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Synkinematic quartz cementation in partially open fractures in sandstones

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Faults and networks of naturally open fractures can provide open conduits for fluid flow, and may play a significant role in hydrocarbon recovery, hydrogeology, and CO_2 sequestration. However, sandstone fracture systems are commonly infilled, at least to some degree, by quartz cement, which can stiffen and occlude fractures. Such cement deposits can systematically reduce the overall permeability enhancement due to open fractures (by reducing open fracture length) and result in permeability anisotropies. Thus, it is important to identify the factors that control the precipitation of quartz in fractures in order to identify potential fluid conduits under the present-day stress field.
In many sandstones, quartz nucleates syntaxially on quartz grain or cement substrate of the fracture wall, and extends between fracture walls only locally, forming pillars or bridges. Scanning electron microscope cathodoluminescence (SEM-CL) images reveal that the core of these bridges are made up of bands of broken and resealed cement containing wall-parallel fluid inclusion planes. The fluid inclusion-rich core is usually surrounded by a layer of inclusion-poor clear quartz that comprises the lateral cement. Such crack-seal textures indicate that this phase was precipitating while the fractures were actively opening (synkinematic growth). Rapid quartz accumulation is generally believed to require temperatures of 80°C or more.
Fluid inclusion thermometry and Raman spectroscopy of two-phase aqueous fluid-inclusions trapped in crack-seal bands may be used to track the P-T-X evolution of pore fluids during fracture opening and crack-seal cementation of quartz. Quartz cement bridges across opening mode fractures in the Cretaceous Travis Peak Formation of the tectonically quiescent East Texas Basin indicate individual fractures opened over a 48 m.y. time span at rates of 16-23 μm/m.y. Similarly, the Upper Cretaceous Mesaverde Group in the Piceance Basin, Colorado contains fractures that have recorded opening histories that lasted several tens of millions of years.
Quartz bridges will form when the increase in fracture aperture is small for single fracture events, the rate of precipitation is greater than the rate of fracture aperture, and fresh non-euhedral nucleation surfaces continue to be created by fracturing. Because of the vast difference in growth rates between the c-axis (fast) and the a-axis (slow) of quartz crystals, the crystallographic orientation of quartz may play a role on the morphology and size of such bridges, and therefore degree of cement infill in fractures. SEM-based backscattered electron diffraction (EBSD) was used to explore the effect of the crystallographic orientation of quartz on the growth of quartz bridges in fractures from the Jurassic-Cretaceous Nikanassin Formation, northwestern Alberta Foothills, the Travis Peak Formation, East Texas, and the Cretaceous Mesaverde Group, Piceance Basin, Colorado. We find that, in all samples, most c-axes are oblique rather than perpendicular to the fracture wall, and well-developed bridges that are oriented at a low angle to the fracture wall are widespread. We conclude that precipitation on anhedral (fractured) surfaces exerts a larger control on the growth of quartz bridges than the orientation of the crystallographic c-axis.