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Modeling the effect of preexisting joints on normal fault geometries using a brittle and cohesive material

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Brittle rocks, such as for example those hosting many carbonate or sandstone reservoirs, are often affected by different kinds of fractures that influence each other. Understanding the effects of these interactions on fault geometries and the formation of cavities and potential fluid pathways might be useful for reservoir quality prediction and production. Analogue modeling has proven to be a useful tool to study faulting processes, although usually the used materials do not provide cohesion and tensile strength, which are essential to create open fractures. Therefore, very fine-grained, cohesive, hemihydrate powder was used for our experiments. The mechanical properties of the material are scaling well for natural prototypes. Due to the fine grain size structures are preserved in in great detail.

The used deformation box allows the formation of a half-graben and has initial dimensions of 30 cm width, 28 cm length and 20 cm height. The maximum dip-slip along the 60° dipping predefined basement fault is 4.5 cm and was fully used in all experiments. To setup open joints prior to faulting, sheets of paper placed vertically within the box to a depth of about 5 cm from top. The powder was then sieved into the box, embedding the paper almost entirely. Finally strings were used to remove the paper carefully, leaving open voids. Using this method allows the creation of cohesionless open joints while ensuring a minimum impact on the sensitive surrounding material.

The presented series of experiments aims to investigate the effect of different angles between the strike of a rigid basement fault and a distinct joint set. All experiments were performed with a joint spacing of 2.5 cm and the fault-joint angles incrementally covered 0°, 4°, 8°, 12°, 16°, 20° and 25°. During the deformation time lapse photography from the top and side captured every structural change and provided data for post-processing analysis using particle imaging velocimetry (PIV). Additionally, stereo-photography at the final stage of deformation enabled the creation of 3D models to preserve basic geometric information.

The models showed that at the surface the deformation localized always along preexisting joints, even when they strike at an angle to the basement-fault. In most cases faults intersect precisely at the maximum depth of the joints. With increasing fault-joint angle the deformation occurred distributed over several joints by forming stepovers with fractures oriented normal to the strike of the joints. No fractures were observed parallel to the basement fault. At low angles stepovers coincided with wedge-shaped structures between two joints that remain higher than the surrounding joint-fault intersection. The wide opening gap along the main fault allowed detailed observations of the fault planes at depth, which revealed (1) changing dips according to joint-fault angles, (2) slickenlines, (3) superimposed steepening fault-planes, causing sharp sawtooth-shaped structures. Comparison to a field analogue at Canyonlands National Park, Utah/USA showed similar structures and features such as vertical fault escarpments at the surface coinciding with joint-surfaces. In the field and in the models stepovers were observed as well as conjugate faulting and incremental fault-steepening.