Mechanics of Engineered Fractures in Discontinuous Rock

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and others

CSIRO

Questions

- Engineering Questions
  - Improvement of caving process (pre-conditioning of rock mass)
  - Roof control
  - Improvement of connectivity of fracture systems
  - Density of engineered fractures
  - Detection and monitoring of fractures (passive and active wave methods, tiltmeters)
- Science Questions
  - Large scale fracture toughness
  - Interaction between engineered fracture and pre-existing discontinuity
  - Continuity and branching
  - Fracture geometry
  - Shear vs opening mechanism

Collaboration CSIRO-CSIR-UBC-UMN

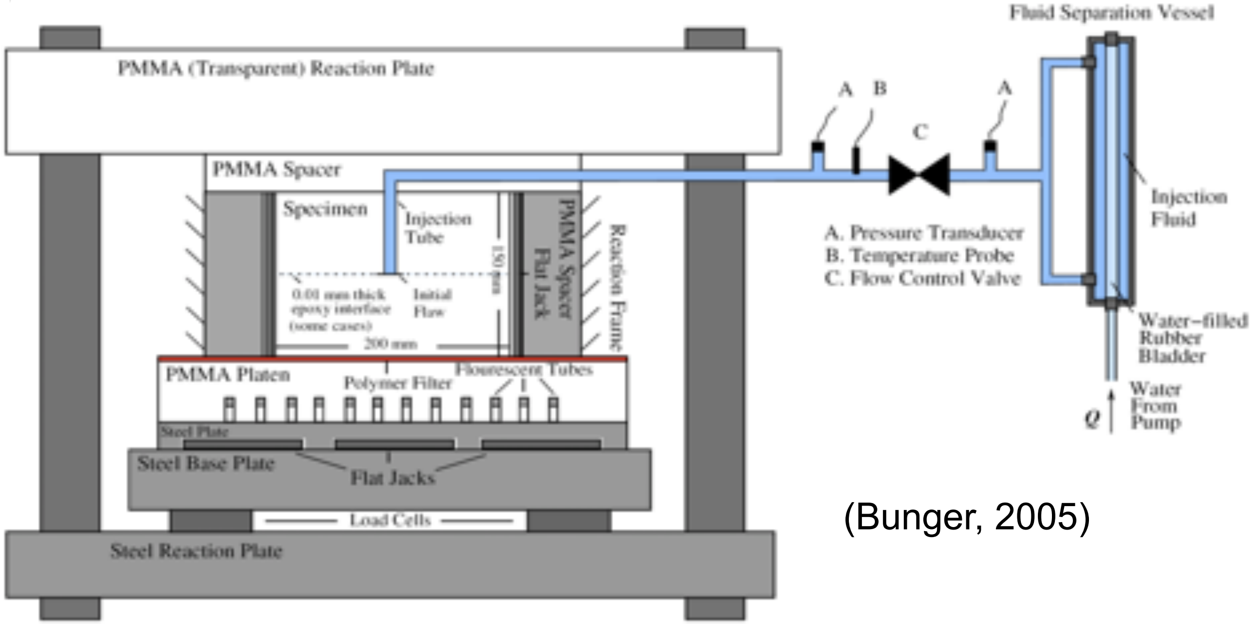
- Laboratory Experiments
  - Fracture curving near free-surface
  - Fracture crossing of discontinuities
  - Experimental validation of tip asymptotics
  - Influence of stress jump
  - Fracture curving
- Field Experiments
  - Fracture geometry
  - Monitoring
  - Interaction with pre-existing discontinuities
- Theoretical Research
  - Scaling analysis
  - HF fracture numerical simulators
  - Influence of a free-surface
  - Parameters influencing fluid lag
  - Fracture recession

Laboratory Experiments (CSIRO)

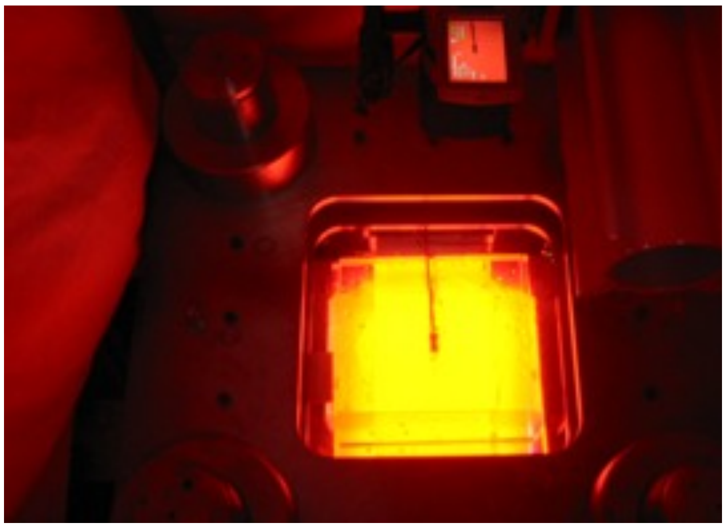
- Experiments in glass and PMMA
  - Fracture curving (free surface)
  - Fluid lag
  - Tip asymptotics
  - Fracture geometry (stress jump)

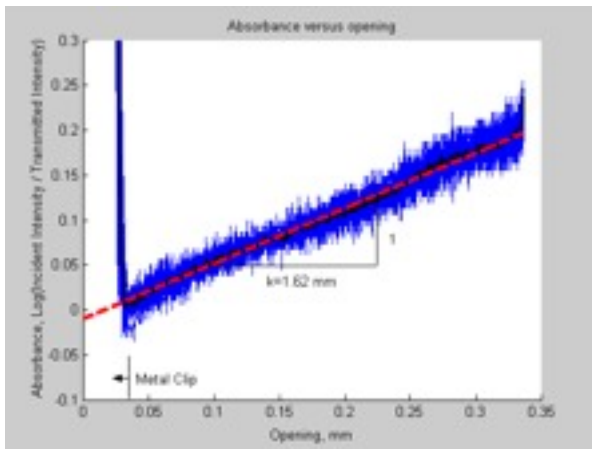
- Experiments in rocks
  - Reorientation from an inclined wellbore
  - Fracture crossing discontinuities
  - Fracture curving

Experiments in Glass and PMMA with Photometric Full-Field Crack Opening Measurement

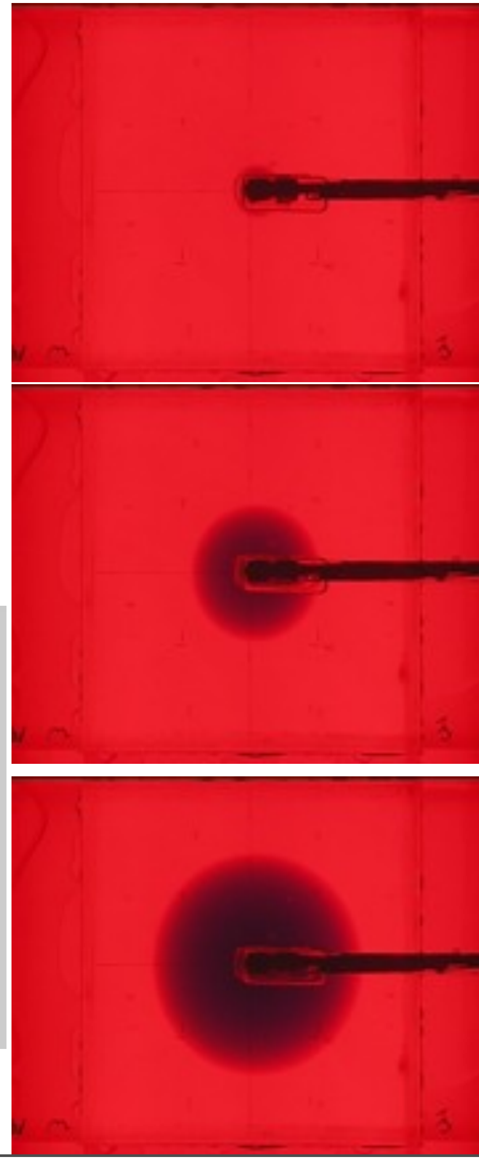


(Bunger, 2005)

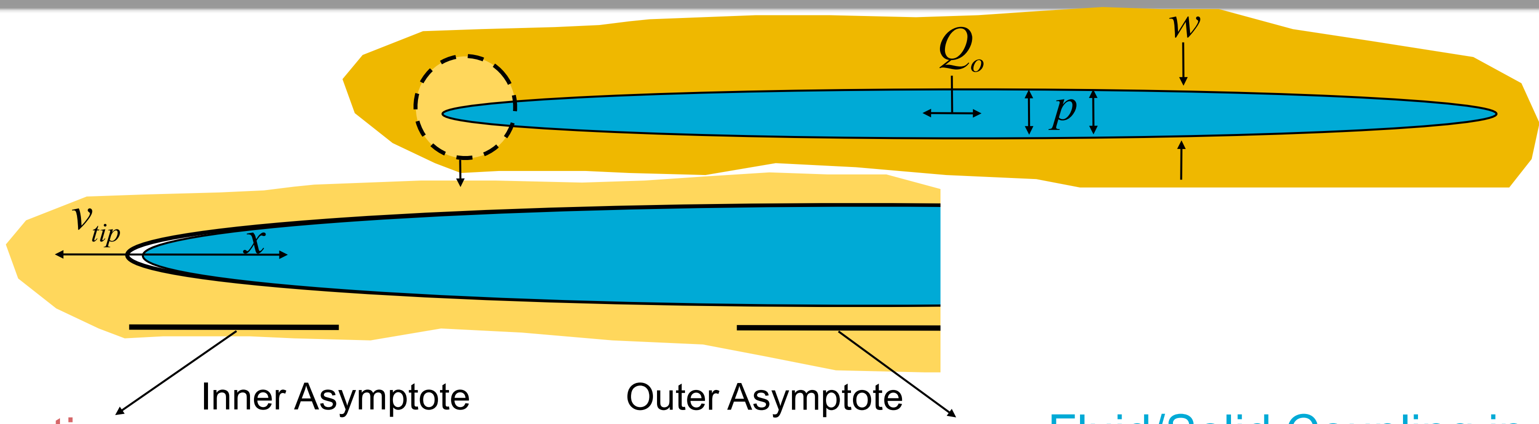




$$A \equiv \log_{10}\left(\frac{I_o}{I}\right) = \frac{w}{k}$$

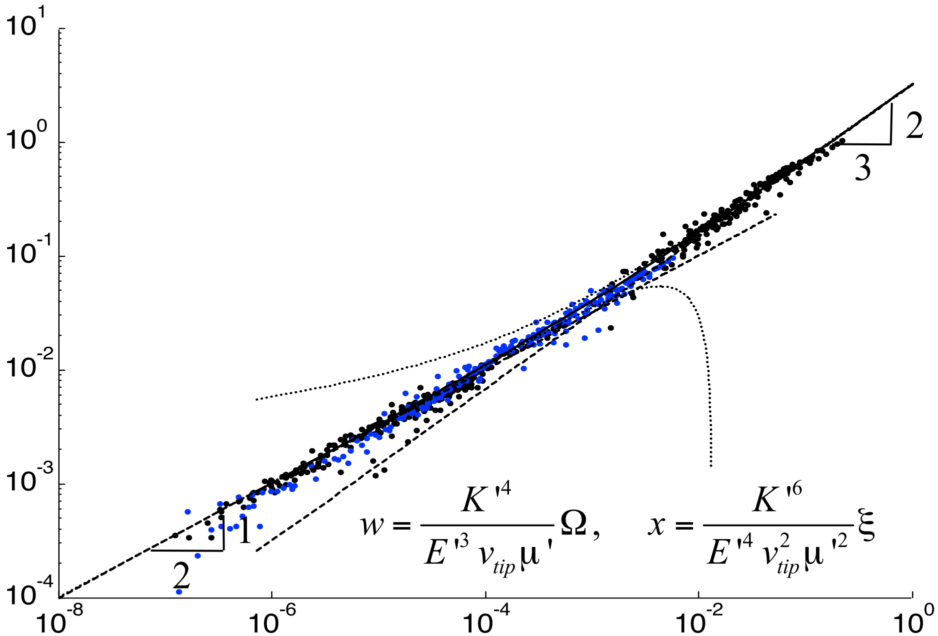


Experimental Results



Linear Elastic Fracture Mechanics

$$w \sim \frac{K'}{E'} x^{1/2}$$



Fluid/Solid Coupling in Tip Region

$$w \sim 2^{-1/3} \times 3^{5/6} \left(\frac{\mu' v_{tip}}{E'} \right)^{1/3} x^{2/3}$$

v_{tip} = Tip velocity

μ' = Dynamic fluid viscosity $* 12$

E' = Plane strain modulus

K' = Fracture Toughness $* (32/\pi)^{1/2}$

Garagash and Detournay, J. Appl. Mech., 2000, 2005.

