SMALL CRATER LIFETIME AND IN-FILL RATES AT THE APOLLO LANDING SITES P. Mahanti[1], M. S.Robinson[1], T. J.Thompson[1], C. H. van der Bogert[2] [1]Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe,AZ,USA (pmahanti@asu.edu);[2]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany.

Introduction: Smaller craters (diameters(D) 30 m to 300 m), form more frequently than larger craters and experience faster degradation rates [1, 2, 3]. Progressive degradation of small craters leads them to be unrecognizable over time, designated as the life time (T_{life}). With increasing time (t) (or the fraction $\frac{t}{T_{life}}$), regolith fills in the crater volume from progressive degradation of rim and walls and nearby impacts (fresh ejecta or existing regolith) [4, 5, 6, 7] such that at $t = T_{life}$, a small crater is filled to the extent of being nearly erased. The accumulated volume inside a crater thus results from a combination of linear (micrometeoritic sandblasting) and non-linear effects (slope proportional and/or seismically induced mass wasting, distal ejecta transport), at any fraction of the crater life time. Target properties also play a role in the modification of crater shapes from formation to the time of observation [8, 9, 10, 11, 12], effecting T_{life} and the regolith accumulation (in-fill) rate. In this work, we use LRO Narrow Angle Camera (NAC) images and derived and digital terrain models (NAC DTMs;[13]) to estimate small crater population lifetimes and discuss the related in-fill rates inside the small craters at the Apollo sites.

Methods and Results: *Data and Morphological limits:* Small craters (30 m $\leq D \leq$ 300 m) were first identified on flat (slopes $< 5°$) geologic units from NAC ortho-photo mosaics, the digital terrain model (NAC DTMs), and derived slope maps for the five sites: Apollo 11 (A11), Apollo 14 (A14), Apollo 15 (A15), Apollo 16 (A16), and Apollo 17 (A17). Crater size-frequency distributions (CSFDs) were then used to identify a common size range (40m - 80m) exhibiting equilibrium. Depth (d) and diameter (D) measurements for this size range were extracted automatically from NAC DTMs followed by computation of $\frac{d}{D}$. The Apollo 12 site was left out for this work since our initial choice of the geologic unit was small, and preliminary analysis suggested insufficient craters for the evolution time computation. Identification and measurement of a crater ($t < T_{life}$) varies with image quality. By using a combination of images and topography, small craters can be identified unambiguously up to limit. Typically, this limit is set by the measurement of a crater feature and the associated uncertainty of the dataset. For topography based identification, this limit can be set by the $\frac{d}{D}$ which is characteristic of the crater shape. For NAC DTMs used in this work, an unrecognizable crater has a $\frac{d}{D}$ value lower than 0.04, which defines a morphological limit (almost-regolith-filled state) to which the degradation of a small crater population can be tracked. Note that the true theoretical lifetime (actual complete erasure) of a crater is much larger, since rate of degradation decreases approximately exponentially [14, 15].

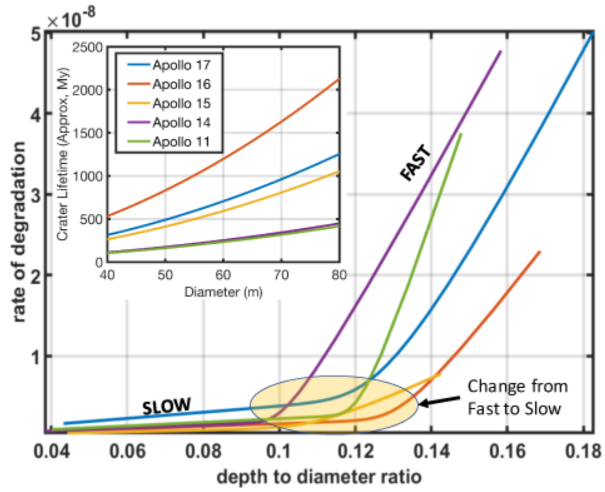

Figure 1: Degradation rates and estimated T_{life} for equilibrium population of craters (D: 40m to 80m) at the Apollo sites

Degradation rate and evolution time: At equilibrium, the degradation rate ($\frac{\partial(d/D)}{\partial t}$) can be expressed as a product of the production rate (Average rate $\sim 10^{-8} km^{-2} yr^{-1}$ computed using Neukum production function [16] was used) and $\frac{\partial(d/D)}{\partial N}$, computed from the relationship of observed $\frac{d}{D}$ and cumulative population (N ; $\#.km^{-2}$). For an exponential decrease of the degradation rate, a similar relationship (i.e $\frac{d}{D}$ vs. N is of exponential nature) can be used to simplify the analysis [14]. Accordingly, an exponential representation for $\frac{d}{D}$ vs. N is used to obtain the degradation rate curves (Figure 1) and compute the average lifetime $\langle T_{life} \rangle$ for the group of small craters at equilibrium. The morphological class definitions considered here are fresh: $\frac{d}{D} > 0.12$ and degraded (nearly unrecognizable): $0.04 \leq \frac{d}{D} < 0.05$. The average evolution time for the population is estimated from the degradation rate curves. Further, by considering the hypothesis that the time scale of removal (T_{life}) of a crater is proportional to the square of the crater's diameter at these diameters (i.e. $T_{life}(D) = \alpha D^2$; [17]), the average population lifetime can be expressed as $\frac{1}{n} \sum_{i=1}^{n} \alpha {D_i}^2$. Using the computed $\langle T_{life} \rangle$ values, the 'α' values (unique to each site) and lifetime for individual craters in the equilibrium population is estimated (Table 1).

