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The origin of Karoo-age diamondiferous lamproites in Zambia

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1. Introduction

The Kapamba lamproites present an opportunity to investigate some of the most debated topics in deep Earth processes, being situated beneath a cratonic precursor rift branch of the East African Rift System, while also recently being proven to show spatiotemporal links to the ca. 180 Ma Karoo LIP magmatism (Tappe et al., 2023). Extensional stresses impacting on ancient continental shields are typically partitioned into the structurally weaker mobile belts along which Archean cratonic nuclei were forged into larger continents throughout the Proterozoic eon. A modern example of such strain partitioning is the East African Rift System. The Permo-Triassic Luangwa Rift of south-central Africa preceded formation of the adjoining western branch of the East African Rift System (Banks et al., 1995), and in a similar fashion it developed along a Proterozoic mobile belt between two major Archean cratons, the Congo-Tanzania craton in the north and the Kalahari craton in the south (Fig. 1). Similar to the western branch of the East African Rift, the 'Karoo' rifts of interior Gondwana are largely amagmatic. However, the Luangwa Rift in eastern Zambia is host to a suite of early Mesozoic diamond-bearing lamproites (Scott Smith et al., 1989) and thus presents a rare case of remobilization of thick cratonic lithosphere (Ngwenya and Tappe, 2021).

The ca. 180 Ma Karoo LIP in southern Africa and East Antarctica presents a classic continental flood basalt province. The majority of petrogenetic models for continental flood basalt volcanism invoke mantle plume sources, with plume–lithosphere interactions contributing to magma type diversification. The Kapamba lamproites represent a ca. 180 Ma old diamondiferous magmatic event beneath the cratonic Luangwa Rift of eastern Zambia, positioned in the northern Karoo LIP, with primitive ultrapotassic lavas constraining the nature of relatively 'pure' alkali-metasomatic mantle components including volatile budgets potentially available for flood basalt volcanism (Tappe et al., 2023). Geochemical data presented here, together with modelling, provide new insights into the deep origins of K-rich hydrous magmas, including the roles they play during plume–lithosphere interactions. We also revise the suggested links between development of the Luangwa Rift and lamproite magma eruptions at Kapamba using new evidence.

