Geophysical Research Abstracts
Vol. 20, EGU2018-15257, 2018
EGU General Assembly 2018

Inclusion formation in pegmatite garnet by oriented nucleation and intergrowth

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Crystalline inclusions in host minerals can preserve important information about the timing and conditions of host crystallization, provided that the inclusion origin is known. However, available microstructural evidence of inclusion origins is rarely independently tested using additional methods, which may cause problems when findings are transferred to new samples with unknown histories.

This study aimed to constrain the origin of solid inclusions in Permian metapegmatite garnets from the Koralpe Complex (European Eastern Alps). The inclusion phases are corundum, zircon, xenotime, apatite, Fe-Mn phosphate, ilmenite, and rutile. Inclusions are abundant in garnet cores and range from a few nanometers to one micrometer in size (longest axis). Variation in abundance, habit and grain size of inclusions defines visible concentric and sector zoning in the host garnets.

The succession of concentric zones is identical for adjacent garnet crystals. Both concentric and sector zones follow garnet facets. Inclusion populations are laterally homogeneous parallel to each garnet facet, but adjacent, crystallographically different facets (e.g {112} and {110}) show different inclusion populations. The zoning features imply that the inclusion distribution reflects garnet growth zones, related to large-scale compositional changes in the pegmatite system. Microprobe measurements of the integrated composition of inclusions and host along profiles perpendicular to the garnet growth zones were made in order to look for stoichiometric variations of elements, which would indicate that inclusions formed via exsolution from compositionally zoned garnet. Results showed a positive correlation between Ti and Al, which cannot be explained by any known garnet exchange vector. The most likely explanation for the data is that the elements present in inclusions were never part of the garnet crystal structure.

EBSD data reveal that the submicrometer-sized inclusions show crystallographic orientation relationships to their host, which implies nucleation of the inclusions upon the preexisting garnet lattice. These data rule out an overgrowth mechanism of inclusion formation, but do not allow differentiation between an exsolution origin and oriented inclusion nucleation at the garnet surface followed by intergrowth with the host phase. Shape oriented rutile needles (0.2-0.5 x 10 – 100 μm) with long axes parallel to the 4 garnet <111> directions are found in outer garnet growth zones. Only needles parallel to garnet <111> directions at a large angle to the garnet growth facet were found. This implies simultaneous growth of garnet and rutile needles, with only rutiles with their fastest growth direction (needle axis) out of the interface plane growing fast enough to avoid being engulfed before forming a needle.

Oriented nucleation of inclusions at the garnet-melt interface and simultaneous crystallization with the host garnet therefore represents the most likely inclusion origin, consistent with the observed microstructural, textural and compositional features of the studied host-inclusion system. This origin is often disregarded in host-inclusion system studies. Although multiple techniques were applied, microstructural observations provided the most unequivocal indications of the inclusion origin.