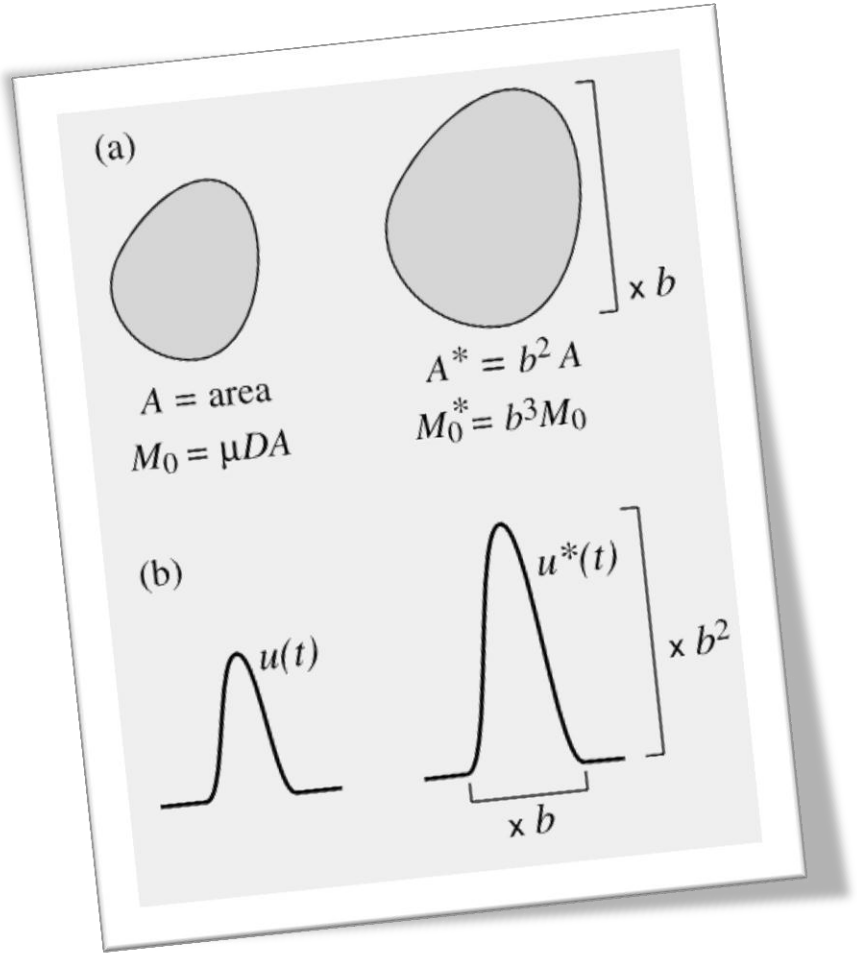
Scaling relations of induced seismicity in picoscale: A case study from Mponeng deep gold mine, South Africa

G. Kwiatek[1], K. Plenkers[1,2] G. Dresen[1] and JAGUARS Research Group

1. GFZ | German Research Centre for Geosciences
2. Now at: KIT | Karlsruhe Institute of Technology

Scaling relations

Are earthquakes self-similar in all magnitude scales?

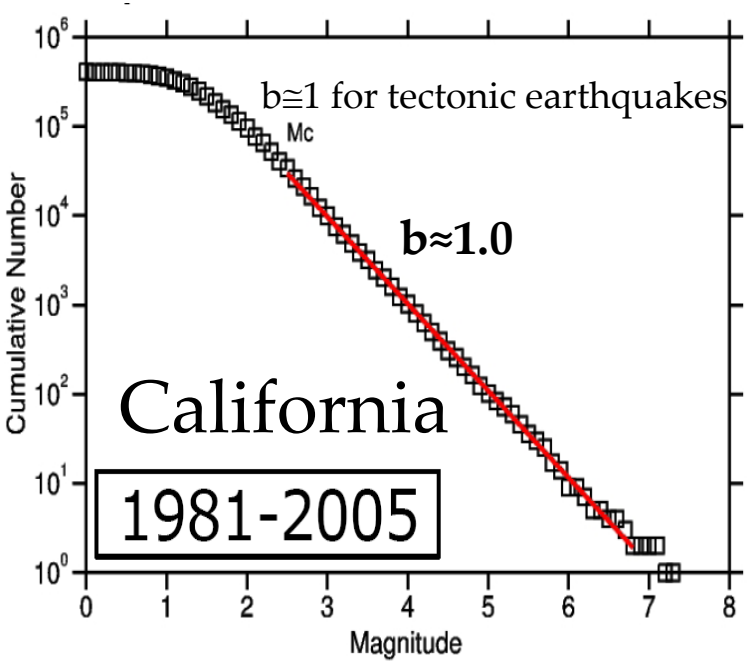


(Prieto et al., JGR, 2004)

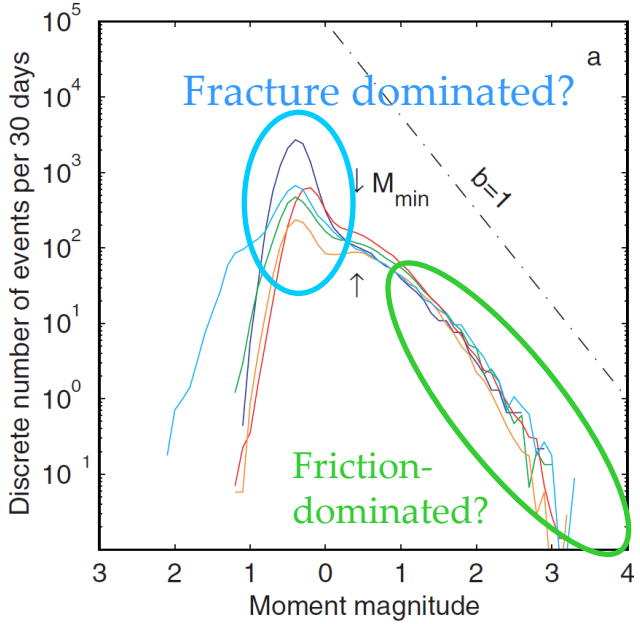
Scaling relations (Gutenberg-Richter relation)

GR scaling law: $\log N = a - bM_W$

The relation observed in a wide magnitude range (7-0) with **b≈1.0**. Straight line of GR ► self-similarity of earthquakes(' occurrence rate).

