Compaction, Permeability, and Fluid Flow in Brent-type Reservoirs Under Depletion and Pressure Blowdown

by

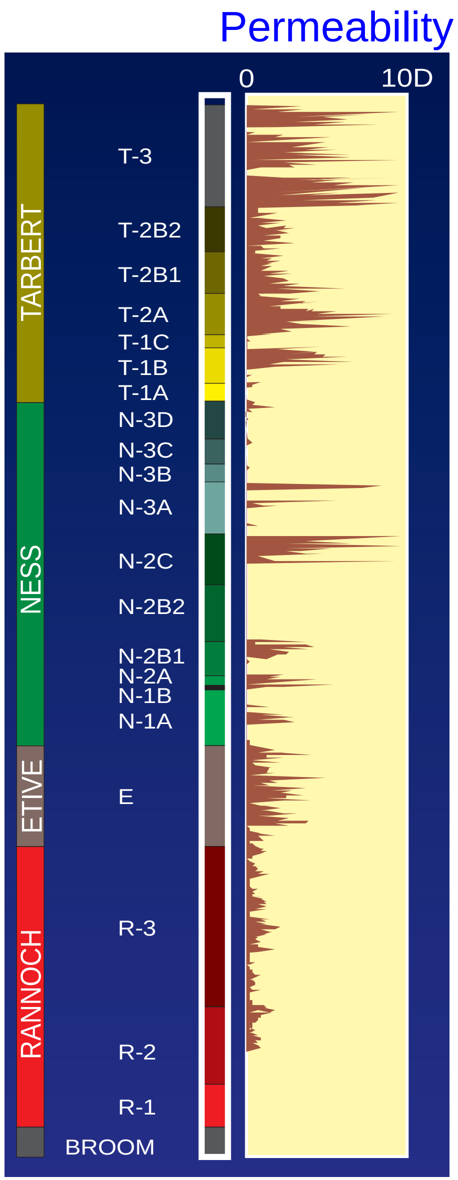
Øystein Pettersen, CIPR

CIPR Technology Seminar 2010

Outline

- ***Experimental & Field Observations***
- ***Theoretical Considerations***
- ***Simulated compaction & permeability***
- ***Influence on Fluid Flow***

