Flow'in Rocks

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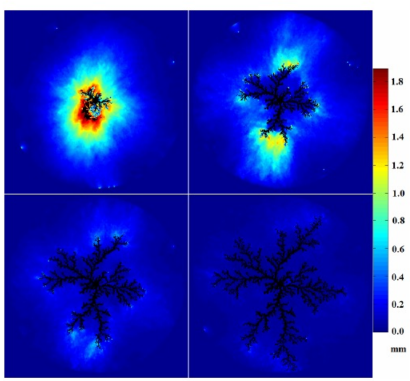
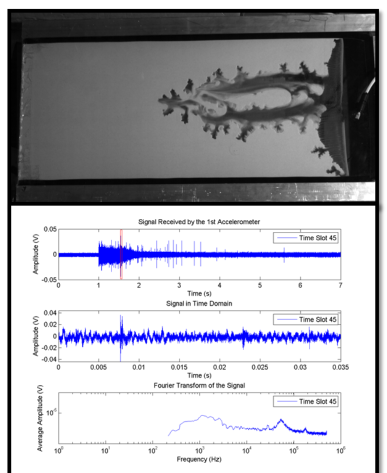
S Santucci, ENS Lyon

Domain : Geophysics and mechanics of flow in natural deforming media



Gas bubble growth in a liquid saturated deformable porous medium- experiment



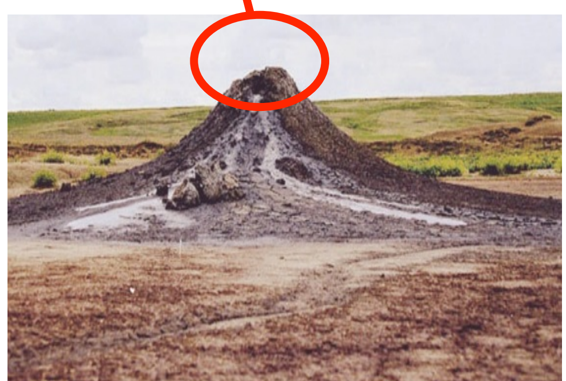
Fracture by fluid injection in a granular medium and associated microseismicity – experiment

Natural examples of flow in rocks, and channeling in flowing rocks

Volcanoes

Geysers

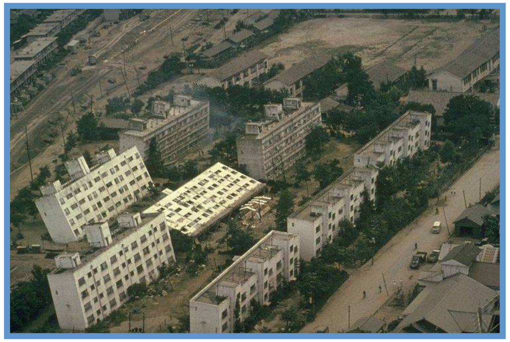
Mud Volcanoes



Karst and cave formation

Examples of soil liquefaction during earthquakes

Niigata, 1964



2010 Canterbury (Darfield) earthquake, New Zealand

The 2013 Pakistan earthquake

Mud Volcanoes

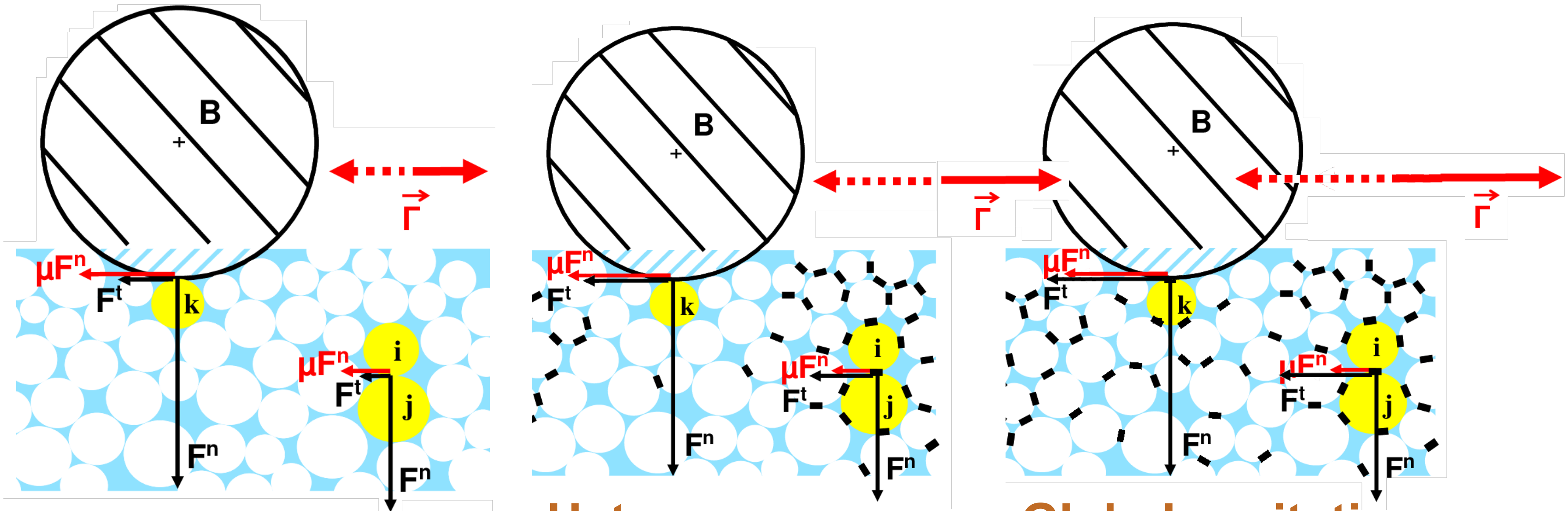
Conventional mechanism explanation: compaction and associated pore pressure buildup.

Can another physical mechanism also cause liquefaction? clue is provided by conventional lab demos of liquefaction, that don't involve high PP (they are drained).

Demonstrates how earthquake liquefaction can affect buildings and buried structures. The brass weight represents a building or structure and the ping pong ball represents a buried storage tank.
Video Credit: YOUTUBE, Robert A. Bauer; Illinois Geological Survey

