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Growth of faults in crystalline rock

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The growth of faults depends on the coupled interplay of the distribution of slip, fault geometry, the stress field in the host rock, and deformation of the host rock, which commonly is manifest in secondary fracturing. The distribution of slip along a fault depends highly on its structure, the stress perturbation associated with its interaction with nearby faults, and its strength distribution; mechanical analyses indicate that the first two factors are more influential than the third. Slip distribution data typically are discrete, but commonly are described, either explicitly or implicitly, using continuous interpolation schemes. Where the third derivative of a continuous slip profile is discontinuous, the compatibility conditions of strain are violated, and fracturing and perturbations to fault geometry should occur. Discontinuous third derivatives accompany not only piecewise linear functions, but also functions as seemingly benign as cubic splines.

The stress distribution and fracture distribution along a fault depends strongly on how the fault grows. Evidence to date indicates that a fault that nucleates along a pre-existing, nearly planar joint or a dike typically develops secondary fractures only near its tipline when the slip is small relative to the fault length. In contrast, stress concentrations and fractures are predicted where a discontinuous or non-planar fault exhibits steps and bends; field observations bear this prediction out.

Secondary fracturing influences how faults grow by creating damage zones and by linking originally discontinuous elements into a single fault zone. Field observations of both strike-slip faults and dip-slip faults show that linked segments usually will not be coplanar; elastic stress analyses indicate that this is an inherent tendency of how three-dimensional faults grow.

Advances in the data we collect and in the rigor and sophistication of our analyses seem essential to substantially advance our ability to successfully predict earthquakes, fluid flow and mineralization along faults, and fault sealing. Particularly promising avenues of research include: (a) collecting high-resolution slip distribution data over fault surfaces (rather than just the maximum slip); (b) refining the locations of microseismic events; (c) conducting large-scale controlled experiments on in-situ faults; (d) characterizing the spatial distribution of fractures along faults (e.g., by back-mining); (e) performing dynamic experiments to evaluate the formation and strength of fault gouge and pseudotachylyte; (f) characterizing the shape of fault surfaces at different scales using laser scanning and differential geometry; and (g) modeling faults mechanically as part of an interacting system rather than as isolated structures.