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Apatite Sr-Nd isotopes record magmatic pulses in the Mountain Pass intrusive suite, California, USA

ERIN K. BENSON[1,2], ANDREA GIULIANI[3], JOHANNES HAMMERLI[1] AND KATHRYN E. WATTS[2]

[1]Washington State University
[2]U.S. Geological Survey
[3]Carnegie Institution for Science

The Mountain Pass intrusive suite consists of seven ultrapotassic alkaline-silicate stocks and one carbonatite stock, which hosts the only active rare earth element (REE) mine in the U.S. Zircon and monazite geochronology indicates magmatism was multiphase, occurring between ca. 1.44–1.37 Ga, with carbonatite emplacement as a late magmatic pulse [1, 2]. Petrogenetic models for the Mountain Pass intrusive suite indicate the melts were derived from a shared mantle source region but do not necessarily represent products of fractional crystallization or liquid immiscibility [3]. Textural evidence supports a hydrothermal rather than magmatic origin for most REE mineralization, although the source of mineralizing fluids remains unconstrained.

In this study, in-situ Sr-Nd isotopes in apatite are used to unravel the petrogenesis of the intrusive suite and identify the origin of mineralizing fluids. Apatite is present in all rock types, with both primary magmatic and fluid-metasomatized populations. Strontium isotopes support three isotopically distinct magmatic pulses in the alkaline intrusions. The most radiogenic signature is reflected in two volumetrically minor stocks ($^{87}Sr/^{86}Sr_i$: ~ 0.7066). The other five, more voluminous stocks contain apatite that is slightly less radiogenic ($^{87}Sr/^{86}Sr_i$: ~ 0.7056). Two fine-grained shonkinite dikes near the carbonatite stock contain apatite with the least radiogenic Sr ($^{87}Sr/^{86}Sr_i$ = 0.7040 ± 0.0004), which overlaps within uncertainty the apatite in the carbonatite stock ($^{87}Sr/^{86}Sr_i$ = 0.7043 ± 0.0002). Initial εNd calculated using an age of 1420 Ma in REE-rich apatite results in locally variable $\varepsilon Nd_{initial}$ values. Most grains exhibit homogeneous Nd isotope signatures supporting derivation from an enriched mantle source ($\varepsilon Nd_{initial}$ = -3.2 ± 1.5). Primary magmatic apatite isotope ranges overlap those of metasomatized apatite in the same samples, indicating a magmatic rather than external fluid origin for the latter. Our results support an enriched, isotopically heterogeneous mantle source region for the Mountain Pass suite, with carbonatite magmatism linked to a low-volume episode of alkaline magmatism. Alteration of primary apatite by magmatic fluids may be related to regional mobilization of REEs.

[1] Poletti et al. 2016, J. Pet., 57, 1555-1598; [2] Watts et al. 2022, Econ. Geol., 117, 1-23; [3] Benson et al. 2025, Lithos, 508-509, 108060.