A mechanism of liquefaction without pressurization: simplified model

Two acceleration thresholds



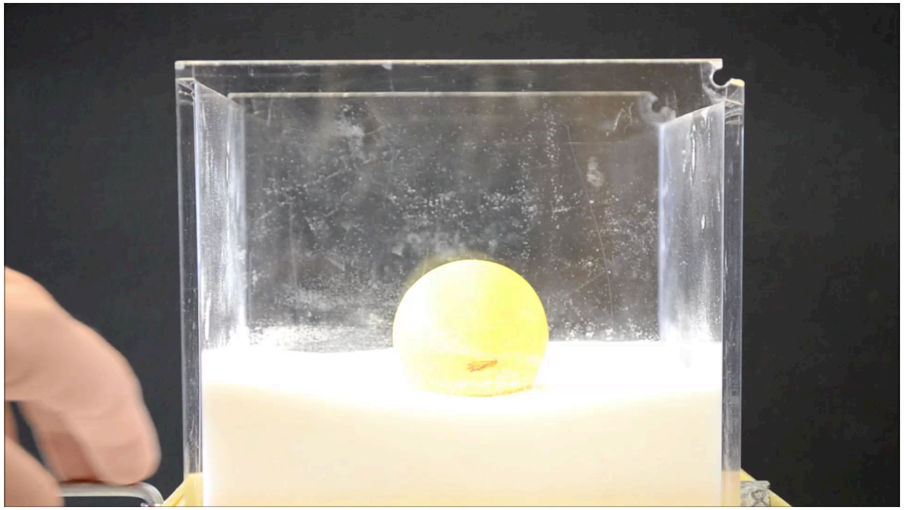
Rigid

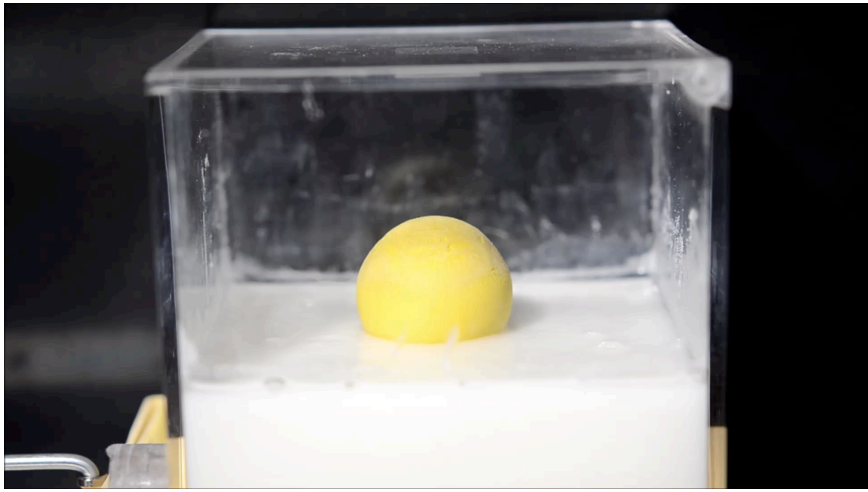
Heterogeneous Liquefaction

Global excitation Liquefaction

Transition from rigid to heterogeneous liquefaction:	$\Gamma_{HL} = \mu \frac{\rho_{solid} - \rho_{water}}{\rho_{solid}}$
Transition from heterogeneous liquefaction to global excitation liquefaction:	$\Gamma_{GEL} = \mu$

Liquefaction Experiments





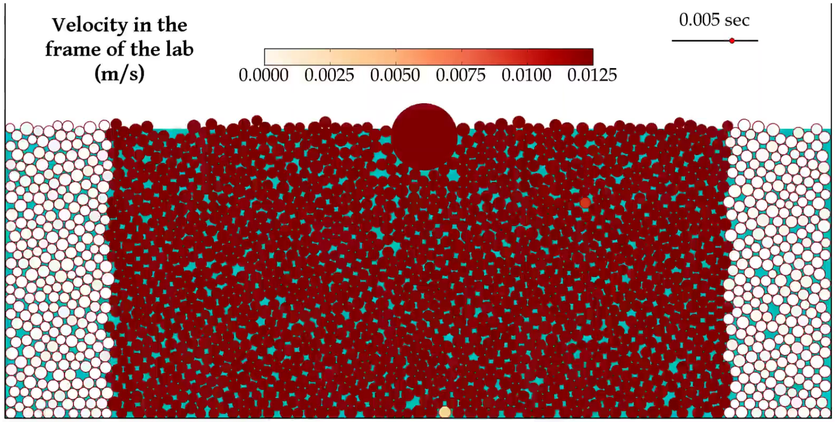
- **Dry f=1.9Hz**
- **Amp=3mm**
- **Γ=a_peak/g=0.03**

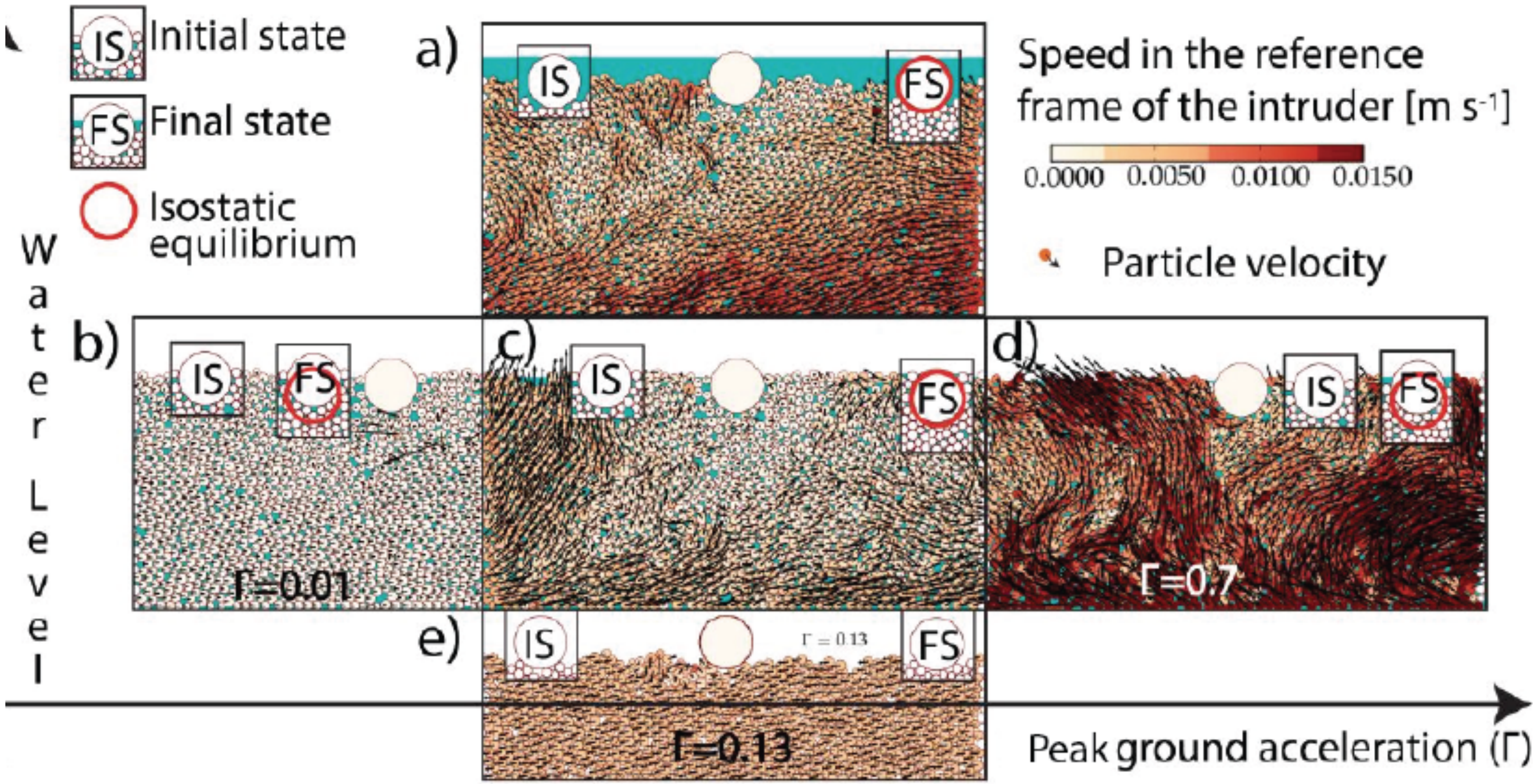
- **Saturated f=0.9Hz**
- **Amp=3mm**
- **Γ=a_peak/g=0.01**

