STRUCTURAL SIGNATURES OF OBLIQUE IMPACTS – INSIGHTS FROM NUMERICAL MODELING.

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Introduction: Meteorites striking the surface vertically are most unlikely [1]. Anyhow, most of our knowledge on the physics of impact processes and especially the crater formation is based on vertical impact experiments. Since oblique laboratory experiments in a velocity range of scientific interest are very costly, numerical studies are a powerful tool to investigate oblique impacts. Using our three-dimensional hydrocode iSALE-3D [2], we are performing extensive parameter studies concerning the influence of the impact angle on those physical processes. Our aim is to extend the validity of existing scaling laws for oblique impacts.

To make the application of such oblique scaling laws feasible for interpreting existing crater structures, identifying the impact angle and direction with those structures is of crucial importance. Here we are presenting some suggestions based on numerical modeling how it might be possible to identify angle and direction of the impactor at real crater structures. With this work we are investigating both the physical processes during an oblique impact and the resulting morphology including the distribution of proximale ejecta.

Trajectory motion model: For a better understanding of crater formation, the change of material motion (trajectories) with the impact angle is very important. Figure 1 shows some trajectories of tracers (massless particles that are placed in the target and follow the material motion) from an oblique impact model (30° measured from target surface).

Our simulations show that the crater rim in uprange direction is degenerated and defined by the so called "forbidden zone" of ejecta distribution (e.g. [3,4,5]). The magnitude of this degeneration is most likely dependend on the impact angle as well as on the impactor's size, friction, strength and other material properties. Identifying this structure at real impact craters is very difficult. Very oblique impacts are also assumed to produce degenerated rim-zones by ricocheting projectile material in downrange direction (e.g. [6]). For those cases it is not clear whether this feature is a result of the forbidden zone or just an effect of ricocheting matter.

Studying the trajectories may provide a better understanding of the general mechanism which leads to the formation of degenerated crater rims. We also found a correlation between the size of the forbidden zone and the impact angle. Since material motion is strongly dependent on the physical properties of both target and projectile material, the influence of friction on the trajectories most likely is important. Therefore we will incorporate a simple strength model (Mohr-Coulomb dry friction) in our simulations to study those influences.

Even though we found some good indicators for the impact angle and direction, identifying such characteristics in nature is much more complicated. We are going to compare our results with some geological studies from impact craters in Australia [Poelchau et al. (this volume)].

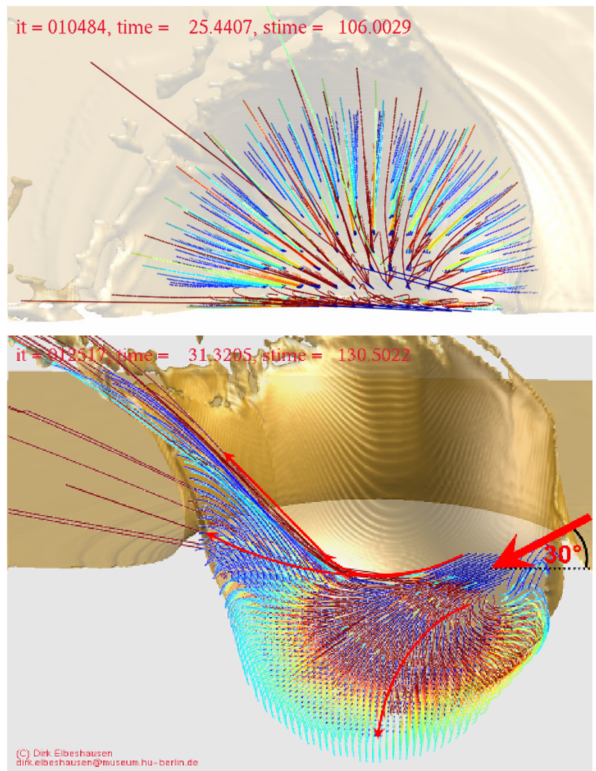

Fig.1: *Visualization of trajectories of an oblique (30°) impact. Trajectories are colorized by the peak shock pressure of the tracer. Tracer particles, which moved less than the projectile diameter are not drawn.*

Top: View from top into the crater (impact direction from right to left)

Bottom: View in a cross-section spaned by the impactors trajectory.

Slope of the crater rim: Although most oblique impacts are leading to circular craters [7], the slope of the crater rim may show local variations due to the impact direction [8].
Here we are trying to find some principles for the slope of the crater rim depending on the impact angle and direction. This is done by both numerical simulations (Fig. 2) and geo-structural studies of impact craters located in Australia [Poelchau et al. (this volume)].