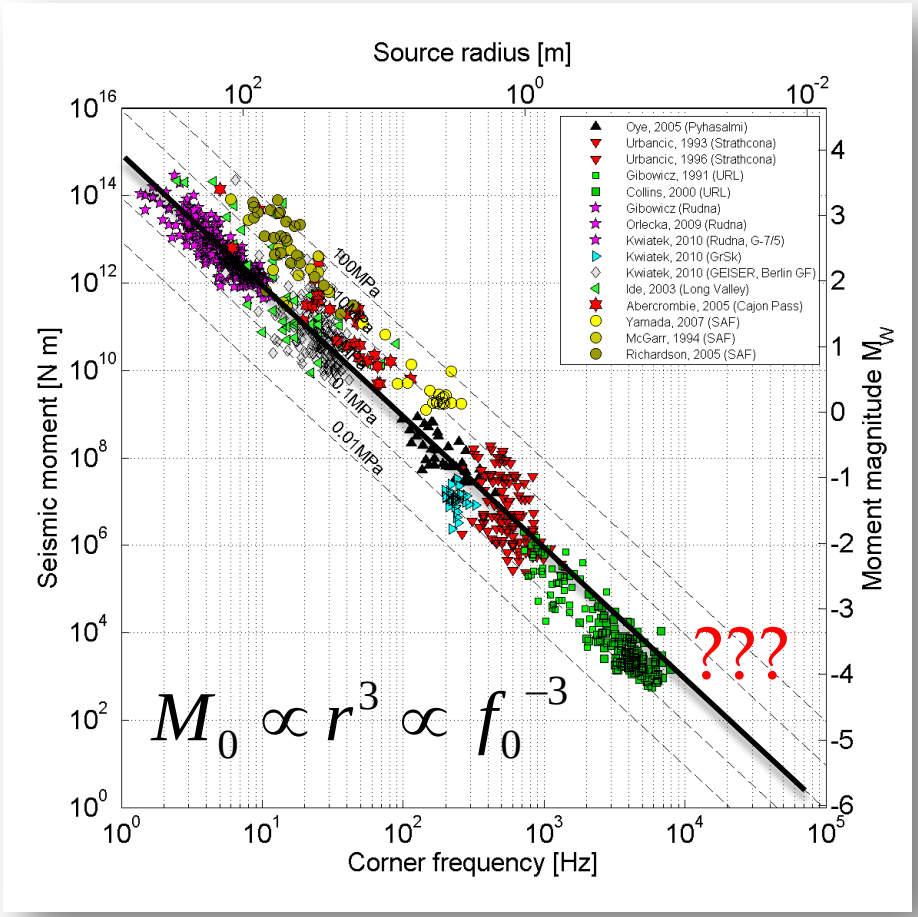


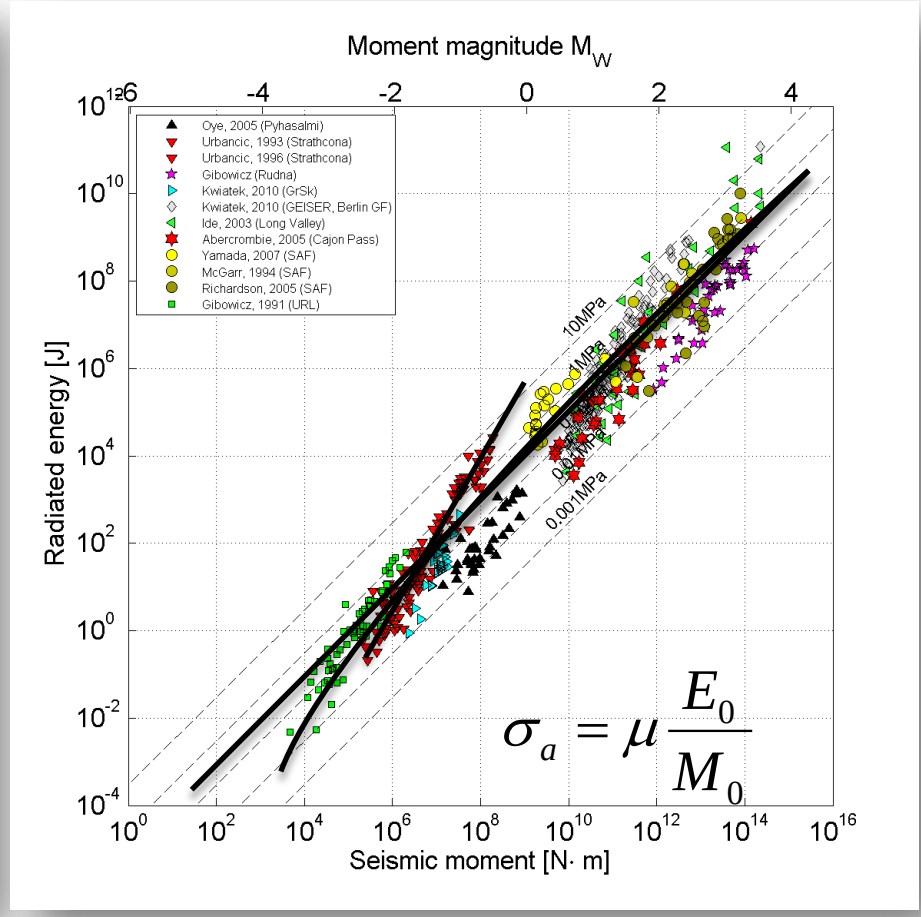
(Prieto et al., JGR, 2004)



(E. Richardson and T. Jordan, BSSA, 2002)

Scaling relations (stress drop & apparent stress)





Motivation

Breakdown in scaling...

...may have a physical background (limits on source size, different faulting process)

...may be an artifact (any process that limits high frequencies/data selection bias)

Essential question:

- Are earthquake processes same at all magnitude (length) scales?
- Is there any breakdown in earthquakes' self-similarity observed?
- What is the lowest magnitude where we still observe the self-similarity?

Prerequisities:

Highly sensitive seismic network (M_W<<-1.0), In-situ geomechanical laboratory, sensors similar to those used in laboratory experiments on rock samples

Self-similarity

K. Aki, A. McGarr, S. Ide, G. Beroza

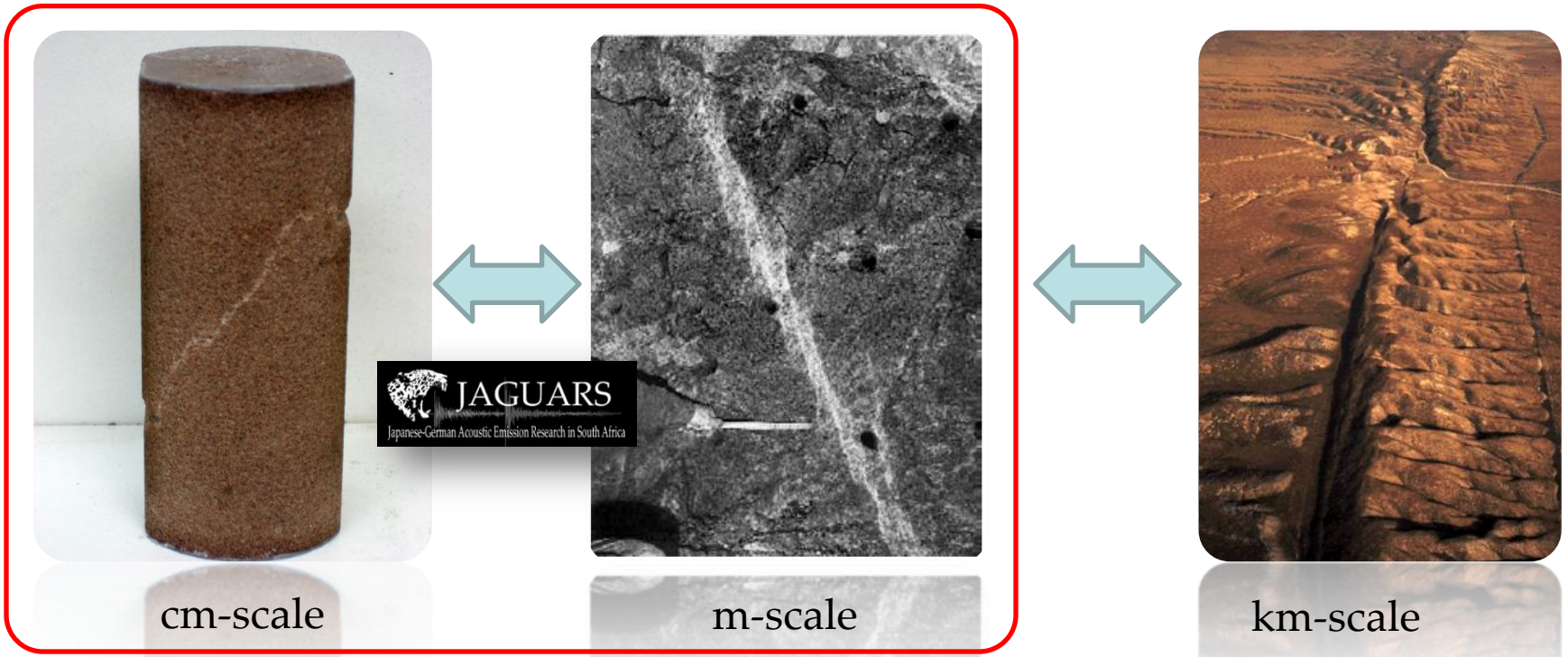
R. Abercrombie, S. Prejean W.L. Ellsworth,

