THE EFFECT OF TERRAIN PROPERTIES ON CRATER MODEL AGE DETERMINATION. M. R. Kirchoff and S. Marchi. Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302. Email: kirchoff@boulder.swri.edu.

Introduction: With the availability of very high resolution and quality imaging from, e.g., Lunar Reconnaissance Orbiter Narrow and Wide Angle Cameras (LROC-NAC/WAC), craters with diameters (D) $\lesssim$ 1 km are now widely used to determine crater model ages of lunar terrains. However, terrain material properties likely alter D $\lesssim$ 5 km crater distributions as indicated by the modern impact scaling law (e.g., Fig. 1, [1-2]). If this is not accounted for, then crater model ages may not be correctly estimated because traditionally used crater densities at D~1 km are within this range. Moreover, crater distributions at smaller diameters obtained from high resolution imaging are even more subject to this effect.

In order to better understand the influence of terrain properties on crater model age assessment, we fit new, expanded crater distributions of Apollo calibration regions with the Model Production Function (MPF; [2]). The MPF provides the expected number of craters per unit surface per unit time as a function of crater size through converting impactor distributions to crater distributions using modern impact scaling laws, which incorporate terrain properties. Thus, we can use the MPF to find the set of terrain properties that result in a crater model ages that best match the known radiometric ages of examined Apollo regions. This analysis provides new constraints on lunar terrain properties, such as material tensile strength, density and porosity, and their affect on estimating crater model ages.

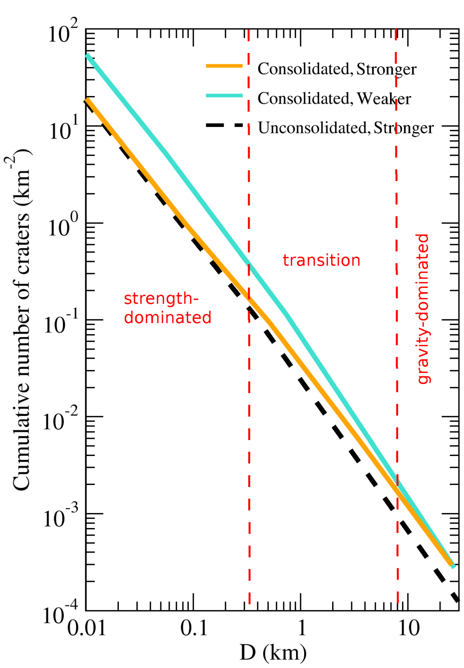

Figure 1. Crater distributions resulting from different terrain properties in the crater scaling law [1-2]. The transition from the strength- to gravity-dominated regime is gradual and occurs over D~0.3-10 km.

Methods: Because the influence of terrain properties on crater distributions becomes more significant for decreasing crater size (e.g., Fig. 1; [1]), and young terrains' model ages are often extrapolated from D << 1 km craters, it is vital to understand the effect of terrain properties on very small craters. Therefore, we are compiling new, expanded crater distributions for Apollo calibration terrains down to D=10 m. To obtain good count statistics for a wide range of diameters, we use a nested technique (e.g., Fig. 2). D ≥ 500 m craters are measured within the largest area on the LROC-WAC mosaic (100 m/pixel). The first, second, third, and fourth nested areas use LROC-NAC images to acquire craters for D $\gtrsim$ 250 m, 90 m, 35 m, and 10 m, respectively. Each area is sized to obtain a statistically reasonable number of craters and positioned to include the landing site area and exclude large areas of dense obvious secondaries.

Once the cumulative crater size-frequency distributions (SFDs) are compiled using standard techniques [3], we quantitatively fit them with distinct MPFs that use broadly different terrain properties. Terrain proper-

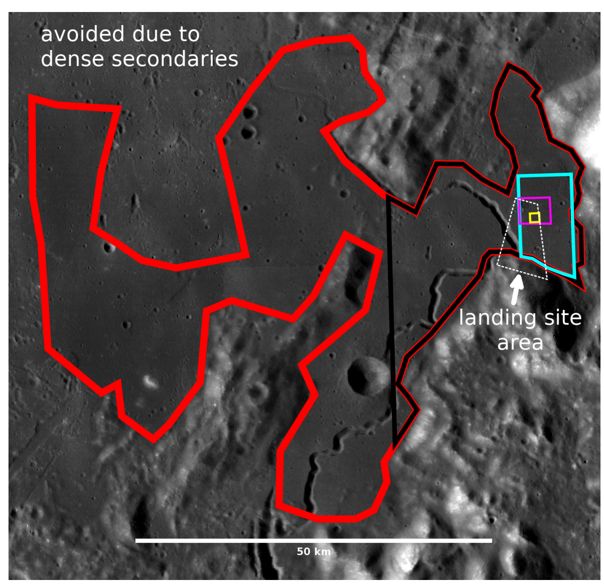

Figure 2. Example of nested technique for Mare Imbrium (Apollo 15). Red outline indicates largest area measured on WAC mosaic. Black outline indicates first nest, cyan for second, magenta for third, and yellow for fourth. NAC images are shown. Landing site area is indicated by white dashed outline. North is up.

