Modelling of Tail Production by Optimizing Depressurization

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Main effects of depressurization influencing oil recovery

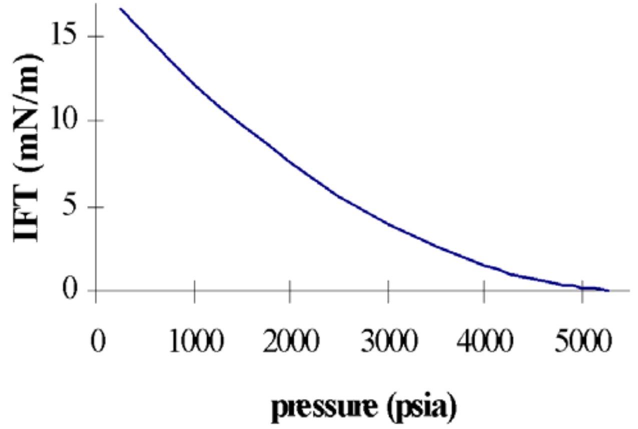
Change in fluid properties

Change in fluid saturation

Change in phase mobilities

Change in rock properties

Main effects of depressurization



Change in fluid properties

Pressure decline will give:

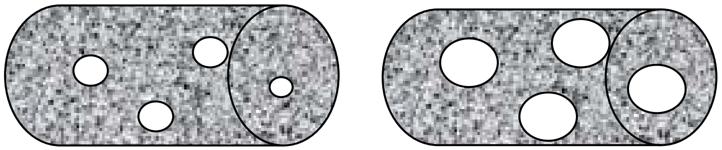
- larger phase viscosities and densities
- G/O capillary pressure will increase
  (because gas-oil IFT is larger at lower pressure)

Change in fluid saturation

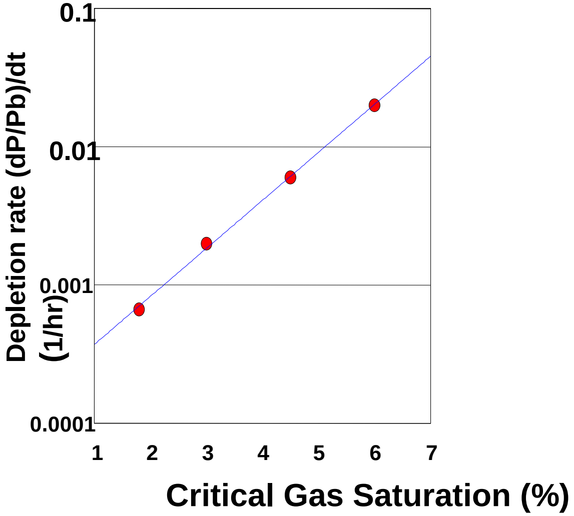
Pressure decline will give:

- shrinkage of oil due to mass exchanges
- gas expansion
- immobile gas (Sgc)

Pressure below bubble point



High Pressure **Lower Pressure**



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Production below bubblepoint

Phenomenological events

- Pressure decline
- below saturation pressure
- supersaturation
- nucleation treshold
- nucleation
- bubble formation
- bubble coalescence
- boyancy movement of gas ganglia
- continuous gas phase

General trend from literature data

higher drawdown rate

↓

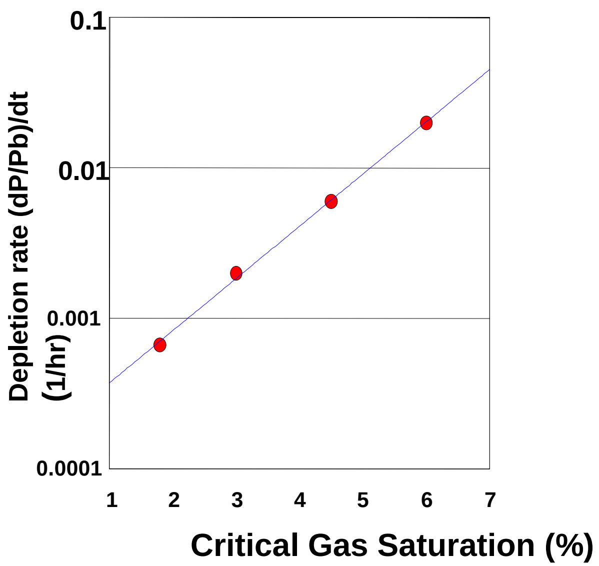
higher supersaturation

↓

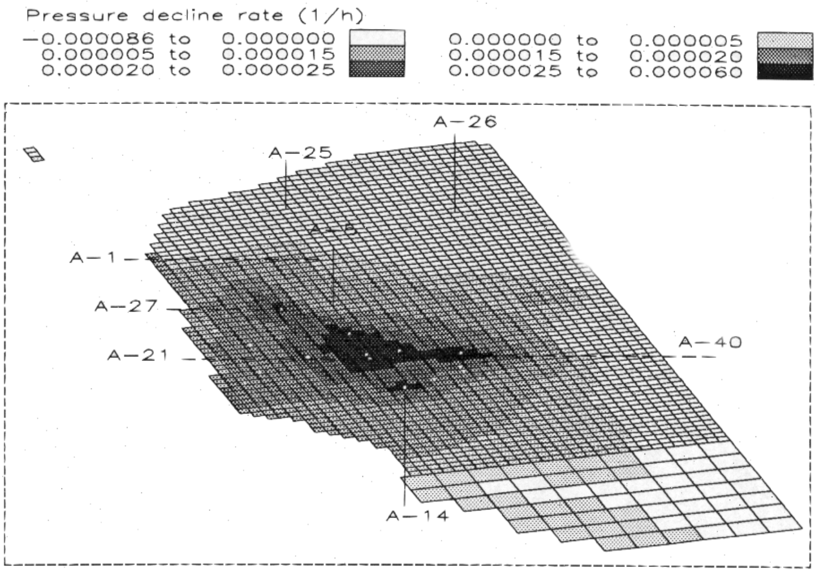
more bubbles nucleated

↓

higher Sgc and Sgt



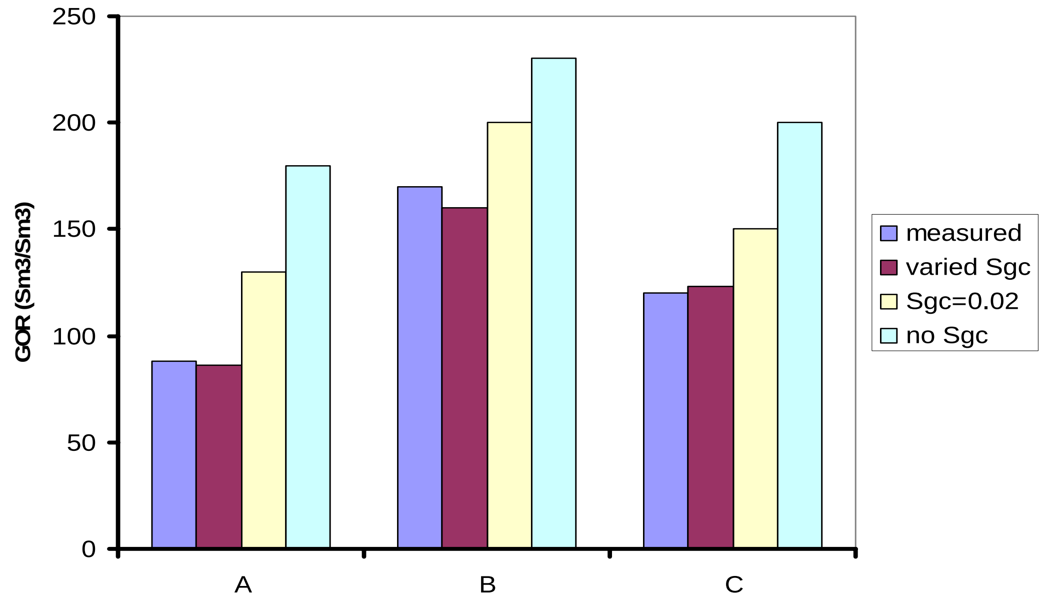
Example of an oil field with poor pressure communication and therefore high Sgcr around production Wells



