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The formation of open fractures in brittle rocks and the evolution of permeability with fault slip- results from analogue and numerical models

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The formation of open cavities as a result of (normal) faulting of a brittle material under low effective stress has profound effects on the hydraulic properties of rocks both near the surface and at depth. It is however often difficult to access the fault zone directly. Here we present the results from a series of analogue models of normal faults in brittle rocks. Fine grained, dry Hemihydrate powder (CaSO_4 * 1/2 H_2O) was used as the truly cohesive analogue material. An extensive characterization of material properties, including the porosity dependency of both tensile strength and cohesion, showed the increase of strength of the powder with burial in the experimental box.

In side view observations of the analogue models three structural zones were distinguished; a pure tensile failure zone at the surface and pure shear failure zone near the bottom of the box. At mid-depths we observed a transitional zone with mixed mode failure and the formation of fault cavities. These cavities initiate at local dip-changes of the fault and can collapse with progressive deformation. The transitions between these zones can be directly related to the increase of material strength due to burial compaction. The intercalation of relatively softer sand layers and relatively stronger layers of a hemihydrate and graphite mixture resulted in a marked increase of the complexity of the fault zone, but the three structural zones remain clearly visible. The sand layers can form decollement surfaces and "sand-smears". The observed structures compare well with fault outcrops and fault related cave systems in carbonates, basalts and consolidated sandstone.

We used Particle Image Velocimetry (PIV) to quantify deformation and strain and observed plastic deformation prior to brittle failure at increments to small for visual inspection. However, the forces involved remain largely unknown. Therefore we have used the Discrete Element Method (DEM) to numerically model the formation of open fractures in brittle lithologies three dimensions. We used the results of the material characterization to define the strength of the brittle-elastic “bonds” between the numerical elements, as well as the repulsive-elastic and frictional “contact”-interactions after these bonds are broken. The three-dimensional numerical models allowed for detailed studies of fault initiation and the evolution of the porosity-connectivity. The DEM-models also are a relatively quick way to test the effects of different fault dips and changes in the material properties. The results from simulations are in good agreement with the analogue experimental results and field observations.