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Circa 50-kyr run-up to Toba caldera supereruption: evidence from petrochronology of erupted mush

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Constraining the mechanisms and timescales of magma assembly and volcanic eruption remains a central challenge in volcanology. At Toba caldera (Indonesia), source of the ca. 74 ka Youngest Toba Tuff (YTT) supereruption, we recover a direct record of these processes via a ~30 cm cognate microgranular plutonic enclave discovered in the Janji Mariatoruan post-caldera dome. Integrating high-spatial-resolution SIMS ^{238}U–^{230}Th zircon and allanite geochronology with mineral chemistry and isotopic analyses, we identify two discrete thermal rejuvenation events at ca. 120 ka and ca. 78 ka that preceded the YTT eruption. The earlier event remobilized a biotite-rich portion of the reservoir, driving amphibole and allanite crystallization as well as the initiation of melt segregation. The later pulse represents a critical recharge episode that acted as the onset of magma reservoir destabilization and primed the YTT magma body for a supereruption. The absence of oscillatory zoning and narrow age spectra of enclave-hosted zircon indicates rapid crystallization during near-solidus storage, demonstrating that mush rejuvenation was episodic rather than continuous. These results establish an absolute temporal framework for the rejuvenation of the Toba magma mush and show that the run-up to supereruption is governed by punctuated, multi-stage reactivation of upper-crustal, crystal-rich mush zones. They further highlight the critical role of near-solidus mush dynamics in controlling both the longevity and reactivation potential of Earth's largest magmatic reservoirs.