The Brent Group – Schematic Overview



High lateral continuity
"Silk sand" areas

Moderate continuity,
low to moderate quality
Small, irregular channels occur

Good continuity
Channel sands

Low to moderate quality
Upwards increasing permeability

Sand strength

Extremely weak

Very weak

Moderate
Weak

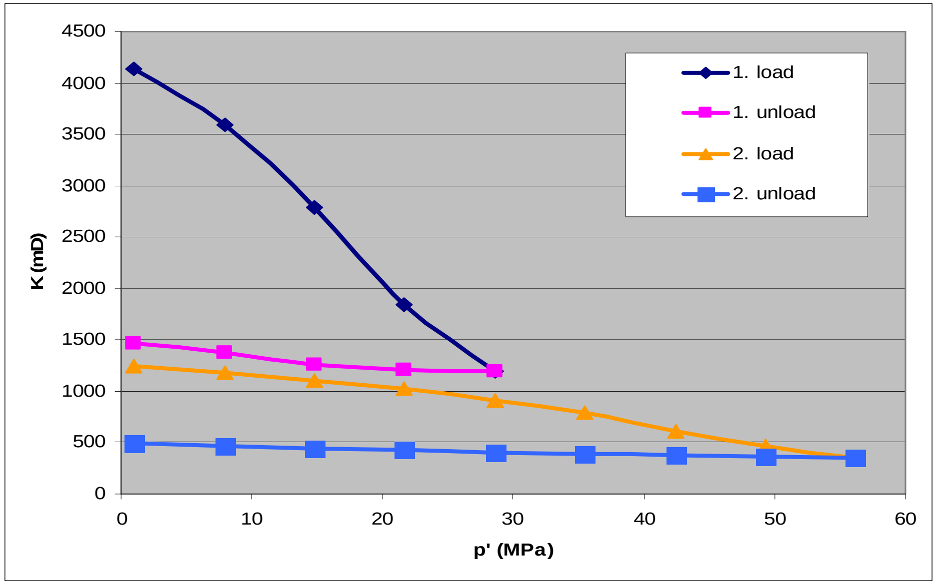
Strong background,
Weak channels

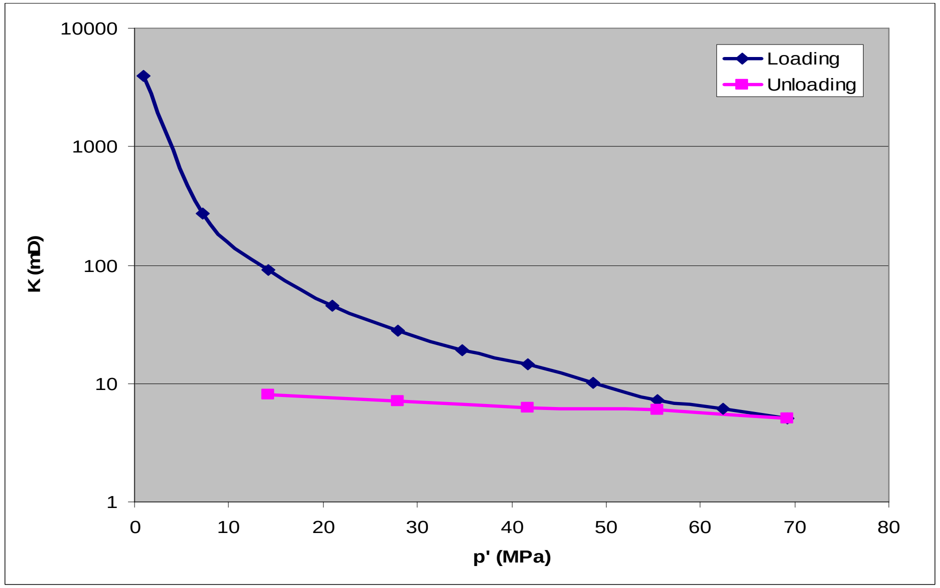
Strong

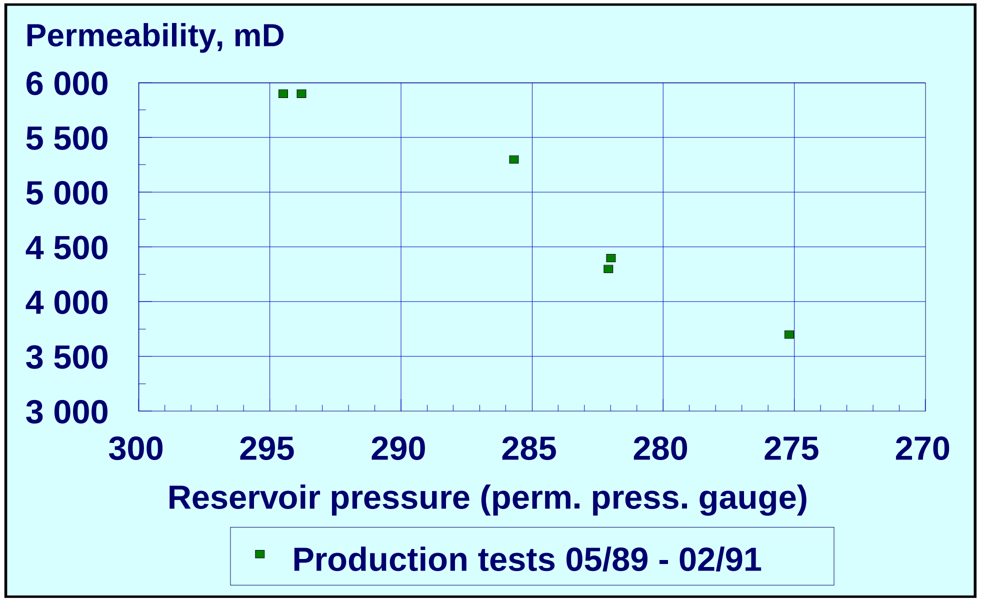
Moderate background,
Very weak channels

Increasing strength
downwards

Examples Permeability vs. Load, Gullfaks







Lower Brent cores

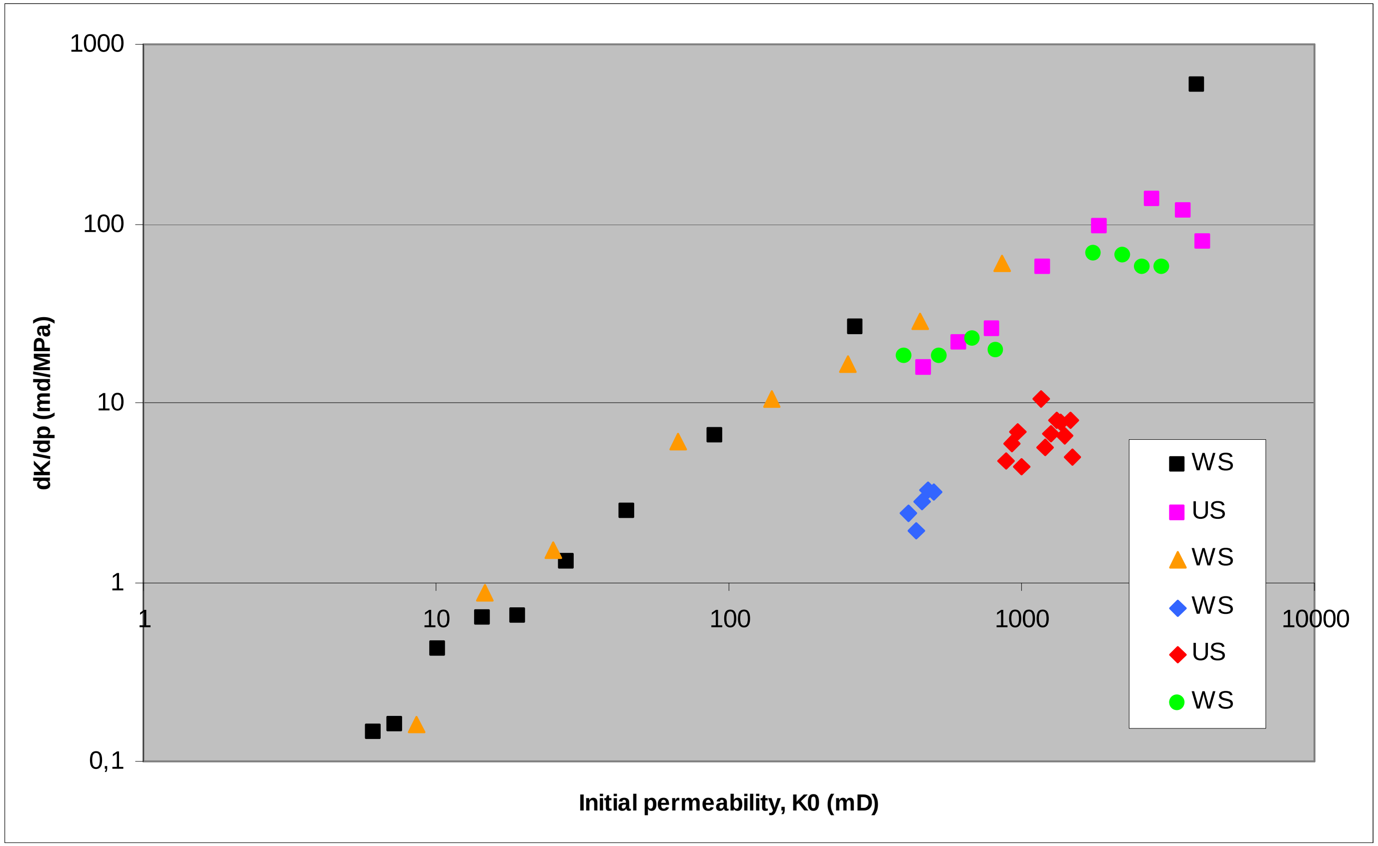
Upper Brent Well Tests Transient Analysis

Observations

- ***Data from a number of North Sea Brent Reservoirs show a permeability reduction of 20 – 95 % at a load increase of 100 bars***
- ***Permeability reduction is (almost) irrecoverable***
- ***Observations are in agreement with Grain Pack Model***

Material Homogenization

Permeability "rate of change" – data from six different Brent Reservoirs



Grain pack model:
Rock under compression becomes increasingly harder to compress.

In agreement with figure:
High initial permeability ⇒ perm.-reduction is larger for 1 bar load increase than when initial perm. is smaller.

Hence, for two materials with initially significantly different permeability the permeability-ratio will approach unity as load is increased.

→ Homogenization

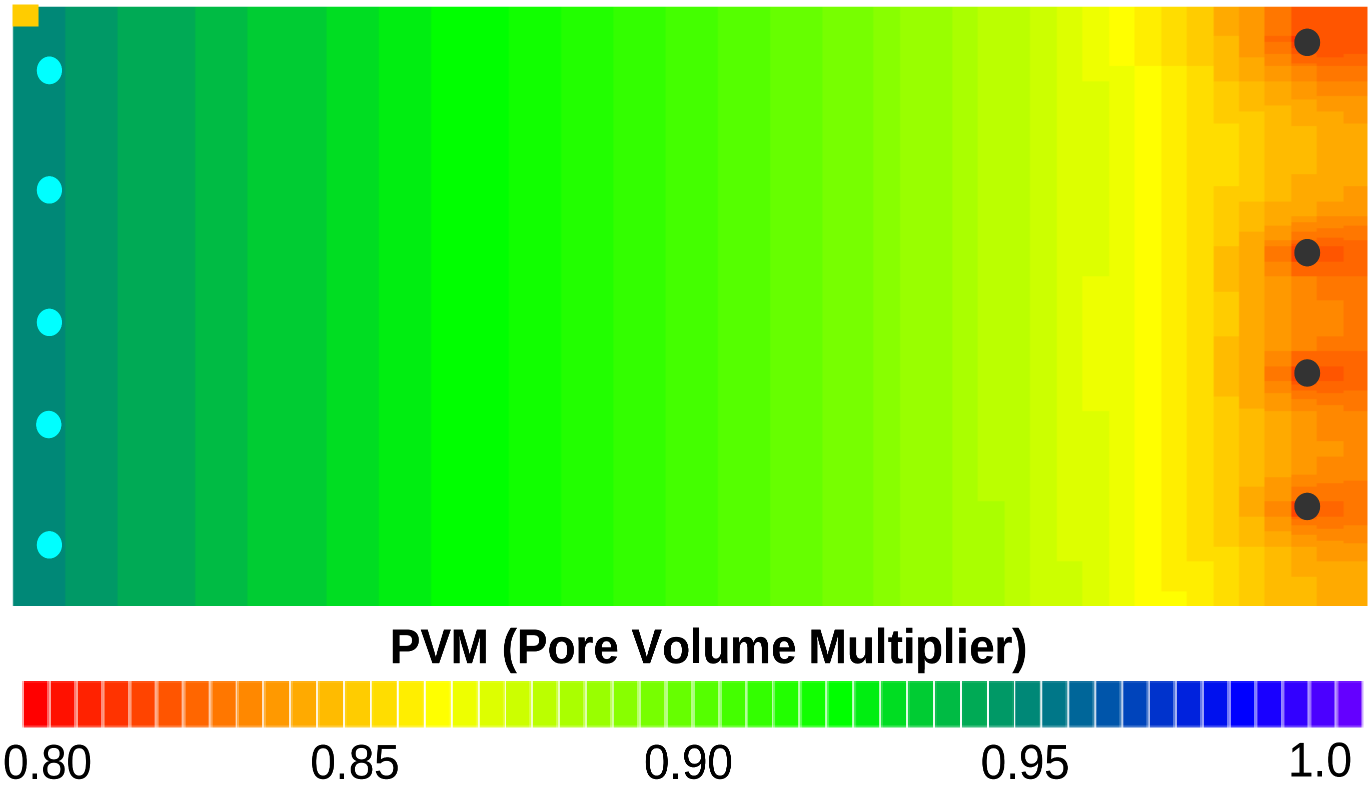
Recapitulation of Previous Presentations

