Couplages thermo-hydro-mécaniques dans les roches réservoirs

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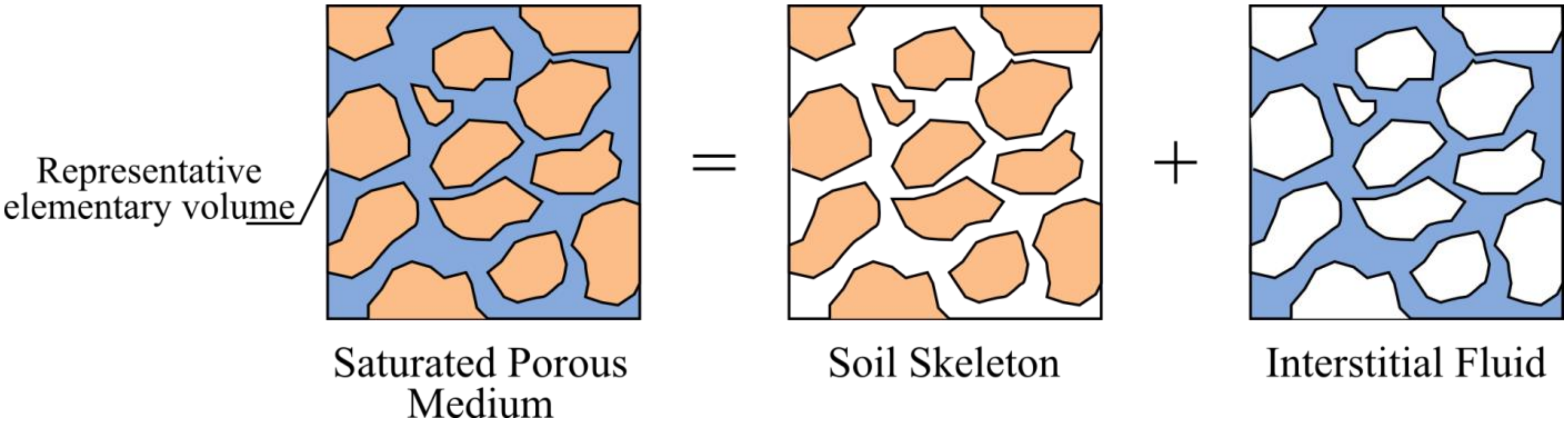
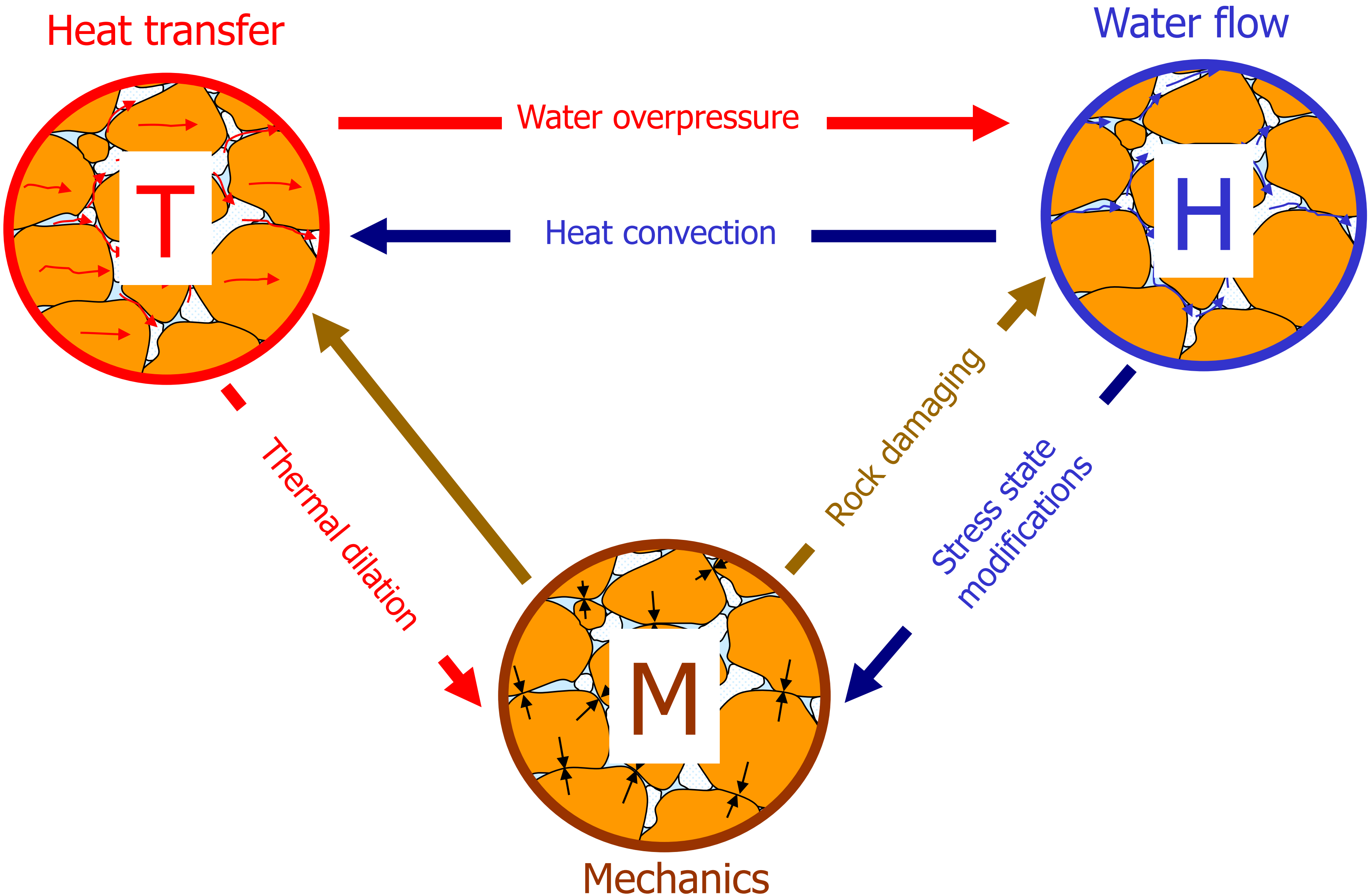
- Introduction to couplings
- Conventional reservoirs
- Unconventional reservoirs (shale gas)
- Lessons from Nuclear waste storage
- Unconventional reservoirs (coal gas)
- Conclusions

Reservoir rock as a saturated porous medium

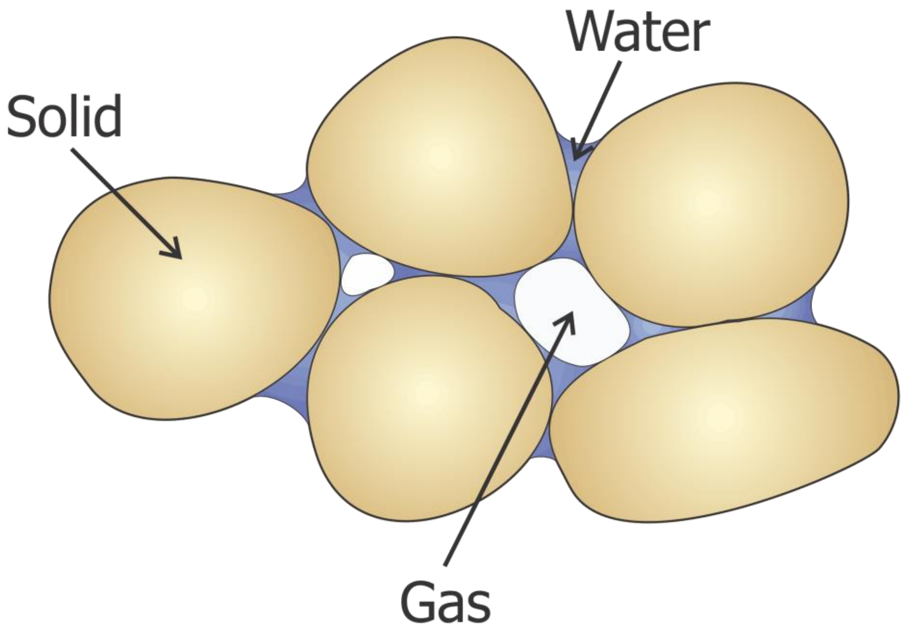


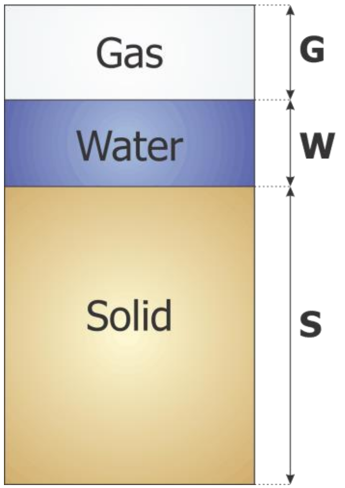
✓ H → M : Terzaghi's postulate $\sigma_{ij} = \sigma'_{ij} + u\delta_{ij}$ (extension to Biot theory)

