Effects to be considered when planning late stage depressurisation

Dag C. Standnes, Arne Skauge and Øystein Pettersen

Centre for Integrated Petroleum Research, University of Bergen, Norway

13th European Symposium on Improved Oil Recovery, Budapest, Hungary, April 25-27 2005

Overview

- Introduction
- Theory vs. experimental data
- Numerical model
- Results
- Conclusions

Introduction

- Depressurisation (DP) of oil fields have been used to increase tail gas and oil production
- DP process will induce changes in:
  - Fluid properties
  - Fluid saturations
  - Phase mobilities
  - Changes in PV and permeability due to rock compaction

Fluid properties

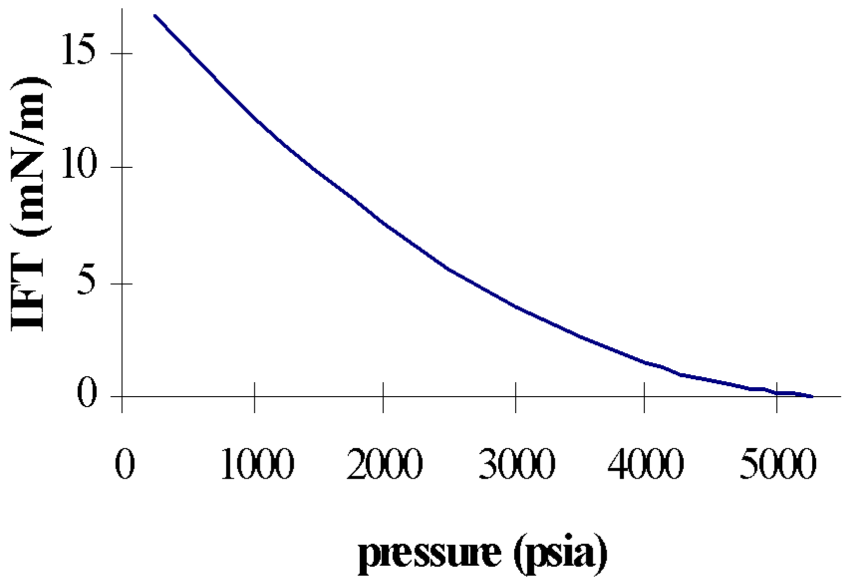
Change in fluid properties

- **Pressure decline will give:**

- larger phase viscosities and densities

- G/O capillary pressure will increase

(because gas-oil IFT is larger at lower pressure)