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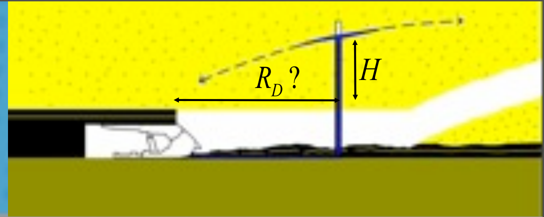
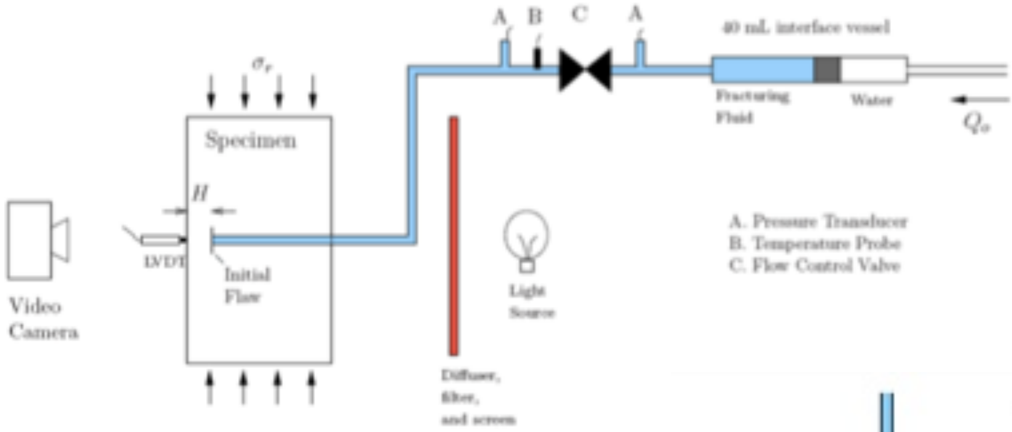
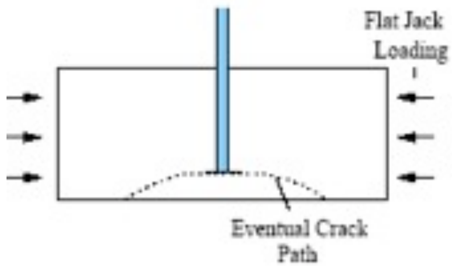
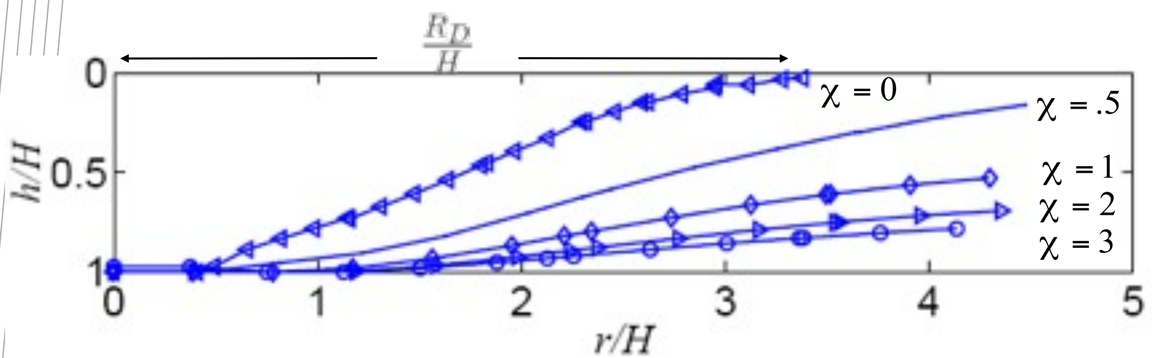
The Parameter Controlling Curvature of Shallow Hydraulic Fractures









Flatter saucers with larger values of:

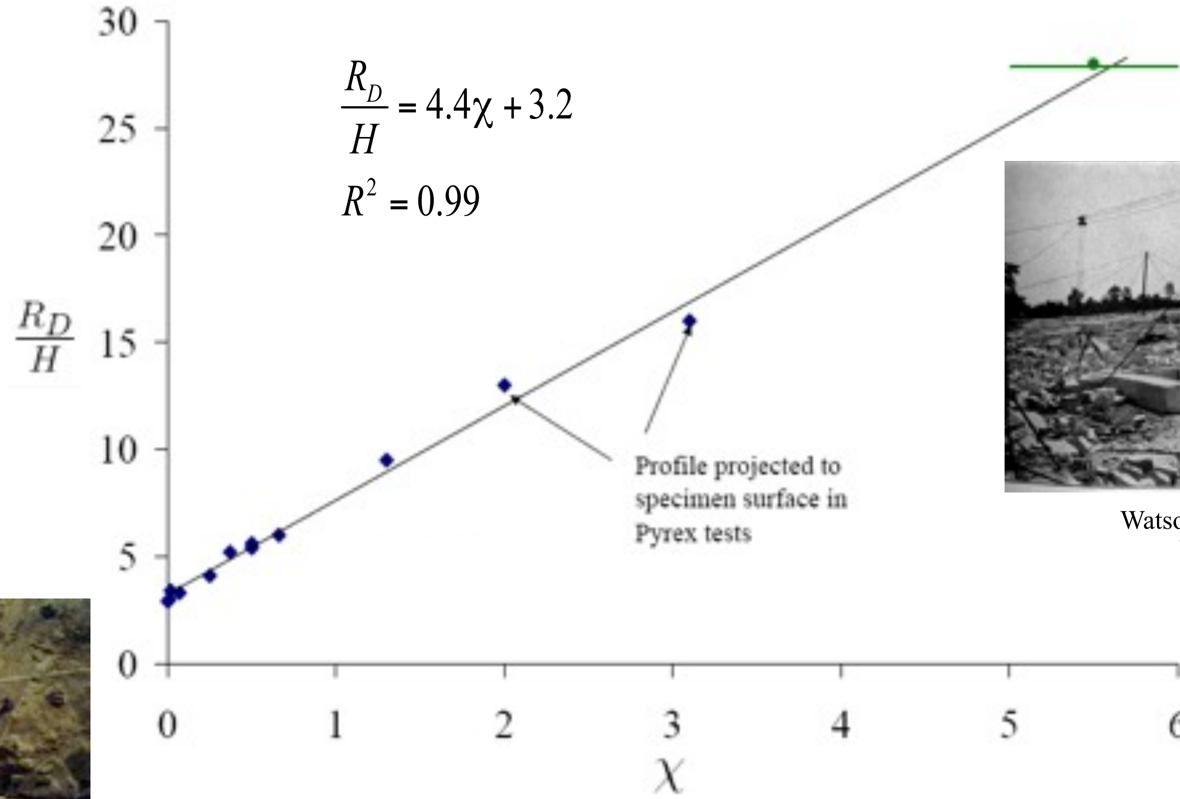
$$\chi = \frac{\sigma_r \sqrt{H}}{K_{Ic}}$$

σ_r = Lateral Far Field Stress

H = Initial Depth

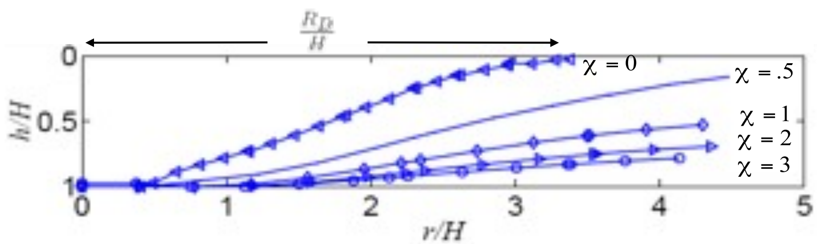
K_{Ic} = Fracture Toughness

Daylighting radius versus χ



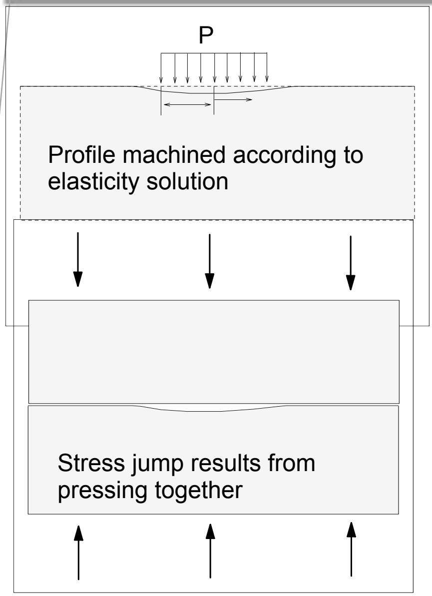
Watson and Laney 1906
Watson 1910

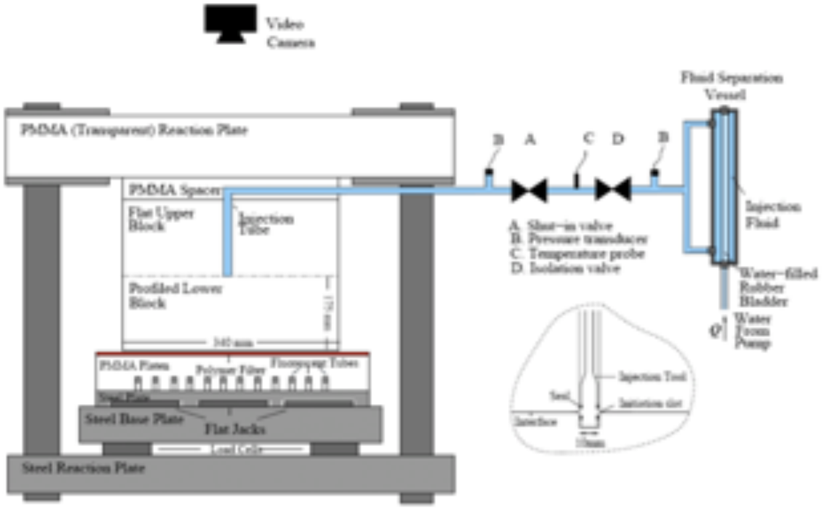
Murdoch and Slack 2002,
www.ces.clemson.edu/geology/murdoch

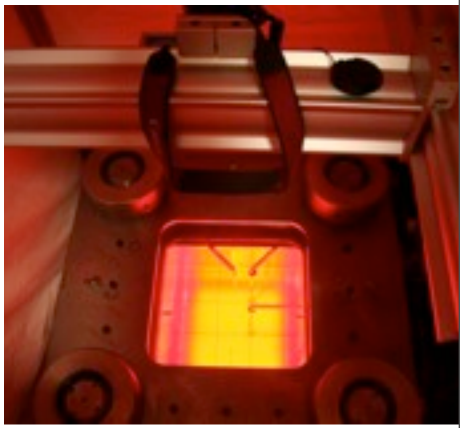


$$\chi = \frac{\sigma_r \sqrt{H}}{K_{Ic}}$$

Stress Jump Control of Hydraulic Fracture Height Growth

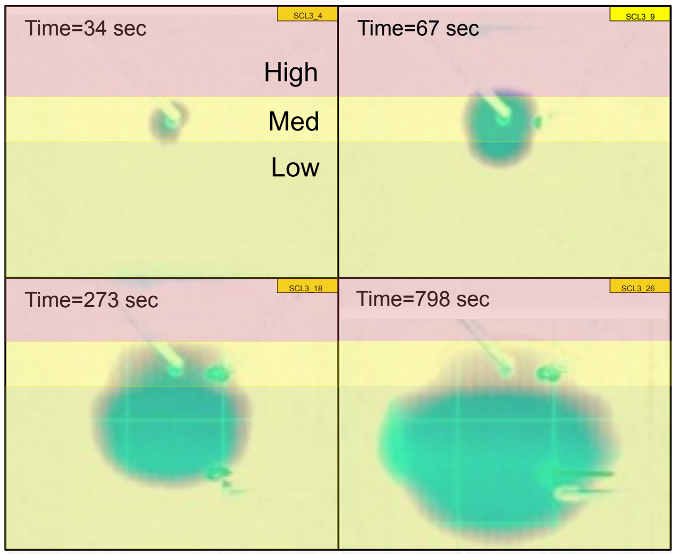




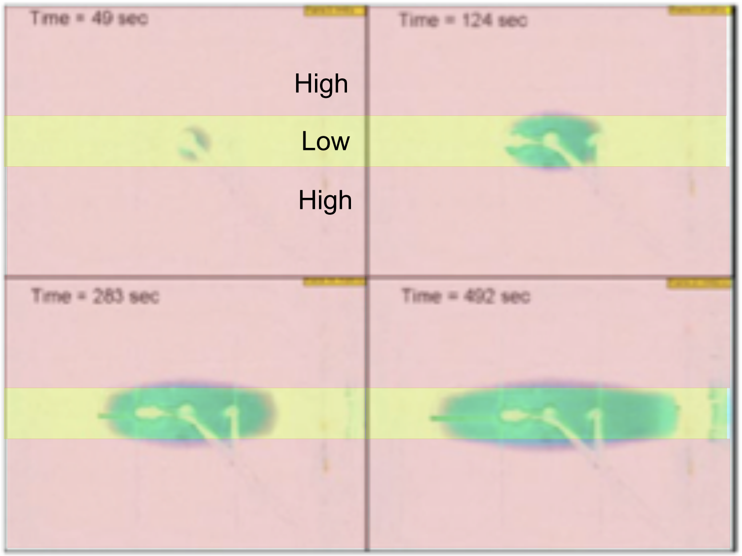


Enhanced Images

Herniation into low stress zone



Confined by high stress zones



Reflectivity imaging

- Tracking crack tip location
- Goal: Obtain image of growing fracture footprint and crack opening

Sample no. (time)

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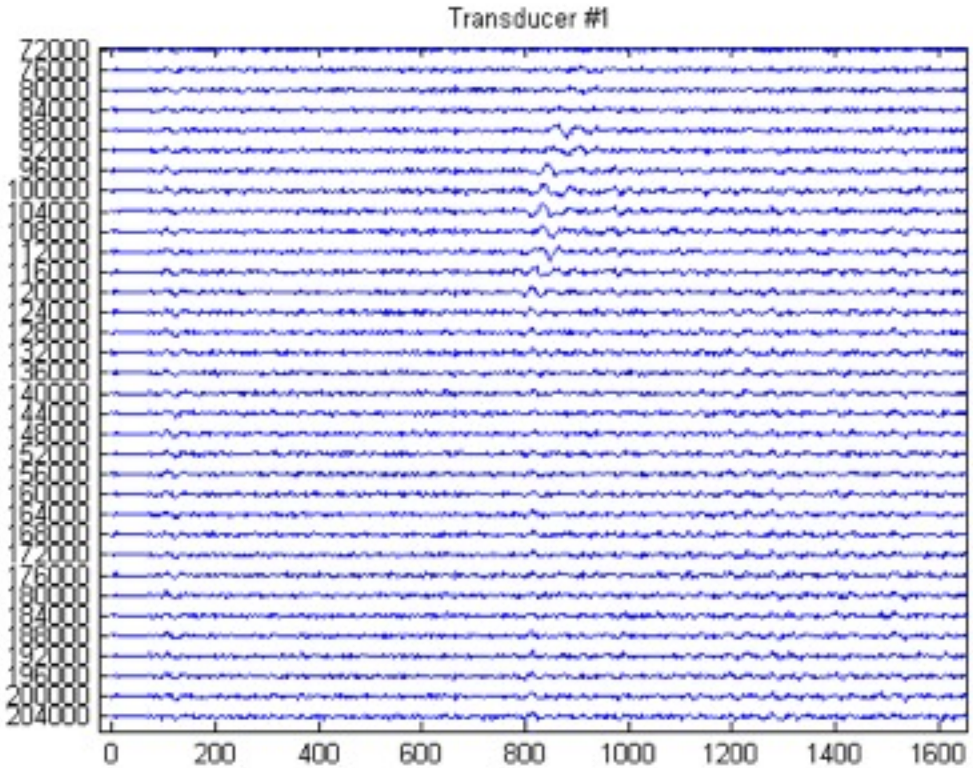

