RPSEA Unconventional Gas Conference 2011: Technical Keys to Unlocking Additional Reserves

Sustaining Fracture Area and Conductivity of Gas Shale Reservoirs for Enhancing Long-Term Production and Recovery

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RPSEA
Research Partnership to Secure Energy for America

Why This Project ?

Motivation

Over the past ten years there has been a revolution related to gas production from shale reservoirs. Industry analysts estimate shale gas to account for half the natural gas production in North America by 2020.

Challenge

Only a fraction of the wells in tight gas shale reservoirs show sustained long term production. The balance, are characterized by marginal production and fast declining rates.

Theorem

Operational experience leads to the hypothesis that in regions of high reservoir quality (1) loss of fracture conductivity and (2) loss of fracture area are among the main factors leading to marginal production.

Project Goal

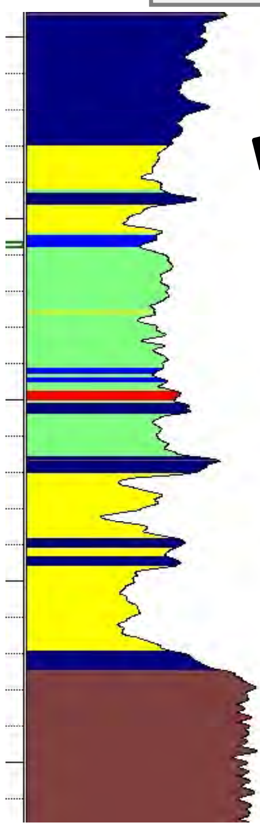
Provide solutions leading to increase production and recoverable gas reserves by targeting three main subjects:

1. **Material characterization**
2. **Loss of productive fracture surface area, and**
3. **Loss in fracture conductivity**

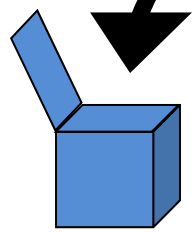
Study conducted on three shale plays: Barnett, Haynesville, and Marcellus

Material Characterization: Rock Quality Index (RQI)

HRA selects rock classes with similar log properties throughout the well



Core data:
- Gas-filled porosity
- Permeability
- TOC
- Fluid saturations
- Maturity

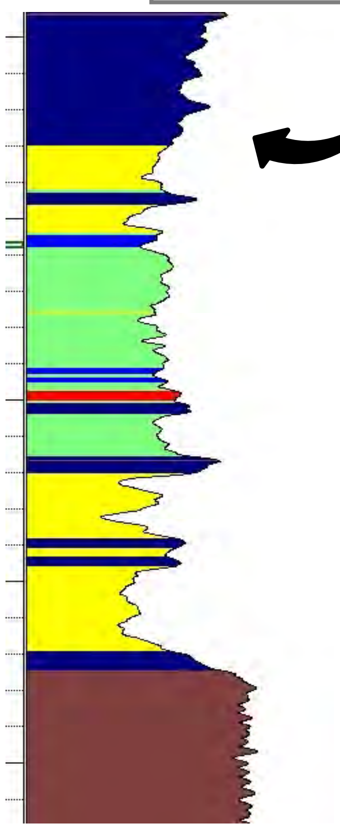


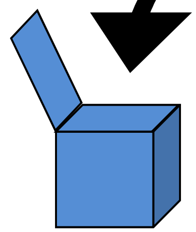
Each rock class classified by its Reservoir Quality Index (CQI)

HRA – Heterogeneous Rock Analysis

Completion Quality Index (CQI)

HRA selects rock classes with similar properties throughout the well





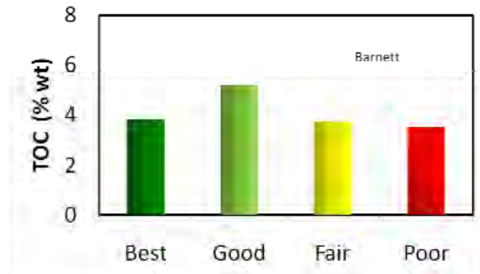
Core data:
- Young's Modulus
- Poisson's Ratio
- In-Situ Stresses
- UCS

Each rock class classified by its Completion Quality Index (CQI)