Scaling breakdown

H. Kanamori, K. Mayeda, J. Mori, T. Jordan

Aims of this study

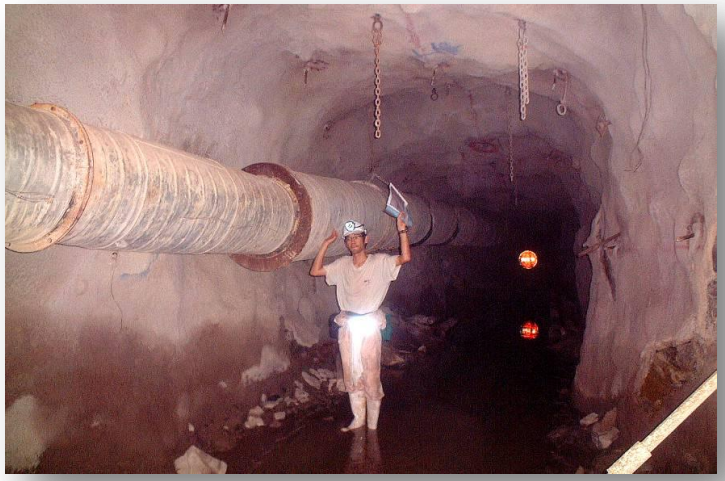
- Link laboratory studies and picoseismicity recorded in-situ
- Investigate the self similarity of earthquake rupture process in as broad magnitude range as it is possible



Courtesy of E. Charalampidou; W.D. Ortlepp, RaSiM5 proceedings; Wikipedia

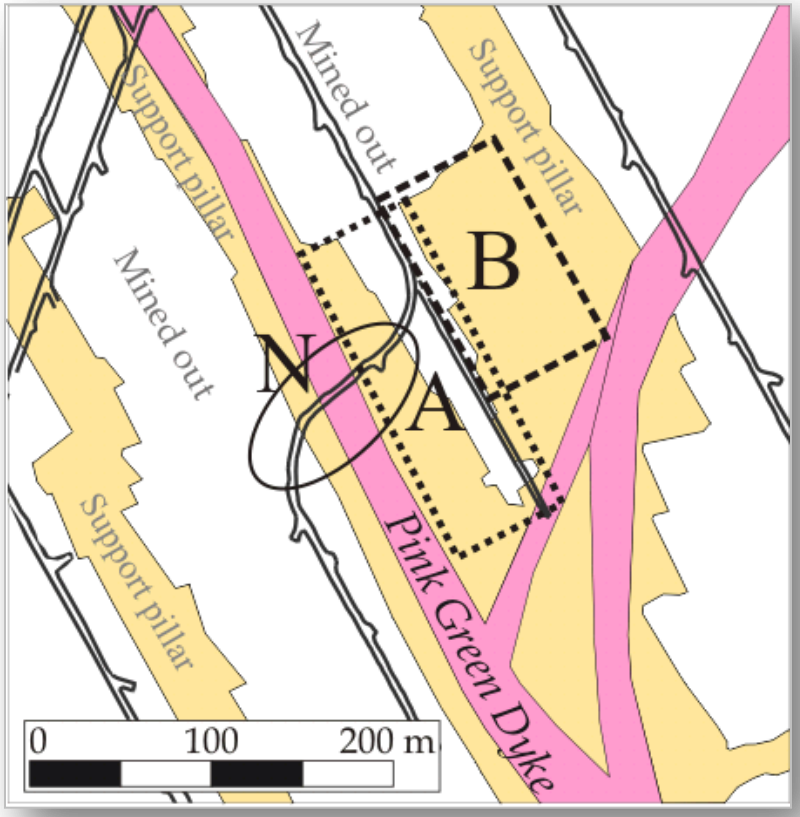
Mponeng Mine

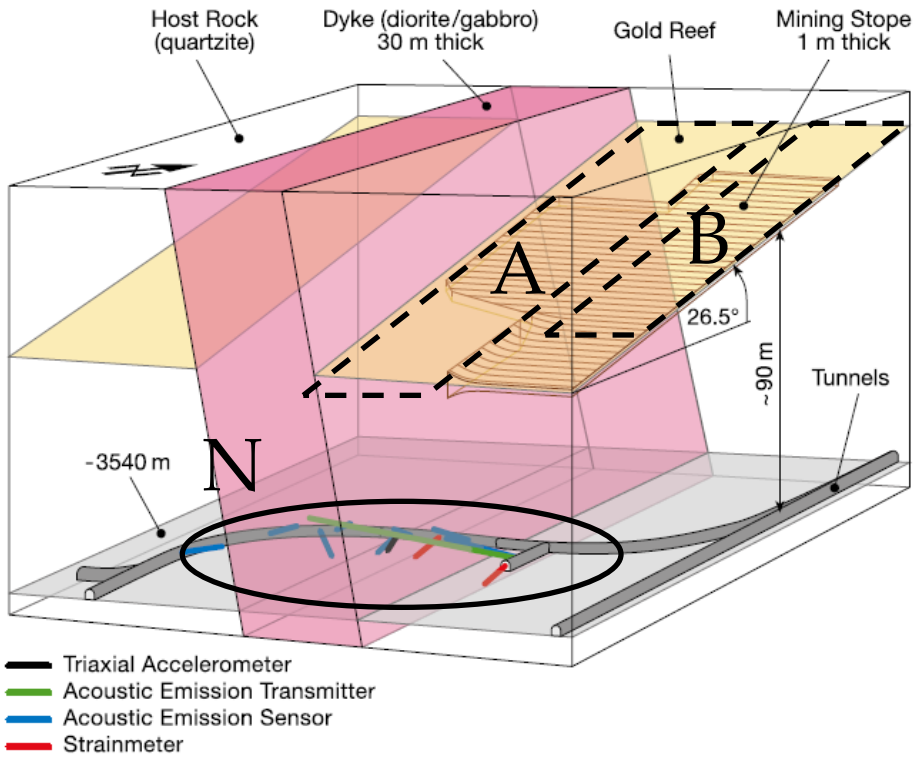
Mponeng gold mine –the deepest mine in the world (working depth 3777m, new deepening project down to 4300m)



Mponeng mine - JAGUARS site

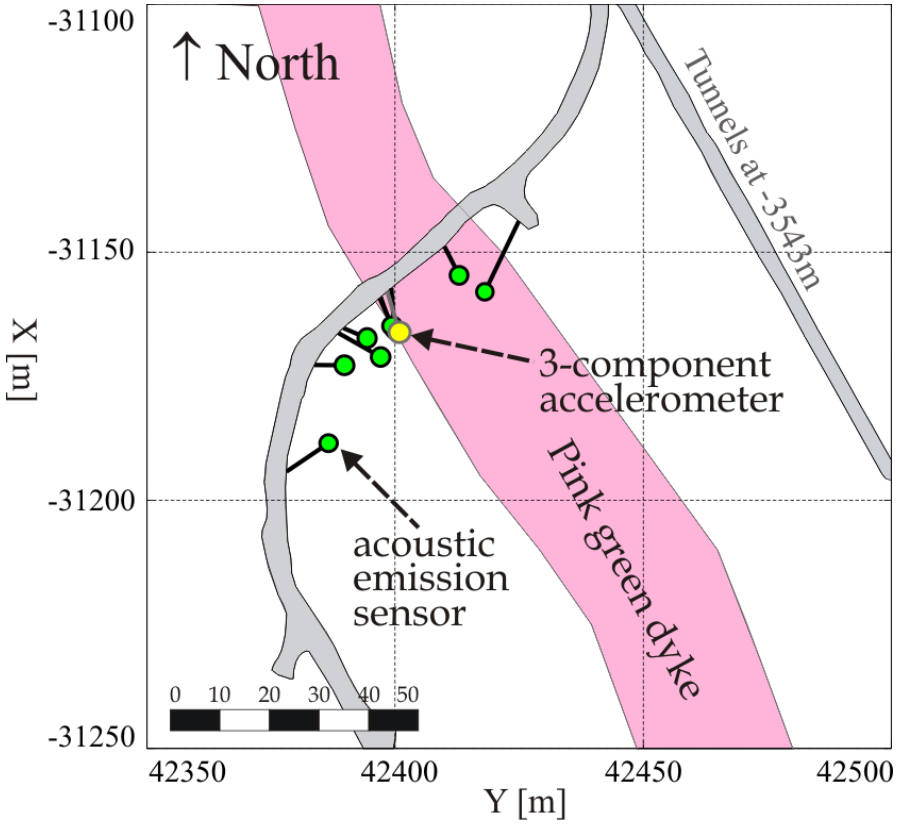
Depth 3540m; vicinity of a **dyke** and **active mining** (exploitation level ~90m above the network). Small area (300x300x300m) monitored.