$Sgc = [\log(dP^*/dt) - \log C)] / D$
Example: $C = 5.4x10-6$ and $D = 25.06$

The pressure decline rate used to calculate the critical gas saturation is defined as pressure decline from time t1 (hours) to time t2 (hours) relative to Pb per hour :

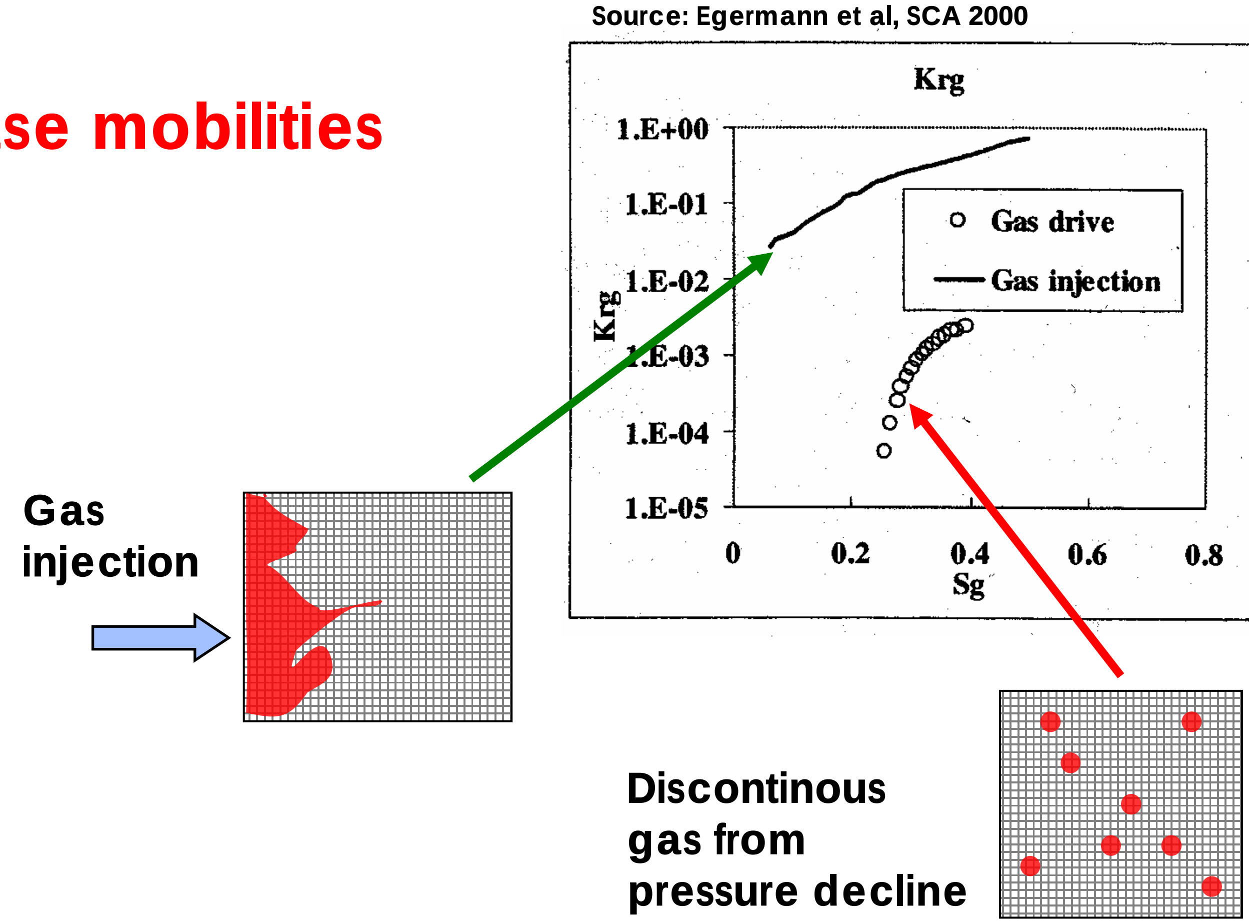
$dP^*/dt = [\, P(t1) - P(t2) \,] \;/\; [\, Pb \times (t2-t1) \,]$



Using a variable Sgcr gives better match of production GOR

Examples from matching GOR in 3 production wells

Change in phase mobilities



Gas originating from depressurization has mobility that may be 2 orders of magnitude lower than injection gas

Background

Experimental data show that relative permeability from internal and external gas drive processes can be different:

