MODELING OF METEORITE IMPACT-INDUCED SECONDARY MASS WASTING - CASE STUDY BY MEANS OF THE BUNTE BRECCIA EJECTA BLANKET AT RIES CRATER, GERMANY. M. H. Zhu[1, 2] and K. Wünnemann[2], [1]Space Science Institute, Macau University of Science and Technology, Macau, mhzhu@must.edu.mo, [2]Museum für Naturkunde, Leibniz Institute for Research on Evolution and Biodiversity, Invalidenstraβe 43, 10115 Berlin, Germany, Kai.Wuennemann@mfn-berlin.de.

Introduction: Most debris ejected during an impact event follow ballistic trajectories [1]. Only the distribution of very small fragments and dust may be affected by the atmosphere and the expansion of a vapour plume [2]. When falling back to the surface, fragments with sufficient kinetic energy form secondary craters and generate an outward surge entraining local material. Finally, a mixture of primary ejecta and local substrate is deposited as the so-called ejecta blanket. The effect of mixing with local substrate, often referred to as secondary mass wasting, significantly contributes to the total volume and thickness of ejecta blankets surround impact craters. Quantitative data have only been obtained from the Ries impact where the ballistic ejecta, the Bunte Breccia, consist of up to ~ 90% of local material [3]. The process of secondary mass wasting is expected to play an important role in the formation of ejecta blankets on all planetary objects including the Moon, and has to be considered for impact gardening and the reconstruction of the lunar cratering record. However, beside empirical estimates of the Ries Bunte Breccia, any quantitative investigation of secondary mass wasting is lacking so far. Here we propose a numerical modeling approach to calculate the contribution of secondary mass wasting to the total volume and thickness of ejecta blankets at impact craters.

Determination of secondary ejecta thickness: iSALE is a multi-rheology, multi-material hydrocode, specifically developed for the simulation of impact processes [4]. It has been used to simulate impact processes from small-scale laboratory experiments [5] to 1000-km diameter lunar basin formation [6-8], and can be used to model the ejecta distribution for arbitrary-scale impact events. Note, we do not account for the formation of an ejecta plume in our models and assume that the effect of atmosphere and vaporized material on the distribution of ejecta is negligible. The total ejected volume equals to the excavated volume of the primary crater that is approximately 33% of the volume of the transient crater [1] and can be easily determined in hydrocode simulation of crater formation. This simple approximation does not account for secondary mass wasting. To include the entrainment of local material, we propose the following steps:

(a) The velocity and launch angle of primary ejecta are required to determine the trajectory of ejecta and the location where they fall back to the surface. We use Lagrangian tracer particles that are initially placed at the center of each computational cell to record the launch parameters of ejecta. All tracers moving above the pre-impact target surface are considered as part of the ejecta curtain. We record their loci and approximate the ballistic trajectories by fitting parabolas to their spatial position as a function of time. The ejection angle, velocity, and launch position are then given by the fitting coefficients [e.g., 9].

(b) The thickness of primary fragments can be calculated from the number of tracers that land at a given distance from the point of impact. We assume that each tracer is representative for the mass of the cell it was initially located in. The surrounding surface of the crater is subdivided into discrete rings. The accumulated volume of primary ejecta in each ring is then estimated by counting the total number of tracers landing into each ring and summing up their representative volumes.

(c) The size distribution of primary fragments and secondary craters can be estimated by a power law size distribution $N(\geq m) = Cm^{-b}$, where $N(\geq m)$ is the total number of primary ejecta fragments with masses greater or equal to m. The mass of the largest fragment is thought to be a function of the total ejected mass: $m_f = 0.8M^{0.8}$, where M is the total mass of the ejecta [1]. The sizes of primary fragments are assumed to vary from 10^{-6} g to m_f. Based on these assumptions, we can calculate the sizes of secondary craters produced by the primary fragments in each of the discrete rings using the well-established π-group scaling relationships [10, 11].

(d) The Cumulative total area covered with secondary craters can be expressed by the percentage of the area covered by secondary craters. Using the relationship for a random flux of primary ejecta (assuming a Poisson distribution) falling on a rectangular surface [12], the cumulative total fraction of area covered by primary fragments for all sizes are then estimated.

