Geothermie Soultz

Hydro-mechanical behaviour of GPK4 during the hydraulic stimulation tests – Influence of the stress field

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Objectives of our modeling work

> **Understand which physical mechanisms are involved in the hydraulic stimulation of the well in crystalline rocks**

> **Extract the main parameters playing a role in the hydraulic stimulation**

➔ **Focus hereafter on the influence of the stress field on the HM behavior of GPK4 during the stimulation test**

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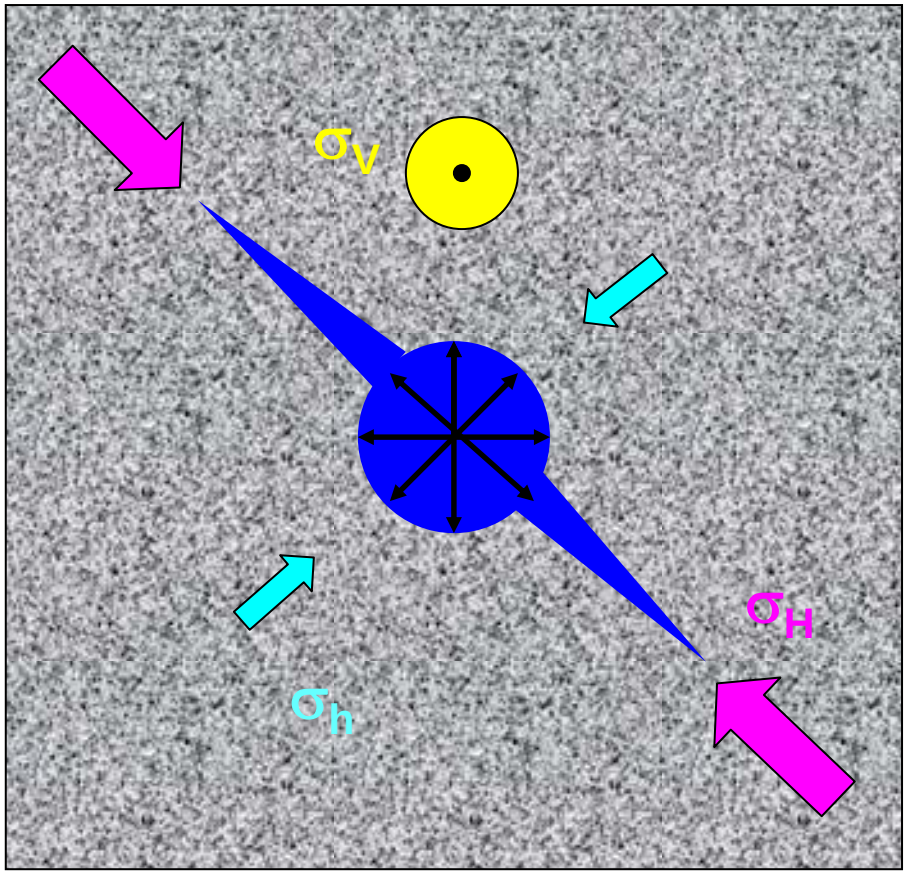
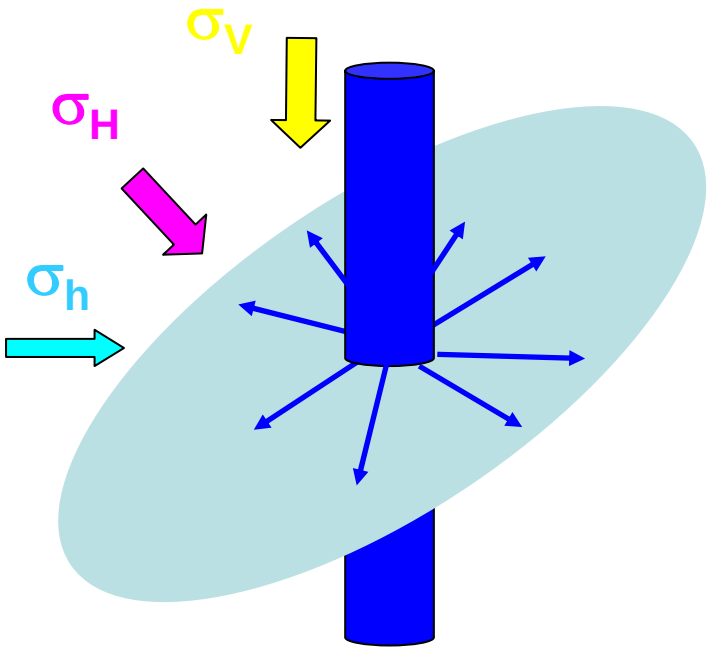
What it could happen during the hydraulic stimulation of a well (if we exclude thermal effect...)



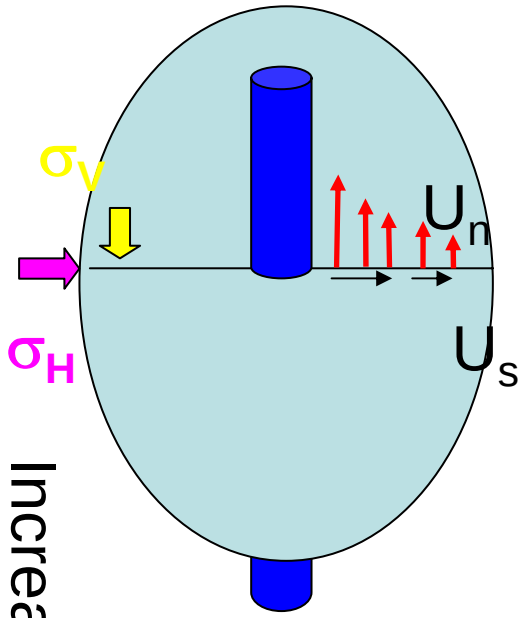
In continuous homogeneous and isotropic medium

