ANALYSIS OF COMPOSITIONAL VARIATIONS AT NON-MARE VOLCANIC REGIONS USING LROC NAC PHOTOMETRY AND SPECTRA OF GLASSY AND SILICIC MINERAL MIXTURES. R. N. Clegg[1], B. L. Jolliff[1], and E. Coman[1], [1]Department of Earth & Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University, 1 Brookings Dr., St. Louis, MO 63130 (rclegg@levee.wustl.edu)

Introduction: Regions of non-mare volcanism on the Moon are rare and returned samples that may be products of these regions are even rarer. These areas correlate with thorium (Th) anomalies, as detected by the Lunar Prospector Gamma-Ray Spectrometer (LP-GRS), and have low FeO (<5 wt%) contents and high reflectance. These characteristics implicate an alkali-suite rock type [1]. Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) images show morphological features that indicate volcanic origin and LRO Diviner spectral data show evidence for silicic compositions at these sites [1-4]. We use the Compton-Belkovich Volcanic Complex (CBVC), the Lassell Massif (LM), the Gruithuisen Domes, and Hansteen Alpha (HA) for this study.

We have used LRO NAC photometry and Hapke photometric modeling coupled with soil composition data to place compositional constraints on these regions and assess variations in reflectance [5]. The background areas at the CBVC are highlands-type materials similar to those seen at the Apollo 16 landing site. Here we present evidence from laboratory spectra that addition of glassy silicic materials to a highlands-type simulant can account for the increased reflectance of these volcanic regions.

Methods: We use NU-LHT-1M, a lunar soil simulant that was created to be an analog to highlands materials. It has a composition based on the average chemical composition of the Apollo 16 regolith and has 16% agglutinates [6]. Rhyolitic pumice from Obsidian Dome in Owens Valley, CA, is mixed with the simulant as an analog for felsic pyroclastics on the Moon.

NAC Photometry: We chose regions of interest at the CBVC, LM, and HA, and one ROI at the Gruithuisen Gamma (GG) dome, and used NAC images with a variety of illumination conditions to obtain reflectance data. We then applied a Hapke photometric function that was optimized from landing site studies [7] to fit the reflectance (*I/F*) data (see [6]). To compare between sites and with our spectral data, we normalize *I/F* to a 30° phase angle, *I/F*(30°).

Spectral Measurements: We measured the pumice using X-Ray diffraction and found that it is completely glassy with no crystalline components, making it a good analog material for our study. The pumice was crushed and mixed in varying proportions by weight (5, 10, 20, and 50 wt%) with NU-LHT. We took spectral measurements of the mixtures using an Ocean Optics Jaz spectrometer (spectral response range of 190-800 nm) with a pulsed xenon light source. All measurements were taken at an incidence angle of 30°, emission angle of 0°, and phase angle of 30°.

Table 1: Reflectance measurements of samples used for this study.

Sample	*I/F*(30°)	Percent increase from NU-LHT
NU-LHT	0.22	
pumice	0.68	
50 wt% pumice	0.51	132%
20 wt% pumice	0.38	71%
10 wt% pumice	0.35	60%
5 wt% pumice	0.33	49%

The LRO NACs have a spectral response from 400-750 nm, with the average falling around 650 nm. We convolve our spectral data to *I/F* values that are consistent with the NAC spectral responsivity. To ensure these comparisons are accurate, we took spectra of several Apollo samples (10084, 14163, 15601, and 71501) and compared their average *I/F* values to those recorded from our studies of landing sites [7].

Results: Extracting *I/F* values for regions of interest at each non-mare volcanic site and using Hapke modeling to determine *I/F* at a common 30° phase angle gives *I/F*(30°) values that range from 0.120-0.20 for the CBVC, 0.090-0.170 for HA, 0.056-0.083 for LM, and average 0.070 for GG. These values are most comparable to those of the feldspathic Apollo 16 landing site, which has an *I/F*(30°) of 0.093 [7].

Table 1 shows the *I/F*(30°) values measured for the pumice, NU-LHT, and pumice+NU-LHT mixtures. The percent increase in reflectance as varying amounts of pumice were added is also reported. Figure 1a shows a plot of wt% pumice mixtures versus *I/F* at 30° phase angle. Figure 1b shows *I/F* as a function of mafics ($FeO+MgO+TiO_2$) estimated for the pumice mixtures, using an average rhyolitic composition for the pumice. The *I/F* values have been convolved to match the peak spectral responsivity for the NACs.

