Mechanisms of Fracture Growth in Sandstones and Granite Insights using the Discrete Element Method

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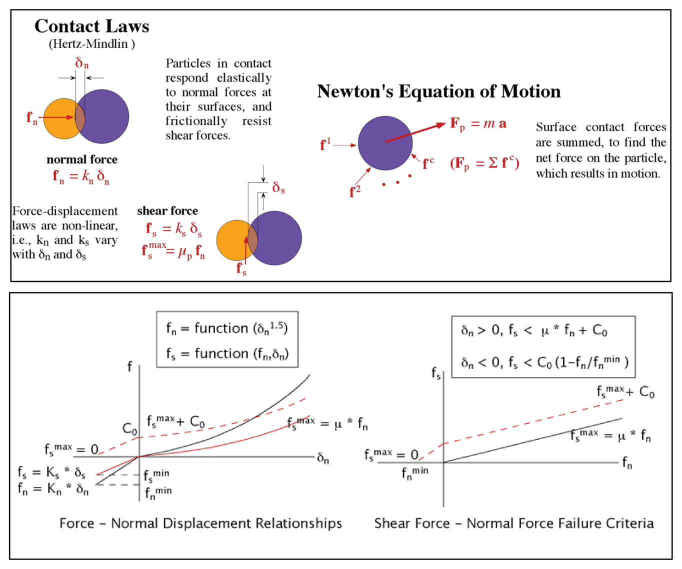
Objective

We analyze the progressive localization of microcracks to :

- **Understand fracture growth mechanisms in sandstone and granite**
- **Analyze the effect of confining pressure on fracture growth**
- **Predict the onset of fractures using seismic signatures**

Discrete Element Method

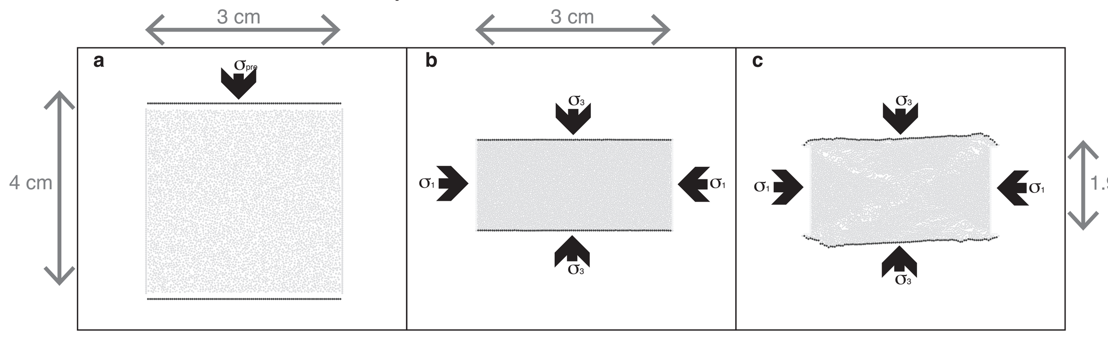
- Construct geologic medium as assemblage of simple particles – disks or spheres
- Apply physical properties to particles: Contact friction, elastic properties
- Implement interparticle bonds to simulate cohesion, which can fail under normal, shear, and rotational stresses
- Resolve forces onto particles and track resultant motion



Model Setup and Methods

1. Setup biaxial experimental setup

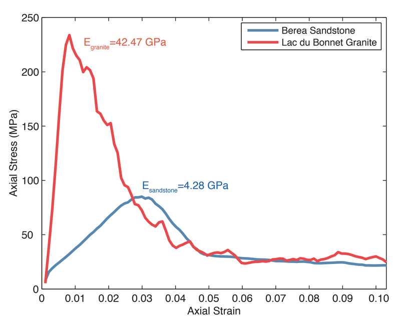
- Domain size: 0.12m x 0.06 m
- 3240 particles with radius of 300 μm
- 2700 particles with radius of 400 μm
- Preconsolidate each sample to 10 MPa

