**RIES CRATER AND SUEVITE REVISITED: PART II MODELLING.** N. A. Artemieva[1,2], K. Wünnemann[3], C. Meyer[3], W.U. Reimold[3], and D. Stöffler[3], [1]Institute for the Dynamics of Geospheres, Moscow, Russia, [2]Planetary Science Institute, Tucson, AZ, artemeva@psi.edu, [3]Museum für Naturkunde - Leibniz-Institute at Humboldt University Berlin, Invalidenstrasse 43, 10115 Berlin, Germany.

**Introduction:** At the 26-km-diameter Ries impact structure (Germany) suevite occurs in three different geological settings [1]: (1) a thick continuous layer in the central crater cavity inside the inner ring ("crater suevite" = CS), (2) thin isolated patches on top of the continuous ejecta blanket ("outer suevite" = OS), and (3) dikes in the crater basement and in displaced megablocks. In this paper we will discuss the first two types of suevite.

**Previous concepts of the genesis of suevite types:** A first concept for the Ries suevite genesis was presented in 1977 [2], with some later modifications in [3, 4]. There was agreement that the OS is derived from the ejecta plume and deposited "non-ballistically" as fallback material from the plume. The interpretation of the CS, subdivided from top to bottom into units A, B, and C (see [1]), was less straightforward. In [4] it was suggested that units B and C had never been ejected from the transient crater cavity (TC), whereas [3] interpreted unit B as fallback material from the plume and unit C as material ground-surged along the floor of the transient cavity (TC). The graded suevite of unit A was seen as true fallback material [2, 5].

Kieffer and Simonds [6] suggested that impacts into volatile-rich material may result in the dispersion of impact melt, the formation of suevite, and, finally, in impact melt deficiency in comparison with craters in crystalline rocks. With reference to this idea, Newsom et al. [7] pointed out a striking similarity between degassing pipes in Ries suevite with features observed in ignimbrites and pyroclastic flows. They argued that the Ries suevite represented fluidized ejecta with volatiles released from molten basement rocks (0.8 wt% of water in igneous rocks and 2.5 wt% of water in metamorphic rocks). Such a water content in the flow allowed "fluidization" but not sorting of suevite. At a later stage, suevite had been subjected to substantial hydrothermal alteration. Water derived from underlying Bunte Breccia (continuous ejecta) was suggested as an alternative source of volatiles [8].

Recently it was proposed [9,10] that surficial (outer) suevites of the Ries had been emplaced as ground-hugging impact melt flows during the modification stage of crater formation. This hypothesis is consistent with the fact that these rocks overlie ballistic ejecta (Bunte Breccia), without any mixing between them. However, the substantial clastic component in suevite (~ 10-30 vol%) and the texture/mineralogy of the melt particles suggests temperatures at deposition below the glass transition temperature of the silicate melt (~750 °C; [11]) leading to an extremely high viscosity of suevite material. Moreover, the distinct "aerodynamic" shape of the large melt bombs [12] is incompatible with the melt flow concept.

**Numerical models and initial conditions.** The Ries impact is modeled with the 3D hydrocode SOVA [13] complemented by a special procedure to describe particle motion in the evolving ejecta-gas plume. We also couple the results derived from the ejecta plume modeling with the iSALE hydrocode [14] capable to simulate the impact-induced deformation of the target. From previous numerical simulations [15,16] it can be assumed that the Ries impactor had a diameter of 1.1 to 1.5 km and density of 2.6 g/cm$^3$. The target stratigraphy is simplified to two layers: 600 m of sediments (approximated with the EOS for calcite) and crystalline basement (granite EOS). To mimic water-saturated sediments (and to exaggerate plume formation) we also use a mixed EOS for 80 wt% of calcite and 20 wt% of water [17].

**First results:** Modeling of crater formation and of the impact plume collapse show: 1) ejecta from all stratigraphic units with velocity < 1 km/s move and are deposited ballistically; 2) high-velocity ejecta (> 1 km/s) contain exclusively sedimentary rocks, whereas low-velocity ejecta are a mixture of all target materials; 3) the impact plume above the crater consists mainly of a sediment-derived vapor/melt mixture and contains very little amount of lithic clasts; 4) the total thickness of plume deposits inside the crater does not exceed a couple of meters; 5) at the end of the modification stage the crater floor is covered by a 100-200 m thick layer of impact melt. Thus, the model can not reproduce the previous hypotheses on suevite origin as plume-related non-ballistic ejecta.

*Plume collapse.* Another inconsistency with the standard model comes from estimates of "ficticious" plume collapse. We model a heavy plume (i.e. loaded by particles with the total mass equivalent to the mass per unit area of outer suevite and with size-frequency distribution of particles similar to a realistic one). Even in the case of a huge initial plume size extending up to 50-100 km above surface, we obtain immediate collapse of this plume with free-fall velocity (~1-2 km/s) near surface without any particle sorting. This means that substantial secondary cratering must take place, which is inconsistent with the knife-sharp boundary observed between Bunte Breccia and Ries suevite.

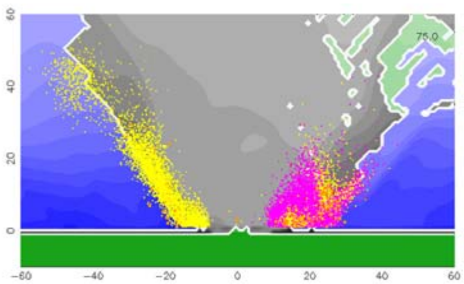


**Fig.1.** Impact plume 75 s after the impact (the crater itself is barely visible at this spatial resolution). The plume, consisting of sedimentary melt/vapor (in gray) is restricted by ballistic ejecta curtains: yellow and orange – sedimentary clasts, magenta – crystalline clasts, red – crystalline melt.

