In situ Characterization of Fracture-Related Processes

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Core from front of a hydraulic fracture. Piceance basin near Rifle, Colorado, 7150 ft depth (Warpinski et al., 1993)

SEGMENTED HYDRAULIC FRACTURE
Mixed Mode I + III

Side View

End View

Pressure Curve

Planar

Pressure (MPa)

Time (min)
SEGMENTED HYDRAULIC FRACTURE

End View

Side View

Pressure Curve

Pressure (MPa)

Time (min)
Surface morphology
Mechanical and hydrologic implications
Asperities, deformation and flow
Some Critical Questions

- How do dilational fractures propagate?
  - Mixed Modes, segmentation, fluid flow, asperities

- How does propagation influence properties of fractures and networks?
  - Asperity propping, preferential flow paths, normal and shear stiffness

- How do fracture properties affect earth processes?
  - Fluid flow and storage, mass transport, deformation
Proposed Activities

1. In situ stress characterization
2. Induced fracture experiments
3. Fracture network laboratory
4. Pressure-deformation experiments
Activity 1: In situ stresses

- **Approach:** Evaluate existing data. Make local measurements as needed.
- **How:** Small hydraulic fractures, other
- **When:** DUSEL Phase I
- **Why:** Data and methods necessary to plan future work.
Activity 2: Induced fracture experiments

**Purpose:** Evaluate and refine conceptual and theoretical models of fracture propagation involving:
- Fracture tip processes
- Mode III contribution
- Fracture energy
- Morphology of surface roughness
- Fluid flow, particle transport
- Interactions with material heterogeneities
- Interactions with neighboring fractures

**Applications:**
- Basic geomechanical understanding
- Joints, veins, dikes, etc.
- Resource recovery
- CO2 Sequestration
- Waste Isolation
Covered
Red Sand
White Sand
Blue Sand
Injection casing

Step on fracture surface.
Dots on downthrown side
Contact inferred
Limit of red sand
Approx. extend of fracture
Strip of blue sand on frx surface
Trench face
**Induced fracture experiment**

**Approach:**
- a.) Select location based on local stress state and material properties,
- b.) Install monitoring instruments,
- c.) create fractures,
- d.) evaluate monitoring data,
- e.) excavate and describe.

**Access:** Multiple tunnels and boreholes

**Monitoring:**
- Tilt, displacement, pressure at points;
- passive microseismicity,
- streaming potential, seismic reflection,
- various cross-hole tomography methods.

**Equipment:**
- Drill rig, pump and mixer,
- geophysics, mining equipment.

**Timing:**
- Take advantage of construction excavation for mineback.
Activity 3: Fracture Network Laboratory

**Purpose**: Evaluate and refine conceptual and theoretical models involving fracture networks, including

- Fluid flow
- Mass transport
- Chemical reactions
- Heat transfer
- Stress-deformation

**Applications**:

- Veins
- Deep water flow
- Hydrocarbons, geothermal
- Waste Isolation
- Remediation
Use hydraulic fracturing to create ideal fractures for experiments.

1. Select location based on principle stresses
2. Create hydraulic fracture of specific orientation and size.
3. Modify stresses by heating
4. New fracture with different orientation
5. Application experiments
   - Assessment methods
   - Heating and transport
   - Other
Fracture Network Laboratory: Assessment Experiment

- Verify and refine in situ methods for assessing fractured rock
  - Hydraulic, Hydromechanical well tests
  - Radar, ER, Seismic tomography
  - Tracer
  - Emerging methods
  - Data fusion—simultaneous inversion of multiple data sets
In situ Assessment Experiment

- **Access**: Tunnel with side drift. Overlying tunnel with vertical borehole.
- **Equipment**: Drill rig, pumps, heaters
- **Timing**: Phase III
Remediation in fractured rock nearly impossible.

Most promising technology involves heating to boiling
Temp, apply suction, induce boiling in fractures and matrix. Recover contaminants in vapor phase.

Looks good theoretically. Need experimental verification.

Fracture Network Laboratory: Heating Experiment

Figure 3. Cross-sectional view of a single element in the electrical resistance heating array used in numerical simulation.

Figure 5. Average TCE concentration and water saturation during field scale simulation.
Heating Remediation Experiment

- **Access**: Tunnel with side drift. Overlying tunnel with vertical borehole.
- **Equipment**: Drill rig, pumps, 6-phase resistive heating
- **Timing**: Phase III
Other Topics

■ Vein formation
■ Effects of natural variations in fluid pressure on fracture displacement
■ Fracture mechanisms in compression
■ Strength degradation vs. stress relaxation
## Fracture Energy and Rock Strength

<table>
<thead>
<tr>
<th>Scale</th>
<th>Fracture energy (J/m²)</th>
<th>Strength (MPa)</th>
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</thead>
<tbody>
<tr>
<td>Lab (m)</td>
<td>$10^2$</td>
<td>100</td>
</tr>
<tr>
<td>Dikes-veins-hydraulic fractures (up to km)</td>
<td>$10^4 - 10^5$</td>
<td>10</td>
</tr>
<tr>
<td>Mid-ocean segments, deep crustal faults (100 km)</td>
<td>$10^7 - 10^9$</td>
<td>1</td>
</tr>
</tbody>
</table>
Hydromechanical well test

slug test

- Time (seconds): 1, 10, 100, 1000
- Head (m): 0, 1, 2, 3, 4, 5, 6, 7
- Displacement (μm): 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5

- Head vs Disp.
- \( \Delta \delta / \Delta h_{\text{Stage4}} \)
Fractures control many processes in geosciences, but basic details remain unclear.

- **Lab studies**: well controlled, but problems with scale and boundaries.
- **Field studies**: Scale and boundaries OK, but control is poor.
- **DUSEL/ HUSEP**: Natural scale and boundaries, good control. Homogeneous conditions good for interpretation. Need different depths and stress states. Possibility for mining fractures.
Cumulative displacements during pressure cycles
Pressure-deformation experiments
Figure 3. Cross-sectional view of a single element in the electrical resistance heating array used in numerical simulation.

Electrode Electrode

Vacuum Well

Insulating Cover

Water Table

Groundwater
contaminated with
10 PPM of TCE in
both fractures
and matrix

16 m

Fractured Limestone

0.1 1 10 100 1000
0 100 200 300 400 500 600 700

Figure 5. Average TCE concentration and water saturation during field scale simulation.

Average TCE Concentration, ug/l

Average Water Saturation

TCE

Sw

0 100 200 300 400 500 600 700
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 1000 100 10 1

0 10 100 1000 10000

Figure 5. Average TCE concentration and water saturation during field scale simulation.
A single internal crack **cannot** grow to an extent sufficient to cause material failure.
Gilsonite (natural asphalt) dike, Eastern Uinta Basin, Utah (Verbeek and Grout, 1993)