Laboratory simulations of fluid-induced seismicity in shallow volcanic settings

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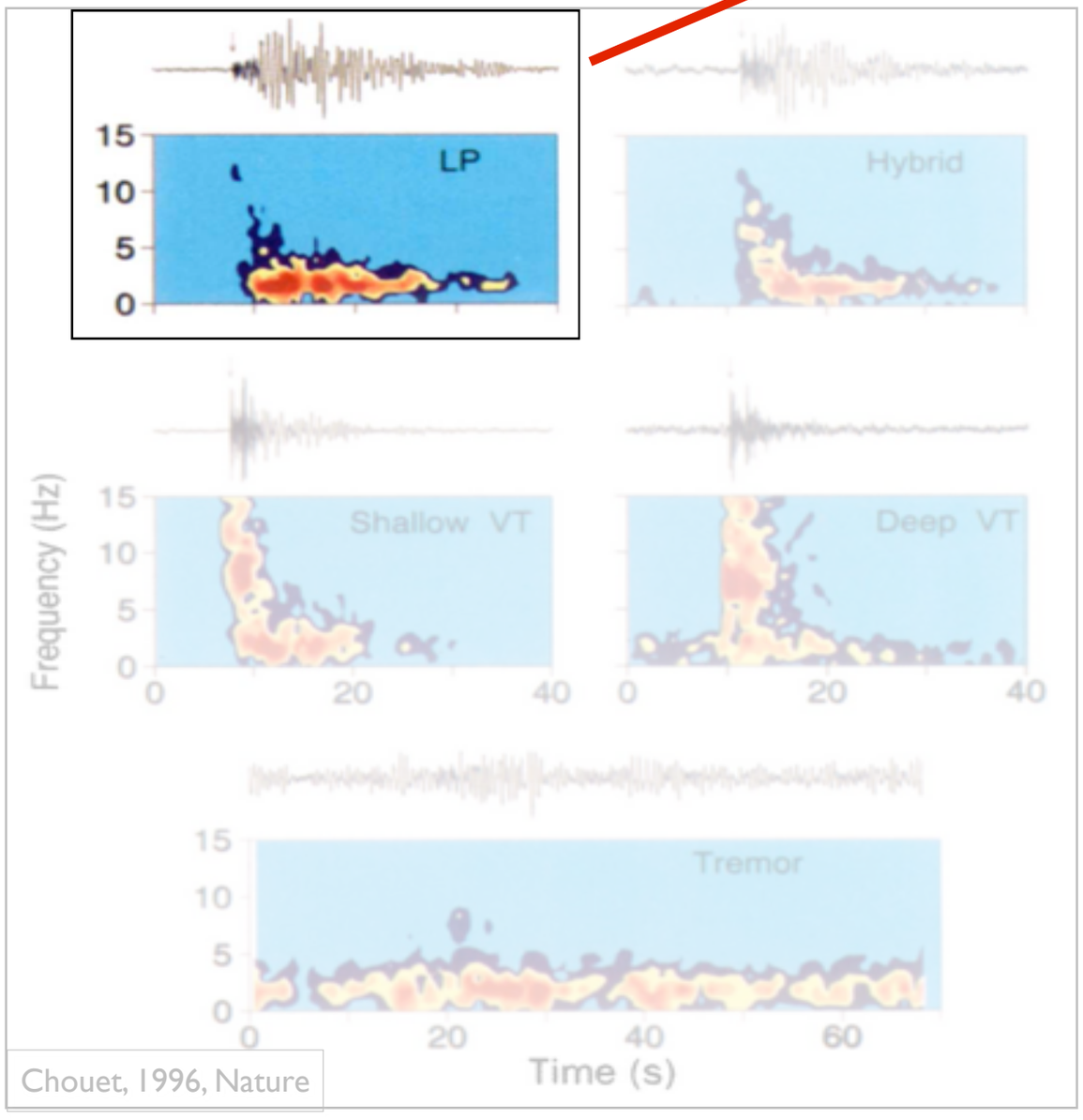
http://www.port.ac.uk/school-of-earth-and-environmental-sciences/research/rock-mechanics-laboratory/

Part 1: Laboratory simulation of VT/LF earthquakes in active volcanic settings

- VT and LF seismicity are key methods for monitoring active volcanoes…
- The precise source of LF seismicity remains controversial, but is generally thought to be linked to fluid movement, resonance, and turbulence (wor).
- AE is easily measured in the laboratory (AE) during



Chouet, 1996, Nature

Rationale:

- Prediction of volcanic unrest is difficult: However, eruptions are often preceded by increasing duration and instances of VT and LF / LP type events

- First, we try to reproduce VT **and especially LF** events in the laboratory using triaxial deformation and rock physics methods: in order to control and explore the physics of such events.....

AE eve

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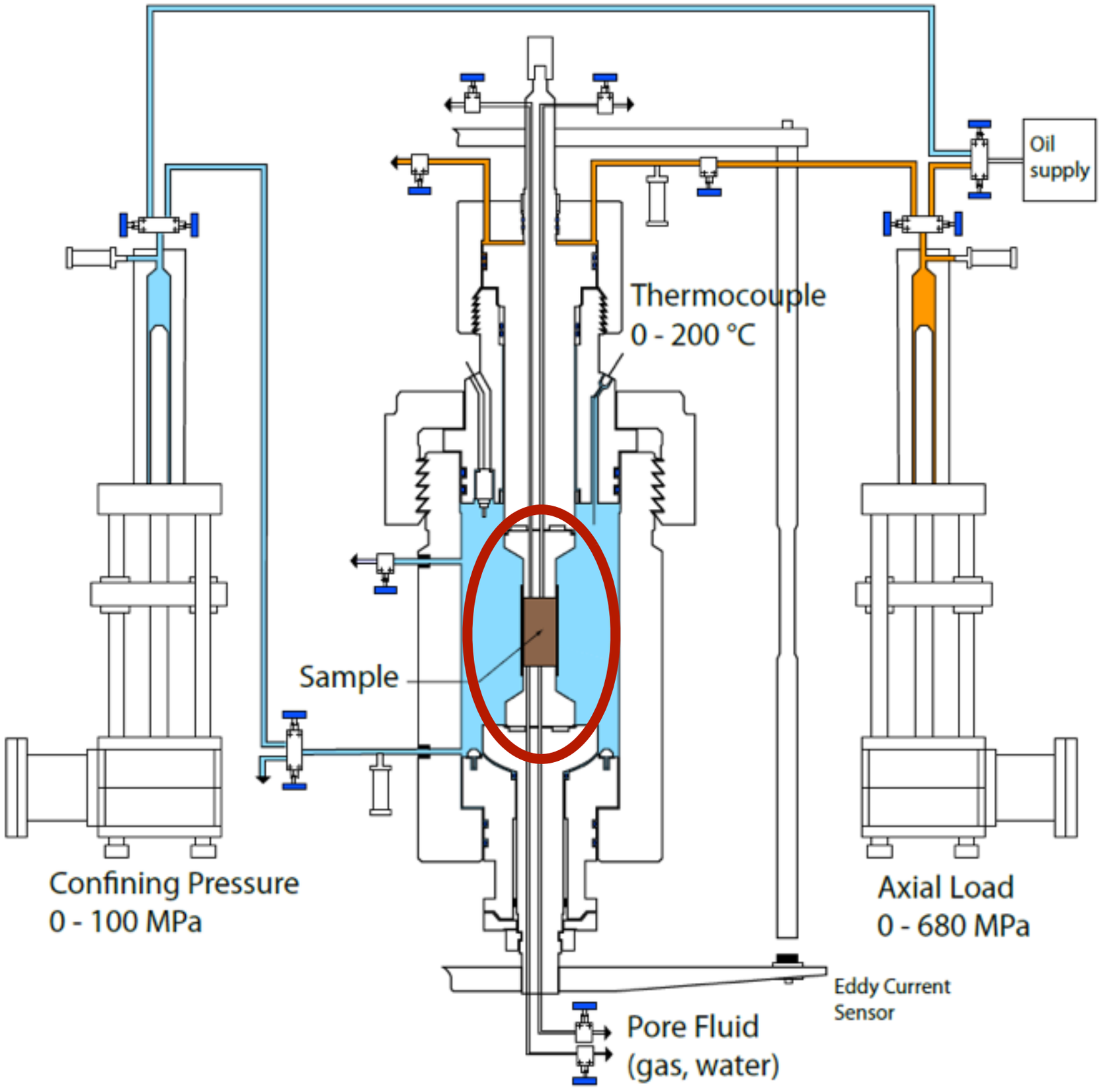
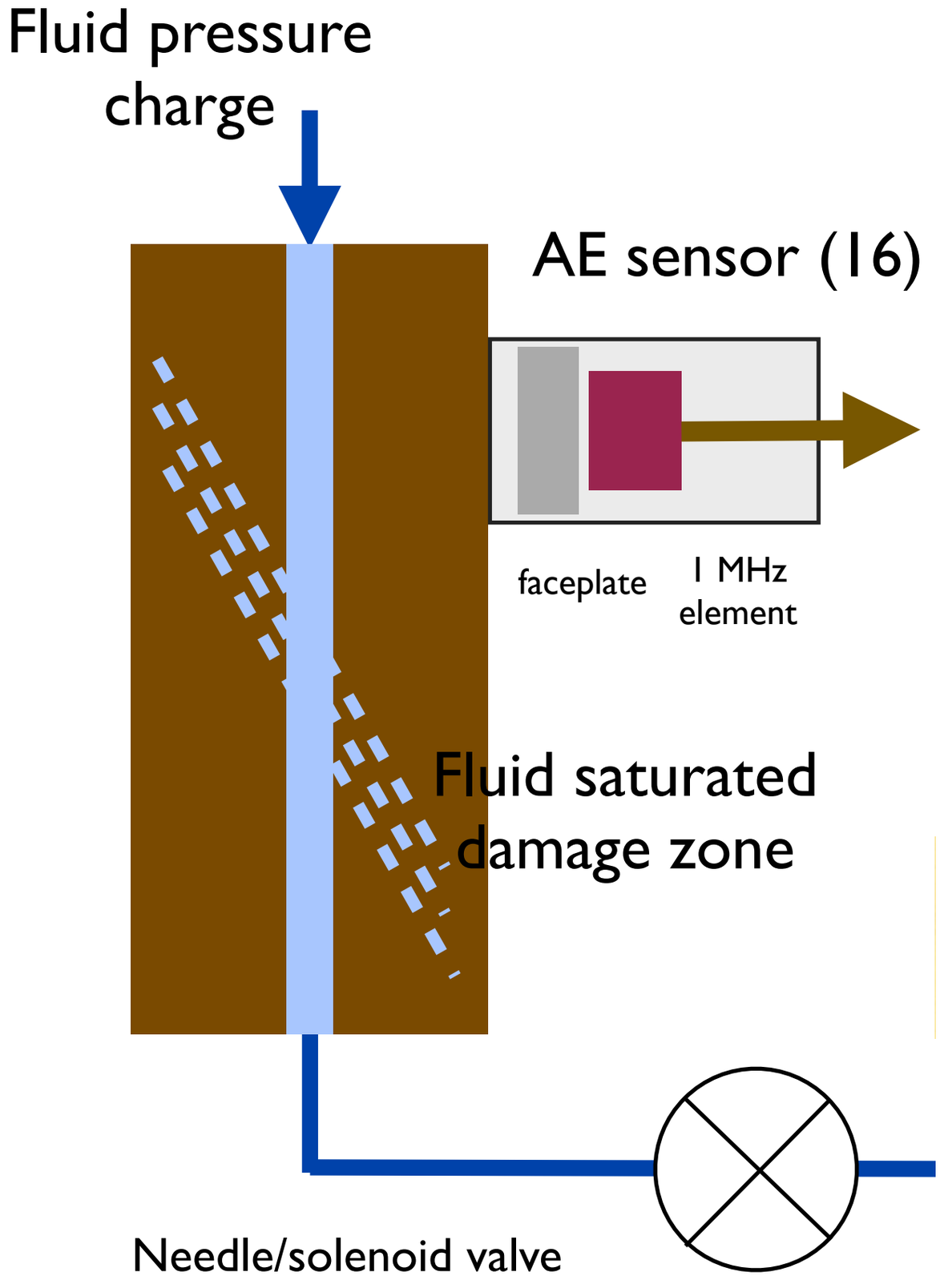
are indicative of fluid movement within cracks and fractures.

Experimental setup



Experimental setup (schematic)



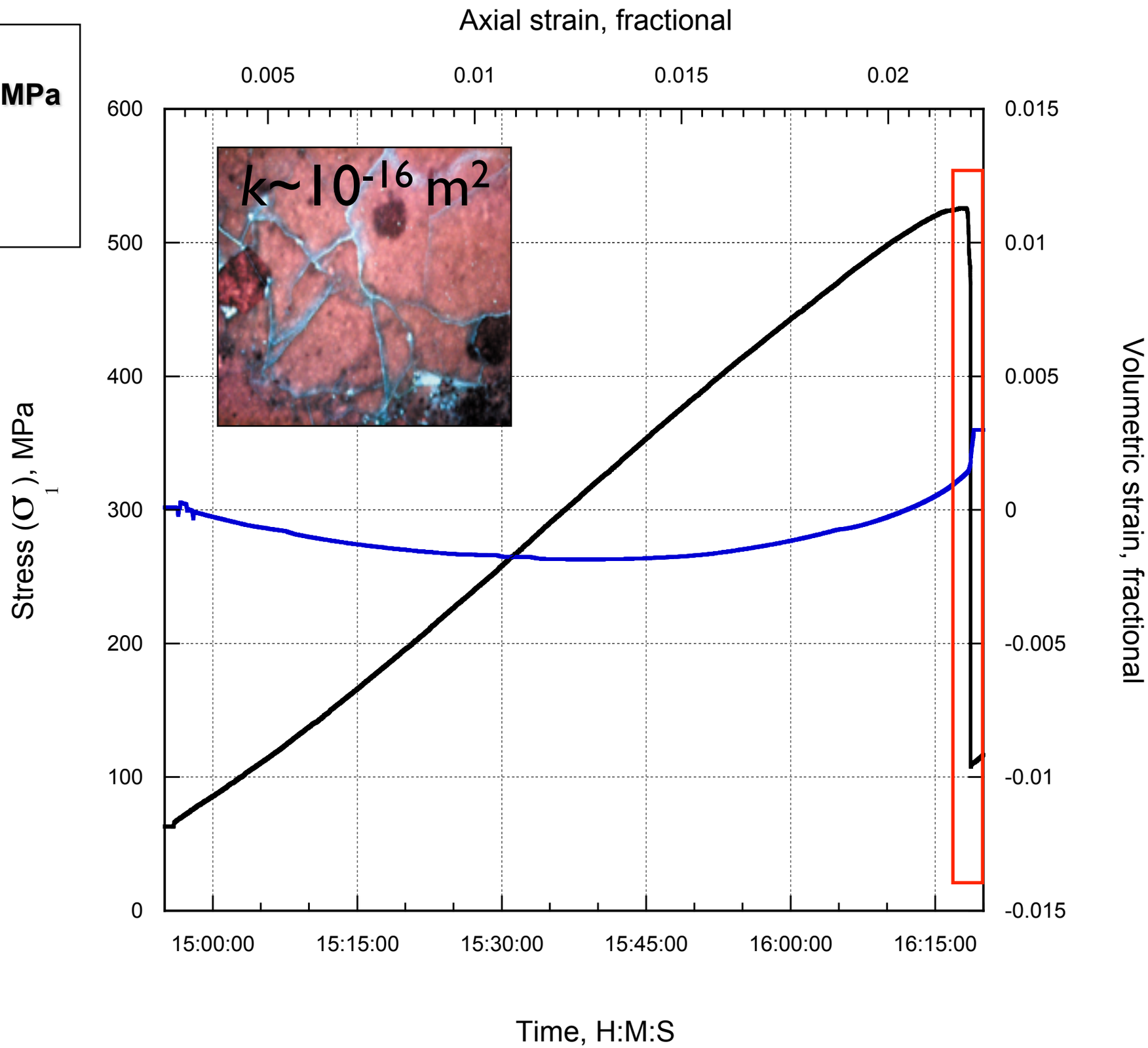
Experiments are conducted in two stages:

1. Standard triaxial deformation to create a fracture and damage zone

2. Pore pressure is rapidly released (decompressed) in order to stimulate rapid fluid movement though that same, characterised damage zone.