Liquefaction Simulations

Rigid simulation
Saturated medium
frequency: 12 Hz, amplitude: 0.02 mm

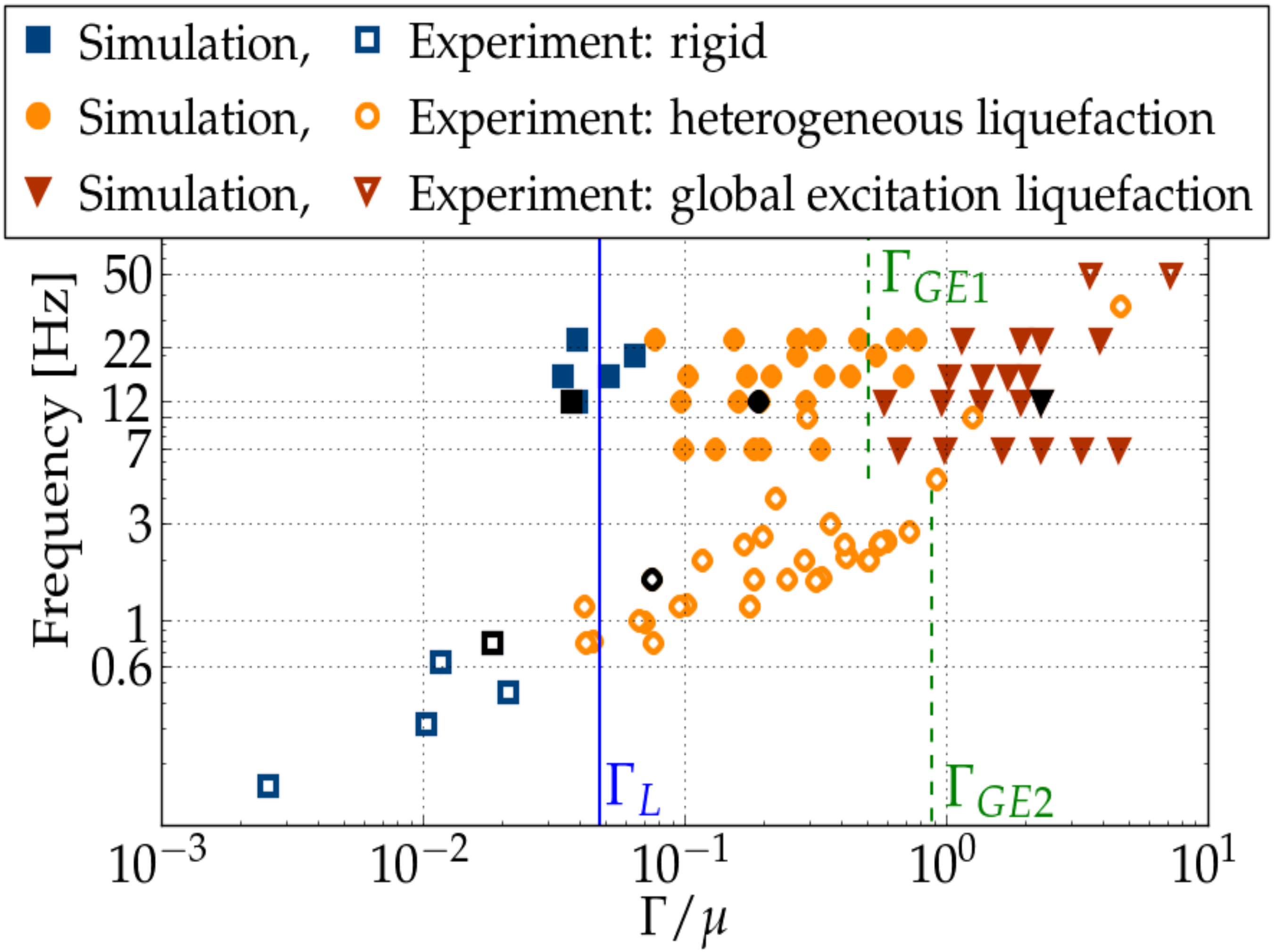
Liquefaction simulation
Saturated medium
frequency: 12 Hz, amplitude: 0.1 mm





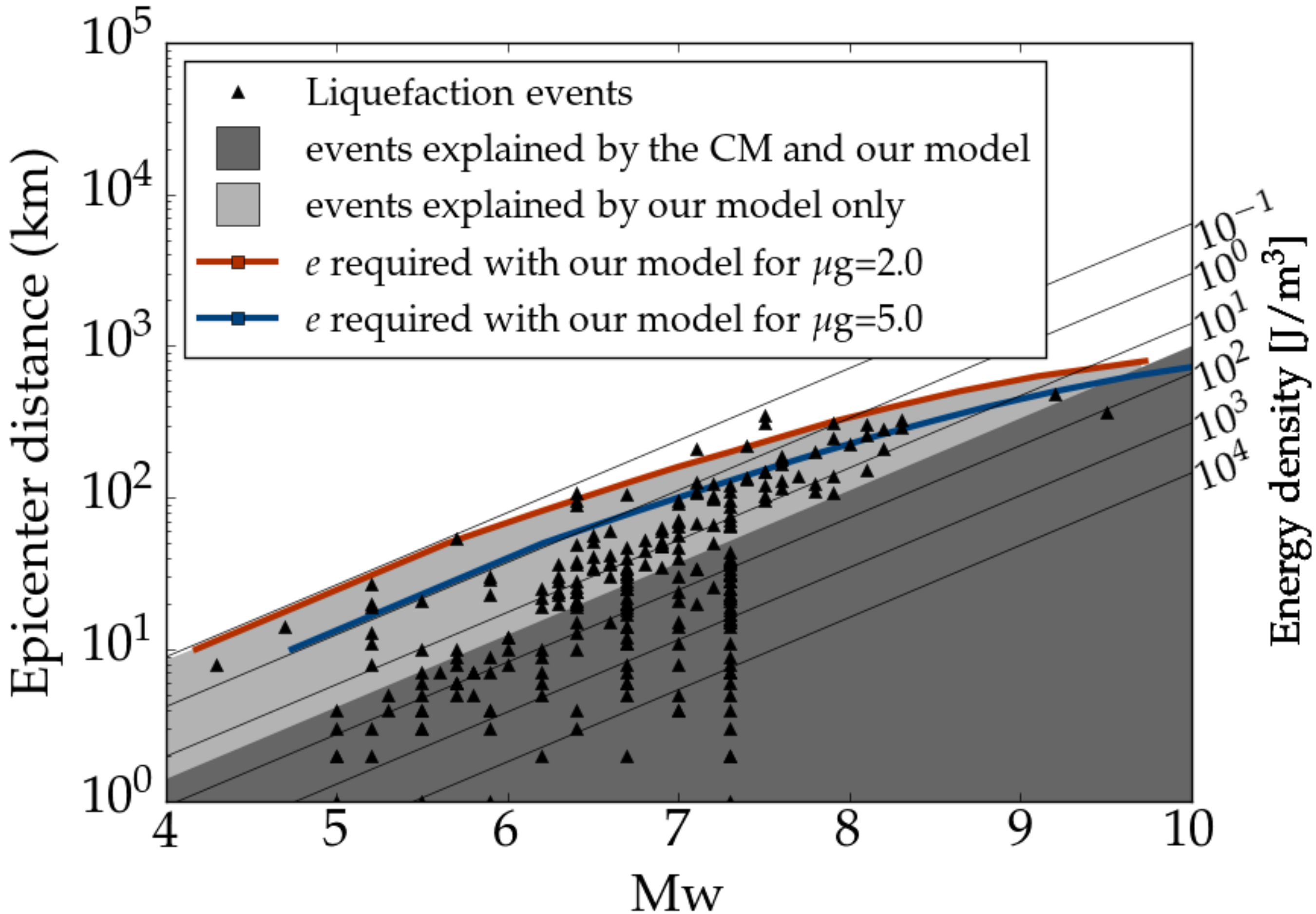
Initial state
Final state
Isostatic equilibrium
Water Level
a)
b)
c)
d)
e)
IS
FS
Γ=0.01
Γ=0.7
Γ=0.13
Γ = 0.13
Speed in the reference frame of the intruder [m s-1]
0.0000
0.0050
0.0100
0.0150
Particle velocity
Peak ground acceleration (Γ)

