MODELING THE FORMATION OF DENSELY CRATERED LUNAR SURFACES UNDER THE INFLUENCE OF DIFFUSIVE CRATER DEGRADATION.

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Background: ***Crater production/equilibrium.*** Impact cratering is a dominant surface process on the Moon and its record has long been used to analyze and date planetary surface processes. The rate of crater formation is typically approximated by a crater production function which defines the number of craters produced per unit area over time. The lunar production function is often described by a polynomial function [1,2], but can also be approximated by a power law [3].

As cratering continues over time, the observed cumulative size-frequency distribution (CSFD) of a given surface area may reach a state where the observed CSFD no longer matches the SFD of the production function [4,5]. Instead, the CSFD may follow a function of crater equilibrium. This function is usually described by a power law [3-6].

Crater obliteration. Crater equilibrium occurs when craters of a given size are erased at the same rate they are produced [4,5]. This condition arises as a natural consequence of the cratering process, as the formation of each new crater contributes to the erasure of old craters. The total number of produced craters on a planetary surface unit in equilibrium may be higher than the number of craters that can be observed.

On the lunar maria, modeling and CSFD observations suggest that crater erasure is dominated by diffusive degradation [7,8]. Diffusive degradation causes simple post-mare craters to lose their rims and become shallower over time until they can no longer be distinguished from the surrounding terrain. Crater equilibrium observed in $D \lesssim 200$ m is likely controlled by diffusive degradation [7-10].

In contrast to the small simple craters of the lunar maria, a different effect may dominate crater erasure on the densely cratered lunar highlands. Investigations of lunar basins show a mismatch between the expected crater production function and obtained CSFDs for Nectarian and pre-Nectarian basins that occurs at size ranges larger than the sizes noticeably affected by crater equilibrium (wherein the CSFD follows an equilibrium function [11-13]). The findings of [13] suggest that this is due to a non-sparseness effect as described by [14]. Non-sparseness occurs when multiple large impacts obliterate smaller craters on impact. As a consequence, multiple large impacts cause large-scale resurfacing events which eventually results in a mismatch between the crater production and observed CSFD due to the presence of different surface units.

Modeling a pre-Nectarian surface unit: We use the Monte Carlo code CTEM [15-17] to simulate a globally cratered surface. Crater production is determined by a crater production function given by [2] and the generated impact craters have diameters of 15-905 km. The number of craters is determined by a visibility function (for details, see [17]). New craters of radius $\check{r}$ contribute to the diffusive degradation state K (with units m^2) over a circular region of radius $f_e\check{r}$ by the degradation function [8, 17]:

$$K_d(\check{r}) = K_{d,1}\check{r}^{\psi},$$

where $K_{d,1}$ determines the relative importance of diffusive degradation and ψ determines the slope of the per-crater degradation power law. In our simulations we use f_e=10 and $\psi = 2$ [17].

For simulated heavily-cratered surfaces in CTEM, the lower the low value of $K_{d,1}$ the more crater erasure is dominated by direct overlap (i.e. “cookie-cutting”) rather than by diffusive degradation. We ran three simulations using different levels of diffusivity to investigate the effects of diffusive degradation on the evolution of a lunar highland-like terrain: (1) $K_{d,1} = 0.003$ m², which corresponds to a value constrained from observations of $D \lesssim 200$ m simple post-mare craters as investigated by [17], (2) $K_{d,1} = 0.0001$ m² to represent a very low amount of diffusive degradation, and (3) $K_{d,1} = 0$, which implies that no diffusive degradation contributes to crater erasure during the simulation. The resulting datasets are analyzed using traditional crater counting (TCC) and non-sparseness correction (NSC) [14] CSFD measurement techniques. We used a modified version of CSFD Tools [18] to allow CSFD analyses from Cartesian measurements.

Results: We use the observations by [13] to investigate the role of diffusive degradation in the formation of a pre-Nectarian lunar surface. To this end, we applied TCC and NSC techniques to our modeled impact crater records and investigated the shapes of the resulting CSFDs. The results are summarized in *Fig. 1*.