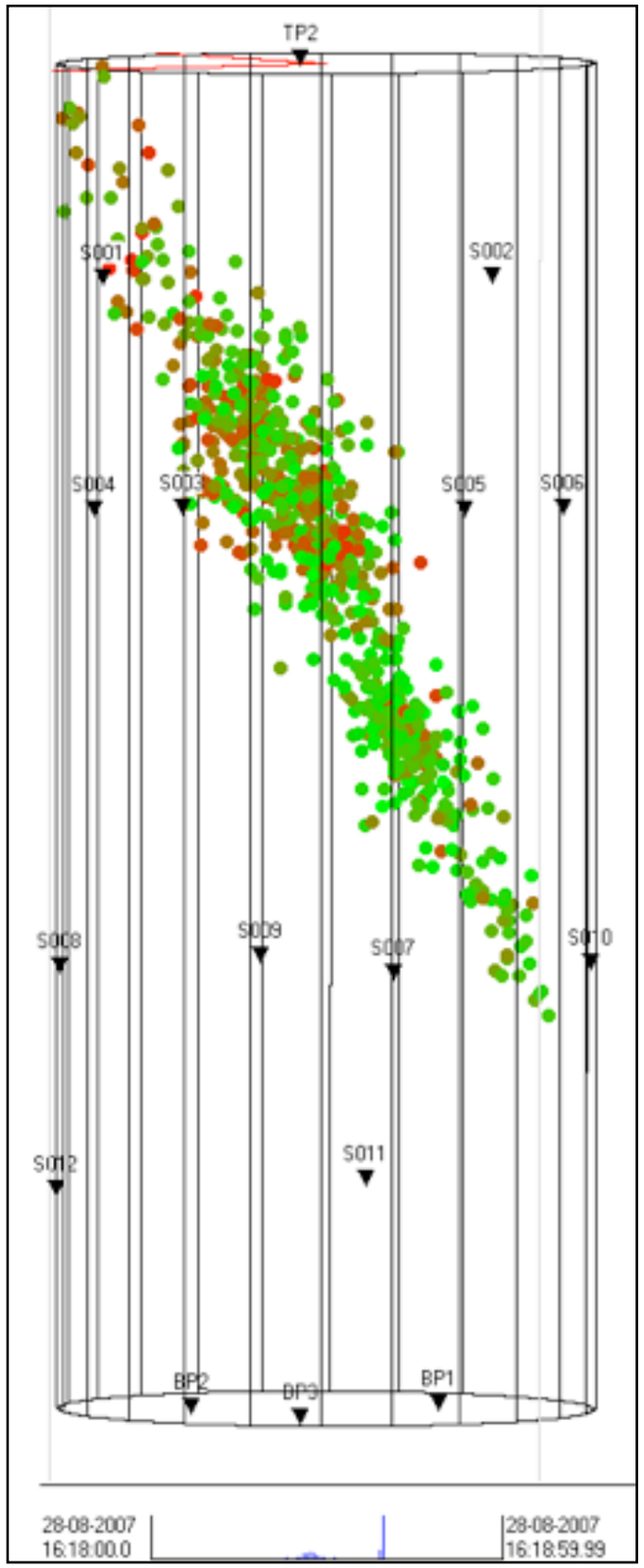
Stage 1: Mechanical response of Etna basalt

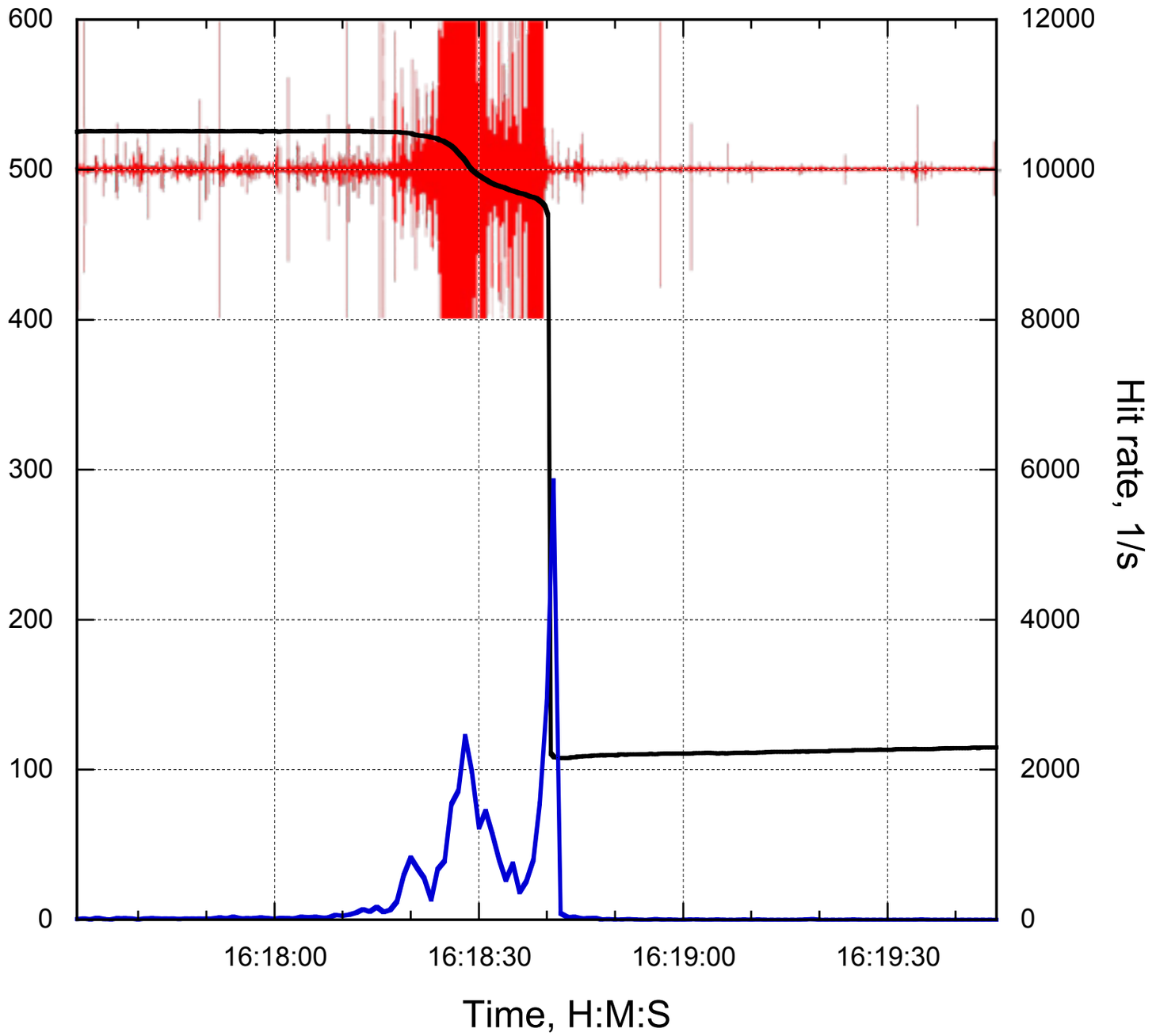
- **Stage 1:**
- **Confining pressure (Pc): 5-60 MPa**
- **Pore pressure (Pp): 5-20MPa (Water)**
- **Strain rate ~0.5 x10^{-6} s^{-1}**



Mechanical response of Etna basalt

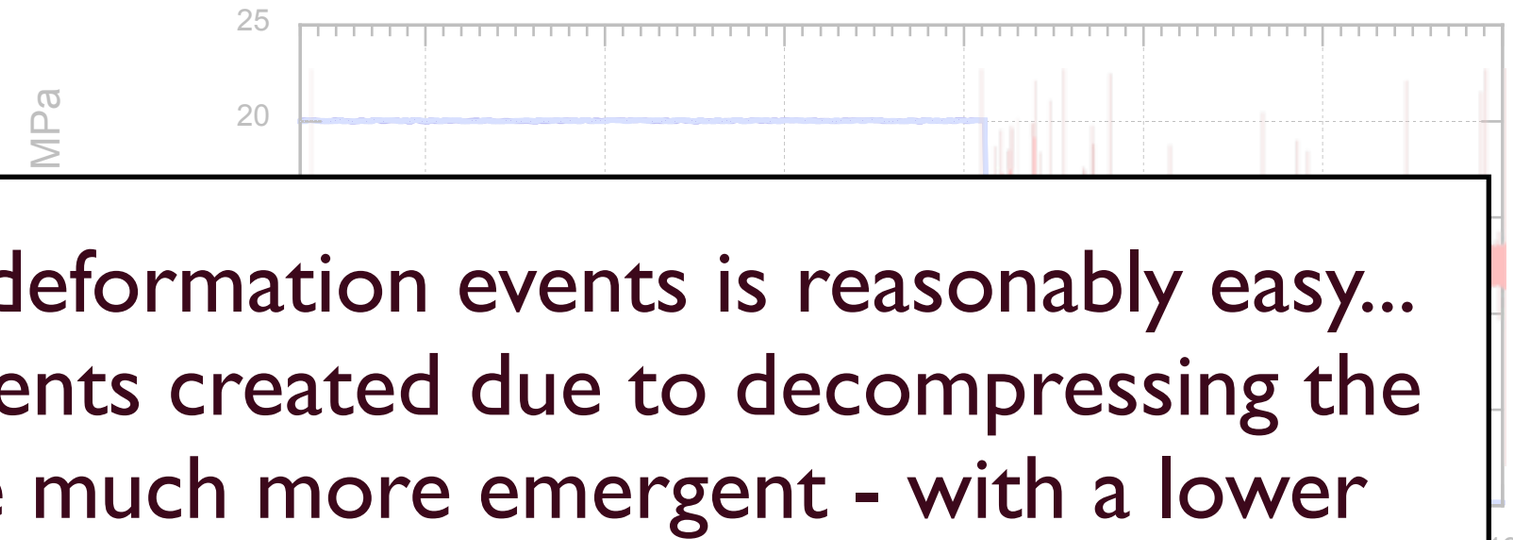
Pc=60 MPa, Pp=20 MPa, T=25C





Stage 2: Decompressing the (located) fault zone

- Stage 2:
- Confining pressure (Pc): 60 MPa
- Pore pressure (Pp): 20MPa (Water)
- Hyd



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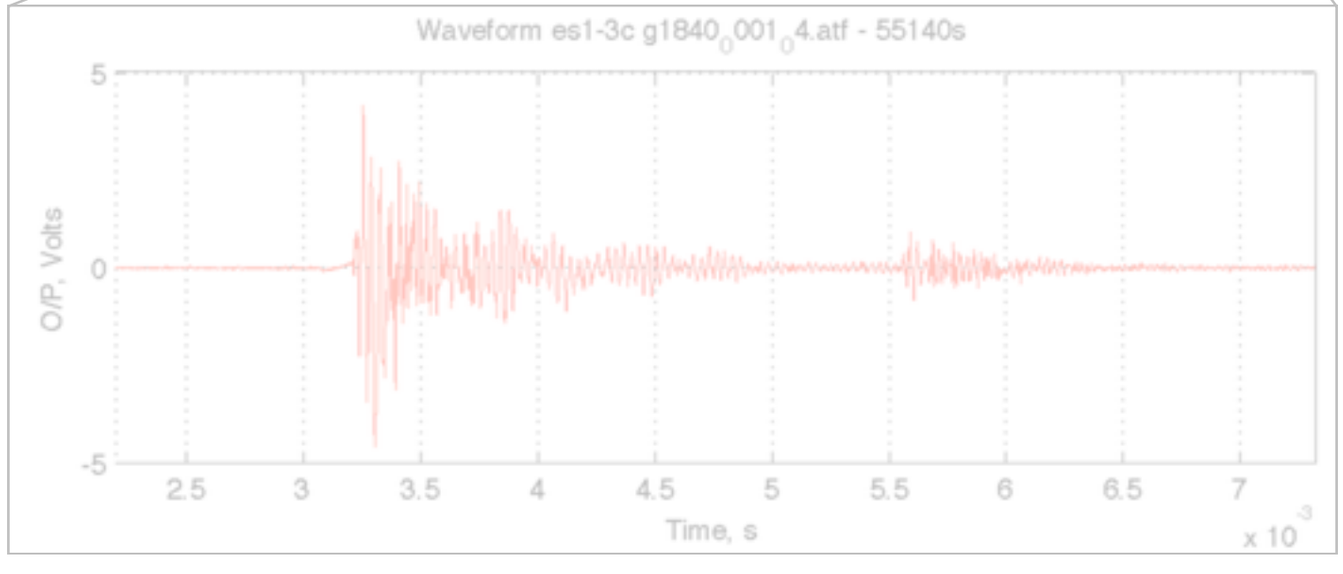
fault previously located by the AE location method

