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The provenance of sub-cratonic mantle beneath the Limpopo Mobile Belt (South Africa)

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ABSTRACT

Petrological, whole rock major element and mineral chemical analysis of mantle xenoliths from the Venetia kimberlite pipes (533 Ma) in South Africa reveals an apparently stratified cratonic mantle beneath the Central Zone of the Limpopo Mobile Belt (LMB) that separates the Kaapvaal and Zimbabwe Cratons. Combined pressure–temperature (P–T) data and petrographic observations indicate that the mantle consists of an upper layer of Low-T coarse-equant garnet + spinel lherzolite (~50 to ~130 km depth). This layer is underlain by a region of mixed garnet harzburgites and garnet lherzolites that are variably deformed (~130 to ~235 km depth). An equilibrated geotherm did not exist at the time of kimberlite eruption (533 Ma) and a localised heating event involving the introduction of asthenospheric material to the High-T lithosphere below 130 km is inferred.

Low-T garnet–spinel lherzolites are highly melt depleted (40% on average). In contrast, the High-T lithosphere (mostly at diamond stable conditions) consists of a mixed zone of variably sheared and melt depleted (30% on average) garnet harzburgite and mildly melt depleted (20% on average) garnet lherzolite. The chemistry of the High-T xenoliths contrasts with that of minerals included in diamond originating from the same depth. Inclusions suggest diamond crystallisation in a more melt depleted lithosphere than represented by either Low- or High-T xenoliths. High-T xenoliths are proposed to represent formerly melt depleted lithosphere, refertilised by asthenosphere-derived melts during the diapiric rise of a proto-kimberlitic melt pocket. This process is coupled to the positive temperature perturbation observed in the High-T xenoliths and may represent a common process in the lower lithosphere related to localised but intense tectono-magmatic events immediately preceding kimberlite eruption.

The presence of clinopyroxene, garnet and abundant orthopyroxene in the Low-T lherzolite implies a history of melt depletion followed by metasomatic addition of Si–Al–Ca, forming high-temperature orthopyroxene from which clinopyroxene and garnet exsolved. Si enrichment is a characteristic feature of the majority of the Kaapvaal Craton to the south of the LMB but not of the Zimbabwe Craton to the north, implying a Kaapvaal origin. The provenance of the High-T lithosphere beneath the LMB is less well constrained as it is intensely modified by kimberlitic magmatism and diamond inclusion chemistry does not show significant systematic variation across the cratons. The presence of rare, mildly silica enriched high-temperature harzburgites suggests that a Kaapvaal origin for the entire lithosphere beneath the LMB is most likely.
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1. Introduction

The Venetia kimberlite cluster in northernmost South Africa was emplaced at ~533 Ma (Allsopp et al., 1995) and is one of South Africa's most diamondiferous kimberlites with a grade of >1.2 ct/ton (Field et al., 2008). In total, 15 bodies were intruded over an area of ~3 km^2 (Tait and Brown, 2008) into the central zone of the Limpopo Mobile Belt (LMB), which forms the ~2.65 Ga (Barton and van Reenen, 1992; Gerdes and Zeh, 2009; Zeh et al., 2007) collision zone between the Kaapvaal and Zimbabwe cratons in southern Africa. The LMB can be subdivided into three distinct zones (Fig. 1). The Northern and Southern Marginal Zones are commonly interpreted to be high grade metamorphic equivalents of the Zimbabwe and Kaapvaal cratons, respectively (e.g., Du Toit et al., 1983; Van Reenen et al., 1992). The Central Zone, hosting the Venetia kimberlite cluster, acted as the overriding plate during the Kaapvaal–Zimbabwe collision (Durrheim et al., 1992) but is itself of a debatable origin (see review in Rigby et al., 2008) and an origin as part of either the Kaapvaal or Zimbabwe Craton has been proposed. Alternatively, the Central Zone could be an allochtonous block that formed at 3.28 Ga (Zeh et al., 2007) and was subsequently incorporated during the Kaapvaal–Zimbabwe collision. The LMB underwent subsequent high grade metamorphism and tectonism at 2.65 Ga, the