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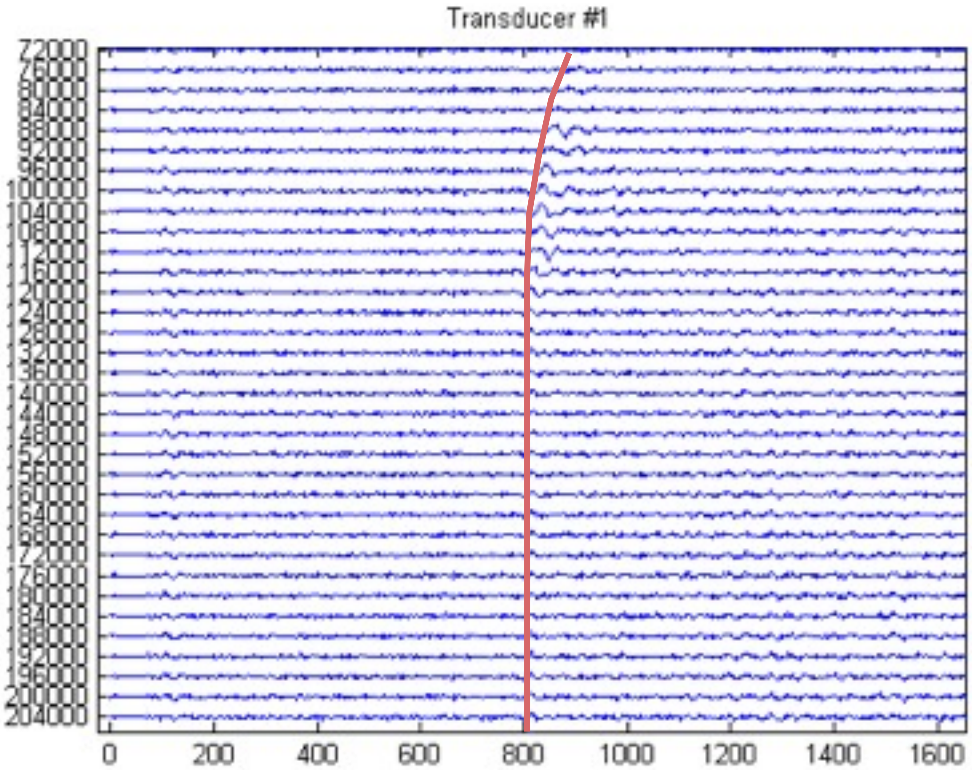

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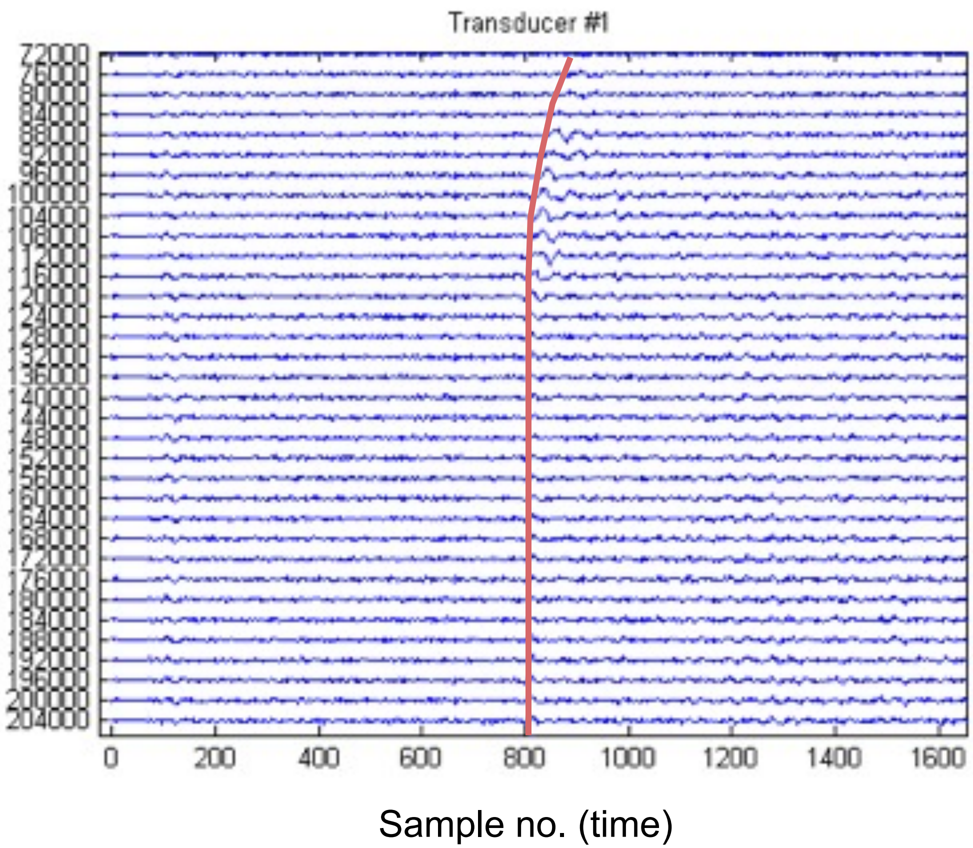

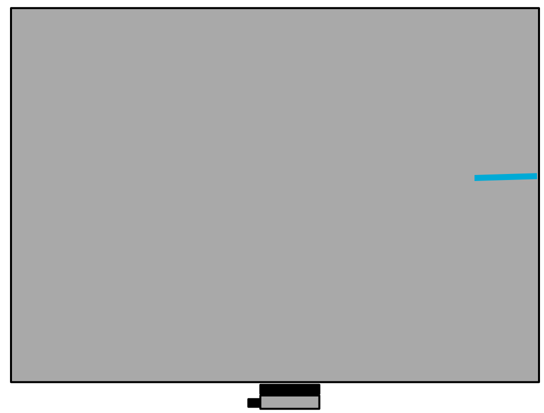

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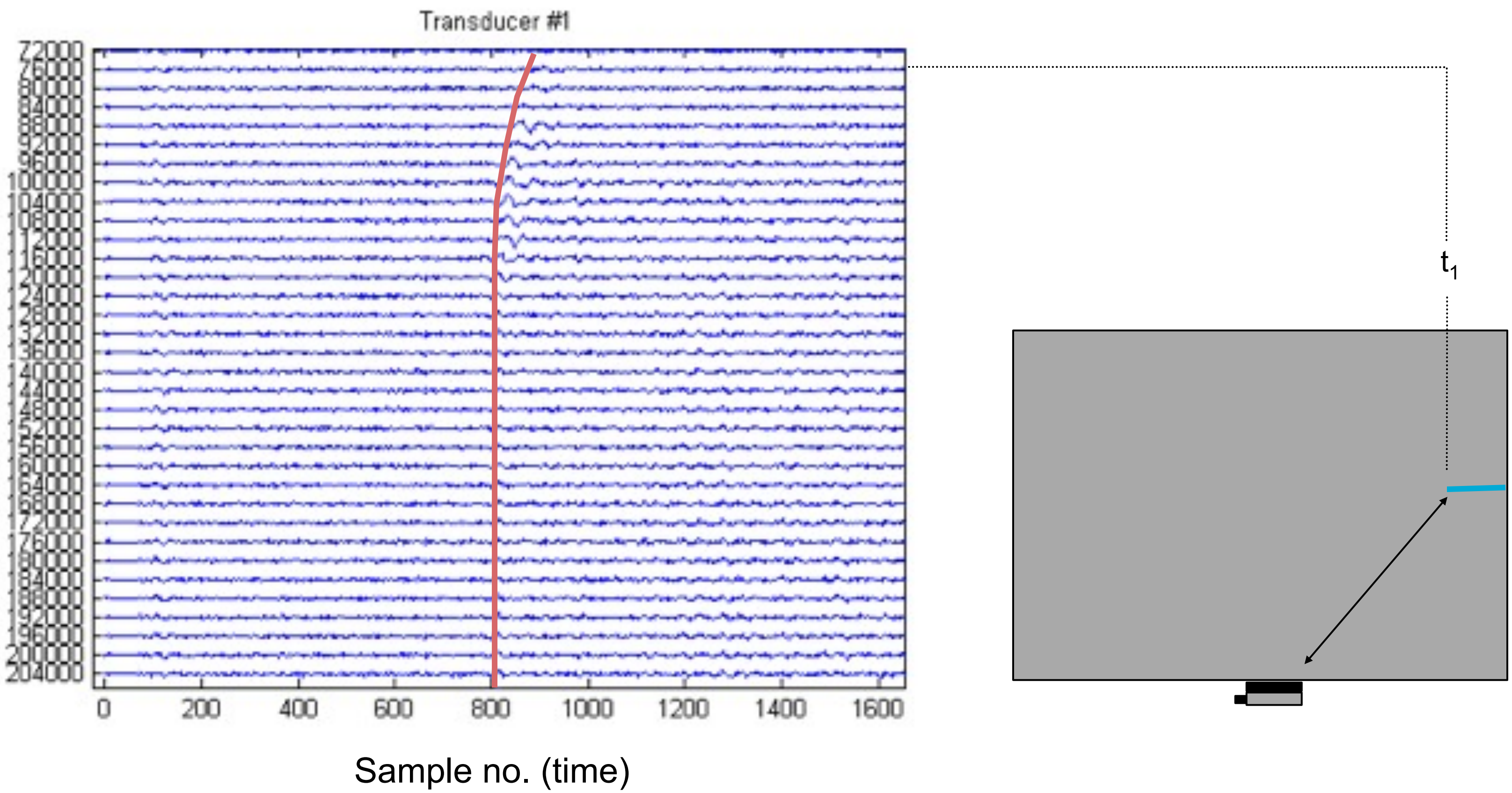

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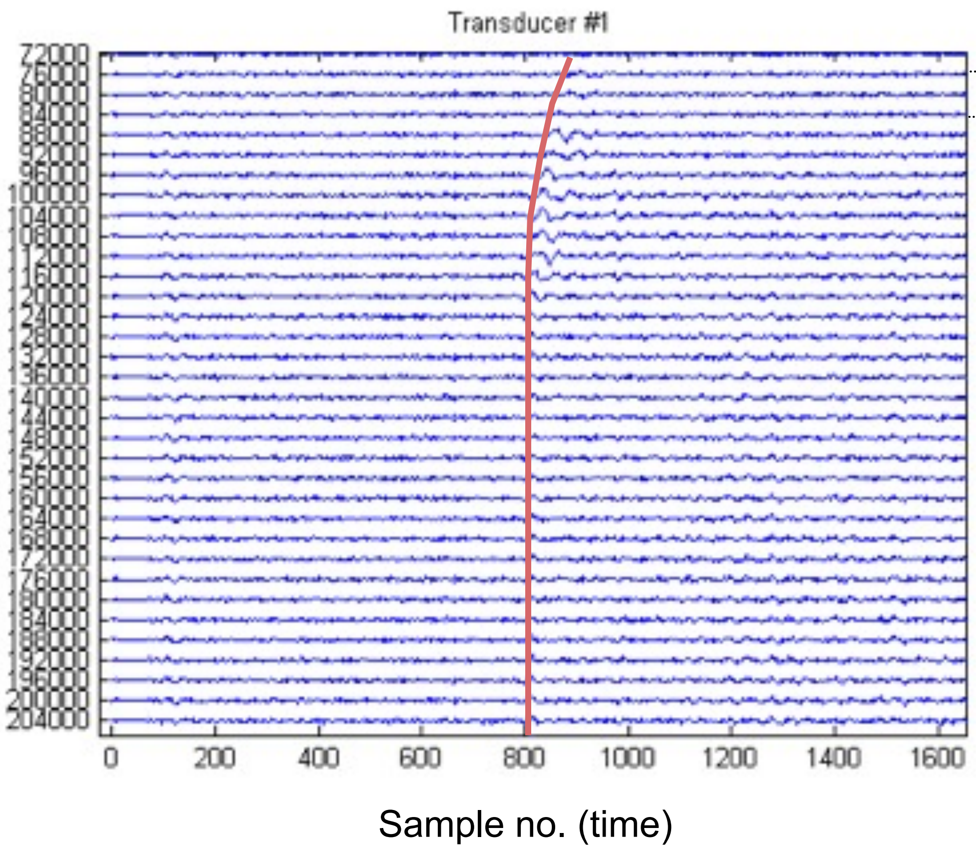

