PHOTOMETRIC INVESTIGATIONS OF YOUNG TECTONIC STRUCTURES: IDENTIFYING AREAS WITH POTENTIAL OPPORTUNITIES, AND HAZARDS, FOR FUTURE EXPLORATION. M. E. Banks1, R. N. Watkins2, J. A. Grier3, J. D. Clark3, T. R. Watters4, C. H. van der Bogert5, J. T. S. Cahill6, M. Lemelin7, T. M. Hahn Jr. 3, N. R. Williams8, and H. Hiesinger9, 1NASA Goddard Space Flight Center, Greenbelt, MD, USA, maria.e.banks@nasa.gov 2Planetary Science Institute, Tucson, AZ, USA 3School of Earth and Space Exploration, Arizona State University, AZ, USA, 4Smithsonian Institution, National Air and Space Museum, Washington, DC, USA 5Institut für Planetologie, Münster, Germany, 6Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, 7Dept. of Earth and Space Science and Engineering, York University, Toronto, Canada. 8Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA USA.

Introduction: Lunar lobate scarps, or thrust fault scarps, are widespread across the lunar surface (Figs. 1, 2). They are among the youngest landforms on the Moon, with some likely still active today [1-4]. Several lines of evidence point to the relatively young age of the lunar scarps, including their pristine morphology and cross-cutting relationships with small diameter craters [3, 5]. Absolute ages estimated from infilling rates for small-scale back-scarp graben (which formed in association with activity along the faults) [6], and from the size-frequency distributions of impact craters proximal to the scarps, show that most studied scarps were active in the late Copernican (<400 Ma), and that fault activity causes surface renewal and disturbance up to kilometers from the scarp trace itself [7, 8]. This young age is further supported by a recent study that connected lobate scarp thrust faults with several revised epicenter locations for shallow moonquakes detected by seismometers emplaced during Apollo missions [9]. These findings have important implications for future human and robotic exploration as potential areas of interest that may host resources or fresh/redistributed regolith particles on or near the surface (for example, small particles with large surface areas for storing volatiles, such as OH).

We have begun a comparison using multiple data sets (i.e., Optical Maturity Index (OMAT), Lunar Reconnaissance Orbiter (LRO) photometry) to analyze the surfaces surrounding lobate scarps and other select tectonic structures interpreted to have been recently active (i.e., some wrinkle ridges, small-scale graben) [10, 11]. Our goal is to understand the characteristics of surface and near-surface materials that have been disturbed by ground motion from seismic slip events during scarp formation, and assess whether they might inform and benefit future exploration. Our investigations aim to bear on issues relating to ongoing scarp-related seismic processes, the grain size and nature of near-surface regolith, the rate of soil maturation, and if/how these characteristics differ regionally. These results would thus be of use toward identifying additional areas of relatively recently disturbed or exposed surfaces that might serve as strategic locations, or even potentially hazardous locations, for future exploration.

Preliminary optical maturity investigations have so far revealed no distinctive signatures for the scarps or surrounding surfaces in OMAT images [12]. This result may suggest that some part of the ongoing scarp-forming processes is erasing any OMAT signature. While more work with OMAT will be done to further test these results, we focus here on photometric investigations of lobate thrust fault scarps.

Methods: Photometry is a valuable tool for assessing how the physical and compositional properties of the regolith may vary in the vicinity of the scarp. To assess how photometric parameters change, we used Hapke formulations [13] and nonlinear optimization techniques in MATLAB to produce photometric parameter maps (5 mpp) from LRO Narrow Angle Camera (NAC) images and NAC-derived Digital Terrain Models (DTMs). Details of the methods can be found in [14, 15]. The parameters of interest here are single scattering albedo (w), b, and c. The b- and c-parameters of the single particle phase function within the Hapke model are correlated with physical variations in surface properties such as surface roughness, grain size/shape, glassy vs. crystalline content, agglutinate content, and backscattering characteristics [16, 17]. Single scattering albedo is dominantly dependent on composition. The b- and c-maps are of particular interest in qualitatively assessing variations in physical properties between the scarp surfaces and nearby surroundings.

Initial results and discussion: Most parameter maps reveal differences immediately on or proximal to the scarp face of the lobate scarps, but no significant gradational variations in the surface surrounding the scarp (Figs. 1, 2a). In particular, the b- and c-maps reveal an abrupt variation in b and c values in close proximity to the scarp face, with values at a relatively consistent background value beyond the immediate scarp face margins (Figs. 1c, d, e, 2a; note the difference in b and c values along the length of the scarp face compared to the surrounding surface). Evaluated together, these differences in b and c values may indicate variations in maturity and/or backscattering characteristics, and therefore differences in physical properties between surface materials on the scarp and on the surroundings [16,17]. This result may potentially reflect the effects of seismic shaking from slip events on the thrust faults which could, for example, increase surface roughness, redistribute regolith particulates, and/or change grain
sizes and shapes by breaking particles apart. The w values do not vary greatly between the scarps and the surroundings suggesting there are no significant changes in composition at this resolution (Fig. 1b).

The Vitello cluster of lobate scarps (Fig. 2b) is within 30 km of the epicenter of a shallow moonquake recorded by the Apollo seismic network [9]. Thus, of the lobate scarps we have investigated so far, faults in this cluster may have experienced the most recent activity. Preliminary results show distinct b and c values not only on the scarp face, but also dispersed on surfaces surrounding the scarp (Fig. 2b). The presence of a fresh crater superposing part of the fault, and its associated ejecta, complicates our interpretation of the results; however, the differences in b and c values for what we interpret to be ejecta and for what we interpret to be materials influenced by tectonic activity appear to vary significantly enough to be differentiated. Potentially one source for the variation in b and c values dispersed in materials beyond the scarp face is very recent seismic shaking from slip events on the fault (within the last 50 years). The other investigated scarps may not have experienced activity quite as recently, such that differences in these values are currently only apparent (at this scale) on the scarp face where the shaking was likely the most severe and/or potentially disrupted grains at greater depths.

For all investigated scarps, reflectance (I/I) values also differ on the scarp face compared to the surrounding surface, leading to a concern that variations in b and c values might represent illumination angle effects. While this concern will be considered in future analyses and interpretations, our method has been shown to correct appropriately for local topography and viewing geometries at these scales [14, 15]; consistent w values across the scenes also support effective correction for topographic effects (Fig. 1b).

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Figure 1. Lobate scarp, Henderson-2 (7.77°N, 152.07°E). Derived model ages estimate that this scarp was active in the last ~75 Ma [7]. a) LROC NAC M1159101897; b) Single scattering albedo map; c) b-map; Note the location of the profile plotted in (c); d) c-map; and e) Plot comparing b values for the scarp face and surrounding surface.

Figure 2. a) Prominent lobate scarp (white arrows) in the Mandel’shtam cluster (~6.90°N, ~161.02°E). This scarp is estimated to have been active in the last ~110 Ma [7] (left: LROC NAC M191895630, right: b-map). b) Lobate scarp (white arrows) in the Vitello cluster (34.50°S, 322.05°E), located near the epicenter of a detected shallow moonquake (left: LROC NAC M190836890, right: b-map).