Changing our ideas about the evolution of magmatic systems with improved temporal resolution: do we get it right?

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Improvements to U-Pb geochronology of magmatic zircon have resulted in temporal resolution at the level of <0.1% for individual $^{206}$Pb/$^{238}$U dates and of 0.02-0.05% for weighted mean $^{206}$Pb/$^{238}$U ages of a statistically equivalent group of single crystal dates from zircon or baddeleyite (50,000 years for a Mesozoic igneous rock). This talk will give a short overview on the challenges and opportunities such high precision age determination implies in felsic and mafic magmatic systems.

Felsic magmatic systems: Zircon dates from the same hand sample cover a temporal range that integrates their crystallization history in the melt. Since each grain crystalizes over a certain time period, the apparent age range is a minimum estimate of the duration of crystallization or the residence in a magma. A major challenge is the mitigation of decay-related lead loss through refined chemical abrasion procedures (Widmann et al., 2019) to avoid erroneous interpretation of zircon dates that appear too young. Apparent trace element or isotopic trends are typically not coherent with time and therefore reflect fractionation processes at different places and different times in the magmatic system, possibly within compositionally different magma batches.

Mafic magmatic systems: Zircon is not a crystallizing phase in a basaltic melt, but can occur after ~90% fractionation of olivine, pyroxene and amphibole, zircon saturation can then be achieved in low-volume granitic melt pockets (depending on the water content). A zircon date is therefore an age information along the crystallization -cooling path of a mafic intrusion (Zeh et al., 2015). In low-Si and low-Zr melts, baddeleyite may arrive at saturation before zircon and can be used for dating as well. There are two clear problems with zircon/baddeleyite geochronology in mafic systems: (i) since baddeleyite saturates earlier than zircon, it should produce slightly older dates in the same rock; however, these minerals often display the inverse relationship. Since no pre-treatment for the removal of decay-damaged portions exists for baddeleyite, we can demonstrate that this discrepancy is due to lead loss. Mitigating lead loss is also difficult for zircon since it crystallized from residual melt patches of granitoid composition high in uranium, often resulting in metamict crystals; (ii) zircon populations from dolerites may spread over >100,000 years even in cases where simple thermal modeling shows that a dolerite sill has crystallized and cooled at $10^3$ years timescales. Beside lead loss, we may suspect that certain zircon grains contain minute portions of pre-crystallization radiogenic lead from crustal contamination. We can explore and quantify cryptic inheritance through Hf, O isotopic analysis of the same dated zircon grains. Heterogeneous
nucleation on relics of incompletely dissolved zircon is more probably than spontaneous nucleation.

As an overarching challenge, we have no technique or independent approach to quantify lead loss and it remains the biggest uncertainty in U-Pb dating.