

# The Widespread Distribution of Swirls in Lunar Reconnaissance Orbiter Camera Images

Brett W. Denevi (1), Mark S. Robinson (2), Aaron K. Boyd (2), and David T. Blewett (1)

(1) The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, (2) School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA. Email: brett.denevi@jhuapl.edu.

## 1. Introduction

Lunar swirls, the sinuous high- and low-reflectance features that cannot be mentioned without the associated adjective “enigmatic,” are of interest because of their link to crustal magnetic anomalies [1,2]. These localized magnetic anomalies create mini-magnetospheres [3,4] and may alter the typical surface modification processes or result in altogether distinct processes that form the swirls. One hypothesis is that magnetic anomalies may provide some degree of shielding from the solar wind [1,2], which could impede space weathering due to solar wind sputtering. In this case, swirls would serve as a way to compare areas affected by typical lunar space weathering (solar wind plus micrometeoroid bombardment) to those where space weathering is dominated by micrometeoroid bombardment alone, providing a natural means to assess the relative contributions of these two processes to the alteration of fresh regolith. Alternately, magnetic anomalies may play a role in the sorting of soil grains, such that the high-reflectance portion of swirls may preferentially accumulate feldspar-rich dust [5] or soils with a lower component of nanophase iron [6]. Each of these scenarios presumes a pre-existing magnetic anomaly; swirls have also been suggested to be the result of recent cometary impacts in which the remanent magnetic field is generated by the impact event [7]. Here we map the distribution of swirls using ultraviolet and visible images from the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) [8,9]. We explore the relationship of the swirls to crustal magnetic anomalies [10], and examine regions with magnetic anomalies and no swirls.

## 2. Data and Methods

The WAC maps the Moon in seven filters from 321 to 689 nm [8]. Denevi et al. [11] found that WAC ratios isolate the steep ultraviolet slope (shortward of ~415 nm) common to fresh silicates, and thus delimit areas that are especially spectrally immature. WAC reflectance properties can also be used to separate

fresh plagioclase-rich materials from their shocked or glassy equivalent in the highlands. Lunar swirls are characterized by this steep UV slope [11], such that a WAC color composite (415 nm, 321/415 nm, and 321/360 nm in red, green, and blue, respectively) reveals their locations (e.g., Fig. 1). We used this WAC composite sampled at 400 m/pixel as the basis for our mapping, noting the locations and margins of the high-reflectance portions of swirls based on their UV ratios and 415 nm reflectance values.

## 3. Distribution of Swirls

The WAC-based map (Fig. 2) reveals a generally greater extent and higher concentration of lunar swirls than prior mapping that was based on albedo alone. For example, we find a higher concentration of swirls than previously observed [7] in the northwestern portion of the South Pole–Aitken basin (e.g., Fig. 1), so that the three previously identified swirl groupings at Hopmann, Ingenii, and NW of Apollo [e.g., 12] are clearly seen to be one continuous group of swirls. The distribution of swirls in that region is similar, but not identical, to the distribution of magnetic anomalies (Fig. 2). A higher concentration of swirls is also seen in the Marginis region, and the Marginis and Firsov swirls are also clearly observed to be one continuous group in the WAC map. Swirls that have not been previously

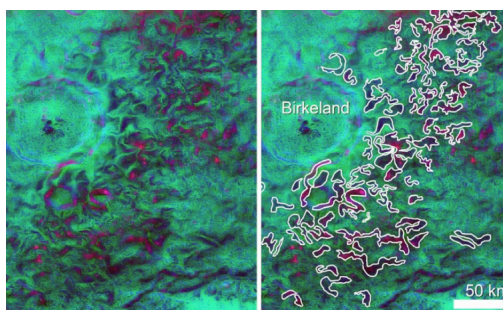


Fig. 1. WAC color composite (415 nm, 321/415 nm, 321/360 nm in red, green, and blue) where swirls appear blue-pink. Annotated version with swirls outlined on right. Scene centered at 31° S, 176° E.

recognized were found in the Crozier, Abel, and Dewar regions (Fig. 2). Each is associated with a local magnetic anomaly.

Nearly all major magnetic anomalies have associated swirls (Fig. 2). We examined the exceptions and found that several are obscured by fresh impact crater ejecta, (i.e., Tycho or Jackson craters), some are at high latitudes for which WAC ratio data is unreliable, and one has an associated bright diffuse patch (Descartes), as previously recognized [12]. However, there are several locations, the most prominent one to the northeast of the Orientale basin near Hartwig crater, where we find no evidence of a swirl in the WAC color composite nor a plausible cloaking mechanism.

