Permeability evaluation from microseismic data (laboratory study)

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Outline

- Preface: Pore pressure diffusion and microseismicity
- Aims and means of the study
- Pore-elastic pressure diffusion approximation of experimental data
- AE variations in time
- Permeability estimation based on AE variation

Pore pressure diffusion and microseismicity

- It was shown by Shapiro et al. 2002, 2005, that for poro-elastic isotropic homogeneous medium the evolution of the critical pore pressure triggering microseismic events can be described by relation

$$r = \sqrt{4\pi D t} \qquad (1)$$

- where *r* is a distance from injection point, *t* is time from injection start, *D* is a hydraulic diffusivity coefficient. The relation (1) is a solution of poro-elasticity equation in simplest form

$$\frac{\partial p}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial p}{\partial x}\right) = \frac{\partial D}{\partial x}\frac{\partial p}{\partial x} + D\frac{\partial^2 p}{\partial x^2} \qquad \frac{\partial p}{\partial t} = D\nabla^2 p$$

- If we find an envelope curve of the type (1) for microseismic event cloud propagation in *r*-*t* coordinates, it would be possible to estimate hydraulic diffusivity and permeability *k*

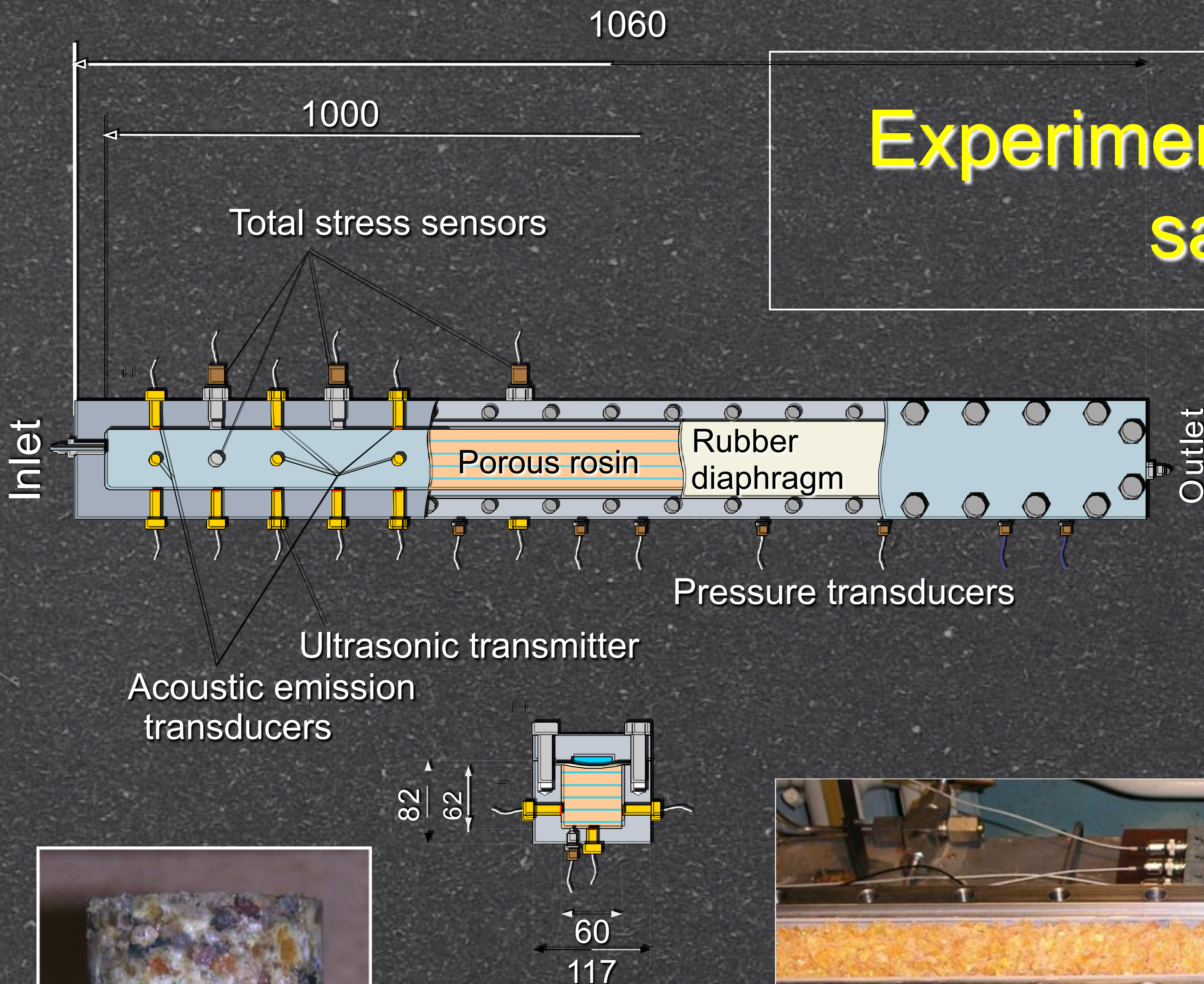
$$D = \frac{k}{\mu_0 \beta m_0}$$

- where μ_0 – fluid viscosity, β – porous sample compressibility, m_0 – initial porosity

AIMS & MEANS

- A possibility to use not only data on microseismicity propagation, but also data on microseismic activity change in time for estimation of the permeability.
- The analysis is based on laboratory study of relation between acoustic emission (AE) activity and pore pressure change due to water injection into a porous sample under load.
- The model is based on an assumption that the microseismic (acoustic) events occurred when pore pressure reaches a critical value, which is distributed under some probability function. As the probability functions, Weibull distribution, Gausian error function and Log-normal distribution are considered.
- The study showed a possibility to resolve an inverse problem of defining local permeability by registering microseismic activity variation in particular volume of the porous medium.

Experimental setup and sample



Parameters of experiments

Registration of AE: 12 channels, 750 kHz.
Registration of pore pressure and stresses: 15 channels, 10 Hz.
Duration of registration up to 100 seconds.
External pressure 10 - 11 MPa.