1. ***Compaction modelling in reservoir simulators is overly simplified, and not sufficiently accurate when compaction is an issue***
2. ***Computation of accurate compaction requires coupled flow- and rock mechanics simulation***
3. ***The most popular procedure is to do coupled simulations with iterative pore volume updates***
   - ***Very costly w.r.t computing time***
4. ***We have developed a procedure whereby compaction can be computed without iterations, without loss of accuracy***
   - ***Introduces pseudo-materials and pseudo compaction vs. pressure relations***

Test Cases

- *~Gullfaks petrophysics & material properties*
- *Grossly simplified geometry*
- *Very different properties in the various zones*
- *Channels in Ness 2 and Etive*
  - *Channel widths: 15, 50, and 100 m*
  - *Channel height: 4 – 12 m*
- *Large or moderate contrast in material strength between channels and background (cases CL & CM)*
- *Moderate to low vertical conductivity*
- *16 years of moderate drawdown*
- *+22 years of maximum drawdown ("blowdown")*

Examples Compaction & Channels

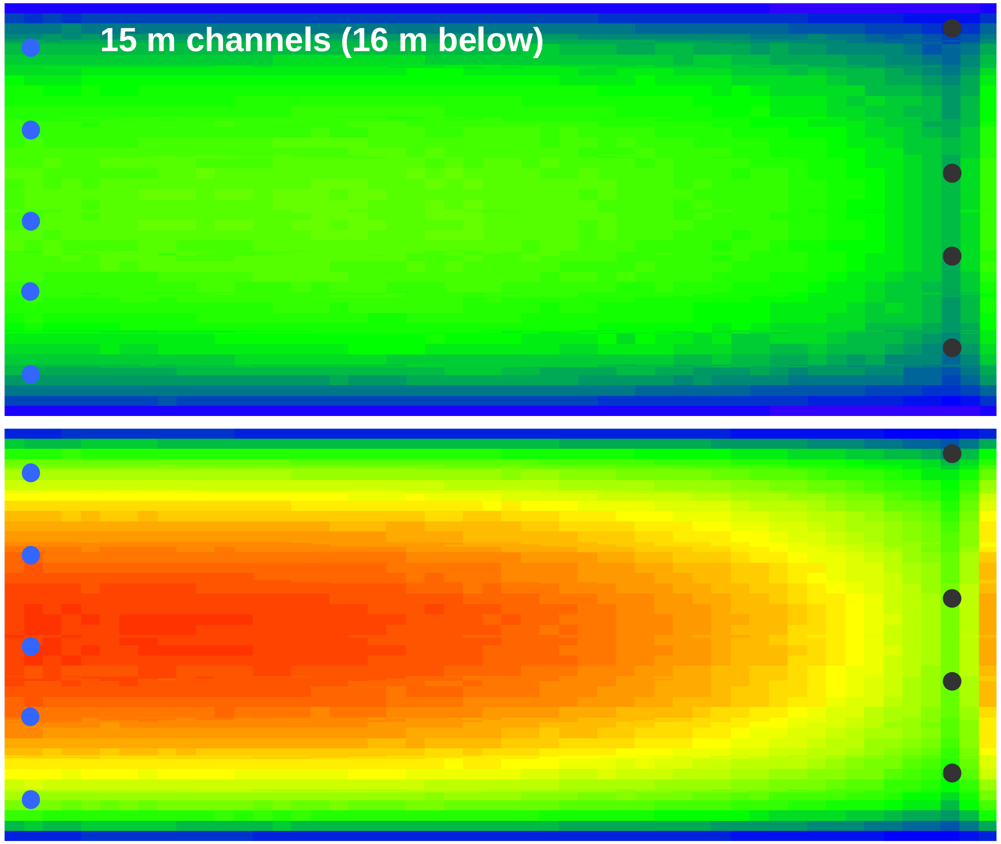


Compaction (by Pore Volume Multiplier) in Tarbert 2, in a West-East water drive.

“Traditional” modelling:

Compaction distribution resembles pressure distribution

Examples Compaction & Channels (2)

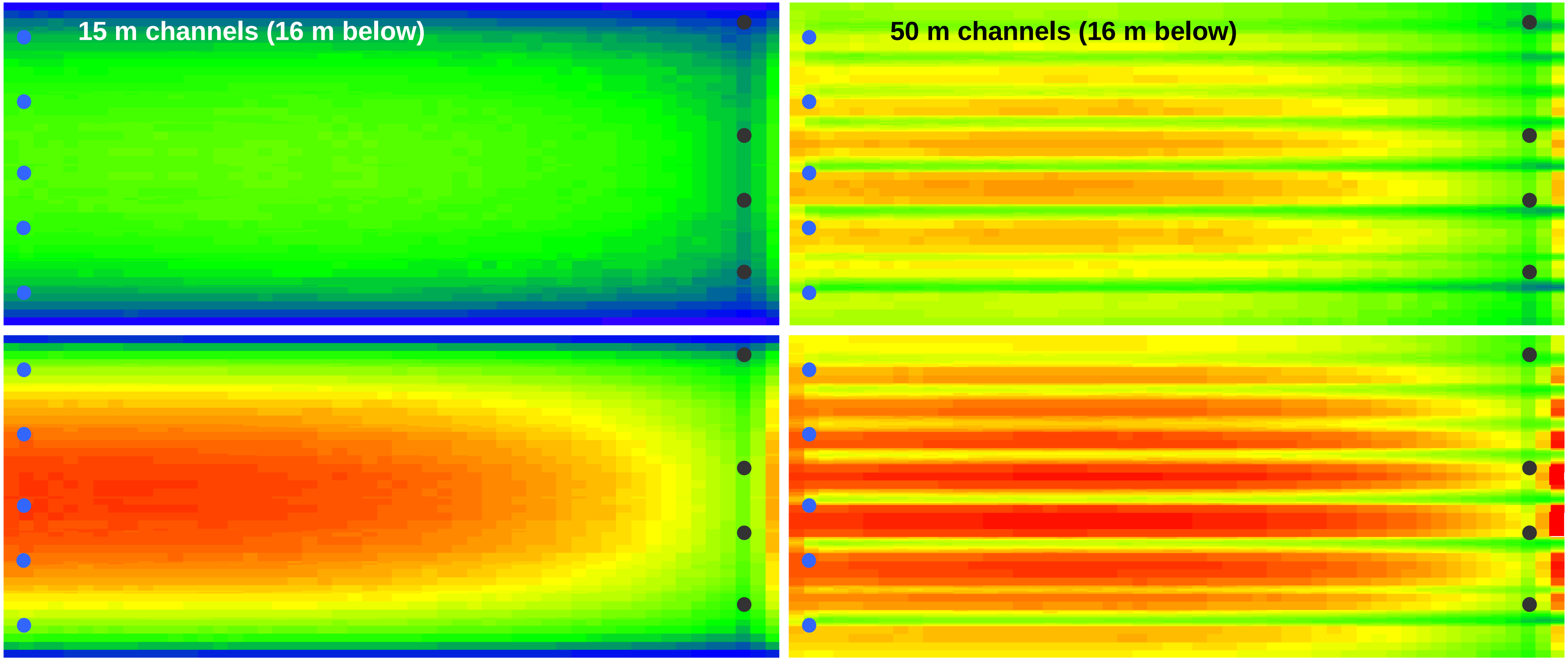


Correct modelling: (compaction computed from strain by stress simulator)

Top: Load 50-100 bars

Bottom: Load 150-200 bars

Examples Compaction & Channels (3)



Correct modelling: (compaction computed from strain by stress simulator)

