STATISTICS OF NUMERICAL EXPERIMENTS WITH MULTI-FRACTURE SYSTEMS

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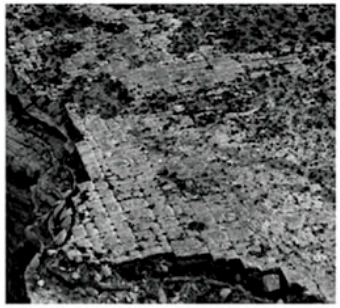
FRACTURED MEDIA

Fractured Porous Media is a topic of high scientific and technical interest, mainly in

SANDSTONE

http://pyrite.igs.indiana.edu/indgeol/reference/

SANDSTONE



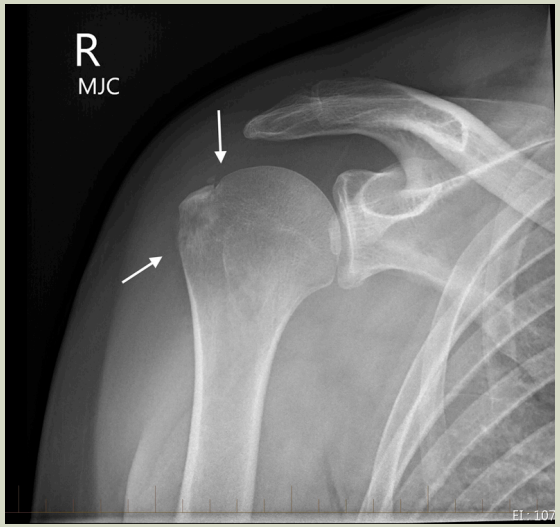
(J.Olson)

SANDSTONE

LIMESTONE

(Roberts 1989)

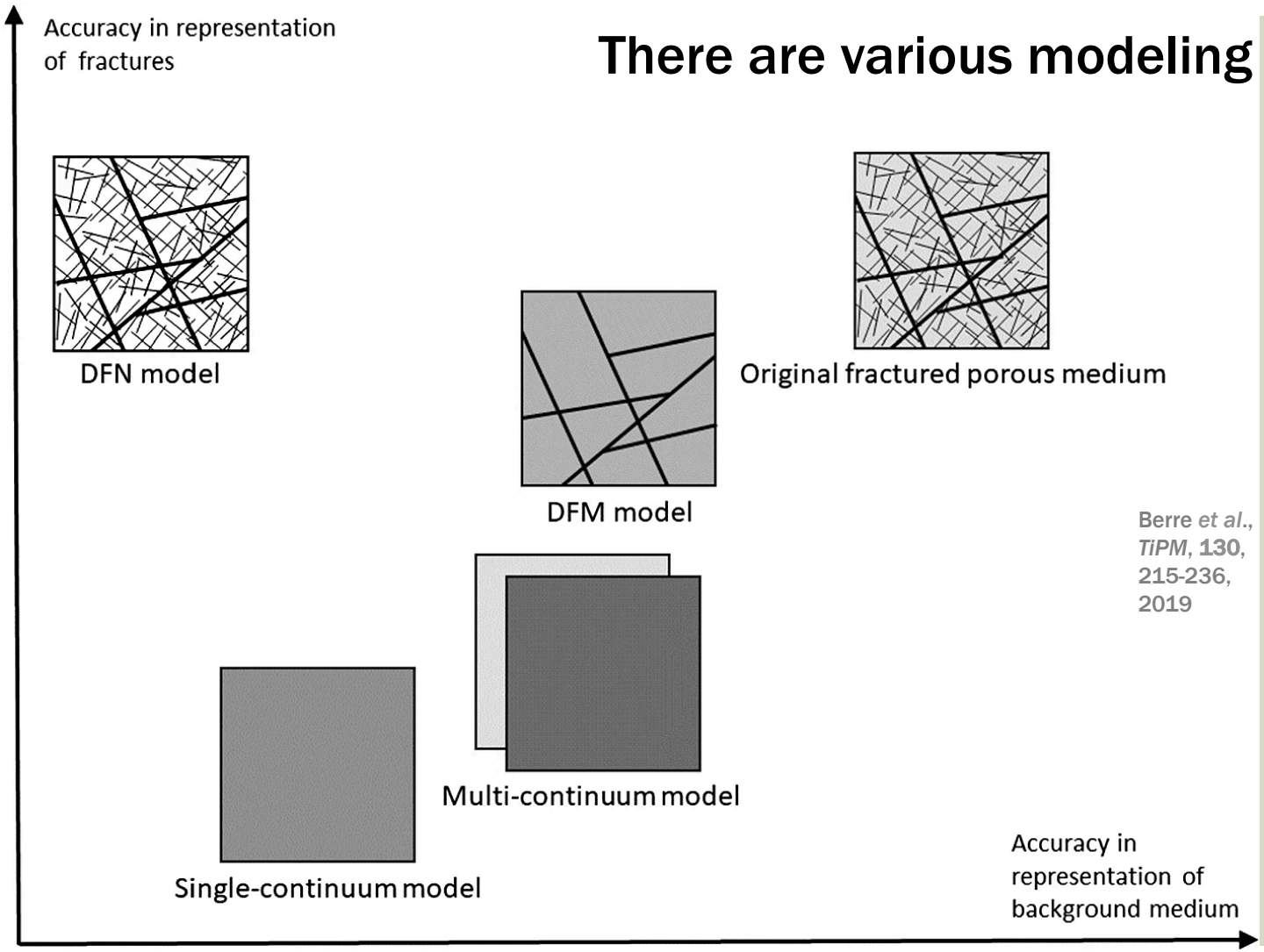
- **Material sciences**
- **Geology**
- **Medical sciences**



