Bulk inclusion dating: a geochronological tool to date low-grade metamorphism

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The petrologic evolution of low-grade metamorphic rocks is essential for a coherent understanding of subduction- and exhumation-related processes during collisional orogeny. Retrieving useful P-T-t-d data from low-grade metamorphic units however is challenging as these rocks commonly lack suitable target minerals for geothermobarometry and/or geochronology. Herein we introduce a new geochronological method termed ‘bulk inclusion dating’ and present an example of a rock sampled at the base of the Stauffen-Höllengebirge Nappe (Austroalpine Unit, Eastern Alps, Austria) that witnessed an Eo-Alpine tectono-metamorphic event in the Late Cretaceous.

The investigated schist contains mm-scale chloritoid porphyroblasts in a foliated matrix consisting of chlorite, muscovite and quartz. Accessory minerals include ilmenite, hematite, rutile, zoned epidote with REE-rich cores, euhedral apatite and zircon. Thermodynamic modeling in the MnCNKFMASHTO system predicts the stability of the equilibrium assemblage in a narrow P-T field between 450–490°C and 5–7 kbar. Ilmenite, rutile and hematite inclusions in chloritoid cores indicate porphyroblast growth within this field, which is consistent with the observed chemical zoning of the chloritoid. The interpreted peak P-T conditions agree with the observation of garnet in a sample from the same outcrop and independent peak temperature constraints around 490°C derived from Raman spectroscopy of carbonaceous material.

Detailed petrographic investigations using high-resolution SEM imaging combined with EDX analysis revealed abundant minute (100 nm – 3 µm), idiomorphic zircons both included in chloritoid porphyroblasts and in the matrix. In the chloritoid rim, zircon comprises >95% of the inclusionary phases. Based on grain size distribution, we interpret zircon growth during prograde metamorphism via dissolution-precipitation mechanism and progressive coarsening due to Ostwald ripening. In situ laser ablation ICP-MS analysis of the bulk zircon population included in the chloritoid rim using a 120 µm spot size yields a U-Pb age of 116.7 ± 6.4 Ma (MSWD: 1.5; n: 79). Combined with the results of thermodynamic forward modeling, we link the age to the late prograde part of the P-T evolution. The latest synorogenic sediments on top of the Stauffen-
Höllengebirge Nappe were deposited at ca. 120 Ma, giving a consistent upper bound the late prograde age. An apatite U-Pb age from the same sample yields 429.3 ± 14.6 Ma (MSWD: 1.2; n: 60). Considering the protolith is an altered tuff and the apatite is likely magmatic, a Devonian protolith age is inferred. That the apatite age was not reset during Eo-Alpine metamorphism is in agreement with the inferred metamorphic conditions. We emphasize that the strength of the bulk inclusion dating approach lies in the improved link of P-T and age data and its relative ease of application compared to other geochronological methods.