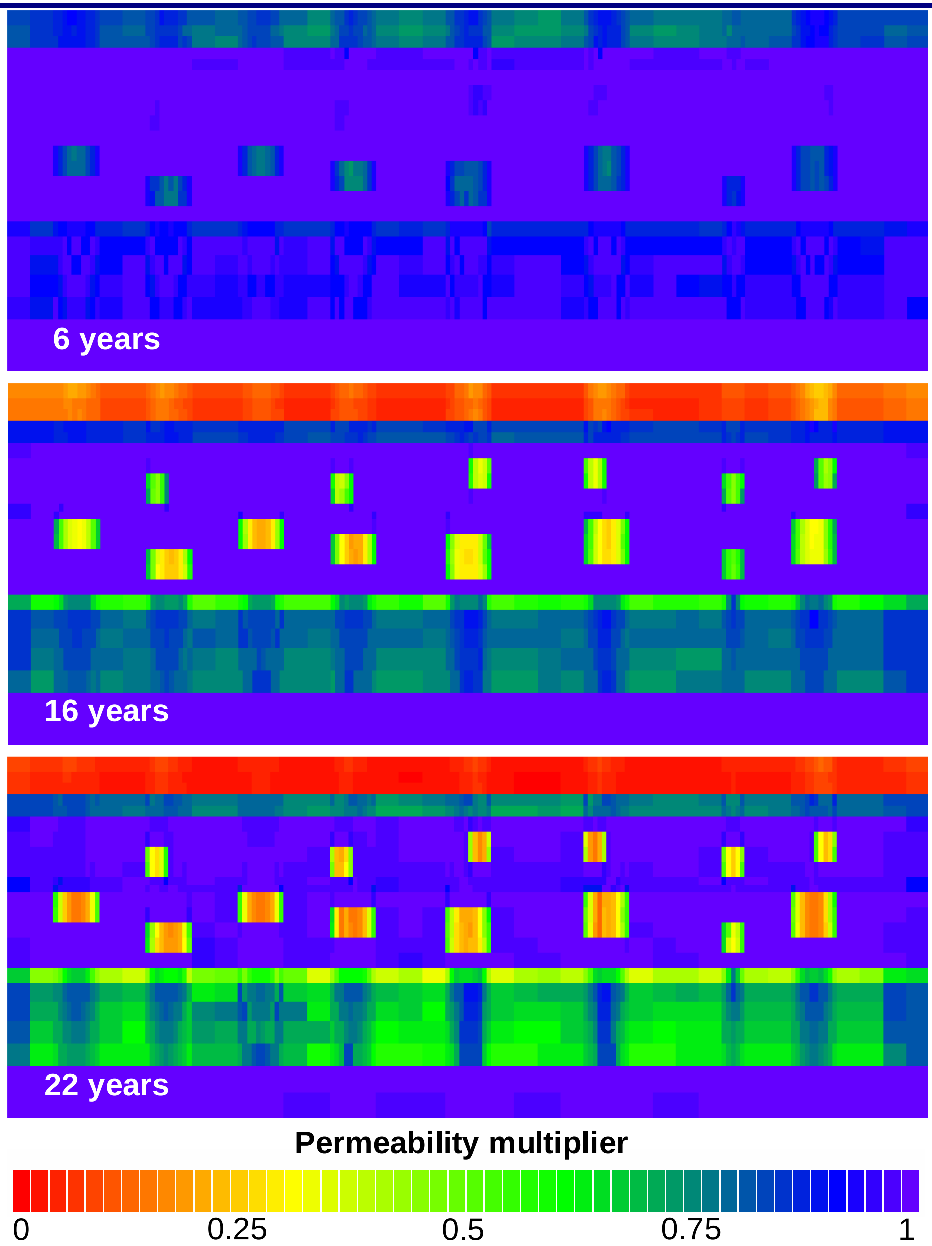
Top: Load 50-100 bars

Bottom: Load 150-200 bars

Left: 15 m wide channels in Ness 2

Right: 50 m wide channels in Ness 2

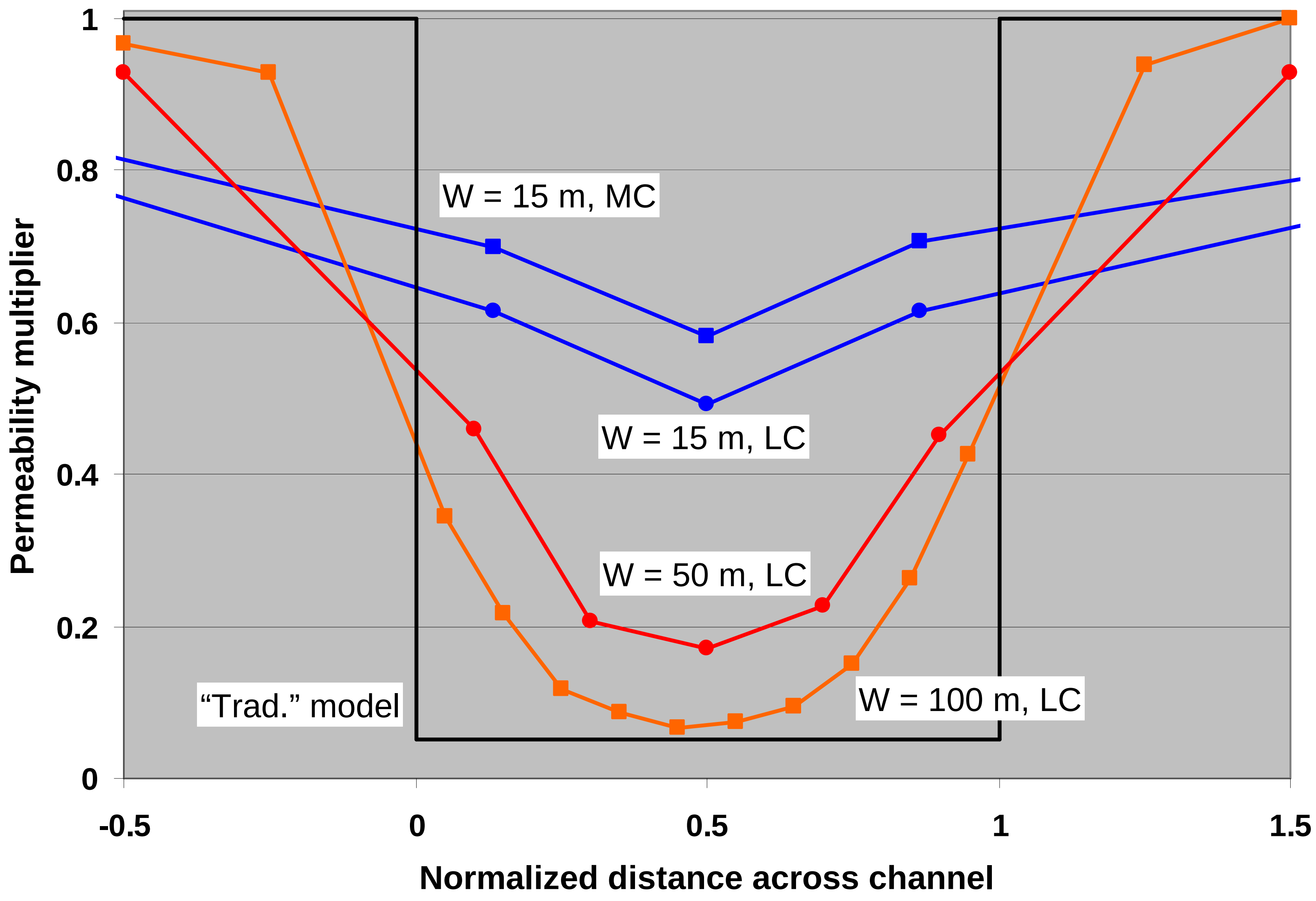
Examples Compaction & Channels (4)



