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Vein patterns and quartz crystallization in the Pfahl shear zone (Bavarian Forest, Germany): clues to understanding interaction of tectonics and fluid flow in a fossil hydrothermal system

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The Pfahl shear zone represents a NW-SE trending dextral strike-slip shear zone at the southwestern margin of the Bohemian massif. Along this crustal-scale discontinuity multiple events took place from 327-342 Ma to 247 $\pm$ 21 Ma. Deformation started at melt-present conditions during the emplacement of Variscan granitoids and continued during decreasing temperatures down to fracturing in the presence of hydrothermal fluids. During this last activity, a 150 km long and 30 to 100 m thick almost continuous quartz dyke formed along the main fault zone and along 150°- to 160°-trending Riedel structures. This dyke indicates the activity of an important hydrothermal system that now can be inspected and studied in detail in quarries and quartz ridges with almost continuous exposures.
The main quartz dyke is surrounded by sheared wall rocks, derived from former granitoids and gneisses. Up to several meters away from the contact these rocks are mostly transformed by metasomatic processes to kaolinite, chlorite and phyllosilicates. The dyke itself exhibits a layered to lenticular and partly symmetric structure with different types of μm- to mm-sized quartz, transected by a complicated network of mm- to cm-thick quartz veins. Locally, fragments or m-thick lenses of wall rocks occur, which mainly consist of kaolinite. Structural analyses of the vein network have been carried out across the entire Pfahl exposed in the Waschinger quarry near Regen and at the main quartz ridge (Grosser Pfahl) near Viechtach. Optical microscopy and cathodoluminescence analyses allowed to recognize four subsequent stages of quartz crystallization.
The earliest formation of quartz led to a homogeneous μm-sized, dark grey or red quartz mass. It contains mm- to cm-sized angular wallrock fragments, completely altered to kaolinite. This first type of quartz occurs as cm- to dm-large angular fragments in a μm-sized quartz mass with light grey to pink color. These colors result from different types and variable amounts of inclusions. Both quartz generations form a mosaic texture with random crystallographic orientation and partly intricate fluid inclusion structures. This suggests formation of both quartz types during two (or several) fragmentation episodes and from silica gel precursors that underwent recrystallization after precipitation.
The third quartz generation was formed as a set of mm- to dm-wide quartz veins roughly parallel to the trend of the Pfahl zone. These veins crosscut the two first generations of fine-grained groundmass and the wall rocks, in connection to intense fracturing and brecciation. Tiny (mm- to cm-thick) veins cut thicker vertical veins, indicating that multiple fluid injection and brecciation occurred. This is further outlined by the presence of crosscutting veinlets filled by coarse-grained quartz with different fluid inclusion content and cathodoluminescence intensity.
The fourth stage led to the formation of steep, roughly N-S oriented mm- to dm-thick quartz veins, oblique to the general trend of the Pfahl. These veins cross-cut the earlier quartz masses and veins and run at least several meters into the wallrock. They are partly open, due to incomplete quartz precipitation, and accompanied by cm- to dm-spaced fractures of the same orientation and with subhorizontal striations which locally indicate dextral shear sense, coherently with the kinematics of the Pfahl shear zone.
Summarizing, the different types of quartz masses and veins allow to investigate the evolution of an hydrothermal system that developed during the latest movements of the Pfahl shear zone. Early quartz formation by precipitation from supersaturated silica solutions was followed by quartz formation from decreasing saline hydrothermal fluids. Brecciation was favored by overpressure stages of fluid flow, leading to fracturing. Later en-echelon veins indicate evolution to less overpressured fluids with still less silica content.