Compaction – Fluid Flow Interaction: The Hows and Whys of Coupled Rock Mechanics and Flow Simulation

IOR Norway, April 2015

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Support & Inspiration: BP Valhall Project

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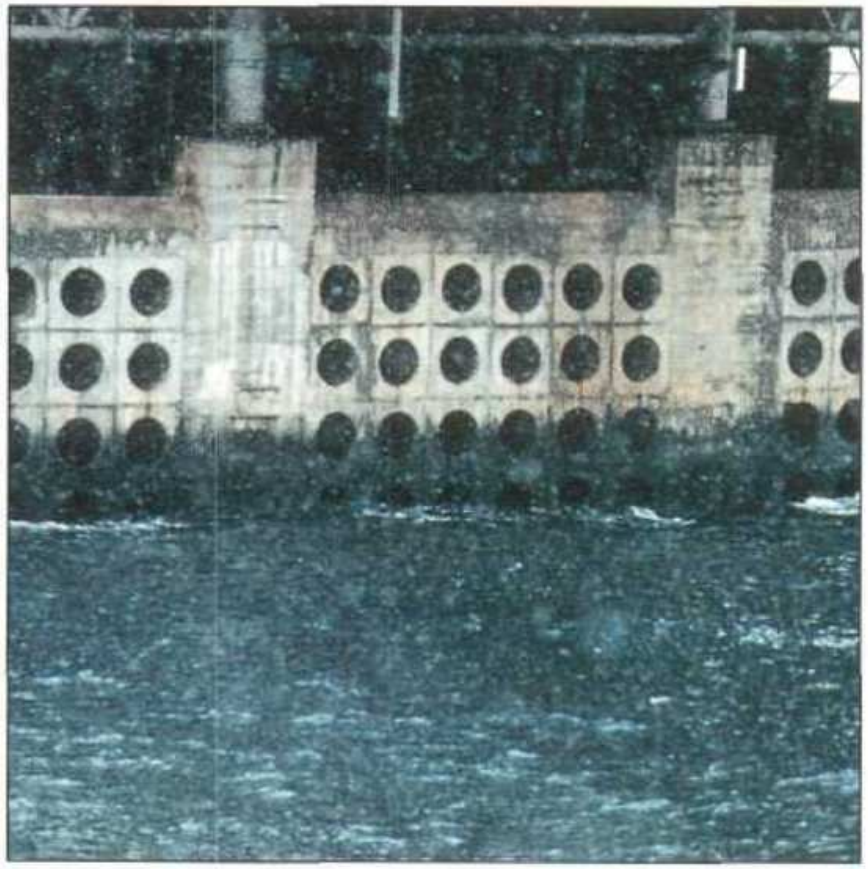
Well known Example of Subsidence

Ekofisk tank in 1975 and 1986

Reservoir displacement observable at surface



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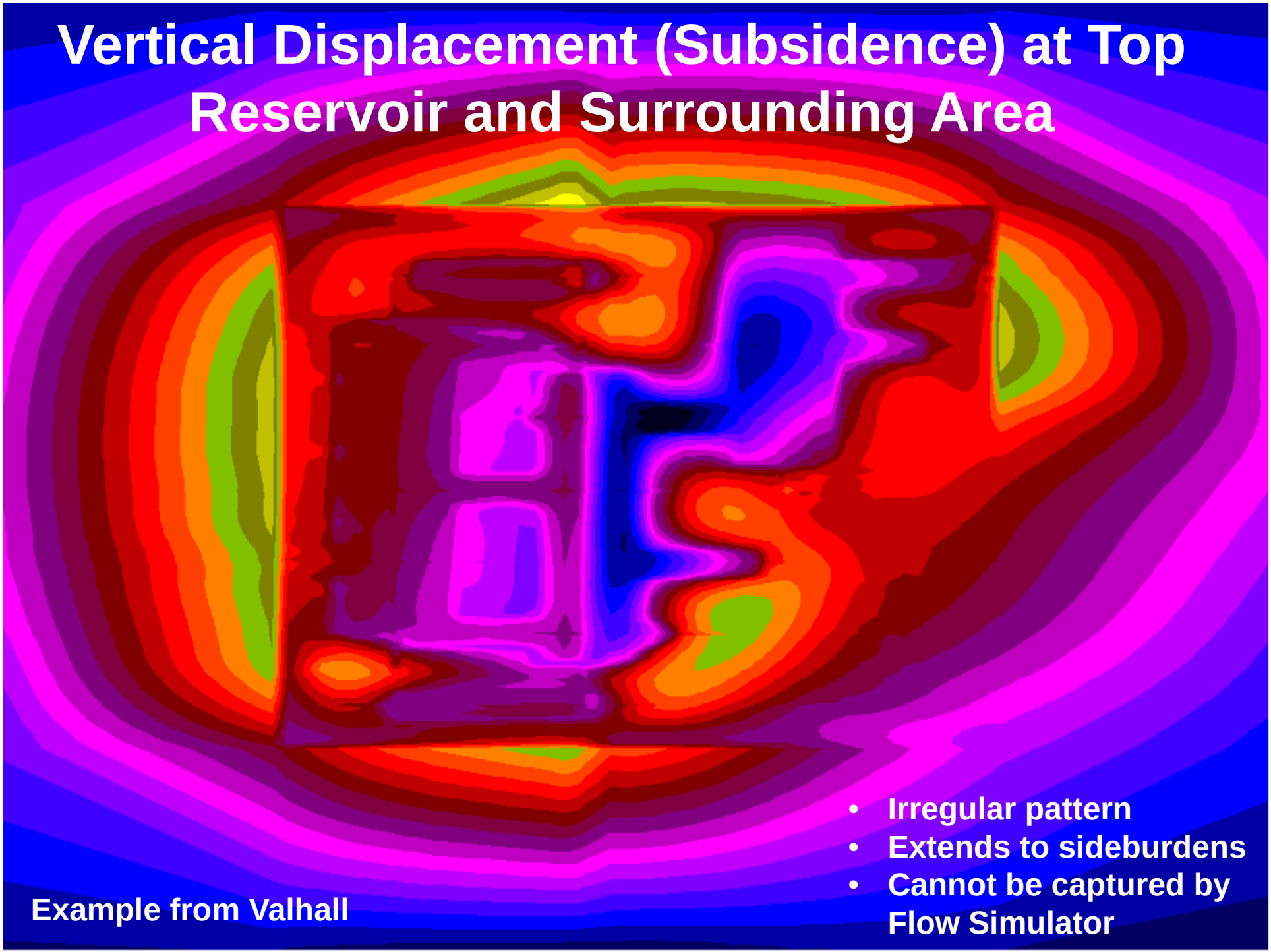
Vertical Displacement (Subsidence) at Top Reservoir and Surrounding Area

