Russell Roundtree

- **Professional Experience**
  - Geophysicist
    - GSI 1983-1985
    - ENAP 1985-1987
    - Advance Geophysical 1987-1992
  - Petrophysicist
    - Halliburton 2004-2007

- **Education**
  - PhD in Petroleum Engineering Candidate, CSM
  - M.Sc in Geophysics, CSM, 1983
  - B.S in Geophysical Engineering, CSM, 1981

- **Expected Graduation Date**
  - May 2009
Outline

- Review of Phase 1 and Phase 2 projects
- Proposed Objectives – Phase 3
- Project scope
- Timeline
- Literature search
- Seismic recording system
- Proposed acoustic measurements
- Applications of research

Project #1 Hydraulic fracture height growth and containment mechanisms
Project #1 Hydraulic fracture height growth and containment mechanisms

Improved Stimulation
Improved Production
Improved Recovery

Project #1
Height Containment

Project #2
Non-Darcy Flow

Project #3
Reorientation

Project #4
CBM Stimulation

Project #5
Biot’s Constant

Project #6
Reservoir Mgt.

Project #7
Slickwater

Project #8
Geostatistics

Project #9
“Shale” Stimulation

Project #10
Horizontal Wells

Project #11
Gel Clean-up and Formation Face damage
Purpose – Phase 1

Further our understanding of fracture extension in the presence of discontinuities by conducting a physical model test of hydraulic fracturing (HF) under laboratory controlled conditions
Objectives – Phase 1

- Capture phenomena of HF in physical model, similar to field conditions
- Assess impact of different material interfaces on HF growth
- Provide baseline data for future HF modeling efforts
Test Design

Preparation of Test Sample: Joint design

Top half measurements are symmetrical with bottom half of block.
Test Results

Fracture #1

Start of test ≈ 2,246 sec

Vertical stress, $\sigma_v$

Shut-in = 8,713 sec

End of test = 9,476 sec

Maximum horizontal stress, $\sigma_{max}$

Waviness due to leak in east-west flatjacks

Minimum horizontal stress, $\sigma_{min}$

Breakdown borehole pressure

Maximum Probe 2 pressure after shut-in

Horizontal stresses reversed for second fracture.

Total injection time ≈ 6,467 sec ≈ 108 min

Injection rate of 0.025 cc/sec

Fracture reaches Probe 2 (west of borehole)

Fluid displaced, cc

Pressure and principal stresses, psi

Time, sec

Project #1 Hydraulic fracture height growth and containment mechanisms
Test Results

Characterization of Fracture #2 Geometry

Project #1 Hydraulic fracture height growth and containment mechanisms
Discussion of Results

- Experiment measurements > predicted net pressures from the dimensional analysis
  - Estimated fluid lag sizes > predictions
  - Influence of confining stress
- Toughness a dominant factor in the propagating process (high toughness material)
- Rates of fracture growth agree with similar scaled experiments, which produced field-like fracture growth
Visco-elastic response from epoxy-filled joint caused fracture arrest.

Contrast in stiffness and joint orientation had no apparent impact in fracture extension across grout-filled joint, given the test conditions.

- Visual observation indicate shearing in grout layer...
Project 1 – Phase 1 References


Proposed objectives – Phase 2

- Conduct HF tests on small blocks to check ability of scaling analysis to be captured in smaller block tests.
- Measure the effects of shear slippage at material property discontinuities.
- Determine if fracture tip tensile failure precedes shear slippage.
- Model boundary interface pressure behavior and influence of stress and different coupling mechanisms.
## Material Property Testing

<table>
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<tr>
<th>Material</th>
<th>Youngs modulus Gpa</th>
<th>Youngs modulus psi</th>
<th>Poissons ratio</th>
<th>Dynamic properties</th>
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Static measurement values used for scaling calculations

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Project #1 Hydraulic fracture height growth and containment mechanisms
Small Block HF testing

\[ \sigma_v \]

\[ \sigma_{\text{min}} \]

\[ \sigma_{\text{max}} \]

Laminated block - 3D view

Stress frame - top view

Project #1 Hydraulic fracture height growth and containment mechanisms
Blocks B3 and B5 used for the HF tests

Laminated Block – B3

Lyons sandstone
Polyurethane base adhesive bond
15.8 ppg cement
Lyons sandstone
Unbonded interface
16.2 ppg cement
Lyons sandstone
Epoxy
15.8 ppg cement

Homogeneous 16.2 ppg cement block – B5

Project #1 Hydraulic fracture height growth and containment mechanisms
TERRATEK’S SMALL BLOCK POLYAXIAL STRESS FRAME

**Max capabilities**

- Rock size (w/ pore pre): 11” x 11” x 15” high
- Rock size (w/o pore pre): 10” x 10” x 14” high
- Central borehole: 1.5” diameter
- Vertical Stress: 4500 psi
- Horizontal Stress 1: 3000 psi
- Horizontal Stress 2: 3000 psi
- Horizontal Stress Diff: 2000 psi
- Borehole pressure: 5000 psi
- Pump intensifier volume: 0.18 gal / 700 cc’s
- Injection rate: 4 gpm / 1500 cc/min
- Injection pressure: 2000 psi
Test #1 - 16.2 ppg Cement block B5

East face of block

West face of block

Project #1 Hydraulic fracture height growth and containment mechanisms
Test #1 - 16.2 ppg Cement block B5 - First Fracture E-W direction

