# Statoil experience on MEOR for Norne

Force workshop – MEOR: From theory to field

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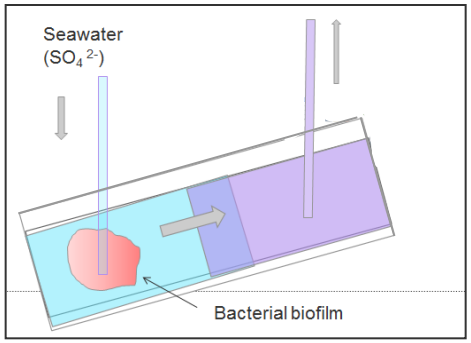
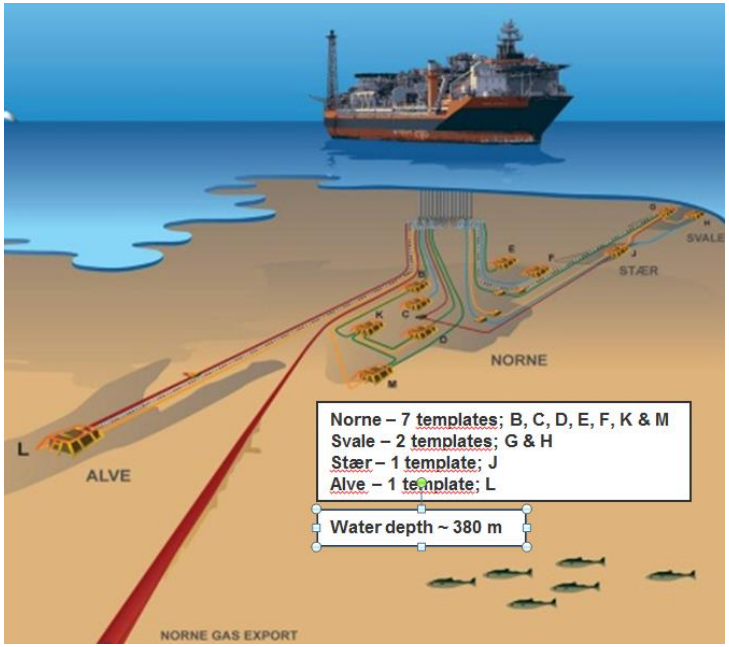
# Agenda

- Norne
  - Concept
  - Initial drainage strategy
  - Performed drainage strategy
- Microbes for EOR
  - Microbial growth
  - MEOR mechanism
- Production data analysis
- Conclusion and way forward

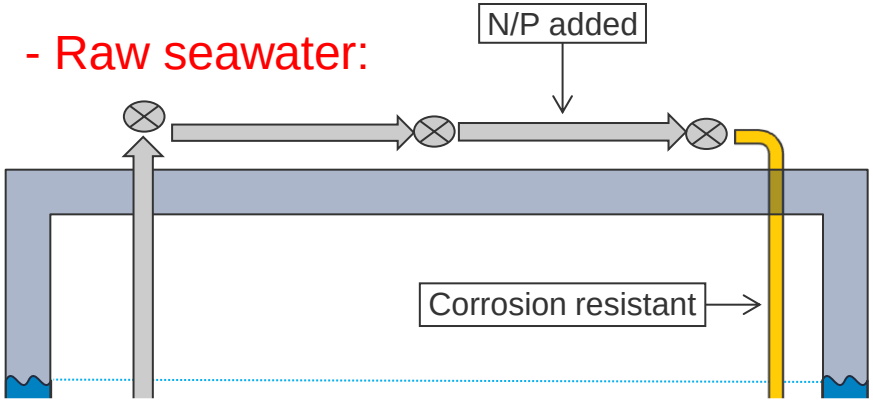


# Norne FPSO concept:

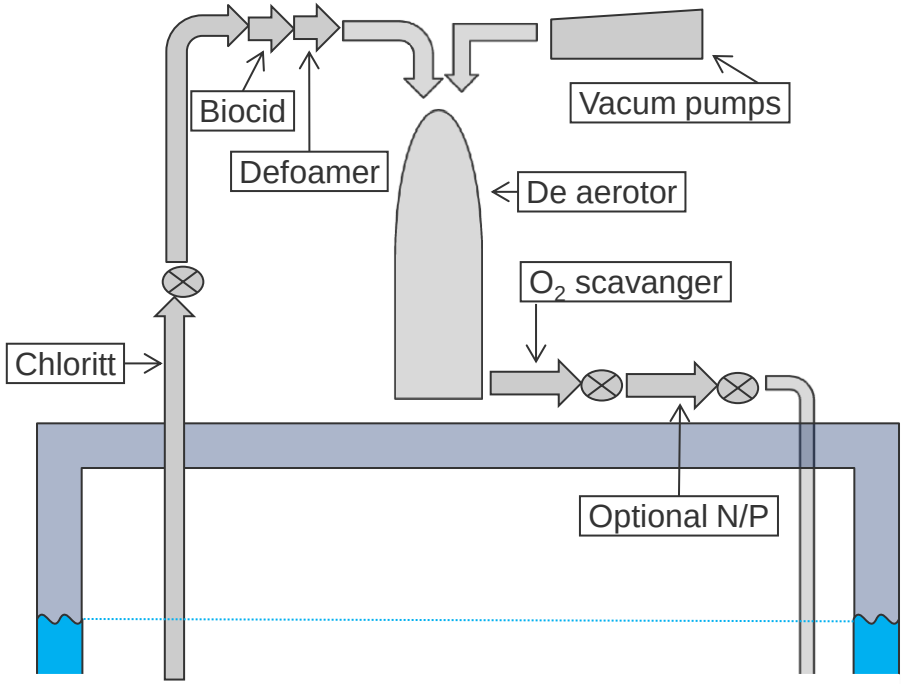
## - Subsea development:




## - Raw seawater:




# Common sea water solution:



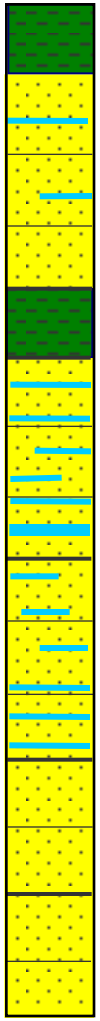

Norne raw seawater solution is copied at Tyrihans and a Brasil offshore field named Albacora, OTC4167

# Norne Reservoir

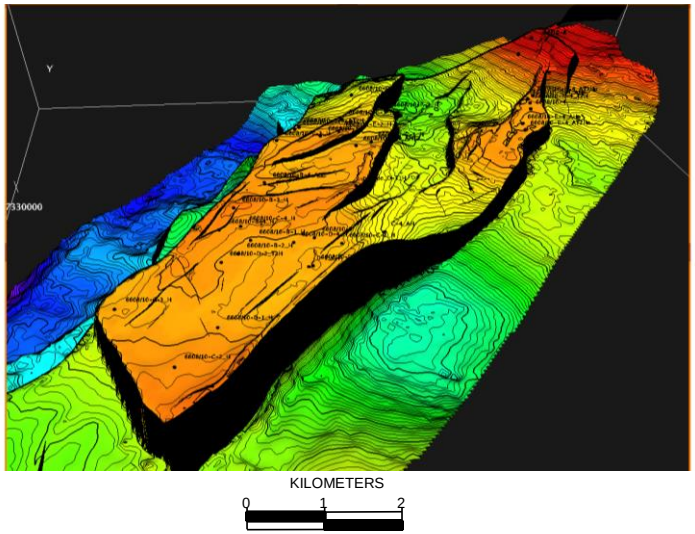
- Generally good reservoir quality:
  Porosity 24 - 28%
  Permeability 100–10000 mD

