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A high-precision $^{40}Ar/^{39}Ar$ age for the Nördlinger Ries impact crater, Germany, and implications for the accurate dating of terrestrial impact events

Martin Schmieder [a,b,c,*], Trudi Kennedy [c], Fred Jourdan [c], Elmar Buchner [d,e], Wolf Uwe Reimold [f,g,h]

[a] *Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058, USA*
[b] *NASA – Solar System Exploration Research Virtual Institute (SSERVI), USA*
[c] *Western Australian Argon Isotope Facility, Department of Applied Geology and John de Laeter Centre for Isotope Research, Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia*
[d] *HNU – Neu-Ulm University, Wileystraße 1, D-89231 Neu-Ulm, Germany*
[e] *Institut für Mineralogie und Kristallchemie, Universität Stuttgart, Azenbergstraße 18, D-70174 Stuttgart, Germany*
[f] *Museum für Naturkunde – Leibniz Institute for Evolution and Biodiversity Science, Invalidenstrasse 43, D-10115 Berlin, Germany*
[g] *Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany*
[h] *Geochronology Laboratory, University of Brasília, Brasília, Brazil*

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Abstract

$^{40}Ar/^{39}Ar$ dating of specimens of moldavite, the formation of which is linked to the Ries impact in southern Germany, with a latest-generation ARGUS VI multi-collector mass spectrometer yielded three fully concordant plateau ages with a weighted mean age of 14.808 ± 0.021 Ma ($\pm$ 0.038 Ma including all external uncertainties; 2σ; MSWD = 0.40, $P = 0.67$). This new best-estimate age for the Nördlinger Ries is in general agreement with previous $^{40}Ar/^{39}Ar$ results for moldavites, but constitutes a significantly improved precision with respect to the formation age of the distal Ries-produced tektites. Separates of impact glass from proximal Ries ejecta (suevite glass from three different surface outcrops) and partially melted feldspar particles from impact melt rock of the SUBO 18 Enkingen drill core failed to produce meaningful ages. These glasses show evidence for excess ^{40}Ar introduction, which may have been incurred during interaction with hydrothermal fluids. Only partially reset $^{40}Ar/^{39}Ar$ ages could be determined for the feldspathic melt separates from the Enkingen core. The new $^{40}Ar/^{39}Ar$ results for the Ries impact structure constrain the duration of crater cooling, during the prevailing hydrothermal activity, to locally at least ~60 kyr. With respect to the dating of terrestrial impact events, this paper briefly discusses a number of potential issues and effects that may be the cause for seemingly precise, but on a kyr-scale inaccurate, impact ages.

Keywords: Ries crater; Impact melt; Tektites; Moldavites; $^{40}Ar/^{39}Ar$ dating; Hydrothermal alteration

1. INTRODUCTION

The ~24 km-diameter Nördlinger Ries impact structure, centered at 48°53′N/10°33′E in Southern Germany (Fig. 1; e.g., Shoemaker and Chao, 1961; Pohl et al., 1977; Hüttner and Schmidt-Kaler, 1999) is widely considered the best-

* Corresponding author at: Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058, USA.
E-mail address: schmieder@lpi.usra.edu (M. Schmieder).

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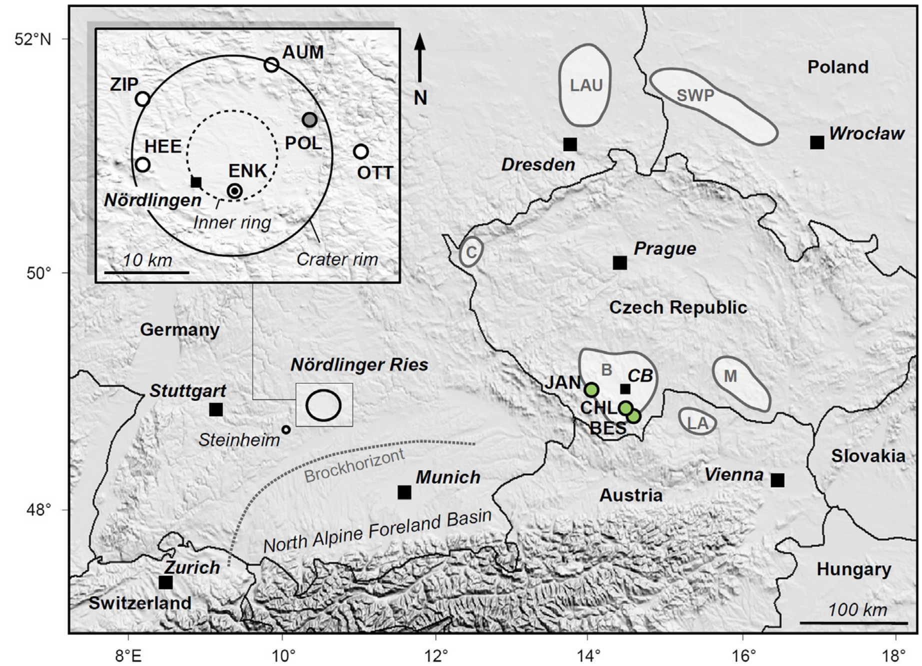

