SURFACE PHYSICAL PROPERTIES OF THE LUNAR REGOLITH AT REINER GAMMA: CHARACTERIZATION AND DISTRIBUTION USING HAPKE MODEL INVERSION.

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Introduction: The Reiner Gamma Formation (RGF), located in western Oceanus Procellarum, is an high albedo feature, forming swirl-like patterns, with no topographic expression. Its main part consists in a bright pattern of elliptical shape, located to the west of Reiner crater (A in Figure 1). From this central elliptical shape, bright elongated patches extend to the north-east in the Marius Hills region (B in Figure 1) and small swirls extend to the southwest (C in Figure 1)(see also [1]). The present study concerns a part of the central elliptical shape (red open box in Figure 1).

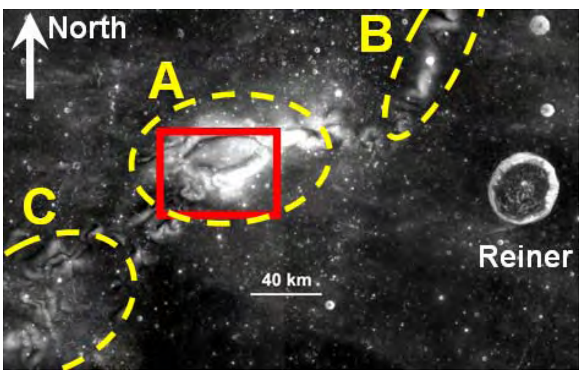

Figure 1. The Reiner Gamma Formation (RGF). The red open box is the region of study in the present work (see Figure 2).

The origin of RGF and other swirls occurring on the lunar surface (e.g., Mare Ingenii) is still unresolved. Given the fact that swirls are associated with magnetic anomalies and that some of them are antipodal to large impact structures, it was suggested that they correspond to magnetized crustal or iron-rich ejecta materials which deflect the solar wind, preventing surface materials to undergo maturation processes [2], thus producing a photometric anomaly. Another mechanism of formation invokes a modification of the superficial regolith structure due to a recent cometary impact [1]. In addition to composition, access to physical surface properties is critical to constrain the mechanisms of formation of the lunar swirls.

Method, data and analysis: Surface properties can be obtained through bidirectional reflectance multi-angular (phase function) observations and applying an inverse method using the Hapke semi-empirical photometric model [3,4]. which is the most adapted model for the case of planetary regolithic surfaces. Following previous investigations [3], the four Hapke parameters describing the phase function form (b-parameter), forward or backward scattering of particles (c-parameter), surface roughness (θ) and the single scattering albedo (w) have been determined and mapped for an area (~50x35km; 0.5km/pixel) located in the central part of RGF (Figure 1), using a unique and limited set of multi-angular observations (phase angles between 7° and 73°) obtained during the Clementine mission (for 900 nm wavelength). In the present study, azimutal dependence of illuminations conditions (incidence ranging from 7° to 32°), i.e., out of the emergence-plane, has been taken into account in the inversion. An image-cube containing the four Hapke parameters (b, c, θ and w) has been constructed and a principal component analysis (PCA) has been performed on this image.

Results: In the PCA analysis, four photometric units have been determined from two populations corresponding to two distinct clouds in the space of components. These units (MB, R1, R2 and R3) are shown in Figure 2. The first population is represented by the MB unit (blue in figure 2b). It spatially corresponds to dark surface materials lying outside the high albedo pattern forming RGF. The second population is represented by the units R1, R2 and R3 (respectively green, orange and red in figure 2b), which are associated to RGF itself (see figure 2a and 2b). A clear trend is observed in the behavior of the Hapke parameters when passing from R1 to R3, via R2: the values of the three parameters w, b and θ increase (respectively from 0.45 to 0.62; from 0.33 to 0.41 and from 17.4° to 26.9°; see figure 2c), while the value of the c-parameter decreases (from 0.64 to 0.32)(all the values given here are the mean values of the units shown in figure 2c). The MB unit is close to R1 unit for the w and θ values (0.44 vs 045 and 19.5° vs 17.4° respectively) and is intermediate between the R1 and R2 units for the b and c parameter (0.37 and 0.51 respectively).

Discussion: A previous PCA and iterative spectral mixing modeling using UVVIS Clementine data for a more extended area of RGF than in the present study has shown that the high albedo photometric anomaly of RGF does not reflect a change in composition but is due to the presence of exposed more immature materials relatively to their surroundings [1]. The MB unit spatially corresponds to the mature mare basaltic materials described in [1], forming the regional background of RGF. The R1 to R3 units spatially correspond to the gradational trend of the most immature materials described in [1] (R2 and R3 corresponding to the RGS unit in [1]). The trends found here for the values of the four Hapke parameters from the MB unit to the R3 unit (notably the increase of the single albedo w and roughness θ at the submillimetric to centimetric-decimetric scale [5]) indicate the presence, at RGF, of surface materials having an increasing degree of immaturity. For the units R2 and R3, the higher b values and the lower c values (c < 0.5, forward scattering) reveal the presence of an anisotropic behavior of the particulate medium, as it is expected for immature materials compared to mature materials [e.g., 6]. Most immature materials (R3 in red, figure 2) are related to the brightest and central portion of the swirls (compare figure 2a and 2b), indicating that the mechanism responsible for the occurrence of immature materials was the most efficient in these areas.