For many of the swirls, the ultraviolet–visible color properties vary across the group. For example, in the Firsov and Gerasimovich regions, which vary little in terms of FeO content [13], the high-reflectance portion of swirls range from having a break in slope at 360 nm, consistent with fresh plagioclase-rich soil,

to having a strong downturn at 415 nm, indicating shocked or glassy soil of plagioclase-rich composition, suggesting variations spectral character consistent with those observed around fresh highland impact craters. We further explore the characteristics of the mapped swirls for comparison with predictions based on the proposed models of formation.

## References

- [1] Hood L.L. and Schubert G. (1980) *Science*, 208, 49–51.
- [2] Hood L.L. and Williams C.R. (1989) *LPSC 19*, 99–113.
- [3] Halekas J.S. et al. (2008) *PSS*, 56, 941–946. [4] Wieser M. et al. (2010) *GRL*, 37, L05103. [5] Garrick-Bethell I. et al. (2011) *Icarus*, 212, 480–492. [6] Pieters C.M. et al. (2014) *LPSC 45*, Abs. 1408. [7] Schultz P.H. and Srnka L.J. (1980) *Nature*, 284, 22–26. [8] Robinson M.S. et al. (2010) *Space Sci. Rev.*, 150, 81–124. [9] Boyd A.K. et al. (2012) *LPSC 43*, Abs. 2795. [10] Richmond N.C. and Hood L.L. (2008) *JGR*, 113, E02010. [11] Denevi B.W. et al. (2014) *JGR*, 119, 2013JE004527. [12] Blewett D.T. et al. (2011) *JGR*, 116, doi:10.1029/2010JE004656. [13] Lawrence D.J. et al. (2002) *JGR*, 107, 10.1029/2001JE001530.

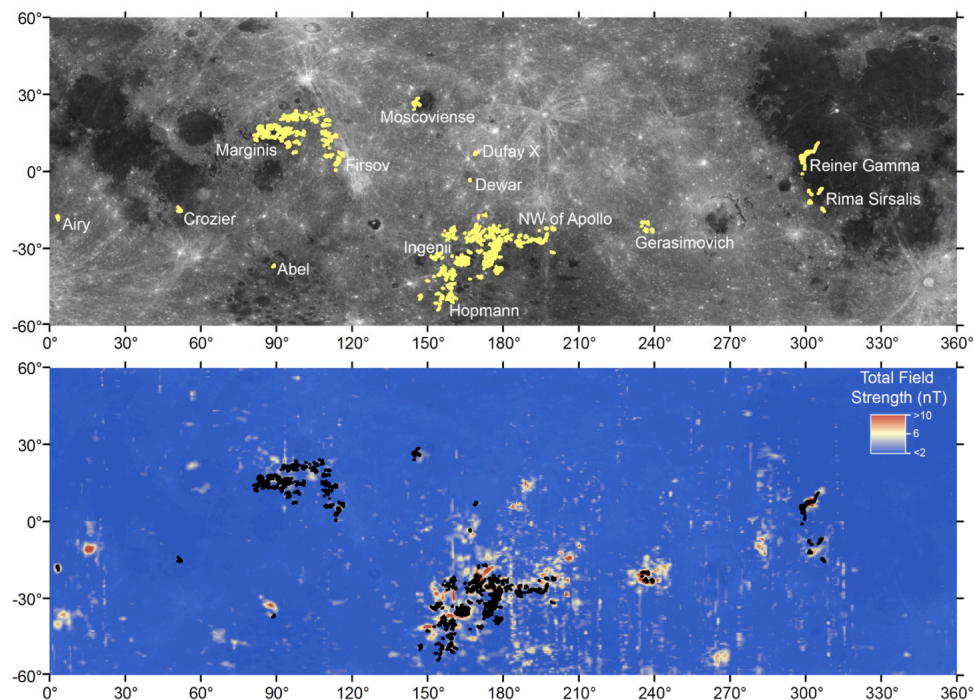


Fig. 2. Preliminary WAC map of lunar swirl locations, cropped to  $\pm 60^\circ$  latitude where WAC color ratio data is most reliable. Top: Swirls shown in yellow on a WAC 415 nm reflectance basemap. Labels correspond to regions examined by Blewett et al. [12], plus Dufay X and Dewar. Bottom: Swirls shown in black on a map of total magnetic field strength from Lunar Prospector [10]. Note that the outlines of swirls are shown in bold to make them more visible at this scale, thus features are slightly exaggerated in size.