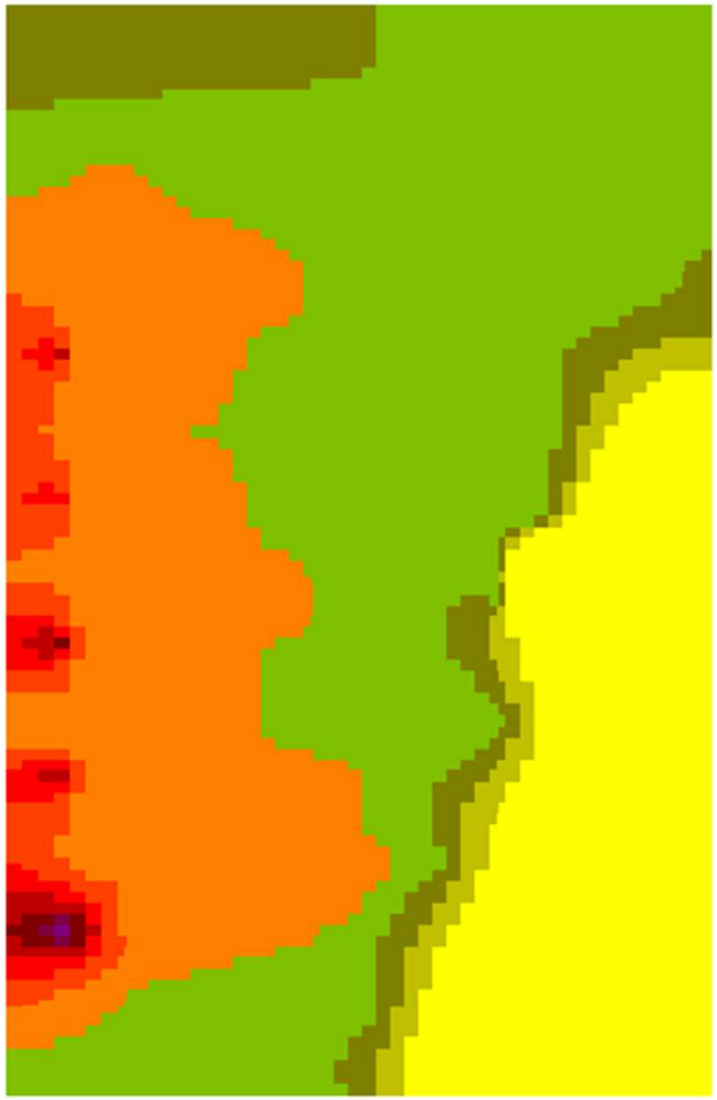


- Irregular pattern
- Extends to sideburdens
- Cannot be captured by Flow Simulator

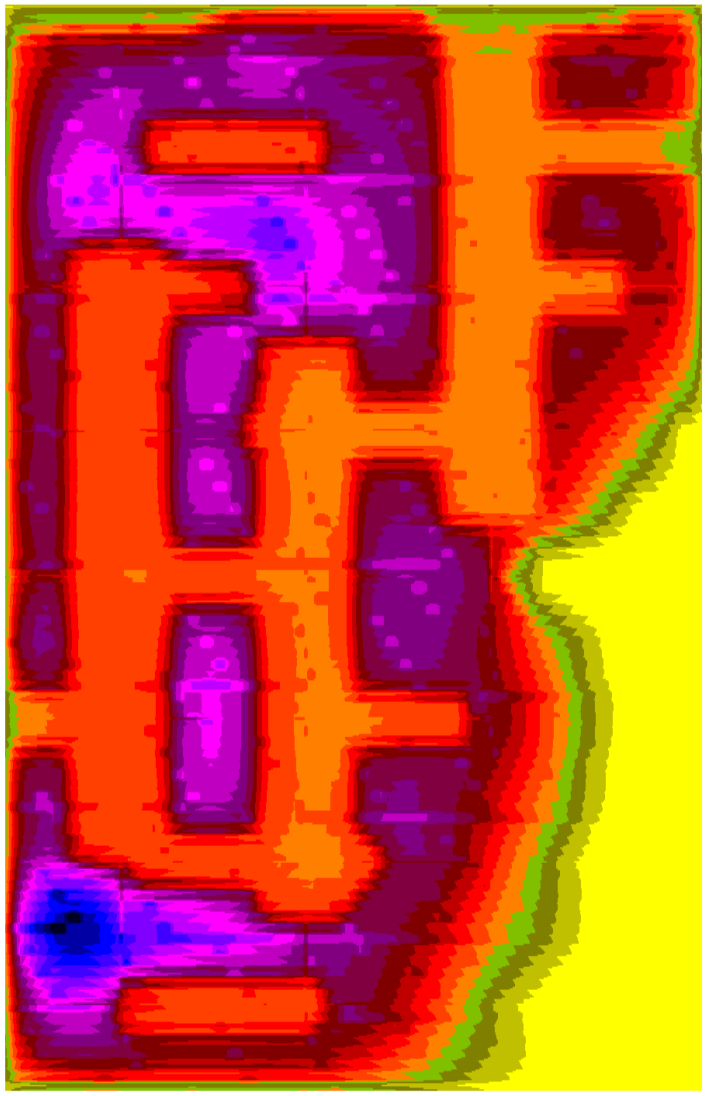
Example from Valhall

Porosity Change Caused by Compaction

(Areal View)



