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Baltica- and Gondwana-derived sediments in the Mid-German Crystalline Rise (Central Europe): Implications for the closure of the Rheic ocean

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ABSTRACT

Combined U–Pb and Lu–Hf isotope analysis of detrital zircons reveals that the Mid-German Crystalline Rise (MGCR) contains Palaeozoic sediments of distinct provenance in close proximity. Zircons from a metapelite of the Brotterode group were derived from a Gondwanan source, whereas zircons from the Rögis quartzite of the Ruhla group point to provenance from Baltica. Brotterode zircons mostly yield ages of 500–720 Ma and 2.0–2.1 Ga, and show an age gap between 1.0 and 1.7 Ga, which is characteristic of Gondwana/peri-Gondwanan detrital zircon populations. Combined U–Pb and Hf isotope data suggest intense crustal recycling at 2.6–2.9 Ga, 1.8–2.1 Ga, and 570–720 Ma as well as formation of juvenile crust during the latter two periods. In contrast, zircons of the Rögis quartzite mostly yield ages between 0.9 and 1.8 Ga, which are typical of southwestern Baltica. Minor age populations at 435–466 and 550–660 Ma indicate that the quartzite is younger than Late Ordovician/Early Silurian, and that the Baltica-derived sediment is contaminated by minor peri-Gondwanan, perhaps Avalonia-derived detritus. Minor age populations at 2.0, 2.56, 2.67, and 2.86 Ga additionally point to a Svecofennian and/or Karelian source. U–Pb and Hf isotope data imply that the Baltica-derived zircons were produced mainly through melting of juvenile Palaeo- to Mesoproterozoic crust. The data presented here indicate that the MGCR hosts the Rheic suture between Gondwana and Balonia, and that this suture zone was closed in a complex sequence of stages from the Late Silurian onwards.

1. Introduction

The geology of Europe is highly complex, resulting from the collision of Africa, Baltica, Laurentia, and numerous Peri-Gondwanan related microterranes which lay in between (Fig. 1). During the Neoproterozoic most of these continents and microterranes were assembled into the Rodinia supercontinent, which finally broke up during the Early Cambrian (Nance et al., 1991). Dispersed continents and microterranes drifted towards the north, and were re-assembled during the Caledonian and Variscan orogenies. This process ceased with the closure of four oceanic basins, the Iapetus, Tornquist, Rheic, and Galicia-Massif Central-Moldanubian basin (e.g., Tait et al., 1997; Winchester et al., 2002). The Mid-German Crystalline Rise (MGCR), a NE–SW trending basement wedge in the Variscan collision zone, is thought to represent part of the Rheic suture, which was formed by final closure of the Rheic ocean during collision between the Avalonia microterranes (comprising Eastern Avalonia and Far Eastern Avalonia) with Cadomia/Saxo-Thuringia (e.g. Oncken, 1997; Franke, 2000; Winchester et al., 2002; Martin et al., 2003; Linnemann et al., 2007; Balintoni et al., 2009; Melleton et al., 2010) — (see Fig. 1a). Presently, this interpretation is highly speculative, since there is little unambiguous evidence about the provenance of the (meta)sediments in the MGCR, and about their depositional age (e.g. Reitz, 1987; Zeh et al., 2001, 2003, 2005). Furthermore, the existence of sediments with an Avalonian provenance in the MGCR is unconstrained. Thus, all geotectonic models which try to explain the evolution of the MGCR and its relation to the adjacent Rhenohercynian fold-and-thrust belt and Avalonia must be considered with great care (e.g. Franke 1989, 2000; Franke and Oncken, 1995; Zeh, 1996; Oncken, 1997; Zeh and Wunderlich, 2003). To set new constrains for the geotectonic evolution, we present new U–Pb and Lu–Hf isotope data, obtained from detrital zircon grains from different metasediments of the Ruhla Crystalline Complex as part of the MGCR. These data in concert with field relationships and existing age data provide the first clear evidence for the existence of a magmatic arc at the southeastern margin of the amalgamated Baltica + Avalonia continent (=Balonia; Torsvik et al., 1993) during the Silurian and Early Devonian. Furthermore, they require the destruction of this magmatic arc during formation of the Rhenohercynian basin in Devonian times, and its accretions to the MGCR during Variscan convergence, accompanied by a flip in the subduction polarity of the Rheic ocean between the Early Silurian and Early Carboniferous. A new model, which takes all these features into account, is presented.

