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Dynamic recrystallization of garnet and related diffusion processes

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ABSTRACT

Electron backscatter diffraction and compositional data of Permian metapegmatite garnet from the Koralpe basement (Eastern Alps, Austria) show the evolution of distinct intracrystalline shear zones in c. 10 mm sized almandine–spessartine garnet. Orientation maps reveal continuous distortion of the crystal lattice. New garnet grains (grain size 20–30 μm) within intragranular deformation zones, oriented subparallel to the main foliation of the metapegmatite, have similar crystal orientations to the host garnet, whereas recrystallized grains along fractures or along growth heterogeneities show a much weaker crystallographic preferred orientation (CPO). Needles of kyanite as well as inclusions of apatite, xenotime and rutile occur along the deformation zones. Together with the Ca variation across the deformation zones these inclusions give evidence of material diffusion related to crystal plastic deformation of garnet. The individual garnet porphyroclasts record the evolution of recrystallization microfabrics. New grains, once formed by subgrain rotation recrystallization, are able to deform partly by diffusion accommodated grain boundary sliding resulting in a weakening of the CPO. Whereas magmatic garnet growth had taken place at LP conditions in equilibrium with andalusite, the occurrence of kyanite in some deformation zones, triggered by the localized crystal plasticity of garnet, indicates that the deformation was related to the Cretaceous HP metamorphic event.

1. Introduction

Garnet is stable over a wide range of PT conditions and bulk compositions and thus is ubiquitous in several rock types of the Earth's crust and mantle. It is therefore of particular interest to obtain knowledge of its deformation mechanisms. In the last 15 years the deformation behavior of garnet was controversially discussed. Den Brok and Kruhl (1996) and Ji and Martignole (1994) showed that there is considerable debate in the interpretation of garnet microstructures with respect to plastic deformation versus diffusion processes controlling deformation of garnet under natural conditions. Thus far, well-constrained examples of plastically deformed garnets are rare. The presence of garnet sub-structure must not be *a priori* related to intracrystalline plastic deformation mechanisms. Trepmann and Stöckhert (2002) interpreted deformation microfabrics (microstructures and related crystallographic orientation data) within elongated and sub-structured eclogite garnets from the Sesia Zone of the Alps being due to cataclastic fragmentation during seismic loading and postseismic creep. Another kind of garnet sub-structure developed by a mechanism other than deformation may result from amalgamation of independently nucleated garnet grains (Spiess et al., 2001; Wheeler et al., 2001; Prior et al., 2002; Dobbs et al., 2003). However, plastic deformation of garnet has been interpreted on the basis of TEM work for naturally deformed garnets (e.g. Voegele et al., 1998a; Ji and Martignole, 1994) and for experimentally deformed garnets (e.g. Voegele et al., 1998b; Li et al., 2006). Indirect evidence of plastic deformation was given by Kleinschrodt and co-workers (Kleinschrodt and McGrew, 2000; Kleinschrodt and Duyster, 2002) for elongated garnets within granulite-facies quartzites from Sri Lanka which show a weak crystallographic preferred orientation (CPO) but exhibit little sub-structure. Prior et al. (2000) related substructures of mantle garnets to high-temperature dislocation creep and recovery. For a long time the key question remained whether garnet may undergo dynamic recrystallization during deformation similar to other rock forming minerals (Urai et al., 1986; Urai and Jessell, 2001). Recently Storey and Prior (2005) presented the first direct evidence of dynamic garnet recrystallization and associated subgrain formation by means of electron backscatter diffraction (EBSD) analyses from elongated garnets from NW Scotland deformed under amphibolite facies conditions at c. 700 °C. The authors suggest a strain dependent evolution of individual garnet porphyroclasts starting from dislocation creep and recovery, followed by dynamic recrystallization by subgrain rotation and finally

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diffusion creep assisted grain boundary sliding of former recrystallized grains.

In this study we present microstructures and related compositional data in order to understand garnet recrystallization due to plastic deformation and associated diffusion processes. EBSD and electron microprobe (EMP) data of a garnet-bearing Permian metapegmatite (sample 04T26K) from the Austroalpine Koralpe basement in the Eastern Alps (Austria) show the evolution of intracrystalline shear zones in coarse-grained metapegmatite garnet with a well-developed grain and subgrain microstructure. Deformational microstructures are correlated with major element compositional changes during garnet recyrstallization, as well as with associated crystallization processes of accessory inclusions.