Initial pore pressure 0.1 MPa

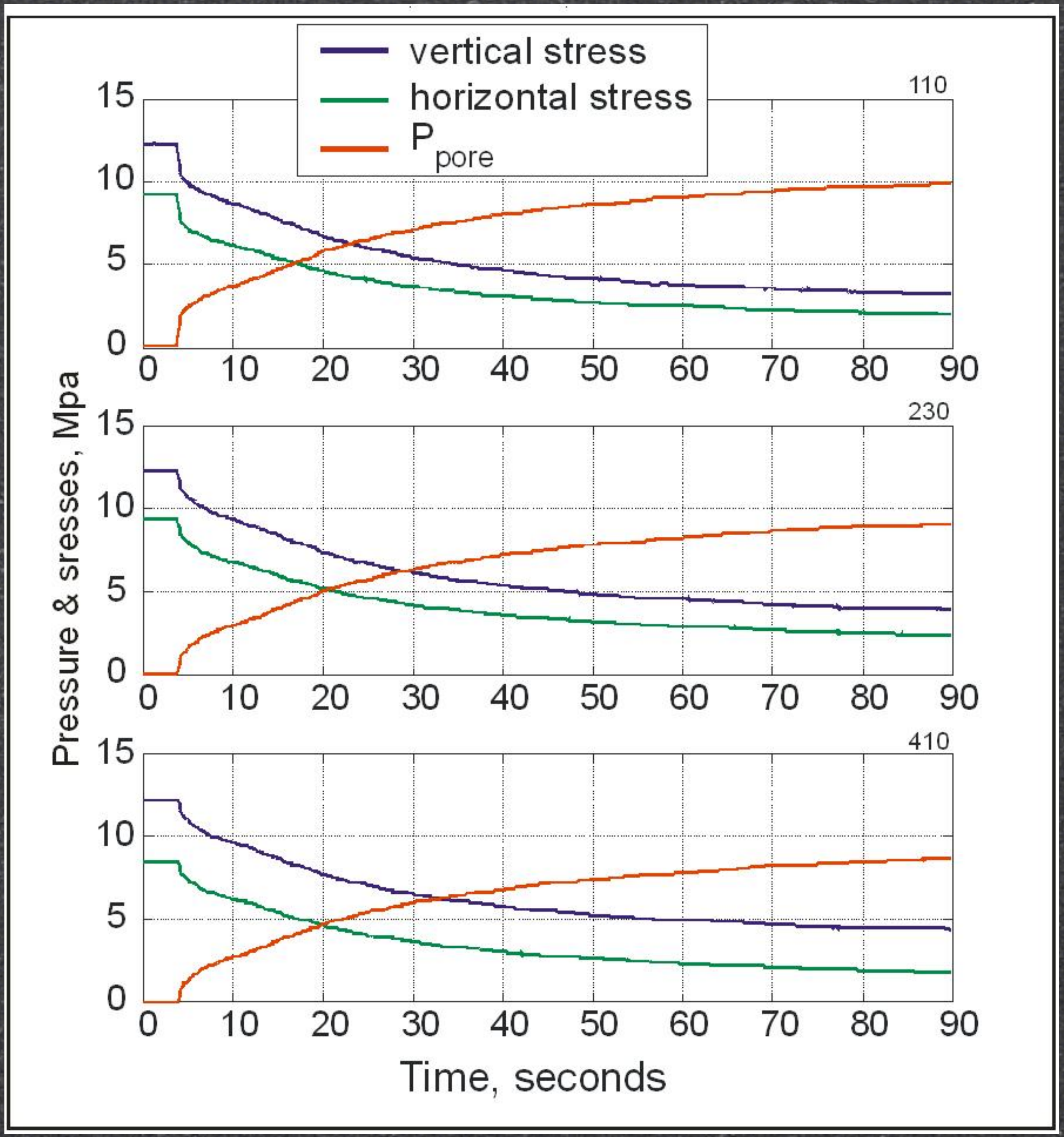
Final pore pressure 9.5 – 10 MPa

Sample: mixture of pebbles (sizes from 2.5 to 5 mm) with crashed pine rosin (fragment sizes from 1 to 5 mm) in proportion 1 : 3