Jaguars project | network

- 8 Acoustic emission (AE) sensors (1-200kHz) + one 3C accelerometer (0.05-25kHz)
- Triggering mode, in-situ location/acquisition, sampling frequency 500kHz



Data

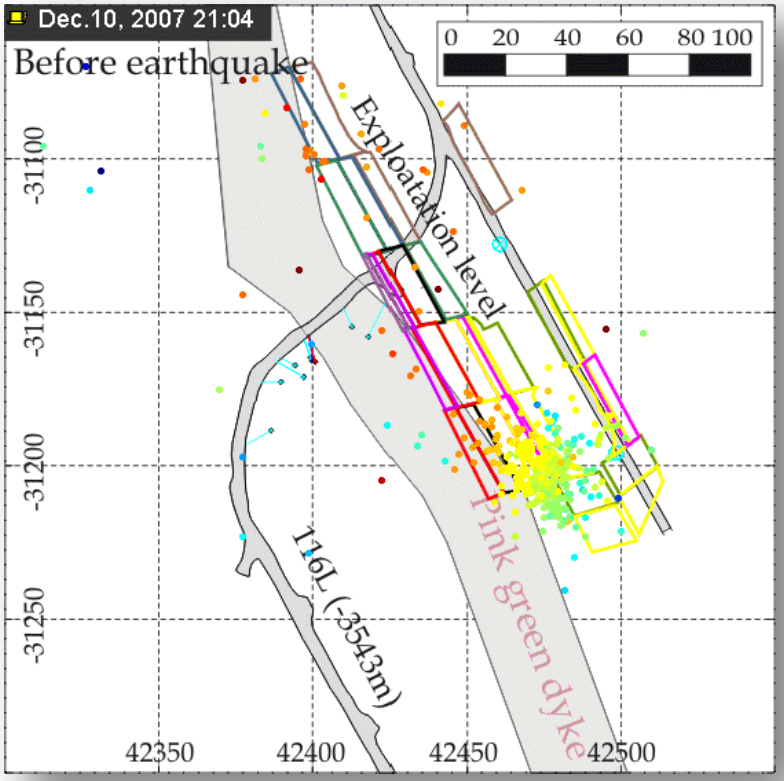
Aftershock sequence of M_W1.9 event

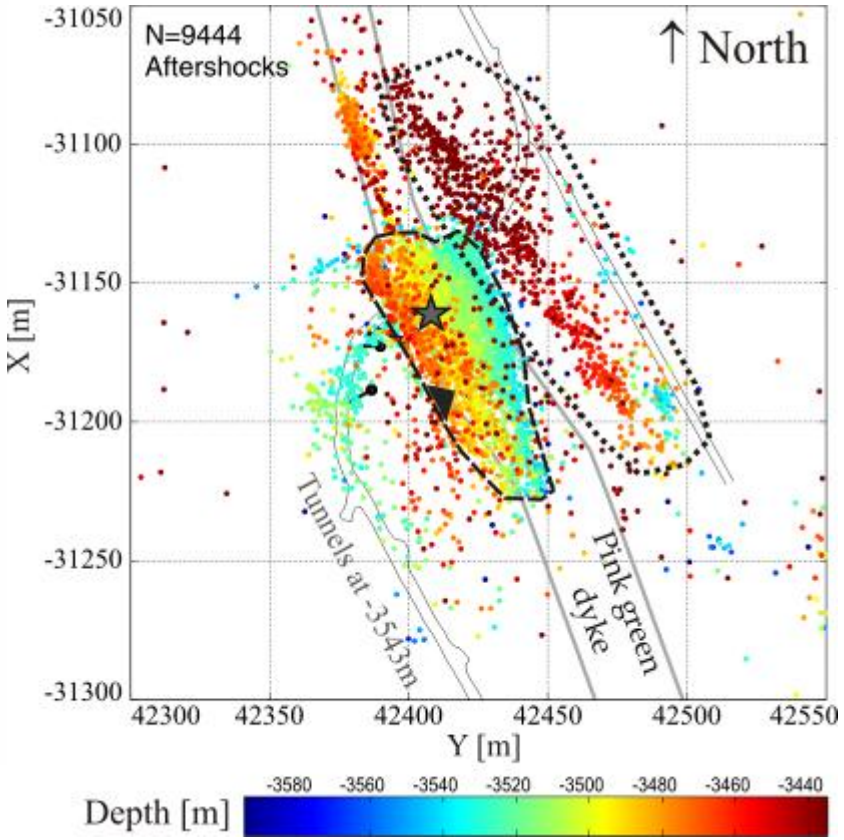
and

Post-blasting seismicity

Data selection: M_W1.9 aftershock sequence

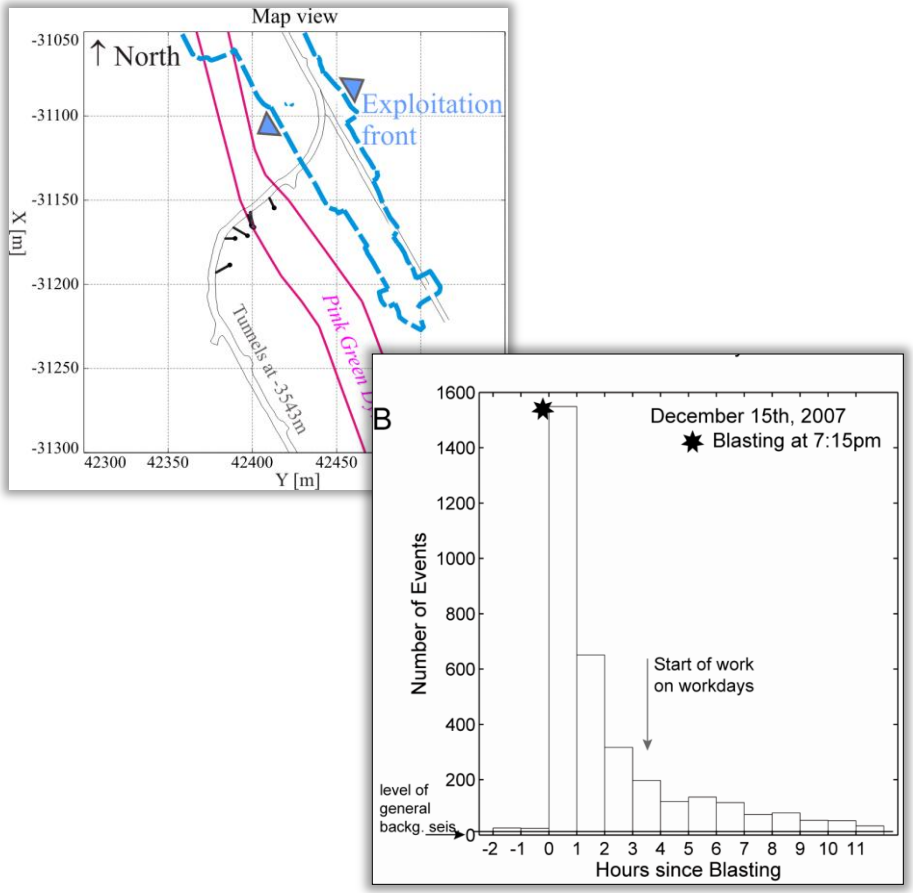
Location: Dyke, ~30m from the network, 20,000 aftershocks (M_W -5.0 to -0.5), manually reviewed, no man-made noises due to Christmas vacation period, N=9444.

