Crater formation in the transition from circular to elliptical impact structures

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Why are some craters circular and others elliptical?

How do elliptical craters form?

(How) does the cratering mechanism change with the impact angle?

We address these questions by conducting a comprehensive numerical study. This enables us to reveal how elliptical craters form, to identify morphological features of elliptical craters and to deliver new insights into crater formation in general.

Simulation setup

Numerical Code: iSALE-3D [1, 2]
• gravity $g=9.81 \text{m/s}^2$
• impact angle $\alpha=90°\ldots5°$
• impact velocity $U=8,12,18 \text{km/s}$
• projectile diameter $L=250 \text{m}, 500 \text{m}, 1 \text{km}, 4 \text{km}$
• Material: granite (Tillotson EOS)
• material strength varied (Drucker-Prager):
  - cohesion $Y_m=0, 5, 20, 100, \text{and } 200 \text{MPa}$
  - friction coefficient $f=0, 0.2, 0.3, 0.4, 0.5, 0.7, \text{and } 1.0$
• 800 3D simulations with a resolution of 16...24 CPPR.

Results

• Crater shape is the result of two competing cratering mechanisms
  - energy transfer along the projectile trajectory in the early stage of impact cratering (“moving point source”)
  - a circular and symmetric energy transfer originating from a point afterwards (“static point source”).
• Morphological characteristics of elliptical craters comprise features in downrange generated by the moving projectile
• Fragmentation or decapitation of the projectile might occur and create additional structures

Elliptical crater formation

Transition regime
• crater growth similar to moderate oblique impacts ($\geq30°$)
• most of the ejected material moves parallel to the target surface
• $\rightarrow$ still nearly circular crater

Ricochet regime
• projectile hardly penetrated into the target while it undergoes shockwave compression
• crater formation initially driven by momentum transfer from projectile to target $\rightarrow$ elliptical crater evolves; subsequently, shock-induced symmetric excavation flow superimposes
• $\rightarrow$ elliptical, but still relatively deep crater

Grazing regime
• projectile barely penetrated into the target
• only small part of impact energy transferred into target (see [1]) $\rightarrow$ Low shockwave amplitude
• Strong pressure gradient in projectile suggest fragmentation or even decapitation (see [3, 4])
• $\rightarrow$ highly elliptical and shallow crater

Morphology of elliptical craters

$\alpha = 20°$

$\alpha = 15°$

$\alpha = 10°$

$\alpha = 5°$

Structures generated by projectile sliding along the surface

Small structure generated by ricocheting projectile

Fig. 4: a) Comparison of crater shapes occurring at different impact angles. The contact point ‘K’ and the geometric center $\text{M}_{\text{geom}}$ of the crater ‘+’ are shown, too. Dotted line: crater shape for $\alpha=45°$, for comparison. b) Shockwave propagation after impact. Shock wave propagates with velocity $c_\text{s}$ from the detonation center located at depth $Z$. Reflection of the shock wave on free boundaries (here: target surface) initiates rarefaction waves travelling behind the shock. c) Distance of the geometric crater center $\text{M}_{\text{geom}}$ and d) depth of burial $Z$, as a function of impact angle.

References:

Acknowledgements:
This work was funded by the Helmholtz Alliance HA-203 / “Planetary Evolution and Life” by the Helmholtz Gemeinschaft Deutscher Forschungszentren (HGF).