Lithos 196–197 (2014) 14–26

Contents lists available at ScienceDirect

Lithos

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

Mantle wedge metasomatism revealed by Li isotopes in orogenic lamprophyres

Khaled M. Abdelfadil, Rolf L. Romer *, Johannes Glodny

Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, D-144743 Potsdam, Germany

ARTICLE INFO

Article history:
Received 12 November 2013
Accepted 22 February 2014
Available online 3 March 2014

Keywords:
Lithium cycle
Lamprophyres
Mantle wedge
Variscan orogeny
Sediment subduction
Mantle metasomatism

ABSTRACT

Variscan orogenic lamprophyres from the northeastern part of the Bohemian Massif (Erzgebirge, Lusatia, Sudetes) have δ^7Li values ranging from −5.5 to 1.9‰, i.e., values that are lower than the compositional range of depleted mantle. Correlations of δ^7Li with Li, Li/MgO, Li/Rb, and Li/Cs demonstrate that these low values are not due to processes related to magmatic emplacement or near-surface low-temperature alterations, but represent genuine signatures from the mantle source of the lamprophyres. The low δ^7Li values of the lamprophyre sources reflect subduction-related Variscan metasomatism of the subcontinental mantle, whereas the regionally different correlations of δ^7Li with other elements (e.g., Li/Yb, Nb/Dy, Li/Cs) imply that this metasomatism shows regional differences that correlate with the nature of the subducted slab, which represents the source of the metasomatic component. The range of the isotopic and geochemical compositions of Variscan lamprophyres in part overlaps with the compositional range of the subducted Paleozoic sedimentary rocks, and in part is more influenced by material derived from the depleted mantle, depending on whether the budget of the respective element is dominated by the metasomatic component or has contributions from both components. The new data demonstrate that subduction does not necessarily result in major changes in the chemical and Li-isotopic compositions of the subducted sedimentary rocks. Our data show that crustal Li is reintroduced into the mantle. The virtual absence of a crustal Li isotopic signature in Oceanic Island Basalts implies that Li is not simply reintroduced into the convecting mantle, but instead is mainly transferred into the suprasubduction zone mantle wedges and thereafter remains in the subcontinental lithospheric mantle.

1. Introduction

The Li isotopic composition of the convecting mantle is remarkably homogeneous (δ^7Li of ~3 to 4‰) and seems to have varied little through time (e.g., Halama et al., 2007, 2008; Tomascak, 2004; Tomascak et al., 2008). In contrast, the Li isotopic composition of the crust is heterogeneous: interaction with seawater shifts the Li isotopic composition of altered oceanic crust (AOC) to higher δ^7Li values (up to ~15‰), whereas weathering of the continental crust shifts the Li isotopic composition of siliciclastic debris to lower δ^7Li values (down to ~−20‰) (e.g., Chan et al., 1992, 2002; Rudnick et al., 2004). Thus, Li entering a subduction zone is isotopically heterogeneous. Field and experimental studies furthermore demonstrate that the Li isotopic composition of material entering a subduction zone may be additionally affected by isotopic fractionation related to fluid loss during progressively higher-grade metamorphism (e.g., Elliott et al., 2004; Marschall et al., 2007; Zack et al., 2003). Thus, the isotopic composition of Li transferred back into the mantle may be highly variable depending both on the subducted material and on the mineralogically controlled partitioning and fractionation of Li between solid phases and fluids escaping during subduction. Dehydration or melting of subducted siliciclastic sedimentary rocks or continental crust at mantle depths should bring along Li with relatively low δ^7Li values (e.g., Agostini et al., 2008) and add this material to the local mantle. Although mantle xenoliths display a broad range of Li contents and δ^7Li values (cf. Elliott et al., 2004; Nishio et al., 2004; Tomascak, 2004), mantle derived melts sampling larger mantle volumes show surprisingly small δ^7Li variations. For instance, different types of OIB with contrasting Sr–Nd–Pb isotope signatures, which should reflect the contrasting nature of subducted material, typically do not show a correlation between δ^7Li and the Sr–Nd–Pb isotope signatures. Instead, the δ^7Li values of OIB largely coincide with the compositional range known for MORB (e.g., Krienitz et al., 2012). This indicates that (i) if significant amounts of crustal Li are introduced into the convecting mantle, its isotopic composition on average should be not too different from the average value of the mantle or (ii) crustal Li is not introduced to a significant amount into the convecting mantle, but is mostly mobilized during subduction and transferred back into the crust or into non-convecting suprasubduction zone mantle wedges (e.g., Elliott et al., 2004; Krienitz et al., 2012). This latter inference is in line with the high Li contents of olivine crystals that crystallize in melts derived from metasomatized mantle (Prelević et al., 2013).