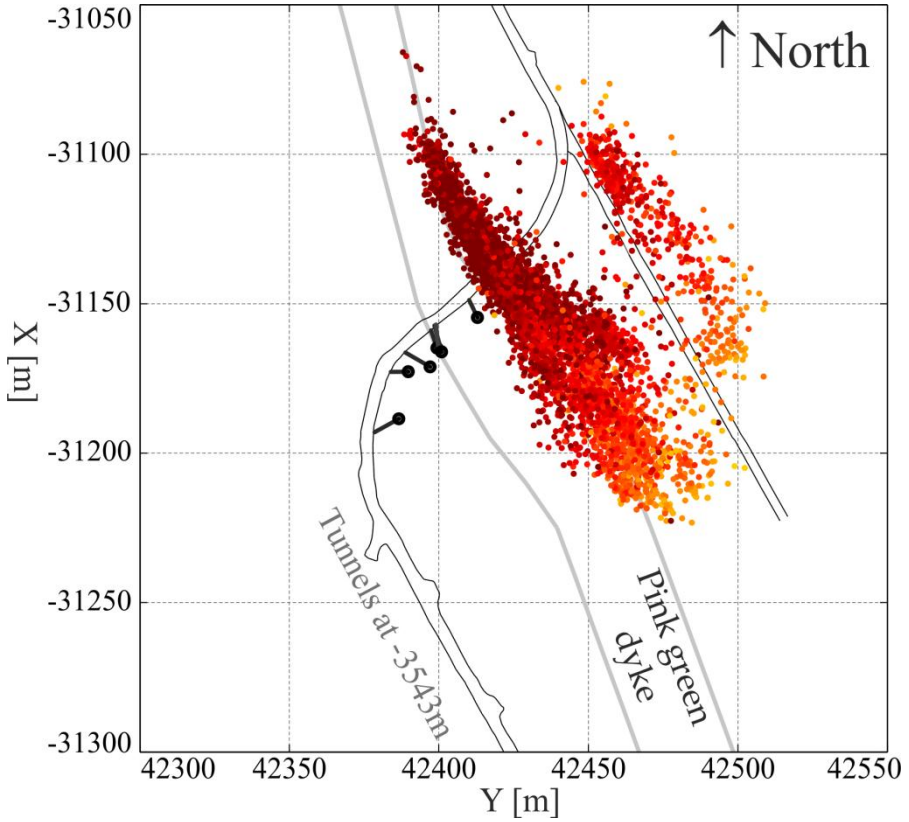




Data selection: Post-blasting activity

The Omori decay is visible even 12 hours after blasting. Excluded all man-made noises (drilling, debris removal), manually reviewed, N=4979 events

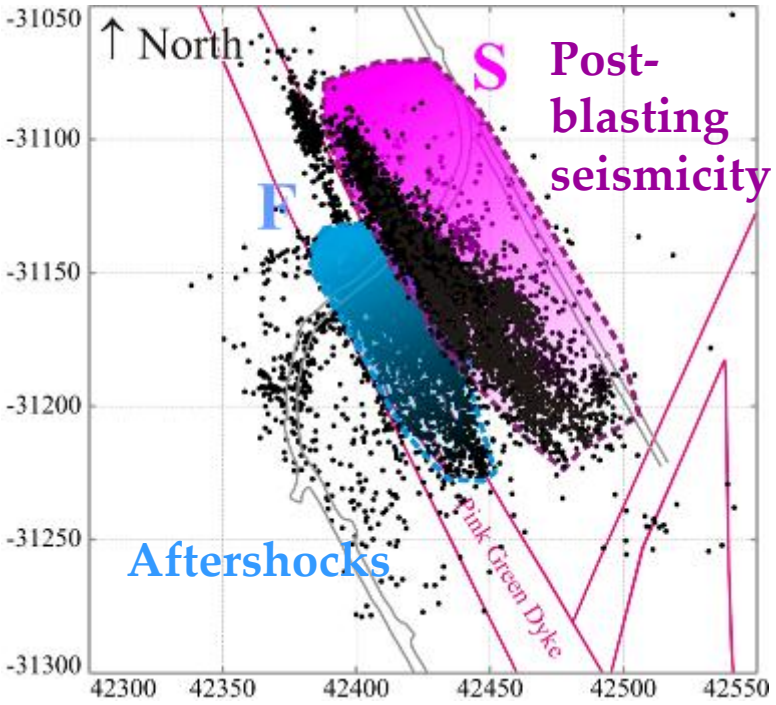


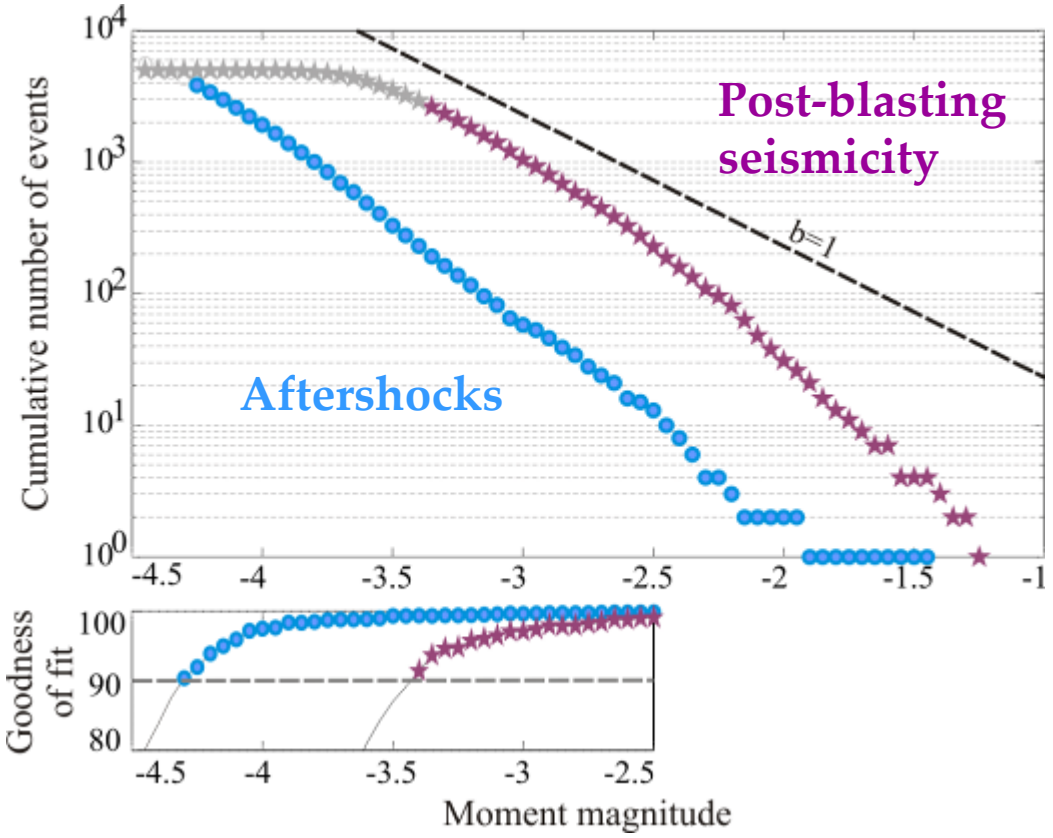


(Plenkers et al., 2010, Seism. Res. Lett. 81)

Scaling of Gutenberg-Richter relation

Self-similarity of Gutenberg-Richter relation visible for picoearthquakes (M_W>-4.5)
ENCOURAGING!





