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Strontium isotopes — A persistent tracer for the recycling of Gondwana crust in the Variscan orogen

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ABSTRACT

Voluminous Cambro-Ordovician quartz-rich sandstones blanket large parts of North Africa and Arabia, as well as terranes that later became separated from northern Gondwana. These sandstones are the result of widespread and intense chemical weathering that gave rise to a strong depletion in Na, Ca, and Sr and, concomitantly, very high K/Na and Rb/Sr ratios. Because of their high Rb/Sr ratios, these rocks developed through time highly radiogenic Sr-isotopic compositions (in part with $^{87}Sr/^{86}Sr_0 > 1.0$). This particular geochemical signature may provide a geochemical provenance indicator for early Palaeozoic sedimentary rocks, which may be used to (i) trace the fate of particular lithological units during orogenic processes and (ii) constrain the provenance of sedimentary rocks on terranes of disputed palaeogeographic position. Among the Palaeozoic sedimentary and volcanic rocks deposited on the Gondwanan shelf of Saxo-Thuringia (Germany), only Lower Ordovician siliciclastic rocks like those of the Tremadocian Frauenbach Group (Schwarzburg Anticline) are characterized by this weathering-related strong depletion in Na, Ca, and Sr. Metamorphic nappes of the adjacent Erzgebirge consist of lithologies originally deposited on the Gondwana shelf. Modeling of the Sr-isotopic composition demonstrates that the high Rb/Sr ratios accounting for the highly radiogenic measured $^{87}Sr/^{86}Sr$ values are not due to metamorphic element mobility, but represent a primary signature already acquired at the time of deposition. Thus, the “Frauenbach Sr-isotopic signature” – similar to the geochemical fingerprint – can be traced through metamorphism even to high-grade conditions. High $^{87}Sr/^{86}Sr$ ratios are also present in siliciclastic rocks derived from the erosion of the exhumed Variscan orogen. The appearance and disappearance of this signature put constraints on the erosion history of the Variscan orogen; its dilution allows a rough estimate of the relative contribution of the high-$^{87}Sr/^{86}Sr$ metamorphic rocks to the erosional debris. Similarly, the high Rb/Sr granites of the Erzgebirge may not be the product of extreme fractional crystallization alone, but may reflect the involvement of protoliths with high Rb/Sr. Granites with radiogenic Sr-isotopic composition share – despite geochemical modification by differential melting of the source and subsequent fractional crystallization – geochemical fingerprints with the Frauenbach Group, in particular increased W, Sn, F, Li, and Rb contents and low Sr abundances. Should it turn out that high initial $^{87}Sr/^{86}Sr$ and high W, Sn, F, and Li of granites are linked to one particular crustal protolith, both Sn-enriched granites of Variscan Europe and Palaeozoic sedimentary rocks with Frauenbach geochemical signatures represent a Gondwana fingerprint.

1. Introduction

Voluminous deposits of mature Cambro-Ordovician quartz-rich sandstones blanket large parts of North Africa and Arabia, from the Atlantic coast to the Persian Gulf (e.g., Noblet and Lefort, 1990). These chemically mature sandstones and quartzites were mainly derived from Neoproterozoic Pan-African basement that was affected by widespread and intense chemical weathering (Avigad et al., 2005), locally resulting in the development of bauxitic laterite and quartz arenite (cf. German et al., 1994; Avigad et al., 2005). Similar mature quartz-rich sandstones are also known from terranes that had been detached from the northern margin of Gondwana by late Cambrian to early Ordovician extension and rifting that eventually led to the opening of the Rheic Ocean (e.g., Nance et al., 2010). Examples for such early Palaezoic sandstones on Gondwana-derived terranes include the Grès Armorican Formation (Armorican Quartzite) of northwestern France (Noblet and Lefort, 1990) and the Tremadocian Frauenbach Group of the Saxo-Thuringian Zone in Germany (Fig. 1; e.g., Lützner et al., 1986; Mingram, 1998). In contrast, Baltica, Laurentia, and Avalonia did not experience such intense chemical weathering at that time (Erdtmann, 1991; Giese et al., 1994). Thus, for Variscan Europe, which formed during the early stages of Pangea formation when Gondwana collided with Laurussia (Laurentia, Avalonia, and Baltica), the occurrence of such mature clastic sedimentary rocks of late Cambrian to early Ordovician depositional age and their metamorphic equivalents provides a tracer for Gondwana provenance.