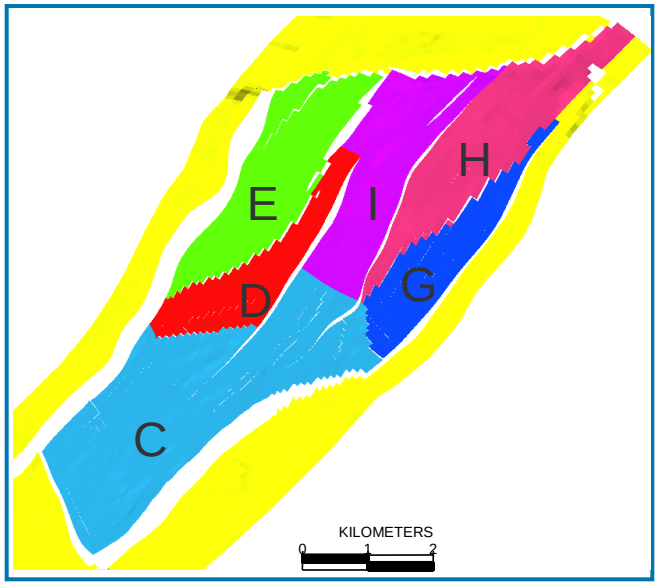
- Reservoir thickness ~ 230 m
  Gas cap ~75 m
  Oil leg ~110 m (light oil)

- Laterally homogenous reservoir
- Faults and carbonate cemented zones have a significant influence on the flow pattern
- Barrier modelling is important:
  - Carbonate cemented layers
  - Faults

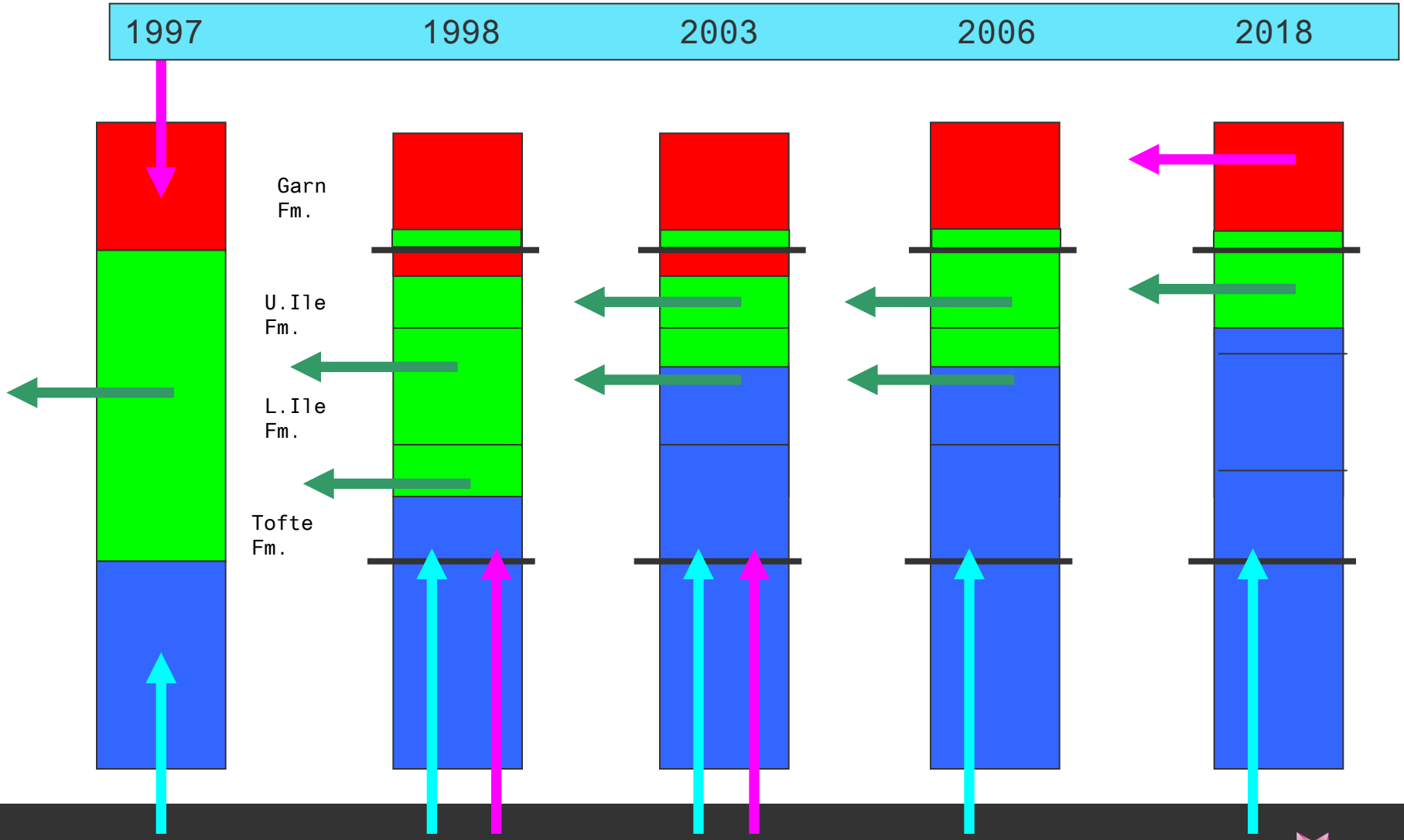


| NORNE 2006 | |
|---|---|
| Not 3 | Upper Not Shale |
| Not 2 (Not sandstone) | Not 2.3 |
| | Not 2.2 |
| | Not 2.1 |
| Not 1 | Lower Not Shale |
| Ile 2 | Ile 2.2 |
| | Ile 2.1 |
| Ile 1 | Ile 1.3 |
| | Ile 1.2 |
| | Ile 1.1 |
| Tofte 2 | Tofte 2.2 |
| | Tofte 2.1 |
| Tofte 1 | Tofte 1.2 |
| | Tofte 1.1 |
| Tilje 4 | |
| Tilje 3 | |