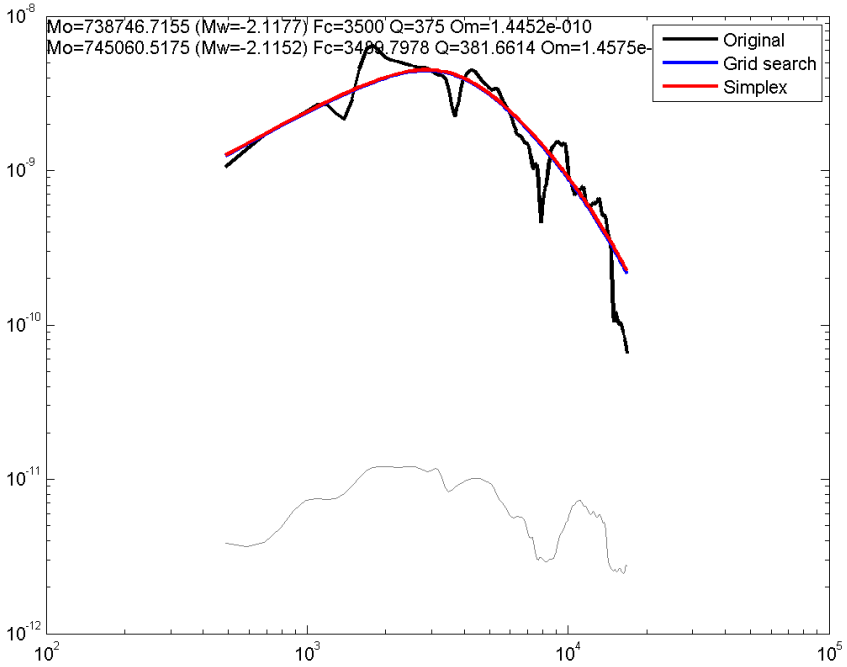
(Kwiatek et al., 2010, BSSA 100, 3)

Spectral fitting method

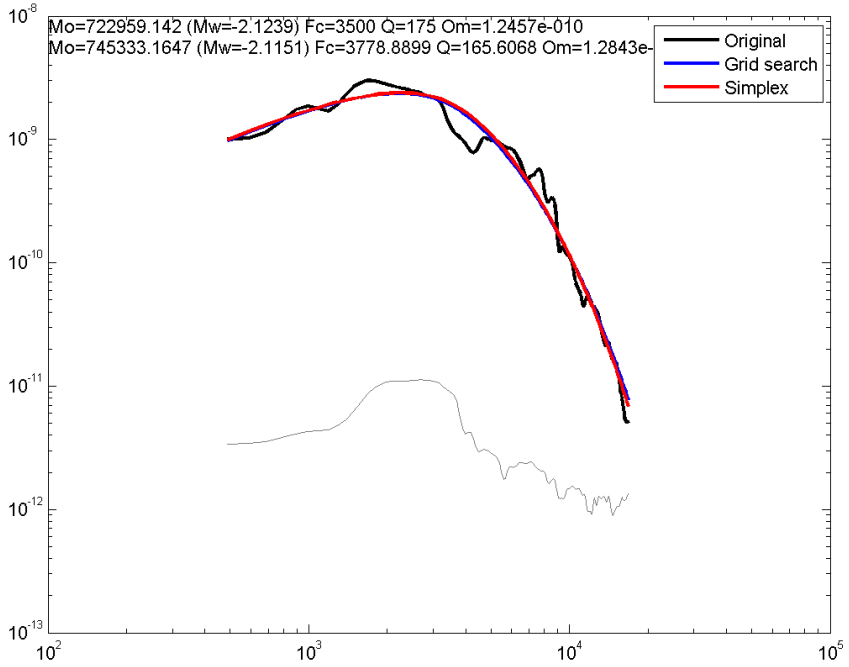
Applied to „low" frequency events (F_0<4-6kHz)

Fitting of ground velocity spectra to Boatwright's source model (M_0, F_0, Q_0)

Event 410850: M_W=-2.11, F_0=~3600Hz (source radius approx. 25cm)



Accelerometer



AE sensor

Spectral ratio method

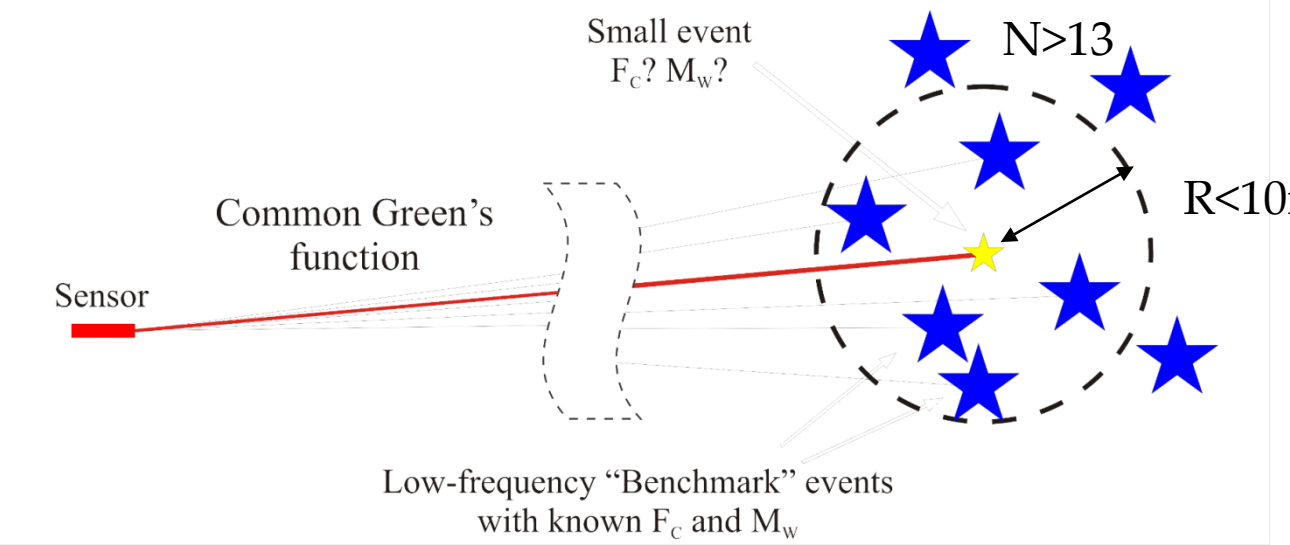
2. Spectral ratio method (e.g. Imanishi & Ellworth, 2004)

Applied to high frequency events (F_0>4-6kHz)

Deconvolution of propagation effects using multiple stronger events located nearby (<10m)