Split block showing E-W fracture

Project #1 Hydraulic fracture height growth and containment mechanisms
Test #2 - Laminated block B3

East face of block

West face of block

Project #1 Hydraulic fracture height growth and containment mechanisms
Modelled Shear Stress no Wellbore

Project #1 Hydraulic fracture height growth and containment mechanisms
4-pane Stress Distribution w/Wellbore

Project #1 Hydraulic fracture height growth and containment mechanisms
Project #1 Hydraulic fracture height growth and containment mechanisms
Project 1 – Phase 2 Results

• Applying two scaling approaches yielded quasi-static fracture growth similar to field conditions.
• Complex, non-planar fracture growth with fracture branching was observed when hydraulic fractures were propagated through the laminated Block B3.
• It is believed that a shear slippage phenomenon occurred at the unbonded interface.
• Stress contrasts across dissimilar layers and shear stresses developed at layer interfaces are observed. Similar conditions could exist in subsurface thinly-laminated reservoirs and should be taken into account while designing fracture treatments.
• FEM shows that a triaxially loaded small laminated block with layers having contrasting material properties experiences boundary effects in terms of stress concentrations. In subsurface formations, these boundary effects would not exist considering the large aerial extent of the reservoir.
• FEM indicated spatial stress variations in the laminated block system. Similar conditions likely exist in subsurface thinly-laminated reservoirs and should be taken into account while designing fracture treatments.
Project #1 Phase 3

Experimental Acoustic Validation of Hydraulic Fracture Propagation in Thinly Laminated Reservoirs
Influence of Geologic Discontinuities on Hydraulic Fracturing Propagation

**UI C Laboratory Testing**
Lance Mesa Verde Outcrop with Natural Fracture Intersection

![Graph showing fracture behavior at joint](image)

**Project #1** Hydraulic fracture height growth and containment mechanisms
Secondary Cracking and Crack Arrest by Delamination/Pre-existing Fracture

[Image of secondary cracking and crack arrest by delamination/pre-existing fracture]

[Image of secondary crack interface and main crack]

[Image of pre-existing fracture and crack in sandstone]

[Image of rigid layer, soft layer, and delamination]

Project #1 Hydraulic fracture height growth and containment mechanisms
• **Inventions and Discoveries.** All inventions and discoveries conceived, reduced to practice or developed under the sponsorship of this Agreement, whether solely invented by employees of CSM or jointly invented by employees of CSM and employees of the Industry Partner, shall be the property of CSM, and any patents related to such inventions and discoveries shall be issued in the name of CSM. CSM shall grant to the Industry Partner and, if applicable, its parent, subsidiaries, and affiliates a worldwide, non-exclusive, royalty-free license to use, make, have made by another, or incorporate into its products any invention or discovery generated during the Industry Partner's consortium membership through research activity sponsored by this Agreement. For a period of one year from the date of disclosure of any invention or discovery to the consortium, CSM shall limit all licensing of such invention or discovery to consortium members. CSM reserves the right to grant licenses for the use of such inventions and discoveries to non-members of the consortium at any time after one year from the date of disclosure to the consortium.
FAST – IP Summary

- Just a reminder…
  - Potential patentable process
  - From your company’s contracts
    - All inventions and discoveries are the property of CSM
    - FAST members will ultimately have the right to use, make, have made by another, or incorporate into its products any invention or discovery generated
  - Please treat the following information as completely confidential to those in this room
Passive Seismic – the leading edge
Objectives – Phase 3

• Conduct scale hydraulic fractures in laminated synthetic blocks to validate acoustic acquisition system.

• Conduct scale hydraulic fractures in thinly laminated Mesa Verde Sandstone in in-situ reservoir conditions.

• Use lab based passive microseismic to monitor fracture progress and extent in Mesa Verde sandstone.

• Use active seismic diffraction to track fracture tip progress.

• Use active seismic reflections for fracture height and width.

• Attempt to use active seismic dispersion to measure width of fluid filled crack.

• Mine back block to validate actual fracture location.
Project #1 Hydraulic fracture height growth and containment mechanisms
Blocks B3 and B5 used for the HF tests

**Laminated Block – B3**
- Lyons sandstone
- Polyurethane base adhesive bond
- 15.8 ppg cement
- Lyons sandstone
- Unbonded interface
- 16.2 ppg cement
- Lyons sandstone
- Epoxy
- 15.8 ppg cement

**Homogeneous 16.2 ppg cement block – B5**

Project #1 Hydraulic fracture height growth and containment mechanisms
Lance Block Extraction

Project #1 Hydraulic fracture height growth and containment mechanisms
Project #1 Hydraulic fracture height growth and containment mechanisms
Microseismic – 10 years running

- Provides our best estimate of created half length, height growth and stimulated reservoir volume.
- Technology is still in its infancy, yet very expensive.
- In 10 years microseismic will likely be a bundled service with all frac jobs.
- Customers lack confidence in precision of fracture location data.
- Microseismic provides unpredictable source.
Research Applications

- Validation of seismic monitoring and actual fracture location will establish credibility.

- Dynamic fracture growth data will help understand thin lamination crack growth behavior in actual reservoir rocks.

- Active seismic during fracture grown may increase our resolving ability substantially.

- Quantification of sources of error in fracture positioning will lead to better data processing.
# Project Plan

## Project #1 Hydraulic fracture height growth and containment mechanisms

### Project 1 - Phase III Research and Thesis Timeline

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<th>Oct-07</th>
<th>Jan-08</th>
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Questions

- Questions
- Comments