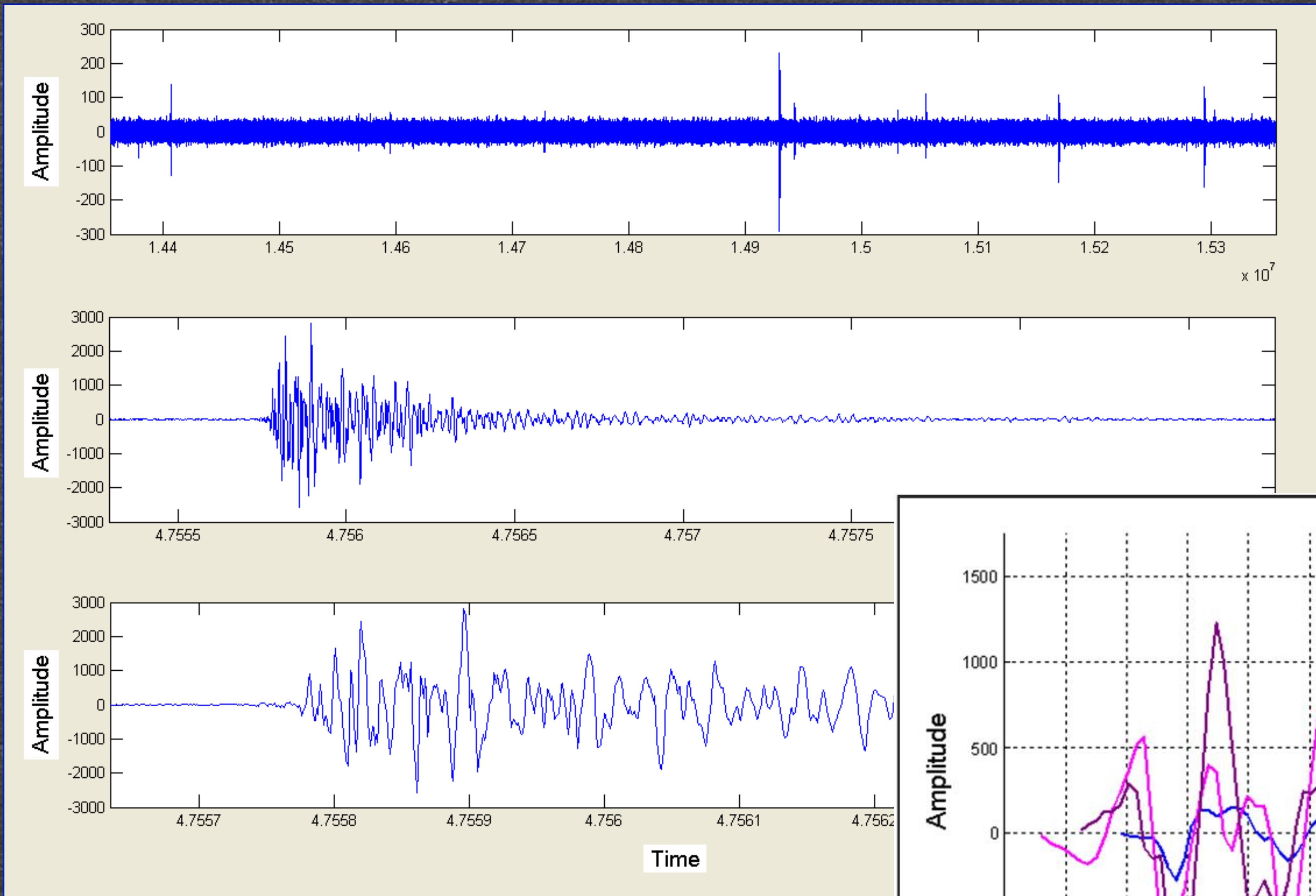
Permeability 8 – 14 mD

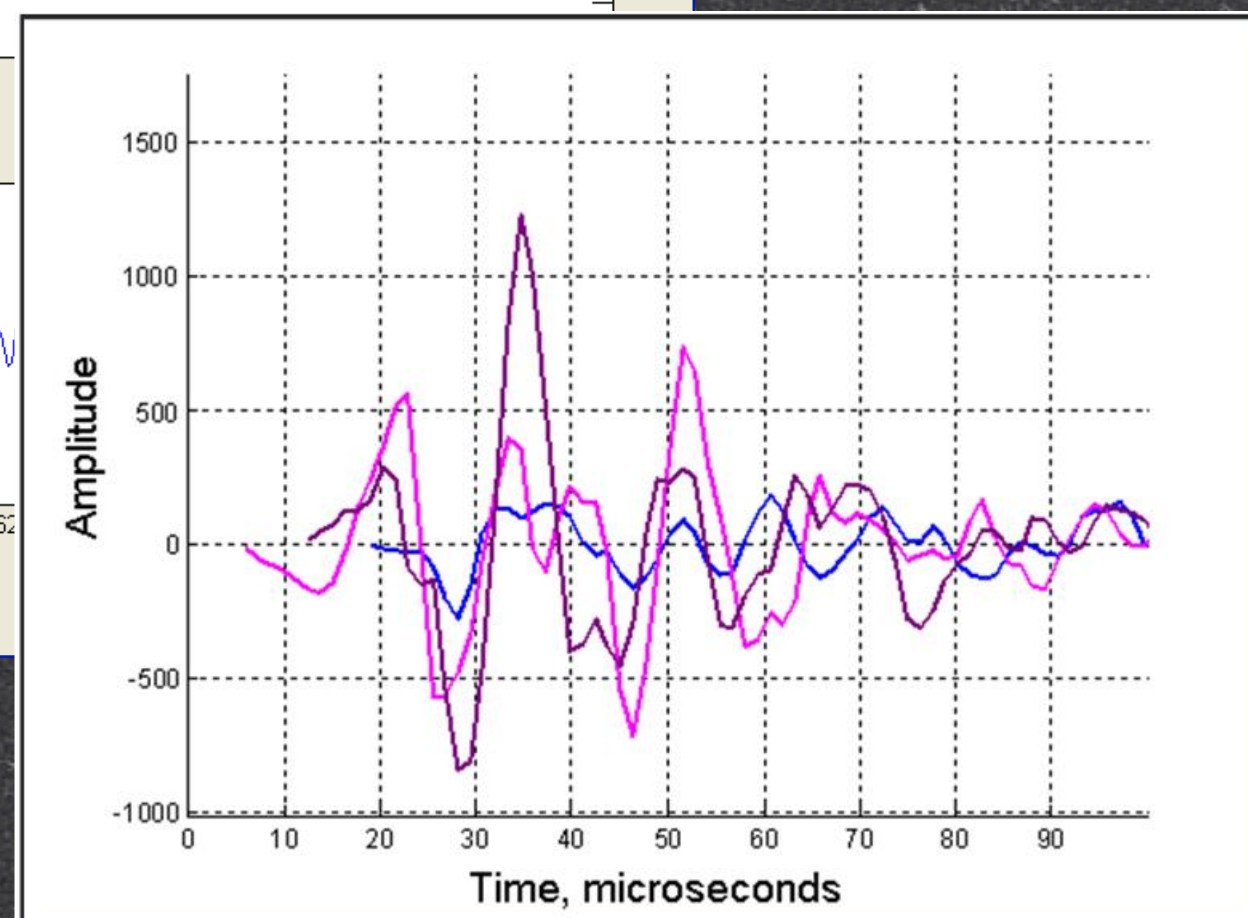
Unconfined compressive strength 0.54 MPa

Change of pore pressure and stresses with time in several points of measurements.