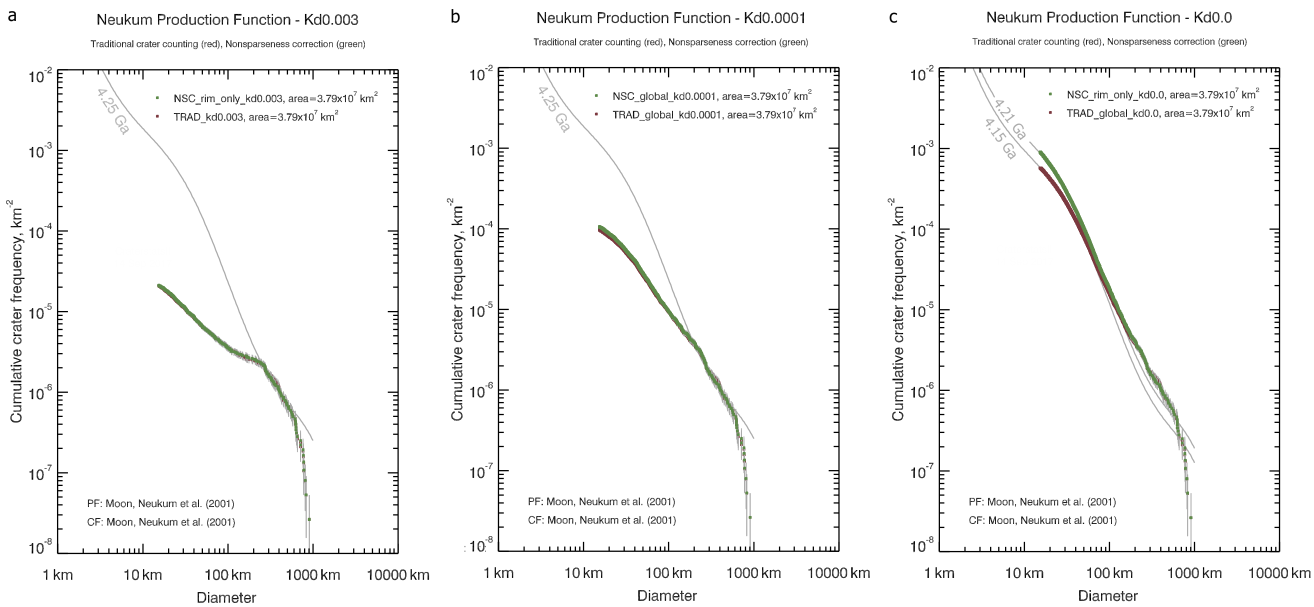

Figure 1: *CSFDs resulting from TCC (red) and NSC (green) measurement techniques for different degradation values. Isochrons of the Neukum [2] production function with corresponding model ages are shown in grey.*

The simulation using the mare-constrained value $K_{d,1}$ = 0.003 m² (*Fig. 1a*) [17] yields a CSFD which mostly does not match either the production function or observations of CSFDs of pre-Nectarian units [11-13]. The same is true for our simulation where $K_{d,1}$ = 0.0001 m² (*Fig. 1b*), however, the simulatied CSFD is less inconsistent than $K_{d,1}$ = 0.003 m², and we observed a minor non-sparseness effect due to the stronger influence of geometric obliteration effects in this simulation. The $K_{d,1}$ = 0 simulation (*Fig. 1c*) yields CSFDs that are largely consistent with the Neukum production function. We see a notable non-sparseness effect in the CSFD from TCC that can be corrected by applying the NSC technique. Since this is consistent with the lunar highland observations by [13], we consider this diffusion level realistic for simulating a pre-Nectarian surface unit at the given crater sizes.

Conclusions: While diffusive degradation dominates crater erasure on the lunar maria, our simulations suggest that the erasure of craters >15 km on pre-Nectarian surface units is dominated by the geometric overprint of small craters by large craters. This indicates that crater erasure is much more strongly scale dependent than that expected from diffusive processes. To further quantify our observations, additional investigations on crater equilibrium on pre-Nectarian surface units and the transition between cookie-cutting and diffusion dominated crater equilibrium need to be conducted.

We also show that the use of non-sparseness correction results in a better match between the observed CSFD and the production function. This result is consistent with the argument of [13] that the apparent difference between the CSFD of ancient heavily-cratered lunar highlands and the Neukum production function is due to crater obliteration effects rather than due to a change in the production function.

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