Analyse du risque de rupture de la cimentation des puits après abandon

Analyse THM couplée multi-échelle & Perspectives

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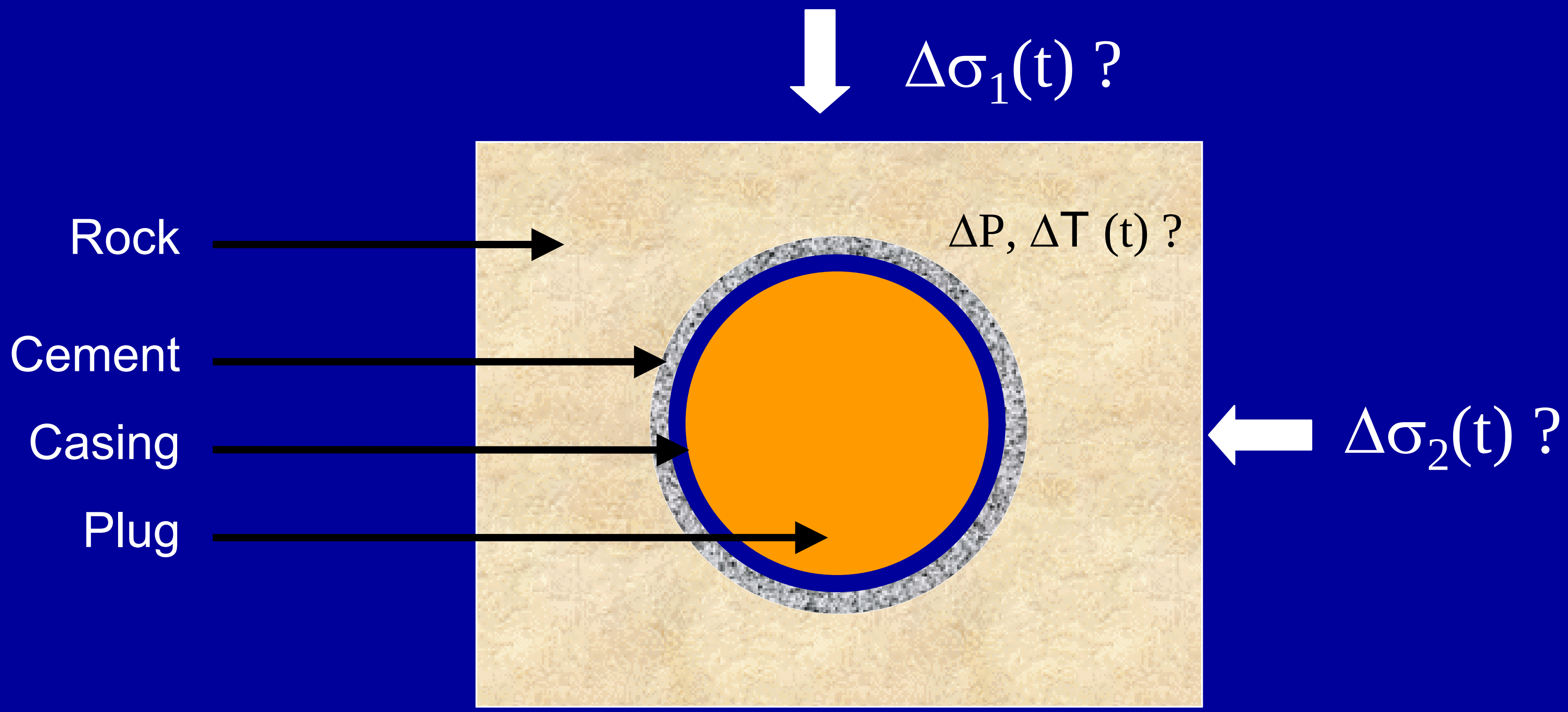
Mechanical Behavior of Plugged Wells

- Context :
  - ✓ abandonment of oil and gas wells drilled for exploration and field production
  - ✓ preventing fluid leakages along the well so that all the fluids will remain permanently confined in the separate strata containing them before plugging
  - ➢ importance of cement setting process : failure due to fluid instability at the interface between the cement slurry and the drilling fluid below the slurry (Crawshaw and Frigaard, 1999)
  - ➢ moreover, even when the cement is properly placed and initially provides an effective hydraulic seal, downhole condition changes after well plugging and abandonment may induce damage to the zonal isolation and lead to fluids leakage

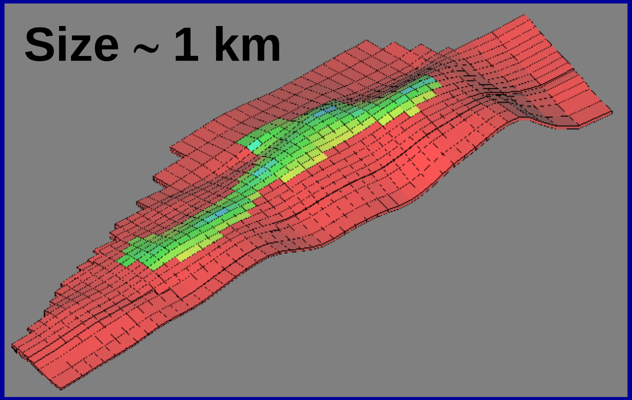
Mechanical Loading on Plugged Wells



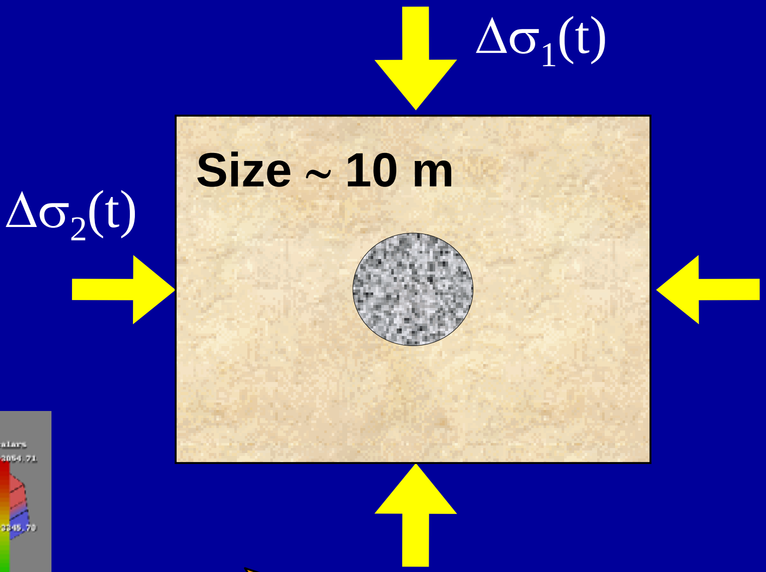
- Stress evolution during abandonment until pressure & temperature balances are restored
- Identification of plug mechanical properties to avoid formation of microannulus and/or cement cracking

