FACTS, THEORIES AND FURTHER QUESTIONS AROUND THE RIES-STEINHEIM SIMULTANEOUS IMPACT EVENT: A REVIEW. K. Mihályi[1], A. Gucsik[2,3], J. Szabó[1], Sz. Bérczi[4]. [1]University of Debrecen, Department of Physical Geography and Geoinformatics, H-4032 Debrecen, Egyetem tér 1., Hungary, P.O. box 9., email: k.mihalyi@freemail.hu; [2]Max Planck Institute for Chemistry, Department of Geochemistry, D-55020 Mainz, Germany; [3]Savaria University Center, University of West of Hungary, Károlyi Gáspár tér 4., H-9700, Szombathely, Hungary; [4]Eötvös University, Faculty of Science, Institute of Physics, Department of Materials Physics, H-1117 Budapest, Pázmány Péter sétány 1/a, Hungary

Introduction: Nördlingen-Ries impact structure (Germany, Bavaria) is one of the best known terrestrial impact structures. Steinheim meteorite crater (often called Steinheim-basin) is located ~40 km from Ries, in the southwestern direction. Diameter of Ries is about 24 km, Steinheim is about 3.8 km. Their age is the same: 15.1 million years [1,2], which is a key-point for these two impact forms: it is strongly suggested not only the occurrence of simultaneous (or nearly simultaneous) impact, but also some kind of relationship between parental meteorites of these two craters (because chance of simultaneous impact of two meteorites in such a small area, without any linking or relationship between them, is very low). Simultaneous, double-impact origin for these two craters is accepted since the early 1960's [1].

General geology of the impact site: Ries and Steinheim impact craters are well investigated complex structures with central uplift (Steinheim) and inner ring (Ries) structures. Pre-impact stratigraphy consists of sedimentary layers for both structures: Tertiary sand, clay, and freshwater limestone on top of Upper Malmian limestone formed a discontinuous layer at the pre-impact surface, in a thickness of 0-50 m. This unit is underlained by ~600-1200 m thick Tertiary and Mesozoic sedimentary rocks (limestone, shale, sandstone), underlain by Hercynian crystalline rocks [1,3].

Post-impact sedimentary: both Ries and Steinheim structures are covered and partially filled with lacustrine sediments (30-50 meters in thickness), as results of post-impact crater lakes [1,6].

Impact breccias: Ries is famous for its characteristic breccia-types (Bunte-breccia and suevit-breccia), which were taken over the international nomenclature.

Moldavite-tektites (as remnants of distal ejecta): according to Ries impact event, tektite-glasses can be found NE from Ries crater, up to a maximum distance of 350-400 km (e.g. in Moldavia), forming a fan, opening in an angle of ~40-50°, branching out from the crater in the northeastern direction (as meteorite arrived from southwestern direction). Geochemical investigations infered that tektites were formed and dropped out by melting of the upper layers (upper 40-50 m) of impact site by impact energy [1,3,5]. Setting of tektites implies an impact angle of 30-50° for Ries event. However, Steinheim structure hasn't such well preserved distal ejecta remnants, but assuming some kind of linking between meteorites formed Ries and Steinheim (as mentioned above), angle and direction of impact must be similar to Ries. Stöffler et al. [1] found 30-45° for ideal impact angle to produce Ries-type tektite (moldavite) strewn-field.

Binary asteroid or broken-up asteroid? Speaking about 'some kind' of relationship between impacting meteorites during double-impact, there are two possible ways: (1) the asteroids were formed separately, but later the smaller became satellite-asteroid of the bigger one, captured by gravitational forces. (2) the other way to form a crater-doublet (or crater field with more than two craters), when a meteorite breaks up during atmospheric entry, because of the increasing drag of atmosphere. This break-up may be related to lines or zones of weakness/instabilities within the meteorite.

Simulations, modelings: as Stöffler et al. [1] presumed, the asteroid breakup occurred at an altitude of about 50 km from surface. In their modeling, initial speed of entry was varied between 11.2-20 km/s, entry angle between 10-60°. They found, that two pieces of a broken-up meteorite couldn't have been diverged from each other until impact, to form the distance of ~40 km between the two craters. In their opinion the binary-asteriod model would be right, with ~1.5 (Ries impactor) and 0.15 km (Steinheim impactor) diameters, arriving from southwestern direction. Pierazzo et al. found similar results for the size of Ries impactor, using hydrocode modeling [3]. Furthermore, SALEB Eulerian hydrocode simulations [4] suggests a minimum diameter of 4-4.2 km for Steinheim-basin and about 50 meters of erosion in the last 15 million years.

