MULTISPECTRAL POLARIZATION MEASUREMENTS OF EIGHT LUNAR SOILS.

P. G. Lucey[1], C.I. Honniball[1,2], R. Brennan[3], L. Burkhard[2], E.S. Costello[1,2], M. Sandford[1,2], L. Sun [1,2], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA, lucey@higp.hawaii.edu; [2]Dept. of Geology and Geophysics, University of Hawaii, Honolulu, HI, USA; [3]Dept. of Chemistry, University of Hawaii, Honolulu, HI, USA

Introduction: Polarization is a fundamental property of light that can provide new insight into the surfaces of planetary objects. Separation of polarized components can shed light on the properties of grain surfaces, now known to be a critical aspect of space weathering, and the interior of grains that may contain more fundamental compositional information. Shkuratov and co-workers [1-4] have shown in a series of papers the unique contribution of polarization to lunar studies using laboratory measurements of lunar samples, lunar analog materials and telescopic observations of the Moon. Recently, Jeong et al. [4] reported extensive multispectral polarization telescopic observations, deriving hemispheric grain size distribution maps and drawing conclusions regarding the differential effects of space weathering on the mare and highlands.

The Korean Pathfinder Lunar Orbiter, a lunar satellite in development by the Korean Aerospace Research Institute, will carry POLCAM, a multispectral imaging polarimeter to lunar polar orbit that will provide unprecedented global and high resolution polarimetry measurements.

These advances led us to conduct imaging polarization measurements of a series of lunar soils for which we have extensive chemical and mineralogical analysis. The eight samples cover the entire range of lunar iron and titanium contents, and for each composition we include a very mature and a very immature sample (Table 1). Our measurements were collected at a phase angle of 90 degrees, near the largest excursion of linear polarization. At this angle the differences between surface scattering and internal scattering enhanced by polarization is at its maximum[4].

Methods: We constructed an imaging polarimeter to collect data in three wavelengths, 430, 656, and 750 nm, near wavelengths used by POLCAM or Shkuratov et al. [4]. The instrument consists of an unpolarized illuminator, a sample stage, a continuously adjustable linear polarizer, a filter wheel, reimaging optics, and a CCD camera. Data were normalized to a Spectralon target. The Spectralon reference shows weak polarization in raw data, so we removed this effect from the final polarized reflectance data.

Sample No.	Is/FeO	TiO2 (wt%)	FeO (wt.%)	Type
10084-97	78.0	7.5 - 8.8	15.8 – 15.9	High-Ti mature mare
12033-52	4.60	2.5	14.2	Low-Ti immature mare
14003-12	66.0	1.7 – 1.8	10.3 – 10.5	Mature mafic highland
14141-21	5.70	1.6	10.2 – 10.4	Immature mafic highland
15013-103	77.0	1.7 – 2.0	14.8 – 15.0	Low-Ti mature mare
67711-58	2.80	~1	3	Immature highland
69961-135	92.0	~1	5.8	Mature highland
74241-4	5.10	7.4 – 8.6	14.7 – 15.8	High-Ti immature mare

Table 1

Results: For each soil and wavelength, data were collected at ten polarization angles. These data were then fit with a cosine to ensure the maximum and minimum polarizations were captured. An example of the reduced reflectance data is shown in Figure 1.

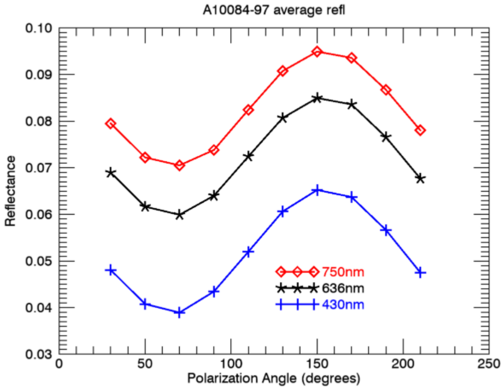

Figure 1 . Calibrated reflectance vs. polarization angle for sample 10084 at 430, 636, and 750 nm. Polarization angle is arbitrary; angles of maximum and minimum polarization were determined by fitting.

