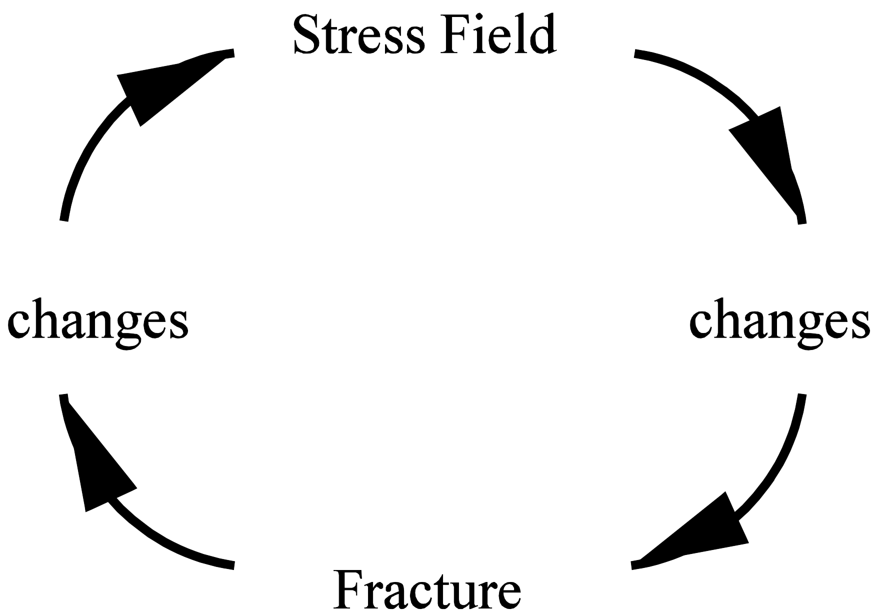
Crack-initiation and fracture propagation in reservoir rocks

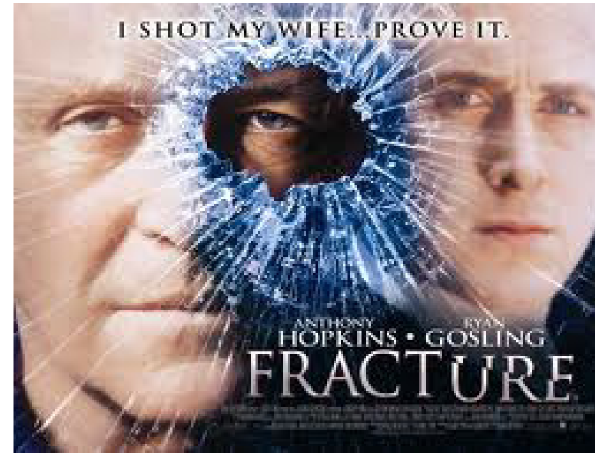
Srutarshi Pradhan

SINTEF Petroleum Research

Fracture & Flow meeting, January 2013,
IMSc, Chennai, India

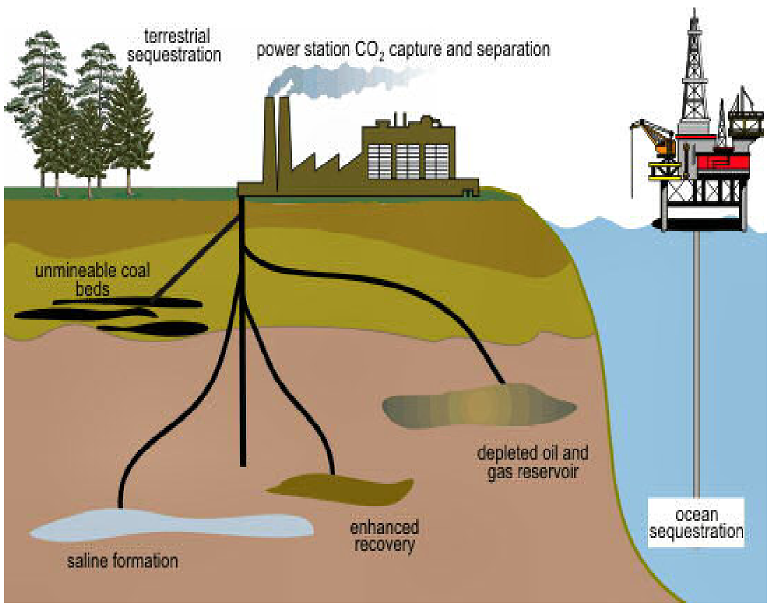
Dynamics of fracture

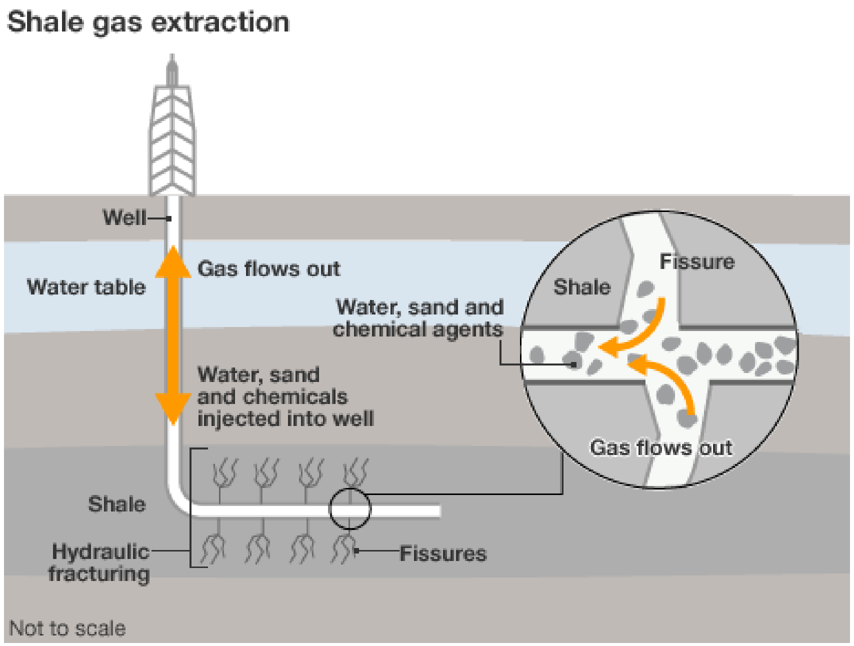




Crack-growth in nano-materials
……onset of earthquake

Fracturing during fluid injection





- Methods:

    1) Fracturing test on core samples
    2) PFC at pore scale
    3) Beam-lattice model at mesoscopic scale
    4) MDEM at macro scale (even resorvoir scale)
    5) FEM using Abaqus

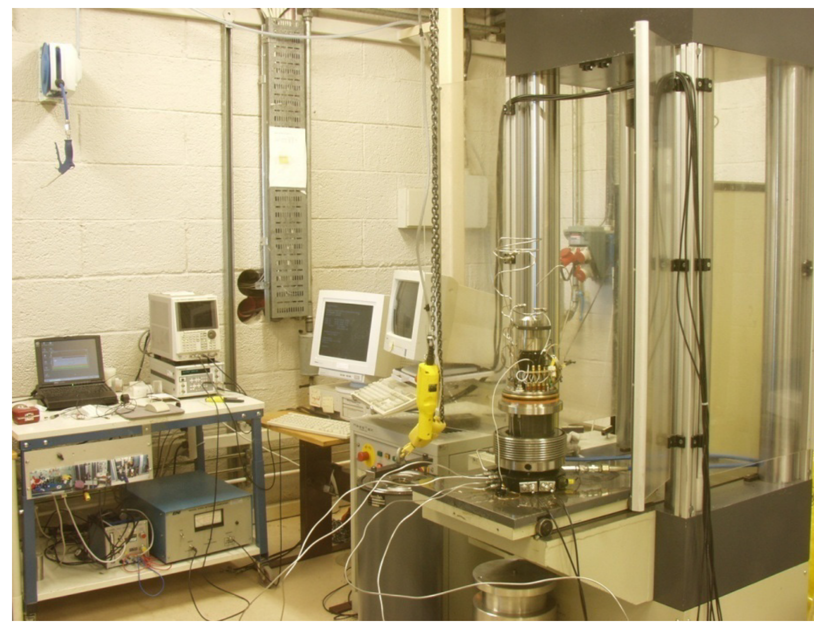
- Application:

    1) Planning safe & efficient drilling (geothermal, shale-gas)
    2) Reservoir characterisation (CO_2 storage)
    3) Prediction of well collapse & leakage
    4) Enhance production by increasing permeability.

