TESTING THE ANTIPODAL EJECTA MAGNETIZATION HYPOTHESIS: CLUSTERED MAGNETIZATION DIRECTIONS OF THE LUNAR GERASIMOVICH MAGNETIC ANOMALIES. R.E. Maxwell[1], I. Garrick-Bethell[1,2]. [1]Dept. of Earth and Planetary Sciences, University of California, Santa Cruz, Santa Cruz, CA, [2]School of Space Research, Kyung Hee University, Yongin, Republic of Korea.

Introduction: Lunar Magnetic Anomalies (LMAs) provide evidence for an early global lunar magnetic field. The mechanism for generating the lunar dynamo, however, is currently unknown [1-2]. Studying LMAs could therefore provide insight into the conditions of the early lunar interior. Indeed, LMAs have been used by a number of authors [3-5] to gain insight into the nature of the lunar dynamo, including its orientation and strength.

Some LMAs are nearly antipodal to large basins, suggesting these anomalies could be formed by shock remanent magnetism (SRM) as a result of the impact of ejecta in the presence of a dynamo or plasma-amplified interplanetary magnetic field [6]. In particular, the Gerasimovich anomaly is nearly antipodal to Mare Crisium, suggesting the Gerasimovich anomalies could be due to SRM acquired when Crisium formed [6,7]. Recent spherical harmonic models [8] show that the Gerasimovich LMA (Fig. 1) is five separate anomalies (Figs. 1b-e): with different geologic contexts [9]: a trio of strong anomalies in the south, and two additional moderate LMAs associated with two craters north of Gerasimovich (Fig. 1e) [9]. The origin of the southern trio of Gerasimovich anomalies (Fig. 1a) has been studied using Apollo data [10] and documented by [11-12], but lacks recent detailed analysis of the rock magnetization directions using Lunar Prospector or Kaguya data. One half of the pair of northern anomalies (Fig. 1e) has been studied [3], but not in parallel with the southern anomalies.

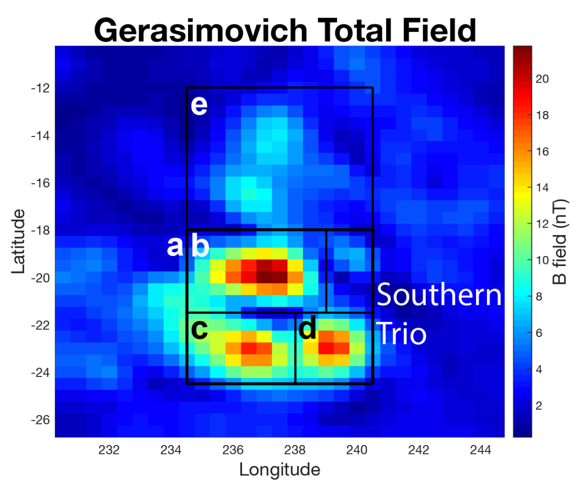

Figure 1. Magnetic field of the Gerasimovich anomalies at 30 km. The southern trio is labeled as (a) and the northern duo as (e). Within (a), there are three individual anomalies (b-d).

Determining the magnetization directions of these five LMAs at Gerasimovich could provide insight to whether its magnetization arises from a thermal remanent magnetism (TRM) or SRM [6]. Specifically, if the rock experienced an SRM, we would expect scattered magnetization directions across the five anomalies, since the ejecta would have likely remained in motion after acquiring its SRM upon initial contact.

Methods: A variety of methods [3-5,13-15,17] have been used to determine the best-fit magnetization direction of various LMAs. Here, we use a spherical harmonic model of the field at 30 km [8] in combination with Parker's Method [4, 14-15] to determine the best-fit magnetization direction of the anomalies in Figure 1. The source body is assumed to be unidirectionally magnetized. A grid of dipoles with uniform direction is placed on the surface of an area that encompasses the magnetic anomaly, and the magnetic moment of these dipoles may vary (Fig. 3). Error is calculated as the root mean square value of the difference between the Tsunakawa data and the model field (Fig. 2). For now, we defer quantifying the uncertainty on each inversion, and note that there is no community-wide agreed upon method of estimating the uncertainty of magnetization directions [16]. We then use the best-fit magnetization directions to determine paleopole locations for each of the anomalies (Fig. 4). We compare our results to the paleopole locations of the Mare Crisium LMAs

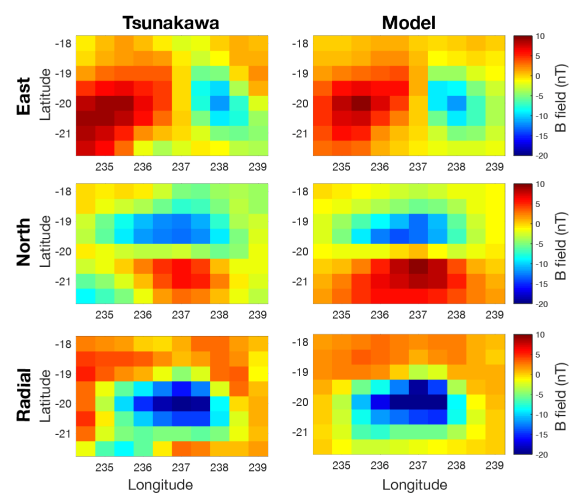

Figure 2. Magnetic fields from the Tsunakawa dataset and model based on the results from Parker's Method are shown for one anomaly (Fig. 1b), showing the east, north, and radial field components.

[17], the northern pair [3], and southern trio calculated from [10].

