Mineralogy, Geochemistry, and Petrogenesis of Paleoproterozoic Alkaline Magmas in the Yilgarn Craton, Western Australia

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Introduction

The Yilgarn Craton in Western Australia is a world-class metallogenic Archean craton hosting considerable metal resources, including komatiite-associated Ni-sulfides and orogenic Au. Interest in the geodynamic evolution of the crust and upper mantle in the craton has increased greatly over the last decade through various studies, which mainly relied on regional scale geophysical datasets, and geochemical, isotopic and geochronological information of subalkaline magmas felsic, mafic and ultramafic magmas (e.g. Blewett et al. 2010; Mole et al. 2013). These previous studies have helped establish the four-dimensional evolution of the lithospheric mantle under the Yilgarn Craton. However, these studies only provide limited information about the composition of the underlying lithospheric-asthenospheric mantle which remains poorly defined from a geochemical and isotopic point of view.

The study of the poorly characterised alkaline magmas (kimberlites, lamprophyres and carbonatites) that are distributed throughout the eastern part of the Yilgarn Craton as well as along its northern margins can address this knowledge gap and provide invaluable information about the nature of the lithosphere and asthenosphere. The aim of this study is to establish the mineralogical, geochemical and petrogenetic features of the alkaline magmas as probes to unravel the composition of the upper mantle under the Yilgarn Craton.

Alkaline Rocks in the Yilgarn Craton

The Yilgarn Craton contains various types of alkaline magmas, including kimberlites, carbonatites and two types of lamprophyres - ultramafic lamprophyres(UML) and calc-alkaline lamprophyres (CAL) - in the eastern area and northern margins of the craton. The spatial distribution of the alkaline rocks in the craton can be subdivided into two groups: off-craton and on-craton. The off-craton alkaline rocks comprise UML and kimberlites on the northern boundary of the craton with ages of 1324 ± 4 and 1900-1700 Ma (Shee et al. 1999) and the Norseman UML on the south-eastern boundary with an age of 849 Ma (Robey et al. 1989). The alkaline rocks within the Yilgarn Craton are older than the off-craton alkaline rocks, with ages of more than 2000. The age of kimberlites, UML and carbonatites in the centre of the eastern part of the craton is 2025 ± 10 Ma (Graham et al. 2004). Most CAL have not been dated except for those in Kambalda with an unpublished U-Pb zircon age of 2684 ± 6 Ma cited in Perring et al. (1989).

The alkaline rocks of the Yilgarn Craton mainly show a volcanic texture comprising phenocrysts of mafic minerals (e.g. olivines, phlogopites, and amphiboles) and felsic matrix phases (e.g. feldspars and quartzs). Phlogopites and amphiboles are common minerals in the Yilgarn alkaline rocks, and occur as macrocrysts (> 0.3mm), microcrysts (0.3-0.1 mm), phenocrysts and groundmass crystals. CAL contain both minerals and clinopyroxenes as variable phases from groundmass to macrocrysts with a matrix of albites, K-feldspars, quartzs, titanites, and apatites. UML generally consist of macrocrysts and microcrysts of phlogopites, and are characterized by primary carbonate minerals (calcites and dolomites) as a groundmass phase with clinopyroxenes, phlogopites, apatites, magnetites and ilmenites and less feldspar than CAL. Yilgarn carbonatites conatin phlogopites and apatites as variable sizes (up to ~0.7 mm) with olivine and magnetite microcrysts, inclduing a groundmass phase of primary calcites and dolomites, and fine-grained pyrochlore and barite (< 20 μm). Kimberlites have an rounded huge olivines (up to ~0.6 mm), including phlogopite, pyroxene, ilmenite, magnetite and monazite groundmasses.

Bulk-rock major element and PGE compositions

Results of whole rock analysis of the Yilgarn alkaline rocks exhibit different geochemical characteristics of major and platinum group elements (PGE) for the different the alkaline rock types. CAL show distinct geochemistry and have higher SiO_2 contents ranging from 50.6 to 59.3 wt.% with lower contents of Fe_2O_3 (5.5 - 8.4 wt.%) and MgO (4.2 – 9.2 wt.%) compared to the other alkaline rocks. Both kimberlites and UML have low SiO_2 contents (27.1 – 47.7 and 20.4 – 42.7 wt. % respectively), while TiO_2 contents in kimberlites are generally lower than those of the UML (0.5 – 3.9 vs. 2.4 – 8.3 wt.%).

Primitive-mantle normalized PGE patterns of CAL show strong fractionation with relative depletion in Os, Is and Ru (IPGE), enrichment in Rh, Pt, and Pd (PPGE) and high $(Pd/Ir)_N$ from 11.64 to 24.58, reflecting a less primitive PGE component (McDonald et al. 1995). In contrast, other alkaline rocks such as carbonatites, UML and kimberlites are characterized by much less fractionation of PPGE from IPGE with low $(Pd/Ir)_N$ values (< 10.60). These characteristics of CAL are similar to off-craton alkaline rocks and alkali volcanics, while UML and kimberlites show similar PGE patterns of on-craton kimberlites reported by McDonald et al. (1995). This may indicate that the source of CAL was shallower in the upper mantle than the other alkaline rocks of the Yilgarn Craton.

