Prozessverständnis, Modelle und Simulationswerkzeuge

Reservoir modelling and simulation

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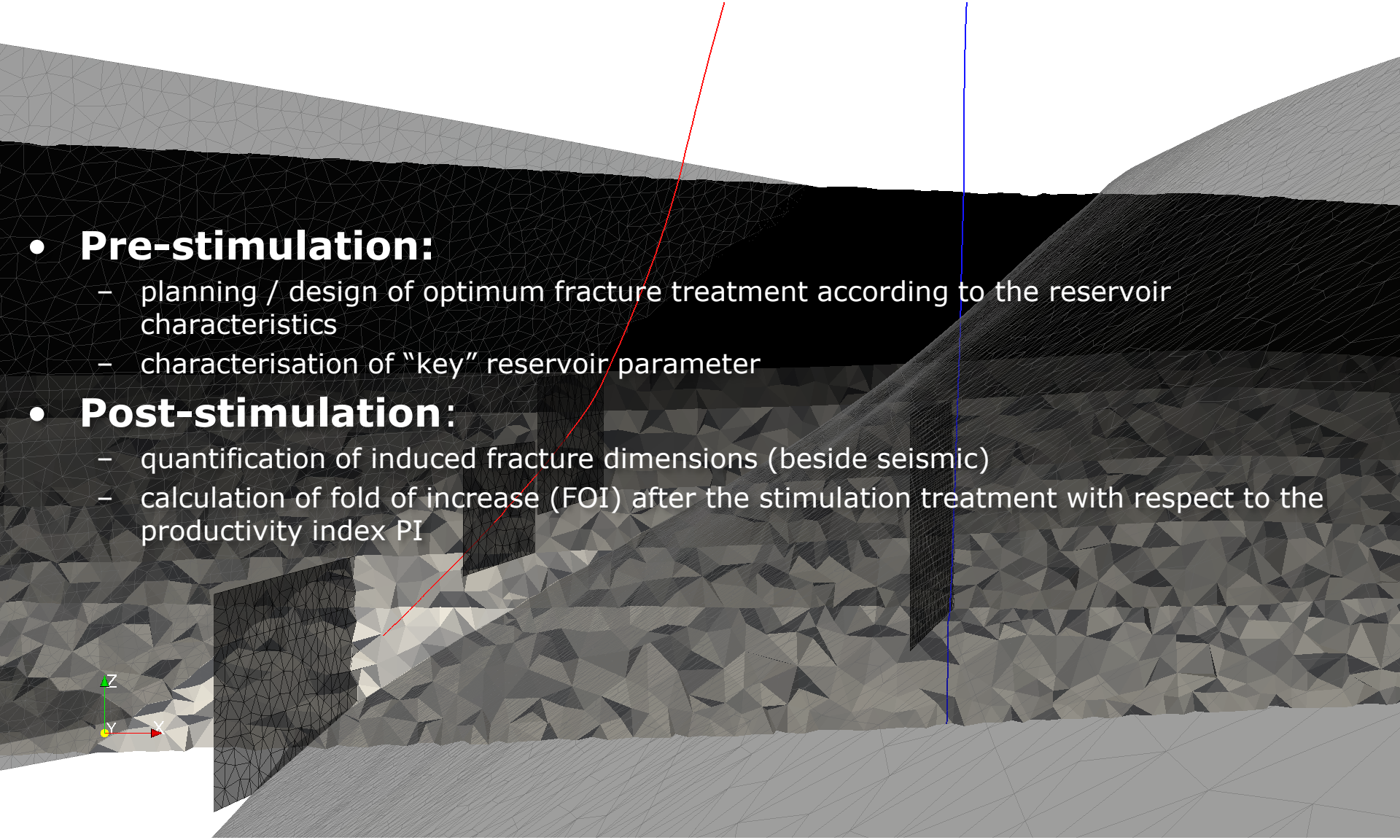
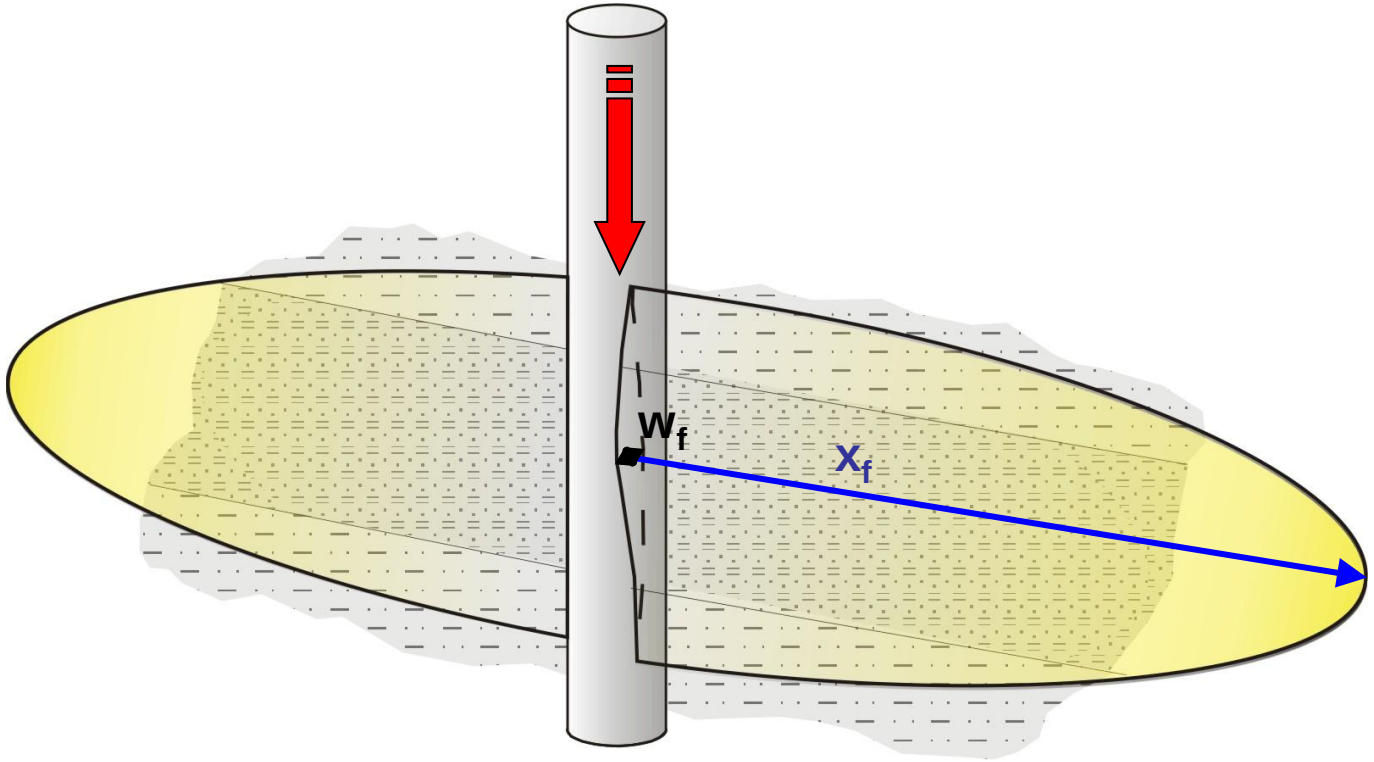


- **Pre-stimulation:**
  - planning / design of optimum fracture treatment according to the reservoir characteristics
  - characterisation of "key" reservoir parameter
- **Post-stimulation:**
  - quantification of induced fracture dimensions (beside seismic)
  - calculation of fold of increase (FOI) after the stimulation treatment with respect to the productivity index PI

Motivation for stimulation simulation

water / low viscous gels:	**η = 1 - 10 cP**
without proppants or small proppant concentration: c	**= 50 - 200 g/l**
long fractures:	**$x_f \leq 250$ m**
small width:	**$w_f \sim 1$ mm**