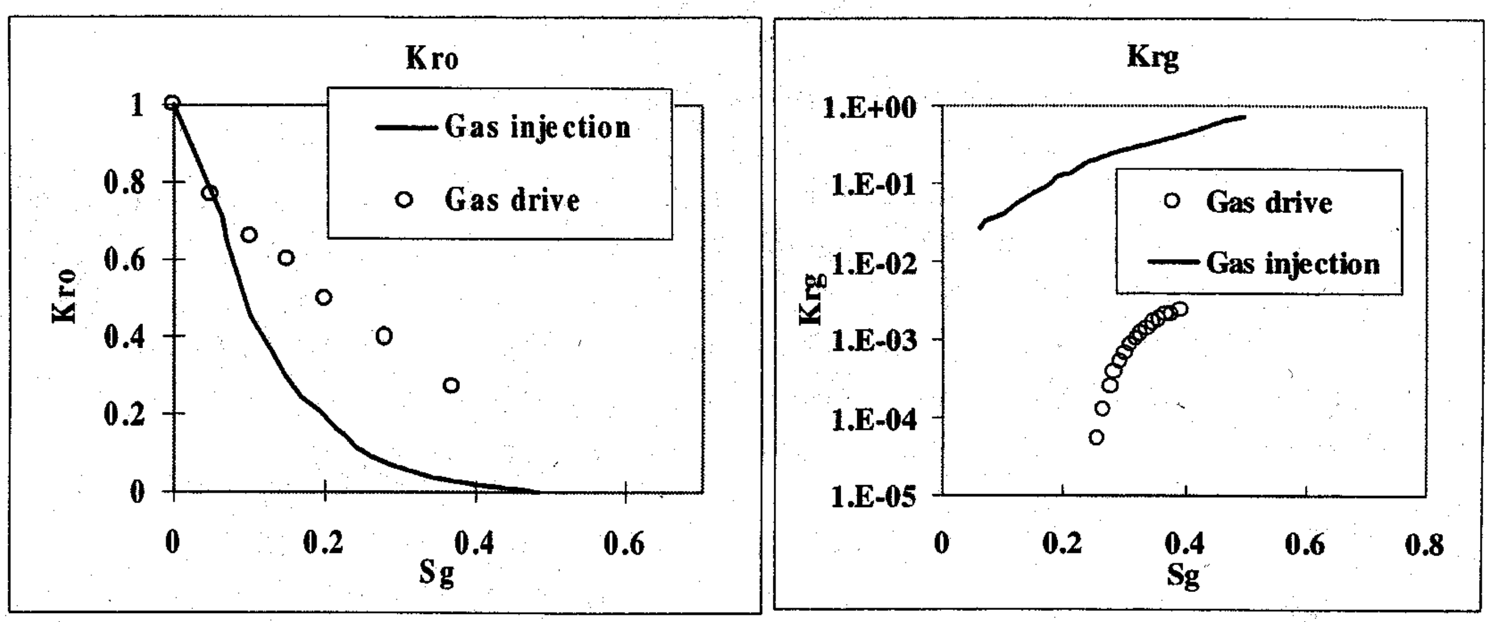
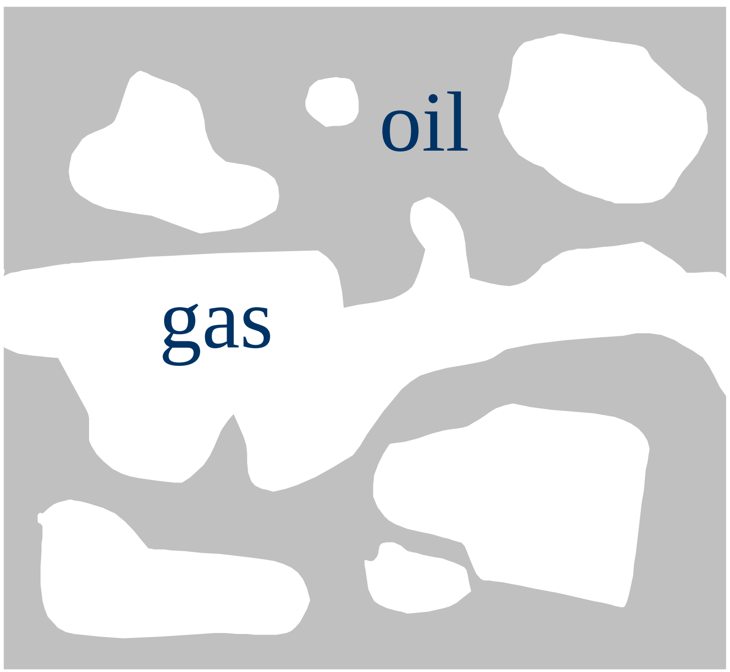


Figure 8: comparison between gas injection and solution gas drive K_r curves

Egermann, P., Vizika, O. (2000). *A new Method to Determine Critical Gas saturation and Relative Permeability During Depressurisation in the Near-Wellbore Region*. Soc. Core Analyst. Proceedings, Oct. 18-22, 2000.

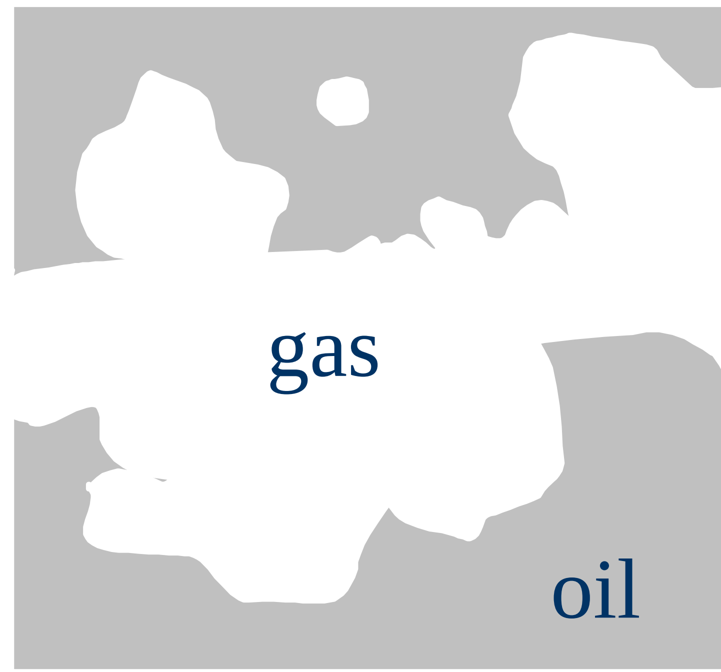
Visualisation of network model results

Many small pores, many bubbles, low coordination number:



Gas phase is *poorly* connected
⇒ krg low & Sgc high

Many large pores, few bubbles, high coordination number:



Gas phase is well connected
⇒ krg high & Sgc low

Summary pore structure and rel perms

1) k_{ro} is controlled by coordination number rather than by the process, the pore size distribution or the bubble density

2) k_{rg} is sensitive to both coordination number, process type, pore size distribution and bubble density

- k_{rg}(external) ≈ k_{rg}(internal) in well connected network with many large pores and at low bubble density
- k_{rg}(external) >> k_{rg}(internal) in poorly connected network with many small pores and a high bubble density

Warning - Be careful about generating internal drive gas relative permeability data based on external drive experiments!

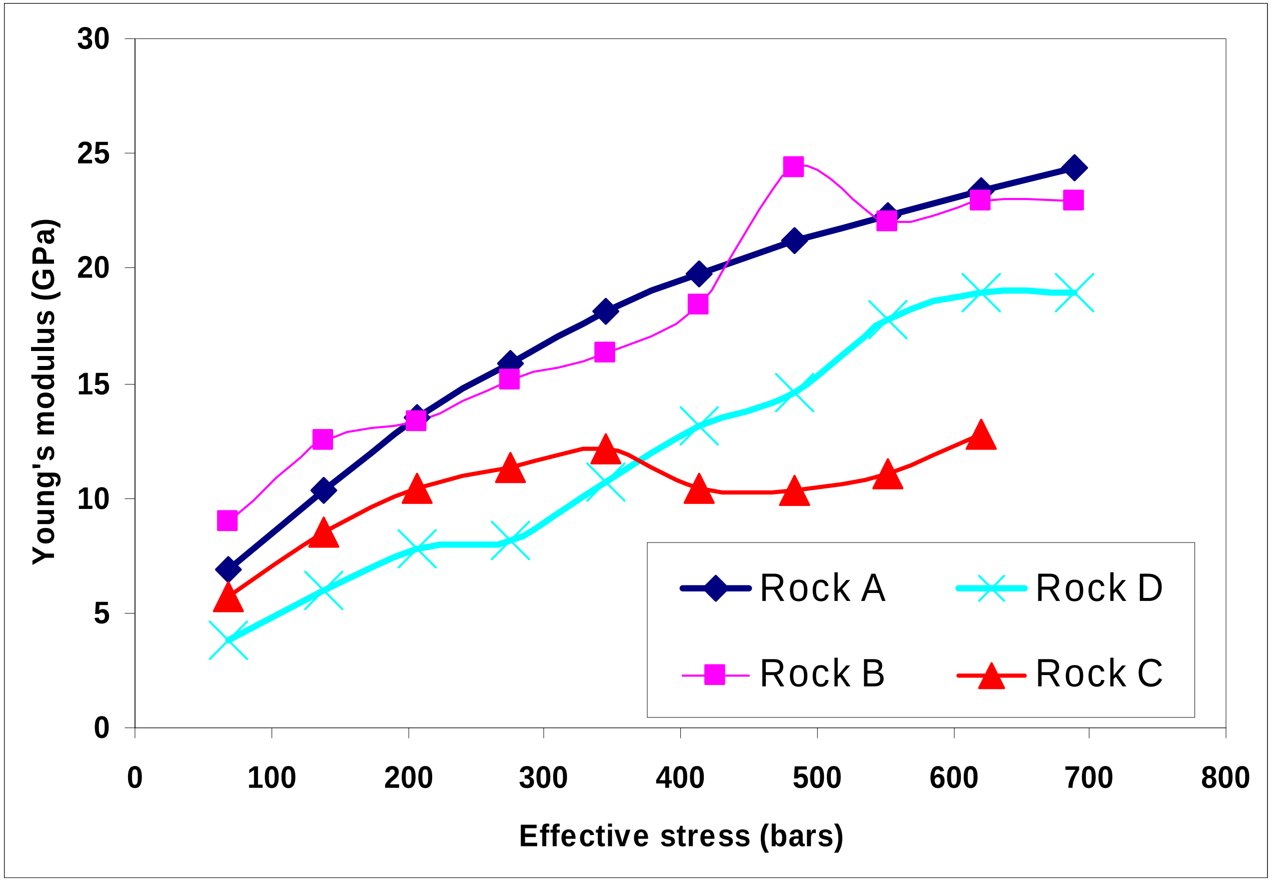
”Comparison of Relative Permeability Resulting From Internal and External gas Drive Processes – A Network Modelling Study”
Susanne Poulsen[1], Steven McDougall[2], Ken Sorbie[2] and Arne Skauge[3]
1. DTU, Denmark 2. Heriot-Watt U. UK 3. CIPR, UoB (Norsk Hydro) Norway
SCA 2001

