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Mineral chemistry and zircon geochronology of xenocrysts and altered mantle and crustal xenoliths from the Aries micaceous kimberlite: Constraints on the composition and age of the central Kimberley Craton, Western Australia

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Abstract

The Neoproterozoic (~ 820 Ma) Aries micaceous kimberlite intrudes the central Kimberley Basin, northern Western Australia, and has yielded a suite of 27 serpentinised ultramafic xenoliths, including *spinel*-bearing and rare, metasomatised, phlogopite–biotite and rutile-bearing types, along with minor granite xenoliths. Proton-microprobe trace-element analysis of pyrope and chromian spinel grains derived from heavy mineral concentrates from the kimberlite has been used to define a ~ 35–40 mW/m^2 Proterozoic geotherm for the central Kimberley Craton. Lherzolitic chromian pyrope highly depleted in Zr and Y, and Cr-rich magnesiochromite xenocrysts (class 1), probably were derived from depleted garnet peridotite mantle at ~ 150 km depth. Sampling of shallower levels of the lithospheric mantle by kimberlite magmas in the north and north-extension lobes entrained high-Fe chromite xenocrysts (class 2), and aluminous spinel-bearing xenoliths, where both *spinel* compositions are anomalously Fe-rich for *spinels* from mantle xenoliths. This Fe-enrichment may have resulted from Fe–Mg exchange with olivine during slow cooling of the peridotite host rocks. Fine exsolution rods of aluminous spinel in diopside and zircon in rutile grains in *spinel*- and rutile-bearing serpentinised ultramafic xenoliths, respectively, suggest nearly isobaric cooling of host rocks in the lithospheric mantle, and indicate that at least some aluminous spinel in spinel-facies peridotites formed through exsolution from chromian diopside. Fe–Ti-rich metasomatism in the spinel-facies Kimberley mantle probably produced high-Ti phlogopite–biotite + rutile and Ti, V, Zn, Ni-enriched aluminous spinel ± ilmenite associations in several ultramafic xenoliths. U–Pb SHRIMP $^{207}Pb/^{206}Pb$ zircon ages for one granite (1851 ± 10 Ma) and two serpentinised ultramafic xenoliths (1845 ± 30 Ma; 1861 ± 31 Ma) indicate that the granitic basement and lower crust beneath the central Kimberley Basin are at least Palaeoproterozoic in age. However, Hf-isotope analyses of the zircons in the ultramafic xenoliths suggest that the underlying lithospheric mantle is at least late Archean in age.

Keywords: Mantle metasomatism; Mantle xenoliths; Chromian spinel; U–Pb geochronology; Lu–Hf

1. Introduction

Direct knowledge of the composition, age and thermal state of the Kimberley Craton, northern Western

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Australia and the underlying continental lithospheric mantle is limited by a lack of exposure of cratonic rocks at the surface, and the rarity of unaltered mantle xenolith suites preserved in the Proterozoic to Tertiary kimberlites and lamproites of the region (Fig. 1). A suite of relatively fresh, diamondiferous garnet peridotite xenoliths from the Proterozoic Argyle lamproite has proven to be an exception (Jaques et al., 1990). Most information has been derived from studies of heavy mineral concentrates, obtained during diamond exploration programs, that contain mantle-derived garnet, *spinel* and chromian diopside xenocrysts (Jaques et al., 1986; Lucas et al., 1989; Ramsay et al., 1994; Smith et al., 1994; Griffin and Ryan, 1995; Wyatt et al., 1999). Another source of direct, although limited, sampling of the Kimberley mantle is provided by diamond inclusion suites from the Argyle and Ellendale lamproites (Hall and Smith, 1985; Jaques et al., 1989, 1994; Griffin et al., 1988). Further constraints on the age and composition of the Kimberley Craton and underlying mantle have been established by indirect detrital zircon (Tyler et al., 1999), isotopic (Graham et al., 1999) and geophysical studies (Gunn and Meixner, 1998).