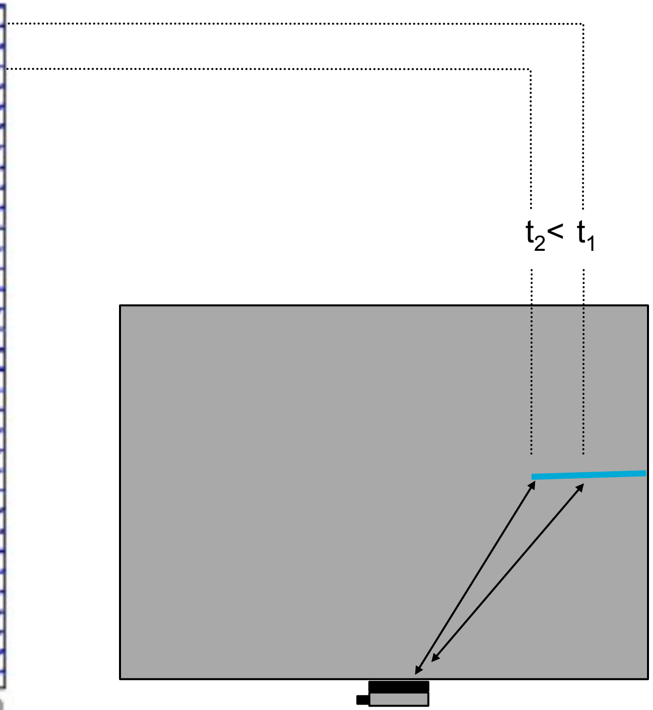

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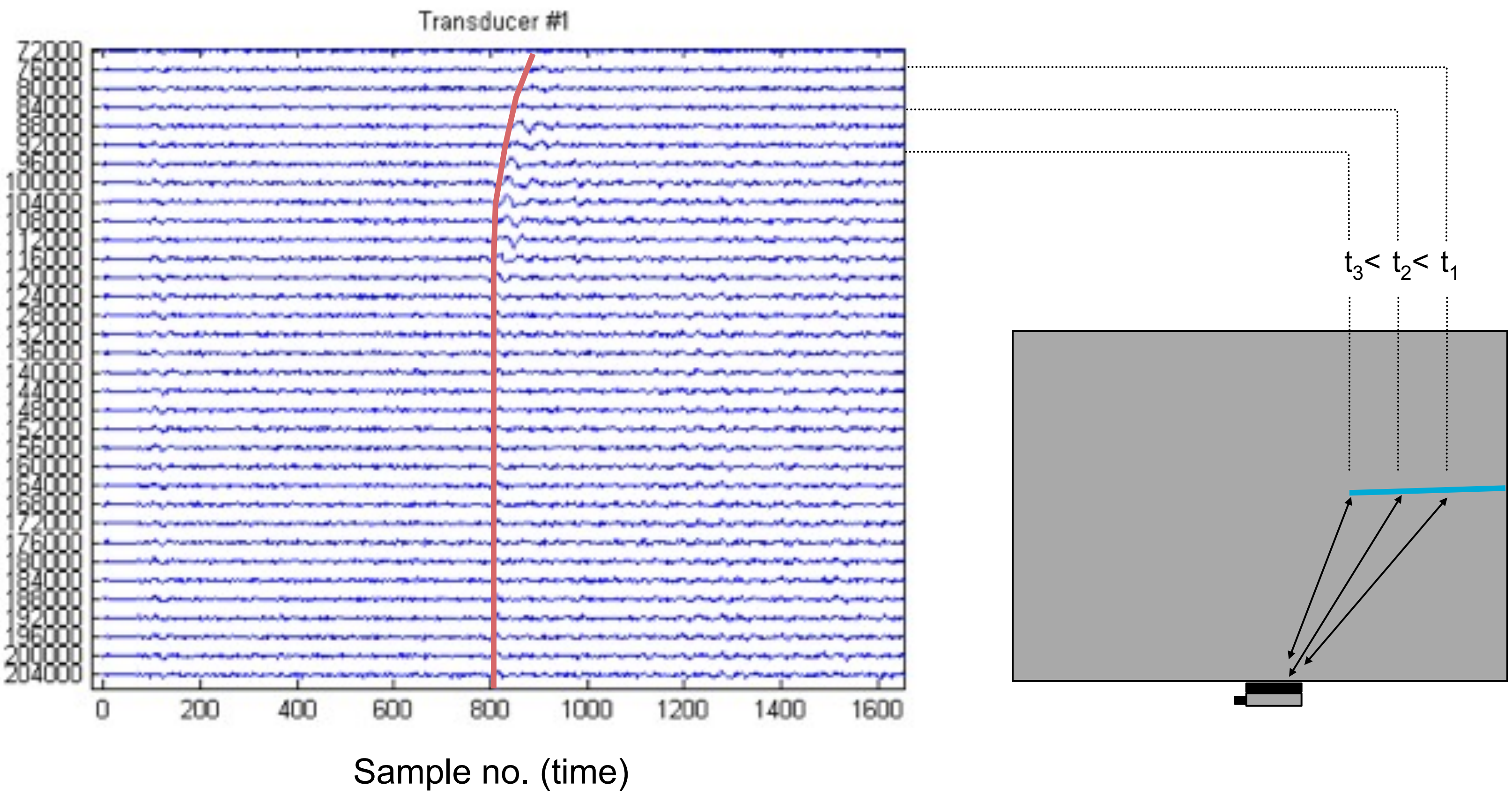

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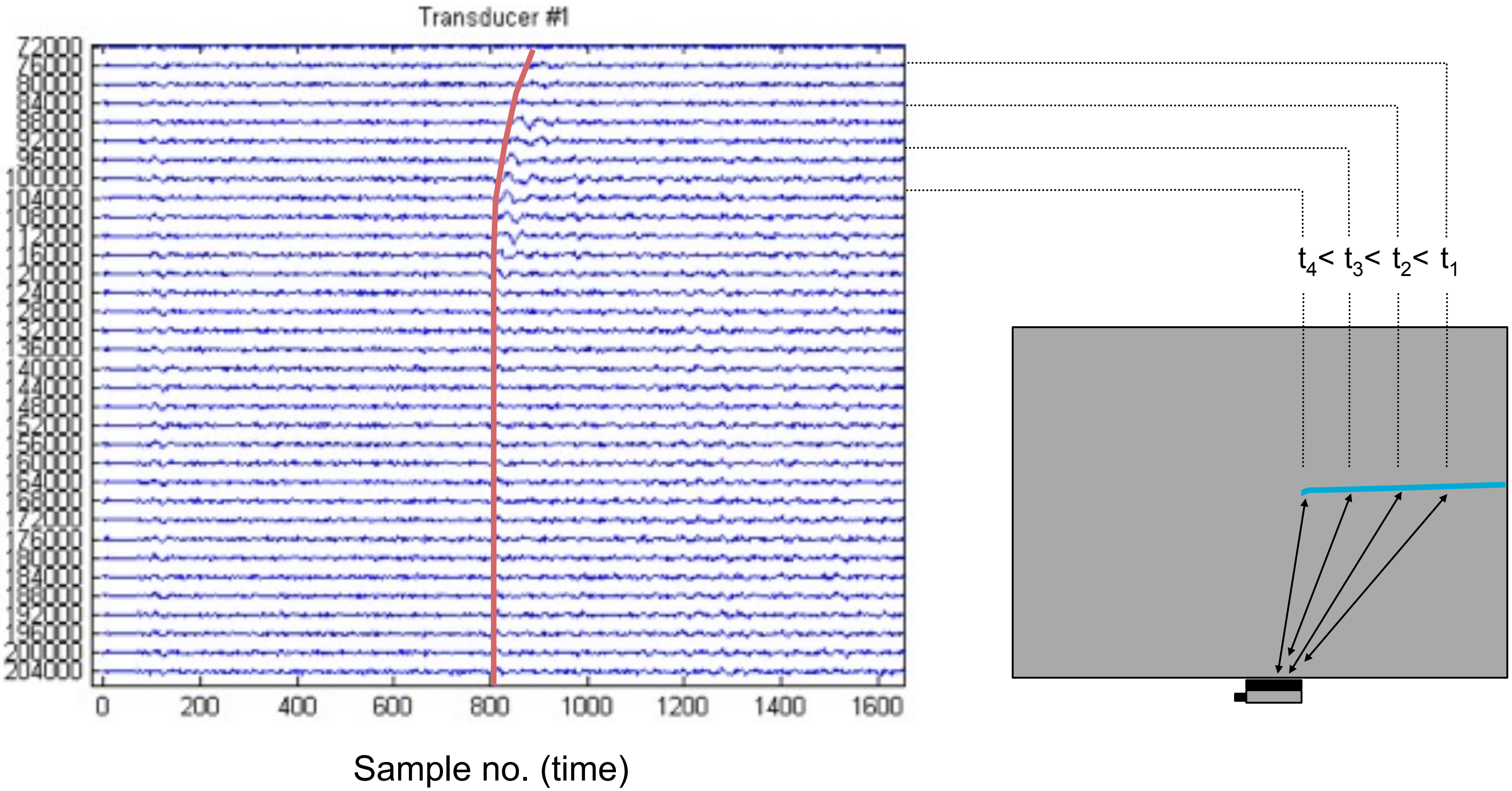

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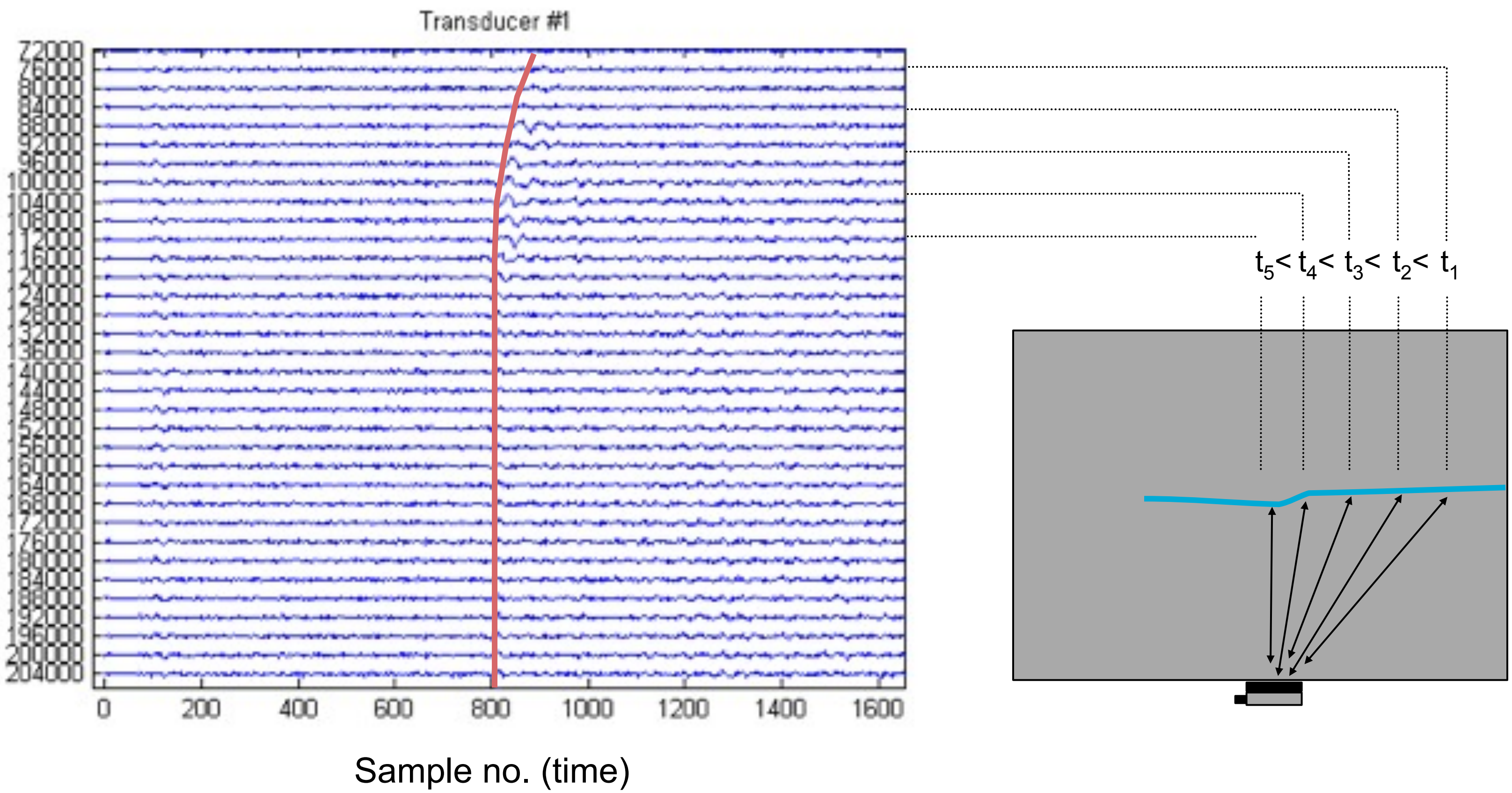
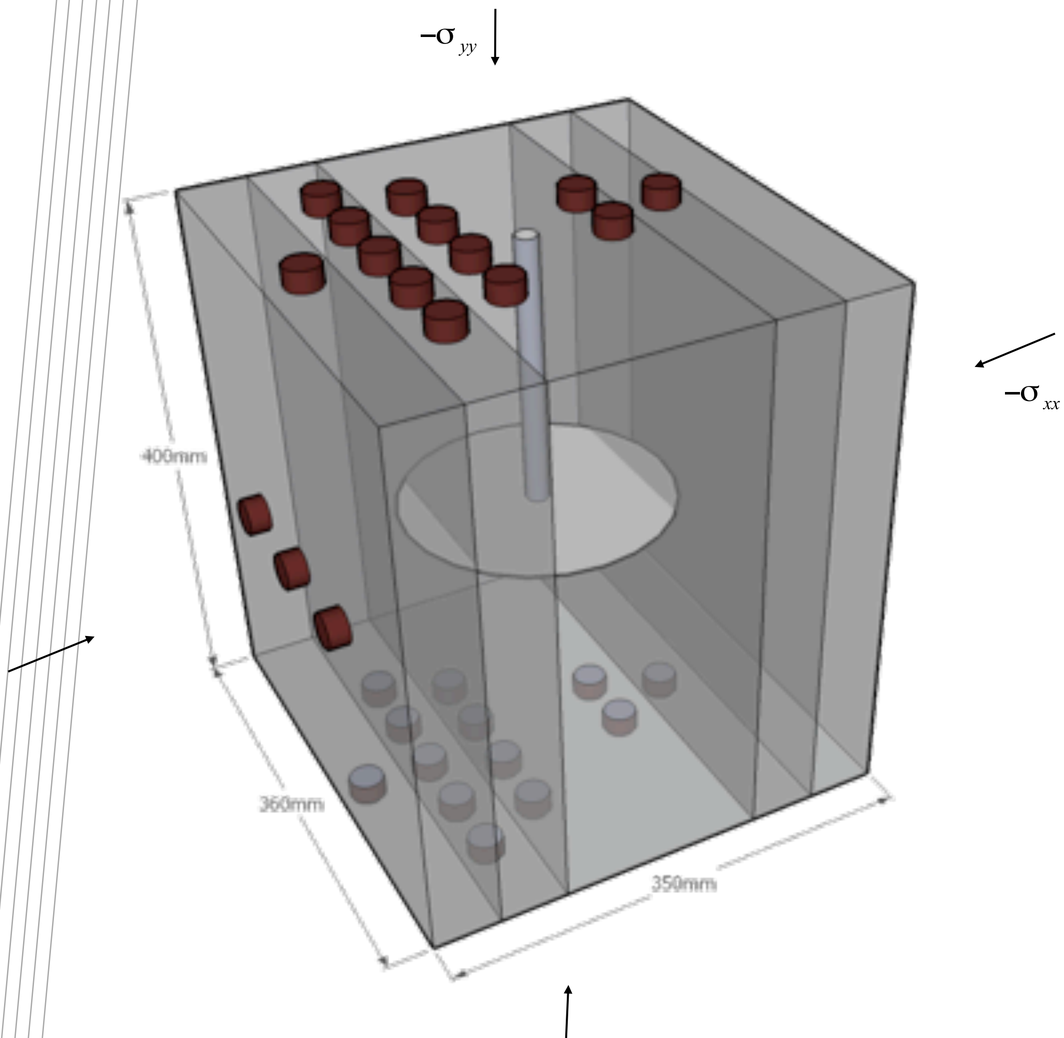
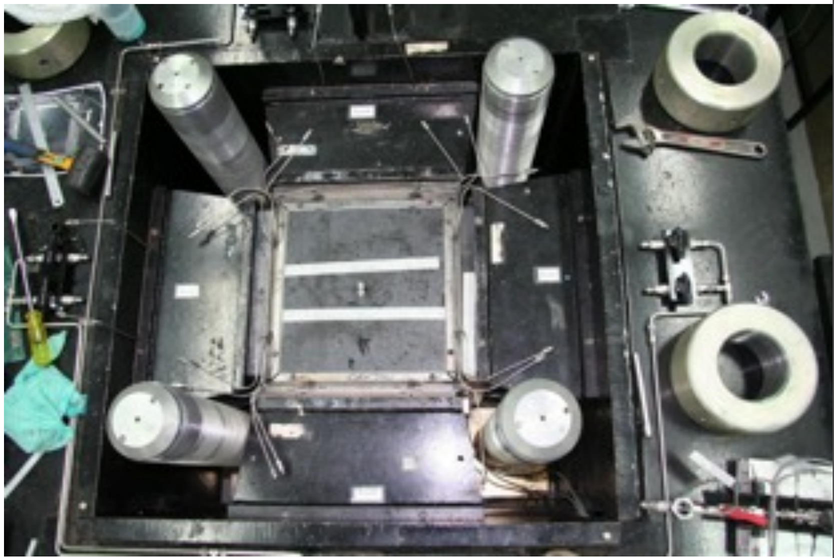
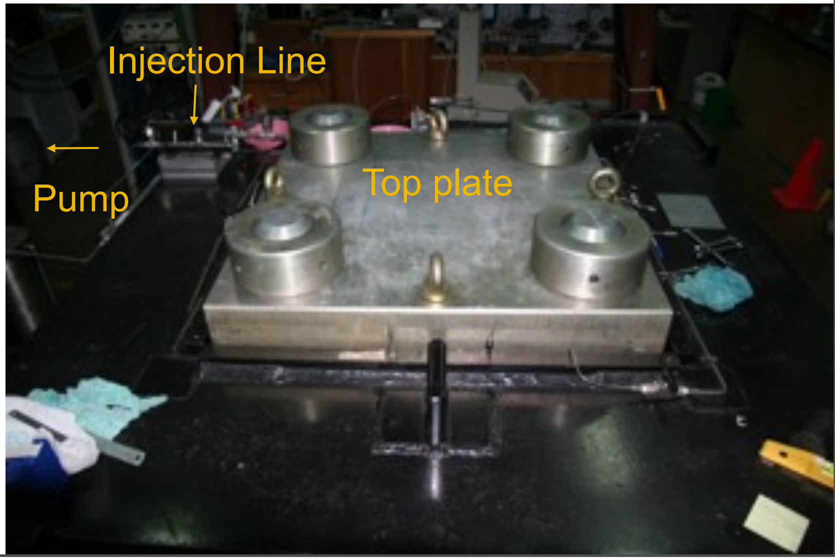