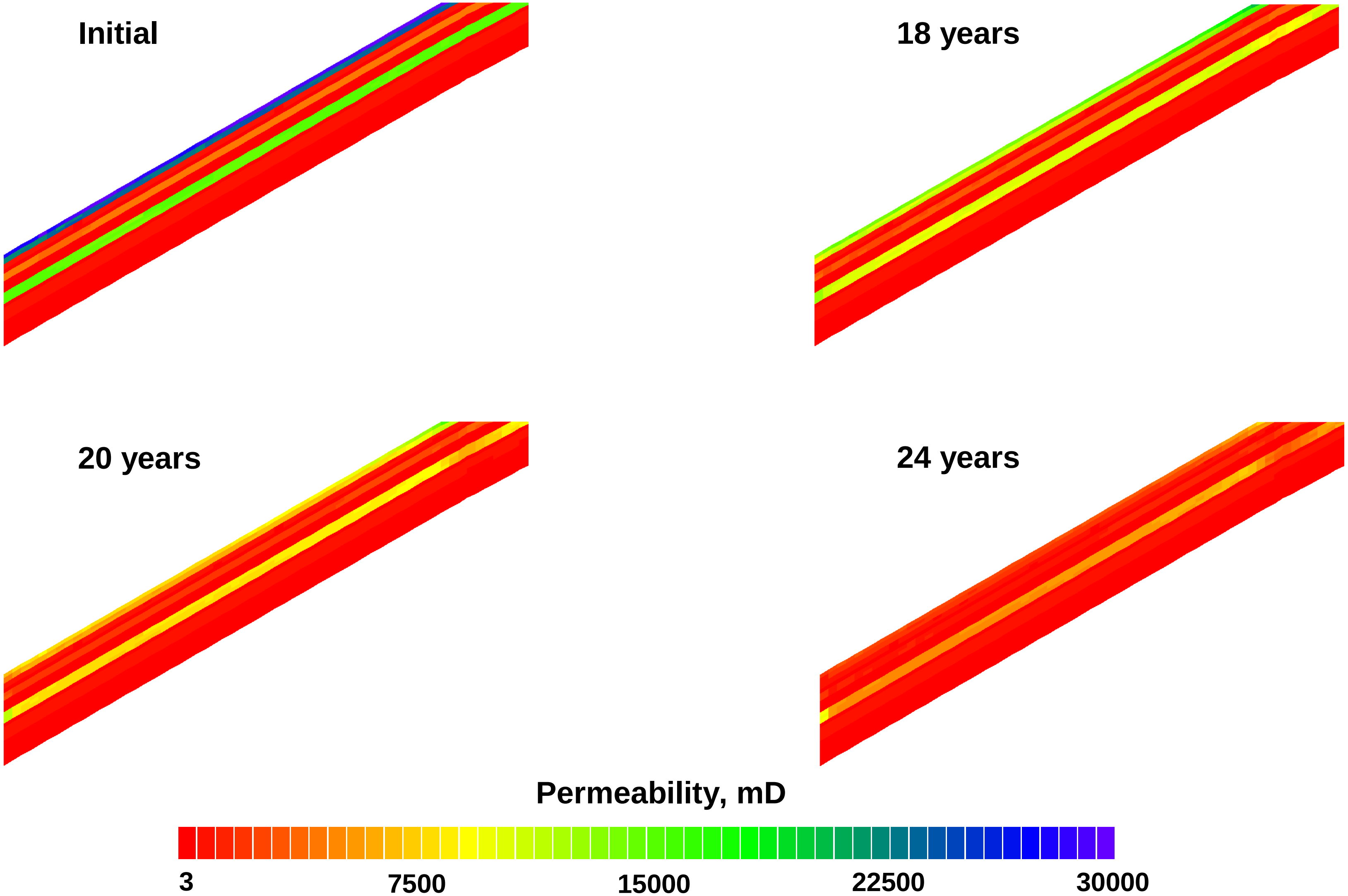
Permeability multiplier
in a (YZ) cross-section
transverse to channels,
near Upper Brent producers.

Note vertical domain of
influence from the channels

Variation of Permeability Multiplier Across Channel



Homogenization (West-East X-section)



Homogenization & Fluid Flow

By homogenization we expect

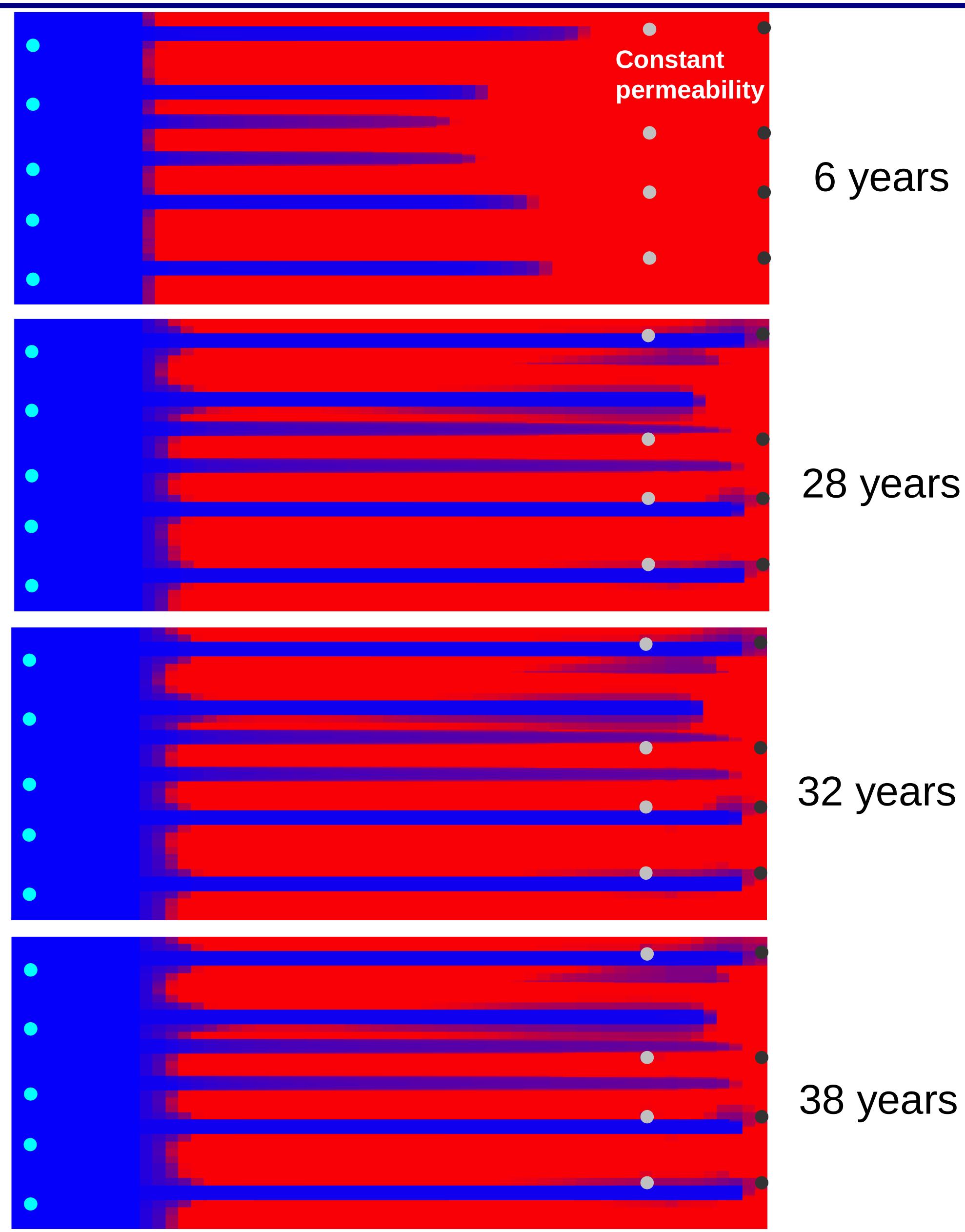
- ***Permeability ratio channel – background approaches unity***
- ***Initially water will flow preferred through high-perm channels***
  - ***Without homogenization: Water cycling after breakthrough***
  - ***With homogenization:***