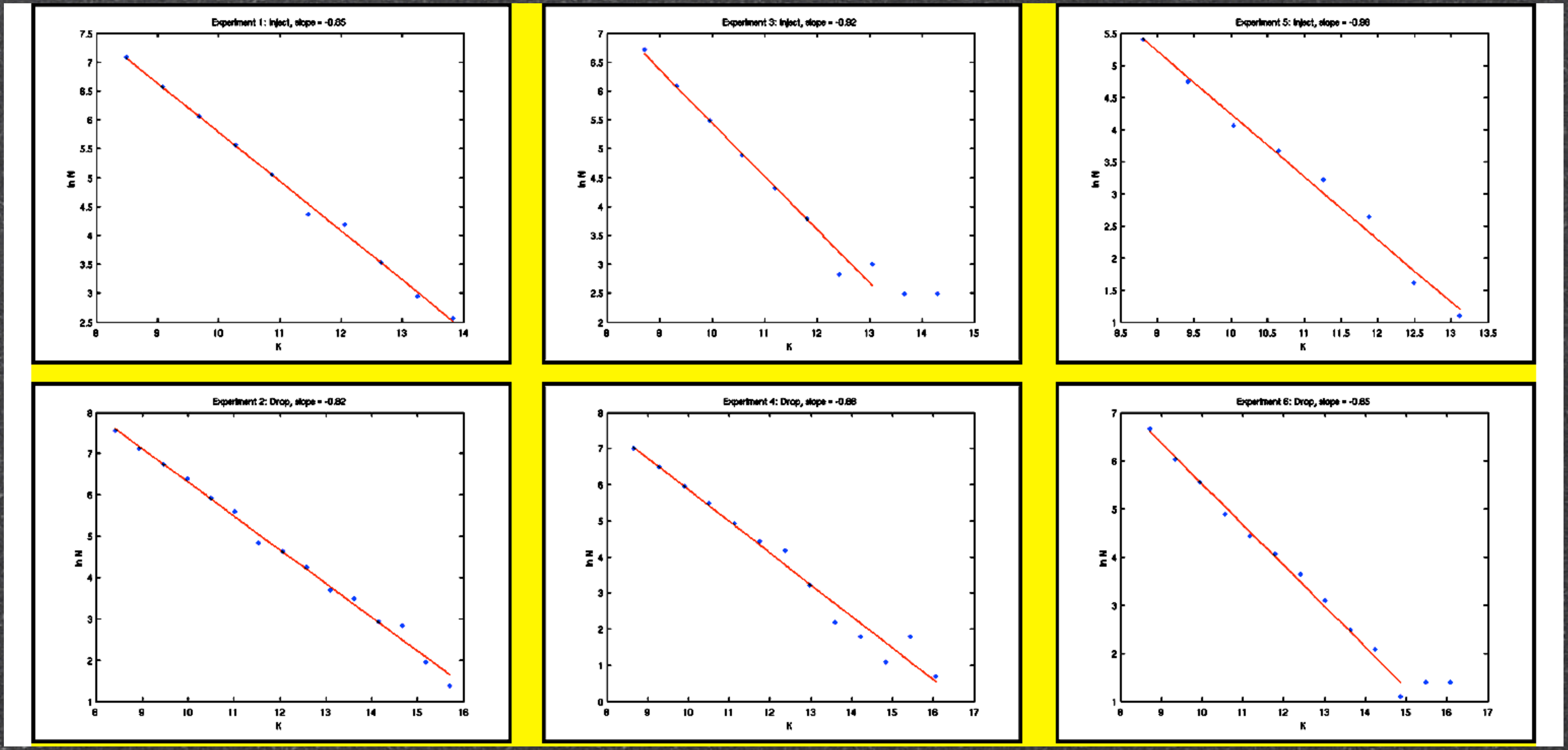


Fragments of AE recorded during water injection

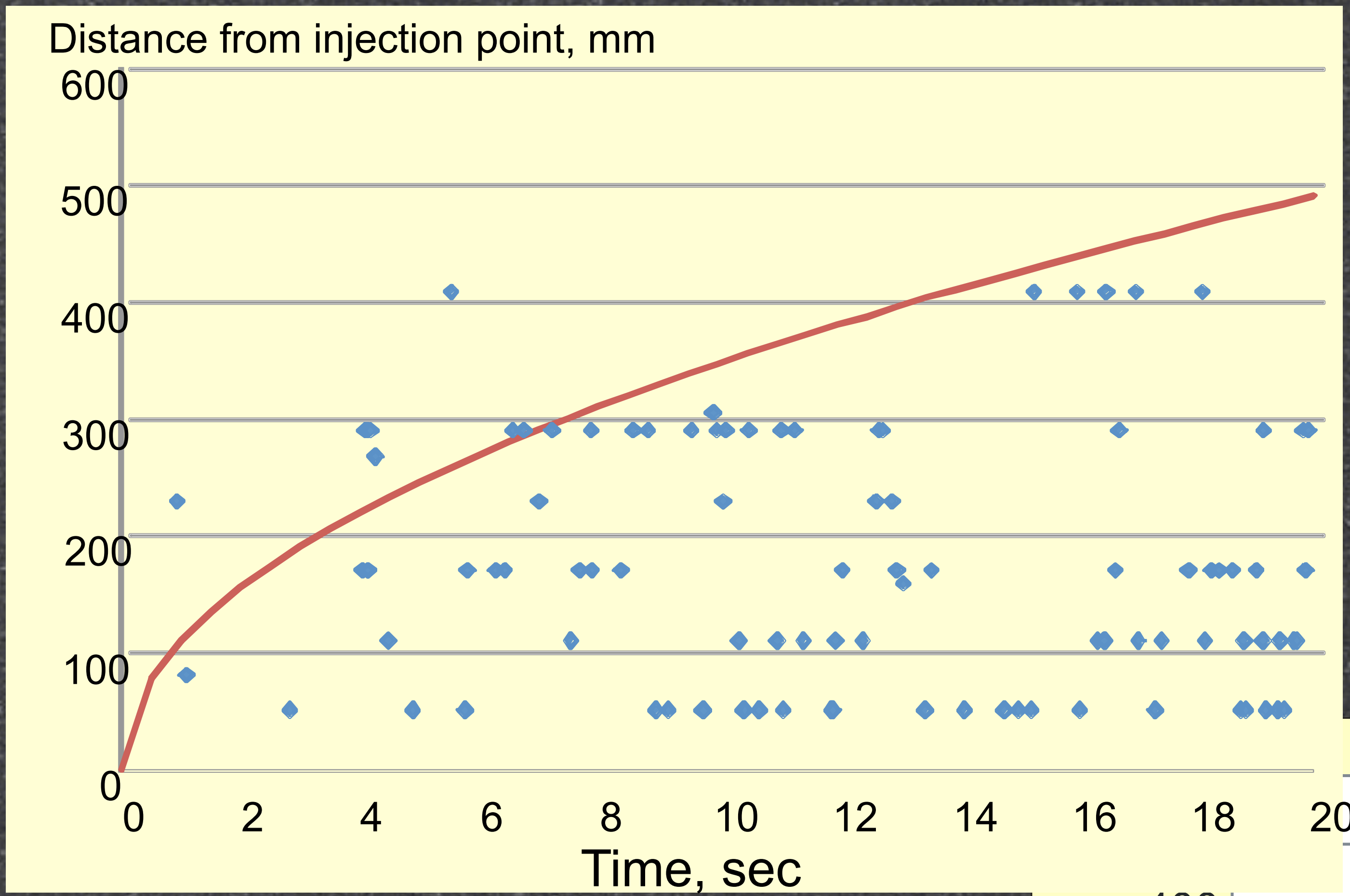




“Magnitude- frequency” relations for acoustic pulses

