

IMPACTS IN TWO-LAYERED TARGETS ON EARTH: EFFECTS OF COVER THICKNESS ON CRATER MORPHO-STRUCTURE. A. Abels¹, ¹Institut für Planetologie, Westfälische Wilhelms-Universität, D-48149 Münster, Germany.

Introduction: Typical crystalline and sedimentary rocks on Earth react differently on a hypervelocity impact. The best documented manifestation of this difference are the different onset diameters for central uplift, viz. ~2 and ~4 km in sedimentary and crystalline targets, respectively (e.g., [1]). Another phenomenon are different types of concentric craters, that is those with a shallow outer and a deep inner crater. They are related to layered targets typically consisting of a relatively high-strength (*hs*) crystalline basement and a low-strength (*ls*) sedimentary cover (Figs. 1a, 2).

In the following, a phenomenological succession is proposed that includes a classification of terrestrial craters into nine general types (Fig. 2). It is constrained by field data (compiled from published literature) and ascribes the variability primarily to a different cover thickness (*t_c*) at impact, further influenced by the impact magnitude. Furthermore, it implies that some variations are initiated during the excavation stage.

Classification: Craters of **Type I** are those in a purely *hs* target, while **Type IX** craters are those in a purely *ls* target. **Type II** craters have a thin *ls* cover (*t_c* < ~170-200 m). They reveal a halo of structural disturbance in the cover and probably underneath, but with an intact stratigraphy. In addition, a rim of *hs* substrate rocks surrounds the deep inner crater and stands above the pre-impact surface. **Type III** craters (*t_c* = ~200-400 m) reveal a shallow inward-dipping outer crater. Allogenic breccias become deposited upon it. At **Type IV** and **Type V** craters (*t_c* = ~400-1000 m) megablock zones form. Concentric normal faults in that zone penetrate into the *hs* substrate. At Type III and IV craters a rim of *hs* substrate rocks can encircle the deep inner crater, but remains below the pre-impact surface. Final craters of **Type VI** (*t_c* > ~1000 m) lack a depression in the substrate, which is however still faulted during the collapse. At Type VI craters the substrate is not uplifted anymore in the wall, as the realm of upward flow is essentially in the cover. From Type V to Type VI craters megablocks become larger and get more and more the character of terraces. At **Type VII** craters the cover becomes a substantial part of the central uplift and the transient crater forms within the cover. Downfaulting of the substrate becomes gradually less. The substrate is still centrally uplifted at **Type VIII** craters, but does not reach the central peak top. Curves separating crater Type IV from V and Type VI from VII are not definable from the data.

Implications: At Type II craters the high-strength crystalline rim appears to largely protect the exterior

cover from being removed and, conversely, at Type III the cover was largely excavated to form an outer crater, because a protective substrate rampart did not develop. This is a significant clue, because it shows that the formation of an outer crater does not predate the uplift of an inner rim, but that it forms rather synchronously. This eliminates early processes, like an air blast or impact cluster ([2], p. 140), as the prime triggers. A brim of shallow excavation has been also observed in sedimentary targets (e.g., Red Wing [1]). Those could be analogous to the shelves in layered targets, despite the finally different phenotype (Fig. 1).

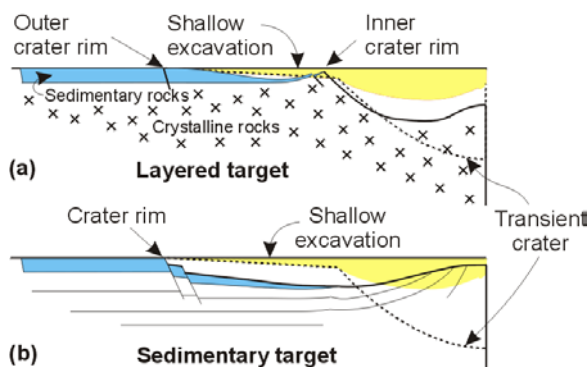


Fig. 1. Crater sections in (a) layered (Type III) and (b) sedimentary target (Type IX). Equal-sized excavation cavities (in yellow) are interpreted to develop to final craters of different phenotype. In both cases peripheral shallow excavation occurs, finally observed in an outer crater (at a) or a flat-floored annular trough (at b). Mass wasting during collapse is more extensive in (b).

At craters of Type IV and V shallow excavation can act as well, but the cover appears too thick for being removed over a substantial width and thickness. Instead it is predominately uplifted, shattered and, after collapse, becomes a megablock zone. Radial (1) ballistic and (2) ground-hugging erosion by ejecta as well as (3) centrifugal thrusting and folding in the wake of strong horizontal compressive forces ([2], p. 87) are attendant processes. It is suggested that funnel-shaped outer craters are an effect of the same cause.

In addition to cover thickness, the post-collapse configuration depends on the impact energy and, thus, the intensity of collapse (among other *secondary* factors). That is why the hatched transition zones in the diagram (Fig. 2) are not horizontal. For instance, the 100 km-Popigai crater was excavated in crystalline basement covered by 1.0-1.5 km thick sedimentary

rocks, but it grossly resembles much smaller Type III craters (e.g., [4]). The energy imposed may have been high enough for the excavation of an outer crater, while at smaller magnitude craters, in targets with a similar or smaller cover thickness, a megablock zone develops. Some of the Type III, IV and V craters show only minor indications for slumping of the inner crater walls or central peaks, if at all. For a reduced weight of the rim, resulting from the excavation of an outer crater, crater base failure and, in turn, central uplift was possibly subdued (e.g., at the Ries). In addition, layer boundaries can act as a décollements.

