Modifications of fluid inclusions in quartz due to post-entrapment ductile deformation: Case study in the Aar Massif, Central Alps, Switzerland

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1. Introduction

Fluid inclusions in quartz are known to modify their shapes, textures, densities and in certain cases even their chemical compositions during shear deformation. These changes have been demonstrated in piston-cylinder experiments by Tarantola et al. (2010) and Diamond et al. (2010). In these experiments, natural fluid inclusions in quartz were deformed by uniaxial compression at high T and high confining P (σ_3) in the field of crystal plasticity. The experiments showed that intact inclusions (Fig. 1) preserve their original densities and compositions, whereas inclusions with strong changes in shape adopt new properties: relict inclusions lower their densities whereas neonate inclusions adopt the density corresponding to the maximum compressive stress (σ_1) during the non-hydrostatic deformation.

Here this experimental result is tested using a well-constrained natural sample of plastically deformed vein quartz from the Aar massif, Central Alps, Switzerland.

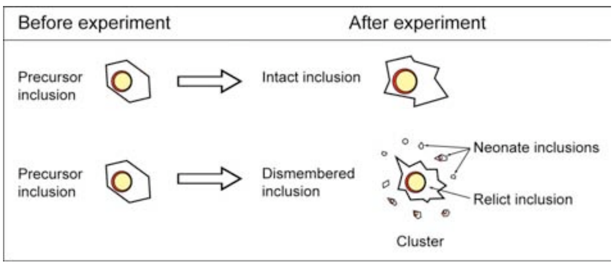

Fig. 1. Summary and nomenclature of shape changes accompanying ~1% plastic strain of the quartz host crystal. View looking down σ_1.

1. Grimsel sample description

A quartz vein within a ductile shear zone was sampled at the Grimsel Pass in the gneiss and schist zone between the Grimsel granodiorite and the southern Aar Granite. The area underwent Alpine greenschist metamorphism and deformation at 25-15 Ma. According to the Si content in phengites (3.2–3.3 p.f.u.) and to the $\delta^{18}O$ fractionation between biotite and quartz (Fourcade et al., 1989), the main shearing event occurred at T = 450 ± 30 °C and $P_{lithostat}$ = 600 ± 100 MPa (Challandes et al., 2008) (top box in Fig. 3).

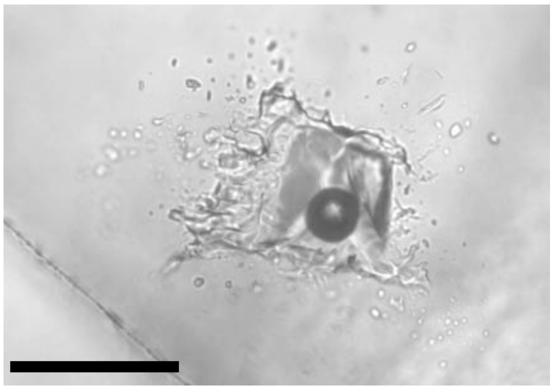

Fig. 2. Cluster of neonate inclusions surrounding their parent inclusion, viewed from direction of flattening. Scale bar is 50 µm.

2. Fluid inclusion petrography

In addition to post-shearing secondary inclusions (not discussed here), the quartz contains early, homogeneously trapped CO_2–H_2O–NaCl inclusions. At T_{lab} these consist of three fluid phases ($L_{aq}L_{car}V_{car}$) and various accidentally trapped minerals. In undeformed domains of the quartz the inclusions have euhedral shapes, and they are therefore classified as precursors (Fig. 1). In deformed domains the inclusions display the same variety of inclusion shapes as produced in the experiments. Some inclusions are deformed but intact, although most are flattened, stretched and dismembered (Fig. 2), defining a planar deformation fabric within the sample. Micro-cracks emanate from acute angles of the inclusion walls, oriented parallel to the fabric. Within the dismembered clusters, abundant neonate inclusions surround the relict inclusions (Figs. 1 and 2).

3. Fluid inclusion *PVTX* properties

Compilation of the volumetric–compositional (*VX*) properties of the inclusions resulted in the *PT* interpretation in Fig. 3. The isochores of the undeformed precursor inclusions define a narrow band (extrapolated to the top-right corner of Fig. 3). The precise *PT* conditions of inclusion trapping within this band are not known, but this is not important to the present study; here the isochores simply serve to illustrate the pre-deformation *VX* properties of the inclusions. Inclusions that are deformed but intact have isochores that define a broader band, indicating that they largely preserve the *VX* properties of the precursors, but with some scatter to higher densities. As expected from the experimental study, the relict inclusions in the dismembered clusters display a wide range of densities, including many cases of significantly lowered densities. Their compositions remain unchanged compared to the precursors. Also in accord with the experiments, the neonates that surround the expanded relict inclusions all show much higher densities. Most of these isochores pass through the box that represents the independently determined conditions of ductile deformation. Recalling that the reconstructed pressure conditions represent mean stress (i.e. $P_{\text{lithostat}}$), it is quite conceivable that the densest isochores reflect the slightly higher value of σ_1.

4. Conclusions

The plastically deformed inclusions in this natural case study closely resemble the deformation-induced changes in shape, texture, density and chemical composition found in the cited experimental studies. This may open the way to interpret the meaning of fluid inclusions in other examples of ductily deformed rocks, e.g. in shear-zone hosted hydrothermal ore deposits.

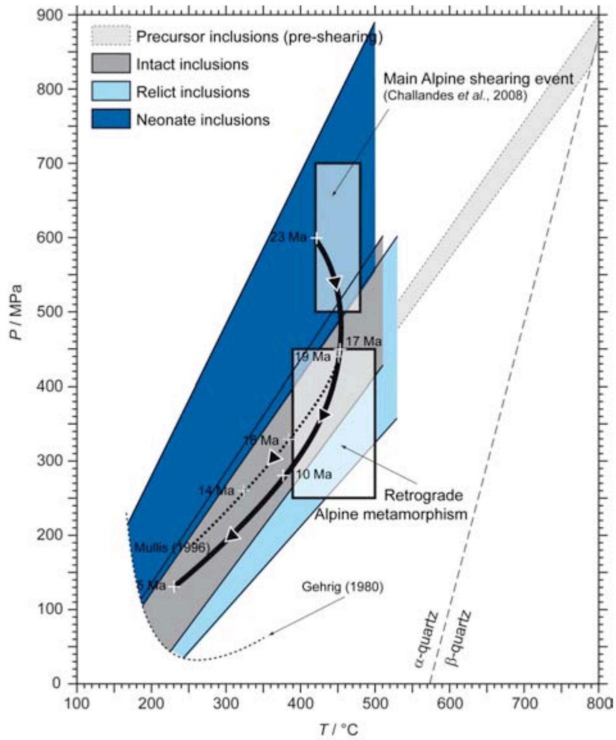

Fig. 3. PT plot of fluid inclusions in Grimsel quartz vein (excluding undeformed secondary inclusions).

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