CRATER FORMATION AFTER SHALLOW IMPACTS – HOW DO ELLIPTICAL CRATERS FORM?

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Introduction: Elliptical impact craters often exert a fascination, despite (or due to) their rare occurrence among the generally symmetric shape of impact structures on planetary surfaces. Nevertheless, our knowledge on the formation of these craters is limited. Why do some impacts result in a circular crater whereas others form elliptical shapes? How does the formation of elliptical craters differ from those of circular craters? Is the formation process comparable to those of elliptical craters formed at subsonic speeds? How does crater formation work at the transition between circular to elliptical craters? By conducting more than 800 three-dimensional (3D) hydrocodes simulations we investigated these questions in a quantitative manner.

Model stup: We used the 3D-hydrocode iSALE-3D [1,2] for our simulations. Assuming terrestrial gravity conditions (g=9.81 m/s^2) we varied the impact angle α from 90° (vertical impact) to 5°. We used impact velocities of U=8 km/s, 12 km/s, and 18 km/s and varied the projectile diameter L over more than one order of magnitude (L=0.25, 0.5, 1, 2.5, and 4 km). We used the Tillotson equation of state [3] with material properties of granite. We employed a Drucker-Prager rheology model, which assumes shear strength Y_s being a linear function of cohesion, internal friction, and pressure P ($Y_s=Y_{coh} + f \cdot P$). This allows for studying the effect of cohesion (Y_{coh}=0, 5, 20, 100, and 200 MPa) and the coefficient of internal friction (f=0, 0.2, 0.4, 0.5, 0.7, and 1.0) separately and independent from each other.

Results: We were able to reveal how these parameters affect the final shape (ellipticity) of craters. We found that elliptical craters are excavated as a result of shock compression (similar to circular craters, but in contrast to subsonic impacts producing elliptical craters by material displacement). The transition from circular to elliptical crater formation can be roughly described by three different regimes (see Fig. 1). The onset of elliptical impact crater formation happens quite abrupt; the corresponding threshold angle seems to depend on cratering efficiency (ratio of projectile size to crater diameter).

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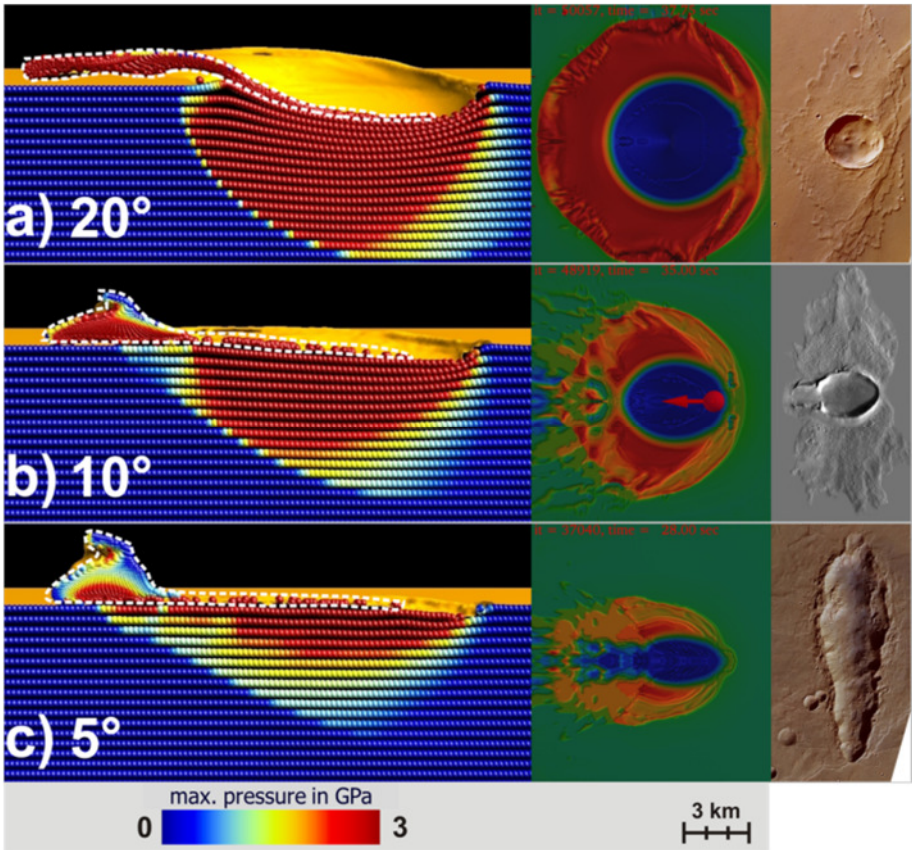

Figure 1: Snapshots of early (left) and late stage crater formation (middle) for three characteristic impact angles (L=4 km, U=8 km/s, Y_{coh}=5 MPa, f=0.3).
Left: Tracers show peak pressures in a range from 0 GPa (blue) to 3 GPa (red). Tracers belonging to the projectile are framed with a white dashed line. **Middle:** Corresponding craters at a late stage. Projectile material has been removed in post-processing to obtain insights in the "real" crater structure. **Right:** Examples for Marsian craters which might be associated with a similar formation process. Top: Crater in the Melas Dorsa region showing an ellipticity of 1.12 (@*ESA/DLR/FU-Berlin, Neukum*). Middle: This crater on Mars shows a butterfly-pattern as well as a secondary structure caused by projectile motion (©*NASA/JPL/ASU*). Bottom: This highly elliptic crater (south of Huygens-Crater) has been formed by an extremely shallow impact event (©*ESA/DLR/FU-Berlin, Neukum*).

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