✓ M → H : Fluid storage


Heat transfer
Water flow
T
H
M
Water overpressure
Heat convection
Thermal dilation
Rock damaging
Stress state
modifications
Mechanics

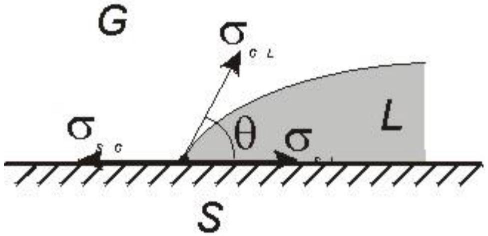
Reservoir rock as a unsaturated (triphasic) porous medium

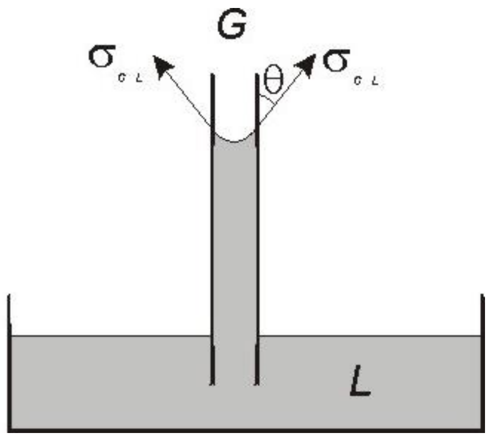


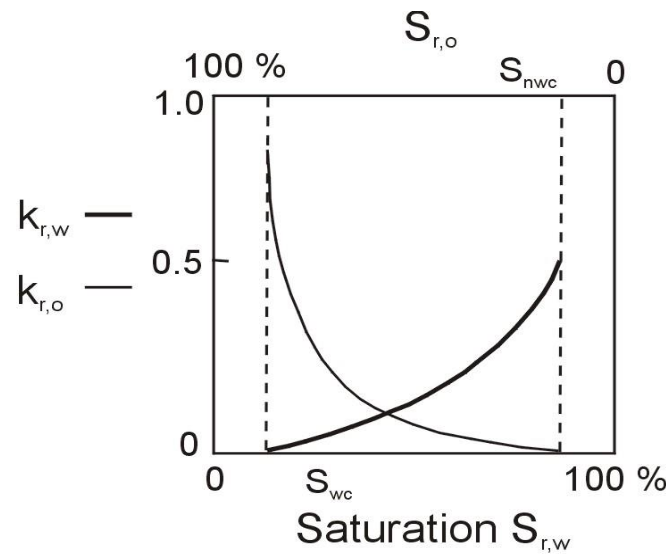


- ✓ **Water content:** $w = \frac{M_w}{M_s}$
- ✓ **Water saturation:** $S_r = \frac{V_w}{V_v}$
- ✓ **Suction**

Reservoir rock as a unsaturated (triphasic) porous medium







Jurin's law: $$p_c = p_G - p_L = \frac{2\sigma_{GL}\cos\theta}{r_c}$$

Permeability

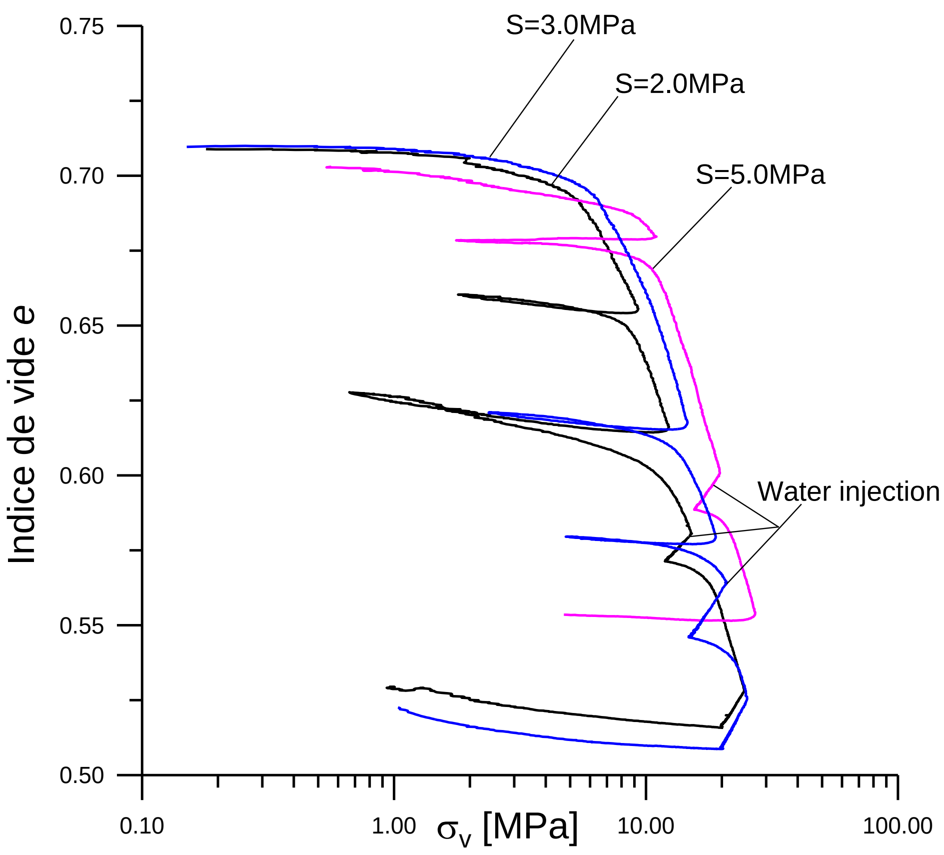
θ : contact angle

σ_{GL} : Surface tension between phases G and L

r_C : capillary tube radius

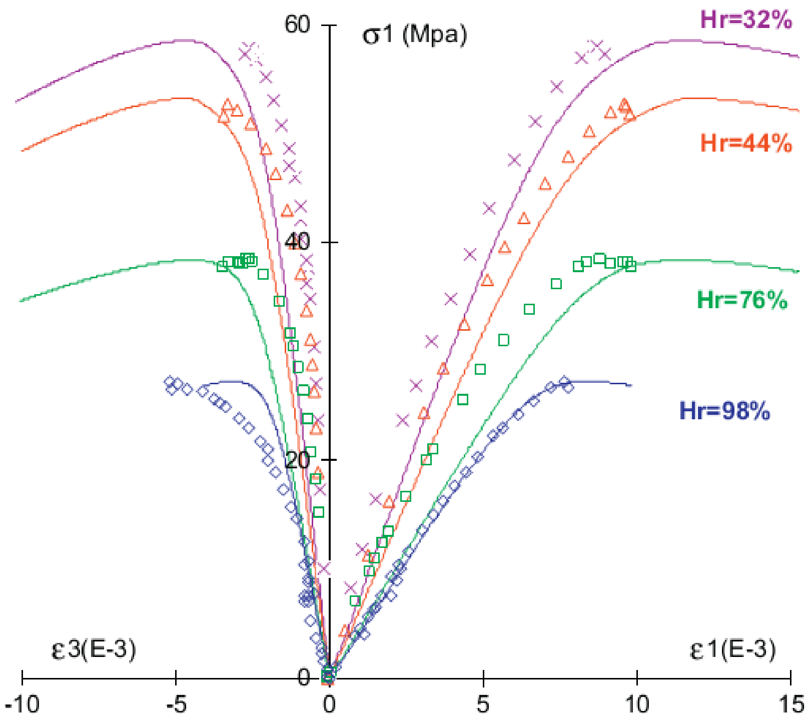
Reservoir rock as a unsaturated (triphasic) porous medium

