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Scaling of impact crater formation on planetary surfaces

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Abstract

Numerical modeling of impact cratering can be used to study the relationship between impact energy and crater size, the so-called scaling relation. Numerical modeling allows for a detailed determination of scaling parameters that depend on target properties. In our numerical models we varied the coefficient of internal friction, cohesion, and porosity independently to investigate the effect on the size of the transient crater. Generally it can be said the higher coefficient of friction, the more porous the target, and the larger the cohesive strength the smaller the resulting crater.

1. Introduction

The observed crater record raises the question: how much impact energy is required to produce a crater of a certain size and morphology on a planet with a given gravity?

To answer this question it is important to note that the final size and morphology of impact structures results from the gravity-driven collapse of a transitional cavity, the so-called transient crater, which represents the maximum extent of shock wave-induced excavation. Accordingly, crater scaling has to be carried out in two steps: (i) calculating the size of the transient crater, and (ii) determine the size of the final crater from transient crater size. Here we focus on the first step, the determination of transient crater size, which is a representative measure of the kinetic energy that was released by an impact event. We present numerical models of crater formation quantifying the size of the transient crater as a function of impact energy, gravity, and material properties of the target (friction, porosity, cohesion). We present results for size scaling of the transient crater and compare the data of our numerical experiments with laboratory cratering experiments [e.g. 1].

2. Scaling of the transient crater

To compare laboratory experiments on a centimeter size-scale with large natural craters ranging from several hundred meters to hundreds of kilometers in size it is useful to introduce dimensionless parameters describing the properties of the impactor (velocity U, mass M, and diameter L, density δ) and the target (gravity g, density ρ). The most successful approach in dimensional analysis of scaling the transient crater is the so-called Pi-group scaling [2,3] where π_2 is the gravity-scaled size of an impact event and π_D is the scaled diameter of the transient crater:

$$\pi_2 = 1.61 gL/U^2 \quad (1)$$

$$\pi_D = D(\rho/M)^{1/3} \propto D/L \text{ (assuming } \delta=\rho) \quad (2)$$

Based on laboratory cratering experiments a power-law relation between the scaled crater diameter and the gravity-scaled size of an event was found [1]:

$$\pi_D = C_D\, \pi_2^{-\beta}, \quad (3)$$

where C_D and β are scaling parameters that may depend on petrophysical properties of the target such as the coefficient of internal friction f, porosity ϕ and cohesion Y_0. To quantify these parameters over a broad range of petrophysical properties we carried out numerical experiments with impactor diameters L ranging from 25-5000 m and varied the coefficient of friction between 0-0.8, porosity between 0-38 % and the cohesive strength between 0-10 MPA. In principle this scaling-law enables the prediction of transient crater size at any scale if impactor velocity, size, and gravity of the target are known, and crater size is limited by gravity (which is the case for all craters in cohesionless material and most craters in planetary surfaces).

We used the iSALE hydrocode [4,5] with an ANEOS-derived equation of state for quartzite [6,7] to model the thermodynamic behaviour during shock wave compression and a Drucker-Prager strength model, where yield strength Y is a linear function of pressure P, $Y=f\,P$, to describe material response to elasto-plastic deformation. Porosity was modeled by ε-alpha porous-compaction model [4].

3. Results

Figure 1 a/b and 2 show a plot of scaled crater diameter π_D versus gravity scaled size π_2. At the upper axis the corresponding projectile size is indicated; note that gravity and impact velocity were kept constant in all numerical experiments (g=1.62 m/s^2, U=5 km/s).

First, we investigated the effect of *friction* on crater size in nonporous targets (Fig. 1a). An increasing coefficient of friction has two effects:

(i) the scaled crater diameter decreases and

(ii) the slope β decreases with increasing friction

In a second step we investigated how *porosity* affects crater size for a constant coefficient of friction of 0.8 (Fig. 1b). Increasing of porosity results also in two effects:

(iii) the scaled crater diameter decreases with increasing porosity

(iv) the slope β slightly increases

Assuming a coefficient of friction f=0.8 and a porosity of 25% the numerical models match the experimentally determined scaling law for water [1] (dashed line in Fig. 1a) and Ottawa sand [1] (dashed line in Fig. 1b) very well.

Finally, we investigated the effect of *cohesion* on the scaled crater dimensions. We kept porosity and friction constant (f=0.8, ϕ=0) and varied the cohesion (Fig. 2). Two effects are observed:

(v) with decreasing π_2 the scaling lines deviate from the line for non-cohesive material approach a constant π_D value, which means that crater size becomes independent of gravity and crater growth is dominated by strength

(vi) for large π_2 values the scaling lines for Y_0=1 - 10 MPA almost lie on top of each other; however, in a transitional regime cohesion significantly affects crater size.

Acknowledgements

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References

[1] Schmidt, R.M., Housen, K.R., 1987, Int. J. Impact Eng. 5, 543-560.

[2] Holsapple, K.A. 1987, Int. J. Impact Eng. 5, 343-355.

[3] Holsapple, K.A., Schmidt R.M. 1987, J. Geophys. Res. 92, 6350-6376

[4] Wünnemann K., Collins, G.S., Melosh, H.J., 2006, Icarus 180, 514-527.

[5] Ivanov, B.A., Deniem, Neukum, G., 1997, Int. J. Impact Eng. 17, 375–386.

[6] Thompson, S.L., Lauson, H.S.,, 1972, Report SC-RR-71 0714. Sandia Laboratories, Albuquerque, New Mexico. 119 pp.

[7] Melosh, H.J., 2007, MAPS 42, 2079–2098.

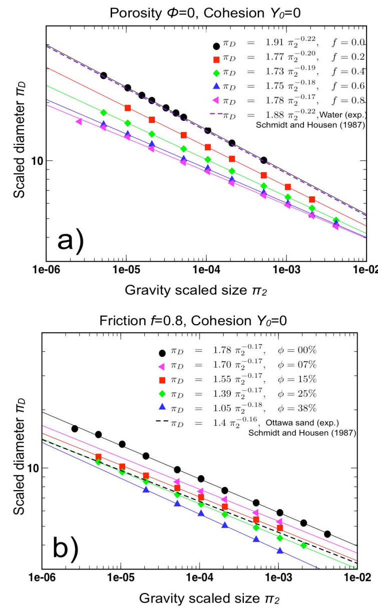

Figure 1: Gravity scaled size π_2 versus scaled crater diameter π_D. (a) Scaling lines for nonporous material and different coefficient of friction f. The dashed line corresponds to an experimentally derived scaling line for water. (b) Scaling lines for a friction coefficient of f=0.8 and porosities 0-38%. The dashed line corresponds to an experimentally derived scaling line for Ottawa sand (f≈0.6-0.8, porosity≈20-30%).

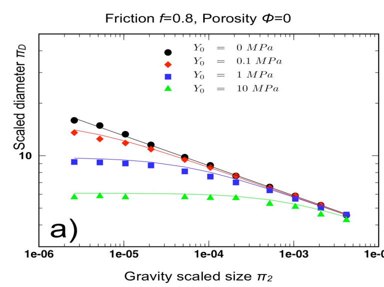

Figure 2: Gravity scaled size π_2 versus scaled crater diameter π_D. Scaling lines for nonporous material, coefficient of friction f=0.8 and different cohesive strength Y_0.