Large-Volume Stimulation of Rock for Greatly Enhanced Fluids Recovery Using Targeted Seismic-Assisted Hydraulic Fracturing

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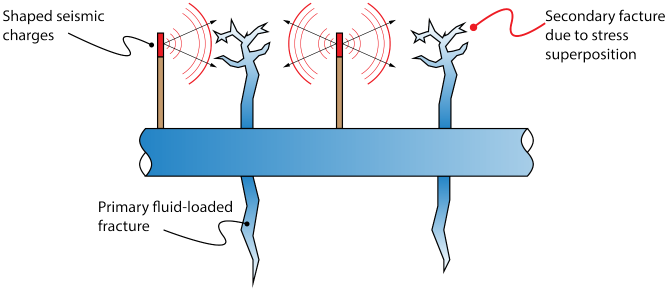
Goals and Objectives—I

Overall Project Goal

Develop and demonstrate a new technology for large-volume and targeted comminution of rock in low permeability formations to enhance recovery from unconventional oil and gas resources.

The technology is based on a strategically designed interaction of multiple induced seismic pulses that assist the hydraulic fracturing process to enhance shear and multi-planar crack formation.



Goals and Objectives—II

Objectives

To develop and demonstrate the proposed technology, this project will investigate two aspects of multi-source excitation:

- superposition of multiple sources of stress wave excitation with each other to generate dynamic stresses large enough to cause rock failure.
- interaction of dynamic stress wave loading with the main hydraulic-fluid pressurized crack to cause transitions from mode I (opening) to mode II (shear) and mode III (non-planar) failure.

Goals and Objectives—III

Research Focus: Year 01

1. development of damage, permeability, and porosity models based on realistic conditions of failure under constraint and dynamic loading rate
2. development and validation of a continuum numerical simulation model for fully-coupled hydrodynamic response and failure

Research Focus: Year 02

development of rock stimulation technology by multi-source excitation

Research Focus: Year 03

demonstration of the multi-source technology using lab-scale field experiments.

Cardinal and Timely Importance

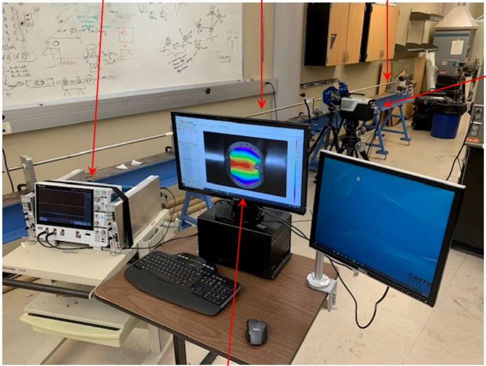
- Realities of UOG resource development using hydraulic fracturing:
  - Recovery efficiency on the order of 10%.
  - Three toggles: spacing, injectant rheology, and production choke management.
  - EOR shows promise, but is invariably limited to immediate vicinity of fractures.
- Constraints on UOG resource development in the US:
  - Space is becoming limited as infill drilling continues.
  - What was done in the past was done: cannot undo a fracturing job.
  - Focus on rate-of-return (leveraged industry) versus net value.
- To sustain this, we need to access greater volumes of these important resources in a **prudent** and **economic** manner!