- The conduit provides direct access to the damage zone

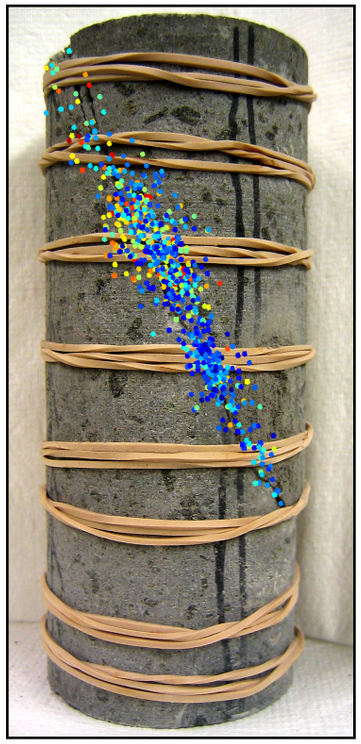
- A 'swarm' of AE activity is recorded

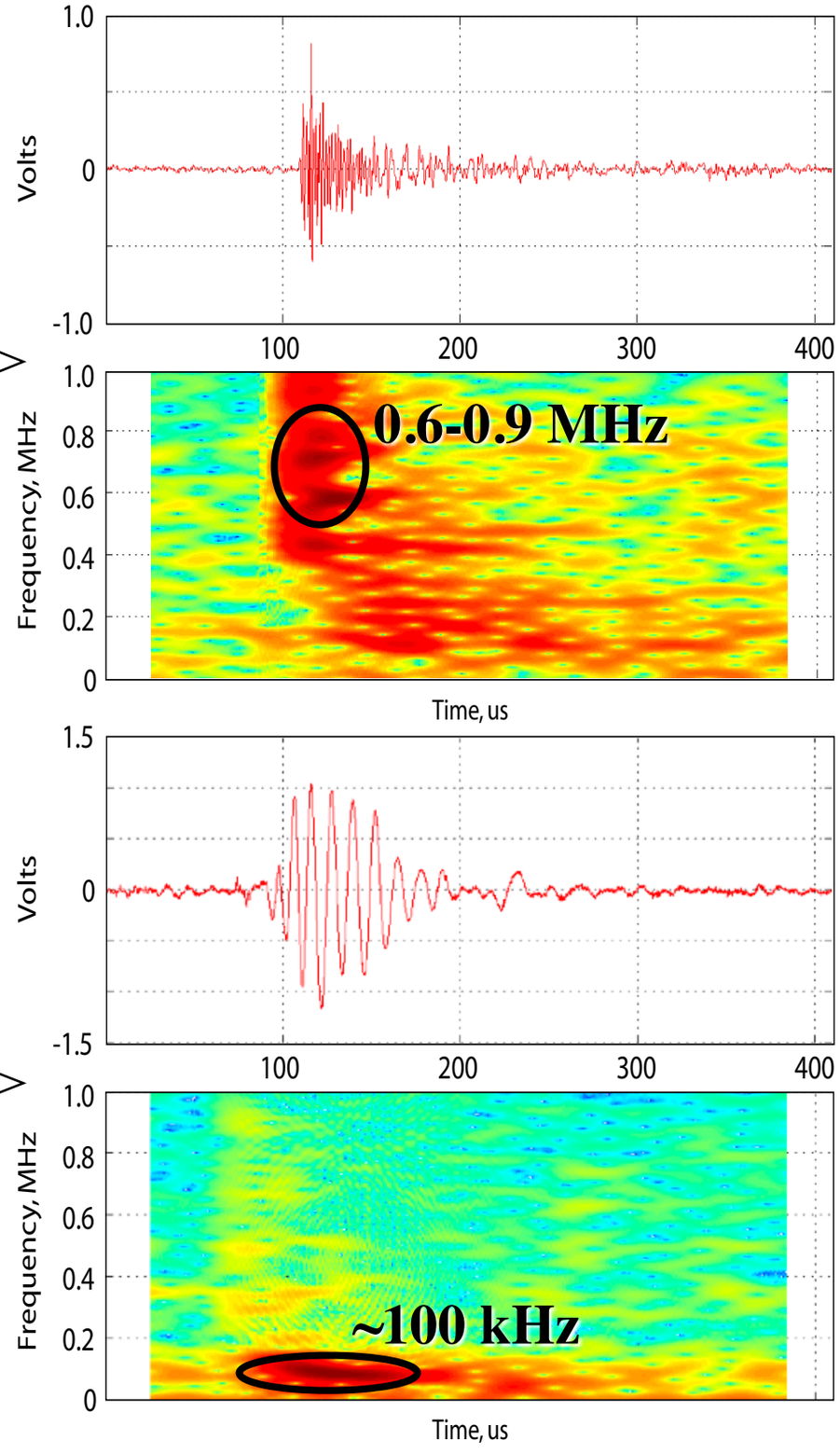
- Locating brittle deformation events is reasonably easy...
- However, the events created due to decompressing the damage zone are much more emergent - with a lower frequency - than brittle events. Picking these accurately is a challenge….