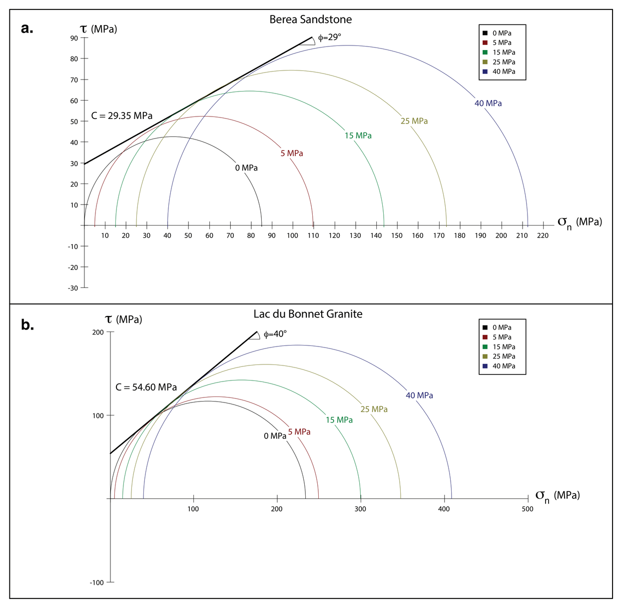


2. Conduct Biaxial Compression Tests under 0 - 50 MPa confinement

3. Calibrate Bulk Physical Properties of Sandstone and Granite

- Unconfined Strength (UCS)
- Young's Modulus
- Mohr-Coulomb Envelope



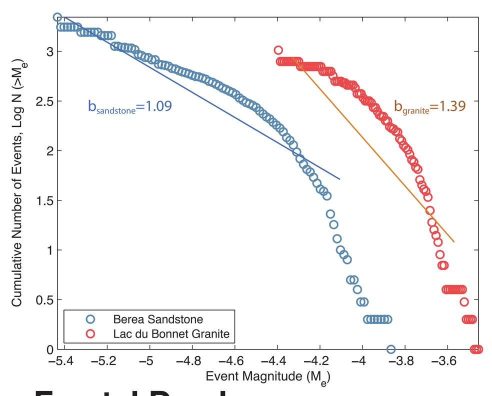


4. Quantify Fracture Energy using Acoustic Emissions and b-value

$E_f = (½)*(\sigma_{cf}^2 v_f / C_f)$

$M_e = (⅔)\log_{10}E_f - 2.9$

E_f : Energy of microcrack
C_f : Elastic Modulus of particle
σ_{cf} : Peak strength of element
v_f : Volume of microcrack
M_e : Seismic moment



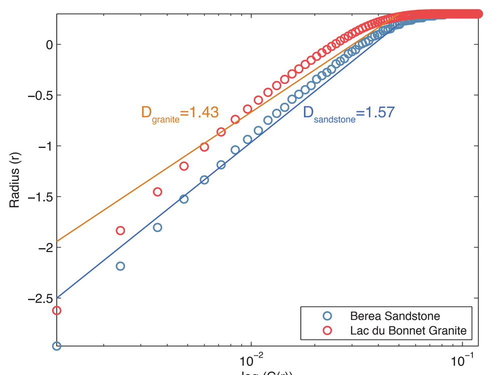
5. Quantify Microcrack distribution using Fractal D-value

$C(R) = 2N_{(r<R)} / N(N-1)$

$C(R) \alpha R^D$

D : Fractal Dimension
N : Number of microcrack pairs
R : Radial distance (m)

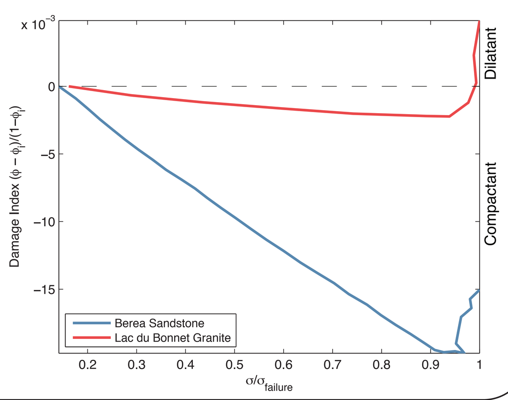
Low D-values: Localizaed microcracking
High D-value: Distributed microcracking