Volumetric



Chalk

Deviatoric



Argillite

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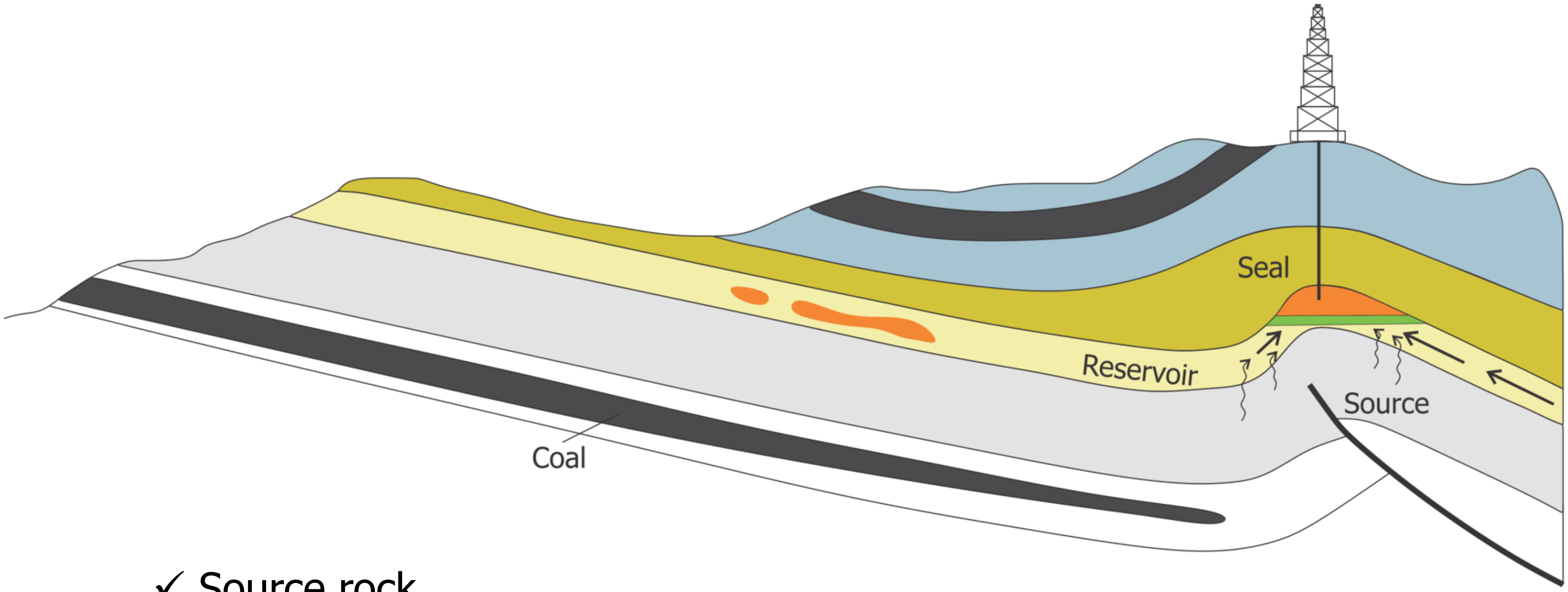
Reservoir Engineering – Conventional reservoir

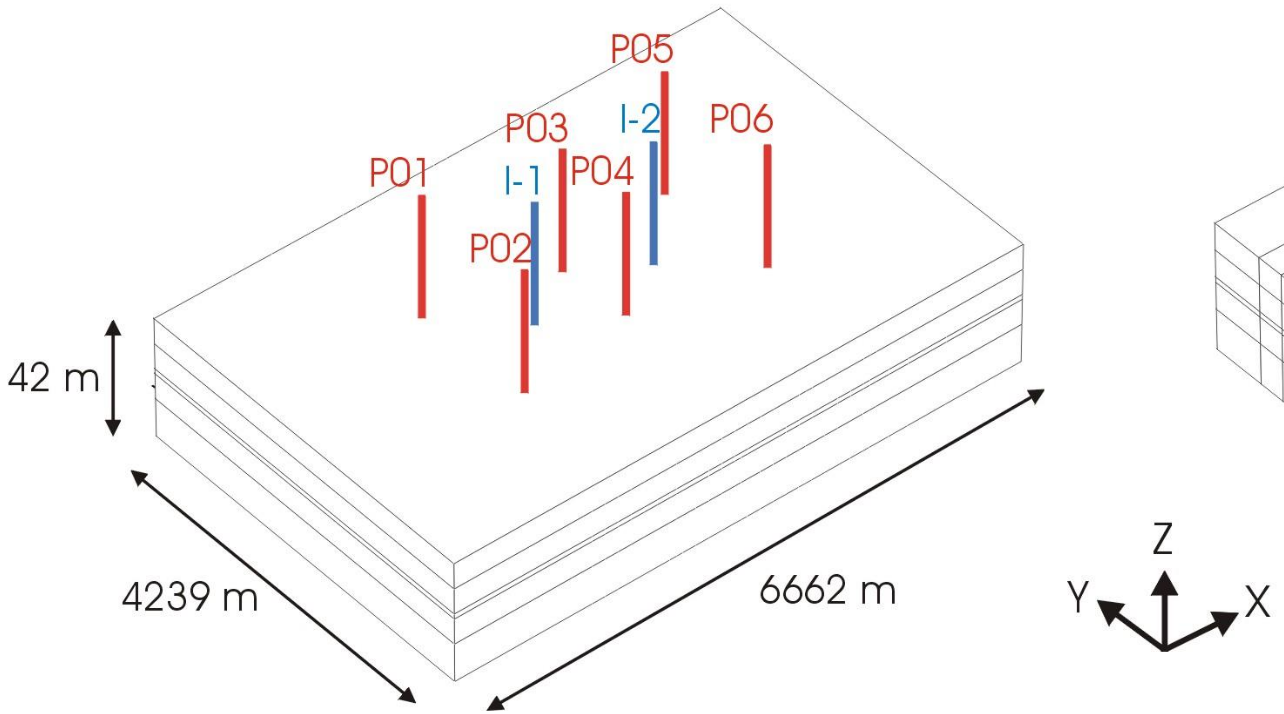


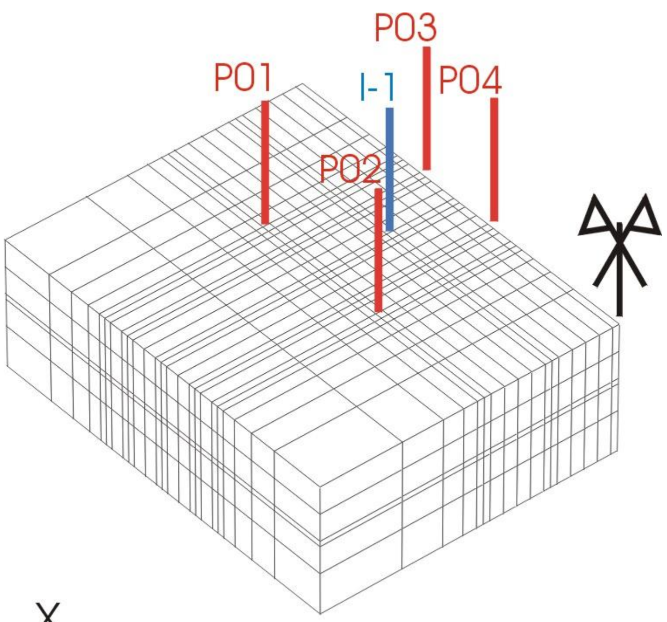
- ✓ Source rock
- ✓ Reservoir
- ✓ Capping

