LUNAR SWIRLS AND CRUSTAL MAGNETIC ANOMALIES: FURTHER EXAMINATION OF THE LINK. Ecaterina I. Coman[1,2], David T. Blewett[1], B. Ray Hawke[3], Jeffrey J. Gillis-Davis[3], and Michael E. Purucker[4]. [1]Johns Hopkins Univ. Applied Physics Lab., 11100 Johns Hopkins Rd., Laurel, MD, 20723 USA (david.blewett@jhuapl.edu), [2]Univ. of Maryland-Baltimore County, Baltimore, MD, 21250 USA, [3]Univ. of Hawaii, Honolulu, HI, 96822 USA, [4]Raytheon/NASA Goddard Space Flight Center, Greenbelt, MD, 20771 USA.

Introduction: This report presents additional results from our on-going study of the lunar swirls, their relation to lunar crustal magnetic anomalies, and the phenomenon of space weathering on airless rocky bodies of the Solar System [1-3].

Lunar swirls are unusual, high-albedo markings found in both the maria and the highlands [4, 5]. These sinuous patches sometimes exhibit dark lanes between bright segments. Swirls have no apparent topographic expression and appear to overprint the surfaces on which they lie. Several origins for lunar swirls have been proposed. These include surface effects produced during relatively recent (<1 My) impacts of meteor swarms [6], a comet coma and nucleus [5], or disrupted comet fragments [7]. Alternatively, the association between swirls and crustal magnetic anomalies has led to the hypothesis that the magnetic anomaly protects the surface from solar wind bombardment [e.g., 8]. Lacking solar wind sputtering and implantation, the swirl has not undergone the normal space weathering (soil-darkening) process to which unshielded areas are subjected [8, 9]. Thus it may be that the presence of a magnetic anomaly preserves a high albedo, even though a magnetically shielded surface would still experience micrometeoroid impacts. A number of magnetic anomalies are correlated with terranes antipodal to a major impact basin [e.g., 10], and the creation of a crustal magnetic anomaly may involve the amplification of existing fields by the expanding vapor-melt cloud produced in a lunar basin-forming impact [e.g., 11]. Very recently, a new swirl formation hypothesis invoking electrostatic dust transportation within a region of magnetized crust has been proposed [12].

We have examined several newly discovered magnetic anomalies and lesser-known swirl markings in order to provide new information on the nature of swirls and their link to crustal magnetic anomalies. The goals of the study are to: 1. Determine if unusual albedo markings are associated with selected magnetic anomalies. 2. Determine if a magnetic anomaly is present at a previously known but little-studied swirl.

Data: We employ a global map of lunar scalar magnetic field strength [13]. The data are based on *Lunar Prospector* magnetometer observations, and have been continued to a common altitude of 30 km. For comparison with surface features, portions of the map were converted to sinusoidal map projection and contoured, and the contour lines superimposed on *Clementine* UV-Vis images. The *Clementine* image cubes (200 m/pixel) used for morphological and spectral analysis are calibrated to reflectance and were obtained from the U.S.G.S. Map-A-Planet website.

Abel: Richmond and Hood [14] reported a relatively strong magnetic anomaly near the crater Abel. The *Clementine* image and magnetic contour map in Fig. 1 show the peak of the anomaly to be centered at ~32° S, 88° E, on a highland promontory between Abel, Barnard and the northern portion of Mare Australe. The anomaly's maximum strength is just over 16 nT. The origin of the magnetized crustal material here is uncertain. No recognized basin is antipodal to this location. The highland units present are Nectarian-age mantled and cratered terra [15]. Richmond and Hood [14] noted that no swirl-like albedo markings were previously mapped at this location [15]. Our examination of *Clementine* and *Lunar Orbiter* images found no clear examples of high-albedo patches similar to those found at other swirl locations. No sinuous markings are present on the various mare units near the magnetic anomaly. A few bluish, high reflectance streaks can be seen on the highlands, but they appear to be portions of long ray segments that cross the area. No Airy-type highland loop/dark lane features [2] are present.

Hopmann: Hopmann crater (88-km-diameter, 50.8° S, 160.3° E), is located in the farside highlands in an area of poor coverage by *Lunar Orbiter* photographs. Of Nectarian age [16], Hopmann has a flat, mare-flooded floor, a small central peak remnant, and terraced walls. The Lunar Photo of the Day for 23 July 2007 drew attention to a small swirl on the southeastern floor in the form of a narrow, tightly sinuous, high-albedo ribbon visible in the *Clementine* images (Fig. 2A, 2C). In addition, we point out an Airy-type [2] elongated loop with a dark lane found on the highlands just outside the crater's northeastern rim (Fig. 2B), and other potentially anomalous high-reflectance markings on the north and northwestern rim and wall.

The magnetic contour map (Fig. 2) shows three peaks with values >6 nT in the vicinity of Hopmann: one immediately to the north, one to the northeast, and one to the northwest. The field intensity over the floor swirl is in the range 3-6 nT and at the rim Airy-type loop the intensity is 6-9 nT. Additional nearby high-albedo patches are found on the floor of Garavito Y and crossing Chretien S and W. The Hopmann swirls, as well as these additional markings, could be related to the major Mare Ingenii (Imbrium basin antipode) swirls that lie to the north. Thus, the analysis demonstrates that the Hopmann swirls are located in an area of elevated crustal magnetism.