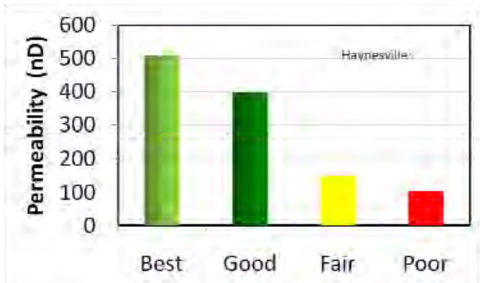
Petrologic Properties

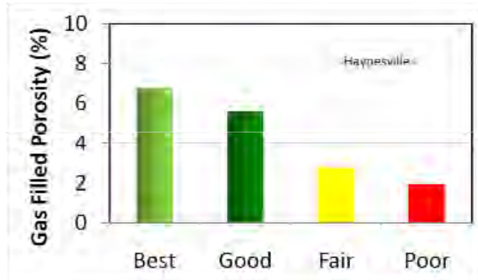
Best
Good
Fair
Poor

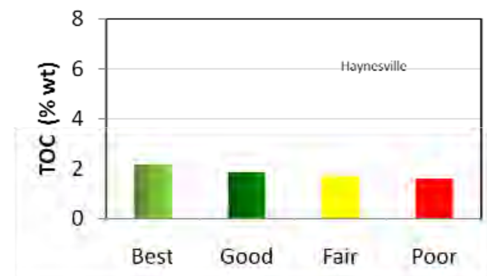
Barnett



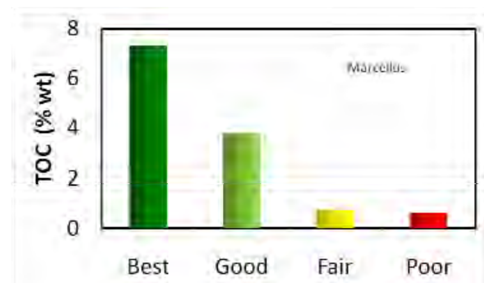
Haynesville





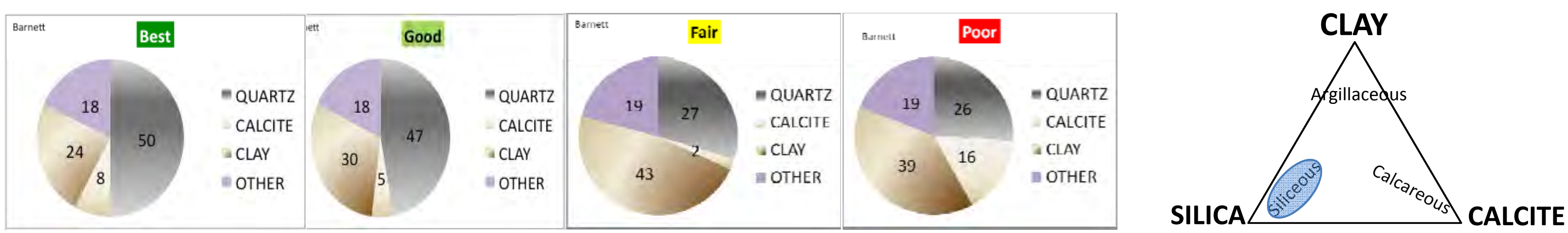


Marcellus

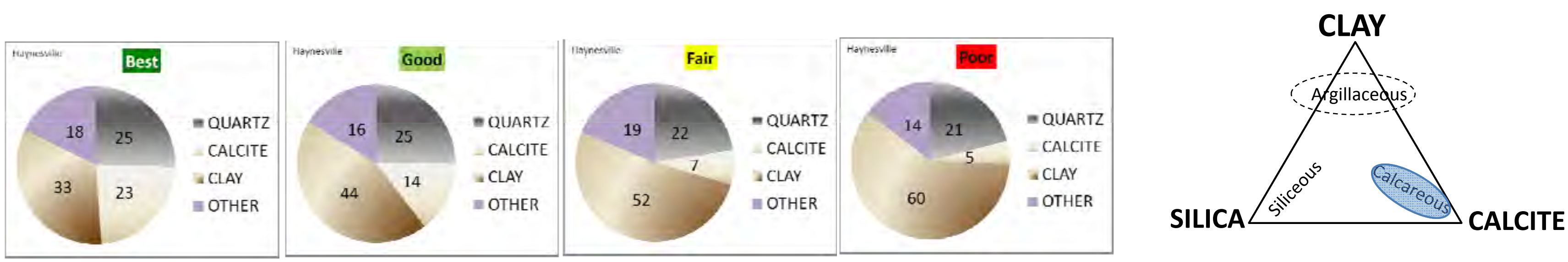


XRD – Matrix Mineralogical Contents

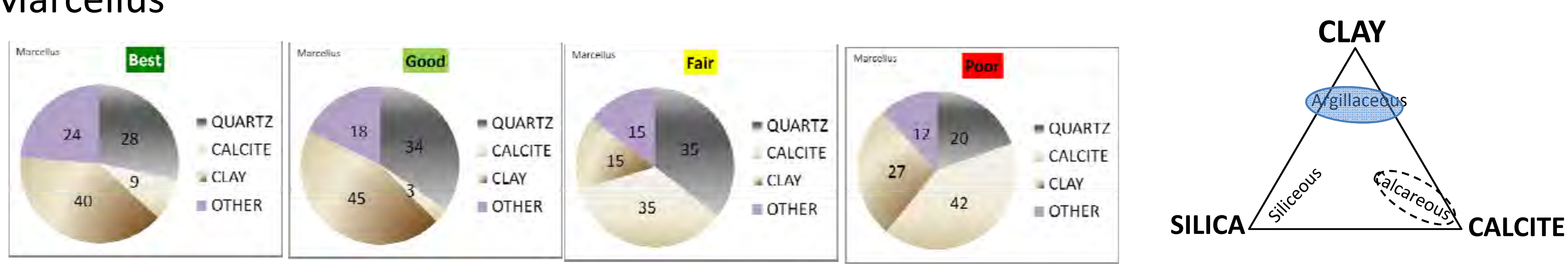
Barnett



Haynesville



Marcellus



Quartz (Grey); Clay (Brown); Calcite (Cream); Other (Purple)