https://www.fifamedicalnetwork.com/764937/

https://csegrecorder.com/articles/view/seismically-guided-fracture-characterization

MODELING



Berre *et al.*, *TiPM*, **130**, 215-236, 2019

There are various modeling approaches:

- **Single continuum**
- **Multi continuum**
- **Discrete Fracture Network (DFN)**
- **Discrete Fracture Matrix (DFM)**

MODELING APPROACH

Discrete Fracture Matrix (DFM) model:

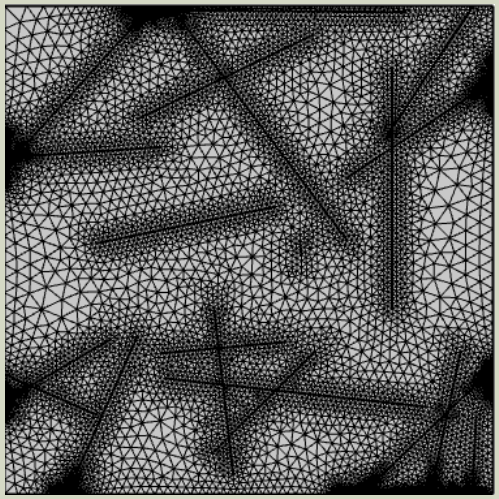
1D fractures in 2D porous matrix

$$\nabla K \nabla h = 0 \quad \text{with} \quad \begin{cases} K = K_m & \text{in matrix} \\ K = K_f & \text{in fracture} \end{cases}$$

$$K = \frac{k\rho g}{\mu} \quad \text{and} \quad h = \frac{p}{\rho g}$$

Dirichlet boundary condition

on opposite boundaries with head gradient Δh



h	hydraulic head
K	hydraulic conductivity
k	permeability
ρ	fluid density
μ	dynamic viscosity
p	pressure
g	acceleration due to gravity

GENERATION USING COMSOL METHODS

In order to examine the influence of the fracture network parameters values of the reference set-up (Table) were altered to obtain new constellations. For each of the constellations a set of 40 scenarios with random fractures was run. For each scenario the hydraulic conductivity was evaluated according to formula:

$$K_{eff} = \frac{\int u_x \, dy}{\Delta h}$$

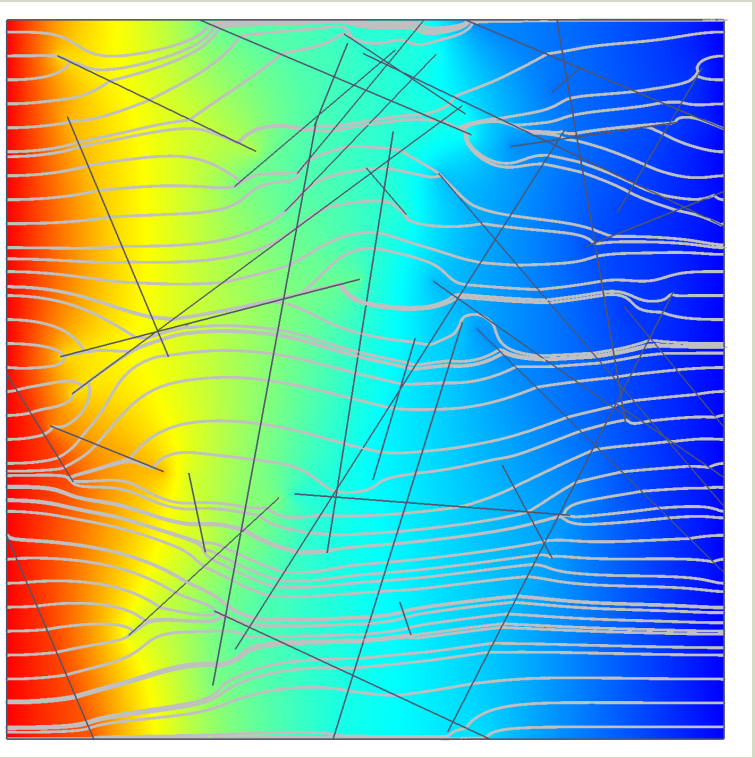
with in- or outflow velocity components u_x