The Neoproterozoic (~ 820 Ma; Smith, 1989) micaceous Aries kimberlite was emplaced in the central Kimberley Basin during a widespread phase of alkaline mafic–ultramafic magmatism that extended from the central to the north and east Kimberley (Fig. 1). It sampled a range of mantle and crustal lithologies during its ascent to the surface, some of which were diamondiferous. Initially, these were identified from the chemistry of garnet and chromian spinel xenocrysts in drillcore and heavy mineral concentrates from the pipe (Edwards, 1990; Edwards et al., 1992; Ramsay et al., 1994). We describe here a suite of altered mantle and basement crustal xenoliths that have been collected from the kimberlite more recently, and provide new data on the composition of the crust and mantle beneath the central Kimberley Craton. Although the silicate mineralogy of the mantle xenoliths is almost invariably replaced by serpentine-group minerals ± talc, *spinel* chemistry provides some indication of the original composition of these xenoliths and their source regions, as well as mantle processes involved in their formation. Rare phlogopite–rutile-bearing xenoliths preserve evidence for Fe–Ti-rich mantle metasomatism beneath the central Kimberley Craton; evidence for modal metasomatism of the Kimberley mantle previously was restricted to one serpentinised former garnet peridotite xenolith from the Argyle lamproite that contained chromian armalcolite (Jaques et al., 1990). Metasomatism of the Argyle xenolith suite proved to be more cryptic in nature (Jaques et al., 1990). Comparisons between the Aries metasomatic mineral assemblage and other metasomatic assemblages from continental garnet- and spinel-facies mantle (e.g. Harte et al., 1987; Erlank et al., 1987; Gregoire et al., 2002, 2003; Menzies and Chazot, 1995) will help to define the style of metasomatism involved.

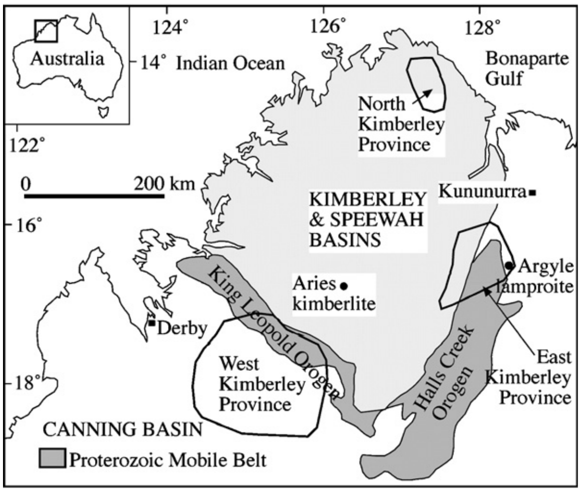

Fig. 1. Map showing the location of the Aries kimberlite and the north, east and west Kimberley kimberlite–lamproite provinces in the Kimberley region of Western Australia.

In addition to descriptions and analysis of this suite of xenoliths, we present proton-microprobe trace-element data for pyrope and *spinel* xenocrysts from heavy mineral concentrates that partially constrain the Proterozoic geotherm for the central Kimberley Craton, by application of the Ni-in-garnet and Zn-in-chromite geothermometers, and the Cr-in-pyrope geobarometer (Griffin et al., 1989; Griffin and Ryan, 1995; Ryan et al., 1996; Griffin et al., 1994). Furthermore, U–Pb SHRIMP (Sensitive High mass-Resolution Ion MicroProbe) and *in-situ* (LAM-MC-ICPMS, Laser Ablation Microprobe-Multi-Collector-Inductively-Coupled Plasma Mass Spectrometer) Hf-isotope analyses of zircons from granite and serpentinised ultramafic xenoliths provide age constraints for the crust and lithospheric mantle in the central Kimberley Craton. This is an important addition to previous dating of the craton reported by Gunn and Meixner (1998), Graham et al. (1999), and Tyler et al. (1999), with implications for tectonic models describing the formation of the craton.

In this paper, spinel-group mineral or *spinel* refer to any member of the spinel structural group regardless of composition. Aluminous spinel refers to spinel-group minerals with <0.50 molar Cr/(Cr+Al), and chromian spinel refers to spinel-group minerals that contain >0.50 molar Cr/(Cr+Al). Magnesiochromite describes chromian spinel with <0.50 molar $Fe^{2+}/(Fe^{2+}+Mg)$.