Complex crater formation: Insight from Numerical Modeling. E. Martellato[1] and K. Wünnemann[1,2], [1]Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany; [2]Institute of Geological Sciences, Freie Universität Berlin (email: elena.martellato@mfn-berlin.de).

Introduction: Complex craters are characterized by central peaks, flat floors, and terraced rims. How these distinct morphological features develop from the gravity-driven collapse of a deep bowl-shaped transient cavity is still not fully understood with respect to the strength properties of target rocks. Standard strength models fail to explain complex crater collapse at the observed simple-complex transition diameter where a significant change in the depth-to-diameter ratio occurs (e.g. for the lunar crater record [1]). [2, 4] showed that a significant temporary strength degradation in rocks surrounding the transient crater is required to explain fluid-like behavior of matter during crater collapse resulting in the formation of central peaks and depth-diameter ratios typical for complex craters. One of the most successful approaches to explain temporary strength degradation is Acoustic Fluidization (AF) [2], which was implemented in the iSALE shock physics code as a simplified variant, the so-called Block Model (BM) [3, 4]. It is based on the assumption that the transient cavity is surrounded by heavily fractured rocks that behave like a granular material (e.g., [4]). Such a system of debris, excited by acoustic waves in the wake of an expanding shock wave, behaves like a Bingham fluid with a Bingham cohesion that depends on the amplitude of the acoustic wave, which is a function of time as the acoustic wave attenuates.

The BM is, among other parameters that are kept constant in this study, defined by the kinematic viscosity of the fluidized region η, and the decay time of the acoustic waves τ [3]. These parameters may be estimated from observables and projectile properties [5]: the viscosity η and the decay time τ may be expressed as functions of the density ρ, average block size h of the fragmented rocks, and period T of the block oscillation. However, this approach does not account for the fact that block size h may vary with the distance from the impact point, or depend on the composition of target material. Further investigations used morphometric measurements as constraints for estimating the dependence of kinematic viscosity and decay time on impact parameters. [3] and [6] used the observed depth-to-diameter ratio of the terrestrial, lunar, and icy satellite crater record to determine η and τ. They showed that these parameters can be described as a linear function of the projectile radius R_p: $\eta=\gamma_\eta\, c_s\, R_p\, \rho$ and $\tau= \gamma_\beta\, R_p / c_s$, where γ_η and γ_β are dimensionless scaling parameters, and c_s is the sound speed. These relationships are based on invariant impact speeds, but they still appear to be the best approximation [7].

This study aims at a better understanding of the mechanics of complex crater formation, by constraining BM parameters [4] by means of additional morphometric crater parameters other than crater diameter and depth such as central peak diameter and height (above crater floor). We present the results of a systematic numerical modeling study, where we tested the effect of the BM parameters on crater morphometry over a broad range of sizes of complex impact structures. Furthermore, we introduce the preliminary results on the correlation between the final and transient crater diameter.

Methods: Numerical models have been carried out with the iSALE shock physics code [8, 9, 10, 11]. In all the simulations we assume the same target setup: a 50-km gabbroic anorthosite crust, overlying a dunite mantle, considering a lunar gravity. The thermodynamic behavior of the crust and mantle are described by the Tillotson equation of state and ANEOS, respectively. The mechanical response of rocks against deformation is described by a pressure and damage-dependent strength model (so-called ROCK.model, [10]) with the following parameters: dunite: intact strength=5.07 MPa, intact friction coefficient=1.58, damaged strength=0.1 MPa, damaged friction coefficient=0.63; gabbroic anorthosite: intact strength=31.9 MPa, intact friction coefficient=1.1, damaged strength=0.1 MPa, damaged friction coefficient=0.71 [12]. No porosity was considered. The projectile is assumed of dunitic composition, with radius varying between 300 m to 9 km, and an impact velocity of 15 km/s.

We compare the morphometric parameters of the final crater (rim-to-rim crater diameter D_c, depth of crater floor from the rim-crest d_c, central peak height above crater floor d_p, width of the central peak measured at the crater floor level D_p, crater floor diameter D_f) in our models with observations from the literature [1, 13, 14].

