The influence of fluid pressure on the phase transition of brittle faulting

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1 Introduction

Earthquakes and the failure of geomaterials have been noted to entail the **gradual localization of damage**. These systems have been studied through the concept of a **critical point** whereby ruptures show **scale-free statistics** that indicate a **predictable transition to failure**. Here, with an innovation of laboratory technology, we aim to investigate the **transition associated with precursory deformation** by accounting **the effect of fluid under pressure**.

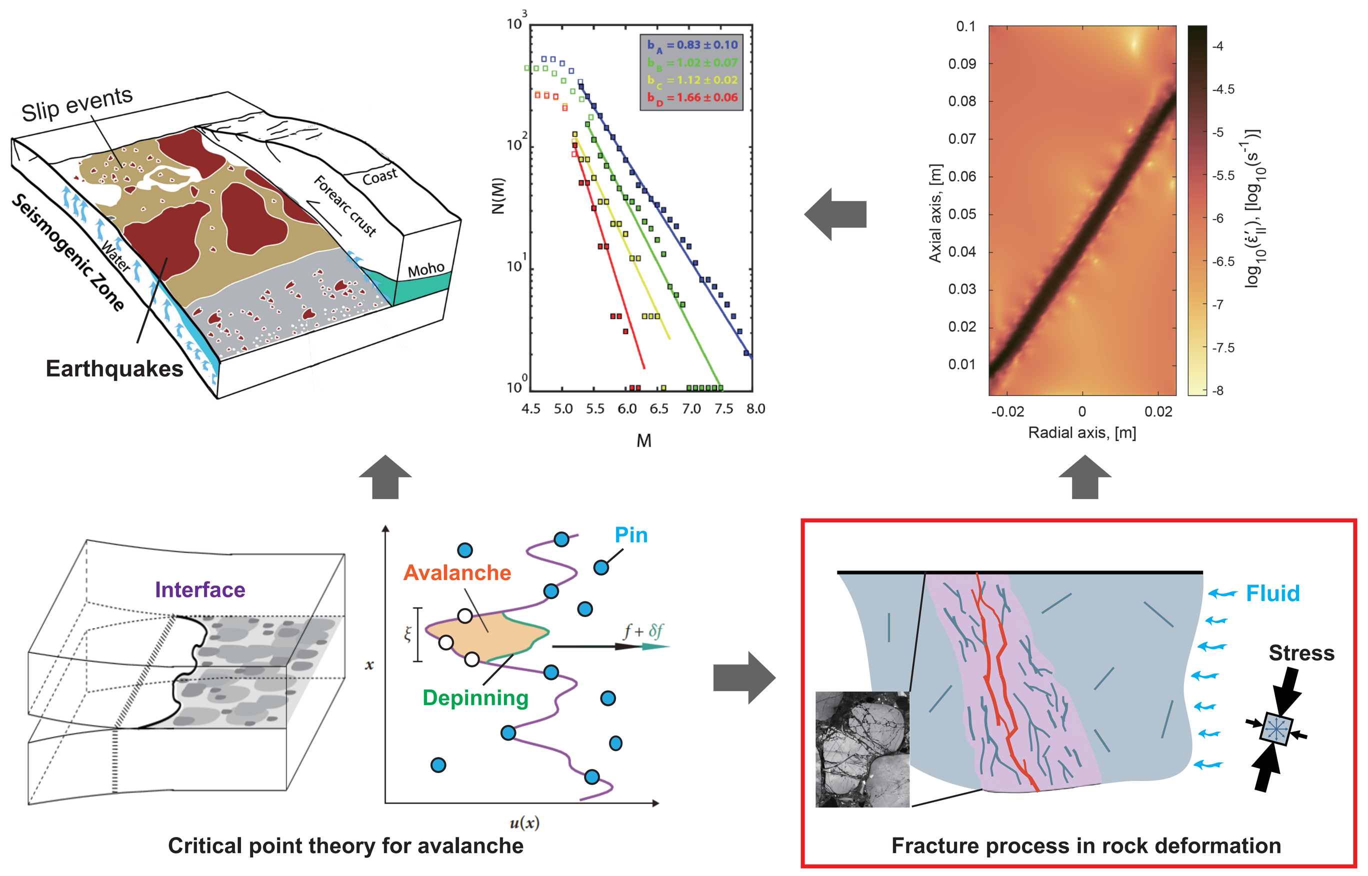

Fig 1. Conceptual diagram summarizing the rupture process at different scales within the framwork of critical point theory.

