Optical Maturity and Magnetic Studies of Lunar Swirls. C. G. Hughes[1], D. T. Blewett[2], B. R. Hawke[3], and N. C. Richmond[4], [1]Dept. of Geology and Planetary Science, Univ. of Pittsburgh, Pittsburgh, PA 15260 USA, cgh1@pitt.edu; [2]NovaSol, 733 Bishop St., 28th Floor, Honolulu, HI 96813 USA, dave.blewett@nova-sol.com; [3]Hawaii Inst. of Geophysics and Planetology, Univ. of Hawaii, Honolulu, HI 96822 USA; [4]Inst. of Geophysics and Planetary Physics, Scripps Inst. of Oceanography, Univ. of California at San Diego, La Jolla, CA 92093 USA.

Introduction: Lunar swirls are sinuous bright markings that occur in all types of geomorphic units on the Moon [1] (Fig. 1) and perhaps on Mercury [2]. Swirls often include dark lanes, low albedo features that are in between or parallel to the bright swirls. Most lunar swirls are also associated with magnetic anomalies. The Moon does not at present have a strong global magnetic field and lacks an atmosphere. As a result, the lunar surface is subjected to solar wind flux and micrometeorite bombardment. This "space weathering" darkens and reddens regolith exposed on the surface [e.g., 3]. Local magnetic fields may protect areas from the solar wind, reducing space weathering and hence preserving the high albedo of swirls [4]. However, some workers have questioned whether the existing magnetic anomalies can provide significant shielding over geologic time [5]. If the magnetic shielding model of swirl formation is correct, swirls could be very old features dating from the creation of magnetic anomalies related to formation of the major impact basins [4]. In this case, swirls have experienced abnormal space weathering because of the standoff of the solar wind, while micrometeorite bombardment continued. Alternately, if swirls are young features produced by cometary or meteoroid swarm impacts [2, 5], their optical properties may be indicative of a young age. We have undertaken an optical and magnetic examination of swirls to determine if their characteristics are more consistent with one or the other model of formation. Improved knowledge of the properties of swirls may also aid in our understanding of the processes of space weathering.

Data and Methods: Seven swirl areas were chosen for study (Table 1). Clementine UV-Vis images were obtained for each area. Several spectral parameter images were constructed from the calibrated UV-Vis data, including OMAT, a measure of optical maturity largely independent of composition [6], the 415-nm/750-nm (UV/Vis) ratio, a measure of relative color controlled by both composition and maturity, and FeO and TiO_2 maps [7].

For six of these seven Clementine areas, matching Lunar Prospector (LP) magnetometer data from the low-altitude portion of the mission was processed. Two versions of the LP magnetic anomaly maps were prepared, one to provide the highest spatial resolution for a given site, and one continued to a common altitude of 35.5 km. The continued data was prepared using an inverse power method [8, 9], with a constant power of 1.5. The high-resolution data offers the most detail for study of an individual site, while the common altitude maps permit intercomparison of field strength between sites. Layers were then overlain so that a comparison could be made between the magnetic data and the UV-Vis image products on a geographic basis.

Regions of interest (ROIs) were defined in each of the seven areas examined, using a Clementine base image. ROIs of four types were chosen. Swirl ROIs were defined by selecting the brightest portion of lunar swirls, with an attempt to exclude fresh craters or crater ejecta within the ROI. Dark lane ROIs were defined by selecting the darkest areas adjacent to bright swirl patches. Two ROI types, located away from the swirls and outside the strongest portion of a magnetic anomaly, were used as references. Fresh ROIs were defined on bright crater ejecta. Mature ROIs were selected from surrounding relatively level background areas. All ROIs were located to minimize or eliminate portions where data was missing from one of the five Clementine bands. Between 13 and 17 ROIs were selected in each area. Average values of the spectral parameters and magnetic field strength were extracted for each ROI.

Findings and Discussion: An interesting case is that of a feature near Airy, a degraded highland crater located at 18.1° S, 5.7° E. The feature is an elongated curved bright area with a central darker lane(Fig. 2). This marking, while not possessing the complex swirl morphology of the Reiner Gamma Formation (RGF, the type lunar swirl), is more swirl-like than an albedo anomaly in the Descartes formation south of the Apollo 16 site that is co-located with a magnetic anomaly [8, 10]. The Airy feature has not, to our knowledge, been previously described as a swirl. The LP data continued to 35.5 km altitude show that the maximum total magnetic field strength at this location is ~7 nT, very close to the maximum strength at the RGF.

Similar to a study [10] of the Descartes albedo feature, we are examining color (UV/Vis ratio) and OMAT trends within a single swirl location and among the study group. Preliminary findings are that all swirls have high OMAT values, consistent with fresh material. Swirls are also bright in UV/Vis ratio images, indicating relative "blue" color.

