A PRELIMINARY LOOK AT LUNAR LOBATE SCARPS THROUGH COMPARISONS OF CRATER COUNTS, PHOTOMETRY, AND OPTICAL MATURITY. M. E. Banks[1], J. A. Grier[2], R. N. Watkins[2], J. D. Clark[3], C. H. van der Bogert[4], J. Cahill[5], M. Lemelin[6], T. M. Hahn Jr.[7] , H. Hiesinger[4]. [1]NASA Goddard Space Flight Center, Greenbelt, MD, USA, maria.e.banks@nasa.gov [2]Planetary Science Institute, Tucson, Arizona, [3]School of Earth and Space Exploration, Arizona State University, Arizona, USA, [4]Institute für Planetologie, Münster, Germany, [5]Johns Hopkins University Applied Physics Laboratory, [6]Dept. of Earth and Space Science and Engineering, York University, Toronto, Canada. [7]Washington University in St. Louis, St. Louis, MO, USA.

Introduction: Lunar lobate scarps, or thrust faults, are widespread across the lunar surface. They are among the youngest landforms on the surface of the Moon; some are likely still active today [1-4]. Several lines of evidence point to the relatively young age of the lunar scarps (i.e., their crisp and pristine morphology, cross-cutting relationships with small diameter craters) [3,5]. Additionally, absolute ages from estimates of infilling rates for small-scale back-scarp graben associated with activity along the faults [6], and from model ages estimated using the size-frequency of impact craters, show that all studied scarps were active in the late Copernican (less than 50-100 Ma), and that fault activity causes surface renewal and disturbance up to kilometers from the scarp trace itself [7,8]. This finding has important implications for future human and robotic exploration as potential locations of resources brought up to or exposed near the surface, and for potential hazards. Thus, such scarps and their proximal terrain are of interest when considering exploration goals.

We have begun a comparison of multiple data sets to analyze the photometric and optical maturity (OMAT) of surfaces surrounding the lobate scarp thrust faults. We strive to understand if photometric and OMAT investigations will reveal distinctive results for the surfaces disturbed by ground motion from seismic slip events during scarp formation, and if such analyses can provide further insight regarding whether or not these surfaces contain materials that might inform and benefit future exploration. Our investigations aim to bear on issues relating to ongoing scarp-related coseismic 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 other potential areas of relatively recently disturbed or exposed surfaces that might serve as strategic locations for future exploration.

Here we present preliminary analyses of the Lee-Lincoln scarp, located in the Taurus-Littrow valley near the Apollo 17 landing site (Figure 1). Using crater size-frequency distribution (CSFD) measurements, the last significant activity on this thrust fault is estimated to have occurred ~75 Ma ago [9,10]. Evidence supports the possibility of multiple repeat slip events occurring on this fault, including activity that formed a small <50 Ma old back-scarp graben [6,9-11].

Methods: *Optical Maturity Index* – Lunar soils change (mature) over time because of micrometeorite impacts, solar wind implanted gasses, and other space weathering effects. The most immature or fresh soils/regolith on the Moon can be identified through remote sensing. Such material appears optically bright in images that have been created to lessen compositional effects (e.g., calcium-bearing minerals can appear bright in visible light images), and to isolate optical maturity [12,13]. This optical maturity index (OMAT) [see 14] trends as expected with the absolute age of impact craters, where craters whose ejecta blankets are bright in OMAT (i.e., high OMAT values) are younger than craters whose ejecta blankets are darker (i.e., lower OMAT values). The OMAT value of a region of lunar regolith has implications directly relevant to landing site considerations that include roughness, hazards, and soil composition. For example, large- and small-scale roughness may be an important factor in sequestration of volatiles on the lunar surface [15].

Photometry – 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 [16] and nonlinear optimization techniques in MATLAB to produce photometric parameter maps (5 mpp) of the Lee-Lincoln scarp from Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images and NAC-derived Digital Terrain Models (DTMs). Details of the methods can be found in [17,18]. The parameter of most interest for this study is the *b*-parameter of the single particle phase function within the Hapke model, owing to its observed correlation with physical variations (e.g., grain size/shape, glass content) in surface properties.

Preliminary Results: Rough or sloped surfaces tend to be brighter and less mature in OMAT. Since the Moon is undergoing a constant "sandblasting" of micrometeorites, slopes and peaks are places where the regolith is always being "refreshed." Less mature material is being uncovered and mixed into the more mature background regolith at these sites. As micrometeorite bombardment takes place, the points and edges of any sharp features are highly vulnerable to this impact erosion and contribute to local increases in soil immaturity (i.e., become brighter in OMAT images). It would be reasonable to suppose that the edge of a cliff face would be a likely place to see this effect, and thus we expect to find the edge of a scarp, in particular, to appear as immature or bright in an OMAT image.

Figure 1 shows the Lee-Lincoln scarp in both an LROC image (left panel) and in an OMAT image from the Kaguya spacecraft (right panel). There is no point along the length of the lobate scarp in which the scarp, or the immediate surrounding surface, shows a distinctive signature in the OMAT image. We checked whether this might be an effect of the topographic corrections conducted by the Kaguya team by extracting the Multiband Imager (MI) reflectance data at the Apollo 17 site and computing the OMAT at 20 mpp using the algorithm of [19]. There is a difference in reflectance at 750 and 950 nm between the scarp and the surroundings, but it disappears in the OMAT calculation; therefore it is unlikely that this absence of an OMAT signature is caused by the topographic correction. It is therefore possible that lobate scarps, unlike sharp cliff faces, are too 'soft' in profile to provide an edge upon which space weathering can act.