Standard Eclipse



Coupled Rock Mech Simulator and Eclipse

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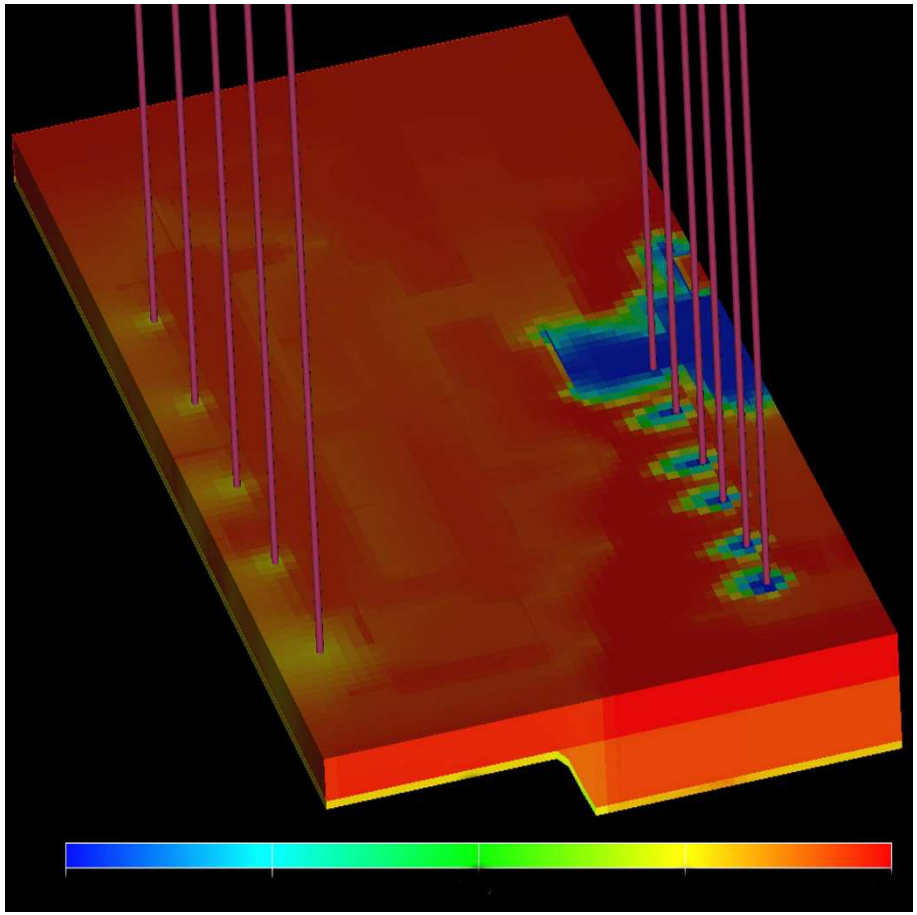
Consequence Fluid Flow Simulation

(Water Saturation)



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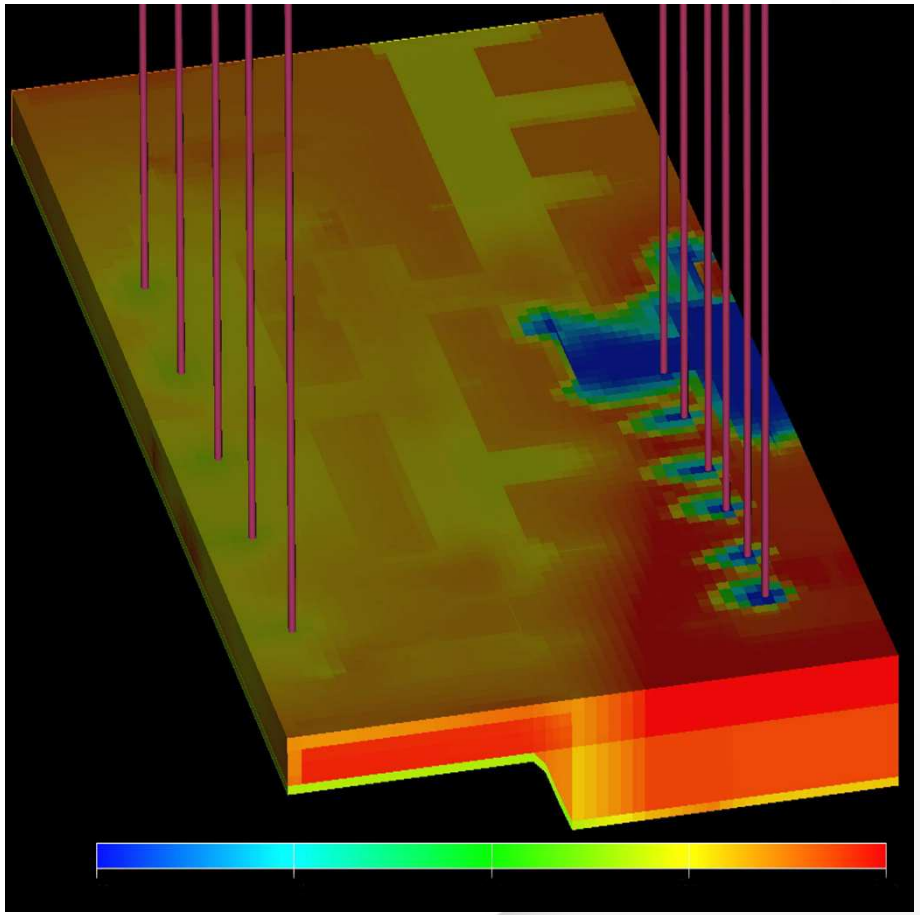

Coupled Rock Mech Simulator and Eclipse

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Rock Mechanics Effects may be important on some “special” fields, like Ekofisk and Valhall,
but for the majority of fields can safely be neglected.

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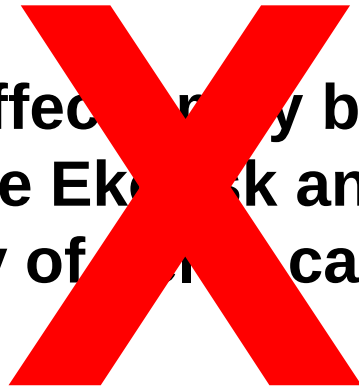
Myth:

Rock Mechanics Effec y be important on some "special" fields, like Ek k and Valhall, but for the majority of can safely be neglected.