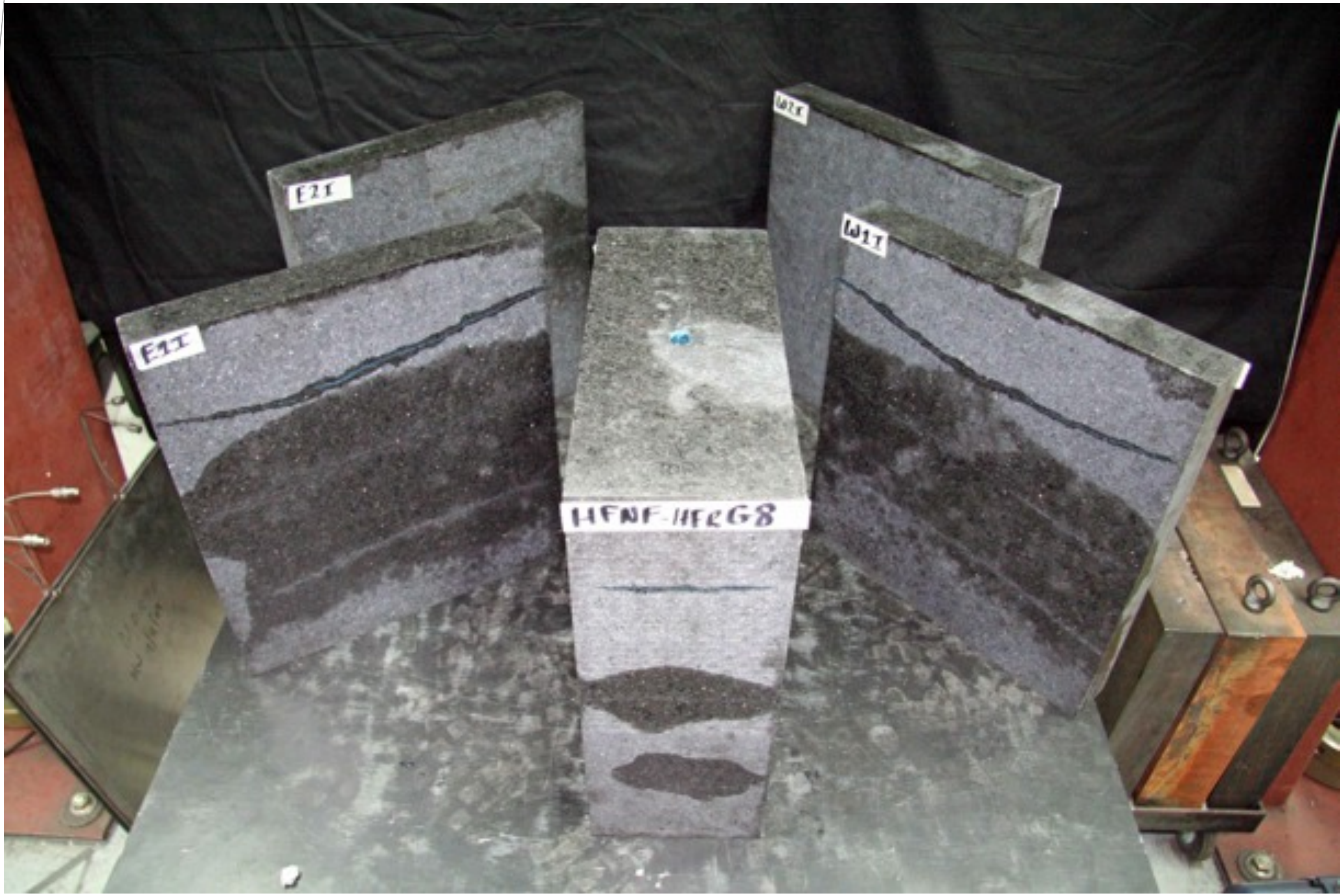
Fracture crossing experiments







Block that has been tested

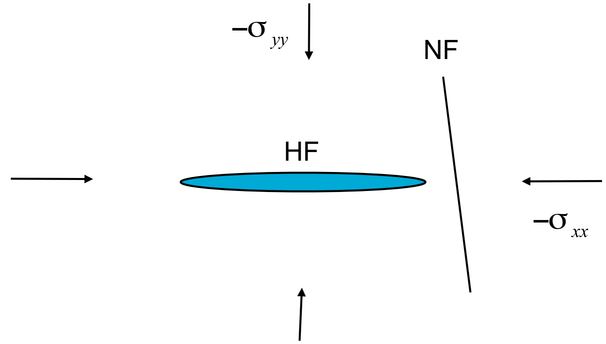


Fracture Crossing

Renshaw and Pollard (1995)

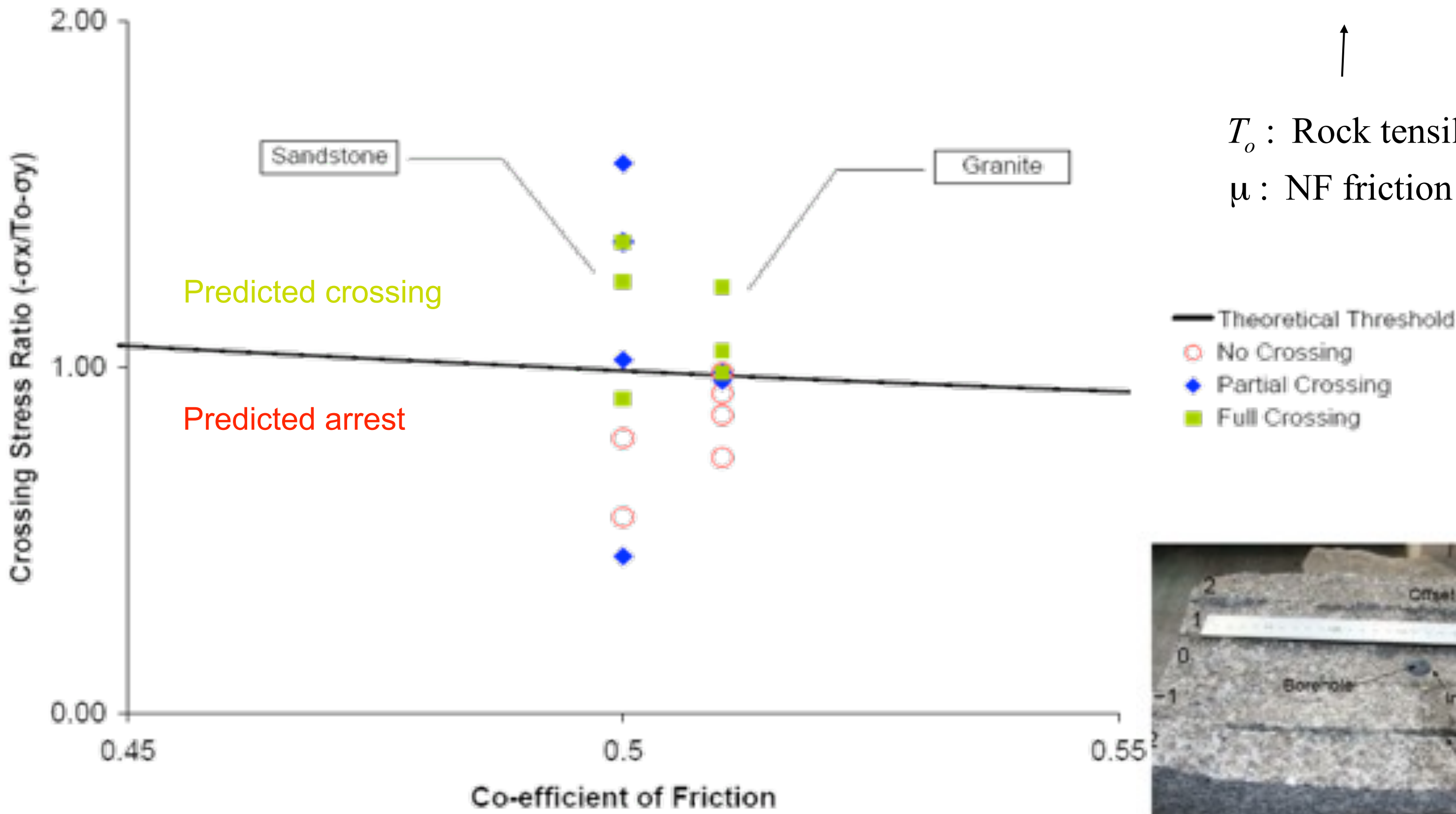
Predict crossing if:

$$\frac{-\sigma_{xx}}{T_o - \sigma_{yy}} > \frac{0.35 + \frac{0.35}{\mu}}{1.06}$$



