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Sulfate incorporation in monazite lattice: potential for dating the cycle of sulfur in metamorphic belts

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Monazite is a common accessory mineral in magmatic and metamorphic rocks that often shows complex chemical zoning at the μm- to nm-scale. The large number of cations that may be accommodated in its lattice, makes monazite particularly responsive to changes in the rock-forming minerals and fluid composition. Chemical zoning resulting from replacement or overgrowth may coincide, or not, with age zoning derived from U-Th-Pb isotopes. In this study, we focus on the potential for monazite to record both the redox condition of its crystalizing medium and an absolute U-Th-Pb isotopic age, during polyphase metamorphism in the Proterozoic province of Rogaland, S. Norway. The metamorphic evolution of several samples is derived from phase diagrams and the oxygen fugacity estimated from the FeO/Fe2O_3 ratio measured by titration. Monazite grains were mapped at high spatial resolution for minor elements with electron microprobe, revealing convolute chemical zoning. Some of these zones yield appreciable content of S (up to 7000 ppm), accommodated following the Ca2+ + S6+ = REE3+ + P5+ substitution vector. The incorporation of sulfate in monazite has been subsequently investigated by TEM thanks to site specific FIB preparations. Besides, LA-ICP-MS U$-$Pb isotopic ages of monazite grains show a remarkable correlation with the sulfate content. It is therefore possible to distinguish different generations of monazite based on their S-content. From our petrological study we conclude that sulfate-bearing monazite reflects incongruent melting of Fe-Cu-As sulfides under oxidizing conditions, coeval with biotite dehydration melting. Monazite may therefore be used to probe the presence of sulfur in anatectic melts from high-grade terrains at a specific point in time. This property can be used to investigate the mineralization potential of a given geological event within a larger orogenic framework.