- **Rock Mech Effects has a significant impact in many (most?) North Sea Fields**

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Rock Mechanics and Fluid Flow Simulators

Rock Mechanics:

- **Many models for Material Behavior**
- **Advanced Failure Models**
- **Complex and tricky computations**
- **Handles (very) complex geometries**
- **Simple / Limited:**
  - **Fluid description**
  - **Wells**
  - **Structural description**

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Rock Mechanics and Fluid Flow Simulators

Flow Simulators:

- **Simplified Compaction model**
- **No other Rock Mech Features**
- **Advanced handling of**
  - **Fluid Description**
  - **Wells**
  - **Structural Description / Petrophysics**
  - **Numerics**

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Rock Mechanics and Fluid Flow Simulators

At present;
Fully Coupled Simulators exist, but none are leading edge on both kinds of options.

Also, Unbalance:
Rock mech simulations computing times typically 10-100 times flow sim.
Hence, often can't afford to compute rock mech solutions at every (flow sim) time step.

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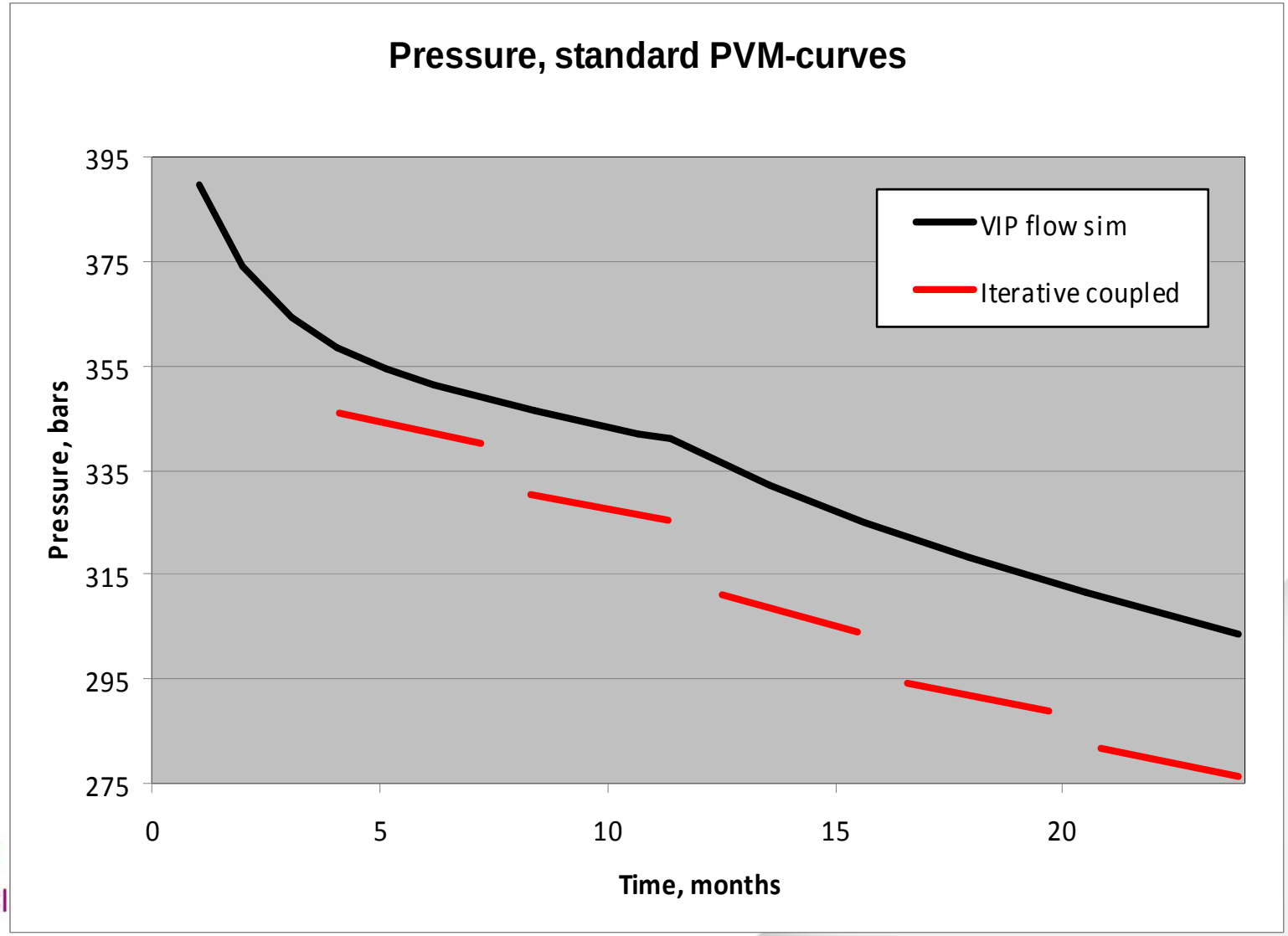
Disadvantage of Large Stress time Steps:

Pressure only correct at stress steps, “drifts” in between



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Existing solutions are not ideal

How to improve on coupled simulations?

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Rock Mech Sim:

Stress σ

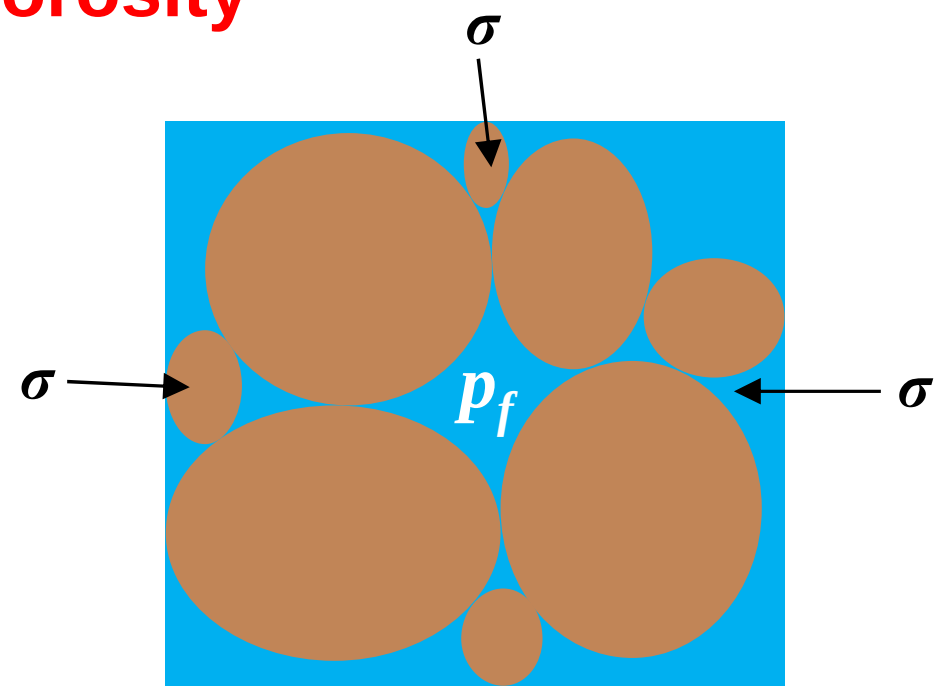
Deformation

Effective porosity

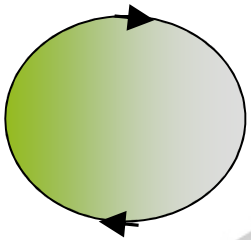
Fluid Flow Sim:

Pressure p_f

Flow velocity



Effective porosity depends on p_f



p_f depends on Effective porosity

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Rock Mechanics and Fluid Flow Simulators

Classic iteration:
Estimate p_f → Calculate effective porosity
→ Recalculate p_f … until convergence

Challenge: Each Rock Mech calculation can take hours, even days.
(Improving – both hardware and software)

Naturally we want to speed this up
(Preferably without accuracy loss)

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The Coupling Term

Flow Simulator assumes porosity depends on pressure, which at the best is inaccurate

Nevertheless we want to construct a *local* porosity vs. pressure relationship.

Use pressure from flow sim to calculate accurate porosity (by stress simulator).

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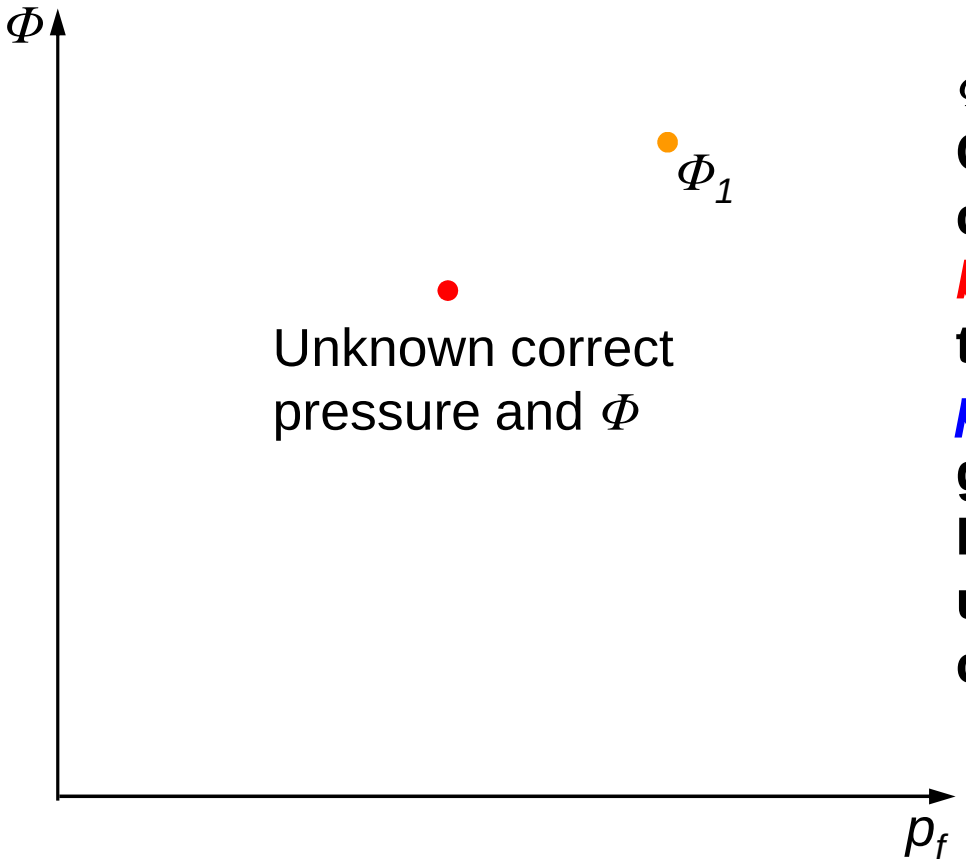
The Coupling Term



Φ_1:
Calculated porosity – pressure combination. Both are wrong, ***but***
the point is a ***valid pressure – porosity combination*** **for the given problem.**
Hence lies on some as yet unknown porosity vs. pressure curve.