Can pressure depletion altered flow pattern caused by change in rock properties?

If so, what are the condition needed to change the flow pattern?

Theory vs. experimental data

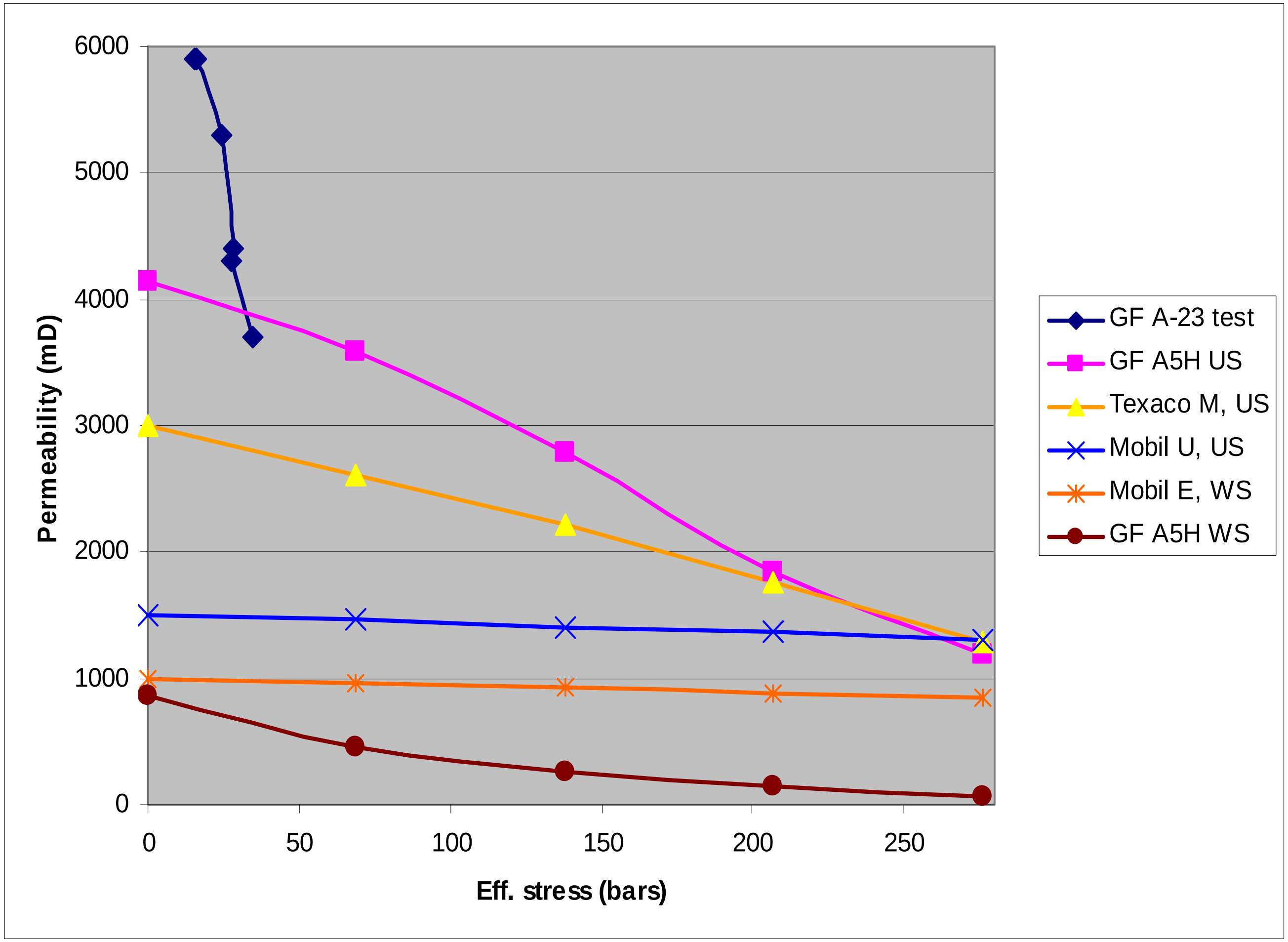
- **Young's modulus vs. effective stress for typical sandstones**



Permeability vs. load – measured data

Weak sands appear to have greater loss of conductivity than strong sands

Proposition: Permeability reduction is “proportional to” initial value, i.e. Medium is homogenized by loading