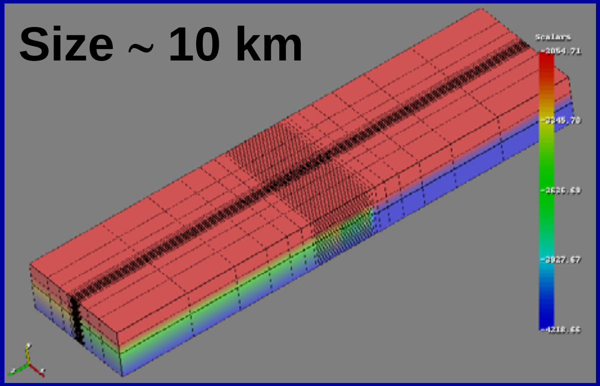
Methodology: Multi Scale Approach

Reservoir Model
ATHOS



Well Bore Stress Model ABAQUS



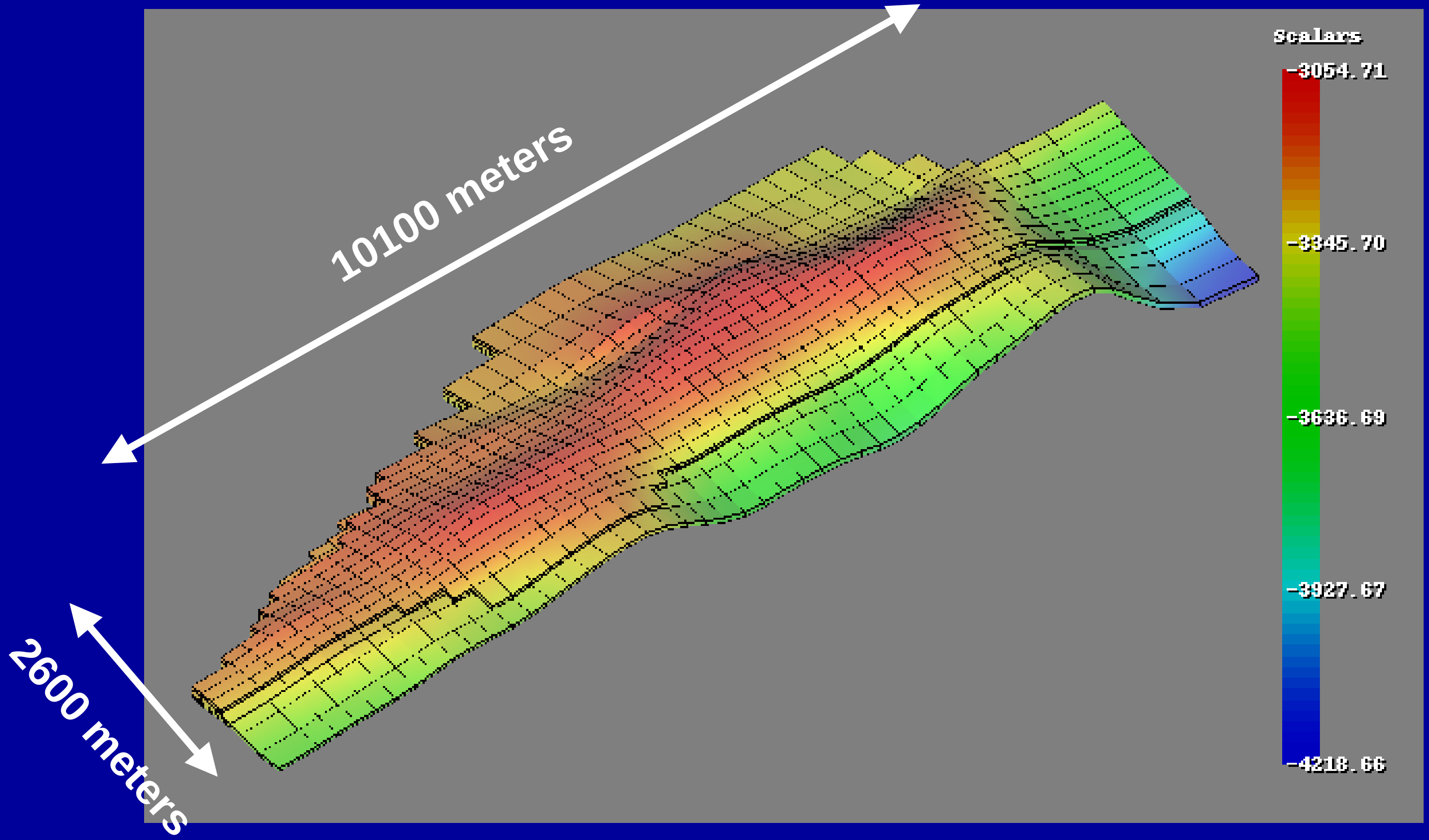


Geomechanical Model

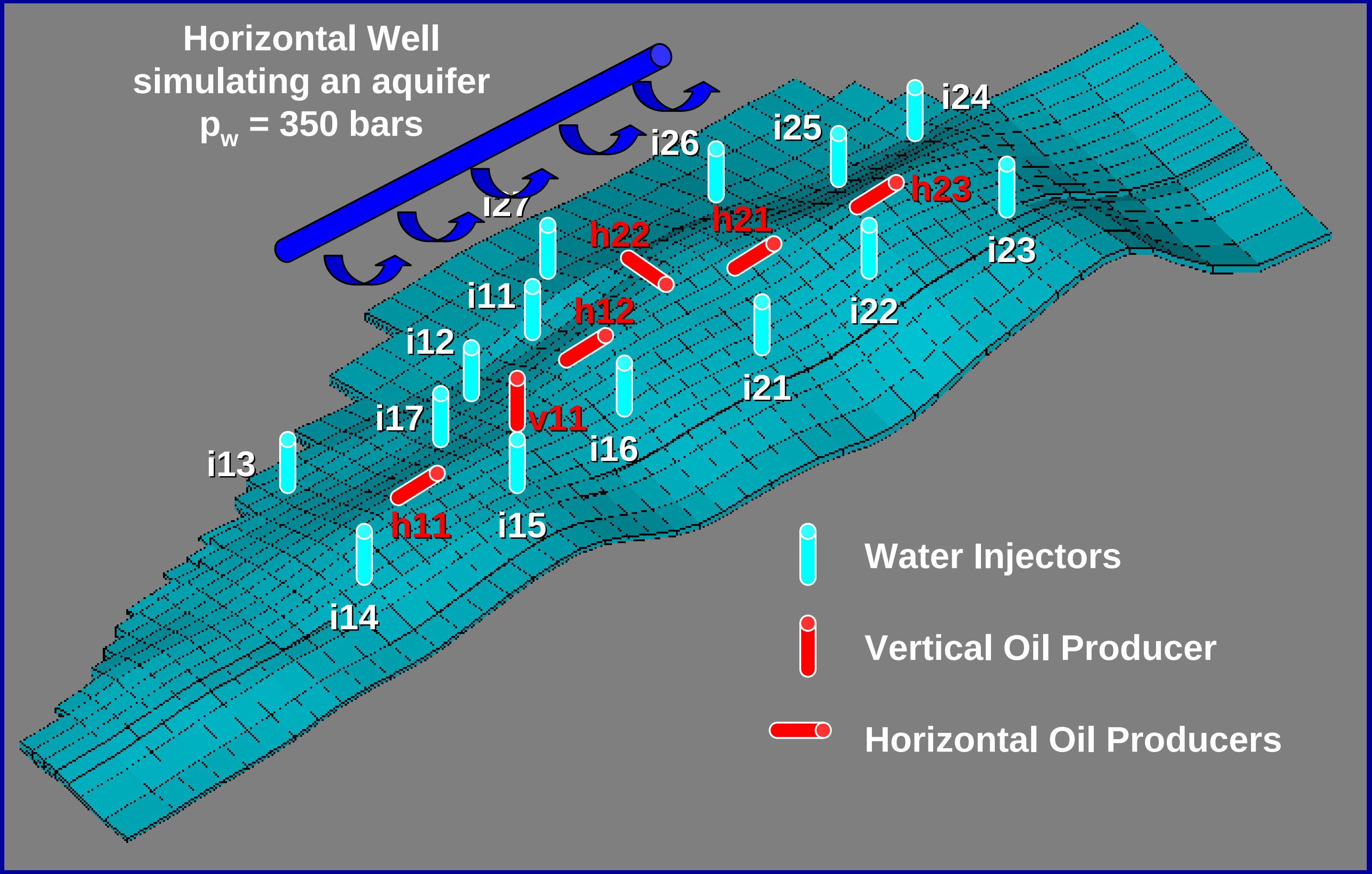
Workflow:

1. Presentation of the reservoir model and simulations,
2. Elaboration of the geomechanical model,
3. Coupled reservoir-geomechanical simulations,
4. Selection of a well with stress history (production and abandonment),
5. Effect of cap rock mechanical properties on stress history
6. Well bore mechanical model: analysis of a reference cement plug.
7. Sensitivity tests on plug elastic properties