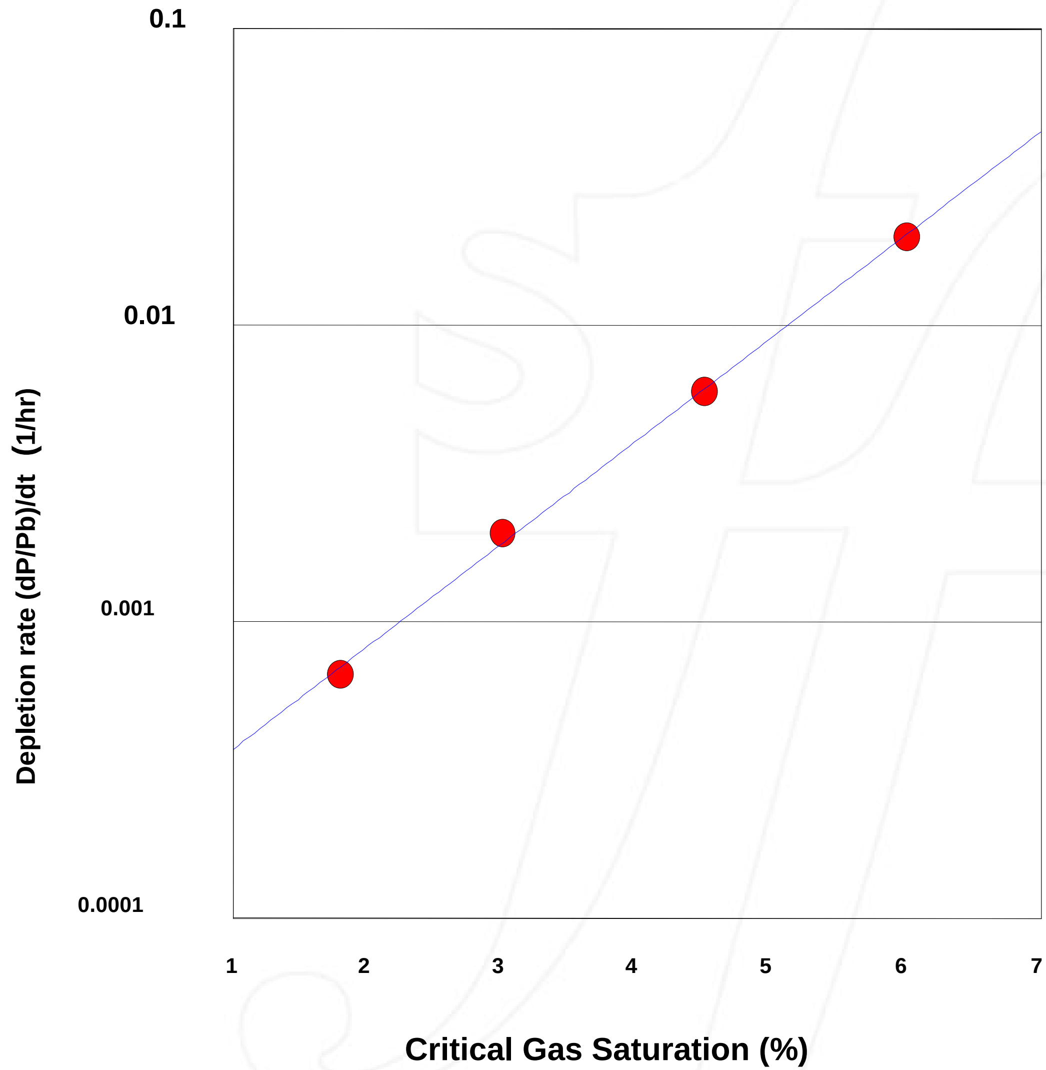
Fluid saturations

- **Change in fluid saturation**
- **Pressure decline will give:**

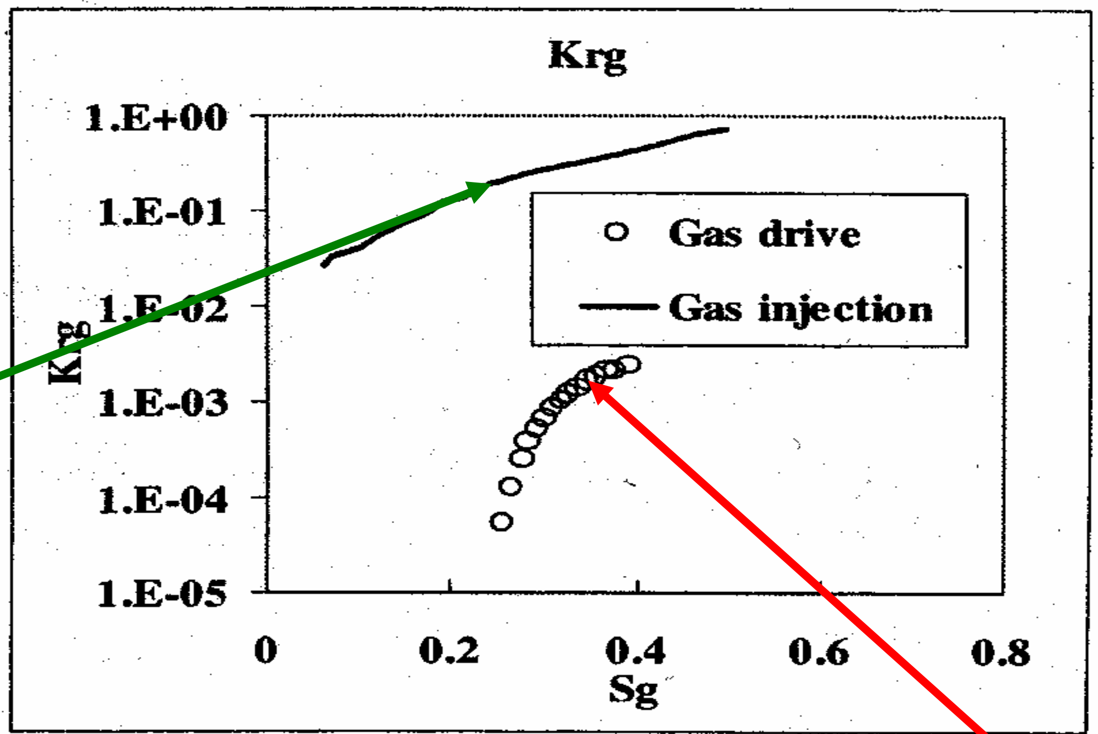
  - shrinkage of oil due to mass exchanges

  - gas expansion

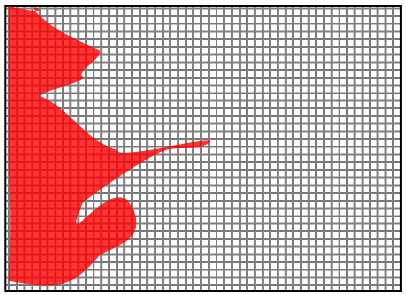
  - immobile gas (S_{gc})



