



Integrated Reservoir Study for Designing CO₂-Foam EOR Field Pilot

M. Sharma*, Z. P. Alcorn#, S. Fredriksen#
M. Fernø# and A. Graue#

* The National IOR Centre of Norway, University of Stavanger

Department of Physics and Technology, University of Bergen

Outline

- Pilot Program
- Field Overview
- Laboratory Studies
- Reservoir Modelling & Simulation
- Conclusion

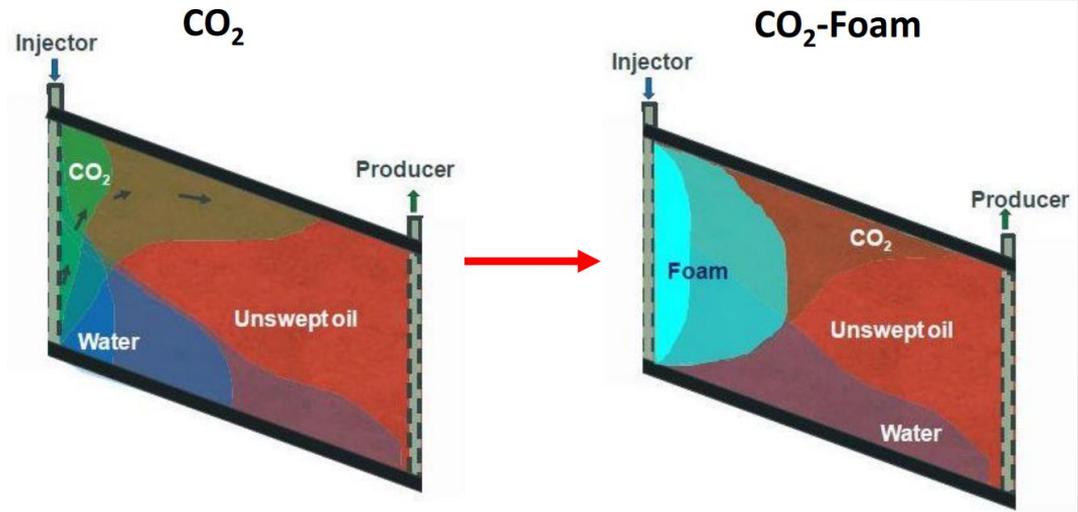
Pilot Program

OBJECTIVE

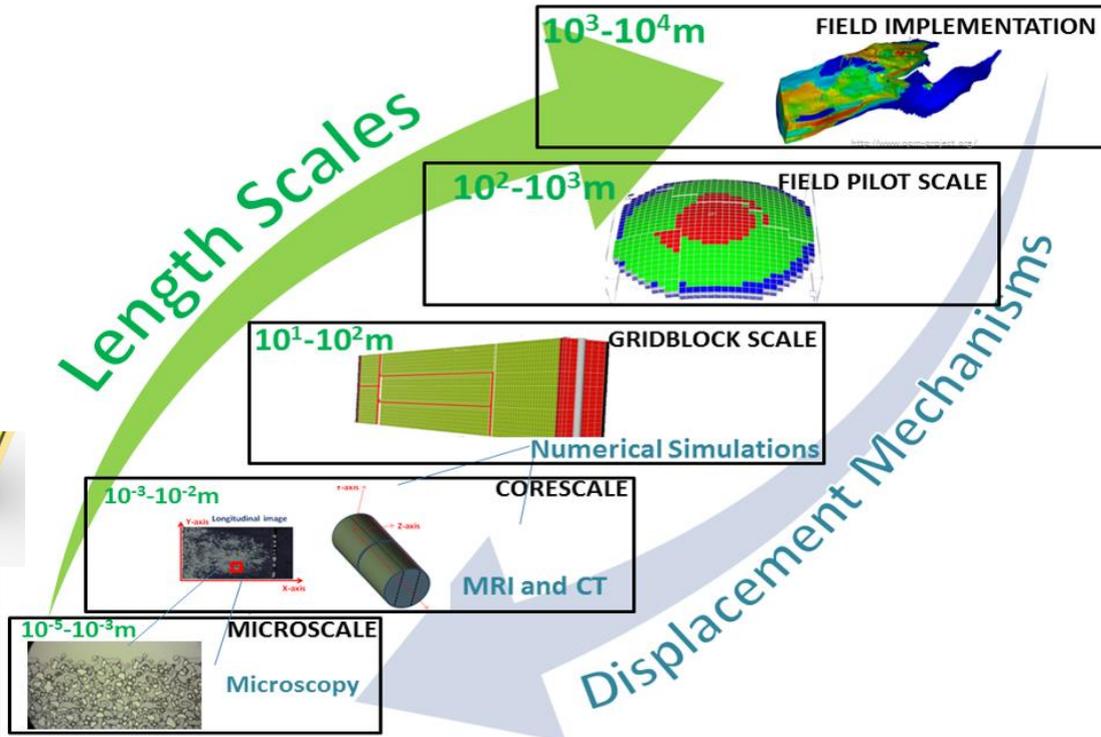
Cost-effective roadmap for mobility control CO₂ EOR implementation on Norwegian Continental Shelf through onshore field trials in Texas, USA