WS: weak sandstone
US: unconsolidated sand

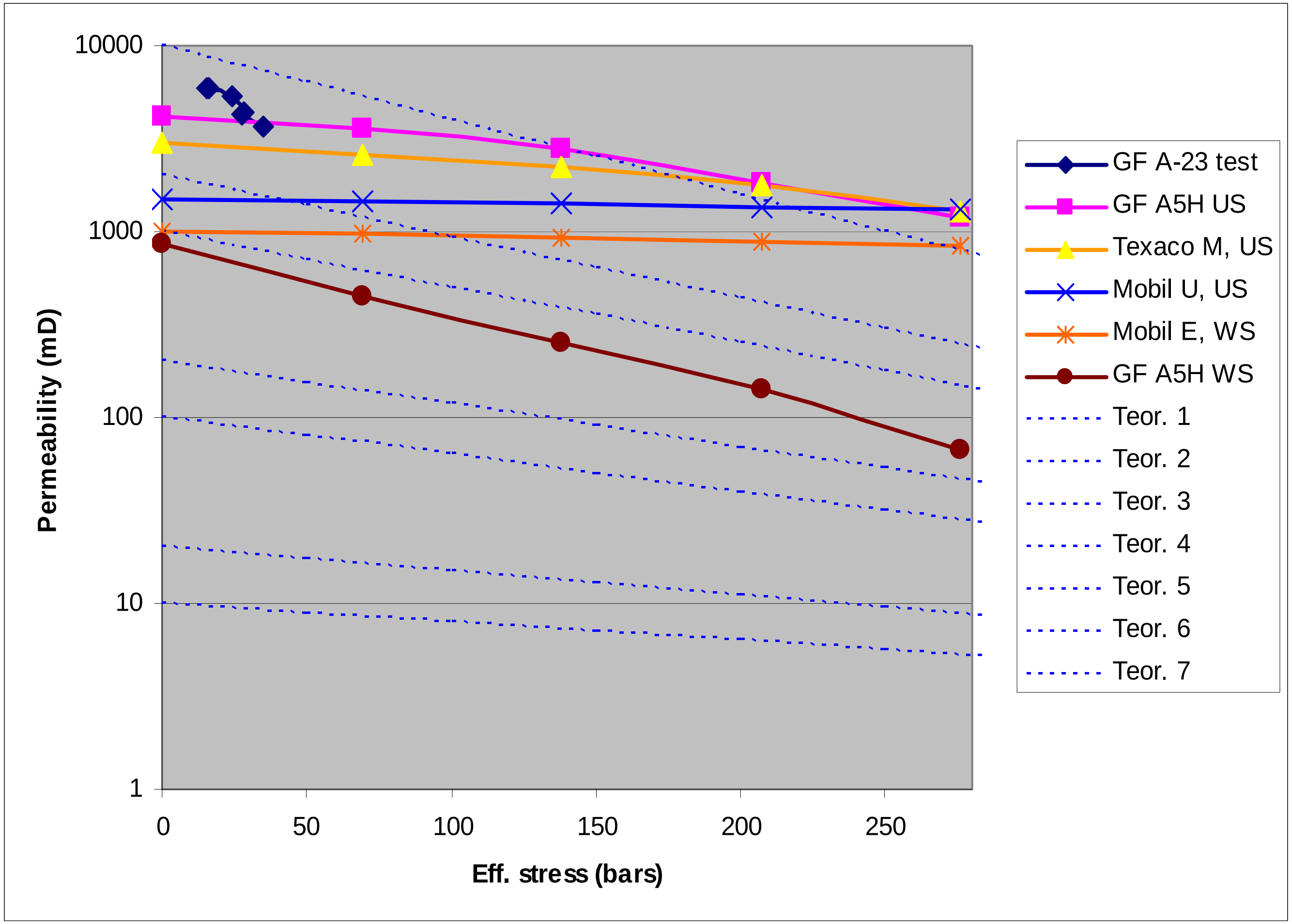
Permeability vs. load – assumption

log(K) linear w. σ,
K(σ*) = 1 mD

σ* = 1000 bars

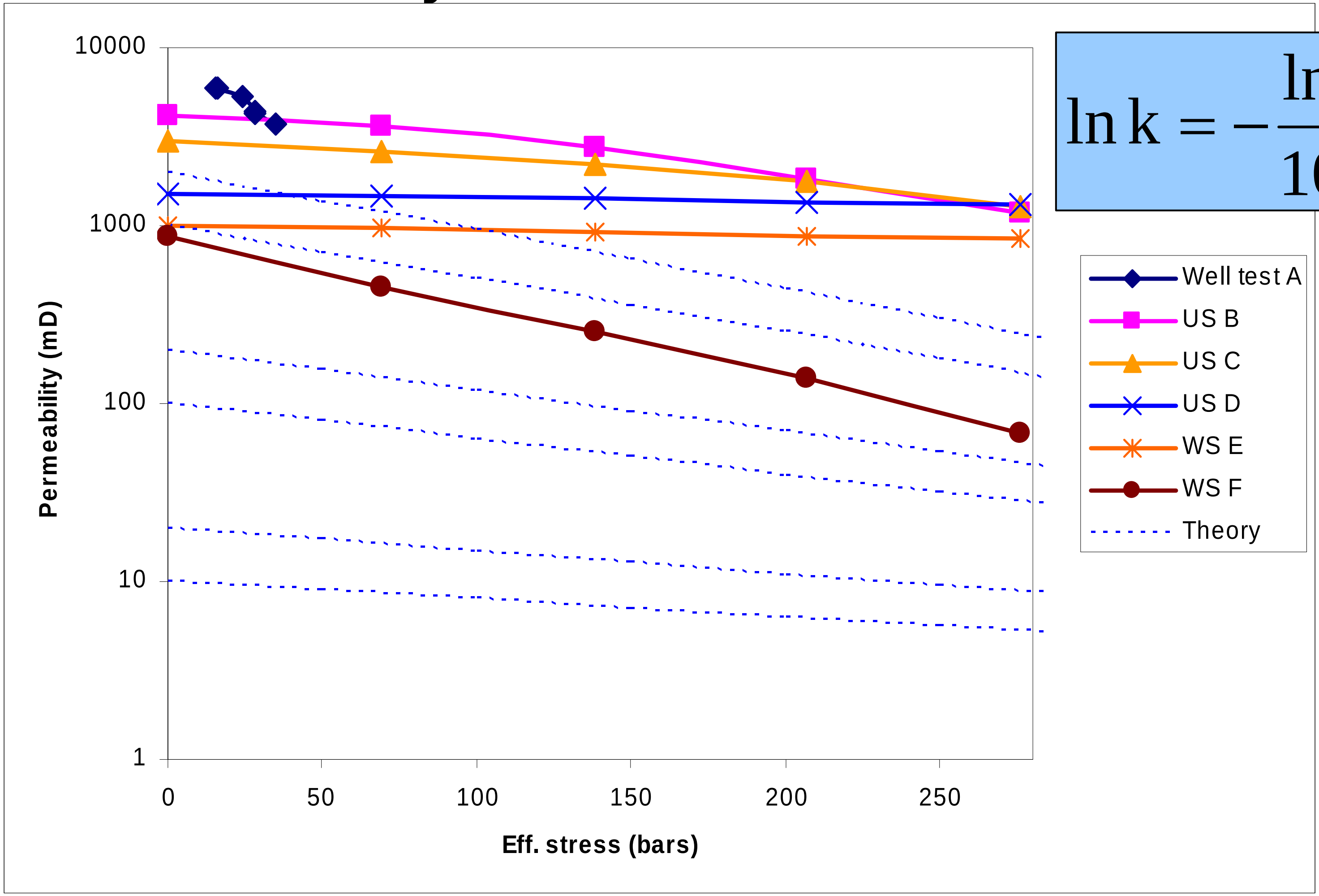
fits GF WS

WS: weak sandstone
US: unconsolidated sand



