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Deformation mechanisms and resealing of damage zones in experimentally deformed cemented and un-cemented clay-rich geomaterials, at low bulk strain

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A microphysics-based understanding of mechanical and fluid flow properties in clay-rich geomaterials is required for extrapolating better constitutive equations beyond the laboratory's time scales, so that predictions over the long term can be made less uncertain.

In this contribution, we present microstructural investigations of rocks specimens sheared in triaxial compression at low bulk strain, by using the combination of broad-ion-beam (BIB) milling and scanning electron microscopy (SEM) to infer deformation mechanisms based on microstructures imaged at sub-micron resolution. Two end-member clay-rich geomaterials from European Underground Laboratories (URL) were analysed: (i) the poorly cemented Boom Clay sediment (BC from URL at Mol/Dessel, Belgium; confining pressure [CP] = 0.375 & 1.5 MPa) and (ii) the Callovo-Oxfordian claystone (COx from the URL at Bure, France; CP = 2 & 10 MPa).

Although as a first approximation the inelastic bahvior of cemented and uncemented clay-rich geomaterials can be described by similar pressure-dependent hardening plasticity models, deformed samples in this contribution show very contrasting micro-scale behaviour: microstructures reveal brittle-ductile transitional behaviour in BC, whereas deformation in COx is dominantly cataclastic.

In Boom Clay, at meso-scale, shear bands exhibit characteristics that are typical of uncemented small-grained clay-rich materials deformed at high shear strains, consisting of anastomosing shears interpreted as Y- and B-shears, which bound the passively deformed microlithons. At micro- down to nano-scale, the strong shape preferential orientation of clay aggregates in the anastomosing shears is interpreted to be responsible of the shear weakness. More over, the reworking of clay aggregates during deformation contributes to the collapsing of porosity in the shear band. Ductile deformation mechanisms represented by grain-rotation, grain-sliding, bending and granular flow mechanisms are strongly involved for the development of the shear band. At the same time, evidence for dilatancy at low confining pressure indicates that deformation involves also brittle deformation. Our observations strongly suggest that the deformation mostly localizes in those regions of the specimen, where the original grain sizes are smaller.

In COx, microstructures show evidence for dominantly cataclastic deformation involving intergranular – trans-granular – and - intragranular micro fracturing, grain rotation and clay particle bending mechanisms, down to nm-scale. Micro fracturing of the original fabric results in fragments at a range of scales, which are reworked into a clay-rich cataclastic gouge during frictional flow. Intergranular and minor intragranular micro fracturing occur in regions of non localized deformation, whereas transgranular micro fracturing occurs at regions of localized deformation. These processes are accompanied by dilatancy, but also by progressive decrease of porosity and pore size in the gouge with the non-clay particles embedded in reworked clay. The mechanism of this compaction during shearing is interpreted to be a combination of cataclasis of the cemented clay matrix, and shear-induced rearrangement of clay particles around the fragments of non-clay particles.