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Stress barriers, distal weakening, and their effect on seismic rupture: Applications to Enhanced Geothermal Systems



Open-access
Paper

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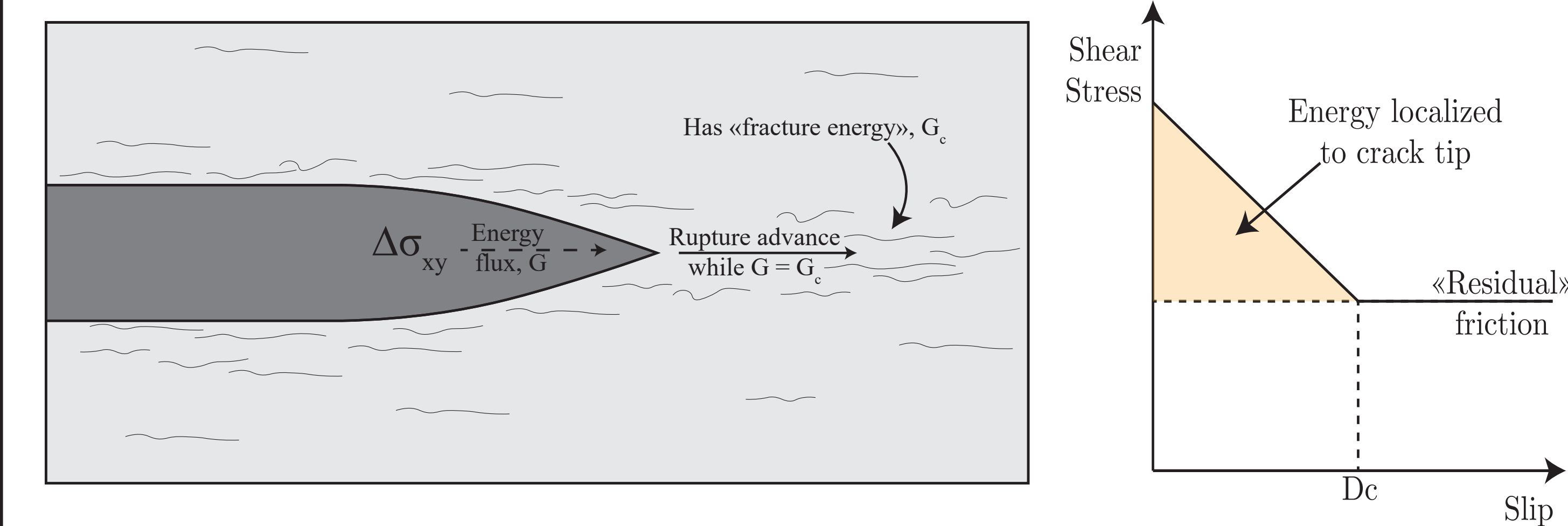
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Summary