Reservoir Model Geometry

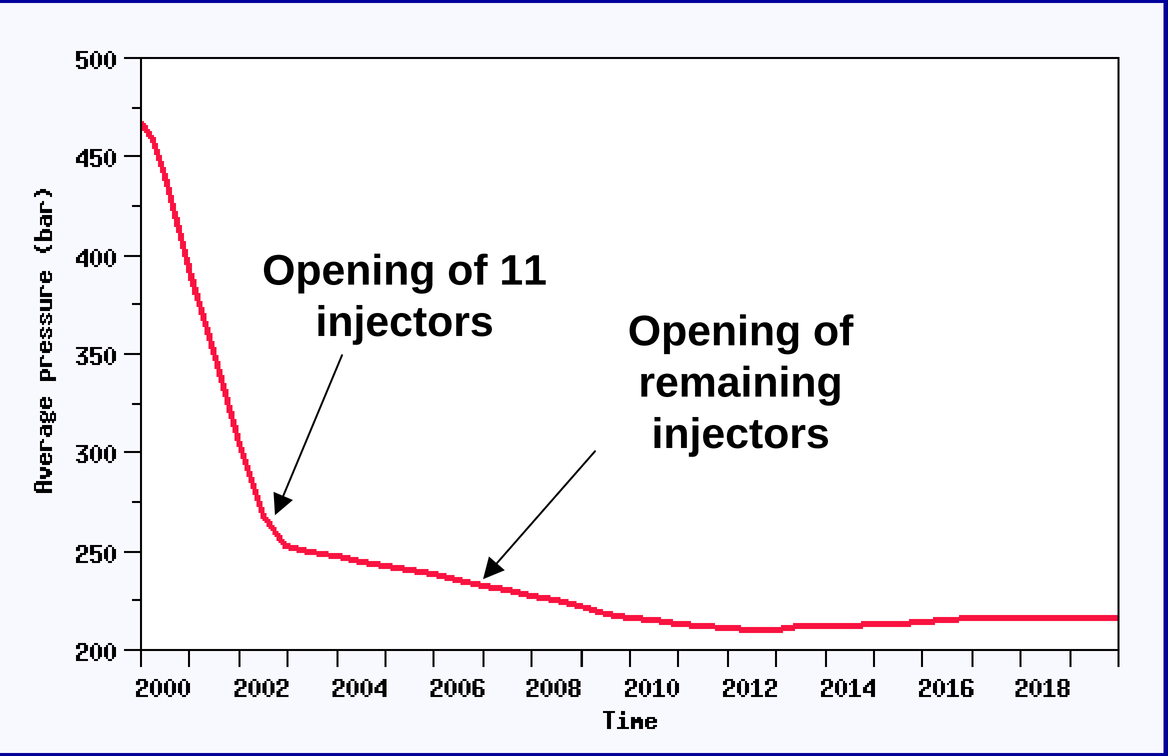


Reservoir Production Pattern



Production History

- Average Pressure vs. Time during the Exploitation Period



End of production

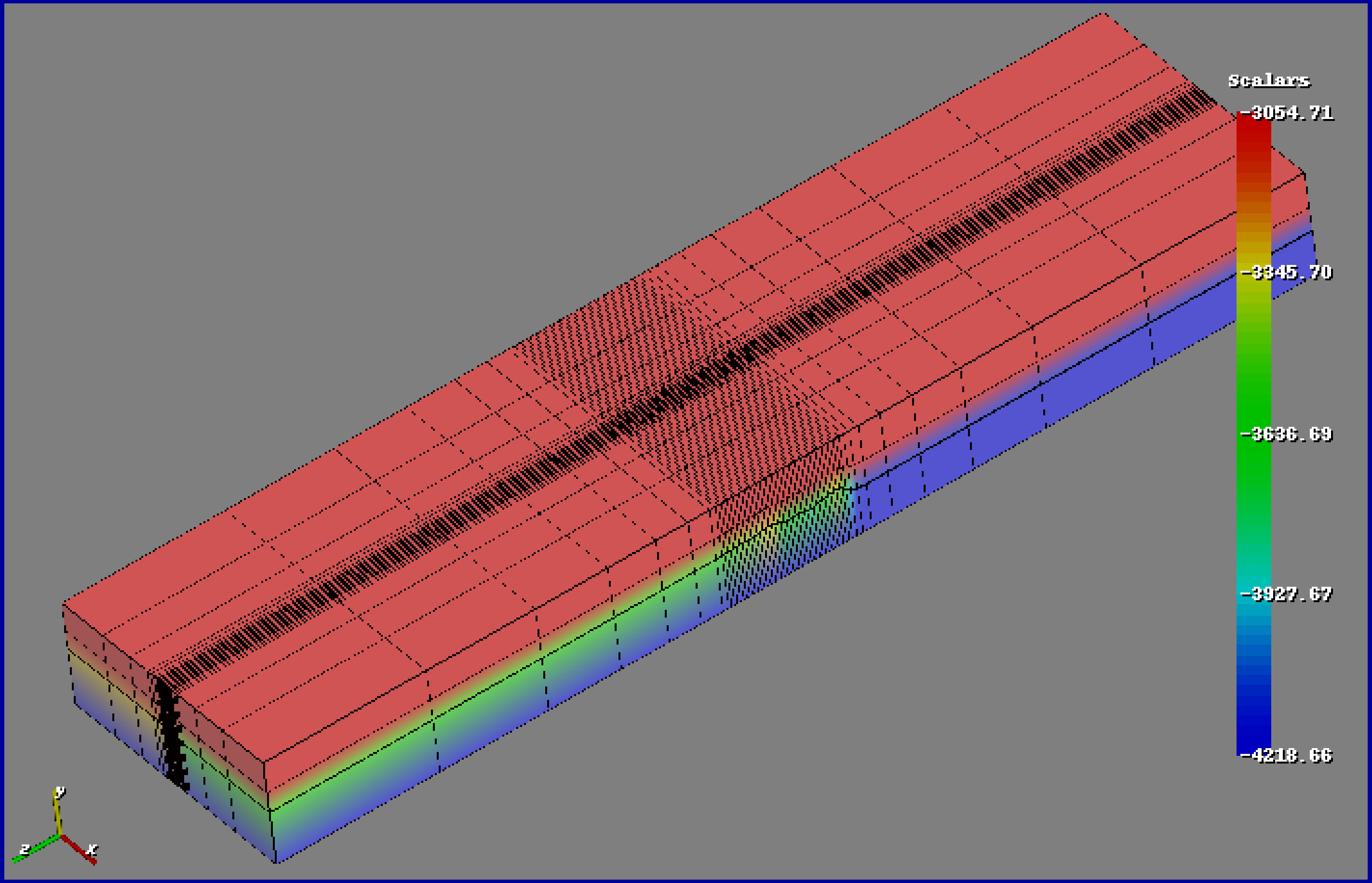
Natural depletion

Production with water injection

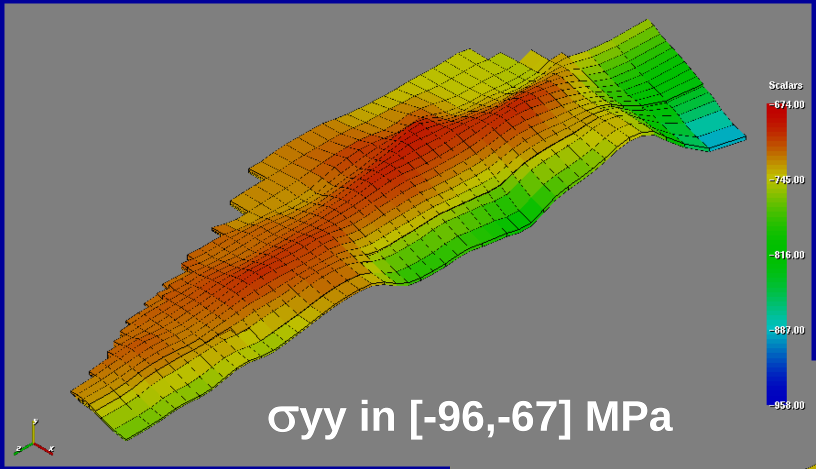
Geomechanical Model

- Finite Element Stress Simulator (THM coupling)
- Large Geomechanical Domain with Various Regions (Rock-Zones)
- Geomechanical Mesh:
  - Superposition of Geomechanical and Reservoir Cells in the Reservoir
  - Construction of an Enlarged Mesh including Surrounding Formations
- Constitutive Laws and Mechanical Properties
- Boundary and Initial Conditions

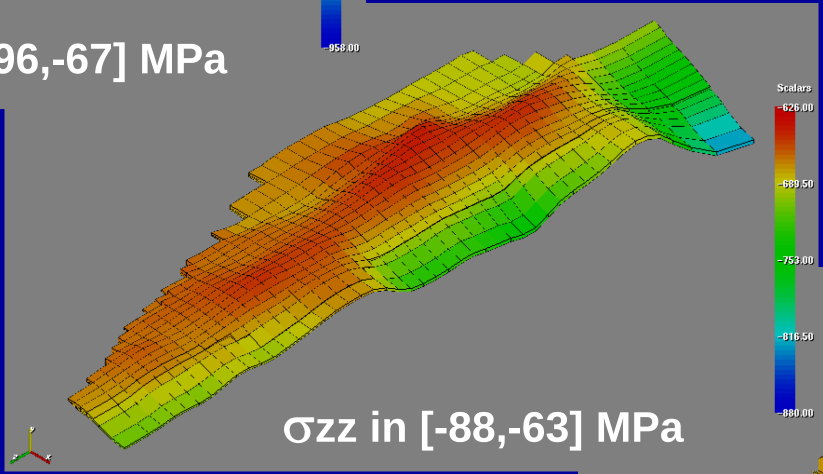
Construction of the Geomechanical Mesh



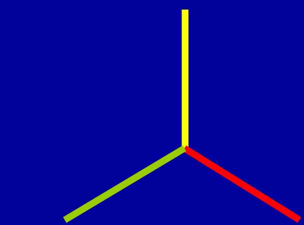
Initial Stress State in the Reservoir



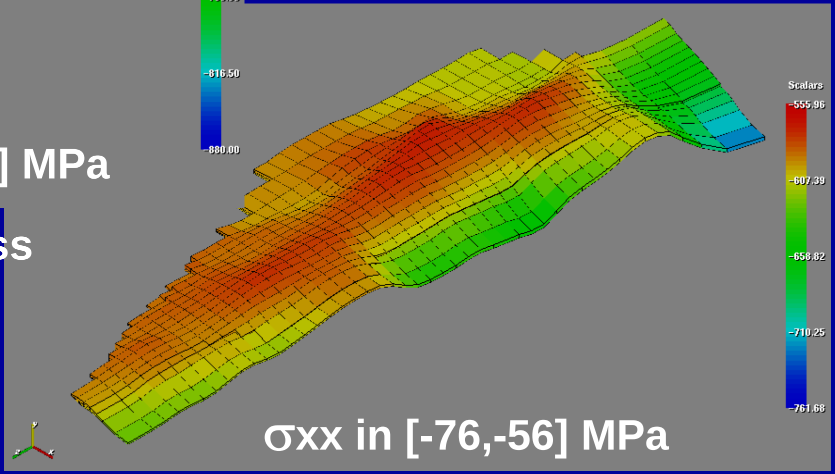
Total Vertical Stress



Total Horizontal Major Stress



KH = 0.8 Kh = 0.5

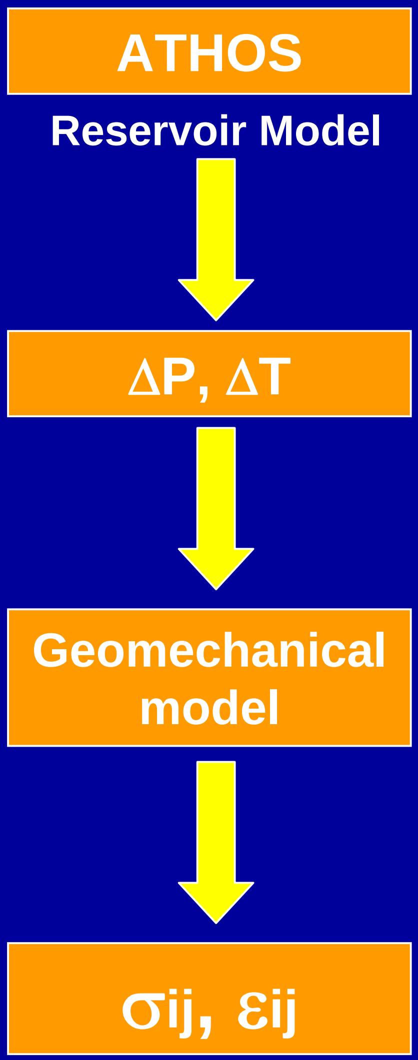


Total Horizontal Minor Stress

Coupling Methodology between Reservoir and Geomechanics

- **ATHOS and VISAGE exchanges during one step of coupling**

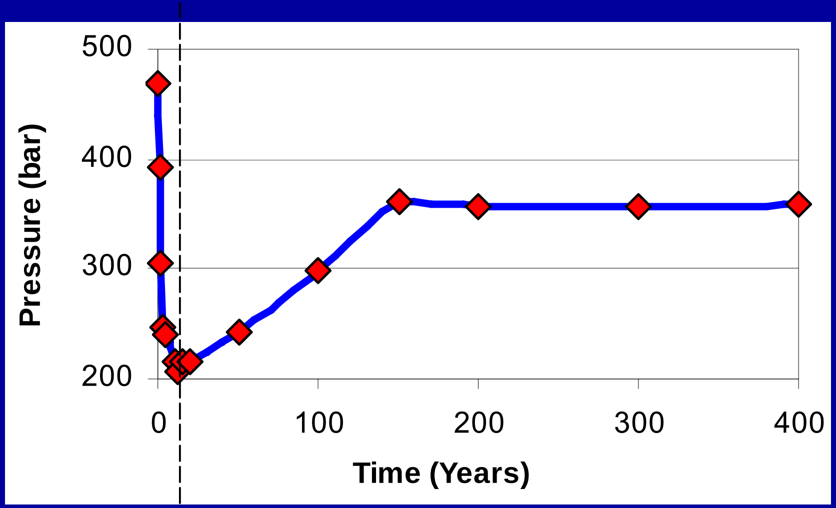
- **One-way coupling: no modification of petrophysical properties induced by reservoir compaction**