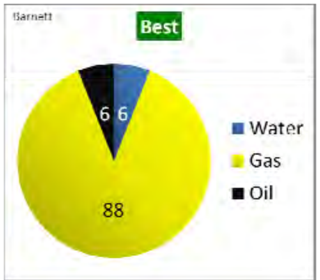
Mobile Fluid Saturations

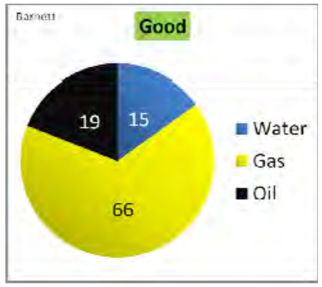
Percentage of Gas

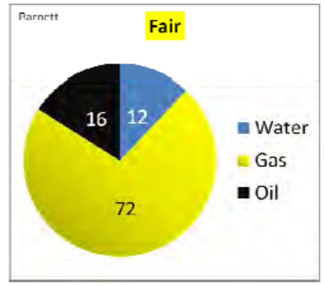
Percentage of Oil

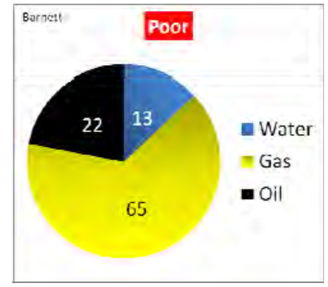
Percentage of Water

Barnett

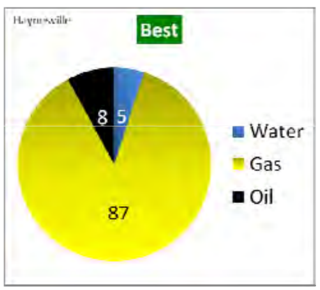


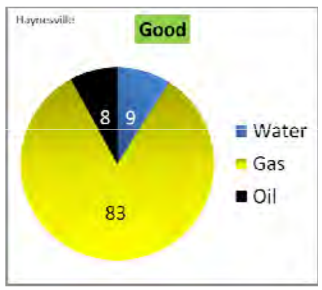


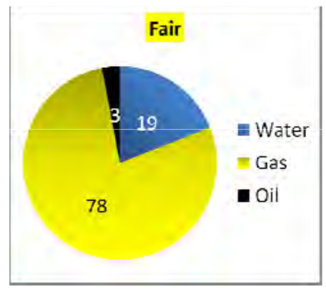


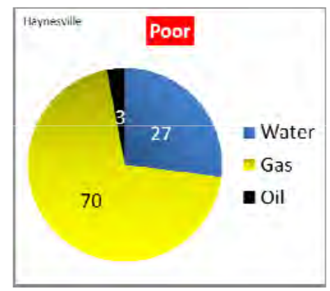


Haynesville

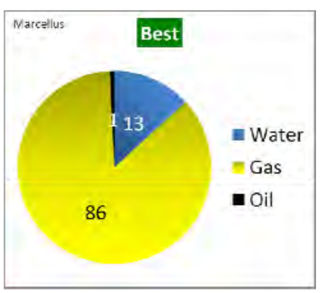


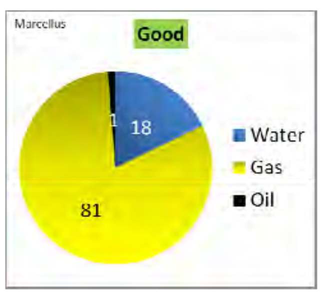


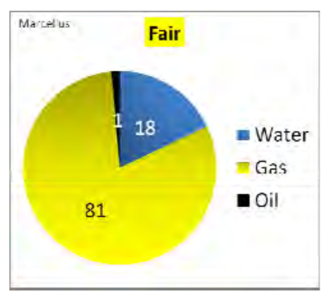


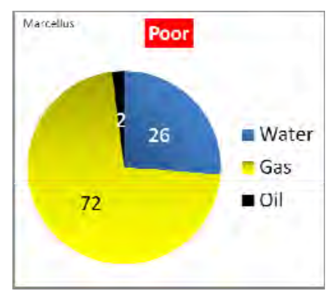


Marcellus

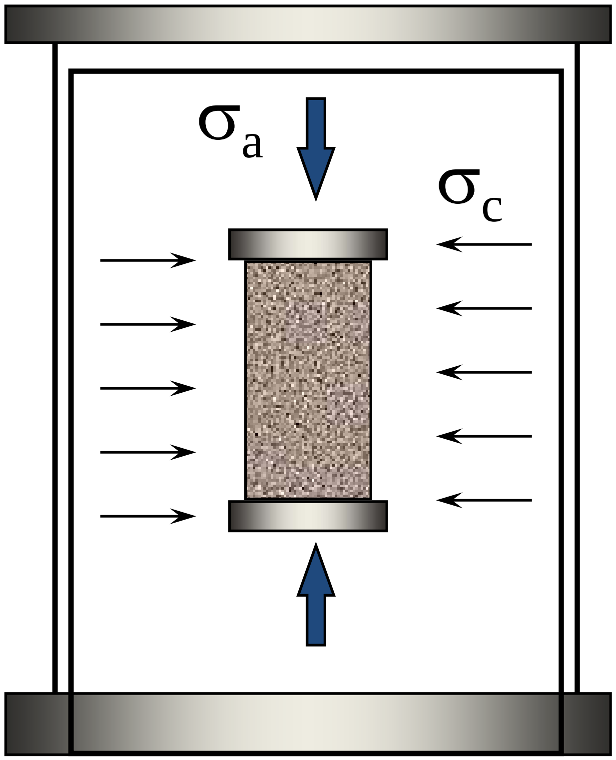




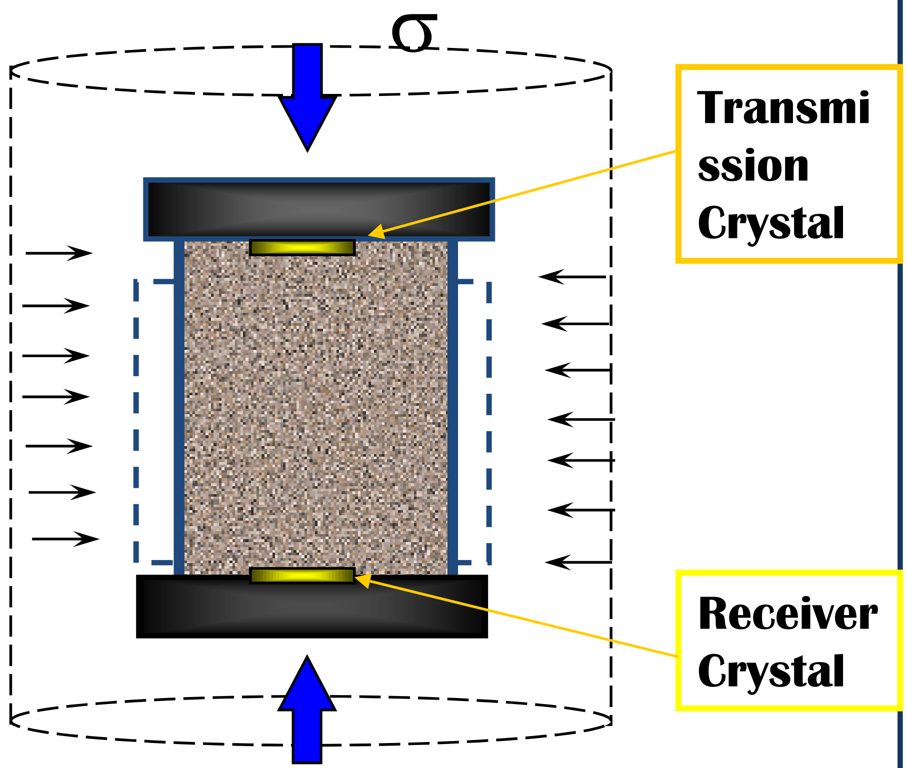




Mechanical Properties - Notation

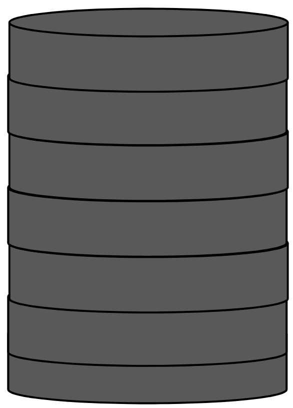


Static Test
Stress Strain Envelope

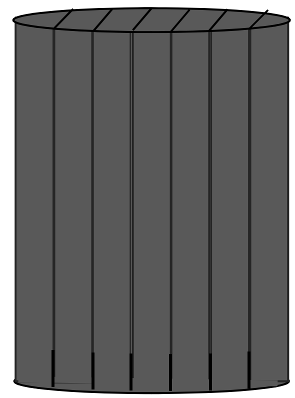


Dynamic Test
P and S velocities

Mechanical Properties - Notation



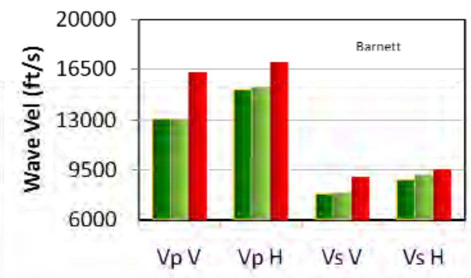
Vertical
Sample cut normal to bedding plane

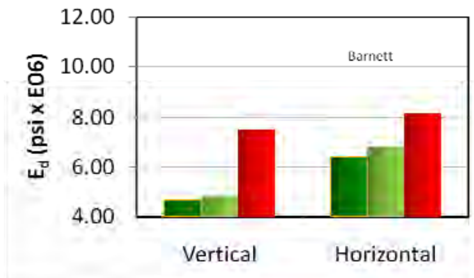


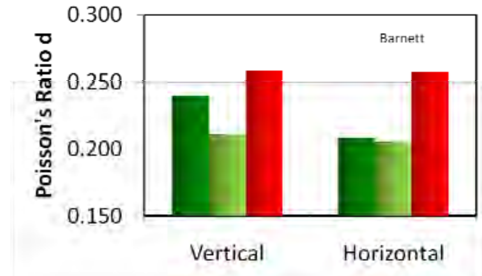
Horizontal
Sample cut parallel to bedding plane

