Deformation mechanisms in experimentally deformed claystones from geological underground laboratories (Boom and Callovo-Oxfordian Clays): preliminary results

G. Desbois*[1], J.L. Urai[1], , N. Höhne[1], P. Bésuelle[2], G. Viggiani[2], B. Laurich[1], S. Noorsalehi – Garakani[1]

[1] Structural Geology, Tectonics and Geomechanics, RWTH Aachen University, Germany

[2] Laboratoire 3SR, Joseph Fourier University, Grenoble, France

Shales display a poorly understood deformation behaviour transitional between rocks and soils. From pilot-tests, we recognize two main classes of deformation mechanisms in shales and illustrates these with an BIB-SEM study of two experimentally deformed shales. Preliminary results were also the occasion to validate a novel approach for the investigation of deformation mechanisms in Shales, combining the use of digital image correlation (DIC) method to localize stress and strain fields within the sample as well as their evolution in time (Lenoir et al., 2007), in addition to the establishment of conventional stress/strain curves. Subsequently, on relevant deformed regions, fabrics and porosity below micrometre scales are performed on very high quality cross sections prepared by broad-ion-beam milling (BIB) suitable for high resolution SEM (Desbois et al., 2009; Houben et al., 2013). Therefore, the combination of conventional stress-strain data, localization of stress and strain fields and microstructural investigation below micrometre scales on a same sample offers the unique opportunity to answer to the fundamental questions: (1) “When”, (2) “Where” and (3) “How” the sample is deforming in laboratory.

Shale A is a Callovo-Oxfordian shale (Bure, Meuse - Haute Marne, France). One test was performed at 2 MPa confining pressure (plane strain compression) followed by planar DIC on optical images and a second one at 10 MPa confining pressure (triaxial compression) followed by volumetric DIC on X-ray microtomography images. Deformed samples contain macroscopic brittle fractures, even at high confining pressure. In respect to stress levels, BIB-SEM shows a large range of microstructures from fracture propagating along clast interfaces, incipient of clast cracking, incipient of cataclastic flow, clast rotation, towards thin cataclastic gouge in the fracture. The main deformation mechanism is grain refinement by grain scale fracturing. First results on porosity analysis indicates an increase of visible total porosity in damaged zones mainly due by an increasing number of cracks and possibly balanced by a change in the power law distribution of other pores.

Shale B is a Boom Clay (Mol – Dessel, Belgium) deformed with increasing confining pressure until the brittle failure of the specimen, results in a non-dilatant shear zone across the sample. Strain is strongly localised in thin, anastomosing zones of strong preferred orientation, producing slickensided shear surfaces common in shallow clays. There is no evidence for intragranular cracking. Deformation mechanisms are bending of clay plates and sliding along clay-clay contacts. Porosity display obvious changes in morphology and distribution from undamaged to damaged zones.

Although as a first approximation the plasticity of both shales can be described by similar Mohr-Coulomb type failure envelopes, these results indicate that the full constitutive models describing their deformation and transport properties under natural conditions should be quite different, due to the different amounts of grain-scale cracking.

Desbois G., Urai J.L. and Kukla P.A. (2009). Morphology of the pore space in claystones - evidence from BIB/FIB ion beam sectioning and cryo-SEM observations. E-Earth, 4 :15-22.

Houben M.A., Desbois G. and Urai J.L. (2013). Pore morphology and distribution in the shaly facies of Opalinus clayn (Mont Terri, Switzerland) : insigths from representative 2D BIB-SEM investigations on mm- to nm- scales. Applied Clay Sciences, 71(C): 82-97.

Lenoir N., Bornert M., Desrues J., Bésuelle P., Viggiani G. (2007). Volumetric Digital Image Correlation applied to X-ray microtomography images from triaxial compression tests on Argilaceous Rock. Blackwell Publishing Ltd, Strain 43, 193-205.