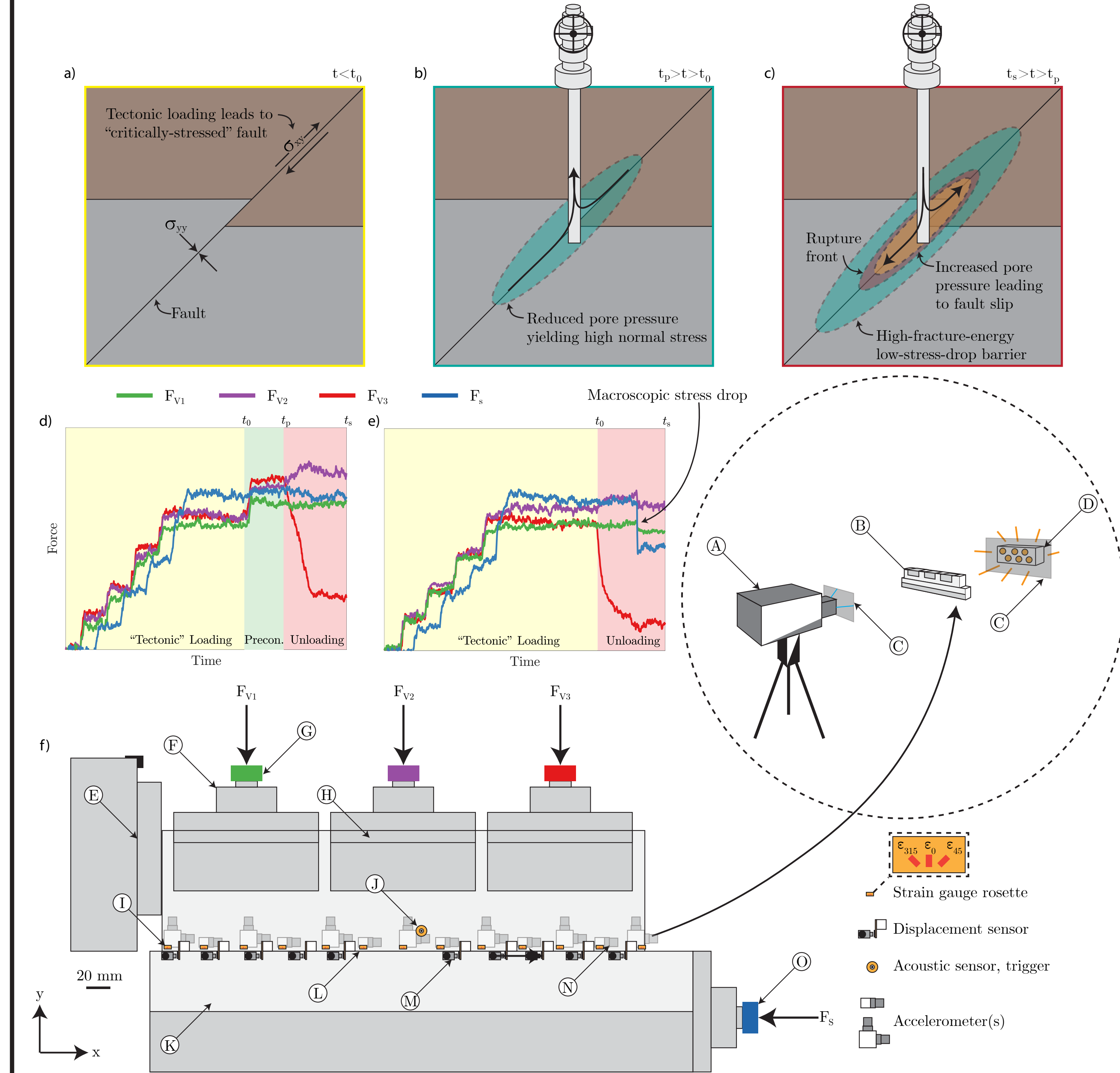
Whether or not energy dissipation is localized in the vicinity of the rupture tip, and whether any distal energy dissipation far from the crack tip has a significant influence on rupture dynamics are key questions in the description of frictional ruptures. These questions are investigated experimentally. The ruptures in these experiments are found to be driven by unconventional singularities, characterized by an ever-increasing breakdown work with slip. As the experimental stress barriers here inhibit slip, they therefore also reduce the breakdown work occurring outside of the cohesive zone. It is shown that this distal weakening, far from the crack tip, must be considered for the accurate prediction of rupture arrest length. These experiments are performed in the context of a proposed stimulation technique for Enhanced Geothermal Systems (EGSs). It has previously been suggested, through theoretical arguments, that stress barriers could be induced through the manipulation of pore pressure such that there is reduced seismic hazard during the shear stimulation of EGSs. This stimulation technique, known as preconditioning, is demonstrated here to reduce the mechanical energy flux to the crack tip, G , while also increasing the fracture energy, G_c . Preconditioning is shown to be capable of arresting seismic rupture and reducing co-seismic slip, slip velocity, and seismic moment at preconditioning stresses which are reasonably achievable in the field. Due to the fully-coupled nature of seismic rupture and fault slip, preconditioning also reduces distal weakening and its contribution to the propagation of induced seismic ruptures.



