

Integrating Zircon Petrochronology and Low-temperature Thermochronology to Assess Magma Fertility and Exhumation at the Sierrita Porphyry Cu–Mo Deposit, Arizona, USA

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Arizona hosts world-class porphyry copper deposits formed during the Laramide orogeny and subsequently exhumed during extensional tectonics. This study focuses on the Sierrita porphyry Cu-Mo deposit associated with the Ruby Star pluton and related porphyries, which together represent a tilted magmatic-hydrothermal system in the Pima mining district.

Zircon petrochronology is used to evaluate the temporal variations in zircon trace element compositions between pre- and syn-mineralization intrusions. Syn-mineralization Laramide intrusions systematically show lower Ti contents, weaker negative Eu anomalies, higher Ce anomalies, and higher oxygen fugacity than pre-mineralization Jurassic and Laramide intrusions. Elevated Ce anomalies are consistent with enhanced zircon Ce⁴⁺ partitioning under cooler, more oxidized conditions, whereas weak negative Eu anomalies suggest higher proportions of melt Eu³⁺ that limit Eu partitioning in plagioclase and/or reflect early amphibole crystallization from a more hydrous melt. Collectively, these results indicate that syn-mineralization intrusions represent more oxidized and potentially more hydrous melts, which are the hallmark of fertile magmas.

Complementary thermochronology and Al-in-hornblende thermobarometry along a paleo-vertical transect constrain the crystallization depths and thermal history of the Ruby Star pluton. Zircon (U–Th)/He, apatite fission track, and apatite (U–Th)/He data record cooling through ~200–45 °C, corresponding to depths of ~6.5–1.5 km assuming a 30 °C/km geotherm. The data reveal two cooling phases: rapid cooling from 33 to 30 Ma followed by slower cooling from 28 to 21 Ma. Integrated with previous structural and geochronologic constraints, these results indicate rapid exhumation and tilting at 33–30 Ma, followed by slower exhumation from 28 to 21 Ma. The earlier cooling phase predates previously recognized exhumation in southern Arizona, whereas the later phase overlaps with exhumation of the nearby Catalina and Coyote metamorphic core complexes. These results identify major extensional zones as prospective targets for the exploration of shallow, tilted porphyry copper systems in the American Southwest.