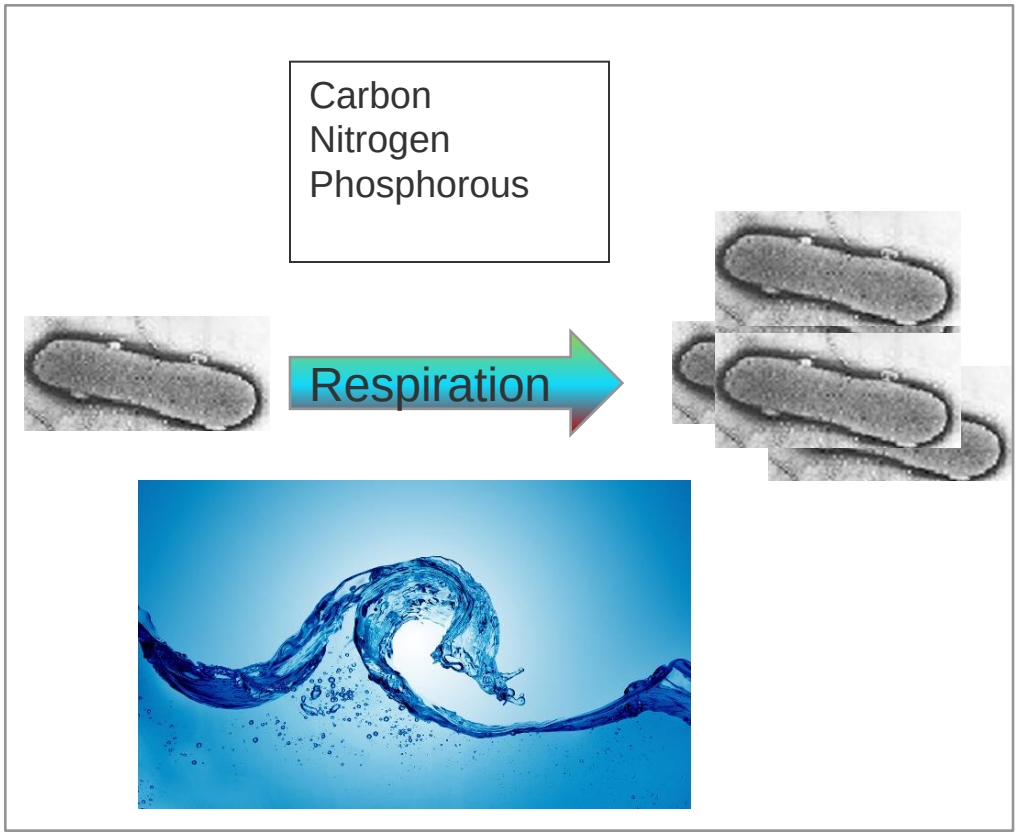
# Norne initial (1997) and performed Drainage Strategy

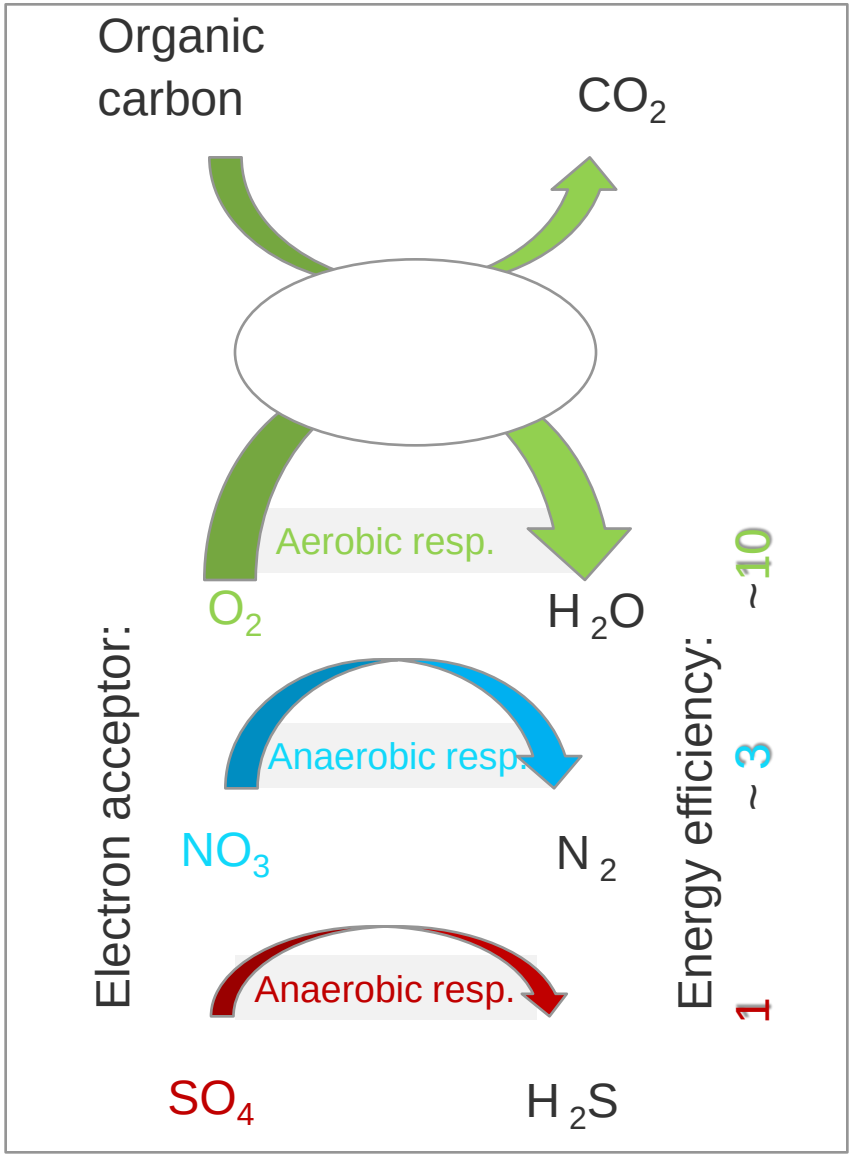


# Drainage strategy

- Pressure support mainly based on raw seawater injection (no oxygen removal)
- Produced water is treated and dumped into the sea
- (A)MEOR ((Aerobic) Microbial Enhanced Oil Recovery) optimized after production start-up by injection of nitrate, phosphate and oxygen to improve the MEOR efficiency (start-up Feb 2001)

# Microbial growth:



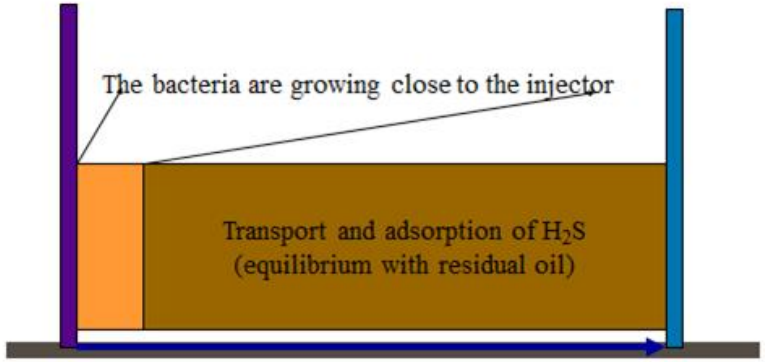



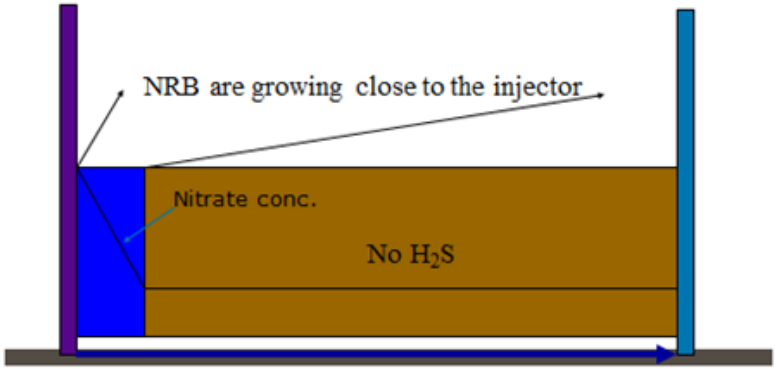
# Microbial growth:

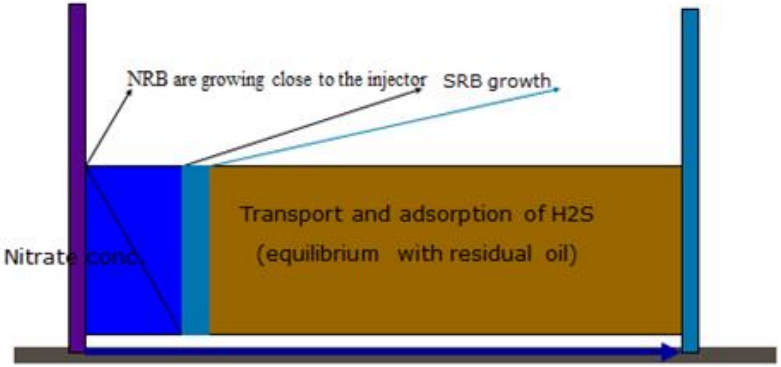
To get growth of bacteria, there are three key constituents required:

- The bacteria must have "food". “Food " means in practice that they need a carbon source and some phosphorus and nitrogen.
- The bacteria must have "energy ". Energy means that they must have an electron acceptor. This may be oxygen ($O_2$), nitrate ($NO_3^-$) or sulfate ($SO_4^{2-}$).
- The bacteria must have an adequate environment to live in (near well area which has been made non toxic during injection of sea water).

