ASYMMETRIES IN COMPLEX CRATERS DUE TO OBLIQUE METEORITE IMPACTS?

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Introduction: Field studies at terrestrial craters, laboratory experiments of crater formation and numerical modeling significantly contributed to our current understanding of the formation of simple and complex crater structures. However, most of this knowledge is based on vertical impact scenarios and the effect of an oblique angle of incidence is often believed to be negligible. Despite the fact that almost all craters are more or less circular in shape it is still a matter of debate whether oblique impacts cause structural asymmetries or not (e.g. [1,2]) and it is basically unknown how far the formation of a crater resulting from a vertical impact resembles crater formation for the much more common case of an oblique impact angle. At vertical impacts the excavation flow differs in vertical (depth) and radial (diameter) direction. For instance, when crater growth has ceased already in vertical direction the radial excavation of the cavity may still continue (e.g. [3]). In case of an oblique impact we have to distinguish additionally between crater growth in up- and downrange direction. This is primarily due to the fact that an oblique impact angle causes an unbalanced material flow in up- and downrange direction with a gradual transition in between [4]. Therefore it is feasible that structural asymmetries exists that may indicate the direction of impact. Hydrocode modeling of oblique impacts [4,5] supports this assumption. However, identifying clear structural indications for the direction of impact at terrestrial craters, on planetary surfaces and in impact experiments is ambiguous and controversial discussed in the literature (see e.g. [6-11]). The only clear indication for the direction of impact is the distribution of ejecta; however, ejecta deposits are only poorly preserved. Erosion may have also removed structural indications in the uppermost section of a crater. For terrestrial craters pre-impact target heterogeneities and, for smaller craters, target topography may also affect crater excavation and could explain crater asymmetries.

We are conducting a systematic parameter study which aims at distinguishing how an oblique impact angle affects (complex) crater formation. In particular we focus on the formation of central peaks and the quest for asymmetries in the target as possible indicators for the impact angle or direction.

Methods and model setup: We are performing three-dimensional (3D) numerical-simulations with iSALE-3D [12], a highly efficient hydrocode optimized for studying late stage crater formation. For the very first beginning of this study we start with simulating a single-layer scenario and using the same material (granite) for both target and projectile. We used earth gravity (g=9.81m/s^2) and kept velocity constant at U=6.5 km/s. To investigate crater formation for different-sized craters we varied projectile radii in a range from [125m…1.5km]. We used Tillotson EOS [13] for granite and assumed a Mohr-Coulomb strength model (where shear strength Y is proportional to pressure P, $Y = Y_{coh} + f \cdot P$) with no cohesion (Y_{coh}=0.). Since we did not consider Acoustic Fluidization [14] so far we chose lower friction coefficients f in a range between 0. and 0.7 for compensation.

Preliminary results: Fig. 1 and Fig. 2 illustrate the shape of the crater for impacts at angles between 90° (vertical) and 30° as cross sections (Fig.1) and in plane view (Fig.2). Snapshots are taken at the time when the central peak reaches its maximum height. Our models show that (1) the height of the central peak decreases with the impact angle (2) the position of the central peak is offset downrange for lower impact angles (3) the time of central peak formation decreases with the impact angle in a sinusoidal manner (4) crater size decreases with the impact angle proportional to the sinus of the impact angle α. Furthermore, our results suggest that for impacts with α<30-60° (a) no overturning of the uppermost part of the layer in uprange direction occurs, (b) the central peak begins to collapse in uprange direction (c) a “forbidden zone” of ejecta deposits in uprange direction emerges.

Future prospects: Here we present preliminary results of a more detailed parameter study that is still in progress. The goal is to quantify the observations listed above (1-4 and a-c) and shown in Fig.1 and Fig.2. Additionally, we want to investigate (a) whether the collapse of the central peak introduces further asymmetries to the crater (b) crater formation for highly oblique impacts (10°<α<30° (c) the relative thickness, radial extent and position of the ejecta layers and/or crater rim as a function of azimuth. Since structural indications for an oblique impact angle in the uppermost strata of the crater is often lost due to erosion, we will also look at deep-seated deformations in the target, in particular below the central peak. Our preliminary results show an unusual tracer distribution beneath the central structure that differs from comparable 2D-simulations for vertical impacts. We suspect that this is an effect of resolution. We are going to study this observation in more detail in order to identify whether it is a numerical artifact or has some real physical meaning that can be correlated with the crater formation.

