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Dilatant normal faulting in jointed cohesive rocks: insights from physical modeling

Michael Kettermann, Christoph von Hagke, and Janos Urai
Structural Geology, Tectonics and Geomechanics, RWTH Aachen University, Aachen, Germany
(michael.kettermann@emr.rwth-aachen.de)

Dilatant faults often form in rocks containing pre-existing joints, but the effects of joints on fault segment linkage and fracture connectivity is not well understood. Studying evolution of dilatancy and influence of fractures on fault development provides insights on geometry of fault zones in brittle rocks and eventually allows for predicting their subsurface appearance. We assess the evolution of dilatant faults in fractured rocks using analogue models with cohesive powder. The upper layer contains pre-formed joint sets, and we vary the angle between joints and a rigid basement fault in our experiments.

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 (joint fault (JF) angles of 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.
Results show robust structural features in models: damage zone width increases by about 50 % and the number of secondary fractures within this zone by more than 100 % with increasing JF-angle. Interestingly, the map-view area fraction of open gaps increases by only 3%. Secondary joints and fault step-overs are oriented at a high angle to the primary joint orientation. Due to the length of the pre-existing open joints, areas far beyond the fractured regions are connected to the system. In contrast, experiments without pre-existing joints show a wider fracture network with a higher fracture density, while at the same time providing less open space.

We conclude that existence of pre-existing joints tremendously affects fault zone evolution. Our systematic study showed that particularly the angle between pre-existing joints and faults has a distinct effect on the network of open fractures, mostly in terms of fracture surfaces and connectivity. Structures in our models compare well with field prototypes such as the grabens of Canyonlands National Park, or basalts in the Campi Flegrei, Italy, suggesting a predictive capability of these models.