EGU2020-6968
https://doi.org/10.5194/egusphere-egu2020-6968
EGU General Assembly 2020
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Synchrotron multi-modal, multi-scale chemical and structural imaging of vein-bearing shales

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The coupling between fluid transport, chemical reactions, and deformation constitutes one of the frontiers of geoscientific research. From an analytical perspective, a fundamental challenge is posed by the fact that sub-nanometre- to micrometre-scale structures play a vital role in the macroscopic (centimetre- to metre-scale) response of deforming, reacting, fluid-bearing rocks. Sample analysis with conventional laboratory techniques quickly becomes prohibitively expensive and laborious when more than four orders of magnitude in length scales need to be resolved. This issue is particularly challenging in very fine-grained rocks such as mylonites and shales.

Here, we investigate calcite-vein-bearing shales to illustrate how synchrotron X-ray fluorescence microscopy, ptychography, and small- and wide-angle transmission scattering can be used for the quantitative multi-scale analysis of micro- and nano-textures in rock. These analytical techniques are applied to thin sections or thin rock slabs on the centimetre-scale and provide information on length scales from hundreds of micrometres down to angstroms. Therefore, the considered array of synchrotron techniques covers up to eight orders of magnitude in length scale in terms of chemical and structural information. In our case study, we demonstrate how this suite of analytical techniques can be employed to reveal, for example, the relative timing of mineralisation events, trace-element chemistry, texture, and the structural width of fluid pathways such as grain boundaries.