- **reduction in costs compared or HPF**
- **application is limited to reservoirs with small permeability**
- **success is dependent on the self propping potential of the reservoir rock**



Introduction - Hydraulic stimulation technique: waterfracs (WF)

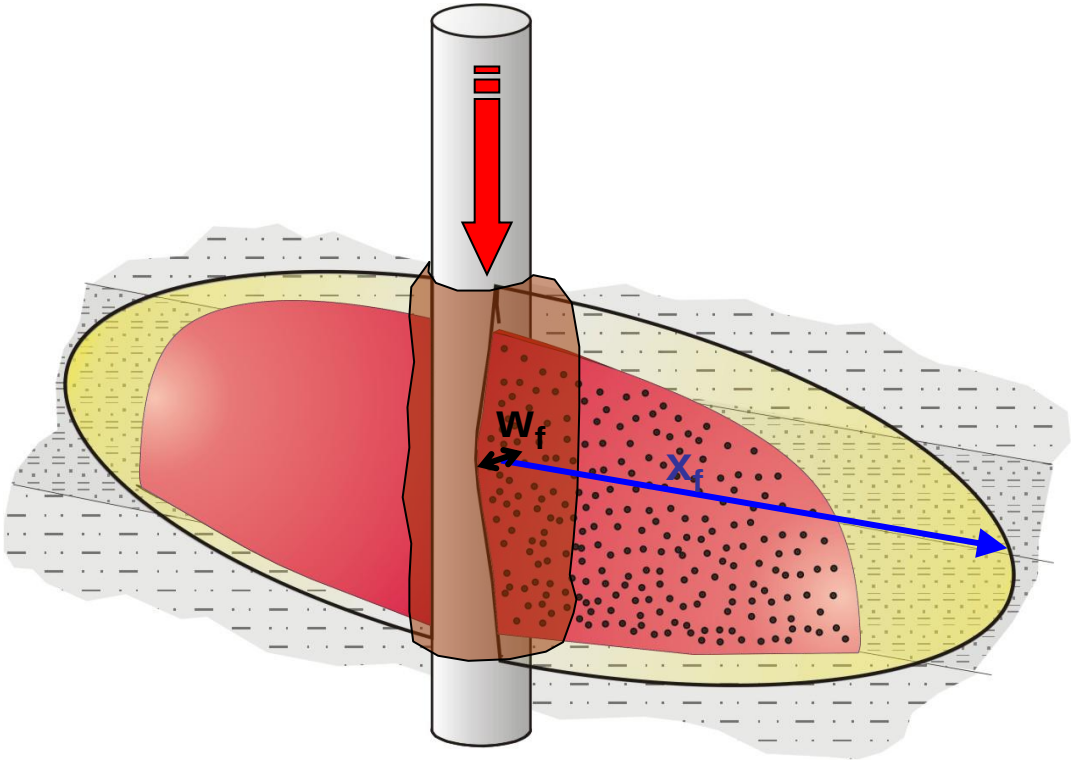
high viscous gels: η = 100 - 1000 cP

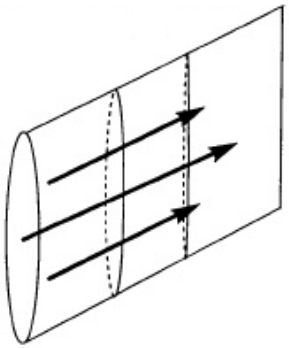
high proppant concentration: c = 200 - 2000 g/l

shorter fractures: x_f = 50 - 150 m

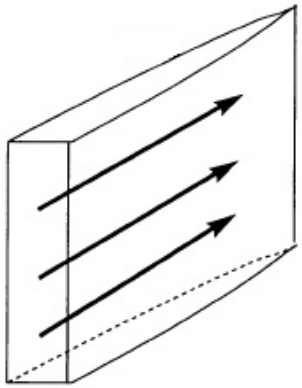
big width: w_f = 5 - 25 mm

- **wide range of formations (permeabilities) can be treated**
- **good control of stimulation parameters**
- **wellbore skin can be bypassed**
- **treatments are more expensive**

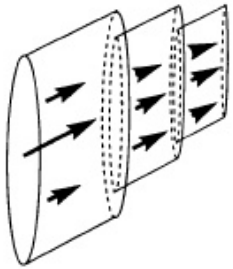




PKN (2D)

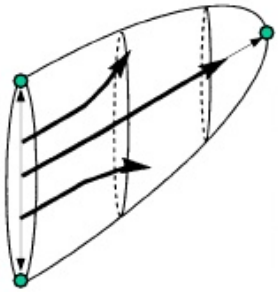


KGD (2D)

