THE MECHANICS OF CRATER CAVITY FORMATION AND MODIFICATION AT THE SIMPLE-TO-COMPLEX TRANSITION ON MARS. R. R. Herrick and L. M. Dorn, Geophysical Institute, University of Alaska Fairbanks, Fairbanks AK 99775-7320 (rrherrick@alaska.edu)

Introduction: We are conducting a global analysis of well-preserved impact craters with diameters 7 < *D* < 9 km, a range that is within the simple-to-complex transition on Mars. Comparing craters of similar diameter on a planetary surface is as close as we can achieve in the natural world to conducting large-scale impact experiments where impact energy is held constant but the target properties are varied. In previous work [1,2,3] we have shown that target geology for these craters influences crater morphology and crater shape in clear and consistent ways. Here we combine inferred knowledge of target material with geologic analysis to discuss how the mechanics of crater excavation and modification are altered under different settings. We discuss craters with three different forms of rim-wall failure and compare these craters to a "standard" of a large simple crater. We show type examples; we have checked their dimensions with others of similar morphologies and settings. All four craters are well preserved; erosion has not significantly altered the craters' shapes since formation.

Crater descriptions and interpretations: The four example craters are shown in Figure 1, and progress in increasing degrees of wall failure from simple, to modest wall slumping, to terracing, to "super terracing" where terracing extends to nearly crater center. In Figure 2 we show stereo-derived topographic profiles through the four craters, scaled to the same pre-terracing diameter. Our analysis included standard photogeologic analysis and using topographic information such as unit thicknesses and wall slopes to evaluate the movement of material during excavation and modification.

Simple crater (Figure 1a) – The crater is located in a flat area of the northern lowlands in Utopia Planitia [Late Hesperian lowland unit of 4]. The area is the location of the largest simple craters on the planet [5] and in the region with large polygonal surface features [e.g., 6]. While the cause of the target deposits has been debated (sedimentary versus volcanic), for our purposes large-polygon formation requires, and the axisymmetric similarity of the simple craters in the area indicates, that the target material is homogeneous vertically (to at least a few km depth) and laterally, well consolidated, and shows no evidence of a mix of clast sizes.

Crater with slumping (Figure 1b) – This crater is located at the northern boundary of Chryse Planitia in an area of thick deposits from Tharsis outflow channels. Within the wall and slump deposits individual blocks/boulders up to 50 m in diameter can be observed. We interpret the target material to be lithologically heterogeneous (a mix of clast sizes) with neither coherent vertical layering nor sharp lateral boundaries and variations. Despite a considerably lower rim-floor height and a central peak that rises ~100 m above the crater floor, the crater rim is ~100 m *taller* above the surrounding terrain than the simple-crater rim. While not universal, this higher rim height is not uncommon in other locales where the craters have wall slumping and a central peak.

The slumped material is predominately on the NW portion of the floor, ~1 km across and typically ~ 100 m thick, with a few ridges and mounds raising the thickness to ~250 m. Because the material did not slide downhill as a coherent unit, we cannot specify how much the rim expanded outward due to slumping. We see no clear correlation between where most of the slumped material occurs and relative rim elevation, the thickness of the rim's cliff-forming unit, or interior wall slopes. These observations, combined with the modest thickness of the slump deposits, leads us to conclude that slumping likely expanded the initial crater diameter by < 150 m. We infer that local near-surface heterogeneities created cohesiveness variations in wall units that enhanced or reduced the amount of slumping.

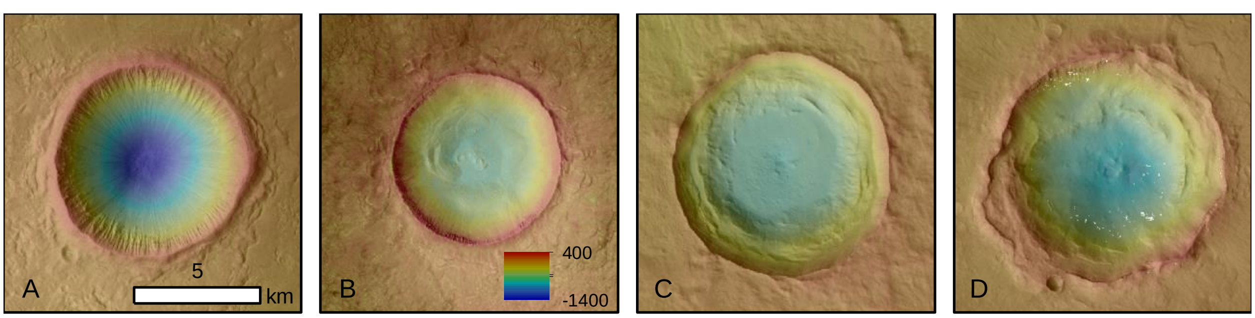

Figure 1. Type examples of craters with progressively increasing wall failure. A) Simple crater centered at 29.59° N, 107.46° E; B) crater with wall slumping, 40.25° N, 41.47° W; C) Terraced crater, 46.57° N, 121.03° W; D) "super terraced" crater, 41.47° N, 4.89° E. The craters are shown at the same horizontal scale, and in all cases we use a color scale for topography that spans 1800 m and sets the pre-impact terrain elevation to ~0.