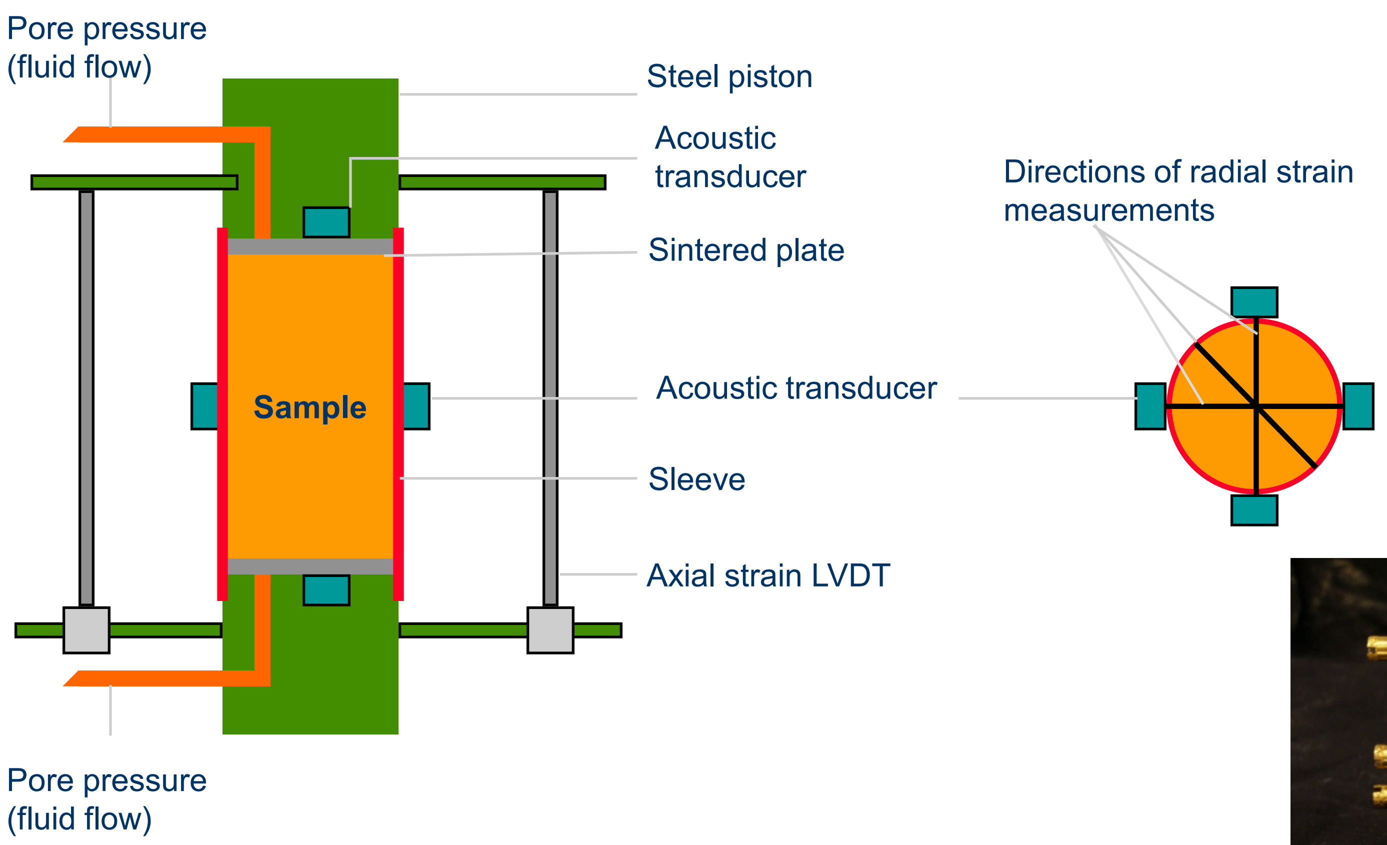
SINTEF Laboratory

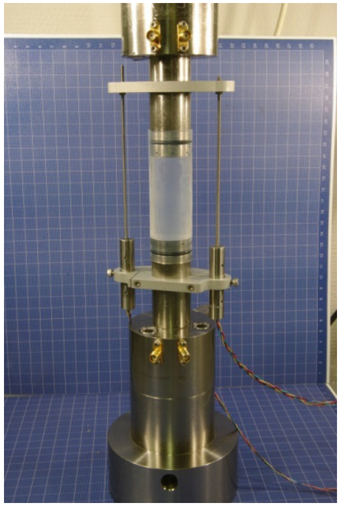
TerraTek system

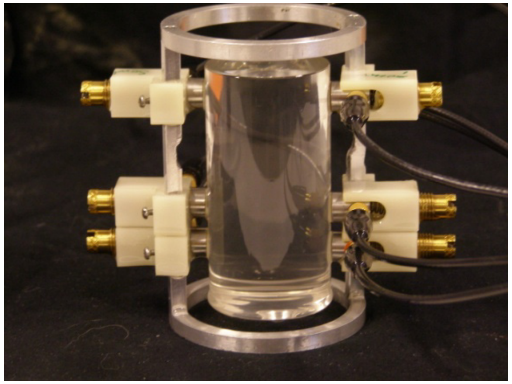
MessTek system



Triaxial cell instrumentation

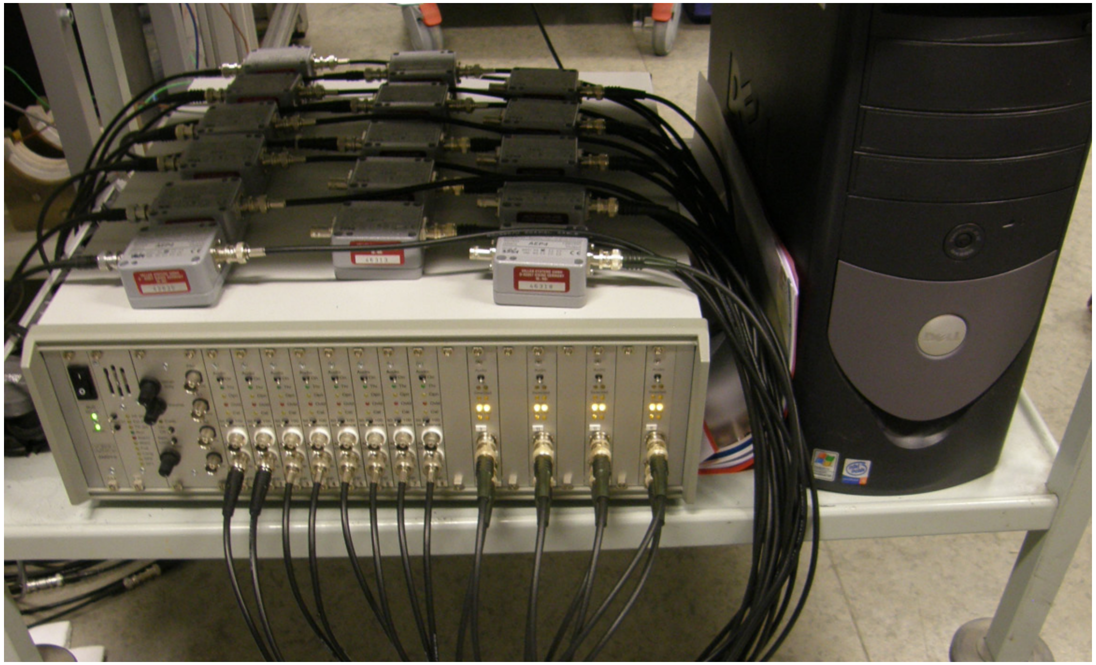






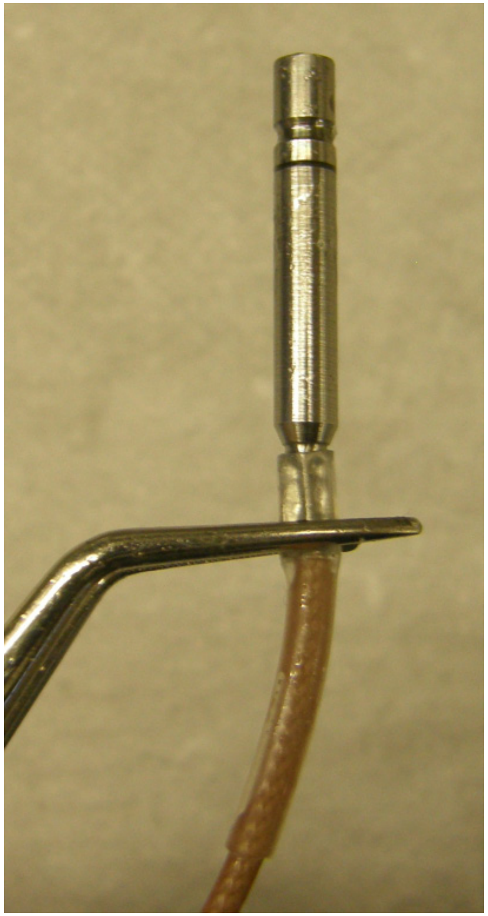
AE set-up

Vallen system



Max capacity => 16 channels
Currently used => 9 channels

AE transducer



Diameter = 3.5 mm
Centre frequency = 1.3 MHz

Samples

Sandstones **Chalk**

Berea

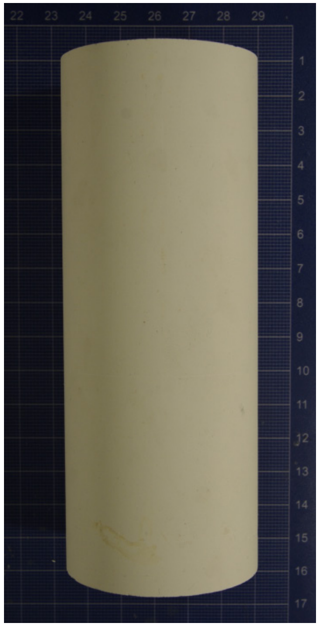
ρ ~ 2150 kg/m^3
Vp ~ 2090 m/s

Castlegate

ρ ~ 1920 kg/m^3
Vp ~ 1830 m/s

Red Wildmoor

ρ ~ 1930 kg/m^3
Vp ~ 1590 m/s

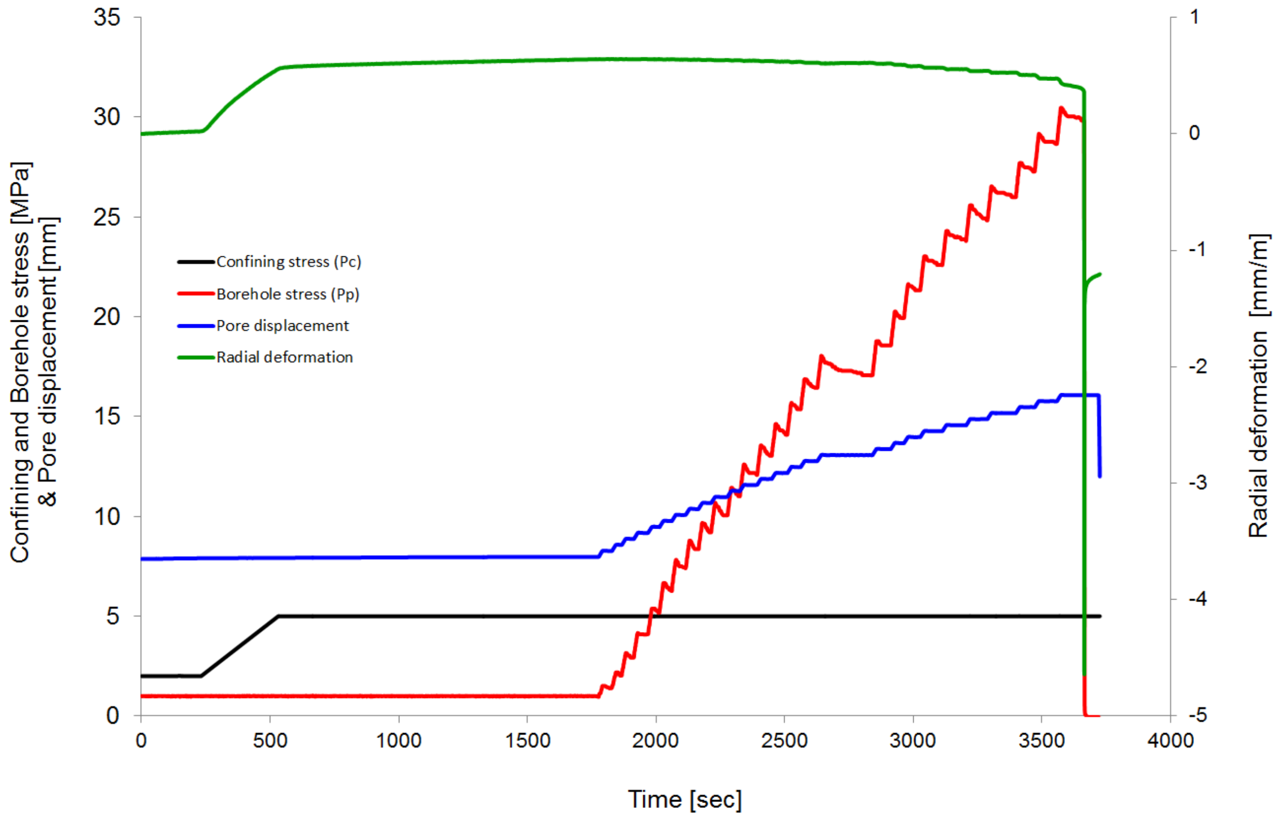


