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Quantifying the thickness of the Archean lithosphere beneath the western Kaapvaal craton at the time of Zero kimberlite emplacement (1.6 Ga)

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Introduction

The formation of the Archean lithospheric mantle was a key event in the Earth's history, resulting in the construction of the first continents (cratons). Seismic tomography shows that the modern-day thickness of the Kaapvaal lithosphere is ~200 km (e.g., Celli et al., 2020) and it is widely believed that this has remained uniform since Archaean up to at least the time of peridotite sampling by Cretaceous kimberlite activity (Michaut et al., 2009). However, diamond stability and low temperatures of diamond inclusions require that the lithosphere was thicker (ca. 300 km) at the time of diamond formation (predominantly in the Archaean and early Proterozoic). Additional support for a thicker lithosphere comes from PT data from Archaean and Paleoproterozoic diamond inclusions, a geotherm fit through the diamond inclusion data intersects the adiabat at ~100 km deeper than the geotherm fit through PT data for Cretaceous xenoliths (e.g., Hoare et al., 2022). This indicates that the lithosphere has been thinned (e.g., by basal drag and/or plume erosion) since Archean up to at least the time of xenolith sampling by Cretaceous kimberlites. Most studied xenoliths have been sampled from Cretaceous kimberlites and they represent modern-day thickness (e.g., Hoare et al., 2022). Therefore, the direction and magnitude of variations in the thickness of cratonic lithosphere through geologic time remain unclear, as do the main process(es) responsible for changes in lithospheric thickness. Here we present new major element data for garnet~~s~~ peridotite xenoliths and garnets in heavy mineral concentrate from the Zero kimberlite pipe in the Kuruman cluster, with the aim of obtaining geothermal gradients and the thickness of the lithospheric mantle in this region at the time of kimberlite emplacement at ~1.6 Ga.

Sample description

The Kuruman kimberlite cluster represents the oldest sampling of the Kaapvaal cratonic lithospheric mantle and yields an emplacement age of ~1.6 Ga (Shee et al. 1986; Donnelly et al., 2012). The cluster includes 12 kimberlite occurrences with only four intrusions dated 1.6 Ga (i.e., Elston, Zero, Bathlaros, and Riries. X007 is dated younger – 120±20 Ma), of which Zero is the only one to yield mantle xenoliths (Shee et al. 1986). The Kuruman kimberlites are situated close to the Kaapvaal craton's western margin, near the well-known Cretaceous-aged diamondiferous Finsch kimberlite (118 Ma; Field et al., 2008) (see Figure 1). Core drilling of Zero kimberlites conducted by DeBeers provided exposure to a suite of mantle xenoliths comprised of peridotites, eclogites, and crustal rocks. For this study, samples were obtained from the DeBeers diamond drill core samples.

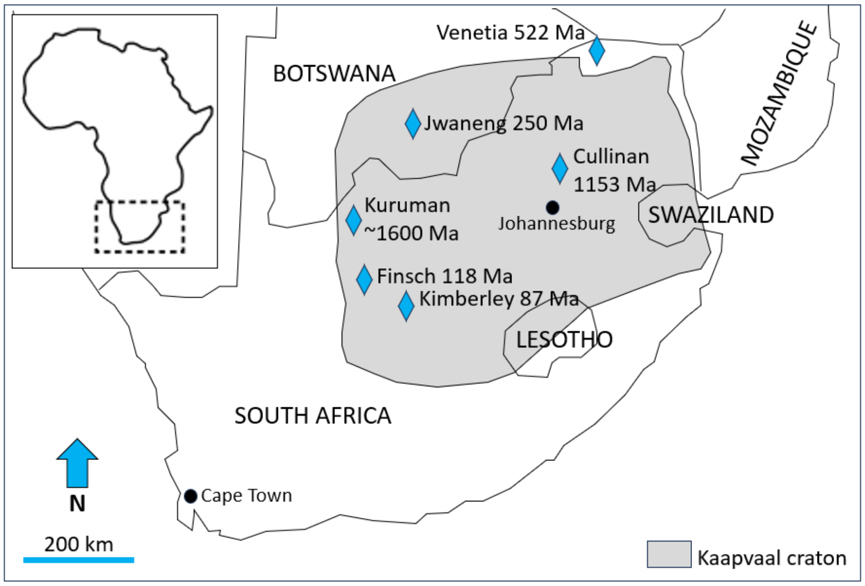

Figure 1: Regional map of southern Africa showing the locality of the Kuruman kimberlite cluster and other major well-known kimberlites and Kaapvaal lamproites in the Kaapvaal craton. Modified after Shee et al. (1986).

