HOW OLD IS THE STEINHEIM IMPACT CRATER (GERMANY)?

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Introduction: The ~4 km-diameter, Mid-Miocene Steinheim Basin on the karstic Swabian Alb plateau of SW Germany is a well-preserved complex impact crater with a prominent central uplift. The impact crater, known for its shatter cones, is set in a sequence of Mesozoic sediments and lies some 40 km SW of the ~24 km-diameter Nördlinger Ries [1]. While geochronologic studies of impact melt samples from the Ries crater (tektites) yielded a high-precision Mid-Miocene (Langhian) Ar-Ar age of 14.81 Ma [2], several attempts to date the Steinheim impact using isotopic techniques failed to produce a meaningful geologic age. This is partly due to the fact that, in contrast to the Ries, impact melt lithologies at Steinheim are rather scarce and, if present, mainly of carbonatic composition [3] or intensely altered to sheet silicates [4]. An Ar-Ar study of a pebble of fluidal, partially melted sandstone found at the Steinheim central uplift [4] produced disturbed age spectra without any representative age signal. (U-Th/He) dating of zircon crystals from the central uplift yielded partially reset (Moldanubian?) ages between ~282 and 247 Ma [5].

The double impact theory: The general notion that the Ries and Steinheim craters must have been produced simultaneously by the impact of a binary asteroid [6,7] is, after all, mainly based on the assumption that two closely spaced asteroid impacts around the same time are (higly) unlikely to occur at random [8]. However, as shown for other suspected terrestrial impact crater pairs, such as the East and West Clearwater Lake impact structures in Canada [9] and the Suvasvesi North and South impact structures in Finland [10], 'false' impact crater doublets do exist on Earth. In such cases, misleading underlying theories can compromise an independent assessment of impact ages [11].

Biostratigraphic constraints: The most promising solution is offered by biostratigraphic constraints on the formation of the Ries and Steinheim impact structures and their respective crater lake deposits. One would assume both crater depressions filled up with freshwater soon after their formation, as expected in a deeply water-saturated, karstified paleolandscape with a high Mid-Miocene groundwater level [12]. Water saturation is, in fact, well demonstrated by aragonitic spring mound deposits (the '*Wäldlesfels*') sitting on top of the Steinheim central uplift [1]. Likewise, the pervasive alteration of impact melt lithologies in the crater-filling impact breccia suggests the fresh Steinheim crater may have hosted a short-lived hydrothermal system [4]. For these reasons, we argue the basal crater lake sediments at Steinheim more or less accurately reflect the timing of the impact. While the Mid-Miocene paleofauna at the Ries crater lake has been assigned to the Mammal Neogene (MN) zone MN 6 (type locality: Sansan, France) [13], with a coarse-grained Ries ejecta horizon in the North Alpine Foreland Basin sitting at a stratigraphic level close to the MN 5/6 transition [14,15], Steinheim is known as a type locality for the somewhat younger MN 7 paleofauna [1,13,16]. The basal lake sediments at Steinheim (the so-called *kleini*, *steinheimensis*, and *sulcatus* beds, named after the gastropod *Gyraulus*) represent the upper MN 6 biozone (Langhian) and are overlain by younger lake sediments (the *trochiformis*, *oxystoma*, *revertens*, and *supremus* beds) that belong to MN 7 (Langhian and Serravallian) [15,17]. In other words, the oldest, basal crater lake sediments at the Nördlinger Ries and Steinheim are separated by approximately one entire mammal biozone.

Discussion and conclusions: From a biostratigraphic point of view, the Steinheim impact appears to postdate the Ries event by several kyr (and potentially ~1 Myr) [1,13]. While the Ries impact has a precise mid-Langhian Ar-Ar age of ~14.81 Ma [2], the current best-estimate age for the Steinheim impact is derived entirely from biostratigraphic constraints. Taking into account stratigraphic correlation and recent geochronologic results for the Langhian/Serravallian boundary (~13.8 Ma [18]), a late Langhian Steinheim impact scenario between ~14.3 and 14.0 Ma appears most plausible. We, moreover, note the Ries and Steinheim impacts correlate well, biostratigraphically, with two spectacular continental seismite horizons in Molasse deposits of the North Alpine Foreland Basin [19]. It remains unclear at this point whether the two impacts are causally related to faunal turnover events in European land mammals at the MN 5/6 (within uncertainty Ries-age) and MN 6/7 (approximately Steinheim-age) transitions [20,21].

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