Results and Discussion: We varied both the dimensionless scaling parameters γ_η and γ_β between 0.001-0.01 and 100-500, respectively. According to our models, the decay time (γ_β) has a stronger effect on both crater collapse and the final crater morphology. Figs. 1, 2, and 3 summarize the results of the simulations for a constant γ_η (0.005) and varying γ_β between 100 and 500. Fig. 1 shows the depth-to-diameter (d_c/D_c) ratio as a function of the crater diameter. With decreasing γ_β, the d_c/D_c ratio for craters larger than the simple-complex transition diameter increases. γ_β >400 best reproduce the observed trend in the lunar crater record [1]. The red-shaded area indicates the d_c/D_c ratio <0.8, where a central peak occurs in our models, suggesting that only a limited range of γ_β allows the development of the central uplift. Fig. 2 and Fig. 3 shows a comparison of the central uplift width D_p and height d_p with literature data [13, 14]. None of the models reproduces observations satisfactory. We spectulate that the linear relationship of BM parameters with the projectile size may be an oversimplification.

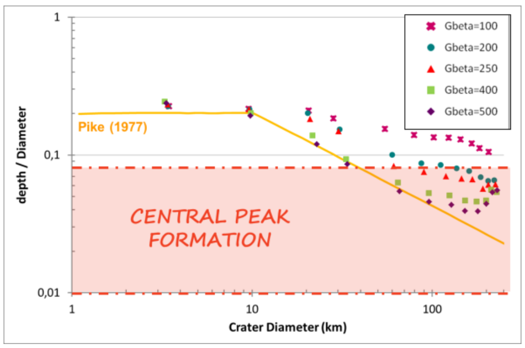

Fig. 1. Depth-to-diameter ratio plotted against crater diameter. The yellow solid line represents measured lunar impact craters [1].

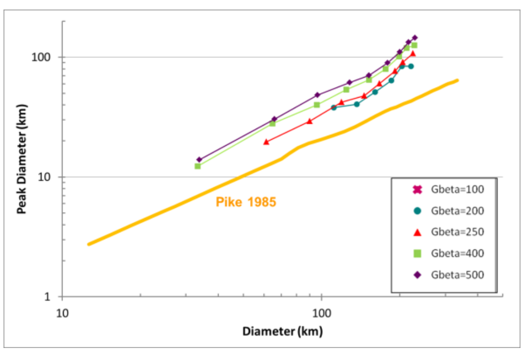

Fig. 2. Width of the central uplift vs. crater diameter. The yellow line represents measured lunar impact craters [13].

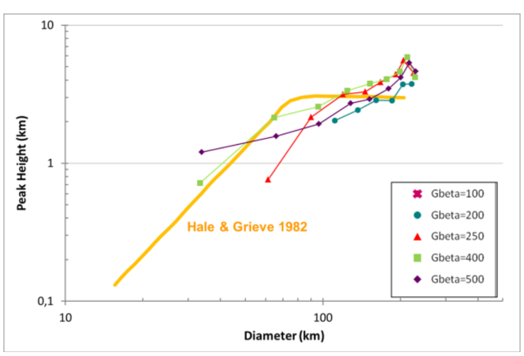

Fig. 3. Height of the central uplift vs. crater diameter. The yellow line represents measured lunar impact craters [14].

Finally, we derive from the model series that shows the best agreement with the observed morphometric parameters (γ_η=0.005 and γ_β=500) a relationship between final and transient crater diameter (Fig. 4). Other sets of BM parameters result in variations up to 20% for the ratio between the transient and final crater diameter. With respect to published scaling laws based on observations ([15, 16, 17] we find generally lower transient-to-final crater diameter ratios in our models.

Our first results show a strong influence of the decay time on crater collapse, and in particular whether or not the central uplift develops. However, the models does not fit accurately all the observational constraints. Therefore, more investigation is required to refine the quantitative relationship between the BM parameters of viscosity η and decay time τ, and the projectile size.

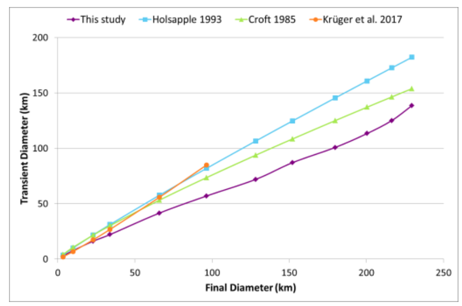

Fig. 4. Transient vs. final crater diameter The violet line refers to this study, and is compared to literature [15, 16, 17].

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Acknowledgements: We gratefully acknowledge the developers of iSALE-2D, including G. Collins, K. Wünnemann, D. Elbeshausen, B.A. Ivanov and J. Melosh (www.iSALE-code.de).

This project was funded by EU Horizon 2020 Marie Skłodowska-Curie program, No. 709122.