- Foam for Mobility Control

Gravity segregation
Reservoir heterogeneity
Viscous instability



Multi-scale Approach

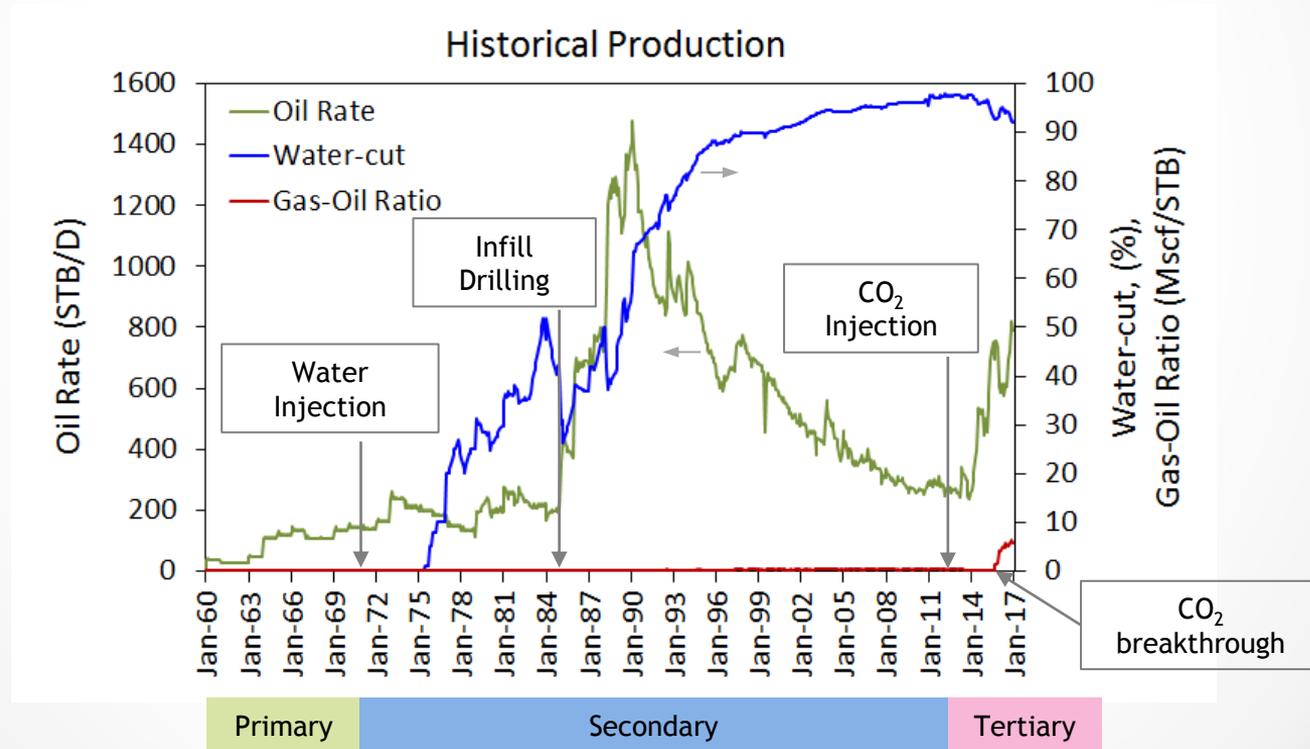


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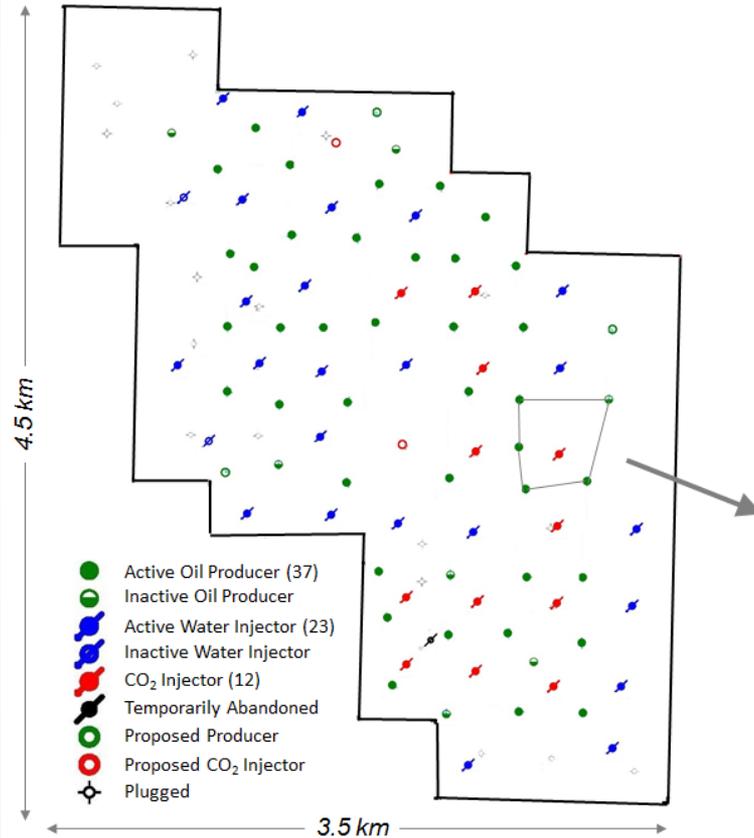
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Field Overview

