Gondwana Research 35 (2016) 198–216

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Petrogenesis of orogenic lamproites of the Bohemian Massif: Sr–Nd–Pb–Li isotope constraints for Variscan enrichment of ultra-depleted mantle domains

Lukáš Krmíček [a,b,*], Rolf L. Romer [c], Jaromír Ulrych [a], Johannes Glodny [c], Dejan Prelević [d,e]

[a] Institute of Geology, Czech Academy of Sciences, v.v.i., Rozvojová 269, CZ-165 02 Prague 6, Czech Republic
[b] Brno University of Technology, Faculty of Civil Engineering, AdMaS Centre, Veveří 95, CZ-602 00 Brno, Czech Republic
[c] Deutsches GeoForschungsZentrum GFZ, Telegrafenberg D-14473, Potsdam, Germany
[d] Geocycles Research Centre, Institute of Geosciences, University of Mainz, Becherweg 21, D-55099 Mainz, Germany
[e] Faculty of Mining and Geology, University of Belgrade, Djušina 7, RS-11000 Belgrade, Serbia

ARTICLE INFO

Article history:
Received 31 January 2015
Received in revised form 29 April 2015
Accepted 30 April 2015
Available online 4 June 2015

Handling Editor: R.D. Nance

Keywords:
Silica-rich lamproites
Sr–Nb–Pb–Li isotopes
Mantle metasomatism
Rheic Ocean
Variscides

ABSTRACT

During convergence of Gondwana-derived microplates and Laurussia in the Palaeozoic, subduction of oceanic and continental crusts and their sedimentary cover introduced material of regionally contrasting chemical and isotopic compositions into the mantle. This slab material metasomatised the local mantle, producing a highly heterogeneous lithospheric mantle beneath the European Variscides. The eastern termination of the European Variscides (Moldanubian and Saxo-Thuringian zones of Austria, Czech Republic, Germany and Poland) is unusual in that the mantle was modified by material from several subduction zones within a small area. Orogenic lamproites sampled this lithospheric mantle, which has a chemical signature reflecting extreme depletion (low CaO and Al_2O_3 contents and high Mg-number) followed by strong metasomatic enrichment, giving rise to crust-like trace element patterns, variable radiogenic $^{87}Sr/^{86}Sr_{(330)}$ (0.7062–0.7127) and non-radiogenic Nd isotopic compositions ($\varepsilon Nd_{(330)} = -2.8$ to -7.8), crustal Pb isotopic compositions, and a wide range of δ^7Li values (-5.1 to $+5.1$). This metasomatic signature is variably expressed in the lamproites, depending on the extent of melting and the nature of the source of the metasomatic component. Preferential melting of the metasomatically enriched (veined) lithospheric mantle with K-rich amphibole resulted in lamproitic melts with very negative, crust-like δ^7Li values, which correlate positively with peralkalinity, HFSE contents and lower εNd. Both the higher degree of melting and progressive consumption of the metasomatic component reduce the chemical and isotopic imprints of the metasomatic end member. The very positive δ^7Li values of some lamproites indicate that the source of these lamproites may have been modified by subducted oceanic lithosphere. Fresh olivine from the Brloh (Moldanubian) lamproitic dyke shows very high Fo (up to 94%) and very high Li contents (up to 25 ppm), demonstrating that the extremely depleted and later enriched lithospheric mantle may have contributed significantly to the Li budget of the lamproites. The regional distribution of lamproites with contrasting chemical and isotopic fingerprints mimics the distribution of the different Variscan subduction zones.

1. Introduction

Potassic to ultrapotassic mantle-derived rocks are volumetrically minor but genetically important magmatic rocks as their geochemistry can be used as magmatic proxy to trace lithospheric processes. Among these rocks, lamproites represent the group with the most extreme composition. According to the Le Maitre (2002) IUGS classification of igneous rocks, whose lamproite classification is based on the pioneering work of Mitchell and Bergman (1991), lamproites are a separate group of Mg-rich rocks that are peralkaline, perpotassic and ultrapotassic, and have low contents of FeO and CaO (<10 wt.%) and very high contents of Ti, Ba, Sr, Zr and La. Lamproites show a specific mineralogy with Al-poor phlogopite and/or K-rich amphibole (potassium is the dominant A-site cation; Mazdab, 2003) as primary mafic OH-bearing minerals. They contain characteristic accessory minerals with K, Ba, Ti, and Zr (e.g., priderite and wadeite).