Positive other effect: Nitrate dosing at lab and field experiences show that this is an effective way to significantly delay/mitigate for an expected unwanted $H_2S$ souring

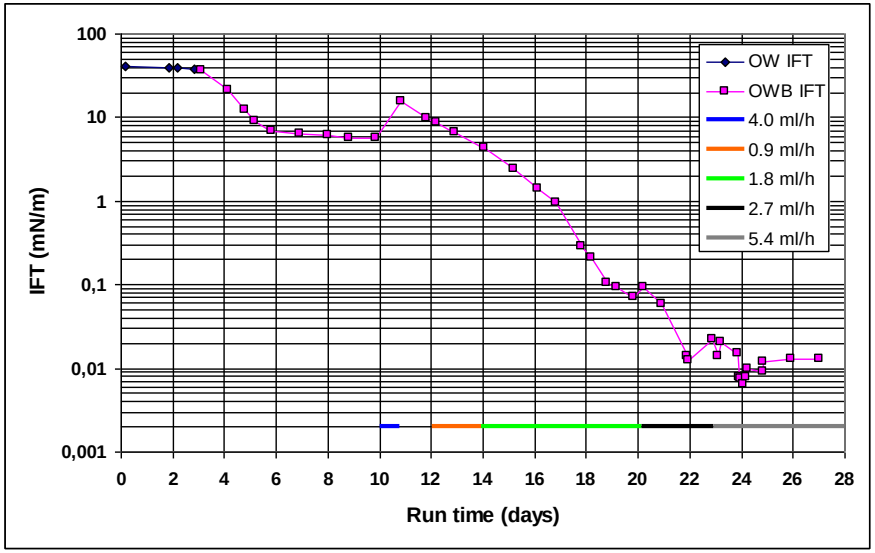


# MEOR mechanism:

## 1. Reduction of Sorw



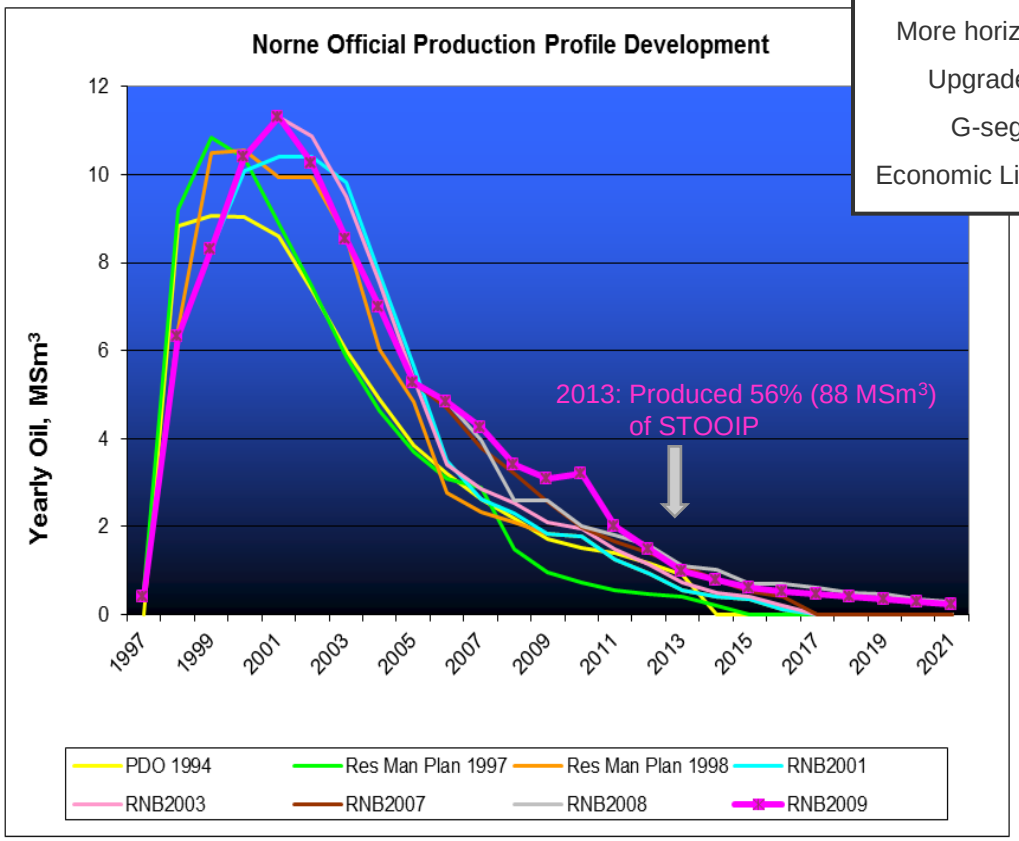

Interfacial tension versus run time measured by laser light scattering.
The stimulated bacteria are growing by continuous supply of nutrients.

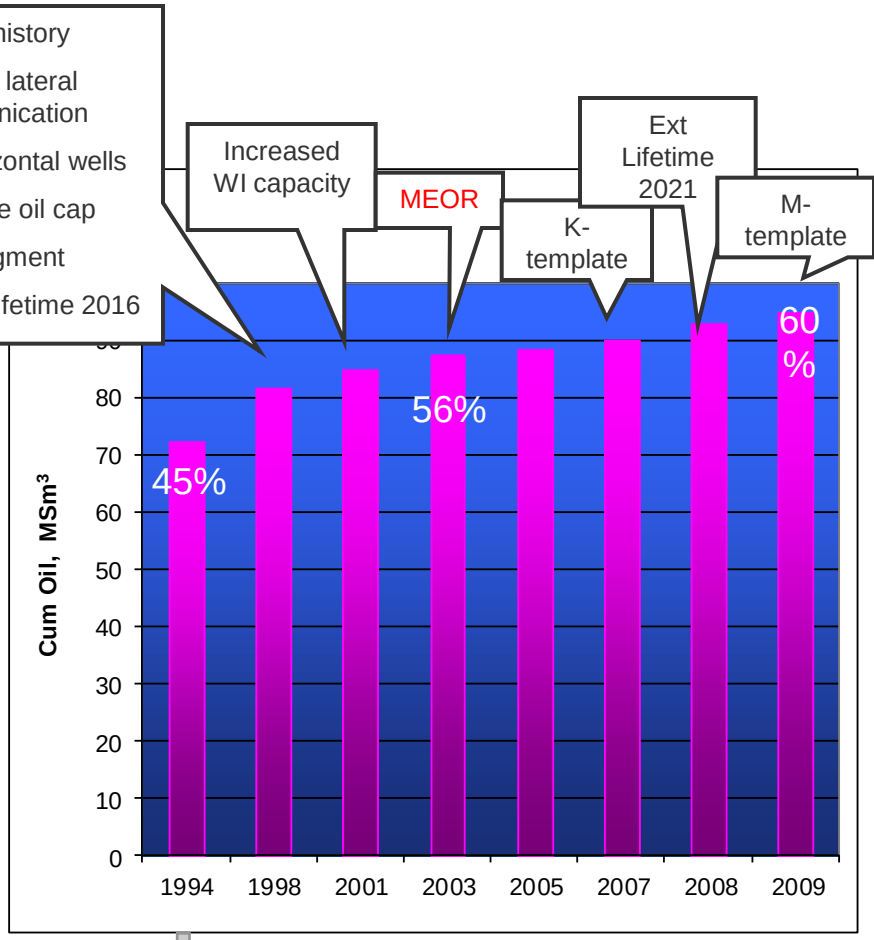
Challenge:
How can local stimulation gives global response?
Can Strand theory, SPE 154138, be valid?
Ref.: Stanley Jones experiments: SPE 12125

