THE SUEVITE CONUNDRUM: NEW CONCEPTS FOR THE RIES CRATER - A RETAKE. D. Stöffler[1], [1]Museum für Naturkunde – Leibniz Institute for Research on Evolution and Biodiversity at the Humboldt-University, Invalidenstraße 43, D-10115 Berlin, Germany, dieter.stoeffler@mfn-berlin.de.

Introduction: The 26 km-diameter Ries crater in Germany, the type locality of suevite since 1901, is unique as major parts of its ejecta blanket are preserved. The main structural features are (Fig. 1): Central crater basin containing a suevitic breccia lens ("*crater suevite*" = CS) and bordered by an uplifted inner ring, the megablock zone, the tectonically modified "structural rim", and an outer ejecta blanket reaching to about 3.3 crater radii. The megablock zone and the outer ejecta blanket are overlain by patches of suevite ("*outer suevite*" = OS) forming the top of a "double layer" ejecta blanket [1, 2, 3, 4, 5]. According to the IUGS Subcommission on the Systematics of Metamorphic Rocks [6] suevite is a polymict impact breccia with lithic and mineral clasts of all stages of shock metamorphism and cogenetic melt particles. This keynote is largely based on a recent detailed study of the Ries suevite and its host crater [1, 2] during which a new genetic interpretation of suevite has been developed based on the concept of "fuel-coolant-interaction" (FCI) of a temporary clast-laden melt pool with water and other volatiles [7].

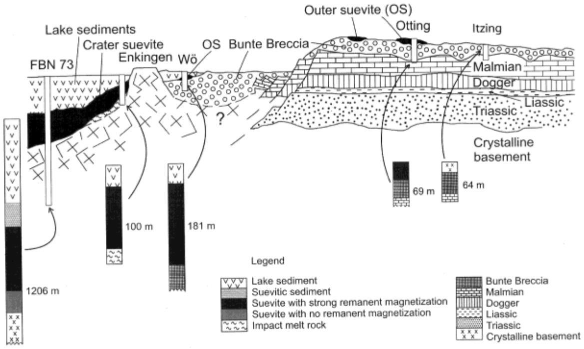

Fig. 1: Cross section of the Ries crater (left part), the inner ring, the megablock zone and the ejecta blanket beyond the structural rim with drill core profiles (from [1]).

Observational boundary conditions for the genesis of suevite [1]**:** The following relevant informations on Ries suevite are available: (1) Geological setting and regional distribution with respect to the host crater, (2) composition of lithic and mineral clasts and of melt particles and their relation to pre-impact lithology and stratigraphy of the target rocks, (3) quantitative modal composition, (4) grain size and other textural characteristics, (5) degree of shock metamorphism of the constituents, (6) parameters indicative of the cooling history (e.g., remanent magnetization and secondary mineralization). With respect to these criteria the two types of suevite are distinctly different from each other. The OS lacks any sorting and gradation. Its constituents are derived mainly from the upper section of the crystalline basement including small amounts of all levels of sedimentary strata. The lithic clasts are much more highly shocked than those of the CS. The CS displays a large-scale layered structure [8] with (1) a basal, melt-poor layer (~ 75 m thick) with no remanent magnetization, (2) a central layer of more melt-rich suevite with remanent magnetization (~ 200 m thick) displaying a sharp transition into an uppermost "sorted" and "graded" suevite (~ 20 m thick) (Fig. 1). The central CS layer is deficient of melt particles compared to OS. It is dominated by lithic clasts from a deeper section of the crystalline basement and lacks clasts from the Jurassic (upper ~ 300 m of the target) completely.

Prime conclusions from observations: OS and the central layer of CS on one hand and the lower layer of the CS on the other hand result from different processes. The lower layer of CS forms a dike-like structure and is interpreted as the result of injections of allochthonous material into the crater bottom *("primary suevite")*. OS is formed by a non-ballistic ejection process and is best interpreted as fall back material from an ejecta plume with a final lateral transport component. The central layer of CS also represents vertically deposited fallback material from an ejecta plume as does the OS (both are *"secondary suevites"*).

Boundary conditions imposed by numerical modeling [2]**:** It has been recognized in 2009 [9] that the existing volumes of CS and OS cannot be derived from the "primary" impact plume formed immediately after impact. Its collapse would lead to less than a few meters of CS and some decimeters of OS and the constituents would be very fine-grained and mainly derived from the sedimentary rocks strata with a minor contribution from the crystalline basement. Moreover, modeling results [2, 9] postulate the existence of a pool of impact melt inside the crater after collapse of the transient cavity. As a consequence a "secondary" impact plume or multiple ejecta plumes have to be postulated which would have to be triggered by a reaction of the clast-laden impact melt layer with water and other volatiles [2], a process which was postulated at the same time also for the "suevitic" Onaping Formation of the much larger Sudbury impact structure [10].

Compatiblity between observations and modeling: We recognize a satisfactory compatibility between observations [1] and modeling constraints [2] in the new hypothesis for the origin of the Ries suevite. However, open questions remain for some essential details.

The main compatibilities are ([1, 2], Figs. 2 and 3): (1) Maximum radial extent of OS (observed 1.8 crater radii R compared to 1.6 – 2.0 from modeling), (2) continuous decrease of the average thickness of OS (90, 40, 24, and <10 m at 0.5, 0.9, 1.3, and 1.7 R, respectively, compared to 60 and 25 m at 0.5 R and 1.3 R in the modeling calculation, (3) remnant of a clast laden melt sheet at the inner slope of the uplifted ring (Fig. 1), (4) total volume of impact melt (4.9/8.0 km^3 minimum/maximum) contained in suevite and patches of impact melt rocks (IMR) compares to a calculated 6.6/11.3 km^3 of melt retained in the central melt pool.