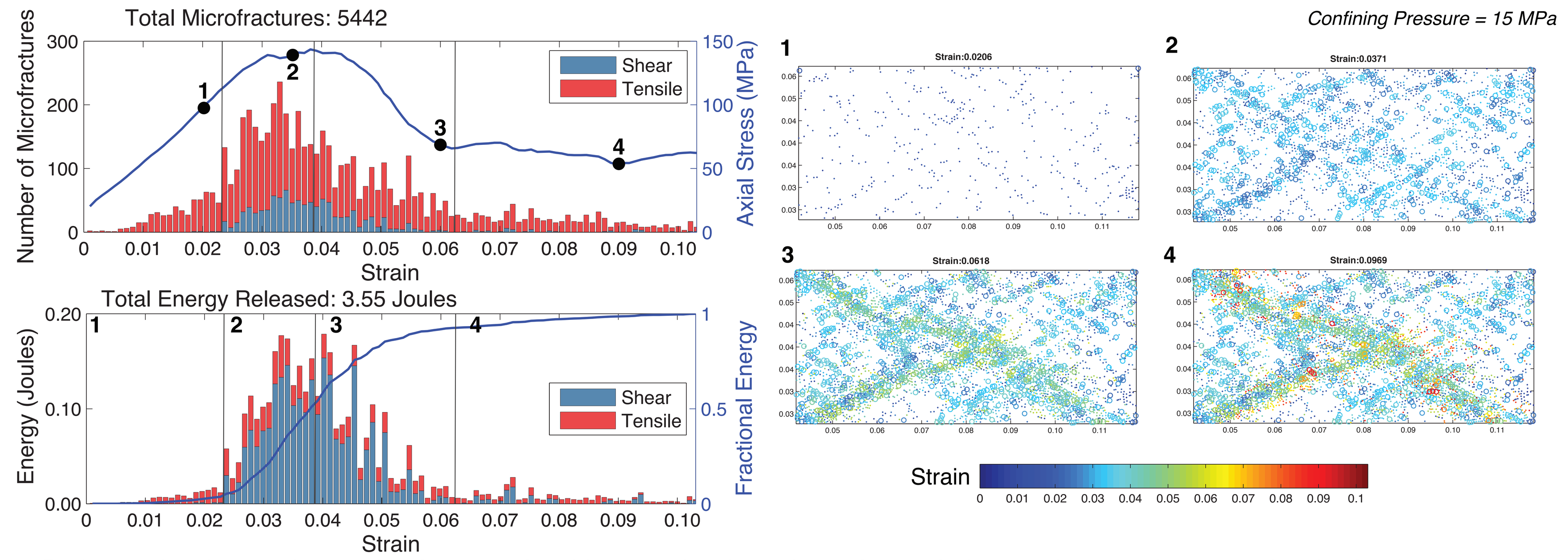
6. Quantify Damage using Porosity

$DI = (\Phi - \Phi_i) / (1 - \Phi)$

DI : Damage Index
Φ : Porosity
Φ_i : Initial Porosity (0.17)

