CRATER DEGRADATION OF KILOMETER-SIZED CRATERS ON THE LUNAR MARIA: INITIAL OBSERVATIONS AND MODELING. C. I. Fassett, Department of Astronomy, Mount Holyoke College, 50 College St., South Hadley, MA 01075 (cfassett@mtholyoke.edu).

Introduction: Impact cratering at all scales has dominated the landscape evolution of the Moon in the period following the emplacement of the lunar maria. As a result, the degradation of craters on the maria has long been thought to be diffusional and controlled primarily by the accumulation of smaller later impacts [1-4].

Recently-acquired topographic data from the Lunar Orbiter Laser Altimeter (LOLA) [5], as well as stereo imaging from the Kaguya Terrain Camera [6] and the Lunar Reconnaissance Orbiter Camera (LROC) [7, 8] provide an excellent basis for improved characterization of the degradation states of craters in a quantitative manner. In this preliminary study, craters in the D=1–3 km size range are explored.

These data have a number of applications. If the most degraded craters of a given size in a locale are the most ancient, a local sequence of craters in a given location can be established. In addition, examining crater degradation states in the context of models for the impact flux allow inferences of absolute degradation rates.

Methods: *Lunar Observations:* A portion of the maria totaling ~2.5×10^5 km^2 was examined (approximately 5% of the maria). Craters were mapped with ArcMap down to ~700 m to assure completeness of the crater datasets at 1 km. Following this initial mapping, a database of LOLA shot data was queried to determine which craters were crossed by profiles; a total of 515 D=1-3 km craters had sufficient data to be assessed. Each crater's mapped position was then redetermined based on the LOLA data by finding the location that maximizes the radial symmetry of the crater profile inside the crater's rim. This step is required because the co-registration of LROC WAC and LOLA shots is imperfect: these data suggest an average offset of ~180 m (~1.8 pixels).

Model Fitting: To analyze these data, a forward model of topographic diffusion was created (explicit FTCS), with the initial conditions representing the fresh crater form based on direct observations of rayed craters.. Results of the diffusion model were then used to establish a lookup database of crater profiles at a range of initial crater sizes (*D*=0.8–5 km) and diffusion times (κT=0–60000). The resulting crater profiles change most significantly in the curvature and position of the rim and overall crater depth as κT changes. Using this database, best-fit degradation states were determined by minimizing the difference between the lookup profiles and LOLA observations of every crater with sufficient data.

Initial Observations and Results. Example of a sequence of 1.2 km craters with different derived degradation states is shown in Fig. 1.

For both the craters shown here and the population as a whole, the fits to data appear to be qualitatively reasonable, which bolsters the idea that degradation is primarily diffusional. The 1σ- uncertainty in fitting κT is estimated to be 2.5% based on the bootstrap method with replacement [9]. Primary sources of misfits are: nearby large craters, deviations from the the initial crater shape model (i.e., if some craters are secondaries), inaccuracy in the spatial location of the crater, and inaccuracy in the determination of the initial elevation of the crater relative to its surrounding surface.

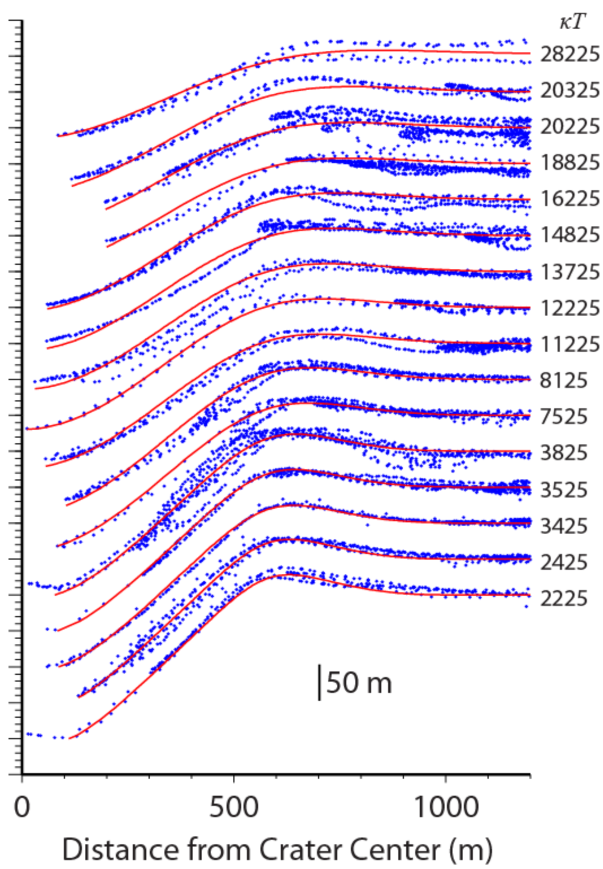

Figure 1. 18 (of the 34) craters measured so far that formed with a diameter of 1200 m, showing the range of degradation states observed (κT). The freshest crater has a depth/diameter ratio of ~0.2, while the most degraded crater has almost no rim and a depth/diameter ratio of ~0.1.