Discussion: As part of our ongoing study of lunar swirls, we have examined a variety of crustal magnetic anomalies and swirl-like albedo markings. We have identified swirl-like patterns associated with the well-studied Rima Sirsalis magnetic anomaly (not shown here). The Rima Sirsalis magnetic and albedo anomaly may represent an extension of the famous Reiner Gamma magnetic anomaly/swirl occurrence. The recently identified Abel magnetic anomaly does not appear to have related unusual albedo markings. A newly recognized swirl at Hopmann crater is located in an area of moderately magnetized crust.

Based on the examples presented here and a more comprehensive survey underway [17], it appears that all swirl-type albedo markings are associated with areas of magnetized crust. However, not all strong magnetic anomalies harbor unusual albedo patterns. The orbital magnetic measurements are averages over relatively large areas. Therefore, swirls found in areas of weak magnetism (as seen in the orbital data) may actually have much greater field strength at the surface. Our findings are generally consistent with a swirl origin by atypical space weathering caused by magnetic deflection of the solar wind [9]. The apparent lack of lunar-like swirls on Mercury [3] is evidence against the comet-impact origin of lunar swirls, since comets should also strike Mercury. Solar wind bombardment (rather than micrometeoroid impact) is thus likely to be the primary agent of space weathering on the Moon. We are conducting spectral studies of regolith maturation trends within and outside of the magnetic anomalies in order to further characterize the space weathering process.

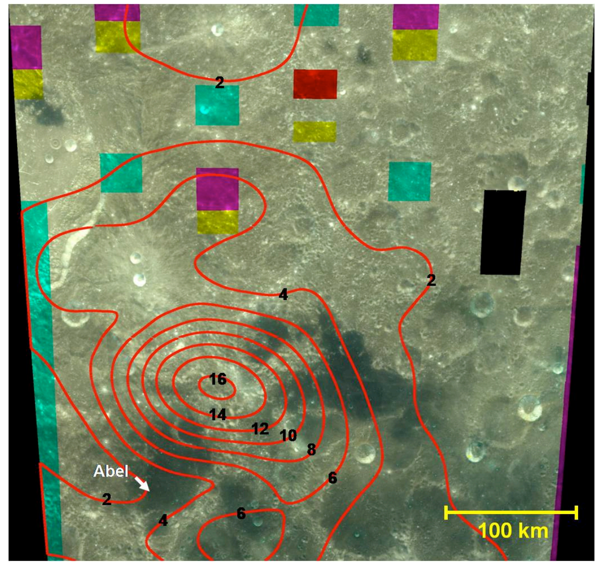

Fig. 1 (top of 2nd column)**. Abel.** *Clementine* color composite image of 950-750-415 nm as R-G-B, with contours of *Lunar Prospector* magnetic field strength. Sinusoidal projection with image center at 30° S, 90° E.

References: [1] D. T. Blewett et al. (2005), *JGR 110*, E04015. [2] D. T. Blewett et al. (2007), *GRL 34*, L24206. [3] D. T. Blewett et al. (2010), *Icarus*, in revision. [4] F. El-Baz (1972), *Apollo 16 Prelim. Sci. Rep., NASA SP-315*, 29-93. [5] P. H. Schultz and L. J. Srnka (1980), *Nature 284*, 22. [6] L. V. Starukhina and Y. G. Shkuratov (2004), *Icarus 167*, 136. [7] P. C. Pinet et al. (2000), *JGR 105*, 9457. [8] L. L. Hood et al. (2001), *JGR 106*, 27825.

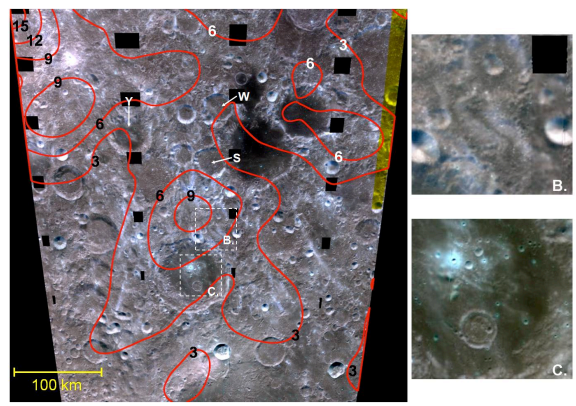

Fig. 2. Hopmann. *Clementine* color composite image with contours of *Lunar Prospector* magnetic field strength in nT. Sinusoidal projection with center at 48.5° S, 160° E. "S" = Chretien S, "W" = Chretien W, "Y" = Garavito Y. Dashed boxes show area of insets B and C.

References, cont.: [9] L. Hood and G. Schubert (1980), *Science 208*, 49; L. Hood and C. Williams (1989), *Proc. LPSC 19th,* 99. [10] R. P. Lin et al. (1988), *Icarus 74*, 529; N. C. Richmond et al. (2005), *JGR 110*, E05011. [11] L. L. Hood and N. A. Artemieva (2008), *Icarus 193*, 485. [12] I. Garrick-Bethel et al. (2009), AGU Fall Meeting. [13] M. Purucker (2008), *Icarus 197*, 19. [14] N. C. Richmond and L. L. Hood (2008), *JGR 113*, E02010. [15] D. E. Wilhelms and F. El-Baz (1977), *U.S.G.S. Map I-948*. [16] D. E. Wilhelms et al. (1979), *U.S.G.S. Map I-1162*. [17] B. R. Hawke et al. (2009), AGU Fall Mtg.; D. T. Blewett et al. (2010), *JGR*, in preparation.