TOPOGRAPHIC CORRELATIONS WITHIN LUNAR SWIRLS IN MARE INGENII. D. L. Domingue¹, J. R. Weirich¹, F. C. Chuang¹, A. A. Sickafoose¹, and E. E. Palmer¹, ¹Planetary Science Institute, 1700 E. Ft. Lowell Road, Suite 106, Tucson, AZ 85719 USA (domingue@psi.edu).

Introduction: The Moon’s high-albedo markings, known as swirls, are defined by broad, bright, on-swirl areas separated by darker off-swirl lanes. Lunar swirls are associated with local crustal magnetic anomalies [e.g. 1, 2], although not all magnetic anomalies display swirls [3, 4]. Several processes have been proposed to explain swirl formation: (i) magnetic shielding of the surface from the solar wind [e.g. 1, 2, 5], (ii) levitation and transport of fine-grained dust through electrostatic charging [e.g. 6, 7], (iii) sorting and relocation of darker, magnetized materials [e.g. 8], and (iv) surface scouring by comet impacts [e.g. 9]. Each process has both supporting and contra-indicating evidence.

We have analyzed two areas in Mare Ingenii and find that the lunar swirls are a few meters lower on average than the surrounding regions (additional details in [10]). This correlation with topography argues for highly mobile dust transport across the lunar surface and could help illuminate the relative roles of the proposed swirl-formation processes.

Data: The Mare Ingenii swirls are located in the southwest corner of the Ingenii basin. Two study areas containing swirls, were chosen for detailed analysis (Fig. 1). Study Area A has a lower-contrast albedo boundary and Area B has a sharper, higher-contrast albedo boundary.

Digital elevation models (DEM) of the two study areas were created using Lunar Reconnaissance Orbiter Camera (LROC) narrow angle camera (NAC) images employing stereophotoclinometry techniques [11, 12]. Stereo heights were determined every 50-60 m and all other heights were determined by photoclinometry relative to the stereo height. DEMs of both study areas at 70-80 cm/pixel resolution (vertical and horizontal) were produced.

Regional slopes in both Study Areas were identified and corrected to prevent slope bias. Additionally, impact craters down to 50 m in diameter and other larger topographically distinct geologic features were masked from the data. As shown in Fig. 1, on- and off-swirl sub-regions were defined in each Study Area, based on the qualitative tonal differences in global LROC wide-angle camera imagery and NAC reflectance albedo data. We have recently incorporated new machine-learning techniques to quantitatively define on- and off-swirl locations [13].

For study area A, the stereo height error was ±1.36 m and there were 7.7M on-swirl points with two concentric off-swirl sub-regions, each containing 9.7M points. Study Area B had height error ±1.89 meters with 8.1M points on-swirl and 3.7M points off-swirl.

Figure 1. (top) Location of Study Areas A and B marked with red boxes, within the lunar swirls of Mare Ingenii (33.7º S, 162.5º E). (bottom) LROC wide-angle camera mosaics in which the locations of the defined on- and off-swirl sub-regions are denoted. Study Area A had sufficient coverage to allow definition of two, similarly-sized, concentric off-swirl sub-regions.

Analysis: To investigate the topography, we compared cumulative distributions between on-swirl and off-swirl locations within each study area (Fig. 2). We evaluated the statistical significance of the topographic differences in the sub-regions using Kuiper’s variant of the Kolmogorov-Smirnov (K-S) test. We then calculated the mean height for each sub-region, including propagation of the errors. The error on the mean height is a function of the inverse of the number of data points; therefore, the mean height of each sub-region achieves millimeter accuracy even though the errors on individual points are at a meter-scale. To quantify the difference in the mean heights between the sub-regions, we derived a confidence interval assuming independent samples with unknown but equal population variances. We used the Z score, based on the cumulative standard normal distribution, and report the difference in mean heights for a 95% confidence interval.

Results: Figure 2 demonstrates visually that the distributions of heights in the on- and off-swirl regions differ, with on-swirl being primarily lower than off-swirl. The K-S tests confirm at a confidence level of greater than four sigma that the on- and off-swirl topographic datasets are not drawn from the same samples at either Study Area. The mean heights for each sub-region are the following:
Study Area A  on-swirl = –3565.5997±0.0005 m  
off-swirl 1=–3563.2138±0.0004 m  
off-swirl 2=–3561.1242±0.0004 m

Study Area B  on-swirl= –3493.4499±0.0005 m  
off-swirl= –3490.8101±0.0007 m.

From the confidence interval analysis, the mean of the on-swirl heights in study area A is 2.386±0.005 m lower than off-swirl 1 and 4.475±0.005 m lower than off-swirl 2. These height differences imply a progressive decrease in elevation from off- to on-swirl in this Study Area. For Study Area B, the mean of the on-swirl heights is lower than the off-swirl, dark lanes by 2.640±0.004 m.

**Conclusions and future work:** By analyzing two areas containing swirls in Mare Ingenii, we find that the on-swirl sub-regions are on average 2-3 m lower than the surrounding terrain. This topographic trend supports the process of dust migration across the lunar surface being a contributing factor to swirl formation. Within these relatively lower swirls, the grain size and deposition process could form a more compact soil structure compared to the average lunar surface. This scenario is consistent with the swirl spectral and photometric properties [e.g. 14, 15]. Additional studies are needed to place boundaries on the relative roles of dust migration and other processes in creating the swirls.

Examination of other swirl regions will potentially clarify the correlation of regional topographic differences around swirls, especially in cases where these features appear on much steeper slopes and drape over impact ejecta. Future work will involve similar analyses in Reiner Gamma with archetypical examples of lunar swirls.

**Figure 2.** Cumulative frequency distributions of the heights in the defined on- and off-swirl sub-regions for Study Areas (left) A and (right) B. The color-shaded areas surrounding each cumulative frequency distribution line represent the height error bars: slight color variations indicate where error bars overlap.

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