Data were then reduced to percent polarization by the ratio of the difference between the maximum and minimum reflectance, to the sum of the maximum and minimum reflectance. Table 2 summarizes the average polarization for the soils in each band, and ranges from a low of 1.2% in the immature highland soil 67711 at 760 nm to 25.6 percent for the mature high titanium basaltic soil 10084 at 430 nm.

Polarization was measured on a pixel by pixel basis, and Figure 2 shows an example of a percent polarization image of soil 10084. Specular reflectance glints of grain surfaces are common, and are highly polarized; the remainder of the soil shows polarization near the average will little variation.

Sample No.	Polarization %		
	430nm	636nm	760nm
10084-97	25.6	17.6	15.2
12033-52	9.0	7.1	6.0
14003-12	15.5	10.0	9.0
14141-21	6.7	4.4	4.4
15013-103	17.9	10.8	9.0
67711-58	1.9	1.5	1.2
69961-135	10.1	6.6	5.8
74241-4	13.3	9.6	8.5

Table 2

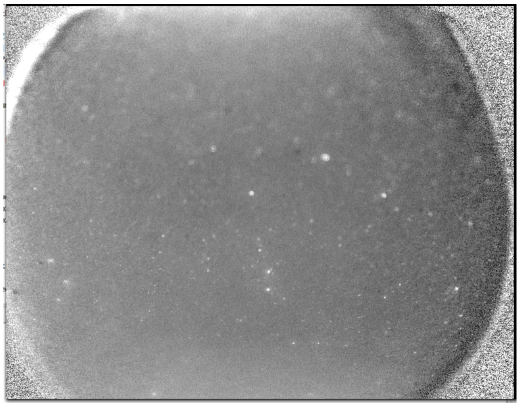

Figure 2 Image of percent polarization of sample 10084. Bright spots are mineral grains in specular reflectance showing very high polarization.

Discussion: A fundamental property of particulate materials in general and the Moon in particular is an inverse correlation of polarization and albedo, known as Umov's Law [6]. Our data do show such a correlation, but it is not entirely linear (Figure 3). Given that the highest albedo soils are immature, some deviation is to be expected as surface coatings evolve with space weathering. Space weathering effects are also discernable in spectral data. We observed spectral differences with maturity and polarization angle. The angle of polarization perpendicular to the plane of the source, sample and observed is most sensitive to specular, surface reflection, and 3-point spectra of the sample at this angle are somewhat redder than the parallel angle that emphasizes internal scattering, consistent with strong surface-correlated space weathering effects.

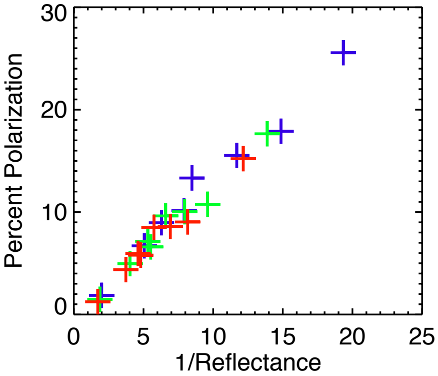

Figure 3 Percent polarization vs. inverse reflectance for all soils, all bands. 430 nm (blue), 636 nm (green), 760 nm (red). The overall curve is somewhat nonlinear, expected as texture and other properties change with maturity that partially controls reflectance.

References: [1] Shkuratov, Y. G., & Opanasenko, N. V. 1992, Icar, 99, 468. [2] Shkuratov, Y. G., Opanasenko, N. V., & Kreslavsky, M. A. 1992, Icar, 95, 283 [3] Shkuratov, Y., Kaydash, V., Korokhin, V., et al. 2011, P&SS, 59, 1326 [4] Shkuratov, Y., Opanasenko, N., Zubko, E., Grynko, Y., Korokhin, V., Pieters, C., Videen, G., Mall, U. and Opanasenko, A., 2007. Icarus, 187(2), pp.406-416. [5] Jeong, M., Kim, S.S., Garrick-Bethell, I., Park, S.M., Sim, C.K., Jin, H., Min, K.W. and Choi, Y.J., 2015. The Astrophysical Journal Supplement Series, 221(1), p.16. [6] Umov, N. 1905, ZPhy, 6, 674