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Regolith Compaction and its Implications for the Formation Mechanism of Lunar Swirls

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Abstract

In this study we have examined spectral trends of Reiner Gamma (7.5°N, 59°W) using the Moon Mineralogy Mapper (M^3) [1] observations. We derived maps of solar wind induced OH/H_2O and a compaction index map of the Reiner Gamma swirl. Our results suggest that the combination of soil compaction and magnetic shielding can explain the observed spectral trends. These new findings support the hypothesis of swirl formation by interaction between a comet and the uppermost regolith layer.

1. Introduction

Lunar swirls are high-albedo curvilinear markings correlated with crustal magnetism but not associated with distinct topography. These features are of specific interest because the geologic origin of these anomalies is still unknown. Swirls are commonly assumed to have formed due to magnetic shielding of the surface from the solar wind [2, 3]. Another plausible mechanism proposed is resurfacing due to one or multiple cometary impacts [4, 5, 6]. Reiner Gamma is one of the best-known swirl features. In this study, we report on a detailed spectral characterization of Reiner Gamma, analyzing OH/H_2O and compaction index maps in order to shed light on its formation mechanisms.

2. Data sets and Methods

We applied the thermal emission removal technique of [7] to level 1B M^3 radiance data processed and converted to absolute reflectance. In addition to M^3 spectral data, we used the map of magnetic flux density at 50 km altitude acquired by the Lunar Magnetometer on-board Kaguya [8] to infer the magnetic shielding effects on estimated surficial OH/H_2O (Fig. 1).

The brightening of the regolith at Reiner Gamma could be a result of reduced space-weathering due to magnetic shielding [3] and/or due to soil compaction [5]. According to the model of [9], the spectral variation due to soil compaction is a change in albedo with negligible effect on spectral slope and absorption band depths. To quantify soil compaction at Reiner Gamma, we empirically defined the compaction index c as a positive real number given by $c = M / RSE$, where M is the reflectance modulation at 1.579 µm between a bright on-swirl and a nearby dark off-swirl spectrum, and RSE is the root square deviation between the dark and the bright spectrum normalized to 1.579 µm reflectance, respectively. Small values of the compaction index correspond to a typical space-weathering trend, whereas large values indicate similarity to a spectral trend induced by compaction. The compaction index is insensitive to the difference in albedo between the on-swirl and off-swirl locations.

3. Results

The 3-µm band is slightly weaker at the swirl than on the surrounding surface (see [10]). Variations from local morning toward midday, indicating the amount of weakly bound OH [7], are significantly smaller for the swirl than for the surrounding surface (Fig. 2), in particular where the compaction index is small (Fig. 3). The compaction index map in Fig. 3 shows variations from the central bright oval part to the “tail” and the small “flower” structures. The weak 3-µm band and the small time-of-day-dependent variations of its depth are consistent with the assumption that the magnetic anomaly shields the lunar surface from solar wind protons [2, 3]. However, the spectral variations observed for high values of the compaction index cannot be explained by magnetic shielding alone and indicate the occurrence of an additional physical process.

4. Conclusion

To explain the swirl areas characterized by high values of the compaction index, we consider an "external" influence such as the interaction between the regolith and cometary gas as proposed by [5] as a plausible process. Alternatively, magnetic shielding may have prevented the formation of the highly porous "fairy-castle" structure [11] found elsewhere in the lunar regolith.

References

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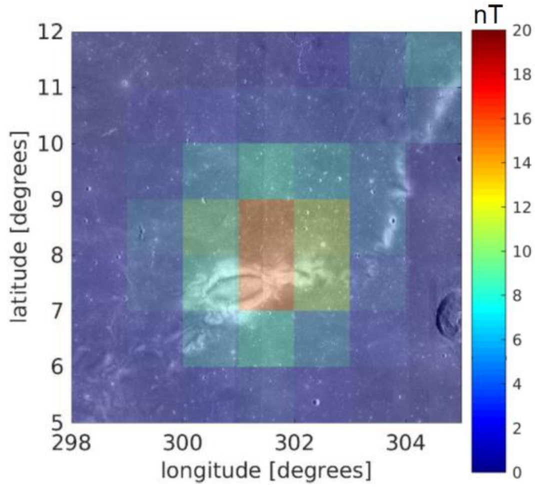

Figure 1: LROC WAC mosaic [12] of Reiner Gamma, overlaid by the Kaguya 50 km altitude magnetic flux density [8].

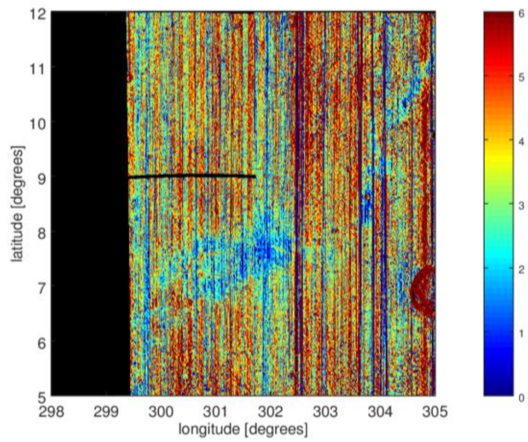

Figure 2: Difference in percentaged 3-µm band depth between morning (08:18) and midday (12:00).

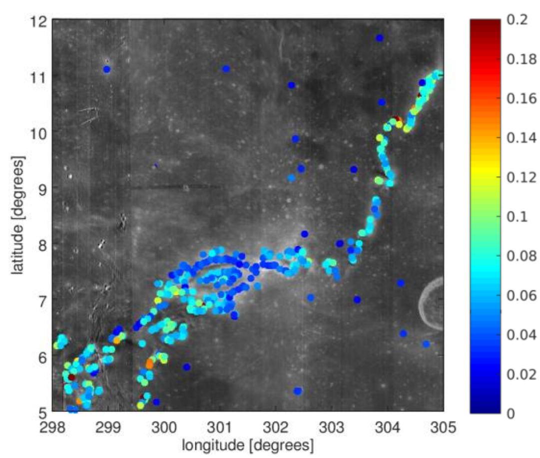

Figure 3: Map of the compaction index of Reiner Gamma, overlaid on the M³ 1.579 µm reflectance.