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Plate tectonic significance of Middle Cambrian and Ordovician siliciclastic rocks of the Bavarian Facies, Armorican Terrane Assemblage, Germany — U–Pb and Hf isotope evidence from detrital zircons

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ABSTRACT

We have examined the provenance and tectonic setting of the Middle Cambrian and Ordovician siliciclastic deposits and associated volcanic rocks of the Bavarian Facies, Franconia, Germany, in the Saxothuringian Zone of the Variscan orogen. The units were deposited on the North African rifted margin of Gondwana and represent deep-water equivalents of the shallow marine mature sandstone successions of the areally extensive Thuringian Facies. U–Pb ages of detrital zircons of the Middle Cambrian Wildensteiner Formation, the Middle Ordovician Plattensandstone of the Randschiefer Series, and the Upper Ordovician Döbra sandstone fall into four distinct age groups: 2.4 to 1.8 Ga (15%), 0.75 to 0.54 Ga (55%) and 0.54 to 0.44 Ga (14%); minor abundances (4%) occur around 1 Ga. This age distribution is consistent with a northern Gondwanan derivation, mainly from the Cadomian continental magmatic arc in northern Africa. The c. 2 Ga ages indicate a provenance from Eburnean or equivalent sources on the West Africa craton and in northeast Africa and Arabia. The scarcity of grains of Kibaran age (c. 1 Ga) is characteristic of a derivation from metamorphic and magmatic sources on the Arabian–Nubian Shield, rather than from distant major Kibaran age terrains. The youngest group mainly reflects Late Cambrian to Ordovician rift magmatism widespread in the northern Gondwanan Cadomian terranes. The Hf isotopic compositions of selected dated zircons at the time of their crystallization ($\varepsilon_{Hf(t)}$; $T = 3.5$–0.47 Ga) vary between −30 and +7. Zircons with positive $\varepsilon_{Hf(t)}$ values are almost exclusively restricted to the age group between 0.5 and 0.9 Ga. The Hf isotope data suggest that magmatism associated with the Cadomian continental magmatic arc and post-Cadomian (late Cambrian-Ordovician) marginal rifts in northern Gondwana mainly involved mixing of juvenile magmas with Paleoproterozoic crust.

1. Introduction

The reconstruction of sedimentary provenance permits the recognition of paleotectonic linkages and terrane derivations and also aids in the determination of the plate tectonic setting of sedimentary basins. Provenance analysis is a key instrument for the analysis of the plate tectonic and geochronologic evolution of source terrains, which may be hidden or enigmatic, and for testing paleogeographic reconstructions. Recently, the analysis of U–Pb age spectra of detrital zircon populations has become an important tool in provenance research and has been successful in discriminating between different source regions (e.g. Sircombe, 1999; Friedl et al., 2000; Dickinson and Gehrels, 2003; Cawood et al., 2007; Linnemann et al., 2007; Veevers and Saeed, 2008; Elliot and Fanning, 2008; Condie et al., 2009). Similarities in age distributions and abundances between different but coeval lithostratigraphic units are taken as strong evidence of a common provenance. However, the presence and abundance of a given zircon age population in a sedimentary rock sample does not unequivocally identify its source. The presence of an age group in several crustal blocks may in fact obscure the actual provenance if little or nothing is known about differences in the crustal evolution of these blocks.

The use of LA-ICP-MS U–Pb ages of detrital zircons integrated with their Hf isotope compositions has evolved into a powerful tool to address more intricate provenance problems (e.g. Patchett, 1983; Amelin et al., 2000; Bodet and Scherer, 2000; Augustsson et al., 2006; Flowerdew et al., 2007; Scherer et al., 2007; Willner et al., 2008; Bahlburg et al., 2009). The initial Hf isotope composition of a dated zircon provides important constraints on the geochemical character of the protolith from which the zircon formed. This permits juvenile protoliths characterized by radiogenic Hf isotopic compositions to be distinguished from evolved crustal components with unradiogenic Hf isotopic compositions. The Hf isotopic compositions of detrital zircons record their time-integrated isotopic evolution and help to distinguish between different crustal domains as sources of the sediment.

