REGOLITH ALTERATION PROCESSES AT REINER GAMMA SHED LIGHT ON THE FORMATION OF LUNAR SWIRLS.

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Introduction: Lunar swirls are curvilinear albedo markings of tens of kilometers size associated with magnetic anomaly regions but not related to distinct topography [e.g., 1-3]. Reiner Gamma (7.5° N, 59° W) is one of the best-known swirl features. It is located in western Oceanus Procellarum and is associated with a localized magnetic field. It is characterized as complex in morphology with extensive looping and combination of dark lanes and bright ribbons. It has been examined using observations at a variety of wavelengths [e.g., 2, 4-6]. Anomalous photometric properties were reported in several different studies [e.g., 7, 8]. An unusually weak absorption band near 3 µm was described in [3] for the bright part of Reiner Gamma.

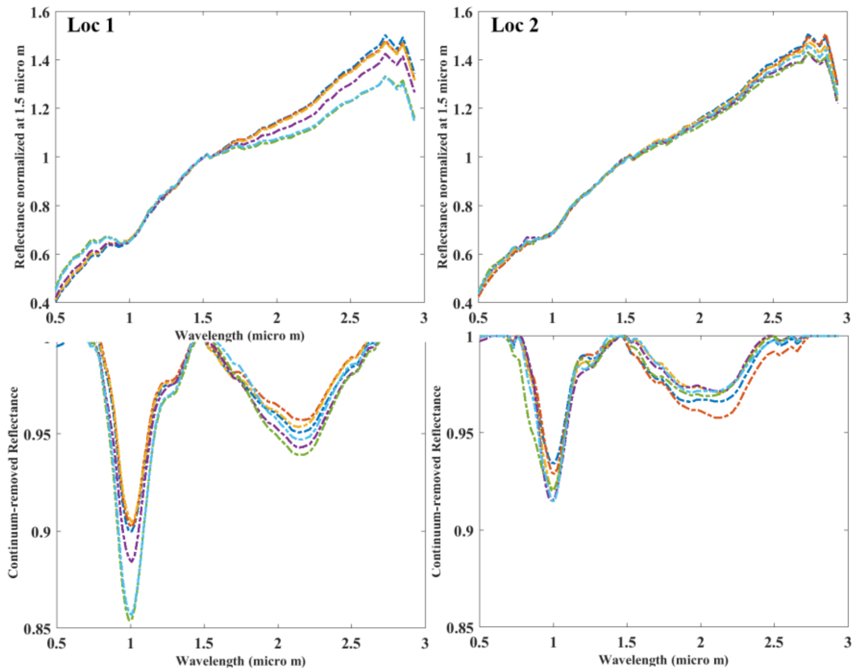

Fig. 2: Normalized reflectance and continuum-removed spectra extracted at the locations marked in Fig. 1. The spectra are color-coded according to their location in Fig. 1.

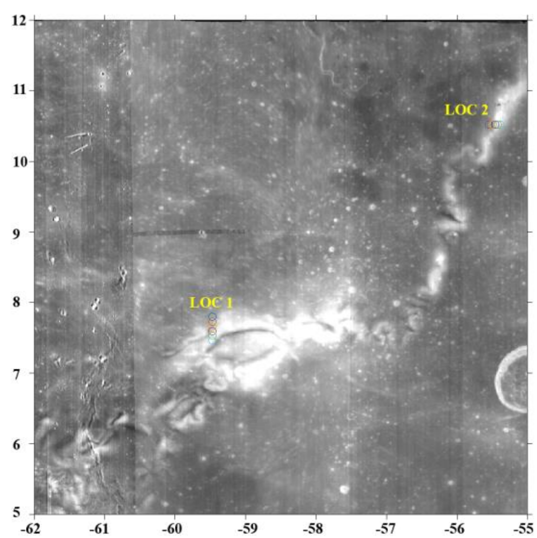

Fig. 1: M³ albedo mosaic (1.5 µm) of Reiner Gamma. The reflectance spectra of locations 1 and 2 are marked as LOC 1 and LOC 2, respectively.

Near-infrared (NIR) spectra of mare swirls are similar to those of immature mare material [e.g., 3]. Thus, as a possible formation mechanism the prevention of regolith space-weathering due to magnetic shielding has been proposed [5, 9]. Alternatively, swirls may have been formed by comet impact events [e.g., 10, 11] leading to interactions between regolith and cometary gas, such as regolith compaction [11].