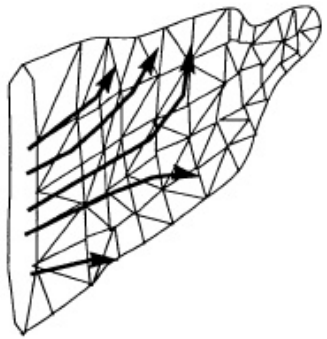


Pseudo 3D
zellenbasiert

FRACPRO



Pseudo 3D
parametrisiert

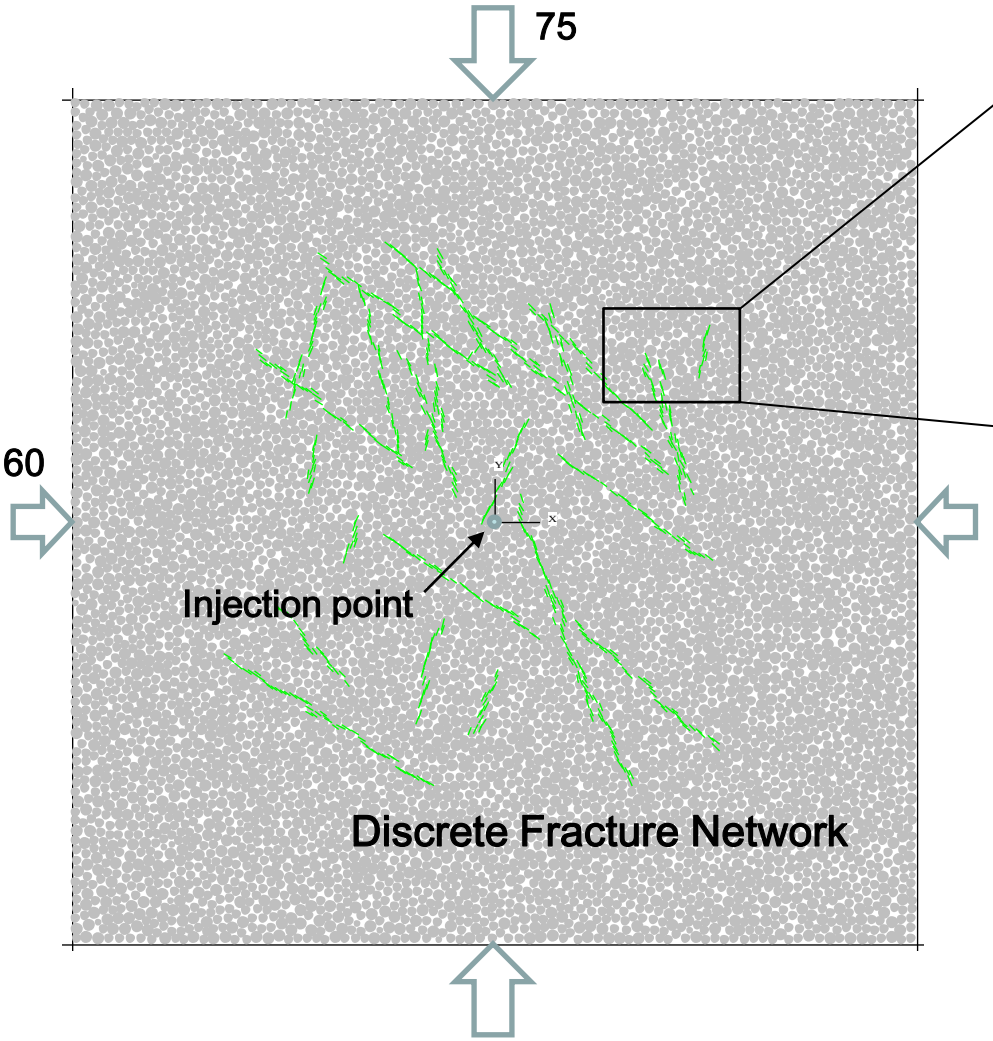


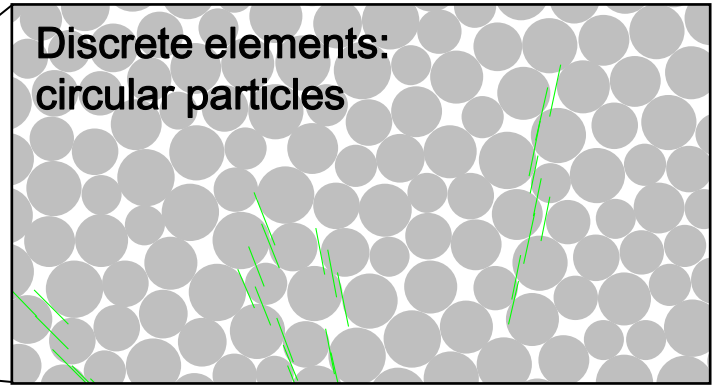
3D FE-Netz

1. two dimensional with constant radius (penny-shaped models)
2. with constant fracture height (PKN, Perkins and Kern, 1961, Nodgren, 1972)
3. cell-based pseudo 3D models
4. lumped parameter 3D models 5.
5. real planar 3D models have been developed (Mack and Warpinski, 2000).

Overview - fracture models

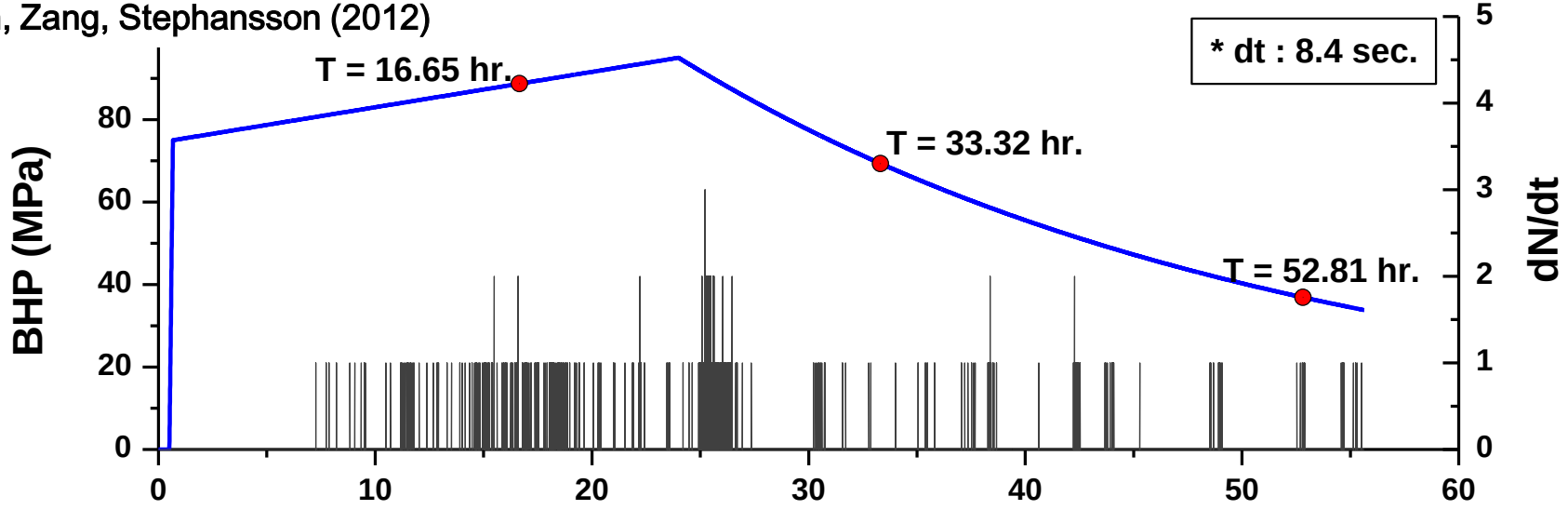
Yoon, Zang, Stephansson (2012)

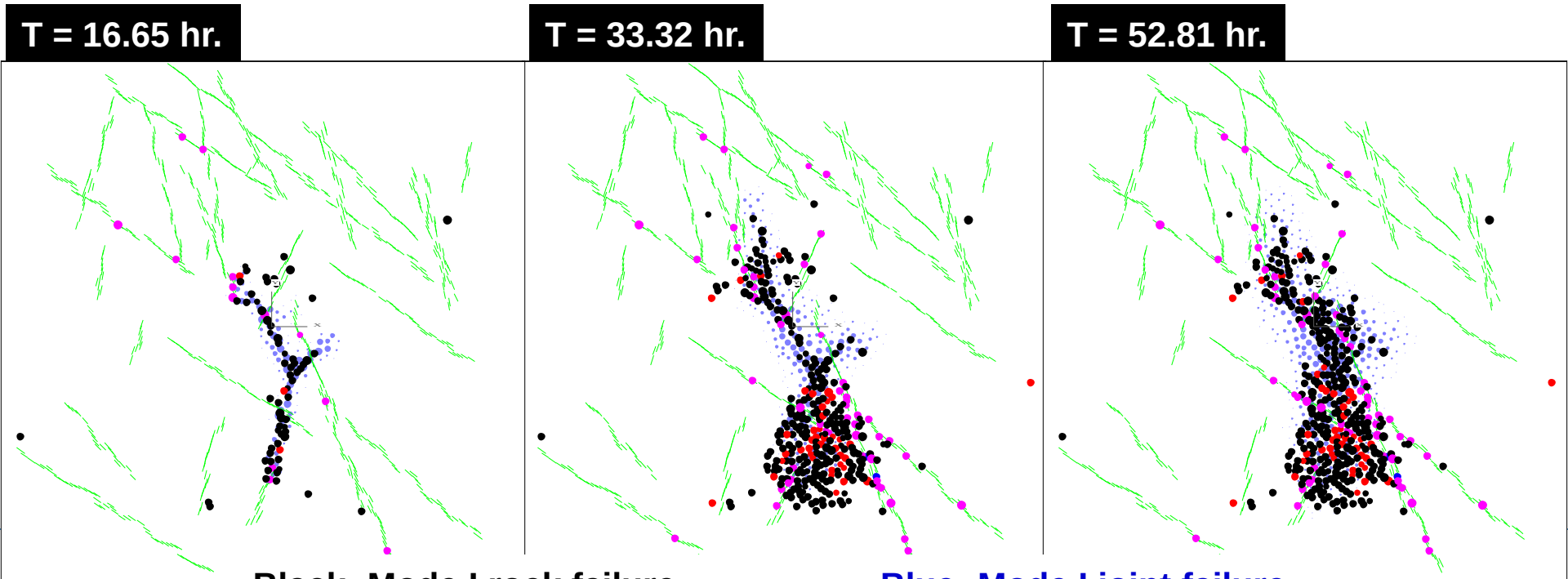




- 2 km x 2 km
- Crystalline fractured reservoir
- Anisotropic in-situ stress
- S_H = 75 MPa, S_h = 60 MPa
- Fluid injection at centre
- 1 cP viscosity
- 1D injection, 1.5D shut-in
- BHP controlled injection

Yoon, Zang, Stephansson (2012)