Synthetic reservoir Model

Reservoir geometry (anamorphose)

Finite element Mesh





- ✓ 2733 Nodes
- ✓ 2040 Height-nodes coupled elements

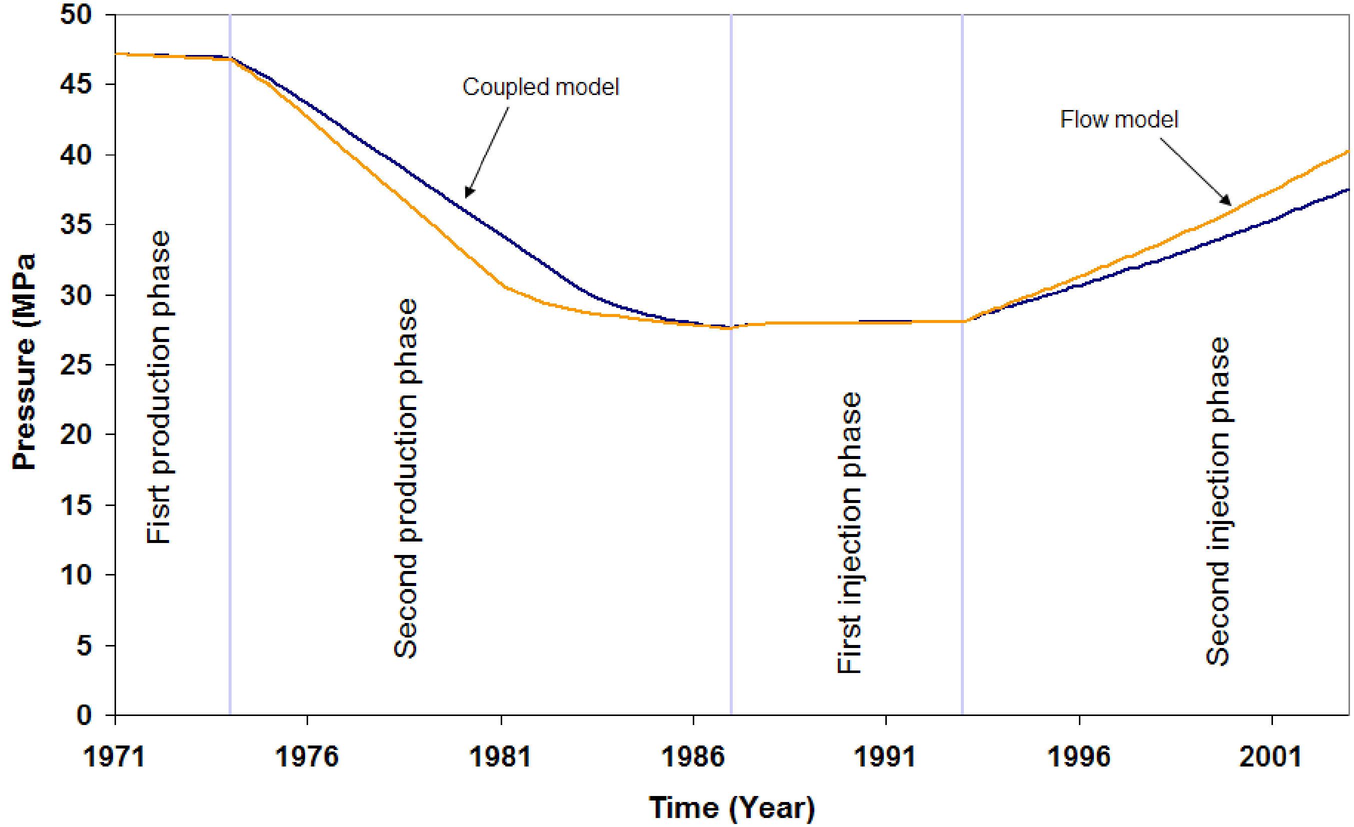
The wells are flow- and pressure-controlled

(Minimum bottom pressure for production wells, maximum bottom pressure for injection wells)

	P01 , P02, P04, P05 and P06		P03		I-1 and I-2	
Year	Liquid rate (stb/day)	BHP (PSI)	Liquid rate (stb/day)	BHP (PSI)	Liquid rate (stb/day)	BHP (PSI)
1971	/		5000	3600	/	
1974	12000	3600	12000	3600	/	
1975	16000	4500	16000	4500	/	
1987	16000	4000	16000	4000	50000	7000
1993	16000	4000	16000	4000	120000	8000

