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Lithium elemental and isotopic disequilibrium in minerals from peridotite xenoliths from far-east Russia: Product of recent melt/fluid–rock reaction

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Abstract

Lithium concentrations and isotopic compositions of coexisting olivine and clinopyroxene (cpx) in well-characterized peridotite xenoliths from Tok (SE Siberian craton) and samples from two other far-east Russian localities reveal strong elemental and isotopic disequilibria, which correlates with bulk rock composition. Lithium concentrations in cpx from Tok (1–12 ppm) are equal to or significantly greater than those in coexisting olivines (1–5 ppm). The Li-rich cpx show core to rim zoning, indicative of Li infiltration from the grain boundaries. Olivines are generally unzoned, although Li concentrations can vary significantly from grain to grain. $^{ol/cpx}D$ varies from 0.2 to 1.0, which is lower than that expected for equilibrium partitioning ($^{ol/cpx}D_{eq}=1.1$ to 2.0), and reflects preferential Li enrichment in cpx. The Li isotopic compositions of both minerals range far beyond normal mantle δ^7Li of $\sim +4\pm2$. $\delta^7\mathrm{Li}_{cpx}$ (-0.8 to -14.6) is systematically lighter than δ^7Li of coexisting olivine (-1.7 to $+11.9$), and $\Delta^7\mathrm{Li}_{ol\text{-}cpx}$ varies from 2.8 to 22.9‰. The greatest elemental and isotopic disequilibria occur in the most fertile samples (lherzolites) and may reflect longer equilibration times and/or enhanced melt permeability in the more refractory samples. Collectively, these observations suggest that the peridotite minerals experienced Li addition via diffusion from a grain boundary melt or fluid shortly before or coincident with their entrainment into the host basalt (i.e., within tens of thousands of years, based on published diffusion coefficients for Li in cpx at the temperatures of equilibration). This diffusional ingress of Li generated large kinetic isotopic fractionation, leading to unusually light cpx and heavier olivines. Thus, low $\delta^7\mathrm{Li}_{cpx}$ do not reflect the influence of an exotic mantle component related to crustal recycling.

Keywords: upper mantle; metasomatism; Li diffusion; Li isotopes; isotopic disequlibrium; peridotite xenolith

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1. Introduction

Studies of Li and its isotopes (^{6}Li: 7.5% and ^{7}Li: 92.5% atomic abundance) in the solid Earth are rapidly increasing in number, as there is great interest in determining whether the Li isotope system will be

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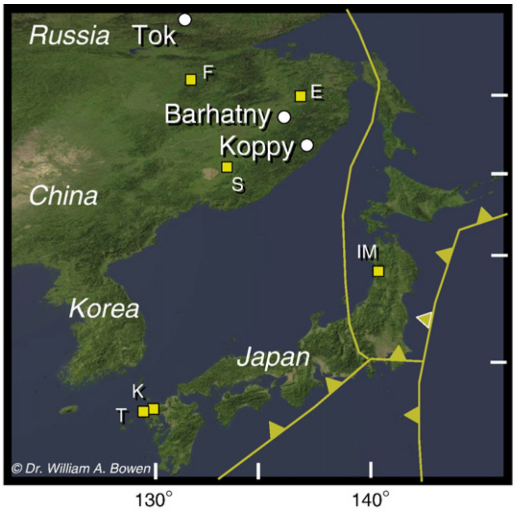

Fig. 1. Map of far-east Russia and vicinity. Circles show xenolith localities investigated here: Tok, Barhatny and Koppy. Whereas Tok occurs within the Precambrian Siberian craton, the latter two localities lie within the Sikhote-Alin Mountains, which run along the eastern seaboard of Russia. Squares are xenolith localities investigated by [29]. F = Fevralsky, E = Ennokentiev, S = Sveyagin, IM = Ichinomegata, T = Takashima and K = Kurose. Cpx from all of the far-east Russian peridotites plus those from Takashima and Kurose have anomalously light δ^7Li. Plate boundaries (subduction zone and transform boundary) are overlain. Latitude and longitude marked in degrees north and east, respectively. Base map courtesy of Dr. William A. Bowen, California Geographical Survey — http://geogdata.csun.edu.

