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On the reliability of multiple mineral geochronometers for a single pluton

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Zircon remains the gold standard for dating granitic rocks. Nevertheless, an increasing number of studies report inconsistencies in zircon ages obtained for large plutonic bodies, such as batholiths or even within single hand specimens. Indeed, zircons often record age spreads of tens of millions of years with some datasets, displaying spreads approaching ~100 Ma. Such age dispersion may reflect inherited domains, post-crystallisation alteration [1, 2], Pb loss, or radiogenic Pb heterogeneity [3]. Screening by cathodoluminescence (CL) or back-scattered electron (BSE) imaging is widely used to avoid compromised analytical domains, yet problematic data often persist despite such precautions. Here we evaluate possible reasons for this age spread in zircon data after imaging-based screening, and assess alternative geochronometers, specifically apatite and titanite U–Pb dating.

Laser-ablation split-stream (LASS; U–Pb plus trace elements) analyses indicate that cryptic chemical alteration can significantly reduce age reliability. Such alteration is not always texturally evident but can be detected through trace-element anomalies (e.g. K, Ca, Al, Mg, Fe, Th/U, LILE enrichment) and distinctive V-shaped REE patterns. We therefore recommend routine LASS monitoring and systematic filtering of anomalous zircon analyses using criteria such as (1) core–rim age inversion, (2) Ba/Hf, and (3) Nd/Sm ratio anomalies to exclude hydrothermally modified grains.

Apatite and titanite show potential as complementary chronometers. Apatite may retain robust ages owing to annealing of radiation damage. After filtering anomalous data using major- and trace-element proxies (e.g. Sr, Zr/Y, Th/U for apatite; Sr/Zr, Sr/Th, Sr/Ca, Zr/Ti for titanite) both minerals can yield dates within uncertainty of zircon ages. However, they may also occur as multiple compositional and age populations, requiring careful interpretation.

Overall, these results demonstrate that thermal closure temperature alone is insufficient for evaluating isotopic system reliability; the degree of chemical alteration exerts a critical control on effective system closure and must be explicitly assessed in high-resolution geochronology.

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