If anomalous space weathering is taking place within a magnetically shielded area, then this may be detectable with the Clementine spectral parameter images. For example, if micrometeorite impact vaporization produces small (<5 nm) Fe particles that are primarily responsible for spectral reddening while implanted solar wind H promotes the formation of larger (>10 nm) Fe blebs in impact-generated melts that mainly cause darkening [11], we may be able to identify spectral characteristics that are suggestive of anomalous weathering (i.e., weathering by micrometeorite impact alone).

References: [1] F. El-Baz (1972), *Apollo 16 Prelim. Sci. Rep. NASA SP-315*, 29-93. [2] P. Schultz and L. Srnka (1980), *Nature 284*, 22. [3] B. Hapke (2001), *JGR 106,* 10039. [4] L. Hood and C. Williams (1989), *Proc. LPSC 19th,* 99. [5] L. Starukhina and Y. Shkuratov (2004), *Icarus 167*, 136. [6] P. Lucey et al. (2000), *JGR 105*, 20,377. [7] P. Lucey et al. (2000), *JGR 105*, 20,297. [8] N. Richmond et al. (2003), *GRL 30*, 1395. [9] N. Richmond et al. (2005), *JGR 110*, E05011. [10] D. Blewett et al. (2005), *JGR. 110*, E04015. [11] S. Noble and C. Pieters (2003), *Sol. Syst. Res. 37*, 31.

Table 1. Lunar Swirl Names, Locations, and Sizes

Swirl Name / Location	Latitude, deg	Longitude, deg	Antipode	Areal Extent (km^2)
Airy Crater	-18.0	5.7	n/a	1300
Apollo Basin area	-25.0	-165.0	Serenitatis	275
Gerasimovich	-22.9	-122.6	Crisium	10,000
Mare Marginis	13.0	84.0	Orientale	50,000
Mare Moscoviense*	26.7	144.0	Humorum	35
Reiner Gamma	7.9	-59.0	n/a	10,000
Van de Graaff / Mare Ingenii	-27.4	172.2	Imbrium	10,000

*Only high altitude magnetic data available.

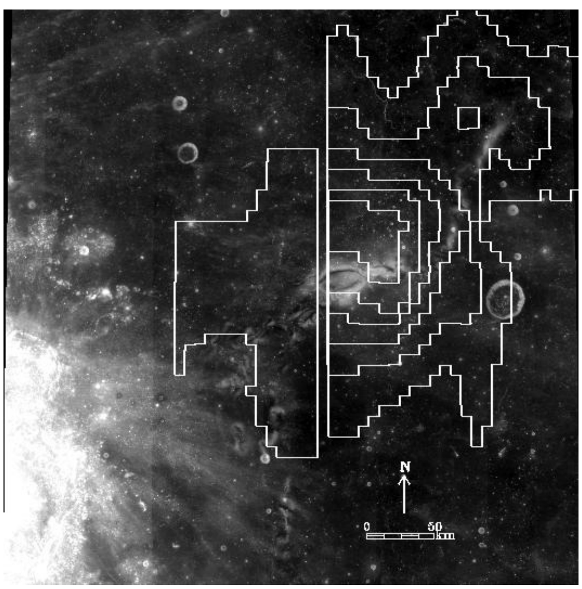

Figure 1. Clementine 750-nm mosaic of the Reiner Gamma Formation lunar swirl, with 1 nT contour lines based on the total strength of the magnetic anomaly at 35.5 km altitude. The maximum contour line is 6 nT. Reiner Gamma is the type occurrence of a lunar swirl. This swirl appears to correlate with regions of the strongest magnetism.

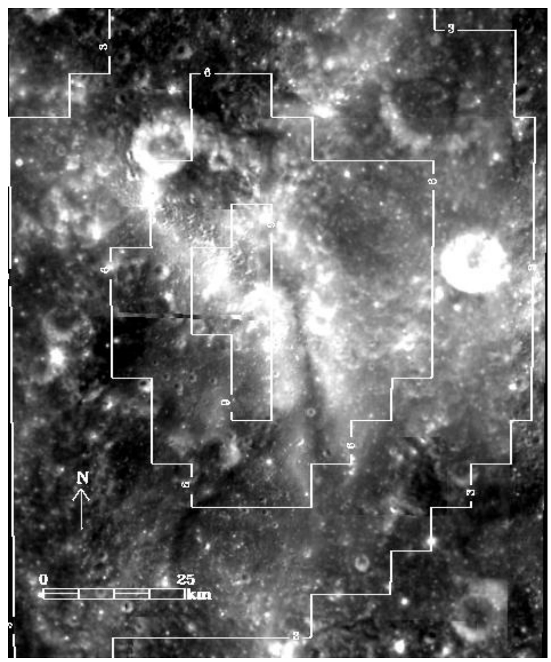

Figure 2. Clementine 750-nm mosaic of a bright swirl-like marking west of Airy crater, with 3 nT contour lines based on the total strength of the magnetic anomaly at 27.9 km altitude. The bright crater near the right center is Argelander D, ~11-km diameter.