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Micromechanical signatures of co-existing fracture and flow in naturally deformed rocks

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The origin of coeval fracture- and flow-related features remains ambiguous, especially within the deeper crust and mantle. As a first step to unraveling this ambiguity, a process-free definition of these contrasting phenomena is necessary. The final state of nominally brittle phenomena observed in nature can be generally defined as discrete surfaces or narrow zones across which fast particle displacements (shear) have occurred, with or without dilatant behaviour; this descriptively meets the criteria for generation of earthquakes. Likewise, ductile flow is a priori associated with slower particle velocities. This reduces the problem to one of how rocks cycle between slow and fast displacements without invoking any first-order reliance on deformation mechanism. Disputes over the origin of this contrasting behaviour resides in characterization of the precursor material state of the rocks; that is, is all fast displacement (fracture) wholly brittle, hence pressure-dependent, or can fast displacements evolve from an ambient ductile flow? In turn, the precursor state will be defined by specific microphysical activity. Particle displacement in the solid-state is limited to three processes: diffusion of individual atoms, glide of packets of atoms and frictional displacement across an essentially free surface. Each of these processes, however large the feature being studied or rapid the displacements, necessitates the sequential overcoming of extant atomic bonding energies. It is argued based on observations from natural examples that paleo-seismic phenomena evolve not only from formation of classic fractures, but also from high-strain-rate zones of intense crystal plastic deformation characteristic of thermal-mechanical runaway. In the final stages of acceleration, it may become moot as to whether the "fracture" is brittle or ductile. Depending on lithology, such behaviour can occur at different crustal levels within windows of transient flow. Because of the overprinting impressed by large displacements, the origin of many individual examples of seismic failure in ductile regimes may remain difficult to establish.