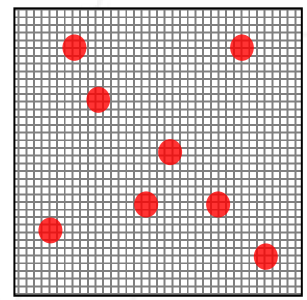
Phase mobilities



Gas injection



Discontinous gas from pressure decline

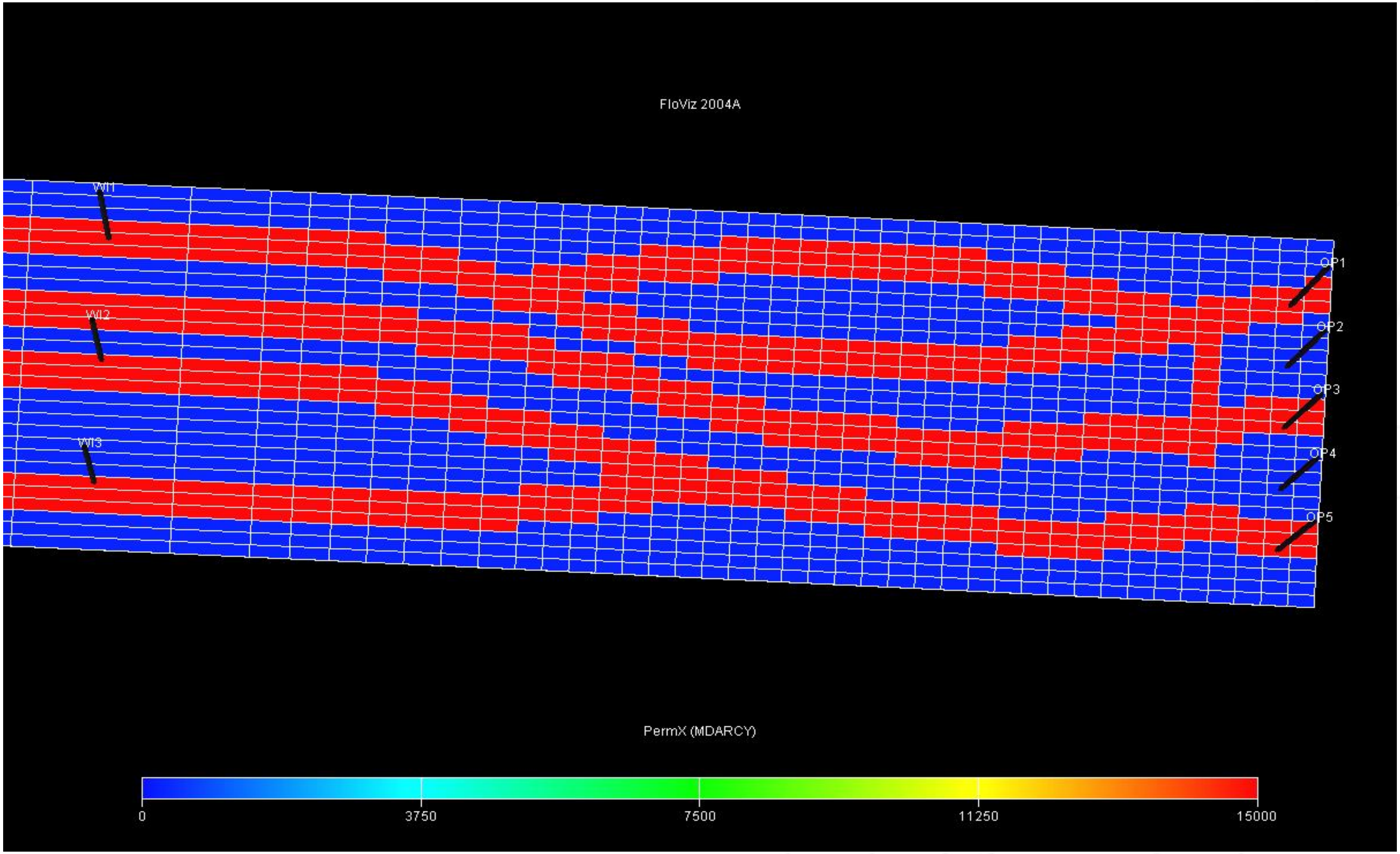


Gas originating from depressurisation has mobility that may be 2 orders of magnitude lower than injection gas

Introduction

- Many oilfields in the North Sea are comprised of layers where high-permeability channels of weak soil exist in a background of more low-permeability stronger soil
- Idealized permeability map of a layer consisting of high-permeability channels in a background of low-permeability soil