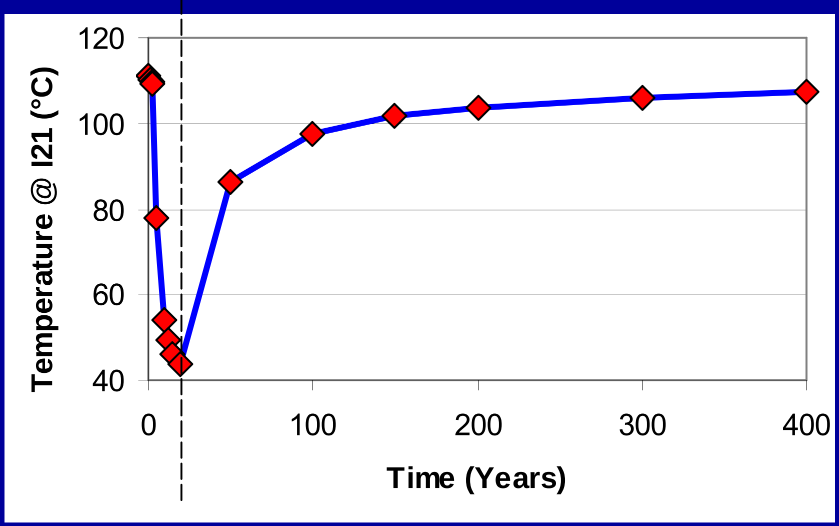


Coupling Periods

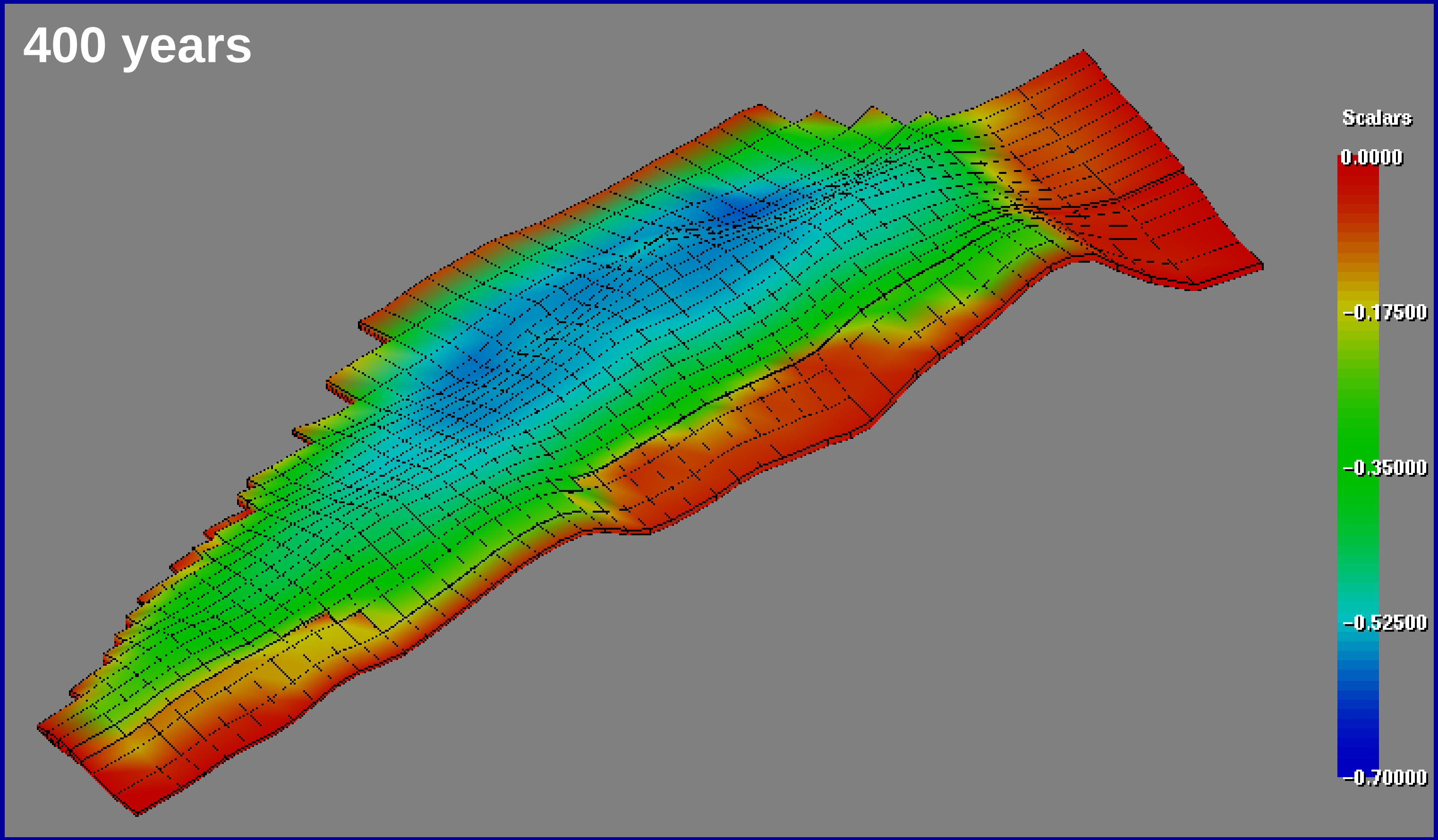
Choice of Coupling Periods :

Step	Time (years)	Events influencing stress changes
0	0	Stress initialization
1	1	High pressure drop due to the reservoir natural depletion
2	2	
3	3	
4	5	Low pressure variation and cooling due to cold water injection
5	10	
6	12	
7	15	Pressure stabilization and low thermal changes
8	20	
8	20	Abandonment
9	50	Reservoir re-pressurization and warming due to abandonment
10	100	
11	150	
12	200	Pressure stabilization and slow warming
13	300	
14	400	

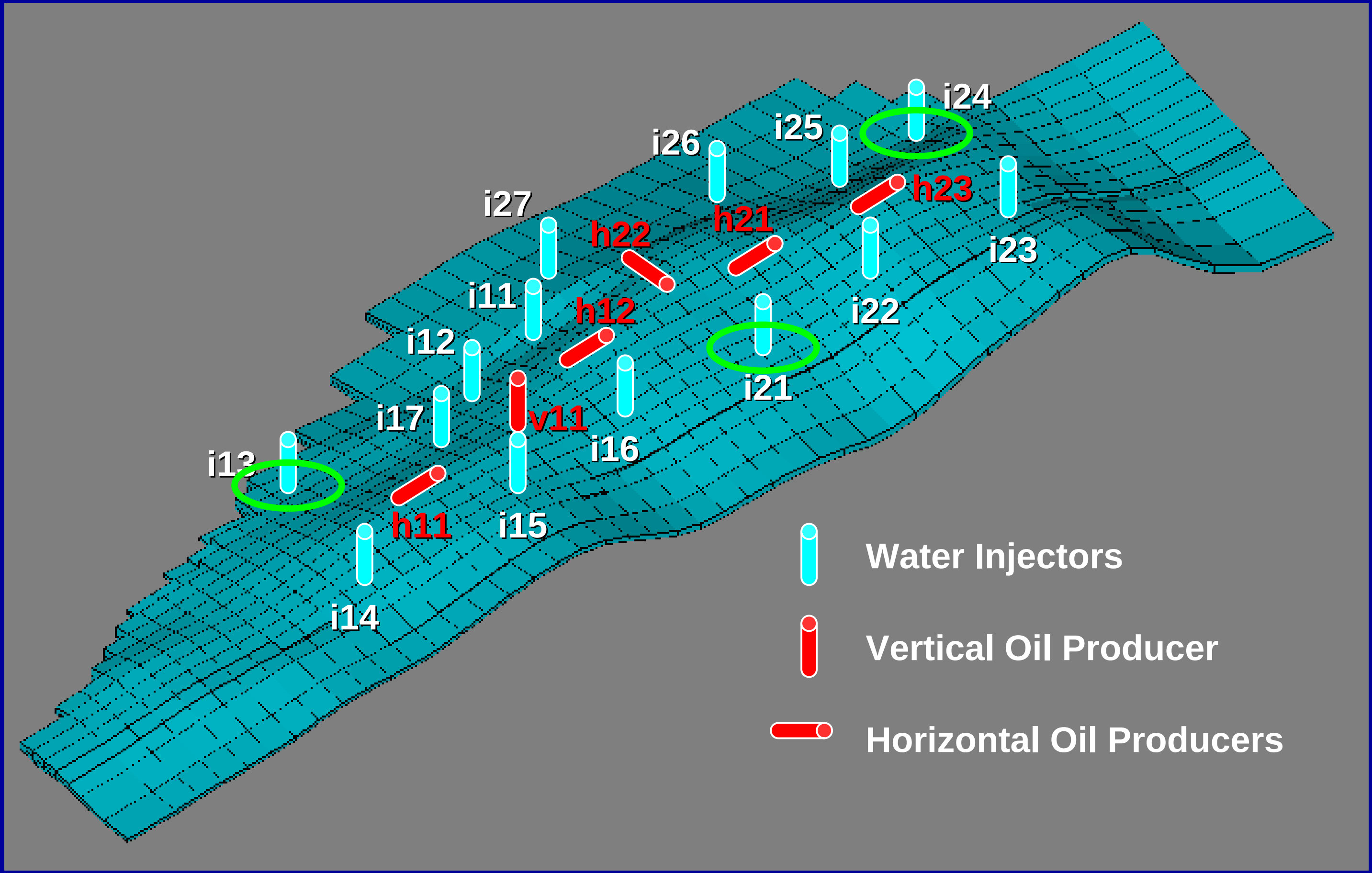




Total Vertical Displacement with Time

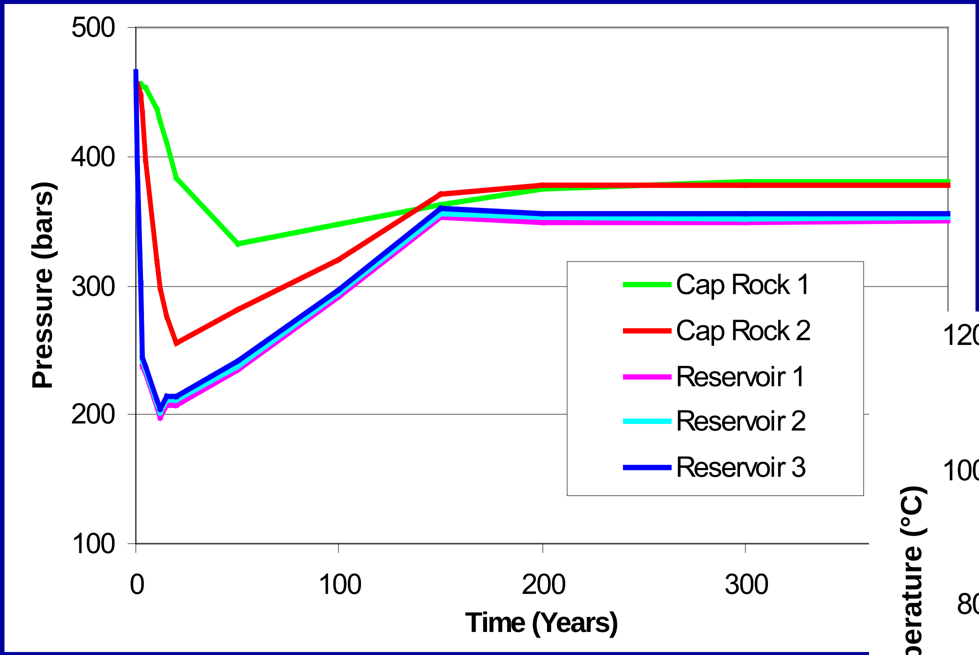


Selection of one Injector (vertical well)