The agreement btw Experiments, Simulations and Theory in a Phase diagram

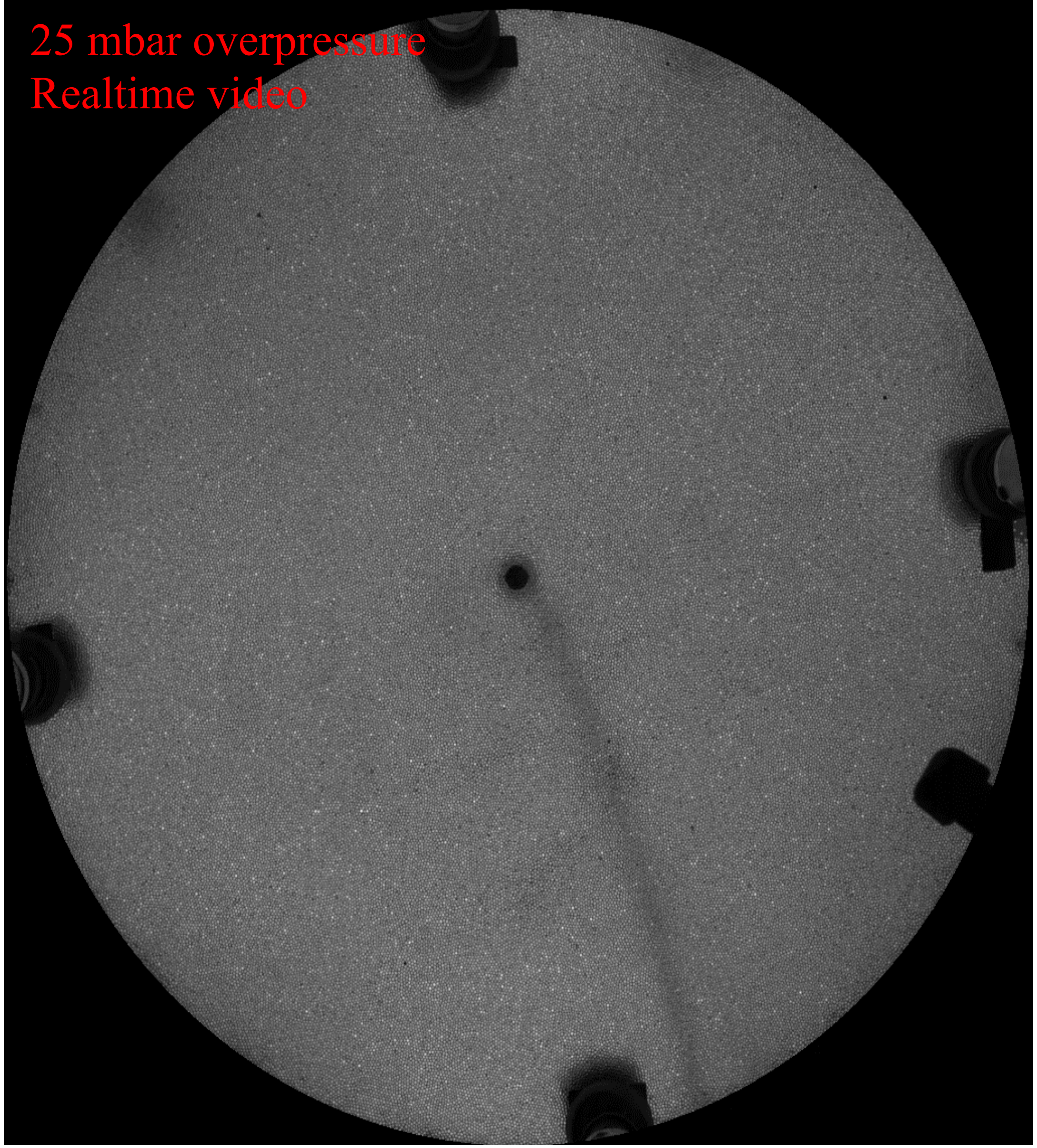


Application to field data: comparison to natural EQs

Catalogue: Wang 2007, Liquefaction beyond the Near Field



$$M_w = 2.7 + 0.7\log_{10}\left(\rho_g\left({}^{g\mu}/_{2\pi}\right)^2\right) + 1.4\log_{10}\left(\frac{\rho_g - \rho_w}{\rho_g}\right) - 1.4\log_{10}(60 - 20\log(r)\ + 2.1\log_{10}(r)$$



10 cm

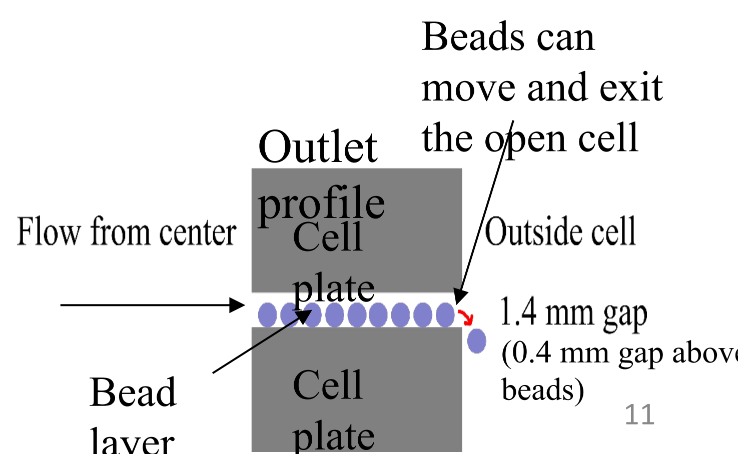
cm

Experiments:

Dynamics of bubbles constrained in a deformable porous medium

Air injection in a liquid-saturated Hele-Shaw cell filled with mobile glass beads

FK Eriksen, R Toussaint, KJ Måløy, EG Flekkøy (2015) [Invasion patterns during two-phase flow in deformable porous media]() Frontiers in Physics 3, 81

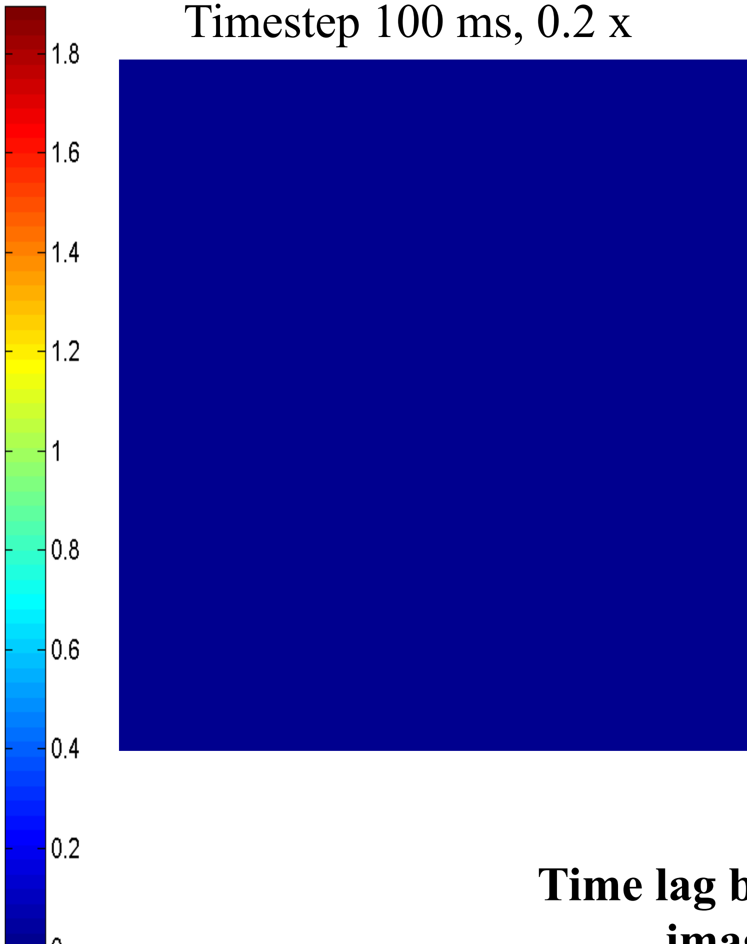


Velocimetry: Image correlation measurements of particle velocity during bubble growth