## 2. Diversion – red. perm. in high perm zones

- sufficient generation of biomass for dynamic plugging
- heterogeneous reservoirs
  - layered reservoir with no communication:
    - only local plugging required
  - communication between layers:
    - plugging at some distance away from the injector

# Norne Reserves Development PDO 1994 → 2009




JPT – April 1996 (296-339)

# Production data analysis

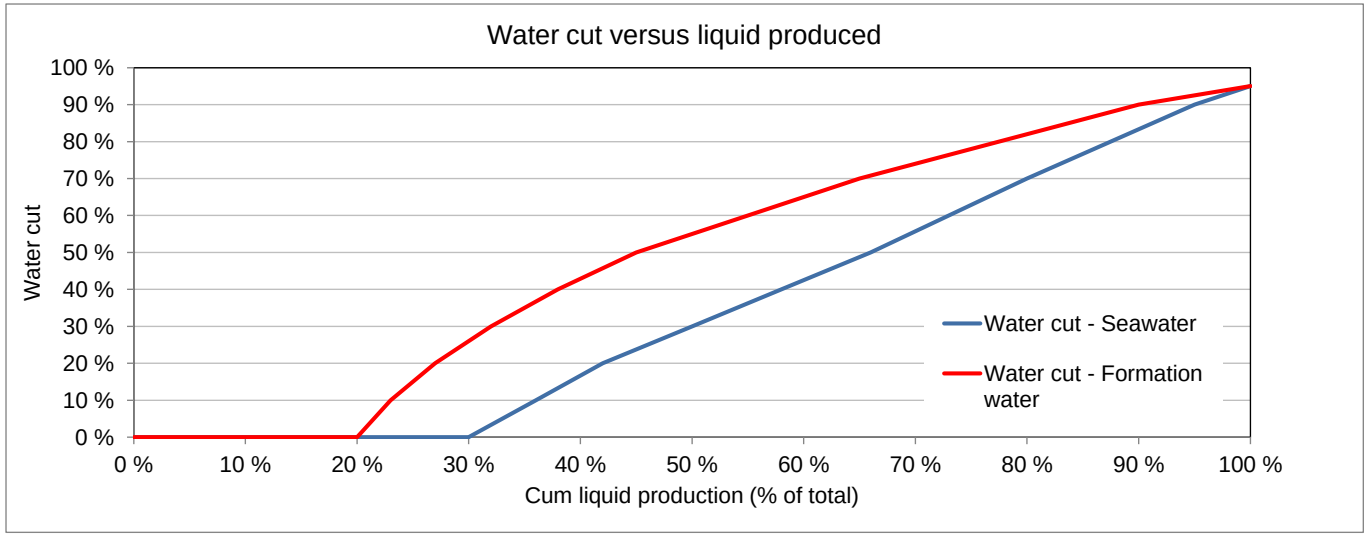
Objectives:

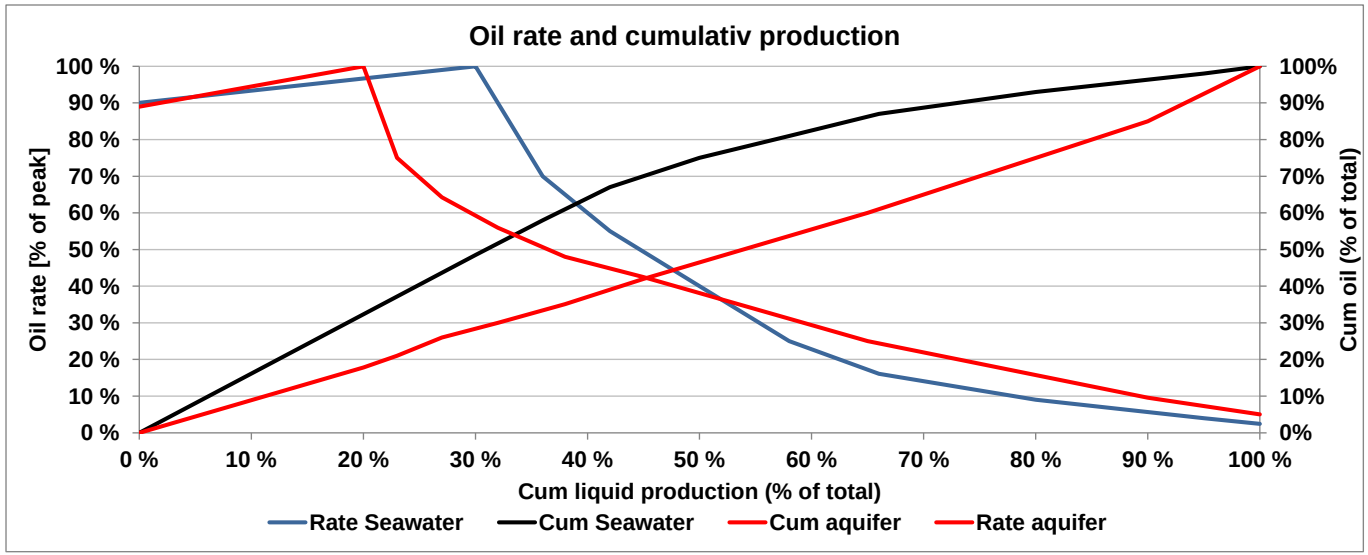
1. How can production performance indicate any MEOR effect?
2. Evaluate production performance in light of quantitative and qualitative seawater fraction during production
   - during plateau phase
   - during decline
3. Evaluate seawater fraction after sea water breakthrough

Challenges: production allocation, operational issues, seawater fraction measurement (frequency, regularity, reliability), lack of baseline, very few wells with low (no) seawater production

# Illustration of assumed production performance:

…if to example injected SW with MEOR give higher recovery than FW/PWRI:




Expected similar:

- Oil rate

If higher recovery / favourable prod. performance:

- Later water breakthrough
- More gradually increase in water cut
- Shorter oil rate tail
- Lower volume of water produced compare to volume of oil produced

# NB: From Dake: «the practice of reservoir engineering…»

NB:
The water cut development is always a function of the reservoir geometry and reservoir characteristics……