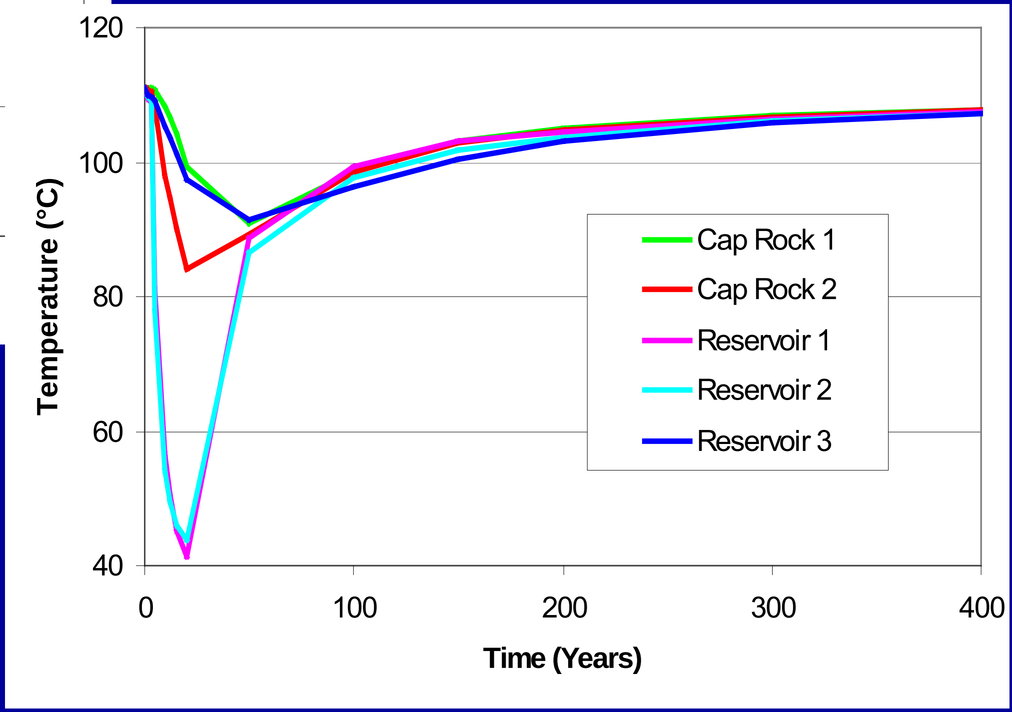


Selection of wells where the P, T or stresses variations are the largest

Pressure and Temperature Changes for I21



Pressure evolution



Temperature evolution

Biot's Coefficient Bounds

- Uncertainty on pressure changes in the cap rock
- Biot's coefficient linked the effective stress changes with pressure changes:

$$\sigma'_{ij} = \sigma_{ij} + bp\delta_{ij}$$

- Biot's coefficient:

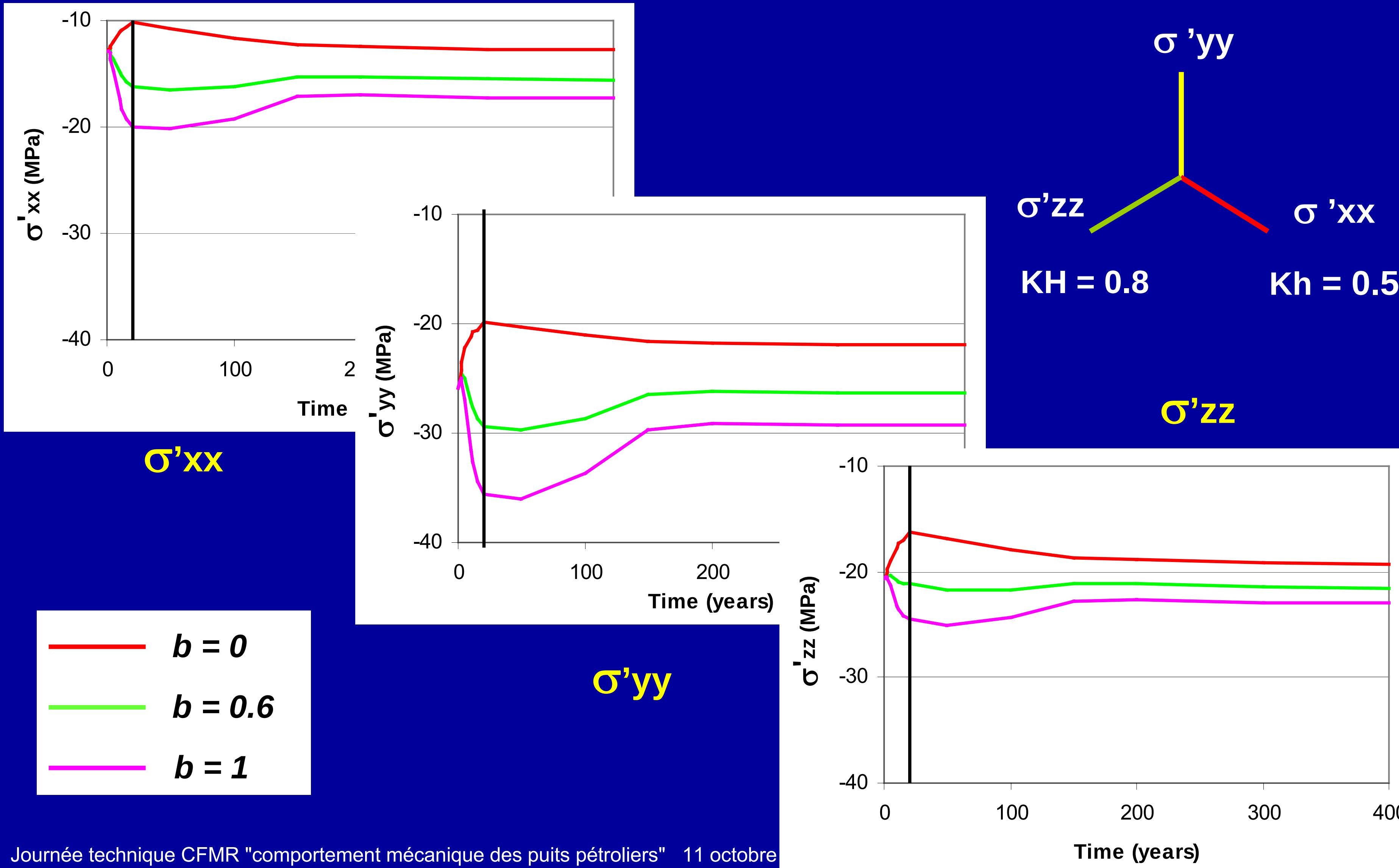
$$b = 1 - \frac{K_d}{K_s}$$

K_d ← drained bulk modulus

K_s ← matrix bulk modulus

- Higher bound for uncompressible skeleton *b = 1*
- Lower bound for low porosity rock *b -> 0*