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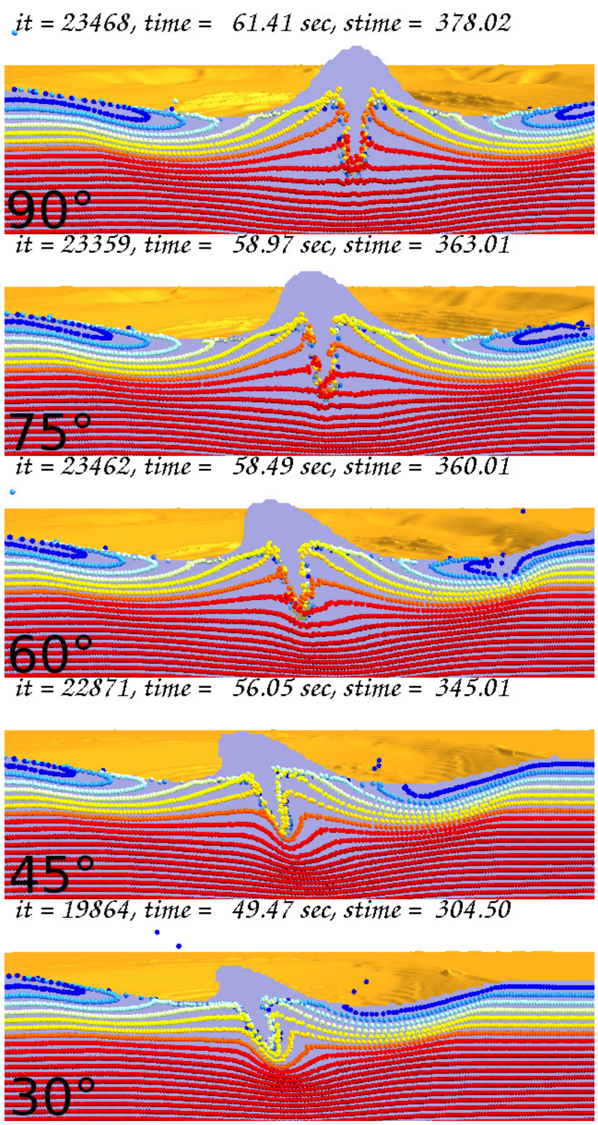

Fig. 1 Snapshots of craters caused at different impact angles at the time when the central peak reaches its maximum extent. Massless tracers are colored by their initial depth.

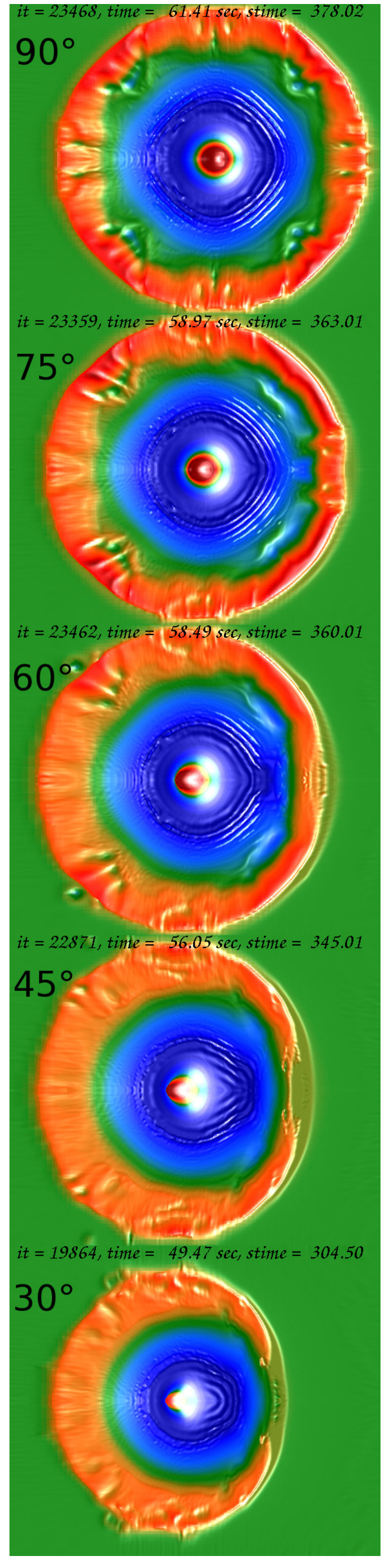

Fig. 2 Top view of the craters presented in Fig. 1. Surface is colored by its height.