Fig. 1. Schematic map of parts of Central Europe with locations of the Ries crater (close-up in inset image in upper left), the Steinheim Basin, and distal impact ejecta. Sub-strewn fields (light gray areas) of the Central European tektite (moldavite) strewn field are: B – Bohemian strewn field; C – moldavites from the Cheb area; LA – Lower Austrian strewn field; LAU – Lusatia (Lausitz) strewn field; M – Moravian strewn field; and SWP – moldavites found in Southwest Poland; also note the 'Brockhorizont' associated with the Ries impact, with major occurrences of coarse-grained ejecta found in northeastern Switzerland and Southern Germany (gray dashed line). Major cities (black squares) are shown on the main and inset maps. Abbreviations for our sample localities (circles) and locations mentioned in the text: BES – Besednice; CHL – Chlum nad Malší; JAN – Jankov (green circle symbols in Bohemian moldavite strewn field); AUM – Aumühle (quarry); ENK – Enkingen (drill core); HEE – Heerhof; OTT – Otting (quarry); POL – Polsingen (sample of Buchner et al., 2010); ZIP – Zipplingen.

preserved complex impact structure on Earth. The Ries crater is characterized by a well-preserved, double-layer ejecta blanket that comprises the lithic Bunte Breccia derived mainly from weakly shocked sedimentary target rock, as well as the overlying Ries suevite that is mostly composed of weakly to intensely shocked, and impact-melted material derived from metamorphic crystalline Paleozoic (Variscan, Moldanubian) basement target rock (e.g., von Engelhardt et al., 1969; Hörz 1982; von Engelhardt et al., 1995; Stöffler et al., 2002, 2013; Kring, 2005). Ries impact melt lithologies predominantly occur in three different modes (e.g., Stöffler et al., 2013): Firstly, as (a) impact glass as constituent of the Ries suevite, which occurs both within the deeper, central moat of the crater, i.e., inside the crystalline inner ring, and which is covered by >300 m-thick post-impact crater lake sediments (e.g., sampled by the Nördlingen 1973 drill core), and (b) as surficial suevite near and outside the tectonic crater rim (e.g., exposed at the Aumühle quarry). Secondly, it occurs as larger lumps of altered, red-stained, impact melt rock that commonly also contains shocked and partially impact-melted clasts of crystalline target rock (e.g., at Polsingen; e.g., Buchner et al., 2010; Reimold et al., 2013); or in the SUBO 18 drill core from the south-central Ries near Enkingen, where melt-matrix breccia grades into suevite; e.g., Pohl et al., 2010; Reimold et al., 2011, 2013). Finally, impact melt occurs in the form of tektites (moldavites – the Central European tektites) distal to the Ries crater, which have been found in Bohemia and Moravia, Czech Republic (e.g., Stöffler et al., 2002; Trnka and Houzar, 2002; Di Vincenzo and Skála, 2009; Skála et al., 2009; and references therein), Saxony, Germany (Lusatia; e.g., Lange, 1996), Lower Austria (Koeberl et al., 1988), and, more recently, in Lower Silesia, Poland (e.g., Brachaniec et al., 2016), at radial distances of ~200–450 km east and northeast of the Ries crater (Fig. 1).

Radiogenic and fission track dating of the Ries impact structure dates back to the early 1960s (e.g., Gentner et al., 1961), i.e., the time soon after discovery of the impact origin of the Ries by Shoemaker and Chao (1961). Since then, a plethora of ages regarding the Ries impact has been accumulated (e.g., Buchner et al., 2010, 2013, and references therein). The recommended age for the Ries was, until recently, 14.83 ± 0.15 Ma (2σ; Jourdan et al., 2012), listing the $^{40}Ar/^{39}Ar$ moldavite age value of Di Vincenzo and Skála (2009) recalculated according to the K decay constants of Renne et al. (2010, 2011). A subsequent paper by Buchner et al. (2013) suggested a $^{40}Ar/^{39}Ar$ age of 14.74 ± 0.20 Ma (2σ; recalculated from Buchner et al., 2010, and references therein) for data from moldavites, suevite glass, and K-feldspathic melt aggregates. This value is in agreement within 2σ error with the recalculated $^{40}Ar/^{39}Ar$ age obtained by Di Vincenzo and Skála (2009). Finally, a recent argon dating study of suevite glass from the Ries by Schwarz and Lippolt (2014) suggested a