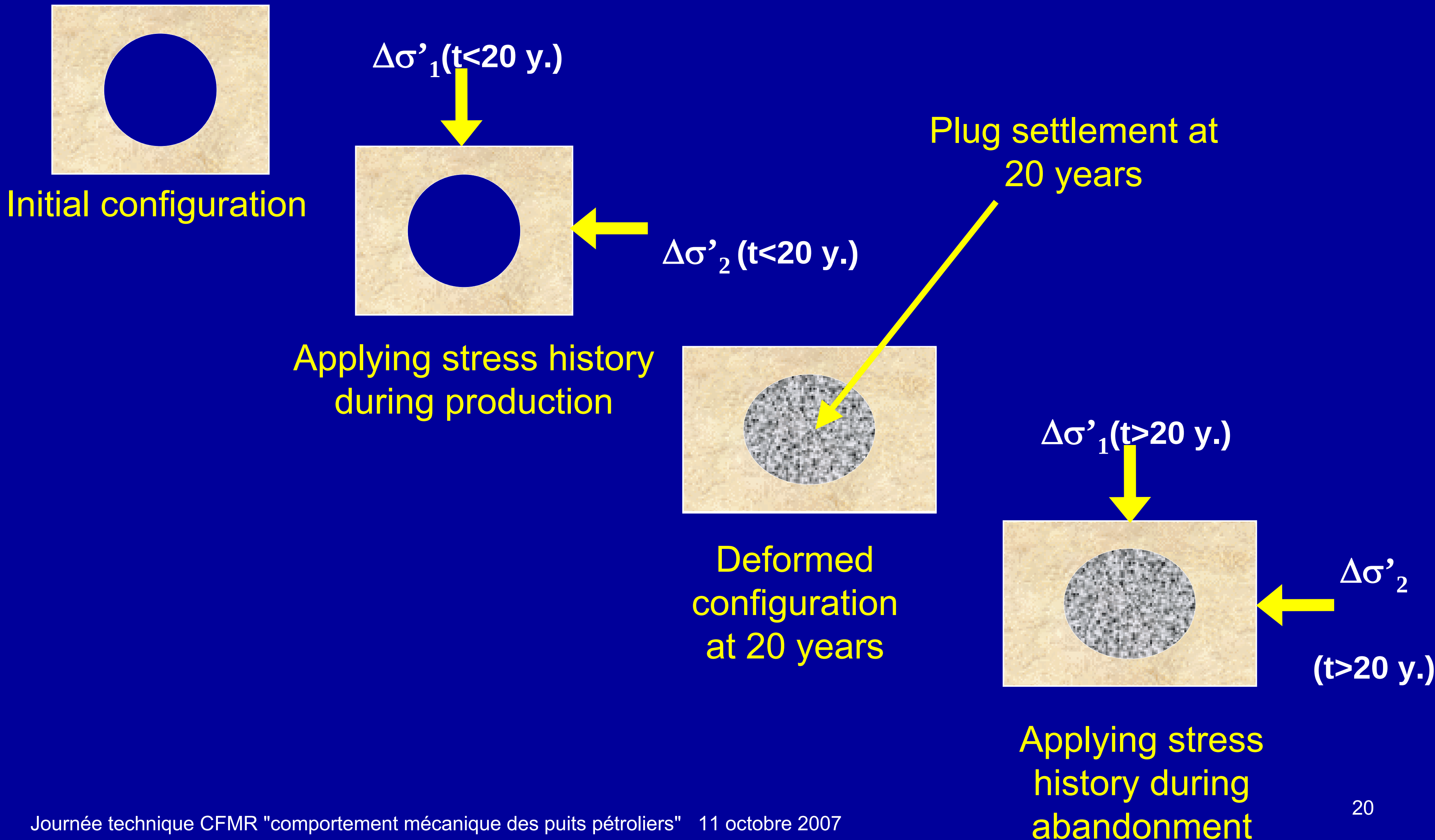
Effect of *b* on Effective Stress Changes in the Cap Rock for I21



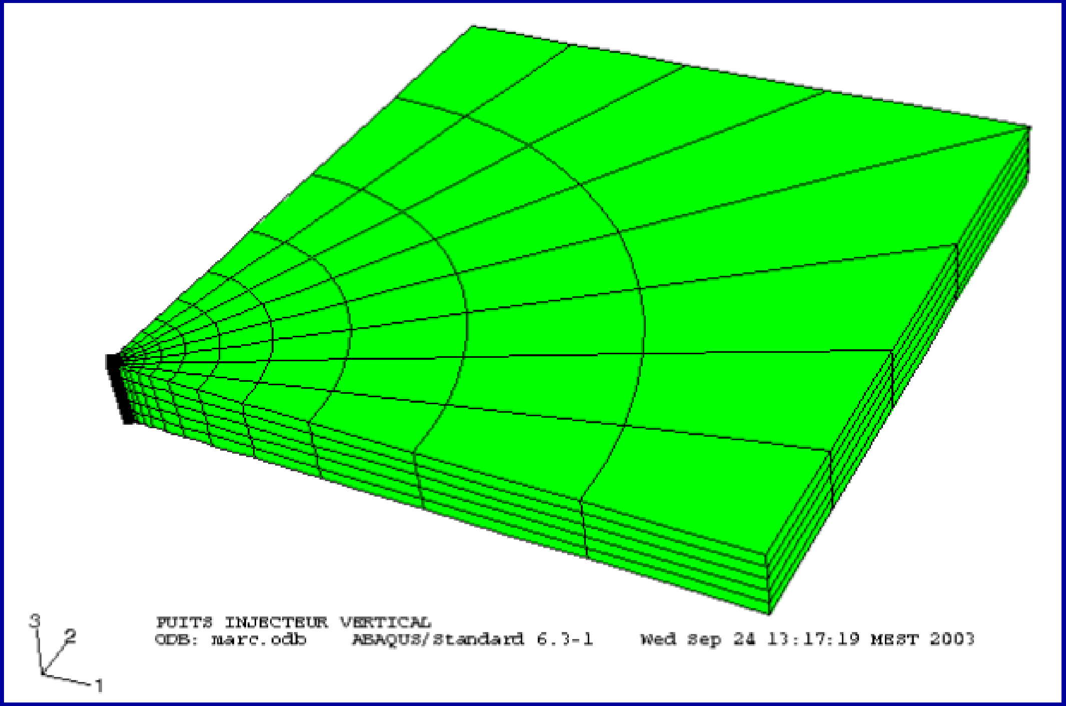
Well Bore Stress Model

- Mechanical modelling of the plug settled in the cap rock
- Model submitted to extreme stress history provided by the Geomechanical simulator
- 3D simulations with ABAQUS Finite Element code
- Open hole configuration
- Analyse performed for a conventional cement plug

Stress History for the Well Bore Stress Model

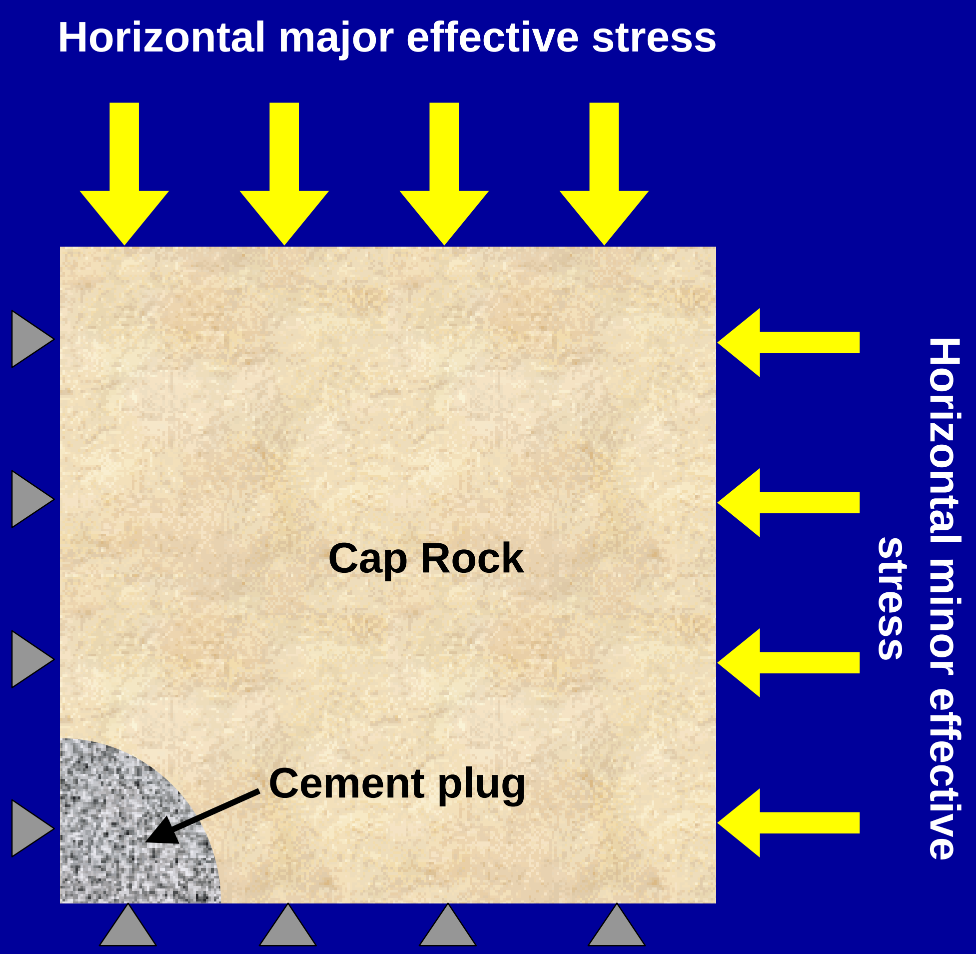


Well Bore Geometry for Vertical Injector I21



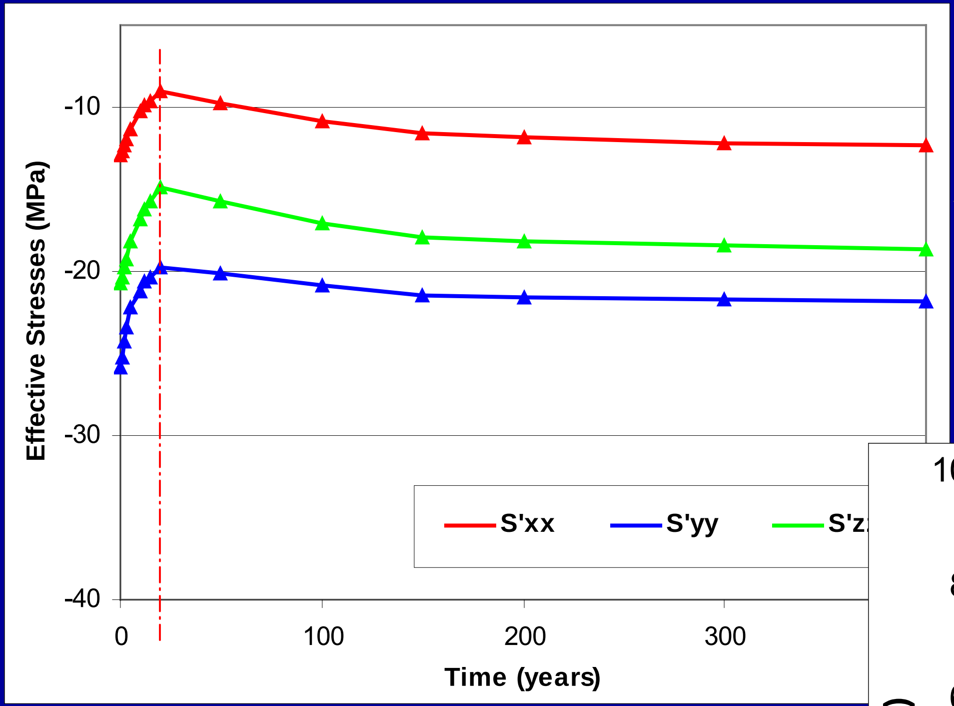
- Horizontal section of the cap rock perpendicular to well axis
- Modeling a quarter of the well
- Section 1 meter tick, 10 meters wide
- Well radius = 10 cm
- 5 finite elements along direction 3