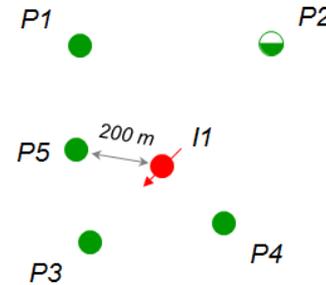
- Mature carbonate reservoir
 - Remaining oil saturation: 30 - 40%



Pilot Site



- Focus on well pair I1 - P5
 - Part of 40-acre pattern
 - Short interwell distance
 - Representative geology
 - CO₂ breaks through within a year



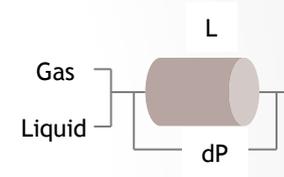
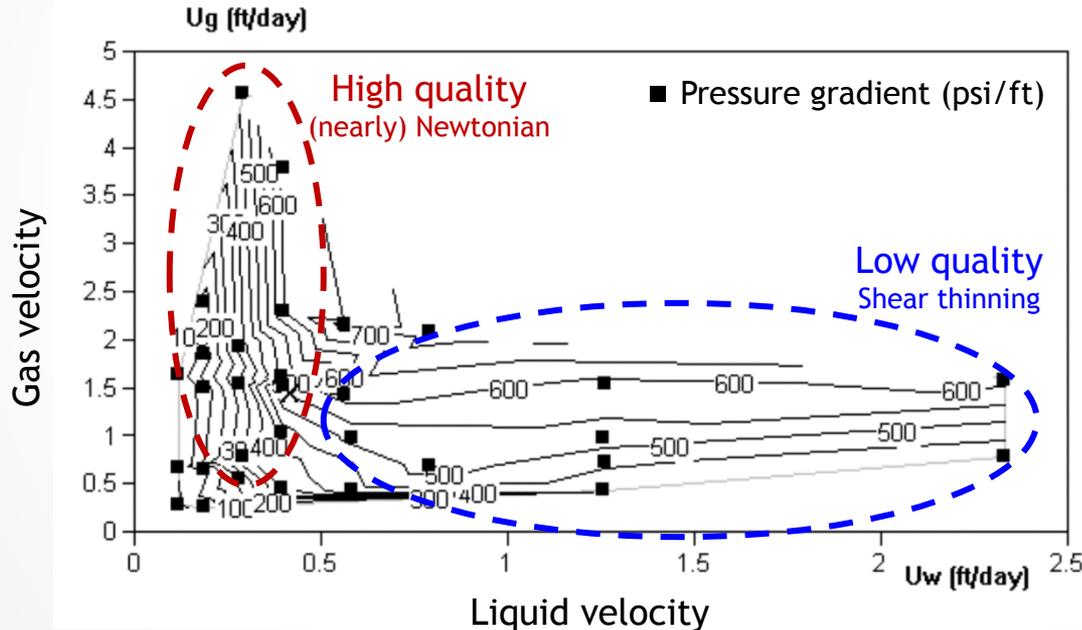
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Laboratory Studies