Black: Mode I rock failure

Red: Mode II rock failure

Blue: Mode I joint failure

Pink: Mode II joint failure

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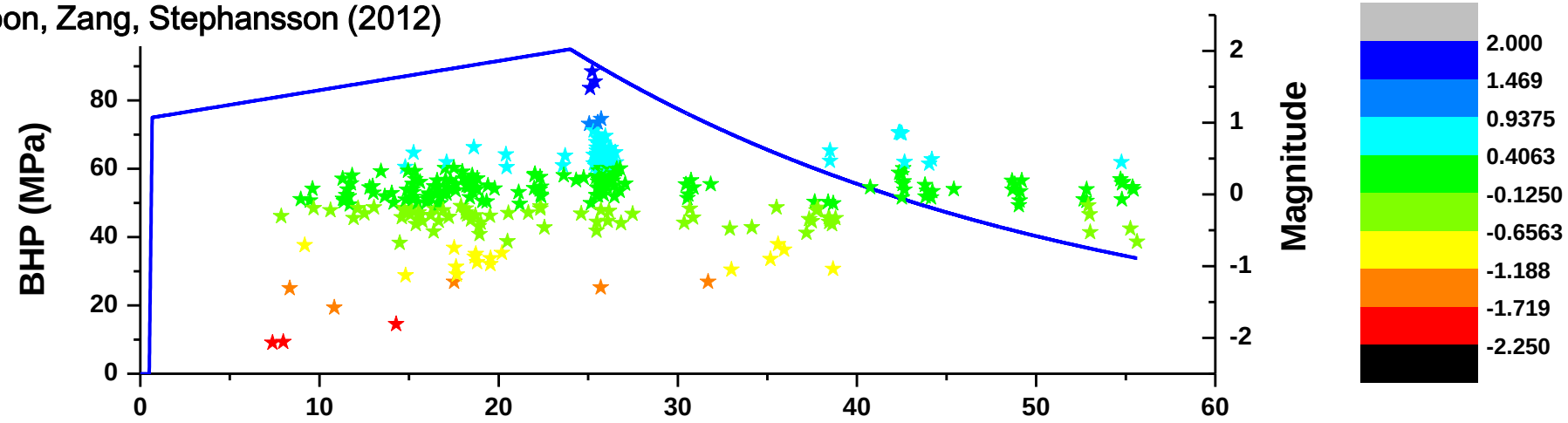
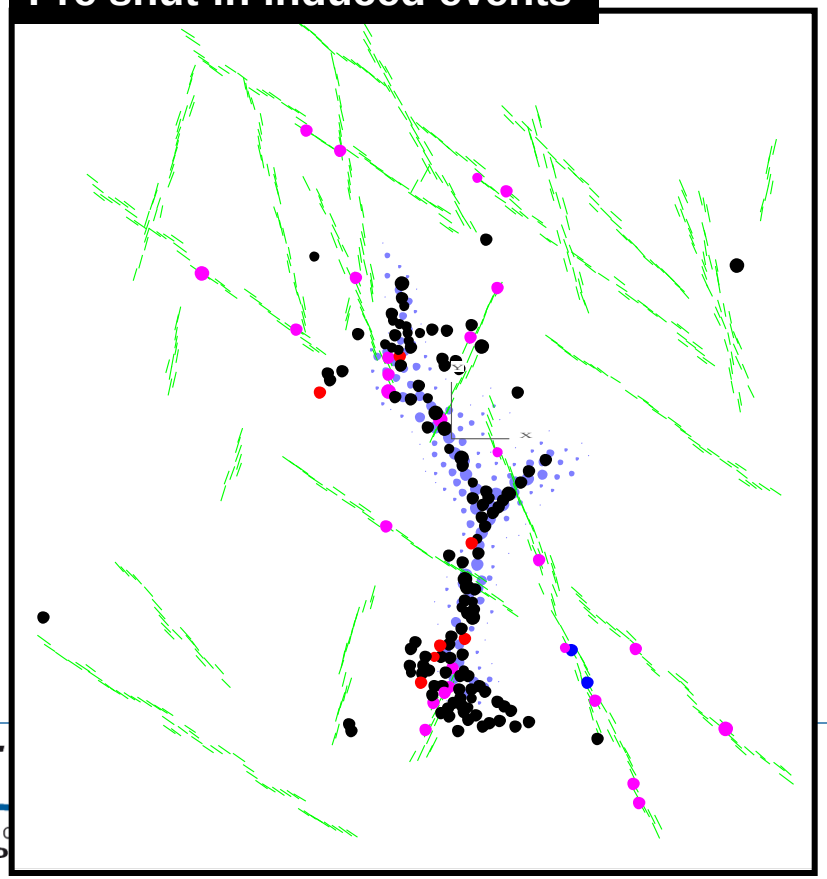
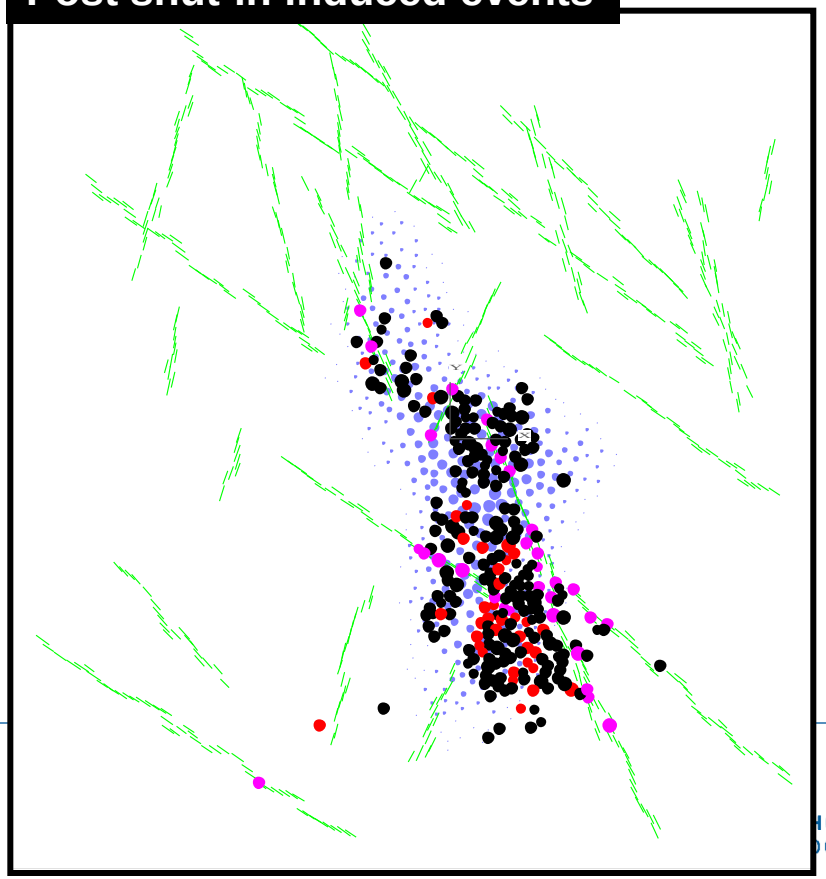
Yoon, Zang, Stephansson (2012)



Pre shut-in induced events



Post shut-in induced events



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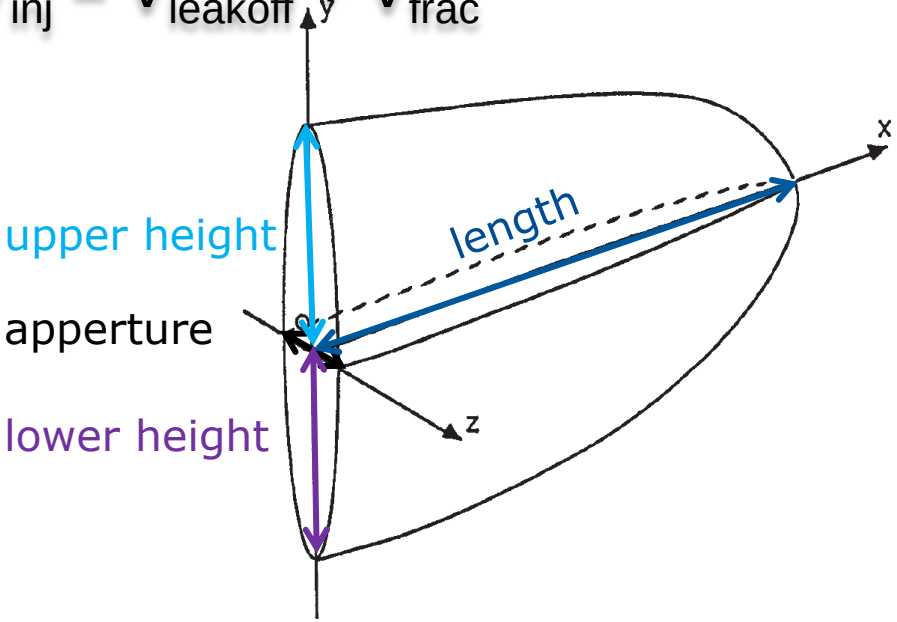
$V_{inj} = V_{leakoff} + V_{frac}$