Mons chalk

ρ ~ 1520 kg/m^3
Vp ~ 2140 m/s

Size of samples: Length ~ 135 mm & Diameter ~ 51 mm/10.50 mm

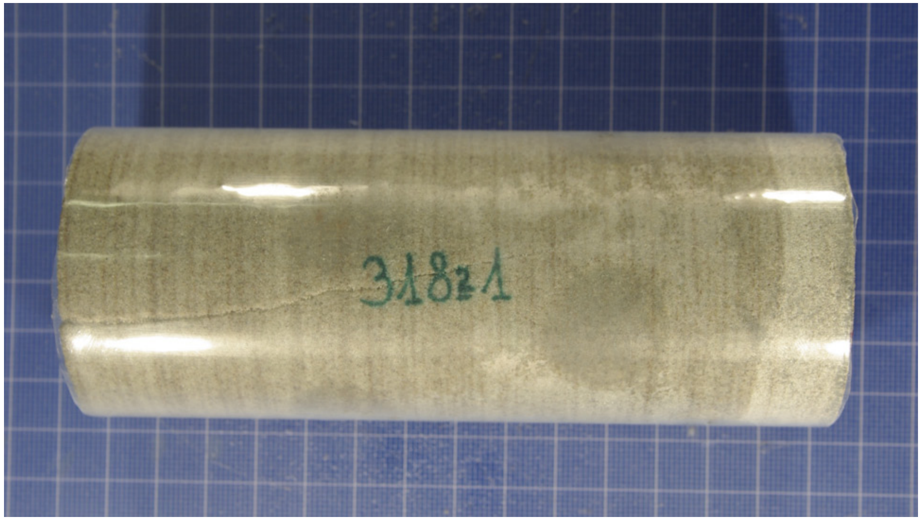
Stress conditions

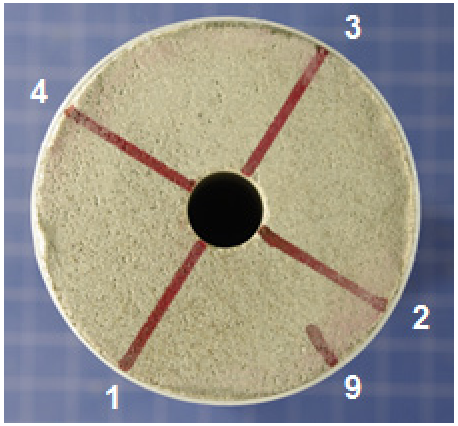


Initial load 2MPa confining pressure (Pc) & 1MPa borehole pressure (Pp) for AE calibration

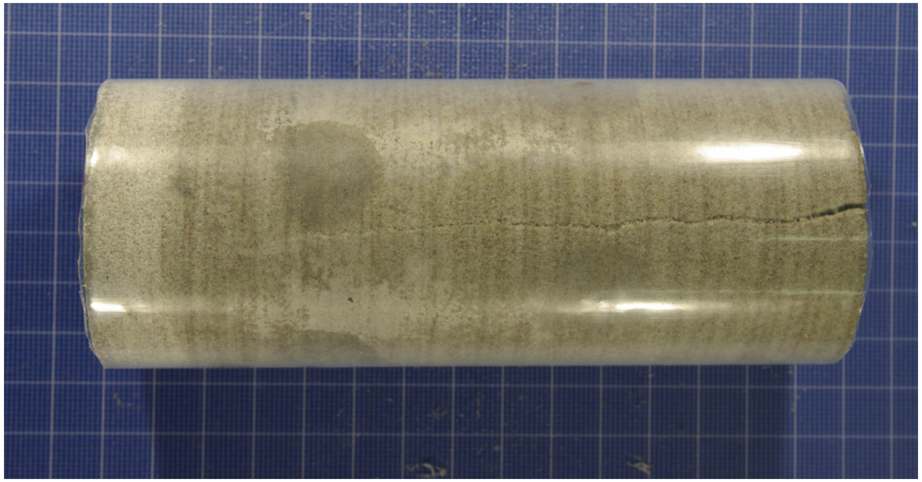
Main test @ const. confinement (Pc = 5 MPa) & stepwise increasing borehole pressure (Pp increase until fracture)

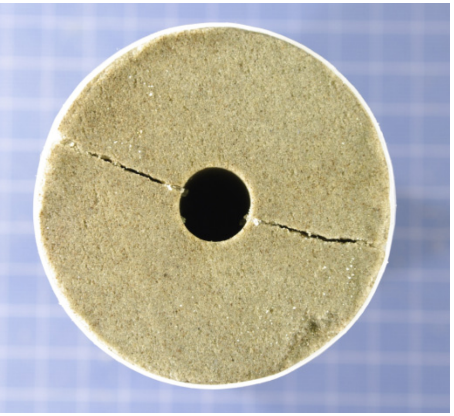
Berea sandstones after test





Top

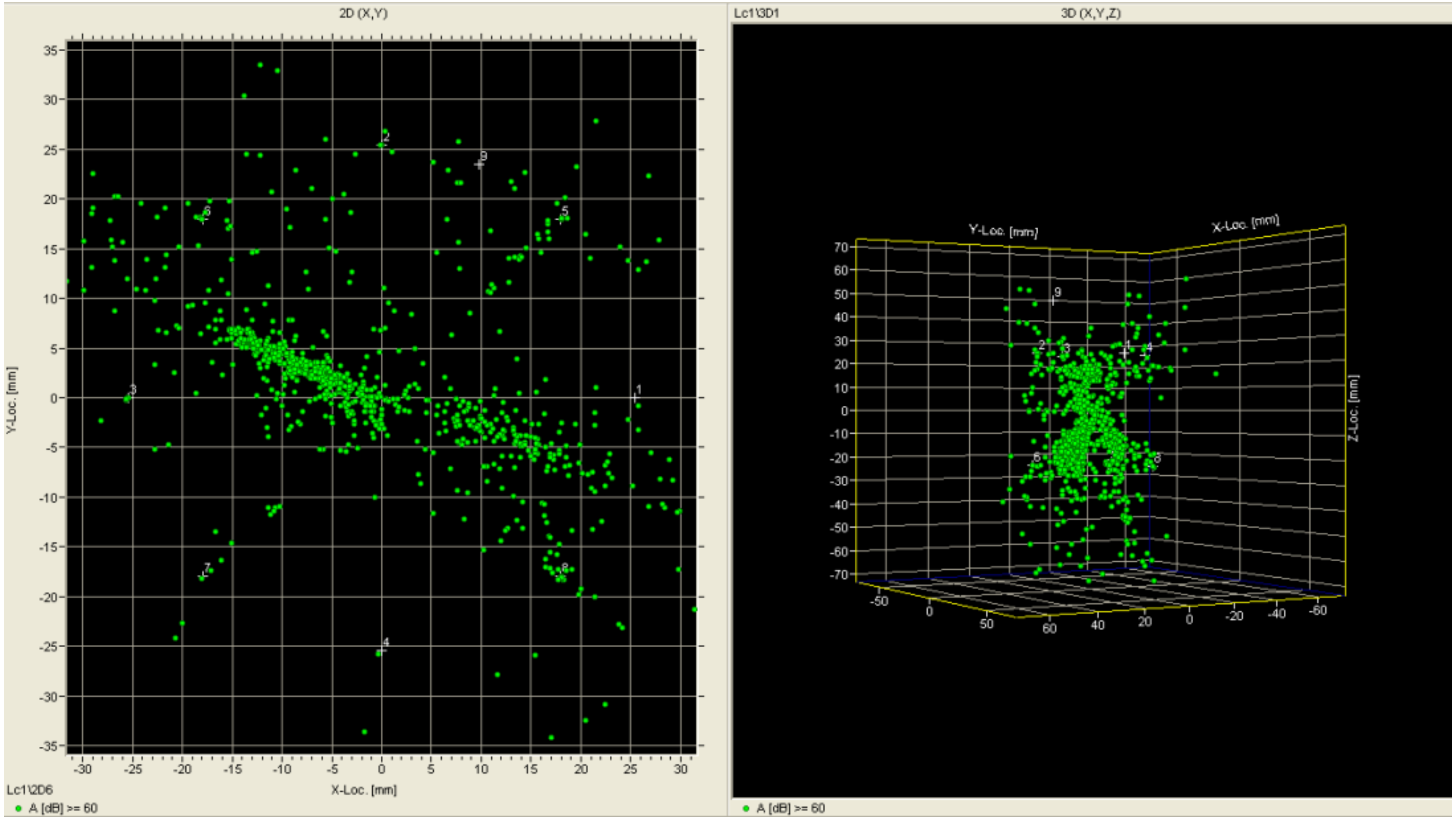




Bottom

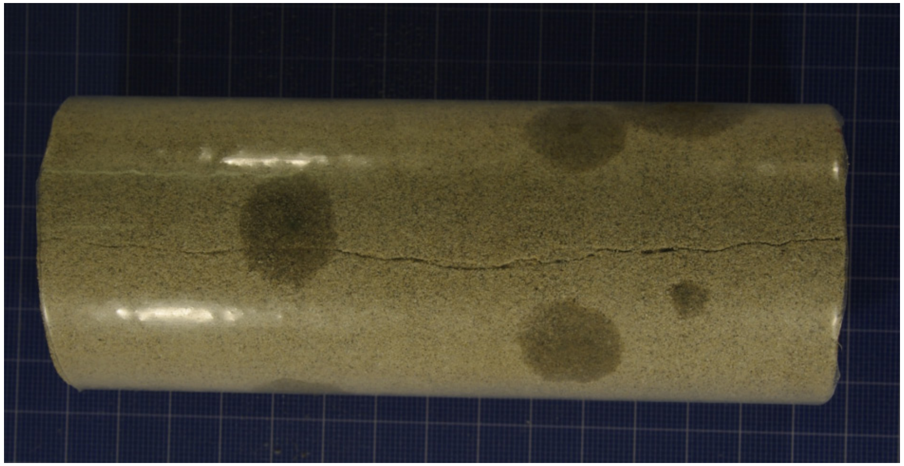
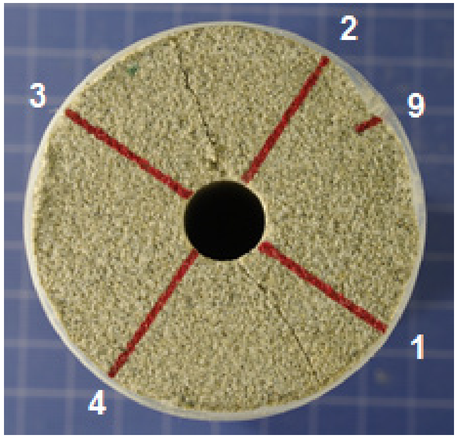
Berea sandstones AE results

