Clay-Gouge thickness and 3D fault zone architecture in normal faults - insights from water-saturated sandbox experiments

Sohrab Noorsalehi-Garakani*, J. L. Urai, M. Kettermann

Structural Geology, Tectonics and Geomechanics, Geological Institute, RWTH Aachen University, Lochnerstrasse 4-20, 52056 Aachen, Germany

The anatomy of clay-gouge is a dominant factor for the fluid transmissibility of fault zones in sand-clay sequences. Clay-smear processes have been subject to numerous studies in the field, the subsurface and numerical and laboratory simulations but the structures of clay-smears and clay-gouge in 3D are not well known.

To improve our understanding of clay-gouge formation and its variations in structure and composition in 3D, we performed analogue sandbox experiments and created models of fault zones in water-saturated sand-clay sequences above a normal fault in a rigid basal layer, building on work of Schmatz et al. (2010a) and Schmatz et al. (2010b).

We developed new methods to excavate the sheared clay after the end of the experiments and high-resolution laser scans from footwall and hanging-wall side were merged to reconstruct the clay-gouge volume in 3D.

In a series of experiments with one single layer of clay between two layers of sand, the excavated clay-gouge showed a segmentation recognizable by breached relays, with a structure similar to those in fault zones at outcrop and seismic scales, as shown e.g. in Childs et al. (1996) Walsh et al. (1999) and Van Gent et al. (2010). Depending on the basement fault dip two classes of structural domains can be observed, a precursor-dominated and a graben-dominated, as it was reported for sandbox experiments by Horsfield (1977) and in agreement to recent findings from finite element simulations of corresponding sandbox experiments by Nollet et al. (2012).

The composition of excavated clay-gouge shows clear variations over the entire volume due to mechanical mixing of sand and clay, predominantly by abrasion processes at footwall and hanging-wall cut-off of the clay layers.

In contrast to earlier 2D observations of Schmatz et al. (2010a) which show, that in this type of experiments only brittle clay forms a non-continuous gouge, our new observations reveal that soft, ductile clay forms a locally discontinuous gouge in parts of the clay-gouge volume above throw-to-thickness ratios of ~7.

Thickness maps of the excavated clay-gouge obtained from the reconstructed 3D volume show a strong variation in thickness along the strike and dip direction of the shear zone, and thin parts correlate with locations which indicate an intense shearing by the presence of a highly mixed gouge.

Our new methods provide a unique way to study the development of fault zones in sequences of soft sediments, and the first intriguing results of excavated models and three-dimensional reconstructions contribute to extend the understanding of the structural and compositional variability of clay-gouge.

Childs, C., Nicol, A., Walsh, J.J., Watterson, J., 1996. Growth of vertically segmented normal faults. Journal of Structural Geology 18, 1389–1397.

Horsfield, W.T., 1977.An experimental approach to basement-controlled faulting. Geologie en Mijnbouw 56(4), 363-370.

Nollet, S., Kleine Vennekate, G. J., Giese, S., Vrolijk, P., Urai, J.L., Ziegler, M., 2012. Localization patterns in sandbox-scale numerical experiments above a normal fault in basement. Journal of Structural Geology 39 (2012) (pp. 199-209).

Schmatz, J., P.J. Vrolijk, J.L. Urai, 2010a. Clay smear in normal fault zones – The effect of multilayers and clay cementation in water-saturated model experiments. Journal of Structural Geology 32 - Fault zones (11), 1834-1849.

Schmatz, J., Holland, M., Giese, S., van der Zee, W., Urai, J.L., 2010b. Clay smear processes in mechanically layered sequences – results of water-saturated model experiments with free top surface. Journal of the Geological Society of India (special issue 03).

Van Gent, H., Back, S., Urai, J., Kukla, P.A., 2010. Small-scale faulting in the Upper Cretaceous of the Groningen Block (The Netherlands): 3D seismic interpretation, fault plane analysis and paleostress. Journal of Structural Geology 32, 537-55.3

Walsh, J.J., Watterson, J., Bailey, W.R., Childs, C.,1999. Fault relays, bends and branch-lines. Journal of Structural Geology 21,1019–1026.