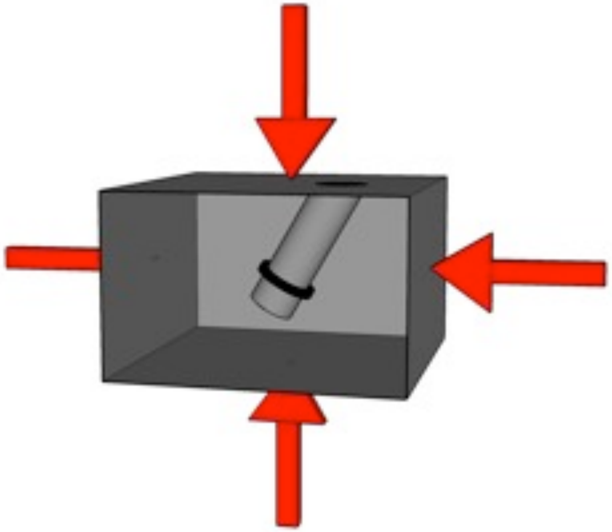
T_o : Rock tensile strength

μ : NF friction coefficient

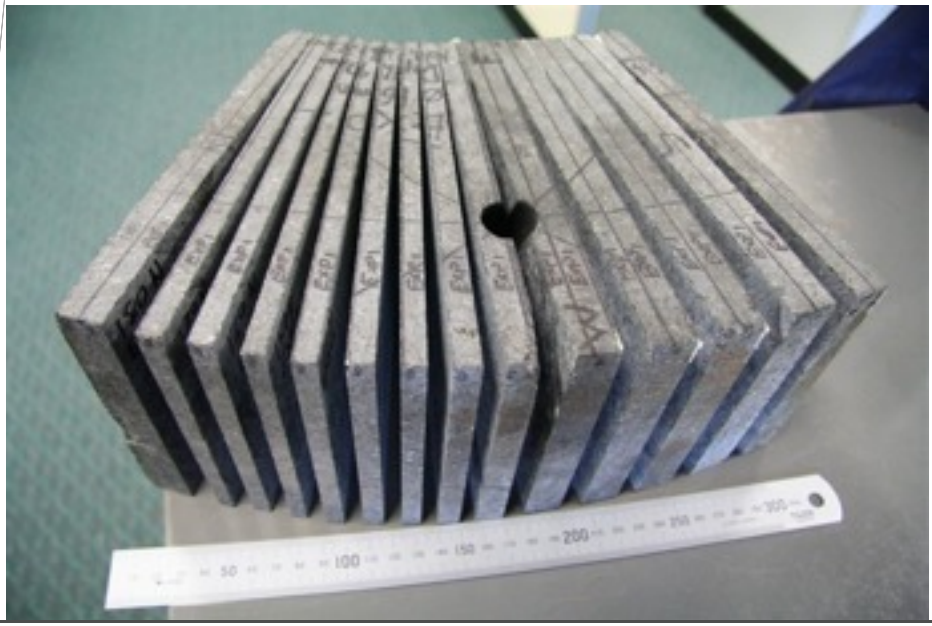


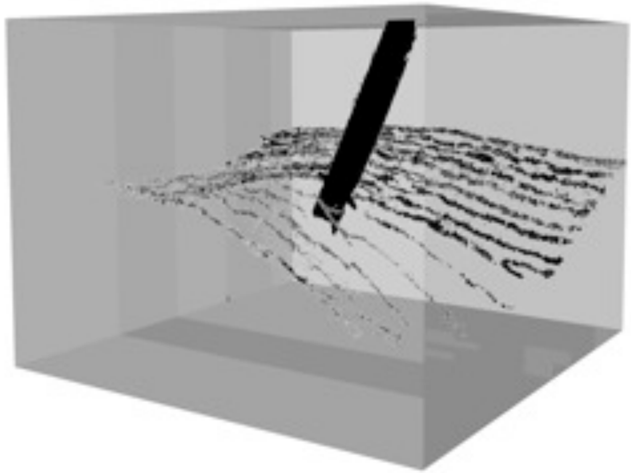
Experiments: Ella Maria Llanos, PhD Thesis, 2009

Reorientation from an Inclined Wellbore



- Classical fracture mechanics problem in 2D
- Not well understood in 3D, with role of wellbore, and in heterogeneous material
- Study through serial sectioning crack surface reconstruction

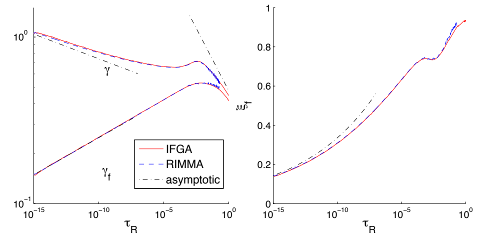




Numerical Modeling

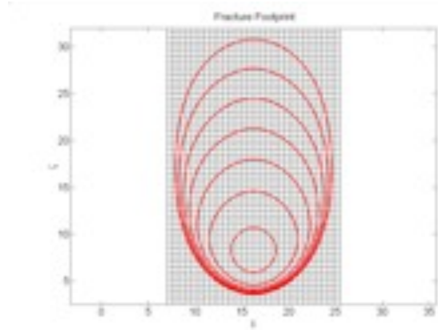
- 2D Simulations with tracking of both fluid front and crack edge

  (UMN, CSIRO)



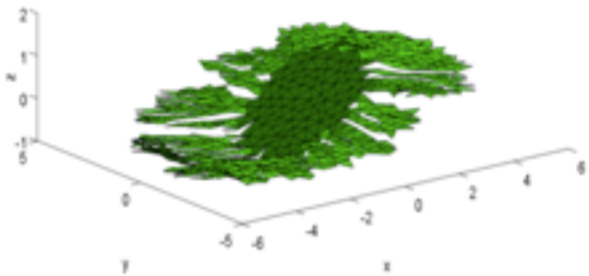
- Planar 3D Simulator

  (UBC, UMN)



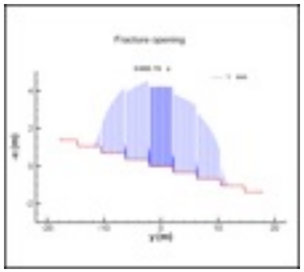
- Non-planar 3D Simulator

  (CSIR)

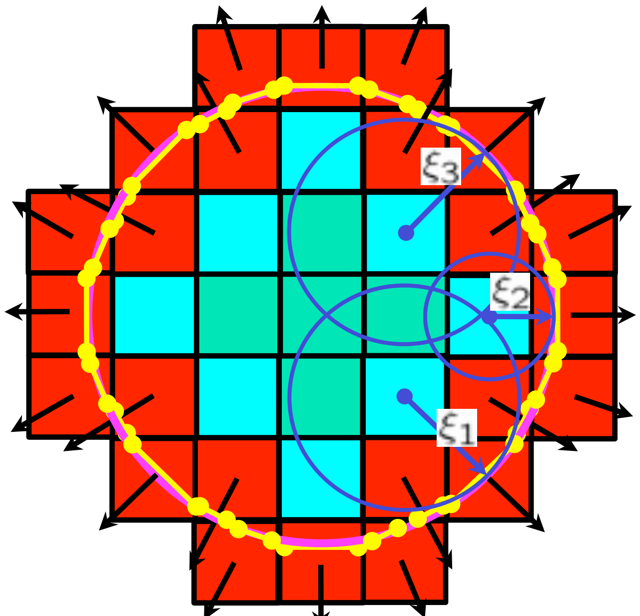


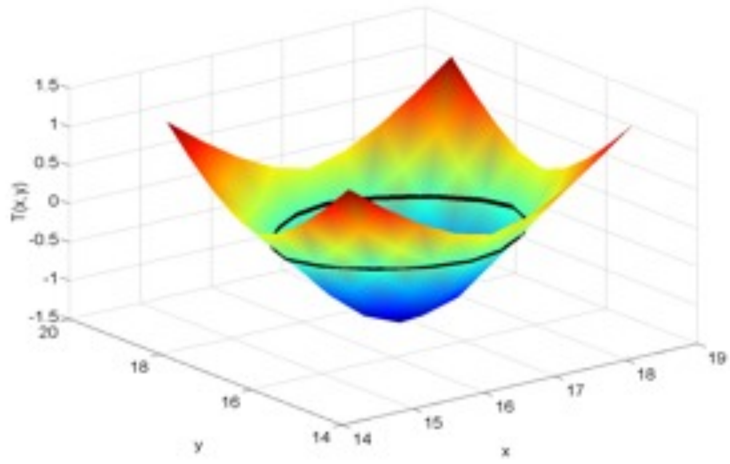
- Interaction between HF Fracture and discontinuities

  (CSIRO, UMN)

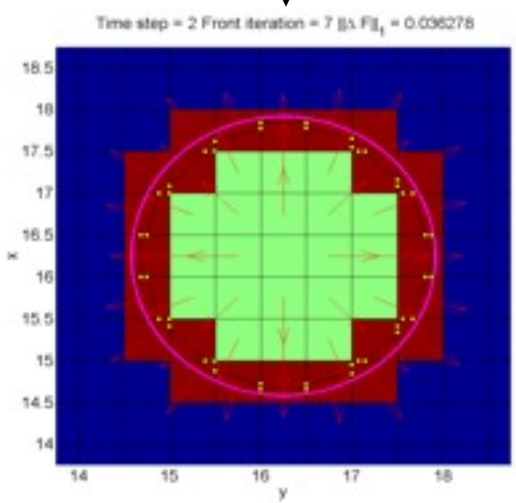


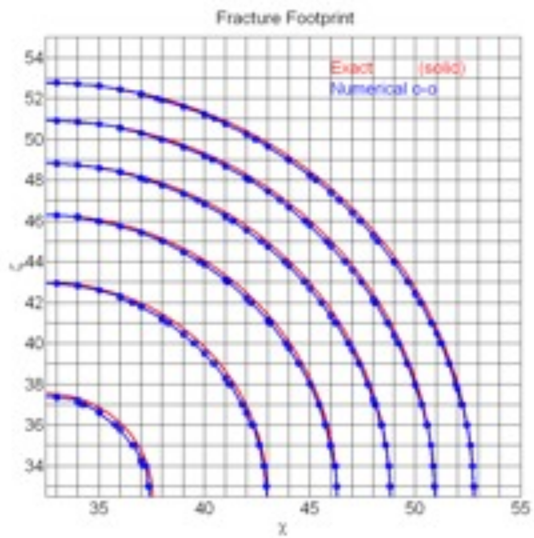
Planar 3D Hydraulic Fracture Simulator



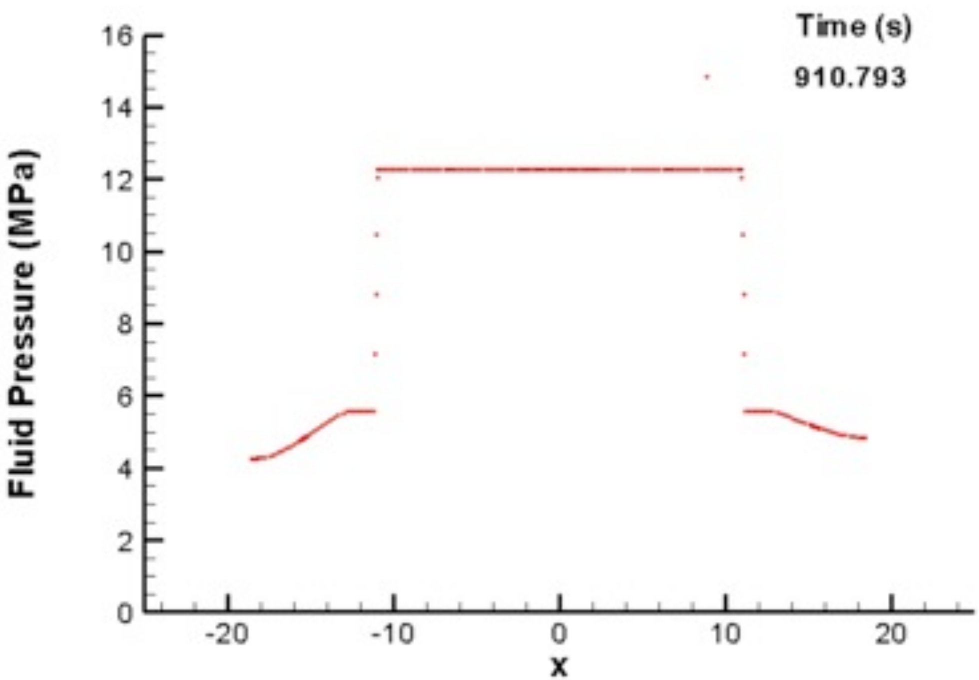


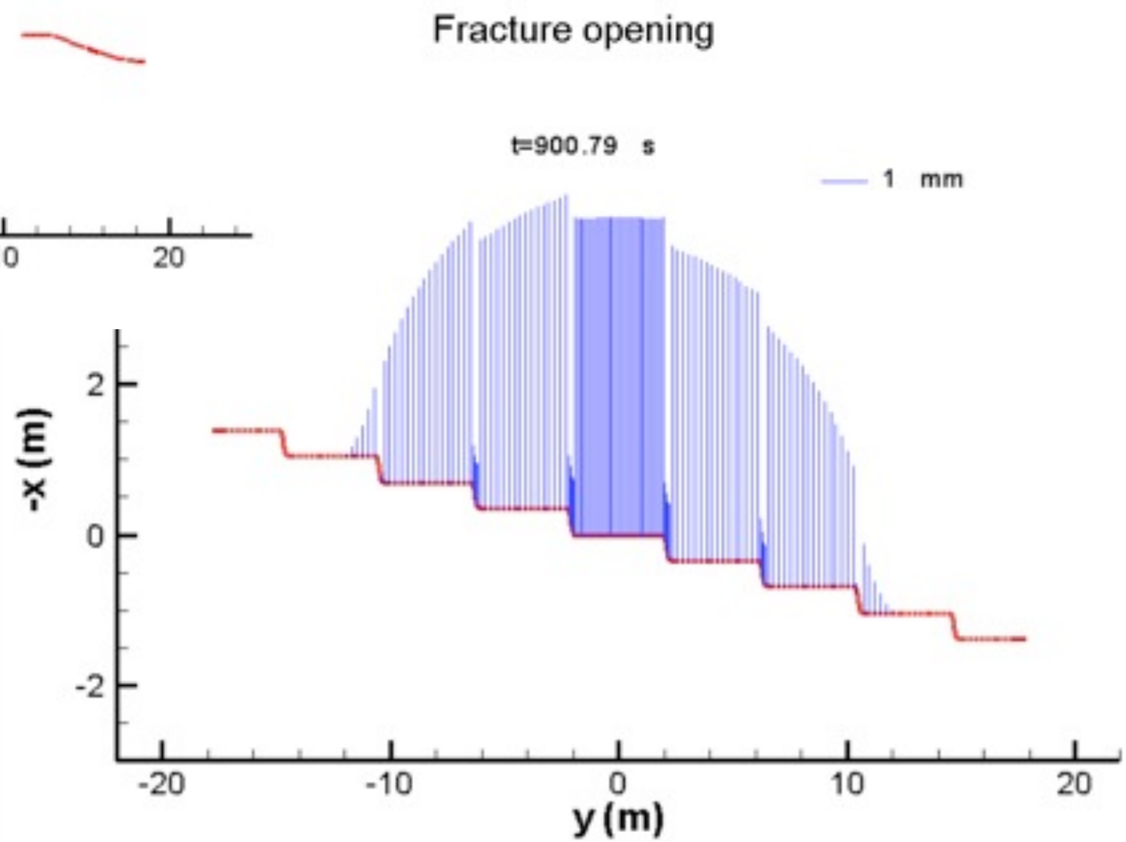
The signed distance function





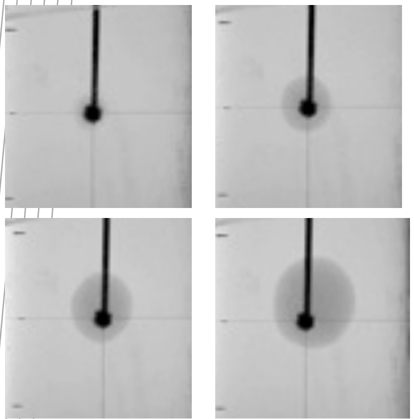
DD HF model of fracture with offsets





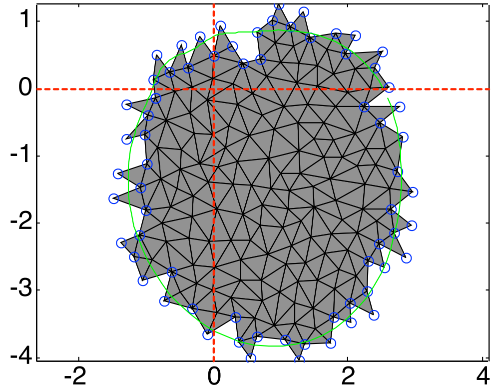
1. Large pressure gradient at offset sites.
2. Large fracture opening behind (upstream of) these points
3. Slower overall fracture growth.