Traditionally, potassic and ultrapotassic igneous rocks have been subdivided into the orogenic group that occurs in subduction-related tectonic settings and the anorogenic group that is confined to stable continental settings (Nelson, 1992). The orogenic lamproites (typically SiO_2-rich) are abundant within the Alpine–Himalayan orogenic belt (e.g., Prelević et al., 2013). However, as the lamproites are the product

---

* Corresponding author at: Brno University of Technology, Faculty of Civil Engineering, AdMaS Centre, Veveří 95, CZ-602 00 Brno, Czech Republic. Tel.: +420 541 147 230; fax: +420 549 245 147.
E-mail address: l.krmicek@gmail.com (L. Krmíček).

http://dx.doi.org/10.1016/j.gr.2015.04.012
1342-937X/

of multi-component mantle melts, a clear distinction between orogenic and anorogenic types is sometimes a matter of debate (Murphy et al., 2002; Davies et al., 2006; Kullerud et al., 2011; Çoban et al., 2012; Prelević et al., 2012).

Orogenic lamproites can be used as deep lithosphere chemical probes to geochemically and temporally characterise the orogenic mantle. Their unusual composition is a result of multi-stage processes, including (i) partial melting of the mantle with a strong depletion in incompatible elements and (ii) re-fertilisation of these depleted rocks by later subduction-related metasomatism. The metasomatic component derived from the subducting slab is commonly enriched in incompatible elements, and typically forms veins in the depleted mantle (Sekine and Wyllie, 1982; Foley, 1990, 1992). Potassic and ultrapotassic rocks originate when metasomatic veins melt and these melts assimilate material from the ambient depleted mantle (e.g., Conceição and Green, 2004; Tappe et al., 2006; Prelević et al., 2008; Conticelli et al., 2009; Prelević et al., 2012). Because of the earlier depletion of the ambient mantle, the incompatible trace element budget of these melts is dominated by the metasomatic component (e.g., Prelević et al., 2008, 2012, 2013).

The large compositional variability of potassic and ultrapotassic mantle-derived rocks reflects (i) the relative contribution of depleted mantle and metasomatic material to the melt, (ii) the extent of depletion of the mantle, and (iii) the composition of the metasomatic component. As the metasomatic component strongly depends on the nature of the subducted material, regional variations in incompatible trace element signatures may reflect regional variation in the nature of the subducted material and also contrasting melting conditions in the subducting slab. Such a regional variation in lamproite composition that corresponds to the contrasting geological history of the crustal blocks shedding sediments into the trench, has been observed for Mediterranean lamproites (Prelević et al., 2008; Conticelli et al., 2009; Prelević et al., 2010a,b; Tommasini et al., 2011).

Orogenic lamproites have recently been recognized within the Variscan orogenic belt (Krmíček, 2010, 2011). Lamproites and their felsic equivalents (i.e., K-rich amphibole and Fe-rich microcline containing, peralkaline, perpotassic and ultrapotassic rocks with, compared with lamproites, a lower Mg-number — herein described under the new term *leucolamproites*), occur along the eastern termination of the Moldanubian and Saxo-Thuringian zones of the Bohemian Massif in the territories of the Czech Republic, Austria, and Poland. Whereas the lamproites can be found in thinner dykes or along quickly chilled margins, leucolamproites are connected to more evolved dyke centres. Compared with lamproites, leucolamproites are typically coarser-grained, microcline phenocryst-bearing rocks. They are unequivocally distinguishable from macroscopically similar syenitic rocks by their exotic mineral paragenesis and geochemistry.

Other lamproitic intrusions, characterised by emplacement ages of 339–337 Ma, are also known from the Balkan segment of the Variscan belt (Buzzi et al., 2010). Based on the dating results, lamproitic magmatic activity may have been widespread during the late stages of the Variscan orogeny immediately after the final collision. This is in line with the results of age determinations for the dykes with lamproitic affinity from the Bohemian Massif (e.g., Awdankiewicz et al., 2009; Krmíček, 2010, 2011).

