LROC NAC PHOTOMETRY AS A TOOL FOR STUDYING PHYSICAL AND COMPOSITIONAL PROPERTIES OF THE LUNAR SURFACE. R. N. Clegg[1], B. L. Jolliff[1], A. K. Boyd[2], J. D. Stopar[2], H. Sato[2], M. S. Robinson[2], and B. W. Hapke[3], [1]Washington University in St. Louis and the McDonell Center for the Space Sciences, 1 Brookings Dr., St. Louis, MO 63130, USA, rclegg@levee.wustl.edu, [2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, [3]University of Pittsburgh, Pittsburgh, PA.

Introduction: Photometry is a powerful tool to investigate physical and compositional properties of planetary surface materials. Factors that affect how the surface of an airless silicate body reflects light include grain size, composition and mineralogy, regolith structure, surface roughness, space weathering, and glass and Fe^0 contents [1,2]. Photometric models are used to test variable parameters that depend on soil properties and composition to determine which parameters most accurately fit the reflectance characteristics.

For our studies, we use Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) images acquired over a range of illumination conditions (incidence, emission, and phase angles) for selected sites. These data are well suited for determination of phase curves and, thus, for normalization to common viewing geometry, allowing for relative comparisons of reflectance and derived parameters among sites. Previously, NAC photometric imaging data were used to study the effects of rocket exhaust on physical changes in lunar soil ("blast zones") at the Apollo, Luna, Surveyor, and Chang'e 3 landing sites [3,4].

By coupling soil composition data with photometric techniques, we assessed compositions and variabilities in reflectance for several silicic volcanic complexes on the Moon (Compton-Belkovich Volcanic Complex, Hansteen Alpha, Gruithuisen Domes) as well as ejecta of unusually silicic composition from Aristarchus crater [5]. Here, we add data from the Lassell Massif and a reference area interpreted to be pure anorthosite (PAN) on the basis of hyperspectral data [6,7].

Methods: We selected areas of interest at each silicic and PAN region and used NAC images with a variety of illumination conditions to obtain reflectance data. We avoid areas near young craters to minimize effects of fresh, immature materials on reflectance. The NAC images were radiometrically calibrated and photometric angles were determined for each image pixel from topography (using NAC DTMs) and viewing geometry. The DN values of the calibrated images represent *I/F* (*IoF*) [8], the "radiance factor" as defined by [1].

We obtain reduced reflectance by fitting NAC data using the Hapke simplified bidirectional reflectance function, which describes the ratio of the radiance, *I,* received at the detector viewing the surface from angle, *e,* to the irradiance, πF, from the source at angle, *i,* and then normalized to the Lommel-Seeliger Function (LS) to mask the effects of viewing geometry [1-3]. Reduced reflectance (*IoF/LS*) is defined as:

$$\frac{IoF}{LS} = \frac{w}{4}[p(g) + H(\mu_0, w)H(\mu, w) - 1][1 + B_{C0}B_C(g, h_c)]S(i, e, \theta)$$

$$LS = {}^{\mu_0}/_{(\mu_0 + \mu)}$$

The single scattering albedo, *w*, is the probability that a photon will be scattered by a particle and depends on composition and grain size. The quantities *w* and *p(g)* describe the scattering by a single particle, $[H(\mu_0, w)H(\mu, w) - 1]$ describes multiple scattering, and $B_{co}B_c(g,h_c)$, the opposition effect. This approximation is reasonably valid away from the limb and terminator. The term $S(i,e,\theta)$ is the shadowing function and depends on the roughness of the surface and mean slope angle θ. In both equations, $\mu = \cos(e)$ and $\mu_o = \cos(i)$. For details, see [1-3]. The use of repeat-coverage NAC images of each site permits determination of the photometric parameters *w* and θ, and allows us to determine *IoF/LS* at a common phase angle of 45° [3]. We optimized this parameter determination using the landing site studies and then applied the same method to silicic volcanic areas.

Finally, we compared the landing site photometric analysis with known soil compositions [9] and found a strong correlation between *IoF/LS*, *w*, and key parameters such as FeO and Al_2O_3 contents [5]. Both *w* and *IoF/LS* increase with increasing feldspar content and decrease with increasing FeO-bearing minerals [5,10]. We then used this correlation to interpret NAC reflectance at sites of silicic volcanism and PAN.

Silicic Materials: We extracted *IoF/LS* (and *w*) for relatively flat, smooth regions at the Compton-Belkovich Volcanic Complex (CBVC), Hansteen Alpha (HA), the Gruithuisen Domes, ejecta from Aristarchus Crater, and the Lassell Massif.

