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# Fracturing and transformation into veins beneath the crustal scale brittle ductile transition – a record of co-seismic loading and post-seismic relaxation

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Metamorphic rocks approaching the crustal scale brittle-ductile transition (BDT) during exhumation are expected to become increasingly affected by short term stress fluctuations related to seismic activity in the overlying seismogenic layer (schizosphere), while still residing in a long-term viscous environment (plastosphere). The structural and microstructural record of quartz veins in low grade - high pressure metamorphic rocks from southern Evia, Greece, yields insight into the processes and conditions just beneath the long-term BDT at temperatures of about 300 to 350˚C, with switches between brittle failure and viscous flow as a function of imposed stress or strain rate. The following features are characteristic:

1. The veins crosscut the foliation and all pre-existing structures;
2. The veins have formed from tensile fractures, with a typical length on the order of $10^{-1}$ to $10^{1}$ m. Vein orientation is uniform on the kilometre scale;
3. Some veins branch symmetrically with an aperture angle of 30˚, which is interpreted to indicate high energy dissipation rates and crack tip propagation velocities approaching the terminal velocity similar to the Raleigh wave speed;
4. Fabrics of the vein quartz indicate that the veins formed during a single sealing stage by mineral precipitation in open cavities.

5. The veins show a low aspect ratio of about 10 to 100 and an irregular or characteristic lenticular shape, which requires distributed ductile deformation of the host rock;

6. The sealing quartz crystals reveal a broad spectrum of microstructural features indicative of crystal plastic deformation at temperatures of about 300 to 350˚C and high stress.

7. Fluid inclusions entrapped in vein quartz reveal a markedly sublithostatic pore fluid pressure during crack sealing.

The features indicate that opening of the fractures commenced immediately after crack arrest. It was controlled by ductile deformation of the host rock at temperatures between 300 and 350˚C, with vein-parallel shortening of less than about 2%. Sealing commenced by crystallization in an open fissure, to become a vein at a later stage. The structural and microstructural record reflects an isothermal switch from short-term brittle failure at quasi-instantaneous loading to decelerating viscous creep with little strain accumulated. The following scenario is inferred: Brittle failure is proposed to be a consequence of short term co-seismic loading related to fault displacement in the overlying schizosphere. Formation of fractures causes an increase in permeability and concomitant dilation a drop in pore fluid pressure, resulting in a diminishing driving force for crack propagation and consequently almost immediate arrest of the fractures. Decelerating viscous deformation during post-seismic stress relaxation causes the opening of the fractures. Sealing of the fissures to become a vein takes place by precipitation of minerals from the pore fluid percolating into the evolving cavity. Opening of fractures and development to a vein is therefore interpreted to be a short-term and episodic process during a stage of post-seismic creep. The record of the exhumed rocks provides insight into earthquake-related damage in the uppermost plastosphere and transient crustal properties during post-seismic creep and stress relaxation.