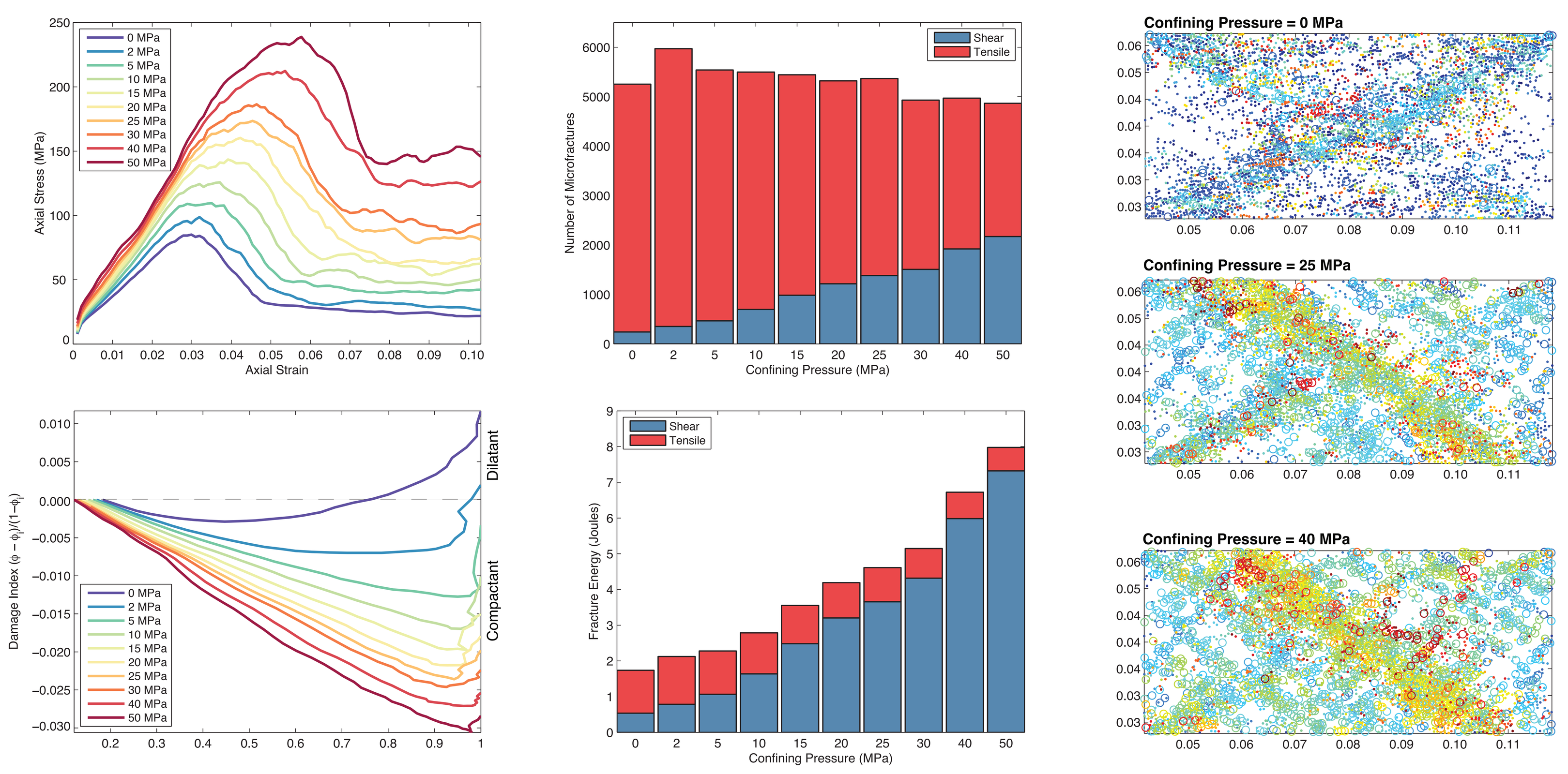


Fracturing in Berea Sandstone



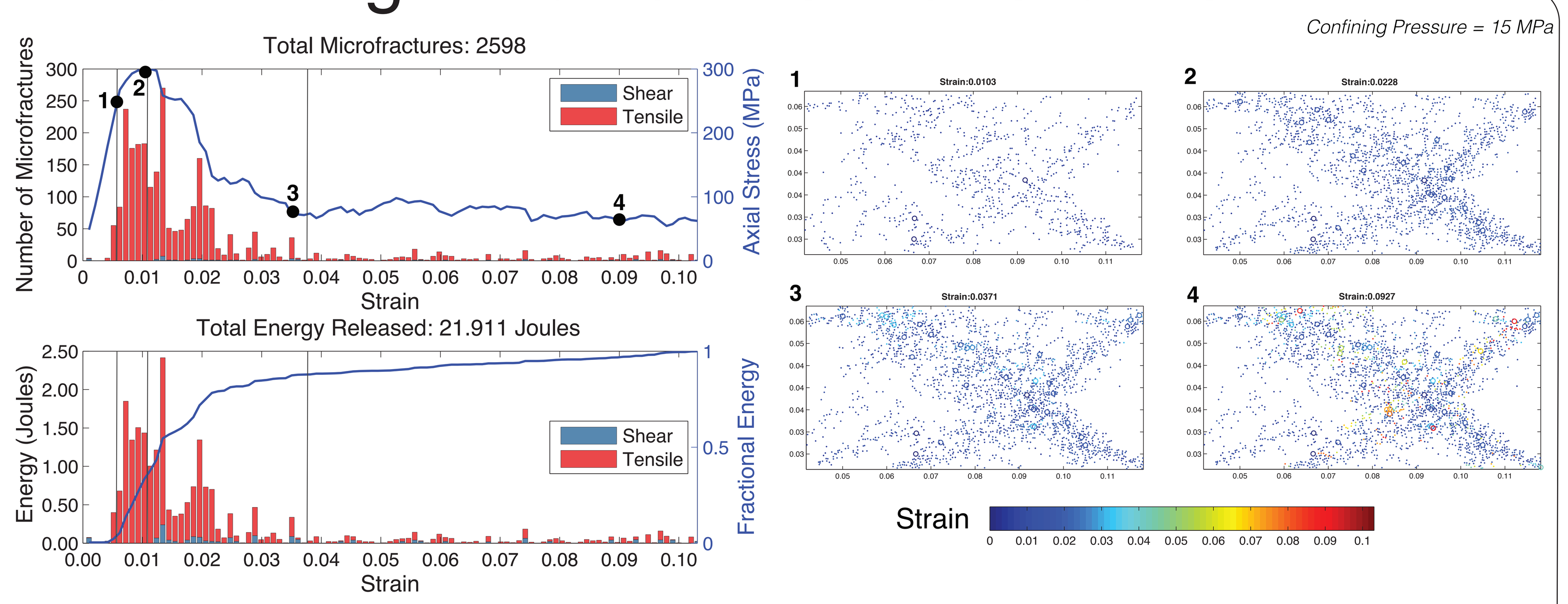
Deformation in sandstone is characterized by localization of tensile and shear microcracks, resulting in the formation of a dilatant fracture zone at low confining pressures

