HYDRATION VARIATIONS AT LUNAR SWIRLS. C. M. Pieters[1], I. Garrick-Bethell[2], [1]Department of Earth, Environment, and Planetary Sciences, Brown University, Providence, RI 02912 [Carle_Pieters@brown.edu], [2]Univ. California, Santa Cruz.

Introduction: All of the mysterious albedo features known as 'lunar swirls' are associated with magnetic anomalies [1]. The origin of these features remains enigmatic, but is expected to be tied to the origin of the magnetic anomalies themselves. Although it has long been thought that the high albedo of the features is due to 'immature' or unweathered soils, recent analyses of the Moon Mineralogy Mapper (M^3) data show this can not be the case [2]. Figure 1 is an illustration of the decoupling of swirl albedo and 'immature' mare soils. Currently, the best explanation for the albedo variations appears to be magnetic sorting of well developed soils containing Fe^0 [3,4]. Although the local magnetic field thus does not affect the development of lunar space weathering products, it has been suggested that it deflects significant amount of solar wind H to cause variations in the OH content of surface soils [5]. The spatial variations of OH as detected by the relative strength of the OH/H_2O feature at 2.8 µm is the focus of the M^3 swirl analyses reported here.

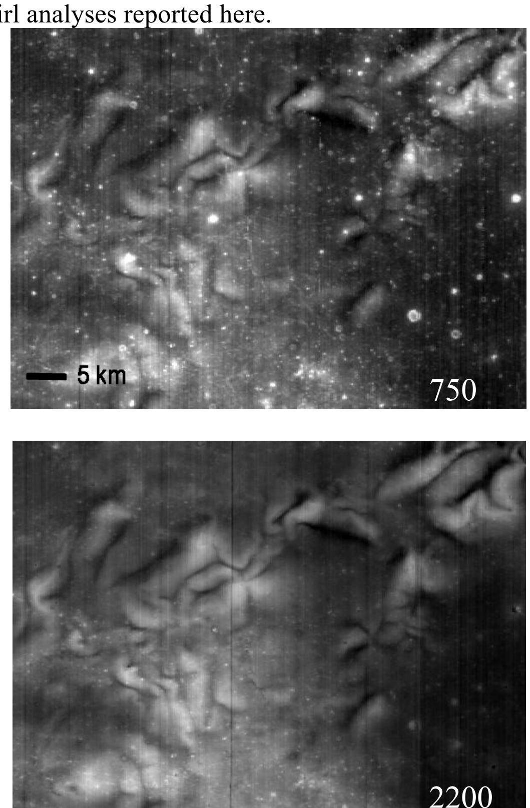

Figure 1. Calibrated M^3 reflectance data for a mare area SW of Reiner Gamma: [Top] 750 nm, [Bottom] 2200 nm. Because 2200 nm is in the middle of a pyroxene absorption band, immature basaltic soils tend to disappear relative to surroundings. The high albedo swirl markings are quite different from immature soils exposed at mare craters.

M^3 Target data for the 2800 nm OH feature. Almost all M^3 data acquired by Chandrayaan-1 was in the 'Global', or low resolution, mode in order to complete global coverage within limited time. Nevertheless, a few passes of full resolution 'Targeted' data were acquired when not conflicting with other mission requirements. M^3 Target data has 300 spectral channels resulting in 10 nm spectral resolution at 2800 (compared to 40 nm for Global data) and has x 4 better spatial resolution. Fortunately, one such pass covered an area of swirls in the Marginis region at good viewing geometry and modest S/C temperature.

A traverse of spectra from a dark lane into a bright swirl is shown in Figure 2 for the same Marginis highland area from Target and Global data. The location of the traverse is shown in the image of Figure 3. The Global data for the region was acquired first during Optical Period 2 and the Target data about a month later. The Global data currently do not contain the 'Ground Truth' correction which improves the 1 µm region [6]. The almost uniform increase in brightness observed across all wavelengths is typical of swirls.

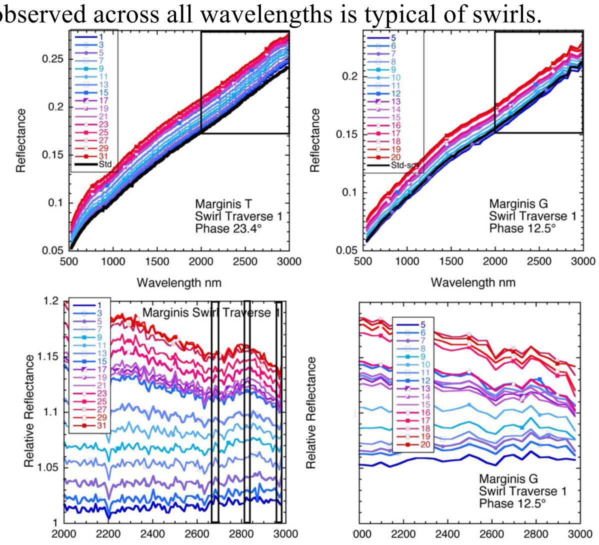

Figure 2. M^3 data with standard calibration for a traverse across a Marginis swirl.: Left-Target; Right-Global; Top-Reflectance; Bottom-Reflectance relative to a non-swirl standard area (shown in black). The boxes are the portion of the spectra shown in the bottom relative reflectance. The three vertical lines are wavelengths (averaged over three channels) used for band strength calculation of Fig. 3.

