Insights into the petrogenesis of the West Kimberley lamproites from trace elements in olivine

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Introduction

Minor and trace element abundances in olivine can provide important information on the origin and evolution of a range of mantle-derived magmas (e.g. Foley et al., 2013). Mantle olivine may record a residue of partial melting, and the impact of metasomatism over time. Magmatic olivines can record the crystallisation history of the magma and help to identify the rock assemblages present in the source region.

We report minor and trace element analyses of olivine from the Miocene (17−22 Ma) olivine lamproites and olivine-bearing leucite lamproites of the West Kimberley province of Western Australia with the aim of assessing the extent to which the trace element inventories of olivine provide information on 1) the nature of the mantle sampled by the lamproites, 2) the mantle processes, including metasomatism, that may have affected the mantle source region of the lamproites, and 3) magmatic processes involved in lamproite formation and evolution.

Petrography

The West Kimberley lamproite province lies at the southwest margin of the Kimberley Craton of Western Australia extending from the Proterozoic King Leopold Orogen bordering the craton across the Fitzroy Trough in the northern Canning Basin. It comprises some 180 individual bodies occurring as volcanic pipes, plugs, sills and dykes clustered in three main fields (Jaques et al. 1984, 1986). The Ellendale field in the north is dominated by olivine lamproite pipes, many of which carry diamonds at low concentrations with Ellendale pipes 4 and 9 being mined in the period 2002−2009. The two other main fields (Noonkanbah and Calwynyardah) as well as the smaller clusters and isolated lamproiite intrusions are dominated by leucite lamproites occurring as pipes, plugs, sills and dykes.

Magmatic olivine occurs as sub- to euhedral phenocrysts and microphenocrysts in olivine-diopside-leucite lamproites with as little as 7 wt % MgO through to the diamondiferous Ellendale olivine lamproites with up to 32 wt % MgO (Jaques et al. 1984, 1986; Stachel et al. 1994). The olivine lamproites are characterised by abundant mantle olivine in the form of dunite micro-xenoliths and xenocrysts (both characterised by solid-state deformation), and anhedral macrocrysts of uncertain origin. In addition to the micro-xenoliths of dunite, sparse small xenoliths of harzburgite containing minor Cr-Al spinel in symplectic intergrowths with Cr-diopside (inferred to be a re-equilibated former garnet) are found in Ellendale 7 (Jaques et al. 1984).

Analytical Results

Major and minor elements were obtained by Cameca SX-100 EPMA operating at 15 kV and 30 nA employing a range of natural and synthetic standards and full ZAF corrections. Abundances of Li, Na, Al, Si, P, K, Ca, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Sr, Y, Zr, and Nb were determined by LA-ICP-MS at the Australian National University using Si values determined by EPMA as an internal standard and NIST SRM 612 as reference standard. Data were processed using the Iolite software package (Paton et al. 2011).

The ***mantle olivines*** have a limited compositional range ($\mathrm{Mg}_{90\text{–}92.5}$) with most being of uniform composition apart from narrow (< 100 µm) rims (Fig. 1a). Mantle olivines with Mg < 91 invariably have more Mg-rich rims ($\mathrm{Mg}_{91\text{-}93}$) whereas the more Mg-rich mantle olivines either have no discernable zoning or normal or reverse zoning. The mantle olivines are all characterised by high Ni (2700−3300 ppm), uniform Mn (600−1100 ppm), and low Ca (≤ 420 ppm). All have low Li (1.2−2.9 ppm), Na (< 190 ppm), Al (≤ 130 ppm), Sc (< 5 ppm), Ti (≤ 160 ppm), and V (3−9 ppm), modest Cr (90−430 ppm) and Co (130−150 ppm), and extremely low Sr (< 0.25 ppm), Zr (< 0.025 ppm) and Nb (< 0.01 ppm). Macrocrystal olivines have very similar Mg ($\mathrm{Mg}_{90.2\text{–}92.9}$) and trace element abundances implying that most are also of mantle origin although a few with lower Ni and higher Mn contents lie outside the mantle cluster and on the magmatic trend (Fig. 1b): these may be early phenocrysts. Olivine in the harzburgite xenolith ($\mathrm{Mg}_{92.4}$) shows strong depletion in lithophile elements, at the low end of the range of mantle olivine values (e.g. 4 ppm Na, 10 ppm Al, 60 ppm Ca, 4 ppm Ti, 45 ppm Cr) but similar Ni, Co and Ni to the other mantle olivines. Olivine inclusions in diamonds from Ellendale (Griffin et al., 1988) show a much wider range in Mg ($\mathrm{Mg}_{93.5\text{–}88.3}$) but, with the exception of the Fe-rich olivine, have Cr, Mn and Ni contents comparable with mantle olivines (Fig. 1a).

The abundances of Al, Mn and V suggest that most of the West Kimberley mantle olivines are derived from garnet peridotite but a few of the macrocrysts are likely derived from spinel peridotite based on the discrimination diagrams of De Hoog et al. (2010) and Bussweiler et al. (2017). Estimated equilibration temperatures based on Al in olivine (Bussweiler et al. 2017) for the mantle olivines (Fig. 1c) lie in the range ~900−1270°C (at an assumed pressure of 5 GPa; Fig. 1c). The mantle olivines display a trend of increasing Ti (and Zr) with decrease in Mg# in olivine (Fig. 1d).

