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Calc-alkaline lamprophyres from Lusatia (Germany)—Evidence for a repeatedly enriched mantle source

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ABSTRACT

Pre-Variscan mantle derived gabbros (c. 400 Ma) and late-Variscan calc-alkaline lamprophyres (c. 330 Ma) were emplaced within the Cadomian basement of Lusatia. They were sampled to characterize the effect of the Variscan orogeny onto the mantle beneath Lusatia. The tholeiitic gabbros originated from a mantle source that had been metasomatized during subduction beneath the Cadomian magmatic arc at c. 570 Ma, which led to enrichment of LREE, Ba/Nb, and LILE relative to primitive mantle. The late-Variscan calc-alkaline lamprophyres (spessartites) have high MgO, Cr, and Ni contents reflecting the mantle source. The spessartites, however, have distinctly higher Rb, Ba, Pb, Sr, Th, and Cs contents, higher La/Yb, $^{87}Sr/^{86}Sr$, and $^{206}Pb/^{204}Pb$ ratios, and lower $^{143}Nd/^{144}Nd$ ratios than the gabbros, which indicates a second, Variscan event of mantle enrichment. In addition, the spessartites have trace element ratios (i.e., Ba/Nb, Nb/U, Th/U, and Th/Nb) that resemble continental crust and Sr, Nd, and Pb isotopic compositions that demonstrate involvement of crustal material by source enrichment during the Variscan orogeny. The calc-alkaline lamprophyres of the Lusatia occupy the same age range as calc-alkaline lamprophyres from the adjacent Erzgebirge and Sudetes. The trace-element signatures and Sr and Nd isotopic compositions of Lusatian spessartites, however, are less enriched than those of comparable dikes in the Sudetes and the Erzgebirge. This implies that the Variscan orogeny resulted in geochemically and isotopically heterogeneous lithospheric mantle on the regional scale, possibly reflecting the contrasting nature of the subducted rocks.

1. Introduction

Calc-alkaline lamprophyres are hypabyssal rocks that commonly form dikes and sills and that are characterized by a panidiomorphic porphyritic texture with abundant phenocrysts of amphibole and/or dark mica. Lamprophyres are widely considered to be primary mantle-derived magmas (e.g., Rock, 1991; Bédard, 1994) that provide not only important information for magma genesis in the mantle, but also on geodynamic processes modifying the mantle and leading to the extraction of lamprophyric melts. Although lamprophyres were long thought to sample a metasomatized mantle source, which may have been enriched during an ancient event, it has become increasingly obvious that the trace-element and isotopic signatures of old crust-derived material may well equally have been introduced during geologically young events (e.g., Hegner et al., 1998; Hoch et al., 2001; Prelević et al., 2005, 2012). The geochemical composition of lamprophyres shows an uncoupling of the major and compatible trace element contents (i.e., high MgO, Cr, and Ni) and high Mg# values, which reflect the mantle source, from the incompatible trace element and rare earth element contents and the isotope composition of Sr, Nd, and Pb, which typically reflect a crustal source. In previous studies, this geochemical uncoupling in lamprophyric magma has been variably linked to a low degree of partial melting of lithospheric mantle peridotites, metasomatized mantle sources in a subduction setting, mixing of mantle and crustal melts, and assimilation with fractional crystallization (e.g., Jones and Smith, 1983; Macdonald et al., 1985; Turpin et al., 1988; Stille et al., 1989; Rock, 1991; Currie and Williams, 1993; Prelević et al., 2004, 2007; Janoušek et al., 2010). Prelević et al. (2005, 2010) noticed a close correspondence between the geochemical and isotopic signature of Mediterranean orogenic lamproites and the sediments in the trench and the sedimentary wedge. This indicates that the local geochemical signature of the material entering into the subduction zone resurfaces in the orogenic lamproites extracted from the mantle above the subducting plate (Prelević et al., 2005). This correspondence not only demonstrates that metasomatism of the mantle in the orogenic lamproite (and more generally in the lamprophyre) source may occur shortly before they are extracted, but also opens the possibility to use orogenic lamproites and lamprophyres to trace the composition of subducting plate in young and ancient orogens. The geochemical signature of orogenic lamproites and possibly also calc-alkaline lamprophyres

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may be used to trace post-collisional interaction between an orogenic lithospheric mantle and a shallow subducting plate (cf. Prelević et al., 2010).

