RIES SUEVITE – PLUME EJECTA, MELT FLOW OR SOMETHING ELSE? N. Artemieva[1,2], K.Wünnemann[3], D.Stöffler[3], and W.U. Reimold[3], [1]Planetary Science Institute 85719 Tucson, [2]Institute for Dynamics of Geospheres 119334 Moscow, artemeva@psi.edu, [3]Museum für Naturkunde – Leibniz-Institute at Humboldt University Berlin, Invalidenstrasse 43, 10115 Berlin, Germany.

Introduction: Suevite occurs in three different geological settings at the 26-km-diameter Ries crater, Germany: (1) a thick continuous layer in the central crater cavity inside the inner ring, (2) thin isolated patches on top of the continuous ejecta blanket (Bunte Breccia), and (3) dikes in the crater basement and in displaced megablocks [1]. Here, we present results of numerical modeling applied to various aspects of Ries crater formation and compare the results with observations. We also analyze existing analog models of suevite emplacement.

Numerical models: We used two different hydrocodes, SOVA [2] and iSALE [3,4], coupled with the ANEOS [5] equation of state, to describe crater formation, plume expansion, and ejecta deposition. With both codes we used tracers (massless particle) to record the thermodynamic history of involved materials. SOVA is also capable of describing the interaction of solid/molten ejecta with vapor/atmosphere in the frame of dusty-flow approximation [6].

Main results: Standard models of impact cratering allow us to reproduce typical features of the Ries crater: 1) crater shape, size, and morphology; 2) composition and extension of the continuous ejecta blanket; and 3) shocked basement clasts versus unshocked sediments within Bunte Breccia. However, some results are in contradiction with observations and/or with previous qualitative models of Ries suevite: 1) the absence of a central peak is difficult to bring into accordance with our current understanding of crater mechanics – this issue is not addressed in this paper; 2) the impact plume above the crater consists exclusively of a sediment-projectile derived mixture; 3) at the end of the modification stage the crater floor is covered by a thick layer of impact melt with a total volume of 6-10 km^3; and 4) ejecta from all stratigraphic units are transported ballistically, i.e., no separation between sedimentary and crystalline rocks, as observed in Bunte Breccia versus suevite, occurs. These inconsistencies can be explained only by the lack of some physical processes that play an important role during crater formation, or shortly thereafter, and that have not been implemented in our current models.

Plume concept and ignimbrite flow: Our models clearly show that the suevite components cannot be part of an impact plume [7,8]. According to our computations, the plume is a rarefied mixture of highly shocked sedimentary rocks and projectile material. Hence, the plume collapse cannot initiate ignimbrite-like flow of crystalline rocks, as suggested in [9]; the plume material is deposited similar to volcanic ash.

Melt flow from the central uplift: To model ground-hugging impact melt flow [10] we consider a melt layer initially overlying a 1-km-high central uplift (two-fold excess of its maximum height, as suggested in models of crater formation in [11]). We neglect melt cooling due to heat exchange with colder rocks, mixing with lithic clasts, and heat radiation to the atmosphere. Instead of radial symmetry, we assume a planar approximation that corresponds to a 2D model of the flow within a channel. However, all these simplifications tend to increase the range of the flow. We varied melt viscosity from zero to a low value of 100 Pa·s (typical for high-temperature basaltic magma) and up to 10^7 Pa·s (typical for highly viscous dacitic magma). As the Reynolds number is high for a low-viscous flow, we expect a highly turbulent behavior (presumably not sufficiently resolved in our models).

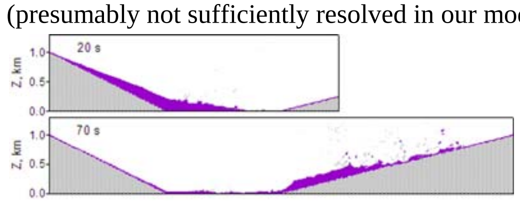

Fig. 1. Melt flow (purple) from the 1-km-high central uplift. At 70s the flow reaches its maximum altitude on the crater wall (and cannot reach the rim).

Although the maximum mass-averaged velocity of the low-viscous flow may be up to a hundred m/s, the flow cannot reach the crater rim with an exception of a few small splashes. After a few "up and down" cycles the non-viscous (or low-viscous) melts are deposited in the central moat. Highly-viscous melts are deposited in the central moat without oscillations. A much higher central uplift is required to propel the melt outside the rim.

