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Magmatic vs. Metamorphic Signatures in Archean Apatite Inclusions: Insights from REE Ratios

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Apatite inclusions in zircon represent a uniquely robust archive of primary magmatic compositions, particularly in Archean terranes where subsequent metamorphism and metasomatism commonly obscure original petrogenetic signals. This is because zircon can shield apatite inclusions from later fluid-mediated alteration and metamorphic overprint, allowing these inclusions to preserve geochemical signatures that are otherwise lost in matrix apatite populations. However, this is preservation is not universal. Consequently, to correctly reconstruct primary melt compositions, volatile budgets, and source characteristics of Early Earth crust-forming magmas from apatite enclosed within zircon, it is critical to distinguish primary magmatic apatite from grains that have been modified by metamorphism or metasomatism.

Trace element systematics, particularly rare earth element (REE) patterns and high field strength element ratios, provide powerful tools for discriminating apatite genesis. Chondrite-normalized Y/Ho and La/Sm ratios are especially sensitive indicators. In typical Phanerozoic systems, magmatic apatite preserves coherent REE fractionation trends governed by melt-controlled partitioning, yielding near-chondritic Y/Ho ratios and smoothly evolving La/Sm values that track primary magma differentiation. However, Archean apatite commonly exhibits distinctive REE patterns—such as pronounced light-to-middle REE fractionation and atypical slope geometries—that can shift chondrite-normalized Y/Ho and La/Sm values into fields conventionally interpreted as metamorphic. This Archean compositional bias introduces an additional layer of complexity, as primary magmatic inclusions may be misclassified if modern geochemical reference frameworks are applied uncritically.

Here we will outline a method that allows to discriminate between magmatic and metamorphic signatures also for Archean apatite, which enables a more accurate reconstruction of primary magma composition, redox state, and volatile content, ultimately strengthening interpretations of early crustal differentiation processes and the geochemical evolution of Earth’s earliest magmatic systems.