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Cretaceous mantle of the Congo craton: Evidence from mineral and fluid inclusions in Kasai alluvial diamonds

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ABSTRACT

Alluvial diamonds from the Kasai River, Democratic Republic of the Congo (DRC) are sourced from Cretaceous kimberlites of the Lucapa graben in Angola. Analysis of 40 inclusion-bearing diamonds provides new insights into the characteristics and evolution of ancient lithospheric mantle of the Congo craton. Silicate inclusions permitted us to classify diamonds as peridotitic, containing Fo_{91-95} and En_{92-94}, (23 diamonds, 70% of the suite), and eclogitic, containing Cr-poor pyrope and omphacite with 11–27% jadeite (6 diamonds, 18% of the suite). Fluid inclusion compositions of fibrous diamonds are moderately to highly silicic, matching compositions of diamond-forming fluids from other DRC diamonds. Regional homogeneity of Congo fibrous diamond fluid inclusion compositions suggests spatially extensive homogenization of Cretaceous diamond forming fluids within the Congo lithospheric mantle. *In situ* cathodoluminescence, secondary ion mass spectrometry and Fourier transform infrared spectroscopy reveal large heterogeneities in N, N aggregation into B-centers (N_B), and $\delta^{13}C$, indicating that diamonds grew episodically from fluids of distinct sources. Peridotitic diamonds contain up to 2962 ppm N, show 0–88% N_B, and have $\delta^{13}C$ isotopic compositions from −12.5‰ to −1.9‰ with a mode near mantle-like values. Eclogitic diamonds contain 14–1432 ppm N, N_B spanning 29%–68%, and wider and lighter $\delta^{13}C$ isotopic compositions of −17.8‰ to −3.4‰. Fibrous diamonds on average contain more N (up to 2976 ppm) and are restricted in $\delta^{13}C$ from −4.1‰ to −9.4‰. Clinopyroxene-garnet thermobarometry suggests diamond formation at 1350–1375 °C at 5.8 to 6.3 GPa, whereas N aggregation thermometry yields diamond residence temperatures between 1000 and 1280 °C, if the assumed mantle residence time is 0.9–3.3 Ga. Integrated geothermobaromtery indicates heat fluxes of 41–44 mW/m^2 during diamond formation and a lithosphere-asthenosphere boundary (LAB) at 190–210 km. The hotter-than-average cratonic mantle may be attributable to contemporaneous rifting of the southern Atlantic, multiple post-Archean reactivations of the craton, and/or proximal Cretaceous plumes.

1. Introduction

Old, cold, and thick roots of lithosphere with the potential to grow and store diamonds extend beneath Archean cratons. This subcontinental lithospheric mantle (SCLM) records the growth and modification of Earth's continents spanning the Archean to present. SCLM minerals and fluids trapped within diamonds permit us to trace ancient mantle processes at 150 km and deeper. Because they are shielded from a constantly changing mantle environment, these inclusions provide insights into the mantle compositions and the thermal states of early continents.

Ancient, cratonic roots are neither homogenous nor static. Plume activity, rifting, and accretion are capable of modifying the parageneses, structure, and thermal state of SCLM, sometimes to the demise of the cratonic root (e.g. Helmstaedt and Gurney, 1995). Thus, characterization of SCLM within and between cratons, viewed in the context of each craton's geodynamic history, helps us to better understand evolution and changes in mantle dynamics.

The SCLM beneath the Kaapvaal, Slave, Superior, and Siberian cratons have been characterized in substantial detail utilizing diamond inclusions. These studies revealed the mantle lithologies, the thermal state and the thickness of the lithosphere at the time of kimberlite emplacement and have been fundamental in constructing models of SCLM evolution. Despite the Congo craton's size confirmed by a high-resolution shear-wave tomographic model of Africa (Begg et al., 2009), few studies have investigated the underlying lithospheric mantle, including only one systematic study of Congo diamond inclusions thus far (Mveumba Ntanda et al., 1982).

To fill this knowledge gap, we studied inclusions in diamonds of the Kasai block of the Congo craton to constrain for the first time the geotherm at the time of kimberlite emplacement, the lithosphere-asthenosphere-boundary, the diamond host rocks, and the diamond-

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forming fluids of part of the Congo craton. These data, obtainable only from diamonds and their inclusions, complement analogous data for other cratons globally and contribute to understanding the general pattern of evolution of the continental mantle.

2. Regional geology

The Congo craton is one of four cratons that comprise the African continent. The craton is composed of several Archean blocks, adjacent Proterozoic mobile belts and areas covered by Proterozoic and Phanerozoic sediments (Fig. 1). The exposed Kasai block in the southeastern part of the craton is a heterogeneous Paleoarchean (3.49–3.33 Ga) granulite complex (De Waele et al., 2008). Zircons from heavy mineral concentrates northward of the Kasai river yield laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS) U-Pb ages as old as 3.6 Ga (Batumike et al., 2009a). The Kasai block is thought to have mostly accreted to the Congo craton by 2.8 Ga (Begg et al., 2009; De Waele et al., 2008). The 1.8 Ga Karagwe-Ankole Belt (KAB) and Kibara Belt (KIB) (e.g., Tack et al., 2010) on the eastern margin of the craton resulted from collision with the Tanzanian craton (Begg et al., 2009). Near 1.37 Ga, a failed intracratonic rift is recorded within the sedimentary and volcanic sequences of the Kibara belt (Tack et al., 2010). The

