What is a magma crystallization age? Insight from micro-sampling of chemical domains in zircon from the Fish Canyon Tuff

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U-Pb geochronology has great potential for constraining the timing and rates of geological processes in rocks as young as 1 Ma. Recent advances in the U-Pb isotope dilution TIMS method allow for the determination of $^{206}Pb/^{238}U$ dates from single zircon grains with precision of ± 0.1% (internal error) and igneous crystallization ages for rocks with precision of ± 0.03% or better. However, analysis at this level highlights subtle intra- and intergrain variability that in many cases precludes determination of a simple "crystallization age". Much of the complexity is likely due to magmatic residence of zircon, which has been shown to be as long as 200 Kyr. Crucial to the determination of high-precision Phanerozoic dates is minimizing of procedural blanks, obtaining high ionization efficiency in the mass spectrometer, precisely analyzing small amounts (<10 pg) of radiogenic Pb, and microsampling of chemical domains guided by knowledge of internal compositional variability.

The Oligocene Fish Canyon Tuff (FCT) is a voluminous ash flow in the San Juan Mountains of Colorado with sanidine that is used as an important $^{40}Ar/^{39}Ar$ standard. Petrological models indicate a complex multi-stage origin for the pre-eruptive magma, although this has not been detected in a previous zircon study. Measurement of Th/U in FCT zircon by laser ablation-ICPMS and backscattered electron (BSE) imaging and Hf mapping by electron microprobe show that cores in many grains are sharply bounded by rims. Relative to rims, cores have lower BSE brightness, higher Th/U (0.5-1.0 vs. 0.4-0.5), and lower Hf (7000-9000 ppm vs. 10000-12000 ppm). Low procedural Pb blanks (average = 0.4 pg) allow for precise dating of small fragments of grains that indicates rims are ~250 Kyr younger than cores (dates were corrected for initial ^{230}Th disequilibrium using previously measured Th/U in glass). Cores are interpreted as having crystallized early in the FCT magma chamber and rims are interpreted as recording the last event before eruption. The sharpness of the core-rim boundaries suggests that growth occurred during discrete events rather than continuously. The reduction in Th/U from 1.0 to 0.4 may be due to crystallization of a Th-rich mineral, such as titanite.

These results prove that (i) zircon resided in the FCT magma for ~250 Kyr before eruption; (ii) the zircon age of eruption is ~1% older than the accepted $^{40}Ar/^{39}Ar$ age; and (iii) U-Pb dating of micro-sampled chemical domains in zircon is capable of resolving events within the duration of a single magmatic system, including relatively old systems (up to 100 Ma).