EVIDENCE FOR THERMAL DEMAGNETIZATION OF THE MOON'S REINER GAMMA MAGNETIC ANOMALY.

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Introduction: Although the Moon no longer possesses a global magnetic field [1,2], localized magnetic anomalies are present its crust. While the magnetic fields of many of these anomalies have been well-measured, there is still no consensus on how the magnetized source bodies formed or what they imply about the nature and history of the lunar dynamo. Investigating the Moon's crustal magnetic anomalies may lead to insights into the Moon's thermal evolution [3,4], and possibly unusual dynamo generation mechanisms [5,6]. In pursuit of these insights, we perform a detailed study of the best available geophysical data around one of the Moon's most prominent magnetic anomalies: Reiner Gamma (Fig. 1). Reiner Gamma is a lunar swirl whose optical properties correlate with magnetic field structure [7,8]. Here we make use of a newly-discovered correlation between its optical features and topography to gain information about the distribution and evolution of the magnetic source bodies.

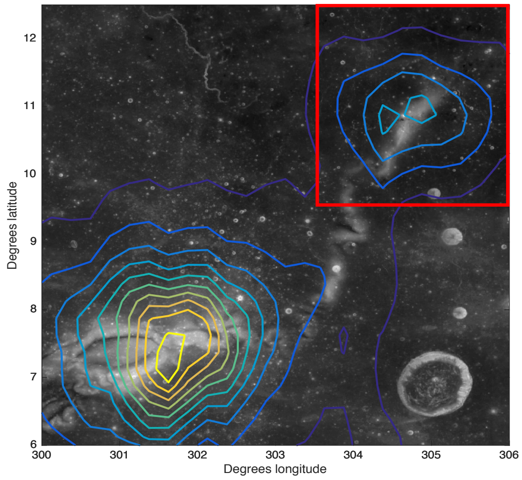

Fig. 1: A 750nm Clementine reflectance image of Reiner Gamma swirl, located at 7.5ºN, 59.0ºW. Contour lines indicate the magnetic field strength (maximum of 43nT). The red box indicates the area shown in Fig. 2.

Reiner Gamma: Reiner Gamma is found on the volcanic plains of Oceanus Procellarum [8]. The northeastern portion of the swirl, herein called the 'tail', extends towards the Marius Hills (Figs. 1 & 2). The Marius Hills are a topographically distinct volcanic region with the highest density of volcanic domes on the Moon [9]. Notably, the high-albedo regions of the swirl are not imprinted on the main body of the Marius Hills; the tail completely terminates at the topographic plateau that defines the region (Fig. 2). Furthermore, the swirl does not pass through the centers of three nearby volcanoes. Because swirl albedo changes are believed to form over millions of years [10], while lunar volcanism ceased billions of years ago, the anti-correlation between the albedo pattern and the volcanic structures is unlikely to be due to volcanic resurfacing that overprinted the characteristic swirl pattern. Therefore, the anti-correlation may be due to heat from the Marius Hills partially demagnetizing the tail source body. In the following material, we test this hypothesis further.

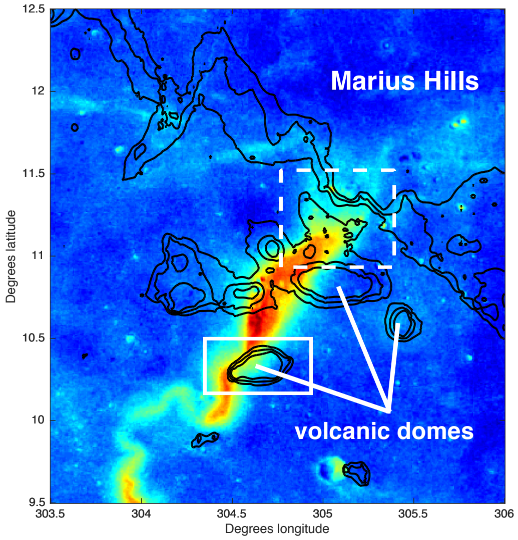

Fig. 2: Swirl spectral parameter β [10] with contours of topography overlain. The lowest/highest topography contours are -2700m/-2500m. The dashed-line white box indicates the area shown in Fig. 3, and the solid-line white box indicates the area shown in Fig. 4.

Correlation between topography and β: In this analysis, a spectral parameter called β is used in place of reflectance because β is designed to highlight lunar swirls. β is found using a ratio of both 750nm and 950nm reflectance values [10]. The topography data used here comes from the LOLA instrument [11].

A closer observation of the tail of the swirl shows that it terminates at the Marius Hills; the dashed-line white inset box (Fig. 2) highlights the area where the tail ends and the topographic plateau that defines the Marius Hills volcanic complex begins (Fig. 3). Two specific observations are: 1) the curvature of the topography at label A is matched by curvature in β (green to light blue pixels), and 2) higher values of β are slightly offset from the steepest slopes. The latter observation suggests that thermal energy from the Marius Hills complex was substantial enough to demagnetize the source bodies at some distance. This is in contrast to the shorter demagnetization length scale we infer at smaller volcanic domes, below.