Boundary Conditions and Loading for I21



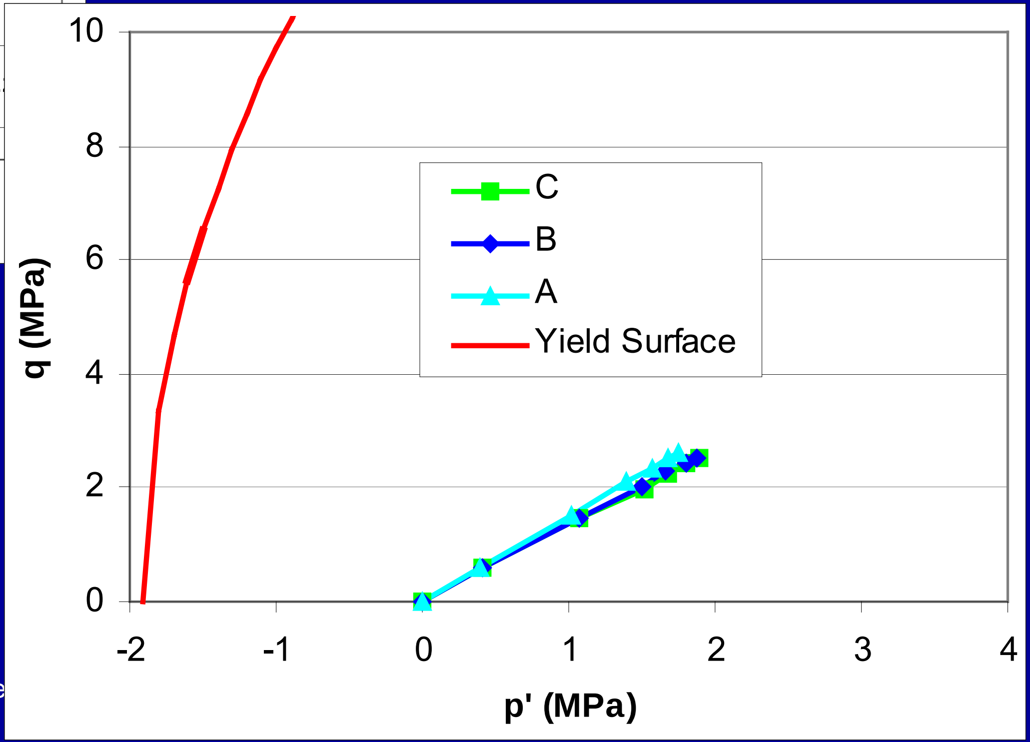
- Extreme effective stress changes provided by reservoir geomechanical simulation
- Thermal load
- No effective stress in the plug at the beginning of abandonment
- The vertical effective stress is perpendicular to the section and is applied only on the cap rock

