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Mechanisms of submicron inclusion re-equilibration during host mineral deformation

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Both brittle and ductile deformation can facilitate re-equilibration of mineral inclusions. The presence of inclusions also influences stress and strain distribution in the host. The processes governing feedbacks between brittle deformation, ductile deformation, and inclusion re-equilibration have been studied using unique microstructures in Permian meta-pegmatite garnets from the Koralpe, Eastern Alps, Austria.
Sampled almandine-spessartine garnets contain highly abundant submicron-sized inclusions, which originated during or subsequent to magmatic garnet growth. The Permian magmatic assemblages were affected by eclogite facies metamorphism during the Cretaceous tectono-metamorphic event. The meta-pegmatite garnet deformed crystal-plastically at this metamorphic stage (Bestmann et al. 2008) and the host-inclusion system was affected by partial recrystallization.
Trails of coarser inclusions (1-10μm diameter) crosscut the magmatic submicron inclusion density zoning in the garnet, defining curviplanar geometrical surfaces in 3D. In 10-40μm broad 'bleaching zones' flanking inclusion trails, the original $\leq 1\mu$m sized inclusions are not seen in the optical microscope or SEM, however inclusions <100nm are still abundant in TEM foils from these areas.
From their microstructural characteristics it is inferred that the trails formed at sites of healed brittle cracks.
FEG-microprobe data showed that inclusion-trails and associated bleaching zones can be formed isochemically, although some trails showed non-isochemical coarsening. In both cases no change in garnet major element composition was observed.
EBSD mapping revealed two phenomena that were investigated by cutting targeted TEM foils.
Firstly, bleaching zones are associated with systematic very low angle (ca. 0.5°) garnet lattice orientation changes along discrete boundaries. TEM foils transecting such a boundary show a lower concentration of dislocations than expected for the lattice rotation inferred from EBSD data, and no subgrain boundaries.
Secondly, garnet lattice rotation of up to 10° around rational garnet crystal axes is observed in connection with some already coarsened inclusions. Strain concentrations are widespread in some trails, but rare in others.
A TEM foil transecting a garnet domain with concentrated lattice rotation in association with inclusions reveals well developed polygonal subgrain walls with few free dislocations. Where dislocation density is greatest, almost no <100nm inclusions are observed, whereas these are more abundant in unstrained garnet domains despite the foil being located entirely within the optically visible bleaching zone. Chlorite inclusions and formation of etch pits at dislocations at the garnet-chlorite interface demonstrate the presence of fluid along subgrain boundaries during this second bleaching process.
In summary, brittle deformation in these garnets led to enhanced transport and inclusion re-equilibration by coarsening, forming inclusion trails. The precise mechanism allowing enhanced transport is still to be determined and may have involved fluid supply with or without pipe diffusion along introduced dislocations. Later ductile deformation via dislocations, concentrated at already coarsened inclusions and enhanced by fluid availability, further affected the nanoinclusion population.
The inclusion trail microstructure records complex small-scale interaction between deformation and reaction, shedding light on the mechanisms by which re-equilibration and strain localisation can influence each other in deforming host-inclusion systems.

Bestmann et al. (2008) Journal of Structural Geology 30: 777-790