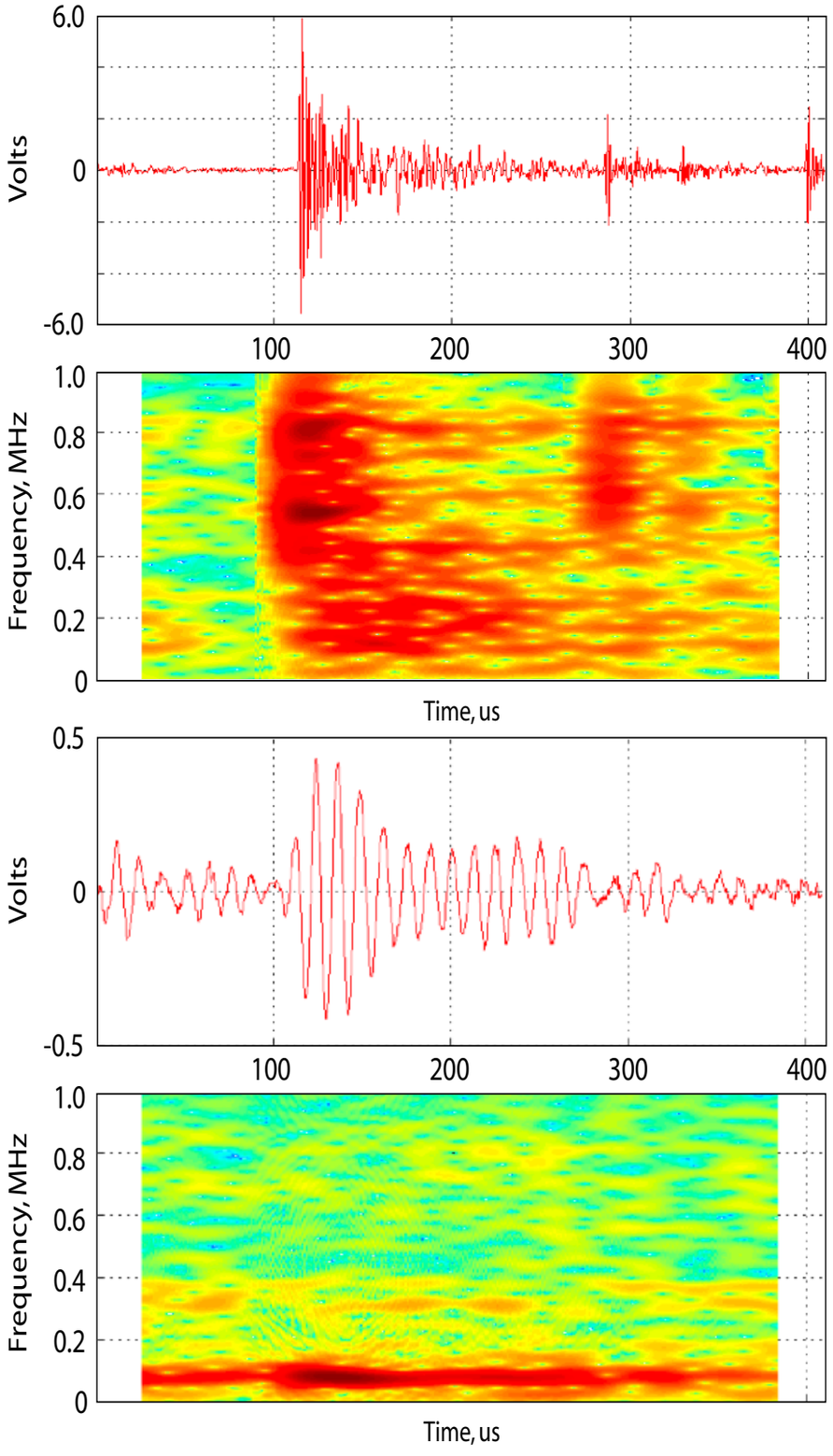


Frequency changes: example

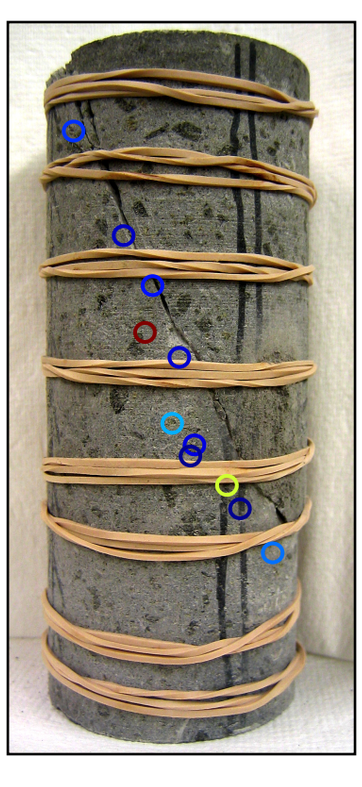
FAILURE







DECOMPRESSION

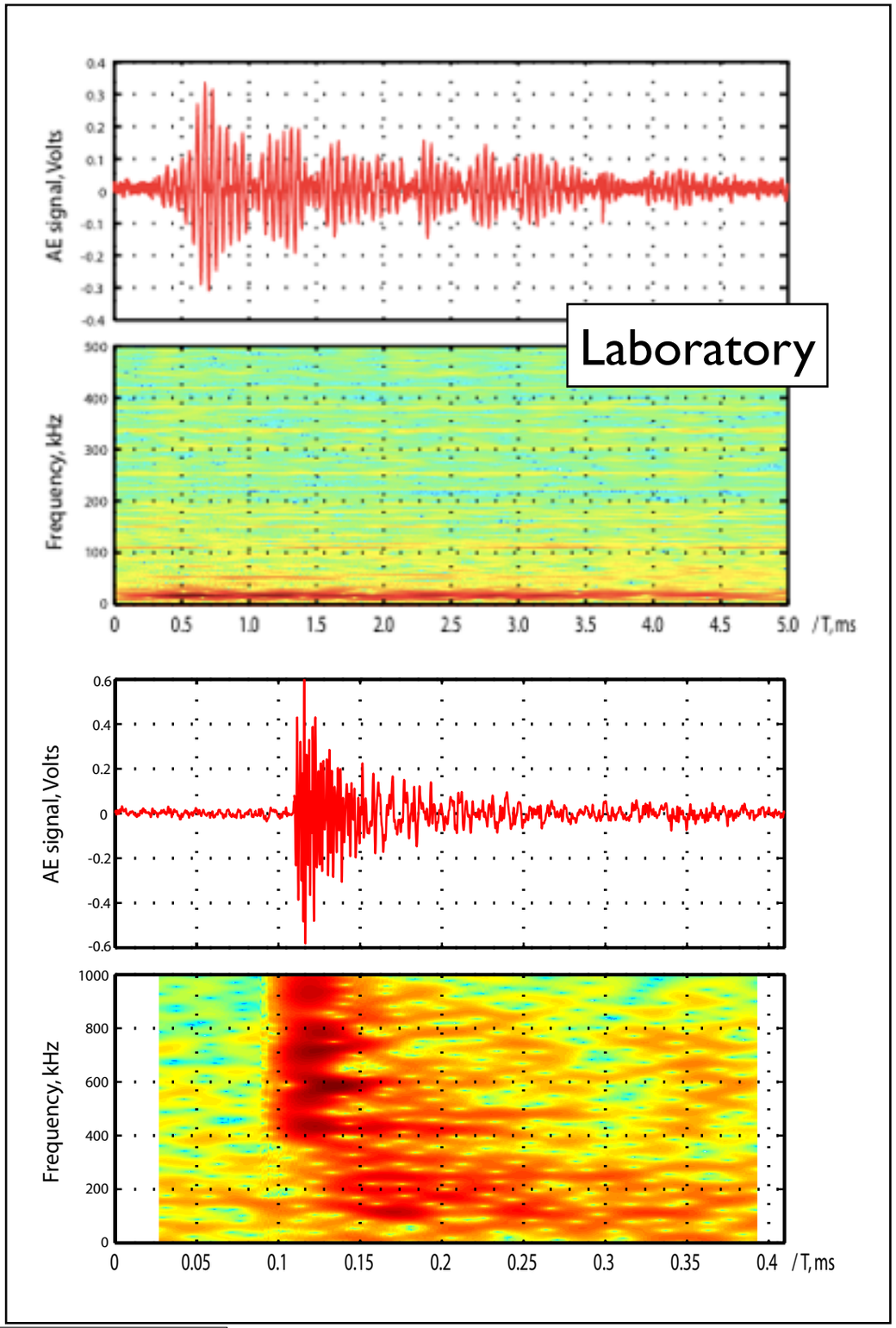


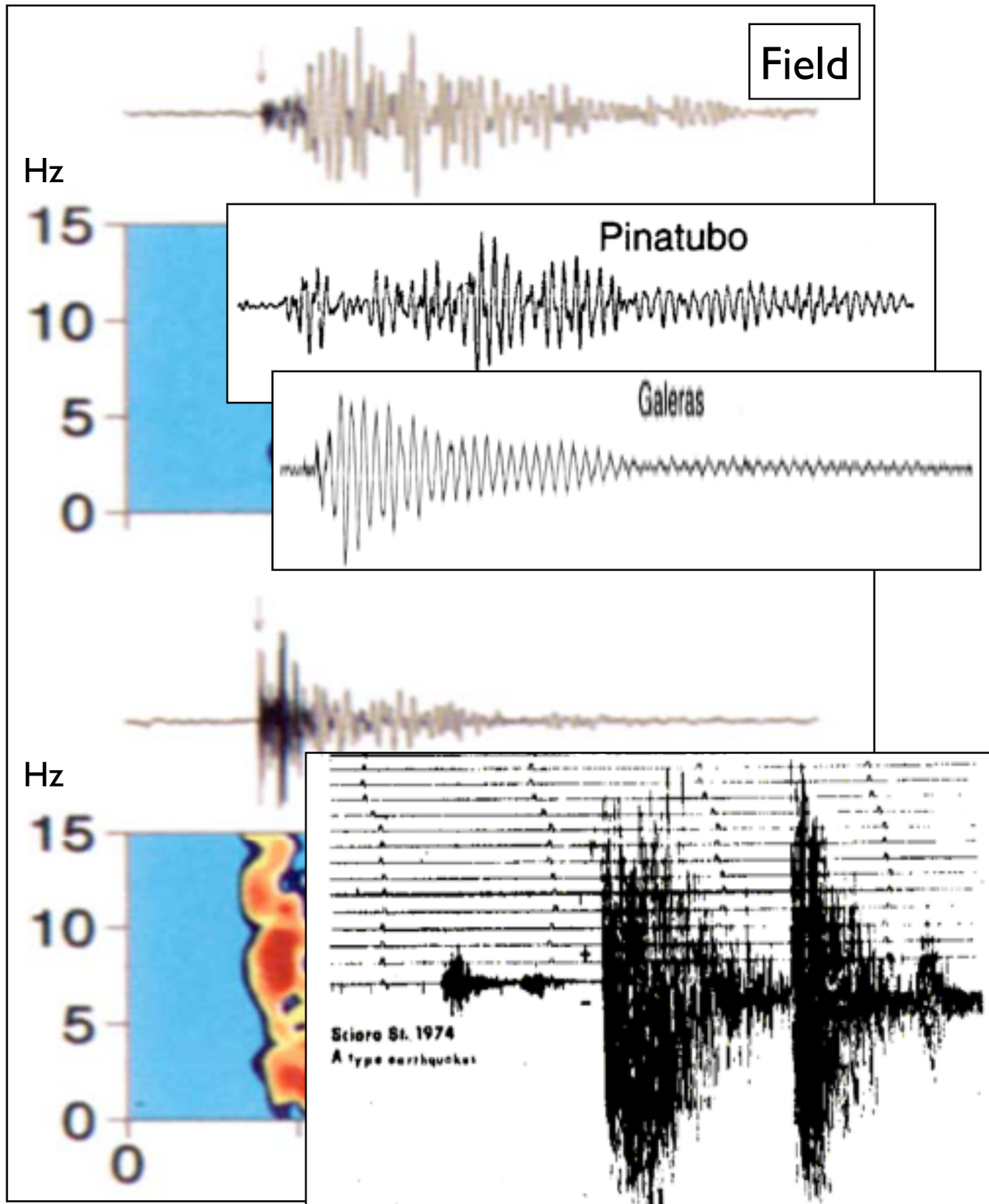
Frequency comparisons: VT/LF

... cheeky but irresistible!

DECOMPRESSION

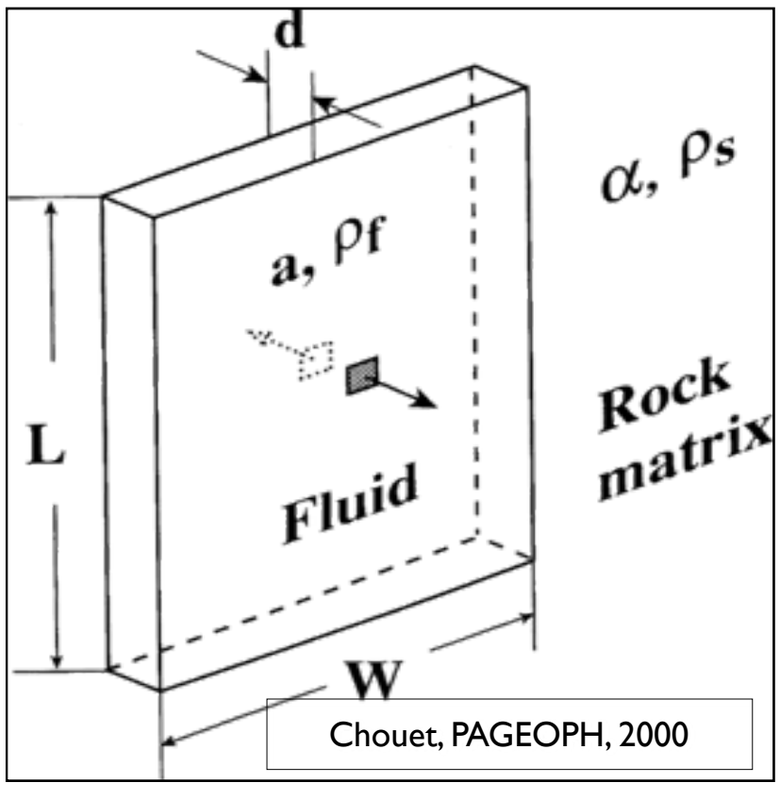
FAILURE



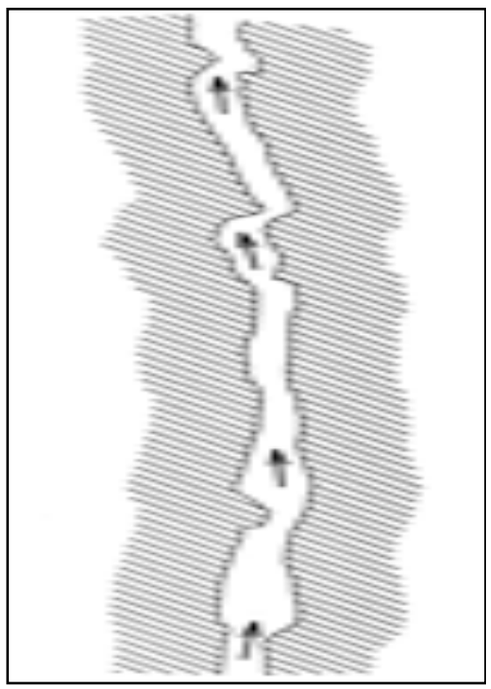


Benson et. al., Science, 2008

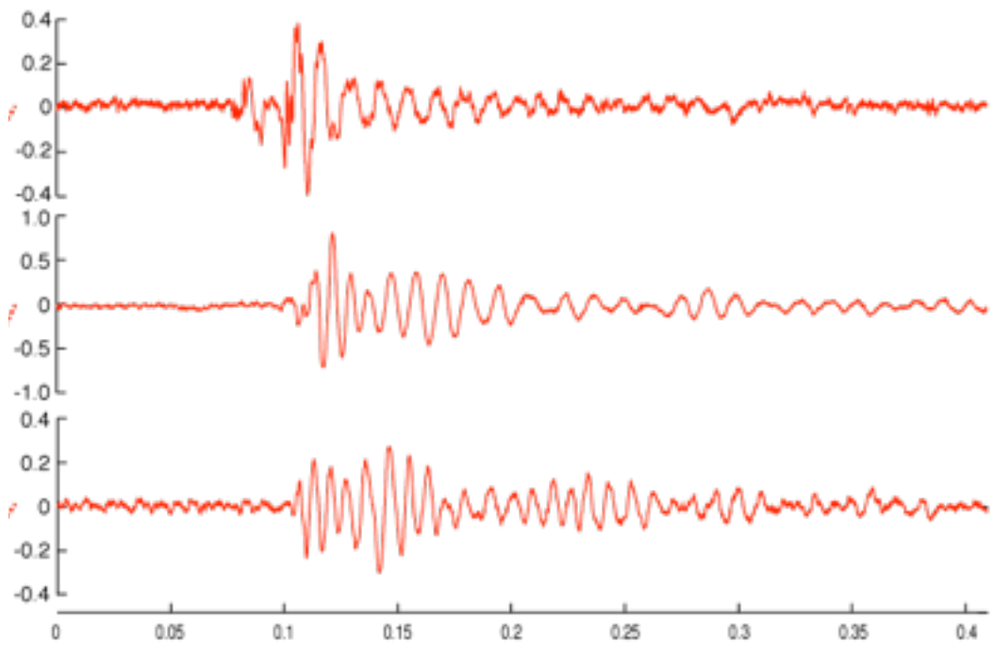
Forensic (SEM) analysis & models

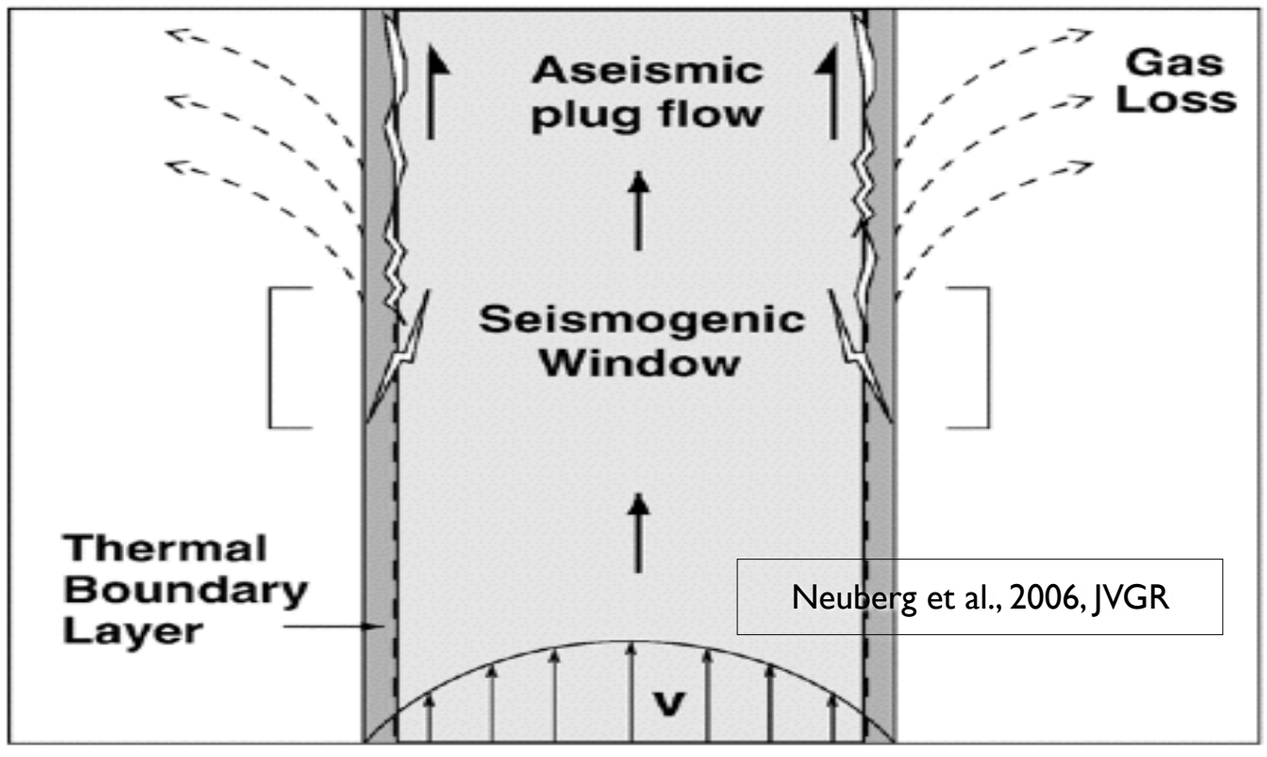


Chouet, PAGEOPH, 2000

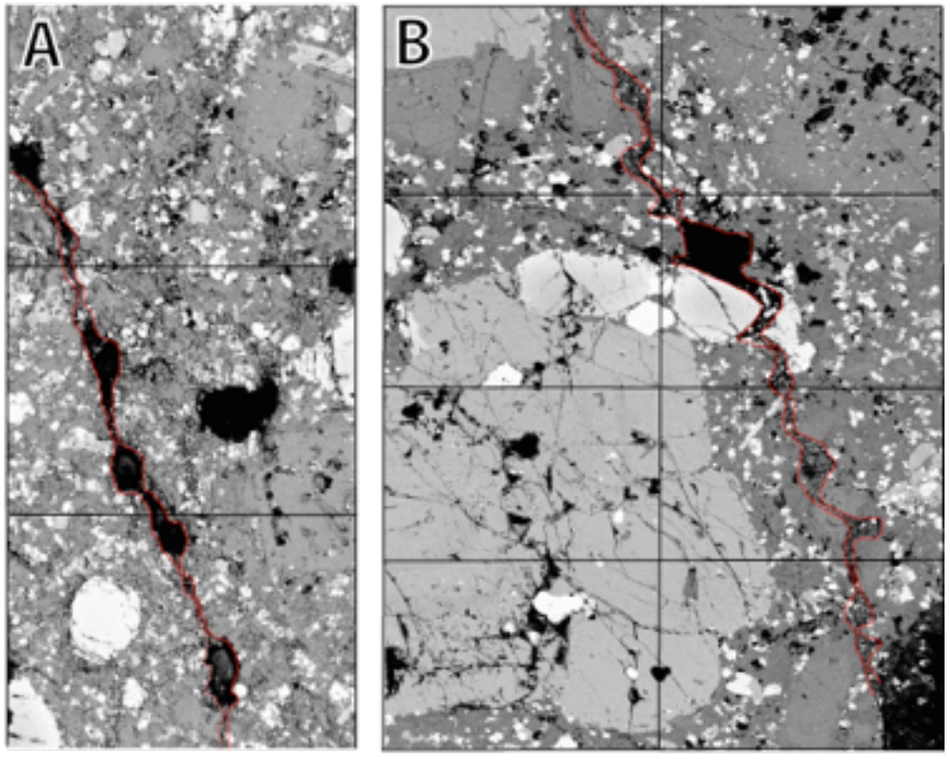


Julian, 1994, JGR





Neuberg et al., 2006, JVGR



Benson et. al., Science, 2008

Part 2) ...Yielding more questions:

New series of experiments (current work-in-progress!):

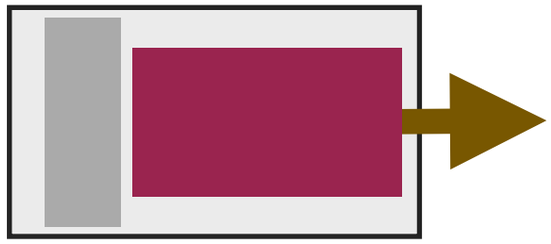
- Modify and develop better **sensors** to better capture the LF data (and concomitant pre-amplifier bandpass)...