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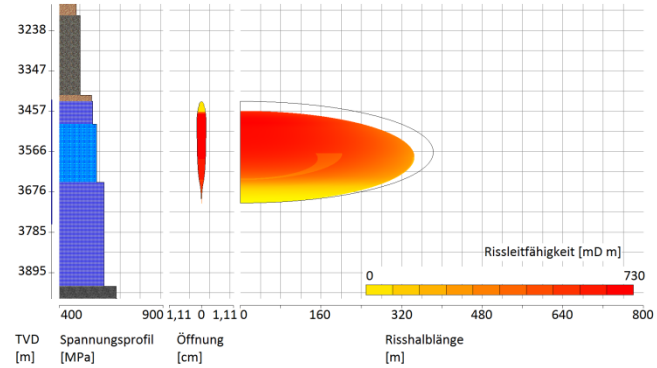
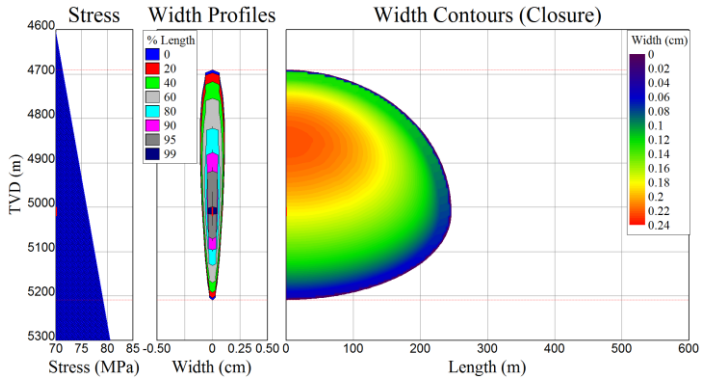
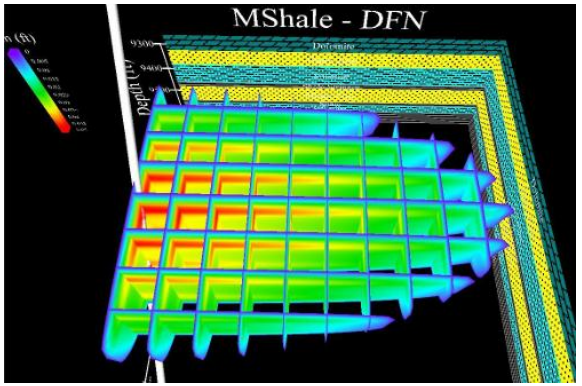


MFRAC



MSHALE

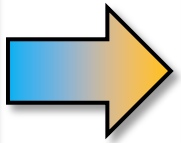


Overview - fracture models

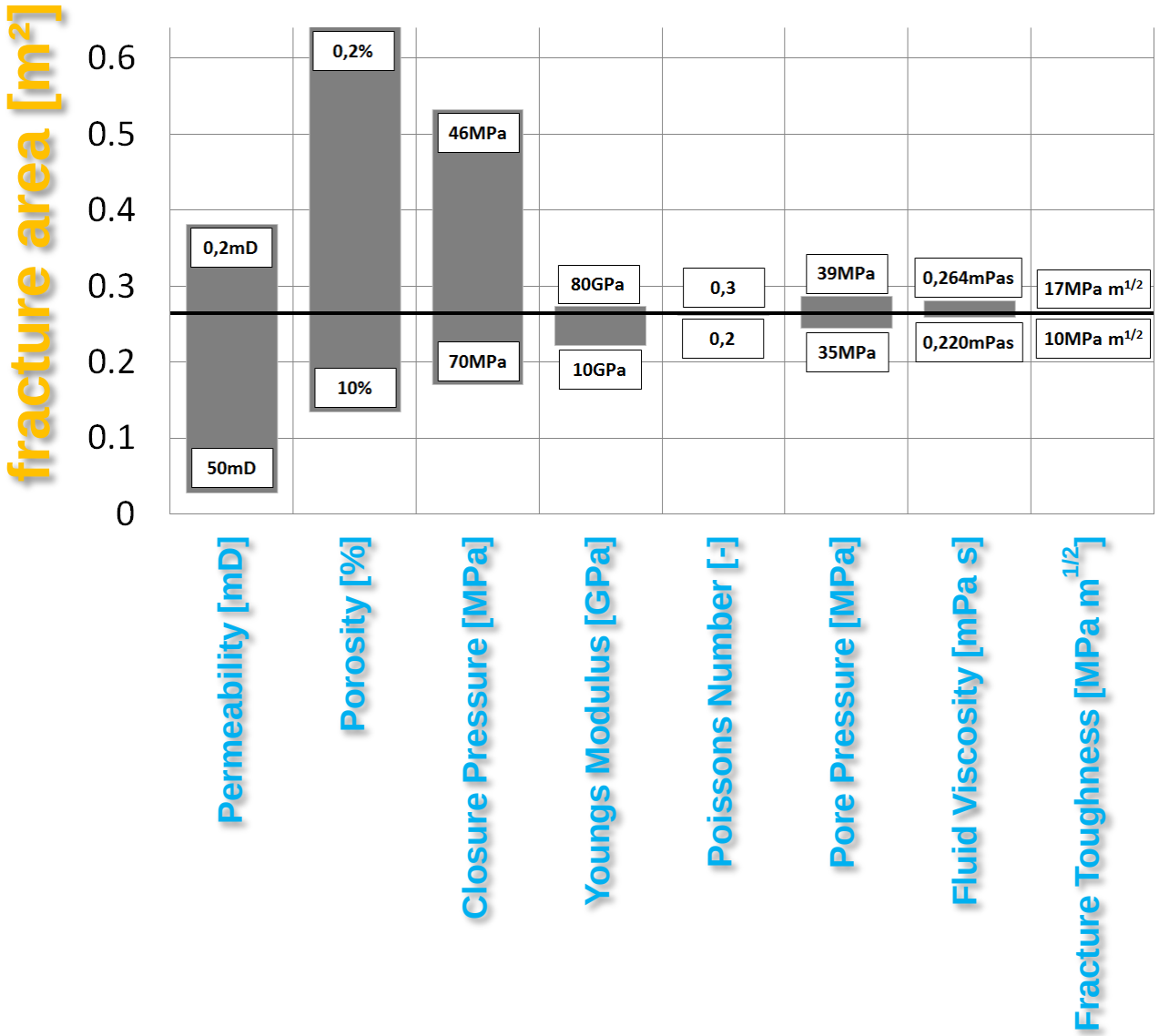
INPUT

OUTPUT

Permeability [mD]
Porosity [%]
Closure Pressure [MPa]
Closure Pressure Gradient [MPa/m]
Youngs Modulus [GPa]
Poissons Number [-]
Pore Pressure [MPa]
Fluid Viscosity [mPa s]
Fracture Toughness [MPa $m^{1/2}$]



Frac length [m]
Frac height [m]
Frac area [m^2]
Aperture [m]
Well head pressure [MPa]