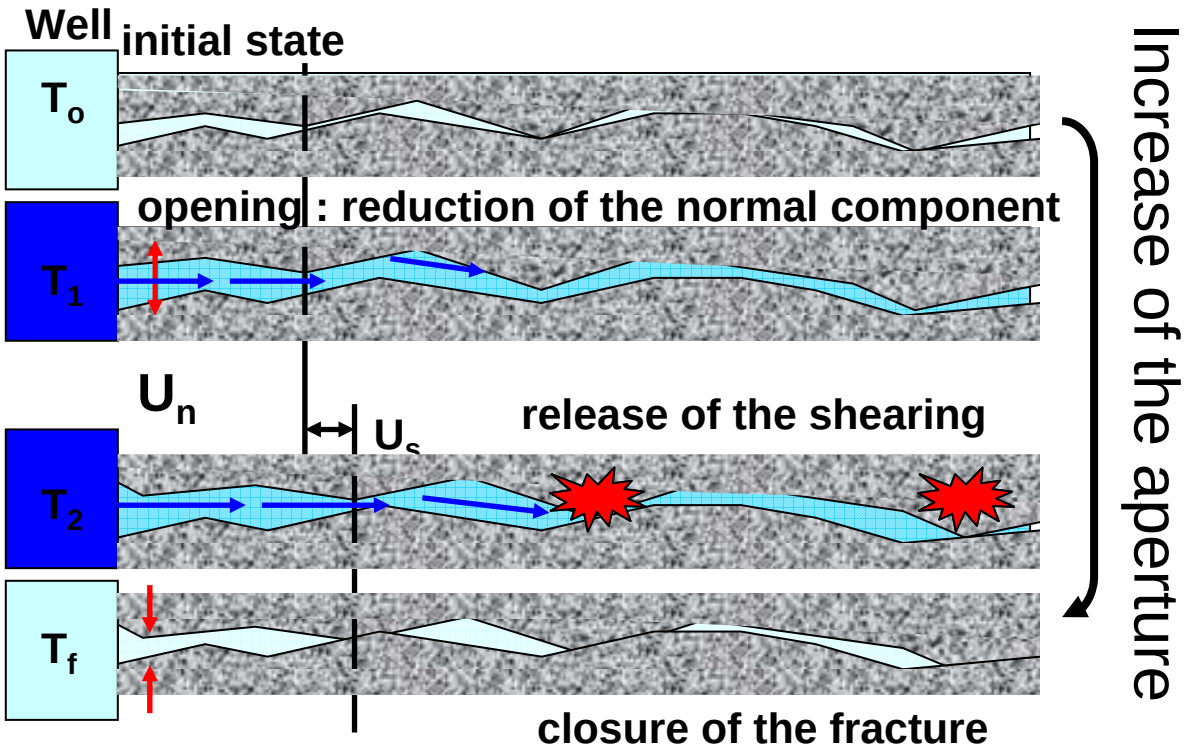


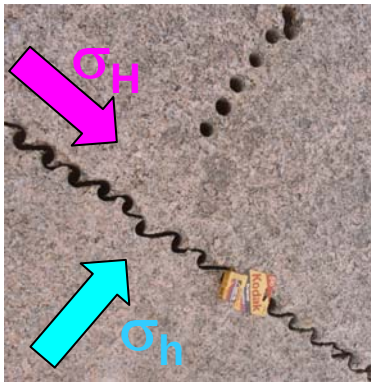
But in general, the granite is already fractured

More in details...

Evolution of the hydraulic aperture is linked to the normal displacement (Un) and the tangential displacement (Us)







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3DEC code

> Based on the Distinct Element Method
- **allows finite displacements and rotations of discrete bodies, including complete detachment,**
- **recognizes new contacts automatically,**
- **➔ perfect for modelling discontinuous media, such as fractured rock masses**

> Fractured rock mass considered as a blocks assembly, cut by joints/discontinuities
- **blocks are rigid or deformable,**
- **joints behaviour is governed by springs that takes into account the opening/closing of the fractures as well as their shearing.**

> Flow takes place only in the fractures (blocks are impermeable). Flow is laminar and obeys the cubic law

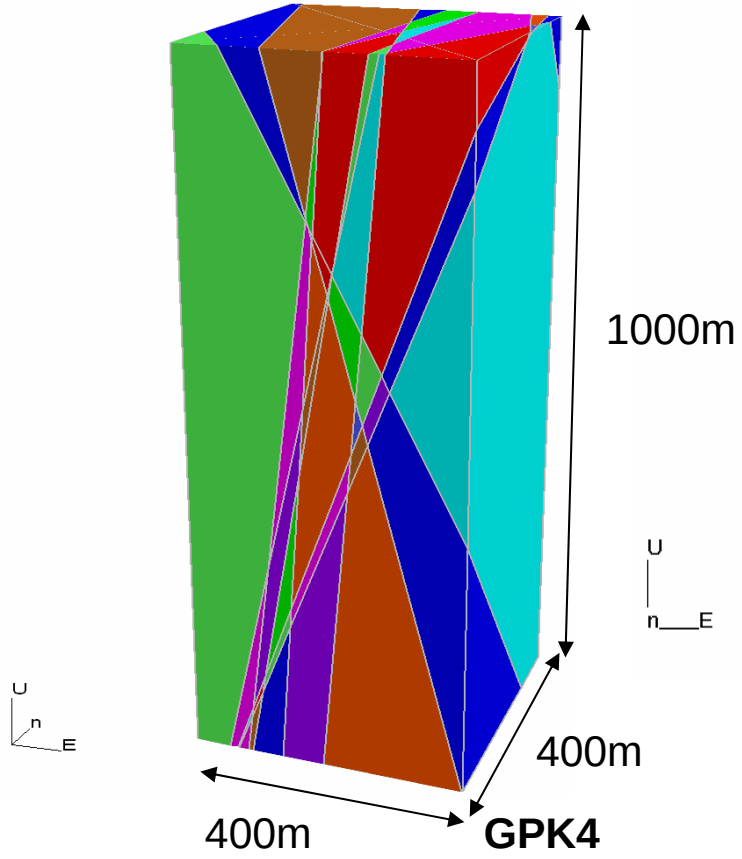
➔ Hydro-mechanical coupling

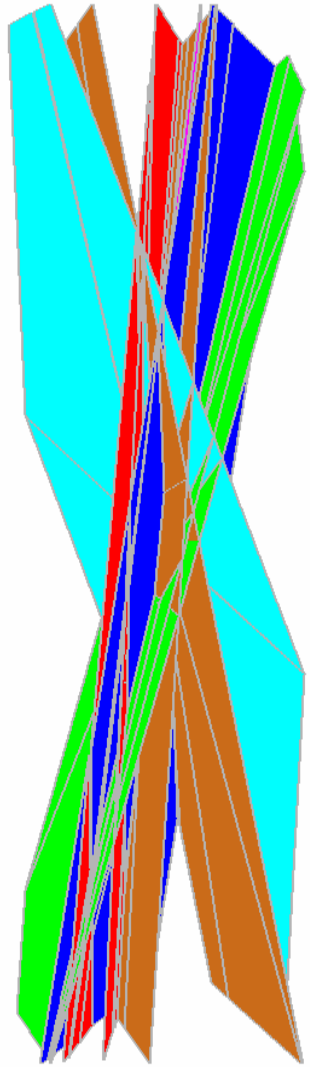
Fractured rock mass

> Take into account with 3DEC the selected fractures that cross the well
  - **9 fractures for GPK4**

> Generate them in a parallelepiped volume

> Take into account the well geometry (here, centred and vertical)

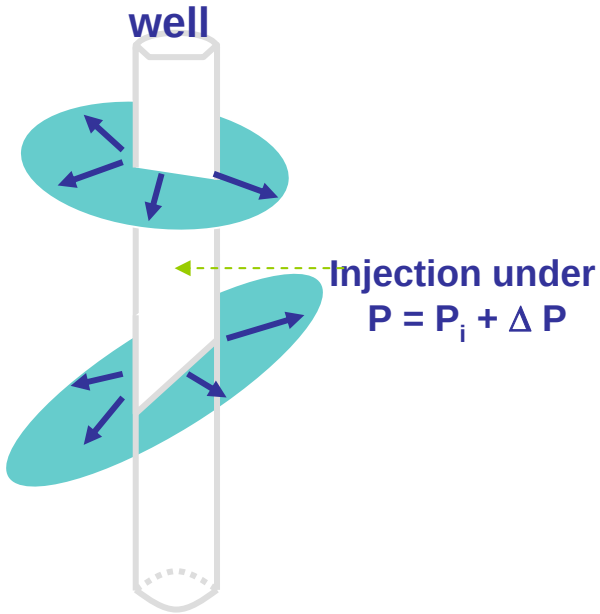




Hydraulic stimulation

> **Stimulation test**

- Apply an overpressure in the well. Value taken from the real stimulation test conducted in the GPK4 well.
- FISH HM coupling procedure
- Calculate the injected flowrate at the well, in each fracture
- Stop the run when equilibrium between in and out flowrates is reached



