Impact cratering and ejection of material on porous asteroids

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The manner in which an impact crater and its ejecta blanket are created involves an interplay between gravity and the strength properties of the target material. Gravity is important because the overburden stress at depth in an asteroid determines the material shear strength, which affects the mechanics of crater and ejecta formation. This has important implications when attempting to use lab experiments to simulate large-crater formation on asteroids.

The only way to perform small-scale experimental simulations of cratering events on asteroids is to adjust the ambient "gravity", g, such that the experiment has the same product of gL as the actual impact event being simulated, where L is an important length scale, such as the projectile or crater size [1]. In this way, the lab crater has the same overburden stress (and shear strength) and ejecta ballistics as a much larger cratering event on an asteroid. Even though asteroids have weak gravity fields, the overburden stress of a multiple-km crater is larger than can be reproduced in the lab at 1 G. Therefore, simulation of large impacts on asteroids requires that the "gravity" of the experiment is greater than 1 G.

Here we report on a series of impact experiments conducted at elevated gravity on a geotechnical centrifuge. These experimental craters are subscale replicas of the much larger craters they simulate; larger G-levels simulate larger craters. Using the Boeing 600-G centrifuge, we directly simulate the formation of asteroid ($g \sim 0.001$ G) craters as large as several tens of km. The target materials are cohesionless with porosity ranging from 35 % to 95 %.

Cratering experiments in soils with small or moderate porosity (<30 %) show a decrease in cratering efficiency (crater volume/impactor volume) with increasing size scale or, equivalently, increasing G in a centrifuge experiment. This well-known gravity-regime behavior is due to the fact that the shear strength of the target material goes up due to the increased lithostatic overburden stresses at large scales.

When the target material has significant porosity, much of the crater volume forms by permanent compaction of void spaces. This compaction volume depends only on the crushing strength of the material, independent of size scale. The crater volume cannot be less than the volume created by compaction. Therefore, at large size scales, the cratering efficiency for porous materials levels out to a constant value rather than decreasing as in the usual gravity-dominated cratering. The transition to this asymptote represents the onset of compaction-dominated cratering.

The presence of a compaction regime of cratering is important because, as our experiments and scaling arguments have shown, the mass of material that is emplaced in a crater's ejecta blanket drops sharply upon transition into the compaction regime. This causes craters to form without ejecting material outside the crater, resulting in an absence of ejecta blankets on porous asteroids, less erosion of existing pre-existing craters, and reduced gardening of the regolith by impacts.

Our experiments now allow us to determine the conditions under which this compaction-dominated cratering and suppression of ejecta occur. In the presentation, these experiments will be summarized, we will show how they are consistent with observations of a lack of ejecta around large craters on Mathilde and Hyperion [2–4], and will discuss the mechanics of cratering on porous bodies.

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References: References: [1] Housen K.R. and Holsapple K.A. (2003) Icarus, 163, 102–119. [2] Veverka et al. (1999) Icarus, 140, 3–16. [3] Chapman C.R. and Merline W.J. (1999) Icarus, 140, 28–33. [4] Thomas P.C. et al. (2007) Nature (Letters), 448, 50–53.