Results and discussion

The Zero peridotite xenoliths comprise garnet lherzolites and garnet-spinel harzburgites, however, bimineralic (garnet-clinopyroxene) eclogite xenoliths are also common. The garnet-spinel harzburgites are characterised by olivine, orthopyroxene, garnet, and less common exsolved spinel hosted in orthopyroxene. These xenoliths exhibit porphyroclastic texture (according to Harte, 1977 nomenclature) although there is no evidence of intense deformation. Garnet lherzolites comprise mostly orthopyroxene and clinopyroxene as the most dominant phases. These lherzolites have a coarse-granular texture with equant grains of variable size (0.3 – 2.0 mm).

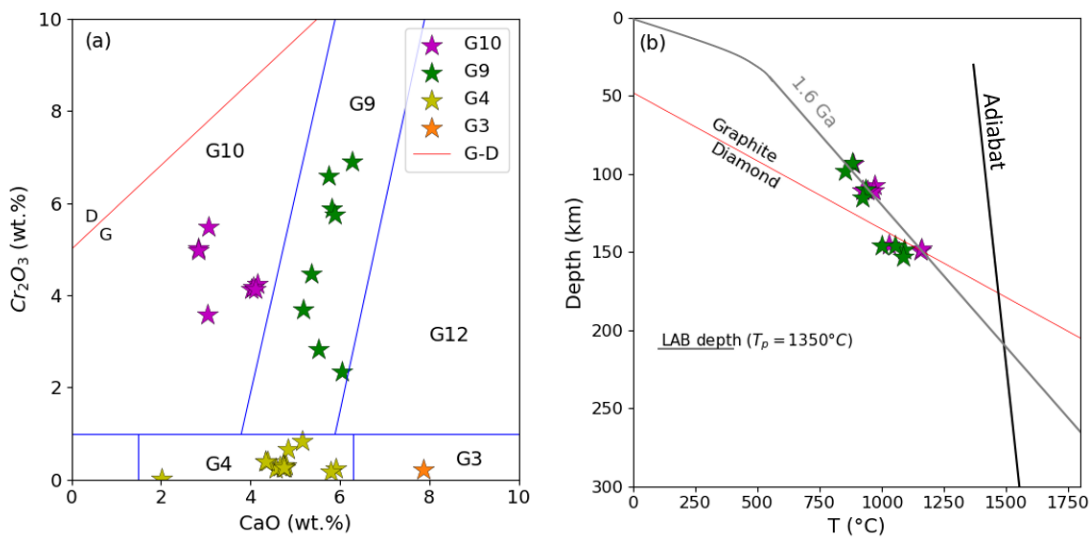

Figure 2: (a) CaO-Cr_2O_3 plot for Zero garnets, classified based on the Grutter et al. (2004) classification scheme. G-D = graphite-diamond constraint as defined by Grutter et al. (2006). (b) Fitted geotherm of xenoliths from 1.6 Ga Zero kimberlites. Note, LAB depth is the lithosphere-asthenosphere boundary

Major element compositions of garnets from Zero xenoliths and garnets from heavy mineral concentrate were analysed by scanning electron microscopy (SEM). The Cr_2O_3- and CaO-based classification scheme of Grutter et al. (2004) shows a wide range of garnet compositions indicating derivation from numerous xenoliths sampled by Zero kimberlites, i.e., G10, G9, G4, and G3 (see Figure 2a). The geotherms were determined from the PT data of G9 and G10 garnets, estimated using a new machine-learning (ML) thermobarometer for single crystal pyrope garnet (O'Sullivan, this meeting). G9 and G10 garnets yield a largely overlapping P and T equilibration of 3–5 GPa and 854–1159ºC respectively (Figure 2b). The Zero geotherm intersects the adiabat at ~215 km, providing an estimate for the thickness of the lithosphere at the time of kimberlite emplacement. Although peridotite xenolith sampling appears to have occurred at depths of ~93–153 km, the constrained geotherm suggests that the lithosphere beneath the Zero pipe was >200 km thick at the time of emplacement at 1.6 Ga. It should be noted that the lithospheric thickness is calculated using a modern mantle potential T (T_p) of 1350ºC (Herzberg et al., 2010) and so represents a minimum estimation, the thickness would be greater if the mantle T_p is assumed to be higher at 1.6 Ga. More PT data points would be required for more accurate geotherm and lithospheric thickness constraint at Zero. Therefore, additional further analyses of PT constraints from xenolith and garnet + clinopyroxene concentrate are still in progress and a large dataset will be presented in the meeting.

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