Boundary and Initial HM conditions

> **Boundary conditions**

> **Pressures**

- Hydrostatic field

> **Stress field**

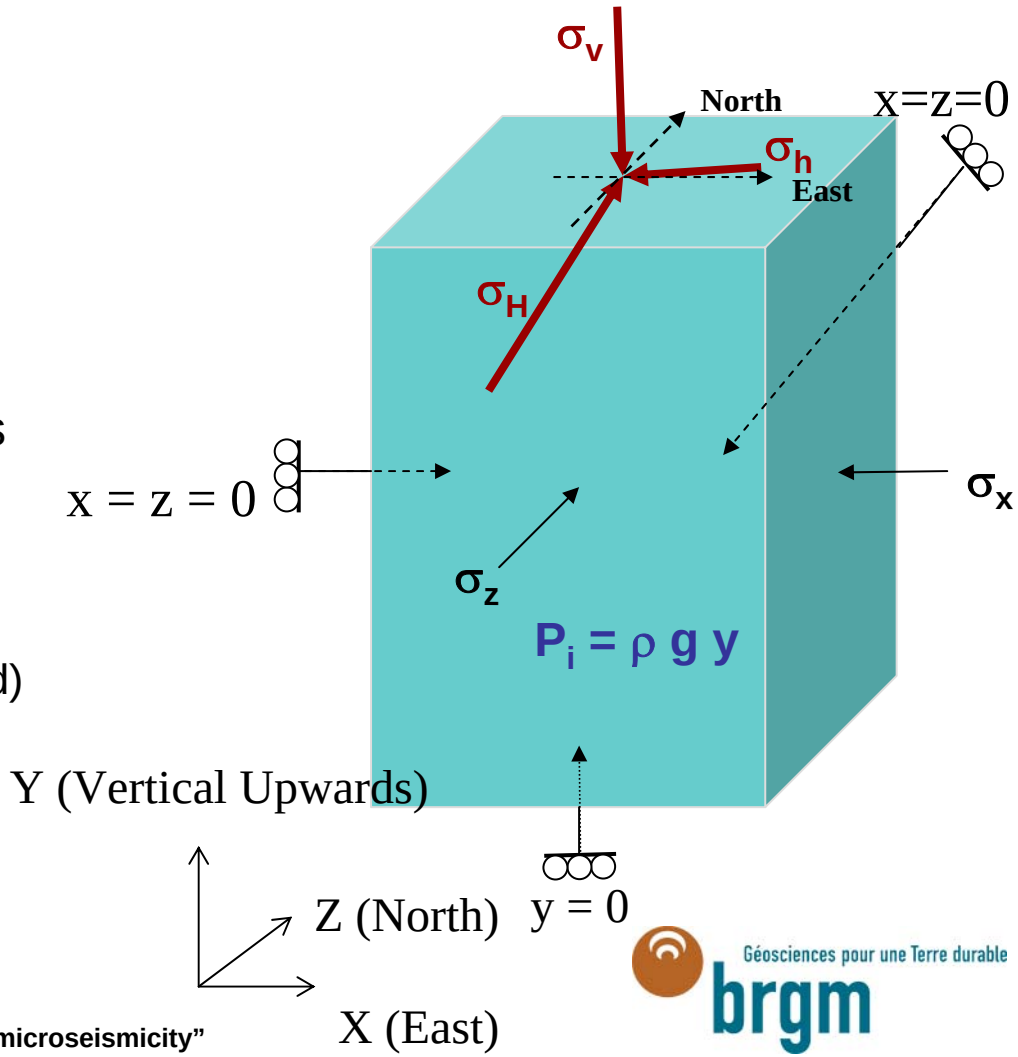
- From in situ measurements

  1) either

  Klee and Rummel, 1993,

  2) or

  Cornet et al. (to be published)



Stress field

> **Klee and Rummel, 1993**

σ_h = 15.8[MPa] + 0.0149[MPa/m] (depth[m]-1458)

σ_H = 23.7[MPa] + 0.0336[MPa/m] (depth[m]-1458)

σ_v = 33.8[MPa] + 0.0255[MPa/m] (depth[m]-1377)

σ_H oriented N170°E ± 15°

> **Cornet et al. (2006, to be published)**

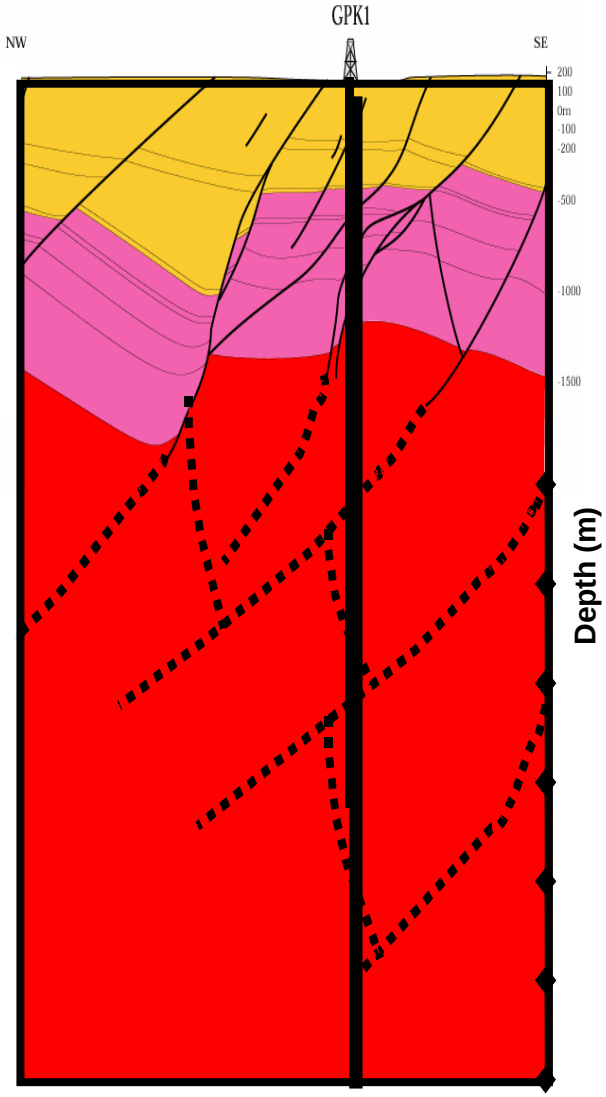
σ_h = (0.54 +/- 0.02)* sv

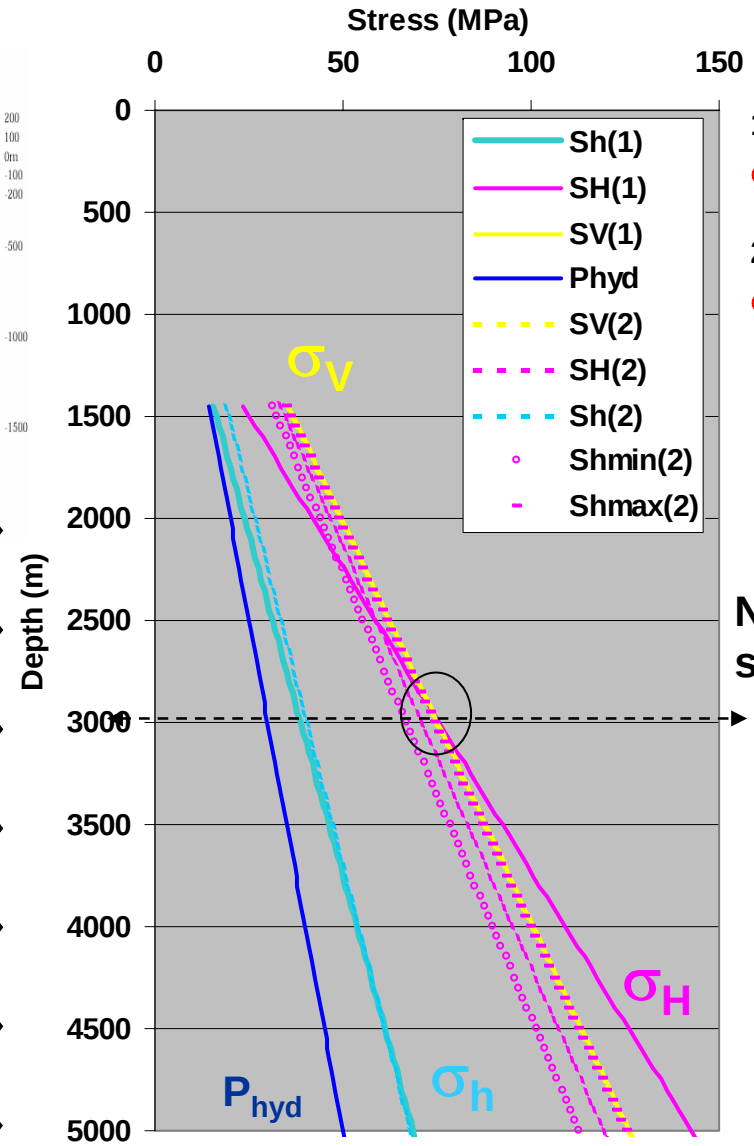
σ_H = (0.95 +/- 0.05)* sv

σ_v = 1377*0.024[MPa] + 0.0255[MPa/m] (depth[m]-1377)

σ_H oriented N175°E +/- 6°

Stress regime ?



