NEW DATA ON THE EFFECTS OF CHEMISTRY, MINERALOGY, GRAIN SIZE, AND MATURITY ON UV-VIS REFLECTANCE SPECTRA AND IMPLICATIONS FOR LROC WAC-DERIVED TiO_2. Ecaterina O. Coman[1], Bradley L. Jolliff[1], and Paul Carpenter[1]. [1]Washington University in Saint Louis, 1 Brookings Dr., Saint Louis, MO 63112 USA (ecatcom1@gmail.com)

Introduction: Titanium concentrations have been used to classify lunar basalts, determine the composition of the lunar crust and spatial variations in mantle compositions, characterize surface volcanism [1], and map ilmenite content as a potential resource for extraction of oxygen and solar-wind gases [2, 3]. Ultraviolet (UV) to visible (VIS) spectral ratios and derived values correlate with TiO_2 concentrations in lunar soils, allowing for an empirically derived determination of TiO_2 content on the lunar surface from remote measurements [1-9]. To first order, empirical correlations can delineate high-TiO_2 soils from low-TiO_2 soils, but deviations in data limit detailed interpretations [6, 7].

Variations in lunar soil spectral response result from differences in chemical composition, soil maturity, grain size, and specific mineralogy of the soils. Differences in spectra resulting from these parameters, in turn, affect UV/VIS ratios and TiO_2-derivation algorithms.

Photometrically well-calibrated global UV coverage from the Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC) [10] at ~400 m/pixel provides additional data for analyses of lunar surface TiO_2 contents. TiO_2 determination using the correlation between UV/VIS ratios and landing site soil TiO_2 contents improves when using LRO WAC data compared to Clementine data [9]. Here we present laboratory measurements aimed at better understanding the effects of maturity, chemical composition, mineralogy, and grain size of soils on UV-VIS reflectance spectra and the UV/VIS ratio and to better understand the correlation observed for TiO_2 and WAC UV/VIS ratios.

Methods: We have done coordinated analyses of laboratory X-ray powder diffraction, energy-dispersive micro-XRF, and UV-VIS spectroscopy on a suite of 13 lunar soils of well-known composition and maturity to compare mineralogy, chemistry, maturity, and grain size effects on the reflectance of the soils. These soils cover a range of TiO_2 concentrations and maturities (defined using I_S/FeO) [11, 12]. The same 25 mg sample aliquots were measured throughout all experiments to ensure consistent relationships and avoid variations that could result from the use of different subsamples of soils.

"Bulk" samples, as used here, consist of soil samples with grain sizes less than 210 μm. We also wet-sieved several size fractions for samples 10084, 70181, and 71501 (100-210, 48-100, 20-48, and <20 μm).

XRD and XRF Analysis: Analyses of lunar soil samples using X-ray diffraction and X-ray fluorescence determined mineralogy and chemistry, respectively. Here we use measured ilmenite proportions and TiO_2 concentrations. Details of the XRD and XRF data collection and methodologies are as stated in [14].

UV-VIS Reflectance: An Ocean Optics Jaz spectrometer with a 2048 element CCD detector and 200 Hz frequency pulsed xenon light source was used to obtain bi-directional reflectance measurements of the lunar soils with fiber optics fixed at 30 degree incidence and 0 degree emission. We collected reflectance spectra from 250-700 nm using the Ocean Optics Spectra-suite software.

TiO_2 and Maturity: We observe consistent trends in spectral response with TiO_2 contents and maturity (measured as I_S/FeO [12]). To first order, for similar TiO_2 contents, increasing maturity leads to decreasing reflectance values (Fig. 1a), and for similar maturity values, soils with higher TiO_2 contents have lower reflectance (Fig. 1b). In Fig. 1b, soil 76501 likely plots at higher reflectance values than 72501 because 76501 is less mature than 72501.

Similar to previously published findings [15, 16 and references therein], these results indicate that increasing maturity decreases overall sample reflectance, and increasing TiO_2 content (which is related to ilmenite content) decreases the UV-VIS spectral slope and increases the 320/415 spectral ratio [e.g., 1 and subsequent investigations].