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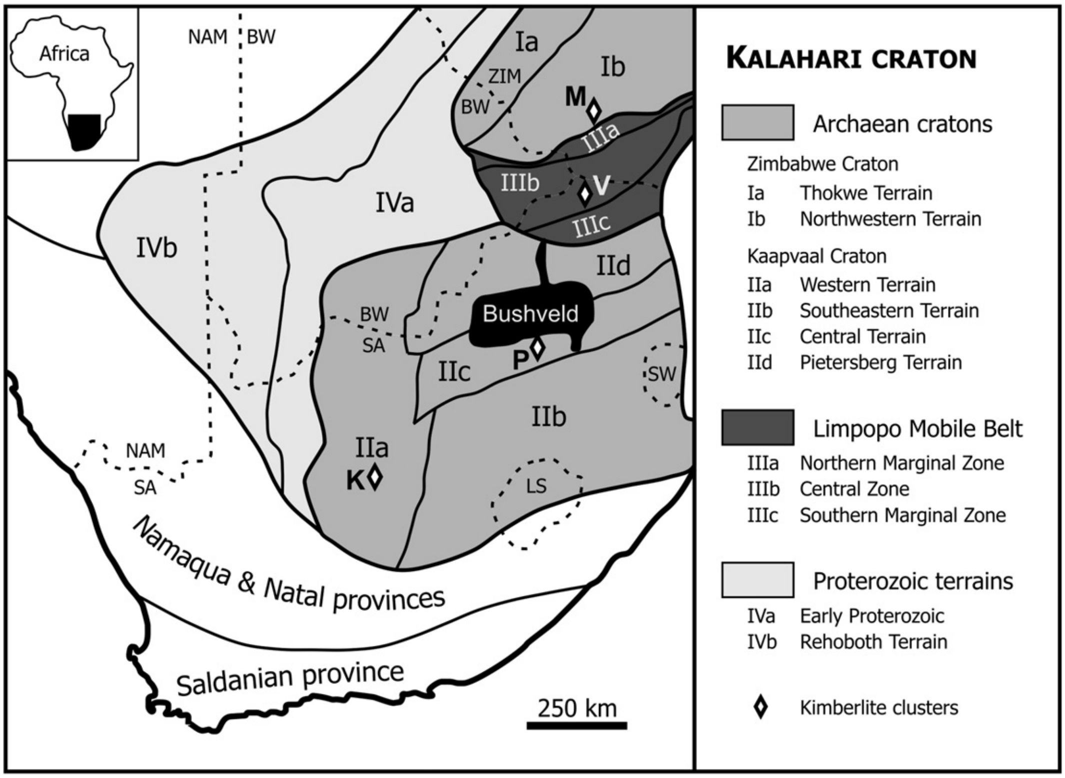

Fig. 1. Map of the Kalahari Craton and subdivision between the separate terrains after Griffin et al. (2003) and Richardson et al. (2009), including the Limpopo Mobile Belt and its subdivision. Selected kimberlites shown for reference after Field et al. (2008): K = Kimberly cluster, P = Premier/Cullinan kimberlite, M = Murowa/Sese kimberlites, V = Venetia kimberlite cluster. Outcrop of the 2.05 Ga Bushveld LIP is shown in black. Dashed lines indicate national boundaries. SA, South Africa; NAM, Namibia; LS, Lesotho; SW, Swaziland; BW, Botswana; ZIM, Zimbabwe.

proposed age of collision and craton stabilisation (e.g., de Wit et al., 1992; Zeh et al., 2007). A second metamorphic episode at 2.0 Ga is related to deformation and mafic underplating which has been proposed to be either associated with the emplacement of the Bushveld Large Igneous Province (LIP) (Millonig et al., 2010; Richardson and Shirey, 2008; see Fig. 1) or due to tectonism as a consequence of the 2.0 Ga Magondi Orogeny on the north-western margin of the Zimbabwe Craton (McCourt and Armstrong, 1998).