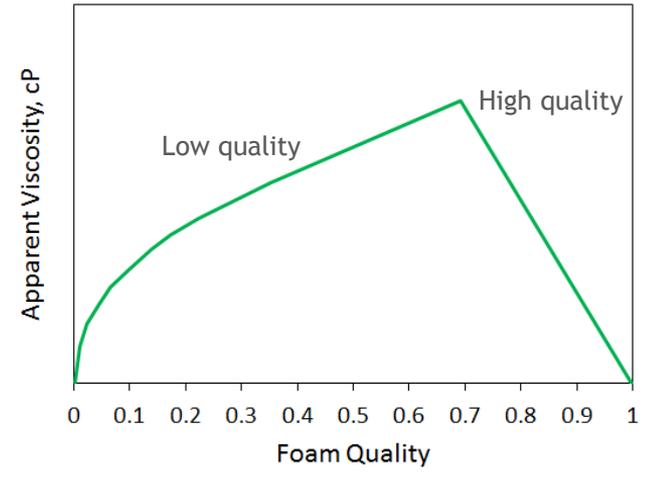
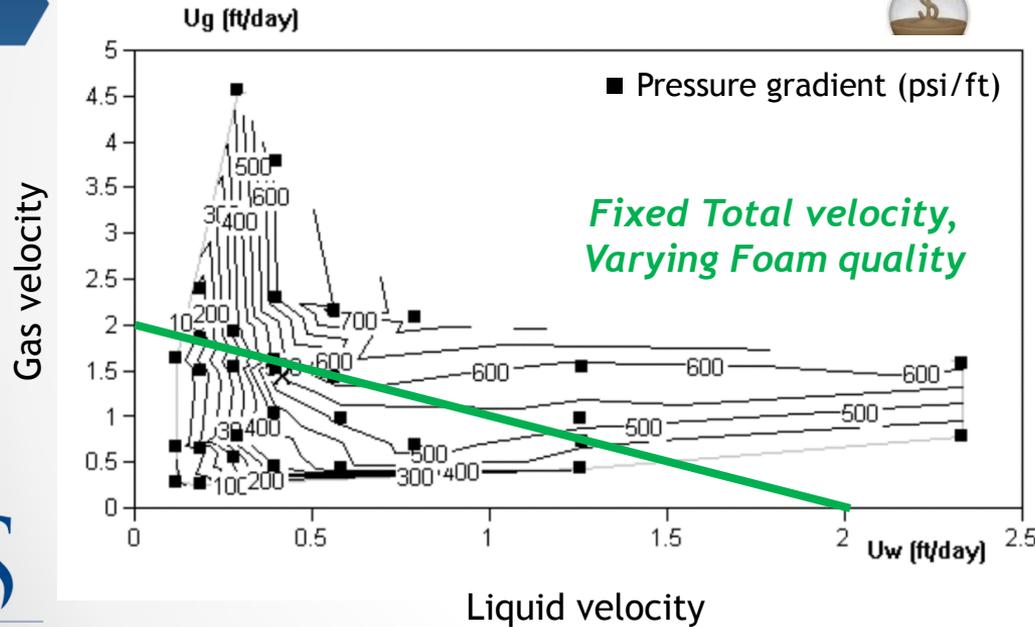
- Steady-state foam rheology

$$\text{Foam quality, } f_g = \frac{V_{\text{gas}}}{V_{\text{gas}} + V_{\text{liquid}}}$$



Laboratory Studies

- Foam quality scan



Foam Model

- Empirical model

Gas permeability in **presence** of foam

Gas permeability in **absence** of foam

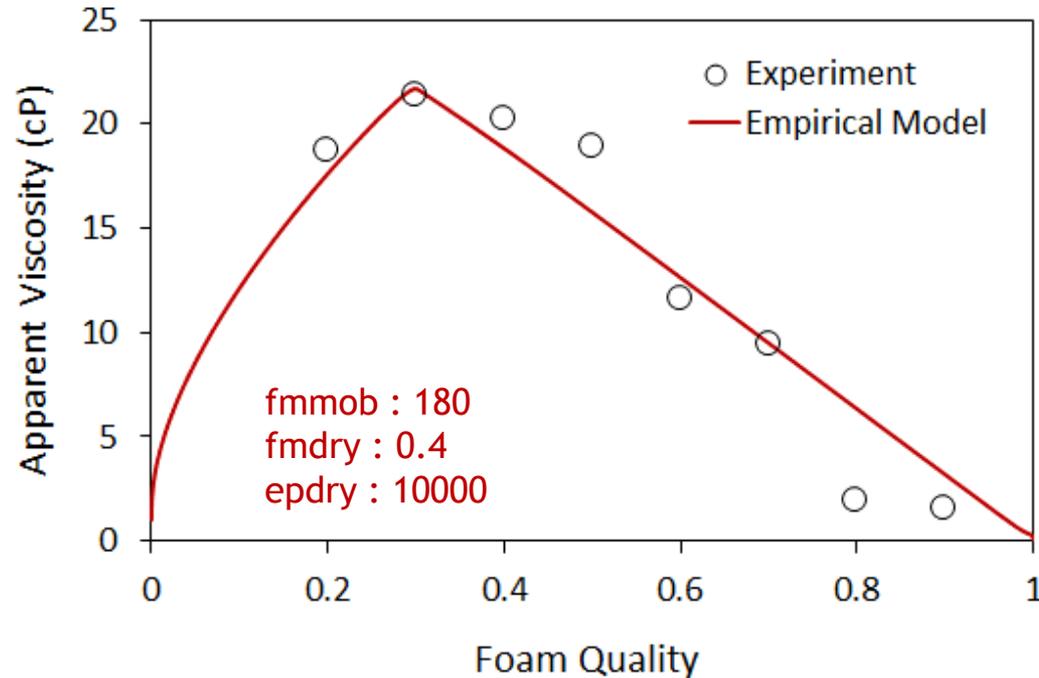
$$k_{rg}^f = k_{rg}^{nf} \times FM$$

Mobility Reduction Factor

$$FM = \frac{1}{1 + fmmob \times \left(0.5 + \frac{\arctan[epdry(S_w - fmdry)]}{\pi} \right)}$$

