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Crack-seal microstructure evolution in multiphase rocks: an example of quartz-chlorite veins formed at the brittle-ductile transition

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For this study we analyzed core samples from the deep geothermal well RWTH-1 (Aachen-Germany), which intersects Carboniferous to Devonian siliciclastics and carbonates deformed during Variscan thrusting and subsequent normal faulting events. From several successive generations of veins, we focussed on quartz-chlorite +/- calcite veins formed by crack-seal processes in the brittle to ductile transition realm (< 390 ºC, 150 – 250 MPa, Lögering, 2008). The veins are common in sections of the well which are interpreted as Variscan thrusts based on image logs and seismic data. Veins are up to 1 cm thick, formed in pull-apart sections of brittle-ductile shear zones.

The change in angle (releasing angle = alpha) of the shear fracture is the main factor controlling vein geometry. Two end-member types of vein geometry can be defined. The first type, the "flat" vein is formed when alpha is less than a few degrees, it contains chlorite and quartz ribbons and commonly shows evidence for ductile shearing. The quartz ribbons often show peculiar "blocky-sawtooth" boundaries. The second type, the “fat” vein quartz forms when alpha is large, up to 90 degrees. Here, stretched-crystal-type fibrous veins are common, with irregular grain boundaries between the chlorite and quartz fibres. Chlorite is present as inclusion bands or trails.

Multiple crack-seal events are interpreted to be the basic microstructural process in the veins. The clearest evidence for this is found in very thin, incipient veins, where “stretched” host rock grains are common. The length of these stretched crystals increases in wider veins, together with an increasing density of healed fractures as shown by fluid inclusion trails.

To understand the microstructural evolution, we extend earlier models of polycrystal growth in fractures (Urai et al, 1991) to the growth of two phases (Quartz and Chlorite) from a supersaturated solution, onto a crack-wall containing both phases. When the relative growth rates of the two phases are different, the grain boundary between the two phases will propagate at an angle (beta) to the fracture boundary. Beta may be rather constant in the rock, or be variable due to local fluctuations in fluid chemistry.

Using different combinations of alpha and beta, we carried out a series of 2D geometric simulations of microstructural evolution in these two-phase veins, for both localized and delocalized cracking. Results compare very well with the observed microstructures, for both "flat" and "fat" veins. The "blocky-sawtooth" quartz veins can be explained by a series of micro-pull apart shear cracks crossing the quartz ribbons in a chlorite surrounding, which are systematically healed by quartz instead of chlorite and quartz.