Volume of in-fill and in-fill rate computation: Volume of in-fill for a particular diameter within the equilibrium population was computed as a difference in cavity volume of the fresh and the degraded craters. Crater cavity volume (V) vs. diameter dependence was modeled as a power law ($V = aD^b$, [18]). For the volume computation, we used a 25% change in fresh crater diameter during the crater lifetime and the average in-fill volume (ΔV_{avg}) corresponds to the median crater diameter ($\sim 50m$ for each site. The in-fill rate (κ) is computed from the average in-fill volume and the $\langle T_{life} \rangle$ values. The accumulated in-fill thickness between fresh and degraded craters was estimated as a difference in depths (Δd) at the median crater diameter for each site.

Table 1: Small (40-80m) craters from Apollo sites

Apollo Site,(n)	$\langle T_{life} \rangle$ **(My)**	α $(My.m^{-2})$	Δd (m)	ΔV_{avg} (m^3)	κ $(m^3.My^{-1})$
A11, (702)	~ 196	6.5×10^4	~ 3	1602	~ 8.1
A14, (387)	~ 205	7×10^4	~ 3.5	2519	~ 12.3
A15, (503)	~ 524	16.5×10^4	~ 4.5	948	~ 1.8
A16, (939)	~ 1036	33.3×10^4	~ 6.5	1690	~ 1.6
A17, (572)	~ 676	19.6×10^4	~ 4	2340	~ 3.5

Discussions and conclusions: Degradation rate vs. d/D curves obtained show that degradation varies from a fast to slow process, similar to the Lunokhod 1 and 2 study areas [14]. We refine (Figure 2) our earlier hypothesis [15] that the observed fast process is possibly a continuation of the significant collapse (or a combination of creep and collapse) of the crater walls, which reduces the transient d/D to value above 0.1 (depending on the local steepness and coherent nature of the target material). Thus, below d/D=0.1, most small craters are in their slow-phase of degradation although the actual transition from fast to slow, varies across sites (target properties and range of diameters).

The estimated $\langle T_{life} \rangle$ varies between $\sim$ 200 Ma and $\sim$ 1000 Ma, with lower individual T_{life} values for smaller craters. Crater lifetime (at fixed D) varies across the sites, with the Apollo 16 site showing the longest retention period. Crater degradation also appears to be slower than previously estimated ([3],[19]) with higher and variable T_{life} values. Since the equilibrium crater population refreshes at these sites every $\sim$ 1 Ga (or smaller period), the local topography also changes at scales below 80 m in this time. The production rate is strongly coupled to the estimated lifetimes and changes in production rate changes the lifetime proportionally.

While the difference in crater cavity volume (fresh $D =\sim 50m$) is approximately similar at the sites (varies between $\sim$ 1000 to $\sim$ 2500 cubic meters), the variation in average population lifetime leads to different in-fill rates. Note that, only a 25% increase in crater diameter was assumed, for a larger increase, the in-fill rates will be much smaller.

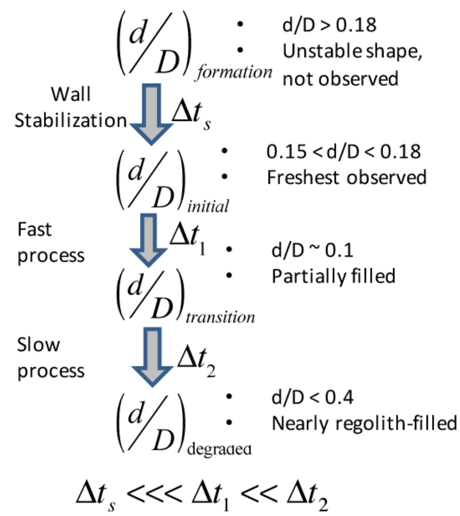

Figure 2: Stages in small crater degradation

The in-fill rate represents an average rate at which topographic depressions from impact cratering fill up at these sites. We propose that the ratio of $\langle T_{life} \rangle$ to Δd is well correlated to the overall regolith refreshment rate at these sites (every $\sim 100Ma$ at a depth of $\sim 1m$, midway between the accumulated depth Δd). The refreshing process includes both lateral and vertical mixing.

Understanding the lifetimes and evolution of small craters can directly influence our knowledge of the equilibrium crater population and the regolith accumulation process. Further analysis of the small crater evolution is ongoing and will be presented in future.

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