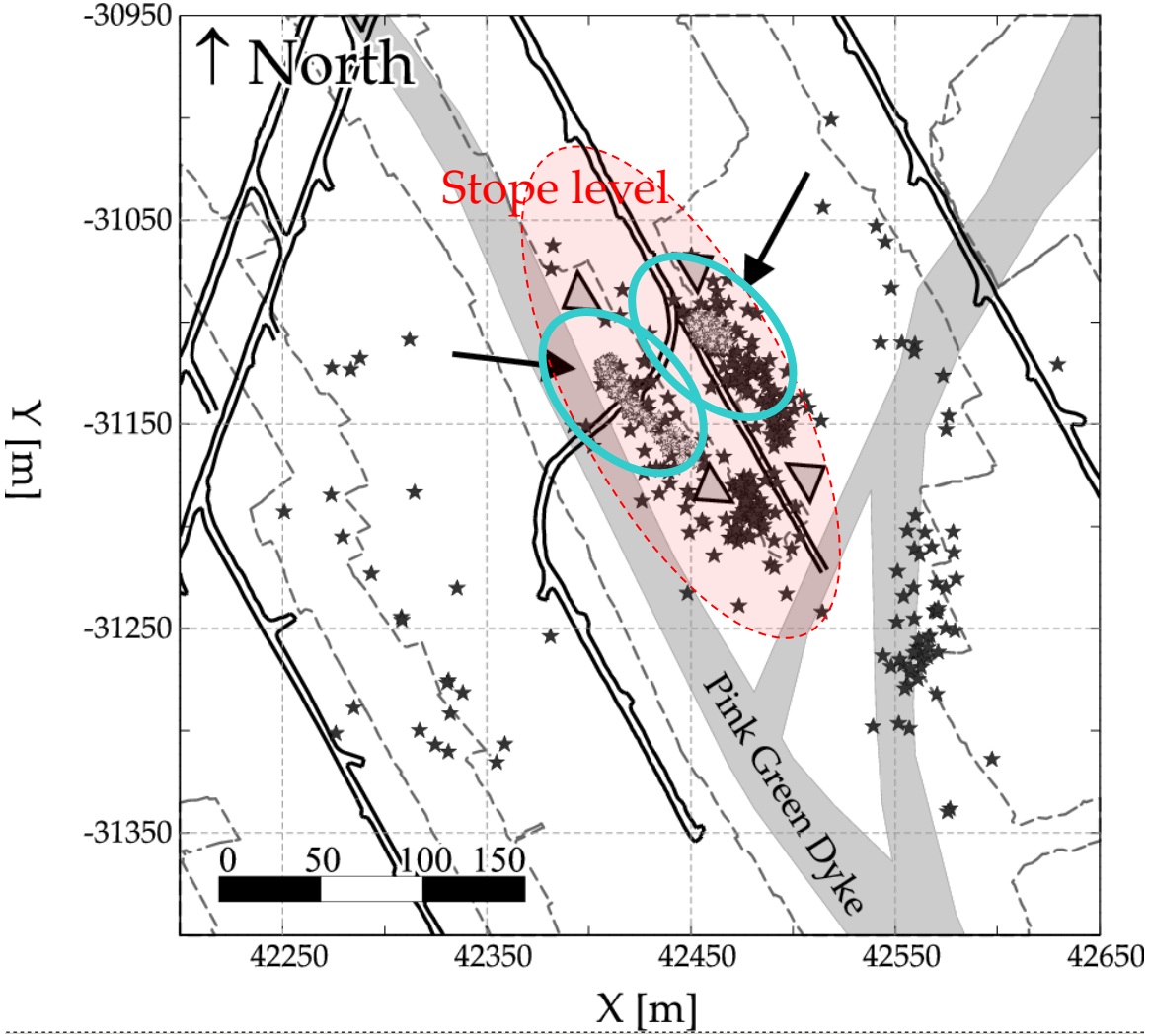
Notes:

- Analysis limited to 0.5-17kHz due to AE sensor in-situ calibration
- 6 sensors used

