

## **Timing and Processes of Carbonatite Formation: A Case Study From the Bears Paw Mountains, Montana**

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Carbonatites are igneous rocks that serve as the primary source of rare earth elements and niobium. The timing and processes associated with the formation of carbonatites are often difficult to resolve due to complex emplacement histories and hydrothermal overprinting. Carbonatites typically form in association with alkaline magmatic systems, and therefore often lack primary minerals such as zircon that are suitable for U-Pb geochronology. The Rocky Boy, an Eocene Age composite intrusion of the Bears Paw Mountains, is an exception where carbonatites and associated alkaline rocks are enriched in zircon, presenting an opportunity to constrain the timing of alkaline magmatism and generation of carbonatites. Zircon U-Pb and trace element data were first determined via LA-ICP-MS and further constrained using single crystal U-Pb zircon CA-ID-TIMS analyses. The U-Pb zircon CA-ID-TIMS results significantly improved upon established K-Ar feldspar and biotite chronologies that indicated a period of protracted magmatism spanning ~4 myr, with many of the K-Ar ages incompatible with the interpreted field relationships. In contrast, the new zircon geochronology indicates magmatism was short-lived, occurring over a sub-myr timescale. Whole rock Sr isotopic data from the alkaline complex are radiogenic, suggesting a strong crustal influence. The new geochronology and geochemistry results provide a framework for constraining processes leading to carbonatite generation and critical element endowment. Additionally, zircon Th/U ratios from the alkaline silicate and carbonatite lithologies deviate strongly from the global average value of 0.6 for igneous zircon, with values up to 5. A global compilation of zircon Th/U from carbonatite and alkaline rocks reveals that these elevated ratios are a unique feature to these rock types. Targeting zircons with anomalously elevated Th/U ratios in global zircon databases or in stream sediments from catchments with suspected alkaline rocks may provide a useful tool for future carbonatite exploration.