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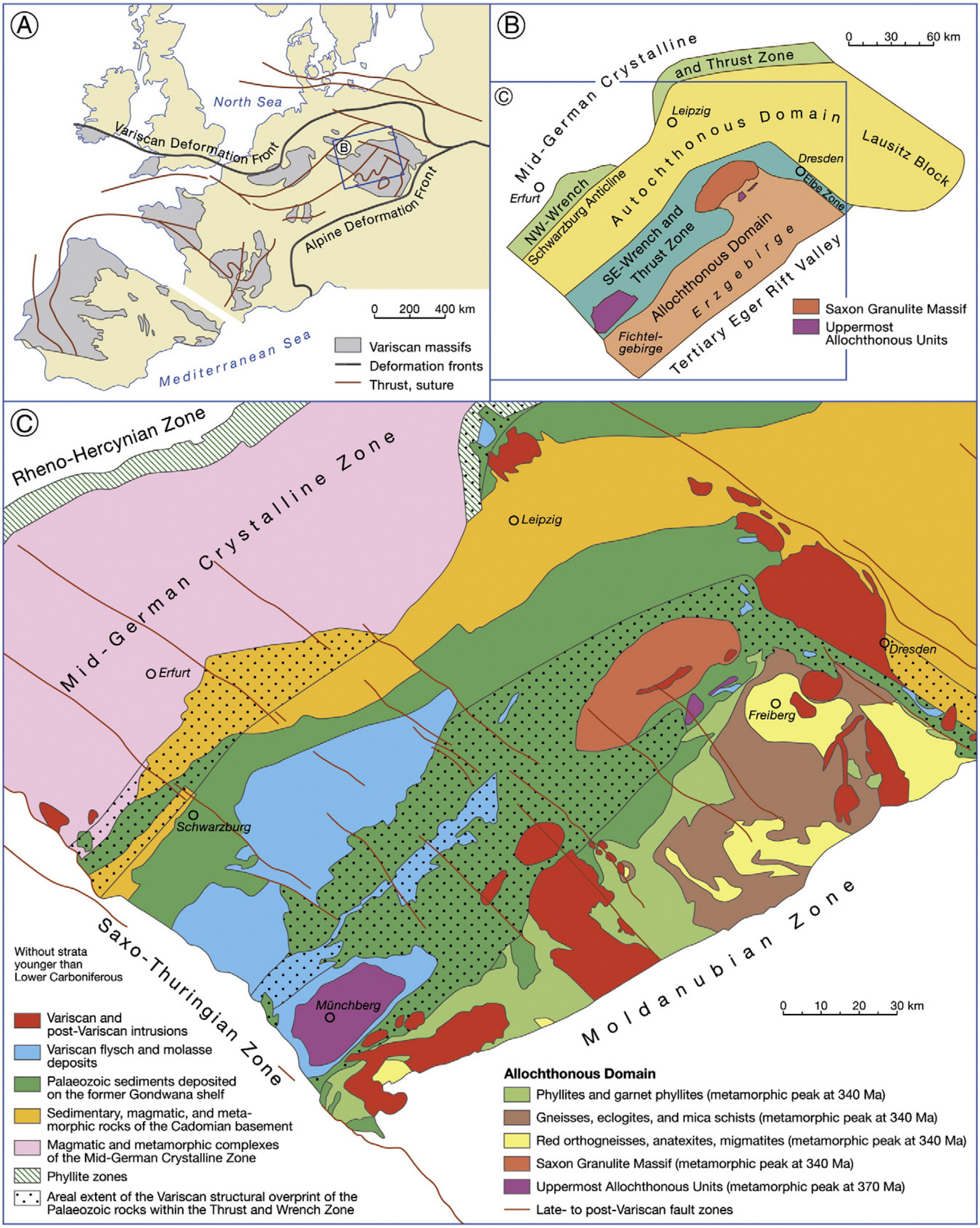

Fig. 1. Geological setting of Saxo-Thuringia. A. Tectonic framework of Variscan Europe showing the distribution of basement blocks and major tectonic lineaments (simplified after Franke, 1989, 2000). B. Subdivision of the Saxo-Thuringian Zone with respect to Variscan overprint (Kroner et al., 2007, 2010). Rocks of the Autochthonous Domain include volcanic, sedimentary, and magmatic rocks of the Cadomian arc (broadly referred to as Cadomian basement) and late Proterozoic and Palaeozoic sedimentary (and volcanic) rocks of the shelf sequence deposited on the Cadomian basement. Rocks of the Allochthonous Domain include the same lithologies as the Autochthonous Domain, forming a stack of nappes that had experienced contrasting grades of Variscan metamorphism (Mingram and Rötzler, 1999; Rötzler and Plessen, 2010). These two domains are separated by the Wrench and Thrust Zone that includes the same lithologies as the Autochthonous Domain, but differs from it by showing late-Variscan folding and schistosity that developed during the emplacement of the metamorphic nappes of the Allochthonous Domain (for details see Hahn et al., 2010, Kroner et al., 2010, Kroner and Romer, 2010). C. Geological map of the Saxo-Thuringian Zone (simplified from Linnemann and Schauer, 1999).