Filter 60 dB

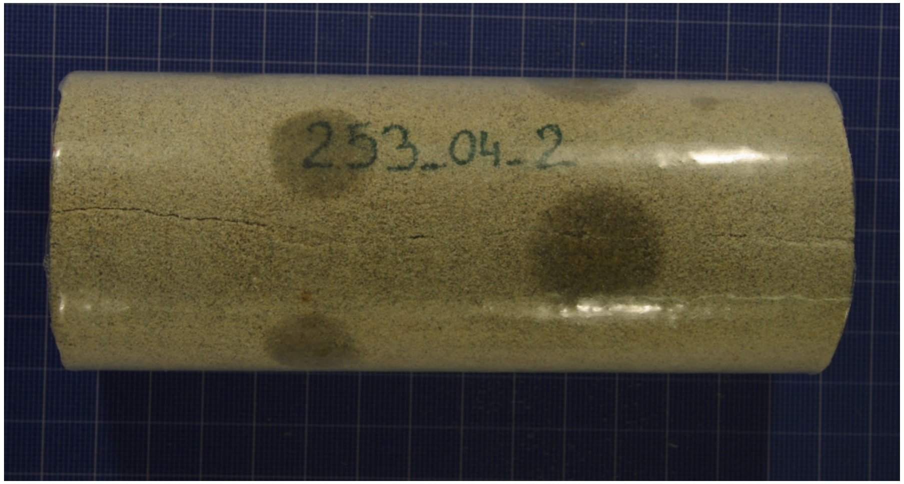


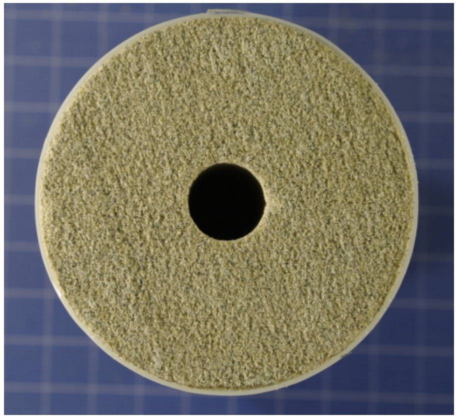
Position of acoustic events (channel threshold 19.3 dB)

Castlegate sandstones after test

Top

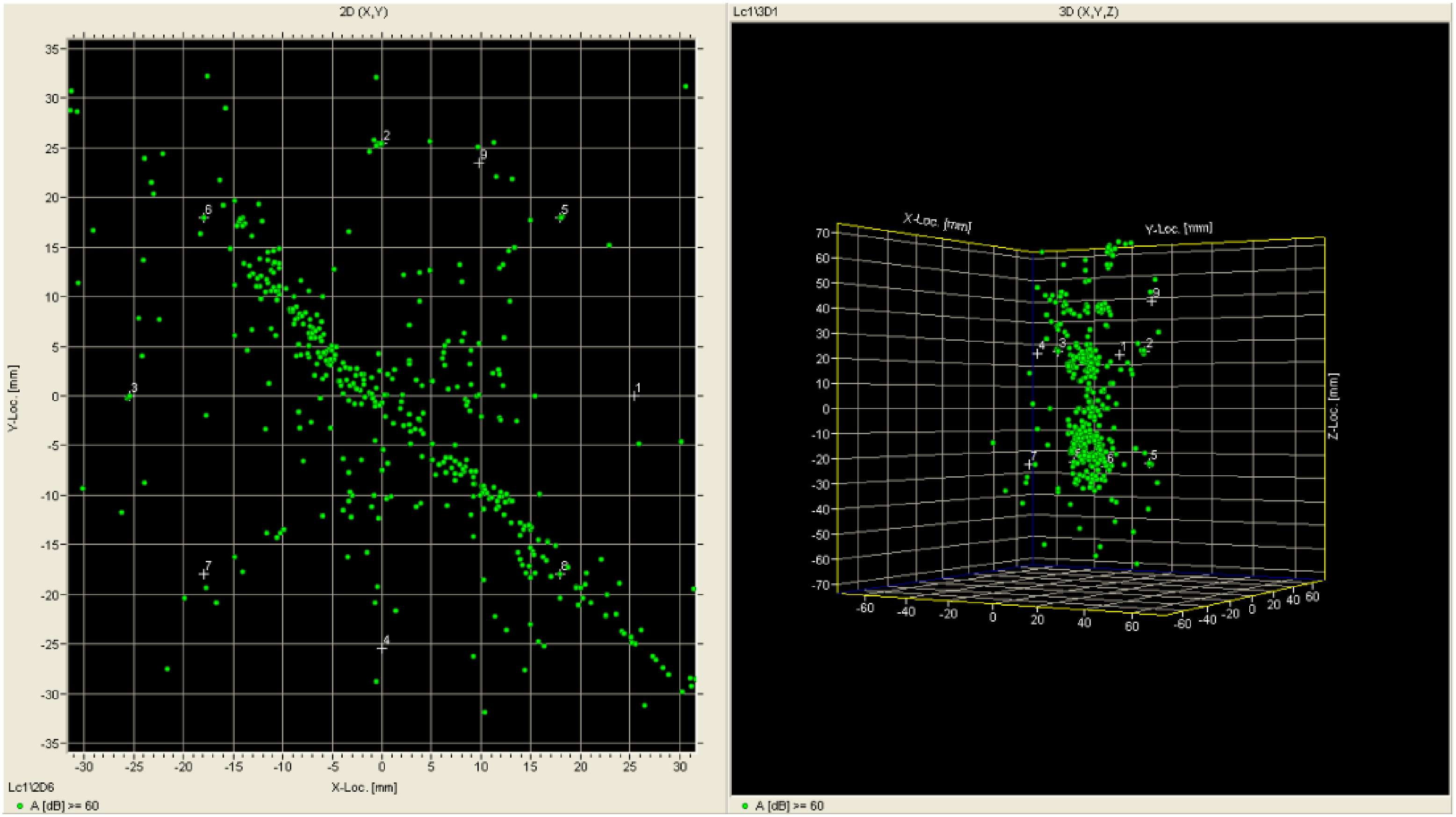




Bottom

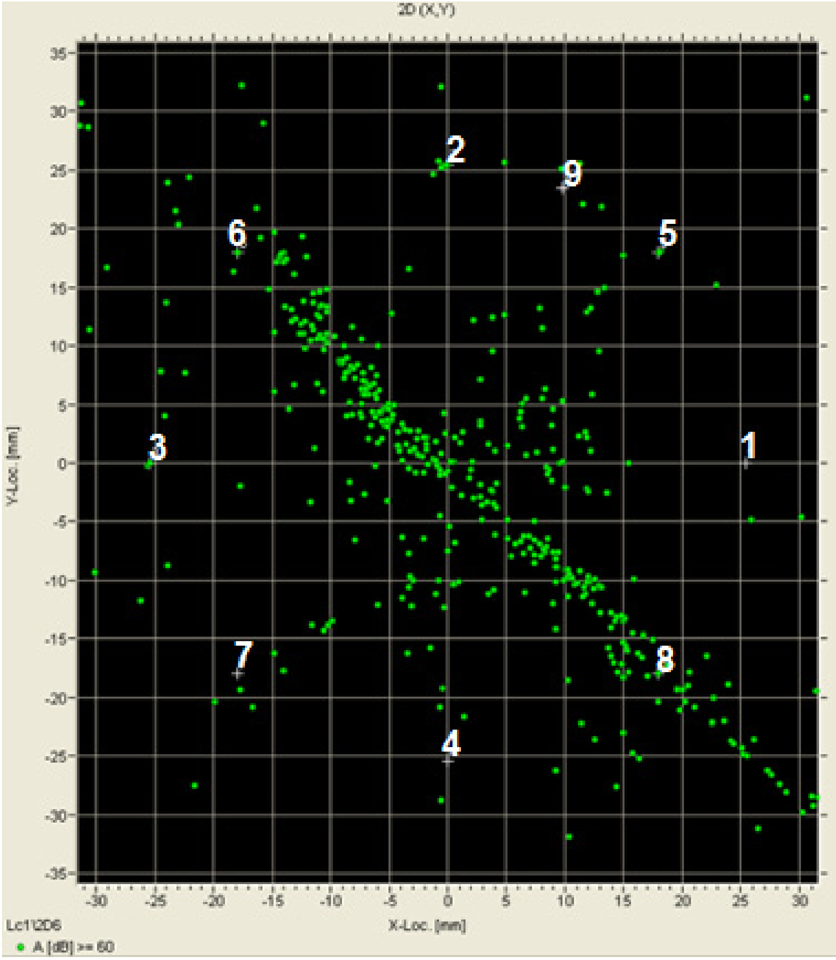
Castlegate sandstones AE results

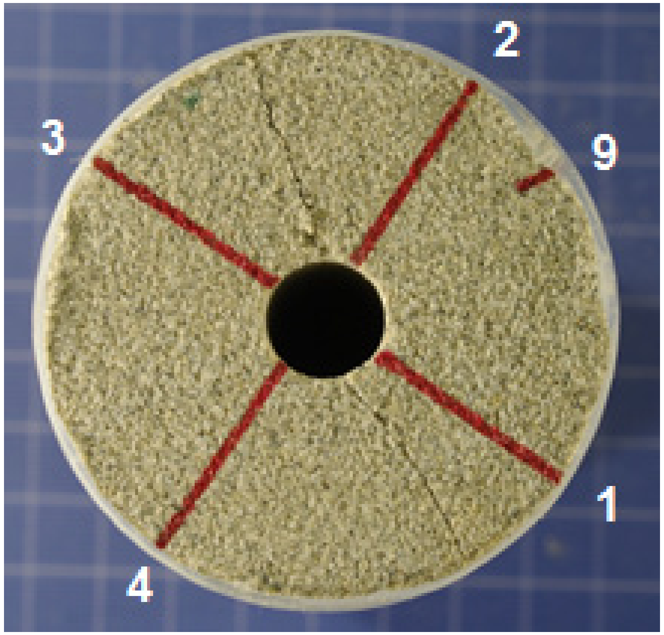
Filter 60 dB



Position of acoustic events (channel threshold 19.3 dB)

Castlegate sandstones AE results

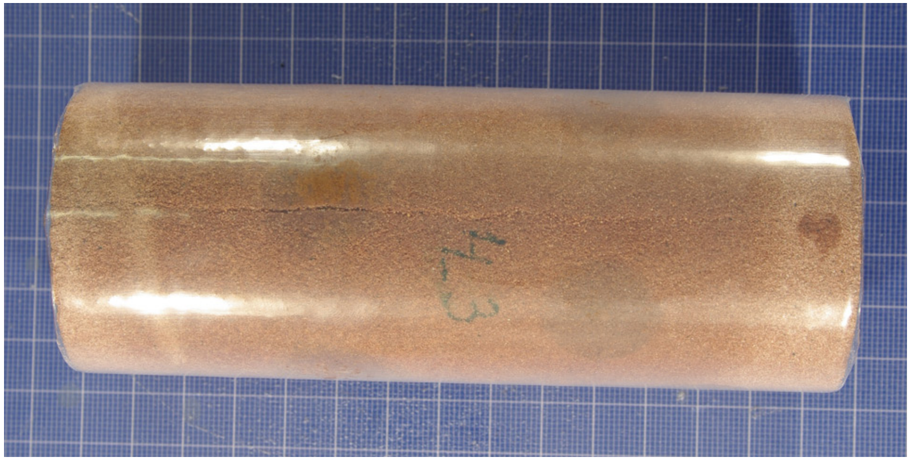


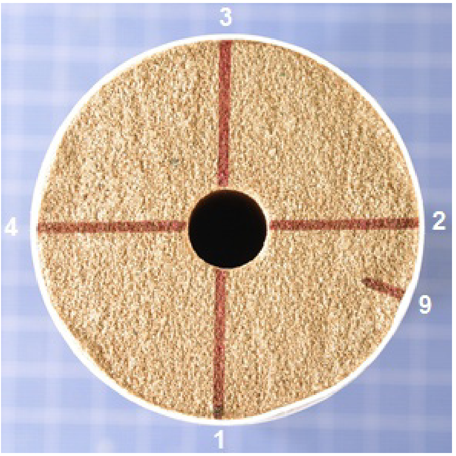


Location of acoustic events indicates two symmetric fractures localized between AE sensors 6 and 8. This fracture is visible as a clear core damage.