Stress Path in the Top Layer for I21 and *b = 0*

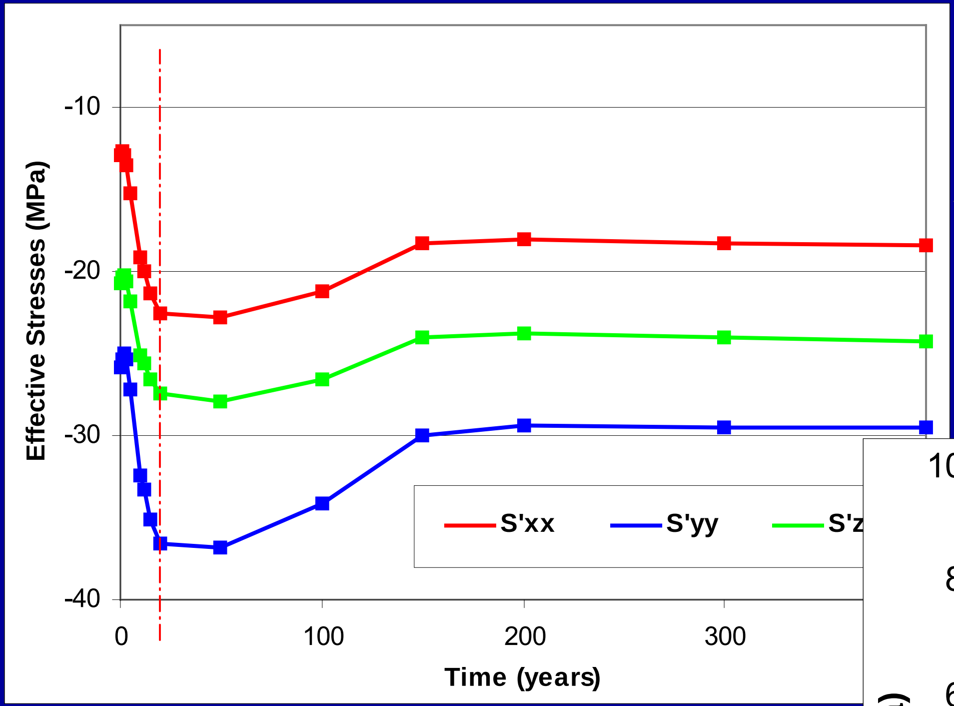


Effective stress load

Stress path in the plug

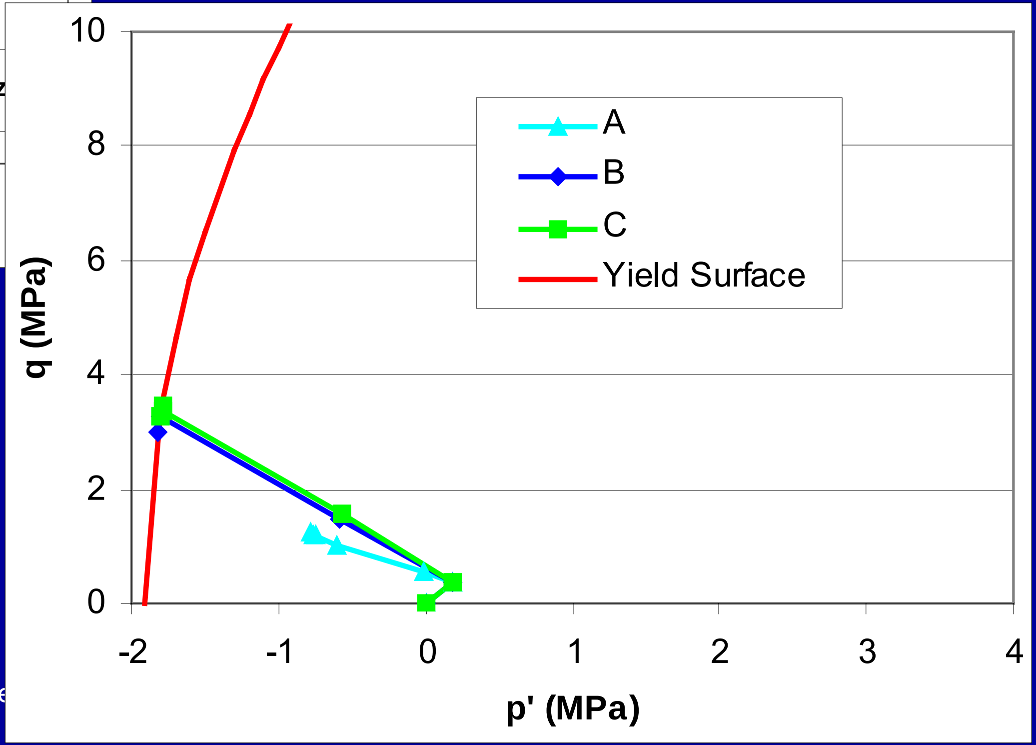


Stress Path in the Top Layer for I21 and *b = 1*

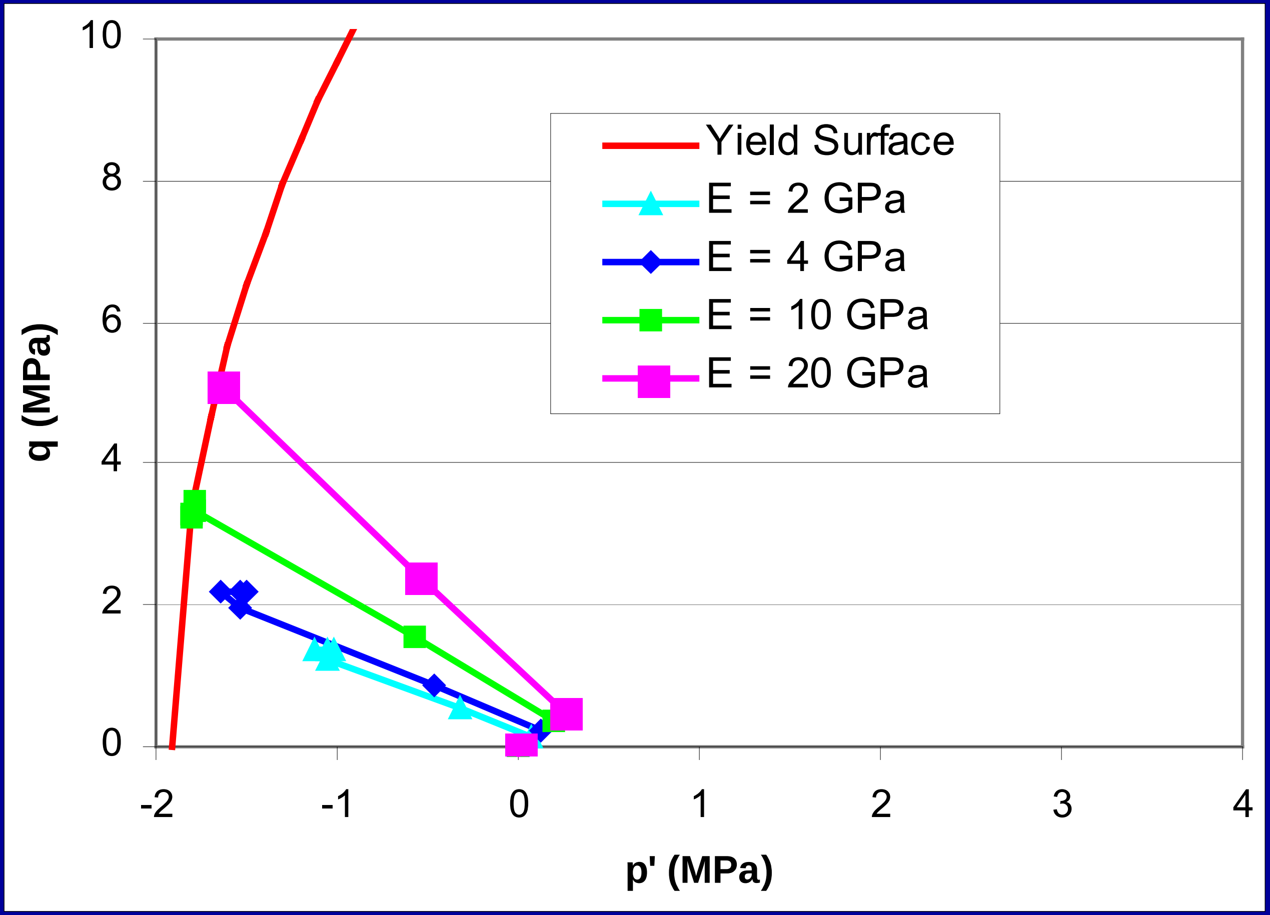


Effective stress load

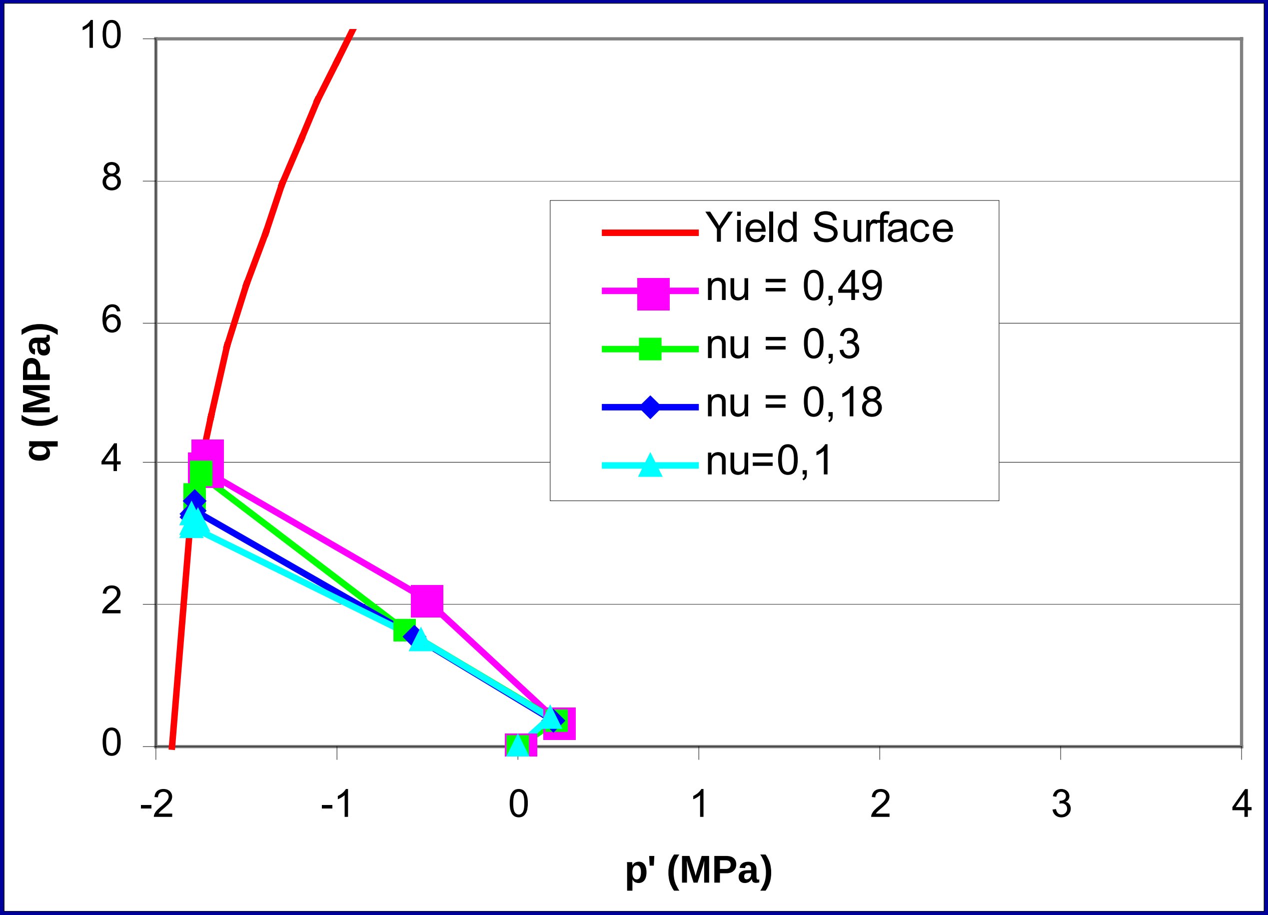
Stress Path in the plug



Sensitivity Test on Young's Modulus



Sensitivity Test on Poisson's Ratio



Conclusions

- Development of a multi-scale methodology to model plugged well behavior during production and abandonment
- Modeling well behavior requires to consider :
    - structural effects
    - material heterogeneity around the well,
    - effect of pore pressure, temperature, chemical effects, ...
    - progressive restoration of P, T, evolution of chemical effects, ..., during abandonment
- Soft sealing materials or initially (thermally) pre-stressed cementitious plugs appear to be more adapted to the downhole condition changes that may occurs after well plugging and abandonment.

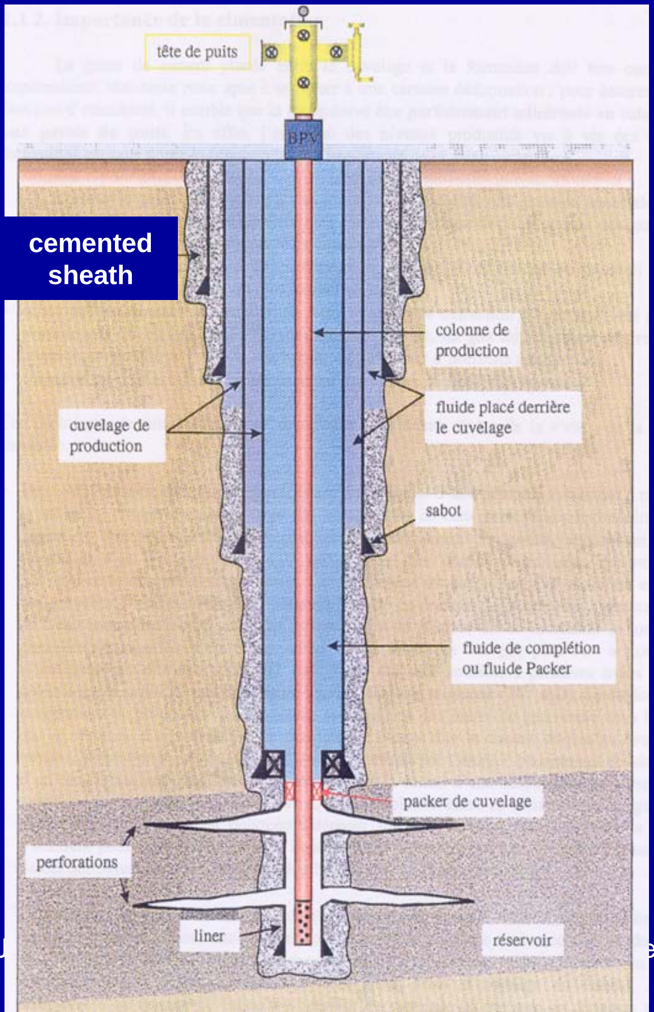
Furthers works

- The risk of debonding at the cement/rock interface must be closely analyzed because it will largely reduce the plug sealing capacity,
- Initial stress state that develops in the plug during and after curing :
    - thesis : December 2006 → 2009 - Estimation of cement stresses after cement setting in oil and gas wells
- Ageing of plug materials
- Integration of chemical effects (CO_2 sequestration)

Thesis : December 2006 → 2009

Estimation of cement stresses after cement setting in oil and gas wells

Phd Student : M. Bourissai
Université Marne la Vallée : G. Bonnet, F. Meftah
IFP : N. Brusselle, F. Adjémian, E. Lecolier



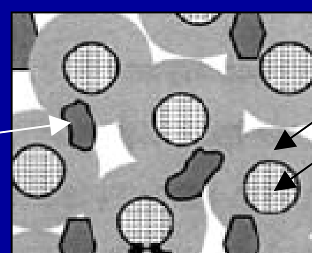
- Some features of setting in the bottom of wells :
  - Setting under stress and temperature : ~ 120 bars, 60°C
  - Evolution of the sheath pressure during setting : possible hydraulic movements between the sheath and the rock
    => risk of gas or fluid coming into the annular :
    - from a microannular resulting from the cement shrinkage
    - or, in a not enough consolidated cement

Cement setting → thermo-chemo-mechanical behaviour at very early age

WATER + CEMENT — *SETTING* — COHESIVE CEMENT PASTE

Mechanical strength development : solid skeleton

Anhydrous cement hydration : exothermic reaction



Scale $10^{-6} – 10^{-4}$ m

Shrinkage of the cement paste // Decrease of pore pressure

Estimation of cement stresses after cement setting in oil and gas wells

- Purpose of the thesis :

  characterization and modelling of the thermochemomechanical behaviour of the cement at very early age, in the porous media framework

– Experimental part
  - DSC analyses: effect of HPHT conditions on hydration
  - Mechanical characterization at several setting times :
    - » creep tests under simple compression, ...
    - » rheological analyses
    - » undrained triaxial tests : experimental characterisation of poroelastic parameters
  - Shrinkage measures and pore pressure evolution

IN PROGRESS

– Modelisation part
  - self-consistent sheme for the determination of K et G during hydration