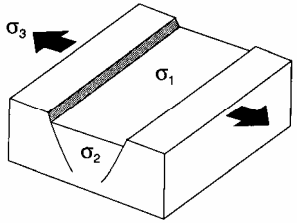


1. Klee and Rummel (1993)

σ_H : N170°

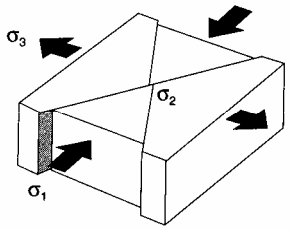
2. Cornet *et al.* (2006?)

σ_H : N 175°



Normal fault stress regime

?



Strike slip regime

ENGINE Meeting, "Stimulation of reservoir and induced microseismicity"

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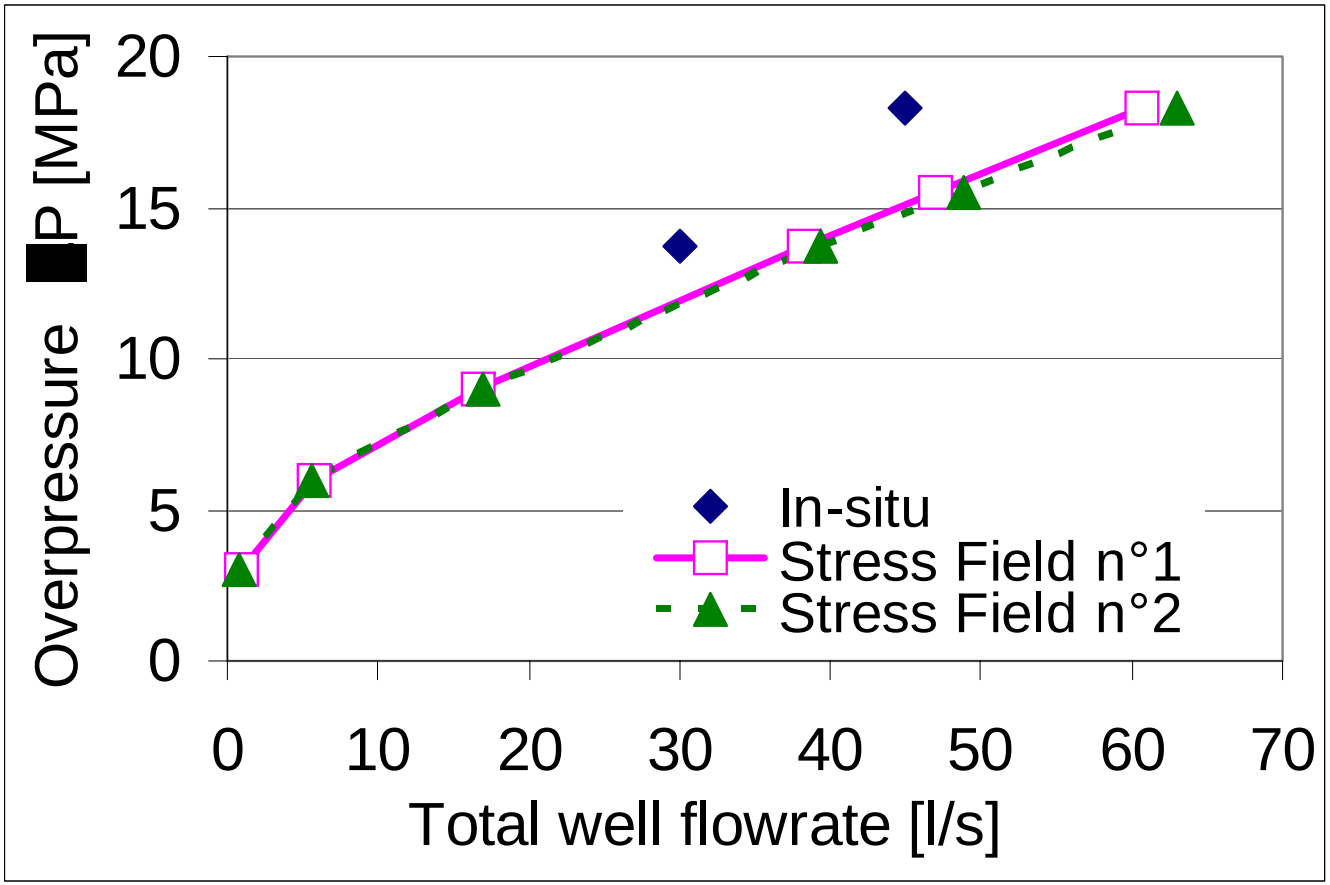
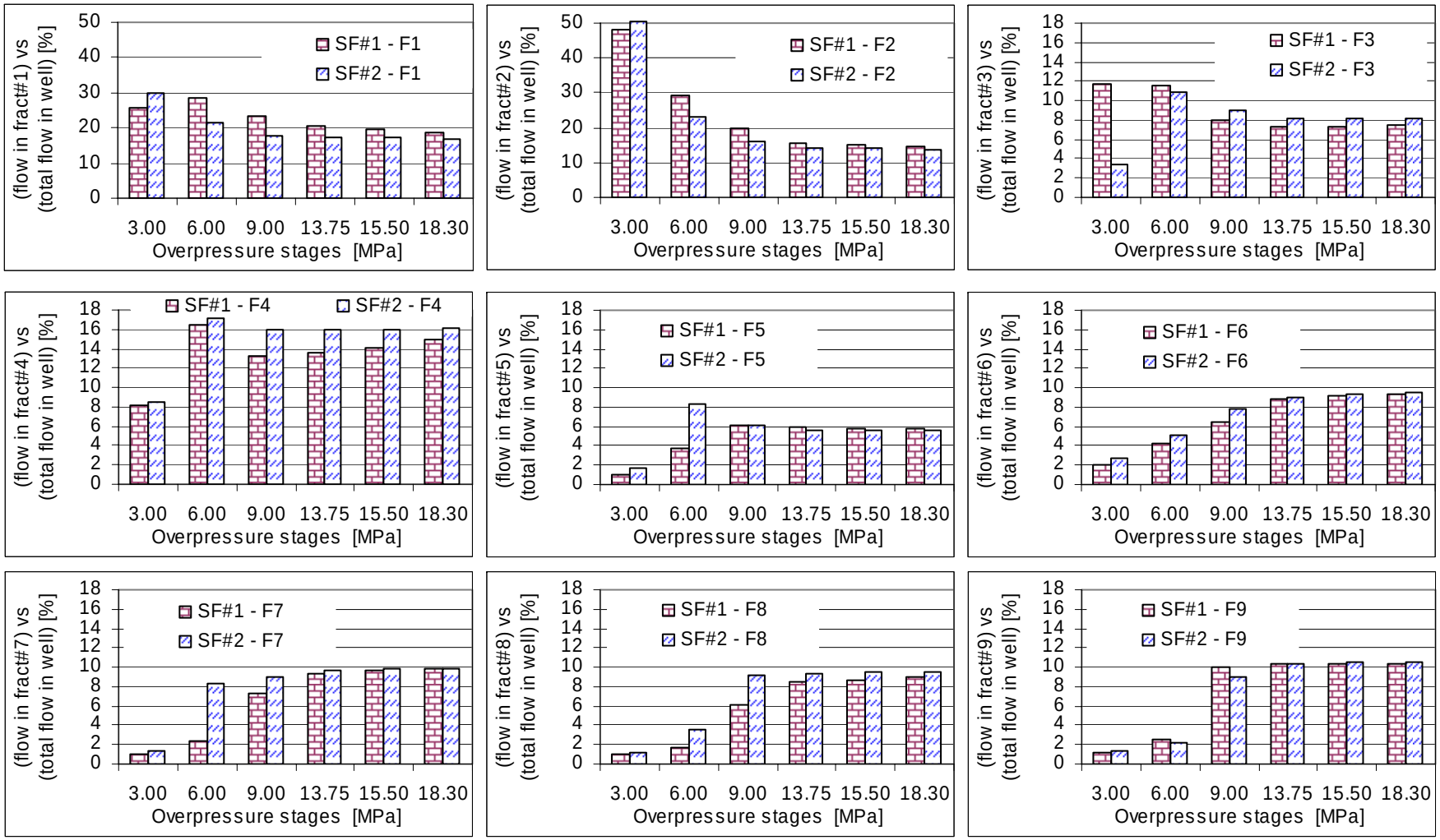
GPK4 - Influence in terms of flow in well