- Improve fracture (eruption) **forecasting strategies** using fracture forecast models (FFM's)

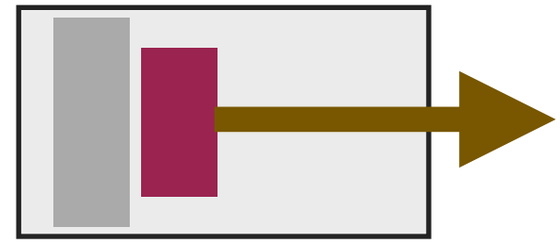
- Explore any "thresholds" for induced seismic response in terms of **pore pressures** and/or **temperatures** required...

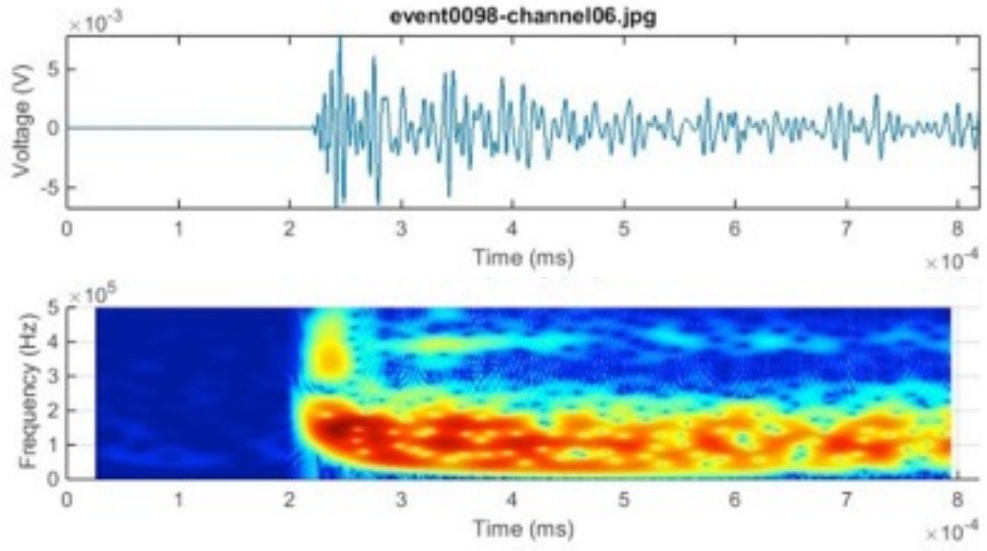
- Investigate the rate of pore pressure decrease (**fluid flux**) - measuring this is not straightforward so pilot data concentrated on using a high but still plausible value (pore pressure of 10-20MPa)...

