

FLUID INCLUSION MODIFICATION IN QUARTZ AS DOCUMENTED IN TEXTURES OBSERVED BY CATHODOLUMINESCENCE TECHNIQUES

VAN DEN KERKHOF, A. M.¹, KRONZ, A.¹

¹Geoscience Centre Göttingen, University of Göttingen, Goldschmidtstr. 3, D-37077 Göttingen.

E-mail: akerkho@gwdg.de

The interpretation of the rock-forming conditions from fluid inclusion data requires knowledge about the fluid inclusion forming mechanisms and later modifications in lower-crustal rocks during uplift. Cathodoluminescence (CL) techniques are helpful in identifying such modifications as well as other evidence of fluid-mineral interaction (Van den Kerkhof, Hein, 2001). In this way a wide variety of micro-textures which are not visible in normal transmitted light can be identified in quartz. Furthermore, information can be obtained about the mechanical and physico-chemical processes during fluid (re)trapping and subsequent changes including the partial leakage of fluid inclusions. Observations in cathodoluminescence show evidence for micron-scale mechanisms, which act at different depths and result in the present appearance of fluid inclusions on the Earth's surface.

Cathodoluminescence of quartz is essentially caused by point defect structures which are mostly related with the incorporation of trace elements in the quartz crystal lattice. The interaction with fluids may result in the local redistribution of trace elements or the development of secondary quartz with a different trace element content compared to the precursor quartz. These changes produce variations of the CL wavelengths and intensities, which can be visualized in images.

Analytical methods

We combined CL-imaging and wavelength resolving trace element analysis (EPMA) by means of an electron microprobe (JEOL JXA 8900RL) equipped with a CL-detector (200-900 nm). In this way the main trace elements (Al, Ti, Fe, K and Na) in quartz can be measured. Quantitative trace element analysis by EPMA require optimized equipment settings and sample preparation (see also Müller et al., 2002). The possible errors caused by overlapping of characteristic X-ray emission lines, curved behavior of the background signal ('Bremsstrahlung') and defects in the sample and the surface coating induced by electron beam irradiation, have been taken into account. The ranges of the detection limits (in ppm) are Al (25-74), Ti (18-43), Fe (14-31), K (11-20). Somewhat lower detection limits could be achieved by measuring with a time delay which takes the surface damage caused by the electron beam irradiation into account. Trace element profile lines have been recorded which include both the contrasting textures and host quartz.

Results

A number of CL micro-textures have been distinguished which are indicative of lower crystal order (higher density of defect structures), whereas other textures indicate higher crystal order (healing). Structural water in quartz causes reduced crystal order. Quartz with high concentrations of micropores shows dark contrasts in CL. After some minutes of electron beam irradiation micropores are contrasted as diffuse dark spots of 1-5 μm in size (e.g. Van den Kerkhof, Grantham, 1999). The changes during the measurement are interpreted to be the effect of amorphization by the release of structural water formed by electron capturing. Intra- and transgranular textures in CL include diffusive zones with lower trace elements, late vein quartz fillings and altered zones along open fractures. Decorated grain boundaries in CL include grain boundary alteration (diffusion) and the formation of intergranular secondary quartz. Both phenomena are often associated with small aqueous fluid inclusions (Fig. 1). The quartz along the grain boundaries is characterized by reduced trace element concentrations.

CL micro-textures around single fluid inclusions (primary or secondary in origin) can be grouped in (a) diffusion textures (b) healing textures associated with micro-fracturing, and (c) quartz recovery textures:

(a) Diffusion textures (leaked fluid inclusions) are essentially dislocations around fluid inclusions and visible in CL as fine darkly contrasting lines. These structures may form as a reaction to stress concentration and probably present the pathways of partial water loss (Bakker, Jansen, 1991; Hurai, Horn, 1992). The CL of quartz around fluid inclusions which show halos of small secondary inclusions -interpreted as a result of implosion-decrepitation- reveal low contrasts (Fig. 2).

(b) Healing textures (secondary quartz) typically consist of a pattern of irregular patches of non-luminescent secondary quartz interconnected by fine healed micro-fractures (Fig. 3). Microfracturing is mainly controlled by the fluid inclusions.