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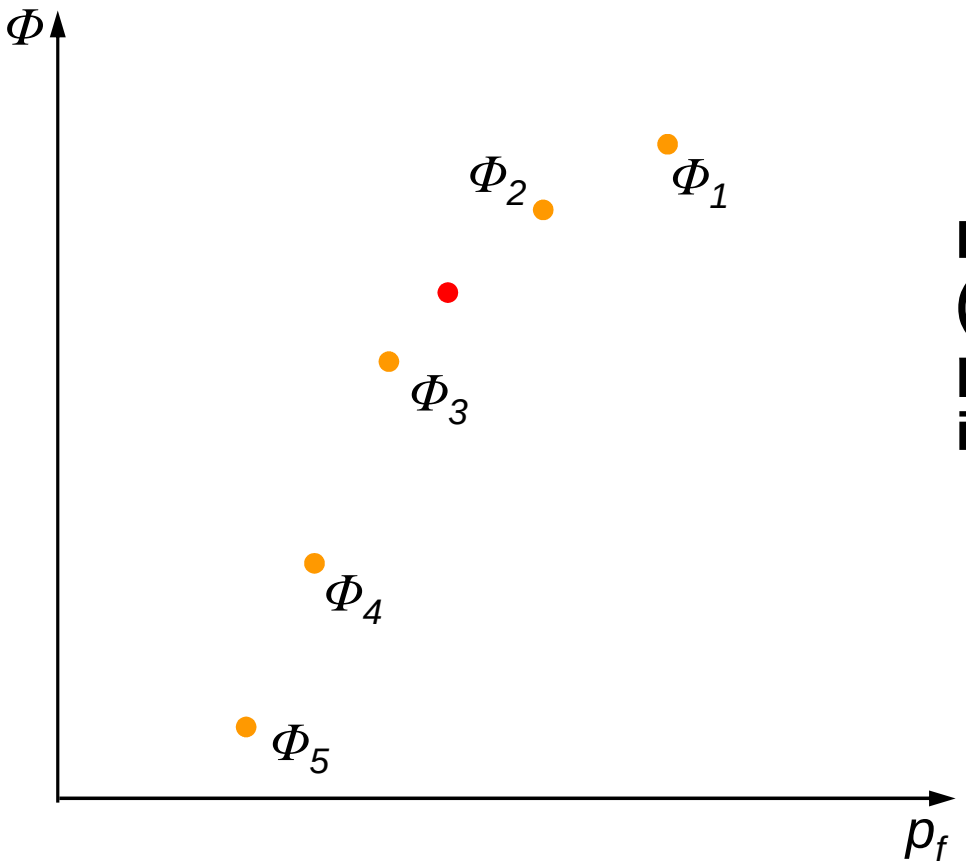
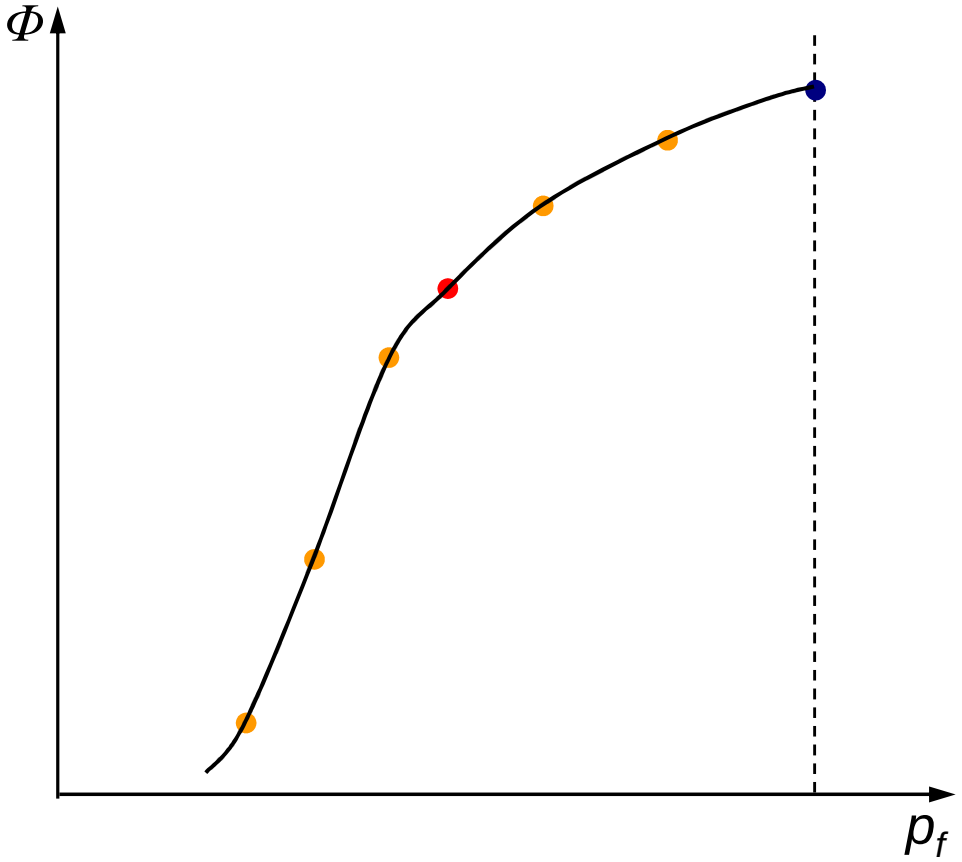
The Coupling Term



Repeat procedure for (preferably) decreasing pressures – obtain points 1 – 5 in Figure.

The Coupling Term



Result:
The desired porosity vs. pressure curve.

NOTE:
Valid at *this point in space only*.
(Need one curve for every point in reservoir.
→ No problem; Flow Sim easily handles hundreds of thousands of curves**)**

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The Coupling Term

Using this relationship in the flow simulator:

- **Get accurate porosity & pressure directly**
- **Get optimal starting point for stress simulator**
  - **No (or few) iterations needed**
- **Experience from actual simulations:**
  90 – 99 % reduction in computing times
  No accuracy loss
- **Can use standard simulators, no exchange code needed**