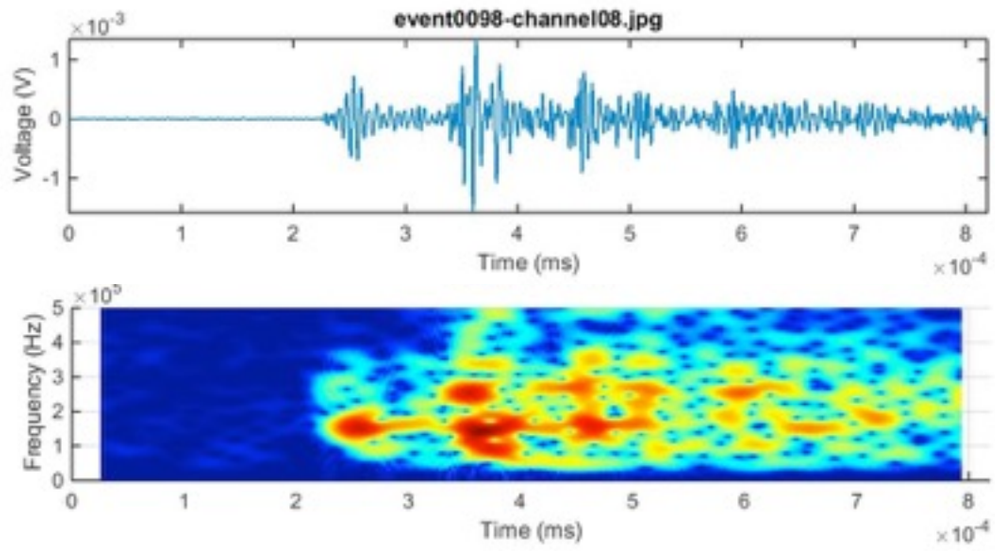
Low Vs. High Frequency sensors



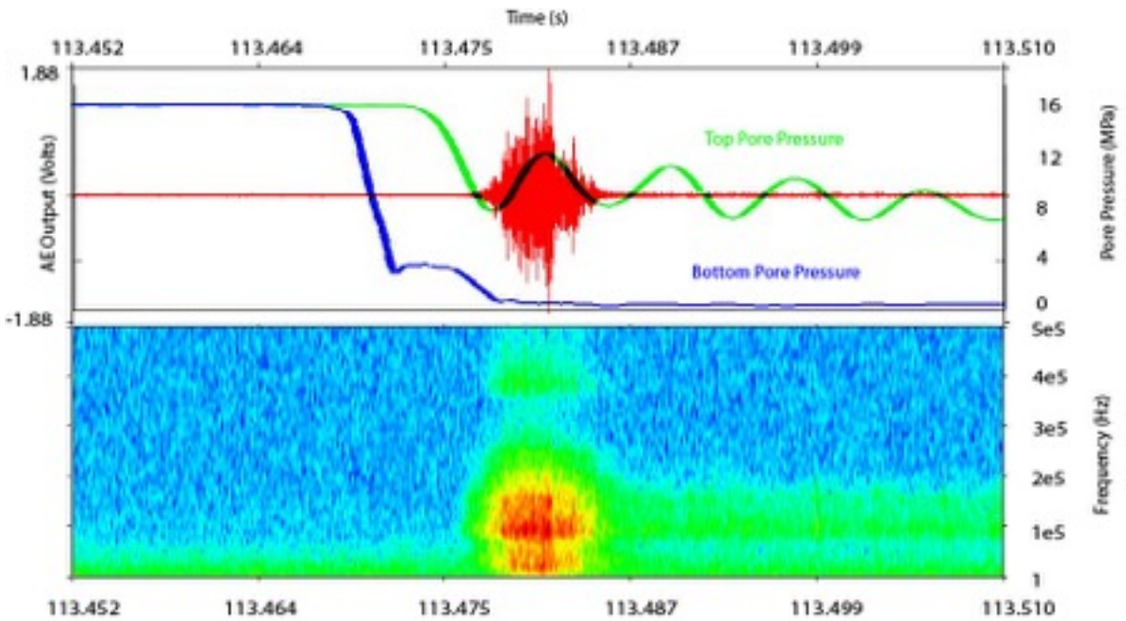
Single Event

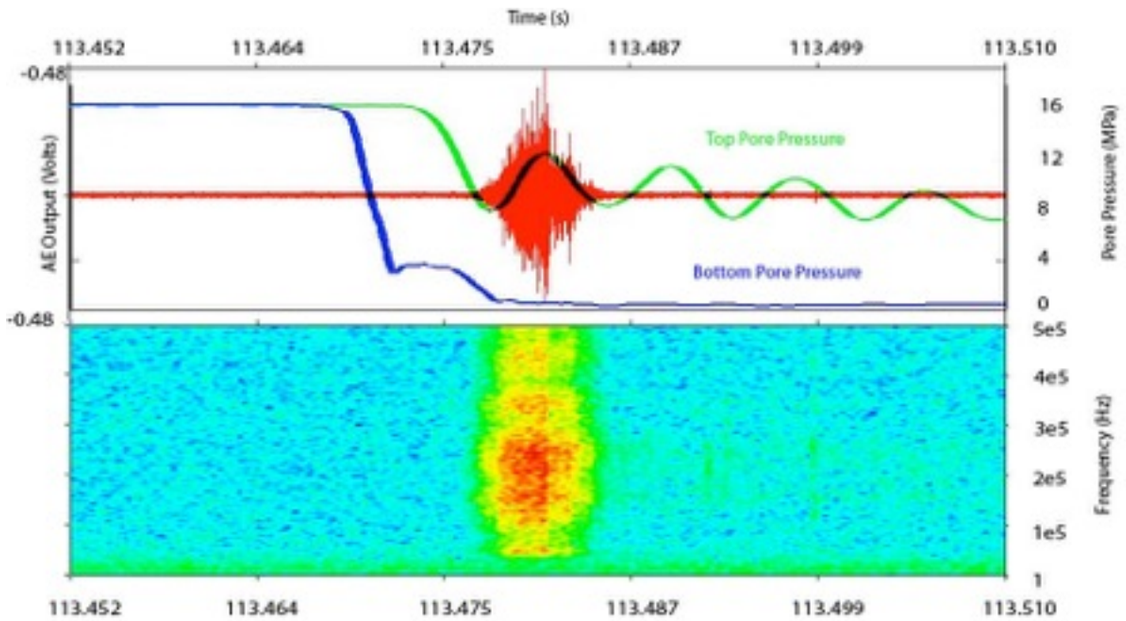




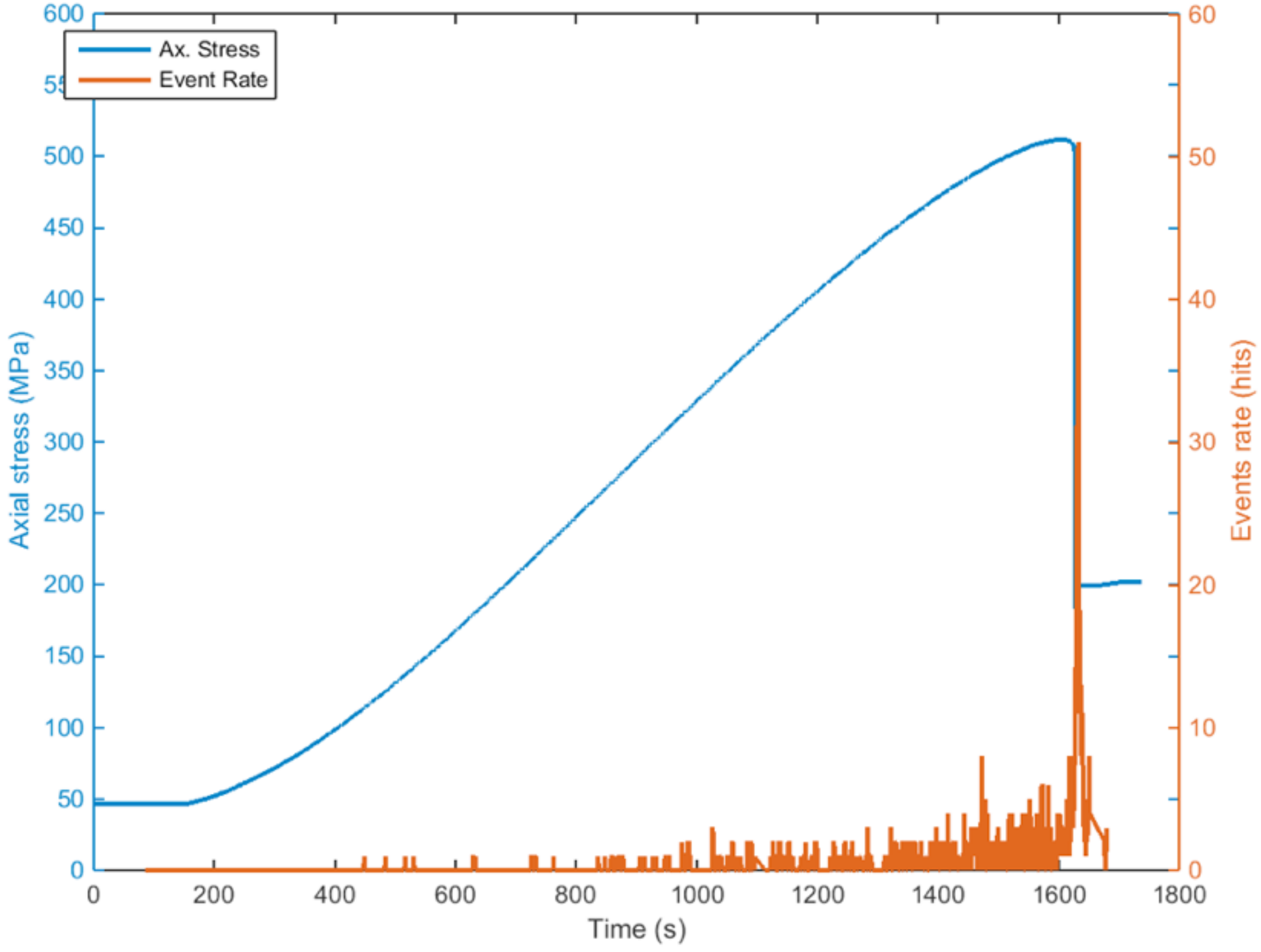


Swarm of AE



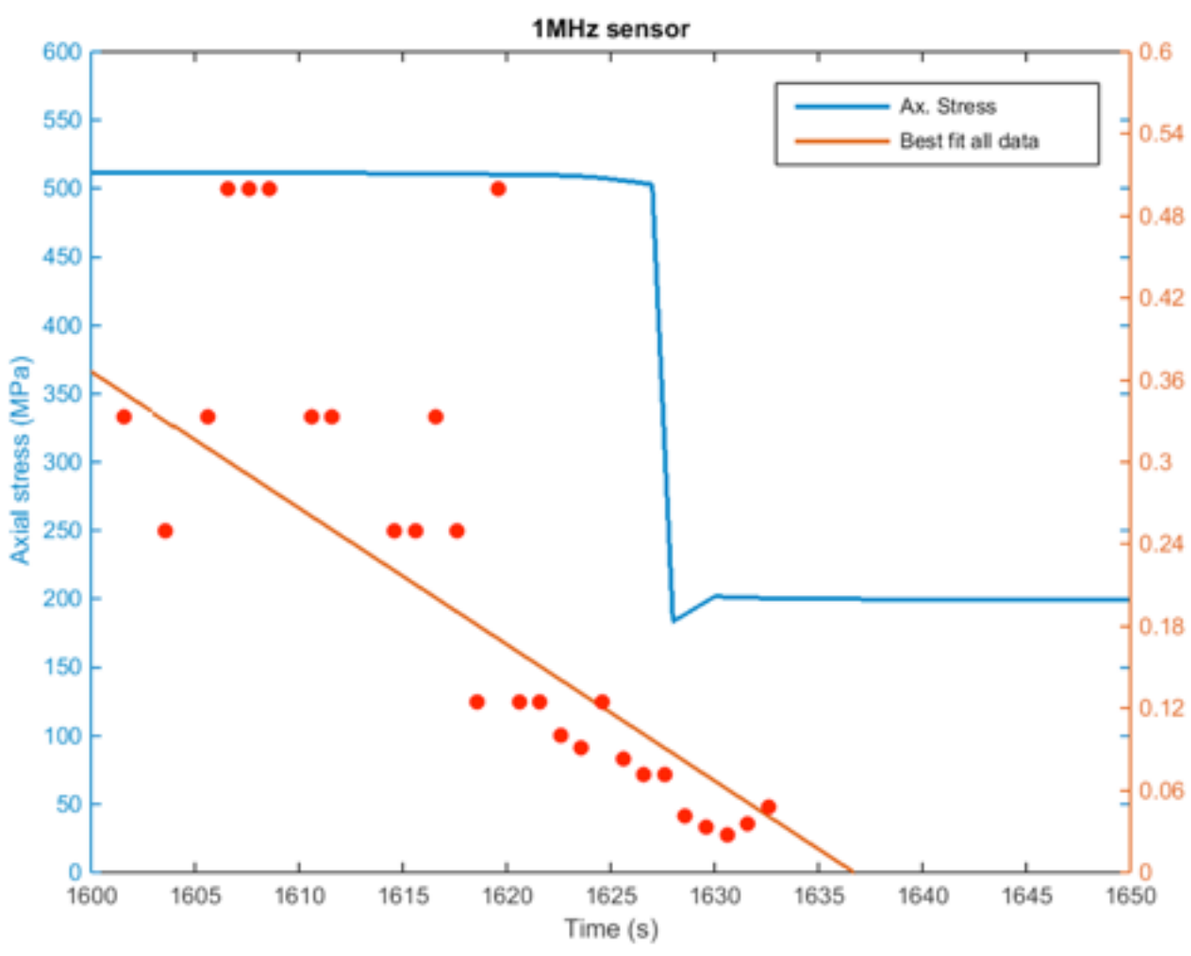


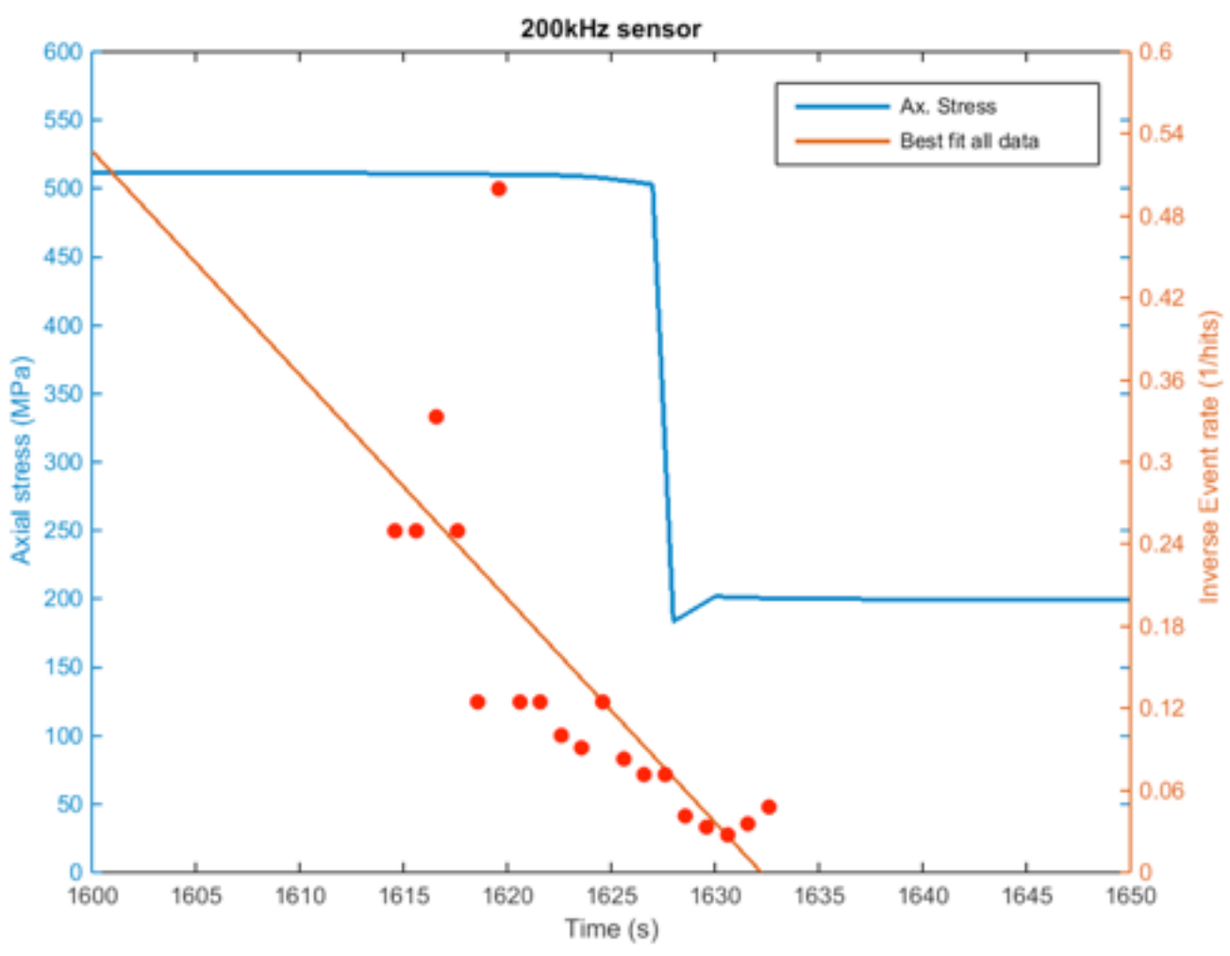
Forecasting (briefly)



Forecasting (briefly)

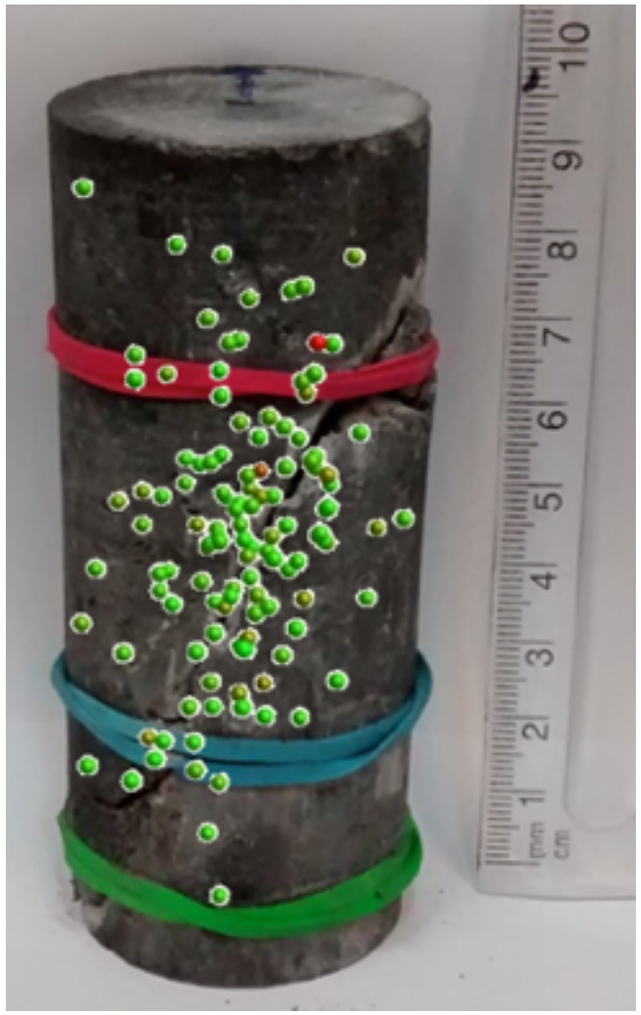
- Use the inverse AE hit rate (Voight scheme); extrapolate to zero at time of "failure" (eruption)
- Often done with HF data (VT)...
- Although simplistic, this works well for volcanoes with long repose intervals (rock is intact), and simulations in the lab back this up:





Influences of pore pressure and temperature

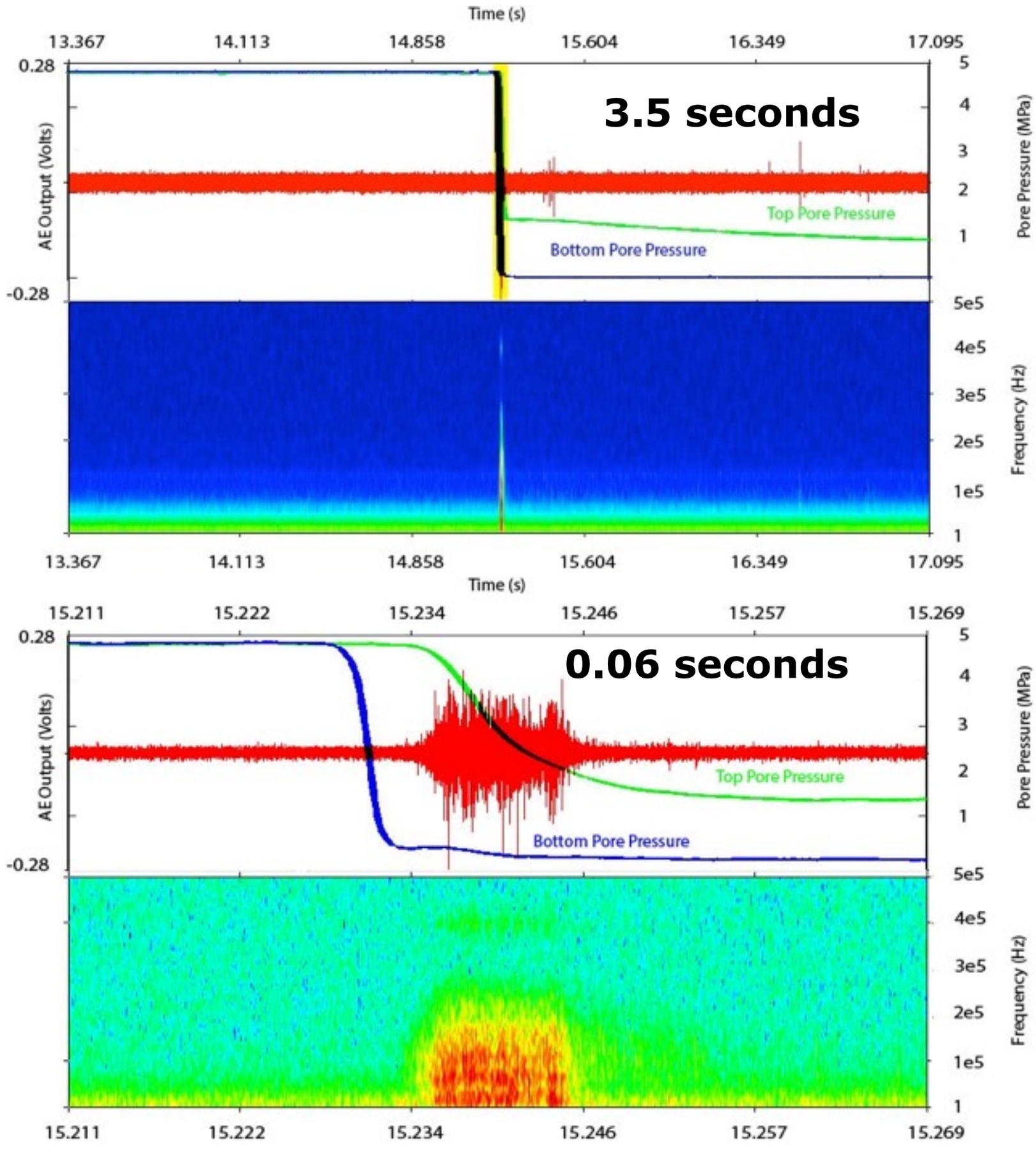
Starting with the same fracture damage / process zone, try different pore-pressure-release "triggers" to examine thresholds for induced seismic response (and temperature/ phase)



T = 25°C ; Pc = 35 MPa ; Pp = 5 MPa

Decompression of pore space:

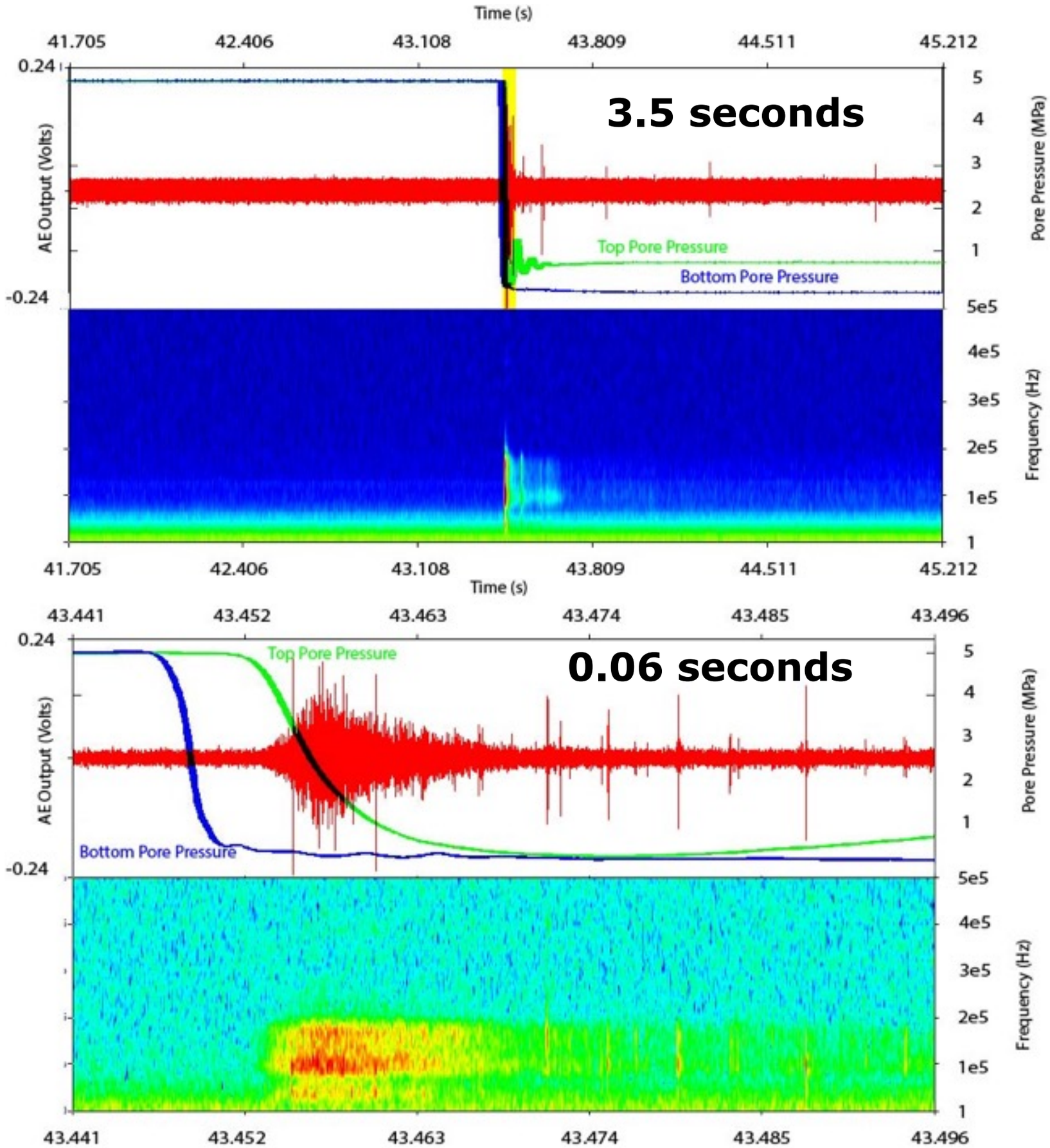
- Water saturated
- Via solenoid valve
  - Approx. 0.02s pressure decay



