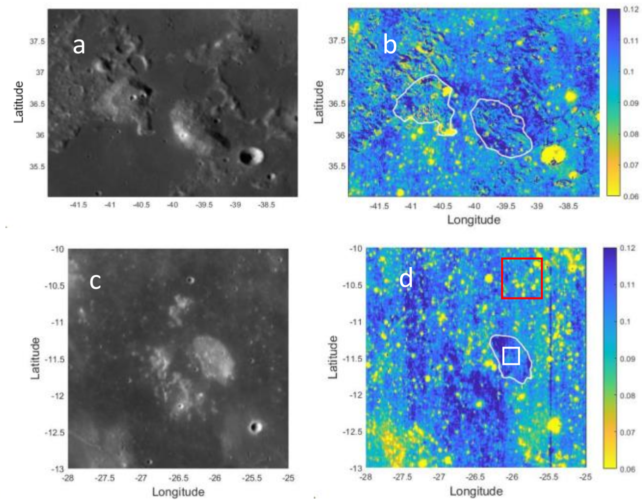

Figure 1: (a) LROC WAC image and (b) regolith H-parameter (meters) map of the Gruithuisen Domes. (c) LROC WAC image and (d) regolith H-parameter map of the Darney red spot feature.

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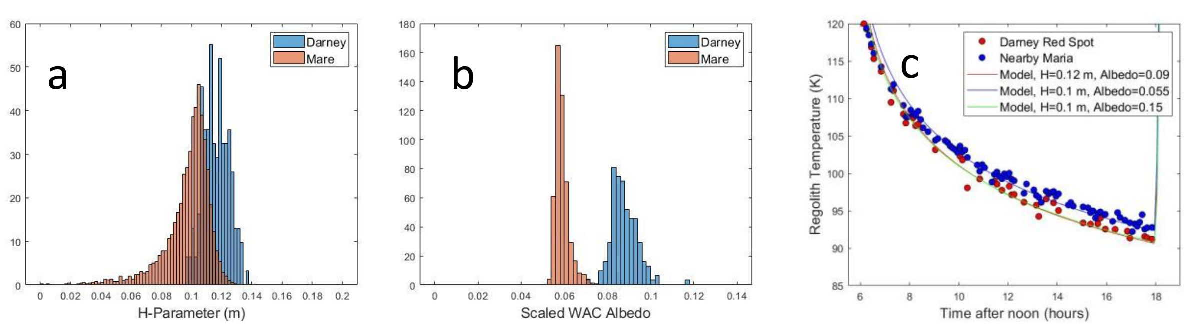

Figure 2: Histograms of (a) H-parameter and (b) Scaled WAC 689-nm albedo for the section within Darney chi (white box in Figure 1d) and for nearby maria (red box in Figure 1d). (c) Nighttime regolith temperature for Darney chi (red circles), nearby maria (blue circles), and best-fit models for different values of H-parameter and albedo (colored lines).