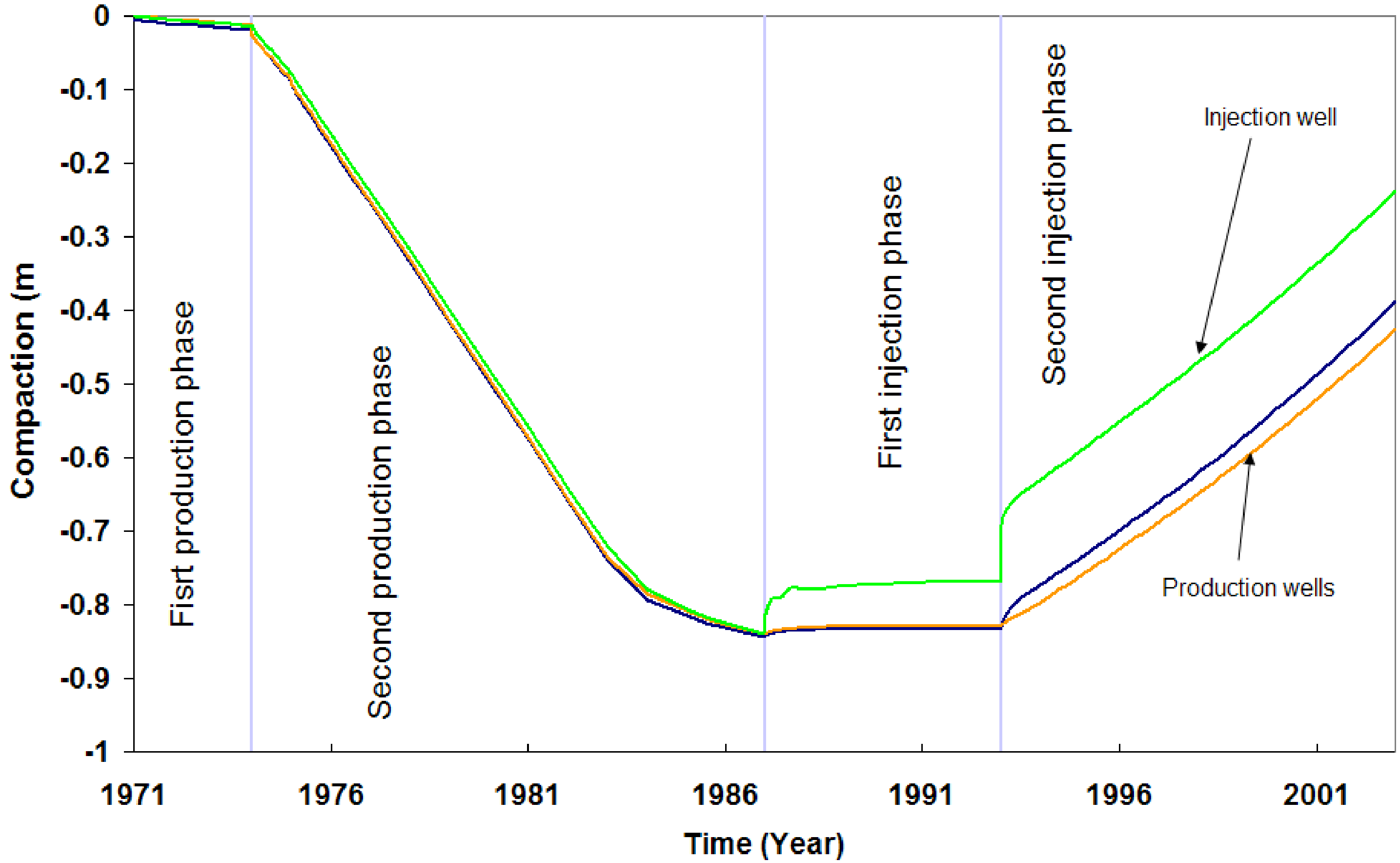
Field pressure

Case 1 – Flow model
Case 2 – HM Elastic model



Compaction at the top of the wells

Case 2 – HM El. model



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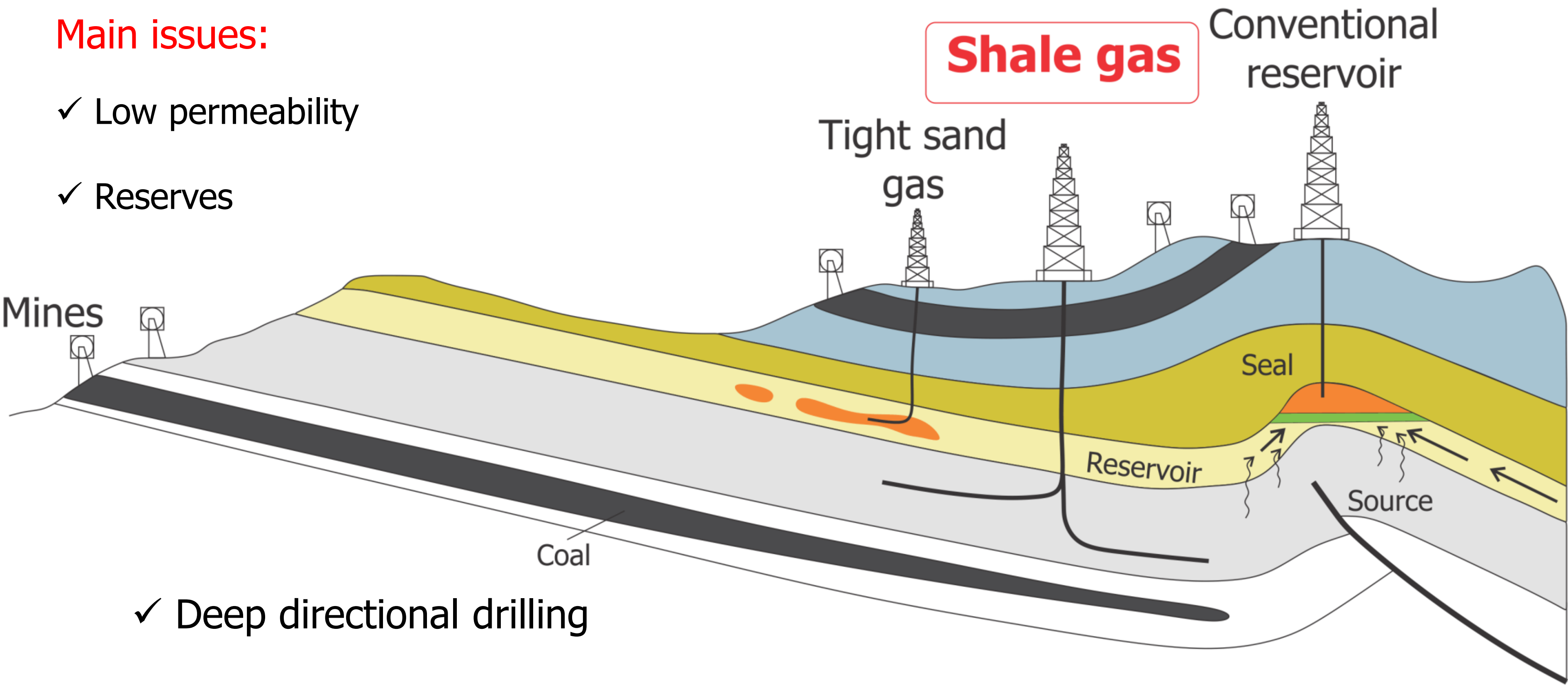
Shale gas – Unconventional reservoir

Main issues:

- ✓ Low permeability
- ✓ Reserves



- ✓ Deep directional drilling
- ✓ Source rock fracturation techniques
- ✓ Logging techniques

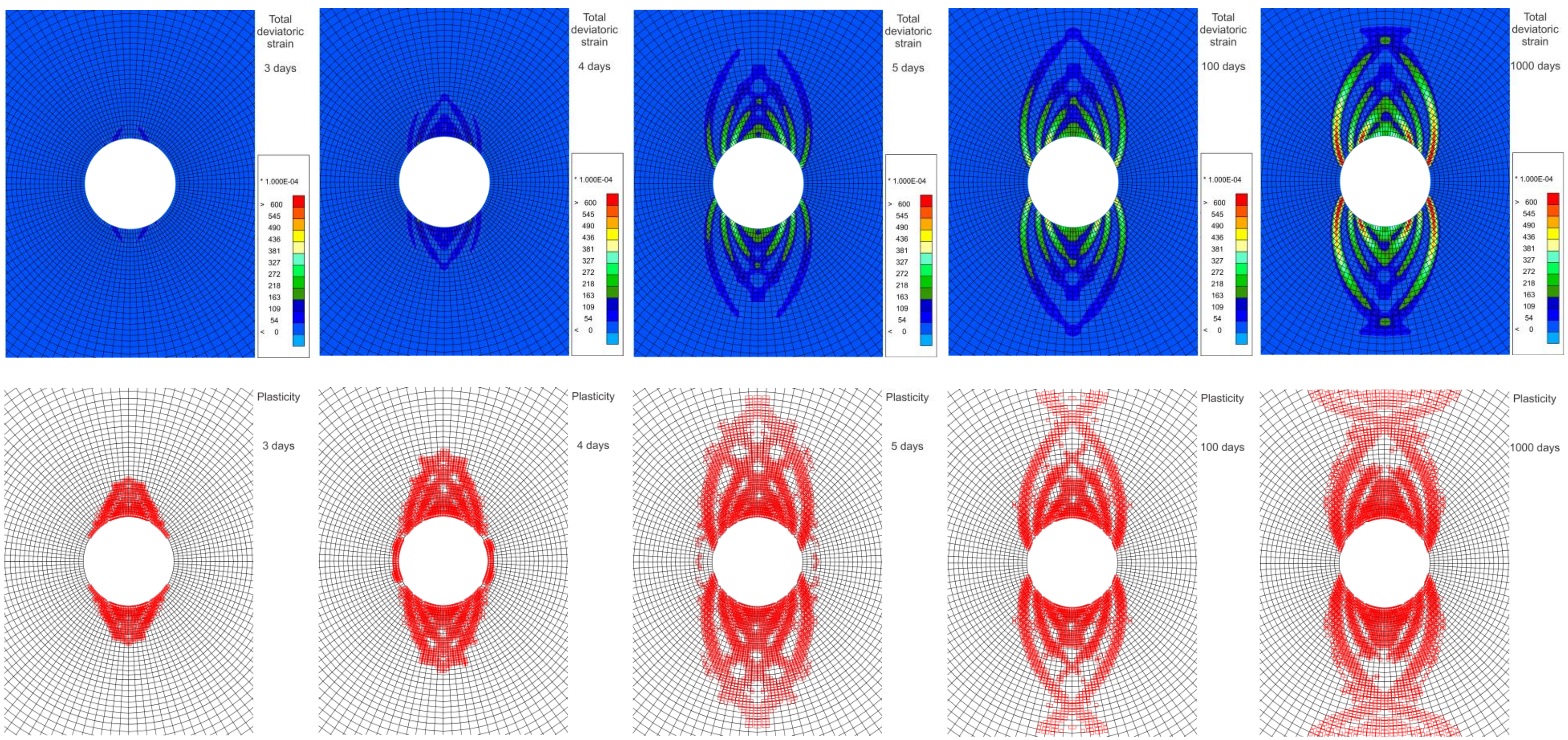
Near field problem:

Anisotropic (σ and k)

End of excavation

Total deviatoric strain

Plasticity



Far field problem:

- ✓ Multiphase flow of water and gas
- ✓ Fracturation process

Complexity of the constitutive model

By essence, the material is:

- ✓ Anisotropic
- ✓ Strain dependent modulus
- ✓ Time dependent
- ✓ Temperature dependent
- ✓ …

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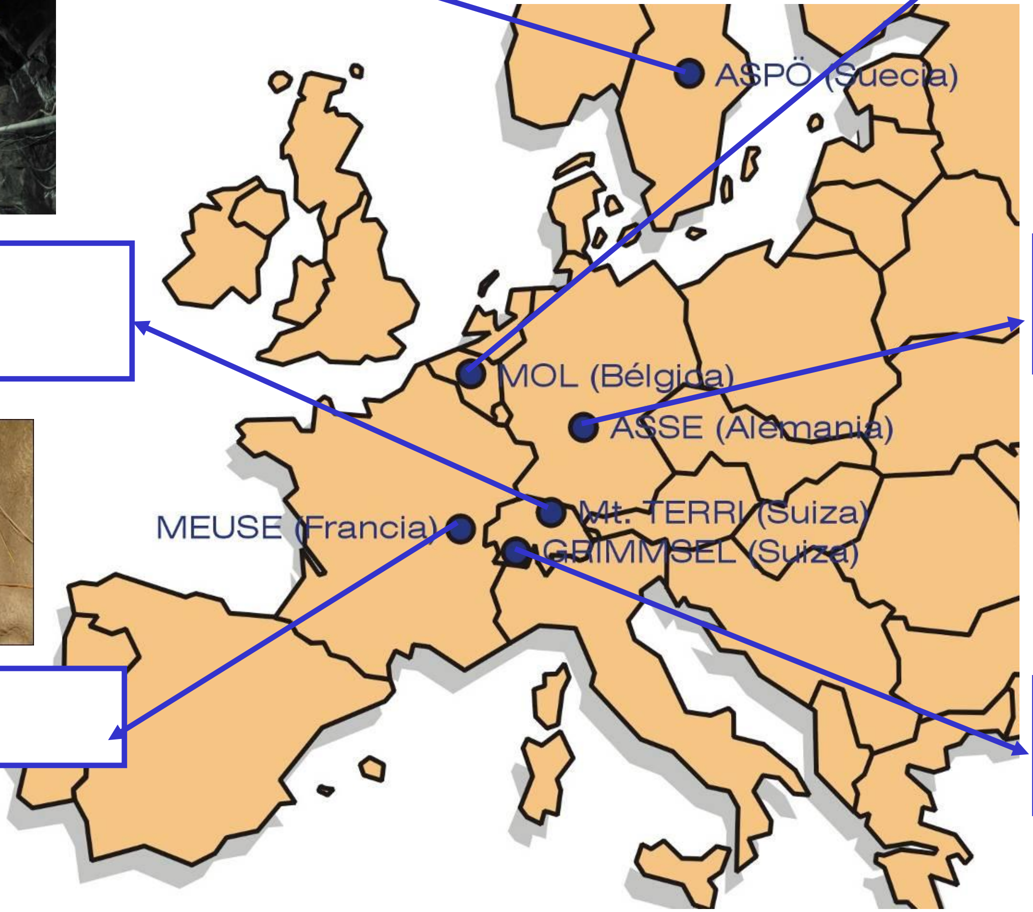
Underground research facilities

Granite
200m – 450 m depth

Opalinus clay
400m depth
Pre-existing

COx Argillite
450m – 520 m depth



(Plastic) Boom clay
230m depth

Salt
490m – 800m depth
Pre-existing (mine)

Granite
450m depth
Pre-existing

Analysis of the multi-physical loadings

- ✓ Gallery excavation → *Mechanical*
- ✓ Water flow → *Flow*
- ✓ Gas movement (corrosion) → *Flow*
- ✓ Heating – Cooling → *Thermal*
- ✓ Tightening of the gallery → *Mechanical, flow*
- ✓…

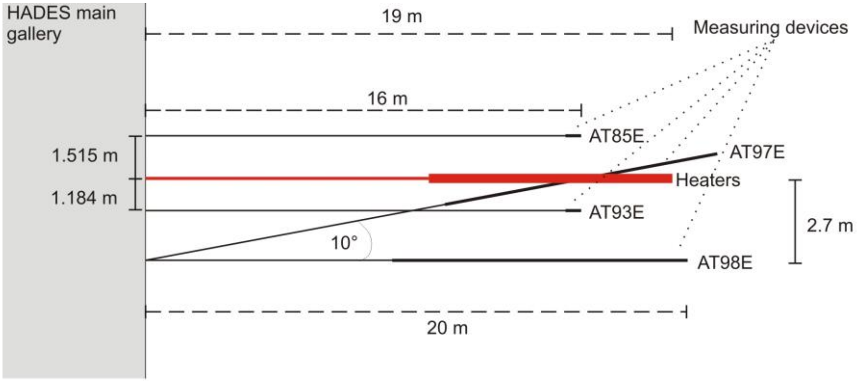
➔ Multi-physical couplings

In-situ experience *ATLASIII*

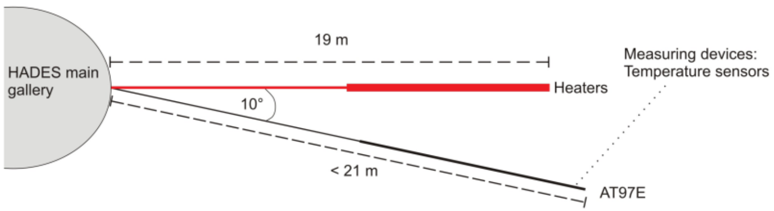
- Caracterisation of the THM behaviour of Boom clay

Experience: 1 main borehole (heating source)

4 additional borehole (piezometres, thermo-couples…)