Mechanical Properties - Dynamic

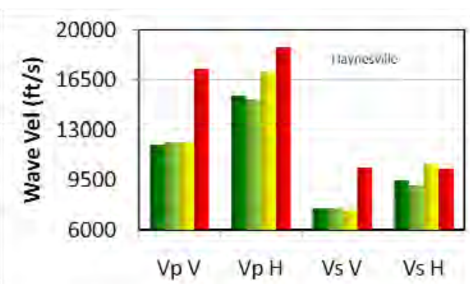
Barnett

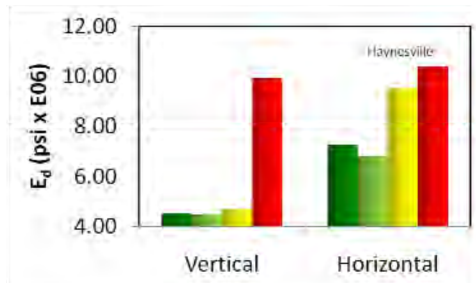


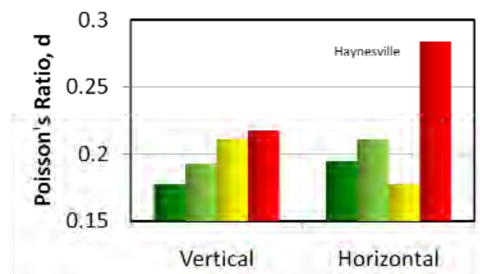




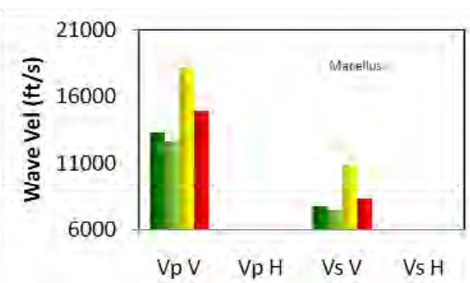
Haynesville

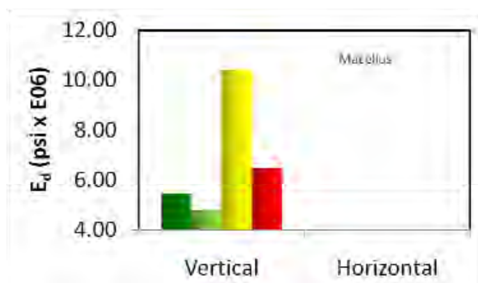


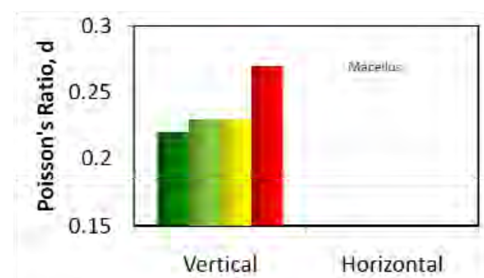




Marcellus

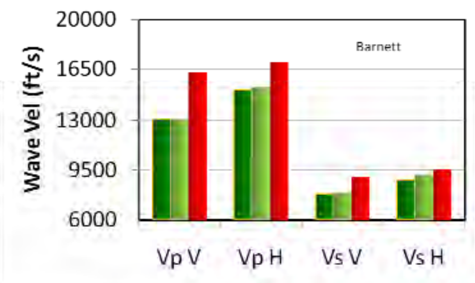




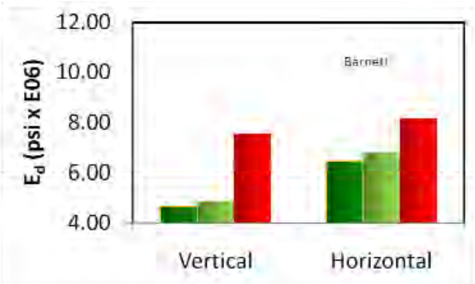


V_p and V_s are compression and shear velocities

Mechanical Properties - Observations

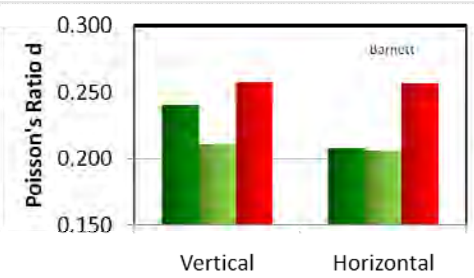


Wave velocities: Slower for good and faster for poor quality rock classes



Young's modulus: Smaller for good and larger for poor quality rock classes.

Anisotropy: Good rock class - higher anisotropy (E_h/E_v ~2/1); poor rock class - lower anisotropy (E_h/E_v ~ 1)*



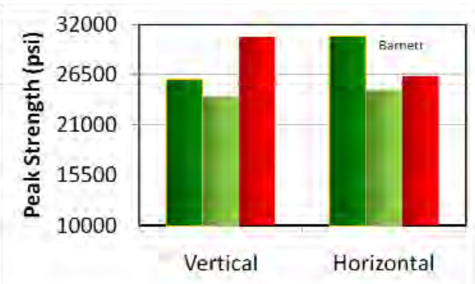
Poisson's ratio: Smaller for good and larger for poor quality rock classes.

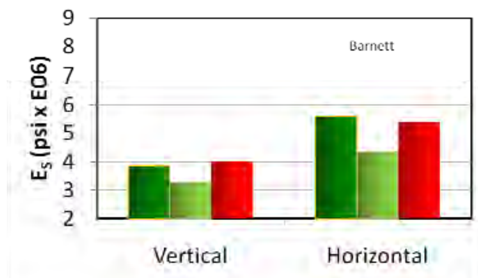
In-Situ stress: Smaller for good and larger for poor quality rock classes.

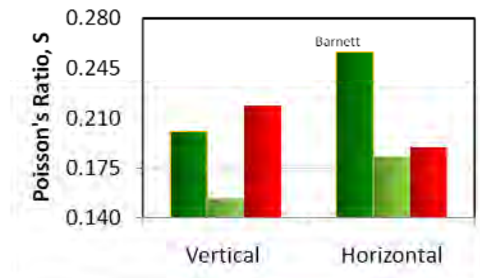
* **Fracture width underestimated by using E_h only**