Theory vs. experimental data

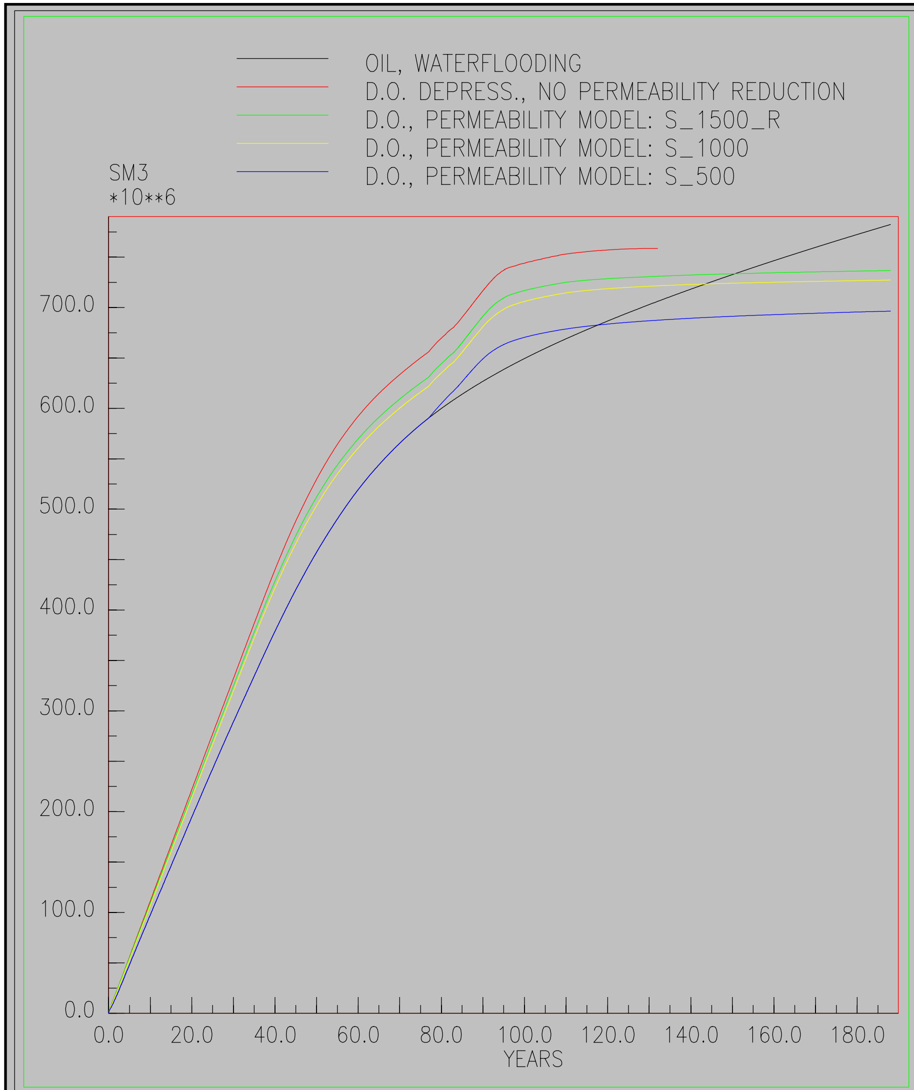
- **Permeability vs. effective stress**

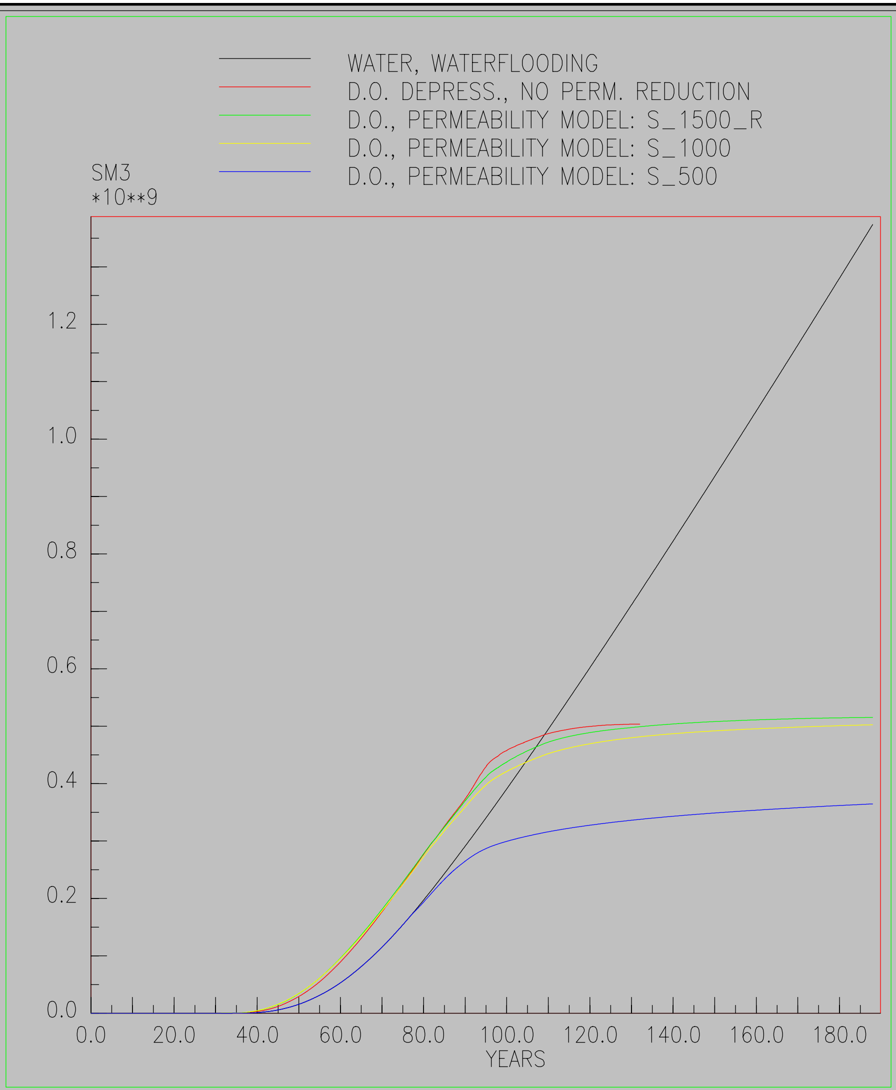


$$\ln k = -\frac{\ln k_0}{1000} \cdot \sigma' + \ln k_0$$

Oil production

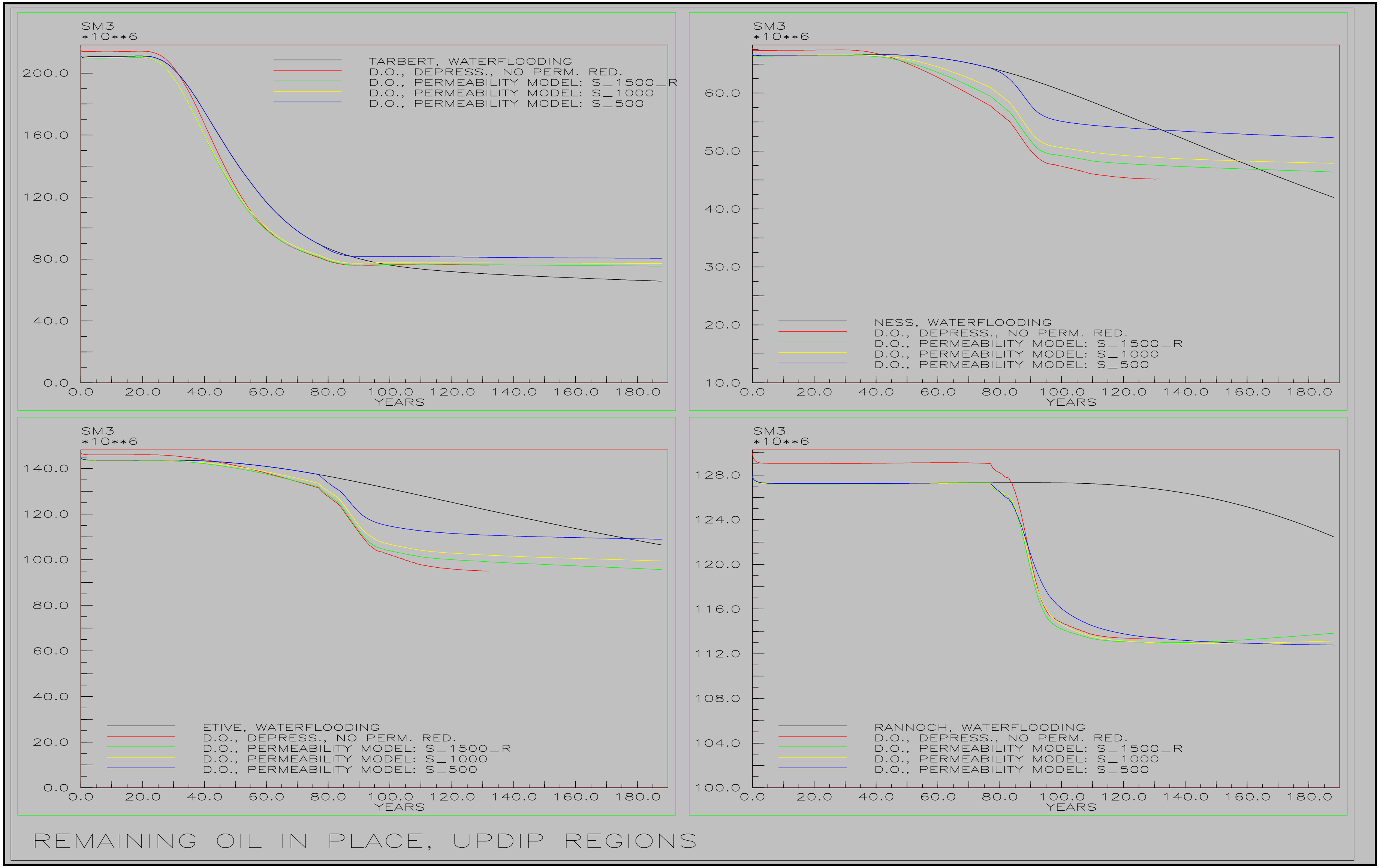
Water production