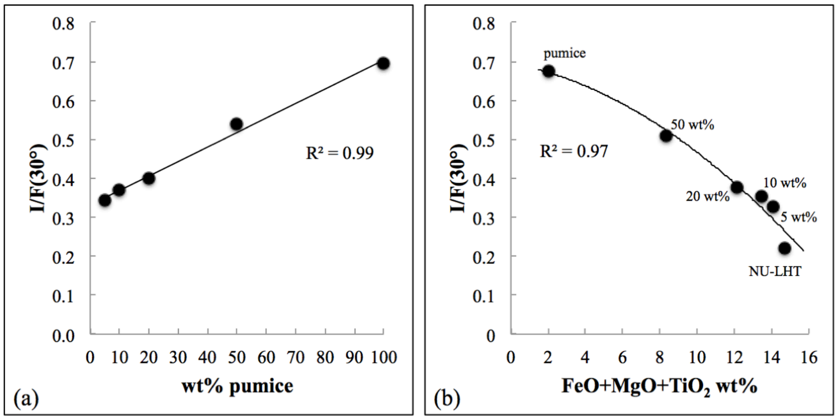

Fig. 1: Relationship between reflectance (*I/F*) at 30° phase angle with (a) increasing amounts of pumice (by weight) mixed with NU-LHT and (b) mafic content for the samples listed in Table 1.

Discussion: Remote sensing data provide strong evidence for the presence of felsic materials at the Compton-Belkovich Volcanic Complex, the Lassell Massif, Hansteen Alpha, and the Gruithuisen Domes. Photometric studies of NAC images and spectral measurements provide insight into possible mineralogical compositions at these areas.

There is a linear correlation (R^2=0.99) between increasing amounts of pumice mixed with NU-LHT and increasing reflectance values (Fig. 1a). In addition, mineralogy of the varying mixtures correlates systematically with reflectance. We have previously shown that there is a strong anti-correlation between the mafic ($FeO+MgO+TiO_2$) content of Apollo and Luna soils and *I/F* and have used this information to extrapolate to higher *I/F* values for the silicic regions [8]. The same is true for our pumice mixtures – as increasing wt% of pumice is added to the simulant, total $FeO+MgO+TiO_2$ content decreases and reflectance increases (Fig. 1b).

The CBVC, HA, LM, and GG exhibit a range of reflectance values, both among the various regions and within each region. This is especially evident at the CBVC, where features such as the volcanic cones and domes are less reflective than regions in the central portion of the complex [8]. The reflectance variations among and within each region may be due to mixing of felsic components, addition of pyroclastic materials, and/or the presence of KREEPy (less silicic) materials. The most reflective surfaces are the mantling deposits, which have been hypothesized as possible pyroclastic deposits [1,9]. A small percentage of glassy materials such as silicic pyroclastics in this area would account for the increased reflectance in these regions, as supported by our measurements.

The most reflective region in the CBVC is 68% more reflective than the background highlands. Comparatively, adding 20 wt% pumice to NU-LHT gives a 70% increase in reflectance. Therefore we infer that the addition of up to 20 wt% glassy silicic materials could account for the increased reflectance at the most reflective regions of CBVC compared to average Apollo 16 soils.

The least reflective areas that we analyzed in the complex, the α- and β-domes [10] are 17% and 28% more reflective, respectively, than the background. Comparing to the reflectance of our pumice mixtures, the domes have less than 5% glassy silicic materials at their surfaces. As these positive-relief features have degraded, any mantling deposits would have been eroded by mass wasting, revealing somewhat higher mafic contents perhaps compositionally similar to KREEP basalts or other intermediate composition materials .

Conclusions: Photometric analysis of NAC images and spectral measurements of laboratory samples provide compositional information for regions of non-mare volcanism on the Moon. The high reflectance at these regions is consistent with the presence of silicic materials and low mafic contents. We have shown with laboratory spectra that the increased reflectance at the CBVC can be accounted for by the addition of ~20 wt% glassy silicic/rhyolitic materials. KREEP-like materials such as those seen in the Apollo 14 soil samples or lower glass contents may explain the lower reflectance positive-relief features within the complex. The lower reflectance values for Hansteen Alpha, the Lassell Massif, and the Gruithuisen Domes may indicate intermediate felsic compositions. The variations in reflectance among and within the CBVC, HA, LM, and Gruithuisen Domes may be attributed to mixing of felsic components, the presence of KREEPy materials, and/or pyroclastic deposits.

Acknowledgements: We thank the LROC Operations Team for image collection and processing, and we thank NASA for support of the LRO mission.

References: [1] Jolliff B. L. et al. (2011) *Nat. Geosci., 4,* 566-571. [2] Ashley, J. W. et al. (2013) *44th LPSC,* Abstract #2504. [3] Glotch T. et al. (2010) *Science, 329,* 1510. [4] Greenhagen B. et al. (2010) *Science, 329,* 1507. [5] Clegg R. N. et al. (2014) *45th LPSC,* Abstract #1256. [6] Stoeser D., et al. (2010) NASA/TM-2010-216438. [7] Clegg R. N. et al. (2014) *Icarus,* 227, 176-194. [8] Clegg R. N. et al. (2014) *LEAG 2014*, Abstract #3032. [9] Wilson J. et al. (2015) This Conf. [10] Jolliff et al. (2012) 43rd LPSC, Abstract #2097.