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Zircon-hosted mineral inclusions distinguish Barberton TTG and felsic volcanic sources with implications for Hadean detrital zircons

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Hadean detrital zircons are the only direct archive of Earth's first ~550 Myr, and most interpretations of early crustal evolution rely on zircon geochemistry alone. An underutilized complementary approach is zircon-hosted mineral inclusions, which may preserve information about source composition, tectonic setting, melt redox state and magmatic evolution. To establish a robust interpretive framework for ancient inclusion assemblages, we investigate zircons from the 3.55–3.20 Ga Barberton Greenstone Belt and coeval tonalite–trondhjemite–granodiorite (TTG) plutons.

Zircon-hosted inclusions, identified using energy dispersive spectroscopy, were grouped into twelve compositional categories. To evaluate the role of secondary fluids and alteration, inclusions were additionally categorized by microstructural context as isolated, crack-associated, or crack-infilling. Crack infilling inclusions are statistically distinct from the others and are interpreted to record secondary fluid-driven precipitation and/or replacement, while crack-associated and isolated inclusions are statistically indistinguishable. We therefore interpret primary inclusion assemblages using combined isolated + crack-associated populations and exclude crack infills.

While zircon mineral inclusions are systematically offset towards more evolved compositions relative to whole rock mineralogy, primary inclusion assemblages vary systematically with rock type. TTG zircons are dominated by apatite (~44%) with subordinate feldspar and mafic silicates, whereas felsic volcanic zircons are quartz-rich (~28–36%) and enriched in K–Al silicates. Inclusion data suggest that detrital zircons are mostly sourced from volcanic rocks, and source–detritus comparisons show broadly similar inclusion assemblages with modest, statistically resolvable shifts consistent with sedimentary reworking (preferential loss of fluid-unstable phases like apatite and relative enrichment of alteration-related chlorite and/or quartz/chert).

Hadean zircon-hosted inclusion assemblages reported for the Jack Hills bear a resemblance to inclusions from Paleoarchean felsic volcanic rocks in Barberton: both groups are rich in quartz and K–Al silicates (including muscovite) and poor in apatite. This observation cautions against assuming an S-type granitic source for the Jack Hills based on inclusion assemblages (e.g., Maas et al., 1992), and underscores the need for comparative inclusion studies anchored in Archean examples, rather than extrapolating primarily from Phanerozoic datasets.

Collectively, our results establish a microstructurally informed framework for using zircon inclusion assemblages as a complementary constraint on provenance and early crustal evolution.