T = 175°C ; Pc = 35 MPa ; Pp = 5 MPa

Decompression of pore space:

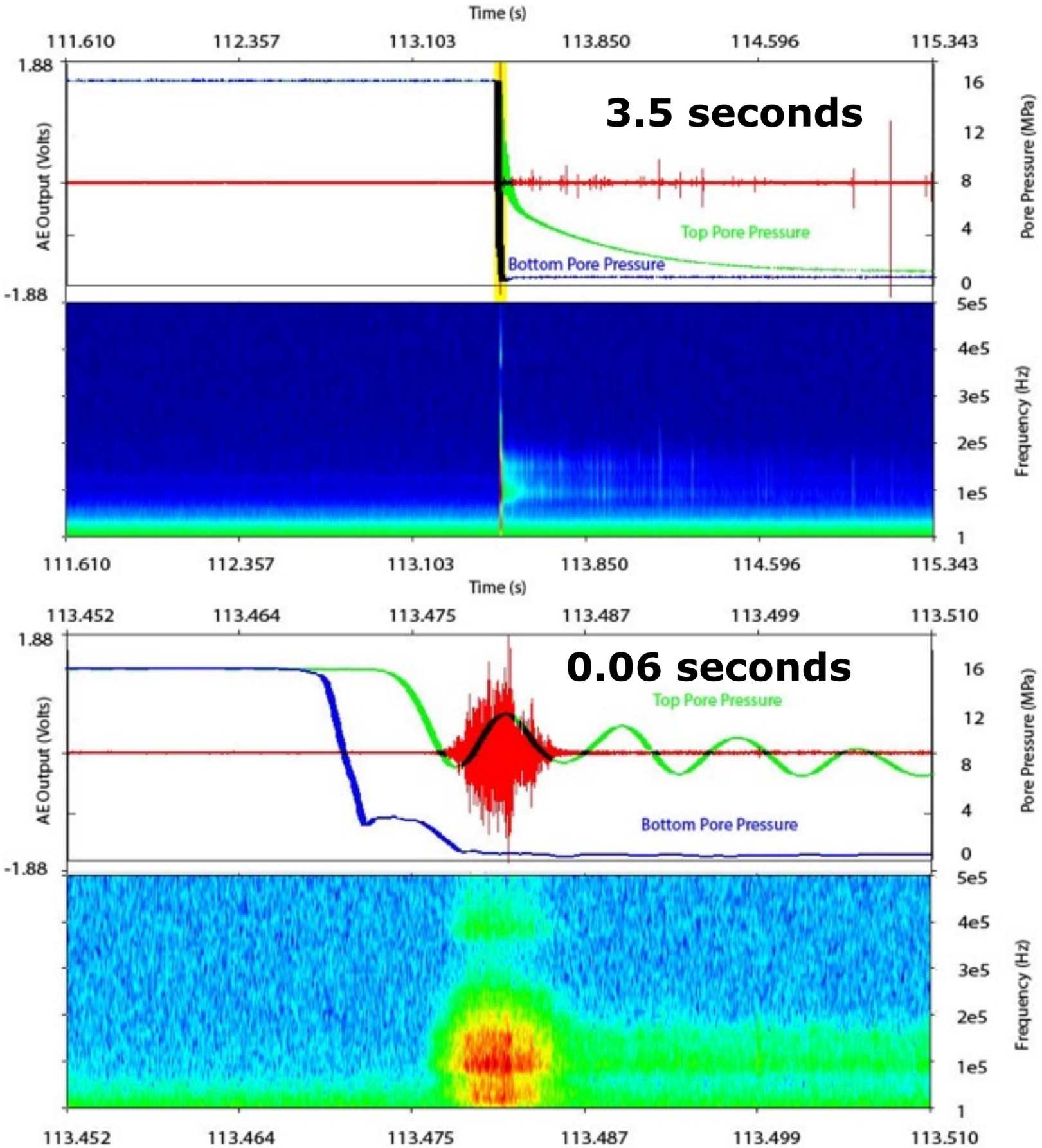
- Water saturated
- Via solenoid valve
- Approx. 0.02s pressure decay (again)
- Slightly different character in power spectra: longer coda



T = 175°C ; Pc = 46 MPa ; Pp = 16 MPa

Decompression of pore space:

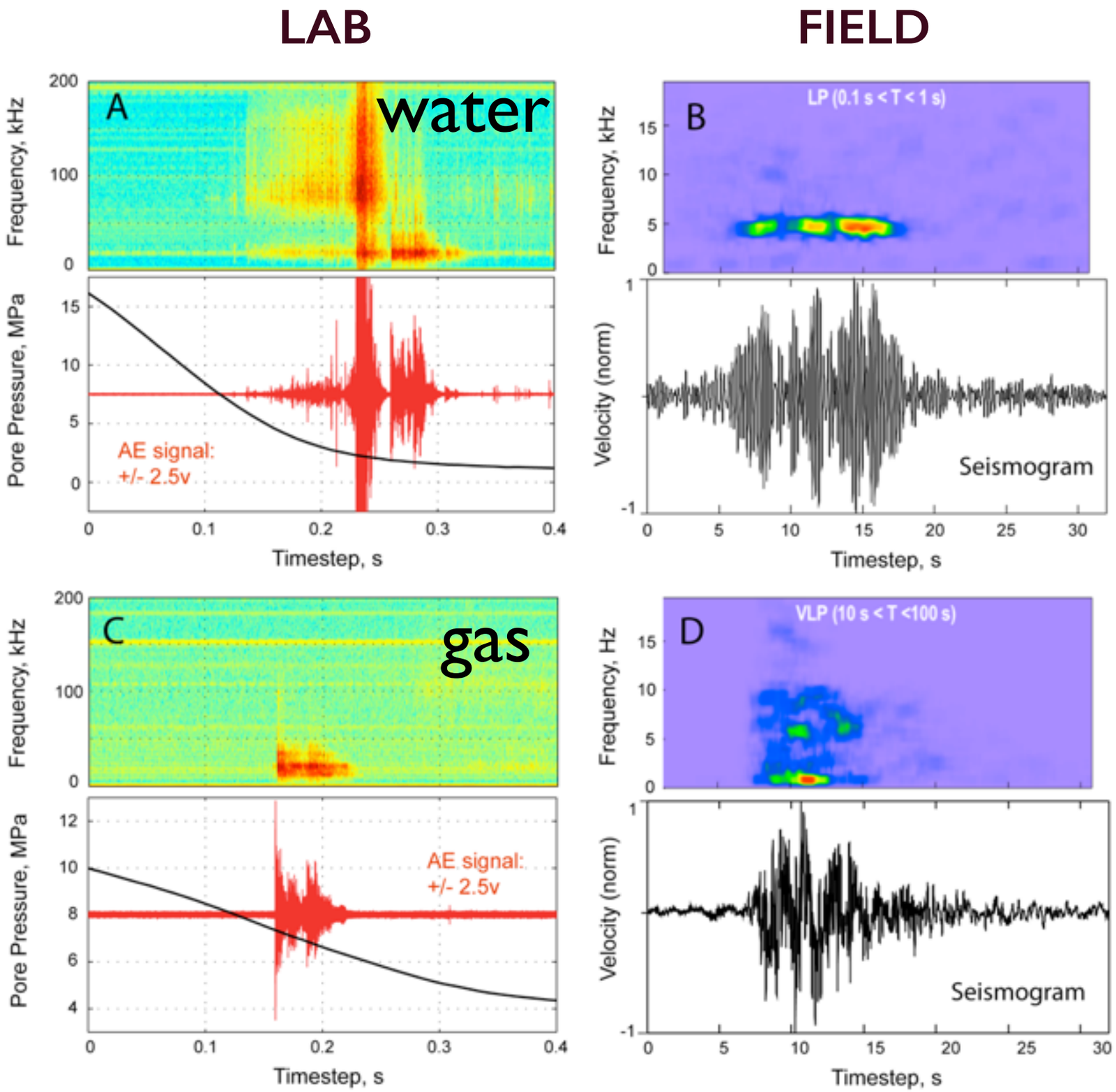
- Water saturated
- Via solenoid valve
- Complex pressure decay (faster?)
- More compact swarm (higher pressure?)
- Stronger component at low frequencies <100kHz?



T = 175°C ; Pc = 60 MPa ; Pp = 20 MPa

Decompression of pore space:

- Water saturated
- Via solenoid valve
- Link pressure decay to fluid phase...
- Evidence for liquid to gas transition confirmed by pure gas experiments....



Benson et al., Frontiers in Earth Science, 2014

Influences of pore pressure and temperature

Thoughts and challenges to date:

- Frequency of the sensors important (and associated response of the recording system)

- Some evidence for evolution of power spectra with fluid and confining pressure, but (clearly) a lot more work needed...

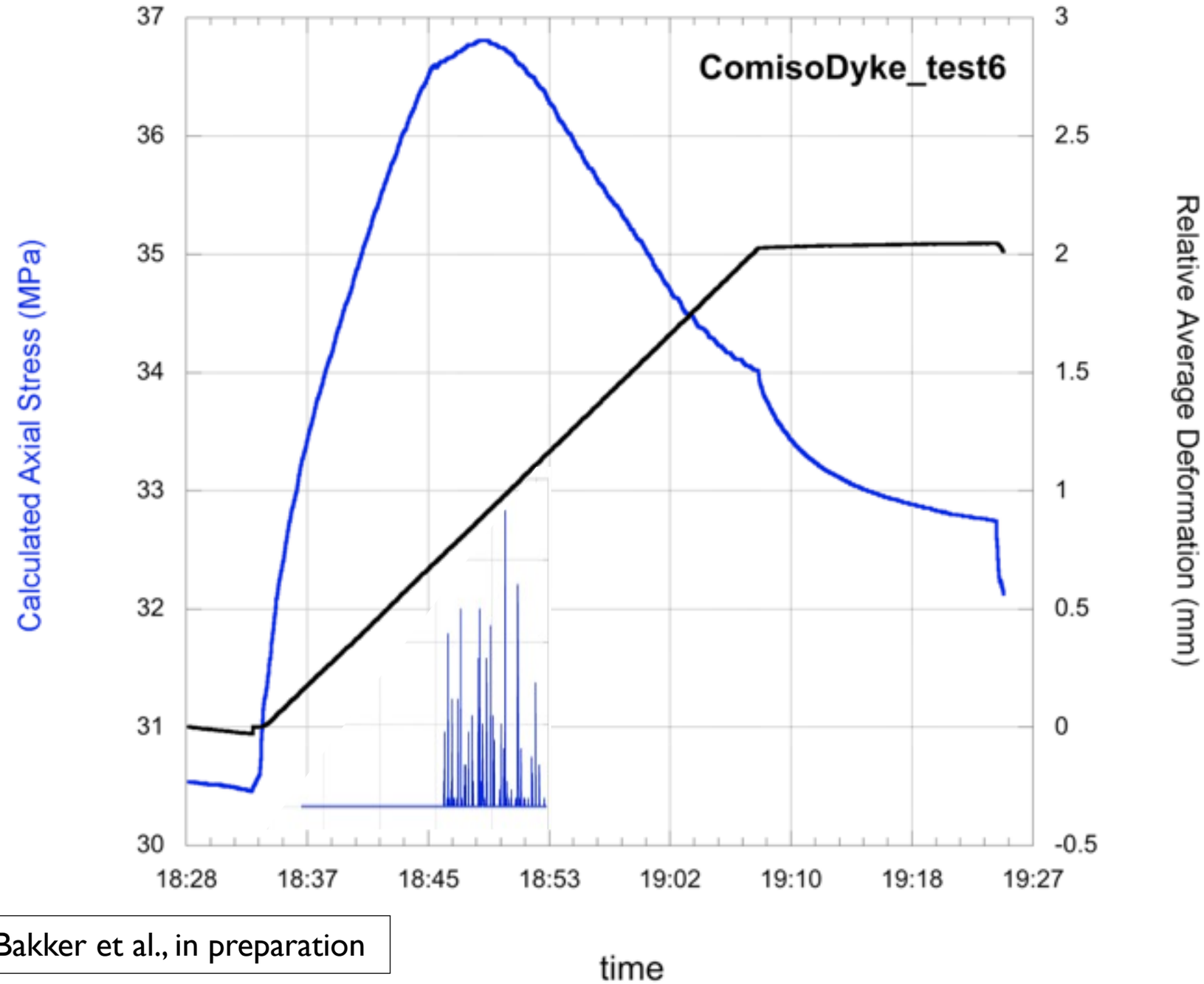
- Clipping a problem...

- Still no solutions to measuring a fluid flux directly: but the pressure drop may allow this to be calculated...

