Constrains on the thermal history of crystal-rich magmas from crystal residence timescales

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Many intermediate and silicic composition volcanic rocks, including some of the largest known eruptions, involve remobilization of magma or crystal-rich mush that has been stored with the crust for significant time periods. Developing a better understanding of the thermal and chemical evolution of magmas within crustal reservoirs has implications for the longevity and mechanisms of generation of chemically diverse magmas and for the mechanisms that mobilize this material for eventual eruption. The physical and thermal states of the system are intimately linked, going from mostly liquid to mushy to potentially solid or almost-solid systems primarily as a function of temperature. Crystal-scale records provide evidence of long-term storage and recycling of crystals within a reservoir system, but the extent to which storage occurs in mostly-liquid vs. mostly-solid or solid bodies is unclear. Numerical models can provide insights into thermal histories at a reservoir scale, and crystal and liquid thermometry can provide insights into the thermal state of the crystals at snapshots in time, but developing thermal histories from the record in erupted products has been elusive.

We have developed an approach for quantifying the thermal histories of magma bodies by combining information about crystal residence times from multiple sources. U-series crystal ages provide the total time since crystals grew (albeit averaged over all crystals/zones in a bulk separate). In contrast, trace-element zoning provides an upper limit to the duration of storage at high temperatures, and crystal sizes and CSDs provide insights into the total growth time of crystals. By combining information from all of these sources, we can link the crystal growth and diffusion ages to thermal states and therefore constrain thermal histories. We use recent eruptive products at Mt Hood as a case study, building off of previous ^{238}U-^{230}Th-^{226}Ra crystal age, CSD, and diffusion modeling results. ^{230}Th-^{226}Ra ages of crystals from the silicic endmember of the two most recent Mt Hood eruptions both have average ages of >4.5 ka and have cores with ages >10 ka. Diffusion of Sr in plagioclase limits the time spent at temperatures >850-900 °C to less than a few decades. Crystal sizes and CSDs constrain the total duration of crystal growth and allow identification of multiple crystal populations in the samples. Collectively, these data constrain models of crystal growth and dissolution as a function of thermal histories, showing that only a small fraction of the total time that the crystals were present could have been spent at temperatures significantly above the solidus, and an even smaller fraction of that time could have been spent at temperatures high enough for trace-element diffusion to be significant. These observations suggest that the state of the reservoir in which crystals at Mt Hood are stored was at near- or sub-solidus temperatures for most of its history, with brief excursions to higher temperature likely related to recharge and eruption (and which may have resulted in some minor dissolution of crystals).

Although Mount Hood is the only system for which a complete data set is available, a summary of data (Figure 1) shows that the general features we observe are a global feature of crustal magmatic systems. Given that the thermal history of magmas is important for understanding a variety of magmatic and eruptive processes the widespread application of the approach detailed herein to magmas produced in different tectonic environments and to systems of different overall size and flux is likely to provide important insight into volcanic processes.

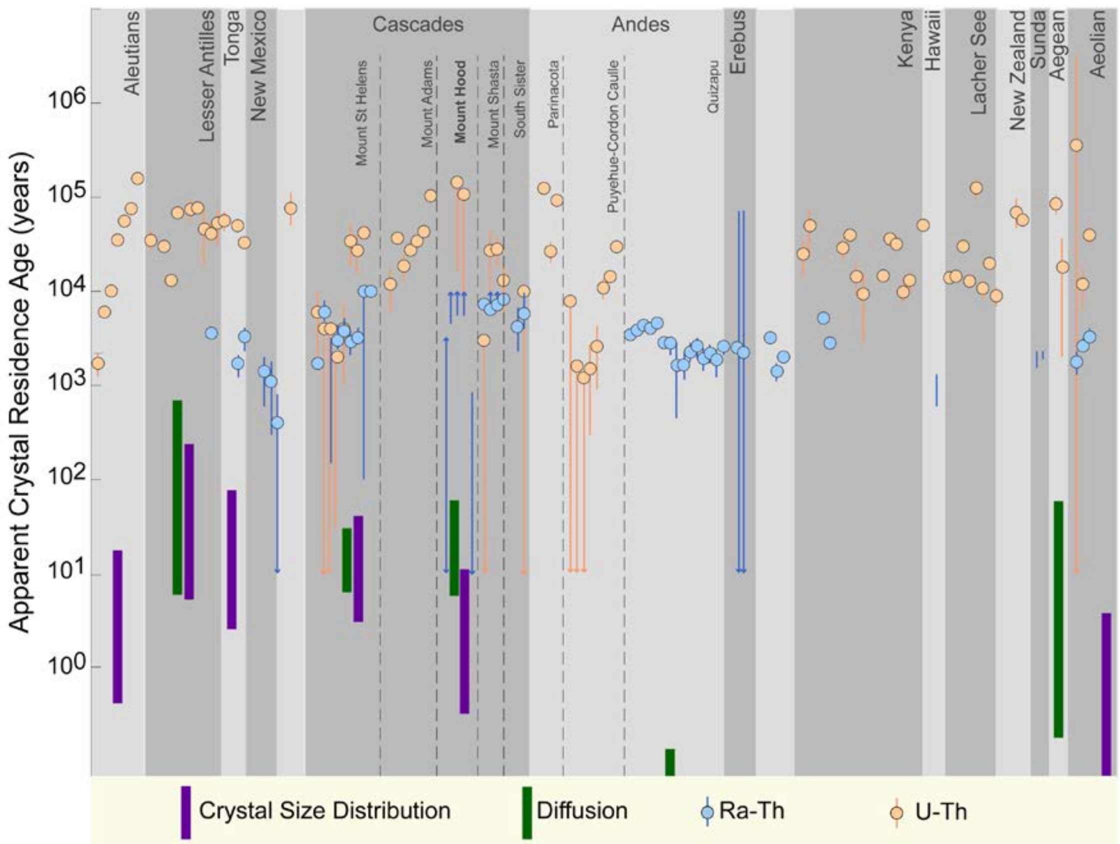

Figure 1. Global summary of U-Th-Ra, diffusion, and crystal size distribution estimates of crystal residence ages in magmas.