Building a giant quartz reef at the Heyuan fault, South China: observations and multiphysics model

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A paleohydrothermal giant quartz reef (at least 75 m wide, 40 km long) and abundant hot springs at the Heyuan fault, South China, provide an excellent opportunity to investigate hydrothermal flows from the Mesozoic through to present-day.

The giant quartz reef has formed in the extensional regime initiated in the Mesozoic, while a change to compressional stress on the Heyuan in the Cenozoic led to the development of cross-cutting strike-slip faults and associated vertical fracture network. Here, we present multiscale observations and analyses from the earlier long-term extensional phase.

Detailed microstructural analyses identified a ‘quartz-reef window’ of formation occurring between ~200-350°C, linking in both quasi-static criteria (accommodation space; massive fluid sources; and a cap rock/seal) and dynamic mechanisms (episodic-dynamic permeability; brittle-ductile cycles; and fluid injection though brittle-ductile equivalent of Sibson’s ‘fault-valve’ behaviour.

This oscillatory brittle-ductile fault-valve is recorded in the field through its apparent contradiction between idiomorphic 5 cm long quartz crystal growth in mode-I fractures, embedded at large-scale inside far from equilibrium fault zones with mylonitic and cataclastic microstructures. Another characteristic feature is the increasing quartz vein frequency towards the core shown by enrichment of SiO\textsubscript{2}, with depletion of K\textsubscript{2}O and Na\textsubscript{2}O in tectonites during alteration from the host granite; a reaction partly sourcing the SiO\textsubscript{2} for the quartz reef.

We present a first theoretical model compatible with the observation of oscillatory macroscale far from equilibrium conditions, followed by long periods of micro-scale local equilibrium. The model can in particular describe mechanisms of abundant SiO\textsubscript{2} dominated fluid release reaching episodically above hydrostatic pressures followed by long periods of SiO\textsubscript{2} precipitation, allowing growth of up to 5 cm long idiomorphic quartz crystals in subparallel open channels, which presumably were held open by high fluid pressures. In this interpretation, the observations instabilities are seen to stem from the multiscale and multiphysics of the mineral reactions at the brittle-ductile transition, promoted by a slow extensional geodynamic driver at the Heyuan fault.

The new approach allows interpretation of rock physics properties in terms of recently discovered
Thermo-Hydro-Mechanical-Chemical (THMC) multiscale wave-like instabilities. In the model short wavelength chemical dissolution-precipitation reaction waves are bouncing between the phyllonitic cap rock and the mylonitic shear zone below. A resonance phenomenon of constructive interference in a finite width around the future quartz-reef triggers the long-time scale steady-state attractor allowing quartz reef growth over geodynamic time scales. We show that this solitary wave limit forms a standing wave matching the characteristic periodic pattern of mode-I quartz veining around the reef and also explaining the fluid overpressures leading to local hydro-fracturing.