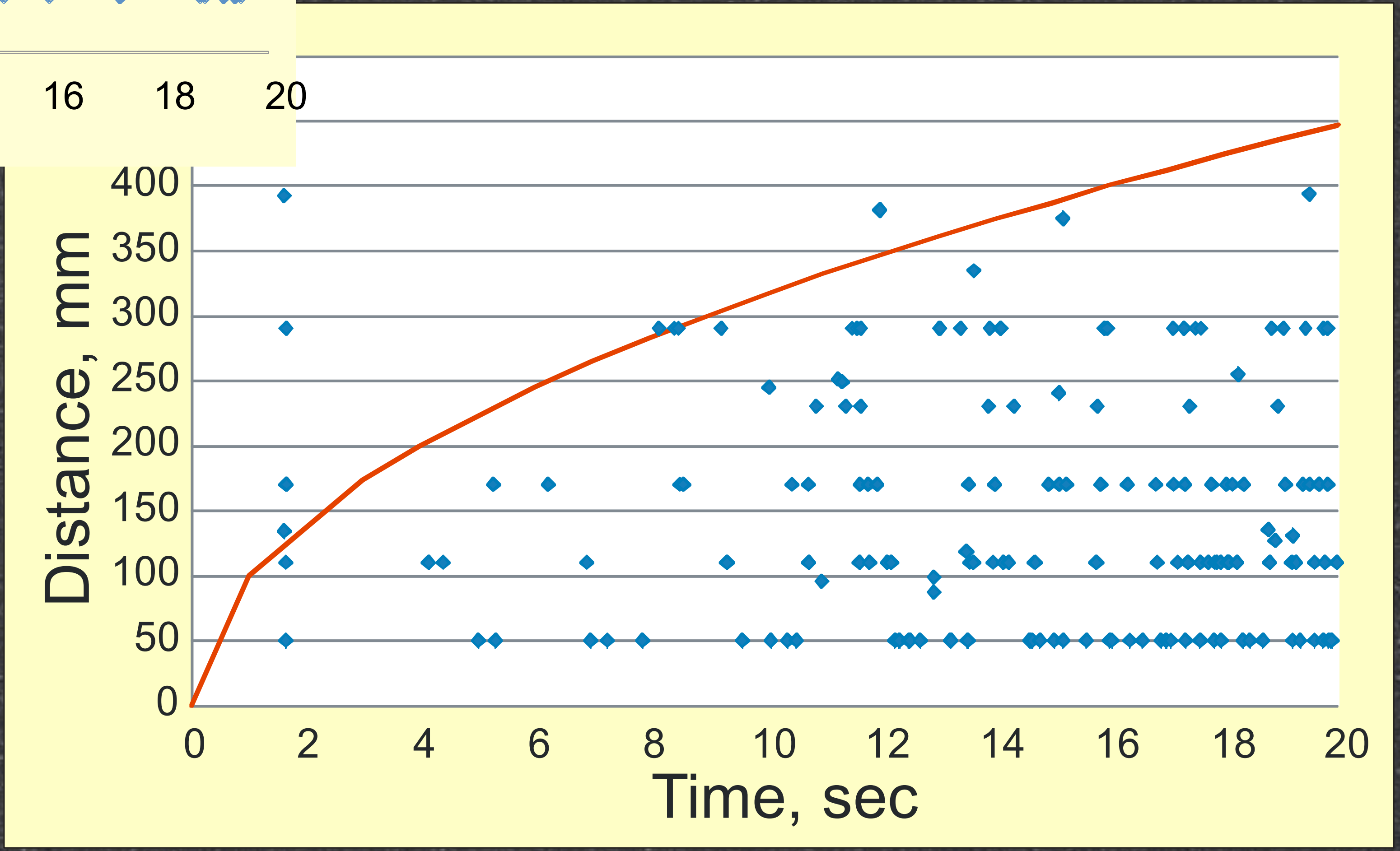


r-t plots of AE propagation



$$r = \sqrt{4\pi D t}$$

$$D = \frac{k}{\mu_0 \beta m_0}$$



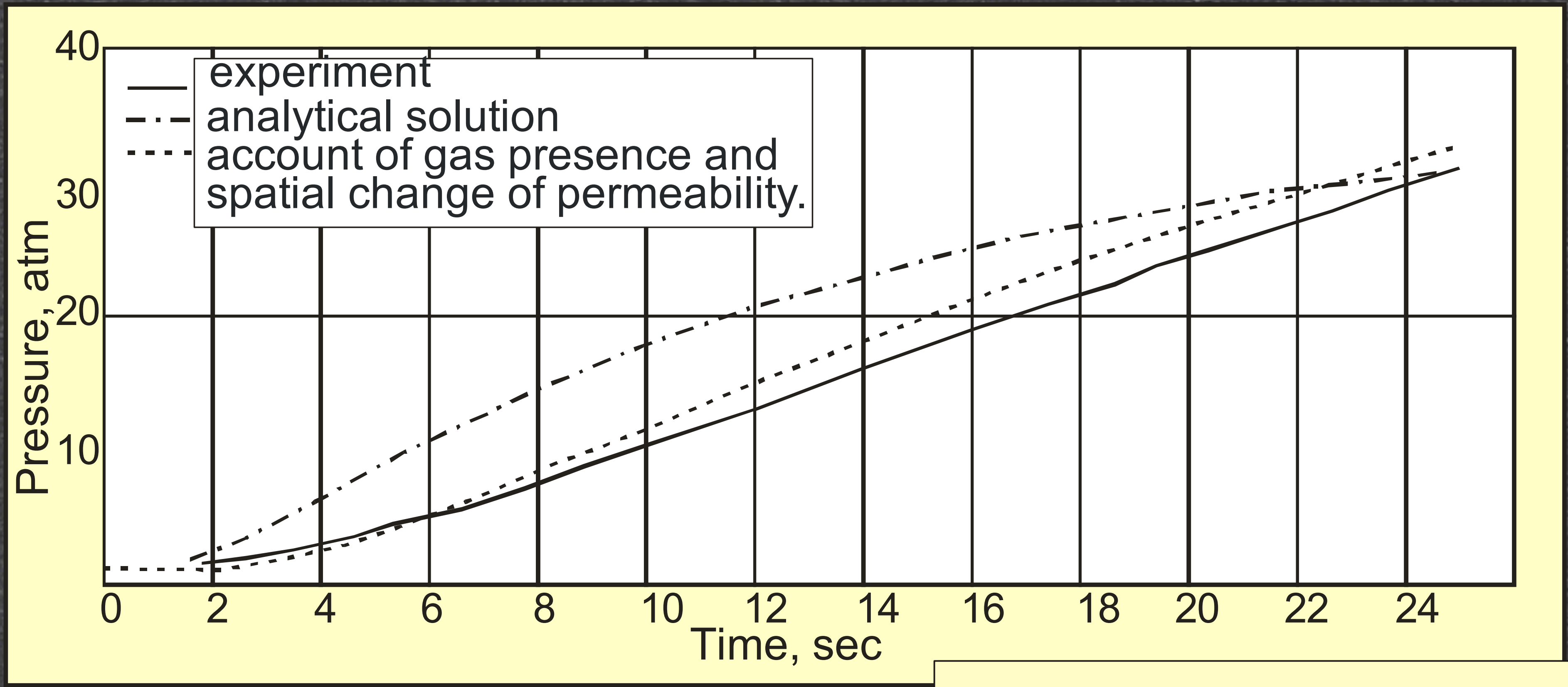
Pore-elastic approximation of experimental data

