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Titanite and allanite as a record of multistage co-mobility of Ti-REE-Nb-As during metamorphism in the Central Alps

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Abstract

The high field strength elements (HFSE) Ti, Nb, and rare earth elements (REE) are commonly regarded as immobile during hydrothermal activity and metamorphism, making them important tracers of geological processes. Here, we report a Ti-REE-Nb-As mineralization recently discovered in quartz, feldspar, muscovite ± biotite, fluorapatite, hematite, epidote, and dravite-schorl veins hosted in quartz ± feldspar ± muscovite ± biotite gneisses from the Monte Leone nappe (Switzerland/Italy). The veins formed during prograde metamorphism and were boudinaged and/or folded during peak metamorphism under lower amphibolite facies. The mineralization consists of megacrysts ($\gg$2 cm) of allanite-(Ce) and Nb-REE-rich titanite-(I). Titanite-(I) displays prominent primary oscillatory- and sector-zonings in Y+REE and Nb. Allanite-(Ce) and titanite are also present as metamorphic minerals disseminated in the host-rock. The vein-hosted megacrysts and their host rocks have identical Nd isotope systematics, indicating that the HFSE mineralization results from small-scale remobilization of host-rock components.

Localized, fluid-assisted dissolution of vein-hosted allanite-(Ce), epidote, and dravite-schorl during retrograde alpine deuteric alteration resulted in cavities lined with chlorite, muscovite, hematite, and diverse REE minerals. The same fluids caused titanite-(I) to break down into a porous assemblage of acicular niobian rutile with lamellae of crichtonite-group minerals and/or hematite and a suite of REE-Nb-Ti micro-minerals. A few titanite (titanite-II) crystals preserve an intermediate stage of the dissolution-reprecipitation process. Unlike titanite-(I), they display a patchwork-like micro-texture (100 μm sized subgrains with inhomogeneous Nb concentrations); they host lamellae of crichtonite-group minerals within cleavage planes of the parent titanite, as well as secondary Y+Nb+REE oxides and calcite along subgrain boundaries. The occurrence of calcite indicates that CO_2-enriched fluids promoted the destabilization of titanite-(I). Highly localized fluid flow accounts for the common occurrence of fresh and altered allanite-(Ce) and titanite in close proximity.

The HFSE-enriched veins reveal a complex history of mobility of minor elements (Ti, Nb, REE, As ± B, Be) together with major components (Si, Al, K, Na, Fe) from the host rock, resulting in their early (prograde) concentration within the veins, and their remobilization upon the action of oxidized CO_2-bearing fluids during retrograde metamorphism. In general, crystallization of enriched phases during prograde metamorphism may be an important step in determining the fertility of a source rock for hydrothermal HFSE deposits.

Keywords: High field strength elements, titanite, allanite, fluid-driven reaction, imaging