Incremental displacement [cm]

CD (100 mbar)

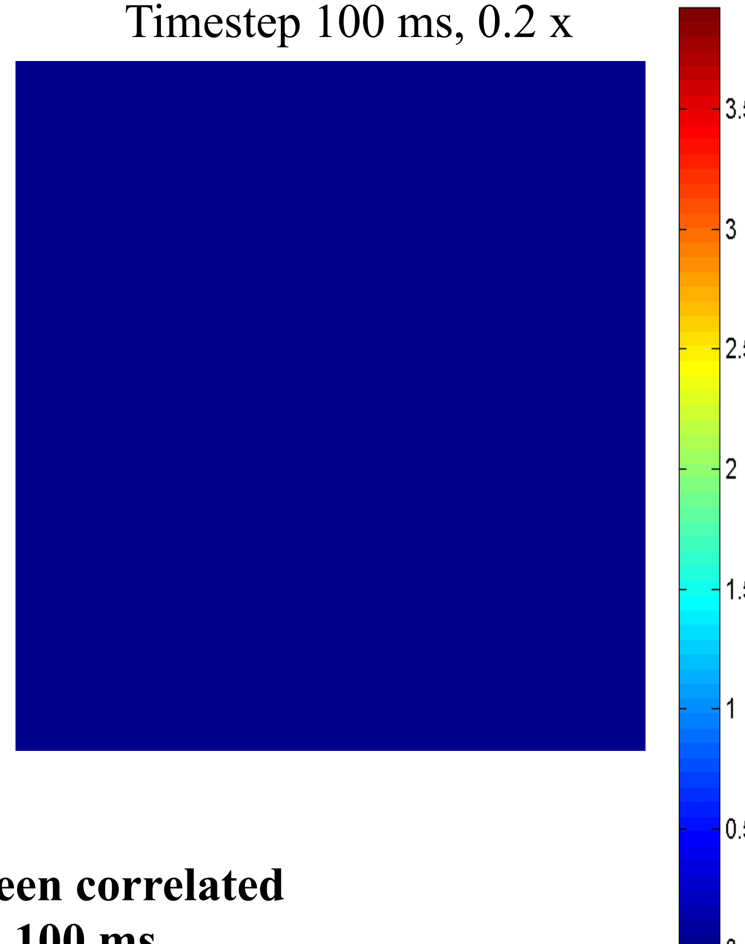
Timestep 100 ms, 0.2 x



OD (100 mbar)

Timestep 100 ms, 0.2 x

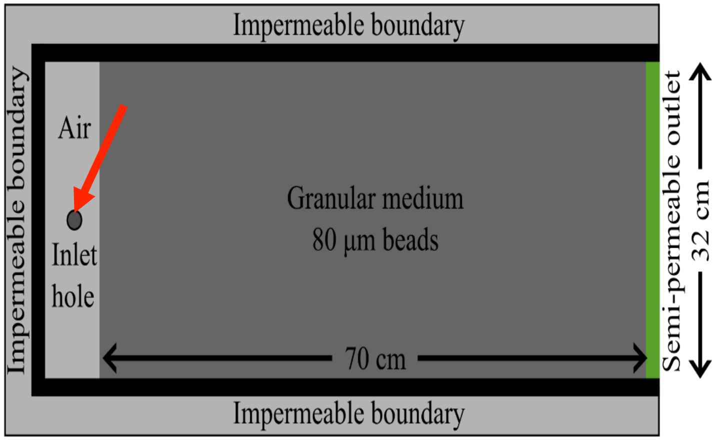
Incremental displacement [cm]

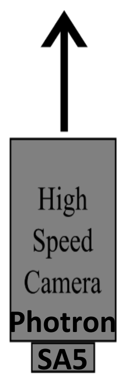


Time lag between correlated images : 100 ms

Experiments – Pneumatic fracture

A) Top view

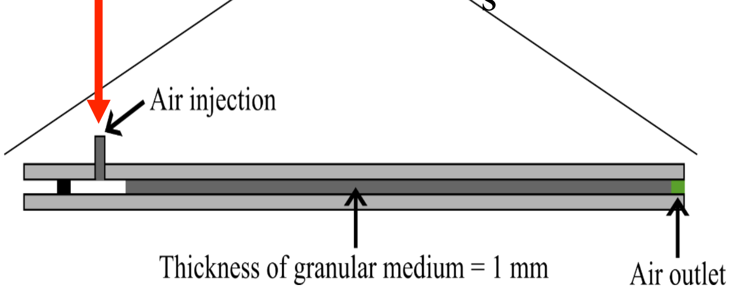




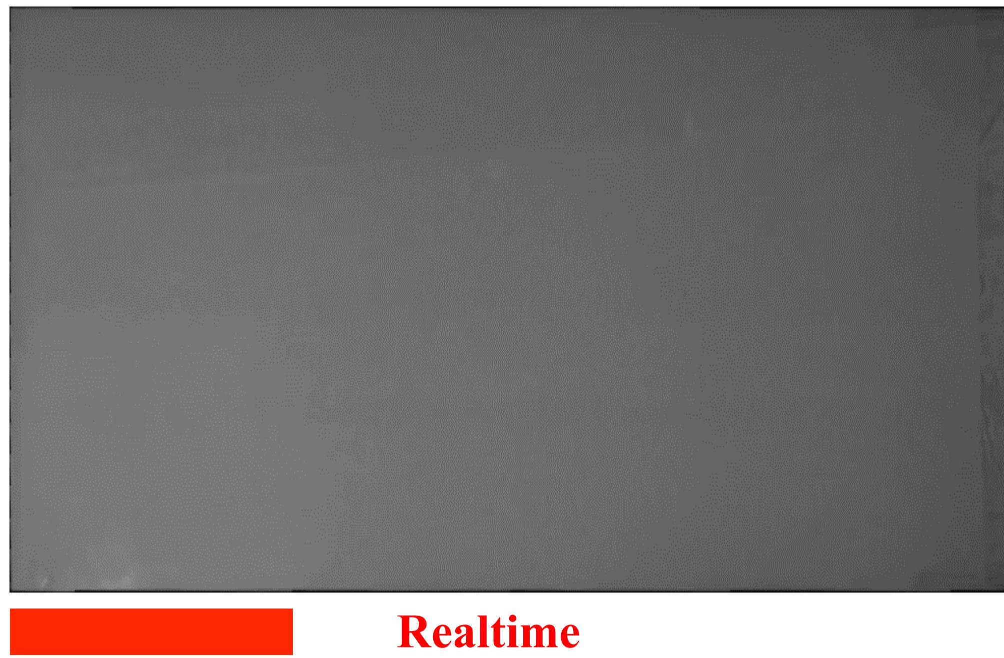
B) Side view

Air is injected at a constant overpressure: 5 – 250 kPa

- 1000 images / s
- Spatial resolution: 990 x 460 pixels
- 1 pixel = 0.7 mm
- Duration = 1 – 5 s



$P_{in} = 100$ kPa



20 cm

S Turkaya, R Toussaint, FK Eriksen, M Zecevic, EG Flekkøy, KJ Måløy (2015)
Bridging aero-fracture evolution with the characteristics of the acoustic emissions in a porous medium. Frontiers in Physics 3, 70

Fast camera Imaging: (500 and 1000 frames /s)