2 Methodology

We performed triaxial experiments on Berea sandstone at a pore fluid pressure **P_f = 0 MPa (dry), 5 MPa and 10 MPa**. The **distributed strain sensing (DSS)** based on optical fiber was implemented on the sample to measure the evolution of the strain field.

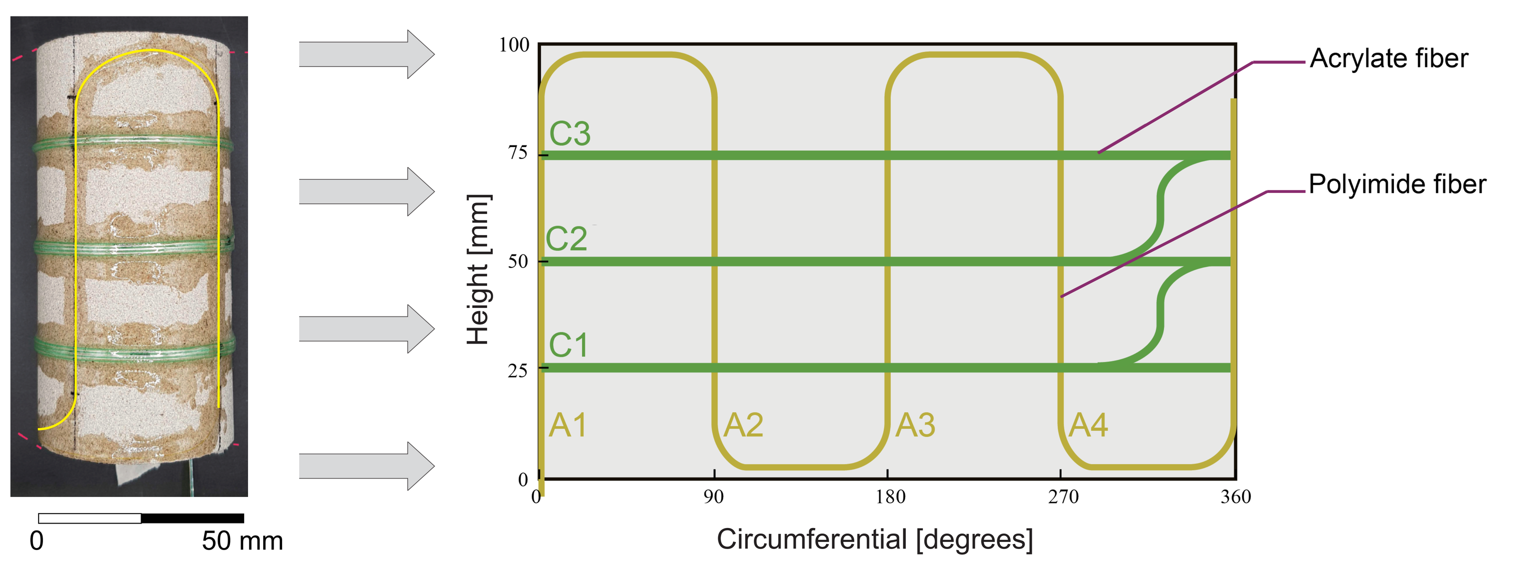

Fig 2. (left) Instrumented sample of Berea sandstone. (right) The layout of **DSS** arrays is shown in an unwrapped representation: poliyimide coated fiber (yellow) in the axial direction and acrylate coated fiber (green) in the circumferential direction.

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3 Results

- **Fluid pressure weakens the rock material**: with increasing fluid pressure the samples exhibit a lower elastic modulus and a **prolonged phase of strain softening**.