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Ultimately, the combination of detrital zircon U–Pb ages with the Hf isotope composition offers more insights into the nature of sediment source terrains than the information given by age dates alone.

An example of the strength of this approach is given by the examination of tectonostratigraphic terranes derived from different parts of Gondwana (Fig. 1). A Neoproterozoic age signature (Pan-African or Brasiliano ages, c. 700 to 500 Ma: Cordani and Teixeira, 2007; Stern, 2008) is common to all terranes derived from Gondwana. These ages are characteristically absent from non-Gondwanan continents like Baltica and Laurentia (Nance and Murphy, 1994, 1996; Keppie and Ramos, 1999; Friedl et al., 2000). Differences in provenance are commonly recognized in the geochronological structure of Gondwana: Western Gondwana with Amazonia at its core (Fig. 1) is characterized by a succession of accretionary orogenies from c. 2.2 Ga to 0.55 Ga. In contrast, northern Gondwana and related terranes have a dichotomous Proterozoic age structure with the Eburnean events of the West Africa Craton around 2 Ga followed by Neoproterozoic events, here called Cadomian (Fig. 1; Murphy et al., 2000; Hirdes and Davis, 2002; Linnemann et al., 2004; Gerdes and Zeh, 2006; De Waele et al., 2008).

The available data, although still somewhat limited, indicates that zircons derived from the different Neoproterozoic orogenic belts may be distinguished by their Hf isotope signatures. Brasiliano age zircons included in Cambrian to Devonian sedimentary rocks of the Ellsworth–Whitmore block in West Antarctica and in Late Paleozoic accretionary complexes along the South American margin, typically have negative ε_{Hf} values. These indicate derivation from crustal domains in western and southern Gondwana through recycling of Mesoproterozoic juvenile crust (Augustsson et al., 2006; Flowerdew et al., 2007; Willner et al., 2008; Bahlburg et al., 2009). In contrast, the few available Hf isotope data on zircons derived from the Cadomian orogenic belt in northern Africa are characterized by positive ε_{Hf} values typical either of derivation from Neoproterozoic juvenile crust or of mixing of a Neoproterozoic juvenile magma with an older crust (Gerdes and Zeh, 2006; Zeh and Gerdes, 2010-this issue).

Terranes and sedimentary successions derived from the Cadomian orogen are major constituents of the Variscan orogen in Central Europe (Figs. 1, 2; Tait et al., 1997, Friedl et al., 2000; Schätz et al., 2002; Gerdes and Zeh, 2006; Linnemann et al., 2004). In this paper we present results of an integrated U–Pb and Hf isotope study of detrital zircons from three sedimentary and stratigraphic units of the Bavarian Facies (Saxothuringian Zone) in the Variscan orogen of Germany. These sediments are of Middle Cambrian to Late Ordovician age. We then use these data to determine the provenance of the deposits and the paleogeographic context of their deposition. The U–Pb and Hf isotope data obtained from