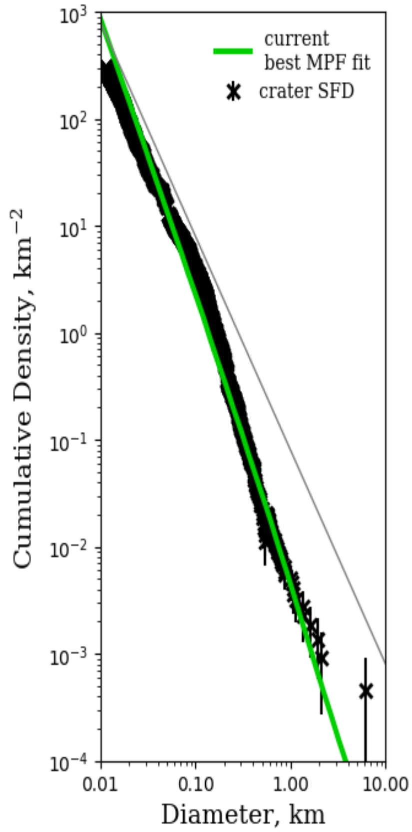

Figure 3. *Current best MPF fit to cumulative crater SFD for Mare Imbrium (Apollo 15). Gray line indicates 2% geometric saturation.*

ties are varied through coarsely altering the parameters in the crater scaling law [1] that represent material type (consolidated, unconsolidated, porous), material tensile strength (intact rock has a strength of $2x10^8$ dyne/cm^3 [4]), and material density (for further details see [2]). The fits output crater retention ages for the terrain, which are then compared to the known radiometric age [5]. We find which terrain properties produce the best match in ages, and assess what the implications are for the mapped terrains.

Results: Fig. 3 shows an example of a good MPF fit for Apollo 15 (Mare Imbrium). The green line represents the fit to the compiled cumulative crater SFD (black x's) that best reproduces the radiometric age. This fit is weighted to favor the data for D≥100 m, since craters smaller than this are likely in saturation equilibrium (as represented by the gray line; [6]). We note that the smallest craters are likely saturated for most terrains; however, since the diameter at which saturation occurs varies with age, we compile all distributions down to D=10 m to determine that limit, and have as much data as possible to use. Table 1 summarizes the results for Apollo 15 and the other regions examined giving the radiometric age from [5], best MPF fit model age, terrain properties for the best MPF fit, and saturation diameter.

Discussion: Results indicate that the near-surface terrain materials (~20 m depth) get more fractured and less consolidated with age, as would be expected for rock that is continually broken up by impacts. Furthermore, we find the diameter at which saturation occurs becomes larger with age supporting previous analyses [e.g., 6]. If other terrain properties are used for any region, the model age is off from the radiometric age by up to ±1000 Myrs [7]. These results demonstrate we can use the MPF with Apollo calibration terrains to better understand lunar terrain properties and how they affect estimating crater model ages.

References: [1] Holsapple K.A. and Housen K.R. (2007) *Icarus*, *187*, 345–356. [2] Marchi S. et al. (2009) *AJ*, *137*, 4936–4948. [3] CATWG (1979) *Icarus*, *37*, 467–474. [4] Asphaug, E. et al. (1996) *Icarus*, *120*, 158–184. [5] Stöffler D. et al. (2006) *Rev. Min. Geo.*, *60*, 519–596. [6] Hartmann W.K. (1984) *Icarus*, *60*, 56–74. [7] Kirchoff M.R. et al. (2015) *46th LPSC*, Abst. #2121.

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Table 1. Apollo region results.

Region	Radiometric Age (Ga) [4]	Model Age (Ga)	Terrain Properties (see Methods for details)	Saturation D (m)
Apollo 12 – Copernicus Melt	0.8	0.8	consolidated, $8x10^7$ dy/cm^3, 3.0 g/cm^3	70
Apollo 12 – Mare Procellarum	3.15	3.1	consolidated, $9x10^7$ dy/cm^3, 3.0 g/cm^3	250
Apollo 15 – Mare Imbrium	3.3	3.4	unconsolidated, $8x10^6$ dy/cm^3, 2.5 g/cm^3	150
Apollo 17 – Mare Serenitatis	3.75	3.7	unconsolidated, $8x10^6$ dy/cm^3, 2.5 g/cm^3	150
Apollo 11 – Mare Tranquillitatis	3.8	3.7	unconsolidated, $6x10^6$ dy/cm^3, 2.5 g/cm^3	200
Apollo 16 – Cayley Fm.	3.77	3.8	unconsolidated, $5x10^6$ dy/cm^3, 2.5 g/cm^3	500
Apollo 14 – Fra Mauro Fm.	3.77	3.9	unconsolidated, $5x10^6$ dy/cm^3, 2.5 g/cm^3	1000