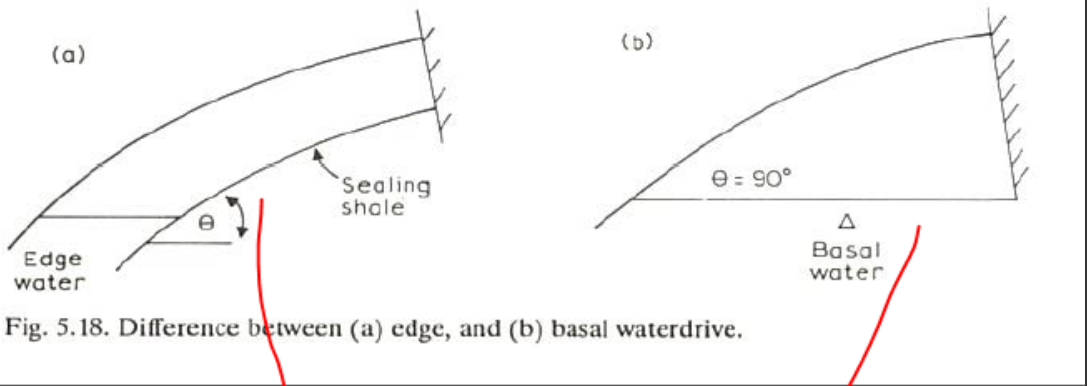



Fig. 5.18. Difference between (a) edge, and (b) basal waterdrive.

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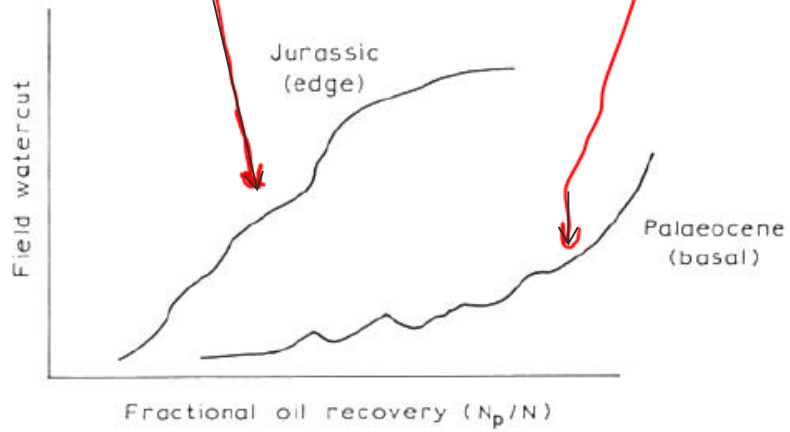
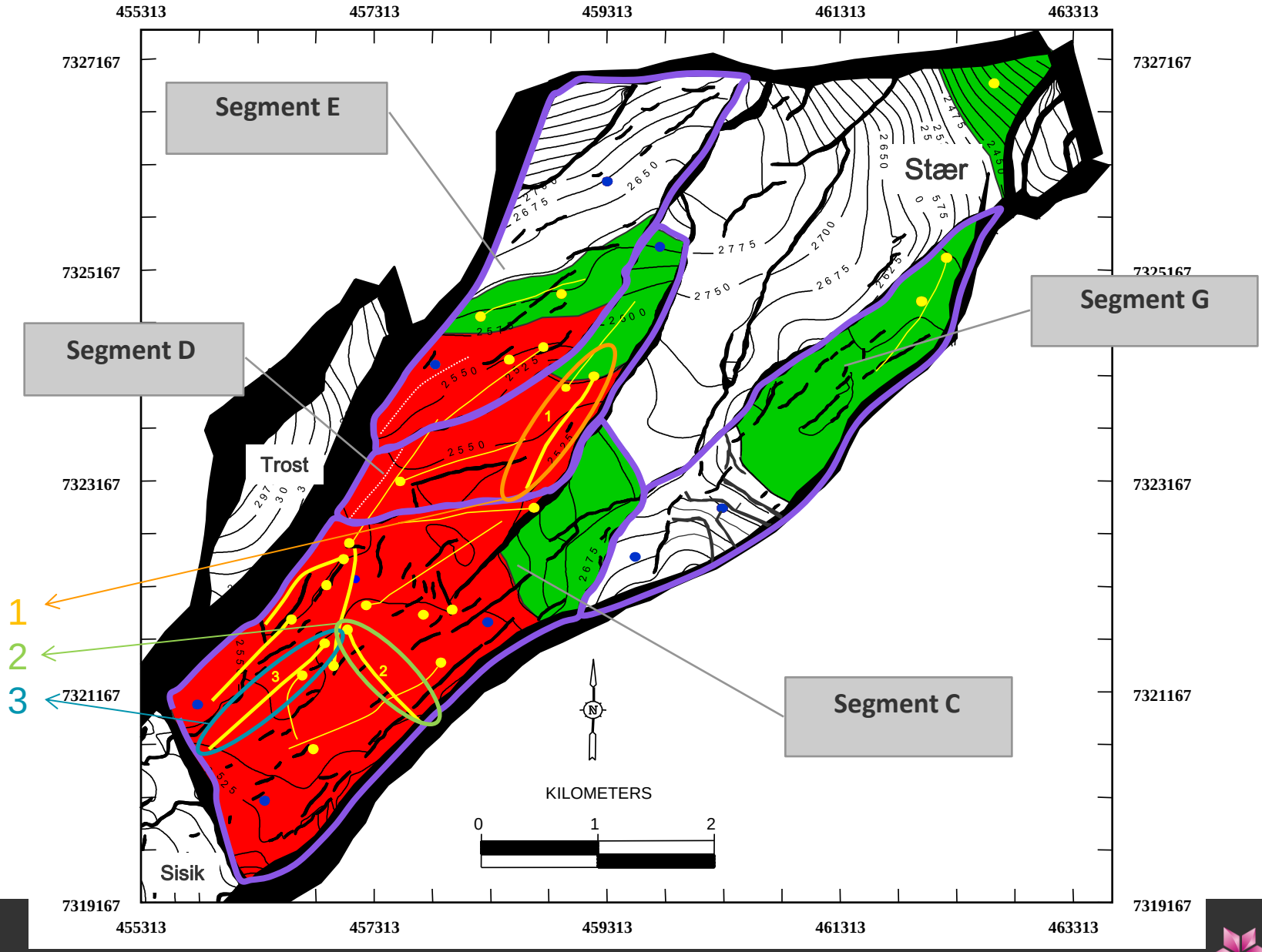


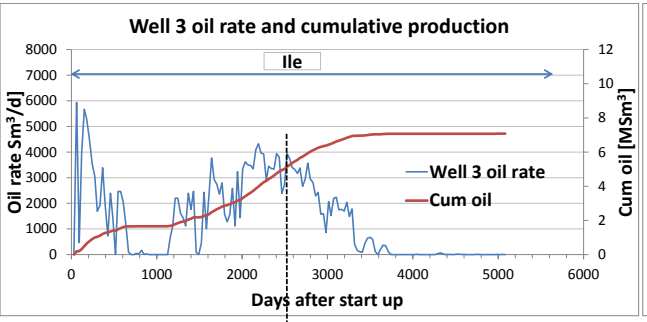

Fig. 5.19. Contrasting watercut developments in edge and basal drive fields.