Sensitivity analyses – fracture area

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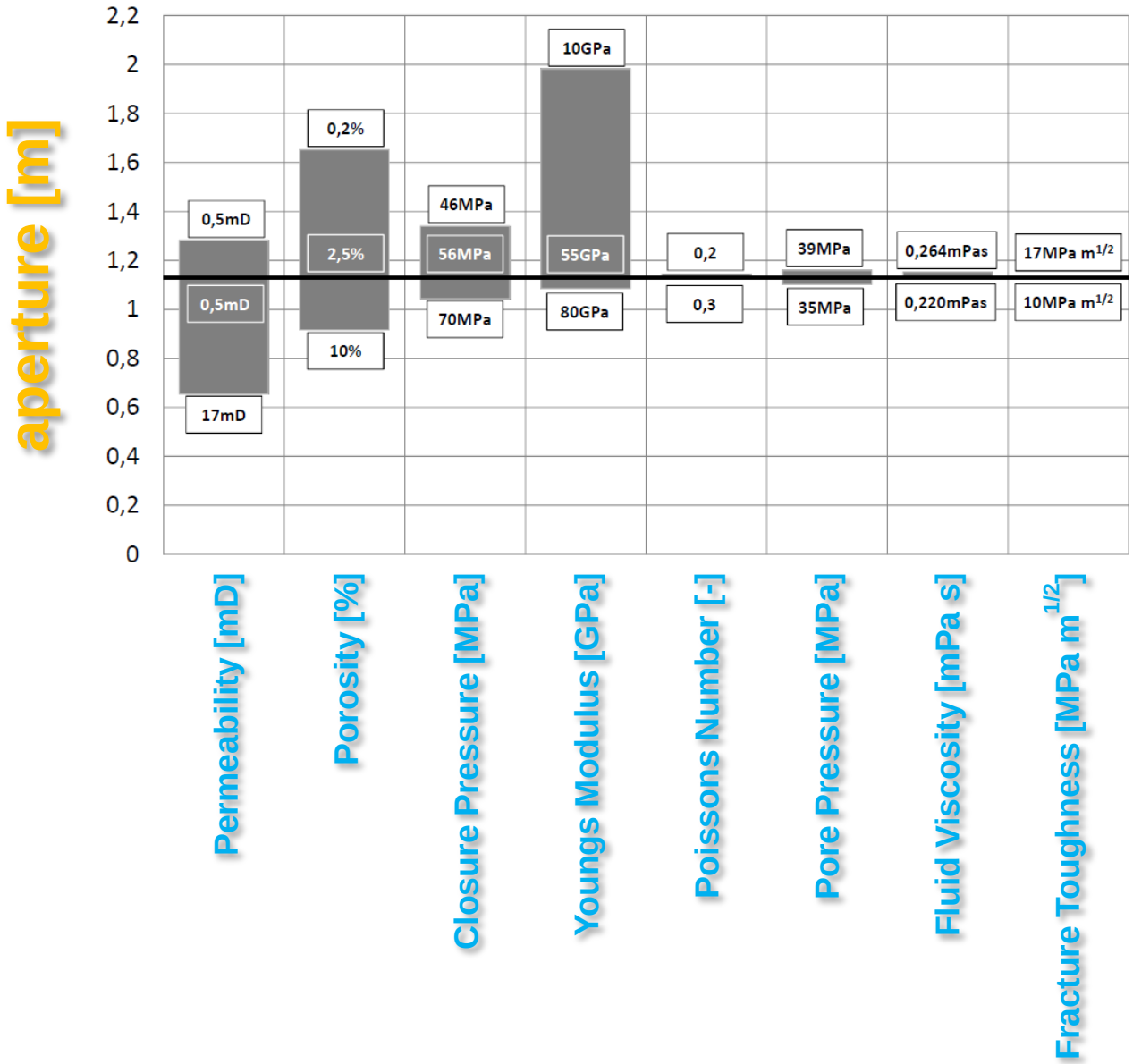
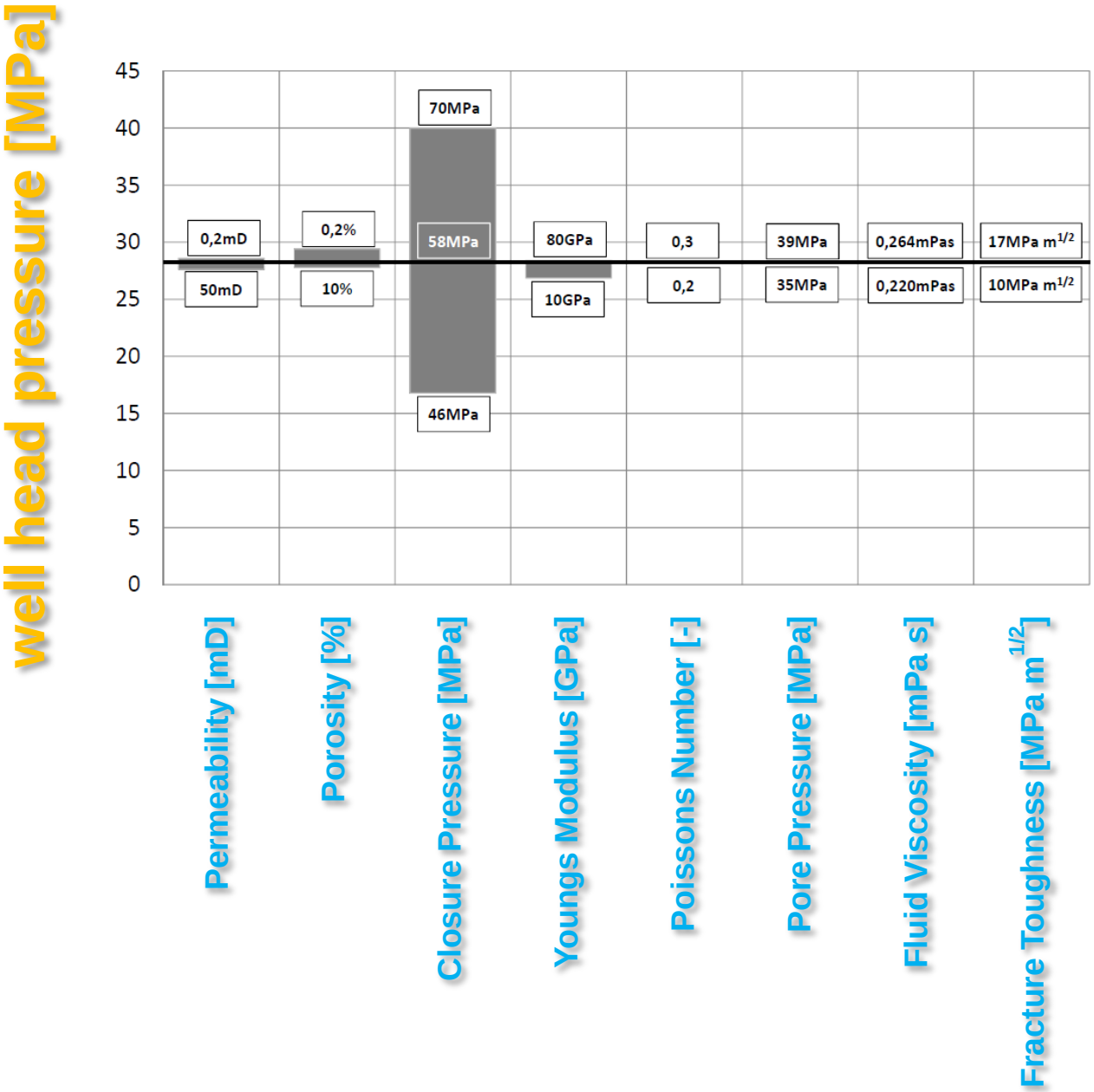
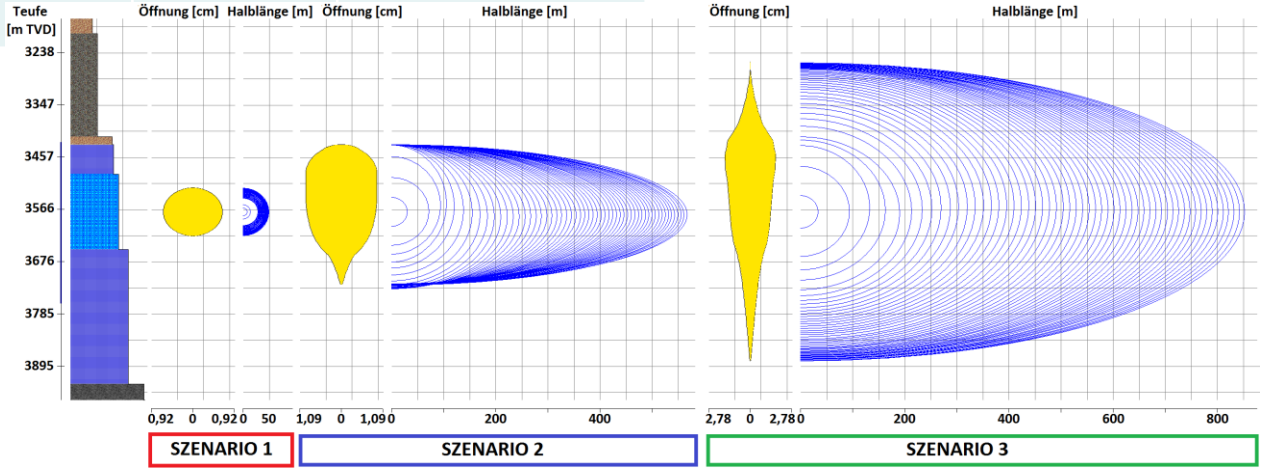