High Strain-rate Testing Setup

Oscilloscope to Measure Dynamic impulse waves

Incident bar

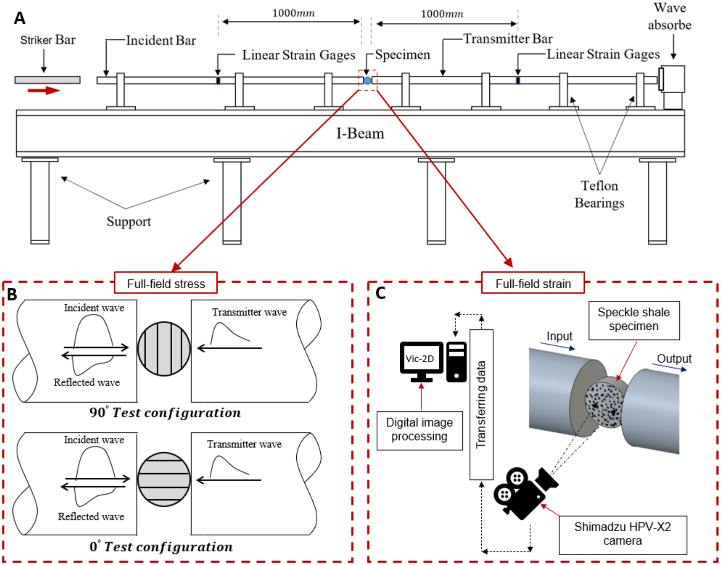
Transmitted bar



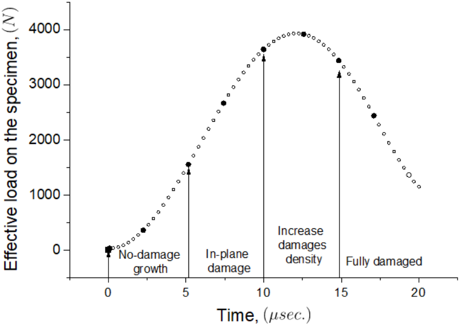
HPV-X2 High-Speed Camera (Up to 10,000,000 fps)

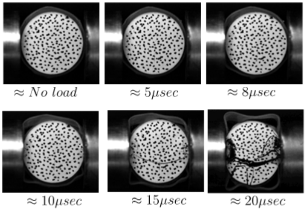
Vic-3D software from Correlation Solutions Inc. DIC used to capture the full-field deformation response

Schematic of Overall Experimental Setup



Damage Progression in Rother Shale (90 degrees)

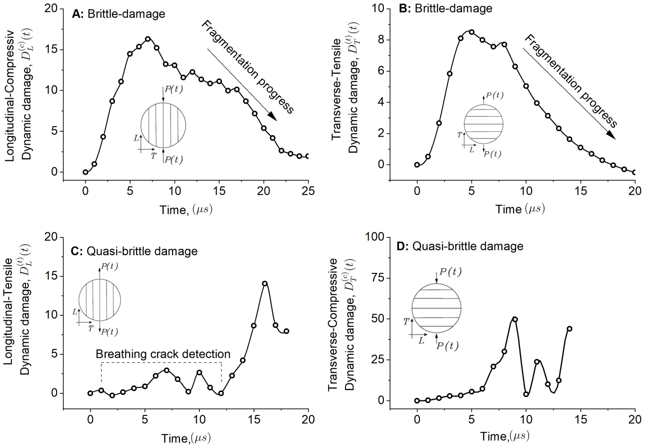




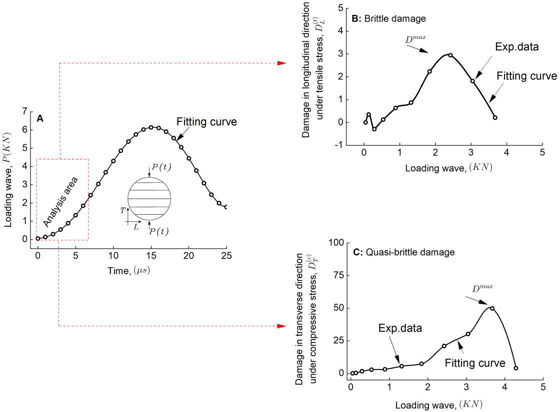
$$e_{xx}(t) = \frac{\sigma_{xx}(t)}{E^o_{xx} D_{xx}(t)} - \frac{\nu^o_{yx}}{E^o_{yy} D_{yy}(t)} \sigma_{yy}(t) \qquad (1)$$

$$e_{yy}(t) = \frac{\sigma_{yy}(t)}{E^o_{yy} D_{yy}(t)} - \frac{\nu^o_{xy}}{E^o_{xx} D_{xx}(t)} \sigma_{xx}(t) \qquad (2)$$