useful for tracing crust–mantle recycling (e.g., [12,38] and references therein). Lithium isotopes can be strongly fractionated at low temperatures, with δ^7Li $(=(^7\mathrm{Li}/^6\mathrm{Li}_{\mathrm{sample}}/^7\mathrm{Li}/^6\mathrm{Li}_{\mathrm{L\text{-}SVEC\ \ standard}}-1)*10^3)$ values ranging from +32 in sea water (up to +56 in some sedimentary pore fluids [48]) to very light isotopic compositions in eclogites (≥ -12), which are interpreted as analogs of dehydrated oceanic crust [49]. As for oxygen isotopes, δ^7Li in altered oceanic crust can be either heavy (up to +14) or light (down to − 2), depending on the temperature of alteration [2,7,8]. Because Li is a fluid-mobile element (${}^{\mathrm{cpx/fluid}}D_{\mathrm{Li}}=0.2$, [4]), it was initially expected that heavy seawater Li incorporated into altered oceanic crust should be removed from the slab during subduction zone metamorphism and follow other fluid-mobile elements into the mantle wedge, ultimately to be sampled again in island arc lavas. However, studies of island arcs show that Li is decoupled from other fluid-mobile elements such as B and Ba, and most island arc lavas have δ^7Li that are indistinguishable from those of MORB ([38], and references therein). Studies of subduction zone metamorphic rocks suggest that δ^7Li may be fractionated during dehydration [49], a supposition supported by recent fluid–pyroxene partitioning data [47]. Thus, the isotopic composition of recycled Li remains a matter of speculation [12].

One way to access the Li isotopic composition of the upper mantle is through the study of peridotite xenoliths, carried in rapidly erupting basalts and kimberlites. Indeed it is through such studies that the composition of the Earth's upper mantle has been defined for major and trace elements [20,27] and for a number of isotopic systems [25,28]. To date, studies of Li isotopes in mantle xenoliths reveal a great range in compositions. The first measurements of whole rock peridotites yielded δ^7Li roughly similar to those of MORB [6,9]. Later studies that focused on mantle xenoliths revealed a more complicated story. Nishio et al. [29] document very large variations in δ^7Li in cpx from mantle xenoliths from far-east Russia and SW Japan. They observed a rough correlation between δ^7Li and Nd and Sr isotopes and suggested that the low δ^7Li reflected a component derived from recycled dehydrated basaltic oceanic crust (EM1, based on Sr and Nd isotopes). In contrast, other studies [21,24,33] find a narrower range of δ^7Li in peridotite xenoliths from a variety of settings (−2 to +4) and, where data exist [33], no correlation between δ^7Li and radiogenic isotope compositions of the cpx.

Here, we report Li concentrations and isotopic compositions of pure olivine and cpx separates from well-characterized and variably (but typically strongly)

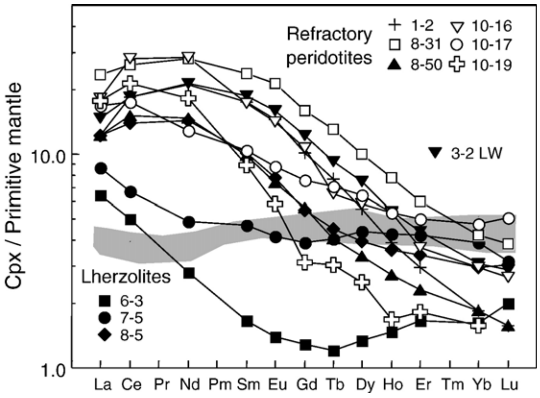

Fig. 2. Primitive mantle-normalized REE patterns of cpx from the Tok xenoliths measured by LA-ICP-MS (data from [15]). LREE-enrichments in the Tok cpx are negatively correlated with modal cpx in the LH series xenoliths [15]. Cpx from refractory peridotites (harzburgites and refractory lherzolites with 3–6% cpx) have strongly enriched LREE and variably depleted HREE. In contrast, cpx from most fertile lherzolites (17% cpx; gray field) have relatively flat patterns at ~5 times primitive mantle. Three moderately refractory lherzolites (10–14% cpx: 6-3, 7-5 and 8-5) show LREE-enrichments. A single wehrlite from the LW series (3-2 LW), for which Li analyses are made, is also shown. Primitive mantle values are from [27].