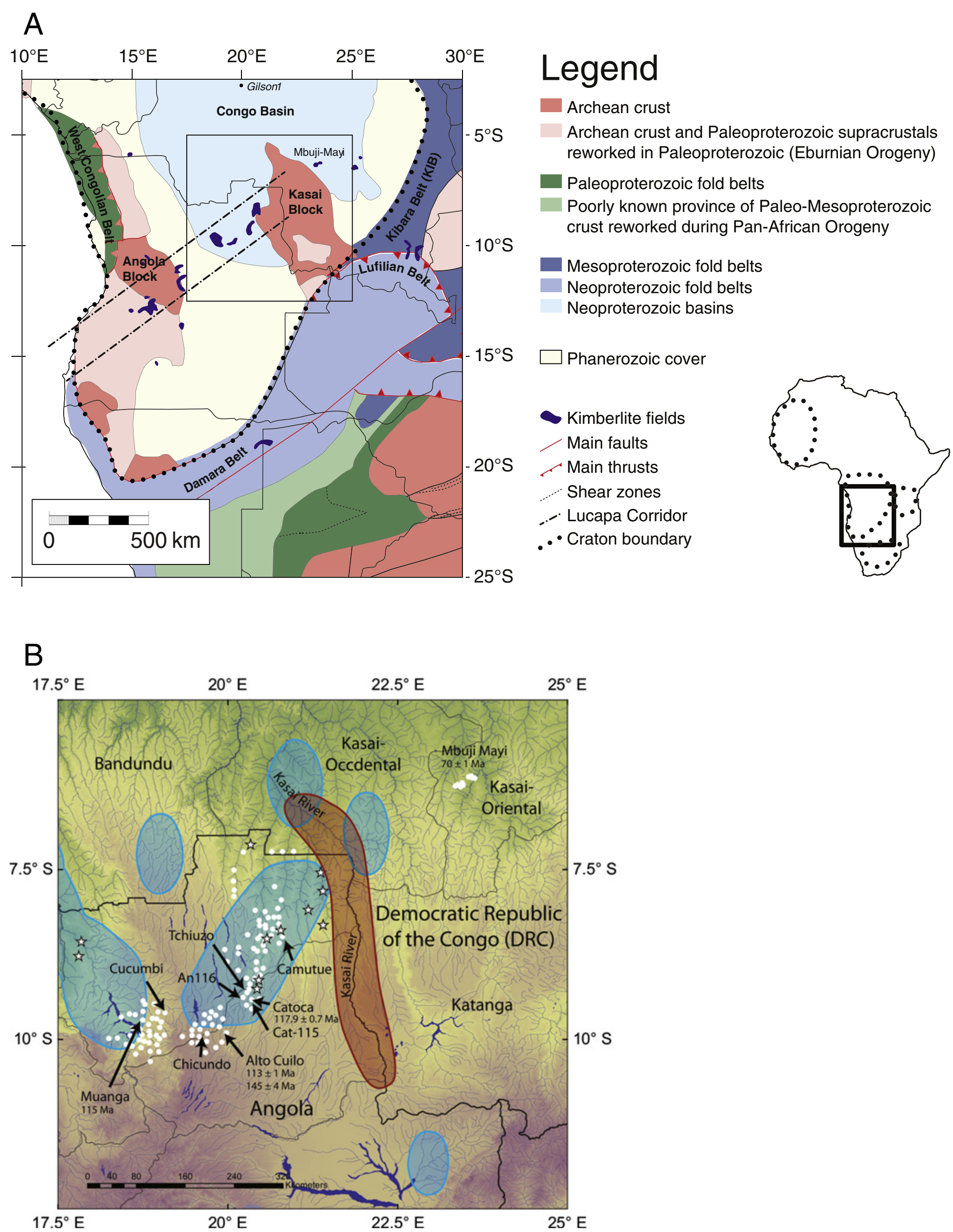

Fig. 1. Geological and geographic positions of sampling locations for studied Kasai diamonds. (A) Geology and tectonic features of central Africa and the Congo craton with locations of known kimberlite fields. The geologic map on the larger panel is modified from Begg et al. (2009) with select legend entries preserved. The Karagwe-Ankole Belt (KAB) is outside the boundaries of the inset to the NE. The dotted line indicates Lucapa corridor. Dark purple areas indicate major kimberlite fields from Boyd and Danchin (1980); Jelsma et al. (2009); Jelsma et al. (2013); Campeny et al. (2014) and de Wit and Jelsma (2015). The Gilson 1 oil well within the Congo Basin (Lucazeau et al., 2015) is the site of the quoted heat flow measurement. The black square outline marks the position of Inset B. (B) Inset from (A), showing the relief and rivers with locations of kimberlites and alluvial diamond mines. Light purple areas represent high altitude, and light green represents low altitude. National and provincial boundaries are in black. White circles represent kimberlites after aforementioned sources and white stars represent exploited alluvial diamond deposits in 2013 (after Chambel et al., 2013). Areas of alluvial diamond concentration (in blue) after Dietrich (2000). Area in red represents the region from which the study samples were collected.