Post-impact interaction: A recent hypothesis suggests that suevite formation took place by (post-)impact interaction of water with an intra-crater melt pool [12-14]. To model this scenario, we start with a 250-m thick and 6-km-radius flat layer (possible size of the Ries melt pool), in which melt is thoroughly mixed with water and solid fragments. Initial temperature of the mixture T_0 is 800 K; water content varies between 2 and 10 wt%. We also assume that water is instantaneously vaporized by heat exchange with melt, reaches an equilibrium temperature, but has no time/space to expand. It means that the vapor pressure is about 0.4-0.8 GPa and so-called fuel-coolant (FC) explosion occurs [15]. First, we allow the mixture of gas and solid particles to expand as a heavy gas without phase separation. When the layer expands to 6-8 km, we switch to the "dusty-flow" model [2,6] to simulate the multi-phase character of the flow (particles and vapor move at different velocities, exchanging momentum and heat). Particle temperature within the flow decreases slowly and, at the end, is ~10 -15% below T_0. This final temperature approximately corresponds to the suevite temperature (>575ºC) after deposition, as derived from geophysical studies [16]. Fig. 2 shows the density distribution in the lower part of the flow. The flow base is 10-100 times denser than the atmosphere, i.e., it is a gravitationally driven flow. At the same time, the volume fraction of particles is 100-10 times lower than the gas volume, i.e., the "dusty-flow" approximation still works. After 90s, the basal layer density decreases below atmospheric density. It means that the uppermost layer of suevite may be layered and graded.

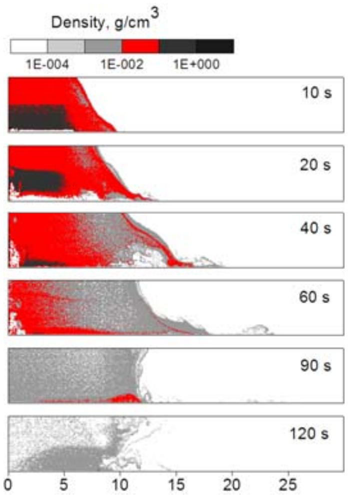

Fig.2. Density distribution within the suevite flow with a water content of 2 wt%. Red color corresponds to density values between 0.01 and 0.1g/cm^3.

The thickness of deposits from the FC-driven flow as a function of distance is shown in **Fig. 3.** Any water content leads to a reasonable distribution of materials deposited from the cloud. Water content of 5 or 10 wt% results in a rampart shape of ejecta deposits. As the flow is gravity-driven, any non-flat features on the surface may lead to non-homogeneous deposits (thicker in valleys, thinner on hills). Although particle sizes vary from 10 µm up to 10 cm (melt bombs), final deposit is non-graded except for the upperost 50 cm.

Source of volatiles: The water content in crystalline rocks of the Ries target varies from 0.56 wt% up to 5.65 wt% [17]. Although these values are at the lower limit of our estimates (>2wt%), two important details ought to be taken into account. First, it is important to inject water into the melt pool after crater formation; otherwise an explosion would not happen. Cratering in water-rich targets (wet porosity) results in higher ejection velocities [18] and, finally, in a comparatively larger crater [19]. Second, we assume instantaneous and homogeneous mixing of two materials on a km-scale, which is difficult to realize in nature. Therefore we presume that the real water flux has to be locally much higher than the average values of our model.

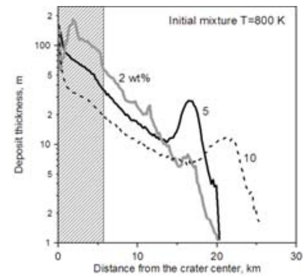

Fig.3. Thickness of suevite as a function of distance from the crater center. Numbers near the curves show water content. Shaded zone corresponds to the initial melt pool.

Currently we may suggest two alternative sources of volatiles: 1) two local rivers [20], whose beds were destroyed by the impact - they would be able to breach the crater rim within a few thousand years after the impact (when the melt pool is still hot enough to vaporize water); 2) unshocked sedimentary rocks deposited not far from the inner ring and slumping into the hot inner part of the crater immediately after the impact.

Planetary applications: Suggested post-impact interaction of melt with volatiles may explain a melt deficiency and/or presence of suevites in terrestrial craters made in mixed targets (Bosumtwi, Chesapeake Bay). Similar mechanisms may work on Mars.

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