Coupling in situ U-Th-Pb REE-epidote geochronology and thermodynamic forward modelling of main and REE-bearing phases: An example from the Tauern Window

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REE-epidote is a solid solution of epidote-group minerals with rare earth elements plus yttrium that is a common phase of greenschist facies metapelites and a popular target for geochronology. Linking the time information to metamorphic conditions is, however, complicated by the diversity of reactions leading to the formation of REE-epidote as these involve REE- (e.g., monazite, apatite) and Ca-bearing phases (e.g., calcite, plagioclase). In order to model equilibrium assemblages and phase chemistry for both main and REE-bearing phases in metapelites, we compiled a thermodynamic dataset in the system NaKCaFeMgAlSiTiHCOCeYPF by combining data from several sources (Berman, 1988; Pourteau et al., 2014; Spear, 2010; Spear & Pyle, 2010). We tested the database on a graphitic micaschist of the Schwarzkopf Formation collected at the foot of the Hochgamsburg (Fusch valley, Tauern Window). The sample shows relatively simple phase relationships and exhibits evidence for only one metamorphic event. The metamorphic assemblage consists of porphyroblasts of chloritoid, kyanite, REE-epidote and apatite in a matrix of muscovite, paragonite, margarite and quartz. Small rutile, graphite, xenotime and zircon are present as inclusions or in matrix. REE-epidote occurs as euhedral to subhedral, 250–500 µm long grains and displays a microstructural and chemical core-mantle-rim zonation. The core has a patchy or oscillatory BSE pattern and is rich in inclusions of amoeboid quartz and minute graphite, as well as subordinate muscovite, chloritoid, rutile, xenotime and thorite. The mantle is discontinuous (< 60 µm thick), inclusion-free and shows a bright smoother BSE pattern. The rim corresponds to dark and thin discontinuous overgrowths (< 20 µm thick). Core, mantle and rim contain decreasing contents of REE+Th+U in the range 0.5–0.6, 0.4–0.6 and 0.1–0.3 a.p.f.u., respectively. The core and mantle are LREE-rich whereas the rim is HREE+Y-rich. Thirty-one LA-ICPMS analyses of REE-epidote mantle define a 27.5 ± 1.3 Ma U-Th-Pb isochron date (MSWD: 0.69) that is consistent with the conventional Tera-Wasserburg U-Pb date of 27.0 ± 2.3 Ma (MSWD: 0.36). Thermodynamic forward modelling indicates that the observed assemblage chloritoid+kyanite+REE-epidote+muscovite+paragonite+margarite+apatite+rutile+xenotime+quartz is stable together with a graphite buffered COH-fluid in a field centred at 11 kbar – 480 °C, in agreement with results of Raman spectroscopy on carbonaceous material. This field corresponds to the innermost part of the REE-epidote stability domain, in which the Ce-concentration progressively decreases from the margin to the center. Modelling helps with interpreting the zonation of REE-epidote. The core grew from U-Th-rich monazite and most likely lawsonite once REE-epidote became stable. Xenotime inclusions represent products of this reaction. The mantle formed during continued growth further inside the REE-epidote stability domain under increasing temperature. The HREE+Y-rich rim finally grew in an environment depleted in LREE, where xenotime was the main REE-source. The U-Th-Pb isochron date 27.5 ± 1.3 Ma represents the timing of the REE-epidote mantle growth and therefore corresponds to conditions close to peak metamorphism at 11 kbar – 480 °C. These PTt constraints are entirely consistent with the Barrovian metamorphic event that is widespread in the Tauern Window.