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Simulation of trajectories and maximum reach of distal impact ejecta under terrestrial conditions: consequences for the Ries crater, southern Germany

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The 14.4 Ma [1] Ries crater in southern Germany is unique as to the state of preservation of its ejecta conserved as a contiguous blanket surrounding mainly the southern part of the crater. In chronological order Ries impact ejecta are subdivided as follows: 1) Ries tektites 2) "Bunte Breccie", 3) "Kristallinbreccie" 4) "Suevite" and 5) "Reutersche Blöcke" or "Ries-Brockhorizont" (RB blocks). The RB blocks are isolated boulders or layers of mainly Upper Jurassic limestones distributed within the middle to late Miocene Obere Süßwassermolasse of the North Alpine foreland basin and considered as distal ejecta [2]. In places the distance to the crater rim surpasses 100 km. Upper Jurassic limestone components have been described from northern Switzerland [3] even occurring at a distance of almost 200 km from the Ries crater rim alleging genetic relation to the Ries event. It is our purpose to discuss whether translation of such blocks may result from an event such as the Ries impact.

Criteria against a genetic relation of the "Ries-Brockhorizonte" with the Ries event are listed in the following: 1) stratigraphic distribution of RB components within the Obere Süßwassermolasse is at random and beyond present means of microstratigraphic resolution. Some components are regarded as autochthonous, others are considered reworked into two or even three horizons; 2) in underlying sediments no indentations have been reported pointing to secondary craters [2]; 3) RB components delineate a longitudinal rather than a radial distribution pattern; 4) the distribution of RB components does not reflect an oblique impact direction from the WSW confirmed by the existence of an ENE-directed fan of distal ejecta; 5) boulders do not show marks of non-tectonic stress or thermal overprint caused by impact loading. One single component showing shattercones was reported [3].

Our strategy to resolve this problem is to simulate ejecta trajectories under a variety of physical conditions that could have existed during the Ries impact. Our simulation includes the following assumptions and variables: 1) boulders are ejected from the interference zone at a very early stage of impact; 2) starting conditions may range between velocities of 1 and 3 km/s and 35˚ to 65˚ for the flight path angle; 3) vacuum and transitional conditions at the impact site are incorporated into the density model of the atmosphere; 4) a typical boulder is represented by an adequate aerodynamic drag model; 5) an aerothermal heat model was used to determine heat load.

The Institute of Space Systems at Stuttgart University has been developing the software REENT6D [4] to simulate the ascent flight and the flight path of space vehicles reentering Earth's atmosphere. The program is sufficiently accurate to serve as a basis for ejecta trajectory simulation. It allows simulation of high altitude flight paths and high flight loads and thus offers a large array of variable starting conditions. Flight path is influenced by 1) starting conditions: flight path angle γ_0(35˚ to 65˚) and flight path velocity v_0 (1 to 3 km/s), 2) atmospheric parameters [5]: range of the zone of vacuum conditions r_1, and of the transition zone r_2. In multiple series of simulations we varied all mentioned parameters. Under the most likely assumptions the RB components will fly between 40 km and 130 km. In all simulations the maximum flight altitude stays below 100 km; in the more realistic case it is below 65 km.

Our results are: 1. With the most likely maximum starting velocity of 2 km/s a limestone boulder may cover distances of up to 110 km. However, this velocity is not sufficient to eject the RB components over a distance of 200 km, even in the case that all variables were set into unlikely dimensions. Ballistic transport over distances of 200 km and more require a minimum starting velocity of 3 – 4 km/s. We conclude that the Brockhorizont in Northern Switzerland situated at about 200 km from the crater rim is probably not related to the Ries impact event. 2. Limestone boulders known as "Reutersche Blöcke" ($<$70 km from Ries crater rim) fall within the reference conditions of our simulations and thus are distal Ries ejecta indeed. Boulders deposited at distances $<$110 km can be considered as distal Ries ejecta if parameters are stretched towards less likely values. 3. Limestone components accelerated to a starting velocity of 2 km/s and translated to distances $<$110 km are not likely to show marks of non-tectonic mechanical stress or thermal overprint.

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