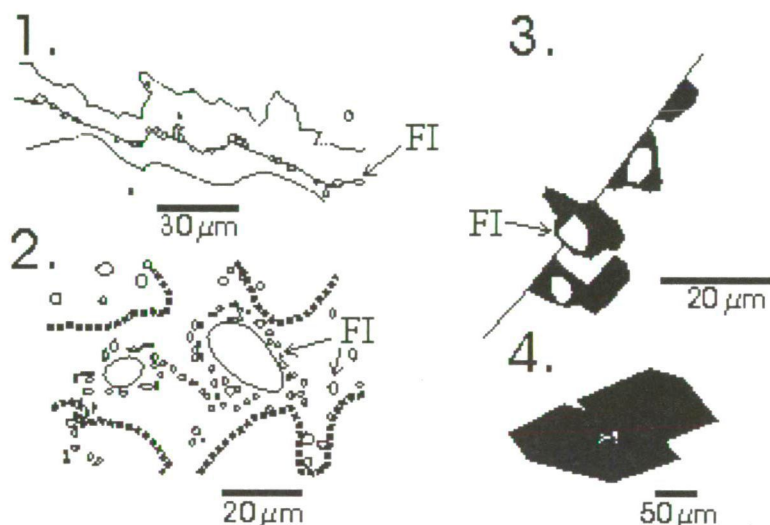
(c) Quartz recovery textures (growth nuclei) have been observed as pure idiomorphic quartz nuclei with low CL intensity (Fig. 4). They show the same crystallographic orientation as the host quartz and have been observed in highly impure host quartz with Al and Ti-concentrations of up to 175 and 190 ppm, respectively. The nuclei are superimposed on brightly contrasting microcracks which are assumed to form at the α - β transformation and evidently formed at lower temperatures. However, they may be transected by healed microfractures and therefore must have formed at higher temperatures than the brittle-ductile transition. Relics of alkali elements in the center may indicate that now disintegrated fluid inclusions may have functioned as a nucleus. The quartz nuclei are assumed to form by volume diffusion of trace elements through lattice defects.

Interpretation

We may largely distinguish between features formed in the ductile and in the brittle deformation regime. In the ductile regime diffusion of water and trace elements are responsible for the CL-contrasting textures, whereas the brittle regime is characterized by the forming of pure secondary quartz in faults, micro-fractures and cataclastic domains. The micro-fracturing is largely controlled by tension concentration around fluid inclusions. During uplift fluid inclusions behave as large metastable defect structures in the quartz: they tend to be healed by dissolution-precipitation, diffusion and quartz re-crystallization.

Changes in fluid inclusions known as 'decrepitation' are actually the result of very different processes which act at a wide range of pressures and temperatures. Various features like grain boundary alteration or secondary quartz fillings are normally associated with the textures around fluid inclusions. Many fluid inclusions which are classified from optical observation as 'decrepitated' should be actually considered as re-trapped fluids in secondary quartz.

CL techniques not only helps in finding evidence of the timing of fluid inclusion entrapment (primary, secondary inclusions), but also show late re-equilibration phenomena which formed after the developing of the fluid inclusion cavity. The various CL textures around fluid inclusions show that fluid inclusions can be grouped principally in leaked ('decrepitated') inclusions and inclusions associated with secondary quartz which precipitates at the fluid inclusion sites. The latter phenomenon is very common in almost all rock types and tentatively designated as 'retrapping decrepitation', i.e. combined fracturing and recrystallization, associated with the forming of pure secondary quartz which shows low CL intensity. The result of both mechanisms mostly can not be distinguished by normal microscopic observation. However, the consequences for the fluid inclusion density and composition are assumed significant: density and molar volume of decrepitated (and selectively leaked) fluid inclusions may be in part controlled by surface effects and therewith not necessarily in equilibrium with the ambient pressure and temperature. On the other hand re-trapped inclusions are expected to re-equilibrate completely. Fluid inclusions and quartz precipitations may form the nucleus for pure quartz zones which replace the precursor quartz.



Examples of fluid-inclusion related CL-images

1. Fluid inclusions along grain boundary sealed by quartz with darker CL caused by reduced trace element concentrations.
2. Fluid inclusions with halos of satellite inclusions interpreted as a result of implosion-decrepitation. The immediate surrounding quartz shows diffusive textures within a zone with slightly brighter CL-contrast.
3. Fluid inclusions with patchy secondary quartz. An example of 're-trapping decrepitation'.
4. Idiomorphic quartz nuclei interpreted as a result of progressive quartz recovery and related fluid inclusion disintegration.

References

- BAKKER, R. J., JANSEN, J. B. H. (1991): Experimental post-entrapment water loss from synthetic CO₂-H₂O inclusions in natural quartz. *Geochimica et Cosmochimica Acta*, **55**, 2215-2230.
- HURAI, V., HORN, E. E. (1992): A boundary layer-induced immiscibility in naturally re-equilibrated H₂O-CO₂-NaCl inclusions from metamorphic quartz (Western Carpathians, Czechoslovakia). *Contributions to Mineralogy and Petrology*, **112**, 414-427.
- MÜLLER, A., KRONZ, A., BREITNER, K. (2002): Trace element and growth patterns in quartz: a fingerprint of the evolution of the subvolcanic Podlesí Granite System (Kruné Hory Mts., Czech Republic) *Bulletin of the Czech Geological Survey*, **77**, No. 2, 135-145.
- VAN DEN KERKHOFF, A. M., GRANTHAM, G. H. (1999): Metamorphic charnockite in contact aureoles around intrusive enderbite from Natal, South Africa. *Contributions to Mineralogy and Petrology*, **137**, 115-132.
- VAN DEN KERKHOFF, A. M., HEIN, U. H. (2001): Fluid inclusion petrography. *Lithos*, **55**, 27-47.