In this study we examine the spectral variability across Reiner Gamma using hyperspectral image data acquired by the Moon Mineralogy Mapper (M^3) [12] instrument during the Chandrayaan-1 mission [13] and compare the observations with commonly observed maturation patterns as well as modeled compaction-related spectral behavior.

Methods and results: The M³ data were processed using the framework of [14]. We processed and combined a total of 13 individual M^3 images that define the study region shown in Fig. 1. Both sets of reflectance spectra in Fig. 2 extracted at LOC 1 and LOC 2 represent gradual changes in spectral characteristics. Although both selected locations are comparable in albedo, we find two different spectral trends possibly representing two different surface alteration processes. The data of LOC 1 in the central part of Reiner Gamma exhibit the typical spectral characteristics of fresh craters (increase in band depth and decrease in continuum slope) as we move from off-swirl to on-swirl soils. However, spectra extracted at LOC 2 show much weaker variations in 1-µm and 2-µm absorption band depth and continuum slope when moving from off-swirl to on-swirl soils. The largely invariable band center positions at both locations suggest compositional similarities between on-swirl and offswirl materials.

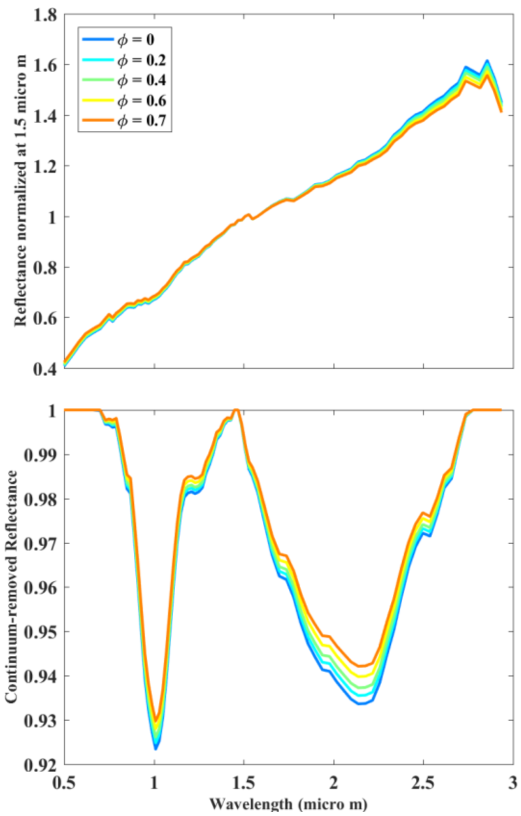

Fig. 3: Model spectra computed based on the M^3 spectrum of LOC 2 for different values of the filling factor ϕ, using the reflectance model in [16].

The reflectance function of regolith [15] has been linked to the regolith compactness in [16]. We selected the reflectance spectrum of the dark mare soil near LOC 2 (Fig. 1) and modeled its behavior for increasing compactness as described in [16] (Fig. 3). Fig. 3 shows that the continuum slope of the normalized spectra slightly decreases for increasing filling factor, i.e., increasing compactness, without significant variation of the band depths.

Discussion: The spectral characteristics of LOC 1 in the central part of Reiner Gamma are similar to those of surrounding fresh craters and could be the result of magnetic shielding [5] or, alternatively, the disruption of the uppermost regolith layer by cometary gas, exposing fresh regolith underneath [4]. Removal of the mature uppermost regolith layer was also proposed in [17] as a result of interaction between the Chang'e-3 landing rocket jet and the lunar surface, in order to explain the sequence of spectra acquired by the VNIS spectrometer on-board the Yutu rover at different distances from the landing site (which has a similar behavior as the LOC 1 sequence of spectra in Fig. 2).

The spectral behavior observed at LOC 2 cannot be accounted for by considering the solar wind shielding model only. In contrast to maturation, an increase in compaction changes the absorption band depths and the continuum slope only slightly while increasing the albedo significantly. To achieve the observed increase in albedo of swirl material relative to the surrounding mare surface, the model in [16] indicates that the filling factor of the regolith has to be increased from its normal value of 0.3 [16] to values around 0.5-0.6. These observations support the swirl formation mechanism suggested in [11] invoking an interaction of high-velocity cometary gas with the uppermost regolith layer, where in [11] the analogy with a landing rocket jet was proposed.

Conclusion: An analysis of M³ hyperspectral data of the lunar swirl Reiner Gamma indicates that two different locations of the swirl can be ascribed to two different predominant formation mechanisms, i.e., regolith compaction vs. absence of space-weathering.

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