Mineral Chemistry

Phlogopites exhibit variable features, depending on the alkaline rock types. Macrocryst phlogopites in UML are characterized by compositional zoning patterns. X-ray mapping of the phlogopite macrocrysts show cores with high Si, Mg and Fe and low Ti and Cr concentrations that are overgrown by two distinct rims which are enriched in Mg, Al and Ba compared to the cores (Figure 1). The low Ti-Cr-Al feature of the cores is similar to that in mantle-derived xenocryst phlogopites of south African kimberlites (Giuliani et al. 2016). The inner rim is enriched in Ti, whereas the outer rim contains high BaO contents up to 2.8 wt.%. Phlogopites in kimberlites are dominantly unzoned, and have lower FeO contents and higher MgO contents than groundmass phlogopites in other alkaline rocks. In carbonatites, phlogopite are either zoned with a xenocrystic core with similar composition to the cores in UML phlogopites and a tetraferriphlogopite rim, or unzoned with tetraferriphlogopite composition (Al = 0.00 - 0.19, Fe = 2.57 – 3.13).

Amphiboles occuring in CAL are dominantly Mg-hastingsite, displaying complex zoning patterns. The cores of macrocrysts and microcrysts are characterized by higher FeO (10.9 - 15.3 wt.%) and Al_2O_3 (9.5 - 13.4 wt.%) than rims, whereas the rims have higher Si (upto 7.62 a.f.u.). Groundmass amphiboles are zoned or unzoned. The zoned groundmass amphiboles have similar features to macrocrysts and microcrysts in that the cores are enriched in FeO (11.4-15.5 wt.%), and Al_2O_3 (10.2-13.4 wt.%), whereas the rims (and unzoned) amphiboles contain higher Si.

The major element geochemistry of phlogopites and amphiboles in the Yilgarn Craton shows distinct zoning patterns and compositional changes from macrocrysts to groundmass, outlining the compositional fractionation of the alkaline magmas. Further researches on these major and trace element chemistry of phlogopites, amphiboles and other minerals such as olivines, clinopyroxenes and apatites will be conducted to understand the petrogenesis of the various types of alkaline magmas and to trace the compositional and geodynamic evolution of the lithospheric mantle under the Yilgarn Craton.

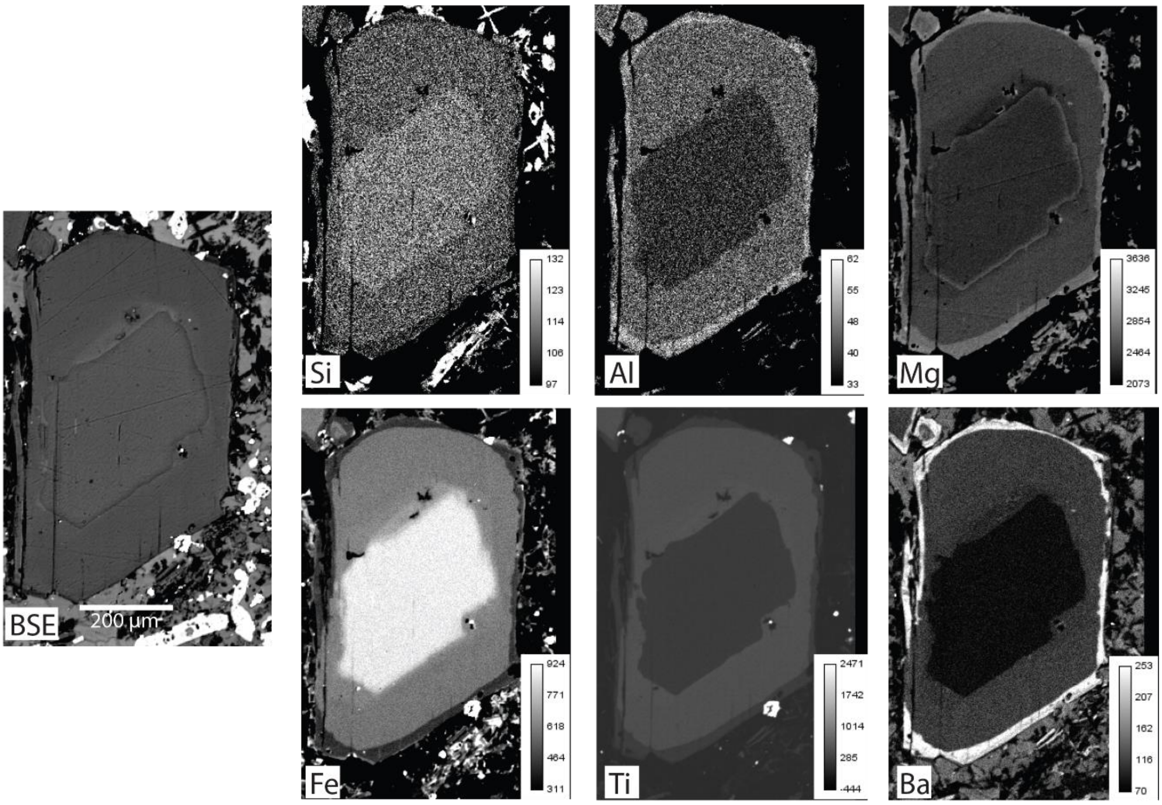

Figure 1: Back-scattered electron (BSE) image and EPMA elemental distribution maps of phlogopite in ultramafic lamprophyres (UML) in the Yilgarn Craton. The coloured scales on the right bottom of each panel indicate the relative concentration of each element

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