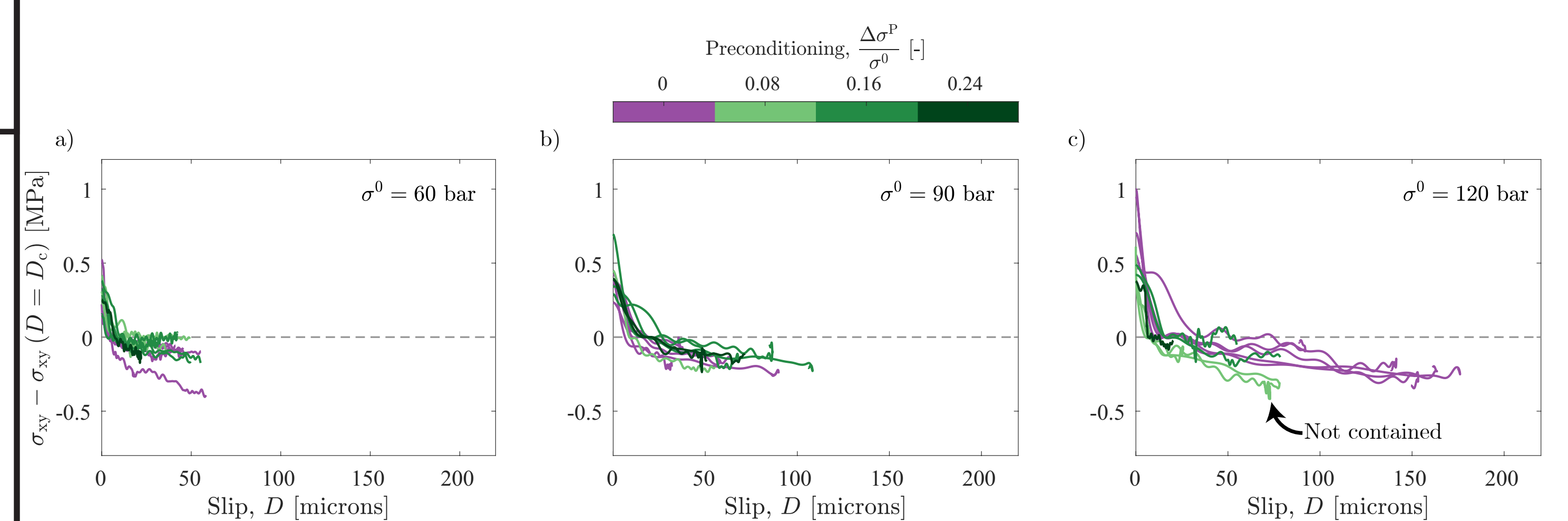
Methods

In order to test the influence of stress barriers, both those created in the context of preconditioning (a-c) and those found in nature, a biaxial apparatus with PMMA plates is used. The apparatus (f) is loaded with three independent pistons providing a normal load and one piston providing a shear load. The sample is loaded to be critically stressed. Then, one normal-load piston is unloaded, simulating injection (d). A seismic rupture nucleates under this piston and propagates through the «high» stress regions under the other two normal pistons. The stress changes caused by this rupture are measured by strain gauges (2 MHz), while the local dynamic slip is