> **Very little difference**

GPK4 - Influence in terms of flow at fractures



> **Very little difference**

ENGINE Meeting, "Stimulation of reservoir and induced microseismicity"

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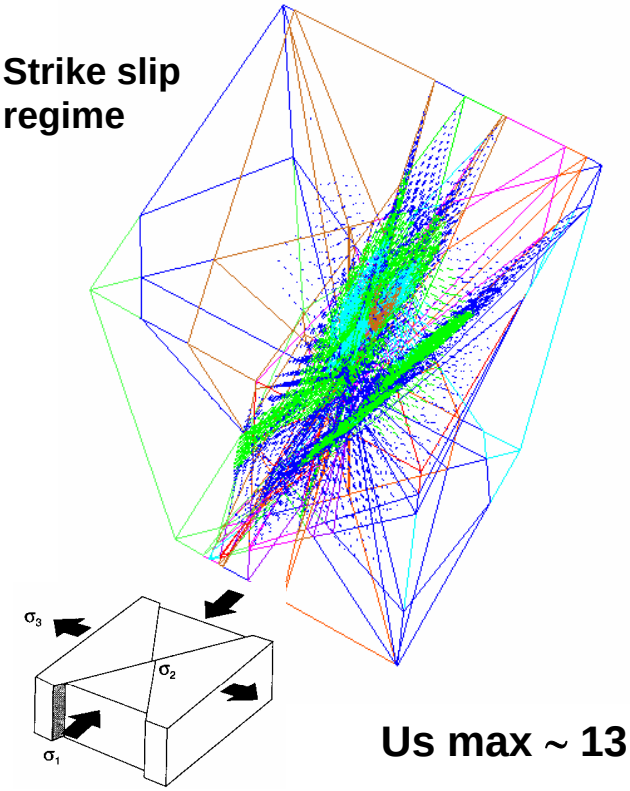
GPK4 - Influence in terms of shear disp.

ΔP = 18,3 MPa

Tangential displacements more concentrated in some fractures

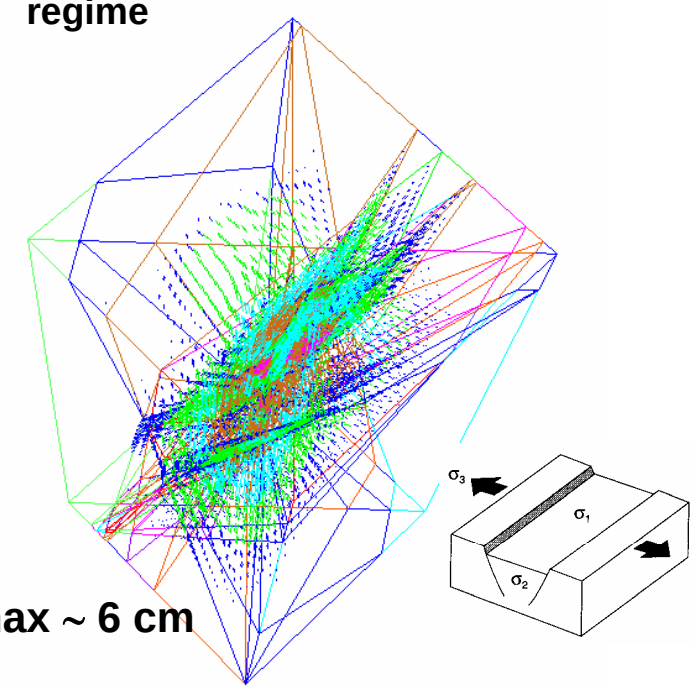
Strike slip regime



Us max ~ 13 cm

Tangential displacements more spread

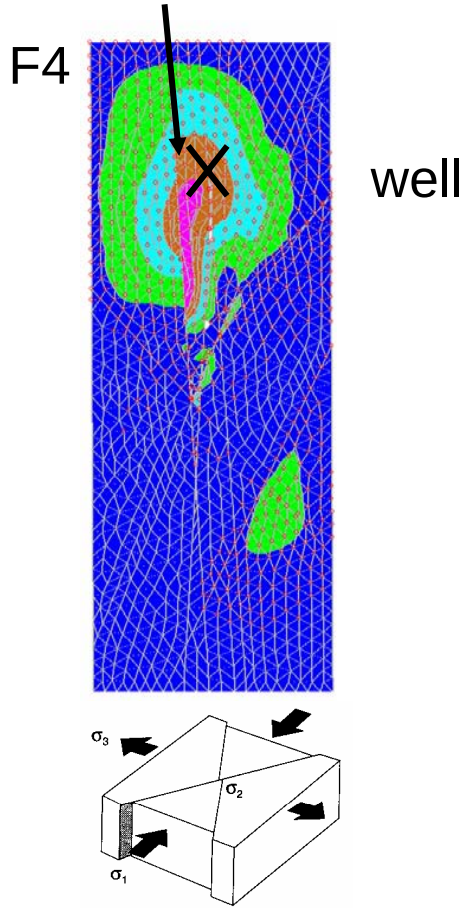
Normal fault stress regime



Us max ~ 6 cm

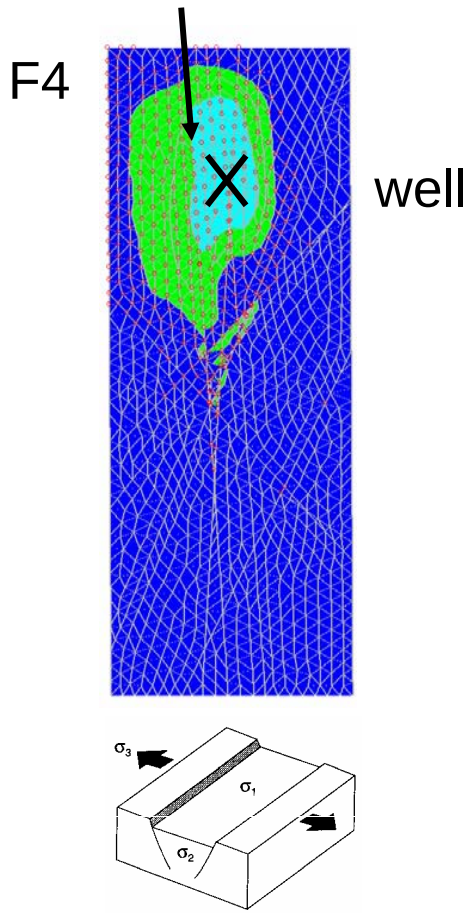
x 2

GPK4 – Influence in terms of F1 shear disp.