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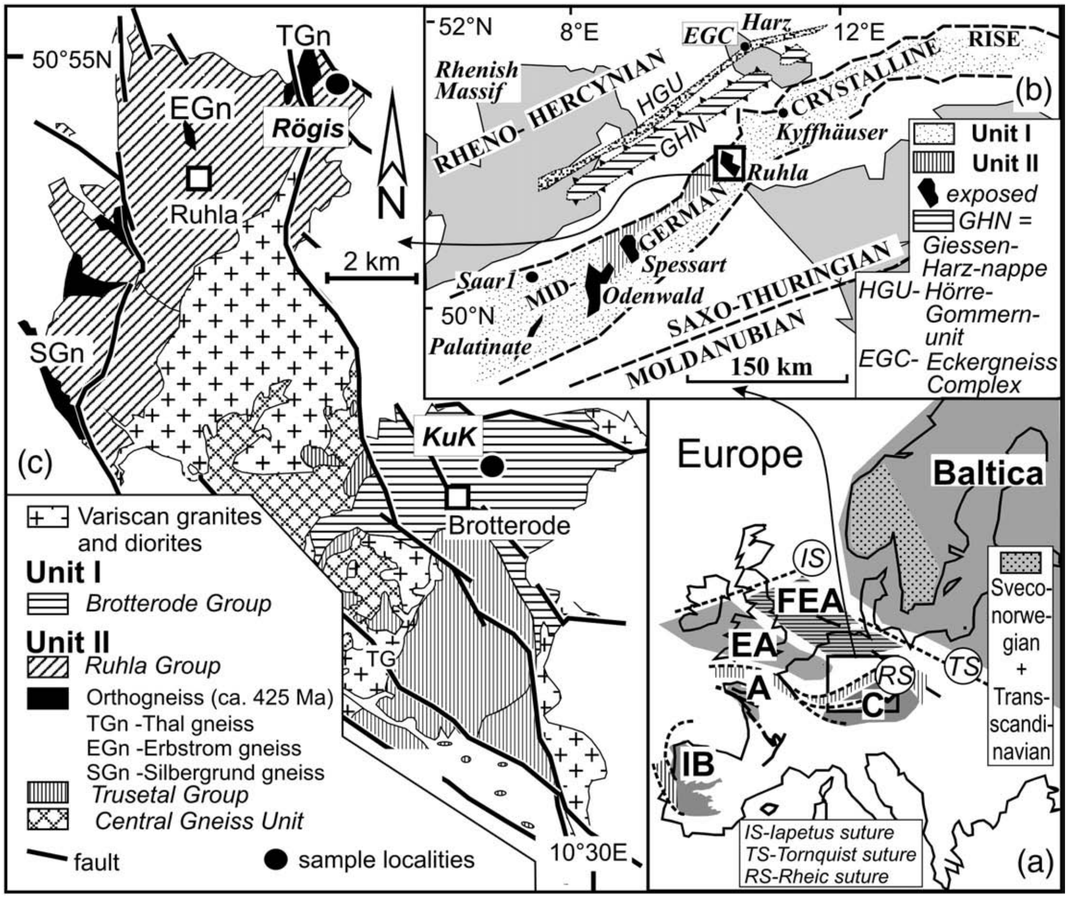

Fig. 1. (a) Distribution of Baltica and peri-Gondwanan terranes in Europe: C — Cadomia/Saxo-Thuringia, EA — Eastern Avalonia, FEA — Far Eastern Avalonia, A — Armorica, IB — Iberia. (b) Geological setting of the Mid-German Crystalline Rise and its surroundings. (c) Geological map of the Ruhla Crystalline Complex with sample localities.