In summary, the observations at terrestrial impact

craters, though still incomplete, suggest that both excavation (concentric craters) and collapse (onset of central uplift, style of rim failure) are not independent of original strength contrasts in the target. An essential factor for the final appearance of the crater in the described two-layered targets is the cover thickness and the position of the cover/substrate interface relative to the geometry of the excavation flow.

References: [1] Grieve et al. (1981) *Proc. LPSC 12A*: 37-57. [2] Melosh H.J. (1989) *Impact Cratering: A Geologic Process*, Oxford Univ. Press. [3] Ormö J., Lindström M. (2000) *Geol. Mag.* 137(1): 67-80. [4] Māsaitis et al. (1999) *GSA Spec. Pap.* 339: 1-17.

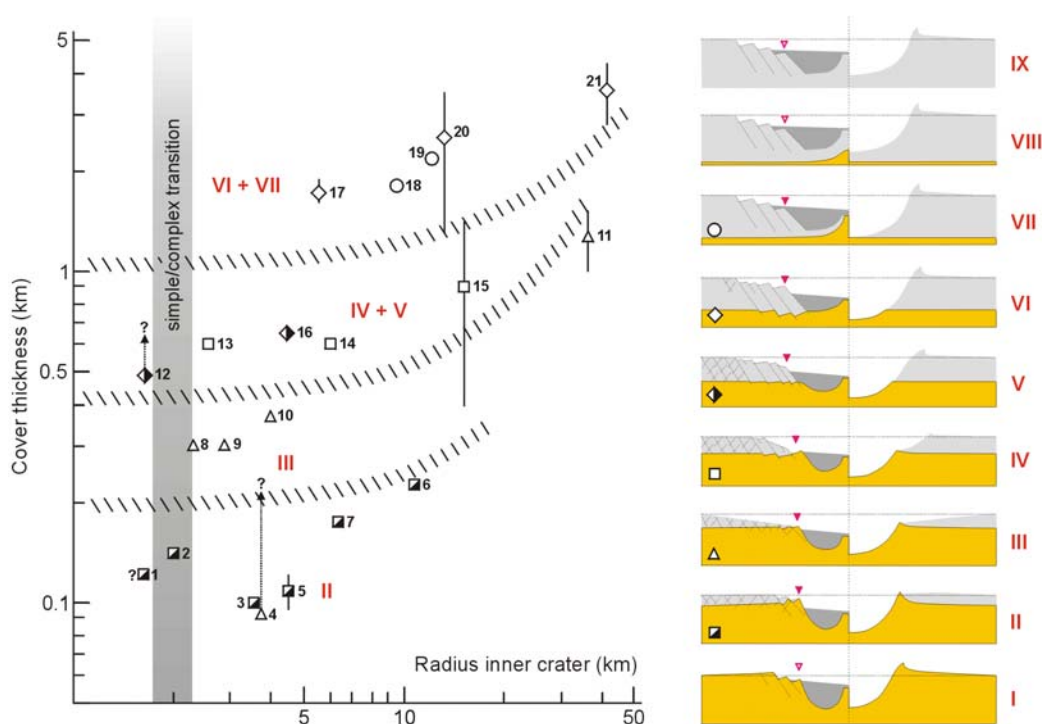


Fig. 2. (Left) Plot of thickness of *Is* cover unit versus radius of observed or inferred inner crater at well preserved terrestrial impact craters. Note log-log scales. Solid vertical bars indicate lateral variation of cover thickness across a single crater. Craters 1 and 6 are constrained by a crystalline rim that stands above the sedimentary cover of known thickness; the presence (at 1) and character of a disturbance halo are hypothetical. Crater 4 with a Type III morphology is a notable exception in the Type II field, probably because of an impact into $\gg 200$ m deep water ([3]). Position of crater 12 (with Type V morphology) in lower part of IV+V field could be erosional effect. Crater 19 has both a terrace zone and, exterior to this, a shallow outer crater within the sedimentary cover. **(Right)** Morphostructural sequence of pristine complex craters, with inner crater

radii of ~ 3 -10 km, from homogenous *hs* target (I, yellow) to homogenous *Is* target (IX, grey). Dark grey is allocthenic breccia lens. At craters in layered targets, the thickness of *Is* cover increases from II to VIII. Right and left part of cross sections show the transient and final crater, respectively. Red arrowheads mark edge of inner crater (or inner boundary of terraces) plotted in the diagram. Note common symbols in diagram and crater succession.

1. Granby*, 2. Kärddla, 3. Neugrund, 4. Lockne, 5. Ragozinka, 6. Saint Martin, 7. Kaluga, 8. Obolon, 9. Zhamareshin, 10. Logoisk, 11. Popigai, 12. Mishina Gora, 13. Ames, 14. Ries, 15. Chesapeake Bay, 16. Mulkarra*, 17. Houghton, 18. Steen River, 19. Puchezh-Katunki, 20. Manson, 21. Chicxulub. All data compiled from relevant literature (*unproven).