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New evidence for an old idea: Geochronological constraints for a paired metamorphic belt in the central European Variscides

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ABSTRACT

New geochronological data reveal a prolonged tectonothermal evolution of the Variscan Odenwald-Spessart basement, being part of the Mid-German Crystalline Zone in central Europe. We report the results from (i) secondary ion mass spectrometry (SIMS) U-Pb dating of zircon, rutile and monazite, (ii) SIMS zircon oxygen isotope analyses, (iii) laser ablation-multicollector-inductively coupled plasma mass spectrometry (LA-MC-ICPMS) zircon Lu-Hf isotope analyses and, (iv) LA-ICPMS zircon and rutile trace element data for a suite of metamorphic rocks (five amphibolite- and eclogite-facies mafic meta-igneous rocks and one granulite-facies paragneiss). The protoliths of the mafic rocks formed from juvenile as well as depleted mantle sources in distinct tectonic environments at different times. Magmatism took place at a divergent oceanic margin (possibly in a back-arc setting) at 460 Ma, in an intraoceanic basin at ca. 445 Ma and at a continental margin at 329 Ma. Regardless of lithology, zircon in eclogite, amphibolite and high-temperature paragneiss provide almost identical Carboniferous ages of 333.7 ± 4.1 Ma (eclogite), 329.1 ± 1.8 to 328.4 ± 8.9 Ma (amphibolite), and 334.0 ± 2.0 Ma (paragneiss), respectively. Rutile yielded ages of 328.6 ± 4.7 and 321.4 ± 7.0 Ma in eclogite and amphibolite, and monazite in high-temperature paragneiss grew at 330.1 ± 2.4 Ma (all ages are quoted at the 2σ level). The data constrain coeval high-pressure eclogite- and high-temperature granulite-facies metamorphism of the Odenwald-Spessart basement at ca. 330 Ma. Amphibolite-facies conditions were attained shortly afterwards. The lower plate eclogite formed in a fossil subduction zone and the upper plate high-temperature, low-pressure rocks are the remains of an eroded Carboniferous magmatic arc. The close proximity of tectonically juxtaposed units of such radically different metamorphic conditions and thermal gradients is characteristic for a paired metamorphic belt sensu Miyashiro (1961). Thus, the Odenwald-Spessart basement represents the first recognised paired metamorphic belt in the European Variscides.

1. Introduction and general tectonic setting of the Mid-German Crystalline Zone

For most of the Palaeozoic Gondwana was separated from the northern continents (Laurentia, Baltica, Siberia) by the intervening Iapetus and Rheic oceans. Towards the end of the Ordovician the Iapetus Ocean closed and Laurentia, Baltica and the microcontinent Avalonia, which had separated from the northern margin of West Gondwana in the late Neoproterozoic/early Palaeozoic (e.g., Nance and Linnemann, 2008; Stampfli et al., 2013) amalgamated to form Laurussia. Diachronous collision of Laurussia with Gondwana in the late Palaeozoic led to the closure of the Rheic Ocean and the assembly of the supercontinent Pangaea (e.g., Stampfli et al., 2013). The formation of the Appalachian-Variscan orogen in North America and Europe is related to that late Palaeozoic collision. The associated suture is referred to as the 'Rheic suture' and is thought to run from Mexico to Europe and beyond (e. g., Nance and Linnemann, 2008). In the European section of the orogen the suture extends from the Iberian Peninsula to NW France and Germany and further into SW Poland (e.g., Nance and Linnemann, 2008) and separates basement rocks with West African Craton or NE Gondwana affinities in the south from Baltica-derived terranes in the north (e.g., Henderson et al., 2016; Zeh and Gerdes, 2010). Some authors (e.g., Franke et al., 2017) proposed that the German segment of the Rheic suture is located at the northern outcrop limit of the Northern Phyllite Zone, whereas others (e.g., Linnemann et al., 2004; Oncken, 1997, 2000; Will et al., 2015, 2017; Zeh and Gerdes, 2010) argued that the suture is situated within the Mid-German Crystalline Zone (Fig. 1), the largest part of which is exposed in the Odenwald-Spessart basement (Fig. 2). Regardless of the exact position of the suture there seems to be a general consensus that the Mid-German Crystalline Zone is composed of rocks with different palaeogeographic affinities and thermal histories. Here, we focus on the

