Experimental formation of pyroxenite veins by reactions between olivine and Si, Al, Ca, Na, and Cl-rich fluids at 800 °C and 800 MPa: Implications for fluid metasomatism in the mantle wedge

THOMAS B. GRANT1,2,*, DANIEL E. HARLOV1, AND DIETER RHEDE1

1Deutsches GeoForschungsZentrum, Telegrafenberg, D-14473 Potsdam, FR Germany
2Department of Geology and Mineral Resources Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway

ABSTRACT

Fluids buffered by a plagioclase matrix are experimentally reacted with olivine megacrysts at 800 °C and 800 MPa (piston-cylinder press, CaF2 assembly) to form secondary veins of orthopyroxene ± clinopyroxene in the olivine. Fluids utilized were varied in both amount (0–2 wt%) and salinity (0–8 M NaCl). Assuming equilibrium with the plagioclase matrix, they are presumed enriched in Si, Al, Ca, Na, and Cl and are thereby similar in composition to slab-derived fluids. The experiments provide controlled, multi-component analogs of Si-metasomatism in the mantle wedge above subduction zones. The veins are dominated by orthopyroxene with minor clinopyroxene and form complex interconnected networks along fractures in the olivine. The reaction is rate limited by interfacial process of dissolution and precipitation. Porosity is developed throughout the veins and along sub-grain boundaries in the olivine megacrysts. These veins strongly resemble the textures observed in secondary metasomatic orthopyroxene veins widely reported in upper mantle xenoliths within arc magmas. A review of literature data on natural samples and experiments suggests that orthopyroxene ± clinopyroxene veins primarily form between 750–950 °C and over a large pressure range from 0.8–3.4 GPa. The abundance and composition of these metasomatic veins may vary as a function of pressure, variances in the fluid-rock partition coefficients, and/or by modification of the metasomatic fluid during the reaction.

Keywords: Experimental petrology, metasomatism, fluid, orthopyroxene veins

INTRODUCTION

During partial melting or dehydration of subducting oceanic lithosphere, Si-rich melts (Schiano et al. 1995; Prouteau et al. 2001), aqueous fluids (Manning 2004), or supercritical liquids (Hermann et al. 2006) are released into the overlying mantle wedge. This leads to Si metasomatism in the mantle wedge by the consumption of olivine and the precipitation of secondary orthopyroxene (as well as other phases). This form of metasomatism can be most simply expressed by the following relationship:

$\mathrm{Mg,Fe}_2\mathrm{SiO}_3 + \mathrm{SiO}_2 = 2(\mathrm{Mg,Fe})\mathrm{SiO}_4$.

Metasomatic orthopyroxene, formed by infiltrating Si-rich melts or fluids in the sub-arc mantle, have been observed in mantle xenoliths within arc lavas (Smith and Riter 1997; Smith et al. 1999; Grégoire et al. 2001; McInnes et al. 2001; Franz et al. 2002; Ariai et al. 2003, 2004; Downes et al. 2004; Bell et al. 2005; Berly et al. 2006; Ishimaru et al. 2007; Grégoire et al. 2008; Ishimaru and Ariai 2009, 2011; Soustelle et al. 2010) and peridotite complexes (Morishita et al. 2003; Malaspina et al. 2006; Vrijmoed et al. 2013). Experimental studies involving melts (Rapp et al. 1999, 2010; Malik et al. 2015) or crystalline quartz + fluid (Yund 1997; Milke et al. 2009, 2011, 2013; Gardés et al. 2012) have also shown that olivine will be consumed to form secondary orthopyroxene.

Reactions between slab-derived fluids or melts and the mantle wedge have significant implications for the recycling of elements at subduction zones and the compositions of arc lavas. It is therefore vital to understand the exchange of major and trace elements during reactions between Si-rich fluids and olivine-dominated peridotite rocks. For example, how do the compositions of pyroxenite veins vary and how are metasomatic fluids modified by reactions in the mantle wedge? These processes are poorly understood (Spandler and Pirard 2013).

In terms of major element chemistry, slab-derived fluids are thought to be rich in Si, Al, Na, K, Ca, and Cl as well as fluid mobile elements such as Li, Rb, and Pb but poor in Mg and Fe (Manning 2004; Berly et al. 2006). Due to large similarities in the trace elements and isotopic signatures of arc magmas and the short timescales of recycling from oceanic crust, it is thought that slab-derived fluids are primarily transported through the mantle wedge by channelized flow (Zack and John 2007). However, pervasive flow of fluids has also been observed (Malaspina et al. 2006), and it is likely that some pervasive flow may occur perpendicular to the main channel. In such a scenario the majority of the fluid may pass unmodified for substantial distances in the mantle wedge, but the peridotite wall rocks become partially modified by the influx Si-rich fluids. Furthermore, diapiric melt/lange zones may also bring felsic material in contact with mafic peridotite rocks (Marschall and Schumacher 2012). Exchange of elements between them, via channelized, Si-rich fluids, can...