Introduction



Introduction

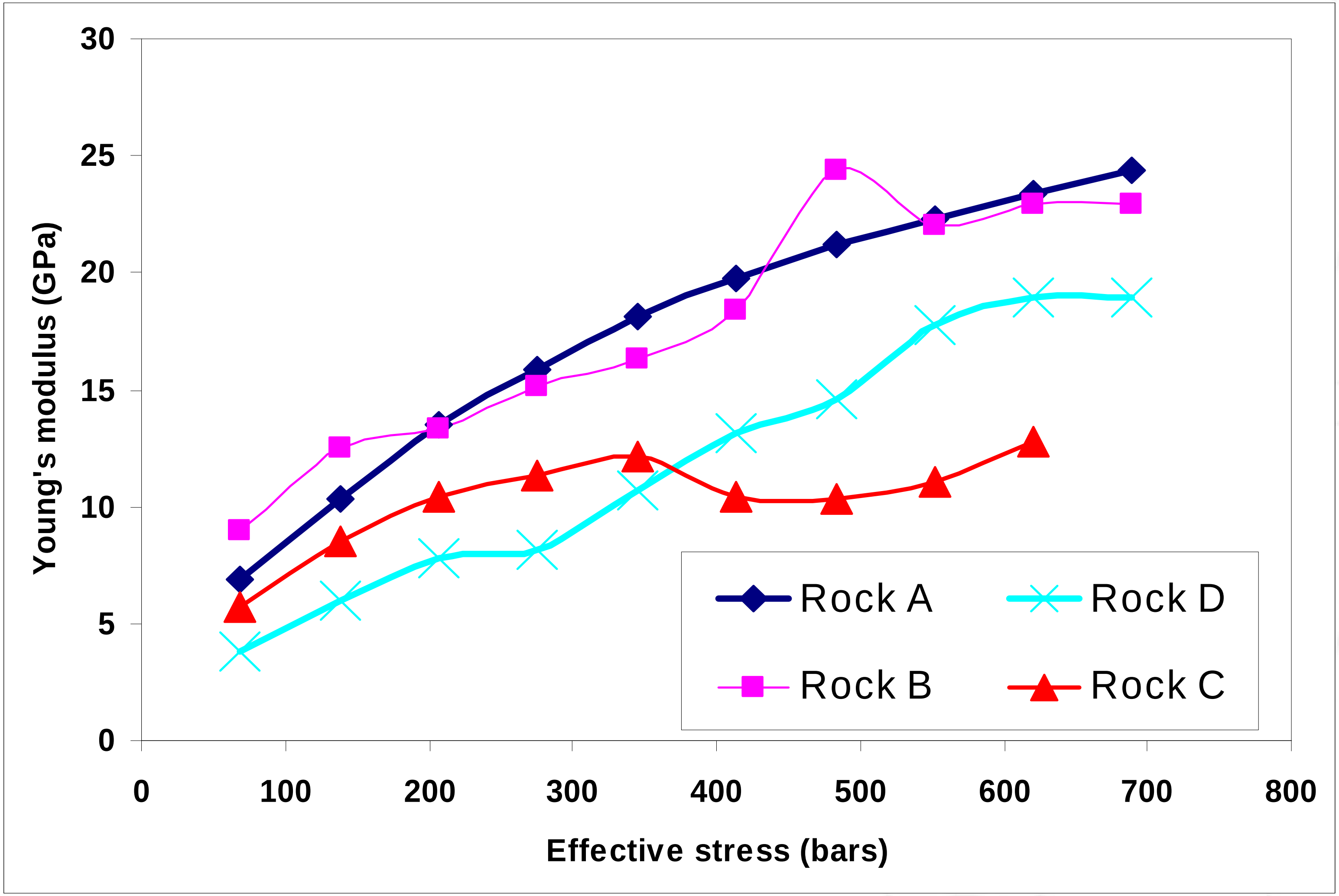
- The permeability of the high-permeability channels will often decrease relatively more than the permeability of the stronger low-permeability background. This selective permeability reduction due to pressure decrease will be referred to as permeability homogenisation

Introduction

- The purpose of this work is to give empirical evidence for the permeability homogenisation process and to demonstrate the effect this process may have on oil/gas production in fields under DP

