POSSIBLE MECHANISMS OF SUEVITE DEPOSITION IN THE RIES CRATER, GERMANY: ANALYSIS OF OTTING DRILL CORE.

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Introduction: The Ries ejecta blanket consists of continuous polymict breccia deposits, called Bunte Breccia, derived mainly from sedimentary rocks (with increasing proportion of locally derived materials with increasing distance from the crater) and extending radially to 45 km from the point of impact. On top of this "megabreccia" there are isolated patches of suevite deposits up to a radial distance of ~23 km from the center of the impact structure [1]. The contact between "ground zero" rocks and Bunte Breccia is characterized by substantial mixing caused by ballistic deposition which initiated a ground surge. On the other hand, the contact between suevite and Bunte Breccia is extremely sharp with a transition zone < 10 cm wide [2].

Until recently, the accepted model for the formation of suevite (i.e., the upper section of fallback suevite - ca. 200 m of a total of ca. 270 m - inside the crater cavity and all suevite on the ejecta blanket) has proposed that material was ejected by an upward-rising hemispherical plume comprising a mixture of lithic and mineral fragments of all shock stages, vapor, and molten material. The collapse of the plume eventually resulted in the deposition of the material as a fluidized turbulent mass flow inside the crater basin and in a more patchy distribution outside the inner ring on top of the Bunte Breccia deposited earlier ballistically [3]. This model can explain the sharp Bunte Breccia/suevite boundary. However, preliminary modeling of alleged fallback ejecta in the Bosumtwi crater [4] shows that the amount of fall-back suevite is very small and may create a layer not more than a few meters thick. An alternative interpretation of the suevite deposits inside/outside the crater basin has recently been given by [5], who argued that the suevite components were transported as melt-dominated viscous surface flows outwards from the transient cavity (where they originated), towards, and possibly beyond, the final crater rim.

Methods. The goal of our project is to revisit the suevite problem in an interdisciplinary study by combining geological and petrograhic observations from available outcrops/drill cores with numerical models of crater and ejecta plume formation/deposition.

Petrological methods: In a first step we investigated the drill core (10 cm in diameter) from the "Otting" suevite quarry, which comprises a 9 m thick suevite sequence on top of Bunte breccia. Otting is situated outside the eastern crater rim, 17 km from the impact point. The drill core has been studied by digital stereometric analysis using the "ImageJ" software [6]. Grain sizes of lithic clasts and melt particles were measured every 5 cm on a section of 5 x 10 cm for particles > 1 mm on the plane surface of the half core. The mean orientation of the particles was obtained from stereoplots taken every 10 cm on a section of 10 x 10 cm. The modal content of matrix, clasts, and melt particles was measured every 10 cm on a section of 7.5 x 7.5 cm. In this case the matrix is defined as particles < 1 mm. In order to define the matrix at higher resolution two thin sections were investigated at sampling depths of 131 cm and 870 cm. Grain sizes and content of particles could be measured for sizes > 125 µm. In this case the matrix is defined as particles < 125 µm.

Numerical modeling. The complex behavior of a multiphase gas-flow is modeled with the three-dimensional (3D) hydrocode SOVA [7], which has been successfully used for the modeling of the Ries distal ejecta before [8-9]. What makes this hydrocode particularly suitable for the given application is the implementation of a procedure to describe particle motion in the evolving ejecta-gas plume with momentum-heat transfer between different phases. Turbulent diffusion and viscosity are taken into account in a simplified manner [10].

We modeled a 1.2-km-diameter, 18 km/s asteroid impacting a Ries-like target (600 m of sediments, underlain by crystalline basement) at 45° to the horizon. Sediments were described either by an EOS for dry non-porous calcite or by an EOS for water-saturated 30% porous calcite (assuming pressure-temperature equilibrium between water and calcite). The resulting 12-km-diameter transient cavity has a depth of 5.5 km.

Observations: The mean particle size of the lithic clasts of the Otting core increases gradually with increasing depth, whereas the mean particle size of the melt particles decreases until about 300 cm depth and thereafter increase downward to the bottom. Generally, the lithic particles are always smaller than the melt particles.