**Fuel-coolant interaction.** Natural steam explosions (phreato-magmatic eruptions, PMEs) are common in terrestrial volcanoes where magma interacts with near-surface water [18,19]. Similar (but not identical) effects, known as "melt-coolant" (or fuel-coolant) interaction, occur in foundries and nuclear power plants [20]. In these cases, explosion efficiency depends on the water:melt ratio and has a maximum for values of 0.1-0.4, depending on the efficiency of water/melt mixing. "Ideal" numerical modeling, assuming a perfect melt-water mixture, gives a value of about 0.2 and a maximum expansion velocity for a vapor plume loaded with molten particles of about 700 m/s [21].

**Discussion.** A sharp boundary between the Bunte Breccia and suevite and an extremely low content of sedimentary target rock (< 1 vol%) in suevite demand 1) a substantial hiatus between ballistic ejecta emplacement and suevite deposition, and 2) low-velocity, high-turbulent flow of suevite above the ballistic ejecta. An analog with pyroclastic flow [7] seems appropriate. However, we need substantially more than 1-3 wt% of volatiles to initiate this flow, to transfer materials up to 25 km from the crater center, and to transform the impact melt sheet within the crater into a "secondary" suevitic layer due to volatile-induced, "phreatomagmatic-like" explosions. Therefore, we suggest that the impact crater rapidly filled with running water. Prior to the impact the Ries area was transected by two major rivers [22], whose beds were destroyed by the impact. We can speculate that these rivers returned back into the crater area some time after the impact, introduced some clastic material from breaching of the crater rim, and initiated "phreatomagmatic" eruptions. Cooling of the Ries melt pool with an assumed thickness of 200 m below the glass transition T (~1000 K) and water boiling temperature (373 K) could have taken 0.3 – 3 kyr, i.e. the crater suevite fill would have to be produced in such a time interval.

*What should we look for to prove this hypothesis?* The presented new hypothesis is much more compatible with the observed distinct homogeneity of the chemical composition of the "glass" bombs in the OS [3,4] than all previous concepts. While microstructure of resulting particles should be similar to the products of PMEs (vesiculation, small size, etc), macrostructure may be substantially different because of another geometry: PMEs are associated with a point source (magma channel) and are usually repeated a few times, creating pronounced bedding with particle sorting within each individual layer. Water interaction with an impact melt pool (being much hotter than magma) may be much more intense and create irregular explosion deposits lacking any sorting and bedding.

*Application to other terrestrial craters and to Mars.* Interaction of water with impact melt revives an old idea [6] that volatiles have a substantial effect on the ejecta emplacement. While degassing of sedimentary rocks demands shock compression above 50 GPa [23], water vaporization occurs at much lower pressure of 10 GPa. Water is quite common on Earth (seemingly was on Mars as well) and may occur as pore water and/or surface water (impacts into a shallow ocean or a river valley). The proposed mechanism may help to explain the origin of suevite in other craters and resolve the apparent problem of impact melt deficiency in sediment-target impact structures (as recently noted in the ICDP drilling projects at Chicxulub, Bosumtwi, and Chesapeake Bay).

**References:** [1] Stöffler D. et al. (this volume). [2] Stöffler D. (1977) *Geol. Bavar., 75*, 443-458. [3] Engelhardt W. v. and Graup G. (1984) *Geol. Rdsch., 73*, 447-481. [4] Engelhardt W. v. (1997) *Meteoritics, 30*, 279-293. [5] Jankowski B. (1977) *Geol. Bavar., 75*, 155-162. [6] Kieffer S.W. and Simonds C.H. (1980) *Rev. Geophys. Space Phys. 18*, 143-181. [7] Newsom et al. (1986) *JGR 91*, 239-251. [8] Wittmann A. and Kenkmann T. (2007) *Bridging the Gap II*, abstr. 8065. [9] Osinski G. R. (2004) *EPSL 226*, 529-543. [10] Osinski G.R. et al. (2004) *M&PS 39*, 1655-1683. [11] Engelhardt, W.v. et al. (2005) *M&PS 32*, 545-554. [12] Hörz (1965) *Beitr. Min. Petr. 11*, 621-661. [13] Shuvalov V. (1999) *Shock Waves 9*, 381-390. [14] Wünnemann K. et al. (2006) *Icarus 180*, 514-527. [15] Stöffler et al. (2002) *M&PS 37*, 1893-1908. [16] Wünnemann K. et al. (2005) *GSA Spec. Pap. 384*, 67-83. [17] Pierazzo E. et al. (2005) *GSA Spec. Pap. 384*, 443-457. [18] Colgate S. A. and Sigurgeirsson R. (1973) *Nature 244*, 552-555. [19] Wohletz K. H. and Sheridan M. F. (1983) *Icarus* 56: 15-37. [20] Sandia Labs (1975) SAND-74-0382. [21] Shuvalov V. and Artemieva N. (2004) *GFF* 126 (1), 50. [22] Bayerisches Geologisches Landesamt (1969), *Geol. Bavar, 61*, 478. [23] Ivanov B. et al. (2002) *GSA Spec. Pap. 356*, 587-594.