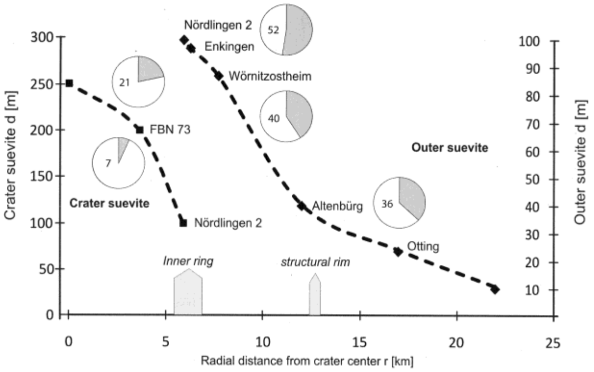

Fig. 2: Distribution, thickness, and melt content of OS and CS as function of the radial distance from the crater center; numbers in circles represent vol.% of melt in any suevite location; FBN 73 = research drilling Nördlingen with bottom layer CS (7 %) and central layer CS (21 %).

(5) composition of melt particles reflects a rather homogeneous mixture of crystalline rocks of the deep basement indicative of a precursor homogeneous melt pool which contains only 5-9 % of sedimentary rocks compared to 25-30 % in the melt zone (Fig. 4, top graph), (6) observed low degrees of shock in clasts of CS in contrast to OS (89.5, 8.5., and 2 vol. % of shock stages I, II, and III, respectively, in CS) compared to the calculated 79, 4.7., and 5.7 km^3 of crystalline rocks of stages I, II, and III retained inside the crater [2].

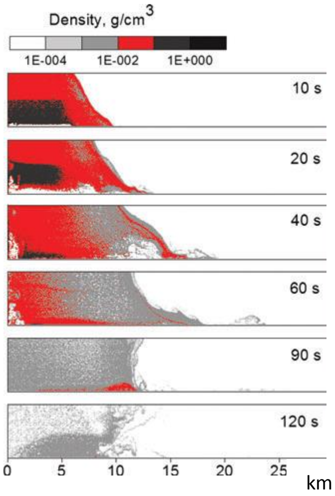

Fig.3: Density distribution within the lower part of suevite flow with a water content of 2 wt%. Red color corresponds to density values between 0.01 and 0.1 g cm^3 (from [2]).

Open questions: Most of the open questions concern the details of the genesis of the OS and CS which show distinct differences in composition, texture, and geological setting (see 2nd paragraph above). Detailed modeling attempts to explain these difference are not yet made. At this point we have to rely on a number of assumptions regarding a possible heterogeneity of the melt pool and its effects on the evolution of the FCI-induced "secondary" phreatomagmatic-like plume or plumes and the time-dependent evolution of such plumes (Fig. 4). OS may be derived from an early formed, melt-rich, clast-poor plume originating from the upper and marginal zone of the melt pool. CS may result from later formed, melt-poor and clast-rich plume(s) originating from deeper, more central zones of the melt pool.

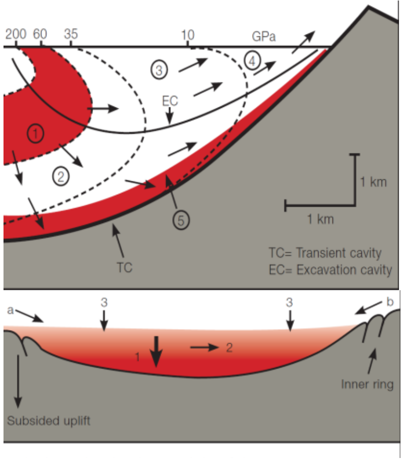

Fig. 4: Formation and compositional model of the temporary Ries crater melt pool before the "secondary" ejecta plume(s) formed; 1 = melt zone, 2, 3, 4 = zones shocked to stages III + II, stage I, and stage 0, respectively; 5 = clast-laden melt at TC floor; a = addition of blocks of crystalline rocks, b = addition of both sedimentary and crystalline material plus water and other volatiles (from [1]).

References: [1] Stöffler D. et al. (2013) *Meteoritics & Planet. Sci.*, *48*, 515-589. [2] Artemieva N. et al. (2013) *Meteoritics & Planet. Sci.*, *48*, 590-627. [3] Kenkmann T. and Schönian F. (2006) *Meteoritics & Planet. Sci.*, *41*, 1587-1603. [4] Sturm S. et al. (2015) *Meteoritics & Planet. Sci.*, *50*, 141-171. [5] Sturm S. et al. (2013) *Geology*, *41*, 531–534. [6] Fettes D. and Desmons J. (2007) Metamorphic rocks – A classification and glossary of terms, Cambridge University Press, pp. 244. [7] Wohletz K. H. and Sheridan M. F. (1983) *Icarus*, *56*, 15-37. [8] Pohl et al. (1977) in Roddy D. J. et al., *Impact and explosion cratering*, 343-404, Pergamon Press. [9] Artemieva et al. (2009) LPS XXXX, Abstract # 1526. [10] Grieve et al. (2010), *Meteoritics & Planet. Sci.*, *45*, 759-782.