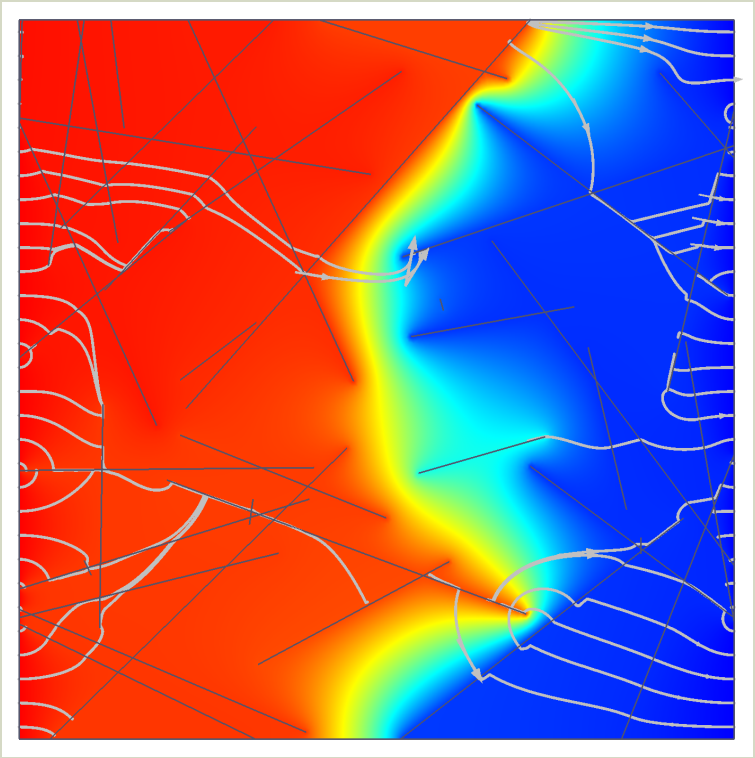
Parameter	Value [Unit]
Domain length	1 [m]
Domain width	1 [m]
Fracture conductivity	0.01 [m/s]
Matrix conductivity	10^{-6} [m/s]
Head gradient	1 [-]
Fracture aperture	5 [mm]
Minimum fracture length	1 [mm]
Maximum fracture length	0.3 [m]
Number of fractures	40

Uniform and power law distributions, using COMSOL methods (see left)

```
model.methodCall("methodcall5").run();
while (ind < NUMBER_OF_FRACTURES) {
  hx = Math.random()*MODEL_LENGTH;
  hy = Math.random()*MODEL_LENGTH;
  ha = Math.random()*Math.PI;
  hl = Math.pow(lmax, alfa)-(Math.pow(lmax, alfa)-Math.pow(lmin, alfa))*Math.random();
  hl = Math.pow(hl, 1/alfa);
  model.component("comp1").geom("geom1").create("ls1"+ind, "LineSegment");
  with(model.component("comp1").geom("geom1").feature("ls1"+ind));
    set("specify1", "coord");
    set("coord1", new double[]{hx+0.5*hl*Math.cos(ha), hy+0.5*hl*Math.sin(ha)});
    set("specify2", "coord");
    set("coord2", new double[]{hx-0.5*hl*Math.cos(ha), hy-0.5*hl*Math.sin(ha)});
  endwith();
  model.component("comp1").geom("geom1").feature("ls1"+ind).set("contributeto", "mf1");
  ind++;
}
```