The R1 unit (green in Figure 2) departs from the trend going from mature (MB) to most immature (R3) mare materials, since it has lower b and θ values, and a higher c value than MB (Figure 2c). Spatially the R1 unit mostly occurs at the periphery of RGF between MB and R2 (respectively blue and orange in Figure 2b). However, it appears to be clearly related to the swirls of RGF, more exactly to their lowest albedo peripherical or intra parts. Also, the PCA shows that the R1 clearly belongs to the RGF materials cluster, forming a trend between R1 and R3. In that case it may represent the least perturbated materials within RGF. Alternatively the R1 unit may indicate the presence of fine mature materials corresponding to the finest fraction of the regolith being removed and deposited in some places during the formation of RGF. These materials, called SWS in [1], are mainly found in the southwestern part of RGF (C in Figure 1) and occurs mixed with MB around the swirls in the region under study (A in Figure 1)[1]. The presence of such materials may account for the low w and θ values (θ being lower than in MB) for the R1 unit.

Conclusion: Using a statistical analysis, photometric units, based on four Hapke parameters (b, c, θ and w), related to surface physical properties, have been mapped for a portion of the Reiner Gamma Formation. A direct approach of the Hapke model, assessing the reliability of the determination of the parameters (see [7]) produce results quite consistent with those presented here. Although the θ-parameter may be not well determined because small (<30°) incidence angles [8], we find values in the range of those measured in situ for the lunar regolith [6]. Besides, these results support the interpretation made from previous work [1]. This study emphasizes how useful forthcoming spot-pointing measurements by the Smart-1 spacecraft on specific lunar regions could be to constrain the mechanisms of formation of lunar swirls and other formations having specific materials (such as pyroclastic deposits) and/or resulting from regolith modifications.

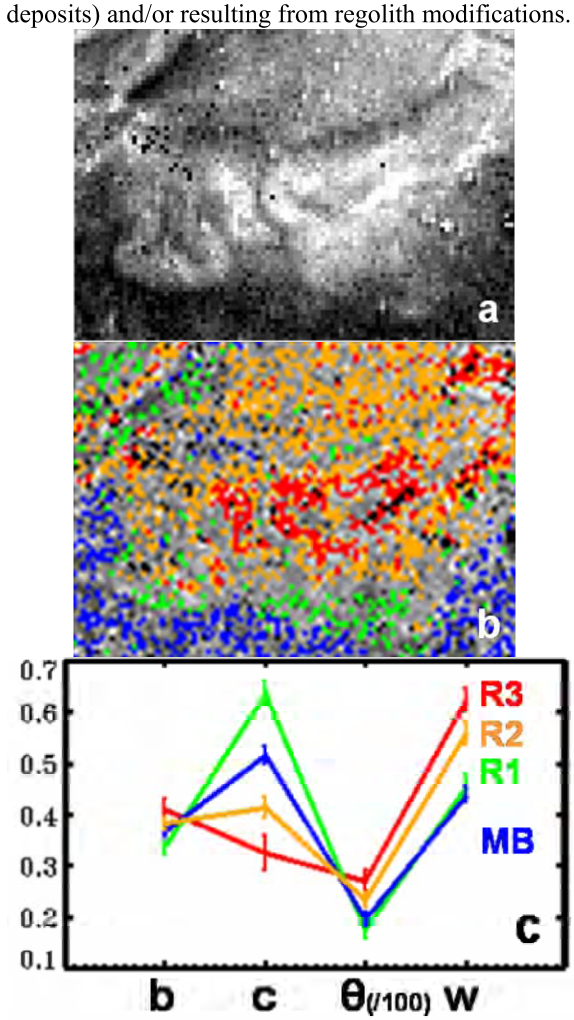

Figure 2: **a**. Map of the w-parameter for the area under study (see Figure 1 for the context); **b**. photometric units determined through the PCA (see text); **c**. Mean values of the Hapke parameters (b, c, θ and w) for each unit shown in b.

References: [**1**] Pinet et al. (2000) JGR, 105, 9457-9475. [**2**] Hood and Williams (1989) *LPSC 19th*, 99-113. [**3**] Pinet et al. (2004) *LPS XXXV,* Abstract #1660. [**4**] Pinet et al. (2005) *LPS XXXVI,* Abstract #1721. [**5**] Cord et al. (2003), *Icarus*, 165, 414. [**6**] Helfenstein and Shepard, 1999, *Icarus*, 141, 10. [**7**] Kaydash et al. (2006) *LPS XXXVII*, *this volume*. [**8**] Baratoux et al. (2006) *LPS XXXVII*, *this volume*.