Dynamic Damage Evolution in Rother Shale

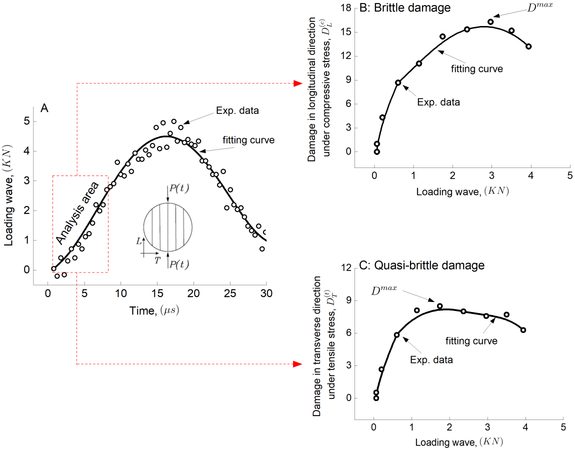


Dynamic Damage vs Time-01



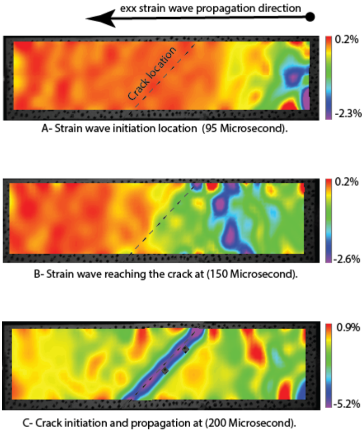
A)Typical Rother shale under transverse-load. B) Damage in longitudinal direction, C) Damage in transverse direction.

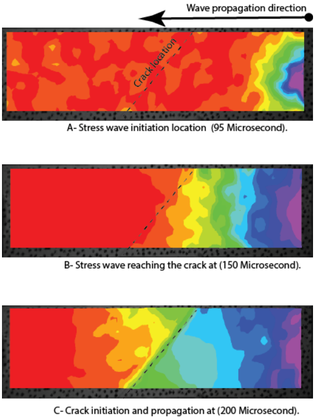
Dynamic Damage vs Time-02



A) Typical Rother shale under longitudinal-load, B) Damage in longitudinal direction, C) Damage in transverse direction

Stress-wave Interactions with Weak Damaged Planes





. F.F. Strain wave, $e_{xx}(t)$ F.F. Displacement wave, $U(t)$

Micro-CT analysis

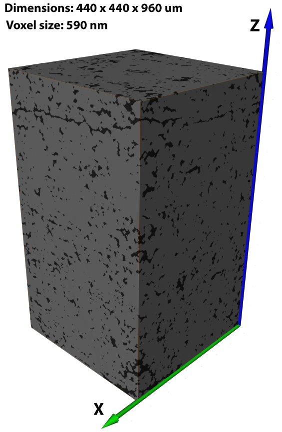
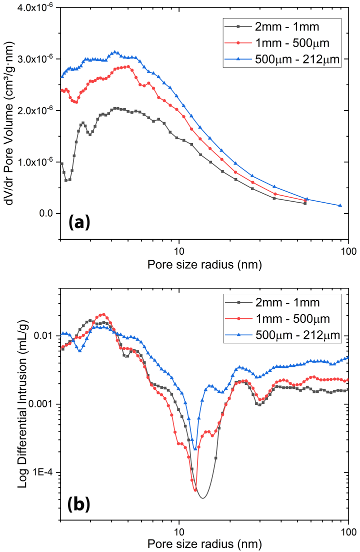