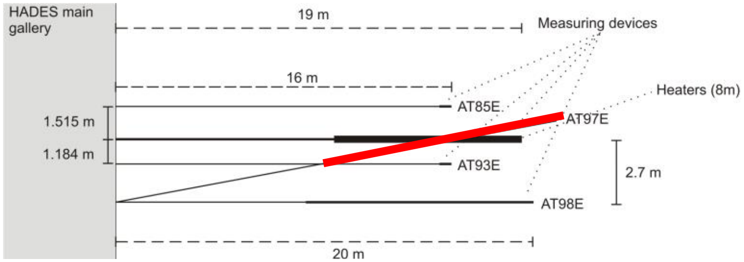
Horizontal plane



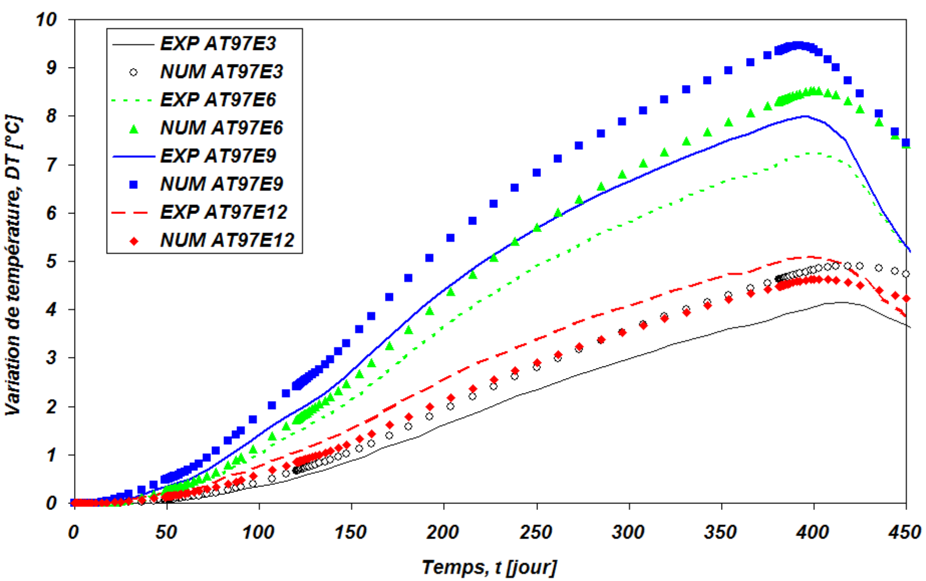
Vertical plane

Experience out of the influence of the main gallery EDZ

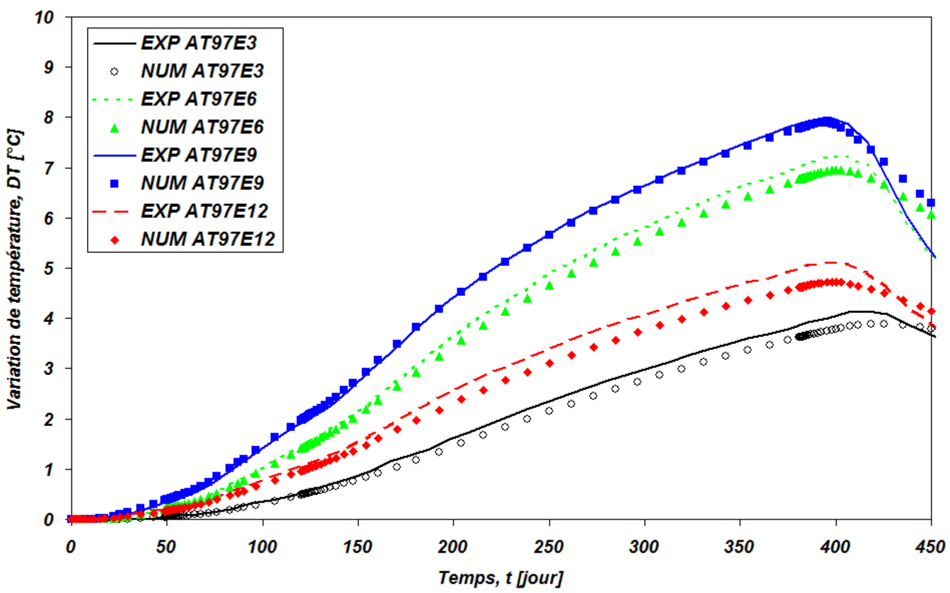
3D full anisotropic model with small strain modulus



Comparison between experimental and numerical results, temperature evolution(AT97E)