Theory vs. experimental data

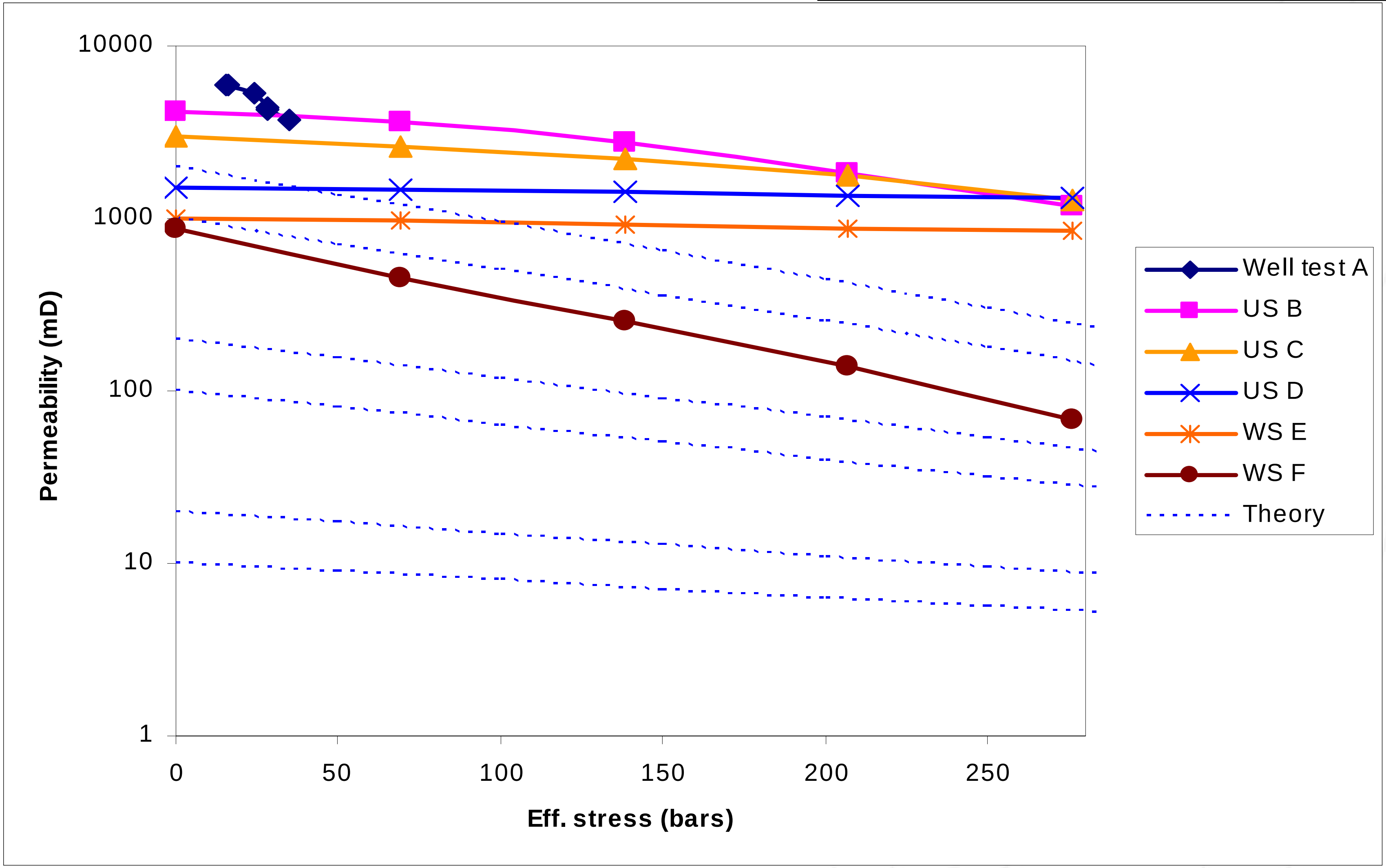
- Young's modulus vs. effective stress for typical sandstones