    Preference to channels reduced

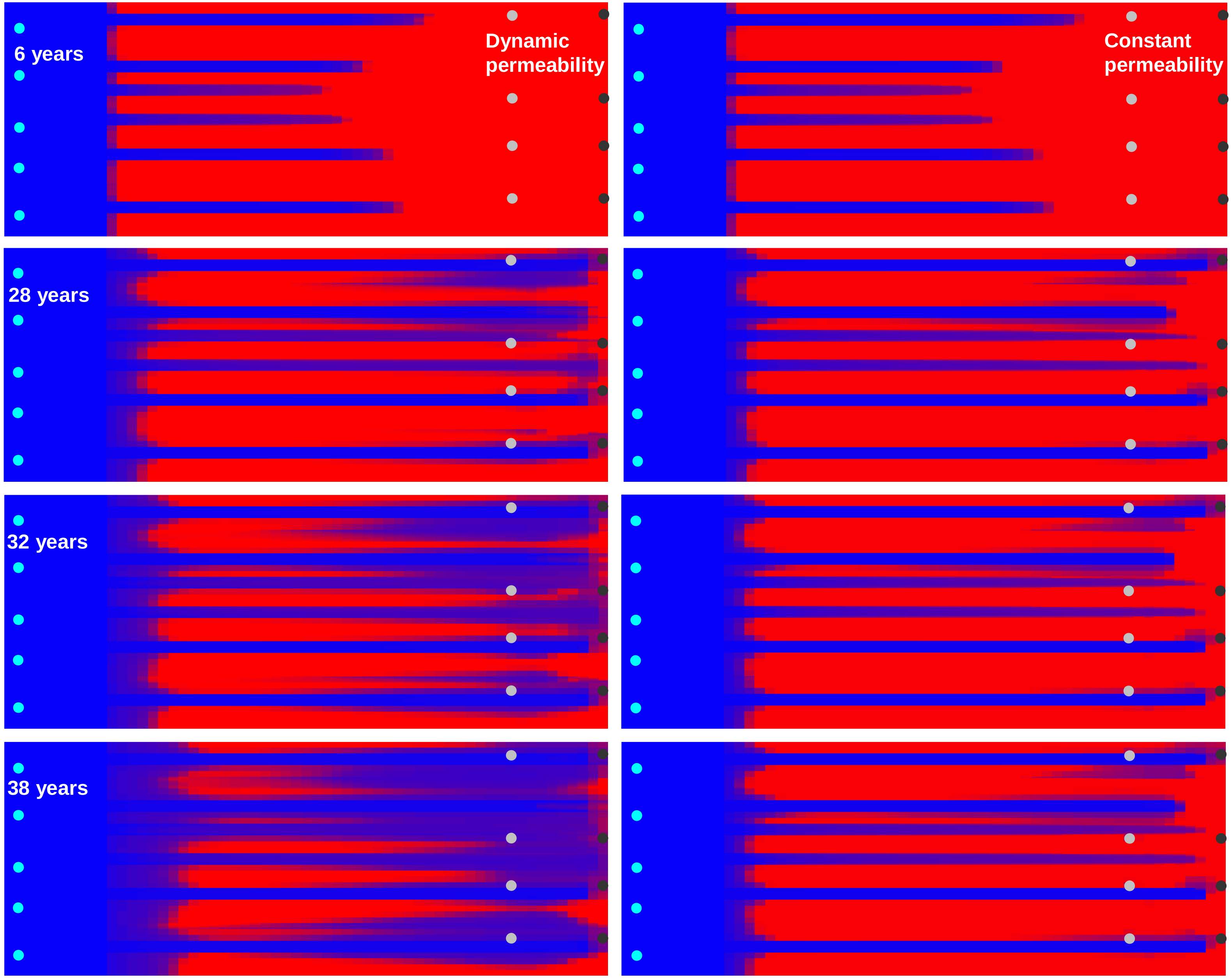
    (not that big difference between channel and b.g. permeability)

    Injection water spreads to background, better sweep

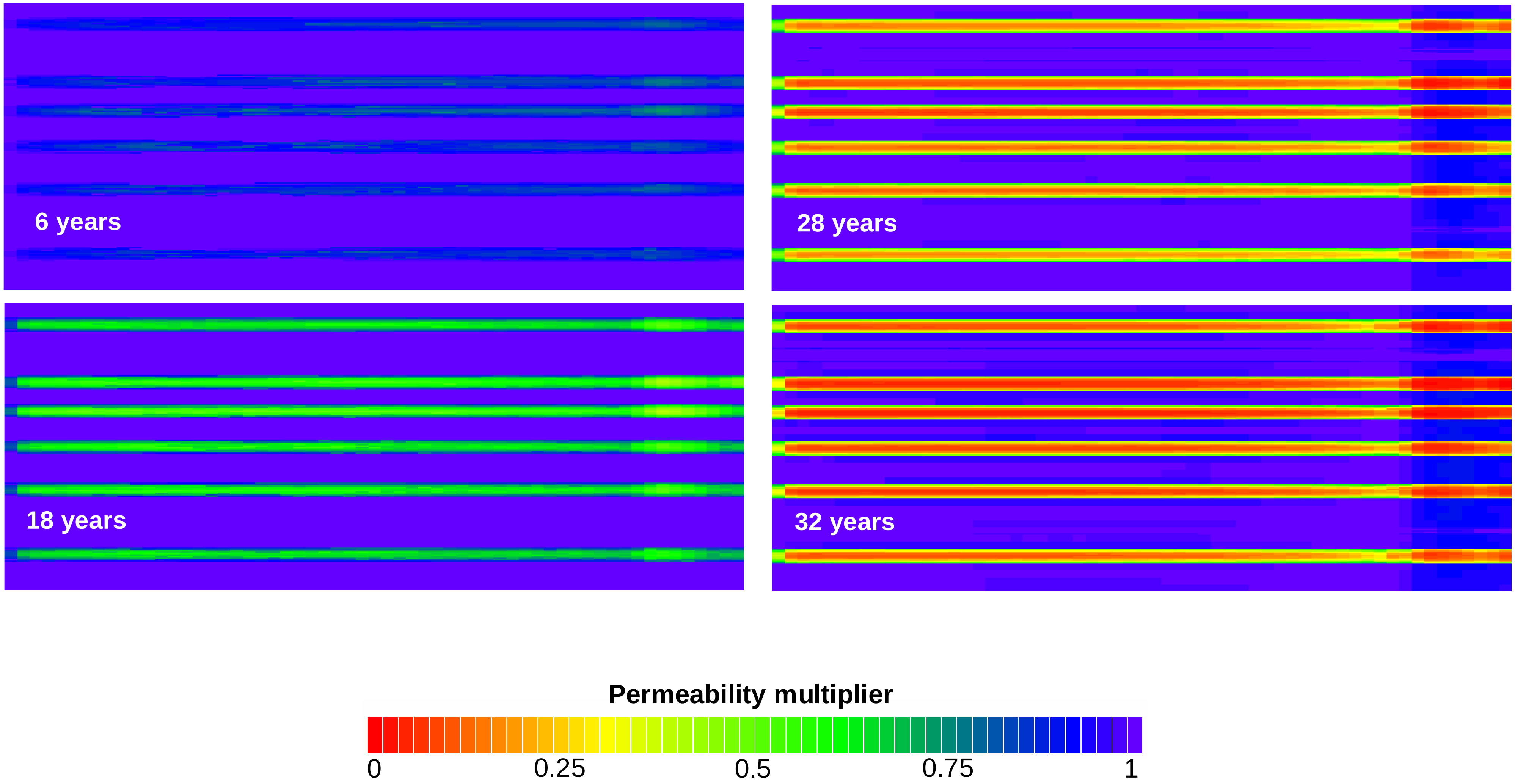
Water saturation in an Etive layer: No homogenization



