Resolving the pace of metamorphic processes within <1 Myr using high-precision Lu-Hf chronology of laser-milled garnet domains

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Unraveling the timing and rate of high-pressure metamorphism requires linking time to the changes in the composition of petrogenetic indicator minerals. Garnet is key in this regard as it forms by mineral reactions that can be linked to pressure and temperature conditions and typically preserves this record as geochemical changes in growth domains. Bulk- or multi-grain garnet dating, using Lu-Hf or Sm-Nd is the norm and can provide important and precise time-brackets on garnet growth. Domain dating, *i.e.*, dating of individual growth zones, moves beyond that in constraining the precise timing of garnet growth reactions. Sample size requirements, nevertheless, make this type of analysis very challenging for 'ordinary' mm- to cm-sized garnet grains, especially considering sample loss using conventional micro-mill sampling. To overcome these limitations, we developed a new method that combines low-loss micro-sampling by laser cutting with a refined Lu-Hf routine.

To test capabilities and analytical resolution, we applied the technique to date multiple growth zones in single garnet grains of two distinct samples, each representing a specific metamorphic context: (1) a sub-cm-sized garnet in a blueschist from Syros Island, Greece and (2) a 1.5 cm-sized garnet from a garnet micaschist from the Schneeberg Normal Fault Zone, Austria. Both samples were chemically characterized by major- and trace-element mapping (EPMA, LA-ICPMS) and distinct micro-domains were extracted using a laser mill. Five zones were sampled in the garnet grain from a glaucophane-bearing micaschist from Syros Island, Greece. The three core and inner mantle zones are chemically comparable and identical in age within an uncertainty of 0.1 Myr (2σ). The outer two zones are chemically distinct and resolvably younger (0.2-0.8 Myr). In the Austrian garnet micaschist, the four zones corresponding to c. 85% of the total garnet volume were extracted and yielded an identical age within a 0.1 Myr uncertainty. The outermost zone, that shows a strong chemical contrast with the rest of the garnet grain, yielded a younger age by 0.2-0.9 Myr. For each zone, two aliquots were analyzed and demonstrate the excellent precision and reproducibility of the method. The timing of distinct garnet-growth episodes, together with the variations in trace-element chemistry, can be tied to specific mineral reactions and/ or constrain important fluid-release reactions, such as chloritoid-breakdown. The data show that the integral history of garnet growth, in both cases, may be extremely short (<1 Myr), but may, even in that short timeframe, consist of multiple short pulses. Our new protocol for Lu-Hf domain geochronology of "common-sized" garnet allows to resolve distinct pulses and pauses of garnet growth within less than a million year. This opens new possibilities for constraining the causes and rates of garnet growth, and determining the pace of tectonic processes in general.