Theory vs. experimental data

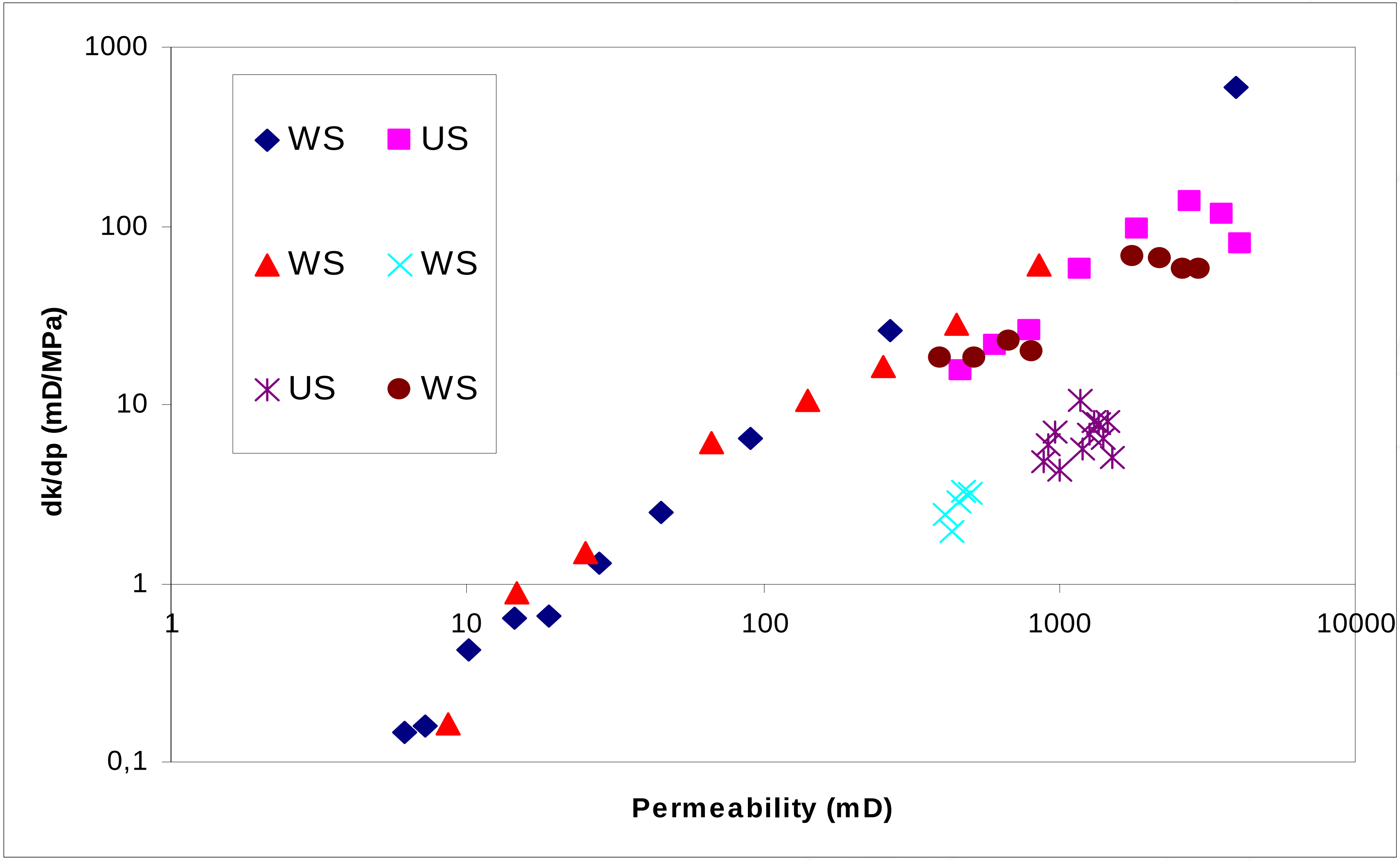
$$\ln k = -\frac{\ln k_0}{1000} \cdot \sigma' + \ln k_0$$

- **Permeability vs. effective stress**



Theory vs. experimental data

- **dk/dp vs. absolute permeability**



Numerical model

- The reservoir modeled is of Brent type and consists of 48x38x29 grid blocks (Cartesian). The field is produced by 5 wells and there are 3 water injectors. The reservoir contains layers built up of 7 different rock types (from unconsolidated sand to very strong sand).

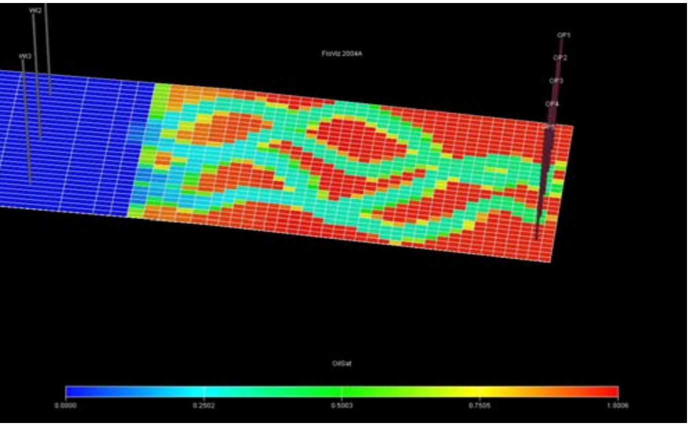
Numerical model

- The effect of pressure decline on the flow pattern (3-phases) was studied by decreasing the water injection rate after 25 years production (start was 1980) over a period of 3 years (bottom hole pressure was also decreased in the same period). Evidence of the permeability homogenisation process was demonstrated by looking at the oil saturation in certain layers some years after the water injection had ceased.