2. Geological setting

The Saualpe–Koralpe Complex is part of the Austroalpine basement units east of the Tauern Window in the Eastern Alps (Fig. 1). Lithologically it consists mainly of poly-metamorphic siliciclastic meta-sedimentary rocks with subordinate marbles and intercalations of meta-gabbros, eclogites, eclogite–amphibolites and metapegmatites. The dominating tectonometamorphic imprint was established during Upper Cretaceous eclogite–facies metamorphism (Miller and Thöni, 1997) and subsequent exhumation. Relic pre-Cretaceous mineral assemblages in metapelites indicate an early low-pressure metamorphic imprint, which was related to the Permian magmatic event (Schuster et al., 2001; Habler and Thöni, 2001). Pegmatite intrusion had occurred between 285 and 225 Ma forming widespread meter- to tens-of-meters-sized bodies in Al-rich metapelites (Thöni and Miller, 2000; Habler et al., 2007). The major deformation of the pegmatites and their surrounding rocks occurred during Cretaceous eclogite facies metamorphism and subsequent exhumation. PT constraints are not available from the immediate sampling location, but for different parts of the Koralpe basement peak PT conditions were given at 600–650 °C/1.8–2.0 GPa (Miller and Thöni, 1997), 640–720 °C at presumed 2.4 GPa (Miller et al., 2007) and 700–750 °C/1.5–1.6 GPa (Gregurek et al., 1997) for eclogites using various thermodynamic data. PT estimates from metapelitic rocks range at 700 ± 50 /1.4–1.6 GPa (Gregurek et al., 1997) and $700 \pm 68/1.5 \pm 0.15$ to 600 ± 63 °C/1.0 ± 0.15 GPa (Tenczer and Stüwe, 2003). The P-variations may be interpreted as due to either the existence of tectonic subunits that passed different PT paths during the Cretaceous HP event, or equilibration at different stages of the exhumation path.

All data presented here were obtained from sample *04T26K*, which stems from the locality Wirtbartl in the southern Koralpe (geographic coordinates: 5177709 N, 504737 E; UTM zone 33N, geodetic datum: WGS84), where metapegmatites form intercalations in Al-rich metapelites with characteristic kyanite paramorphs after andalusite (Habler et al., 2007; Thöni et al., in press).

3. Analytical methods

3.1. Sample preparation

Optical microscopy, EBSD and EMP measurements were carried out on polished thin sections cut perpendicular to the deformation foliation. The thin sections were SYTON-polished (Fynn and Powell, 1979; Lloyd, 1987; Prior et al., 1996) and carbon coated for EBSD and EMP analysis.

3.2. EBSD analysis

Full crystallographic orientation data were obtained from automatically indexed EBSD patterns collected in a LEO (Zeiss) Gemini 1530 scanning electron microscope fitted with a thermionic field emission gun (Schottky emitter). Working conditions for automated beam scans were: 30 kV acceleration voltage, 4 nA beam current and 20 mm working distance. The EBSD patterns were indexed by using the program CHANNEL 5.03 from HKL software. The center of 7–8 Kikuchi bands was automatically detected using the Hough transform routine (Schmidt et al., 1991; Adams et al., 1993) with a resolution of 120 (internal Hough resolution parameter in the software). The solid angles calculated from the patterns were compared with a match unit of almandine containing 80 reflectors to index the patterns.

The accuracy of individual EBSD orientation measurements is better than 1°. 2° is the minimum misorientation angle between adjacent points that can be reliably identified (Prior, 1999; Humphreys et al., 2001). The misorientation angle was calculated by selecting the minimum misorientation angle and its corresponding axis from all possible symmetric variants (Wheeler et al., 2001).

EBSD orientation data are presented as processed orientation maps. Non-indexed points were partly replaced by the most common neighboring orientation. The degree of processing required to fill non-indexed data points in this way, without introducing artifacts, was tested carefully by comparing the resulting orientation map with the pattern quality map, which represents the grain boundary network (Bestmann and Prior, 2003).

3.3. Grain size analysis

Grain size (gs) distributions were analyzed by means of the EBSD orientation maps (step size 2 μm). Grains were automatically identified by the EBSD software CHANNEL 5 and measured when completely surrounded by boundaries with misorientation angles

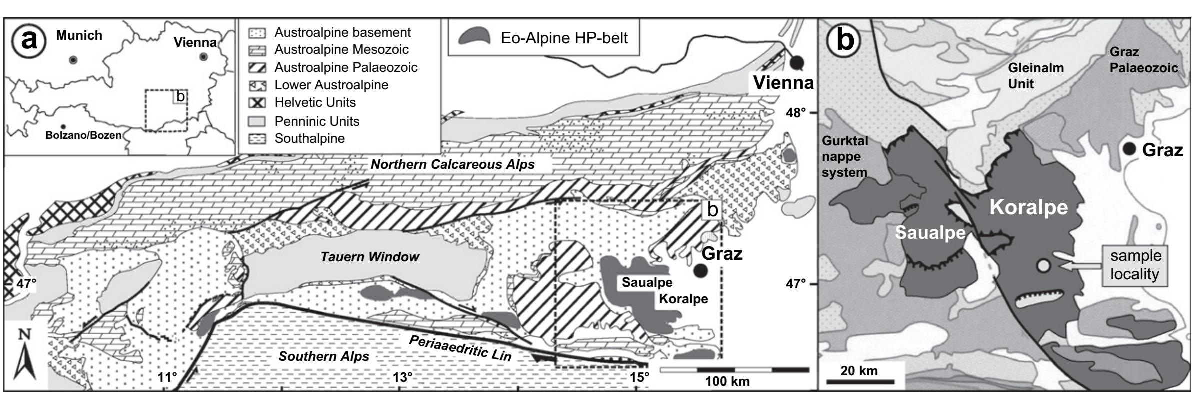

Fig. 1. Tectonic map of (a) the Eastern Alps (modified after Frey et al., 1999) and (b) the Saualpe–Koralpe Complex (modified after Schmid et al., 2004, and Faryad and Hoinkes, 2003).