TOTAL RESERVOIR FLUID PRODUCTION

Remaining oil in place for different rock formations



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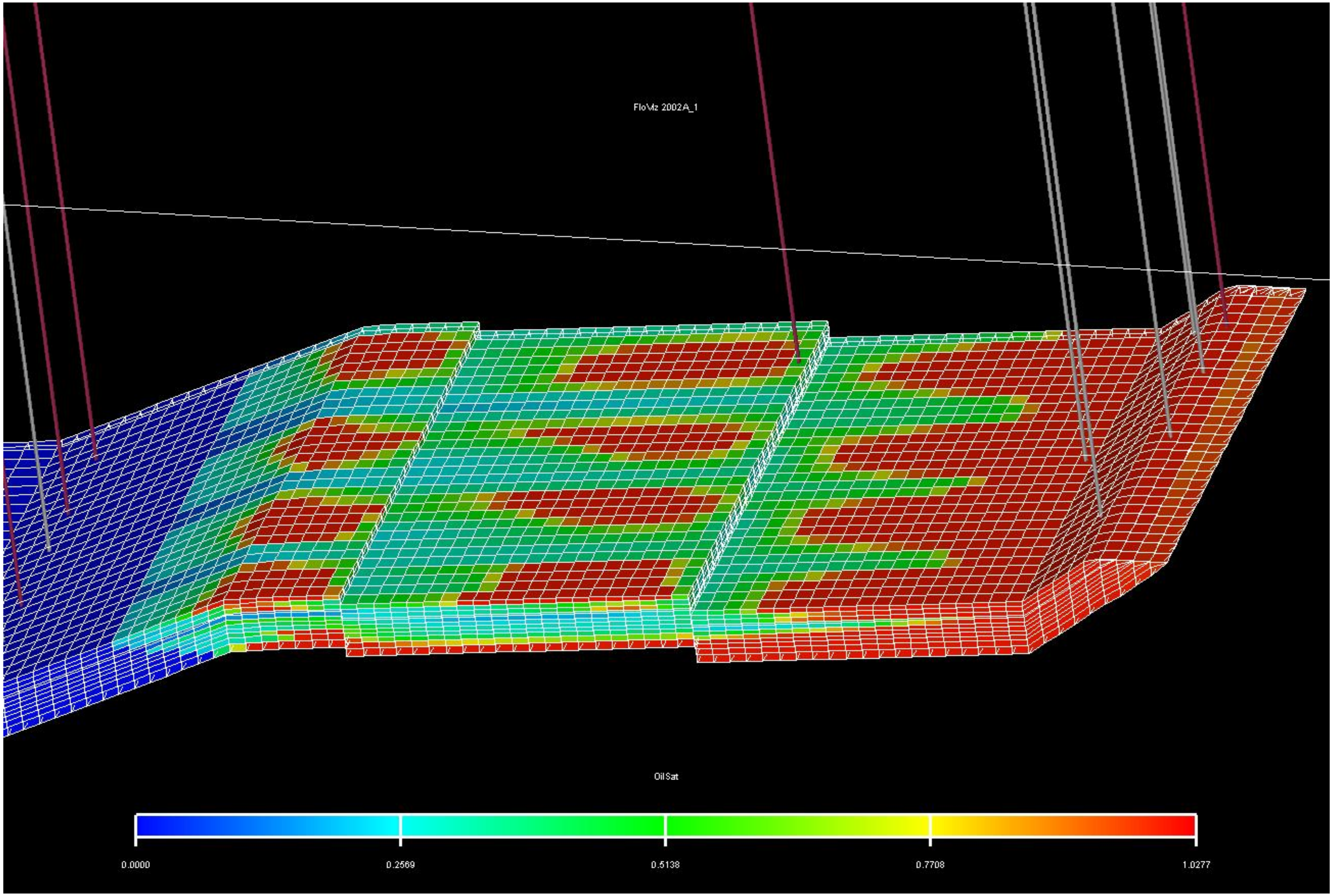
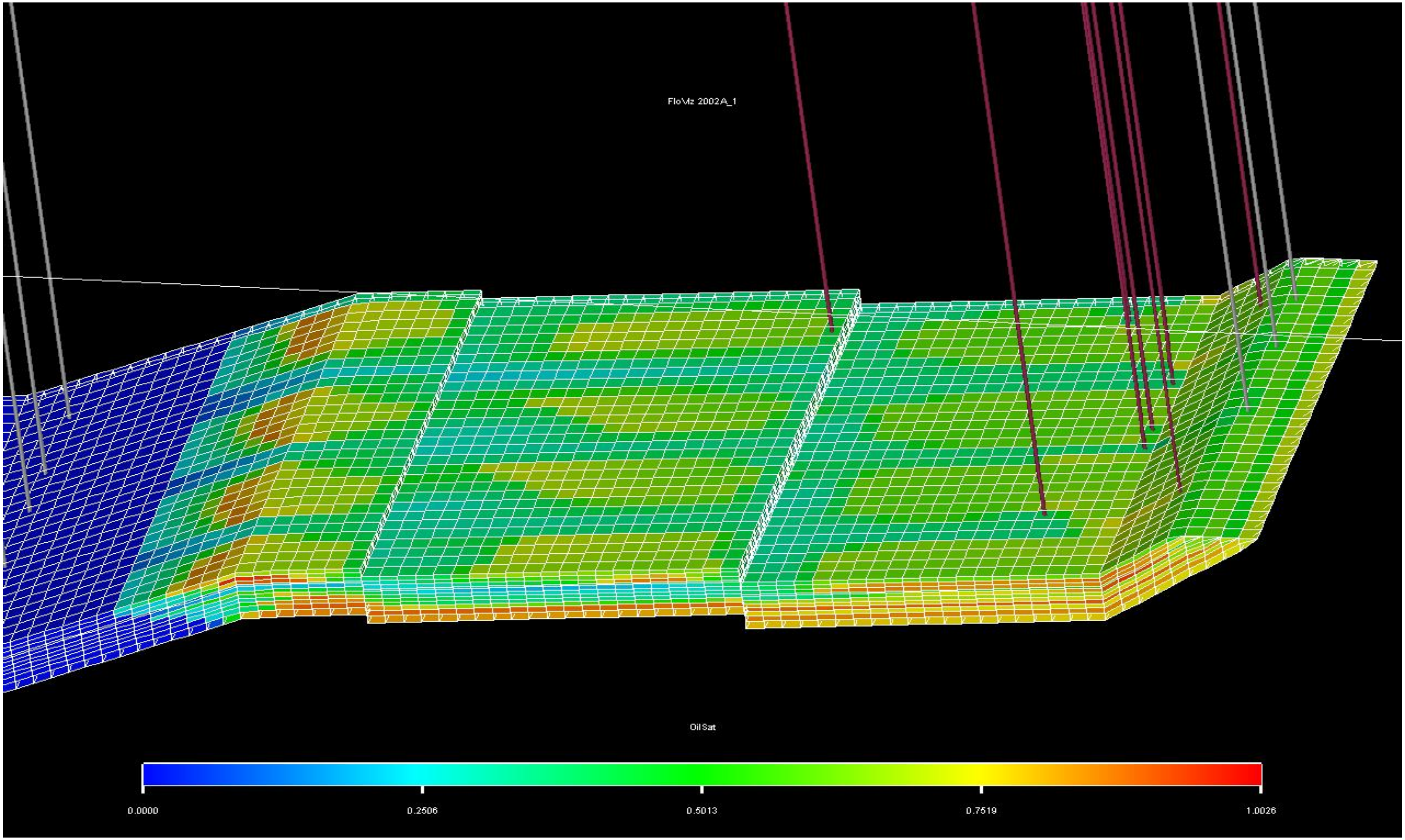
Moderate channel perm, low background perm