Erosion and channel formation

Cat. 5, P_{in} = 150 kPa

20 cm

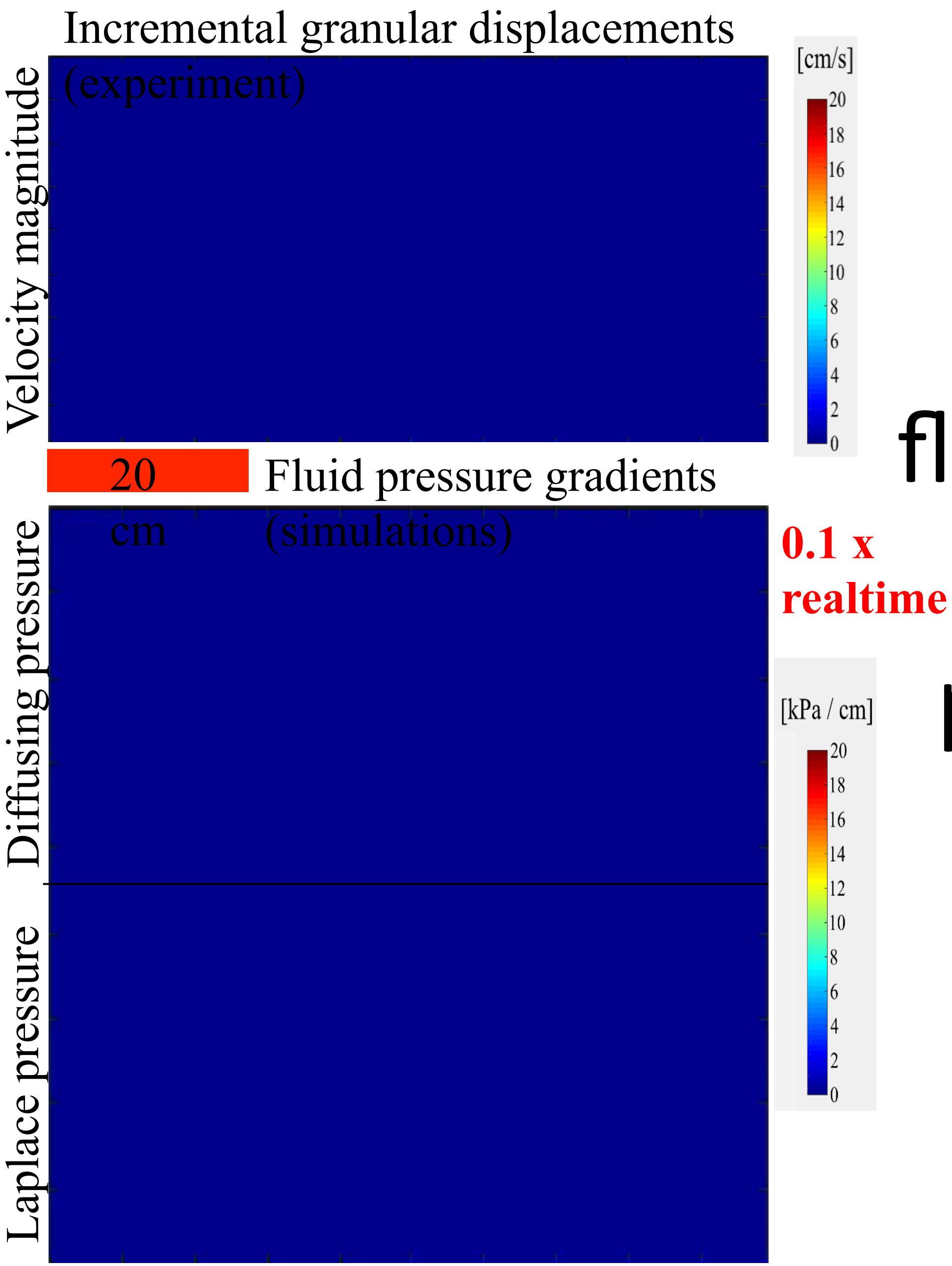
0.25 x realtime

Cat. 6, P_{in} = 250 kPa

20 cm

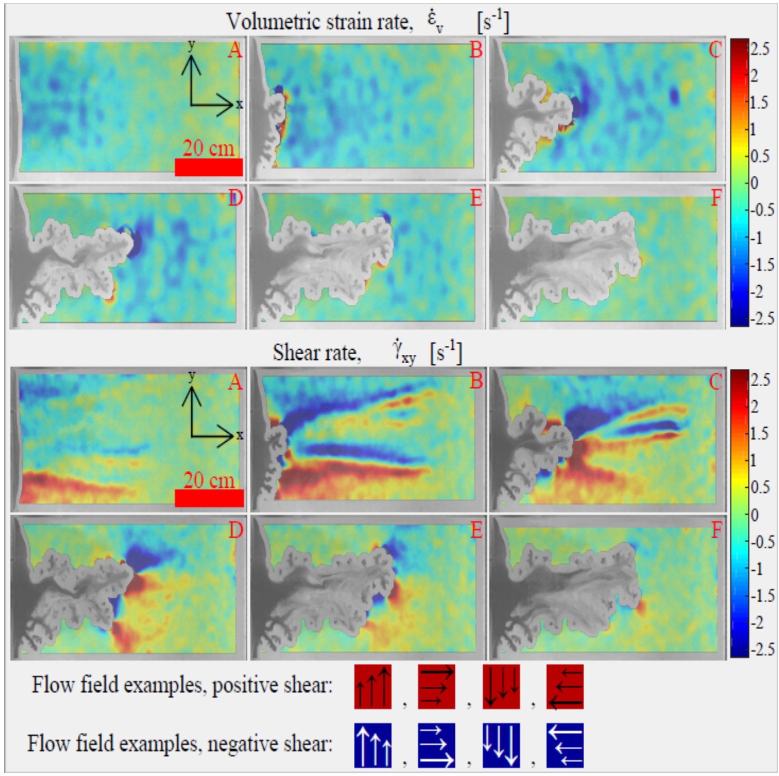
0.05 x realtime

10 ms between correlated images

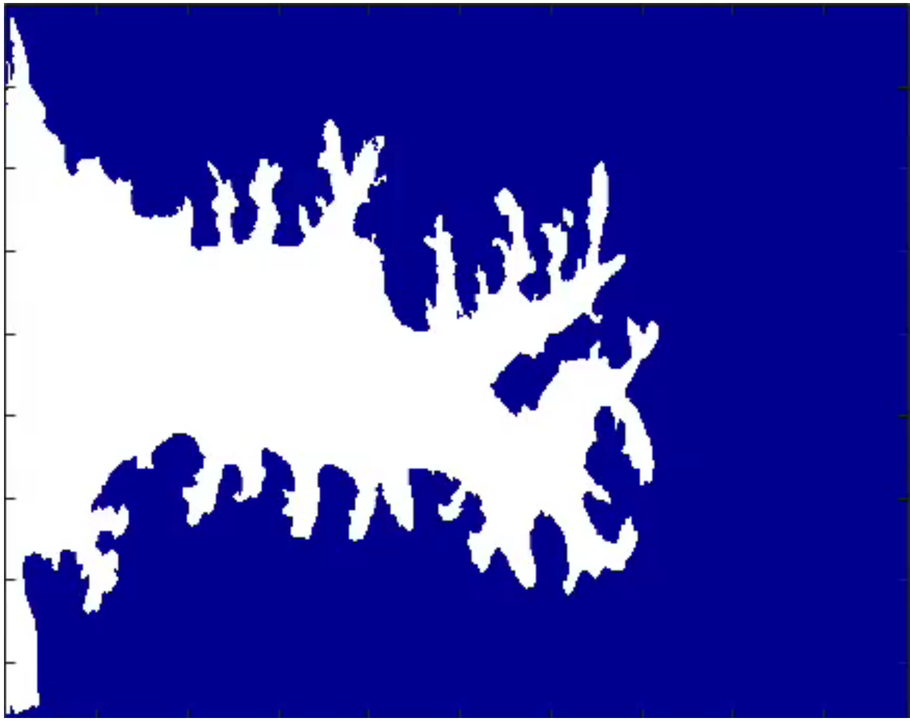


Link between fluid pressure gradient and particle velocity field

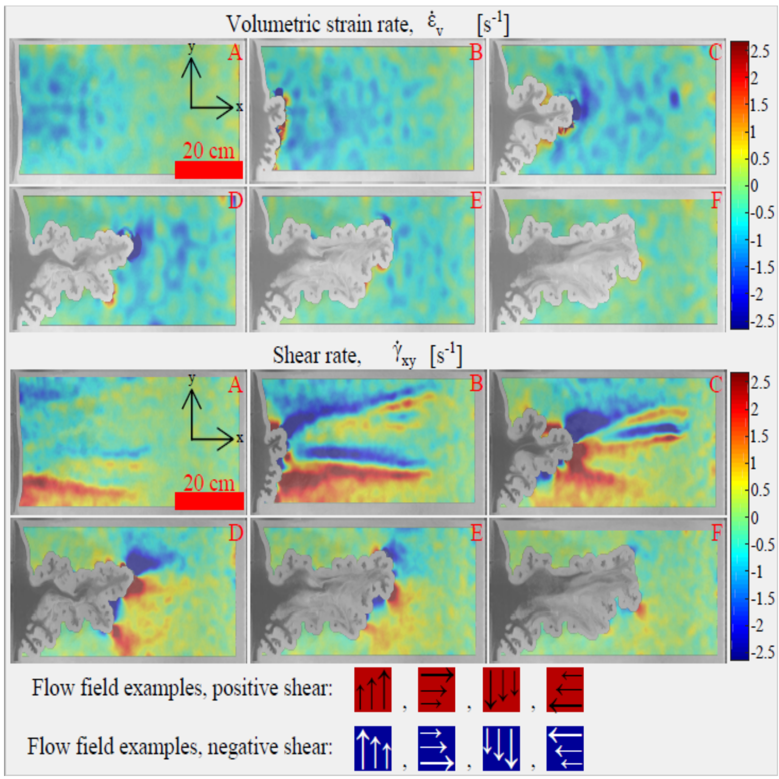