Figure: MicroCT render of Rother shale with segmented pores and cracks

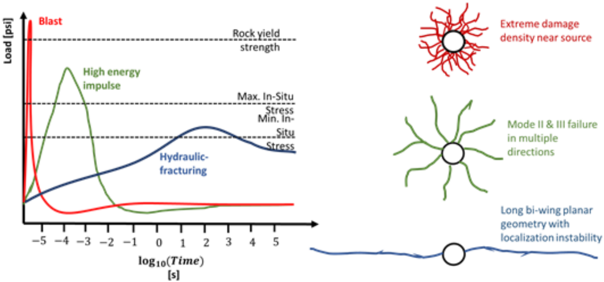
- X-ray micro-CT will be used for non-destructive analysis of pre- and post-cracked shale samples
- Analysis of pore greater than 1μm will be possible
- In Rother-shale pores and cracks contribute to less than 1.5% porosity

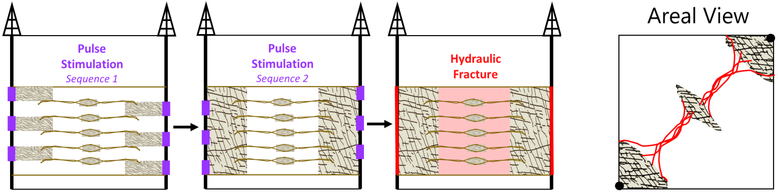
Mercury Intrusion (MIP) vs. Gas Adsorption (GA)



- Pre- and post-cracked disc samples can be studied by MIP; GA requires further reduction in sample size
- Effect of Rother-shale sample-size reduction on pore distribution compared for GA and MIP
- (a) GA: Particle-size reduction increased specific pore volume; no other information on pore-geometry modification is accessible
- (b) MIP: Enhanced pore access (geometry) observed with particle size reduction; negligible change in overall pore-volume
- Conclusion: MIP will be the method for analysis of pores (3-300000 nm) in pre- and post-cracked samples

Prospects as a disruptive engineering technology





Modelling to test major hypotheses: the model

Developed high-resolution numerical simulation model capable of:

- Coupled poroelasticity and multiphase flow with discrete and continuum damage representations
- Hydraulic-fracture propagation with complete representation of matrix and fracture
- Explicit fracture closure, opening, and tangential slip
- Full treatment of time-dependent mechanics (seismic deformation)
- Incorporate continuum damage time evolution with damage dependent constitutive models

G. Ren et al., "A Model for coupled geomechanics and multiphase flow in fractured porous media using embedded meshes", Adv. in Wat. Res., 122:pp113-130 (2019)

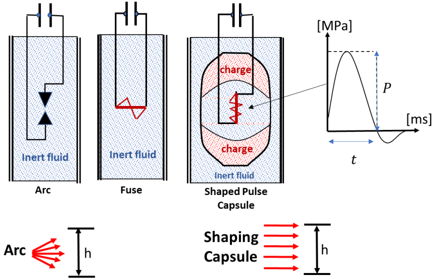
G. Ren and R.M. Younis, "An integrated numerical model for coupled poro-hydro-mechanics and fracture propagation using embedded meshes", Comp. Meth. in Appl. Mech. and Eng. 376, (2021)

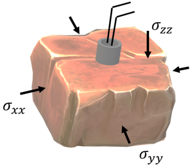
G. Ren and R.M. Younis, "A Quasi-Newton method for physically-admissible simulation of Poiseuille flow under fracture propagation", in review.

G. Ren and R.M. Younis, "Efficient co-solution of time-step size and independent state in fluid-driven fracture propagation simulation using embedded meshes", in review.

Z. Han et al., "A model for unified fractured reservoir and seismic simulation enabled by adaptive time stepping", in review.