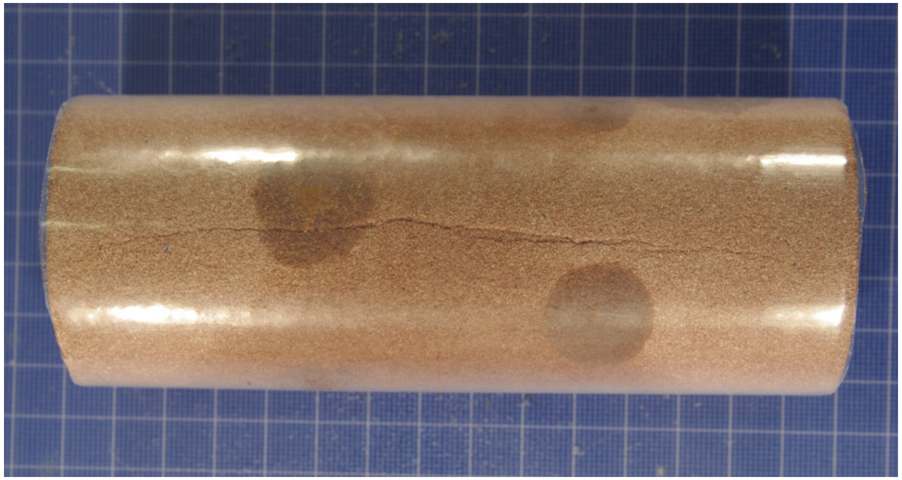
Two additional (symmetric) fractures can be located in direction of AE sensor 5 and 7, but these are not visible with the bare eye.

Red Wildmoor sandstones after test





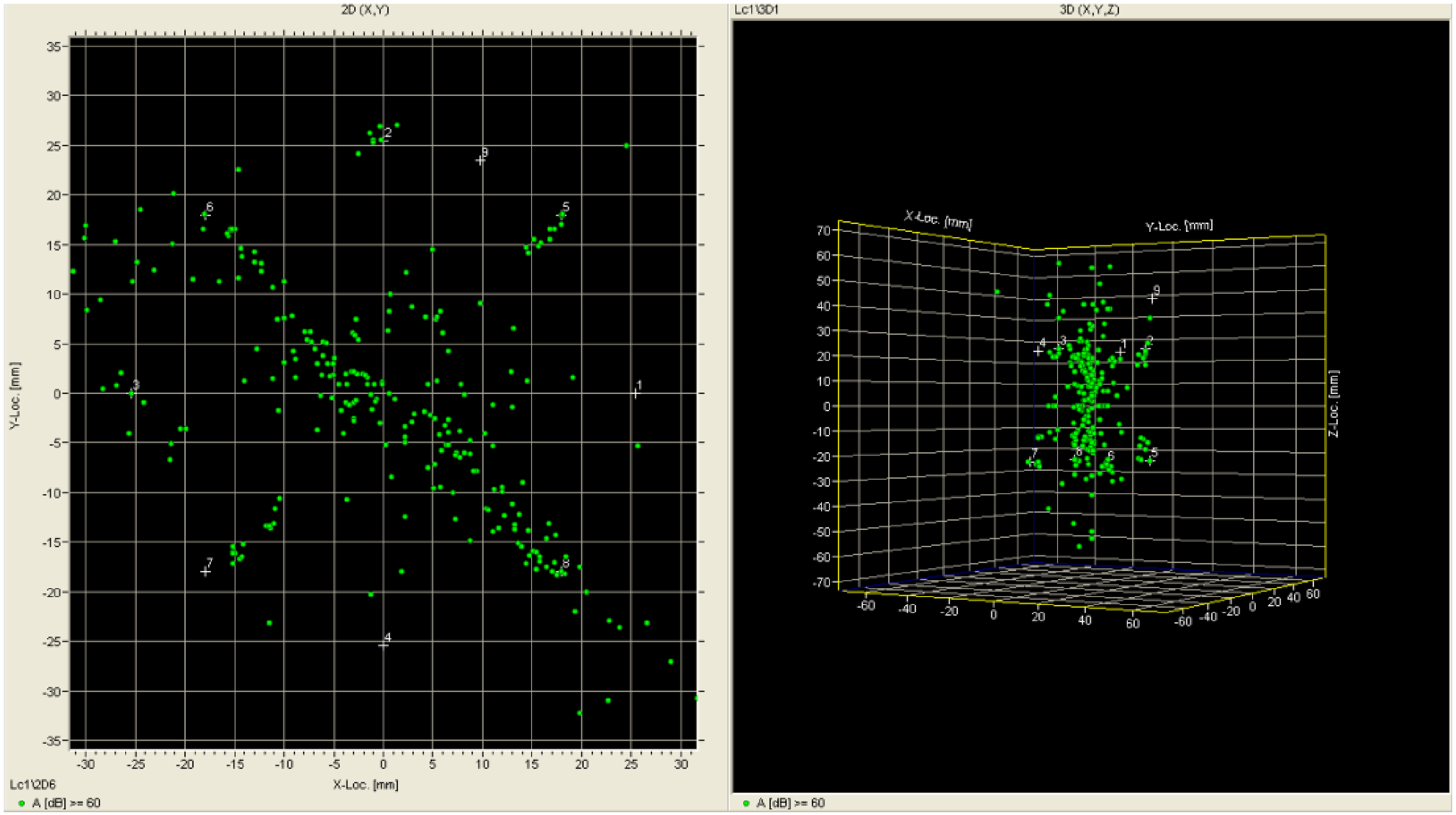
Top



Bottom

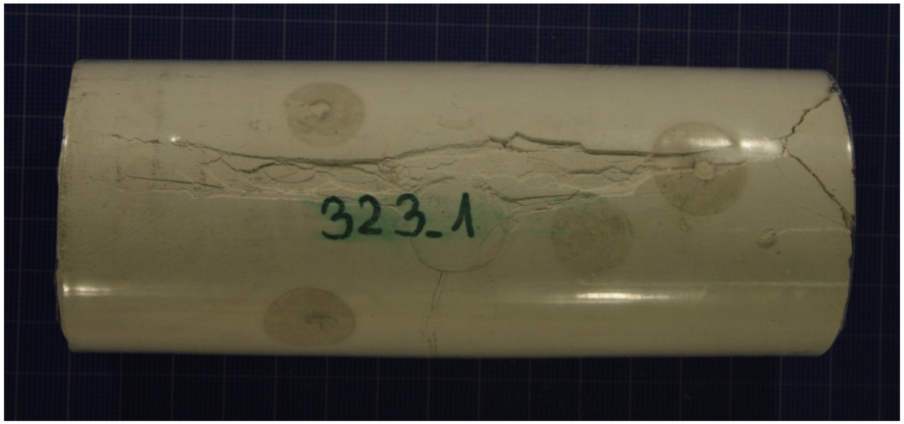
Red Wildmoor sandstones AE results

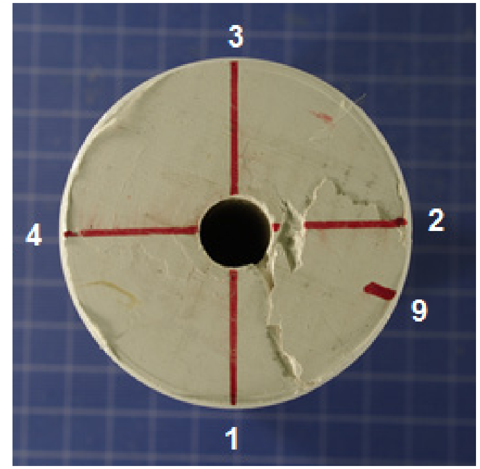
Filter 60 dB



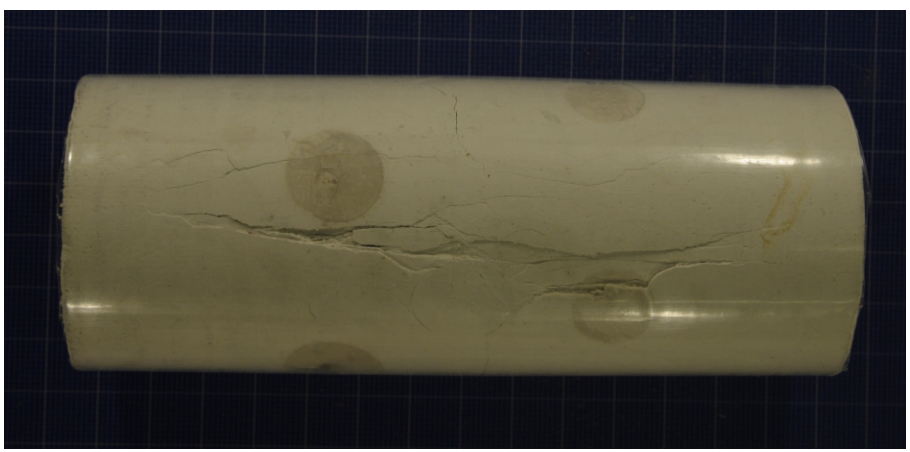
Position of acoustic events (channel threshold 19.3 dB)