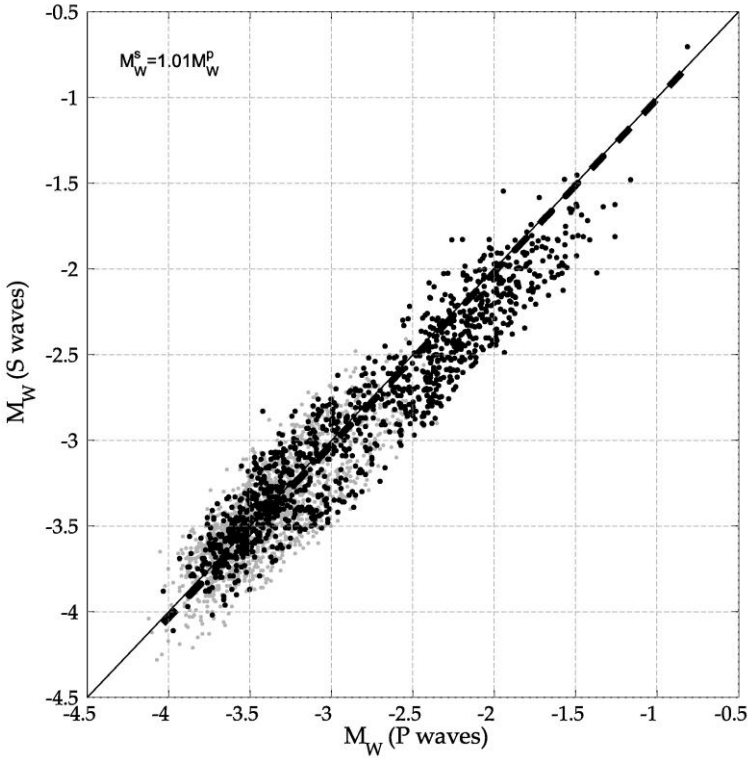


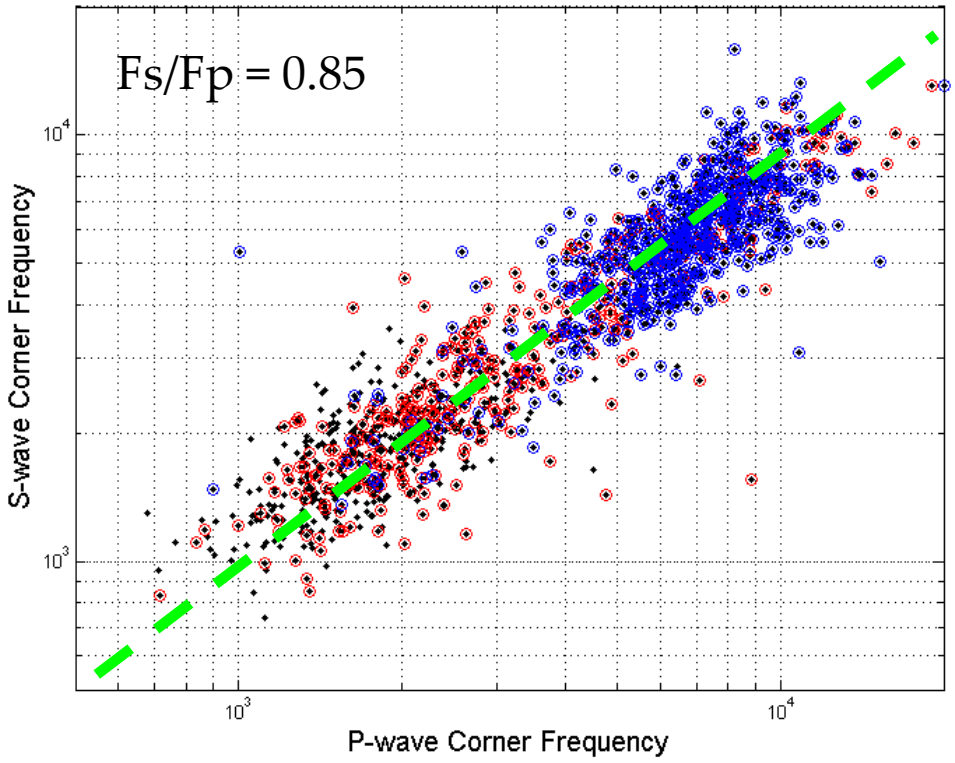
Spatial distribution of analyzed events

N=~1000 events
Manually reviewed



P & S phase data, interesting facts

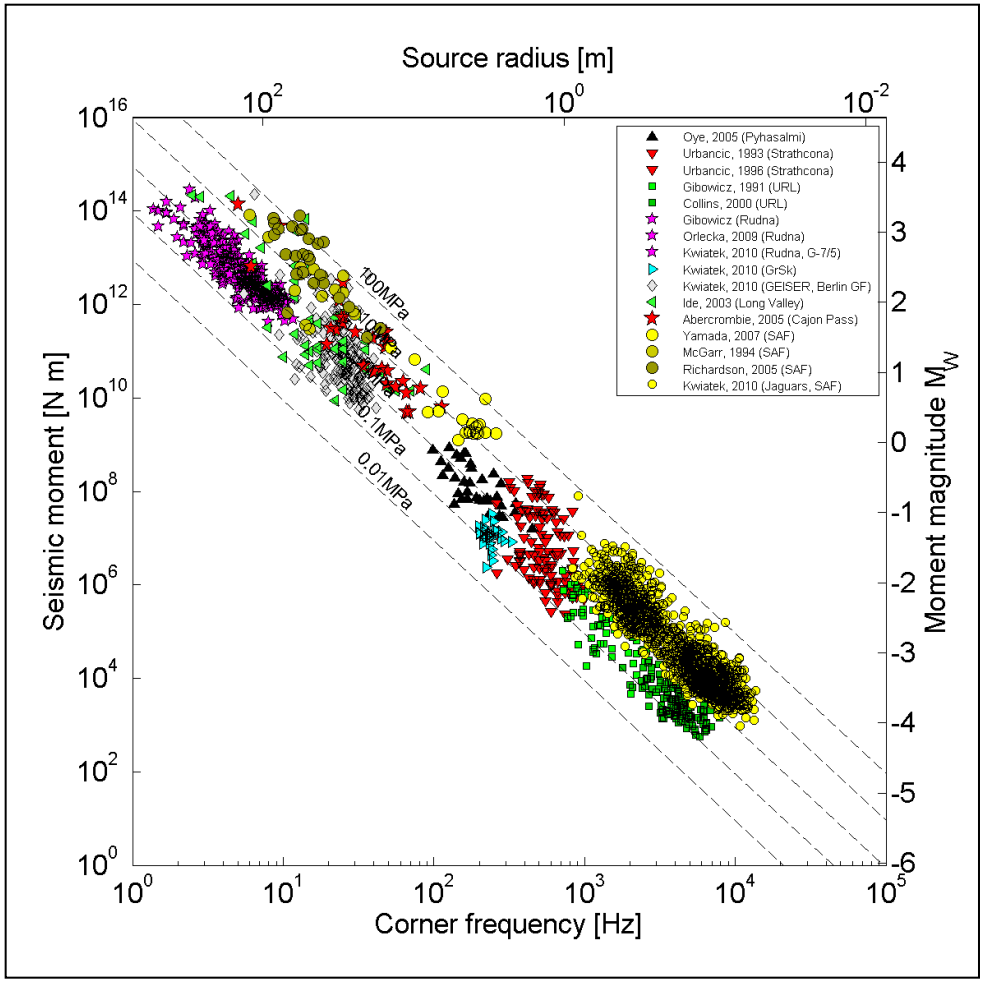




- Attenuation of P waves is stronger than S waves (Qp~400, Qs~600). No frequency-dependence observed

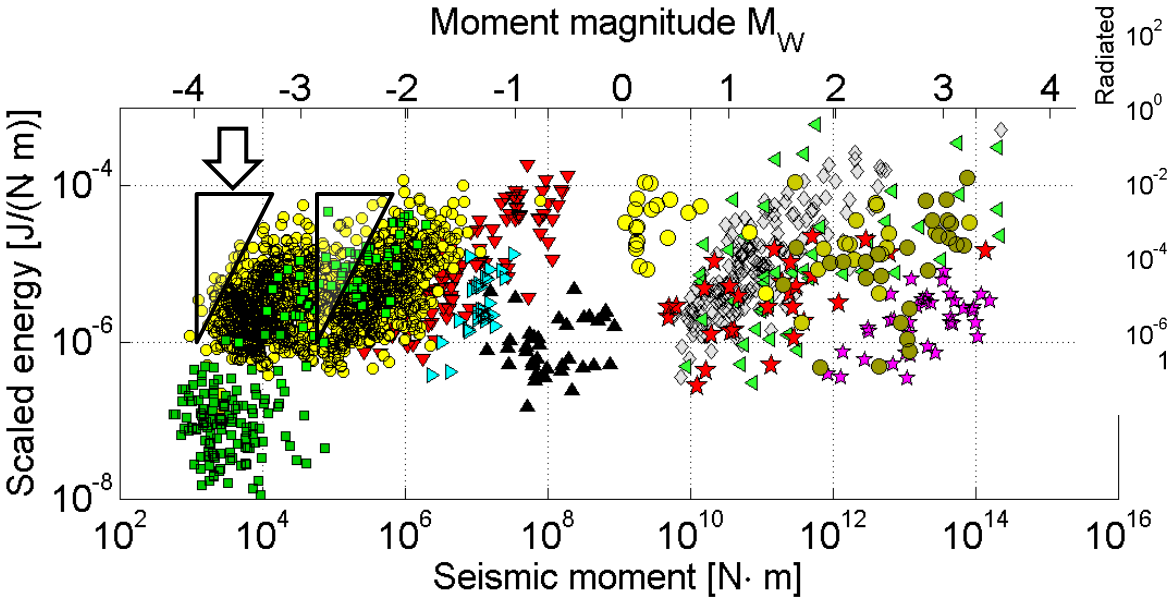
Scaling relations - stress drop revisited

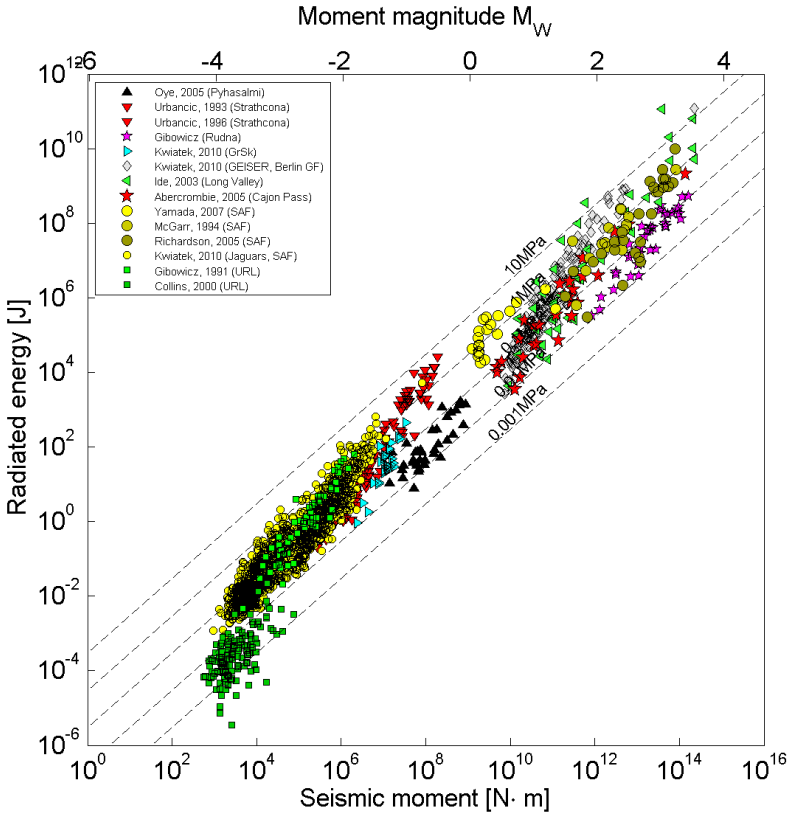
- Constant static stress drop scaling relation observed between M_W -1.0 and -4.1
- Frequency range 500-17kHz (source radius 4m-5cm)
- Stress drop 1-10MPa observed



Scaling relations – apparent stress revisited

- No overall dependence of apparent stress on seismic moment observed
- Substantial part of energy @ high frequencies is modelled due to limited frequency band (~48% for Fc=10kHz)
- Data selection issue confirmed ⇩





Conclusions (1)

- Both post-blasting and aftershock datasets can be described using GR power law. The self-similarity is observed in a wide range of extremely low magnitudes (from -4.4 to -1.9 for the aftershocks and -3.5 to -1.5 for the post-blasting dataset)

► Self-similarity of GR relation may be extended down to the M_W-4.4 (source size of a few cm)

- *b* values of aftershocks and post-blasting activity are similar to natural seismicity.

Conclusions (2)

- Constant constant static stress drop $\Delta\sigma$ scaling relation between M_W -0.8 and -4.1 with average $\Delta\sigma$=~10MPa.
- Apparent stress seems to be slightly dependent on seismic moment when results from two methods applied are treated separately. Together, no dependence on seismic moment is visible.

► Both methods suggest rupture process is self-similar for moment magnitudes from -0.8 to -4.1.

- It is possible to use AE sensors in studies of source parameters

Thank you for your attention!