(e) The amount of mass wasting, the substrate mixed uniformly with the primary fragments is assumed to be equal to the excavated material by the largest primary ejecta fragment that lands in each ring increment. The amount of the secondary ejecta at a given location (e.g., mass, volume, and thickness in a certain ring increment) is then the ratio of the exca-

vated material by the largest fragment to the total material (including the volume of the primary ejecta plus the local excavated material). The cumulative fraction is finally calculated according to the size distribution of primary fragments in a certain area.

The Ries crater as a case study: The 26 km-diameter Ries crater is the only impact structure where the amount of secondary mass wasting was ever determined [3, 13-15]. The Bunte Breccia is thought to be almost fully preserved representing the ballistic ejecta.

We conducted iSALE simulation assuming a stony non-porous projectile with a diameter of 1.1 km impacting the target vertically at 12 km/s [2]. By means of the above described steps we quantified the amount of secondary mass wasting and compared the results with observational data. The target is simplified to be a granitic layer (crystalline basement) covered by 600-m-thick sediments. The resolution of the simulation is 20 CPPR. We assume increments for the discrete rings of 320 m beyond the tectonic rim at 13 km distance from the point of impact.

Results and discussions: The total volume of excavated sedimentary rocks is ~ 67 km^3 and ~ 20 km^3 of crystalline rocks, which is consistent with previous estimates [2, 14]. The thickness of primary fragments in the continuous blanket decreases from 78 m near the rim to 5 m at 45 km distance from the crater center. This is consistent with the a power-law decline of the thickness of the primary ejecta proportional to the power of -2.9 [3]. (Fig. 1). The estimated thickness of secondary ejecta decreases from 33 m to 5 m and is consistent with the observations from drill cores of the Bunte Breccia as a function of distance r (Fig. 1, red points, [3]) for $r > 18$ km. Closer to the rim ($r < 18$ km) our model significantly overestimates the amount of secondary mass wasting. We believe that this is primarily due to the application of π-scaling law, which is only suitable for hypervelocity impacts. Close to the crater rim the primary ejecta hit the surface at relatively low velocity generating secondary craters with a much smaller cratering efficiency. Therefore, the use of π-scaling law leads to a significant overestimation of the total volume of secondary ejecta and, thus, the amount of secondary mass wasting.

Future work: Crater-scaling for the low-velocity impacts will be investigated for secondary cratering at the Ries and then applied to calculate the secondary mass wasting close to the crater rim. In our model of secondary crater formation we do not account for the fact that ejected fragments impact at an oblique angle of incidence (obviously, the angle is the same as the launch angle). Assuming that ejecta impact normal to the surface overestimates secondary cratering efficiency in particular at larger distances where the impact velocities of ejecta are high. We intend to fix this simplification by assuming that only the vertical velocity component contributes to the formation of secondary craters [16, 17]. This will reduce the amount of secondary mass wasting gradually with increasing distance in our model.

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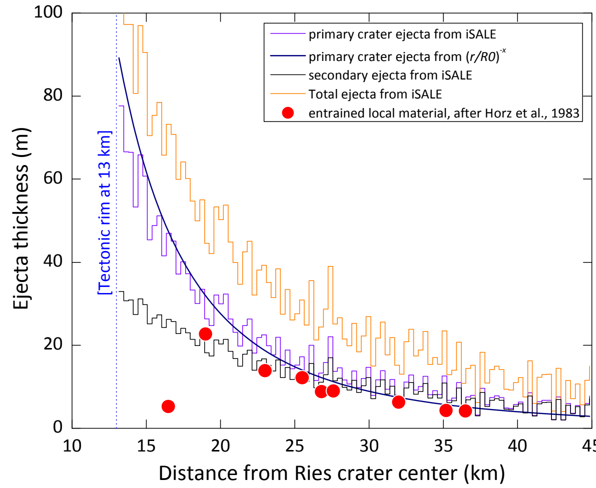

Fig. 1 Predicted ejecta thicknesses (primary and secondary) in the Ries crater by using iSALE models and comparison with observations from drill cores of the Bunte Breccia [15].

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