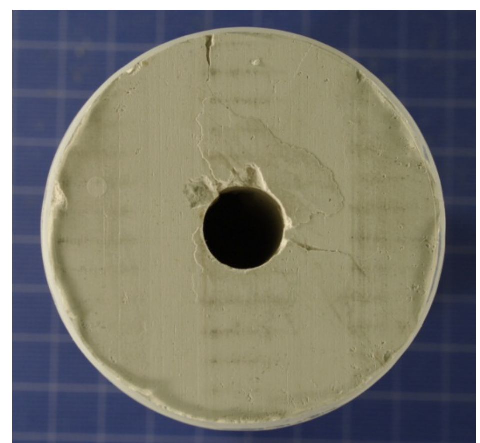
Mons chalk after test





Top

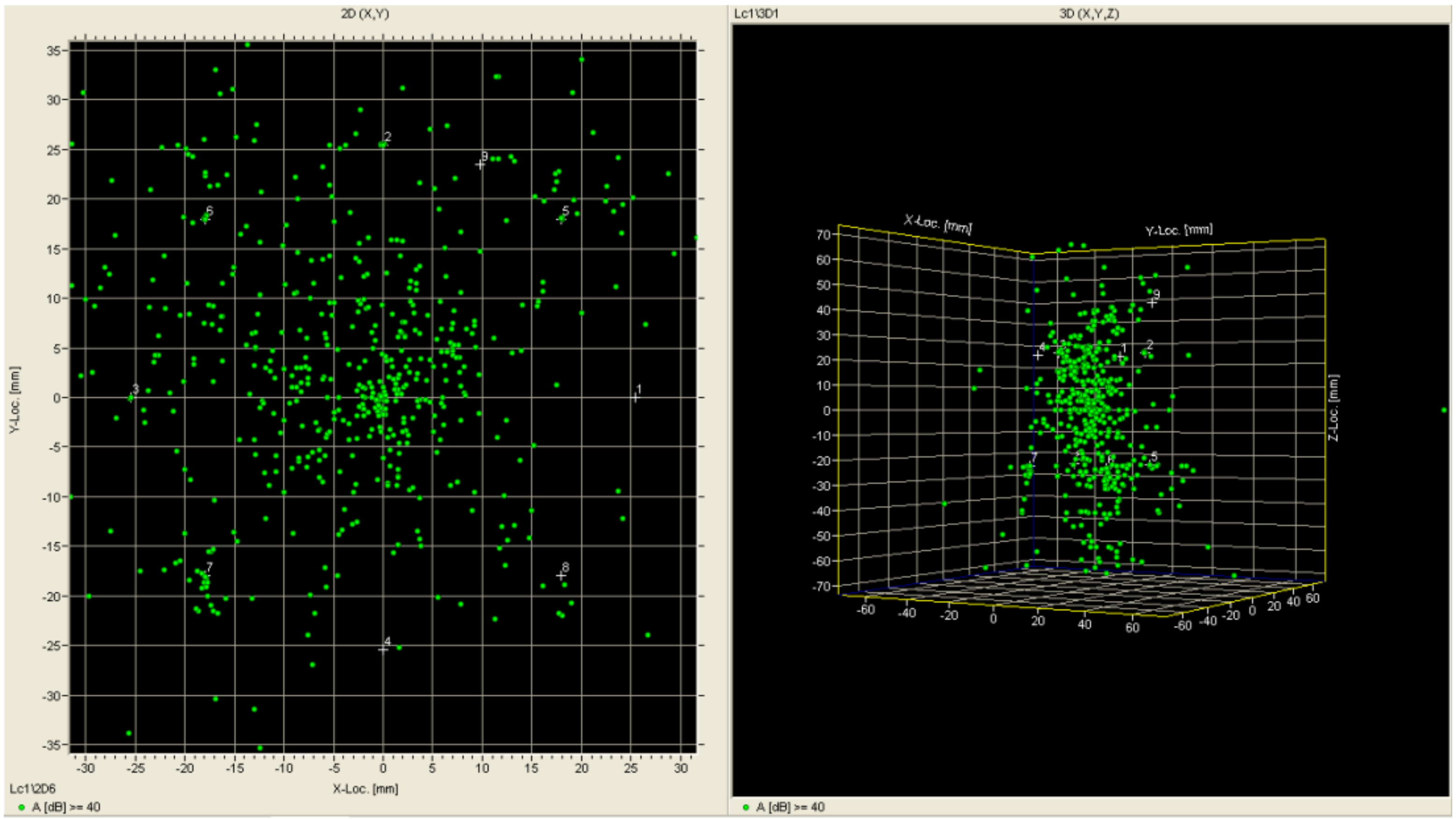




Bottom

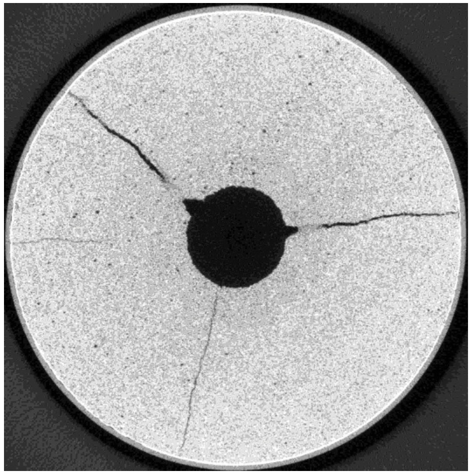
Mons chalk AE results

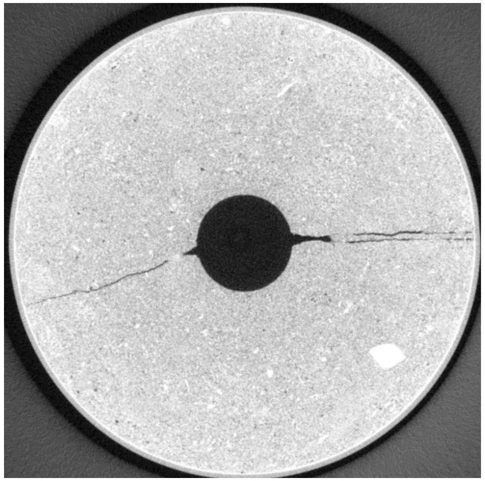
Filter 40 dB



Position of acoustic events (channel threshold 19.3 dB)

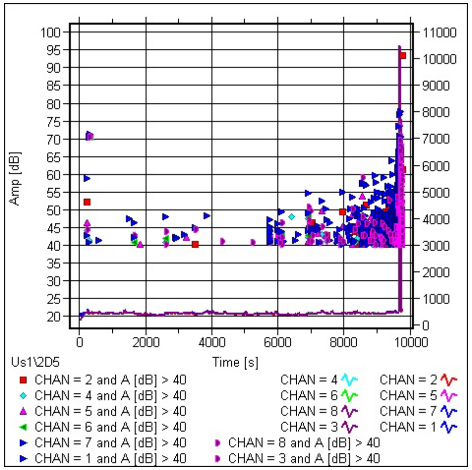
AE events during the test

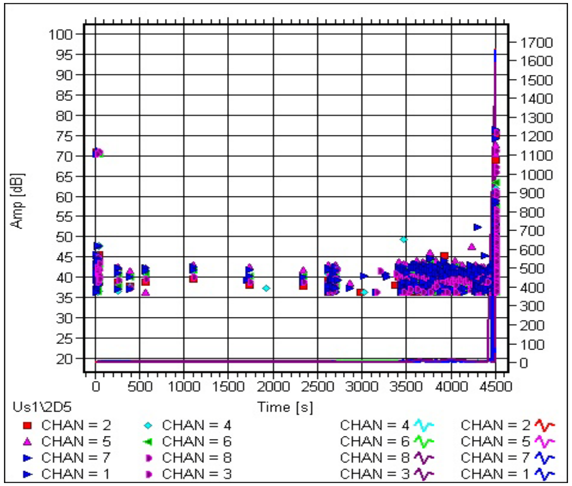




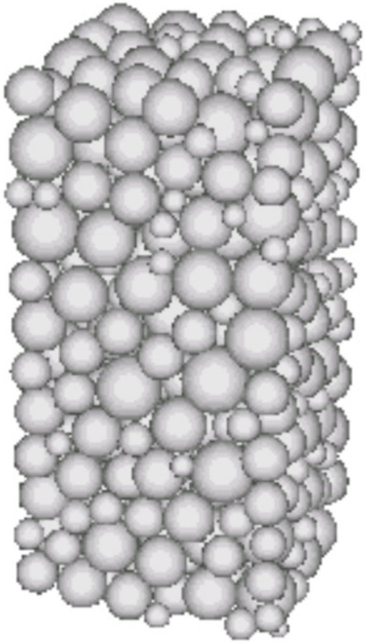
sandstone

limestone





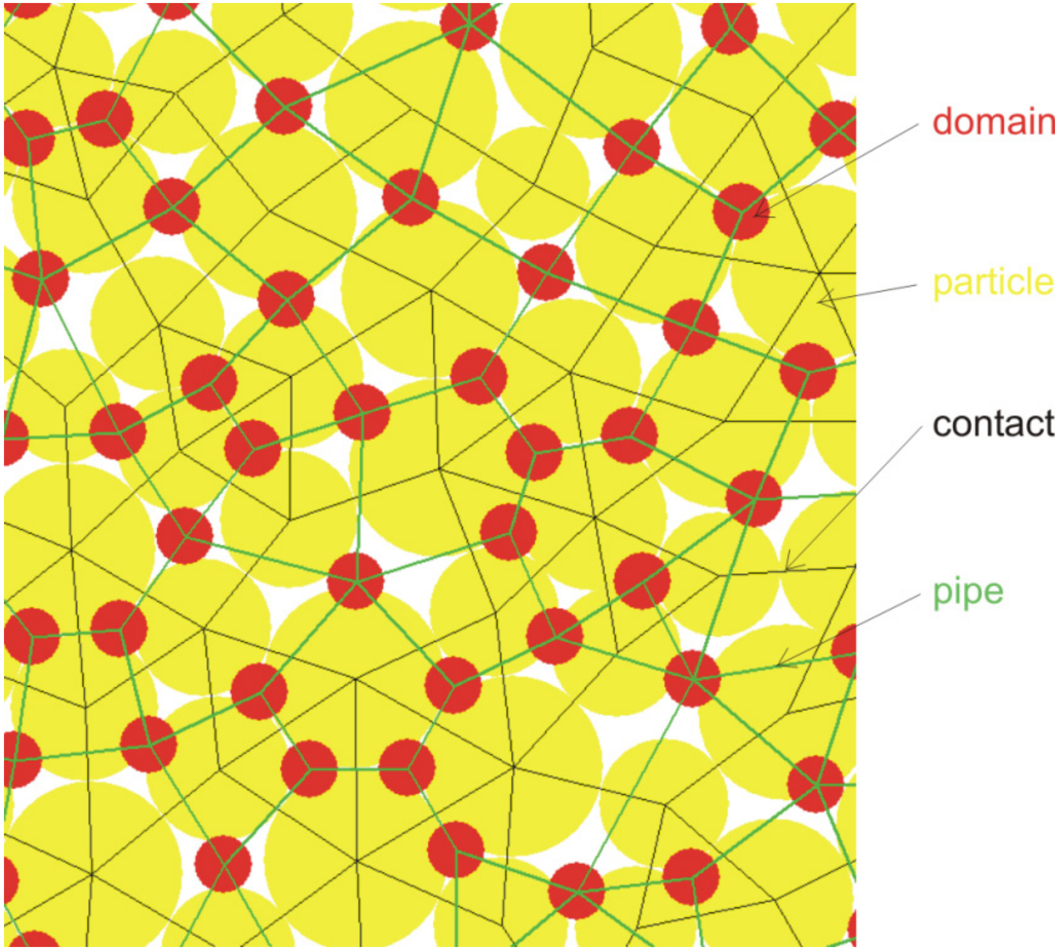
Pore scale modeling: using PFC



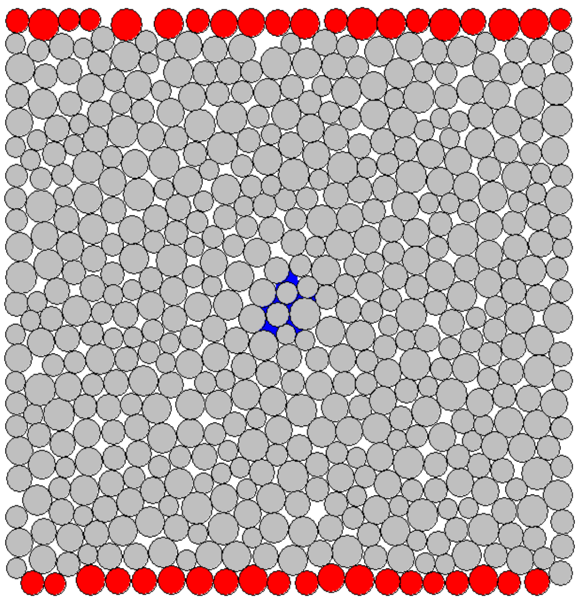
- PFC (Particle Flow Code) is a code based on the Discrete Element Method (DEM).
- PFC solves the equations of motion directly.
- In each time step, the movements of all the particles are calculated according to the motion law, and the forces at all the contacts are calculated according to a contact law.

