Olivine from aillikites in the Tarim large igneous province as a window into mantle metasomatism and multi-stage magma evolution

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Abstract

Aillikites are carbonate-rich ultramafic lamprophyres, and although they are volumetrically minor components of large igneous provinces (LIPs), these rocks provide important clues to melting and metasomatism in the deep mantle domain during the initial stages of LIPs. In this study, we investigate the Wajilitag “kimberlites” in the northwestern part of the Tarim LIP that we redefine as hypabyssal aillikites based on the following features: (1) micro-phenocrystic clinopyroxene and Ti-rich andradite garnet occurring in abundance in the carbonate-rich matrix; (2) Cr-spinel exhibiting typical Fe-Ti enrichment trend also known as titanomagnetite trend; and (3) olivine showing dominantly low Mg values (Fo < 90). To constrain the magma source and evolution, the major, minor, and trace element abundance in olivine from these rocks were analyzed using electron microprobe and laser ablation-inductively coupled plasma-mass spectrometry. Olivine in the aillikites occurs as two textural types: (1) groundmass olivines, as sub-rounded grains in matrix, and (2) macrocrysts, as euhedral-anhedral crystals in nodules. The groundmass olivines show varying Mg (Fo89–Fo80) with high-Ni (1606–3418 ppm) and Mn (1424–2860 ppm) and low-Ca (571–896 ppm) contents. In contrast, the macrocrysts exhibit a restricted Fo range but a wide range in Ni and Mn. The former occurs as phenocrysts, whereas the latter are cognate cumulates that formed from earlier, evolved aillikite melt. The two olivine populations can be further divided into sub-groups, indicating a multi-stage crystallization history of the aillikite melt. The crystallization temperatures of groundmass olivines and macrocrysts in dunite nodules as computed from the spinel-olivine thermometers are 1005–1136 and 906–1041 °C, respectively. The coupled enrichment of Ca and Ti and lack of correlation between Ni and Sc and Co in the olivine grains suggest a carbonate-silicate metasomatized mantle source. Moreover, the high 100·Mn/Fe (average 1.67) at high Ni (up to 3418 ppm), overlapping with OIB olivine, and the 100·Ni/Mg (~1) of primitive Mg-Ni-rich groundmass olivines suggest a mixed source that involved phlogopite- and carbonate-rich metasomatic veins within mantle peridotite.

Keywords: Trace elements, LA-ICP-MS, olivine, aillikites, carbonate-phlogopite metasomatism, Tarim large igneous province

Introduction

Ultramafic lamprophyres (UMLs) generally mark the earliest magmatic activity in some large igneous provinces (LIPs) (Queen et al. 1996; Riley et al. 2003; Tappe et al. 2006). Aillikites (or carbonate-rich UMLs) are high-Ca (12–20 wt% CaO) and low-Si (22–37 wt% SiO2) hypabyssal rocks, rich in Mg, Ni, Cr, Ba, Sr, REE, and volatiles (Rock 1991; Tappe et al. 2006, 2007, 2008). Although aillikites are volumetrically insignificant in LIPs, their deep-mantle derivation, unique geochemistry, and close relationship with diamonds make them potential targets for scientific investigations and economic significance (Tappe et al. 2006; Francis and Patterson 2009; Mitchell and Tappe 2010; Hutchison et al. 2018). The genesis of these ultramafic rocks has remained controversial, primarily because of the uncertainty in the source rock lithology. Petrological and geochemical studies suggest that their formation involved CO2- and H2O-rich melting, with the presence of phlogopite and carbonate in the source (Andronikov and Foley 2001; Upton et al. 2006; Foley et al. 2009; Tappe et al. 2017). However, isotope and trace element data seem to indicate a mixed source involving distinct carbonate- and phlogopite-rich veins within depleted peridotite, instead of a homogeneously metasomatized lithospheric mantle (Tappe et al. 2006, 2008; Nasir et al. 2011).

Olivine, the earliest crystalline phase in mantle-derived magmas, acts as a good proxy to evaluate the primitive composition of magmas and their mantle source lithology (Sobolev et al. 2005, 2007; Arndt et al. 2010; De Hoog et al. 2010; Herzberg 2011; Foley et al. 2013; Cordier et al. 2015; Seager et al. 2015; Giuliani and Foley 2016). Forsterite-rich [Fo = 100·Mg/(Fe+Mg) molar] olivine in volcanic rocks, for instance, carries information on the mantle source. The distribution of some elements (Ni, Mn, Co) in olivine, which depends upon the bulk partition coefficient during mantle melting, can be employed to infer the modal abundance of olivine in the residual mantle (Sobolev et al. 2005, 2007; Straub et al. 2008; Foley et al. 2011, 2013). In addition, the content of other trace elements (Ca, Ti, Li, Zn) in olivine, governed dominantly by their primitive content in the source, can be used to decipher the nature of metasomatic agents (Prelevi¢ and Foley 2007; Foley et al. 2011, 2013; Prelevi¢ et al. 2013; Rooney et al. 2020).

In this paper, we investigate the mineralogy and mineral