- The pore-elastic equation: $$\frac{\partial p}{\partial t} = \frac{k}{\mu\beta m}\nabla^2 p$$
- where $\beta = a_m + a_p$ is effective compressibility of the porous medium. Initial condition $$p(x,0) = p_0$$
- A constant fluid rate Q at the inlet end of the cell and constant pressure at the outlet end were taken as boundary conditions
- $$p(1,t) = p_0 \qquad \frac{\partial p(0,t)}{\partial x} = -b, \qquad b = \frac{Q\mu_0}{Sk}$$
- The solution can be written as:

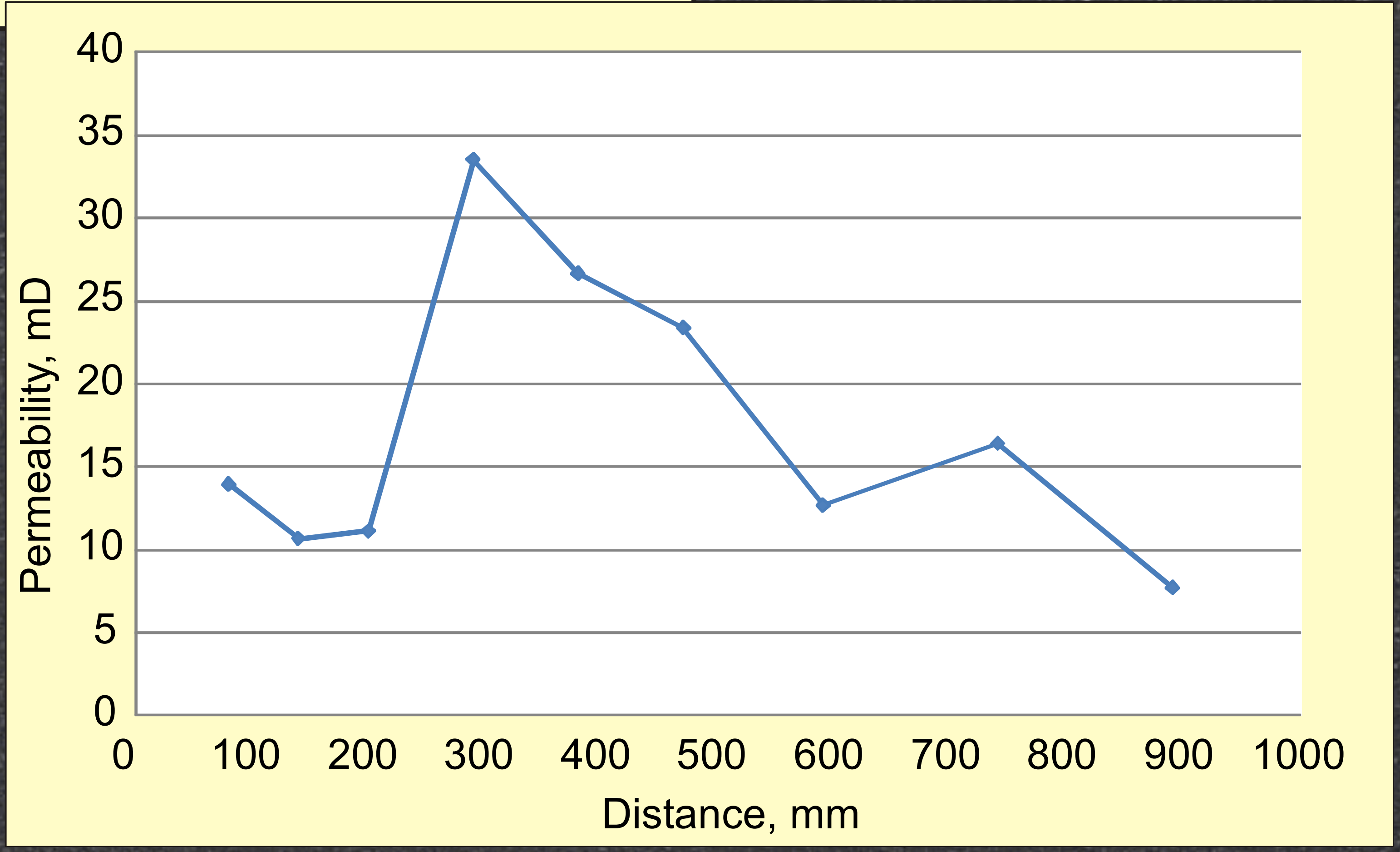
$$p(x,t) = p_0 + b(1-x) - 2b\sum_{k=0}^{\infty}\frac{e^{-\mu_k^2 a^2 t}}{\mu_k^2}\cos\mu_k x,$$

$$a^2 = \frac{k}{\mu_0\beta m_0},\ b = \frac{Q\mu_0}{Sk}\ ,\ \ \mu_k = \frac{\pi}{2} + \pi k,\ \ k \in \{0\} \cup N$$

Pore-elastic approximation of experimental data



Pore pressure change, account of gas and the sample inhomogenety.