The Variscan orogen resulted from the collision of Laurussia with Gondwana and several smaller crustal blocks (i.e., Bohemia, Brittany, Iberia) between them. These crustal blocks, dominated by Cadomian basement (c. 570 to 545 Ma), are bordered by belts of Variscan high-grade metamorphic rocks (e.g., Erzgebirge, Sudetes, Vosges, Black Forest) that are interpreted to trace belts of Variscan subduction zones (e.g., Matte, 1991; Franke, 2000; Matte, 2001). The scarcity of subduction-related magmatism indicates that along these zones predominantly thinned continental crust – and its sedimentary cover – was subducted. These rocks are now largely preserved in Variscan high-grade metamorphic rocks. Post-collisional magmatism includes voluminous syn- and post-tectonic granitoids that are mostly derived from crustal melting (e.g., Turpin et al., 1990; Finger et al., 1997; Förster and Romer, 2010). Subduction of thinned continental crust and its sedimentary cover resulted in the metasomatism of the mantle above the subducted plate. This metasomatized mantle was sampled by a suite of late-orogenic lamprophyre dikes, most importantly among them calc-alkaline lamprophyres (Turpin et al., 1988; Wenzel et al., 1991; Hegner et al., 1998; von Seckendorff et al., 2004; Awdankiewicz, 2007; Seifert, 2008). In analogy to the geochemical variability of the Mediterranean orogenic lamproites that reflect the regional variability of the subducted sediments, the regional distribution of calc-alkaline lamprophyres may reflect the distribution of Variscan subduction zones and the regional geochemical variation among these lamprophyres may trace the contrasting character of the subducted material.

Lusatia is one of these Cadomian blocks that largely escaped Variscan metamorphism and deformation and that differs from adjacent parts of the Bohemian Massif by the absence of piles of Variscan high-grade metamorphic rocks. The Cadomian basement of Lusatia (greywackes and granodiorites; Fig. 1) has been intruded by pre-Variscan gabbros and by late-Variscan lamprophyres. The compositional variations between the pre-Variscan gabbros and late-Variscan lamprophyres allow us to characterize the effect of material subducted during the Variscan orogeny on the mantle beneath Lusatia. Furthermore, the contrasting Variscan development of Lusatia and adjacent regions with Variscan high-grade metamorphic rocks may find its expression in contrasting metasomatism of the mantle source for the lamprophyric magmatism. In this paper, we present mineralogical, geochemical, and Sr, Nd, and Pb isotope data of pre-Variscan gabbros and late-Variscan calc-alkaline lamprophyres to characterize the geochemical and isotopic effect of the Variscan (and possibly Cadomian) orogeny on the mantle beneath Lusatia.

2. Geological setting

The Cambrian to Ordovician rifting of the northern margin of Gondwana, which eventually led to the opening of the Rheic Ocean, resulted in the formation of two types of continental crust, i.e., blocks with continental crust of normal thickness that are separated by thinned continental crust that developed into shelf areas with marine sedimentation (e.g., Linnemann et al., 2000; Kroner et al., 2007; Linnemann et al., 2008; Heuse et al., 2010; Kroner and Romer, 2010; Linnemann et al., 2010a). The blocks of normal crustal thickness are dominated by metamorphic and voluminous magmatic rocks of the former Cadomian magmatic arc (570 to 545 Ma, Linnemann et al., 2000, 2008). The areas of thinned continental crust developed into sedimentation areas that record the successive development of rift-bound sedimentation with siliciclastic debris from the Cadomian arc to shallow and eventually to deep shelf sedimentation (Linnemann et al., 2004, 2010b). During the Variscan orogeny, these blocks of thick Cadomian continental crust and the zones of thinned continental crust behaved differently: The areas of thick crust were not subductible, whereas the areas of thin continental crust were subductible (cf. Kroner et al., 2007; Kroner and Romer, 2010). The closure of the Rheic Ocean initially was accomplished by consumption of oceanic crust beneath the Mid-German Crystalline Zone, eventually leading to the docking of Gondwana-derived blocks to Laurussia. Once a block of thick Cadomian continental crust had docked to Laurussia, a new subduction zone was initiated behind this block. In these later subduction zones, thinned continental crust and its sedimentary cover was subducted until the next block of thick Cadomian continental crust arrived and collided, resulting in the generation of yet another subduction zone. With the arrest of subduction, the subducted continental crust escaped from beneath the blocks of thick Cadomian continental crust – either by lateral escape or backflow in the subduction channel – and was emplaced as stacks of nappes of contrasting metamorphic history on adjacent terranes (cf. Kroner et al., 2007, 2010; Kroner and Romer, 2010). Subduction of thinned continental crust and formation of new subduction zones behind blocks of thick crust (i) explains the occurrence of high grade metamorphic rocks in close spatial association with areas of little Variscan overprint, (ii) accounts for the scarcity of subduction-related Variscan magmatism, and (iii) brings thinned continental crust and its sedimentary cover to mantle depth (e.g., Kroner et al., 2007, 2008; Kroner and Romer, 2010). Fluid-loss from these sediments and possible partial melting of the sediments and their crystalline substratum provides the agents that may metasomatize the mantle above the subducting plate.

