9th International Kimberlite Conference Extended Abstract No. 9IKC-A-00157, 2008

Trace element and isotopic effects of mantle metasomatism by carbonatitic and alkaline silicate melts in the lower cratonic mantle lithosphere

Stephen F. Foley and Dorrit E. Jacob

Institute for Geosciences, University of Mainz, 55099 Mainz, Germany

It has long been recognized that the radiogenic isotope signatures of many alkaline rocks from cratons and surrounding areas (kimberlites, lamproites, carbonatites, ultramafic lamprophyres, nephelinites and melilitites) require source components which have been isolated from the convecting mantle for hundreds or even thousands of millions of years (Smith, 1983; Nelson et al., 1986; Nowell et al., 2004; Tappe et al., 2007). However, the mechanisms of enrichment, whether pervasive metasomatism (Lloyd & Bailey, 1975) or veined lithosphere (Foley, 1992), and the type of melt are still debated.

The types of melt produced by partial melting of volatile-bearing peridotites are especially poorly known for pressures of 4-8 GPa corresponding to the lower half of cratonic mantle lithosphere. Many alkaline rocks such as kimberlites, carbonatites and ultramafic lamprophyres appear to require oxidizing conditions in which CO_2 and H_2O would be present during melting, whereas many lamproites appear to be formed in reducing conditions in which H_2O and perhaps CH_4 , but no CO_2 can be present (Foley, 1989).

In oxidizing conditions in the presence of CO_2 and H_2O , initial melts are thought to range from carbonatitic at the solidus to compositions intermediate between carbonatite and alkaline silicate at higher temperatures, but still low degrees of melting (Dalton and Presnall, 1998; Brey et al., 2008), but trace element compositions of such melts have only very recently become available to test the trace element and long-term isotopic effects of metasomatism by such melts (Brey et al., 2008; Foley et al., 2008).

Ever since the discovery in high pressure experiments that carbonatite melts should result from melting of peridotite in the presence of small amounts of CO₂ and H₂O, a role for ephemeral carbonatite melts in metasomatism of mantle peridotite at depths of 55-65 km has been emphasized (Green and Wallace, 1988), and the possibility of the origin of some carbonatites as primary melts of the mantle has been entertained. Due to the strong reduction in solidus temperature at 19-21 kbar, carbonatitic melts moving towards the Earth's surface should react with peridotite, increasing the proportion of pyroxenes in the mantle, and releasing CO_2 in fluid form. Evidence for this increase in modal clinopyroxene has been identified in many mantle xenoliths (Yaxley et al., 1991; Ionov et al., 1993; Rudnick et al., 1993).

The role for carbonatitic melts at higher pressures (30-60 kbar) is controversial due to the paucity of experimental constraints on melt compositions close to the mantle solidus. Furthermore, the exact role of carbonatitic vs. carbonate-silicate melts is debated: ultramafic lamprophyres and kamafugites appear to require the involvement of distinct metasomatic vein assemblages with modal carbonate and phlogopite (Foley et al., 2002; Tappe et al. 2007), and not the elimination of carbonatitic melts by thorough metasomatic reaction with peridotite.

Recent calculations of the isotopic effects of metasomatism by carbonatitic melts emphasize the short-lived nature of carbonatite melts in the mantle, but artificially divorced the effects of the carbonate and silicate



components (Bizimis et al. 2003). These studies predicted that carbonatite metasomatism would lead rapidly to $\varepsilon Nd - \varepsilon Hf$ signatures well outside the terrestrial array, and, therefore, that carbonatite metasomatism has not been of any long-term importance in mantle evolution. If correct, this amounts to an important constraint from isotope geochemistry on petrological mechanisms operating in the source regions of alkaline magmas.

Here, we calculate the trace element enrichment and isotopic effects of metasomatism by a range of realistic carbonatite, carbonatesilicate and aklaline silicate melts at pressures between 20 and 60 kbar, constrained by requirements from alkaline rock geochemistry and recent high pressure experimental studies. Trace element contents in carbonatite and carbonate-silicate melts at 5 GPa pressure (Foley et al., 2008) indicate that low-degree melts of peridotite in oxidizing conditions will not be substantially enriched relative to the restite (enrichment factors mostly 2-19) nor will significant inter-element fractionation occur. In terms of trace elements, this means that the high Zr/Hf and low Ti/Eu and Y/Ho thought to be characteristic for carbonatite metasomatism will not be caused by carbonate-rich low-degree melts of peridotite at these high pressures. This is partly in agreement with experimental partitioning studies at lower pressures in which strong fractionation of Zr from Hf could not be verified (Klemme et al., 1995). Furthermore, enrichment in light REE appears to be less than at lower pressures of 2–3 GPa (Brenan & Watson, 1991; Blundy & Dalton, 2000). In terms of radiogenic isotopes, the carbonaterich initial melts do not strongly fractionate the parent and daughter element pairs Sm/Nd, Lu/Hf and Rb/Sr, so that time-integrated isotope ratios will not lead to strong deviations from the initial position of the host peridotite even after long spans of geological time. These carbonate-rich near-solidus melts cannot cause the strong deviations from bulk earth or peridotite positions in⁸⁷Sr/⁸⁶Sr or particularly ɛNd, ɛHf. Strong deviations from the terrestrial $\operatorname{arrayin} \varepsilon Nd - \varepsilon Hf$ of the type described by Bizimis et al. (2003) is not to be

expected; their conclusions stem from the assumption that the carbonate portion of initial mantle melts devoid of the silicateoxide portion represents the character of incipient mantle melts. Real mantle melts at high pressures have compositions intermediate between those normally considered to be carbonate or silicate melts, and have 10-15 wt% of SiO₂, MgO, CaO and K₂O (Foley et al., 2008).