Foam Model

- Parameters for pilot-scale simulation

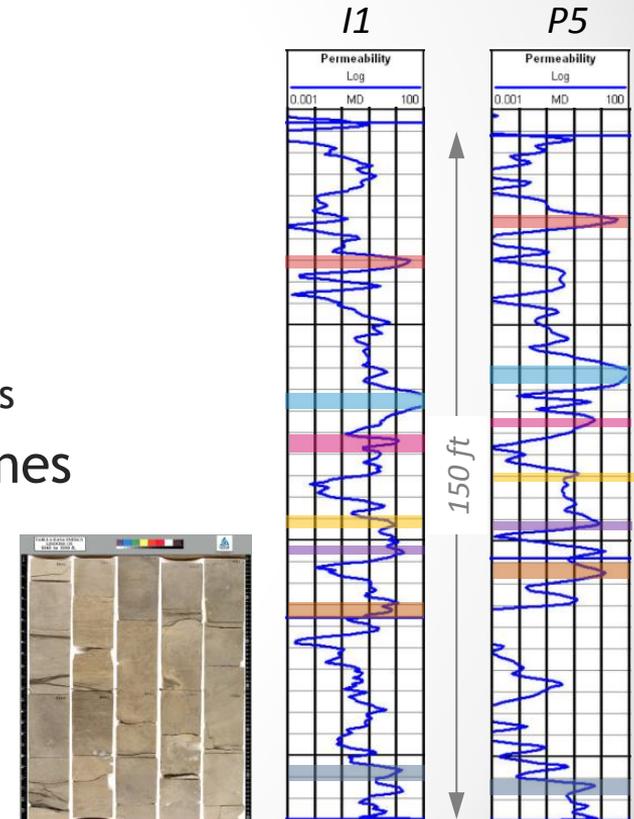


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Reservoir Characterization

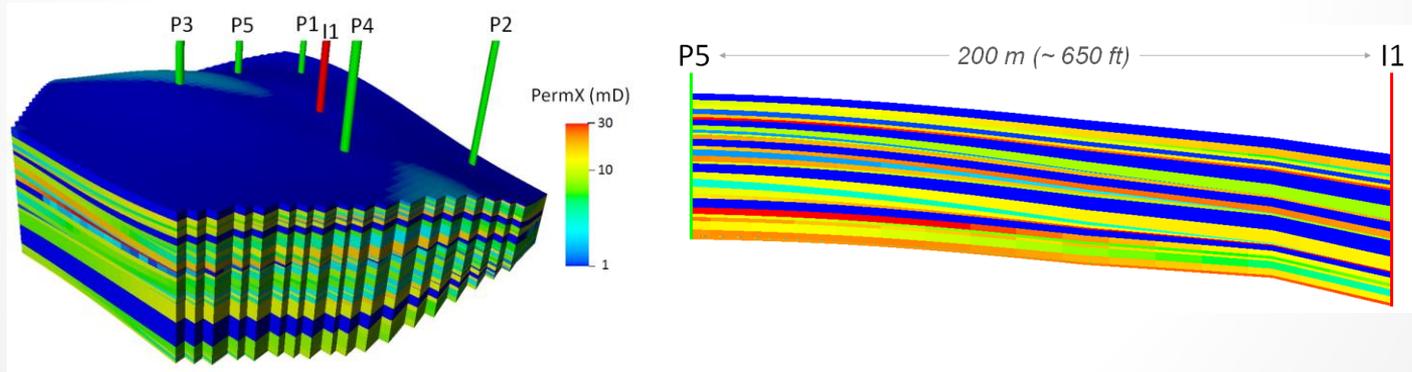
- Available data
 - Petrophysical well logs
 - RCA (porosity, permeability, Sw)
 - Core photo (for 1 well in pilot area)
- Cyclical sequence of carbonate rocks
 - Consists dolostones, packstones and grainstones
- Geologic framework based on flow zones and cyclicity



Geologic Model

- Spatial distribution of petrophysical properties using stochastic simulation

85,000 active cells
50 ft x 50 ft areally

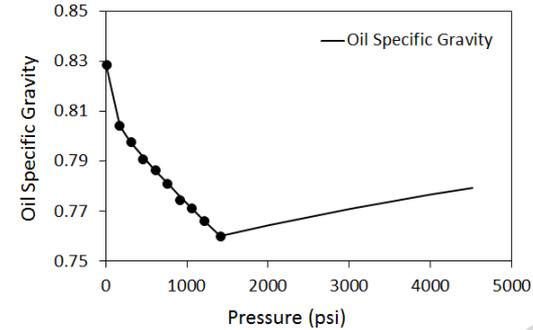
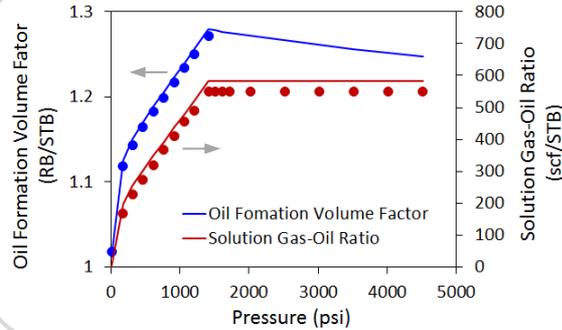