Asymmetry of the central uplift: Fig. 3 shows a snapshot of an oblique impact at the time when the central uplift reaches its maximum extend. A slight asymmetry is observable at this stage for low impact angles. With both numerical modeling and geological observations [Poelchau et al. (this volume)], we want to identify the influence of the impact angle and direction on the morphometry, location [9] and especially the structure of the central uplift.

Conclusion: This is just the beginning of an interdisciplinary study of oblique impacts and the influence of obliquity on the geological structure of the resulting impact craters. Although our numerical study shows some very useful indicators for the impact direction, finding such indicators at real crater structures is much more complicated and might be impossible due to the state of preservation of most terrestrial impact structures. Therefore we tackle the objective to define characteristic indicators for the direction and angle of impact at crater structures by an interdisciplinary approach combining numerical modeling with structural geology [Poelchau et al. (this volume)]. Numerical models provide important information on structural peculiarities of oblique impact craters and what field geologist should in particular pay attention to. Results from field observations can be used by numerical modeling to conduct more detailed studies of the physical processes of oblique impacts. This may be another step forward in understanding oblique impact processes and their crater formation.

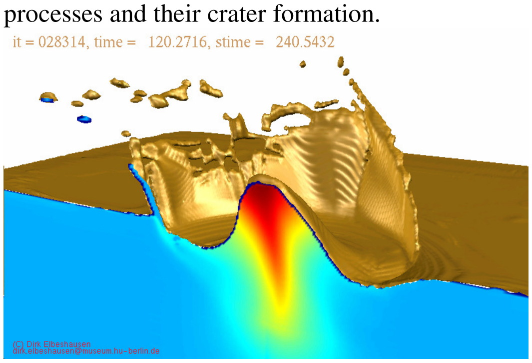

Fig.3: *Snapshot of an impact simulation with 30° impact angle (impact direction from top-right to bottom left). Front face shows temperature.*

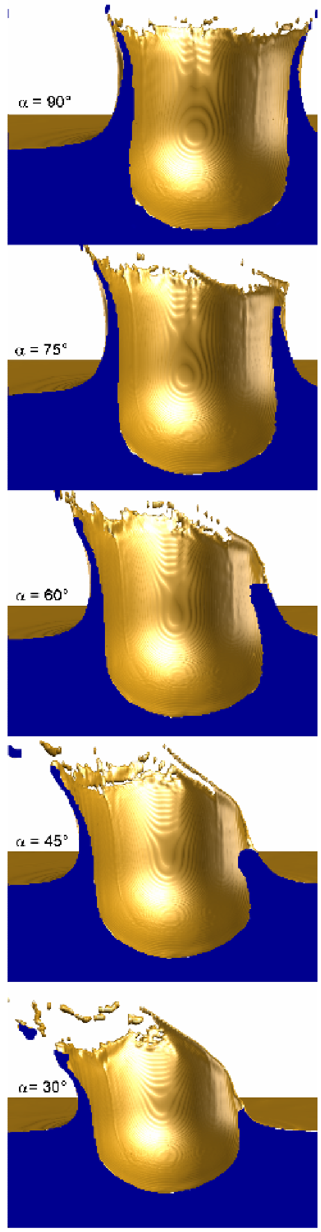

Fig. 2: *Crater shape depending on the impact angle*

Here are shown some crater profiles along the area spaned by the impactor's trajectory. These profiles are taken approx. at the time when the maximum crater volume is reached. The crater centre is moving slightly downrange with the impact angle. Also the angle between the ejecta trajectories (especially in downrange direction) and the target surface is getting lower with decreasing impact angle. The degeneration of the crater rim in uprange direction is stronger for lower impact angles. Surprisingly, the depth of the crater is nearly the same in a range between 90° and 60°. Afterwards, the depth of the crater decreases in a sinusoidal manner. This may be a first indicator for scenarios, where crater formation becomes more and more dependent on the momentum of the projectile [Elbeshausen et al. (this volume)].

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References: [1] Shoemaker, E. M. (1962) *Physics and Astronomy of the Moon,* 283-359. [2] Elbeshausen, D. (2007) *LPSC XXXVIII*, #1952. [3] Artemieva, N. A. and Ivanov, B. A. (2001), *LPSC XXXII*, #1321. [4] Artemieva, N. A. and Ivanov, B. A. (2004), *Icarus 171*, 84-101. [5] Artemieva, N. and Pierazzo, E. (2003), *Workshop on impact cratering*, #8022. [6] Chappelow, J. E. and Herrick, R. R. (2007) LPSC XXXVIII, #1419. [7] Gault, D. E. and Wedekind, J. A. (1978), *Proc. LPSC IX,* 3843-3875. [8] Poelchau, M. H., Kenkmann, T., Scherler, D. and Quart, S. (2007) *LPSC XXXVIII*, #1698. [9] Shuvalov, V. V. (2003) 3rd Int. Conf. Large Met. Imp. #4130.