The Bohemian Massif and in particular the Lusatian block are special as they are among the first Gondwana-derived blocks to collide with Laurussia. The approach of Bohemia and Laurussia resulted in the thrusting of the Tepla-Barrandian Unit onto other parts of the Bohemian Massif, the formation of the Sudetes, and in establishing a new subduction zone to the SW of the Bohemian Massif. Lusatia was at that time not a part of the Bohemian Massif and continued to move toward Laurussia. The strike slip zone between Bohemia and Lusatia later was reactivated during the subsequent lateral escape of subducted crustal rocks from beneath Bohemia and their emplacement onto the Saxo-Thuringian Zone to form the Erzgebirge (cf. Kroner et al., 2007, 2010; Kroner and Goerz, 2010; Kroner and Romer, 2010).

Lusatia, located at the northeastern margin of the Bohemian Massif, is bordered to the SW by the Elbe-Fault Zone and to the NE by faults paralleling the Görlitz slate belt (Fig. 1). These structural elements have been active during the Variscan orogeny and have been repeatedly reactivated since. To the south, Lusatia is bordered by the Tertiary Eger rift, which largely follows the strike slip zone along which Lusatia had slipped by the Bohemian Massif during the Variscan orogeny. To the north Lusatia is separated from the Mid-German Crystalline Zone by a major shear zone. In the southern part of Lusatia, where Cadomian granodiorites predominate, several stocks and dike swarms of gabbroic rocks, in particular gabbro norite, olivine gabbro, and diorite (Kramer et al., 1977), had intruded. Kramer et al. (1977) reported a K–Ar whole rock age of 400 Ma for the gabbros in Lusatia. This age later was confirmed by a Pb–Pb age of 390 ± 8 Ma (zircon evaporation; Kindermann et al., 2003) for a gabbro near Valtengrund (Fig. 1). The gabbros have been emplaced in stable crust and show within-plate geochemical signatures (e.g., Peschel et al., 1973; Kramer, 1988; Heinrich, 1993). The occurrence of gabbroic rocks of this age and setting in Lusatia is unusual: in other parts of the Saxo-Thuringian Zone, gabbros are much older and related to the opening of the Rheic Ocean (e.g., Vesser Zone, Kemnitz et al., 2002; Münchberg, Stosch and Lugmair, 1990). In the West-Sudetes (i.e., at Braszowice and Sleza) occur gabbros of corresponding age, i.e., 400 ± 10 Ma (Kryza and Pin, 2010) and 420 ± 20 Ma (Oliver et al., 1993), but there, the gabbros are part of ophiolitic successions (Kryza and Pin, 2010).

The Cadomian granodiorites and greywackes and the pre-Variscan gabbros of Lusatia are intruded by (i) dike swarms of alkaline basalt with unknown – but pre-Variscan – age (Kramer, 1988) and (ii) late-Variscan dikes of older calc-alkaline lamprophyres (this study), and 315–304 Ma old post-Variscan granite intrusions (Eidam et al., 1995; Fig. 1), as well as post-Variscan dike swarms of (iii) andesites, rhyodacites,