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Tracking the growth of plutons: the contribution of high-precision U-Pb zircon dating

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A growing body of high-precision U-Pb data from magmatic zircon indicates that plutons grow over timescales of 10^5-10^6 years. A complex interplay of processes – including accumulation of melt batches from lower and middle crustal levels, crystallization, remelting of solidified crystal mushes, mixing and mingling, transfer of pheno- and xenocrysts between melt portions, and many more – results in equally complicated pluton structures and rock textures. The use of (^{202}Pb-) ^{205}Pb-^{233}U-^{235}U tracer solutions in U-Pb dating of magmatic zircon can lead to a precision of 0.1% in the ^{206}Pb/^{238}U age of an individual zircon analysis, and to as low as 0.02% for a weighted mean of 6-10 coeval analyses. Such uncertainty is well within the time interval of zircon crystallization and residence in intermediate and acid magmatic liquids and allows resolution of incremental accumulation of melt batches in plutons.

We demonstrate that we can achieve sub-permil precisions with MSWD values of around 1 on weighted mean dates by analyzing simultaneously precipitated zircon from H_2O-enriched residual liquids within zircon-undersaturated basalt. Any age variation in granitoid rocks beyond this analytical spread is therefore considered real age dispersion, leading to an array of non-equivalent, analytically concordant points (within decay constant uncertainty). The reasons for such age dispersion may be the following: (i) incorporation of antecrystic zircon (Miller et al. 2007) from earlier magma batches of the same magmatic system, which have crystallized 10^4 to 10^5 years earlier; (ii) protracted zircon crystallization within a single batch of magma during its ascent and emplacement; (iii) presence of smallest xenocrystic cores in the analyzed zircons which contain a small proportion of older lead (iv) minor degrees of unresolved lead loss that lead to slightly young ages. Though Pb-loss can largely be avoided by applying chemical abrasion prior to analysis (Mattinson, 2005), its effects are difficult to rule out completely. Resolving these different sources of age dispersion is rather simple at the 10^6 year level, but becomes extremely delicate at the 10^5-10^4 year level. The hot-zone model of Annen et al. (2006) would imply maximal age dispersions of a few 100 ky during the formation and transfer of residual melt batches from the root zone into the upper crust.

We will present examples of granitoid rocks that record a variety of processes in the age dispersions of their zircons. In some, more extended age dispersion up to 2 m.y. point very likely to the presence of inherited (pre-magmatic) Pb components, possibly combined with incorporation of antecrystic zircon from previous melt batches. In other case studies, some granites of the same magmatic system may display simultaneously precipitated populations, while others exhibit age dispersions of 250 ky, compatible with protracted magmatic growth and incorporation of antecrystic zircon in evolving magma. In such a case, precise analyses do not allow calculation of a common crystallization age at 2 sigma level, because MSWD values are exceedingly large (5-30). We will have to refer to such distributions of ages as durations of zircon growth. The youngest analyses could theoretically be representative for the autochthonous magmatic growth (autocrysts; Miller et al. 2007), if we can exclude any influence of post-crystallization lead loss. We can demonstrate such effects in plutonic rocks as old as 100 Ma, and in volcanic rocks as old as 200 Ma. The bottom line is that incorporation of antecrystic zircon and/or prolonged zircon growth, combined with our increasing ability to resolve such small periods of time, are very common phenomena in magmatic systems. This realization is forcing us to abandon the notion of a single “crystallization age” for many types of plutonic systems and also hampers the ultraprecise determination of eruption ages of volcanic ash beds used for time-scale calibration purposes.

References:

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