THE STEINHEIM IMPACT CRATER, GERMANY: MODELING OF A COMPLEX CRATER WITH CENTRAL UPLIFT.

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Introduction: The Steinheim impact crater [1,2] (D = 3.8 km) was most propably formed simultaneously with the much larger Ries crater (D = 24 km) by an oblique, ENE directed impact of a double asteroid some 15.0 Ma ago [3,4,5,6]. The Steinheim Basin has a rather well preserved morphology with a ~ 1 km diameter central uplift which rises some 50 m above the present basin floor formed by post-impact lake sediments. The primary crater rim is eroded to some degree but is still visible as it stands some 90 - 100 m above the basin floor. The crater was formed in a sequence of horizontally layered limestones, marls, shales and sandstones of Jurassic and Triassic age. This contribution is a first attempt to apply the most advanced methods of computer code calculations to model the Steinheim event constrained by the presently available geological observations.

Geologic database: The target rocks of Steinheim impact consisted of a horizontally layered sequence of sedimentary rocks comprising (from top to bottom) ~380 m of Malmian limestones, ~210 m of Dogger shales and sandstone, ~90 m of Liassic shales, ~250 m of Upper Triassic (Keuper) shales and sandstones, and ~250 m of Lower Triassic and Permian sandstones (Fig. 1). The top of the Hercynian crystalline basement ist at ~ 1180 m depth [7]. Observations from drillings [2,4] indicate that no rocks deeper than Keuper have been displaced by the impact. The original rim crest diameter of the Steinheim crater is estimated to about 4.2 km. The depths of the apparent crater and of the crater floor (measured from ground zero) are ~ 190 m and ~ 260 m, respectively. The crater floor is overlain by a layer of polymict fallback breccia of 20 - 70 m thickness. It contains lithic clasts from only the Malmian and Dogger (upper ~ 600 m of the target section) with low degrees of shock metamorphism including shocked quartz and shatter cones in limestone fragments. The central uplift is formed by a polymict megabreccia containing all stratigraphic units from Malmian to Keuper [2,4]. The apparent crater is filled by up to ~ 50 m of post-impact lake sediments. [4, 8].

Limited gravity survey [9] reveals the boundary of Malmian limestones and Dogger sandsones and puts some restrictions to the position of the annular trough around the central mound. Some useful data have been obtained in [10] via comparison between Steinheim and other impact and explosion craters.

Target modeling: To make numerical modeling possible we introduce a simplified target reflecting the main stratigraphy units. The model target (Tillotson's EOS) is constructed of ~400 m of limestone (density ρ= 2.665 gcm^{-3}, Poisson ratio ν = 0.2, longitudinal wave velocity c_L = 5.48 km s^{-1}), ~600 m of sandstone (ρ = 2.46 gcm^{-3}, ν = 0.33, c_L = 3.33 km s^{-1}), and granite basement (ρ= 2.7 gcm^{-3}, ν = 0.25, c_L = 5.94 km s^{-1}). The layers' thickness varies from run to run to take into account erosion of upper surface (50 to 200 m).

Numerical modeling uses SALEB Eulerian hydrocode. Computation cells are of 12x12 m to 15x15 m in cratering area (with the extended acoustic buffers outside the area of interest). The projectile is modeled as a limestone sphere (ρ= 2.665 gcm^{-3}, 16 cells per projectile diameter; diameter varies from 195 m to 244 m) with the vertical impact velocity 12 or 14 km s^{-1}. In total, some 20 computer runs were done to make a parametric study. Initially intact rocks experience shear and tensile failure during cratering. Damaged rocks behave as Mohr-Coulomb media with dry friction (see mechanical model details in [11]). Acoustic fluidization (AF) model [12] is used to simulate temporary friction decrease around the growing and collapsing crater. The strength of AF oscillations exponentially decay in time with characteristic time of ~7 s (varies from run to run as a fitting parameter).

Modeling results: After the primary parameter fitting, all model runs form a crater with the rim diameter 4 to 6 km. The crater morphology varies from a simple crater (for a target without AF, Fig. 3) to a complex crater with the central uplift (Fig. 2). Parameter's variation results in variation of the central mound diameter and depth of the annular depression. Geological and geophysical data are used to compare cross-sections of observed and modeled craters. Several sets of parameters give similar results – the inverse problem has no unique solution. One of the best examples is presented in Figs. 2 and 4 (D_{proj} = 195 m, impact velocity 12 kms^{-1}, limestone thickness 350 m, basement at depth of 1050 m). The comparison with observed crossection and gravity model (Fig. 4) gives the best fit assuming ~ 50 m of erosion of the pre-impact surface. The model reproduces relatively well the central mound width and the vertical uplift. However, this parameter set does not reproduce mixing of rocks of different lithologies observed in B23 drill hole (Fig. 1). Such a mixing demands a collapse of a transient cavity similar to what our model produces in the absence of AF plus twice decreased friction in sandstone (Fig. 3).