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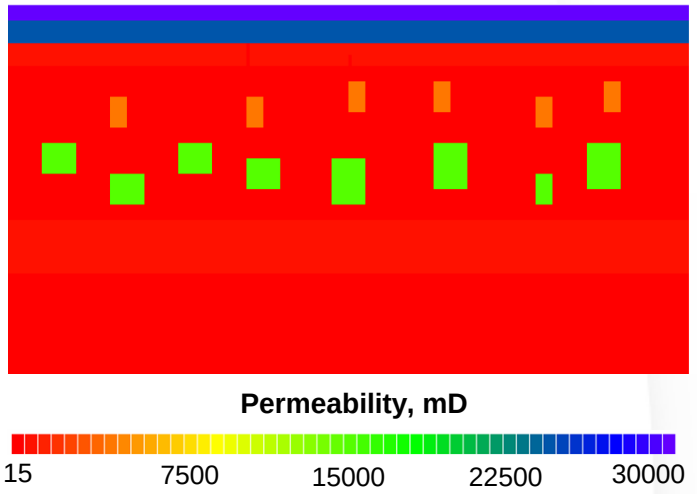
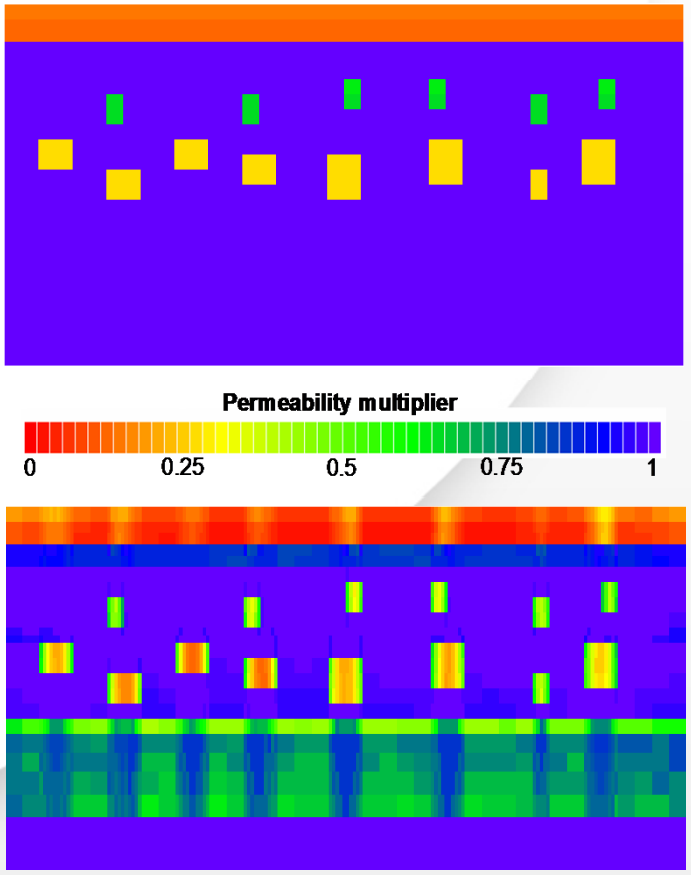
Example: Permeability Multipliers in a Fluvial System – Standard Flow Simulator vs. Coupling Procedure.





Upper: Initial permeability

Middle: Permeability multiplier, flow simulator

Lower: Permeability multiplier, coupled procedure

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Compaction as an IOR mechanism (?)

Permeability decreases with porosity reduction

Permeability “rate of change” is largest when initial permeability is high

→ Homogenization by compaction (pressure reduction)

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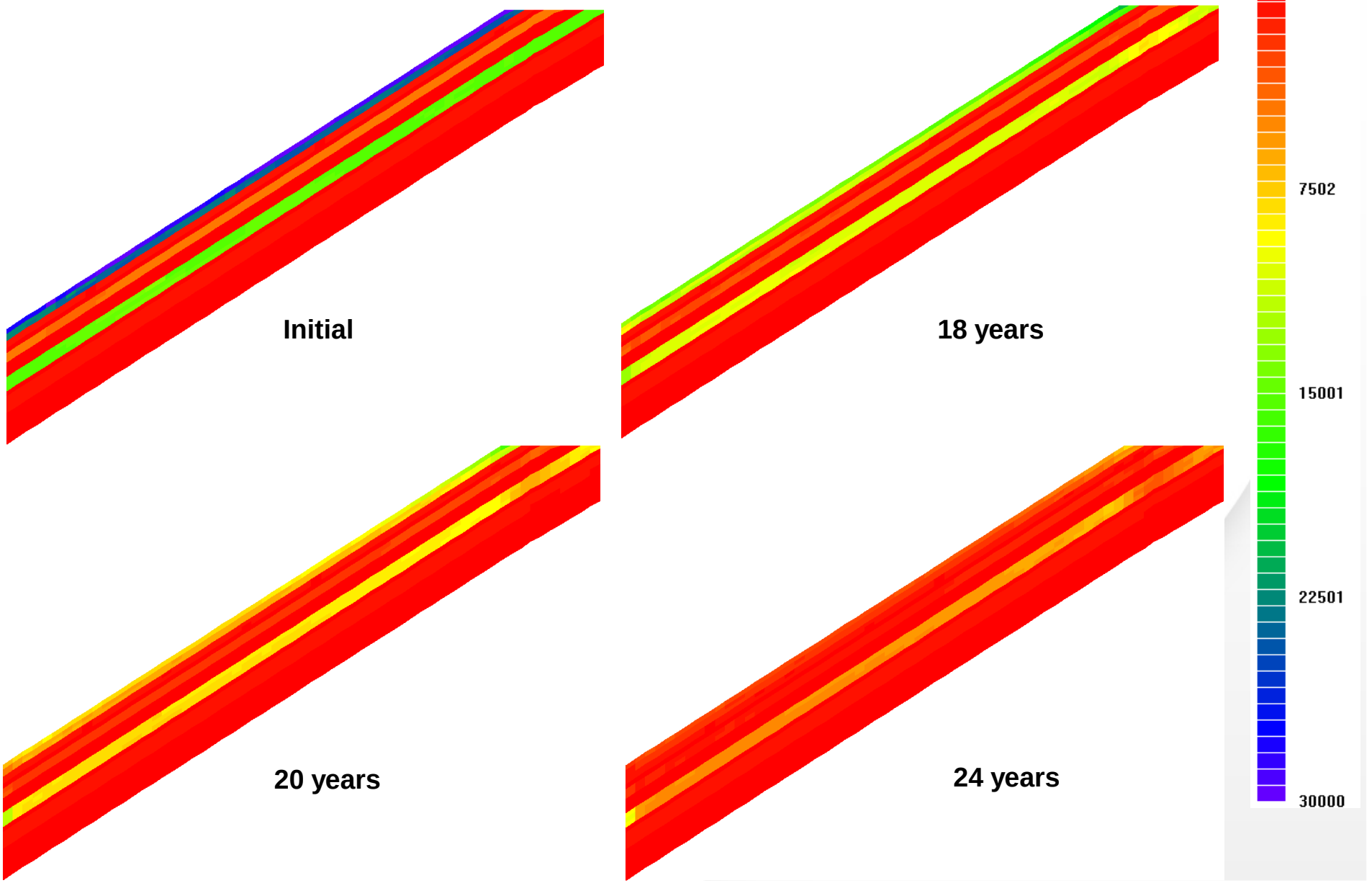
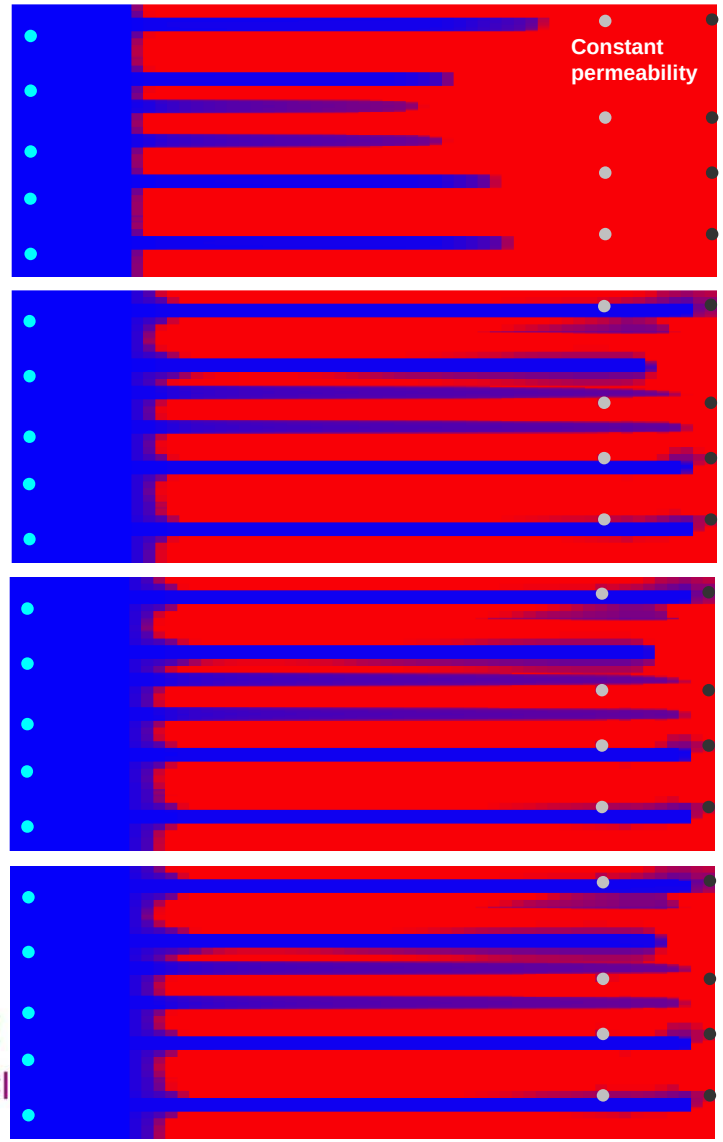
Permeability Homogenization (by 100 bars pressure reduction)