Permeability

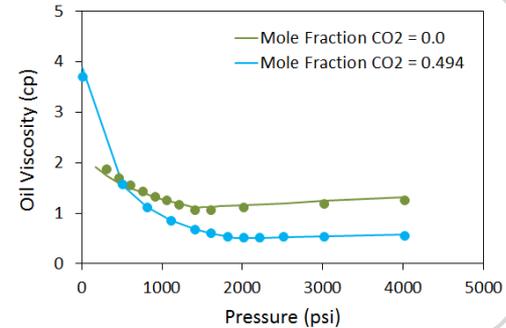
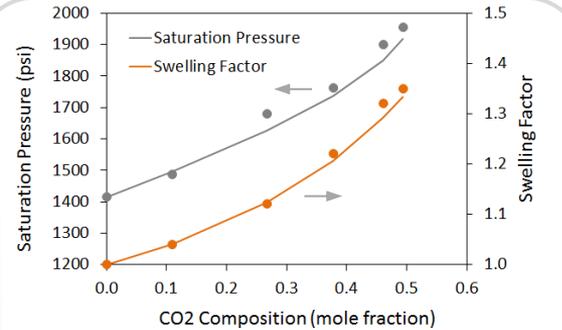
PVT Model

- PR EoS (8 components) tuned for available PVT data