Relative reflectance spectra (bottom of Fig. 2) are often prepared in order to suppress systematic calibration artifacts found in spectra. All spectra are divided by the spectrum of a standard area obtained under the same measurement conditions. For these Marginis data an undisturbed non-swirl background area of soil to the north of Fig.3 was selected. Its spectrum (shown in black in Fig 2) superimposed on the swirl spectra suggests the dark lanes are very similar to surrounding mature soils. Variations in continuum slope are more easily recognized in the relative reflectance: the bright swirls are relatively 'bluer' [or 'flatter'] than the dark lanes and surroundings. In spite of the measurement and calibration challenges encountered by M^3 [7], the fundamental properties of the swirl areas can be seen in both Global as well as Target M^3 data. Nevertheless, this comparison with full resolution Target data underscores the actual data quality had M^2 been able to fully operate as intended.

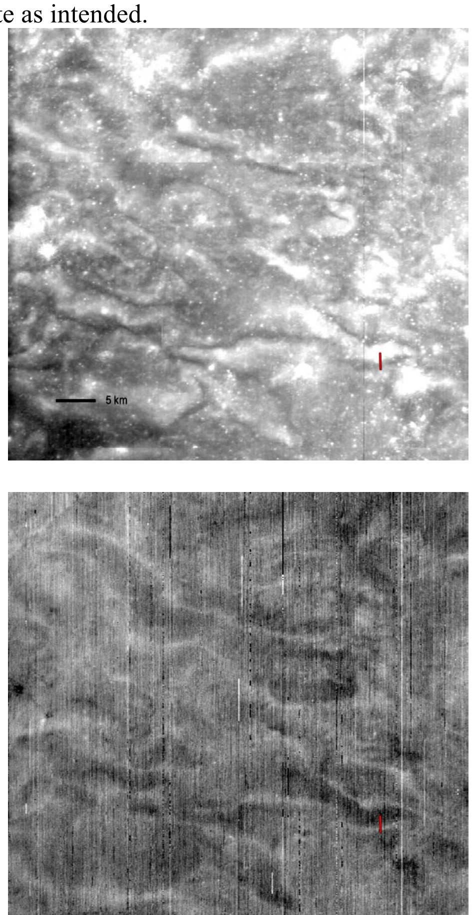

Figure 3. M^3 Target data for a Marginis swirl-rich area in the highlands. Top: 755 nm sub-image. Bottom: Band depth parameter image for the strength of the 2800 nm OH absorption (dark is weak band). The small red line is the location of the traverse in Fig. 2. Variations in OH band strength is distinct across the swirls, but small (<2%).

Currently, the M^3 Target data across some of Marginis swirls are the best spectroscopy data available for any swirl, and they allow the character of the 2800 nm OH absorption to be examined in detail. In order to minimize undesirable artifacts in the spectra, calibration of M^3 data was also necessarily linked to measured properties across the Moon and a lower limit of thermal removal [6, 8, 9]. This resulted in a red-sloped, but near featureless average background highland soil, especially from 2000-3000 nm. Global data, however, include significantly more residual artifacts than Targeted data as seen in Fig. 2 (Top).

Although not shown here, background highland soil, as well as non-swirl bright soils in the Marginis region of Target data, exhibit featureless spectra 2500-3000 nm. The upward concave feature centered near 2800 nm observed for the high albedo portion of the swirl traverse of Fig. 2 indicates the high albedo portion has a weaker absorption (negative feature) than the dark lane. The magnitude is ~2%, although the specific swirl in the traverse has one of the weakest OH features of the region (Fig. 3). This indicates the dark lanes and background soils have up to 2% stronger OH absorption than the bright swirls.

Conclusions.

- As predicted from preliminary M^3 Global data [5], variations in OH are confirmed to exist across swirls with improved calibrated data. High albedo areas have the weakest OH absorption and the dark lanes have the strongest. Reliable measurement of weak lunar OH bands is best performed with high spectral resolution data.

- Since bright swirls have a weaker OH absorption than surrounding mature highland soils (featureless in current calibration), the latter, lunar bulk soil, must have an undetected 1-2% OH absorption band.

- If solar wind H is the primary source of surficial OH, the pattern of OH absorption and anti-correlation with swirl albedo markings is highly suggestive that the local magnetic field has an effect on the interaction of solar wind H with surface materials, deflecting it more from the bright swirl areas.

- Lunar swirls are excellent targets for further exploration to constrain the relative rates of OH production, thermal desorption, photodesorption, and photodissociation, all of which are critical to fully explain lunar surface water processes [10]. Example first-order measurements include low-altitude (< 3 km) measurements of the 3D solar wind flux over the bright and dark portions of swirls at high spatial resolution (~1 km), coupled with direct measurement and orientation of the local magnetic field.

Acknowledgements: SSERVI support (NNA14AB01A)

References: [1] Blewett et al., 2011, JGR 116, E02002 [2] Pieters et al. 2014 LPSC45-1408; 2014 AGU P11D-10 [3] Pieters et al., 2015 JGR in preparation [4] Adams and McCord, 1973, PLSC4th [5] Kramer et al., 2011, JGR 116, E00G18 [6] Isaacson et al., 2013, JGR 118, 369-381 [7] Boardman et al., 2011, JGR 116, E00G14 [8] Lundeen et al.2011, M3 PDS Doc., DP-SIS [9] Clark et al. 2011, JGR, 116 E00G16 [10] Garrick-Bethell et al., 2015, LPSC46 (these volumes)