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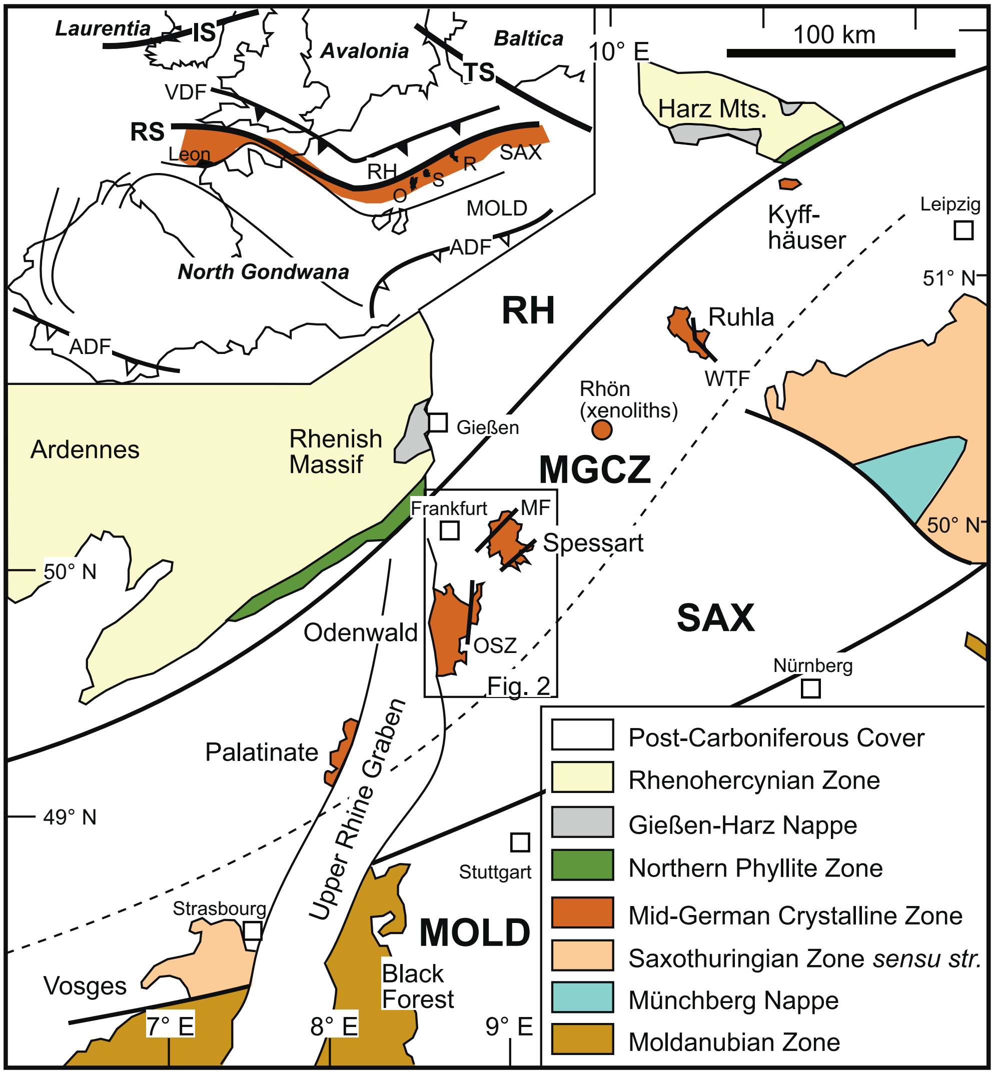

Fig. 1. Location of the Mid-German Crystalline Zone (MGCZ) in Central Europe (modified after Will et al., 2015). RH-Rhenohercynian Zone, SAX-Saxothuringian Zone, MOLD-Moldanubian Zone; only the exposed areas are shown on the map. Additional abbreviations in inset: IS-Iapetus Suture, TS-Tornquist Suture, RS-Rheic Suture; VDF-Variscan deformation front, ADF-Alpine deformation front; MF-Michelbach Fault, OSZ-Otzberg Shear Zone, WTF-West Thuringian Fault; O-Odenwald, S-Spessart, R-Rhön.

tectonothermal evolution of the Odenwald-Spessart basement, whose metamorphic conditions as well as the tectonic settings in which many basement rocks formed are reasonably well known (Will et al., 2015; Will and Schmädicke, 2001, 2003; Zeh and Will, 2010). However, except for a recent study by Will et al. (2017), who determined the age of monazite grains in low- to high-grade schist and gneiss by in-situ U-Th-Pb electron microprobe (EMP) dating, direct geochronological constraints on the age of metamorphism are sparse (see below).

Thus, with the aim of better constraining the age and tectonothermal evolution of the Odenwald-Spessart basement and its position within the central European Variscides we present geochronological data of zircon, rutile and monazite from one metasedimentary and five mafic meta-igneous samples determined by secondary ionization mass spectrometry (SIMS). In addition, we present zircon Lu-Hf and oxygen isotope data that were collected by SIMS and MC-ICP-MS (multi-collector laser ablation inductively coupled plasma mass spectrometry) techniques and zircon trace element data obtained by LA-ICP-MS. Zircon, rutile and monazite are particularly useful minerals for providing geochronological information on magmatic and metamorphic events because of their high closure temperatures (e.g., Cherniak and Watson, 2000; Heaman and Parrish, 1991; Vry and Baker, 2006) and/or because radiogenic Pb is believed to be retained in the minerals even under granulite-facies metamorphic conditions (e.g., Cherniak et al., 2004; Copeland et al., 1988; Taylor et al., 2016). Zircon in mafic rocks could be of igneous or metamorphic origin (e.g., Grimes et al., 2007, 2015; Bolhar et al., 2016). Thus, based on textural and geochemical criteria we attempt to clarify whether our zircon data specify an igneous or a metamorphic event. In contrast, rutile and monazite in our samples grew during metamorphism and, hence their (re-)crystallisation ages should closely constrain the time of metamorphism. Rutile, as a typical high-pressure mineral (e.g., Kylander-Clark et al., 2008; Li et al., 2011) may allow determining the age of high-pressure metamorphism and, monazite is a useful mineral to provide information on the timing of high-temperature metamorphism.

2. Regional geology

The geological setting of the Odenwald and Spessart basement areas has been described in detail by several authors (e.g., Nickel, 1975; Krohe, 1992, 1996; Weber, 1995; Stein, 2001; Zeh and Will, 2010; Okrusch et al., 2000, 2011; Will et al., 2017; and references therein) and is only outlined briefly. However, the mafic meta-igneous rocks, which are the main subject of the present investigation, are described in somewhat more detail. The results of previous geochronological studies are summarised in Fig. 3.