EVOLUTION OF *MATURE* SOILS AT LUNAR SWIRLS.

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Introduction: With their high albedo and association with prominent local magnetic anomalies, lunar swirls are sometimes thought to represent soils that have not weathered relative to surrounding terrain. However, modern imaging spectrometer data (e.g., M^3) show that swirls do easily not fit into a classical low space weathering model. Their continuum slope is always sloped toward longer wavelengths and mafic absorptions (if present) are weak except near craters [compare Fig. 1A and 1B]. At swirls within basaltic mare, relatively immature soils exposed by craters (on and off swirls) are bright but tend to disappear when imaged at wavelengths in the middle of a pyroxene absorption. The swirls are unaffected, indicating a fundamental difference between bright swirls and unweathered soil. This disappearance of fresh craters is illustrated in the example M^3 image of terrain near Reiner Gamma shown in Fig. 2.

A distinct difference between bright swirls and immature soils becomes apparent as imaging spectrometer data enables more detailed analyses than previous spectral parameters and allows full spectroscopic information to be evaluated in spatial context. What has been learned is that swirls are brighter than surrounding terrain not just at visible wavelengths (where most mapping is performed), but at *all* wavelengths into the near-infrared (Fig. 1B). This is simply not seen in normal space weathering where accumulation of $npFe^0$ darkens the soil preferentially toward shorter wavelengths, imparting the 'red-slope' to the continuum (Fig. 1A) [1].

Resolution of the swirl enigma is most likely linked to the near-surface magnetic environment associated with swirl terrain, including a pattern of 'mini-magnetospheres'. Early Apollo analyses by J. B. Adams and T. B. McCord recognized that the complex and dark agglutinates that dominate optical properties of soils contained abundant microscopic metallic iron. They prepared magnetic separates of a suite of Apollo soils hoping to separate the agglutinate component in the magnetic separate for study [2]. Although it was later recognized that some agglutinates (with minor metallic iron) are also found in the 'non-magnetic' separate, the resulting spectra of natural lunar soil separates (e.g., Fig. 1C) provide a new option for understanding optical properties of swirls. It is proposed that a traverse across a swirl (Fig 1B) documents a process in which magnetic components (with abundant metallic Fe) that naturally form in a mature soil gradually migrate out of an area and into what are now dark lanes of a swirl, effectively leaving a brighter low-magnetic component behind. Normal soil gardening initiates migration, local magnetic field components provide grain direction, and time gradually completes the process creating the patterns we observe.

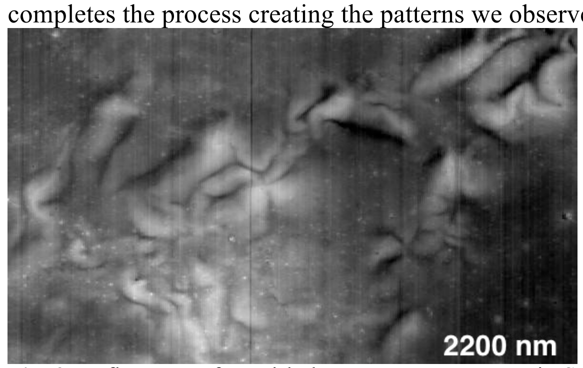

Fig. 2. Reflectance of a swirl cluster across mare terrain SW of Reiner Gamma as imaged by M^3 at 2200 nm. Since this wavelength is in the middle of a pyroxene absorption band, immature basaltic soils (e.g., at craters) become largely invisible, leaving only the swirl (see Fig. 1A,B). [FOV is ~50 km]

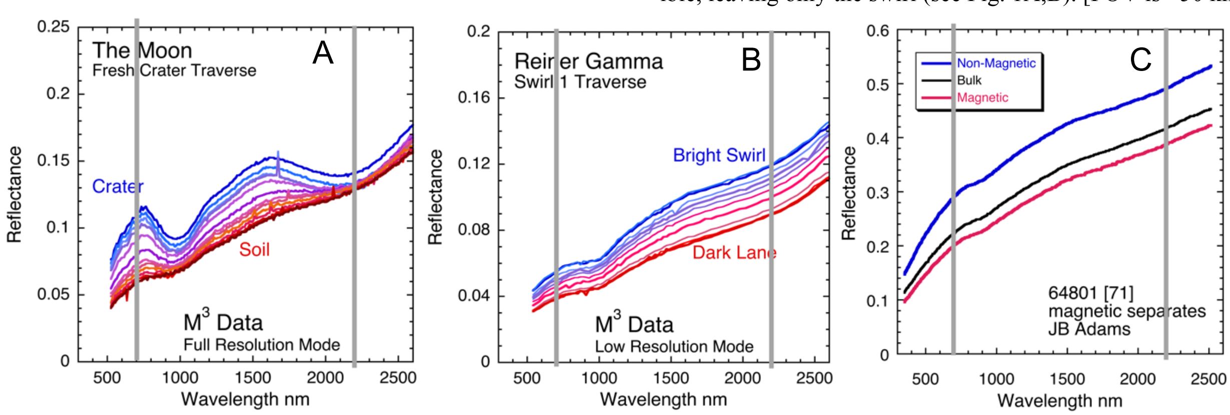

Fig. 1. Near-infrared remotely sensed spectra of lunar areas [A & B] compared to laboratory spectra of lunar samples [C]. Grey vertical lines are provided for reference at visible wavelengths (700 nm) and near the center of a common lunar pyroxene absorption (2200 nm). [A] M^3 spectra of a traverse across a fresh crater into surrounding mature soil. [B] M^3 spectra of a traverse across a swirl of Fig 2. [C] Directional hemispheric spectra of magnetic separates of a mature Apollo 16 lunar soil by J. B. Adams [2].

References: 1] Noble et al., 2007, *Icarus*. Pieters & Noble 2016 *JGR*, 121. [2] Adams and McCord, 1973, *PLSC4th*, *GCA*.