Fig. 4 compares computed crater and central mound profiles with the profile published by Reiff et al. [4] and the profile averaged over 32 radial directions [9]. The shift of modeled profiles 50 m upward gives the best fit for the central uplift. One can use this shift as the tentative minimum estimate of possible general erosion in the area. Deformation of two selected initially horizontal layers is shown in Fig. 4 (open circles) to illustrate that the prominent "bump" in the apparent crater profile coincides with the area where deformed layers sub-vertically approach the apparent crater floor.

Fig. 5 shows isobars of maximum shock pressure in rock under the final crater. The important result (not sensible to model parameters) is the very low shock metamorphism beneath the crater floor (<20 GPa in the central uplift and <0.5 GPa below crater walls). This is compatible with the observation of shocked quartz and shatter cones.

Conclusions: Reconnaissance modeling of Steinheim crater gives encouraging results. However more work is needed to satisfy all known details of the crater structure.

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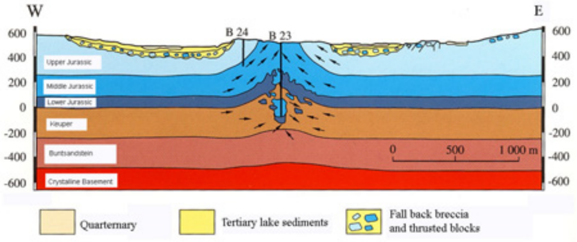

Fig. 1. Simplified geologic cross-section of Steinheim [4].

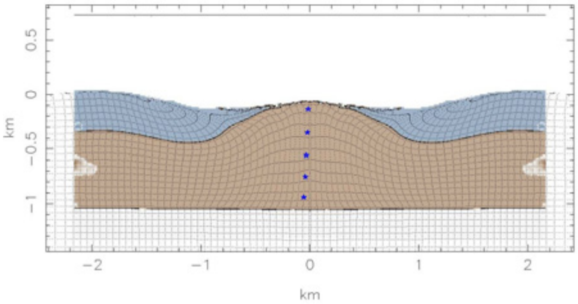

Fig.2. Modeled crater (AF both in limestone and sandstone)

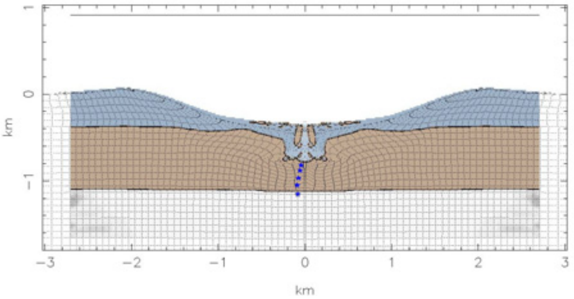

Fig. 3. Modeled crater (AF in limestone only).

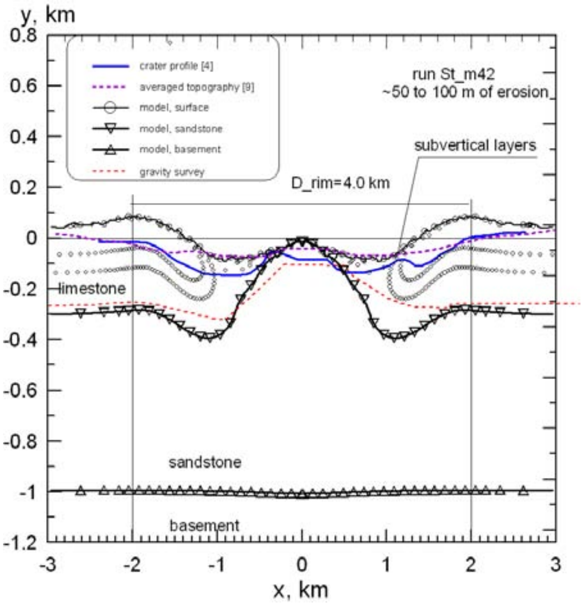

Fig. 4. Modeled crater structure in comparison with observational data [4, 9]. Note the vertical exaggeration.

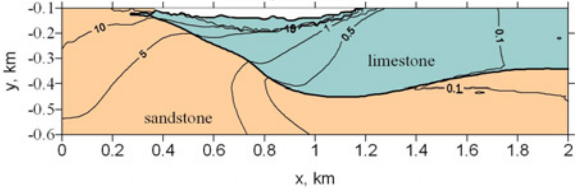

Fig. 5. Shock pressure isobars under the final crater.