Results: The directions of the trio of southern anomalies are similar, with a maximum arc distance between the best-fit directions of 43.4°. However, the best-fit directions for the two anomalies in the craters to the north of Gerasimovich are 137.5° distant from the southern trio. The trio of stronger anomalies (Fig. 1a) are different from the results for Gerasimovich found by [10] by at least 89°, but we suggest that this discrepancy is due to improvements in the data used. The paleopoles of the weaker anomalies (Fig. 1e) plot closer to those of [3] (Fig. 4, dot e and green dots).

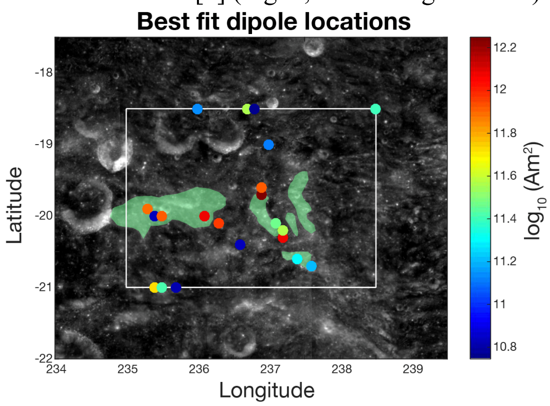

Figure 3. Location of the best-fit dipole locations for the solution shown in Fig. 2. Color bar shows magnetization strength. Translucent green indicates swirls. White box shows allowed extent of dipoles.

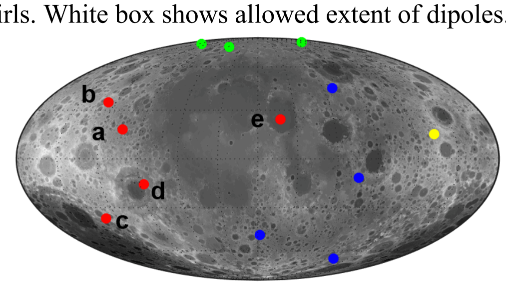

Figure 4. Paleopole locations of the Gerasimovich anomalies from this study (red) are labeled following Fig. 1. Also shown: paleopoles calculated from [10] (yellow), from the northern anomalies [3] (green), and from the Mare Crisium anomalies [17] (blue).

Discussion: The similarity of best-fit magnetization directions for the trio of southern Gerasimovich anomalies (Fig. 1a) and their proximity, suggests a similar formation mechanism. It is likely these anomalies formed through TRM in a long lived field, rather than SRM, since the source bodies would be shocked immediately upon impact, yet remain in motion (above). It is important to note that while this helps to rule out SRM as the formation mechanism, it does not rule out the antipodal ejecta hypothesis [7], as hot ejecta may have acquired a TRM. We also suggest that the difference in magnetization direction observed between the southern trio and northern pair of anomalies, and the latter's overall weaker magnetization, could be evidence for SRM there. That is, the northern pair may not be unidirectionally magnetized. Finally, the difference in directions between the southern trio and anomalies inside Mare Crisium [17] may be due to the difference in cooling timescales. The deeper Mare Crisium anomalies may have cooled over millions of years, while the Gerasimovich ejecta deposit would have cooled faster and thereby recorded a different field.

A need for low altitude data: When we compare the locations of the magnetic sources returned by Parker's Method, we find they do not correlate well with swirls in the area (Fig. 3). The area over which Parker's Method distributes the dipoles is much larger than the swirl area. Presently, the rock magnetization enclosed in the inversion area (Fig. 3) is 1.37 A/m, assuming a 1 km thick source, but could increase by at least an order of magnitude if the source is fully located within the swirls. Lower altitude data are needed to isolate the size and magnetization of the source [18]. If the source area of magnetization was localized to just the swirls, it could increase by a factor of ~20 to ~30 A/m, making large lunar fields (~10 µT) nearly inescapable, unless the source materials are quite exotic. Furthermore, lower altitude data at the northern anomalies would improve the inversion quality and help refine their actual magnetization direction, if it is unidirectional.

Conclusions: The similar magnetization directions of the southern trio of anomalies at Gerasimovich is compatible with acquisition of TRM at the Crisium antipode. The rock magnetization at these anomalies and magnetization direction(s) of the northern pair of anomalies remains unexplained.

References: [1] Weiss, B.P. and Tikoo, S.M. (2014), *Science, 346*, 6214. [2] Evans, A.J., et al. (2018) *Geophys. Res. Lett*. 45, 98. [3] Arkani-Hamed, J. and Boutin, D. (2014), *Icarus, 237*, 262. [4] Oliveira, J. S. and Wieczorek, M. A. (2017), *JGR, 122*, 383. [5] Nayak, M., et al. (2016), *Icarus, 286*, 153. [6] Lin, R.P. et al. (1988), *Icarus, 74*, 529. [7] Hood, L.L, and Artemieva, N. A. (2008), *Icarus, 193*, 485. [8] Tsunakawa, H., et al. (2015), *JGR, 120*, 1160. [9] Kelley, M.R. and Garrick-Bethell, I. (2019) *LPSC*, abstract 2071. [10] Hood, L.L (1982), *LPSC Proc. 12*, 817. [11] Hood, L.L, et al. (2001), *JGR, 106,* 27,825. [12] Blewett, D.T., et al. (2011), *JGR, 116*, E02002. [13] Hemingway, D.J. and Garrick-Bethell, I. (2012), *JGR, 117*, E10012. [14] Parker, R. L. (1991), *JGR, 96*, 16,101. [15] Lee, J.-K., et al (2019) *Icarus*, *319*, 869. [16] Maxwell, R.E., et al (2017) *LPSC* 48, abstract 2486. [17] Baek, S.-M., et al. (2019) *JGR,* in press. [18] Garrick-Bethell, I., et al (2019) *LPSC*, abstract 2786.