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Testing the influence of vertical, pre-existing joints on normal faulting using analogue and 3D discrete element models (DEM)

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Brittle rocks are often affected by different generations of fractures that influence each other. We study pre-existing vertical joints followed by a faulting event. Understanding the effect of these interactions on fracture/fault geometries as well as the development of dilatancy and the formation of cavities as potential fluid pathways is crucial for reservoir quality prediction and production. Our approach combines scaled analogue and numerical modeling. Using cohesive hemihydrate powder allows us to create open fractures prior to faulting. The physical models are reproduced using the ESyS-Particle discrete element Modeling Software (DEM), and different parameters are investigated.

Analogue models were carried out in a manually driven deformation box (30x28x20 cm) with a 60° dipping pre-defined basement fault and 4.5 cm of displacement. To produce open joints prior to faulting, sheets of paper were mounted in the box to a depth of 5 cm at a spacing of 2.5 cm. Powder was then sieved into the box, embedding the paper almost entirely (column height of 19 cm), and the paper was removed. We tested the influence of different angles between the strike of the basement fault and the joint set (0°, 4°, 8°, 12°, 16°, 20°, and 25°). During deformation we captured structural information by time-lapse photography that allows particle imaging velocimetry analyses (PIV) to detect localized deformation at every increment of displacement. Post-mortem photogrammetry preserves the final 3-dimensional structure of the fault zone.

We observe that no faults or fractures occur parallel to basement-fault strike. Secondary fractures are mostly oriented normal to primary joints. At the final stage of the experiments we analyzed semi-quantitatively the number of connected joints, number of secondary fractures, degree of segmentation (i.e. number of joints accommodating strain), damage zone width, and the map-view area fraction of open gaps. Whereas the area fraction does not change distinctly, the number of secondary fractures and connected joints increases strongly with increasing angles between basement fault and joint strike. Integrating these models with a 3-dimensional DEM code using the ESyS-Particle software allows for retrieving 4D information from the models, as well as for testing other parameters such as joint spacing or joint depth. Our DEM models are capable of robustly reproducing all characteristic features observed in the analogue models, and will provide a quantitative measure of the influence of joint-fault angle on permeability of cohesive rocks that have experienced more than one brittle deformation phase.