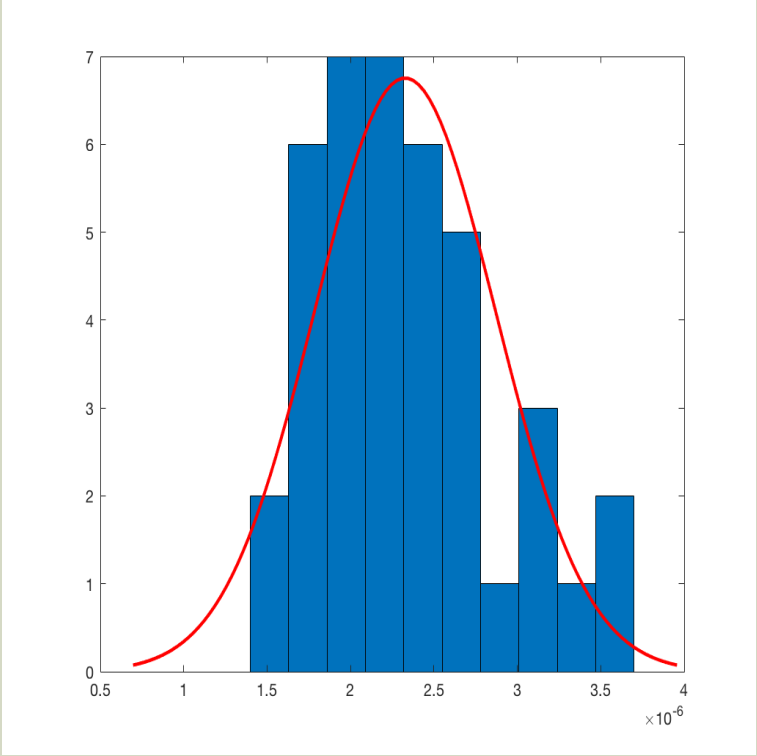
RESULTS EXAMPLES

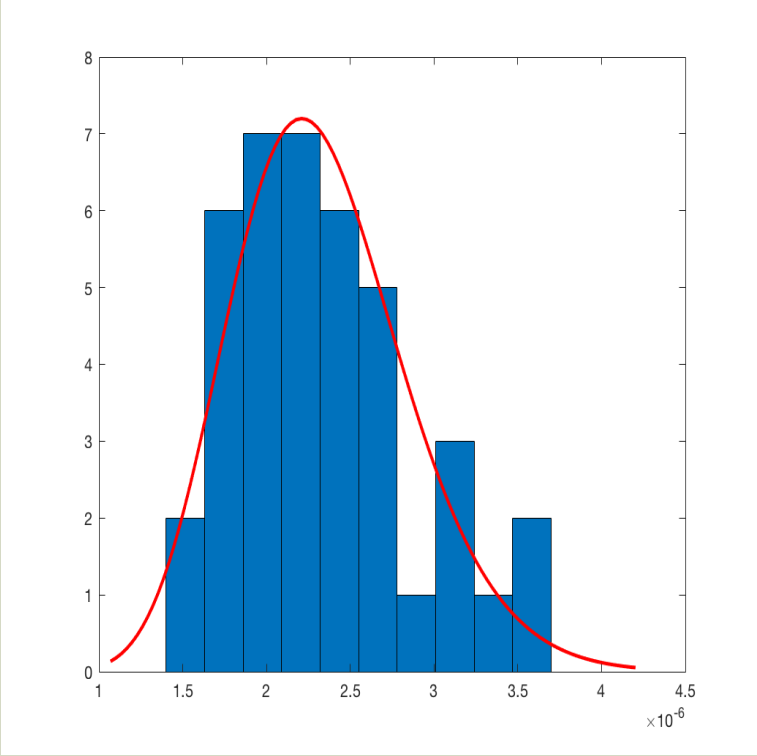




Head gradient from left to right, visualized by colormap
fractures = black, streamlines = grey

