Squaring the Circle: Impact Craters as a Diagnostic of Pre-Existing Sub-Surface Target Features.

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Pre-existing faults and inhomogeneities in the target geology are known to affect the formation and final geometry of an impact crater. Here we present an exploration of the effects of differences in target compressive and tensile strength, pre-impact target damage, and shock damage from the impact itself on the evolution and final 2- and 3-dimensional geometry of impact crater models in the RAGE hydrocode.

Introduction

The best-known example of this phenomenon is Meteor crater in Arizona [1], which landed on an intersection between to perpendicular faults [2]. The rock nearest each fault is more fractured, so it's weaker, which means that the crater opens up preferentially along the fault and slower at the 45 degree angles between the two faults, leading to a squared-off crater during the excavation [3] or modification [4] phase. Polygonal craters on Mars also appear to track ring faults around the Hellas and Isidis impact basins [5]. Other examples have been seen on Venus [6] and the moon [7]. Here I present an exploration of the effects of differences in target compressive and tensile strength, pre- impact target faulting, and shock damage from the impact itself on the evolution and final 2- and 3- dimensional geometry of impact crater models in the RAGE hydrocode [8, 9]. I also explore the benefits and uncertainties inherent in using craters, which sample the target surface randomly, but have length scales controlled by established size-frequency distributions (SFD's).

Models

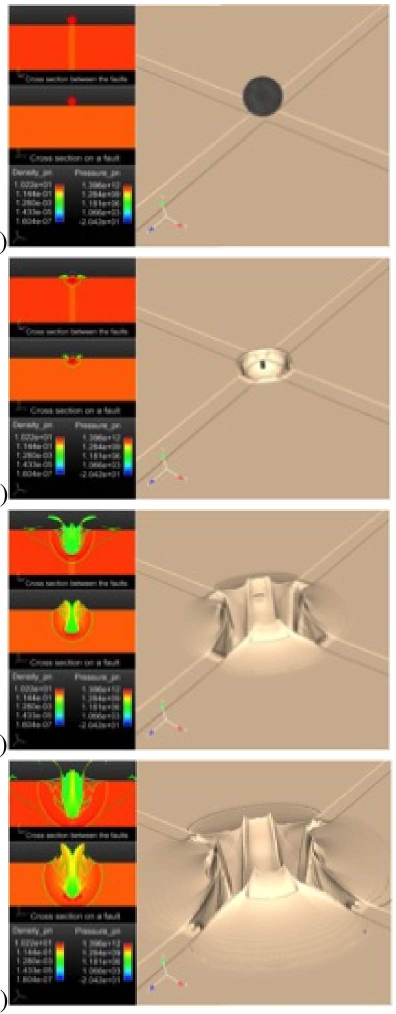
The models are 3-D Cartesian models of an impact into a target similar to the Meteor Crater target rock. The intent was not to model Meteor Crater exactly, but to study the effect of the cross faults. In order to reduce the problem space, I used a vertical impact of a solid impactor, instead of the commonly accepted acute angle fragmented projectile initial conditions for Meteor Crater. I also reduced the problem size in order to make it feasible given available computing resources. The impactor is 2 m in diameter and strikes a sandstone target at vertical incidence with an impact velocity of 15 km/s. I approximate a fault zone or joint in these models with vertical inclusions of strength-less, lower density rock. The thickness of the fault zone is variable, but for the models presented here it is 1 m, shown at t = 0 below. The initial mesh is 40 x 20 x 40, with 1 m^3 initial zone volumes that are allowed to refine down to minimum zone sizes of 30 cm^3. I used the Eulerian hydrodcode RAGE, with SESAME equations of state for sand, Nevada alluvium, air and iron [10], and the OSO computational geometry design software to set up the initial meshes for all of the models.

Cross-Fault Model Results

The images shown here are a composite of an iso-surface of target material density at 1.5 g/cm^3 (right) and density plots with contours of pressure at two 2-D traces on and at 45 off the faults. The end of the contact and compression phase above, t = 94 μs, Fig. 1(b), shows a round crater. The excavation flow begins to distort as the flow in the weaker, more porous fault material moves radially ahead and is thrown out of the crater at a lower density (t = 200, 400 μs) Fig. 1(c). The impedance mismatch in the two materials distorts the outward propagating shock precursor and the crater depth to diameter ratio (t = 600, 800 μs). The rim begins to fold back preferentially along the corners where the faults intersected (t = 0.0102, 0.0108 s), Fig. 1(d). The crater enters the terminal regime about 2.0 s after surface contact, and the final crater is indeed squared off, as in Fig. Fig. 2.

Ongoing Work

Strike-slip faults with little dip are only one of many fault morphologies that an impact crater might imprint on. I am working on further models to explore the effects of other fault geometries on crater morphology.



a) b) c) d)

Figure 1: RAGE model progression, isosurface of density at $rho = 2.4$ g/cm^3.

Target Sampling Statistics

Craters are approximately randomly distributed across the target surface. Each crater has a length scale, diameter, which is a function of the kinetic energy (diameter and velocity) of the original impactor. The crater will be sensitive to target properties at different length scales in ways that depend on the impact energy. For example, a Chixulub-sized impactor would not express strong morphology changes in response to the Meteor Crater cross-faults, but overall target porosity would affect the outcome. The crater population, although random in location, is described by SFDs with their own uncertainties. This will affect the probability of the impact population on a given target surface sampling sub-surface features. It may be possible to make statements about the number or size of such features, but the sampling effects will need to be taken into account.

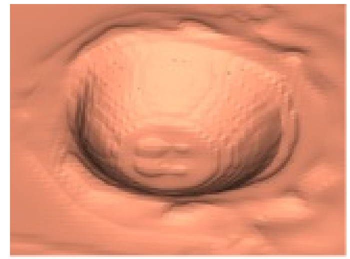


Figure 2: RAGE model final crater, isosurface of density at $rho = 2.4$ g/cm^3.

References

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