American Mineralogist, Volume 84, pages 794–805, 1999

Tourmaline-rich pseudomorphs in sillimanite zone metapelites: Demarcation of an infiltration front

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ABSTRACT

Textural features combined with mineral chemistry preserved in metamorphic rocks provide insights into metamorphic reaction mechanisms as well as open vs. closed system processes. Prograde tourmaline-rich muscovite pseudomorphs after staurolite develop in sillimanite zone metapelites adjacent to peraluminous granitoid intrusives in NW Maine. Tourmalines occur in discrete domains restricted to central regions of muscovite-rich, quartz-poor pseudomorphs with biotite-rich margins. These tourmaline grains are relatively large (≤1.0 mm), lack detrital cores and exhibit only minor compositional zoning, in sharp contrast to matrix tourmaline from other samples. These features suggest fluid-infiltration as the causative mechanism for the formation of these tourmaline-rich mica pseudomorphs after staurolite.

Irreversible thermodynamic models of local reactions and material transport in combination with mineral chemistry allow evaluation of reaction mechanisms that produced these pseudomorphs. Thermodynamic models in the NKCMTFASHOB system mimic the observed textural features if a three-stage process is used. Stage 1: Staurolite replacement is initiated by infiltration of an aqueous phase that adds K+Na+H_2O to the rock with the concomitant removal of Al+Fe. Because the system is initially undersaturated with respect to tourmaline, a pseudomorph containing muscovite with minor biotite develops at the expense of staurolite. Stage 2: With continued infiltration, concentration of B increases, tourmaline saturation is exceeded, tourmaline nucleates and grows. Local material transport constraints mandate that tourmaline precipitation be spatially restricted to regions of staurolite dissolution. Consequently, tourmaline forms in clusters at sites containing the last vestiges of staurolite in the pseudomorph core, also evidenced by staurolite inclusions within several tourmaline grains. Resultant domains of staurolite replacement during this stage contain about equal amounts of muscovite and tourmaline. Typical staurolite poikiloblast pseudomorphing reactions require silica transport, matrix quartz dissolves from the surrounding host resulting in a local enrichment of biotite and plagioclase at the pseudomorph margin. Stage 3: Small amounts of sillimanite nucleate and grow throughout the rock. Late-stage aqueous fluids from the adjacent monzonitic intrusive are likely to be the primary B source.

Theoretical, textural, and compositional modeling combined with observational data indicate that boron must have been derived externally from the rock, that the modal amount of tourmaline is very sensitive to the B content of the fluid, that tourmaline is stable throughout the sillimanite zone depending on other cation activities and pH of the fluid, and that these pseudomorphs provide insight into B contents of metamorphic fluids and the timing of the B influx. The outer geographic extent of the tourmaline-bearing pseudomorphs marks the boundary of a reactive geochemical front, and thus defines an advective isograd. Interpretation of subtle textural features preserved in the rock in conjunction with irreversible textural modeling provides a powerful tool with which to understand the chemical evolution of metamorphic rocks and the fluids involved.