THE METEORITE FROM STEINHEIM, SW GERMANY: PROBABLY A PALLASITE.

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Introduction: The Miocene ~3.8 km in diameter Steinheim impact structure (SW Germany), featuring a prominent central uplift, exposes Middle to Upper Jurassic sedimentary rocks and is known for its well-developed shatter cones [1]. Shatter cones mainly formed in Upper Jurassic limestone [e.g., 1,2]. Recently, the find of a metal fragment trapped in a fracture within a shatter-coned limestone block from this impact structure was reported by Buchner et al. [3], and interpreted to represent a possible remnant of the Steinheim impactor.

Sample and Sample Locality: A ~1 m-size limestone block with shatter cones, which is stored at the Meteorkrater-Museum Steinheim [1], was investigated. Although the exact provenance of this block of Upper Jurassic (Kimmeridgian-Tithonian; *ca.* 150 Ma) limestone is undocumented, it likely stems from a limestone clod in the eastern crater rim domain. The block exhibited a prominent (once healed) fracture, along which a loose piece of the limestone block was removed for safety reasons. In this fracture, a ~2 cm-long, light to dark gray fragment of metallic luster became visible. More details about the finding situation are provided by Buchner et al. [3].

Analytical Methods: The metallic fragment was first analyzed by scanning electron microscopy (SEM) – energy dispersive X-ray spectroscopy (EDS) and electron probe microanalysis (EPMA) on raw sample material and polished thick sections at the University of Stuttgart, Germany, and then by EPMA at the Natural History Museum, Vienna, Austria. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) spot analyses were conducted at GEOMAR, Kiel, Germany, on the same material. Bulk chemical ICP-MS analyses were carried out on a solution made of a 180 µg particle of light metallic matter at the Institute of Mineralogy, University of Stuttgart. Ultra-high sensitivity noble gas mass spectrometry to obtain cosmic-ray exposure ages of the meteorite fragment is currently being carried out at the ETH Zurich, Switzerland.

Results: Compositionally, the metallic fragment can be subdivided into two portions: 1. A light gray domain of metallic luster, predominantly composed of kamacite, taenite, tetrataenite, and schreibersite. This material has elevated Ga, Ge, and platinum group element (PGE) concentrations. 2. A dark gray, nonlustrous domain, mainly composed of Fe and S. This domain contains brecciated fragments of troilite, surrounded by Fe-rich oxide phases with variable S. Nickel, Co, Ga, Ge, and PGE are enriched, but less abundant than in the light gray metallic phase. Recent EPMA conducted in Vienna also yielded kamacite, taenite, troilite, and two undetermined iron oxide phases (i.e., alteration products), as well as rare small schreibersite crystals. Locally, due to preferential alteration, a Widmanstätten pattern is visible. Moreover, a crystal of olivine (140 x 330 µm in size) with a composition of $Fa_{11.4}$ was found.

Discussion: The light gray portion of the metallic fragment contains minerals characteristic for various types of meteorites. The bulk chemical composition suggests this material represents a portion of an iron or stony-iron meteorite. Platinum group element concentrations are elevated, and internal PGE ratios are meteoritic. Gallium (~40 ppm), Ge (~80 ppm), and PGE concentrations in kamacite match those of IIIAB iron and stony-iron meteorites [4]. The dark gray portion with brecciated troilite and a groundmass of highly variable Fe/S phases can be interpreted as (partially) altered troilite. The olivine crystal has a composition typical for olivine in main group pallasites [5]. Although olivine typically occurs in other types of meteorites (i.e., rarely as inclusion in iron meteorites), its chemical composition, together with the Ga, Ge, and PGE concentrations in kamacite, suggest the metal fragment in the limestone fracture is most likely a pallasite. Two possible scenarios for the origin of the meteorite fragment are currently discussed: 1) The fragment was injected into an open fracture in the limestone target rocks of the crater floor during the Steinheim impact event some ~14.8 Myr ago, and is, thus, a fragment of the Steinheim projectile; 2) The fragment is a fossil meteorite that had fallen much earlier, in Late Jurassic times, and was then embedded into the ~150 Ma old Kimmeridgian/Tithonian marine limestones. Cosmic-ray exposure ages of the meteorite fragment may help to discriminate between the two possible scenarios.

References: [1] Heizmann, E. P. J. and Reiff, W. (2002) Der Steinheimer Meteorkrater. 160 pp. [2] Schmieder, M. and Buchner, E. (2013) *ZDGG* 164:503–513. [3] Buchner, E. et al. 2017. *Meteoritics Planet. Sci.* S52:6014. [4] Wasson, J. T. (1985) Meteorites. 267 pp. [5] Buseck, P. R. (1977) *Geochim. Cosmochim. Acta* 41:711–740.