Modeling the Ries-Steinheim Impact Event and the Formation of the Moldavite Strewn Field

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It is generally agreed that the Ries (D=24 km) and Steinheim (D=3.8 km) impact craters, S. Germany, and the moldavite strewn field (Bohemia, Moravia and Lusatia) were formed in a single impact event some 15 Ma ago [1,2,3,4]. Despite of almost 40 years of modern research, a comprehensive understanding of the process that formed the double crater and the tektites in one impact/ejection event is still lacking. We have started a numerical modeling project for the Ries-Steinheim-moldavite event [5,6,7] to better understand this particular impact cratering event.

Impactors origin: The investigation of the motion of two bodies in the atmosphere after breaking up at a given altitude indicate that no combination of reasonable impact velocities, impact angle and height above the surface could reproduce the Ries-Steinheim separation of ~42 km. The maximum separation at the surface was around 3 orders of magnitude smaller. Therefore, the Ries/Steinheim craters could not have been formed as a result of the breakup of an asteroid upon entering the Earth's atmosphere or by the separation of a contact binary asteroid. The alternative is that they were formed by a binary object with a pre-impact separation at least similar to the distance between the two craters [8]. This implies the existence of well separated binary asteroids as small as ~1.5 and 0.15 km, which currently cannot yet be observed for technical reasons (Ida/Dactyl being much bigger objects).

Impact ejecta: In contrast to Steinheim, large parts of the Ries continuous blanket are preserved (polymict clastic matrix, or Bunte Breccia, <200m thick), covered by "fallout" suevite patches (~5 to 90m thick) [1] extending radially to about 45 and 23 km, respectively [9]. Moldavite tektites extending radially from ~200 to 400 km [1,3] represent distal melt ejecta from the Ries. The tektite melt originates from the top 50m of mainly sandy Tertiary deposits of the Ries target [10] whereas the other type of Ries impact melt, confined to suevite of the crater itself, is derived from the melt zone in the crystalline basement. A layer of coherent melt rocks is missing in the Ries crater but two huge melt lumps ("red" crystallized melt rock, ~50 m in size) were deposited at the eastern crater rim [11]. They are inside the East part of the fan defined by moldavites. Such melt has not been found anywhere else in the Ries.

Impact Modeling: We carried out 3-D impact simulations with the hydrocode SOVA [12] coupled to the ANEOS equation of state package [13]. SOVA is unique among hydrocodes used for impact cratering in that it includes a procedure to model particle motion in the evolving ejecta-gas plume, allowing to model the formation and distribution of tektites. The simulations model spherical asteroids (granite; 5% porosity) striking Earth's surface at angles of 45°, 30°, and 15° from the surface with velocities of 12, 20 and 40 km/s. To model a single transient cavity size (D~12.2 km), the projectile sizes have been varied according to the Pi-scaling law [14]. Spatial resolution has been optimized to best represent the target lithology, ranging from 10m (surface layers) to 60m away from the impact site.

The target rocks of both the Ries and Steinheim craters consisted of a ~620m and ~1180m thick layered sequence of Tertiary and Mesozoic sedimentary rocks (limestone, shale, sandstone) respectively, resting on Hercynian crystalline rocks (gneisses, granite, metabasites) [9]. Tertiary sand, clay, and freshwater limestone on top of Upper Malmian limestone formed a discontinuous layer at the pre-impact surface (0–50 m thick) [9]. We have modeled the target as a 600m thick sedimentary layer divided as follow [6,7]: 40m of quartzite (30% porosity) to model the uppermost Tertiary sands; 140m of calcite (no porosity) to model the Malmian limestone; 420m of quartzite (20% porosity) to model the Jurassic/Triassic sands and shales. The crystalline basement is modeled as non-porous granite.

Model Results: For each simulation we estimated the amount of melting of the various layers modeled, including the crystalline basement. The simulations results show maximum melt production for a 20 km/s, 30° impact. The decrease in projectile size eventually counteracts the increase in impact velocity by focusing the impact energy on a smaller region (decreasing the projectile's footprint). Regardless of impact velocity, however, 30° is the most favorable angle for maximizing near surface melting.

In modeling the formation and distribution of tektites, we find that the most favorable conditions for tektite production occur for impact angles between 30° and 45°, at least for an impact velocity of 20 km/s. A large amount of cm-size particles are distributed in a narrow-angle fan at distances of 200 to 400 km from the Ries. The modeling results account also for the asymmetric distribution of coherent melt lumps observed only at the eastern crater rim.

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