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Crater Formation in a Layered Lunar Crust – Effects on Crater Chronology

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Abstract

We conducted a suite of numerical models of crater formation on the moon assuming a layered lunar crust consisting of a regolith layer overlying megaregolith, intact basement rocks, and the lunar mantel. We varied impactor size between 1 m and 35 km and determined the diameter of the transient crater. The results of the numerical experiments provide a detailed scaling relation for crater size as a function of impact energy that is used to derive a refined crater-size-frequency production function for the moon assuming a NEO orbital distribution model.

1. Introduction

The surfaces of all planets, satellites, and other objects are more or less scarred by impact structures. The size-frequency distribution (SFD) and the morphology of impact craters are known to be important observations to determine the age of surfaces and to estimate the change of properties and composition of the crust with depth. Empirical lunar chronologies [e.g., 0] have been derived based on the assumption that the effects of target properties on the cratering on different terrains are negligible. The lunar crater chronology can be exported to other planetary surfaces by modeling the flux of impactors and the formation of craters [0]. For the latter so-called scaling laws are required that relate the kinetic energy of an object (diameter L, mass m, velocity U) to the diameter D of the crater formed after impact. So-called Pi-group [1-4] scaling is probably the most successful approach in dimensional analysis of impact crater scaling and has been successfully used to theoretically model the lunar crater production function [5,6,7]. However, existing scaling laws predict the size of the transient crater (not the final crater) only for a homogeneous target with material properties that can be approximated by analogue modeling on a laboratory scale [8]. Numerical modeling of crater formation enables more systematic parameter studies to analyze the effect of material properties such as porosity φ, cohesion Y, friction f [3] and impact angle [9] on crater size. Here we present a suite of numerical cratering experiments to develop new refined scaling relationships for layered targets approximating more realistically the conditions for the lunar crust.

2. Numerical Experiments

We conducted a suite of numerical experiments of crater formation on the Moon with the hydrocode iSALE [10 and reference in there]. iSALE was successfully validated against laboratory experiments [11] and systematic numerical scaling studies [3] show good agreement with scaling-laws derived from laboratory experiments [1,4,8]. We modeled vertical (90°) impacts of asteroids with a diameter range of 1 m-35 km and an impact velocity of 12.6 km/s. The projectile is composed of the same material as the target and we use an ANEoS for basalt to model the thermodynamic response of material to shock wave compression. The target is composed of a 50m thick regolith layer overlying megaregolith that gradually transitions into fully intact basement material at 1000m depth. We account for the differences in porosity and material strength in the three different layers by using a porosity compaction model [10] and a strength model described in [12]. Due to the large number of numerical experiments required for this study the resolution in all models is only 10 cells per projectile radius which causes an error for crater diameters of approximately 10% [3,11].

3. Results

We determined the diameter of transient crater D in the numerical experiments at the time when the crater volume reaches its maximum [9]. Note, for large craters (several tens of km) gravity driven collapse uplifting the crater floor may occur while the crater is still growing in radial direction which results in an erroneous determination of the transient crater. Following Pi-group scaling [4] the measured crater diameter is expressed in terms of the dimensionless ratio $\pi_D = D(\rho/m)^{1/3}$ where ρ is the density of the target. Despite variations of density due to porosity in the layered target we use ρ=2.65 kg m^{-3} to determine π_D for all data points. In Fig.1 π_D is plotted versus the gravity-scaled size $\pi_2=1.61gL/U^2$ where g is the gravity of the Moon.

4. Discussion

The preliminary results show that target properties significantly affect the scaling of crater dimensions. For the range of projectile diameters (π_2-values) all craters are dominated by gravity. For smaller π_2-values crater scaling for competent rock (blue line) transitions into the strength regime. While craters in homogeneous targets can be scaled by power-laws (straight lines) in the gravity regime, craters formed in layered targets show a much more complex scaling relationship between π_2 and π_D; however, the curve (cyan line) roughly follow the scaling line for regolith (brown line). Due to an overemphasized contrast in strength properties between the regolith and megaregolith in our models smaller craters (small π_2-values) show morphologies similar to so-called "nested craters" (Fig.1, upper left snapshot). The radial extent of those craters may exceed the size of craters in pure regolith targets as the projectile can penetrate less deep into a layered target where strength increases significantly at the transition into the megaregolith layer.

5. Conculsion

Our preliminary results show that the scaled crater size for a layered target differs up to 40% from craters in a homogeneous target of basement material and up to 10% from craters in a homogeneous target of regolith, respectively, for the same impact conditions. This difference, as well as the change in the shape of the crater scaling law, may significantly affect the crater retention age determination. In a next step we plan to use the new scaling laws for crater formation in layered targets to reproduce the crater production function for the Moon.

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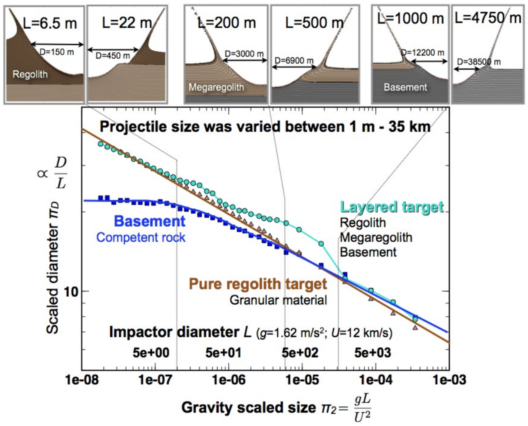

Fig.1 Gravity-scaled size π_2 vs. scaled crater diameter π_D for 3 different target conditions. The brown line correspond to a pure regolith target, the blue line represents a homogeneous half space of basement rock and the cyan line shows the transient crater diameter for the 3-layer case as described in the text. Vertical lines mark the transition from a "nested crater" to the onset of excavation of the 2nd layer, and the transition where the transient crater reaches into the basement. Snap-shots of the transient crater for different projectile diameters L are shown for the different regimes