Strongly enriched trace element patterns and strongly enriched radiogenic isotope signatures imparted to the lower cratonic lithosphere by melt metasomatism are more likely due to alkaline silicate melts caused by melting under reducing conditions. These are more efficient causes of time-integrated enriched isotope signals where they result in separate vein assemblages with accessory phases that are not stable or not common in peridotites.

References

- Bizimis M, Salters VJM & Dawson JB (2003) The brevity of carbonatite sources in the mantle: evidence from Hf isotopes. Contributions to Mineralogy and Petrology 145, 281-300.
- Blundy JD & Dalton JA (2000) Experimental comparison of trace element partitioning betwen clinopyroxene and melt in carbonate and silicate systems, and implications for mantle metasomatism. Contributions to Mineralogy and Petrology 139, 356-371.
- Brenan JM & Watson EB (1991) Partitioning of traceelements between carbonate melt and clinopyroxene and olivine at mantle P-T conditions. Geochimica et Cosmochimica Acta 55, 2203-2214.
- Brey GP, Bulatov VK, Girnis AV & Lahaye Y (2008) Experimental melting of carbonated peridotite at 6-10 GPa. Journal of Petrology 49, 797-821.
- Dalton JA & Presnall DC (1998) The continuum of primary carbonatitic-kimberlitic melt compositions in equilibrium with lherzolite: Data from the system CaO-MgO-Al₂O₃-SiO₂-CO₂ at 6 GPa. Journal of Petrology 39, 1953-1964.
- Foley SF (1989) Experimental constraints on phlogopite chemistry in lamproites: 1. the effect of water activity and oxygen fugacity. European Journal of Mineralogy 1, 411-426.
- Foley S (1992) Vein-plus-wall-rock melting mechanisms in the lithosphere and the origin of potassic alkaline magmas. Lithos 28, 435-453.
- Foley SF, Andronikov AV & Melzer S (2002) Petrology, geochemistry and mineral chemistry of



ultramafic lamprophyres from the Jetty Peninsula area of the Lambert-Amery Rift, Eastern Antarctica. Mineralogy and Petrology 74, 361-384.

- Foley SF, Yaxley GM, Rosenthal A, Rapp RP & Jacob DE (2008) Experimental melting of peridotites in the presence of CO₂ and H₂O at 40-60 kbar. 9th Kimberlite Conference Ext. Abs 9IKC-A-00156.
- Green DH & Wallace ME (1988) Mantle metasomatism by ephemeral carbonatite melts. Nature 336, 459-462.
- Ionov DA, Dupuy C, O'Reilly SY, Kopylova MG & Genshaft YS (1993) Carbonated peridotite xenoliths from Spitsbergen: implications for trace element signature of mantle carbonate metasomatism. Earth and Planetary Science Letters 119, 283-297.
- Klemme S, Van der Laan SR, Foley SF & Günther D (1995) Experiemntally determined trace and minor element partitioning between clinopyroxene and carbonatite melt under upper mantle conditions. Earth and Planetary Science Letters 133, 439-448.
- Lloyd FE & Bailey DK (1975) Light element metasomatism of the continental mantle: the evidence and the consequences. Physics and Chemistry of the Earth 9, 389-416.
- Nelson DR, McCulloch MT & Sun S-S (1986) The origins of ultrapotassic rocks as inferred from Sr, Nd and Pb isotopes. Geochimica et Cosmochimica Acta 50, 231-245
- Nowell GM, Pearson DG, Bell DR, Carlson, RW, Smith CB, Kempton PD & Noble SR (2004) Hf isotope systematics of kimberlites and their megacrysts: new constraints on their source regions. Journal of Petrology 45, 1583-1612.
- Rudnick RL, McDonough WF & Chappell B (1993) Carbonatite metasomatism in the northern Tanzanian mantle: petrographic and geochemical characteristics. Earth and Planetary Science Letters 114, 463-475.
- Smith CB (1983) Pb, Sr and Nd isotopic evidence for sources of southern African Cretaceous kimberlites. Nature 304, 51-54.
- Tappe S, Foley SF, Stracke A, Romer RL, Heaman LM, Kjarsgaard BA, Joyce N. (2007) Craton reactivation on the Labrador Sea margins: ⁴⁰Ar/³⁹Ar age and Sr-Nd-Hf-Pb isotope constraints from alkaline and carbonatite intrusives. Earth and Planetary Science Letters 256, 433-454.
- Yaxley GM, Crawford AJ & Green DH (1991) Evidence for carbonatite metasomatism in spinel peridotite xenoliths fromwestern Victoria, Australia. Earth and Planetary Science Letters 107, 305-317.