Mechanical Properties - Static

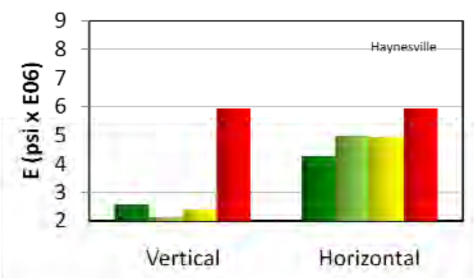
Barnett

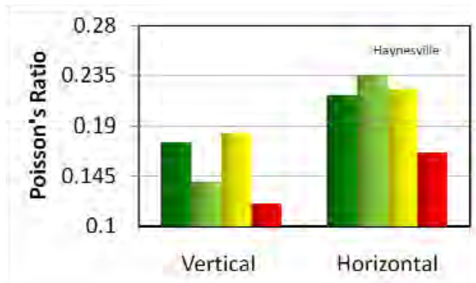




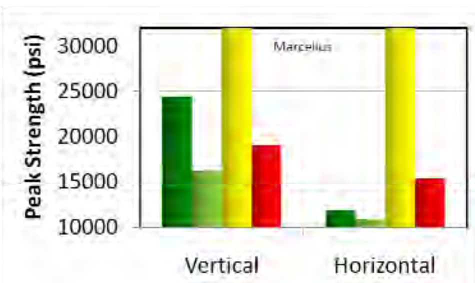


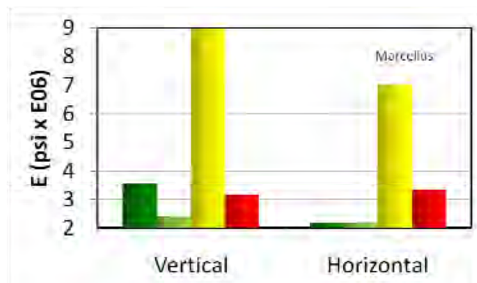
Haynesville

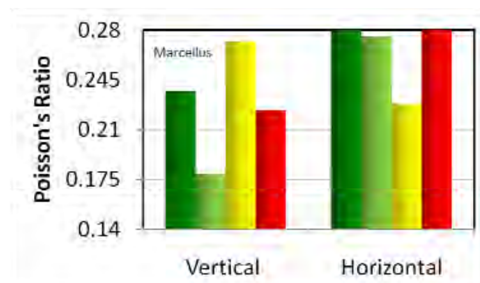




Marcellus



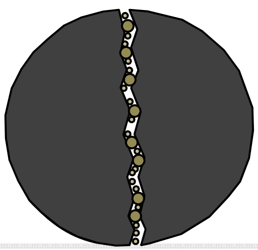




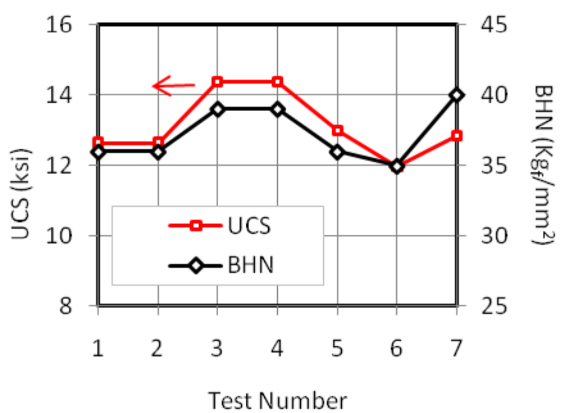
Fracture Conductivity Tests

Objective – Simulate effects of:

(1) Fracture roughness,
(2) changes in proppant mesh size, and
(3) changes in temperature in creep tests



Test	Pressure	Temp.	Fracture	Proppant
1	500 – 10000 psi	70 °F	Saw Cut	N
2	500 – 10000 psi	70 °F	Brazil	N
3	500 – 10000 psi	70 °F	Saw Cut	40/70
4	500 – 10000 psi	70 °F	Saw Cut	100
5	500 – 10000 psi	70 °F	Saw Cut	100 & 40/70
6	5000 psi	70 °F	Saw Cut	100
7	5000 psi	140 °F	Saw Cut	100

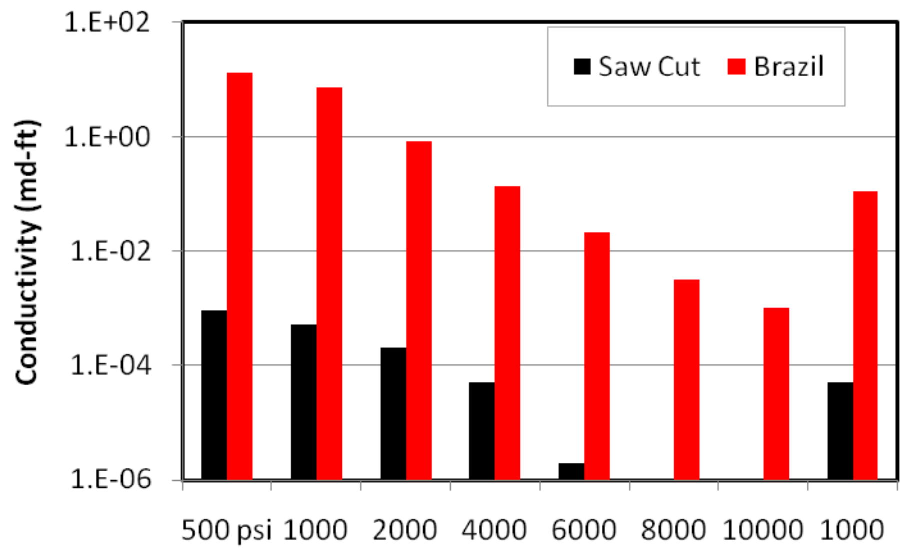


Samples – Best reservoir quality Barnett

Fracture Roughness Effects

Saw cut

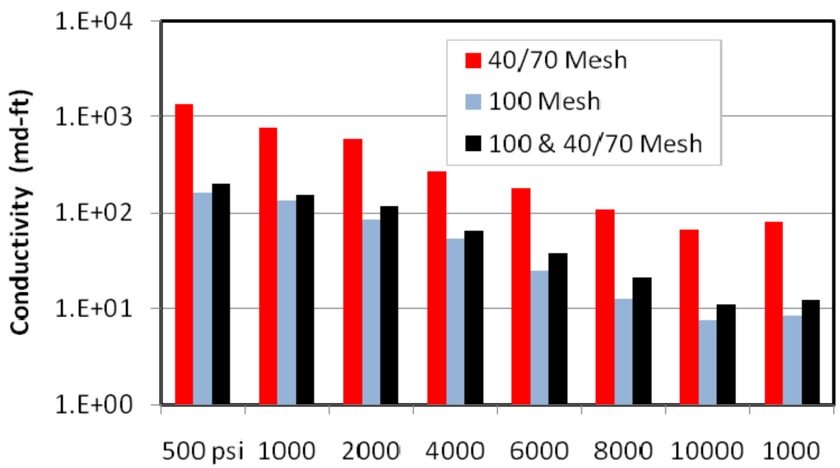
Brazil Fracture

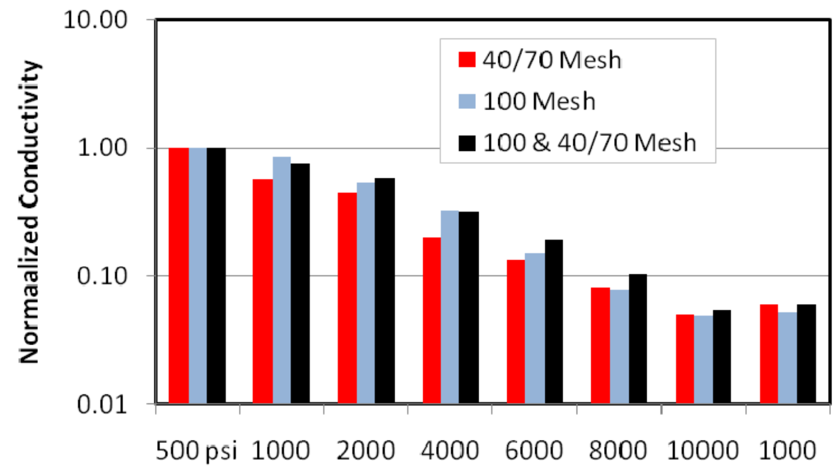


Saw cut (smooth surface) results: Negligible fracture conductivities less than 0.01 md-ft. Used as reference for sensitivity tests.