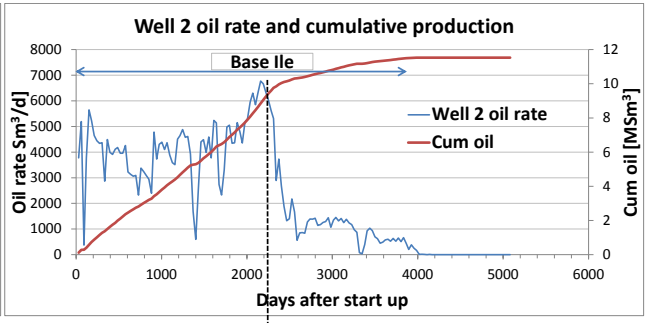
# Norne, Wells pattern

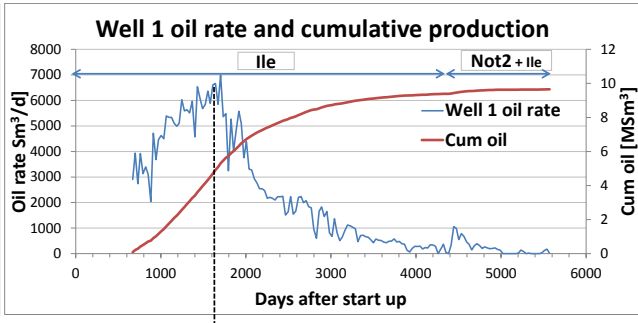


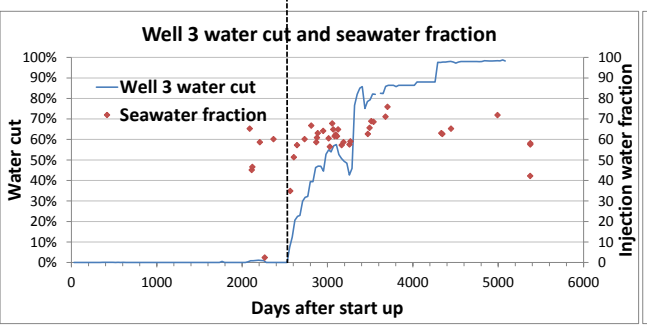

Statoil

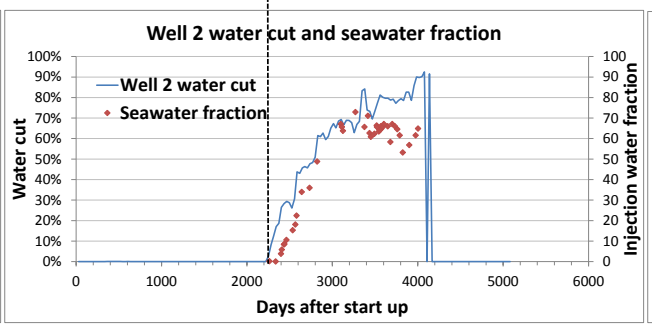
# Production performance, 3 ILE producers