With respect to the mechanics of forming the crater floor and the central peak, it is clear that collapse of transient crater walls cannot account for more than a small portion of the difference in terrain-floor depth between this crater and our simple crater; among other problems, this would require that the pre-slump rim height be considerably greater even though it is already higher than the simple crater's.

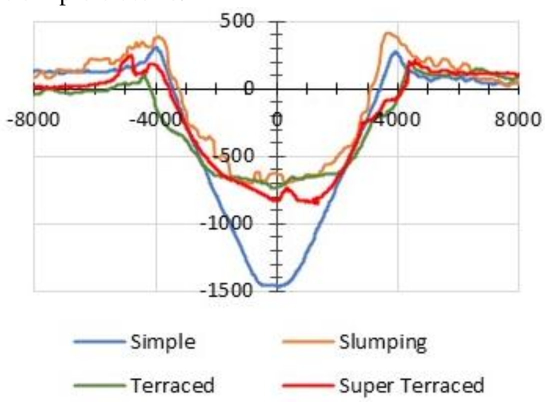

Figure 2. Scaled, representative profiles from each crater. For craters with terraces, the pre-terraced diameter is determined by estimating how the rim would have extended inward if the terrace blocks were slid outward and upward into their original location after transient cavity formation. The profiles have been proportionally scaled to each have a pre-terracing $D = 8$ km and a terrain elevation of 0.

Crater with terracing (Figure 1c) – Crater is in the lowlands NW of Alba Patera. The regional terrain is gently sloping, rising NNW - SSE at ~1°. The crater straddles the margin of a ~40 m thick lava flow that runs downhill to the NNW; this plus proximity to Alba Patera leads us to interpret the target terrain as layered lava flows (Amazonian and Hesperian volcanic unit [4]).

Despite being more than 1 km larger in diameter than the simple crater, the rim height for the terraced crater is 135 m lower. The terracing for this crater occurs in discrete enough units that we can estimate the pre-terracing rim diameter and elevation with some confidence. We interpret terracing to have expanded the crater's diameter by ~900 m and to have reduced the rim elevation by ~100 m. After rim reconstruction and scaling the craters to similar diameters, the rim height for this crater is still ~50 m lower than for the simple crater. We tentatively conclude that this is typical after spot checking other terraced craters with pits or flat floors.

The terrain-floor depth is considerably less than for the simple crater, and comparable but perhaps ~100 m shallower than the craters with slumped walls. There is a pitted, wavy texture on the floor that we interpret as melt, but it is thin/viscous enough that it does not fill the ~80 m deep central pit. Excluding the central pit, the floor is flat with a few tens of meters elevation variation over its multi-km span. We interpret our observations to conclude that layering created a transient cavity for this crater that was shallower and broader than the simple crater (the "inverted sombrero" cavity [e.g., 7]); vertical strength variations also guide terrace formation.

"Super-terraced" crater (Figure 1d) – We refer to this crater as super-terraced because the terraces extend almost to the crater center in places, and this type is much rarer among the 7-9 km crater population. Unlike the terraced craters with a pit or flat floor, within the terracing the floor transitions to a central peak structure (~70 m high), so that there is not an expansive flat area at crater bottom. Examination of the terracing/slumping suggests that the difference with normally terraced craters is not that the amount of material that terraced is much greater, but that it slid farther down the crater walls. We estimate that the overall diameter was decreased by ~1 km and the rim height by ~150 m.

After replacing the terraced units onto the rim, the crater cavity would resemble the craters with modest slumping, including the presence of the small central peak. The geologic setting of this particular crater is on the edge of Chryse Planitia just a few tens of km away from the edge of the heavily cratered Arabia Terra terrain, and it is likely that highlands terrain is shallowly buried by the Planitia deposits. Another super-terraced crater (23.74° S, 171.53° W) is on the floor of a relatively fresh $D = 33$ km highlands crater. We suggest that super-terraced craters form from having a coherent layer tens of meters thick (e.g., melt sheet) overlying more poorly consolidated material; the coherent layer fails and slides downhill as terraces during modification.

Other general observations, and conclusions: Outside of polar regions (< ~60° N/S) we did not need to invoke variation in target volatile content to explain observations. We saw no evidence that slumping/terracing affected ejecta emplacement. It is clear that wall slumping/terracing does not meaningfully contribute to the terrain-floor depth reduction of small complex craters compared to simple craters; a shallower transient cavity and/or floor "rebound" is responsible. The higher rim heights for some craters with slumping suggests a difference in transient cavity shape compared to simple craters that needs further thought. Lateral and vertical heterogeneities in the target lower the simple-to-complex transition diameter.

References: [1] Herrick R. R. and Hynek B. M. (2017) *MAPS, 52*, 1722-1743. [2] Herrick R. R. et al. (2020) *LPSC 51*, abs. #2899. [3] Dorn L. M. and Herrick R. R. (2020) *LPSC 51*, abs. #2937. [4] Tanaka K. L. et al. (2014) *PSS, 95*, 11–24. [5] Boyce J. M. et al. (2006), *GRL, 33*, L06202. [6] Cooke M. et al. (2011) *JGRP, 116*, E09003. [7] Horton J. W. et al. (2006) *MAPS, 41*, 1613-1624.