Effect of Confining Pressure



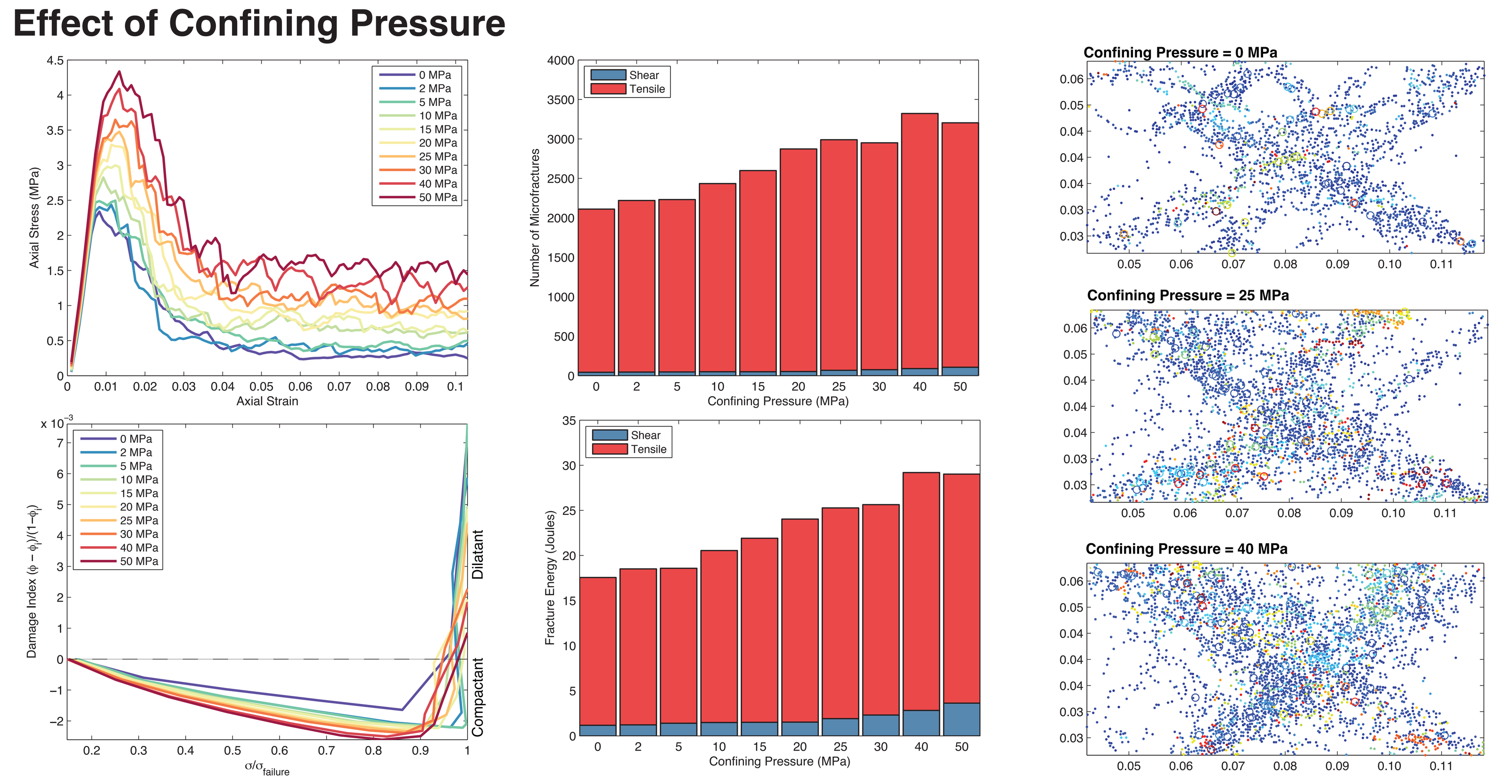
- Microcracking activity remains constant with confining pressure, transitioning from tensile to shear mode
- Fracture zone is characterized by compactant character from increasing shear microcracking with confining pressure