The New 3D Fracture Simulator Gives Promising Match to Experimental Observations For:

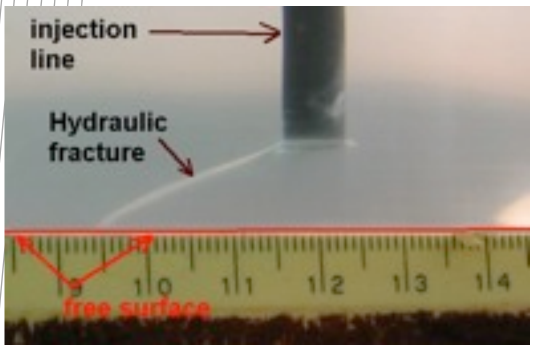


⬅ Experiment

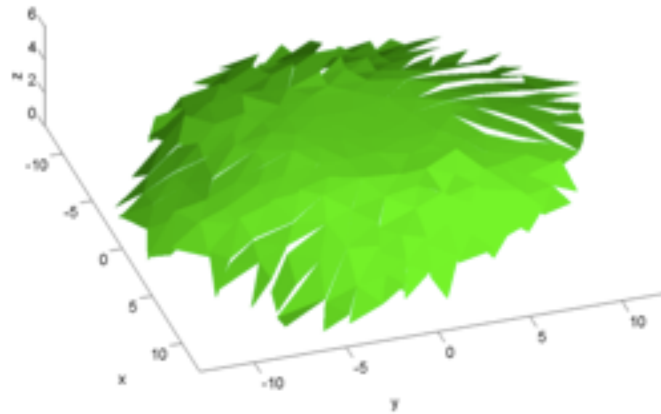
Simulation ➡



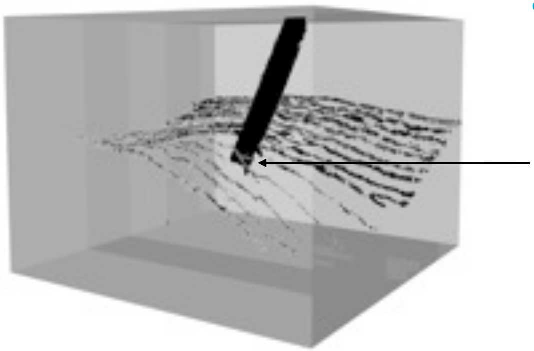
- Breaking of initial symmetry, i.e. movement of the crack centre

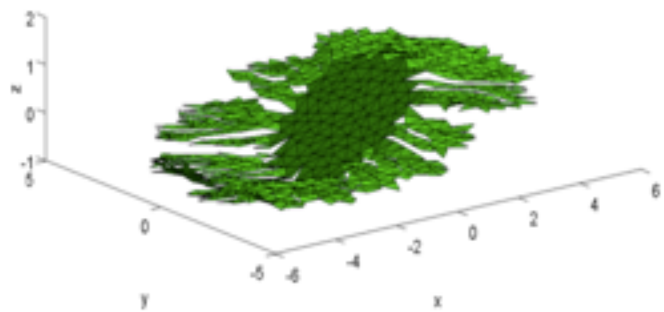


- Shallow fracture crack path and fine scale features such as river line surface roughness

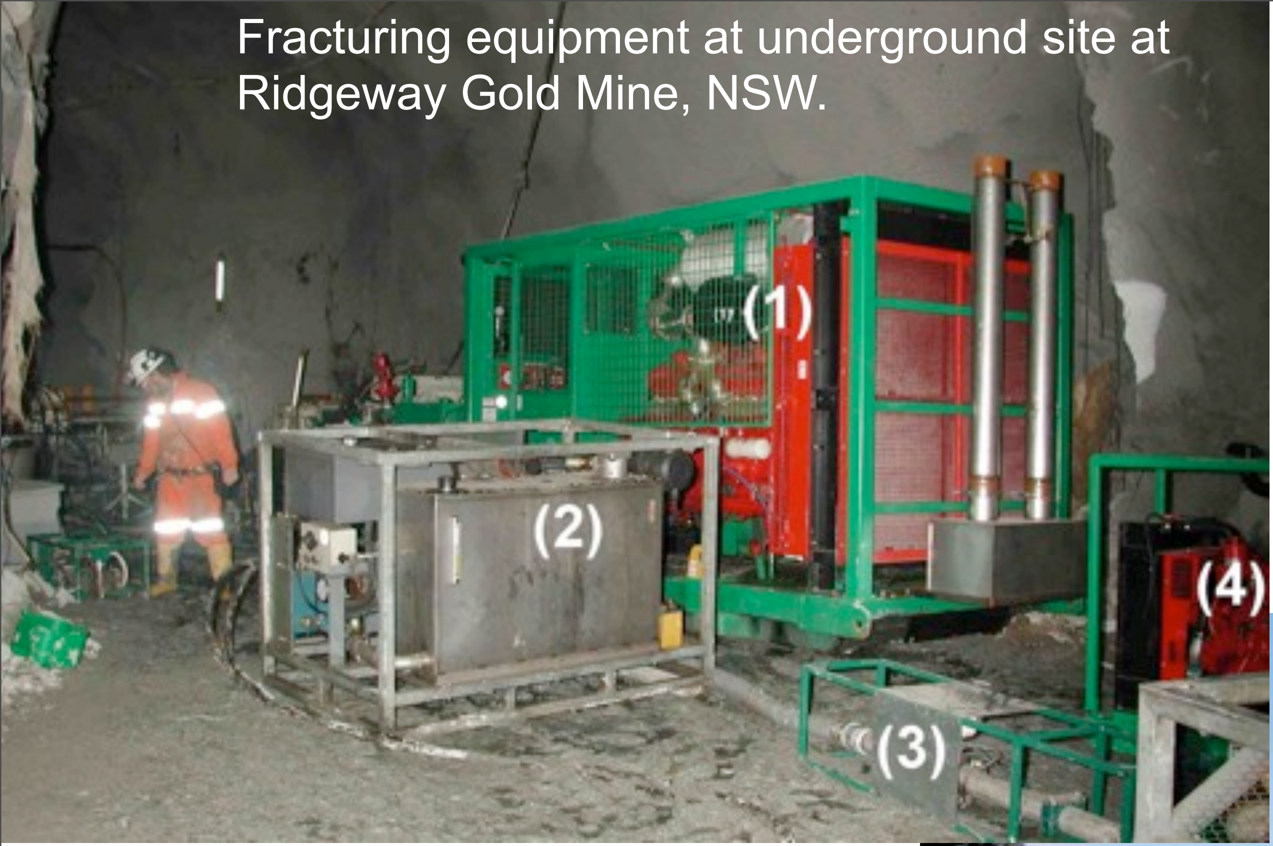


- Formation of petals near initially inclined hydraulic fractures





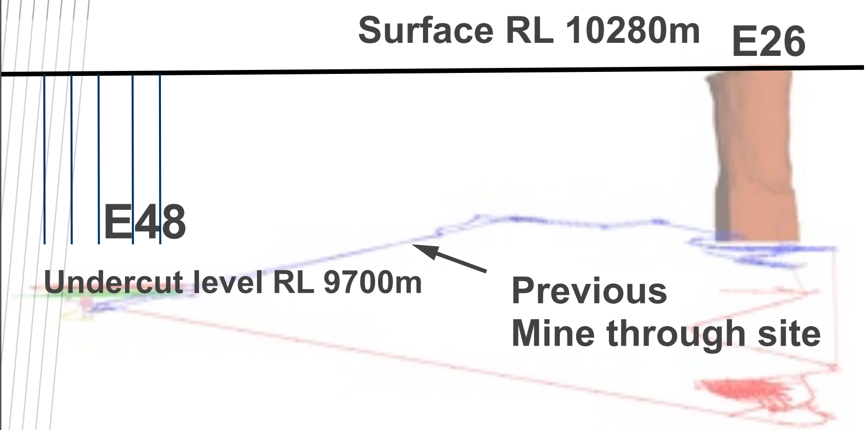
Former Field Experiments (CSIRO)


Fracturing equipment at underground site at
Ridgeway Gold Mine, NSW.
(1)
(2)
(3)
(4)

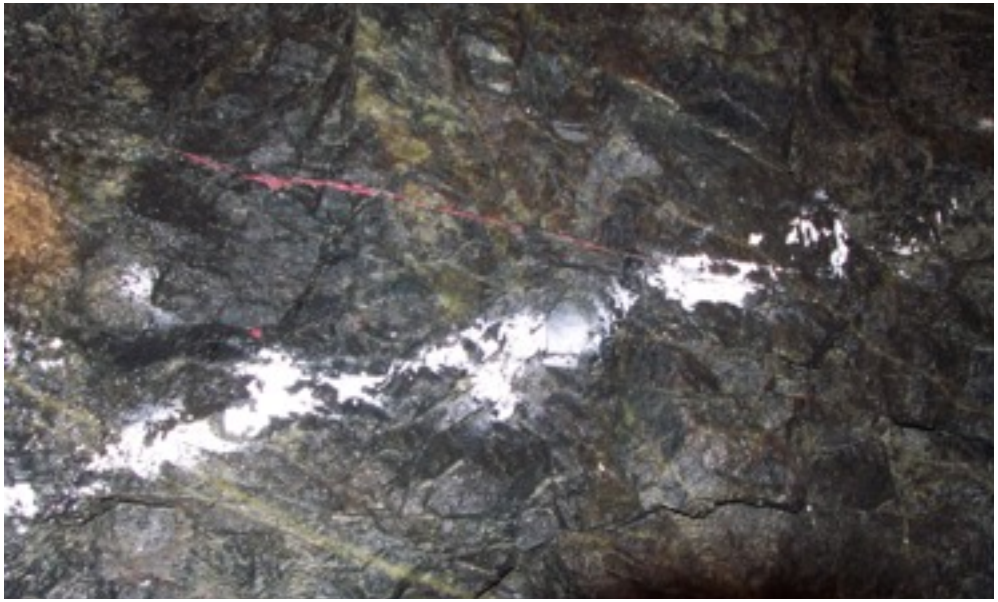

Surface site at Moonee

Preconditioning

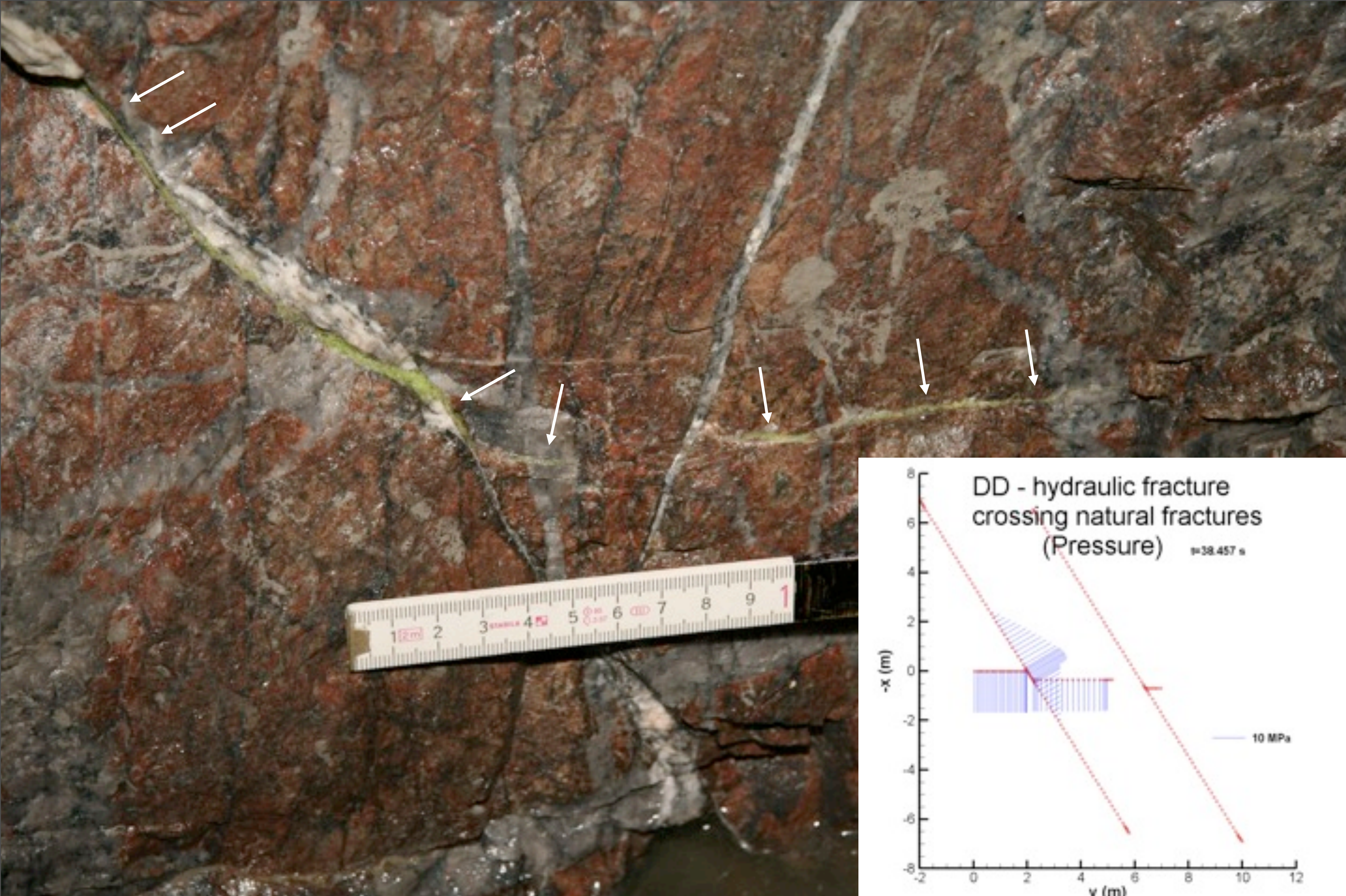
- Characterize rock mass
- Instrument site
- Place 4-8 HFs
- Post-frac rock mass measurements
- Map & sample fractures (mine-through)
- Evaluate model predictions against data



