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Crystallographic and textural evidence for precipitation of rutile, ilmenite, corundum, and apatite lamellae from garnet

Duncan S. Keller[1,*] and Jay J. Ague[1]

[1]Department of Geology and Geophysics, Yale University, PO Box 208109, New Haven, Connecticut 06520-8109, U.S.A.

Abstract

Garnet is a common metamorphic and igneous mineral with extensive solid solution that can be stable to mantle depths ≥400 km. High-*T* and/or high-*P* garnet may contain oriented lamellae of other minerals, most commonly simple oxides (e.g., rutile, ilmenite), apatite, and, in ultrahigh-*P* cases, silicates including pyroxene and amphibole. Lamellae have classically been considered to be precipitation features preserving a record of former garnet chemistry richer in the lamellae nutrients (e.g., Ti^{4+}). Such microtextural origins in precipitation systems (e.g., alloys) have long been studied via the crystallographic orientation relationships (COR) that form between a host and a separating phase, and by the shape-preferred orientation (SPO) of the lamellae. Recently, however, alternative hypotheses to precipitation have been suggested that require emplacement of lamellae in garnet by fluids, or co-growth, overgrowth, or inheritance mechanisms. These hypotheses posit that lamellae cannot be used to study former garnet chemistry. Moreover, they predict that lamellae phases, SPO, and COR should differ widely between localities, as lamellae formation will be controlled by various local rock-specific factors such as fluid presence, fluid chemistry, or mineral growth sequence. On the other hand, if lamellae characteristics are largely consistent between localities, it likely reflects control by precipitation energetics, rather than external factors. There have been few comparative COR studies in geologic systems, but the integrative assessment of COR, SPO, and lamellae assemblages should fingerprint lamellae growth process. To test the precipitation and alternative hypotheses, we collected large electron backscatter diffraction (EBSD) data sets for rutile, ilmenite, and apatite lamellae in garnet from the Brimfield Schist, Connecticut (≥1000 °C metamorphism; Central Maine Terrane, U.S.A.). We analyzed these data alongside published EBSD data for rutile, ilmenite, and corundum from metapegmatites metamorphosed in the eclogite facies from the Austrian Alps (Griffiths et al. 2016). The apatite data set is the first of its kind, and reveals that apatite preferentially aligns its close-packed direction parallel to that of garnet ($c\text{-axis}_{apatite}//<111>_{garnet}$). We also recognize a rutile-garnet COR related to those in meteorites with Widmanstätten patterns that are unequivocal products of exsolution. This is the first identification of direct similarities between silicate-oxide and metal-metal COR of which we are aware. Significantly, this rutile-garnet COR is found in diverse geologic settings including Connecticut and Idaho (U.S.A.), Austria, Germany, Greece, and China over a broad range of bulk-rock compositions. Results for all lamellae minerals show that COR are largely consistent between localities and, furthermore, are shared between apatite, ilmenite, and corundum. Moreover, between 70% and 95% of lamellae have COR and there is a dominant COR for each lamellae phase. Calculations show that *d-spacing* ratios of host-lamellae pairs can successfully predict the most commonly observed specific COR (those COR with two or more axial alignments with the host). These results, especially similarity of COR from markedly different geologic settings and a low diversity of lamellae minerals, are fully consistent with lamellae formation by precipitation (likely via exsolution). In contrast, the alternative hypotheses remain unsupported by COR results as well as by mineralogical and petrological evidence. Lamellae with similar traits as those in this work should thus be considered precipitates formed during unmixing of garnet compositions originally stable at elevated or extreme pressures and temperatures.

Keywords: Garnet, rutile, ilmenite, corundum, apatite, crystallographic orientation relationship, precipitation, Widmanstätten pattern