Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.34942

Experimental constraints on zircon growth in kimberlite melts

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Kimberlites are the deepest-sourced ultramafic magmas to reach the Earth's surface. They can provide important insights into the mantle processes, including metasomatism in the subcontinental lithospheric mantle. Zircon is a widespread, robust silicate mineral offering invaluable information about magma sources due to its ability to incorporate trace elements. Zircon occurs in kimberlites, typically forming "megacrysts" but can be found as grains of various sizes. Kimberlitic zircons differ from crustal zircons by their low trace-element contents, suggesting a different origin. They may form during mantle metasomatism or precipitate directly from kimberlite melt. The unclear link of megacrystal zircon to kimberlite magmatism complicates the interpretation of Hf isotopes and U–Pb ages in studies of kimberlite magmatism. Existing models predict high zircon solubility in such silica-undersaturated melts as kimberlites. However, our previous data have shown that zircon stability increases with pressure. In this study, we examine zircon stability in kimberlite melts at high pressure. This project addresses the origin of mantle-derived zircon and its relationship to kimberlite magmatism.

We investigated zircon saturation and Zr diffusivity in synthetic kimberlite melts with variable carbonate contents at 1–3 GPa using a piston-cylinder apparatus and at 7–15 GPa using a multi-anvil apparatus. ZrO_2 concentrations in the glass at the melt–zircon interface were measured by electron microprobe analysis. Our results demonstrated that zircon dissolved incongruently, forming baddeleyite, at pressures < 3 GPa and congruently ≥ 3 GPa. At 3 GPa, the ZrO_2 compositional profile in the melt shows zircon dissolution, with the highest concentration at the interface decreasing with distance. At higher pressures (7 GPa and above), the ZrO_2 concentration at the interface decreases, indicating zircon crystallization (Fig. 1).

We established that at the base of the lithosphere (~7-10 GPa) zircon crystallization requires 2.5-3.5 wt% ZrO_2 in the melt, where zircon stability decreases in a carbonate-rich melt. Formation of baddeleyite rim on kimberlitic zircon is likely controlled by decompression rather than variations in the melt composition. The change in zircon saturation profiles with pressure suggests that zircon can crystallize after its dissolution due to the boundary layer enriched in Zr.

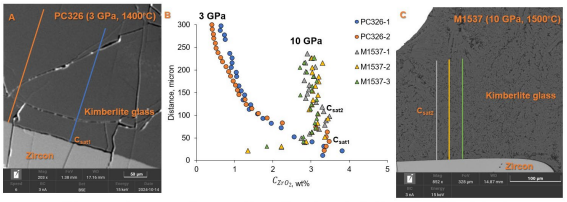


Figure 1. BSE images of experimental runs at 3 GPa (PC326) (A) and 10 GPa (M1537) (C) with location of the parallel compositional profiles at the zircon–melt interface. Changes in Zr concentrations in the glass vary with distance (B). Profiles in PC326 demonstrate Zr diffusion into the melt, while profiles in M1537 show typical Zr behavior due to zircon crystallization, indicating zircon saturation and subsequent growth during the experiment.