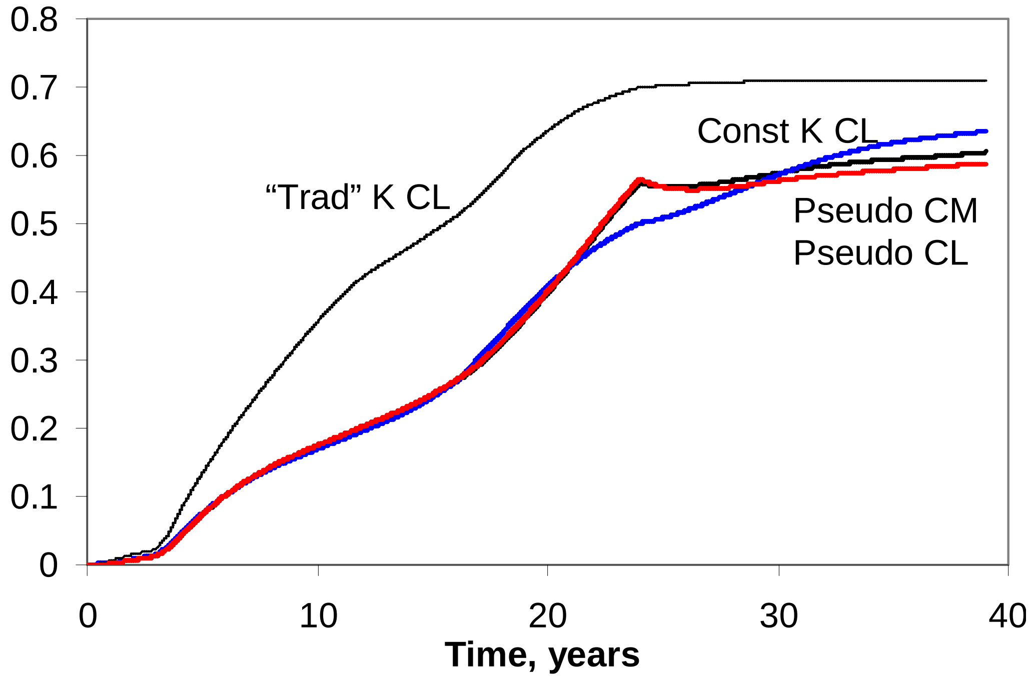
Water saturation in an Etive layer: W. homogenization



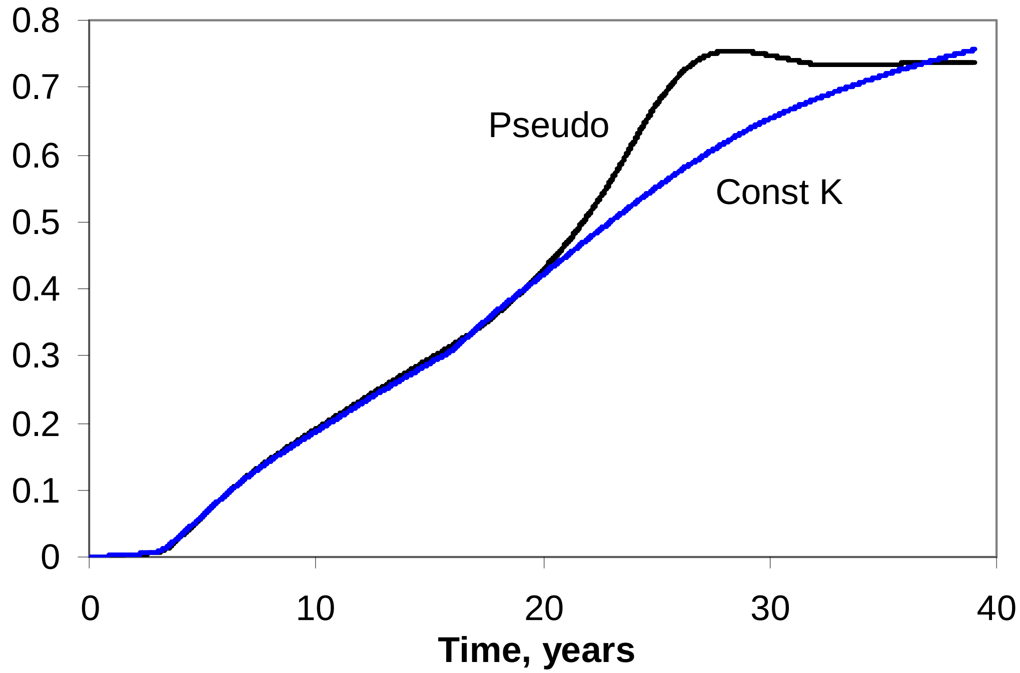
Perm-multiplier in the Etive layer w. homogenization