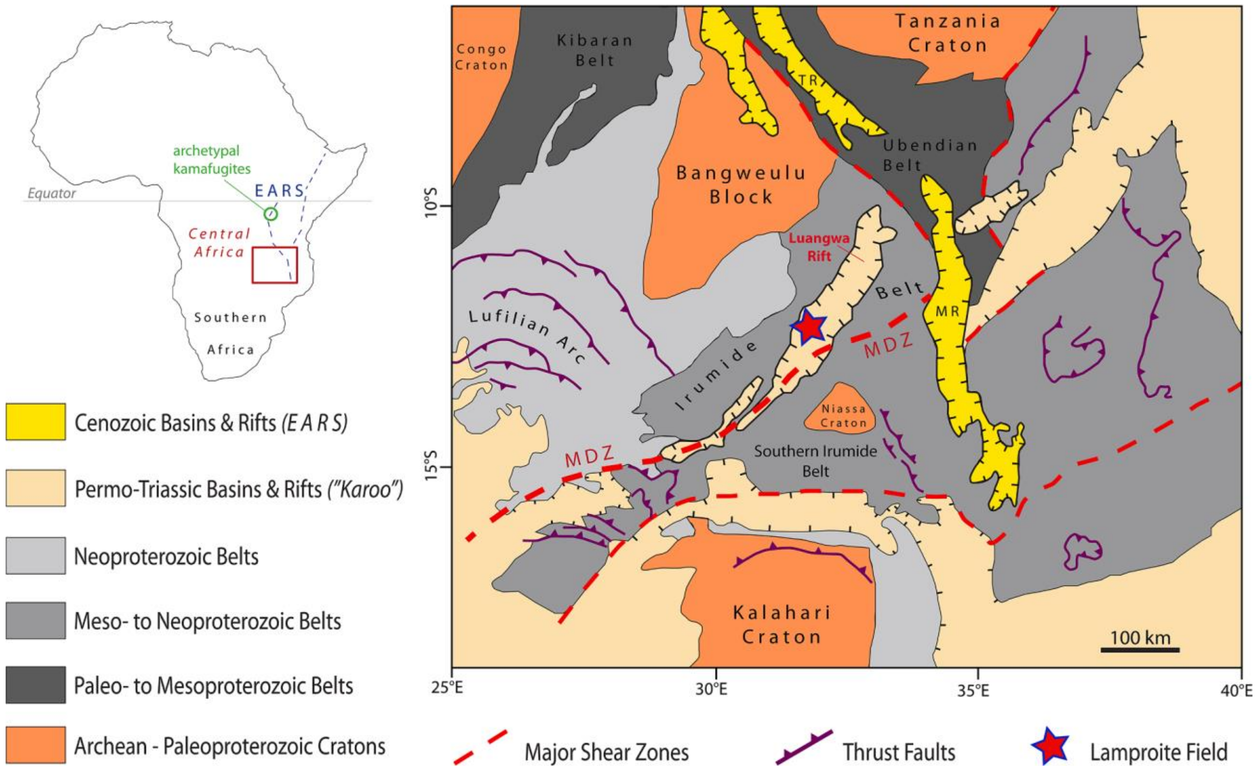

Fig. 1: Geological map of south-central Africa, where the red star locates the ca. 180 Ma Kapamba lamproites within the 'failed' Permo–Triassic Luangwa Rift structure (Tappe et al., 2023).

2. Background

The Kapamba lamproite field comprises 14 volcanic pipes and several narrow dykes within a ~30 km long corridor within the southern sub-basin of the Luangwa Valley rift. Formed above a steep mega-shear zone, the Luangwa Valley is a ~600 km long and on average ~60 km wide rift structure that forms part of a larger Permo–Triassic Karoo rift basin system stretching from Tanzania in the NE to Zimbabwe in the SW (Fig. 1). The rift valley is host to the lamproite pipes but the volcanism was unrelated to rifting, as recently demonstrated by U/Pb perovskite age determinations, which yielded Jurassic ages of ca. 180 Ma (Tappe et al., 2023).

The Kapamba lamproites were first described in public by Scott Smith et al. (1989), but had been initially classified as kimberlites in the 1970s, mainly because more than half of these pipes contain small quantities of macro-diamonds despite their setting within the Proterozoic Irumide Belt (Pipe-2 has a grade of 5 cpht; Tappe et al., 2018). Recently, much progress has been made in the understanding of the tectonic evolution of south-central Africa and the petrology of lamproites, which requires a revision of the origin of diamondiferous lamproite volcanism in eastern Zambia.

3. Results

The fresh magmatic rocks contain microphenocrysts of olivine, diopside and leucite (converted to analcime) set in a fine-grained to cryptocrystalline groundmass dominated by olivine, diopside, phlogopite and sanidine (<100 μm in size), plus silicate glass. The lamproite groundmass also contains minor amounts of spinel-group minerals, sulphides, richterite amphibole, apatite, ilmenite and perovskite, all <50 μm in crystal size. This mineralogical composition indicates a petrographic continuum between primitive olivine lamproites and slightly more evolved olivine-leucite lamproites, with broad resemblance to certain orangeite localities on the Kaapvaal craton and to certain kamafugite varieties in the western branch of the East African Rift System (Ngwenya and Tappe, 2021).

Temperature estimates for peridotite-derived olivine xenocrysts suggest that the Luangwa Valley is an aborted cratonic rift that retained a relatively cold (≤42 mW/m^2) lithospheric mantle root down to 200 km depth during the early Mesozoic (Ngwenya and Tappe, 2021). This result allows us to conclude that the Irumide Belt has a cratonic nature with remnant Archean components beneath a thick-skinned and granite-intruded Proterozoic fold-and-thrust belt, implying that remobilization of cratonic lithosphere during collision or rifting is largely restricted to the crust. Elevated Li concentrations in magmatic olivine of up to 18.5 ppm at 86–90 mol.% forsterite, plus strong Sr–Nd–Hf–Pb isotopic enrichment of the host lamproites suggest partial melting of phlogopite-metasomatized lithospheric mantle domains. The mantle-like δ^7Li values of the most pristine lamproite samples are compatible with source enrichment by asthenosphere-derived melts, without significant involvement of recycled sedimentary components, a signature in contrast to the K-rich volcanic rocks from collision zone settings. Olivine major and trace element compositions support the presence of an Archean mantle root that has been progressively metasomatized toward its base, while isotope modelling demonstrates that the Kapamba lamproites originate from a MARID-style metasomatized peridotitic mantle source that underwent incompatible element enrichment at ca. 1 Ga, during tectonic activity associated with Rodinia supercontinent formation. At 180 Ma, plume-sourced basaltic and picritic magmas of the Karoo LIP interacted with such K-rich hydrous lithospheric mantle domains, thereby attaining enriched incompatible element and radiogenic isotope compositions. Nd–Hf isotope mass balance suggests that up to 25% of MARID-sourced lamproite melt component contributed to some of the high-Ti flood volcanic units, and our findings suggest that cratonic lamproites can represent integral parts of large igneous provinces (Tappe et al., 2023).

4. References

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