Change of permeability along the sample

AE triggering model

The simplest model of AE excitation due to fracturing process can be based on two suggestions:

- a fracture appears when the pore pressure reaches some critical threshold value;
- the threshold value spatial distribution can be described by one of the following distributions:
  - normal distribution
  - Weibull distribution
  - Log-normal distribution

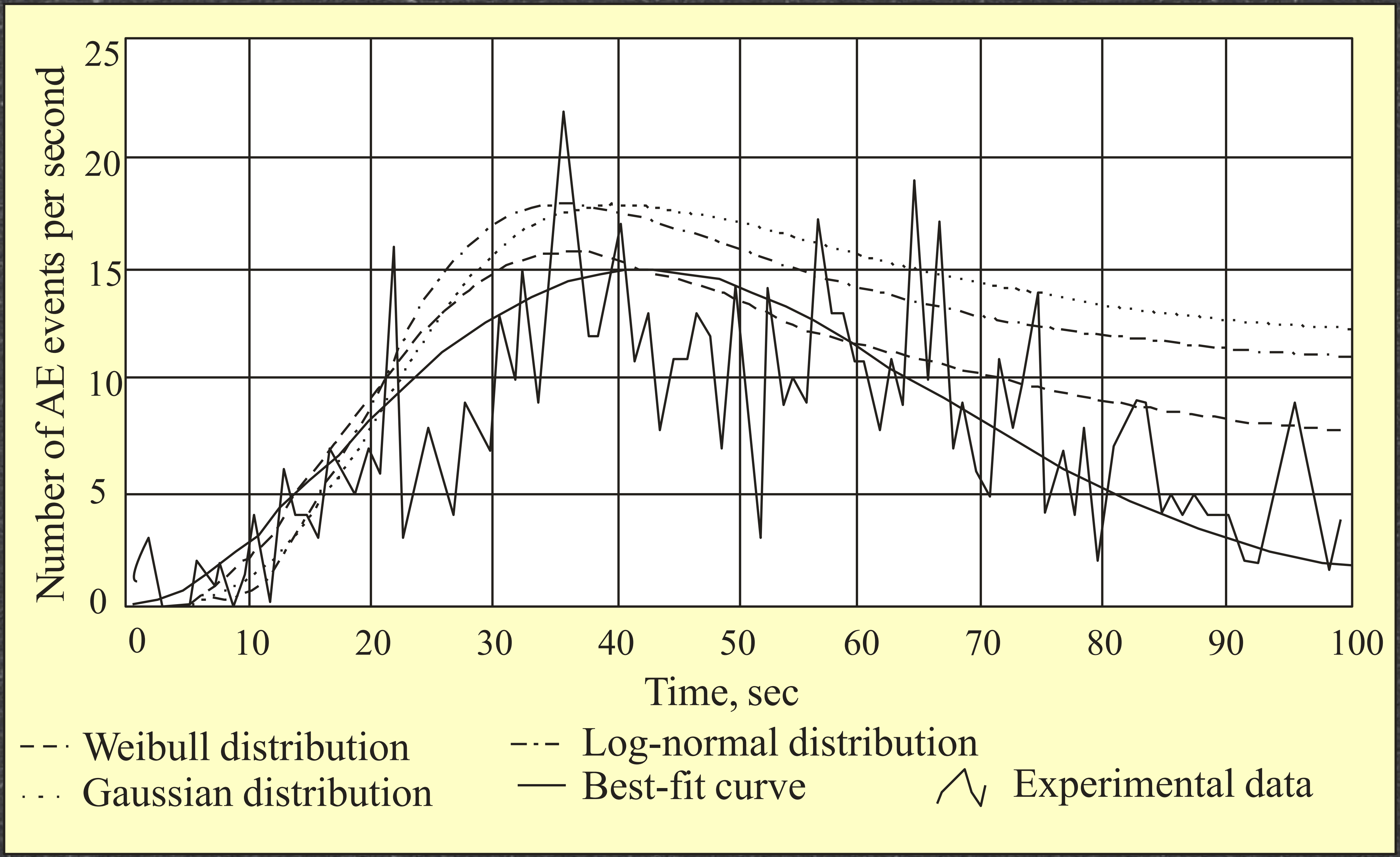
$$N(p^*) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(p^*-M)^2}{2\sigma^2}}$$

$$N(p^*) = ba^{-b}\left(p^*\right)^{b-1} e^{-\left(\frac{p^*}{a}\right)^b}$$

$$N(p^*) = \frac{1}{p^*\sigma\sqrt{2\pi}} e^{-\frac{(\ln p^*-\mu)^2}{2\sigma^2}}$$

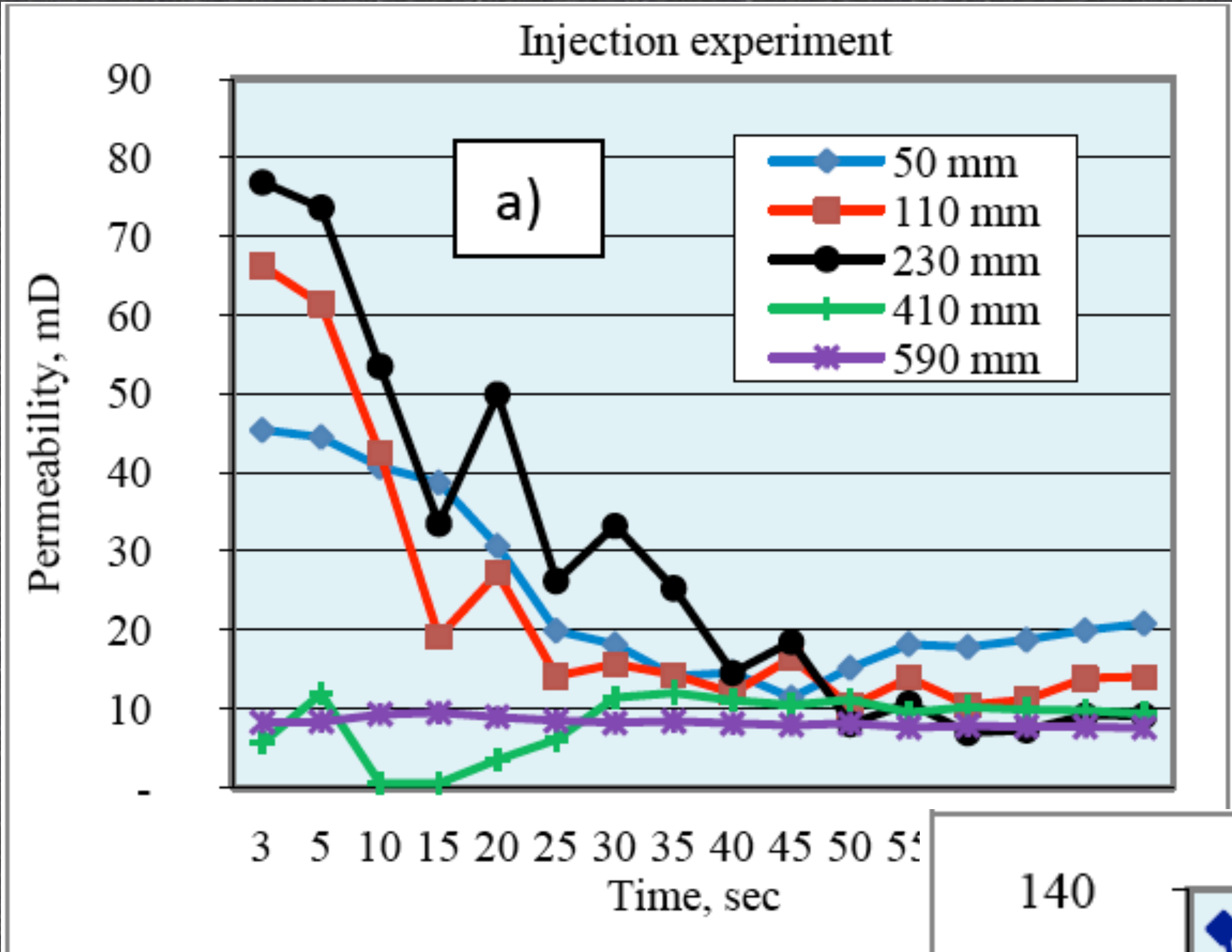
- where M, σ, a, b, μ – distribution parameters.