On average the melt content of the core is 4 times higher than the content of lithic clasts. This could be confirmed by the analysis of the thin section from 131 cm depth. The abundance of the lihic clasts is constant throughout the length of the core whereas in the macroscopic analysis the melt content seems to decrease over the lowermost meter of the core. The investigation of the thin section from 870 cm depth shows that most of the melt particles in this lowermost section are below the detection limit of 1 mm. With this microscopic analysis we found that the melt content (about 35 %) is as high as in the rest of the drill core. At the macroscopic scale (> 1 mm) the matrix fraction is about 70 % in average and at the microscopic scale (> 125µm) it is about 65 %. The modal composition of the suevite matrix remains to be determined in the ongoing work.

Magmatic and metamorphic lithic clasts could be observed throughout the core. Sedimentary rock clasts were more often found in the lower part of the suevite and most frequently in the last meter above the bottom.

The orientations of the melt particles, which have mostly a strong elliptical shape, are almost horizontal throughout the core, whereas the lithic clasts with their almost isometric shape do not show a preferred orientation.

Deposition of dense ejecta curtains. The numerical modeling yielded the following results: The total amount of ejected material amount to 160 km^3 (with an average sediment/basement proportion of 3:1). The maximum ejection velocity for crystalline rocks does not exceed 1 km/s. Ejecta deposited within a ring with 16-18 km radius (similar to the position of the Otting site) have a deposition velocity of ~350 m/s and consist of a sediment/basement rock mixture.

Using pure ballistics (i.e. motion under gravity but without atmospheric drag) for ejected materials, we receive a reasonable estimate for the total thickness at Otting, i.e. tens of meters of sediments and basement rocks. There are no basement ejecta in the uprange direction. The deposition velocity allows substantial reworking of and mixing with target rocks. The average shock compression of basement rocks is at least 4 times higher than in sediments for any azimuthal angle (16 GPa versus 4 GPa).

Conclusions and discussion. Our modeling results relevant to ballistic deposition do not allow to reproduce the observed ejecta in the suevite layer of Otting: 1) there is just very little melt in the modeled ejecta and 2) separation of sedimentary rocks from basement rocks (i.e. Bunte Breccia and fallout suevite) does not occur. Separation and gradation of two layers (BB and suevite) by atmosphere (fallout) seems improbable as the total ejecta mass per unit area at the Otting site is substantially higher than the mass of the involved atmosphere. Deposition of a suevitic layer as a viscous flow [5] seems also improbable, as viscosity of the flow with solid fragments (i.e. with temperature below the solidus) increases dramatically and prevents spreading to a few km from the transient cavity. We need another mechanism of the ejecta flow "fluidization". One possibility is a gas release (mainly water vapor from sediments) which allows dispersal of the smallest particles and suevite deposition above the ballistically deposited Bunte Breccia (similar to propagation of pyroclastic surge in volcanology) [12].

To verify this assumption by geological investigations we plotted the median grain size of all lithic and melt particles in the suevite against the mean grain size (Fig. 1). In volcanic rocks it is possible to distinguish fallout deposits from pyroclastic flow deposits by dividing such a plot into two areas for the different kind of deposits [11]. Most of our grain size data of the particles would plot in such a figure in the area of pyroclastic flow deposits. One should keep in mind that the grain size distribution of particles in the suevite matrix has not yet been measured in contrast to volcanic deposits. However, plotting the results of our thin section analyses from 131 cm depth (resolution 125 µm) in the diagram the points fall also into the "pyroclastic flow"-field (solid square and circle). But still 65% of the grain size fraction is unclear and should be taken into account, before a final conclusion about the meaning of these data can be reached.

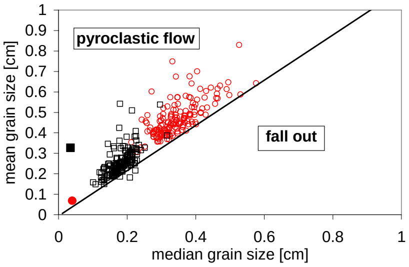

Fig. 1 Distinction between pyroclastic flow and fall out deposits used by [11] for volcanic deposits. Red circles: melt particles; black squares: lithic clasts of the suevite of the Otting drill core

It is quite possible that the mechanism of the suevite deposition was much more complicated: the occurence of density currents with various gas/solid material ratios makes a combination from diluted fallout to a dense basal flow deposition possible.

References:

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