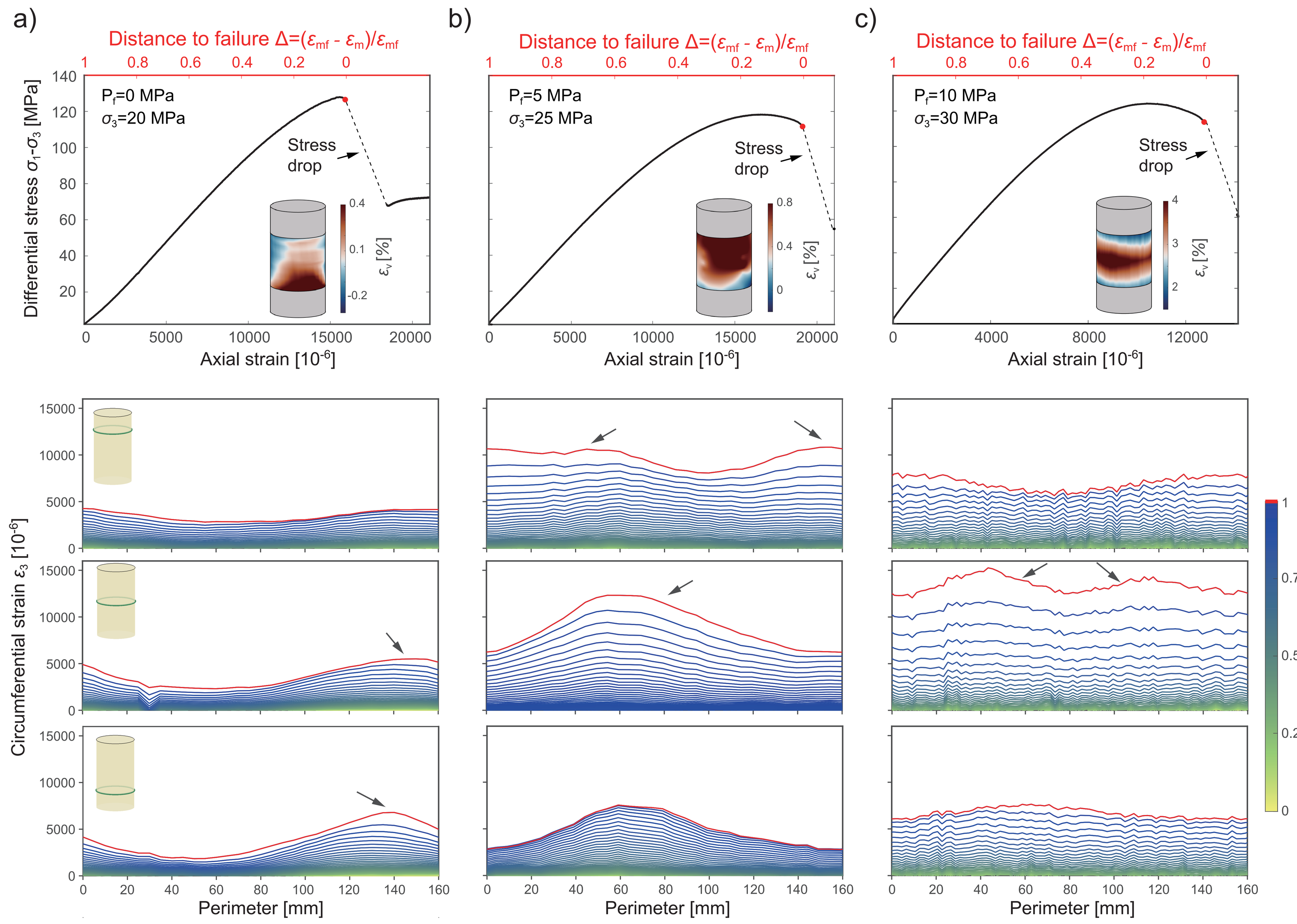

Fig 3. (top) Mechanical data recorded for the three experiments at fluid pressures Pf of (a) 0 MPa, (b) 5 MPa and (c) 10 MPa. The distance to failure is tracked in terms of axial shortening. Insets display the mapping of volumetric strain at failure. (bottom) Spatial-temporal evolution of DSS circumferential strains along each of the three DSS cables.

- Distributed strain fields capture how **deformation localizes**: large strain clusters **develop rapidly near the final fault plane** as failure approaches, corresponding to a decrease in elastic modulus.
- **Pore pressure influences the microcracks mechanisms**: higher fluid pressure leads to **more diffuse deformation**, resulting in larger overall circumferential strain.