Strain rate tensor (space and time derivative of the velocity field)



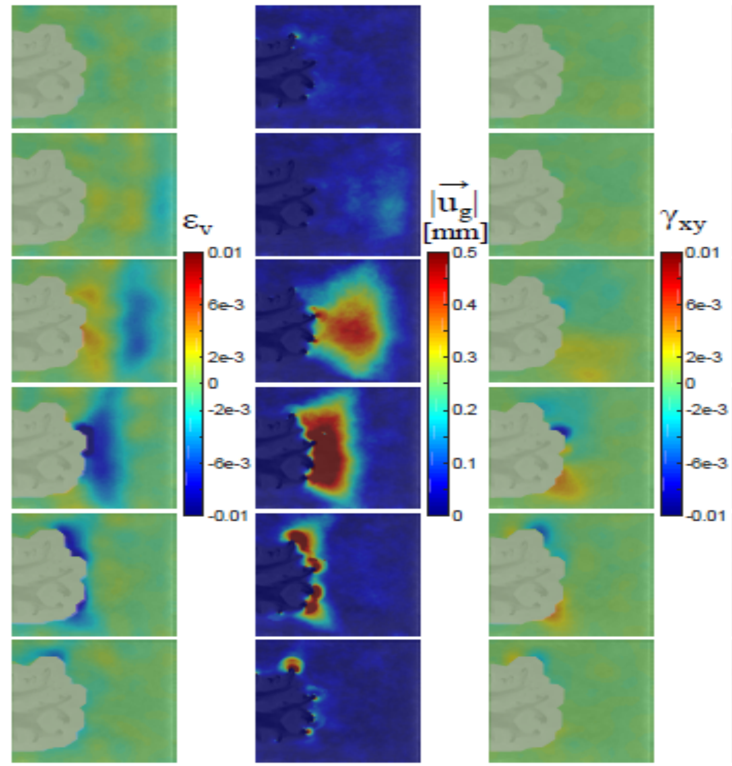
Fast imaging and image correlation: slip function resolved in space and time during a microseism associated to a slip event, (slow stress relaxation stage) – Total duration of acoustic event: 5 ms

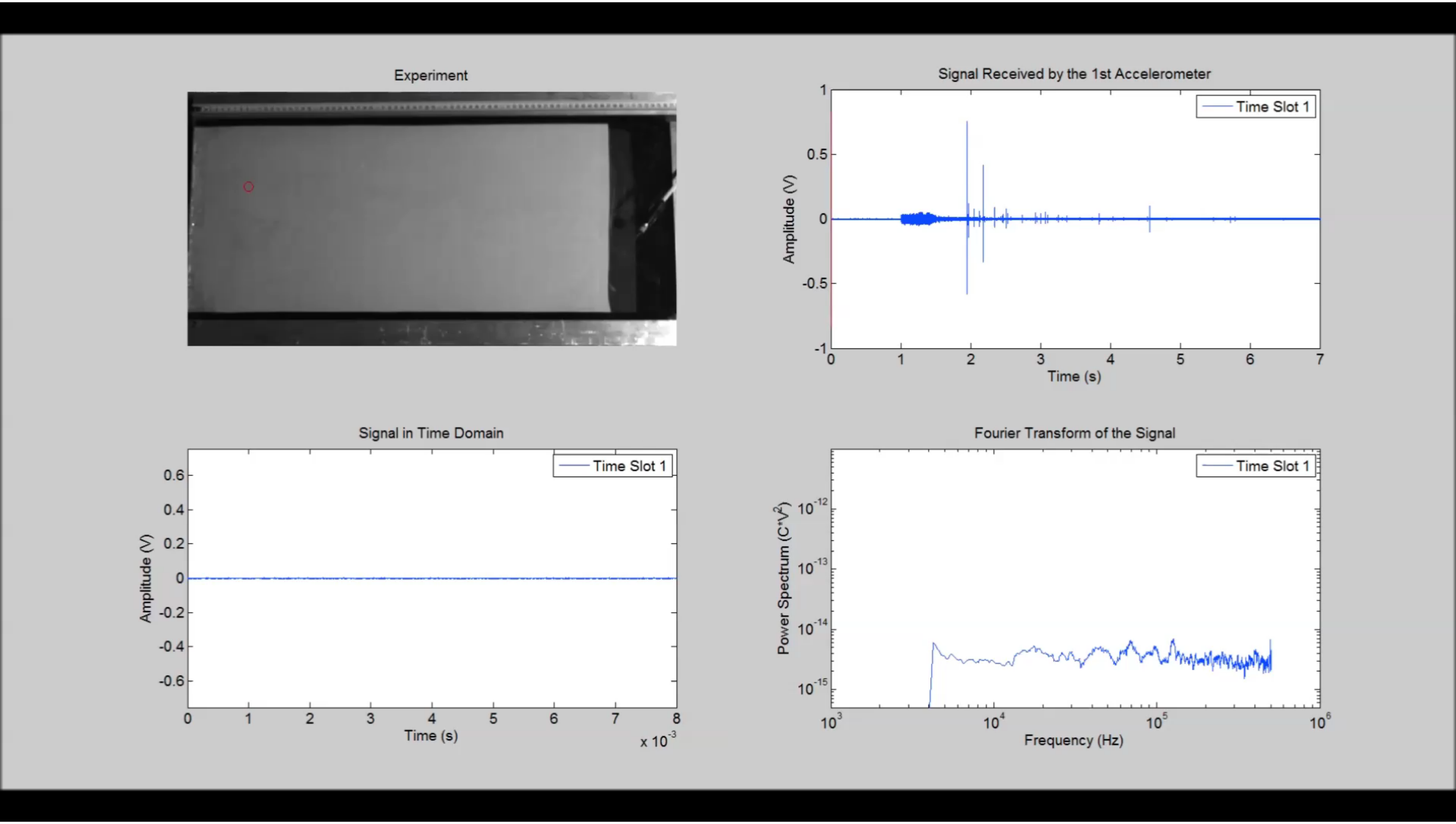


Strain rate tensor (space and time derivative of the velocity field)



