THE LUNAR CRATERS BESSEL AND EULER - CALCULATION OF EJECTA THICKNESS AND STRUCTURAL UPLIFT FOR COMPLEX CRATER RIMS.

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Introduction: Crater rims of simple and complex craters have an elevation that is formed during the excavation stage of crater formation. The elevation of the crater rim is due to several factors:

I. Structural uplift of the pre-impact surface by radial shortening and plastic thickening of target rocks beneath the steep cavity walls.
II. Injection of excavated material into the developing crater wall.
III. Deposition of proximal ejecta material on top of the crater rim (overturned flap) [1, 2, 3].

It is believed that the elevation of simple crater rims is the sum of two equal parts, the thickness of the most proximal impact ejecta blanket plus the thickness that results from plastic deformation including injection [1, 2, 3]. The rim elevation of complex craters and its development, is not yet fully understood and this work tries to precisely constrain the ejecta thickness and structural uplift of lunar crater rims to understand what the main contributor to the elevated rim is. High-resolution imagery of the two lunar craters Bessel (21.8° N, 17.9° E; Copernican [4]) located in Mare Serenitatis and Euler (23.3° N, 29.2° W, Copernican [5]) located in Mare Imbrium show several outcrops of basaltic material (Fig.1) [e.g., 6, 7].

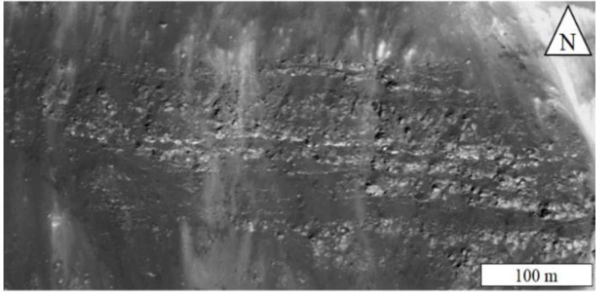

Fig.1: Outcrop of layered basaltic material at Euler crater (23.3° N, 29.2° W).

These layered formations occur in the upper part of the crater wall and, for Bessel, can be observed nearly throughout the complete crater wall, whereas Euler shows these formations in 2 large distinct locations in the northern and southwestern part of the crater wall and in one small location in the northeastern crater wall. Both craters are regarded as complex craters. However, Bessel, 16 km in diameter, is near to the simple-to-complex transition and exhibits slumping without terracing and a central peak. Euler crater, 28 km in diameter, is a complex crater, showing slumping, terracing and a central peak [1].

Data: For our investigations we used high-resolution LROC-NAC, SELENE-TC-Ortho and LROC-WAC images combined with SELENE and WAC-GLD100 digital elevation models (Table.1) [8, 9, 10, 11].

Table.1: Spatial and height resolution for Selene and LROC-WAC DTM.

Resolution	Selene-DTM	WAC-GLD100
Spatial [m/pxl]	10	100
Height [m/pxl]	> 20	10

Methods: With the combination of high-resolution imagery and digital elevation models, we analyzed the crater walls of both craters in detail. We incrementally determined the pre-impact surface by linear interpolation along a tie line that connects two points at the edge of the continuous ejecta blanket (a – a`), the crater center and the measurement point at the crater rim that is located at the boundary between the uppermost exposed layer and the superposed ejecta (Fig.2). The elevation of the pre-impact surface was calculated ”S_{pi}” for each point at the boundary (Fig.2, Table.2). The second step was the exact calculation of the ejecta thickness at each point (Fig.2, Table.2). In a third step, with the exact spatial location of the layered outcrops, we could calculate the structural uplift of the exposed layered outcrops at each point (Fig.2, Table.2). With these data available, we could calculate the total crater rim elevation, the thickness of the structural uplift and the thickness of the superposed ejecta.

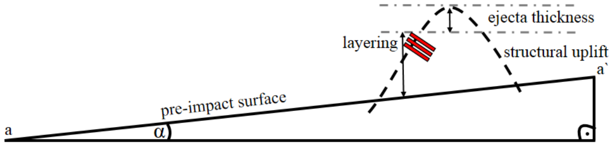

Fig.2: Geometric correlations for the calculation of ejecta thickness and structural uplift. Dashed line correspondes to a schematic crater.