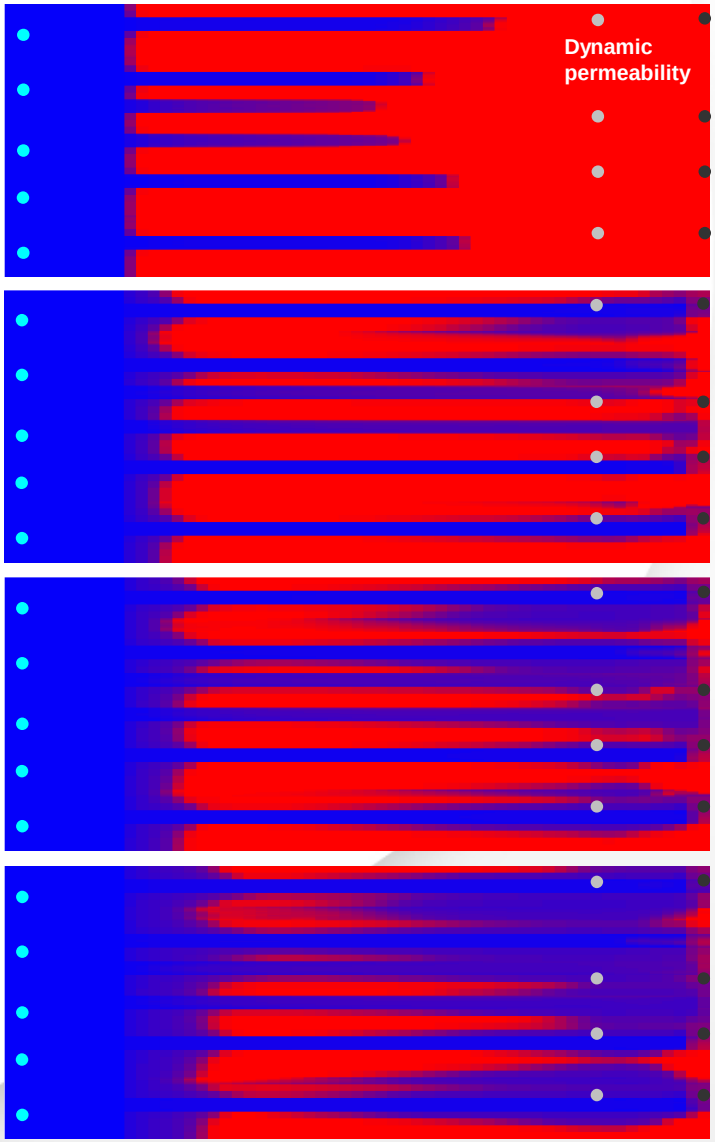
Displacement Efficiency

Fluvial System

Standard Eclipse



Coupled Simulation



6 years

28 years

32 years

38 years

Concluding Remarks

Rock Mechanic Effects have a large impact on reservoir behavior and production in many fields – often more than we think

By the described coupling technique, coupled simulations become affordable, and

- **rock behavior can be honored**
- **impact on fluid flow can be uncovered**

Thank You!

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