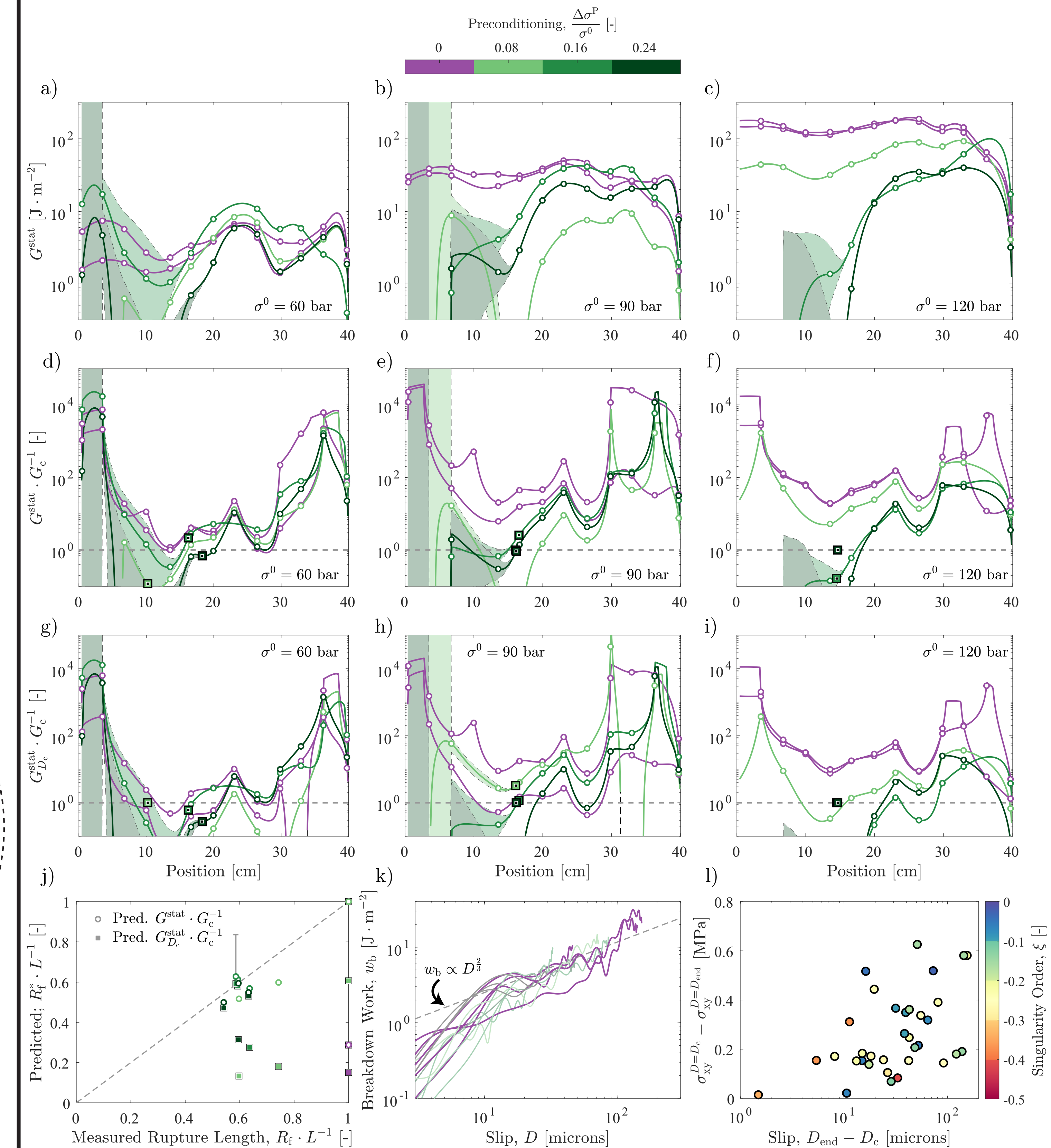
found from accelerometers (2 MHz). The rupture is traced used a high-speed camera (500 kHz) and the photoelastic properties of PMMA. To alter the size of the stress barrier, the load applied by the normal pistons is increased by a given amount after the fault has been loaded to criticality (e). The size of this stress barrier is presented as the amount of «preconditioning»: 0 is no stress barrier, 0.24 is a large stress barrier.



Results



In the above figure, the weakening at various strain gauge rosettes along the fault is shown for experiments at (a) 60, (b) 90, and (c) 120 bar nominal normal stress. The horizontal dashed line corresponds to the stress drop when the slip is equivalent to D_c . However, weakening continues after this point. Does this weakening influence arrest?



In the above figure, the energy flux to the crack tip is estimated using the full stress drop (a-c). This provides reliable predictions (d-f, j) of the rupture arrest length when compared to the fracture energy, G_c . Conversely, when the stress drop is only considered to influence rupture arrest up to a slip of D_c , the approach under predicts the rupture arrest length (g-i, j). This implies that the continued accumulation of breakdown work after a slip of D_c (k), which leads to unconventional singularity orders (l), influences rupture arrest. This implies that there is no separation of scale, indicating a scale dependence of seismic rupture.

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