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Dating the accessory phase record of dynamic rhyolite evolution

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Allanite crystals in the voluminous (>2800 km^3), ca. 73 ka Younger Toba Tuff (YTT) of Sumatra, Indonesia, grew for up to 40 thousand years, and a subset of those allanite crystals grew for ca. 100 thousand years longer than the others, based on ^{230}Th-^{238}U ion microprobe dating. The relative youth of these allanites shows that the YTT tapped a rhyolitic magma produced after the demise of the 500 ka Middle Toba Tuff magma chamber, possibly by fractionation from voluminous magmas resident in the lower portions of the Toba system. In contrast, the crystallization ages of YTT zircon are significantly more distributed, with half of the grains containing domains that are within error of ^{238}U-^{230}Th secular equilibrium (>250 k.y.). ^{238}U-^{206}Pb dating reveals that most of the zircon growth occurred since eruption of the Middle Toba Tuff, and that crystallization was progressive, if episodic. Some grains, including the core of an otherwise young zircon are, however, 100-200 k.y. older than the 0.84 Ma eruption age of the Early Toba Tuff. Collectively, the data suggest that nucleation and growth of most YTT zircons occurred at least intermittently for 400 k.y. before eruption, but that other zircons are recycled from the solidified remnants of earlier magmatism.

Both the distribution and relatively older ages of the zircons compared to those of allanite are consistent with a magma reservoir undergoing secular cooling and stochastic liquid-crystal separation. The duration of allanite crystallization is, moreover, permissive of the time scales required for thermal rejuvenation of a voluminous granitoid mush by an influx of mafic magma or fractionation differentiation of a batholithic mush by compaction and/or hindered crystal settling. However, the record of zircon growth is significantly more protracted than observed in previous studies, even when the oldest (>0.9 Ma), likely recycled, grains are excluded. Additionally, even though zoning profiles in the allanites are regular and appear to be more or less continuous, their compositional oscillations and disparate histories require heterogeneous conditions of crystallization, whether in mush or liquid-rich domains. By analogy to the plutonic record, the subvolcanic magma reservoir must have disrupted frequently over 400 k.y. by rejuvenation and/or differentiation but it appears to have followed a secular trend towards stabilization of evolved (up to 77 wt. % SiO_2), allanite-bearing rhyolites.

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Crystal isotope clues to subvolcanic magmatic evolution and eruption triggering

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It is now widely recognized that initial isotopic diversity exists at a mineral scale within many volcanic rocks. This observation implies that the crystal cargo of such magmas has been aggregated from discrete components, which have evolved in different places within the magma system, and possibly at different times. The existence of isotopic zoning within single crystals also constrains the timescales over which crystals may have resided in a high temperature magma and argues against protracted (10's to 100's of kyr) residence. Isotopic (^{87}Sr/^{86}Sr) zoning among feldspars in intermediate composition magmas (e.g. El Chichon, Lassen Peak, Stromboli, Parinacota, Campi Flegrei) commonly converges rim-ward on the measured or inferred composition of the host magma. This suggests that a period of growth occurred after crystal aggregation into the magma, and before eruption. In many instances a mafic recharge event appears to have preceded and potentially triggered eruption, implying that any rim grown in equilibrium with a host hybrid magma must have grown during the period of hybridization that preceded eruption. Interestingly, there is a suggestion among silicic systems (e.g. Taupo, New Zealand, Fish Canyon USA) that no such growth occurred during hybridization, because, so far as can be resolved, the outermost rims of feldspars are commonly *not* in ^{87}Sr/^{86}Sr isotopic equilibrium with the host magma. In the case of the Fish Canyon magma system, K-feldspar, plagioclase, apatite and sphene are not in isotopic equilibrium with adjacent glass, suggesting that they represent a remobilized crystal fraction from a pre-existing isotopically heterogeneous crystalline, igneous precursor, erupted before significant re-equilibration with, and growth from, the newly-formed magma can occur. The implication is that partial melting and crystal remobilization of large volumes of crystalline material may take place surprisingly rapidly.