2. Geological setting

The MGCR consists of medium- to high-grade metamorphic gneisses and granitic rocks, which separate the very low- to low-grade metasediments and volcanic rocks of the Northern Phyllite Belt and the Rhenohercynian domain in the north-west from the rocks of the Saxothuringian domain in the south-east (Fig. 1). Rocks related to the Rhenohercynian domain are assumed, so far, to have an Eastern Avalonia affinity, whereas the Saxothuringian domain forms part of Cadomia/Saxo-Thuringia (e.g., Linnemann et al., 2007; Kroner et al., 2007). In this context it should be emphasized that the microterrane Avalonia (comprising Western, Eastern, and Far Eastern Avalonia) and Cadomia/Saxo-Thuringia originally formed part of the Avalonian–Cadomian Belt, which was situated at the northern margin of Gondwana (=peri-Gondwana) during the Neoproterozoic (Nance et al., 2002; Linnemann et al., 2007). Subsequently, during the early Cambrian, the Avalonian–Cadomian Belt became dispersed, and the originally aligned terranes underwent different drift evolutions, associated with the opening of the Rheic ocean (Nance et al., 1991; Linnemann et al., 2007). While the Avalonia microterrane drifted to the north and amalgamated with Baltica and Laurentia in Ordovician/Silurian times, the Cadomia/Saxo-Thuringia terranes remained at or near to the northern margin of Gondwana until the Variscan orogeny (Linnemann et al., 2004; Kroner et al., 2007).

Investigations carried out over the last ten years indicate that the MGCR is not a coherent basement wedge, but consists of contrasting rock units (Fig. 1b), which are assumed to have formed in different geotectonic environments and were juxtaposed during Variscan collision (Zeh, 1996; Oncken, 1997; Hansch and Zeh, 2000). Rocks of unit I are interpreted to represent relics of a Variscan magmatic arc which contains sediments as old as Cambrian/Ordovician (Zeh et al., 2001, 2003) and formed at the north-western margin of the Saxothuringian domain (upper plate) between 360 and 330 Ma (e.g., Zeh, 1996, Brätz, 2000; Anthes and Reischmann, 2001; Zeh et al., 2005). In contrast, rocks of unit II comprise a metasediment–metabasite succession of unknown age, which is assumed to have been deposited in the Rhenohercynian domain (Zeh, 1996; Oncken, 1997), and contains Late Silurian/Early Devonian orthogneisses (425–390 Ma) with calc-alkaline signatures. These are interpreted to represent relics of a Late Silurian/Early Devonian magmatic arc (e.g., Dombrowski et al., 1995; Brätz, 2000; Reischmann et al., 2001). Rocks of unit I are exposed in the Kyffhäuser mountains, in the northeastern part of the Ruhla Crystalline Complex (Brotterode Group), in the western Odenwald Crystalline Complex (Bergsträsser Odenwald), and the Palatinate forest (Fig. 1b), whereas rock of unit II form the western and southern part of the Ruhla Crystalline Complex (Ruhla Group, Trusetal Group and Central Gneiss unit), most parts of the Spessart Crystalline Complex, as well as the eastern part of the Odenwald Crystalline Complex (Böllstein Odenwald). The Silurian orthogneisses, which were penetrated in the drill hole Saar 1 (Sommermann, 1993) perhaps also belong to unit II. It is worth noting that the Late Silurian to Early Devonian granite gneisses of rock unit II were emplaced at the same time as the Rhenohercynian basin, to the north of the MGCR, started to subside, as is supported by geochronological data and the sedimentary record (see Franke, 1995; Hansch and Zeh, 2000; Zeh and Wunderlich, 2003). Franke (1995) and Floyd (1995) suggested that the opening of the Rhenohercynian basin ended up in the formation of the Lizard–Giessen ocean, as is supported by basalts with WPB and MORB signature in the Rhenohercynian basin (see Floyd, 1995), and that basin formation resulted from NW-directed subduction of a mid-ocean ridge