Sensitivity analyses – fracture aperture

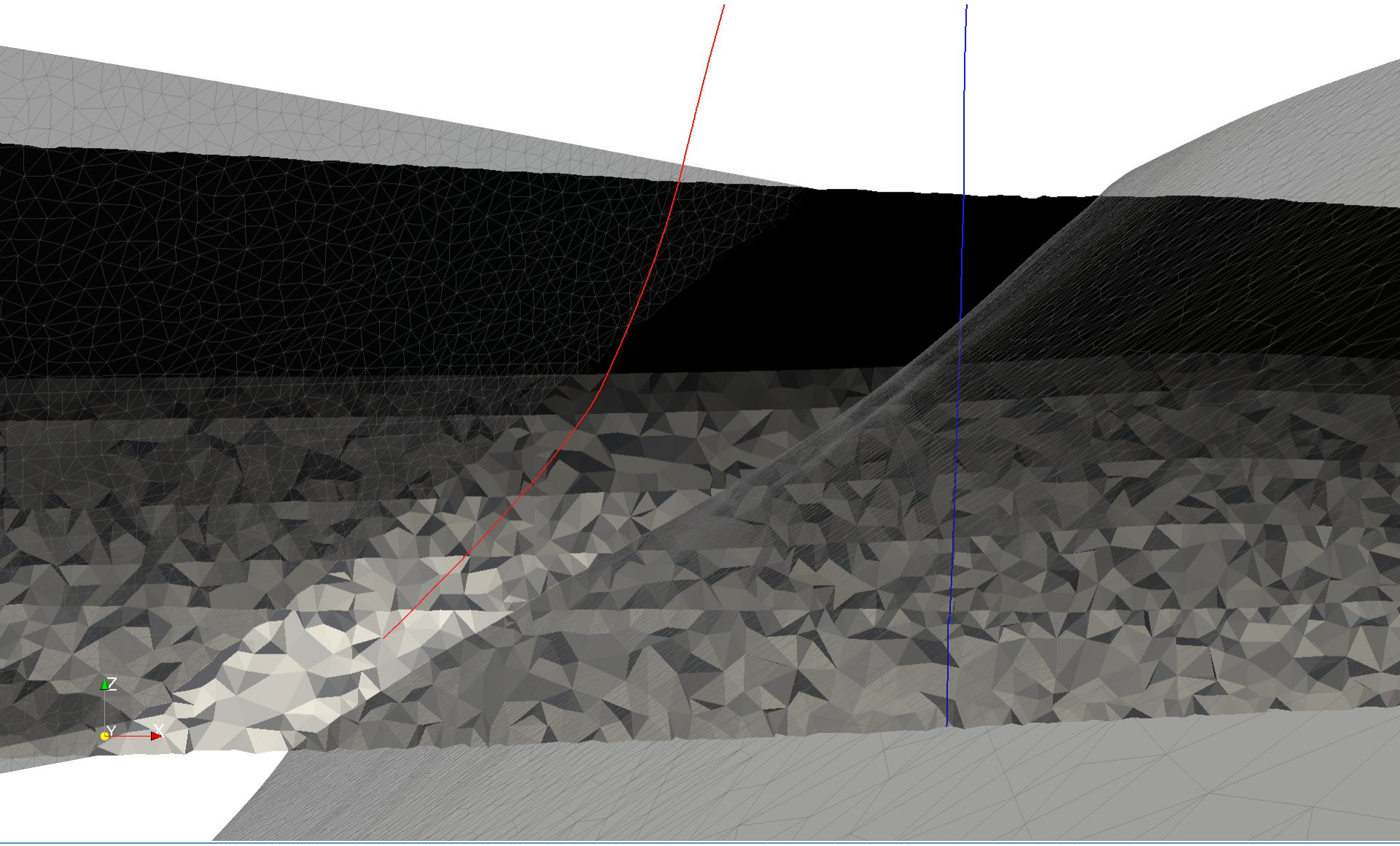


Sensitivity analyses – well head pressure

Parameter	Length	Height	Width	Wellhead pressure
Leak-off parameters				
Permeability	---	---	---	-
Porosity	++	+	+	o
Pore pressure	++	+	+	o
Fluid viscosity	+	+	o	o
Mechanical parameters				
Young's modulus	--	++	---	+++
Stress	---	---	--	+++
Poisson's number	o	o	o	o
Fracture toughness	o	o	o	o
Treatment parameter				
Flow rate	+++	+++	+++	+++
Injection volume	+++	+	+	o



Sensitivity analyses – results



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Increase of productivity - model implementation

