METEORITIC MATTER ON FRACTURE SURFACES OF SHOCKED FOSSILS (SHATTERED BELEMNITES) FROM THE NÖRDLIGER RIES IMPACT STRUCTURE, SOUTHERN GERMANY

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Introduction: The ~24 km Nördlinger Ries, e.g., [1] and the ~3.8 km in diameter Steinheim Basin, e.g., [2] impact craters are situated on the Upper Jurassic limestone plateau of the Swabian-Franconian Alb in southern Germany. Both impact structures are thought to have formed simultaneously some 14.8 Ma ago [3] by the impact of a binary asteroid [4]. The Nördlinger Ries impact crater is unique in terms of the state of preservation of the crater shape and its impact ejecta blanket. The Ries (and the Steinheim Basin) craters count among the best studied impact structures on Earth with respect to crater forming processes, and the evolution and distribution of impact ejecta. In contrast, little is known about the character of the projectiles that formed the Ries and Steinheim craters [1].

On the surfaces of shatter cones from the Steinheim Basin, [5] described an exotic mineralization that might represent meteoritic matter from the Steinheim impactor – possibly an iron meteorite [2] – that was remobilized during impact-induced hydrothermal activity. Motivated by this study, we here investigate the fracture surfaces of some shattered belemnites (Fig. 1) from an Upper Jurassic limestone block that is part of the eastern morphological carter rim of the Ries impact structure in search of possible remnants of the Ries meteorite.

The Ries-Steinheim projectiles – a brief review: A first search for impactor signatures in Ries impactites on PGEs, Ni, and Cr was carried out by [6]. Their data may be interpreted assuming an achondritic impactor (aubrite?). [7] found high concentrations of Ir, Co, Ni, and Cr in the top layer of the crater suevite of the FBN73 Ries research drill core, with element pattern that best match aubrites. Previously, [8] found Fe-Cr-Ni-Co veinlets in basement rocks of FBN73 and stated that the veinlets were produced by condensation of a vaporized chondrite (carbonaceous chondrite?). [5] reported exotic mineral coatings on shatter cone surfaces of the Steinheim Basin. The elements enriched suggest a general affinity towards an iron meteoritic source. This is in agreement with Fe-Ni-Co sulfides and Fe-Ni-droplets associated with the Steinheim melt lithologies suggesting an iron meteoritic impactor [2].

Samples and analytical techniques: Shattered belemnites were collected in the old quarry of Gosheim (48°49’58” N 10°43’29”), in rocks forming the “Kalvarienberg” hill at the eastern morphological crater rim of the Nördlinger Ries crater. The overturned and steeply westward-dipping blocks consists of partially deformed and slightly to intensely brecciated Upper Jurassic limestones.

The internal skeletons (rostra) of belemnites are solid and usually bullet-shaped structures. Due to their stable calcitic constitution, the rostra are mostly the only remains of the animals preserved. Shattered belemnites are commonly fragmented and microfaulted into mm- to cm-sized slices arranged in an *en échelon* pattern (Fig. 1). The macroscopic shock features are thought to form by the interference of shock waves at low-level shock pressures (~0-2 GPa), corresponding to the occurrence of the shocked belemnites in slightly or intensely brecciated limestones.

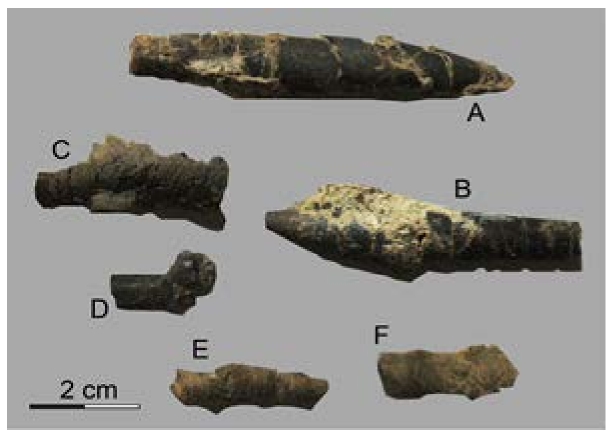

Fig. 1: Shocked (shattered) belemnites from Ries target rocks (Upper Jurassic limestones) investigated in the present study.

Geochemical analyses on the belemnite fracture surfaces were carried out using a CamScan SC44 scanning electron microscope (SEM) coupled with an EDAX PV 9723/10 system, at a beam current of 70 nA and an acceleration voltage of 20 kV. Imaging was done in secondary electron and backscattered electron mode.

Observations: On shattered belemnites, we discovered metallic veinlets, metallic and silicate spherules, as well as metal-rich flakes of exotic mineral composition. The occurrence of these features is restricted to the fracture surfaces. Metallic veinlets (up to 100 µm; Fig. 2) have geochemical compositions within narrow limits. Six of the larger veinlets were analyzed;

they mainly consist of FeO_2 (68.38-72.91 wt%), NiO (12.52–18.83 wt%), CrO (10.60–11.13 wt%), and CoO (1.20–1.99 wt%), with minor SiO_2 and CaO. The Ni/Co ratio is ~10, the Ni/Cr ratio ~1.5, and the Fe/Ni ratio ~5. Most of the spherules on the belemnite fracture surfaces belong to two spherule populations. The first type (Fig. 2) is closely related to the Fe-Ni-Cr-Co veinlets and essentially features similar composition and similar element ratios (Fig. 3). The second spherule population is represented by silicate spherules with high Ca content. This type of spherules also contains significant amounts of Fe, Ni, Co, and Cr with a Ni/Co ratio of ~10 and a Fe/Ni ratio of ~4. Exotic Cu- and Au-rich particles with minor Fe, Ni, Co, and Cr also occur on fracture surfaces of the Ries belemnites.