Us max = 7-9 cm

ΔP = 18.3 MPa



Us max = 3-5 cm

> **Max shear along intersection with F4, not close to the well, greater with strike slip regime**

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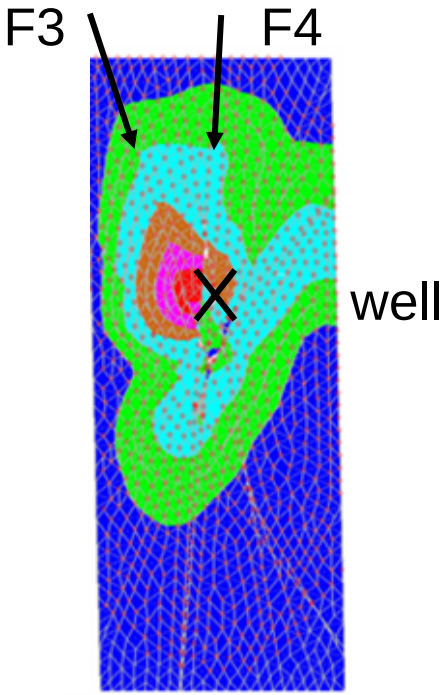
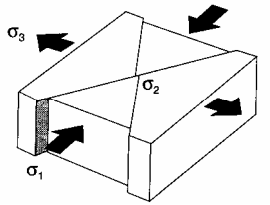
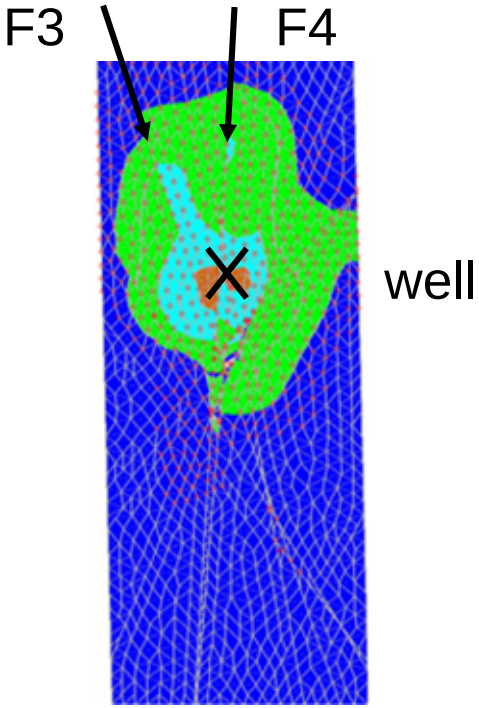
GPK4 – Influence in terms of F2 shear disp.

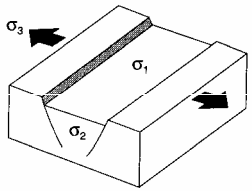




Us max = 9-11 cm

ΔP = 18.3 MPa

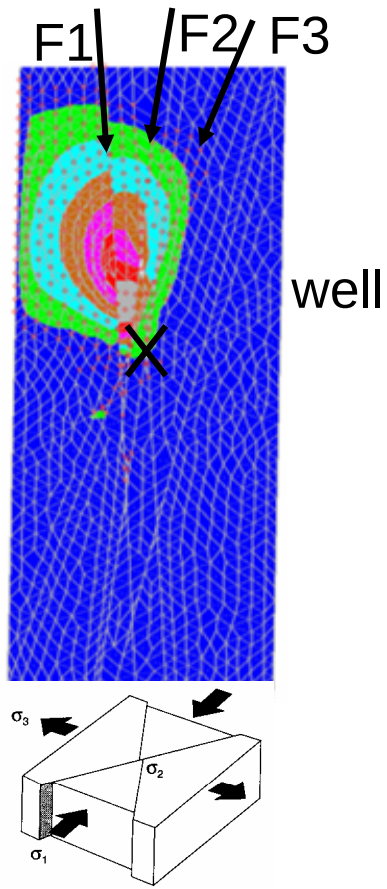




Us max = 5-7 cm

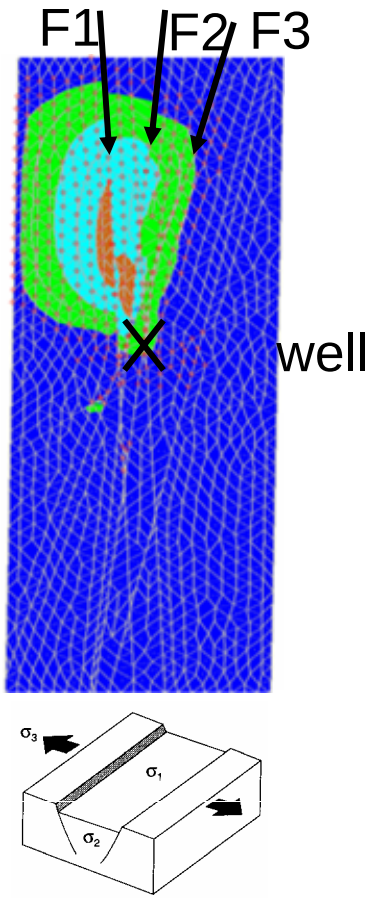
> **Max shear along intersections with F3 & F4, greater with strike slip regime**

GPK4 – Influence in terms of F4 shear disp.



Us max = 13 cm

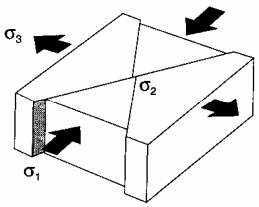
ΔP = 18.3 MPa

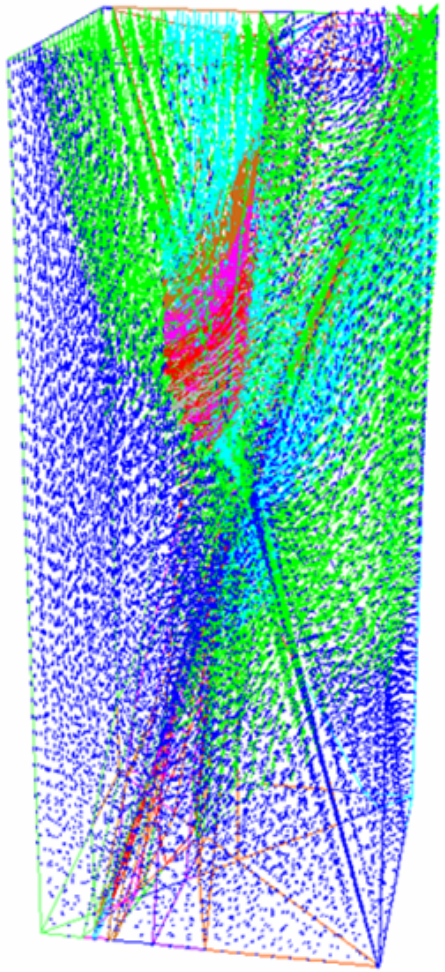


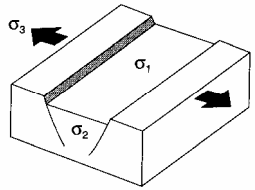
Us max = 5-7 cm

> **Max shear along intersections with F1 & F3, greater with strike slip regime**

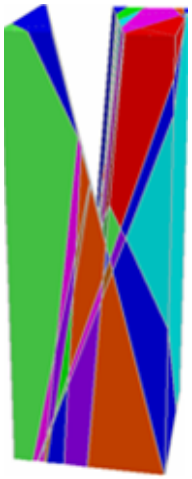
GPK4 – Influence in terms of block disp.