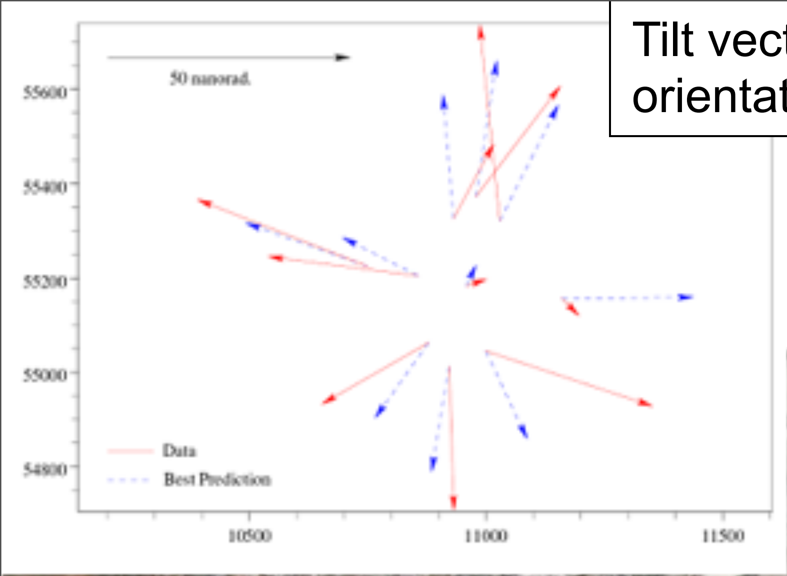
4850 level



Jeffrey 2001, CSIRO

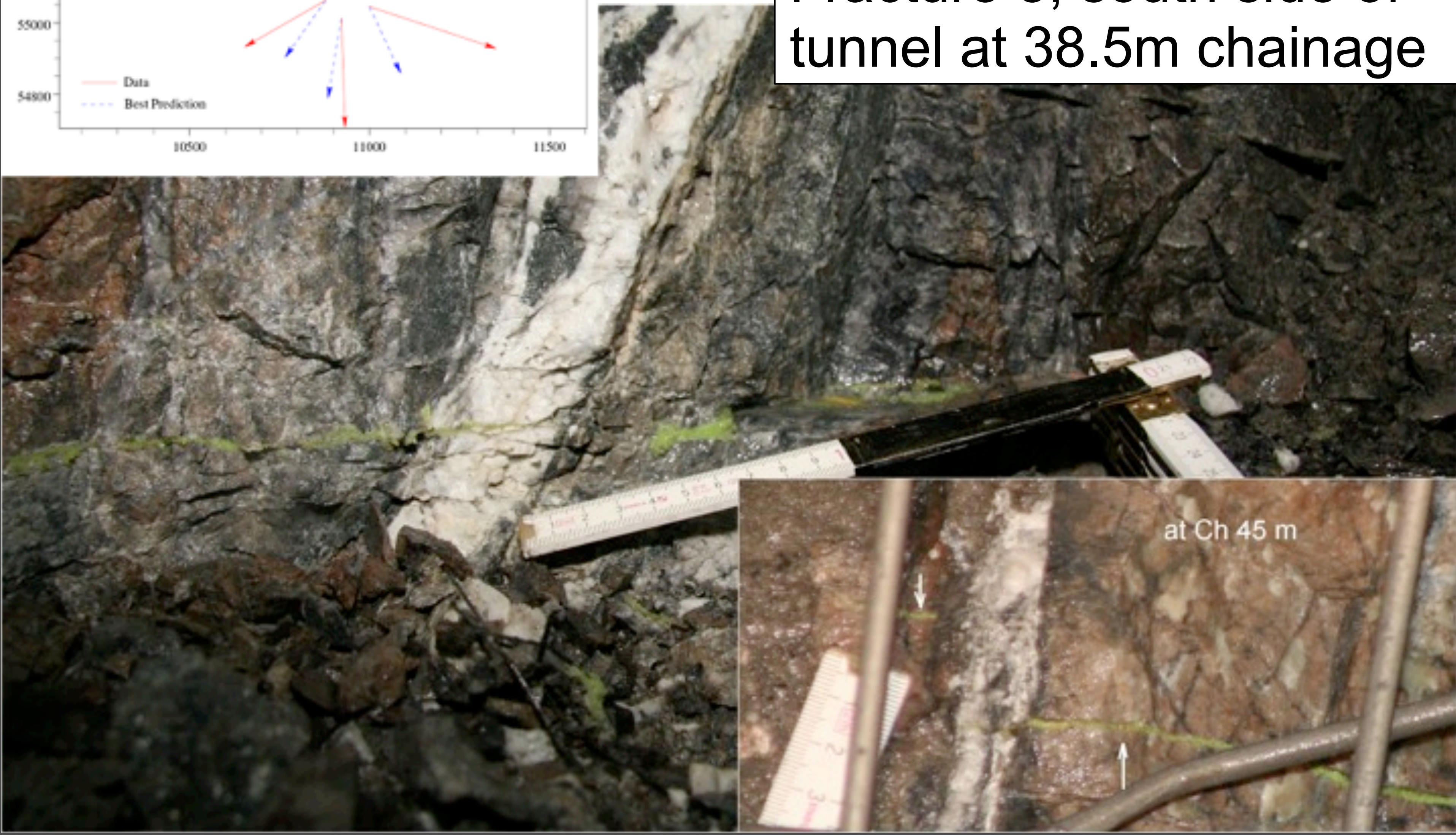


Green plastic proppant in hydraulic fracture placed during E48 consortium project

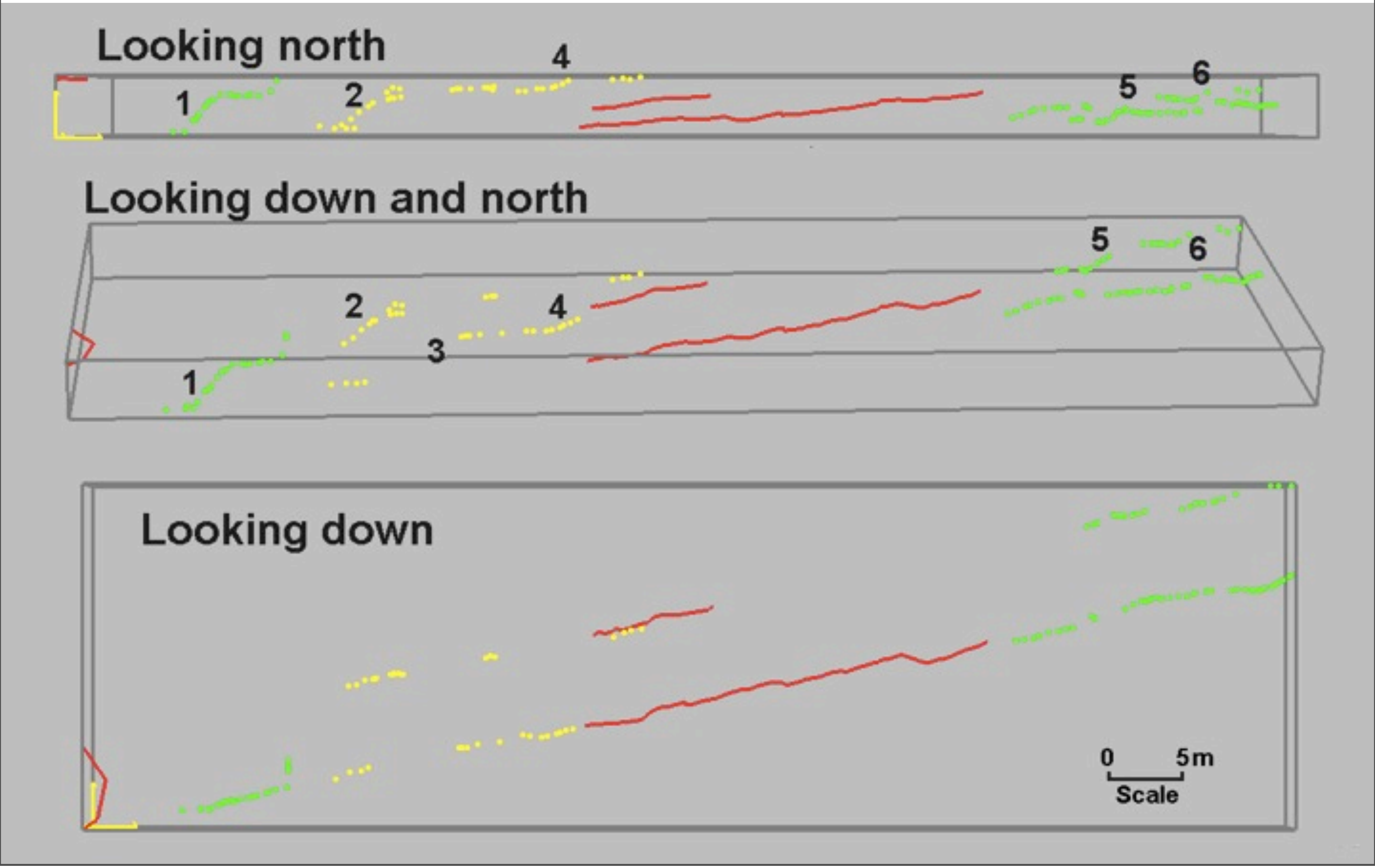


Tilt vectors for E48 fracture indicating sub-horizontal orientation.

Fracture 8, south side of tunnel at 38.5m chainage



Fractures mapped in E48 tunnel – three views shown.
Large offsets are indicated by numbers.

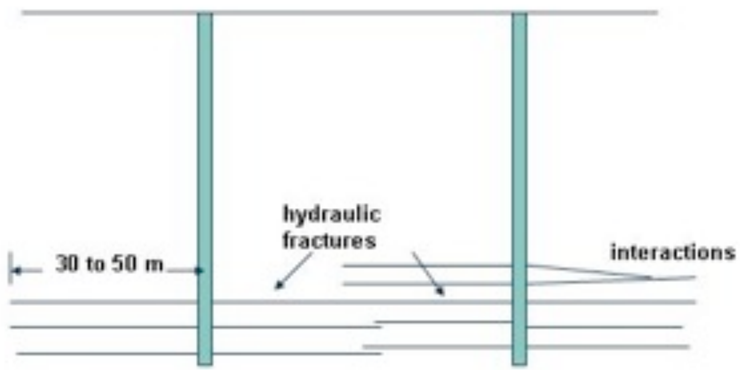


Engineered fracture

Preconditioning:

The experiments will consist of several stages:

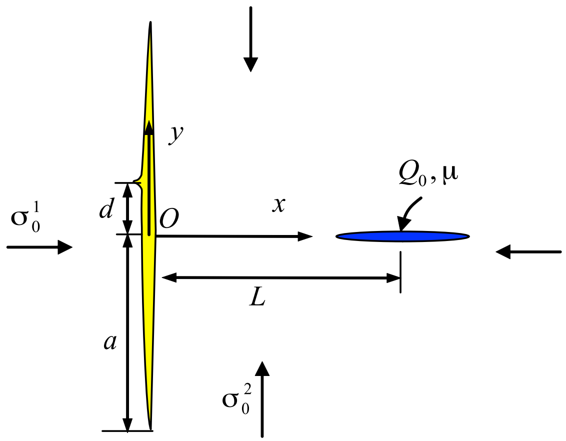
1. **Analyses and designs of fracture treatment**
2. **Characterization of local site conditions**
3. **Installation of monitoring instrumentation**
4. **Mobilization of fracturing equipment and materials**
5. **Fracturing and measurement of response**
6. **Post - fracture characterization**
7. **Mine through and mapping**
8. **Analytical and numerical modeling**
9. **Supporting laboratory experiments**



Preconditioning

Engineered fractures in discontinuous rock

- **Crack initiation**
- **Scaling**
- **Crack interactions**
- **Interface fracture**
- **Shear v opening mechanisms**
- **Coupled processes**
- **Microseismics & imaging**



Mine-through

- Combine with cutting research
- Fracture geometry, width & extent
- Continuity & branching
- Interaction w/ existing fractures