Brazil fracture (rough surface) results: Fracture conductivities from 13.5 to 0.001 md-ft. About 0.2 md-ft at Barnett in-situ conditions

Mixing Proppant Effects



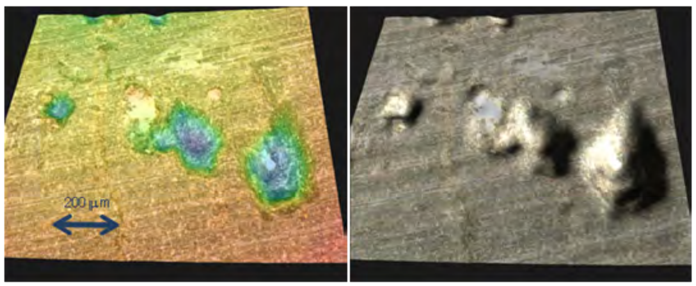


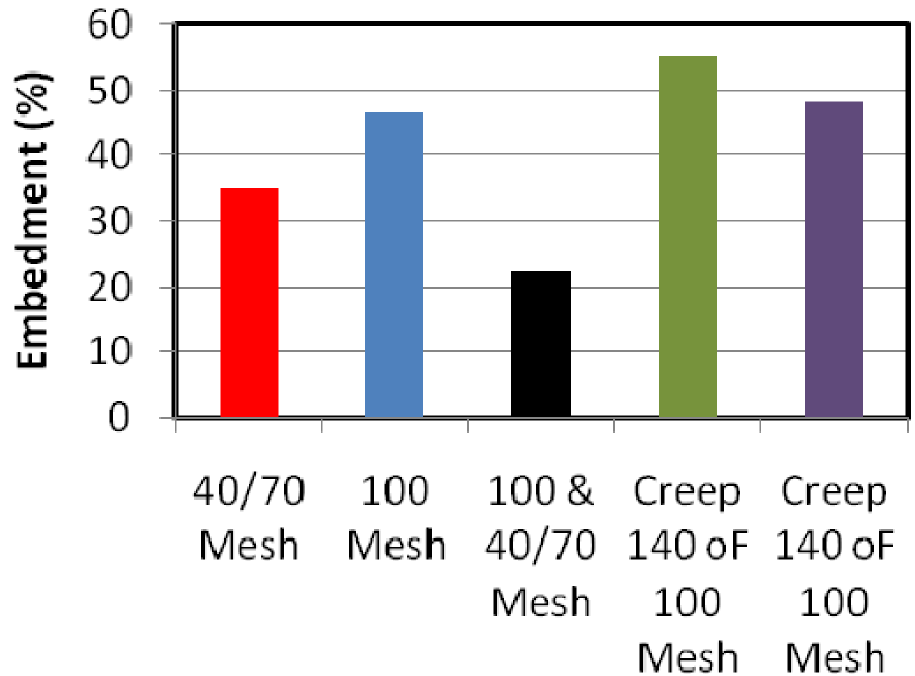
Mixing proppant sizes objective: Improve long term conductivity by controlling embedment; allowing the larger proppants offset embedment of smaller ones.

Was the objective achieved?

Average embedment was lowest; and normalized fracture conductivity (right plot) shows: With stress increase, fracture conductivity surpasses the other conductivities

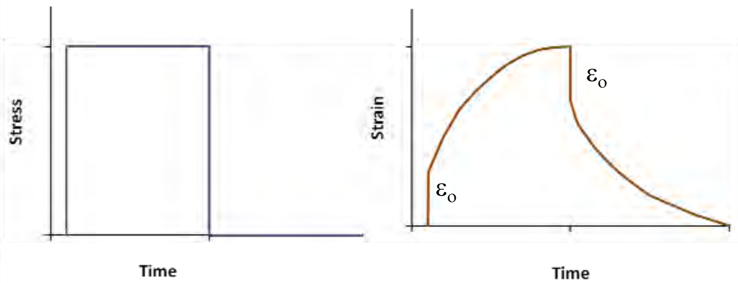
Embedment Values



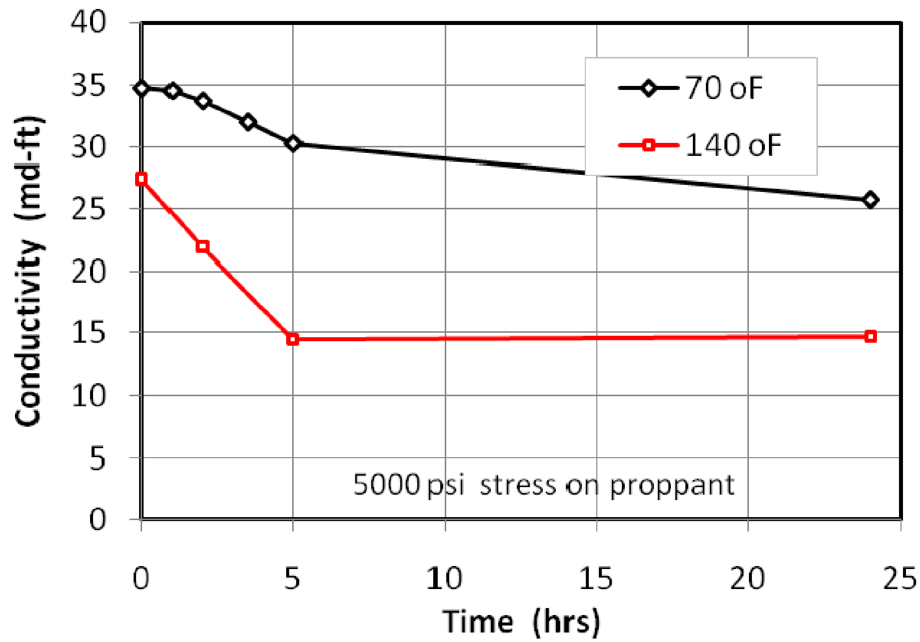


Digital microscopic images showing embedment craters for test with mixed proppant sizes (left) and average embedment for all tests with proppant (right)

Creep Effects



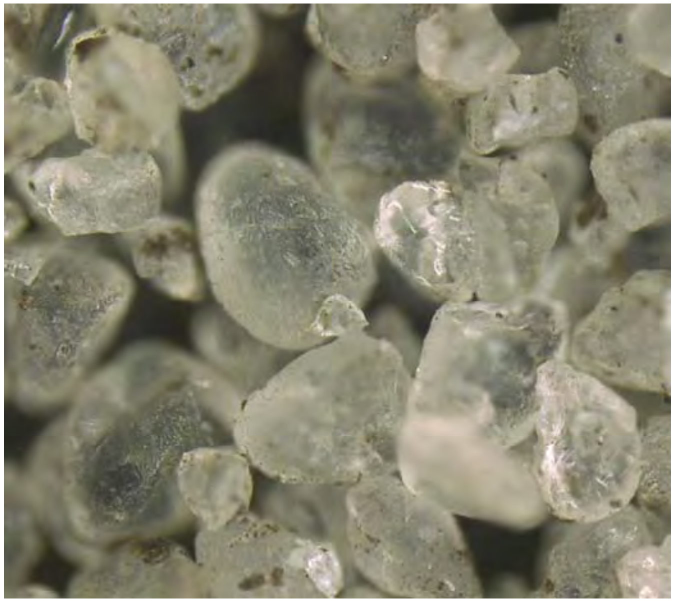
Constant stress creep response:
Loading - instantaneous elastic strain (ε_o), and delayed creep strain.
Unloading - elastic strain dissipates immediately; creep strain dissipates gradually to a residual or zero strain.



