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The Role of Target Heterogeneity in Impact Crater Formation: Numerical Results

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Abstract

Target heterogeneities, such as cracks, faults, joints, and blocks, are known to influence impact crater morphology on planetary surfaces. We perform a preliminary investigation into how the relationship of target heterogeneity size to projectile size affects the cratering process and final crater morphology for a fixed impact velocity. We use the CTH hydrocode to numerically simulate these impacts into a strong target with idealized heterogeneities where the ratio of the projectile size and heterogeneity size is varied. When the projectile is significantly smaller than the size of the heterogeneities, the pressure field decay is similar to that for a half-space impact into a homogenous target. In contrast, when the projectile size is comparable to or larger than the heterogeneities, we observe more efficient attenuation of the shockwave, resulting in decreased cratering efficiency. The attenuation of the shockwave is caused by rarefaction waves reflecting off of the free surfaces of the heterogeneities and internal energy losses resulting from void space collapse when the target strength is overcome by the impact energy.

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Keywords: Impact craters; Planetary Science; CTH models; Target Heterogeneity

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1. Introduction

Pre-existing heterogeneities in a target are known to affect the crater-formation process and the final crater shape [e.g., 1, 2, 3, 4]. Sources of target heterogeneities include pre-existing tectonics (such as joints and fractures), large blocks, megaregolith, heterogeneities in the bedrock composition or variations in the composition of a single rock. Pre-existing fractures might have contributed to the square shape of Meteor Crater, Arizona [5] and several craters on 433 Eros [6]. Some studies have suggested that target heterogeneities could also influence cratering efficiency (the ratio of the mass displaced by the formation of the crater to the mass of the projectile) especially on asteroids [7, 8], because many asteroids are thought to be fractured monoliths [6] or rubble piles [9].

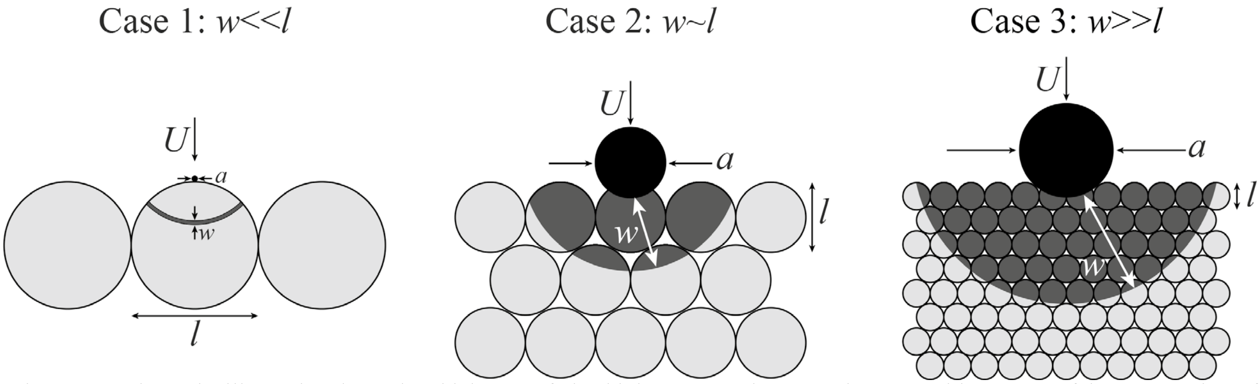

Figure 1. Schematic illustarting how the thickness of the high-stress region may interact with targets of heterogeneties of different length scales.

Nomenclature

w	thickness of high stress region
a	diameter of projectile
l	length scale of target heterogeneity
U	projectile velocity
d	depth of crater
D	diameter of crater
π_v	cratering efficiency

Heterogeneities on the surface of, and within the subsurface of, an asteroid may affect the formation of small craters. The presence of widespread surface clasts, as well as interior voids on an asteroid, could lead to a process called self-armouring, especially when the heterogeneity is in the form of pre-existing boulders on the surface with about the same size as an impacting projectile. Such an impact scenario would result in considerable energy being expended on crushing or fracturing the boulders, with the result that no recognizable impact crater would be formed. An experimental study of impact cratering at impact velocities below the sound speed in the target [3] varied the ratio between the projectile diameter and the length scale of the target heterogeneity (represented by uniform sized spheres). Results of this study found that projectile was smaller than the target heterogeneity, the resulting crater diameters were smaller relative to when the projectile was larger than the target heterogeneity. They also discovered that substantial impact energy went into fragmentation at this scale. In the previous study no numerically modelling was done to explore how the shock and pressure field were related to the resulting craters.

In this study, we use a numerical investigation to explore the effects of target heterogeneities on crater formation and efficiency. Our numerical simulations use a projectile velocity of ~5 km s^{-1}, which exceeds the bulk sound speed of the target. Such impacts differ from the subsonic impacts investigated experimentally in [3]. Our numerical models explore three scenarios (Figure 1) for how the thickness of the high-stress region, w (a function of projectile size, a, and velocity, U), interacts with heterogeneities whose characteristic dimension, l, is much larger than w,