Fracturing in Lac du Bonnet Granite



Deformation in granite is characterized by localization of tensile microcracks, resulting in the formation of a dilatant fracture zone

Effect of Confining Pressure



- Microcracking activity increases with confining pressure, occuring dominantly in tensile mode.
- Fracture zone is characterized by dilatant character from tensile microcracks, which declines with confining pressure

References

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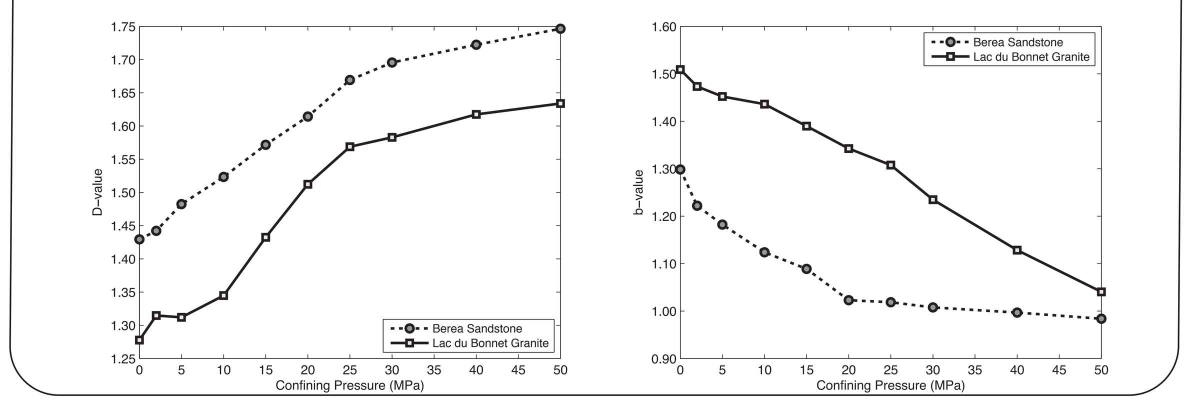
Effect of Confining Pressure

As confining pressure on rock increases:

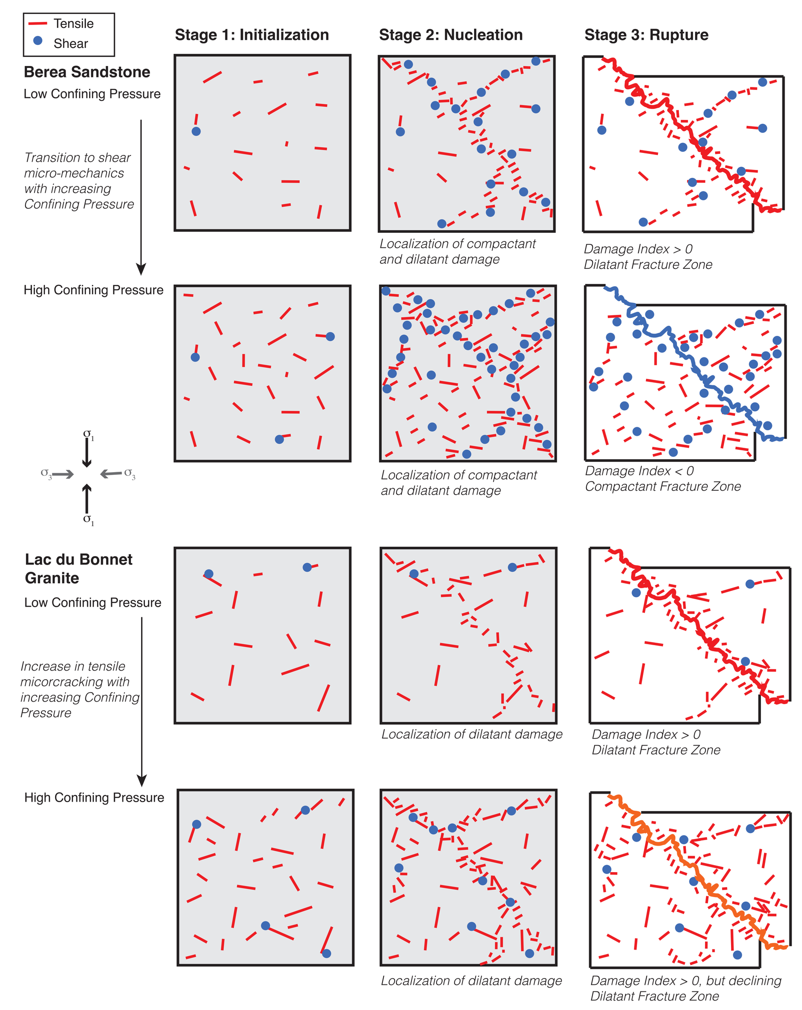
- Distribution of microcracks increases: larger fractal D-values
- Distribution of Moment Magnitudes decreases: declining b-values