Fracture conductivity results:
Most of the decline (15% and 40% loss) occurred within the first 5 hours of testing. No significant decrease in fracture conductivity afterwards.
Large embedment of comparable magnitude to the tests where pressure was ramped.
Temperature significantly decreases fracture conductivity.

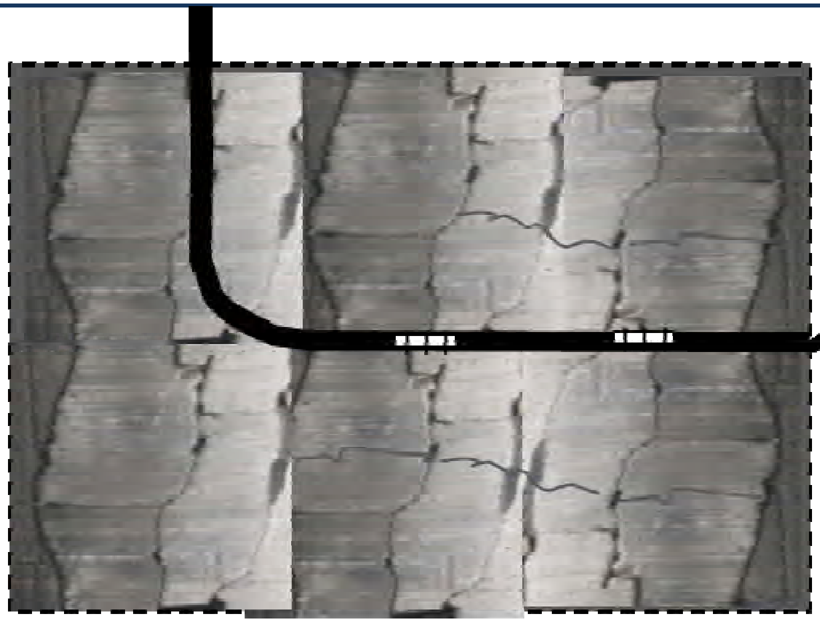
Creep Tests Images

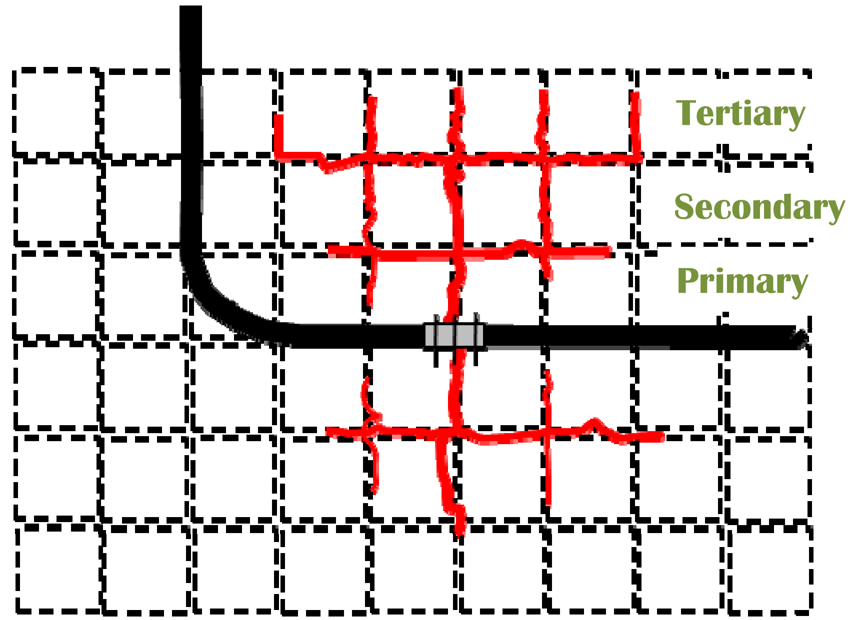
Pre and post pictures for creep test



Digital image of post test proppant showing about 10% proppant crushing .

Fracture Modeling

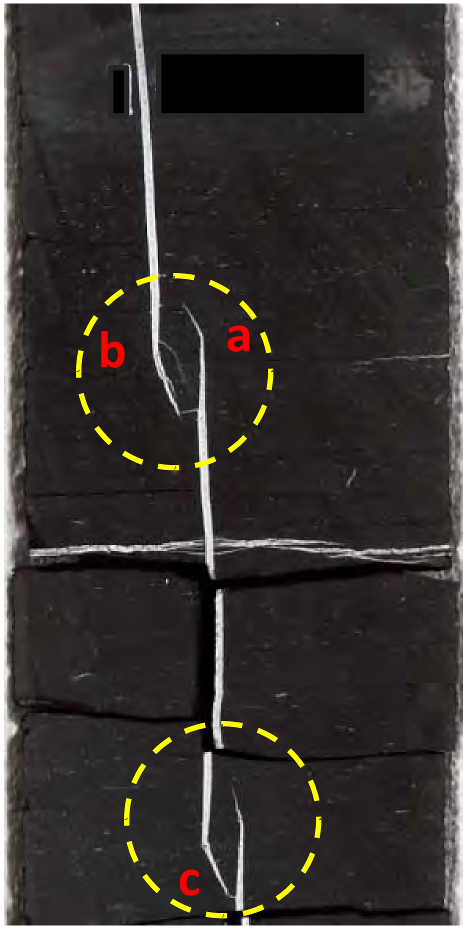


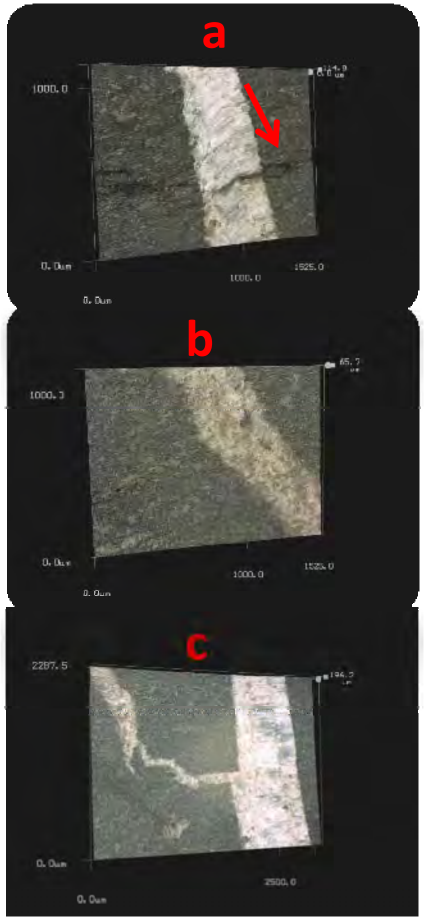


Eclipse production modeling of complex fracture networks indicate:

1. Fracture conductivity changes in primary fractures have insignificant effect on production.
2. Fracture conductivity changes in tertiary fractures have significant effect on production.

