

A mixed message from U-series crystal ages

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To quantify the tempo of magmatic processes, the disparities between the different constraints on crystallization timescales must first be reconciled. When compared to crystal ages based on kinetic considerations (e.g., crystal size distributions, diffusional relaxation), U-series ages are generally an order of magnitude or more greater. Moreover, although limited in number, when both U-Th and Th-Ra ages are obtained for the same mineral aliquots (n=18), the ages are discordant in more than half the cases. In addition, those pairs of ages that are concordant are arguably too old in many cases to have simply crystallized from their host magmas, considering the magnitudes of Ra excesses in the hosts. Diffusion is likely a subordinate factor in producing these effects.

In situ dating of accessory phases in rhyolites has revealed evidence for refractory phases from crustal anatexis or contamination (xenocrysts), crystals recycled from earlier genetically-related magmatic activity, and crystal cores that significantly predate eruption. Discordant and otherwise “old” U-series ages for mineral aliquots could similarly be explained as the product of variable degrees of mixing between such crystal populations. For contamination by xenocrysts to be largely responsible for the discordia observed, the average age of phenocryst growth would be >0.5 k.y. in virtually all cases and xenocrysts would constitute a significant and therefore recognizable fraction of the crystal population (likely 10-30%). Alternatively, the U-series ages could reflect multiple episodes of crystal growth. Those which are discordant require a significant fraction of the crystal population to be several tens of k.y. old whereas those which are concordant may be explained by up to ~15 k.y. of growth. The crystal ages cannot therefore be explained simply by remobilization of crystals near the solidification front. Very deep scouring of extensively mushy rinds of magma reservoirs, continuous or repeated exposure of crystals to melt, and/or stochastic intrusion and crystal re-entrainment in sill/dike complexes may be able to reconcile the U-series ages with kinetic constraints on crystallization. For the discordant ages, magma intrusion into earlier (co-genetic and mushy?) intrusive bodies may be required.

Time scales of chemically zoned magma chamber formation: U-series disequilibria in the Fogo trachyte deposits, São Miguel, Azores

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Fogo volcano, located on the island of São Miguel, Azores, has produced two chemically zoned trachyte deposits over the past 5,000 years, providing an excellent opportunity to investigate the time scales over which magma differentiation has taken place. Here we report high precision plasma ionization multicollector mass spectrometry measurements of ²²⁶Ra-²³⁰Th-²³⁸U disequilibria and Ba contents on pumices and glass separates from the Fogo 1563 A.D. (~0.14 km³) and the ~4.6 ka Fogo A (~0.7 km³) chemically zoned trachyte deposits. We suggest that continuous differentiation models may be more realistic than instantaneous models, and that they better explain the observed ²²⁶Ra-²³⁰Th variations within the deposits. These models suggest magma residence times prior to eruption of ~50 to 80 years for Fogo 1563, and ~2 to 4 ka for the larger volume Fogo A eruption. These time scales represent liquid residence ages rather than the crystallization ages documented in most previous magmatic time scale studies and allow constraints to be placed on the time scales necessary for the development of chemical zonation within the Fogo magma chamber. Our results indicate that calculated time scales are relatively insensitive to the precise nature of the continuous differentiation models. Meaningful magma differentiation time scales can be obtained despite open system behavior, because the ²²⁶Ra-²³⁰Th disequilibria are overwhelmingly controlled by feldspar fractionation. However, calculated time scales are extremely sensitive to $D_{\text{Ra}}/D_{\text{Ba}}$ ratios. We emphasize the crucial importance of better constraints on the relative partitioning of Ra and Ba when employing ²²⁶Ra-²³⁰Th disequilibria data to constrain the rates and time scales of igneous processes.