Geochemical investigations for shock-wave distribution: Micro-Raman spectroscopical studies for shocked zircon samples from Ries crater [4] implies the possibilty of antisymmetric shock-wave distribution during impact, which is probably caused by impact angle and layered sediments of the impact site (shock-wave refractions/reflections and interferences caused by layer boundaries).

Possible environmental effects of Ries-Steinheim impact event: impact energy, released during such a big impact process as Ries-Steinheim event, devasting all kind of lifeforms at impact site and in the surrounding area by thermal radiation, fireball extended in tens of kilometers, fallback ejecta (as secondary impacts, which can cause widespread wildfires in hundreds of kilometers distance), fallback ash cover, hurricane force winds mixed with rock debris, regionally modified climate, increased acidity, etc [7]. But in a longer period of time, benefits can be occurred for some adaptable species and taxa (e.g. fern taxa pike after cretaceous-tertiary Chicxulub impact event and according mass extinction) [7], in a way of new succession, by such features and processes as: extinction of previously dominant species; changed environmental features (brecciation and mineral accumulation according to post-impact hydrothermal activity; new soils; crater lakes and lacustrine sediments; changed landscape morphology, etc.) [7].

Further questions: although Ries and Steinheim are well investigated craters, there are questions too, e.g. what happened between the two craters? – Heavy shock-waves in target rocks (generated by both Steinheim and Ries impacts) maybe was not able to reach and ‘collide’ when they spread in front of each others. – But what about ejecta-blankets? Previous studies discussed Ries ejecta emplacement [8,9] focusing on discontinuous/distal ejecta blanket remnants (moldavite strewn-fields) and/or continuous/proximal ejecta blanket remnants, can be found south- and northeastern to the rims of Ries. The results suggest that main mass of Ries ejecta was dropped out in northeastern direction, as the impactor came from southwestern direction (Fig. 1.), and only a little mass of ejecta was dropped in southwestern direction. Similar modelings and field-studies for Steinheim are missing, hence there is unknown, if ejecta blankets of the two impact events were able to collided/stratified/mixed or not (*b*, and *c*, on Fig. 1.)? The other important question is whether the soils, which were developed on the impactites such as Bunte breccia and suevite, could provide higher nutrient supply for plants and microorganizms than the regular soils in the surrounding area of the imapct structures.

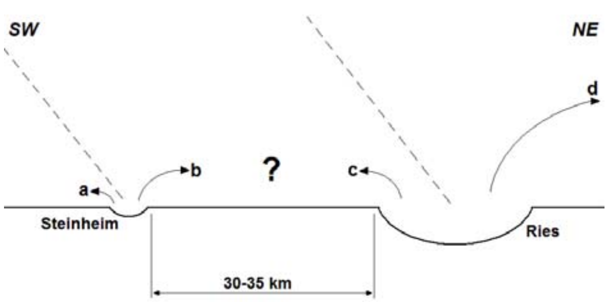

Figure 1. *Simplified SW-NE sketch for impact angles and presumed impact ejecta emplacement. Keys: grey dashed line is presumed angle of impact (~40-50°, as mentioned above);* ***a*** *– presumed flight direction for smaller mass of Steinheim impact ejecta;* ***b*** *– presumed flight direction for larger mass of Steinheim impact ejecta (presumptions based on Ries analogues).* ***c*** *– presumed flight direction for smaller mass of Ries impact ejecta;* ***d*** *– presumed flight direction for larger mass of Ries impact ejecta (containing moldavites). Question-mark shows the locality, where b, and c, ejecta masses would be probably able to collide. Note: figure does not correspond to sizes and distances.*

Conclusion: studying probable impact ejecta mixing and/or stratification between ‘forvard’ dropped Steinheim ejecta and ‘backvard’ dropped Ries ejecta (*b*, and *c*, on Fig. 1.) (if even happened collision or any kind of ejecta-overlapping), would provide aid to determine, which impact happened previous to the other one. In the near future, we plan to establish an international research team between Germany and Hungary emphasizing the organization of field trips (yielding geological and soil samples for the lab work), and simulation software for the reconstruction of the Ries impact event. It is also planned to perform a complex paleoecological research project of this area.

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