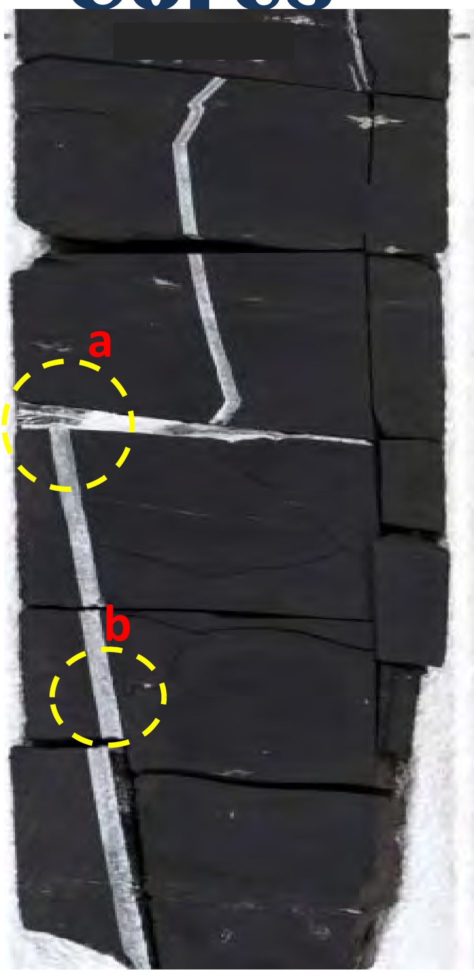
Fracture Observations from Cores

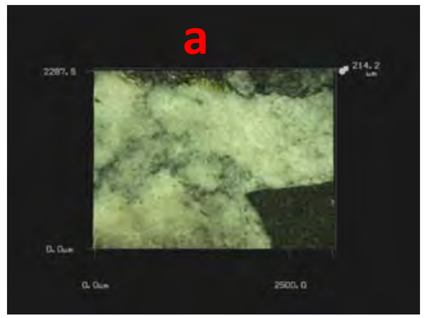


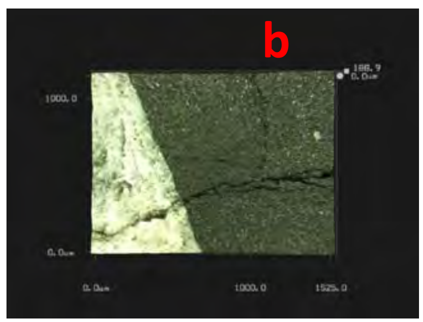


1 Offset at tips of collinear fractures
2 Induced fracture growth controlled by calcite filled natural fractures (a and b)
3 Merging of collinear fractures (c)

Fracture Observations from Cores







1. Parallel fractures connected by a horizontal (shear) fracture
2. Induced fracture intercepting a calcite filled natural fracture (b)

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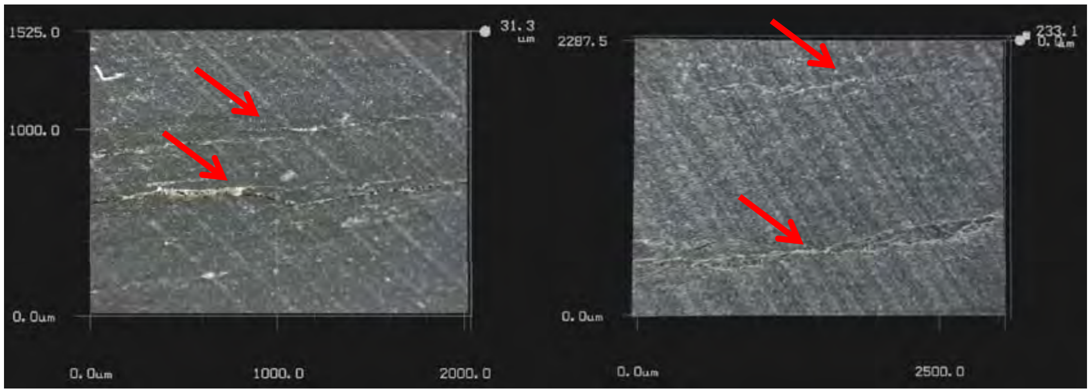
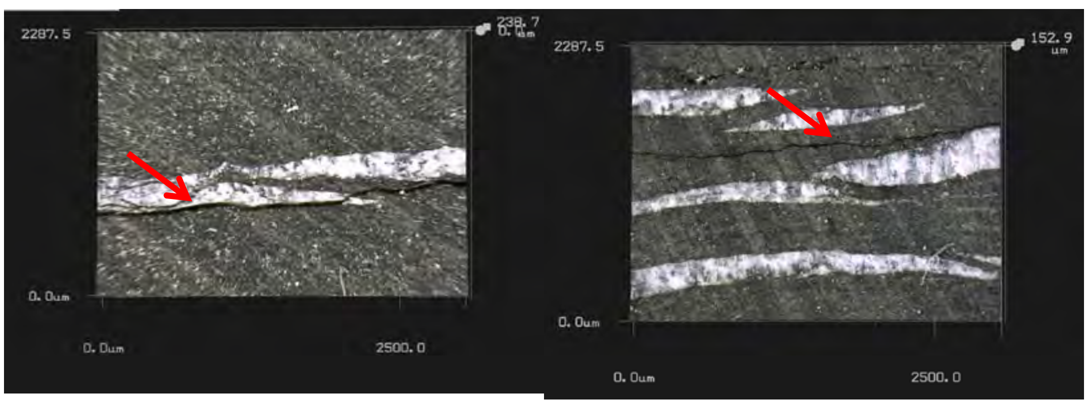


Images showing micro fractures



Induced fracture tends to follow weak paths along filled natural fractures

Conclusions: Mechanical Properties

- **Wave velocities**: Slower for good and faster for poor quality rock classes
- **Young's modulus**: Smaller for good and larger for poor quality rock classes.
- **Anisotropy**: Good rock class - higher anisotropy (Eh/Ev ~2/1); poor rock class - lower anisotropy (Eh/Ev ~ 1)
- **Poisson's ratio**: Smaller for good and larger for poor quality rock classes.
- **In-Situ stress**: Smaller for good and larger for poor quality rock classes.

Conclusions: Fracture Conductivity Tests

- Fractures with asperities (Brazil Test) provide small conductivity – less than 0.2 md-ft at typical closure pressures for the Barnett reservoir.
- Conductivity for tests with mixed proppant sizes (100 & 40/70) provide longer sustained production as corroborated by the lowest embedment and conductivity surpassing companion tests.
- Creep tests showed that loss in fracture conductivity happen within the first few hours of testing.
- Temperature effects significantly decrease the fracture conductivity.

Conclusions: Fracture Modeling

- Fracture conductivity changes in primary fractures have insignificant effect on production.
- Fracture conductivity changes in tertiary fractures have significant effect on production.

Acknowledgments

Partners inspecting shale cores on the 2010 review meeting

- RPSEA
- Shell Exploration and Production,
- Encana Oil & Gas, and
- Pennsylvania General Energy Company.

Project Tasks

Task 1 – Project management plan
Task 2 – Technology status assessment
Task 3 – Material property characterization
Task 4 – Loss of fracture area in fracture networks
Task 5 – Conductivity of un-propped fractures on core
Task 6 – Conductivity of propped fractures on core
Task 7 – Integration of loss of effective surface area and conductivity in fracture networks and degradation of fracture conductivity
Task 8 – Field testing of Tasks 4 to 7
Task 9 – Roadmap for reservoir characterization and production and recovery maximization
Task 10 – Technology transfer