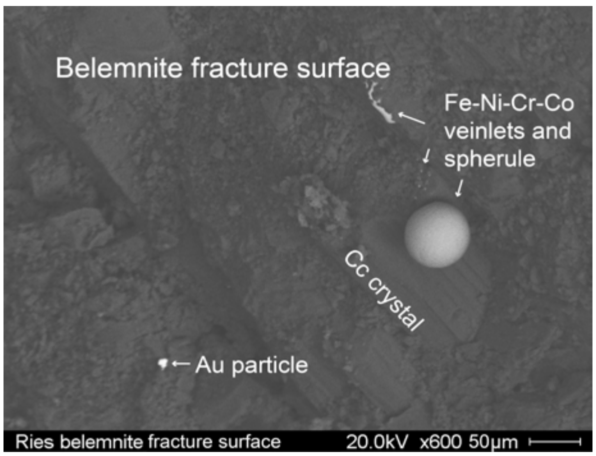

Fig. 2: Fe-Ni-Cr-Co veinlets and spherule and Au rich particle on a fracture surface of a shattered Ries belemnite.

Discussion and Conclusions: [8] reported on basement rocks of FBN73 near the crater center that contain Fe-Ni-Cr-Co (and minor Si-Ca) veinlets of apparent meteoritic origin that are strikingly similar in composition to the metallic veinlets and spherules discovered in this study. The only difference is the higher amount of Ni and Co in our samples. The Ni/Co ratio of ~20 in the basement rock veinlets of [8] is chondritic and the overall Cr content is high. [8] concluded that the metallic particles were condensed from the iron-rich portion of a stony meteorite, with enrichment of chromium due to condensation concentration, concluding that the impacting body of the Ries crater was likely a chondrite (carbonaceous chondrite). Although the Cr content is also high in our samples, the Ni/Co ratio of ~10 is rather iron meteoritic [9] and the Fe/Ni ratio of ~5 is characteristic for kamacite-taenite [9]. As a result, the Fe-Ni-Cr-Co particles may be interpreted as a product of the vaporized projectile that was composed of variable amounts of kamacite and taenite, chromite, and a minor silicate component.

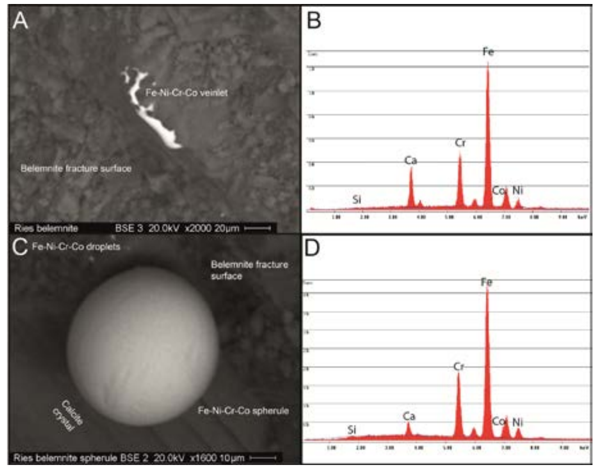

Fig. 3: Fe-Ni-Cr-Co veinlets and spherules on fracture surfaces of belemnites feature essentailly similar composition.

Most of the spherules discovered in our study geochemically resemble the Fe-Ni-Cr-Co veinlets and could be also interpreted as the melted remains of the largely vaporized Ries projectile. The second type of Ca-rich silicate spherules may be interpreted as a mixture of the vaporized uppermost sedimentary target rocks and the projectile.

Exotic Cu- and Au-rich (sulfide) particles on belemnite fracture surfaces are very variable in composition. [10] reported on similar multiphase Fe-Cu-Ni sulfide particles in assemblage with Fe-Ni-Cr-Co metal veinlets from basement rocks of the Rochechouart impact crater, France. This might suggest a similar meteorite type responsible for the Ries and Rochechouart impact events. [11] proposed an non-magmatic iron meteorite as Rochechouart projectile based on the interelement ratios of PGEs, Ni and Cr. For the iron meteoritic Ni/Co and Fe/Ni ratios of the metallic veinlets (and spherules) in our samples and the further reasons discussed here, one might consider an iron (or stony-iron) meteorite as the most likely Ries impactor, but we cannot exclude a chondritic or achondritic meteorite on the basis of our geochemical data.

References:[1] Stöffler et al. (2013) *Meteoritics & Planet. Sci., 48*, 515-589. [2] Buchner and Schmieder (2010) *Meteoritics & Planet. Sci., 45*, 1093-1107. [3] Buchner et al. (2013) *ZDGG 163*, 433-445. [4] Stöffler et al. (2002) *Meteoritics & Planet. Sci., 45*, 1893-1907. [5] Buchner and Schmieder (2015) *78th Meeting Met. Soc., Abstract* #5007. [6] Morgan et al. (1979) *GCA, 43*, 803–815 [7] Schmidt and Pernicka (1994) *GCA, 58*, 5083–5090 [8] El Goresy and Chao (1976) *EPSL, 31*, 330-340 [9] Wasson and Hoppe (2012) *GCA, 84*, 508-524. [10] Horn and El Goresy (1980) *Lunar Planet Sci. XI*, 468-470 [11] Tagle et al. (2003) *Lunar Planet Sci., XXXIV*: Abstract #1835.