---

* Corresponding author. Tel.: +49 331 288 1405; fax: +49 331 288 1474.
E-mail address: romer@gfz-potsdam.de (R.L. Romer).

http://dx.doi.org/10.1016/j.lithos.2014.02.021
0024-4937/© 2014 Elsevier B.V. All rights reserved.

Orogenic lamprophyres are formed from melts of the metasomatized suprasubduction zone mantle wedge (e.g., Foley, 1992; Prelević et al., 2008, 2010a; Rock, 1987, 1991). They have a mixed geochemical signature with high MgO, FeO, Cr, and Ni contents and a high Mg# (Mg/(Mg + Fe) cation ratio), which demonstrates their derivation from a depleted mantle source, combined with high LILE and HFSE contents and REE and trace element pattern that resemble typical crustal rocks (e.g., Abdelfadil et al., 2013; Conticelli et al., 2009; Foley, 1992; Foley et al., 1987; Peccerillo and Martinotti, 2006; Prelević et al., 2008, 2010a). The distinctness of the crustal signature depends on (i) how prominent this signature is in the metasomatized mantle and (ii) the relative proportions of metasomatized and depleted mantle that are involved in the formation of the lamprophyres. For instance, small amounts of melting will result in melts with a geochemical signature strongly resembling the metasomatic component in the mantle, whereas for large amounts of melting, this metasomatic component is fully consumed and diluted by increasingly higher proportions of depleted mantle. This mixed origin of lamprophyres results in a geochemical uncoupling of the elements that predominantly derive from the metasomatized mantle (e.g., alkali elements, REE, and Sr, Nd, and Pb with their respective isotopic compositions) from those dominantly provided by the depleted mantle (e.g., Mg, Cr, and Ni). Furthermore, this uncoupling implies that the isotopic composition of Sr, Nd, and Pb does not provide age constraints on mantle metasomatism (cf. Prelević et al., 2008; Rock, 1987, 1991). Instead, the crustal signature of the metasomatized mantle could be derived from a subducting slab and may – in the extreme case – be extracted from the wedge when subduction still is going on (e.g., Agostini et al., 2008; Prelević et al., 2010b, 2012; Tonarini et al., 2005). Prelević et al. (2008, 2010a) demonstrated that the geochemical and isotopic compositions of the metasomatic component of Mediterranean orogenic lamproites – a subgroup of lamprophyres (Rock, 1991) – closely correspond to the geochemical and isotopic signatures of sediments that enter the subduction zone. Thus, metasomatism of the wedge is directly related to subduction processes and the geochemical and isotopic compositions of lamprophyres closely correspond to the subducted material. Furthermore, lamprophyres occurring in the same area, but extracted at different times and under different conditions, use to show the same metasomatic signature (whereby the in situ isotopic evolution of the metasomatic component has to be taken into account), implying that the metasomatized subcontinental mantle is not taking part in mantle convection, but remains attached to the continental crust (e.g., Tappe et al., 2006, 2007). Thus, lamprophyres represent samples coming from the metasomatized mantle wedge that allow to trace the nature of the subducted material. Especially because of the observed spatial relation between geochemical signatures of the subducted material and the lamproite and lamprophyre compositions in young orogens (e.g., Prelević et al., 2008, 2010a), the nature of the crustal signature in orogenic lamprophyres may be used to distinguish and outline the extent of compositionally different mantle wedges, which are related to compositionally distinct subducted slabs, in old orogens.