Differential Liberation* Expansion*

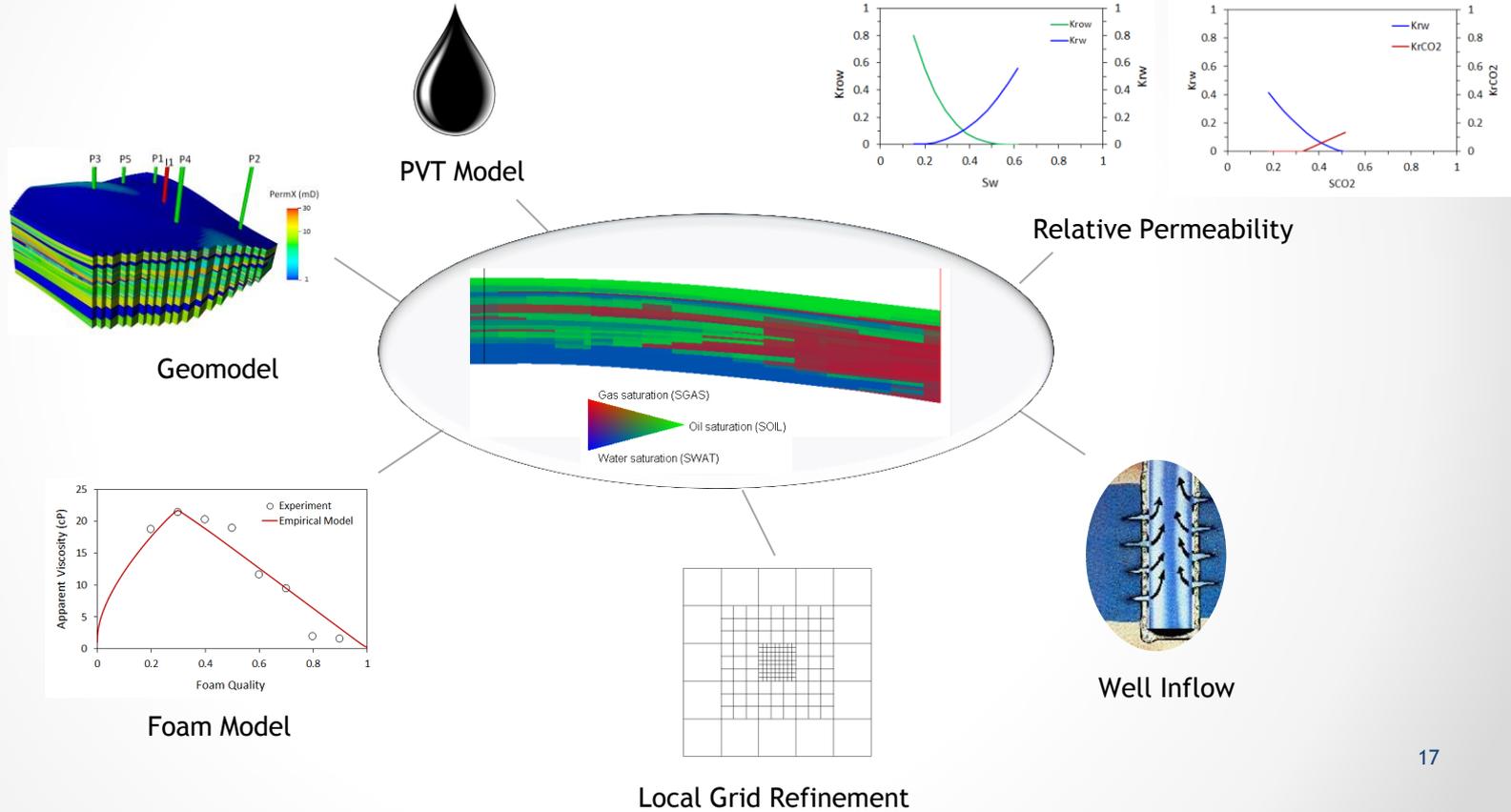


Swelling Test*

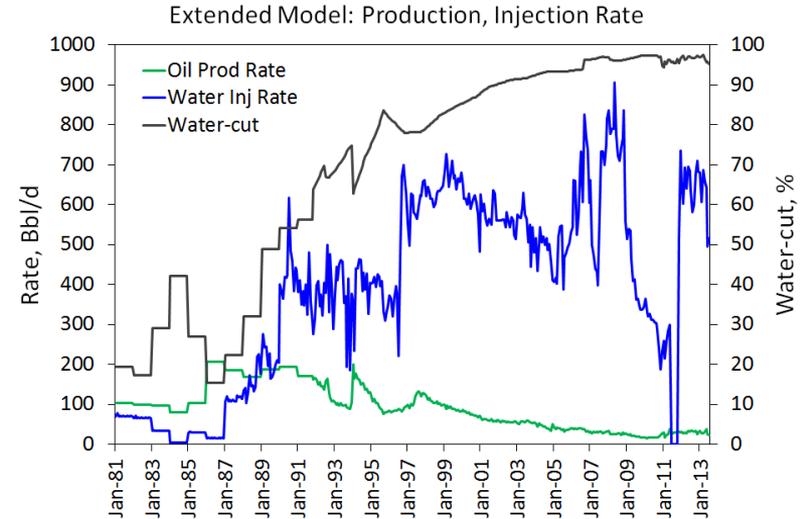
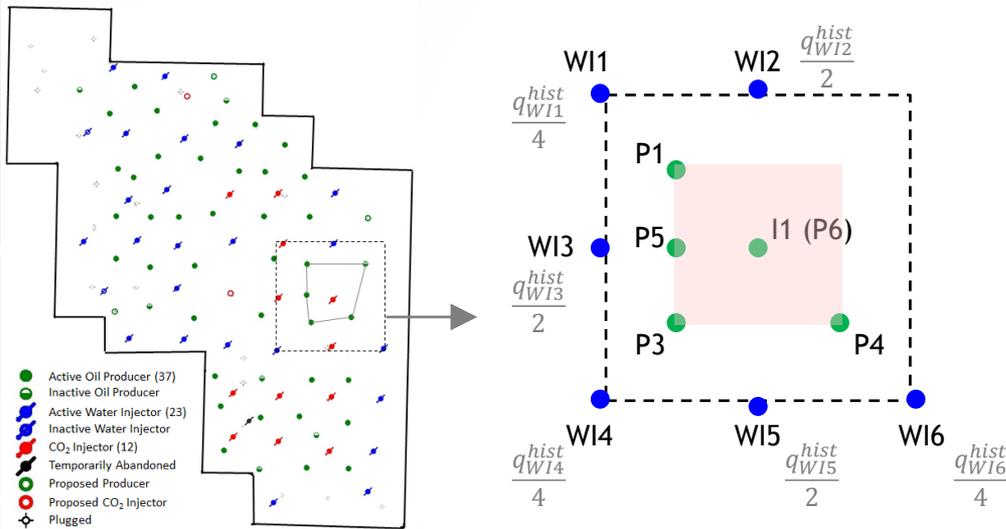


