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The influence of joint parameters on normal fault evolution and geometry: a parameter study using analogue modeling

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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 into geometry of fault zones in brittle rocks and will eventually allow for predicting their subsurface appearance.
In an earlier study we recognized the effect of different angles between strike direction of vertical joints and a basement fault on the geometry of a developing fault zone. We now systematically extend the results by varying geometric joint parameters such as joint spacing and vertical extent of the joints and measuring fracture density and connectivity. A reproducibility study shows a small error-range for the measurements, allowing for a confident use of the experimental setup.
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. We varied the vertical extent of the joints from 5 to 50 mm. Powder was then sieved into the box, embedding the paper almost entirely (column height of 19 cm), and the paper was removed. 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.
A counterintuitive result is that joint depth is of only minor importance for the evolution of the fault zone. Even very shallow joints form weak areas at which the fault starts to form and propagate. More important is joint spacing. Very large joint spacing leads to faults and secondary fractures that form subparallel to the basement fault. In contrast, small joint spacing results in fault strands that only localize at the pre-existing joints, and secondary fractures that are oriented at high angles to the pre-existing joints.
With this new set of experiments we can now quantitatively constrain how (i) the angle between joints and basement fault, (ii) the joint depth and (iii) the joint spacing affect fault zone parameters such as (1) the damage zone width, (2) the density of secondary fractures, (3) map-view area of open gaps or (4) the fracture connectivity. We apply these results to predict subsurface geometries of joint-fault networks in cohesive rocks, e.g. basaltic sequences in Iceland and sandstones in the Canyonlands NP, USA.