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Crater size-dependent degradation of lunar surface features on the mare and highlands

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Abstract

Recently, Minton et al. [3] used mare terrains in crater equilibrium to show that the topographic degradation of $D < 1$ km craters is dominated by topographic diffusion driven by distal ejecta Here we use the models developed to understand crater equilibrium of the lunar mare for $D < 1$ km craters to the problem of equilibrium in the $D > 10$ km heavily cratered lunar highlands.

1. Introduction

Hirabayashi et al. [2] developed an analytical model for crater accumulation and degradation, which can be used to model craters in equilibrium. The crater production can be approximated as a power law, with its cumulative size frequency distribution (SFD) taking the form: For the craters relevant to our study, we can model production function as a power law of the form:

$$n_{p,>D} = n_{p,>D_1} X D^{-\eta}, \tag{1}$$

where, $n_{p,>D_1}$ is a coefficient that gives the cumulative number of craters larger than unity in diameter (in the chosen unit system) per unit surface area, and η is the slope of the production function. The variable X is the same as that used in Hirabayashi et al. [2], and is a non-dimensional time factor used to scale the production function by the exposure age of the surface. We use a similar model can define the accumulation and degradation of countable craters using a first-order linear differential equation: we can define the accumulation and degradation of countable craters using a first-order linear differential equation:

$$\frac{d}{dX}\left(\frac{dn}{dD}\right) = \frac{d}{dX}\left(\frac{dn_p}{dD}\right) - k'\left(\frac{dn}{dD}\right), \tag{2}$$

where dn/dD is the differential number of countable craters, dn_p/dD is the differential form of the production function, and k' is a dimensionless degradation rate parameter that is defined as the fractional change in the differential number of countable craters per dimensionless time unit X. In equilibrium. The equilibrium differential SFD in differential form is given as:

$$\frac{dn_{eq}}{dD} = \frac{1}{k'}\frac{d}{dX}\left(\frac{dn_p}{dD}\right). \tag{3}$$

The equilibrium SFD is also commonly written as in cumulative form as power law, given as:

$$n_{eq,>D} = n_{eq,>\mathrm{D}_1} D^{-\beta}, \tag{4}$$

where $n_{eq,>\mathrm{D}_1}$ is a coefficient that gives the cumulative number of craters larger than unity in diameter (in the chosen unit system) per unit surface area, and β is the equilibrium slope. In this model, the equilibrium SFD is controlled by both the production function and the dimensionless degradation rate parameter, k'.

For craters of the lunar mare, the production function can be approximated as a power law with a constant slope $\eta \approx 3$. On these surfaces, the dimensionless degradation rate parameter can be defined in terms linear topographic diffusion. The evolution of a topographic surface in linear classical diffusion may be given by the diffusion equation of the form

$$\frac{\partial h}{\partial K} = \nabla^2 h. \tag{5}$$

We cast the dimensionless degradation rate parameter, k' in terms of topographic diffusion using two functions to, each of which is defined in terms of the degradation state K. We call these the *visibility function* and the *degradation function*. The visibility function, given by $K_v(D)$, quantifies the amount of accumulated degradation required to fully degrade an old crater of diameter, D. The degradation function is more complicated, but a simplified form may be on in which each new crater of diameter $\breve{D}$ contributes a uniform amount of degradation, $K_d(\breve{D})$ over a finite region of diameter $f_e\breve{D}$.

2. Equilibrium solutions

Minton et al. [3] constrained the visibility function for simple mare craters using a human crater counter calibration study, and constrained the degradation function using the equilibrium SFD. They found that the visibility function was well described by a power law, where:

$$K_v(D) = K_{v,D_1} D^{\gamma}. \qquad (6)$$

For geometrically similar simple craters, $\gamma = 2$. Using the equilibrium SFD of lunar mare terrains, they found solutions to the degradation function for which the solution to equation (3) was the observed equilibrium terrain.

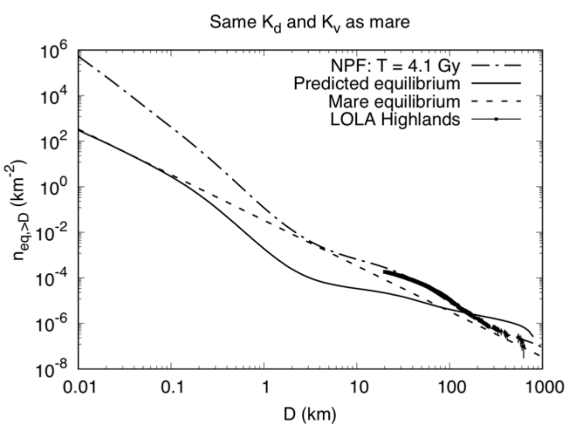

Figure 1: Analytical models for crater equilibrium. Short dashed line: Equilibrium SFD of lunar mare craters from Minton et al. [3]. Dash-dot line: Cumulative crater SFD for the Moon for a model age of 4.1 Gy using the Neukum Production Function [4]. Points: Crater counts of the lunar highlands from the LOLA-derived catalogue of craters [1]. Solid line: Predicted lunar equilibrium SFD using degradation and visibility functions derived of the lunar mare.

Using the same visibility function, K_v, and degradation function, K_d, derived for the mare by Minton et al. [3], we compute a predicted equilibrium SFD for all size craters using the Neukum Production Function [4]. Figure 1 shows the predicted equilibrium SFD using the analytical model, along with the SFD of the simple craters of the lunar mare, and crater counts of the lunar highlands from the LOLA-derived catalogue of craters [1]. The observed crater counts of the lunar highlands are much higher than that predicted by the analytical model.

Because fresh complex craters are shallower than fresh simple craters, complex craters should require less degradation (lower value of the visibility function) to fully degrade compared to that predicted by a simple extrapolation from simple craters. This should suppress the equilibrium SFD for large craters and basins even further below the predicted equilibrium SFD shown in Figure 1. Therefore, there must also be a very strong reduction of the degradation function at large sizes in order for highlands craters to reach the observed high crater number density. In other words, relative to their size, large complex craters must be much less destructive to the pre-existing landscape than small simple craters.

References

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