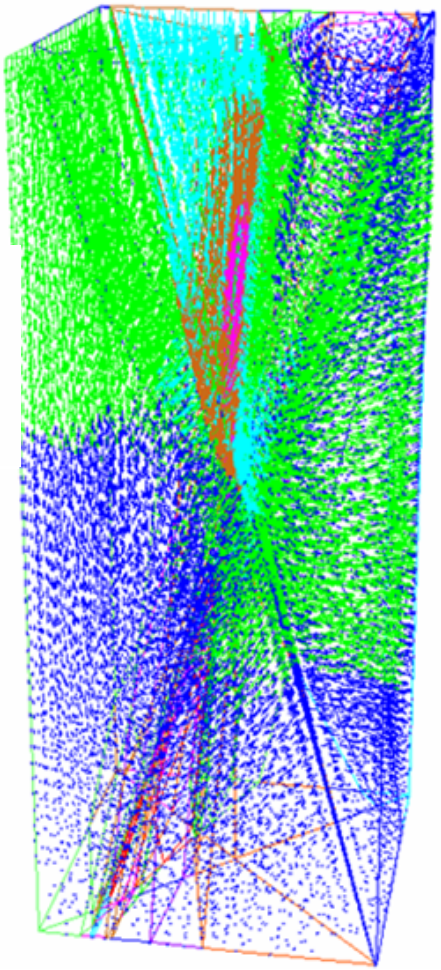






ΔP = 18.3 MPa





> **Blocks instability with strike slip regime**

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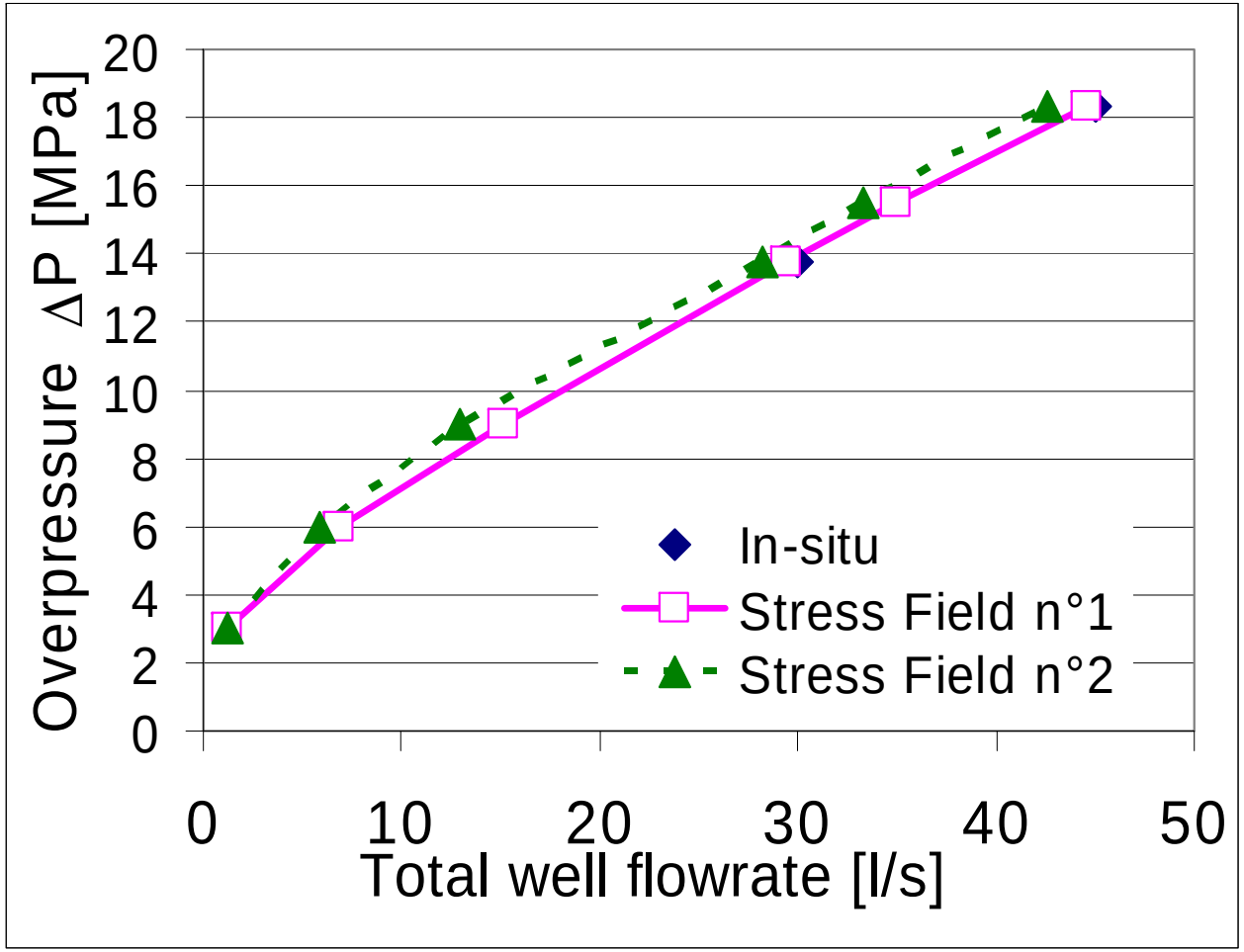
GPK4 – best fit of ΔP-Q stimulation curve

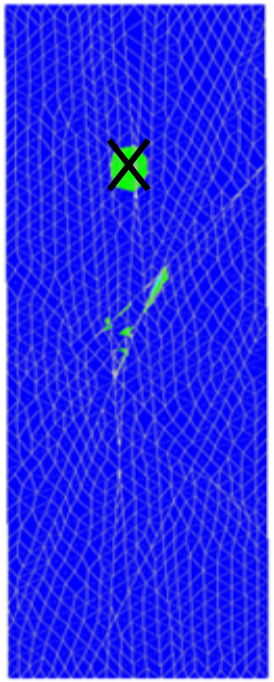
	Fracture N°	Initial aperture a_0 [mm]	Resid. aperture a_{res} [mm]	Max. aperture a_{max} [mm]	Friction angle φ (°)
Previous runs	F1 to F9	5.0	2.5	150	45
Best fit	F1	**0.5**	**0.25**	**15**	45
	F2	5.0	2.50	150	45
	F3	5.0	2.50	150	**40**
	F4	**2.5**	**1.25**	**75**	**40**
	F5	5.0	2.50	150	45
	F6	5.0	2.50	150	**40**
	F7	5.0	2.50	150	**40**
	F8	5.0	2.50	150	**40**
	F9	**0.5**	**0.25**	**15**	45

GPK4 – best fit – influence in terms of flow

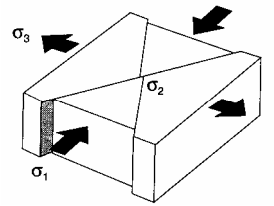


> **Very little difference**

GPK4 – Best Fit – F1 shear disp.