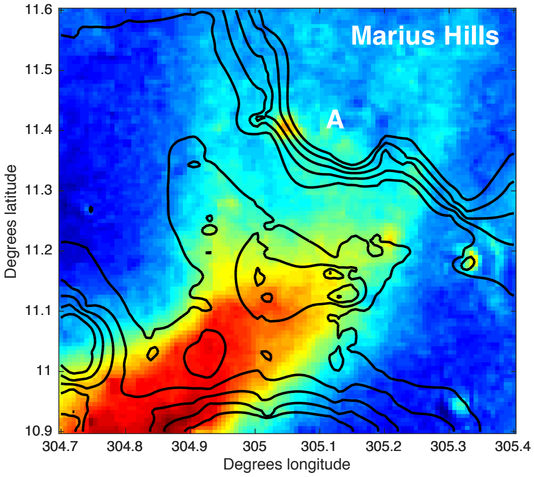

Fig. 3: Swirl spectral parameter β with contours of topography overlain for the second subset box shown in Fig. 1. The swirl appears to terminate at the main body of the Marius Hills.

A close observation of the curvature of part of the tail shows that it matches that of a small volcano's flank (Fig. 4), with low β values found at the highest elevations. Note that the lower topography contours overlap with the high β interior portions of the swirl. These lower topography contours likely represent material that originated from depth closer from the central region, and then flowed outward. If the source bodies are sufficiently buried and lie below the highest β pixels, we would not expect them to be demagnetized by such a superficial layer of hot material. In other words, the flanks of the volcanoes may show positive or no correlations with β, while the central portions of volcanoes, which were hot at depth, should always be anti-correlated with β.

We test the above relationship with a scatter plot of topography as a function of β for all pixels in the study area (Fig. 5). This comparison allows us to estimate the slope (topography divided by β) of pixel clusters that show correlation or anti-correlation. The red, orange, blue, and purple clusters of points at low β represent volcanoes that are unassociated with Reiner Gamma. In contrast, the grouping of green points at higher β represent a volcano that is adjacent to the tail: two distinct trends are clearly seen. These two trends represent the pixels that form a transect that runs northwest to southeast, labeled A/B (Fig. 4): moving along the line to the southeast, topography increases monotonically while β changes from dark (on the mare) to bright (on the swirl) back to dark again (on peak of the volcanic dome). If the volcano was randomly associated with the β pattern, we would not expect to see the β values decrease monotonically up to the highest topography.

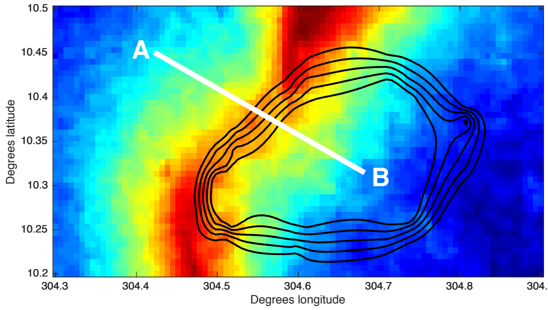

Fig. 4: Swirl spectral parameter β with contours of topography overlain for the subset box shown in Fig. 1. The curve of the swirl appears to follow the curve of the volcano flank.

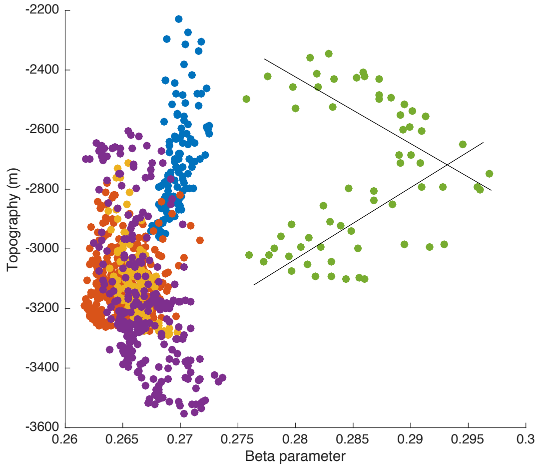

Fig. 5: β vs. topography. The groupings of points to the left represent four volcanoes distant from the swirl, and the green points to the right represent a volcano that is adjacent to the swirl (Fig. 4). Two sample linear fits showing different trends are shown in black.

Conclusions: Because Reiner Gamma appears to have been thermally demagnetized by intrusive volcanic bodies, we can rule out an origin related to the same volcanic event that produced the Marius Hills. This tentatively supports the hypothesis that Reiner Gamma may be a magnetized ejecta deposit.

References: [1] Weiss, B. P. and Tikoo, S. M. (2014) *Science, 346,* 1246753. [2] Tikoo, S. M. et al. (2017) *Sci. Adv., 3,* e1700207. [3] Stegman, D. R. et al. (2003) *Nature*, 421, 143. [4] Zhang, N. et al. (2013) *JGR* 118, 1789-1804. [5] Dwyer, C. A. et al. (2011) *Nature*, 479, 212. [6] LeBars, M. et al. (2011) *Nature*, 479, 215. [7] Hemingway, D. J. and Garrick-Bethell, I. (2012) *JGR*, E10, E10012. [8] Hood, L. L. and Schubert, G. (1980) *Science*, 208, 49. [9] Kiefer, W. S. (2013) *JGR*, 118, 733. [10] Hemingway, D. J. et al. (2015) *Icarus*, 261, 66-79. [11] Smith, D. E. et al. (2010) *GRL*, 18, L18204.