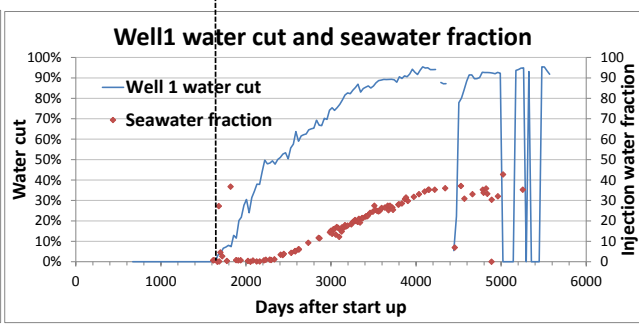


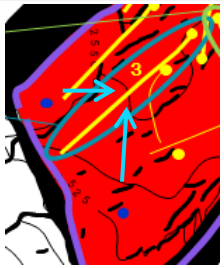



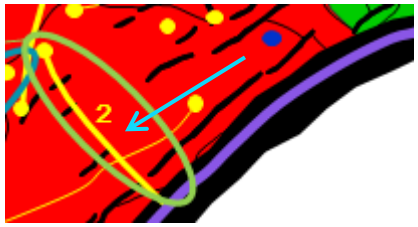



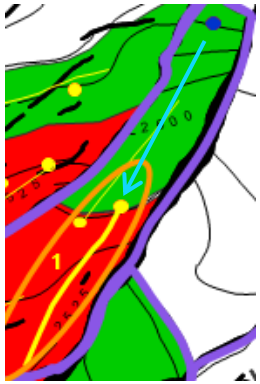



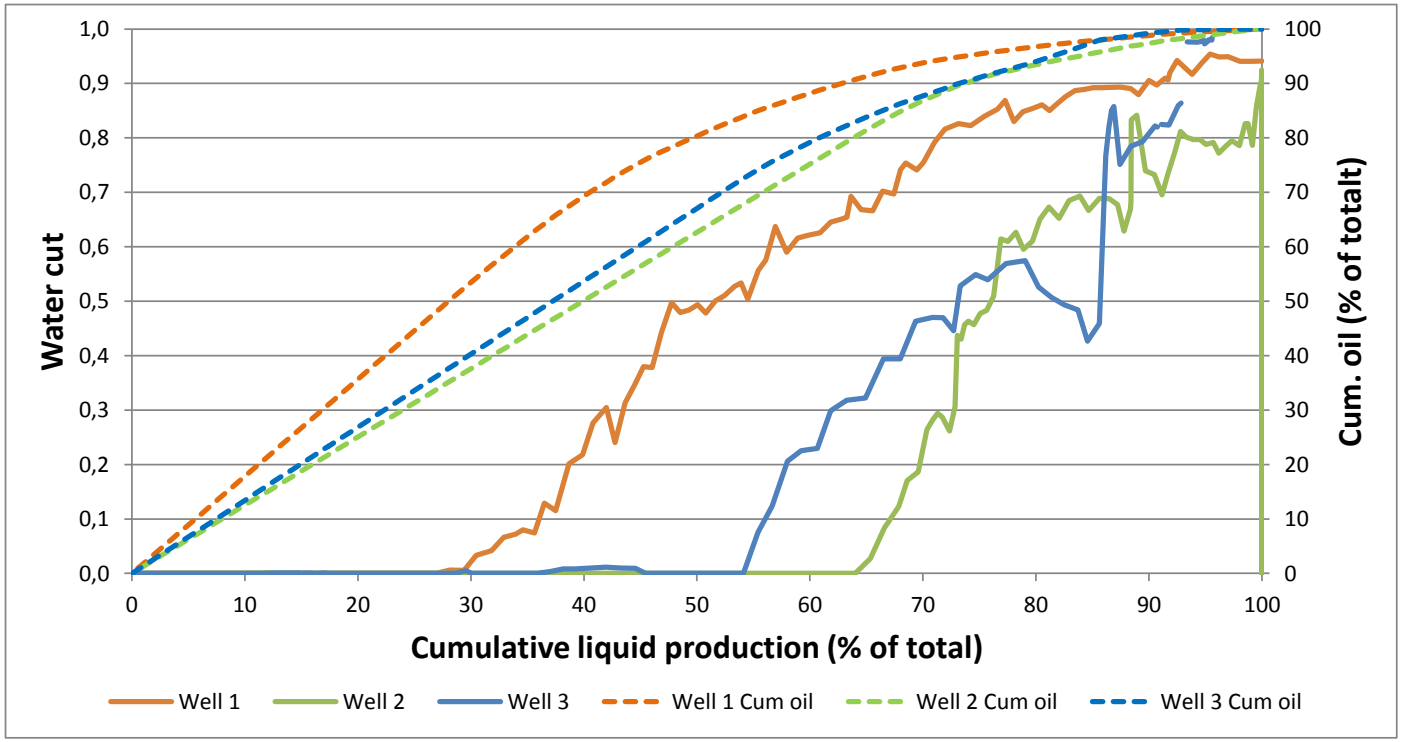



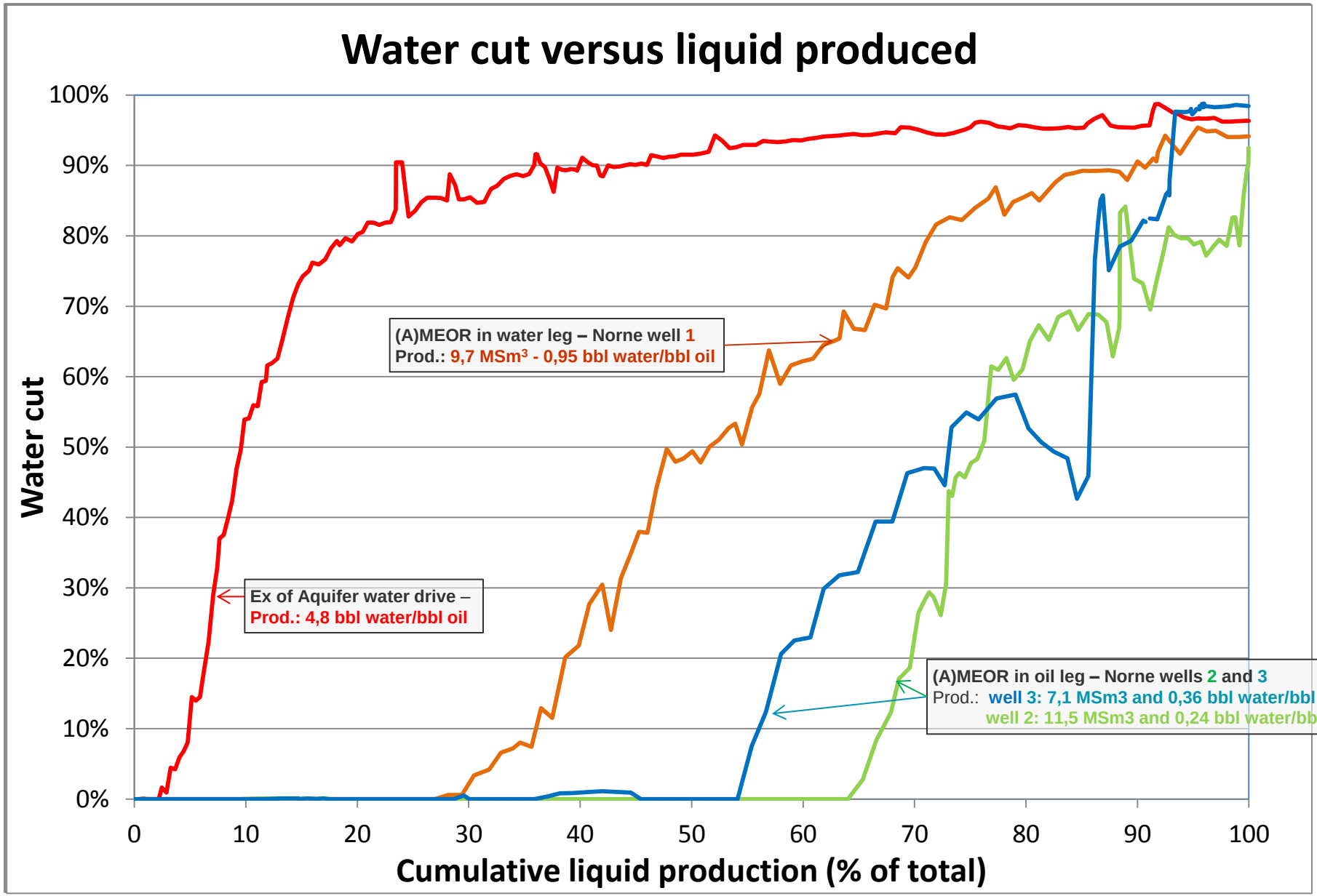




- High productivity and high cumulative production
- With seawater support, the wells are producing more before water breakthrough

# Water cut development and cumulative production for well 1, 2 and 3 on Norne




| Well | Cumulative oil production | % oil of total produced after water breakthrough | Produced water / produced oil |
|---|---|---|---|
| | $MSm^3$ | | Bbl. water /bbl. oil |
| 1 | 9,65 | 38 | 0,95 |
| 2 | 11,53 | 15 | 0,25 |
| 3 | 7,08 | 24 | 0,34 |


Water cut versus liquid produced
Water cut
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
80
90
100
Cumulative liquid production (% of total)
(A)MEOR in water leg – Norne well 1
Prod.: 9,7 MSm3 - 0,95 bbl water/bbl oil
Ex of Aquifer water drive –
Prod.: 4,8 bbl water/bbl oil
(A)MEOR in oil leg – Norne wells 2 and 3
Prod.: well 3: 7,1 MSm3 and 0,36 bbl water/bbl oil
well 2: 11,5 MSm3 and 0,24 bbl water/bbl oil

# Production performance on Norne, some results

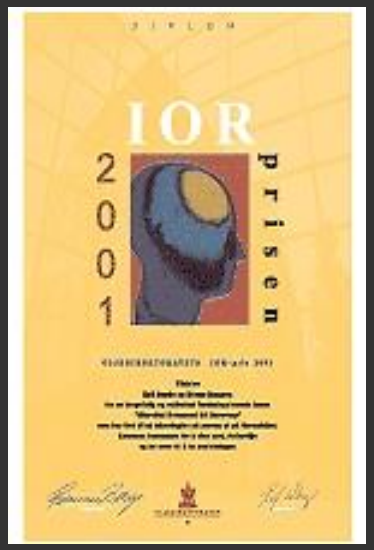
- **30 %** of STOOIP is produced at water breakthrough (defined at 0.10 water cut)
- After 15 years of production, recovery is **56 %** and it has been lifted on average **0.43 bbl. water / 1.00 bbl. of oil** at this time!
- Water cuts gradient of the field has a nearly linear development.
- The wells in the study are typical Norne wells with high productivity and high cumulative production (7-11 $MSm^3$ )
- Well 1 produce a lot more oil after water breakthrough compare to well 2 and 3. Sea water production shows that well 1 has less contact with injector well compare to well 2 and 3. This prod. performance can indicate higher residual oil saturation / less sweep efficiency compare to segment B/D with wells 2 and 3. This condition can partly be caused by MEOR??

# Conclusions and way forward

- Norne wells production is in general quite good and led to very high Recovery Factor
  - Good reservoir properties, few barriers to flow
  - Good reservoir management, use of 4D seismic, etc
  - MEOR?
- Indication that raw seawater injection helps to improve the well production efficiency with a higher production on plateau and relatively small volume of oil produced after water breakthrough.
- Not able (yet) to quantify the contribution of MEOR based on production data and simulation. However, the production performance is as expected if MEOR works as prognoses, the production performance indicate low remaining oil saturation in the zones penetrated by injection water
- Learnings: lack of base line survey, more regular/reliability of seawater sampling, production allocation must be improved

- Way forward: use of tracers data, field analogues re-injecting produced water, saturation logs ($\rightarrow$ uncertainty in Sorw?), analyze $H_2S$ production data

# There's never been a better time for good ideas




Acknowledge:
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Janiche Beeder – Microbial growth mechanisms
Synøve Tevik – History Norne, data input (slide 10)