Fast imaging and image correlation: slip function resolved in space and time during a microseism associated to a slip event, (slow stress relaxation stage) – Total duration of acoustic event: 5 ms

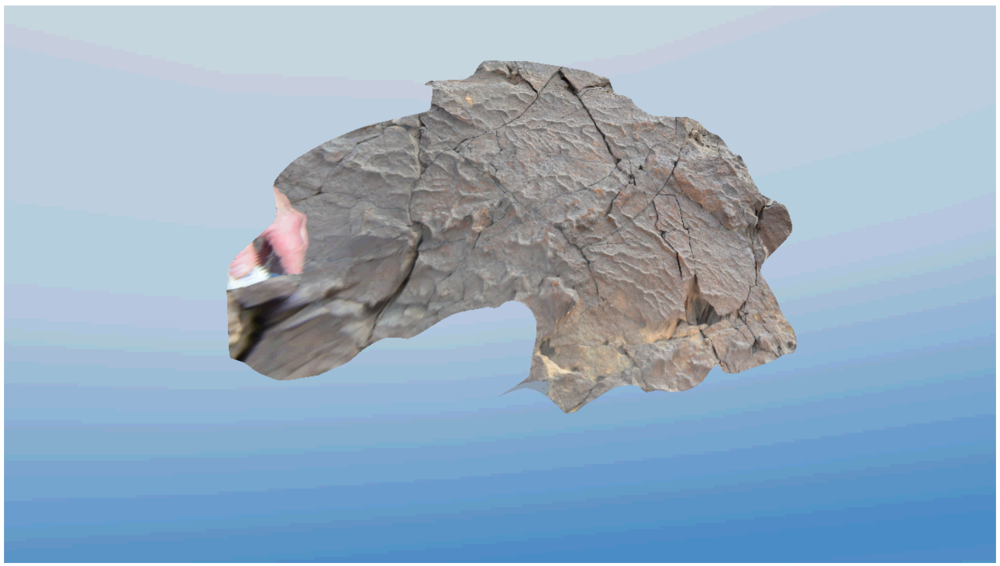




Experiment
Signal Received by the 1st Accelerometer
Time Slot 1
Amplitude (V)
Time (s)
Signal in Time Domain
Time Slot 1
Amplitude (V)
Time (s)
x 10^-3
Fourier Transform of the Signal
Time Slot 1
Power Spectrum (C*V^2)
Frequency (Hz)

Formation of frictional fingers during dyke formation (magmatic intrusion):

Grain Accumulation in front of biphasic fluids interface

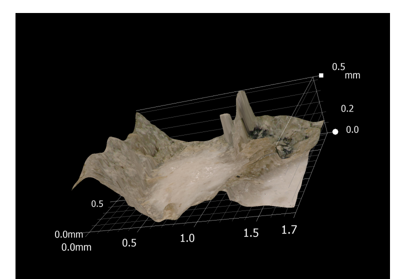


Simulations: fingering and friction (grain accumulation) in front of a fluid/air interface

JA Eriksen, R Toussaint, KJ Måløy, E Flekkøy, B Sandnes (2016)

[Pattern formation of frictional fingers in a gravitational potential]

arXiv preprint arXiv:1605.07436

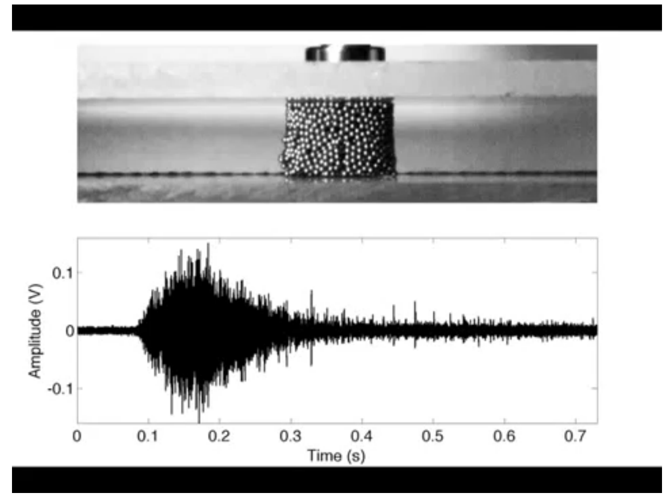


Stylolite (microscope)

Fast Imaging and dynamic rupture in granite: (300 000 images/s)
Rock pulverization

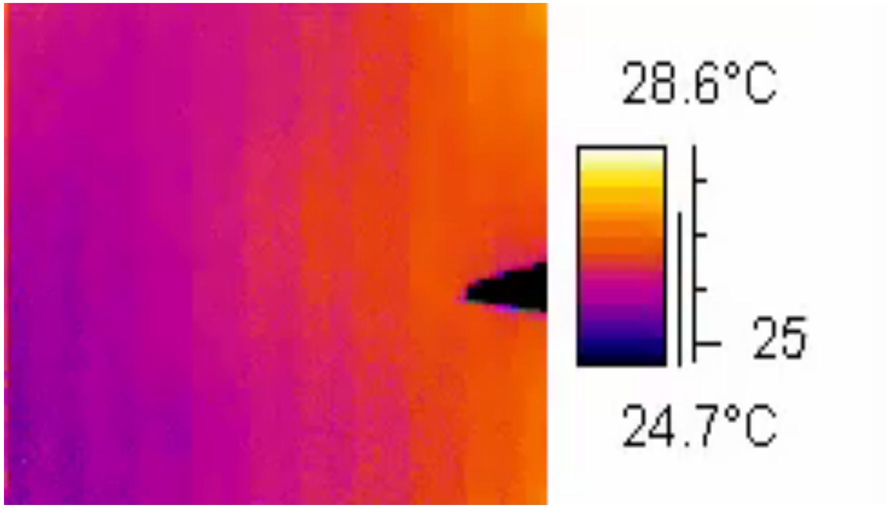
FM Aben, M-L Doan, TM Mitchell, R Toussaint, T Reuschlé, Michele Fondriest, J-P Gratier, F Renard (2016)
[Dynamic fracturing by successive coseismic loadings leads to pulverization in active fault zones]()
Journal of Geophysical Research: Solid Earth 121 (4), 2338-2360

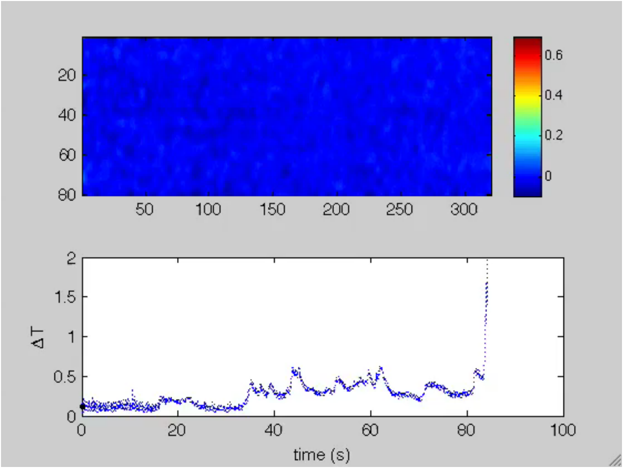
Avalanches and associated seismic radiation: granular column collapse (1000 images/s)



Farin et al., thesis, 2015

Infrared imaging and evaluating the energetic budget of rupture propagation in torn paper – role of chemistry on the process





R Toussaint, O Lengliné, S Santucci, T Vincent-Dospital, M Naert-Guillot, KL Maloy (2016)
[How cracks are hot and cool: a burning issue for paper]
Soft matter 12 (25), 5563-5571

Thank you !

Stéréophotogrammétrie et reconstitution de relief

Education et interdisciplinarité (projet en collège – lien avec formations de la Maison pour la Science en Alsace):

reconstitution à partir de 40 photos, interdisciplinarité, technologie et patrimoine culturel