Grain Size Effects: Sieved size fractions show systematic variations, but the differences in reflectance from the bulk soil spectrum (Fig. 2) are small compared to differences in composition and maturity. On the other hand, reflectance of a crushed subset of the bulk 70181 soil is significantly higher, resulting from the generation of fresh grain surfaces. From these results, we conclude that composition (in this case, TiO_2 or ilmenite content) and maturity control reflectance to first order.

Chemistry and Mineralogy: The XRD data show small but systematic increases in ilmenite content with decreasing grain size (Fig. 3). This trend is consistent with analyses of grain mounts from [17] but counter to trends obtained by [18, 19]. Because ilmenite content increases in smaller grain sizes, one might expect the UV/VIS spectral slope to be higher for the <20 μm grain size fraction. Instead, this fraction has the lowest UV-

VIS slope (Fig. 2). However, I_S/FeO also increases with decreasing grain size [18,19], implying that reddening and attenuation of absorption features caused by space weathering effects have a greater impact on reflectance spectra with decreasing grain size than the increase in ilmenite content.

UV/VIS Ratio: For samples with similar TiO_2 but different maturities, 320/415 ratio ranges from 0.78 to 0.93 (Fig. 1a). For samples with similar maturity but different TiO_2, 320/415 ratio ranges from 0.81 to 0.93 (Fig. 1b). The 13 samples examined show a wide range of 320/415 ratios. These ratios are poorly correlated with TiO_2, with an R^2 value of 0.27 (Fig. 4, all points). When immature samples with I_S/FeO <40 are excluded (orange points), ratios of remaining submature to mature samples show an improved correlation to TiO_2 and an R^2 value of 0.86 (Fig. 4, blue points). This correlation is consistent with that from [9] found using LRO WAC spectra.

We also examined various ratios other than 320/415 (360/645, 360/605, 360/565, 360/415, 320/645, 320/605, 320/565) but found the 320/415 value to give the best correlation when using the submature to mature soil subset.

Conclusion: Space weathering appears to have the greatest effect on UV-VIS spectra of soils with grain sizes below 210 µm. LRO WAC data and our laboratory data show a similar correlation between UV/VIS ratios and TiO_2 concentrations because LRO WAC, on average, detects mature soils at ~400 m/px resolution.

References: [1] Charette, M. P., et al. (1974) J. Geophys. Res. 79, 1605-1613; [2] Johnson, J., S. Larson, and R. Singer (1991a), J. Geophys. Res.–Planets 96, 18861-18882; [3] Johnson, J. R., et al. (1991b) Geophys. Res. Lett. 18, 2153-2156; [4] Blewett, D. T., et al. (1997) J. Geophys. Res. 102, 16319-16325; [5] Giguere, T. A., et al. (2006) Meteorit. Planet. Sci. 35, 193-200, 2000; [6] Gillis, J. J., et al. (2003) J. Geophys. Res. 108, 10.1029/2001JE00 1515; [7] Gillis-Davis, J. J., Lucey, P. G., Hawke, B. R. (2006) Geochimica et Cosmochimica Acta 70, p. 6079-6102; [8] Robinson, M. S., et al. (2007) Geophys. Res. Lett. 34, L13203; [9] Robinson, M.S., et al. (2011) Lunar Planet. Sci. 42, #1842; [10] Robinson, M. S., et al. (2010) Space Science Reviews 150, 81-124; [11] Meyer, C. (2012) Lunar Sample Compendium, NASA Johnson, Houston; [12] Morris, R. V., et al. (1983) *Handbook of Lunar Soils*, NASA Johnson Space Center, Houston; [13] Pieters, C. M. (1978) Lunar Planet. Sci. 9, 2825-2849; [14] Carpenter, P.K., et al. (2014) Lunar Planet. Sci. 45, Space Center, Houston; [15] Pieters, C.M., et al. (2000) Meteorit. Planet. Sci. 35, 1101-1107; [16] Cloutis, E., et al. (2010) Lunar Planet. Sci. 41, #1139; [17] Kong, W. G., et al. (2013) Icarus 226, 891-897; [18] Taylor, L. A., et al. (2001a) J. Geophys. Res. 106, 27985-28000; [19] Taylor, L. A., et al. (2001b) Meteorit. Planet. Sci. 36, 285-299.