In this paper, we use late-Variscan lamprophyres from the Erzgebirge, Lusatia, and the Sudetes at the northern margin of the Bohemian Massif (Fig. 1) as samples of the Variscan subcontinental mantle to study the interaction of slab-derived material with the overlying mantle. As the subcontinental mantle of these three regions has been modified by material released from different kinds of subducting slabs and associated sedimentary rocks (e.g., Abdelfadil et al., 2013; Kroner and Romer, 2010, 2013), we expect the geochemical and isotopic signatures of late-Variscan lamprophyres to show regional differences that correspond to the contrasting nature of the subducted material. Our new Li isotope data from late-Variscan lamprophyres from the Erzgebirge, Lusatia, and the Sudetes – in particular in combination with Sr, Nd, and Pb isotope data and geochemical data – demonstrate regional differences both in the importance and in the geochemical character of the metasomatic component in the local subcontinental mantle sources of these lamprophyres.

2. Geological setting

The Paleozoic convergence and subsequent collision of Laurussia and Gondwana, i.e., the Variscan orogeny of central and western Europe, resulted in the formation of several short-lived subduction zones within the complex plate boundary zone between these two plates (Kroner and Romer, 2010, 2013). The position and behavior of these subduction zones are controlled by the spatial distribution of thick crustal blocks (Fig. 2), which are not subductable, and thinned continental crust together with its volcanosedimentary cover, which is subductable (Cloos, 1993; Kroner and Romer, 2013; Kroner et al., 2007; van Hunen and Allen, 2011). During the convergence of the two continental plates, oceanic crust of the Rheic Ocean was consumed in a subduction system sustaining a magmatic arc (Fig. 2), whose deeply eroded remains are preserved in the Mid-German Crystalline Zone (Fig. 1; Anthes and Reischmann, 2001; Zeh and Will, 2010). With the consumption of the oceanic crust of the Rheic Ocean, the continental fragment of Armorica collided with the Midland craton at c. 400 Ma (Fig. 2), displacing it to the northeast, a process resulting in extensional tectonics and mafic magmatism in the area of the Rheno-Hercynian Zone (Kroner and Romer, 2013). Farther to the east, the Teplá–Barrandian Unit collided with Laurussia and indented into Laurussia, which led to a local flip of the subduction polarity (Fig. 2) forming the Sudetes orogenic belt. A new subduction zone developed farther to the southwest (Fig. 2), allowing for continued convergence between Laurussia and Gondwana. In this younger subduction system, thinned continental crust with its volcanosedimentary cover was subducted from the southwest beneath the Bohemian Massif. Parts of the subducted thinned continental crust eventually resurfaced by lateral escape in the metamorphic belts to the northwest and southeast of the Bohemian Massif (i.e., the Erzgebirge and the Gföhl area; for details see Kroner and Romer, 2013). Peak metamorphism in these areas of high-grade rocks was reached at c. 340 Ma (e.g., Kröner and Willner, 1998; Willner et al., 2000), whereas peak metamorphism in the Sudetes was reached slightly earlier (i.e., c. 345 Ma, Marheine et al., 2002), as this belt is genetically linked with the arrest of the older subduction system (Kroner and Romer, 2013).

The position of the Bohemian Massif within the Variscan orogen is specific as the upper mantle beneath the massif has been affected by material released from several different subduction systems, whereas the mantle beneath Lusatia, which has been slid along the northern limit of the Bohemian Massif to its present position (Fig. 2), has been affected by this subduction-related metasomatism to a lesser extent (Abdelfadil et al., 2013). Lamprophyres emplaced soon after the emplacement of the metamorphic rocks in the tectonic nappes of the Erzgebirge and the Sudetes sampled the mantle along the northern margin of the Bohemian Massif and, thus, should record both contrasting signatures and contrasting extent of metasomatism related to the Variscan orogeny. In such a scenario, lamprophyres from the Erzgebirge should show strong mantle metasomatism by crustal material, whereas those from Lusatia should reflect less strongly metasomatized mantle that possibly was affected by oceanic crust and sedimentary material deposited on it. In contrast, lamprophyres from the Sudetes are expected to be more heterogeneous in their metasomatic signature, as this mantle was affected first by subduction of oceanic crust and subsequently by subduction of thinned continental crust and its volcanosedimentary cover (Kroner and Romer, 2010, 2013).

3. Analytical methods

The chemical data presented in the Supplementary material (Table A1) have largely been published before and analytical details are given in the original works (Abdelfadil et al., 2013; Awdankiewicz, 2007). For some older analyses from the literature, rare earth element (REE) and trace element contents had not been reported. For these samples, we complemented the original chemical analyses using aliquots of the originally analyzed sample powders. Analytical procedures and