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Lithium Abundances and Li Isotope Compositions of the Roberts Victor Kimberlite and its Olivines

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INTRODUCTION

Kimberlites are volcanic rocks originated at great mantle depths. Various source reservoirs have been proposed, such as continental lithospheric mantle, convecting upper mantle, subducted oceanic crust, lower mantle and core-mantle boundary (Haggerty, 1994; Kesson et al., 1994; Mitchell, 1986; Nowell et al., 2004; Sharp, 1974; Smith, 1983). On their way to the surface kimberlites entrain components from various mantle reservoirs and also from the crust. Geochemical and isotop characteristics of the kimberlite sources are therefore prone to be highly corrupted. However, kimberlites commonly contain phenocrysts and megacrysts, and they may be the means to identify the uncorrupted composition. It has been shown that lithium and its isotopes are useful indicators for various mantle and subduction related processes as well as contamination and alteration (e.g. Marschall et al., 2007; Seitz et al., 2004; Seitz and Woodland, 2000; Tomascak et al., 2002; Woodland et al., 2002). Lithium concentrations and Li isotope characteristics of the kimberlite and its constituents may therefore help to a better understanding of the kimberlite genesis.

We studied the diamondiferous kimberlite from Roberts Victor (South Africa) and its olivine phenocrysts, megacrysts and xenocrysts.

METHODS

Mounted olivines were analysesd for major elements by electron microprobe (EPMA) and for Li and transition metals by Laser-Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS). Mineral separates and kimberlite whole rock were also analysed for Li-isotopes with Multi Collector (MC) ICPMS. All analyses were carried out at the Institut für Geowissenschaften, J.W. Goethe Universität Frankfurt. Rock digestion and column chemistry for Li separation followed the procedure of Seitz et al., 2004.

The MC-ICPMS allows simultaneous measurement of both ⁶Li and ⁷Li. Measurements were performed using a Cetac Aridus® nebuliser fitted with a PFA spray chamber and an ESI microconcentric-nebuliser with an uptake rate of 20µl/min. With the Finnigan standard cones (H-Cones) an intensity of 30-40 pA (=3-4 V using $10^{11} \Omega$ resistor) for ⁷Li at a 10 ppb concentration level is achieved. An analysis is carried out sequentially by 'bracketing' the sample with the L-SVEC standard (Flesch et al., 1973). Isotope compositions are expressed as per mil deviations from NIST L-SVEC the standard: δ^{7} Li=[[⁷Li/⁶Li]_{sample}/[⁷Li/⁶Li]_{L-SVECstd}-1]*1000. Internal precision is typically between 0.2-0.6‰ (2SE) and the long term reproducibility, determined on replicate measurements of the geological standard JB-2, is about 1.2‰ (2SD).

RESULTS

The Roberts Victor kimberlite is extremely rich in Li (> 60 ppm) and has a very light Li isotope signature $(\delta^7 \text{Li})$ of -3.4‰.

On the basis of major and minor elements three types of olivines with Mg-values (Mg#) of 90, 91 and 93 can be distinguished: Olivines with refractory Mg# of 93 and 91 have Li abundances of around 0.8 and 1.3 ppm and Sc concentrations of 0.6 and 2.1 ppm, respectively. Such values are typical for mildly to strongly depleted mantle sources (Fig. 1).

The third group, comprising more Fe-rich olivines (Mg# ~90), shows elevated and variable Li and Sc abundances (2.3 to 3.2 ppm and 4.3 to 12.3 ppm, respectively). Enrichment or depletion trends are similarly displayed by other transition metal elements such as V, Mn, Cr, Co or Ni.

The three olivine groups also reveal distinct Liisotope compositions, ranging from +6‰ for Mg# 93 olivines, through +3.4‰ for olivines with Mg# 91, to +1.8‰ for the more Fe-rich members (Mg# 90). The negative correlation of δ^7 Li with Mg# is mirrored by



the Li concentrations (Fig. 2). Based on Mg# as well as trace element abundances, refractory olivines are believed to be xenoxrysts, while the more Fe- and trace element rich olivines are phenocrysts.



Figure 1: Scandium concentrations plotted against lithium abundances of the three different olivine groups. Trace element concentrations of Mg# 93 and Mg# 91 olivines follow a depletion trend, while the more Fe-rich members plot along a crystal fractionation path. PUM: Field for 'Primitive Upper Mantle' composition. An olivine composition of a relative primitive garnet lherzolite from Vitim (Siberia) is depicted for comparison (Seitz et al., 1999; Seitz and Woodland, 2000).



Figure 2: Li isotope composition plotted against Lithium concentration for the three different olivine groups. Data for BSE (Bulk Silicate Earth) are taken from Seitz et al., 2007.

DISCUSSION AND CONCLUSIONS

The Li isotope composition of the relatively fresh Roberts Victor kimberlite is extremely light (δ^7 Li -3.4%) which is absolutely untypical for mantle derived melts such as MORB or OIB (e.g. N-MORB has a δ^7 Li of +3.4‰ ±1.2, (Tomascak et al., 2008). The suspicion is that this light signature stems from the incorporation and assimilation of the crustal wall rocks rather than from a mantle reservoir modified by the recycling of crustal material. Evidence for contamination by crustal material comes from the high Li concentrations of 64 ppm. From the Li abundances in the ol-phenocrysts and with $D_{Li}^{ol/melt}$ of 0.2-0.3 (e.g. Brenan et al., 1998) a Li concentration of 7-15 ppm can be expected in the kimberlite magma. This is 4 to 6 times lower than the measured concentrations. The calculated concentrations are within the range of mantle melts, i.e. the olivine phenocrysts reflect the original melt composition including a δ^7 Li of +1.9‰. This should be the non-corrupted magmatic value because the refractory olivine xenocrysts have their individual Li isotopic signature preserved. This should not be the case if the demonstrated fast Li diffusion and kinetic isotope fractionation in mantle minerals at magmatic temperatures (Jeffcoate et al., 2007; Lundstrom et al., 2005; Parkinson et al., 2007; Richter et al., 2003; Teng et al., 2006) was acting for a sufficiently long time on these xenocrysts. The assimilation of the Li-rich and isotopically light material must have occurred briefly before or upon eruption. Furthermore, the presence of the two olivine xenocrysts groups that retained the Li-signatures of their sources, argues for a very rapid transport to the surface after the entrainment in the kimberlite host. As the olivine compositions are not corrupted by late contamination with crustal wall-rock, it is justified to estimate the 'primary' kimberlite melt composition from the olivine phenocryst composition. They give Li abundances and Li isotope compositions for the kimberlite within the range of MORB or OIB compositions.

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