By using the uppermost outcrop of the layered material, we ensured to calculate the minimum of the structural uplift and the maximum of the superposed ejecta thickness. This was done for all outcrops of layered material, with radial 1° steps for Euler (Fig.3) and 0.1° degree steps for Bessel.

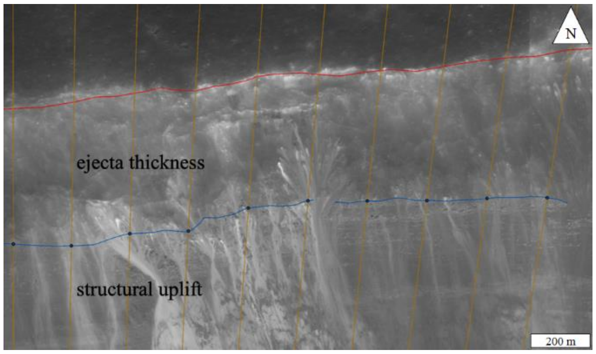

Fig.3: Crater Euler with 1° radial measurments for the northern part boundary between structural uplift and superposed ejecta. The uppermost outcrop of layered material is shown in blue and the craterrim is shown in red. The 1° radial steps are shown in brown.

Results: Mean values of measured thicknesses of the structural uplift and the ejecta are summarized in Table 2, for Euler crater and Bessel crater, respectively. The measured superposed ejecta thickness amounts to approximately 33% - 40% of the total rim elevation. These results differ from the results of previous studies [e.g., 1, 12, 13]. For the determination of mean values we used only data from high quality, lateraly extensive outcrops, to minimize the chance of ill-defined boundaries due to coverage with regolith or modifications by later wall failure. We determined a minimum structural uplift, because we could not exclude that buried outcrops exist on top of the used uppermost layer.

Table.2: Minimum structural uplift and maximum ejecta thickness. Numbers given are mean values.

	Euler (28 km)	Bessel (16 km)
Pre-impact surface elevation "S_{pi}" [m]	-1352 ± 30	-2567 ± 10
Structural uplift (min) "Su" [m]	475 ± 100	290 ± 15
Ejecta thickness (max) "E_t" [m]	315 ± 100	140 ± 15
Total rim height [m]	790 ± 100	430 ± 15
Structural uplift content (min) [%]	60 ± 10	67 ± 3
Ejecta thickness (max) [%]	40 ± 10	33 ± 3

Discussion and Conclusion: Early studies and models show that the elevation of the crater rim is equally distributed between structural uplift and superposed ejecta deposits [1, 3]. Whereas this might be true for simple craters, our results show that for complex craters, this correlation is modified. The measured structural uplift (Table 2) suggests that the injection of material into the crater wall is not a major process for rim uplift at this distance from the transient cavity. It is possible that the mechanism of plastic thickening and reverse faulting play a more dominant role for larger craters. These mechanism should also contribute more to rim elevation than the emplacement of overlying ejecta. This result is astonishing as the final crater rim is at a greater lateral distance to the transient cavity wall than for simple craters. Estimates of the transient cavity size for Euler range between 22.6 km [1] and 26.0 km [14] and for Bessel between a diameter of 14.0 km [1] and 15.5 km [14]. It seems unlikely that dike injecting length exceed more than a kilometer. Ejecta thickness models for lunar craters show great differences in predicting the amounts of emplaced ejecta onto the crater rim. T, the ejecta thickness at the crater rim, is defined as either

$$(1)\quad T = 0.033R \text{ by [15]}$$

or

$$(2)\quad T = 0.14R^{0.74} \text{ by [13].}$$

Applying

$$(3)\quad t = T\,(r/R)^{-3.0} \text{ [13, 15]}$$

where t is the ejecta thickness at a particular target location, R is the radius of the transient crater [1], and r is the distance between crater center and the target location gives a wide range of ejecta thicknesses. Using equation (1) the calculated amount of ejecta at Euler is 310.76 m and applying equation (2) the amount of ejecta is only 116.29 m. For Bessel the calculated amount is 143.7 m (1) and 262.8 m (2). The ejecta thickness according to [15] is consistent with our findings, whereas [13] predicts different amounts of ejecta thickness. The results of this work are consistent with the work of other authors [e.g., 1, 12, 13], showing that for complex craters the structural uplift is a more dominant effect than ejecta emplacement. Similar results are derived for martian craters by [16].

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