The photometric parameter maps reveal slight variation in *b* values in close proximity to the scarp, with values leveling out to a consistent background value with increasing distance from the scarp margins. The scarp itself has lower *b* values, which may indicate the presence of less mature soils and/or variations in physical properties, such as agglutinate content or grain size compared to the background values [20,21].

Future Work: We will continue to refine our preliminary results and methods and will apply this approach to multiple additional lobate scarps in various locations and on different terrains. We will combine topographic data and analyses to better characterize the nature of the edges and slopes, associated with the scarps, that do and do not show differences in optical maturity. Comparison of these results with OMAT of the local and regional surrounding terrain will enable us to look for trends or inconsistencies. We will also consider how the processes that both mature and refresh soils are the same or different from those associated with impact events and their craters. In addition, we plan to create *b*-maps for more scarps, and to improve the one created for Lee-Lincoln by increasing the number of iterations and range of *b* values the MATLAB code uses. We can compare the range of *b* values seen at the scarp to those seen at the Apollo 17 soil sampling stations (where grain size/composition is better understood) [18] and at other fresh surfaces, such as young impact craters, to better understand the physical characteristics of the materials on the scarps and surrounding surfaces. Finally, we will assess the potential implications of our OMAT and photometric results for future investigations into space weathering, grain size, and the nature of the upper regolith, including the properties of regolith that have experienced coseismic shaking.

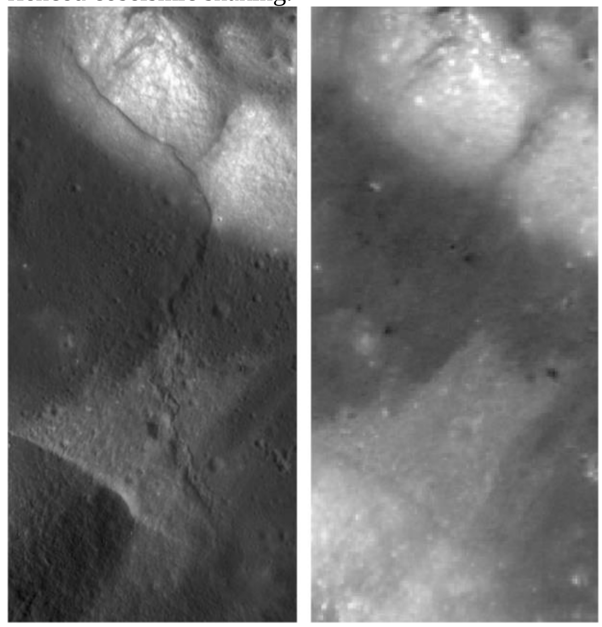

Figure 1 : Left panel – LROC NAC view of Lee Lincoln scarp (NAC image M104318871; image width is ~7 km), which runs roughly on a vertical path through the image. Right panel – Same region viewed in an OMAT image from the Kaguya spacecraft. Albedo differences in this image indicate differences in regolith maturity. Note that the scarp cannot be readily identified in the OMAT image.

Acknowledgments: This material is based upon work for the TREX team supported by the National Aeronautics and Space Administration (NASA) through the Solar System Exploration Research Virtual Institute 2016 (SSERVI16) Cooperative Agreement (NNH16ZDA001N). Additional support provided from the NASA SSERVI VORTICES team (Cooperative Agreement NNA14AB02A).

References: [1] Watters T. R. and Johnson C. L. (2010) in *Planetary Tectonics*, Cambridge Univ. Press, 121–182. [2] Binder A. B. (1982) *Earth, Moon, and Planets, 26*, 117–133. [3] Binder A. B. and Gunga H.-C. (1985) *Icarus, 63*, 421-441. [4] Schultz P. H. (1976) University of Texas Press, Austin, TX. [5] Watters, T.R. et al., (2010) *Science*, 936-940. [6] Watters et al. (2012) *Nature Geoscience*, DOI: 10.1038/NGEO1387. [7] van der Bogert et al. (2018) *Icarus*, *306*, 225-242. [8] Clark et al. (2015) *LPSC XLVI*, Abstract #1730. [9] van der Bogert C.H. et al. (2012) *LPSC XLIII*, Abstract #1847. [10] van der Bogert C.H. et al. (2019), *LPSC L*, Abstract #. [11] Watters et al. (2015) *Geology*, *43*, 851. [12] Lucey et al. 1995, *Bull. Am. Ast. Soc*., 27. [13] Lucey et al. 2000, *JGR*, *105*, No E8. [14] Grier et al. 2001, *JGR*, *106*, No E12. [15] Farrell et al, 2015, *Icarus*, *255*, 116-126. [16] Hapke B. (2012) Cambridge Univ. Press, 2nd Ed. [17] Clegg-Watkins R.N. et al. (2017) *Icarus*, *285*, 169-184. [18] Hahn T. et al. (2019), *LPSC L*, Abstract #1976. [19] Lemelin M. et al. (2018) *PSS*, *in press.* [20] Sato et al. (2014) *JGR*, *119*, 1775-1805. [21] Hapke (2012) *Icarus*, *221*, 1079-1083