Moderate channel perm, low background perm, Permeability reduction model $\sigma^* = 1000$



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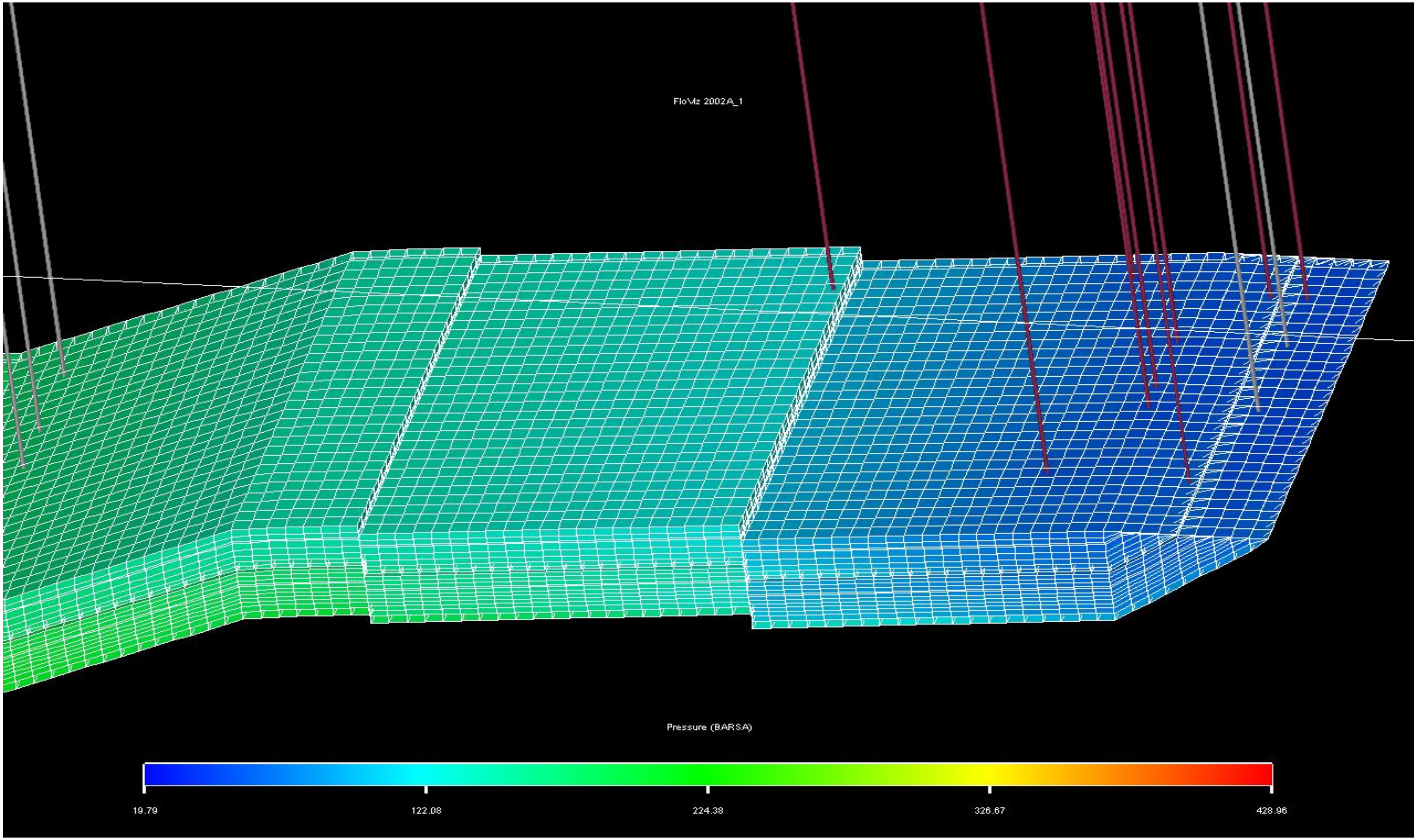
Pressure distribution "some time" into depressurization, consequence for wells' PI



Inferences – effects of compaction during depressurization

+ Reduces pressure reduction rate – energy supply
+ Reduces permeability contrasts – stops water cycling through high permeability channels

- Reduces well productivity
- Reduces general conductivity
- May induce pore collapse / sand production

? Production scheme may be critical
? Late stage injection may be advantageous
? Stimulation, fracturing, gas lift may be necessary

Summary of change in rock properties

- Empirical data show that permeability reduction due to increase in stress is stronger for high initial permeability

- Selective permeability reduction may occur in reservoirs comprised of weak high-permeability soils in a background of stronger low-permeability soils

  This permeability homogenization may increase the sweep efficiency by reducing water cycling through high permeability layers

Guidelines for simulation of depressurization

Capillary forces will vary with pressure decline, and may affect the buoyancy movement of gas

Correct pVT data for the pressure decline range is needed

The simulator has to handle gas relative permeabilities coming from different sources (influx versus internal generated gas in the grid block)

Rock material with;
- low coordination number
- low permeability (more exact description - many small pores)
- experiencing high depletion rate

will have the largest demand for the complex gas rel perm model

Sgcr should be coupled to grid block historical pressure decline rate

The necessary geomechanical modelling (improved modelling of rock compaction) needs to be coupled to the reservoir simulator