The reduced reflectance for a 45° phase angle ranges from 0.23 – 0.34 at the CBVC, from 0.16 – 0.30 at HA, from 0.109 – 0.113 at Gruithuisen Delta, from 0.10 – 0.15 for the Lassell Massif, and averages 0.13 for the Gruithuisen Gamma dome and 0.16 for Aristarchus ejecta. These values are most comparable to those of the feldspathic Apollo 16 landing site, which has the highest reduced reflectance values of the studied landing zones (see [3] for detailed results), with an *IoF/LS* value of 0.16 at 45° phase (Fig. 1).

We extracted modeled *w* values of 0.38 for the Gruithuisen Gamma dome and 0.53 for Aristarchus ejecta. Modeled *w* values range from 0.40 – 0.62 for HA, 0.35 – 0.46 for the Lassell Massif, and the CBVC has the highest values for the silicic regions studied, ranging from 0.53–0.66.

PAN Materials: We also extracted *IoF/LS* and *w* values from a region of pure anorthosite (PAN) exposed along the Inner Rook Ring of Orientale. This area has essentially no detectable mafic minerals and is of interest as a highland endmember composition [6,7]. The PAN study area has the highest measured reduced reflectance for a 45° phase angle with values ranging from 0.32 – 0.37 (Fig. 1). The PAN area at Orientale also has relatively high modeled *w* values, ranging from 0.62 – 0.72.

Discussion: Applying the Hapke model used for our reflectance studies of spacecraft landing sites to areas of silicic composition on the Moon, we determined *IoF/LS* values at 45° phase angle and used these values to compare with compositional parameters. The Lunar Prospector Gamma Ray Spectrometer detected high Th and low FeO content at these areas, suggesting an alkali-suite rock type [11]. NAC images of these regions reveal unique morphologic and reflectance characteristics that suggest a volcanic origin and mineralogy that differs from mare basalts [12-15]. LRO Diviner spectral data also show evidence for silicic compositions at these sites [16,17]. It is also possible that pyroclastics contribute to the increased reflectance seen at CBVC [11]. Photometry provides another line of evidence for highly reflective minerals such as alkali feldspars and quartz at these areas.

The silicic volcanic regions are all, on average, more reflective than the spacecraft landing sites. The Compton Belkovich Volcanic Complex has the highest reduced reflectance of the silicic sites studied, and the exposure of PAN has the highest reduced reflectance for any of the sites we have studied thus far. Using the relationship for *IoF/LS* and mafic content of Apollo and Luna samples, we find a strong anticorrelation between reduced reflectance and the mafic content of lunar soils. Extrapolating to higher *IoF/LS* values for the silicic regions is consistent with very low FeO+MgO+TiO_2 contents and with interpretations of felsic rock types (Fig. 1). We also find that PAN values fall well beyond this extrapolation, which is also consistent with the interpretation that there is very little, or no, mafic mineral exposure in PAN areas such as the example at Orientale. Further work such as analysis of Mini-RF radar data and surface morphologies, as well as reflectance studies of silicic pyroclastic materials in the laboratory, is needed to verify if pyroclastics also contribute to the high reflectance seen at silicic regions.

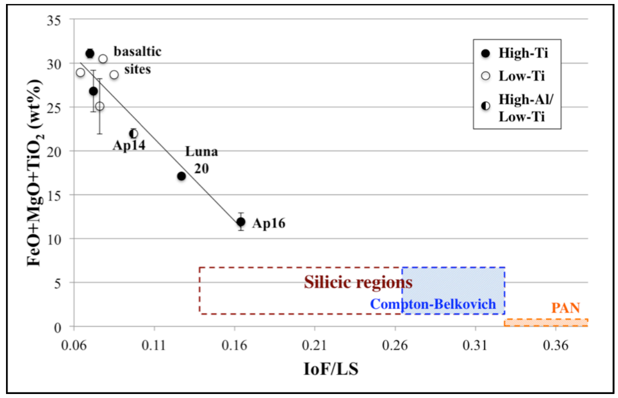

Figure 1: Relationship between reduced reflectance at 45° phase angle and mafic content for Apollo and Luna samples. Silicic volcanic regions and PAN extrapolate to the dashed regions.

Conclusions: We have shown, using LROC NAC images, that photometric models can be used to investigate physical changes in lunar soil and to infer compositional properties at areas of unusal composition on the Moon. The silicic volcanic regions have high reflectance that is consistent with different proportions of highly reflective minerals and low concentrations of mafic minerals. On the basis of Diviner data, we know that these areas have silicic compositions and therefore we infer that their mineralogy is dominated by SiO_2 and alkali feldspar and low contents of Fe- and Ti-bearing minerals. Areas thought to be exposures of pure anorthosite have even higher reflectance values, consistent with the interpretation that these areas contain little to no mafic mineral components. Our future work includes acquiring reflectance measurements of Apollo samples of different compositions and surface textures (roughness, compaction, porosity, etc.) to use as "ground truth" with remote sensing reflectance measurements of the sample sites.

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