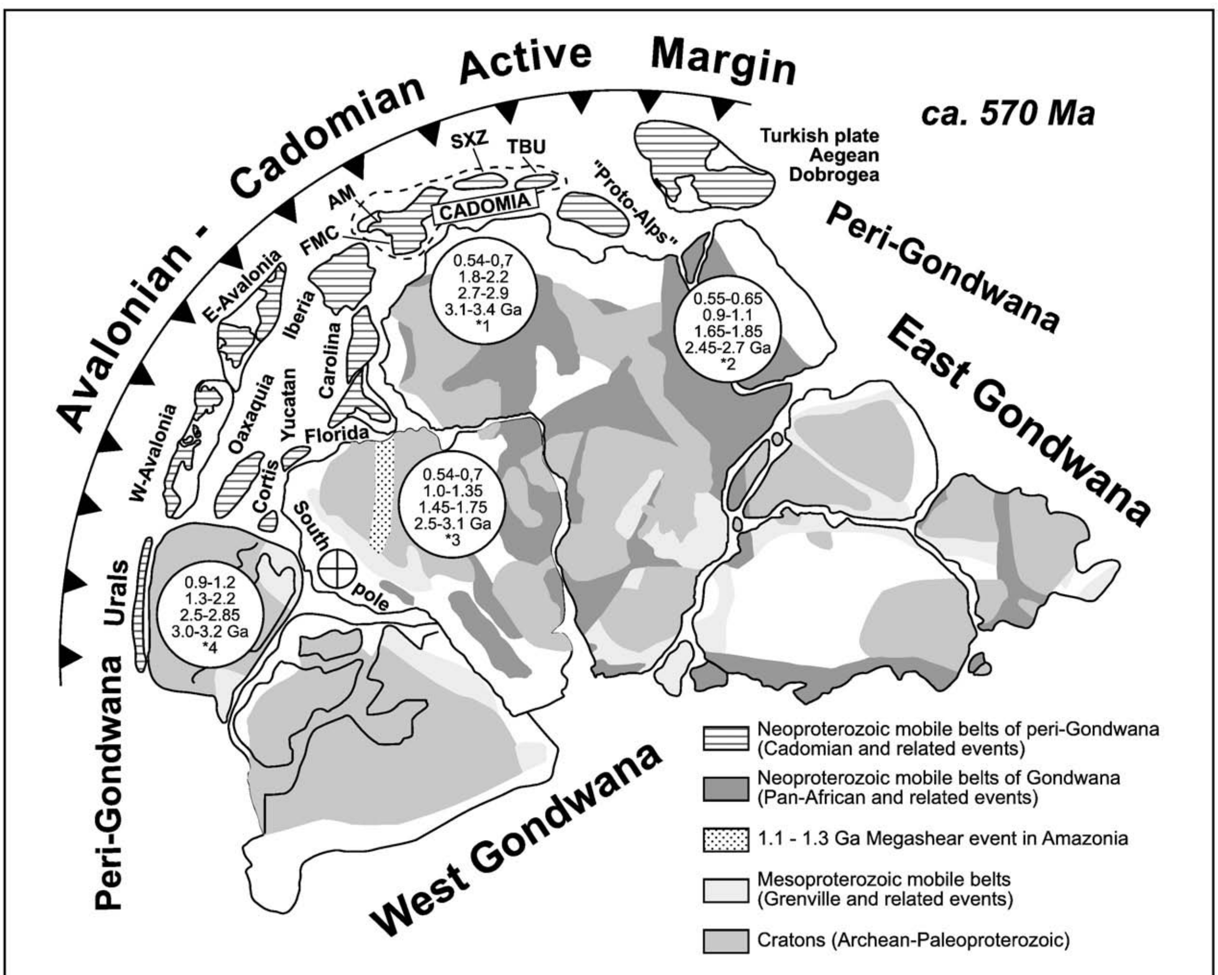

Fig. 1. Paleogeography of the Cadomian–Avalonian active margin and related major peri-Gondwanan terranes at c. 570 Ma, modified from Linnemann et al. (2004). AM, Armorican Massif; FMC, French Massif Central; SXZ, Saxo-Thuringian zone (part of the Bohemian Massif); TBU, Teplá-Barrandian unit (part of the Bohemian Massif). Numbers in circles: zircon ages from the cratons in Ga. *1, from the compilation of Nance and Murphy (1994 and references therein); *2, from Avigad et al. (2003), Kolodner et al. (2006), Ali et al. (in press), Be'eri-Shlevin et al. (2009a); *3, from Schneider Santos et al. (2000); *4, from the compilation of Zeh et al. (2001). Paleogeography of the Gondwanan continental plates after Unrug et al. (1996).