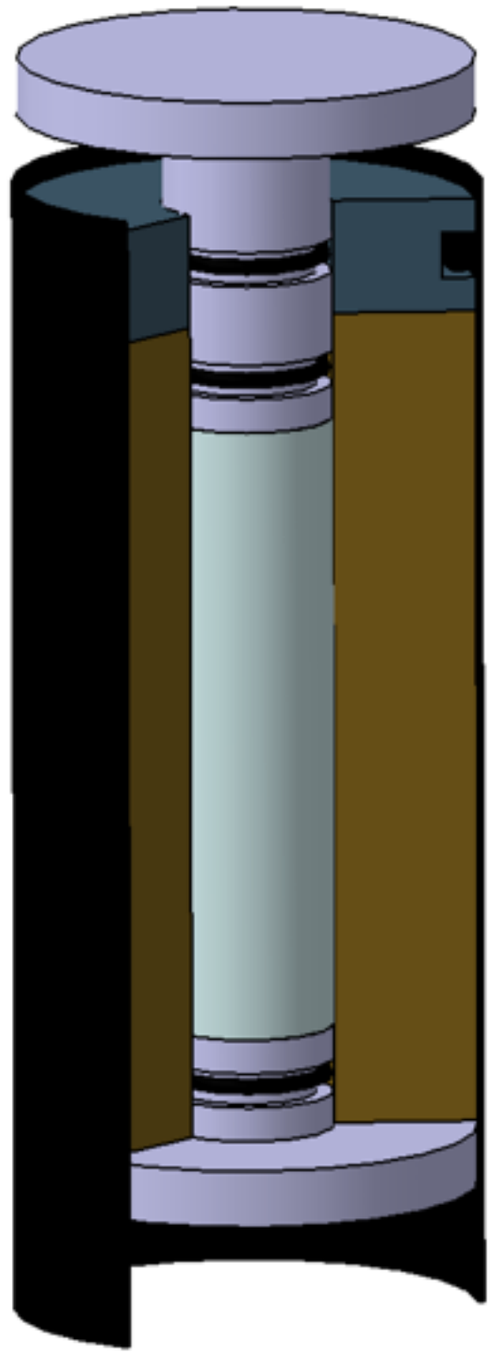
Bonus!) Lab simulation of dykeing

- High temperatures = nightmare! However.... PMMA, as an analogue, has been found to be very versatile as a substitute "glass" in TX experiments

- And with larger samples, easier to interpret the deformation

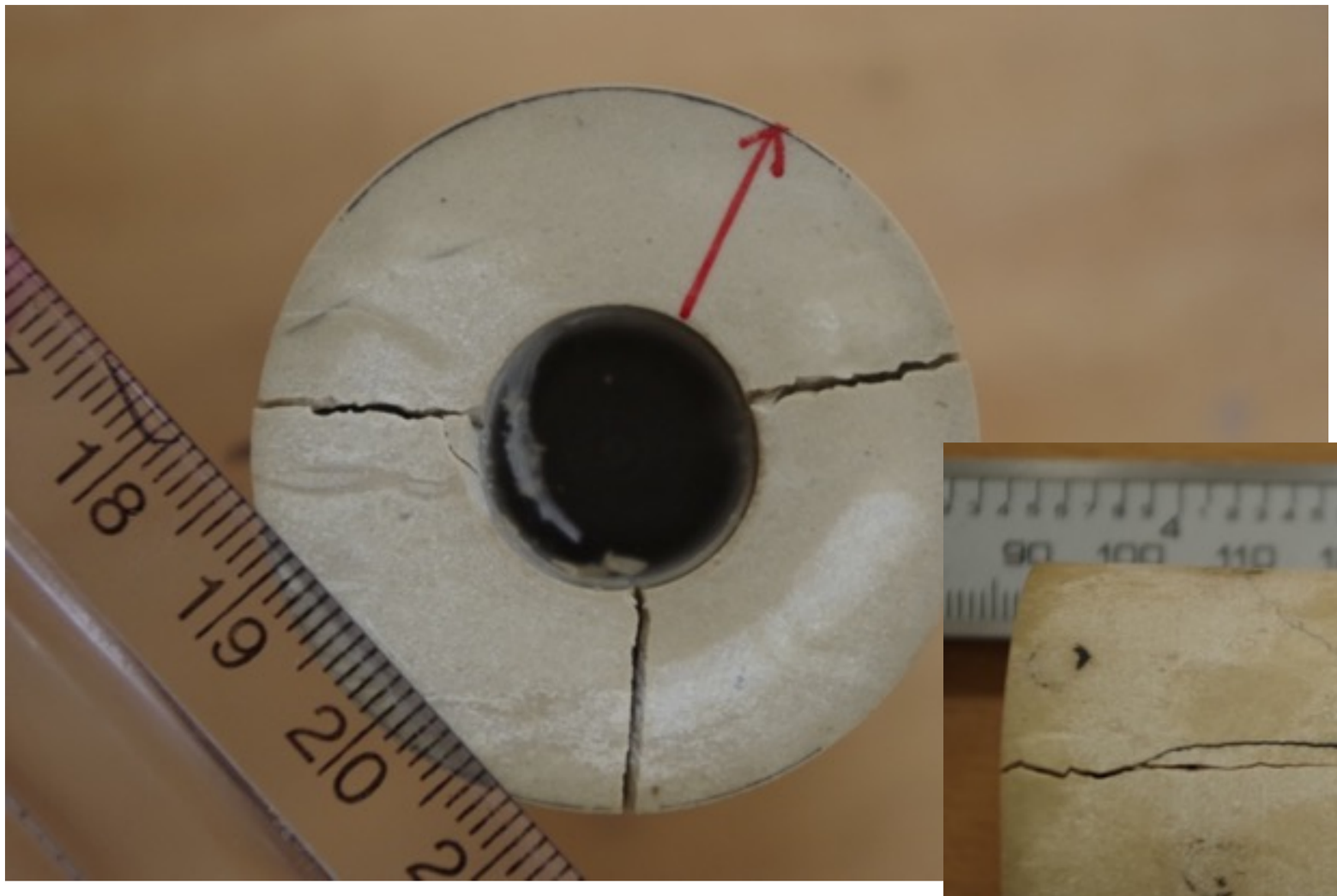


Bakker et al., in preparation



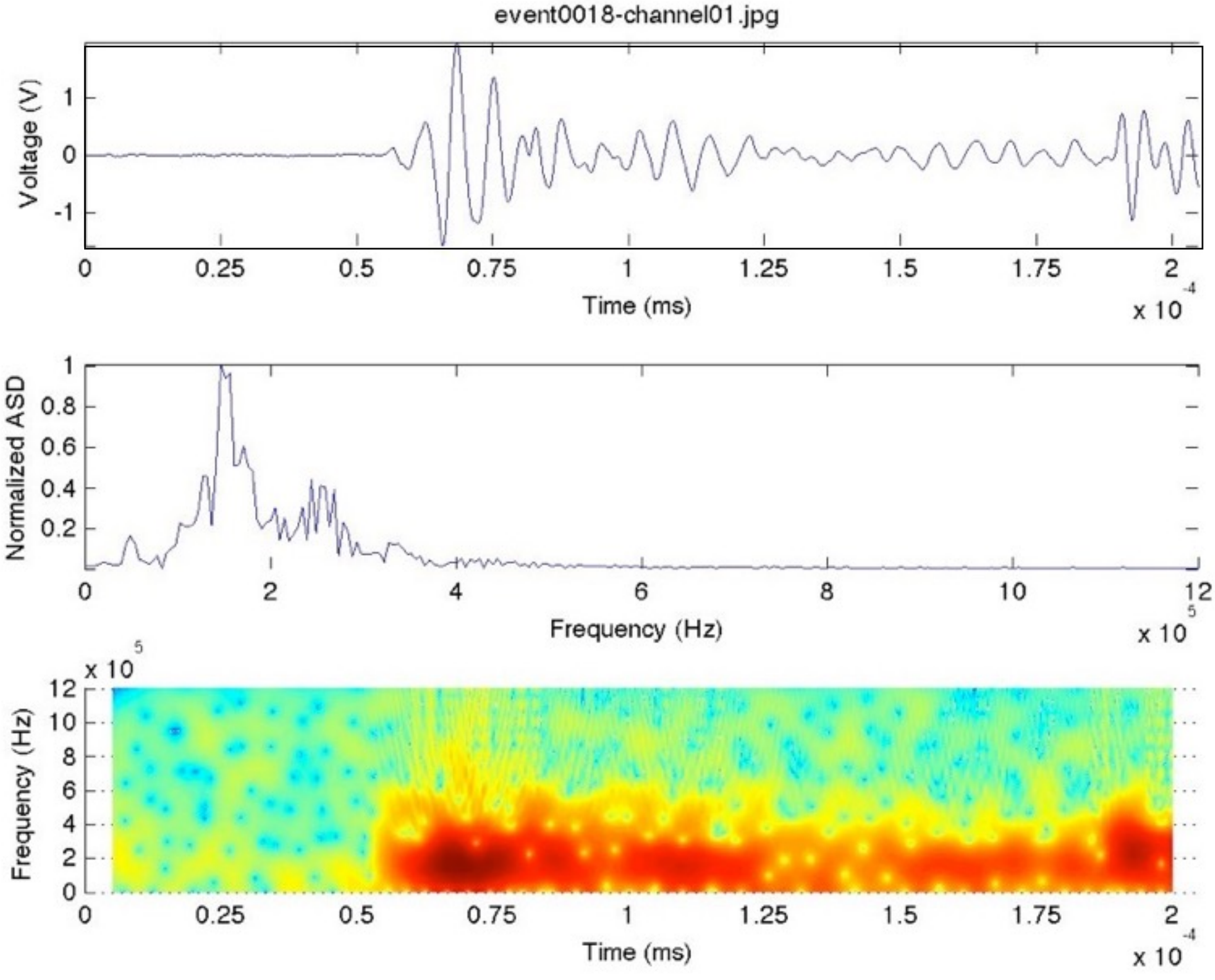
Lab simulation of dykeing

- Sample fails in tension... produces stress drop, and AE...



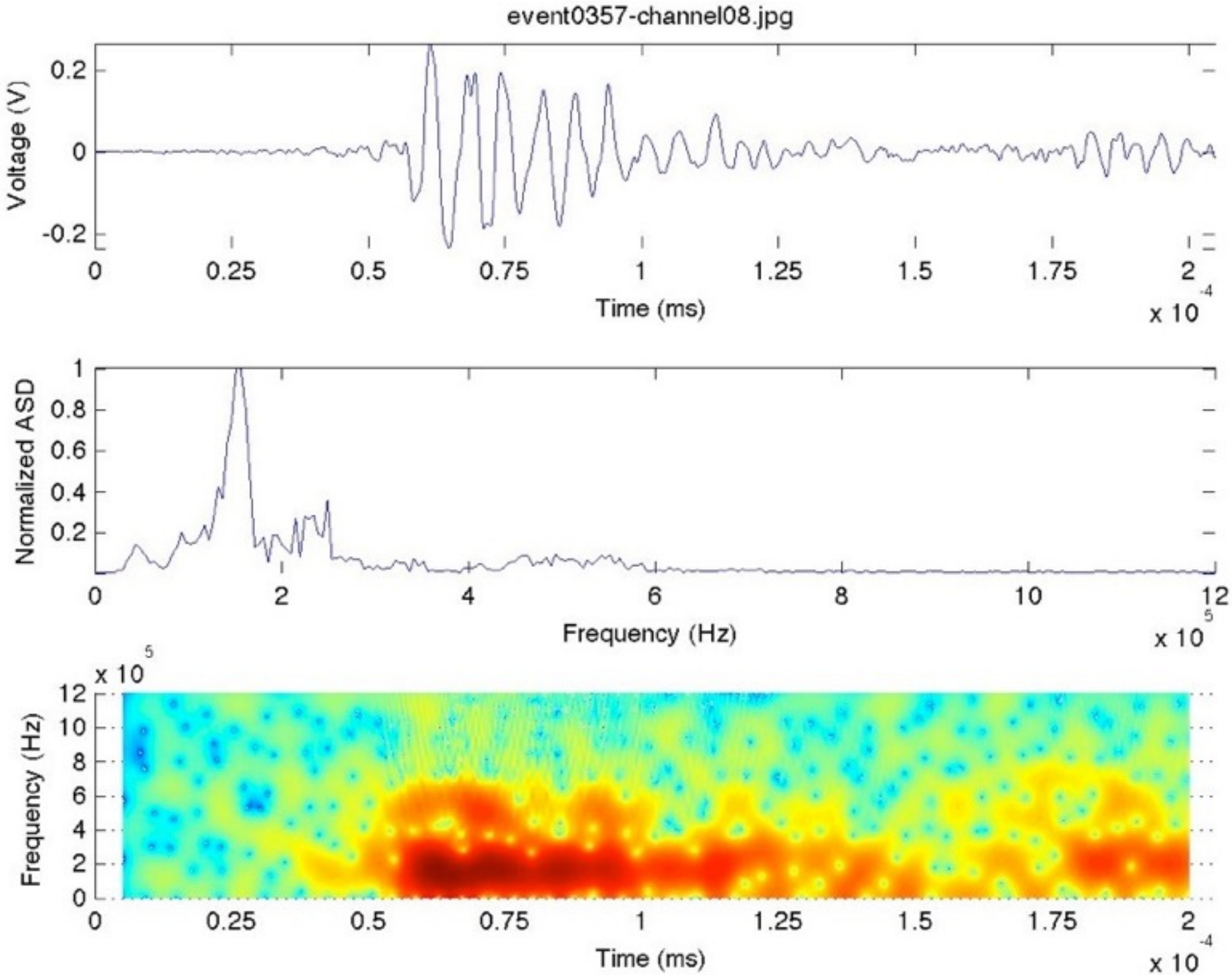
Dyke induced LF events?!?

CL



Dyke induced LF events?!?

EB



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11th EURO-conference on Rock Physics and Geomechanics 2015

SECOND CIRCULAR

Holistic rock physics: integrating theory, observation and applications in space and time

6–11 September 2015

University of Cumbria, Ambleside, Lake District, UK

In this second circular, we are pleased to provide you with further information on the 11th EURO-conference.

Confirmed keynote speakers are: Prof. Brian Evans (MIT), Prof. Ian Jackson (ANU), Prof. Ernest Rutter (Manchester), Prof. Chris Spiers (Utrecht), and Prof. Paul Young (Toronto).

Sessions will include: (1) micromechanics of the brittle/ductile transition, (2) viscoelastity and poroelasticity in crustal rocks, (3) laboratory to field scale rock deformation, (4) fault healing and sealing, and, (5) fluid driven fracture mechanics and induced seismicity.

http://www.bgs.ac.uk/news/events/euro2015/home.html

Local organising committee: Philip Benson, Pete Rowley, Sergio Vinciguerra, Ian Main, Yan Lavallée, Tom Mitchell, Dan Faulkner, Linda Hetherington.

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