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Coupled stress and pore fluid pressure changes in the middle crust – the vein record of coseismic loading and postseismic stress 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, while still residing in a long-term viscous environment. The (micro-)structural record of monogenetic syntaxial quartz veins in 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. The following features are characteristic:

1) The veins crosscut the foliation and syn-metamorphic structures; 2) the veins have formed from tensile fractures, with a typical length on the order of 10^{-1} to 10^{1} m; 3) some veins branch symmetrically with an aperture of 30°, which is interpreted to indicate unstable crack propagation close to the terminal velocity; 4) Vein orientation is uniform on the kilometre scale and is consistent with $\sigma_1 = \sigma_v$ and $\sigma_3 = \sigma_h$; 5) the veins formed during a single sealing stage by mineral precipitation in open cavities; 6) the veins show a low aspect ratio of about 10 to 100 and a characteristic lenticular shape, controlled by distributed ductile deformation of the host rock, with vein-parallel shortening by typically less than 1%; 7) the intensity of crystal plastic deformation in the vein quartz decreases from the vein walls towards the center; 8) fluid inclusions trapped in the vein quartz record a time series of pore fluid pressure (P_f) during progressive sealing, with low P_f at the vein walls (early stage) to high P_f in the vein core (final stage).

These features indicate: Opening of the fractures commenced immediately after crack arrest, controlled by ductile deformation of the host rock at temperatures between about 300 and 350° C. The crack opening rate exceeded the rate of sealing, so that

the quartz crystals grew into an open cavity. For opening of fractures to provide space for mineral precipitation, the effective stress on the fracture walls must be tensile and the fluid pressure must be similar to that of the magnitude of the least principal stress $P_f \approx \sigma_3$. If $P_f > \sigma_3$, fracture propagation would re-initiate, resulting in a drop in P_f. The evolution of the pore fluid pressure recorded by the fluid inclusions is therefore interpreted to reflect the relaxation of remote stress during progressive opening and sealing of the vein, as $\sigma_1 = \sigma_v$ = const.

The structural and microstructural record of these monogenetic veins reflects an isothermal switch from brittle failure to decelerating viscous creep. The total strain accumulated is low. The following scenario is inferred: Fracturing is proposed to be a consequence of co-seismic loading related to fault slip in the overlying upper crust. Within the large-scale midcrustal damage zone, fractures develop and dilation causes a drop in P_f. Subsequently, the fractures open controlled by viscous creep of the host rock with a concomitant restoration of P_f during stress relaxation. Sealing of the fissures to become veins takes place continuously by precipitation of minerals from the pore fluid streaming through the evolving cavity. The lenticular monogenetic veins are therefore interpreted to record a short-term and episodic process. Such type of record of exhumed rocks provides insight into earthquake-related damage beneath the seismogenic layer and into the nature of transient crustal properties in the earthquake cycle.