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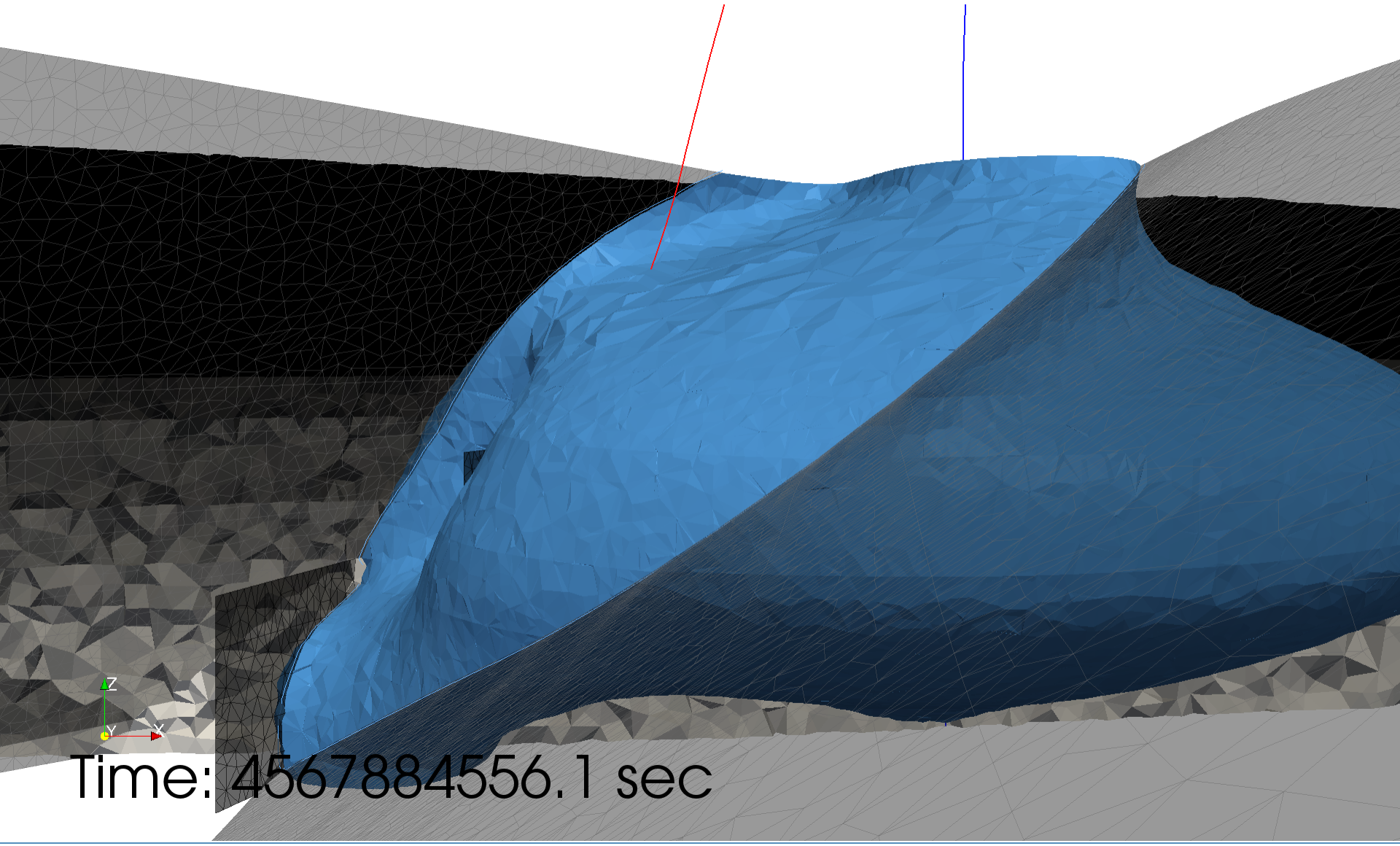

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Increase of productivity - model implementation

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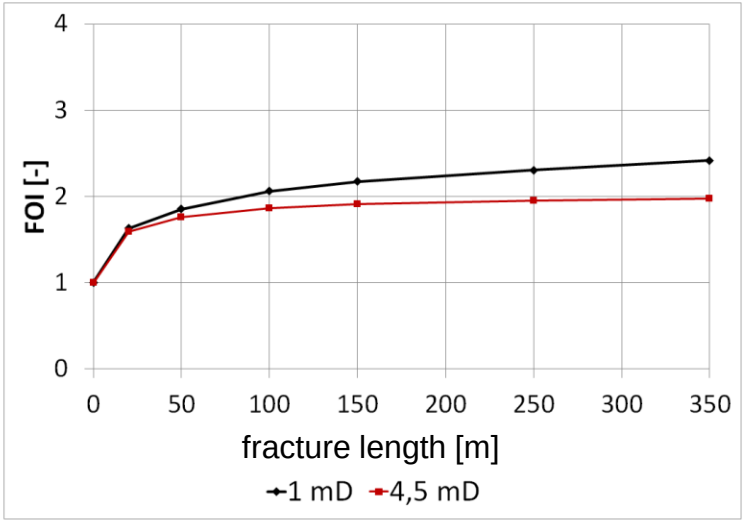
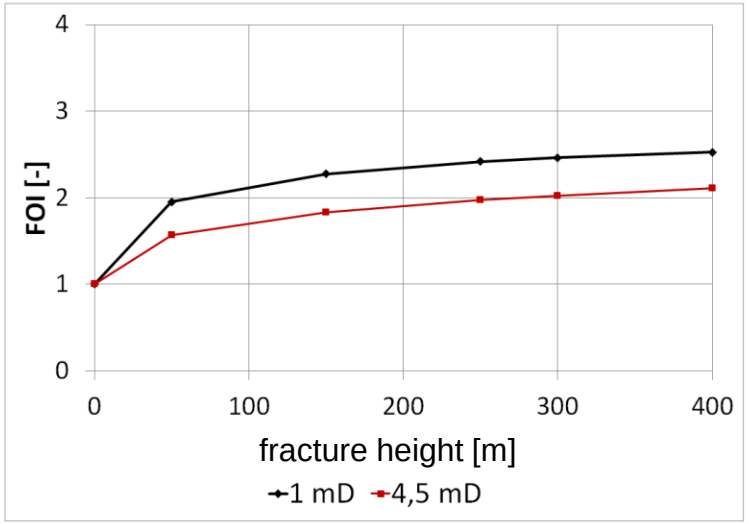
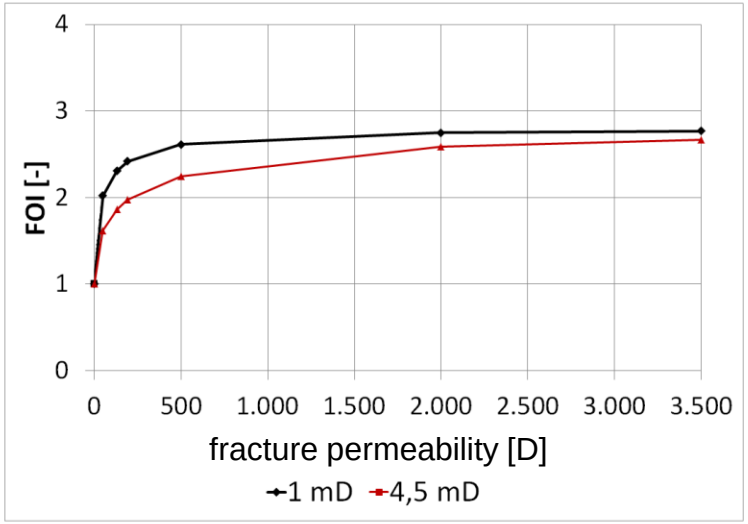
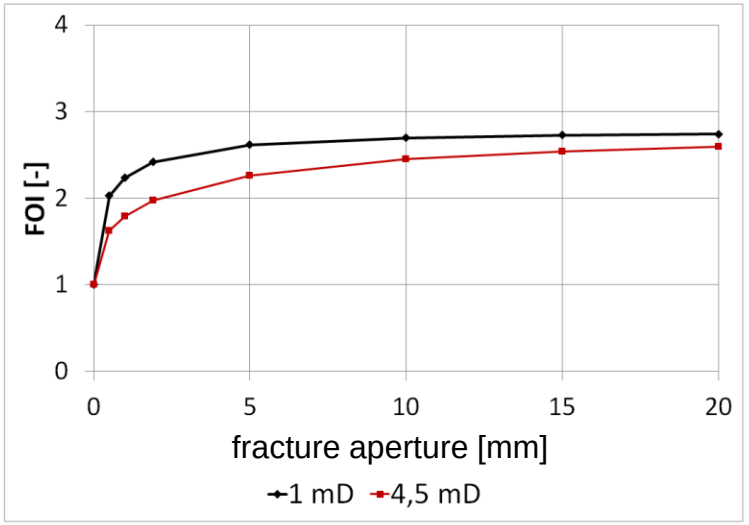
- $FOI = \frac{PI_{postfrac}}{PI_{prefrac}}$
- the higher matrix permeability the lower productivity increase
- 2-3 times productivity increase









Increase of productivity - results

- hydraulic fracturing simulations give a first idea about the expected wellhead pressures and the expected range of fracture geometries assuming the tensile opening
- potential productivity enhancement is provided by the reservoir simulations
- productivity enhancements between 2 and 3 were shown to be possible for most of the scenarios
- sensitivity analysis of the reservoir parameters showed the importance of a detailed knowledge about permeability, porosity, Young's modulus and stress state
- important zones with high fluid leak-off and closure pressure need to be identified
- increase in flow rate increases especially fracture width and height
- increase of injection volume mainly increases the fracture half-length