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Precipitation of rutile and ilmenite needles in garnet: Implications for extreme metamorphic conditions in the Acadian Orogen, U.S.A.

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Abstract

We report the discovery of oriented needles of rutile and ilmenite in garnet crystals from granulite facies metapelitic rocks of the Merrimack synclinorium, Connecticut, and present a precipitation model for their origin. The rocks were strongly metamorphosed and deformed during the Devonian Acadian orogeny. The needles are primarily elongated parallel to <111> in garnet. Rutile has anomalous extinction angles as great as ~35° (cf. Griffin et al. 1971). Rutile and ilmenite needles are typically a few hundred nanometers to several micrometers in diameter and are several tens of micrometers to nearly a millimeter long. Other oxide inclusions that may be present include submicrometer- to micrometer-scale twinned rutile bicrystals, as well as srilankite and a crichtonite group mineral. Some garnet cores have unusual, box-shaped quartz inclusions, which coexist with Ti±Fe oxide needles and commonly contain micrometer-scale rods of F-OH-Cl apatite. Negative garnet crystal "pores" are also widespread. Ti±Fe oxide needles are restricted to garnet core regions; rims have a distinctly different inclusion population dominated by granulite facies minerals including sillimanite, spinel, cordierite, and K-feldspar. Consequently, the garnet core regions represent an earlier, distinct period of growth relative to the rims. Garnet cores contain ~25–35% pyrope, and a host of minor and trace constituents including TiO_2 (0.07–0.6 wt%), Cr_2O_3 (0.01–0.10 wt%), Na_2O (0.01–0.03 wt%), P_2O_5 (0.01–0.09 wt%), and ZrO_2 (up to ~150 ppm). Na_2O and ZrO_2 correlate positively with TiO_2. Titanium zoning is preserved in some garnets; zoning profiles and two-dimensional chemical mapping show that Ti and, to a lesser degree, Cr are depleted around Ti±Fe oxide inclusions. Therefore, we conclude that the needles are precipitates that formed from Ti-bearing garnet during exhumation and cooling. Garnet contained sufficient Ti to form precipitates; no Ti source external to garnet was necessary. Titanium-bearing garnets that contain oriented Ti±Fe oxide needles are known primarily from ultrahigh-pressure metamorphic rocks, mantle peridotites and pyroxenites, and high-pressure granulites. Thus, the presence of needle-bearing garnets in Connecticut strongly suggests that a previously unrecognized domain of extreme pressure and/or temperature metamorphism exists in the Acadian orogen.

Keywords: Metamorphic petrology, precipitates, rutile needles, ilmenite needles, high-pressure studies, high-temperature studies