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The Record of Dynamic Magmatism in Zircon Heterogeneity

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Crustal magmatism encompasses a suite of complex processes spanning time and space. Despite the growing convergence on the magma "mush" paradigm, pressing questions remain about the scales of crystal-melt interactions. Estimates of these interaction scales form the basis of geochemical and geochronological interpretations. Here, we present how zircon, a premier geochronometer and excellent record of trace element geochemistry, sheds light on the scales of crystal-melt interactions.

Geochemical proxies of conditions and processes are especially useful for interpreting the evolution and complexities of single magma systems, but when applied to different settings, zircon populations show patterns of compositional heterogeneity and homogeneity that are difficult to interpret at face value. There is also an inherent zircon "core bias" because most analyses are conducted on the polished interior of grains; an exemplar effect of this is seen in the significant compositional overlap within common discrimination schemes, despite zircon rims often preserving more disparate compositions. Depth profiling, analyzing a grain from the rim inwards, improves our resolution of magmatic evolution unique to tectonic setting and locality. Importantly, depth profiling allows access to the outer, lower-temperature growth zones that best capture the complexity of late-stage magma dynamics.

Our new depth profiling analyses and literature compilation of grains from samples of different igneous classifications (~65,000 integrations from ~4,000 grains) permit comparison of the geochemical variability across multiple sampling scales. We expand on prior work by examining how the average chemistry and corresponding variability affect zircon comparison at the grain, hand sample, locality, and igneous classification scale. This comparison reestablishes zircon's efficacy as a petrogenetic tracer, while confirming that individual grain analyses capture only parts of the magmatic evolution trend within samples and localities. This finding, coupled with the observation that zircon variability accumulates sharply from the grain scale to the hand sample scale, but notably does not increase much at the location scale is misaligned with models of large-scale mixing-induced heterogeneity. This trend in variance is consistent across *most* petrologic classifications and highlights that variance originates on the order of millimeters to centimeters, suggesting a unifying scale of crystal-melt interactions within magmatic systems.

