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Mechanical basis for slip along low-angle normal faults

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The existence of active low-angle normal faults is much debated because (1) the classical theory of fault mechanics implies that normal faults are locked when the dip is less than 30° and (2) shallow-dipping extensional fault planes do not produce large earthquakes (M > 5.5). However, a number of field observations suggest that brittle deformation occurs on low-angle normal faults at very shallow dip. To reconcile observations and theory, we use an alternative model of fault reactivation including a thick elasto-plastic frictional fault gouge, and test it at large strain by the mean of 2D mechanical modeling.

When the dilation angle of a thick fault zone is smaller than its friction angle, elastic strain occurs within the fault zone to ensure the compatibility of displacement. This strain results in a rotation of principal stresses within the fault and therefore modifies the effective friction of the fault. In this paper, we demonstrate that a component of compaction of the fault zone leads to a significant drop of the effective friction of LANFs which allows faults with internal friction of 0.3 to slip at dip as low as 20°. In this regime, the thick fault model predicts that deviatoric stress rises with accumulated plastic strain on LANFs, favoring a stable slip regime. These predictions are well supported by seismological observations and geodesy in the Gulf of Corinth.

However, within the rotated state of stress of the fault zone, it is also possible to newly form secondary faults. These smaller faults form in a slip-weakening regime and are to that respect dynamically unstable. Their orientations depend on the dilation angle of the fault zone but in general, they are confined to the width of the fault zone and therefore their size is limited. Therefore, seismic activity on these secondary shears is necessarily of limited magnitude as it is often observed on active LANFs and other weak faults. Finally, the state of stress within the LANFs being close to steady state, the orientation of the instable secondary shear structures is constant in time, which favors the occurrence of multiplets along the shallow-dipping normal fault zone.