This study focuses on the whole-rock chemical and isotopic characteristics of orogenic lamproites and leucolamproites from the Bohemian Massif. As the mantle beneath the Bohemian Massif was modified by metasomatic material from different subduction zones during the Variscan orogeny, the regional distribution of our data set can be used to test whether regional differences in the chemical and isotopic signatures of Variscan lamproites correlate geographically with inferred subduction zones in the framework of the tectonic model of Kroner and Romer (2013). On a larger scale, we want to address the petrogenesis of these exotic rocks by combining trace element compositions of fresh olivine, whole rock compositional data, and a new set of Sr–Nd–Pb–Li isotope data.

2. Geological setting

2.1. Position of the Bohemian Massif within the Variscan orogen

The Rheic Ocean was closed during the convergence and collision of the major continental blocks — Laurussia and Gondwana. This convergence included processes assigned to the Acadian, Variscan, and Appalachian orogenies and lasted from about 400 to 275 Ma (cf. Matte, 1991; Franke, 2000; Kroner and Romer, 2013). Different segments of the plate-boundary zone between these two continental blocks underwent contrasting tectonic evolution, largely because of the Armorican Spur (sensu Kroner and Romer, 2010, 2013), which collided in an early stage and stopped subduction of oceanic crust in Central Europe. To the west of the spur, subduction of oceanic crust continued until the Rheic Ocean was completely consumed preceding the Appalachian–Mauritanide orogeny. To the east of the spur, subduction continued without complete consumption of oceanic crust of the Rheic Ocean. Instead, in the east, the Palaeotethys developed in the area of the former Rheic Ocean (Kroner and Romer, 2013). The Armorican Spur itself was heterogeneous and consisted of thick blocks of continental Gondwana crust separated by domains of thin continental Gondwana crust, which formed during the extension of peri-Gondwana and was covered by thick sequences of Palaeozoic sedimentary rocks (Kroner et al., 2007). As the thick blocks did not subduct (low-strain domains within the Variscan belt), their arrival in the subduction zone resulted in a reorganisation of the plate boundary zone with subduction of domains consisting of thin continental crust and the associated volcano-sedimentary Palaeozoic cover rocks. Specific Variscan belts that include piles of metamorphic nappes reaching up to ultra-high pressure and ultra-high temperature conditions, make up the traces of these continental subduction zones. The final stages of the Laurussia–Gondwana collision are characterized by escape tectonics of the thick-crust, low-strain domains of the former Armorican Spur and a change of relative motion between Laurussia and Gondwana, leading to (i) closure of the Rheic Ocean between northern America and Africa, (ii) extension in Central Europe, and (iii) development of the Palaeotethys Ocean farther to the east (Kroner and Romer, 2013).

The Bohemian Massif consists of crustal fragments that were originally derived from the Cadomian magmatic arc (i.e., from peri-Gondwana), and brought to their present position during the Variscan orogeny. Remains of the Rheic Suture are preserved in the magmatic rocks of the Mid-German Crystalline Zone at the northern margin of the Bohemian Massif (Zeh and Will, 2010), along the eastern part of the Sudetes (Kryza and Pin, 2010), and between the Moldanubian Zone and the Brunovistulian Terrane of the Moravo-Silesian Zone of the Bohemian Massif (Fig. 1; Finger et al., 1998; Soejono et al., 2010). Although the Brunovistulian Terrane consists of the Cadomian magmatic arc exposed in the Brno and Dyje Batholiths (Leichmann and Höck, 2008), it is a part of Avalonia and had been accreted to Laurussia before the Variscan orogeny (e.g., Kalvoda et al., 2003, 2008; Kalvoda and Bábek, 2010). The Bohemian Massif preserves a geological record starting with the development of the Armorican Spur (in the Palaeozoic sedimentary and volcanic rocks of the low-strain domains of the Teplá–Barrandian Unit and Saxo-Thuringian Zone) and the orogenic processes leading to the assemblage of the Bohemian Massif (in the high-strain domains of the Saxo-Thuringian and Moldanubian zones). The high-strain domains locally contain c. 380 Ma old eclogites and granulites and c. 360 Ma old blueschists that are related to different stages of the development of the plate boundary zone between Laurussia and Gondwana (e.g., Klemd, 2010; Kryza et al., 2011; Faryad and Kachlík, 2013). All high-strain domains contain 340 Ma old metamorphic rocks,