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Gypsum dehydration under stressed conditions – a study on the feedback mechanisms between reaction and deformation

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The interplay between pore fluid pressure, mineral dehydration and deformation has been suggested to be of great importance for crustal fault zones in a wide range of settings. Dehydrating hydrous minerals represent one source of metamorphic fluids, and, given the usually positive total volume change caused by the released fluid, the build-up of high pore fluid pressures can be expected. During prograde metamorphism, reaction progress, pore fluid pressure build-up and rock deformation are hypothesized to be coupled via chemical-hydraulical-mechanical feedbacks. Details of the mechanisms of these feedbacks are undocumented though, which leaves key concepts in tectonics, e.g., the hypothesized importance of high pore-fluid pressure on thrusting, insufficiently supported by observational data.

We investigate chemical-hydraulic-mechanical feedbacks during dehydration of a Volterra alabaster sample at non-hydrostatic stress conditions. A mm-sized monophase, polycrystalline sample cylinder was subjected to 15 MPa confining pressure and constant differential stress of 23 MPa. The sample was then heated to 115 °C, destabilizing gypsum and leading to the gypsum dehydration reaction $CaSO_4 \cdot 2H_2O$ (gypsum) = $CaSO_4 \cdot 0.5H_2O$ (bassanite) + $1.5H_2O$. Using an X-ray transparent deformation rig, we documented the reaction in 240 time-resolved 3D micro-CT scans in order to study 1) the influence of an anisotropic stress state on the reaction and its advance in the sample and, 2) the rheological effects of newly formed bassanite on sample deformation.

Within the limits of the spatial resolution (2μm), the sample shows no evidence of damage, nor evidence of reaction for the first ~4 hours. Then, weakly localized mode I micro-fractures start to form parallel to the applied differential load. Roughly simultaneously with the formation of the first micro-fractures, the first bassanite grains start to form. At 4h 15min, the sample failed by localized shear failure.

Bassanite grains align with the largest fractures, though not all fractures trigger local dehydration. After failure, dehydration accelerated significantly in both, the fault and the host rock. However, the fault rock exhibits higher dehydration rates and markedly smaller bassanite grain- and pore sizes. The main fault continues to creep for 9 minutes, before it arrests and heals. The un-faulted gypsum volume took ~85 min to dehydrate and dehydration decelerates over that time. Bassanite grains in these domains appear randomly oriented. No further strain localization can be observed in the reacted domains.

Our data show grain-scale evidence for how damage localization in an anisotropically stressed sample, drainage and reaction advance are initially coupled. They support a model where an initially subcritically stressed sample destabilizes once the reaction initiates, and strain localization affects sample drainage. Ultimately, this conclusion is limited by the spatial resolution of our data. However, our data also point to more complexity in the system. At this stage, it remains unclear what controls dehydration of the unfaulted domains after sample failure. It is further unclear how sample rheology evolves on the grain scale as alabaster turns into pores and comparatively small bassanite grains. Our current analytical efforts focus on these aspects.