Despite a tectonic setting within a mobile belt, the LMB central zone is underlain by thick cratonic lithosphere (James et al., 2001; Kopylova et al., 1997). Previous studies of mantle xenoliths (Barton and Gerya, 2003; Hin et al., 2009; Stiefenhofer et al., 1999), diamond inclusions (e.g., Viljoen, 2002; Viljoen et al., 1999) and garnet concentrates (Griffin et al., 2003) from the Venetia kimberlites have shown that the subcontinental lithospheric mantle (SCLM) is depleted in magmaphile elements. This melt depletion is thought to have occurred in the Archaean as suggested by xenolith whole rock rhenium depletion ages of >2.5 Ga (Carlson et al., 1999). Moreover, the petrography of mantle xenoliths at Venetia suggests that the underlying SCLM lacks the extensive phlogopite metasomatism common elsewhere in South Africa (Hin et al., 2009; Stiefenhofer et al., 1999). The occurrence of eclogite in the LMB central zone cratonic mantle is rare. Deines et al. (2001) report that less than 10% of inclusion-bearing diamonds are of eclogitic origin and only 10% of the mineral inclusions in diamonds analysed by Viljoen et al. (1999) were of pyroxenite or eclogite composition. Following extensive studies of xenolith populations by staff and students from the VU University (~4 man months), only one mantle-derived eclogite xenolith has been identified to date. This contrasts with other kimberlites within the Kaapvaal Craton where the abundance of eclogitic xenoliths can locally be as high as 15% (Schulze, 1989) but lower eclogite abundances seem normal for the Zimbabwe cratonic lithosphere (Bulanova et al., 2012; Smith et al., 2009). Eclogitic sulphide inclusions in diamond have been dated as being coeval with the emplacement of the Bushveld LIP at ~2.05 Ga (Richardson and Shirey, 2008). The significance of this age is difficult to assess and may indicate diamond growth with only minor modification of the lithosphere (Cartigny et al., 2009; Thomassot et al., 2009) as Venetian eclogitic silicate diamond inclusions are interpreted to originate from subduction processes, not a LIP (Aulbach et al., 2002). A combined Sr–Nd isotope study of four peridotitic silicate diamond inclusions from Venetia does not produce coherent age relationships. The limited data set is interpreted to indicate that diamonds have a maximum age of 2.3 Ga (Richardson et al., 2009). These workers also report an isotopic study of garnet macrocrysts from the Venetian kimberlite and argue for modification of Archaean mantle by Bushveld type magmas at circa 2.0 Ga.

The Cambrian emplacement age of the Venetia kimberlite predates Phanerozoic regional magmatic events in Southern Africa such as the Karoo flood basalts (Marsh et al., 1997) and the Mesozoic group 1 and 2 kimberlites (Smith et al., 1985). Hence, mantle xenoliths from Venetia have the potential to retain petrographic and geochemical information about the structure and composition of the SCLM, unaffected by the Mesozoic magmatism that influences a large proportion of xenoliths beneath the Kaapvaal Craton (e.g., Simon et al., 2003, 2007). Such processes are thought to modify the lithosphere sampled by kimberlites and thus post-Archaean thermo-chemical processes are a major component recorded in the mantle xenoliths (Kobussen et al., 2008, 2009). When using mantle xenoliths to describe Archaean processes it is therefore important to identify these later events that altered the mantle and to assess how they affected mantle chemistry and thermal conditions. As noted above, although the Venetian kimberlite predates major kimberlite activity in the region, collision at 2.65 Ga and the emplacement of the Bushveld LIP have been proposed to have had some effect on the Limpopo SCLM (Richardson and Shirey, 2008; Richardson et al., 2009).

This article aims to provide a better understanding of the origin of the cratonic mantle beneath the LMB central zone and its development

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