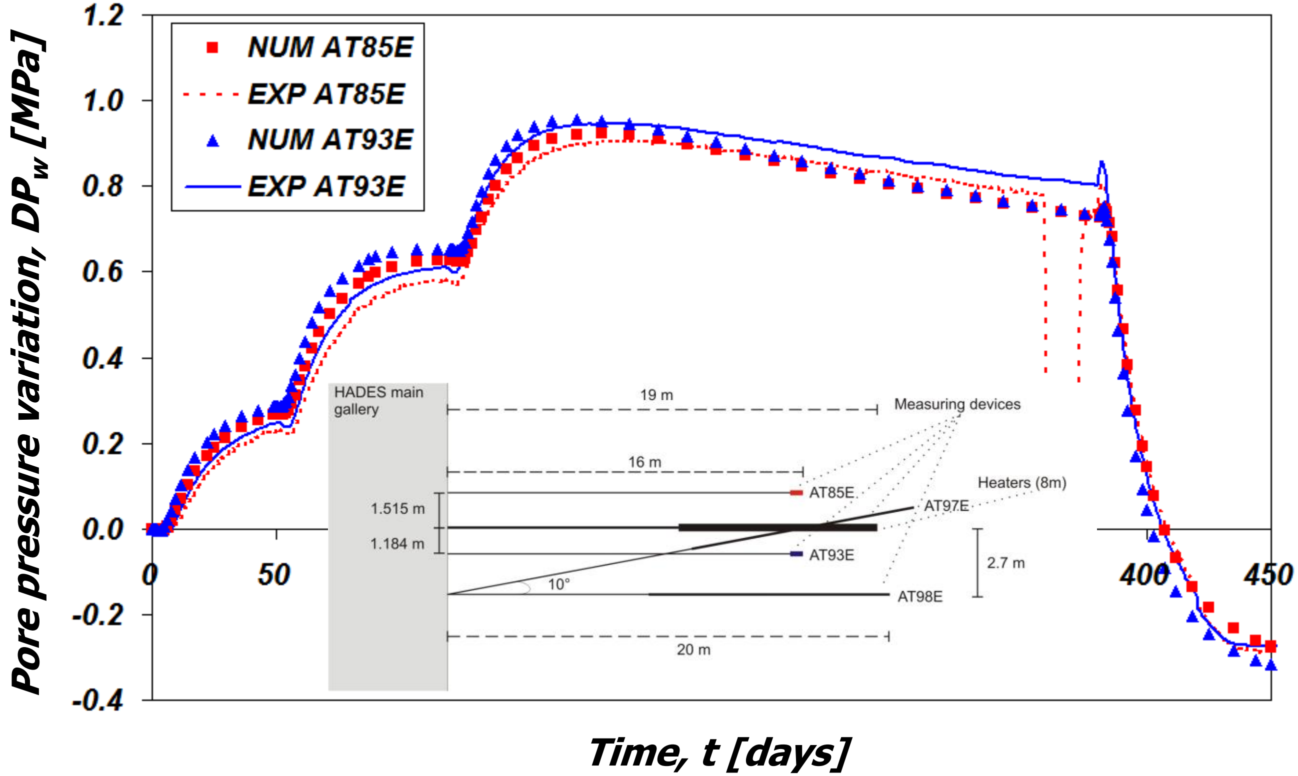


Istotropic thermal conductivity model



Anistrotropic thermal conductivity model

3D full anisotropic model with small strain modulus



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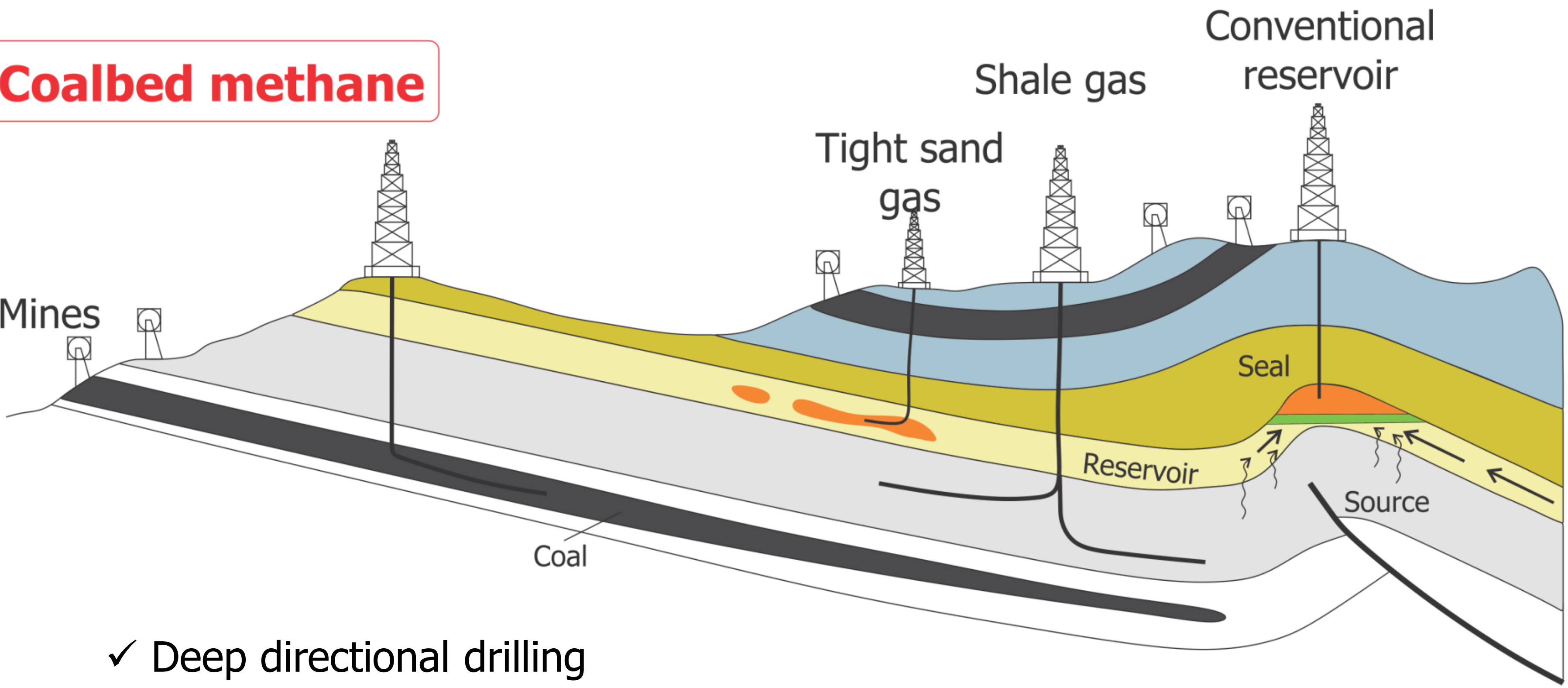
Coal gas – Unconventional reservoir

Coalbed methane



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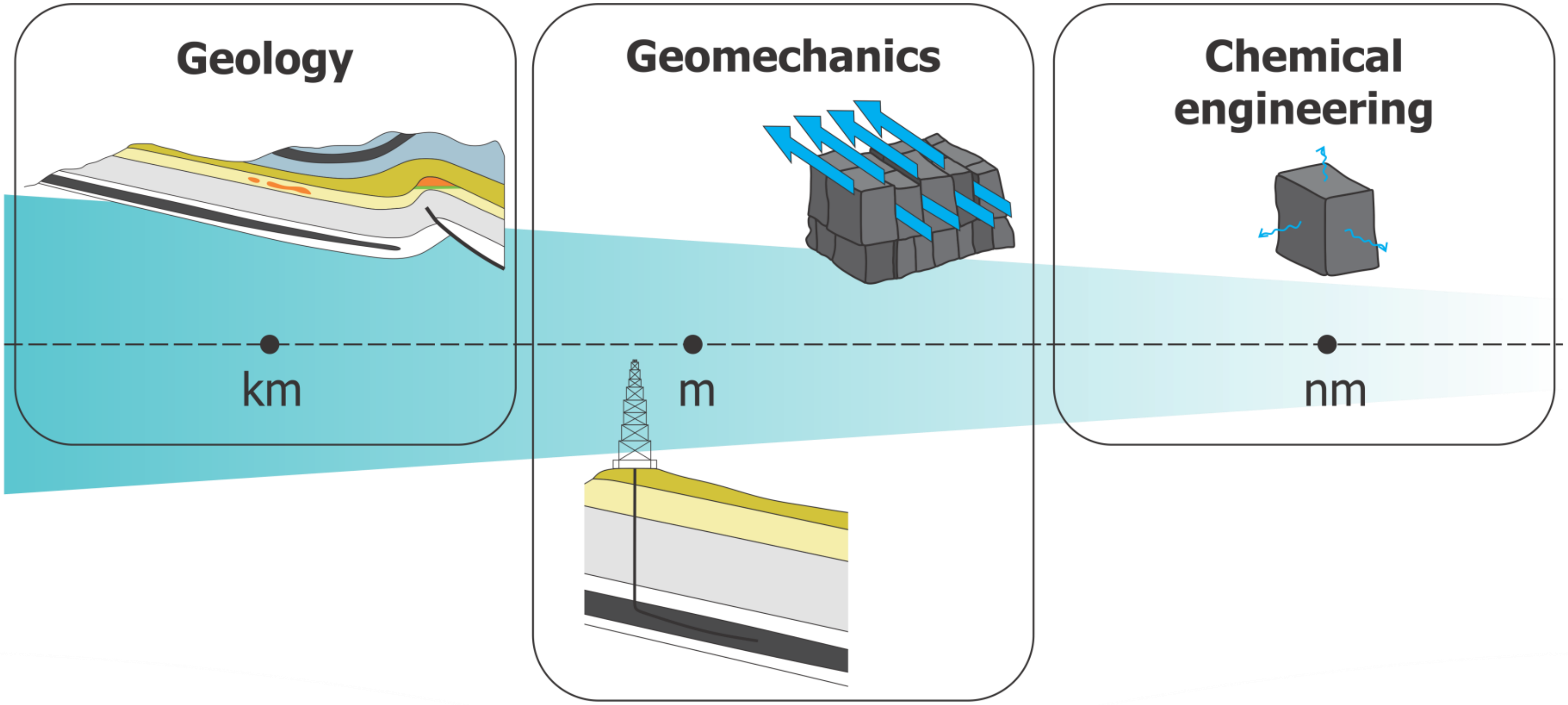
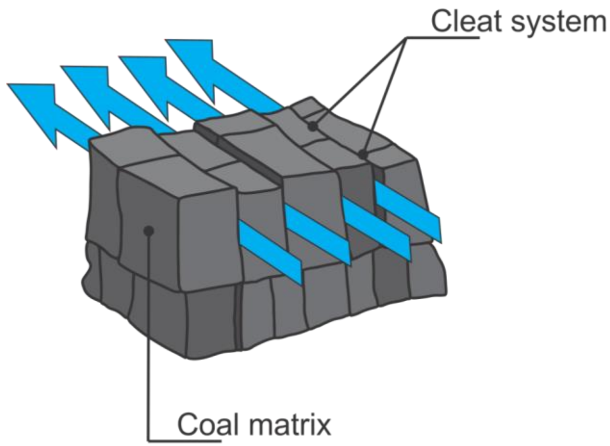
Coal gas production:

different aspects, specific length scale



Coal gas – Microstructural effects

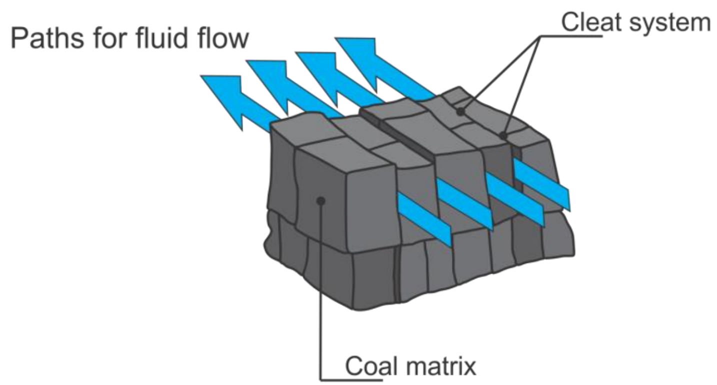


Specific structure of the coal:

- ✓ Coal matrix
- ✓ Cleat system

Specific structure of the coal:

- ✓ Adsorbed gas mainly in the Coal matrix
- ✓ Gas transport mainly in the Cleat system



Due to the microstructural effects, the HM couplings are magnified (analogy with bentonite).

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Conclusions

- ✓ Many THM couplings in reservoir rocks
- ✓ Some of them may be neglected … or not
- ✓ Chemical aspects are also of primary importance
- ✓ Challenges in constitutive modeling
- ✓ Multidisciplinary approach is essential