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Mechanisms of clay smear formation in 3D – a field study

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Clay smears in sedimentary basins are important factors defining the sealing properties of faults. However, as clay smears are highly complex 3D structures, processes involved in the formation and deformation of clay smears are not well identified and understood. To enhance the prediction of sealing properties of clay smears extensive studies of these structures are necessary including the 3D information.

We present extraordinary outcrop data from an open cast lignite mine (Hambach) in the Lower Rhine Embayment, Germany. The faults formed at a depth of 150 m, and have Shale Gouge Ratios between 0.1 and 0.3. Material in the fault zones is layered, with sheared sand, sheared clay and tectonically mixed sand-clay gouge. We studied the 3D thickness distribution of clay smear from a series of thin-spaced incremental cross-sections and several cross-sections in larger distances along the fault. Additionally, we excavated two large clay smear surfaces.

Our observations show that clay smears are strongly affected by R- and R'-shears, mostly at the footwall side of our outcrops. These shears can locally cross and offset clay smears, forming holes. Thinnest parts of the clay smears are often located close to source layer cutoffs. Investigating the 3D thickness of the clay smears shows a heterogeneous distribution, rather than a continuous thinning of the smear with increasing distance to the source layers.

We found two types of layered clay smears: one with continuous sheared sand between two clay smears providing vertical pathways for fluid flow, and one which consists of overlapping clay patches separated by sheared sand that provide a tortuous pathway across the clay smear.

On smaller scale we identified grain-scale mixing as an important process for the formation of clay smears. Sand can be entrained into the clay smear by mixing from the surrounding host rock as well as due to intense shearing of sand lenses that were incorporated into the smear. This causes clay smears to thicken and reduces permeability as long as the clay volume exceeds the pore space of the sand.