Modelling to test major hypotheses: canonical problem 1





$$\Pi_1 = \frac{v_p}{vs}$$

$$\Pi_2 = \frac{p}{E}$$

$$\Pi_3 = \frac{\sigma_t}{E}$$

$$\Pi_4 = \frac{\sigma_c}{E}$$

$$\Pi_5 = \frac{h}{vs \cdot t}$$

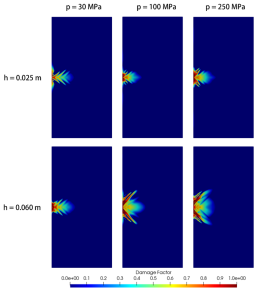
$$v_p = \sqrt{\frac{E\,(1-\nu)}{(1+\nu)\,(1-2\nu)\,\rho}}$$

$$v_s = \sqrt{\frac{E}{2\,(1+\nu)\,\rho}}$$

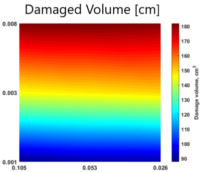
Characterize damage intensity and volume as function of:

- Pulse peak pressure, P
- Pulse duration, t
- Pulse geometry; arc versus planar

Canonical problem 1: results with pulsed-arc

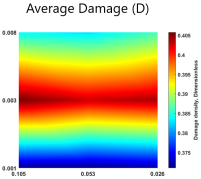


$$\Pi_2 = \frac{p}{E}$$



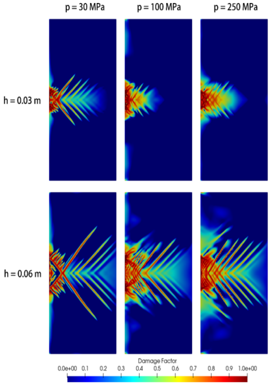
$$\Pi_5 = \frac{h}{v_s t}$$

$$\Pi_2 = \frac{p}{E}$$

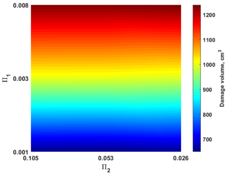


$$\Pi_5 = \frac{h}{v_s t}$$

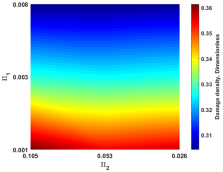
Canonical problem 1: results with shaped charge



Damaged Volume cm



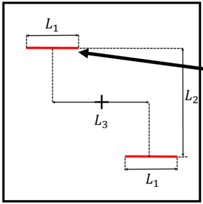
Average Damage, D

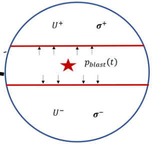


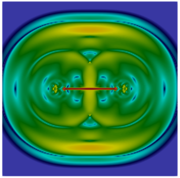
$$\Pi_1 = \frac{p}{E} \qquad \Pi_2 = \frac{h}{v_s t}$$

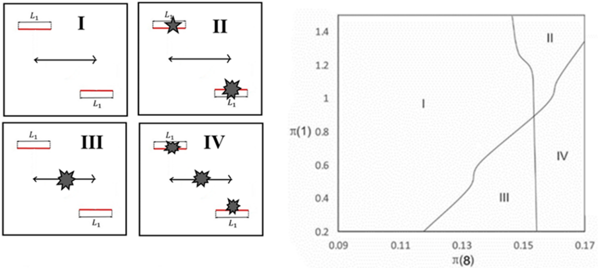
Modelling effort to test major hypotheses: canonical problem 2

R.M. Younis and Y.J. Jing. "A Computational Investigation Of Seismic Wave Focusing As A Novel Means To Fracture Shale Reservoirs." *ECMOR XVI*.

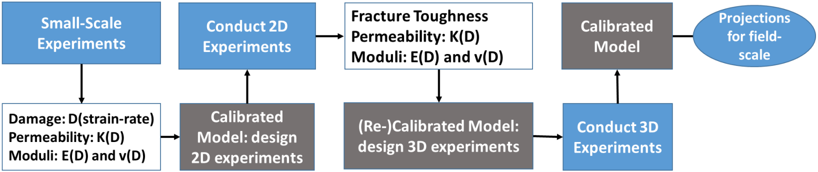








Combined Modeling–Experimental Research Paradigm



Thank you.