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Modular, portable and low-cost x-ray- and neutron-transparent cells for the experimental study of fluid-rock interaction and rock deformation

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Our current means to quantify fluid-rock interaction and rock deformation in space and time are limited: Field-centred studies are constrained to the interpretation of fossilized, exhumed and retrograded micro fabrics. Classical laboratory experimental methods can, with few exceptions, only monitor the bulk response of a rock, and interpret samples post-mortem. Both approaches struggle to discern critical developments on the micro-scale. Consequently models to explain fluid-rock interaction are based on an incomplete understanding of the underlying grain-scale processes. The advent of fast x-ray and neutron imaging has opened up new possibilities to study fluid-rock interaction on the grain scale where suitable x-ray/neutron transparent vessels allow reproduction of geological conditions in situ. This contribution gives an overview of a range of devices that we have designed, built and used over the past years. Our goal is to inspire new experiments and motivate imitation to facilitate a wider uptake in experimental geosciences.

Our design philosophy aims for modularity, portability and low-cost, and as a consequence our experimental environments share several advantages:

1) The advantage of modular designs is that the devices can be easily adopted to specific experiments, and the beam path length of the attenuating pressure vessel can be minimised subject to P, T and load requirements. This allows optimizing of data quality.

2) Many x-ray and neutron imaging beam lines are currently specializing on meeting specific experimental requirements. Taking advantage of this development requires the equipment to be transported to the most suitable x-ray and neutron sources for any experiment. As a consequence, each of our cells packs into a single item of airline cabin luggage, and the ancillary laboratory equipment can easily be transported by courier.

3) To minimize the manufacturing costs of our cells, we try to use standard and readily available materials and components, in particular with regard to actuators and fluid couplings. All components can be machined in any standard mechanical workshop.

Our x-ray/neutron transparent experimental environments have been used in studies of pressure solution creep, dehydration, carbonation, failure in granite, multiphase fluid flow, and more. Our cells have demonstrated their potential to transform our understanding of fluid-rock interaction: Time-resolved (4D) micro-tomographic data allow quantifying the evolution of parameters that describe fluid-rock interaction on the grain scale. These include the proportion of participating minerals and porosity, their spatial distribution, percolation, the size of individual mineral grains and pores, their geometry and orientation and relation to each other. Advanced volume correlation codes further allow the quantifications of local strains and strain rates.

Our current efforts aim to significantly increase the temperatures and confining pressures. In the near future, we will be able to conduct confined fluid-rock interaction experiments with mm-sized samples at 300°C. Subject to funding, we will build a prototype of a new triaxial deformation rig that can reach 450°C, 100 MPa Pc and control pore fluid pressure. We are pairing these capabilities with advanced data processing and analyses tools including data mining and machine learning algorithms and numerical modelling to test established theories on 4DμCT data.