Scale dependent U-Pb Systematics: generalizing multi-domain element mobility (MDEM) beyond zircon

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Uranium-Lead dating is one of the most widely utilized techniques for generating quantitative temporal information in the geosciences. This stems from (1) the abundance of phases that incorporate U and Th in sufficient quantities to enable precise measurement of U, Th and Pb ratios, and (2) the ability to evaluate U-Pb isotope systematics (e.g. initial Pb, common Pb, and open system behavior (i.e. "concordance")) based on comparison of the independent $^{238}U \rightarrow ^{206}Pb$, $^{235}U \rightarrow ^{207}Pb$, and $^{232}Th \rightarrow ^{208}Pb$ decay chains. Despite decades of work, there remains limited understanding of Pb behavior, particularly Pb mobility at the nanoscale in the presence of microstructural and crystallographic changes through time. Recently, atom probe tomography (APT) has documented the presence of nanoscale domains enriched in Pb in zircon [1,2], and presented evidence that $^{207}Pb/^{206}Pb$ ratios within nanoclusters can be preserved (i.e. "locked in") over billions of years, even during subsequent Pb migration. These observations have prompted modeling of multistage Pb evolution in zircon, including clustering, and domain-specific Pb loss [3]. This contribution seeks to expand modeling of "multi-domain element (Pb) mobility" (MDEM) [3] to phases with significant/arbitrarily large proportions of initial Pb.

As in minerals with negligible non-radiogenic Pb, the presence of nanoscale domains and their behavior can have significant effect on the resulting data arrays in concordia diagrams, as multistage Pb migration generates systematic offsets based on the initial Pb composition, the timing of crystallization, the timing of cluster formation, and the timing of Pb mobility. Importantly, combined clustering and Pb loss has a minimal effect on unique identification of the initial/common Pb components in three dimensional concordia space. We utilize the modeling results to further highlight (1) the importance of assumptions and Pb behavior in different mineral systems (presence/absence, cluster stability, etc.) and (2) micron-scale trends that may indicate MDEM type behavior. Ultimately these results reinforce the unique information accessible via multi-scale U-Pb characterization to study the accommodation and distribution of Pb components, and the nanoscale manifestations of discordance.

[1] Valley et al. (2015) *Am. Min*. [2] Blum et al. (2018) *AGU Monogr* **232**. [3] Blum et al. (2020) EGU.