Region Oil Efficiency

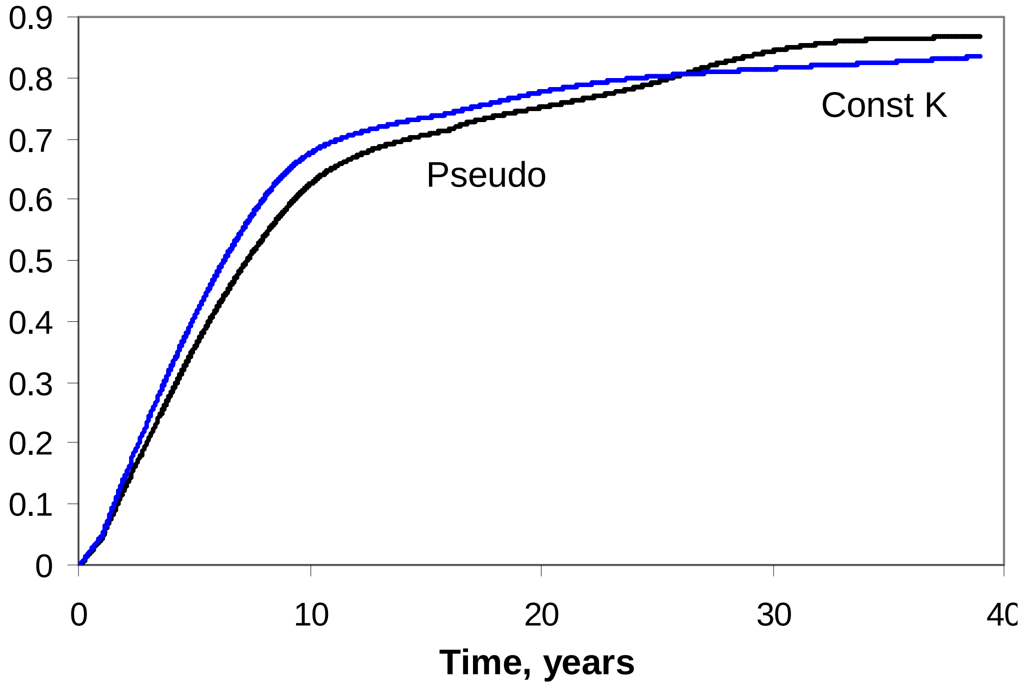


Ness 2 channels, 15 m channels

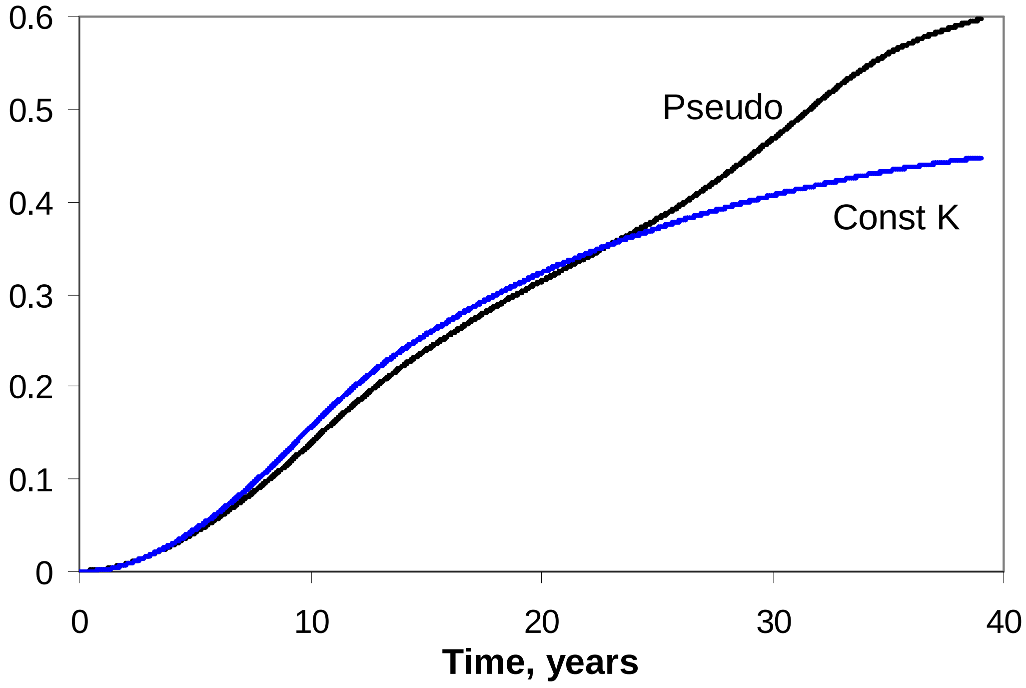


Ness 2 channels, case CL, 50 m channels

Region Oil Efficiency, Etive, case CL, 100m Channels

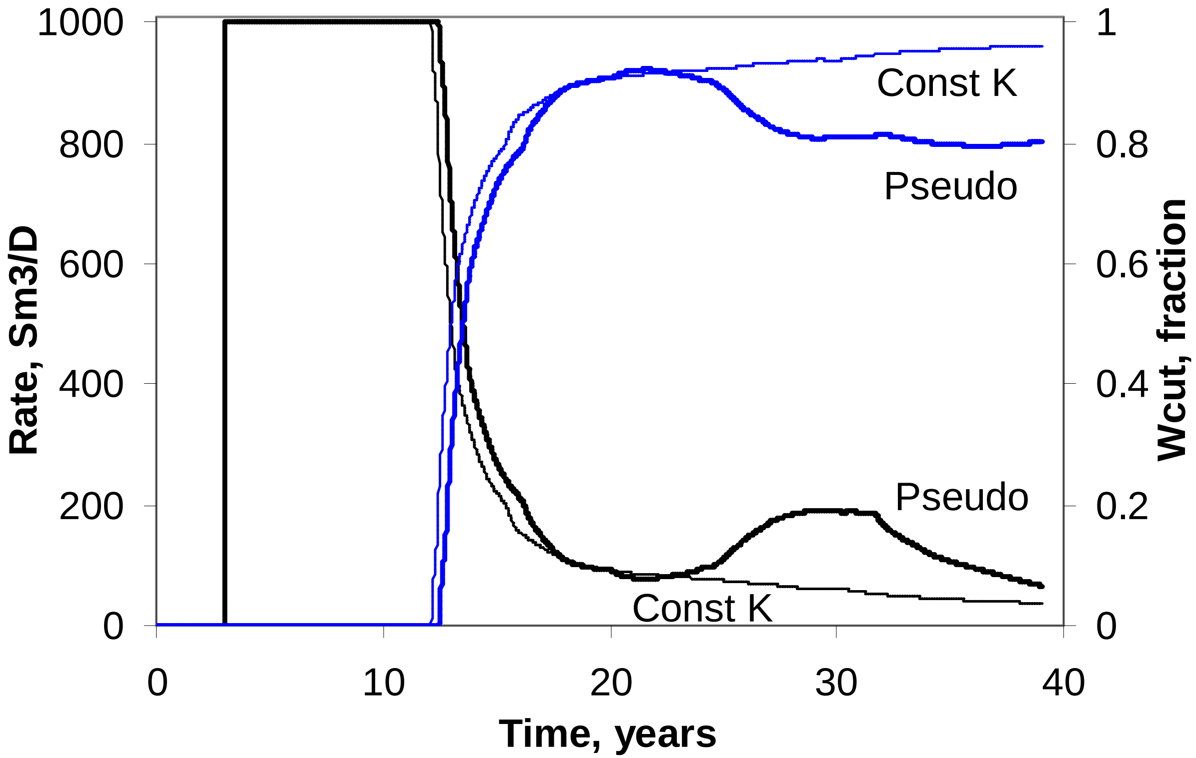


Channels



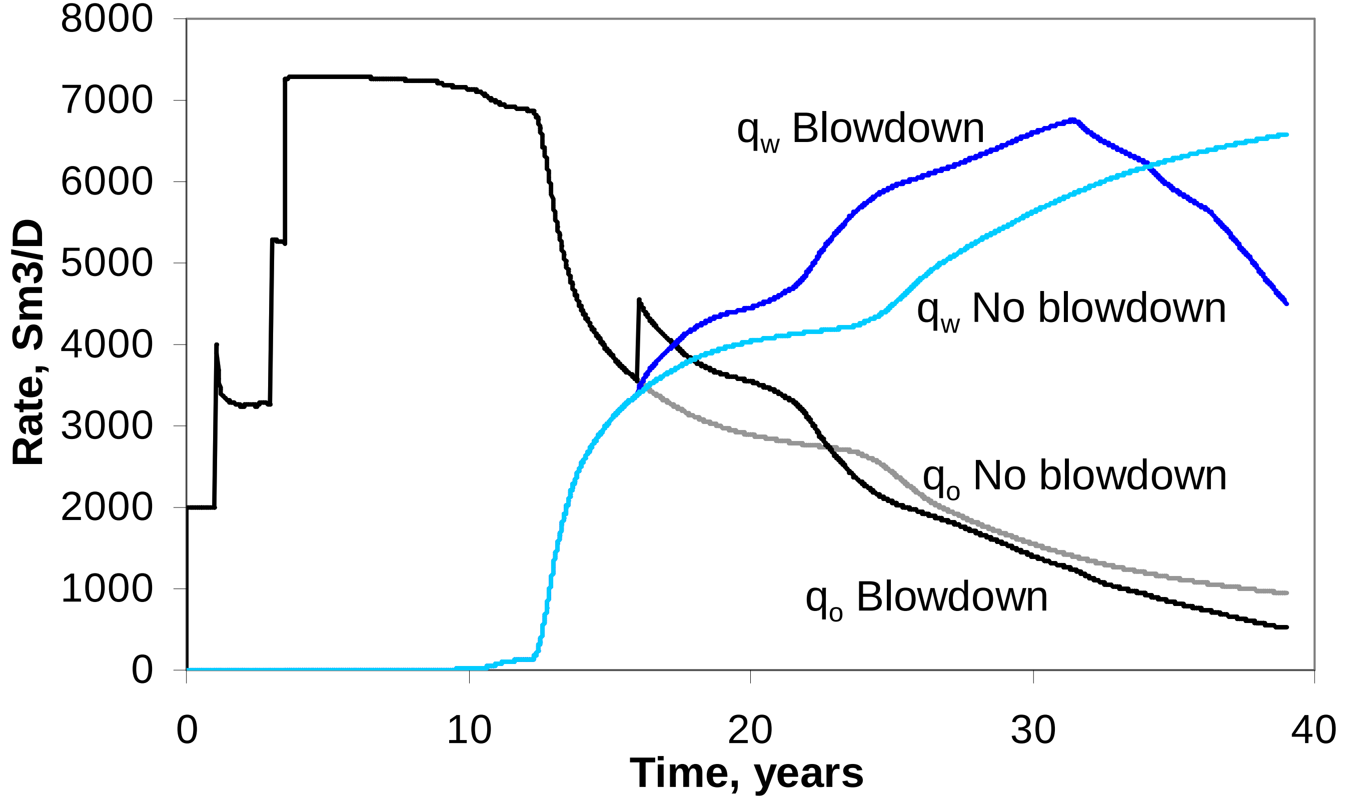
Background

Well Oil Rates & Water Cut, Central Upper Brent Well



50 – 100 m channels, Case CL

Comparison With & Without Blowdown



50 – 100 m channels, Case CL

Summary

1. ***Permeability reduction in a sand / sandstone reservoir can be large even at moderate pressure drawdown***
2. ***Compaction and permeability reduction can have large impact on fluid flow in a large class of reservoirs***
3. ***Weak and strong materials behave differently when loaded, and by pressure reduction the initial permeability distribution can be altered; having strong influence on flow pattern***
4. ***Reservoir deformation / compaction is more complex than ”traditional” pressure-dependency-assumption.***
   - ***Rock mechanics simulations required***

Summary, cont'd

5. ***Coupled flow sim – stress sim computation time has been significantly reduced by novel procedure***
6. ***Material behaviour in a depletion or pressure blowdown process can contribute positively to recovery in many kinds of reservoirs***
7. ***Factors influencing flow pattern change***
   - ***Perm. contrast strong – weak materials***
   - ***Initial perm. in low-permeability materials***
   - ***Perm vs. load relationship***
   - ***Geometry (extent & distribution of strong / weak matr's***
   - ***Overall vertical conductivity***