Advances in microseismic monitoring and understanding of hydraulic fracturing: the contribution of the SHEER EU project.

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Session 1: Induced seismicity from hydraulic fracturing and waste water management.
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European on-shore basins and their potential for shalegas/-oil

Gas production in UK dropped 1/3 since 2000.
Shale exploration with strict regulations
70 shale gas licences

Expected shalegas production in USA in 2040 (EIA, 2014): 53%
Four projects under EU-LCE-16-2014 on impacts and risks of shale gas

1. Fracrisk - Furthering the Knowledge Base For Reducing the Environmental Footprint of Shale Gas Development
2. M4ShaleGas - Measuring, Monitoring, Mitigating, Managing the environmental impact of Shale Gas
3. STX, ShaleXenvironmenT, Maximizing the EU shale gas potential by minimizing its environmental footprint
4. SHEER - SHale gas Exploration and Exploitation induces Risks

Objectives:
- Groundwater contamination by chemical contained in flow back and produced water
- Air pollution by migration of methane & other gases through fractures
- Induced seismicity by fracking and injection of waste water

Global aspects of induced and triggered earthquakes

Main scientific challenges:

a) Understand and predict probability of larger earthquakes (EQ)
b) Monitor small induced EQ and use them for characterization (e.g. traffic light)
**Mechanism of induced seismicity**

Main industrial activities which can "induce" or "trigger" seismicity

- Mining operations (IV)
- Hydrocarbons storage and extraction (I)
- Shale gas exploitation (II)
- CO\(_2\) sequestration (V)
- Dams (VI)
- Geothermal energy exploitation (III)

(a, b)

(a, c)

Earthquake rupture:

- nucleates where Coulomb stress exceeds fault strength
- is driven by shear stress

**Monitoring network Wysin**

Detection performance:
- Synthetic catalogue
- Real data

2x11 stages in Jun/Jul 2016, 17E3 m\(^3\)

- vertical fracking drilling
- horizontal fracking drillings (depth ~ 4000 m)
- broadband stations
- short period stations
- shallow borehole stations (depth ~ 55 m)
Detections during/after fracking operations

a) Potential triggered events?

- The most of local detections (M>0.4) corresponds to sources close to the surface. E.g., two EQ with $M_w$ 1 and 0.5 likely occurred close to the surface.

- Weak EQ (M<0.4) associated with fracking operations detected only in the three borehole stations.

- The number of fracking induced high frequency events are (unusual) low. Instead, un-typical long period events were recorded.

- Some transients / peaks in methane observed after fracking

- No ground water anomalies

f) Long period signals

Some transient / peaks in methane after fracking

New waveform detection/location approach

$M_w \approx 1.0$. Near surface source (wave velocity = 400 m/s). $M_c \approx 0.45$
What happens at the fracture at the borehole?

- Micro-earthquakes occur in shear mode at fracture tip
- Opening of fractures generate long period transients (e.g. measured on tilt or broadband sensors)
- Magnitude of events increases with injected volume and duration. Largest events often after stop of injection
Sequence of mine-fracs using “frac-monitoring tool”

Goals of the field experiment:
- verify soft stimulation concepts
- test hydraulic fracturing seismicity models

Hydrofrac experiments in massive granite (Äspö, Sweden)

Zang et al. (2017) GJI
Is seismicity controlled by pressure or by deformation?

- BB ground velocity
- Long period transients
- Injection pressure HF2
- High freq. microcracks
- Event rate ($M_{AE} > 1.25$)
- High freq. microcracks
- Event magnitudes

Duration of fracture opening ($T_r$) is $\approx 1.6 \times$ duration of injection ($T_d$)

$T_r = 0.6 \times T_d$
First results: $M_{AE_{\text{max}}}$ is controlled by fracture size (stress anomaly)

Note: - $M_{\text{max}}$ does not correlate to injection pressure
- Event rate correlate with $P_i$

Summary (Wysin / Åspö)

- Monitoring of $M<0.5$ EQ is challenging and needs borehole sensors
- Significant EQ ($M>3$) can be induced by fracking. Wysin experiment did not induce EQ with $M>1$
- Long period events have been recorded in Wysin – LP transients measured close to well (e.g. tilt) are associated with frac opening
- Fracture after-growth after stop of injection measured by tilt signals
- Frac tip EQ rate is controlled by injection pressure
- Frac-induced EQ magnitude is controlled by size and not pressure