Conclusions

1. Fracturing in sandstone is characterized by tensile and shear microcracks
- **Increase in confining pressure results in transition to shear dominated micro-mechanics**

2. Fracturing in granite is dominated by tensile microcracks
- **Increase in confining pressure results in greater tensile microcracking activity**

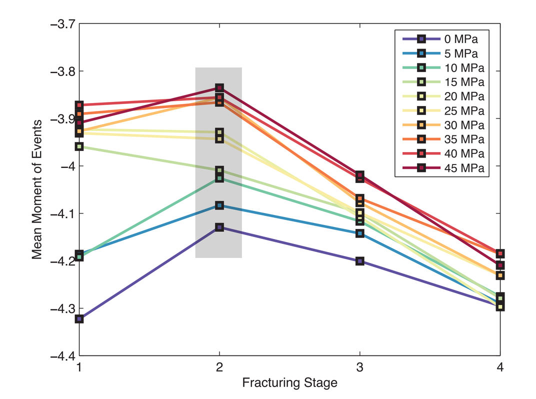


3. Increase in confining pressure on rock results in
- **Greater spatial distribution of microcracks**
- **Range of seismic moments decreases**

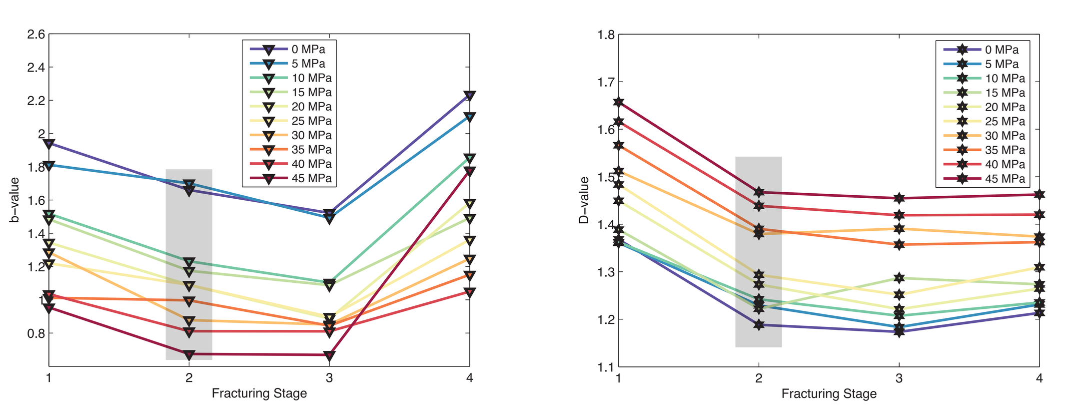
Predicting Fractures

Temporal Analysis of baxial experiments yields distinct precursory characteristics for critical point fracturing in brittle rocks:

- Rapid increase in microcracking and seismic activity
- Onset of shear microcracking, occuring in process zone of fracture
- Increase in mean moment magnitue of microcracks
- Decline in range of moment magnitude of microcracks



- Sharp decline in seismic b-values and fractal D-values



Future Work: Apply Machine Learning techniques on precursory seismic signatures to predict:

- Critical point for failure in rock
- Stress state (confining pressure) on rock
- Sensitivity of calculated precursory signatures