Comparison of the experimental data on AE activity variations during pore pressure increase with mean AE activity calculated in accordance with several critical pressure distributions



Permeability estimation based on AE variation

- The pore pressure change with time can be found from poro-elastic equation, permeability can be treated as a parameter.
- Relation between pore pressure and the number of AE pulses induced by injection is defined by critical pore pressure distribution.
- That means, that one can estimate numerically the permeability k in a time interval, if one knows the pore pressure and the number of AE pulses at that time interval.

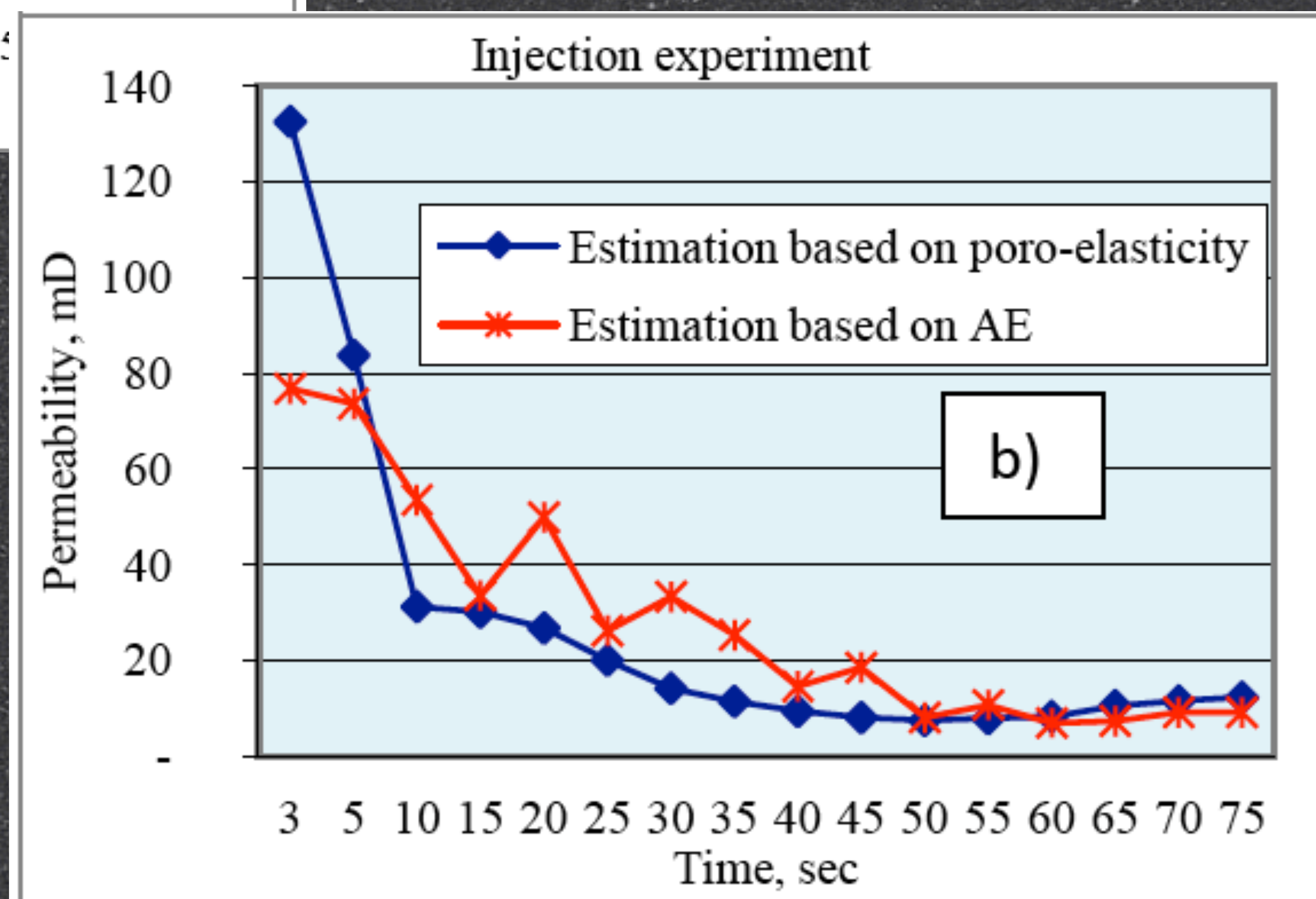


Permeability change calculation based on the pore pressure measurements

$$\frac{\partial p}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial p}{\partial x}\right) = \frac{\partial D}{\partial x}\frac{\partial p}{\partial x} + D\frac{\partial^2 p}{\partial x^2}$$

Permeability change calculation based on AE measurements

$$N(p^*) = ba^{-b}\left(p^*\right)^{b-1} e^{-\left(\frac{p^*}{a}\right)^b}$$



CONCLUSIONS

- The mean AE activity variation can be described as the process controlled by two factors: pore pressure change and change of the number of potential fractures, which can be activated by pore pressure change.
- The distribution of these potential fractures can be approximated by Weibull distribution.
- The change of the sample permeability with time during fluid injection was detected.
- A possibility to resolve an inverse problem of defining local permeability by registering microseismic activity variation due to pore pressure change in particular volume of porous medium is shown.

Thank you for attention!