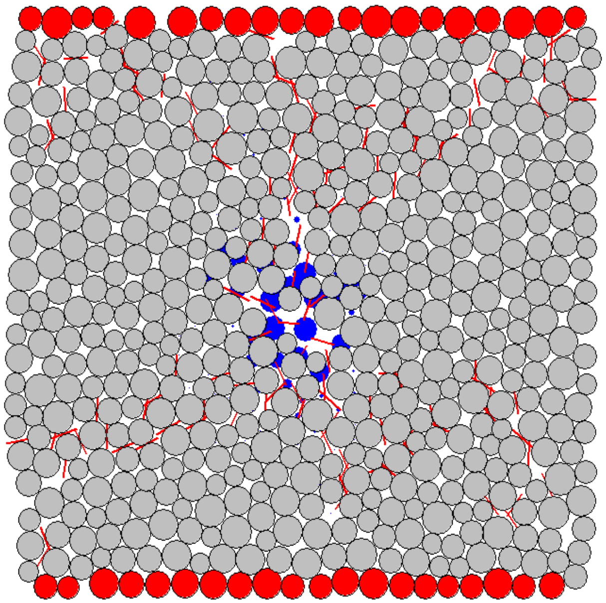
ITASCA, USA

PFC: Particle-fluid interaction



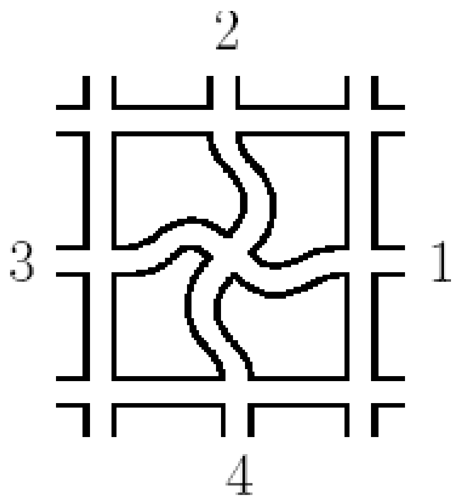
Hydraulic fracture: PFC 2D



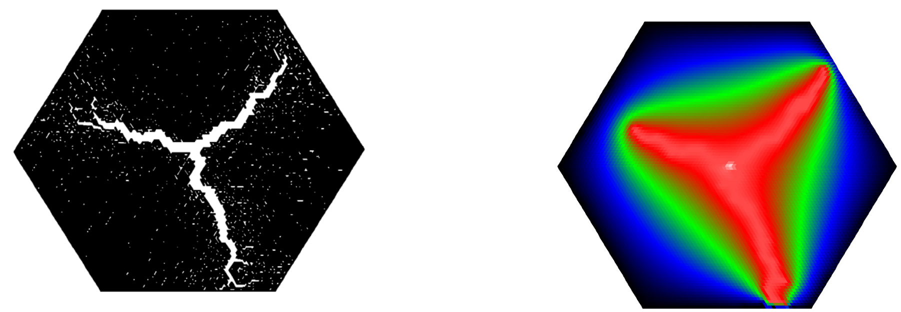


Fracture modeling at mesoscopic scale

Bjørn, NTNU



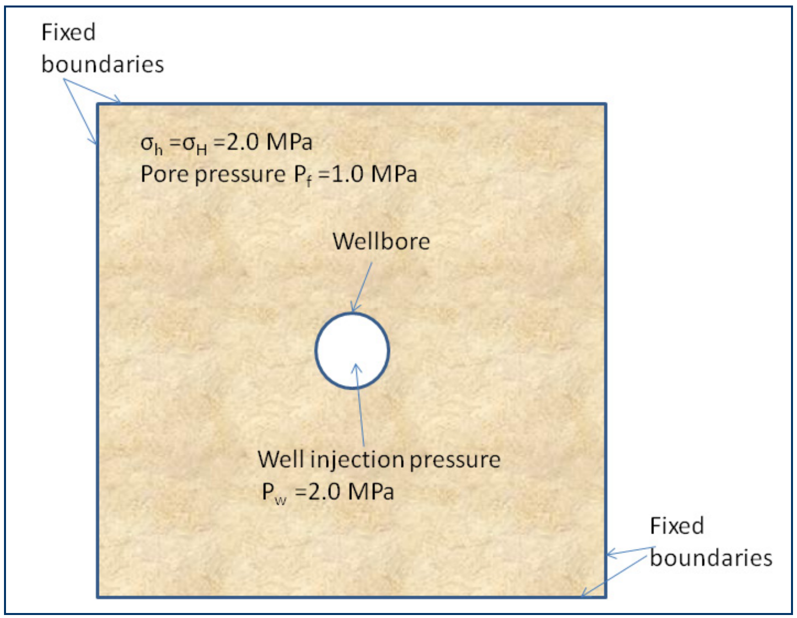
Elastic beam lattice model

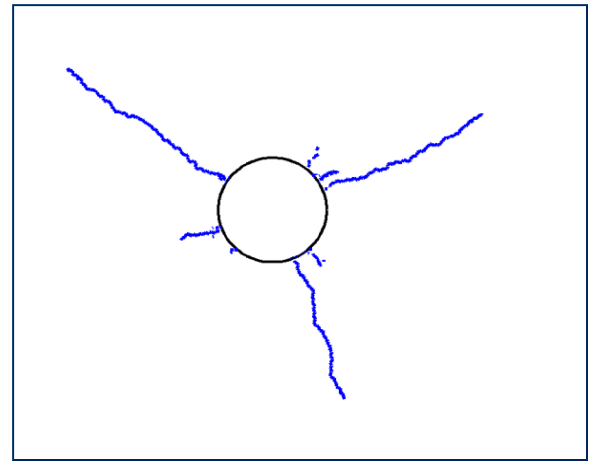


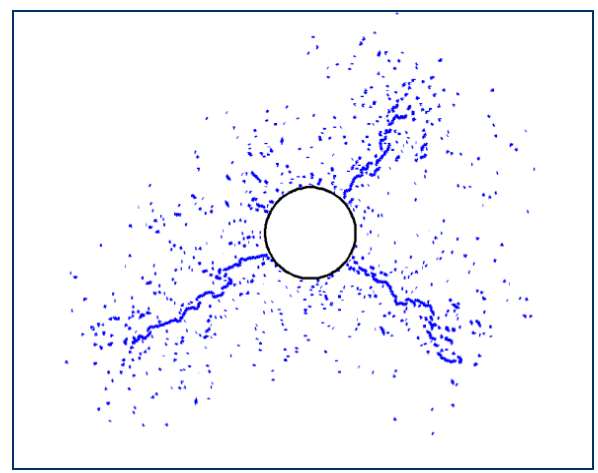
Fracture pattern and pressure distribution

Macro-scale modeling: MDEM

Haitham, SINTEF



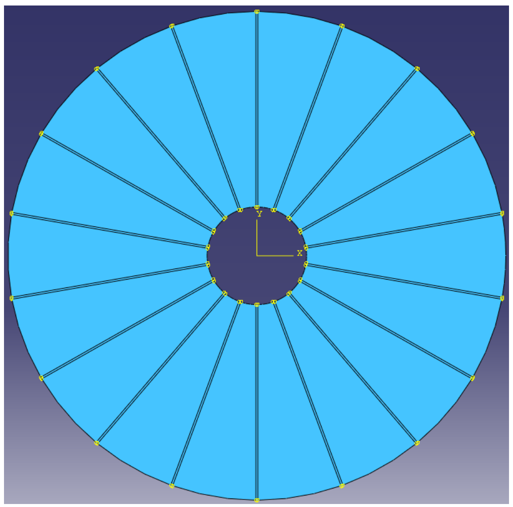




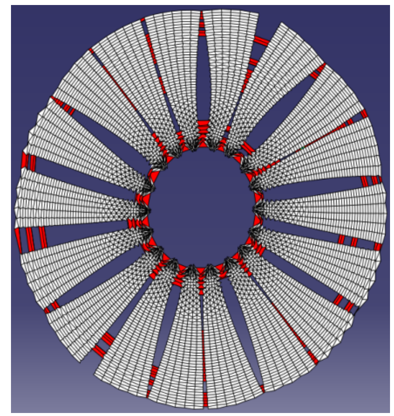
Finite element modeling (ABAQUS)

Alexandre, SINTEF

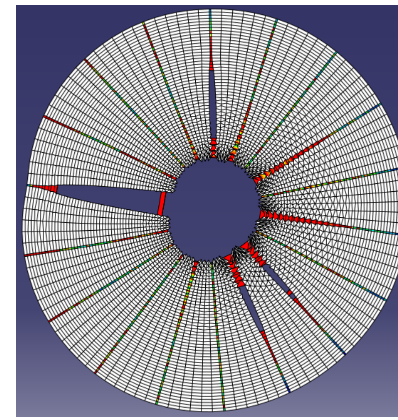
Fracture pattern for Gaussian dist. of tensile strength with different heterogeneity level



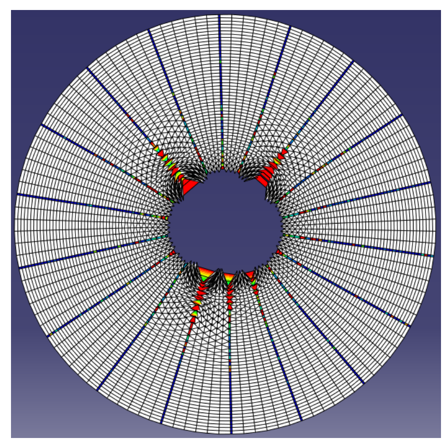
ABAQUS model of a hollow cylinder specimen with 18 built-in cohesive interfaces