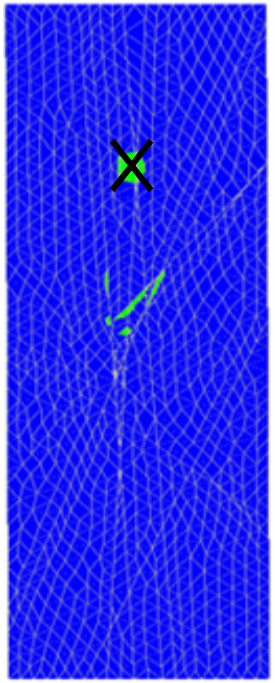


well

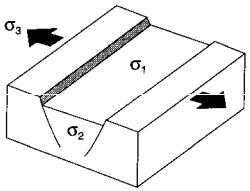


Us max = 1-3 cm

ΔP = 18.3 MPa



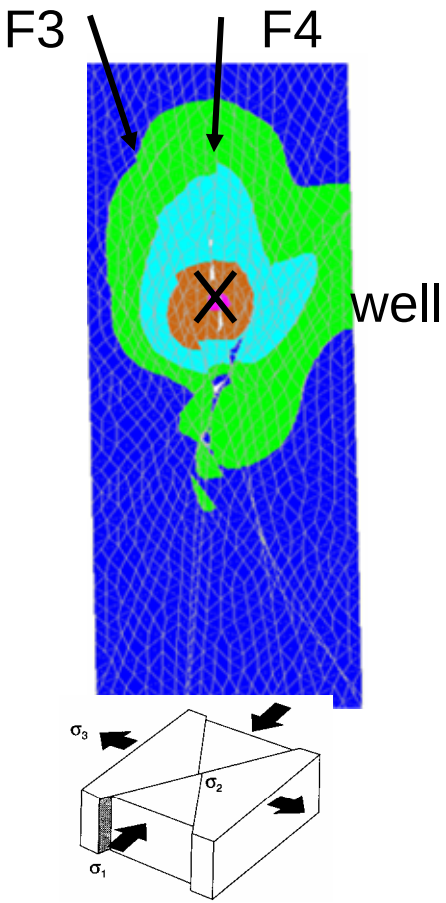
well



Us max = 1-3 cm

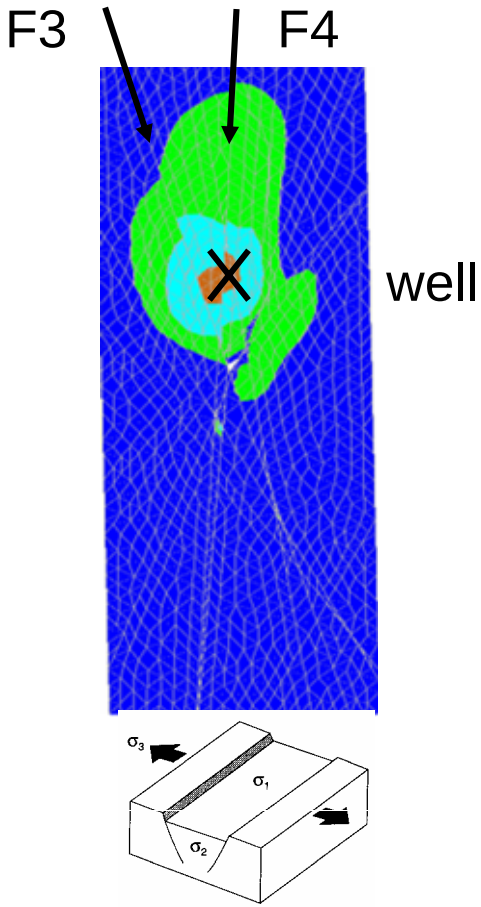
> **Limited and comparable F1 max shear, around the well**

GPK4 – Best fit – F2 shear disp.



Us max = 7-9 cm

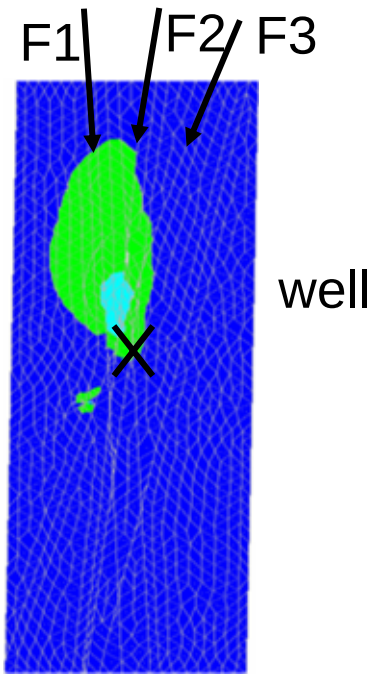
ΔP = 18.3 MPa

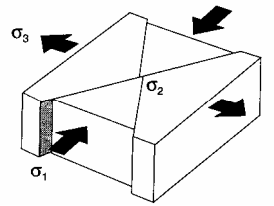


Us max = 5-7 cm

> **F2 max shear around the well, and along intersections with F3 & F4**

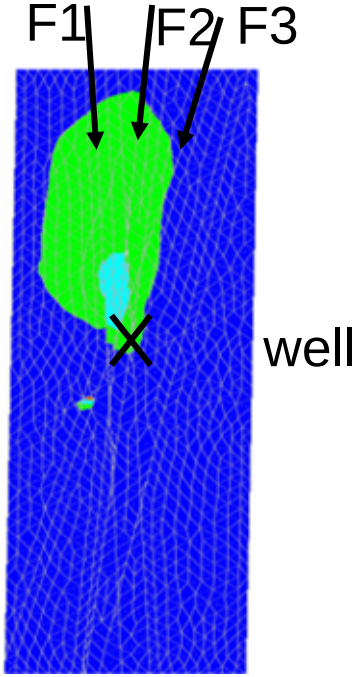
GPK4 – Best fit – F4 shear disp.

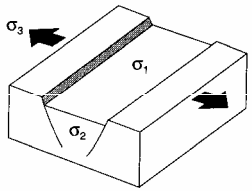




Us max = 3-5 cm

ΔP = 18.3 MPa

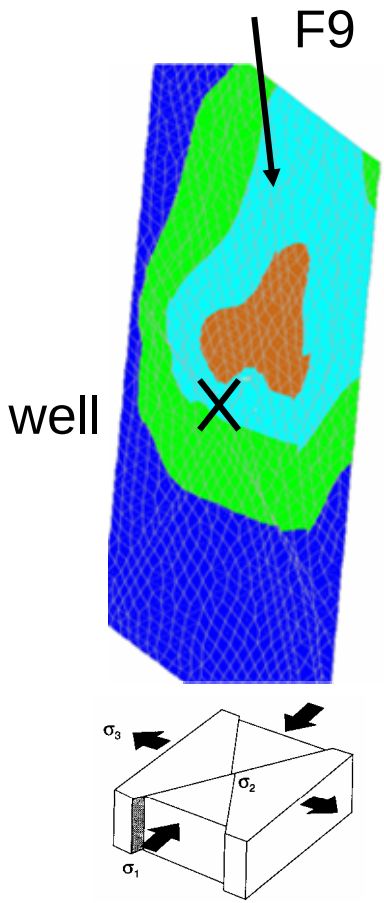




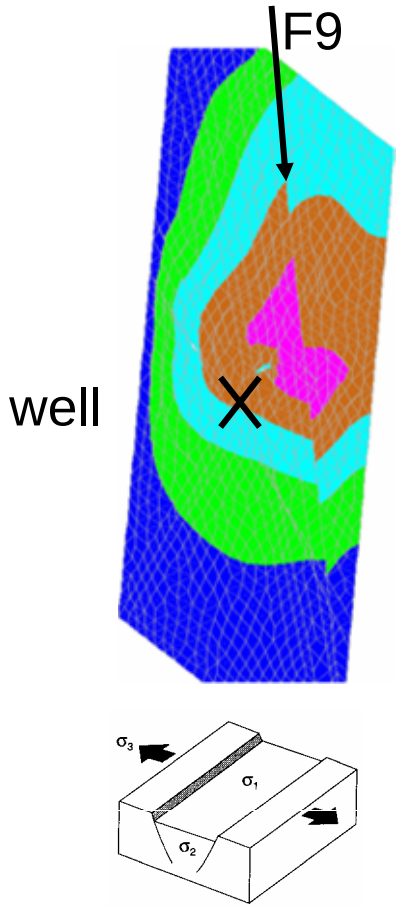
Us max = 3-5 cm

> **/2 F4 hydro apertures change drastically the F4 HM behaviour. Max shear not close to the well**

GPK4 – Best fit – F7 shear disp.



ΔP = 18.3 MPa



Us max = 5-7 cm

Us max = 7-9 cm

> **F7 max shear disp. far away from the well, greater with normal fault stress regime**

Conclusions

> Great importance of the stress field, depending on the HM fractures properties

> Looking only at the ΔP-Q stimulation curve obtained with 3DEC is not satisfactory

> Max shear displacements are not located close to the well

> Blocks instability with the strike slip regime is unrealistic

- **Either the stress field taken into account does not reflect the real in-situ one,**
- **And/or, the HM fractures properties are not appropriate.**

Work in progress

> New Fractures constitutive law taking into account damage during shearing

> New conceptual hydraulic model, taking into account the 3 wells

> Thermal coupling

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