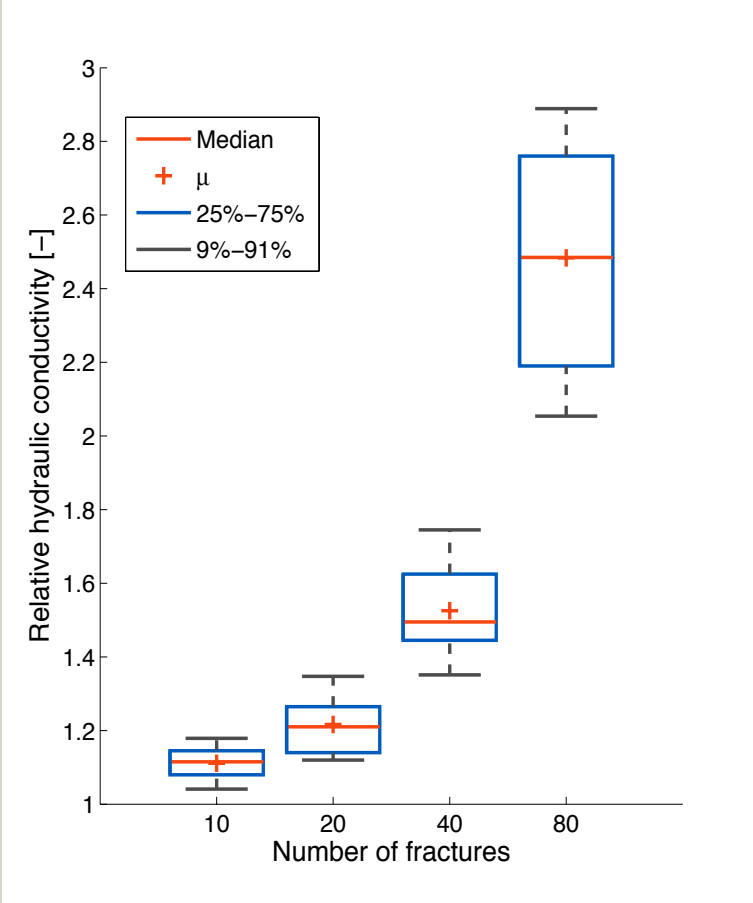
STATISTICS 1: CONDUCTIVITY DISTRIBUTIONS

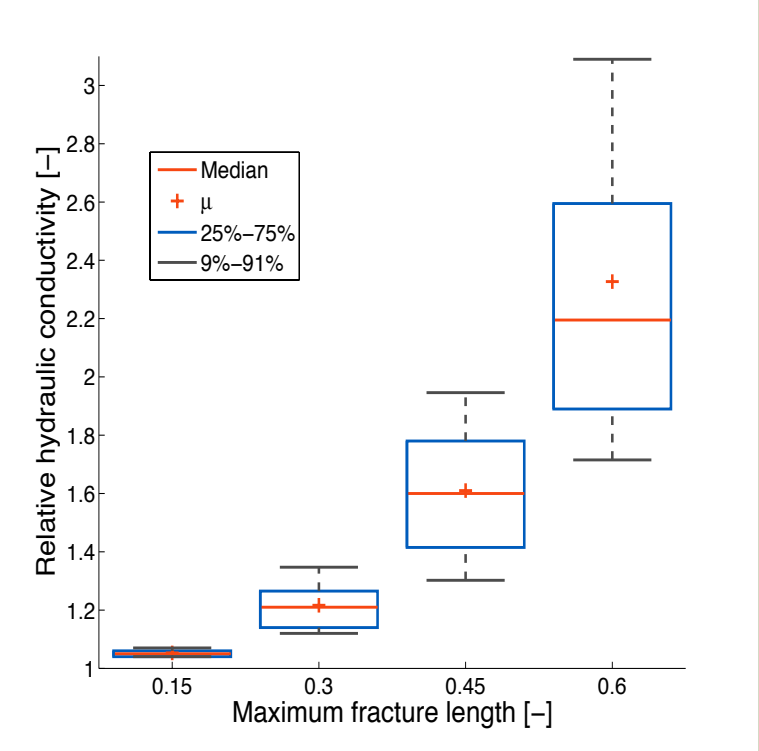




Example of the hydraulic conductivity distribution from 40 scenario runs with fitted statistics; left: fitted normal distribution, right: to gamma distribution

STATISTICS 2: BOXPLOTS





Boxplots showing mean, median and percentiles of relative hydraulic conductivity in dependency of number of fractures and maximum fracture length

CONCLUSIONS

- There is a relative increase of the effective hydraulic conductivity with each additional fracture by 0.02 (with regression coefficient R^2=0.9756)
- There is a quadratic relationship of effective hydraulic conductivity and maximum fracture length (R^2=0.9917)

$$K_{eff} / K_m = 1.53 - 4.05x + 9.33x^2$$

- The effective conductivity increases with the ratio of hydraulic conductivities K_f / K_m
- The results of the simulations and the statistics provide clues how the hydraulic conductivity of a sample is affected by properties of the fracture system. The presented approach may enable the prediction of conductivity from basic fracture characteristics.

THANK YOU

For details see the conference paper

or:

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