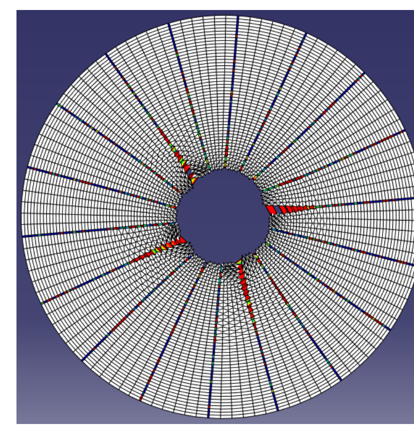
1 %



20 %



50 %



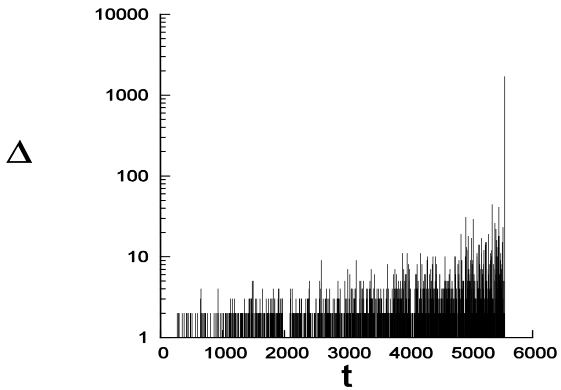
100 %

AE bursts

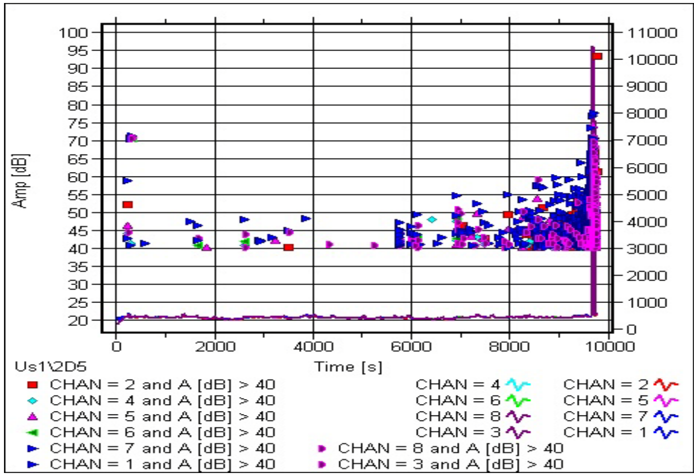
Theory

More fracturing activities near breakdown point

Simulation

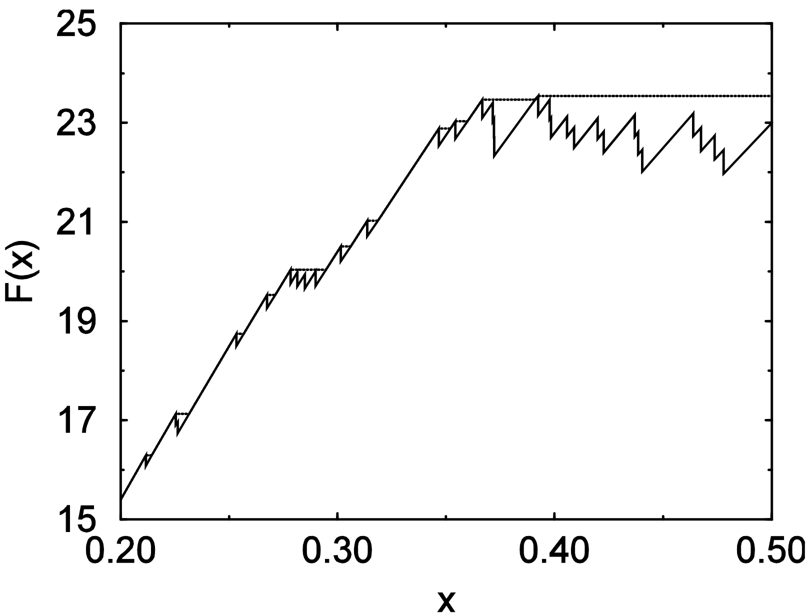


Experiment



FBM: Avalanche statistics

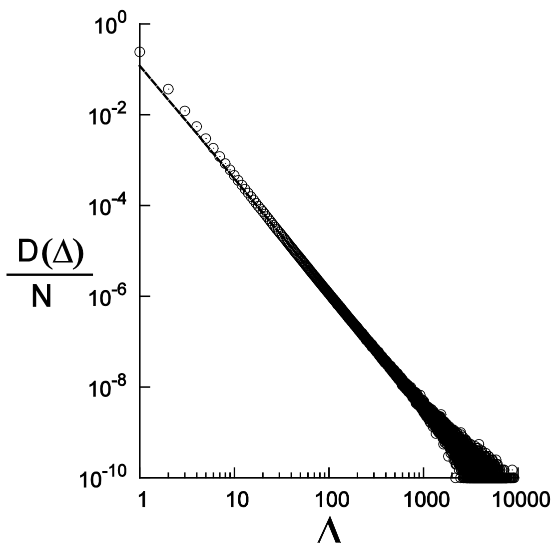
- Burst or avalanche



$$F_k = (N + 1 - k)x_k$$

$$D(\Delta) \propto \Delta^{-5/2}$$

Hemmer & Hansen, 1992



$$N = 10^6; avg = 20000$$

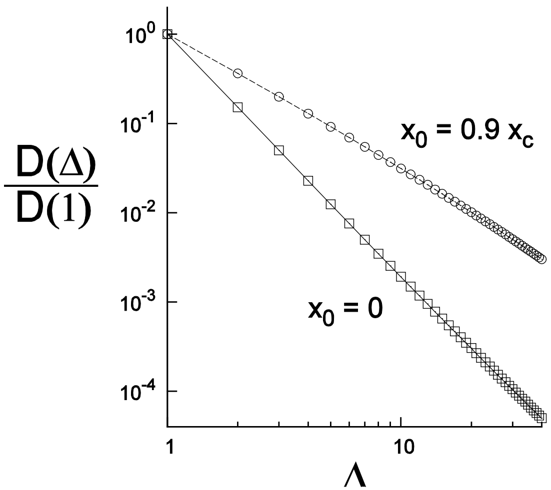
Prediction of failure point

- Crossover behavior

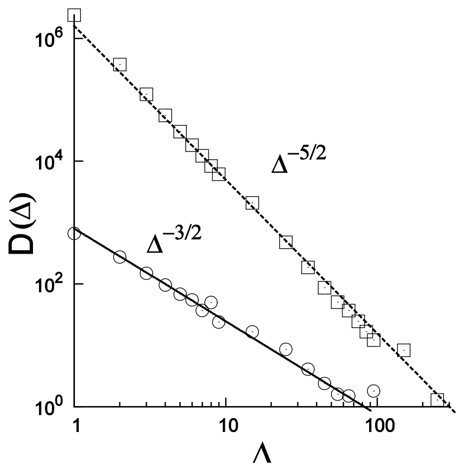
$$D(\Delta) \propto \Delta^{-5/2}(1 - e^{-\Delta/\Delta_c})$$

$$\Delta_c = \frac{1}{8(x_c - x_0)^2}$$

(Pradhan, Hemmer & Hansen; PRL 2005)

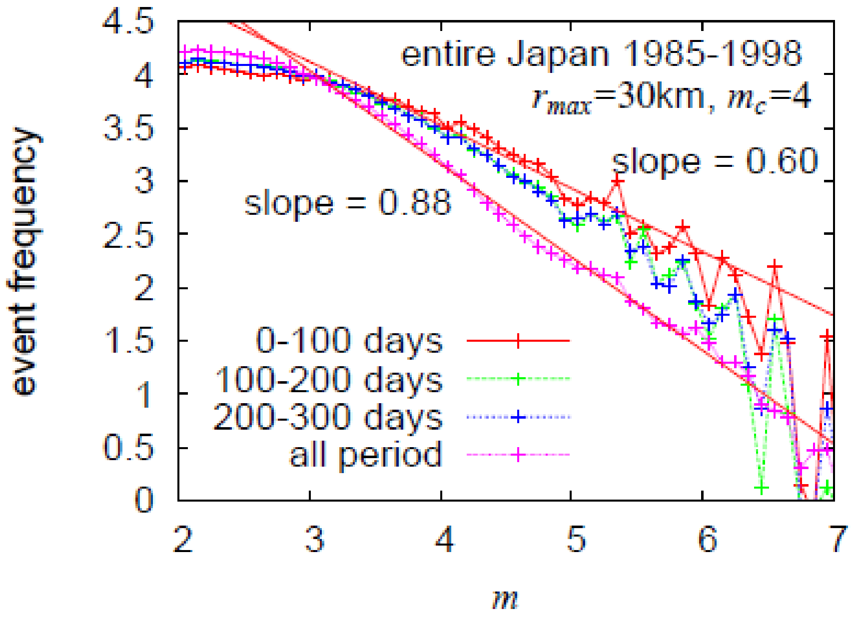


$$N = 10^6; avg = 50000$$

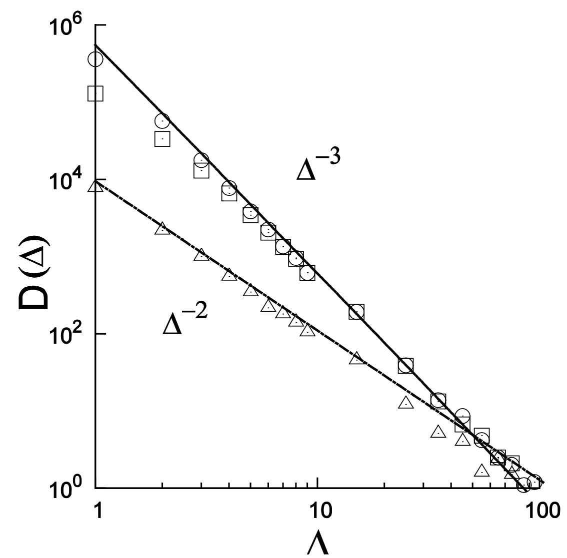


Single sample $N = 10^7$

Crossover behavior: In other systems



Seismic data prior to a mainshock (Kawamura et al, 2006)



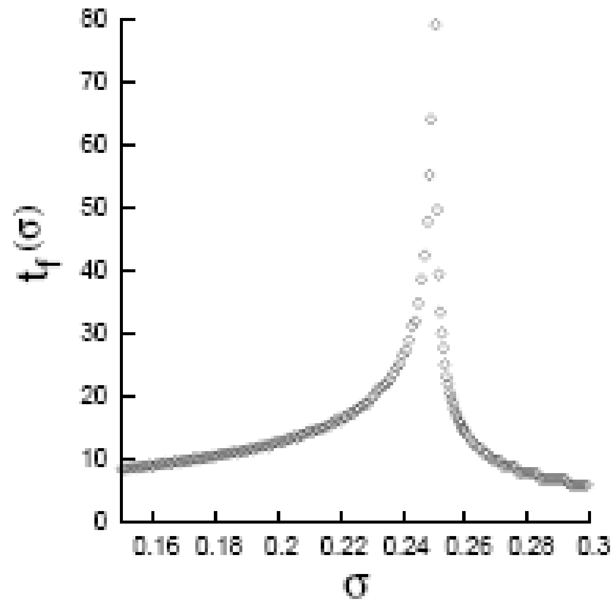
Burst distribution in Fuse model

Failure dynamics: Two-sided divergence

Above critical stress

$t_f(\sigma)$ is the failure time

$$t_f(\sigma) = \frac{\pi}{2}(\sigma - \sigma_c)^{-1/2}$$



Below critical stress

$t_f(\sigma)$ is the time to reach the fixed point

$$t_f(\sigma) = \frac{\ln(N)}{4}(\sigma_c - \sigma)^{-1/2}$$

(Pradhan & Hemmer; PRE 2007)

The Fiber Bundle

Modeling Failure in Materials

A. Hansen, P. C. Hemmer and S. Pradhan

In the book series

"Fracture, Breakdown & Earthquake"

Edited by B. K. Chakrabarti and P. Ray

- INDNOR project activity

Collaborators

Jørn, Anna, Hans, Eyvind, Haitham, Alexandre, Erling SINTEF

Alex Hansen, Per C. Hemmer, Bjørn Skjetne, NTNU

Bikas K. Chakrabarti, P. Bhattacharyya, SINP

FUNDING: **RESEARCH COUNCIL OF NORWAY (NFR)**

THROUGH **CLIMIT** AND **INDNOR** (RENERGI)