Fracturing and vein formation in the middle crust - a record of co-seismic loading and post-seismic stress relaxation *Vortrag*

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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 kilometer 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.

Fractures propagated in a single step. Therefore, fluid overpressure as the only source of crack-driving energy is excluded. The drop in pore-fluid pressure related to incremental growth would cause arrest of the fracture until recovery. Hydraulic fracturing is therefore expected to result in cyclic veining, which is not observed in the present case. Opening of the fractures, commencing immediately after crack arrest, was controlled by ductile deformation of the host rock. Vein-parallel shortening is less than about 2%. 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. Individual veins are the result of a single sequence of events:

1. A major stress peak is imposed to the uppermost part of the plastosphere, probably as a consequence

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of co-seismic loading by fault displacement in the overlying schizosphere (timescale is seconds).

2. Fractures presumably initiate after a stage of enhanced stress corrosion with sharpening of earlier blunt flaws, resulting in a rise of the stress intensity factor K_I (timescale is not certain, but estimated to be between seconds and days).

3. Flaw sharpness rises abruptly after critical fracture initiation and results in a K_I peak. The fracture propagation velocity increases extremely in this early stage. Dilation during fracturing causes an instantaneous drop in pore fluid pressure; this implies a drop in driving force and consequently an arrest of the fractures. The time span from initiation to arrest must be a few milliseconds.

4. After fracture arrest, 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. This process is estimated to take some time on the order of 10^0 to 10^4 years.

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.