Numerical model

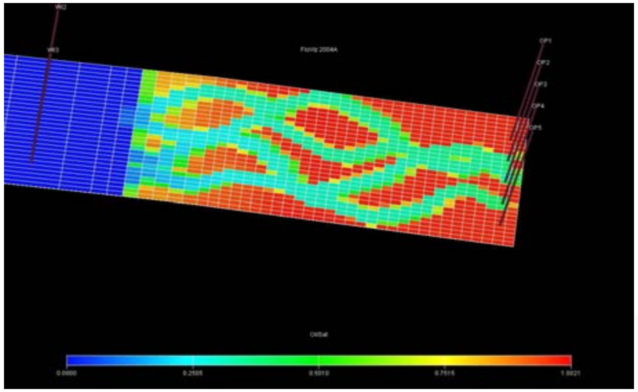
- Two-phase simulations were also performed with two different permeability ratioes between channel and background (static permeabilities corresponding to fluid pressures 327 and 100 bars). The water-injection rate was adjusted so waterbreakthrough occured approximately at the same time

Results (3-phase)

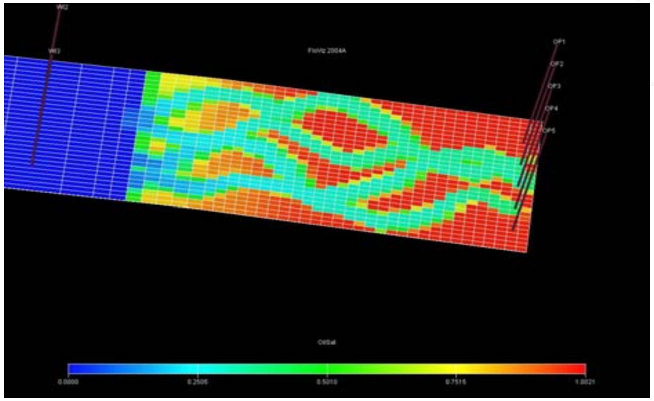


Start of DP 2005

No DP

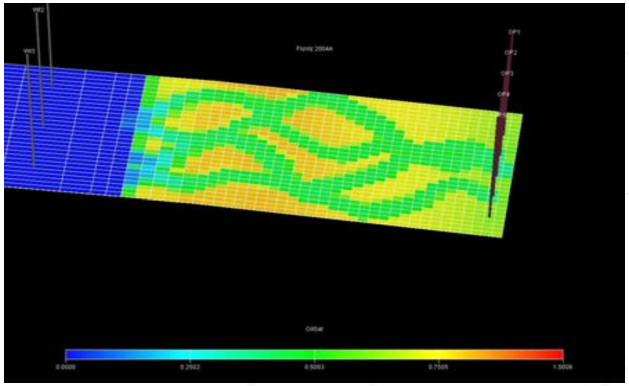


2008

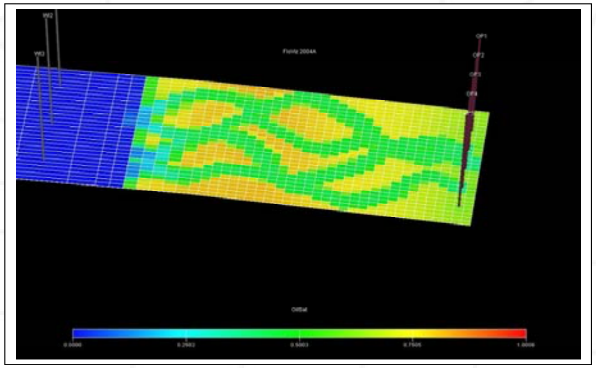


2015

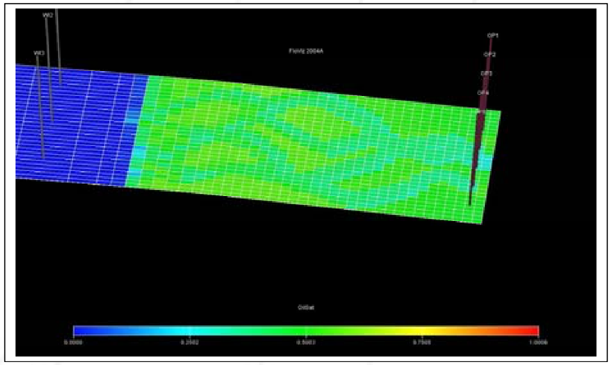
With DP



2006



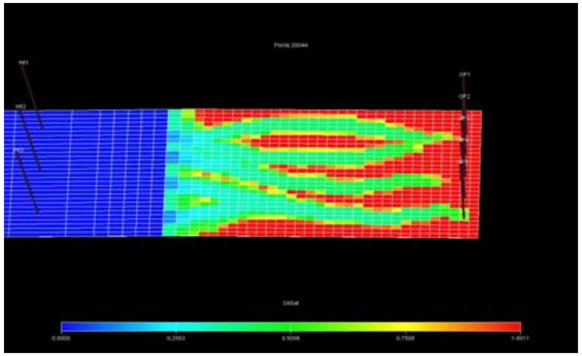
2008

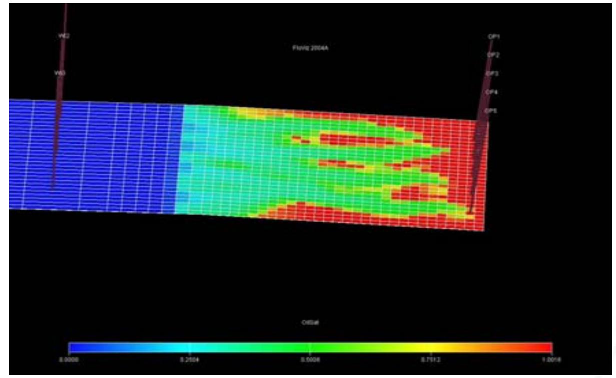


2015

Results (2-phase)

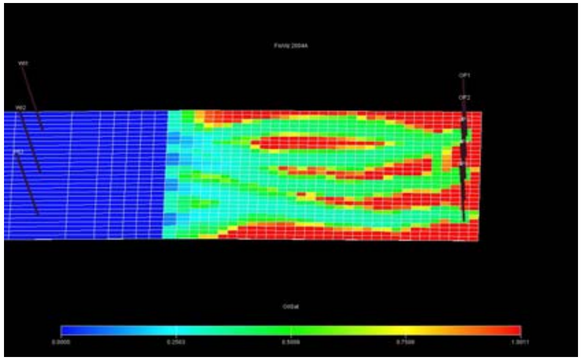
JAN. 93

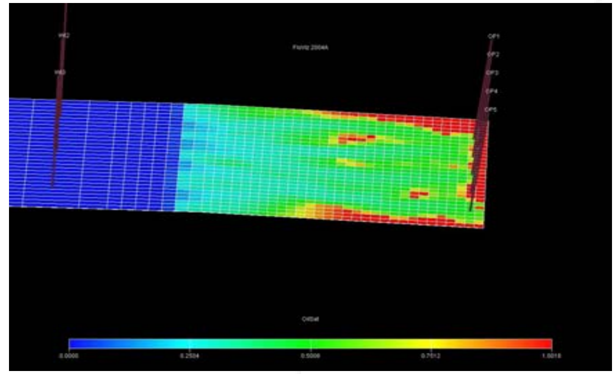




JUL. 93

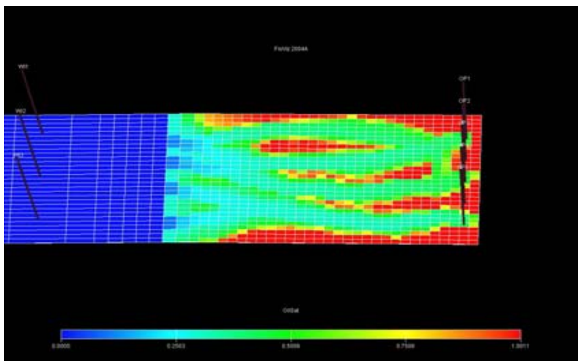
JAN. 98

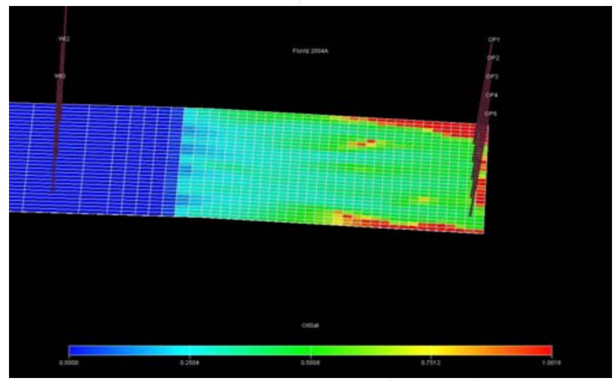




JAN. 99

JAN. 03





JAN. 03

kc = 15,000 mD and kb = 250 mD, kc/kb = 60

kc = 730 mD and kb = 74 mD, kc/kb ≈ 10

Conclusion

- Empirical data indicate that weak rocks will compact relatively more than stronger rocks when loaded
- Empirical data also show that permeability reduction due to increase in stress increases with increasing 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 homogenisation may increase the sweep efficiency by reducing water cycling through high permeability layers

Conclusions

- Evidence of improved sweep for certain layers has been demonstrated by numerical simulation. However, it was not easy to demonstrate positive effects of permeability homogenisation on field basis
- Improved modeling of rock compaction and flow in channel systems are required in order to investigate the effect of permeability homogenisation further