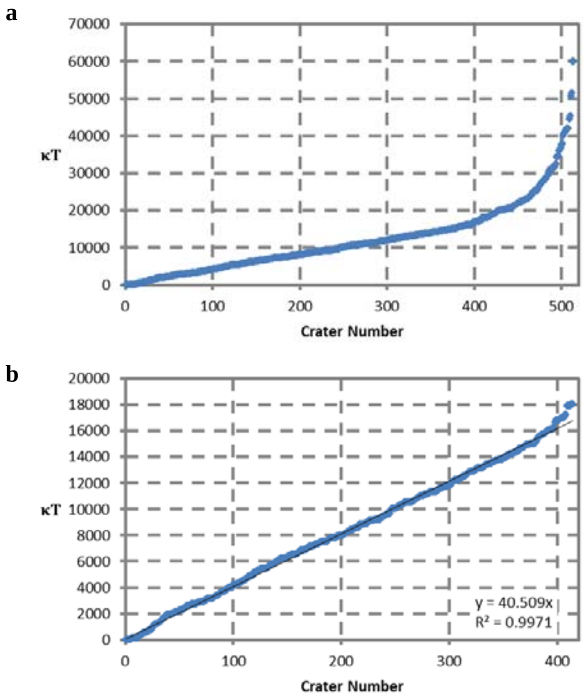

Fig. 2 (a) Ranked scatter plot of degradation states for the 515 craters measured so far. (b) Ranked scatter plot of degradation states of craters with κT< 18000. For this range (containing ~80% (412) of the craters of this size on the mare), the degradation states are evenly distributed (increase linearly).

The range of crater degradation states measured to date is shown in Fig. 2. This curve is linear (Fig. 2b) for craters with $\kappa T<18000$. The reason for the steep upturn (Fig. 2a) for the most degraded craters ($\kappa T>\sim18000$) is unclear. Possible explanations include (a) more rapid degradation of the earliest craters (potentially consistent with the much higher impact flux early), (b) contamination by secondary craters, or (c) a sampling bias caused by the range of age in the sampled mare regions. Determining which of these explanations is most likely is a subject of future work.

Average Rate of Diffusion/Erosion: Assuming the period with "steady" degradation represents 2–3.5 Gyr, we can estimate the average diffusion rate on the Moon over from the slope of this curve (Fig. 2b). The result is $\kappa=0.005$–0.008 m^2/Kyr, which is ~160× less than what is typically measured in the western United States (κ~1 m^2/Kyr) [10]. This estimate of the diffusivity can be converted into an average erosion rate on the maria if the characteristic curvature of the maria is known. Kreslavsky [11] reported a value for the curvature of the global LOLA dataset of 5.8×10^{-5} m^{-1}, which would imply an average erosion rate of ~0.3–0.5 mm/Myr. This is somewhat larger than the characteristic lunar erosion rate reported by [4] (0.2 mm/Myr).

Modeling: Along with these observations, Monte Carlo simulations have been employed to attempt to better understand the observed degradation process. Soderblom [2] suggested that the reason for diffusional evolution of a crater is preferential transfer of ejecta downslope for impacts much smaller than the crater being eroded. A code was created to directly simulate this effect by generating small craters using the Neukum production function [13] and tracking the evolution of a fresh, 1 km crater. Results of this modeling imply that the changes in crater topography from ejecta are far too slow to explain the degradation states actually observed. This suggests that other downslope mass movement processes must be much more important than differential ejecta transport. A similar result was anticipated by Ross [1], who noted that erosion is significantly enhanced mass wasting beyond what would be expected from ejecta and ballistic sedimentation alone.

Future Work: Additional observations are necessary to help bolster the initial results from this study. In particular, stereo digital terrain models (particularly from Kaguya) may help address the sparse sampling of the LOLA dataset. We also plan on substantially expanding this dataset to other areas of the maria and comparing topographic degradation with the radar signature from craters as they age [13]. Future analysis may provide a viable pathway for testing models for spatial [14] and temporal variations [e.g., 15] in the impact flux on the lunar surface.

References: [1] Ross, H.P. (1968) *JGR, 73,* 1343–1354. [2] Soderblom, L.A. (1970) *JGR, 75*, 2655-2661. [3] Soderblom, L.A. & Lebofsky, L.A. (1972) *JGR*, *77*, 279-296. [4] Craddock, R.A. & Howard, A.D. (2000) *JGR*, *105*, 20387-20401. [5] Smith et al. (2010), *Space Sci. Rev., 150*, 209-241. [6] Haruyama, J. et al. (2008) *Earth Pl. Sp.*, *60*, 243-255. [7] Robinson, M.S. et al. (2010), *Space Sci. Rev.*, *150*, 81-124. [8] Mattson, S. et al. (2012) *LPSC 43*, 2630. [9] Efron, B. & Tibshirani, R. (1986), *Statist. Sci., 1,* 54–75. [10] Pelletier, J.D (2008). *Quantitative Modeling of Earth Surface Processes*. [11] Kreslavsky, M.A. (2011), EPSC-DPS 2011, 1494. [12] Neukum, G. et al. (2001). *Space Science Rev., 96*, 55-86. [13] Bell, S.W. et al (2012), *JGR*, *117*, E00H30. [14] Le Feuvre, M. & Wieczorek, M.A. (2011) *Icarus*, *214*, 1-20. [15] Hartmann, W.K. et al. (2007) *Icarus, 186,* 11–23.