References

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4 Scaling analysis of strain increments

- **Distribution of the strain increments** follows a **power law truncated by a cutoff** at large values.
- The slope of distribution (**left columns**) decreases as failure approaches under dry conditions whereas it remains constant in the presence of fluid.
- **Largest strain increment** (**right columns**) exhibits a **power law approach to failure under dry conditions** and an **exponential approach under wet conditions.**

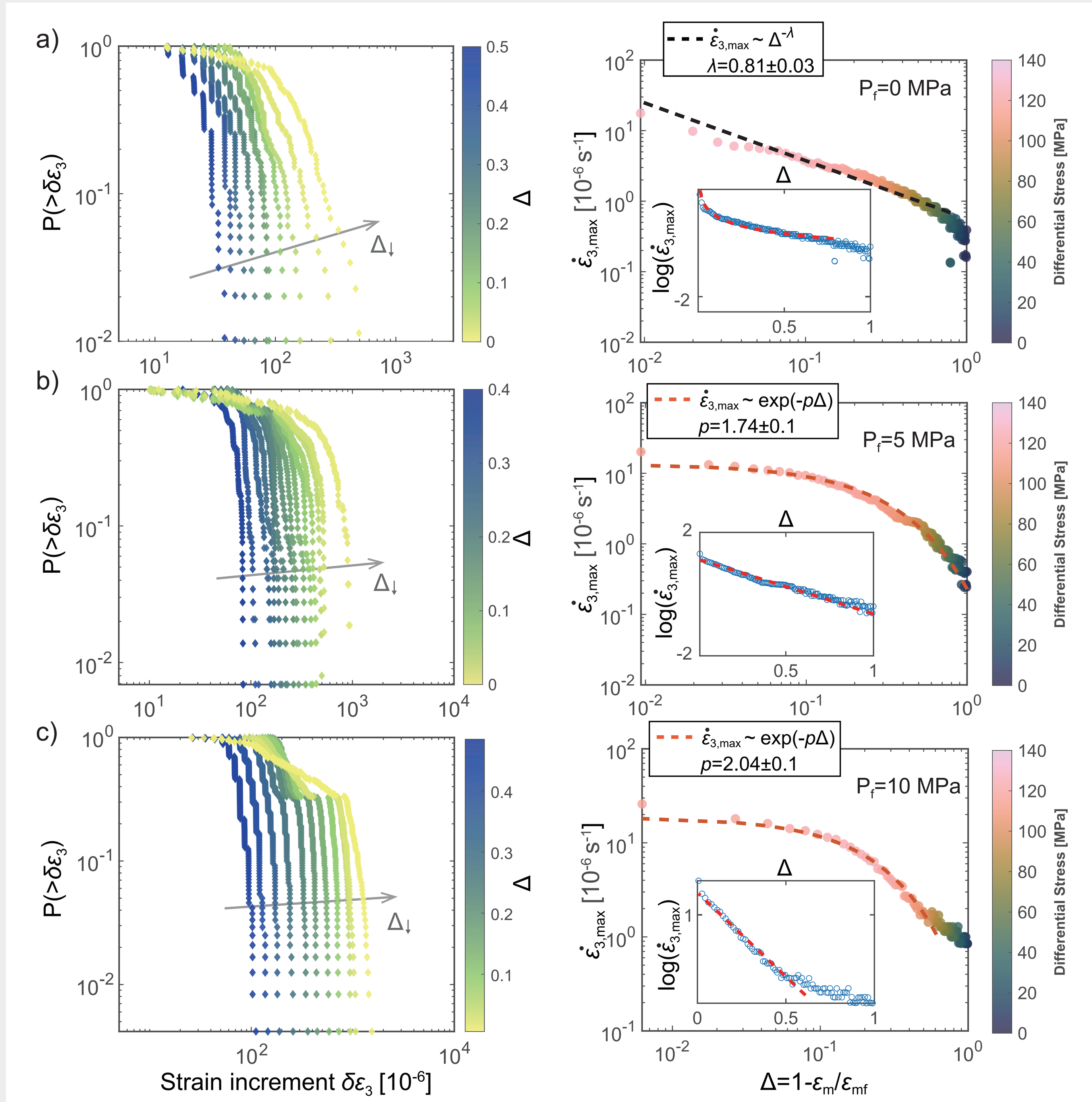

Fig 4. (left) Evolution of the distribution of strain increments for the three experiments. (right) Evolution wirh the largest strain increment towards failure. The dashed line show the best fits accoring to the power-law or exponential model. Insets show the same data on a semi-logarithmic scale.

5 Conclusion

1. Distributed strain measurements reveal precursory signals indicating the transition to catastrophic failure. The power law distribution of strain increments suggests a **critical transition under dry conditions**, allowing for **the identification of failure in advance**.

2. **Fluid inhibits the coalescence of cracks** into large clusters but promotes the growth of smaller damage, resulting in **diffuse, slow faulting**. This stabilization effect shifts the style of phase transition into a **first-order, unpredictable event.**