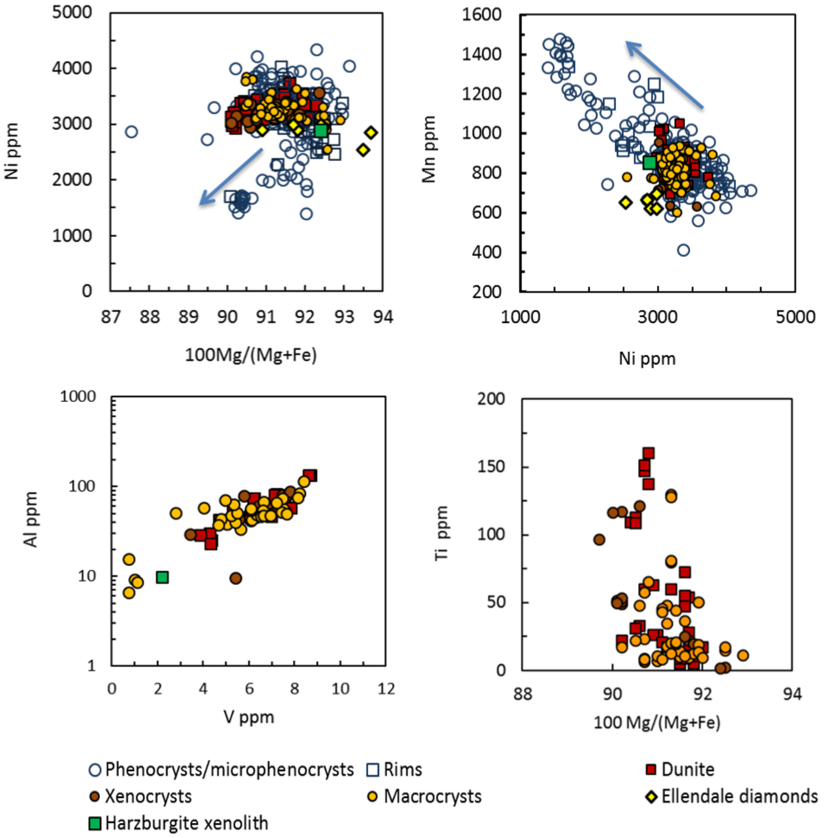

Figure 1. Minor and trace element variation in the West Kimberley olivines: a) 100Mg/(Mg+Fe) versus Ni (ppm, EPMA data); b) Mn versus Ni (ppm, EPMA data); c) V versus Al abundances (ppm) in dunite, xenolith, and macrocyst olivine (LA-ICP-MS data); d) Ti versus Zr abundances (ppm) in dunite, xenolith, and macrocyst olivine (LA-ICP-MS data). Arrows indicate direction of magmatic trends.

The ***magmatic olivines*** have a wider range in Mg ($Mg_{87.5\text{-}93}$) and most trace element abundances than the mantle olivines. The magmatic olivines show a decrease in Cr and Ni, and an increase in Mn abundances with falling Mg# (Fig. 1a, b), consist with fractional crystallisation. Fractionation trends range from 4300 ppm to 1400 ppm for Ni and from 550 to 1500 ppm for Mn. The microphenocrysts in the olivine-diopide-leucite lamproites commonly have high Ni, Mn and Ca contents. Rims on the mantle olivines have an identical compositional range to the phenocrysts and microphenocrysts, confirming their magmatic origins. Trace element abundances generally overlap the compositions of the mantle olivines but show a greater range in Cr (20−1050 ppm) and extend to higher abundances of Li (to 6 ppm), Na (to 260 ppm), Al (to 150 ppm), Ca (to 1230 ppm), Ti (to 190 ppm), Sr (to 1 ppm), Y (to 40 ppb), Zr (to 1.2 ppm), and Nb (to 350 ppb). Abundances of many elements (e.g. Na, Al, Ca, Ti, Co, Mn) increase with decrease in Mg# and Ni, consistent with melt fractionation.

The mantle olivine Mg-values and trace element abundances are typical of moderately refractory sub-cratonic mantle of garnet (and minor spinel) peridotite equilibrated at ~900−1270^{o}C (at 5 GPa). Variations in major and trace elements in olivine are inferred to reflect variable degrees of depletion during partial melting of the mantle. However, olivines with higher Fe, Ti, Sr, Zr and Nb may record metasomatism of previously more refractory mantle.

The West Kimberley lamproites are believed to have been derived from formerly depleted mantle peridotite that has undergone ancient (>2 Ga) geochemical enrichment that likely involved addition of a subducted sedimentary component based on their K/Rb, K/Ba, Ba/La and Th/U ratios and Sr, Nd and Pb isotope compositions (Jaques et al. 1984; Nelson et al. 1986). However, the low Li contents of the West Kimberley olivines are typical of cratonic mantle, and unlike those in potassic magmas from orogenic regions (up to 45 ppm; Foley et al. 2013). These observations can be reconciled if Li added to the mantle from subducted sediment in the past has been largely lost by diffusion over time.

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