Viscosity *

Simulation Model

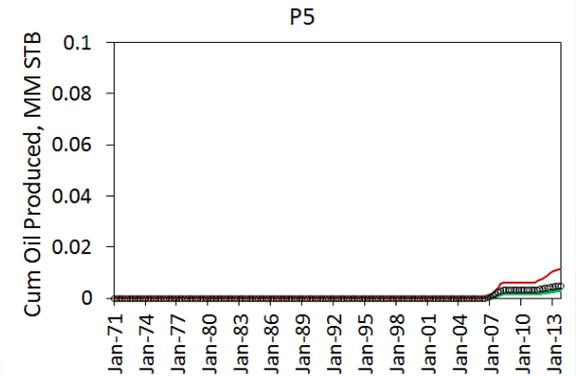
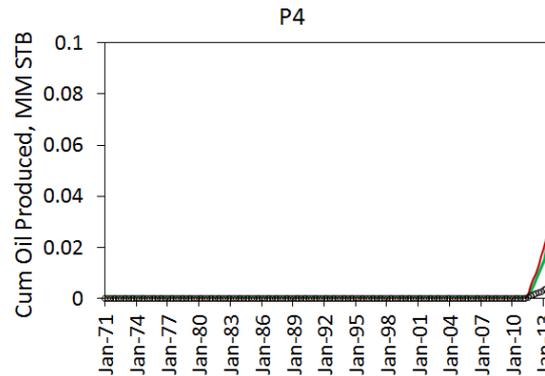
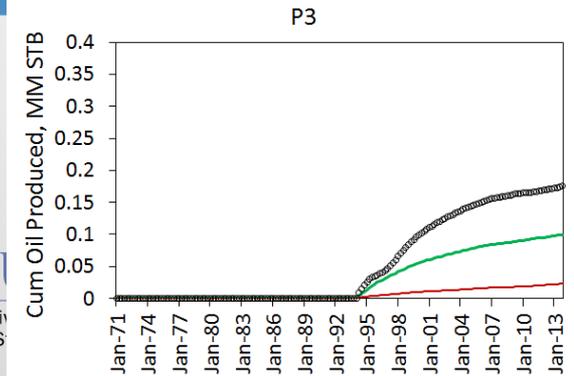
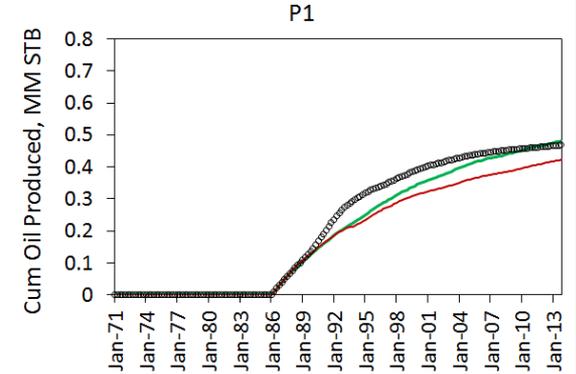
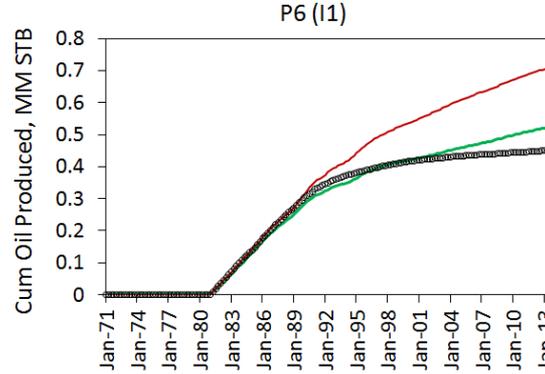
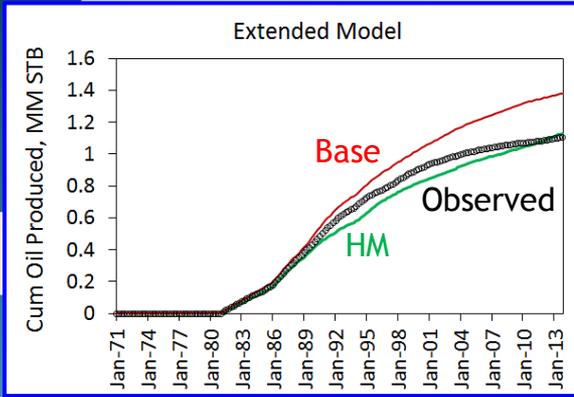


Historical Water Injection



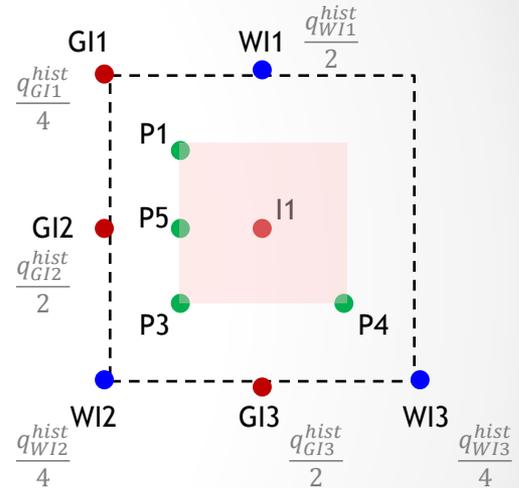
- BO Model (Includes peripheral injectors)
- Focus on updating volumes, and interwell permeability

Waterflood Match: Cum Oil Produced



CO₂ Injection Simulation

- 4 years of CO₂ injection
 - Gas b/t in all pilot producers
- Compositional model
 - Composition based on PVT report
- Initialization from HMed waterflood
 - Pressure and Saturation (O/W)
- History matching in progress...



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Summary

- Foam behaviour at core scale captured using fit-for-purpose lab studies and models
- An integrated approach for reservoir modelling and simulation allows to incorporate all available data
- Looking ahead
 - Calibrate model for CO₂ injection period
 - Baseline survey
 - Optimal injection strategy

Acknowledgements

We acknowledge the Research Council of Norway CLIMIT program for financial support under grant number 249742 - *CO₂ Storage from Lab to On-Shore Field Pilots Using CO₂-Foam for Mobility Control in CCUS* and the industry partners; Shell E&P, TOTAL E&P and Statoil Petroleum AS.

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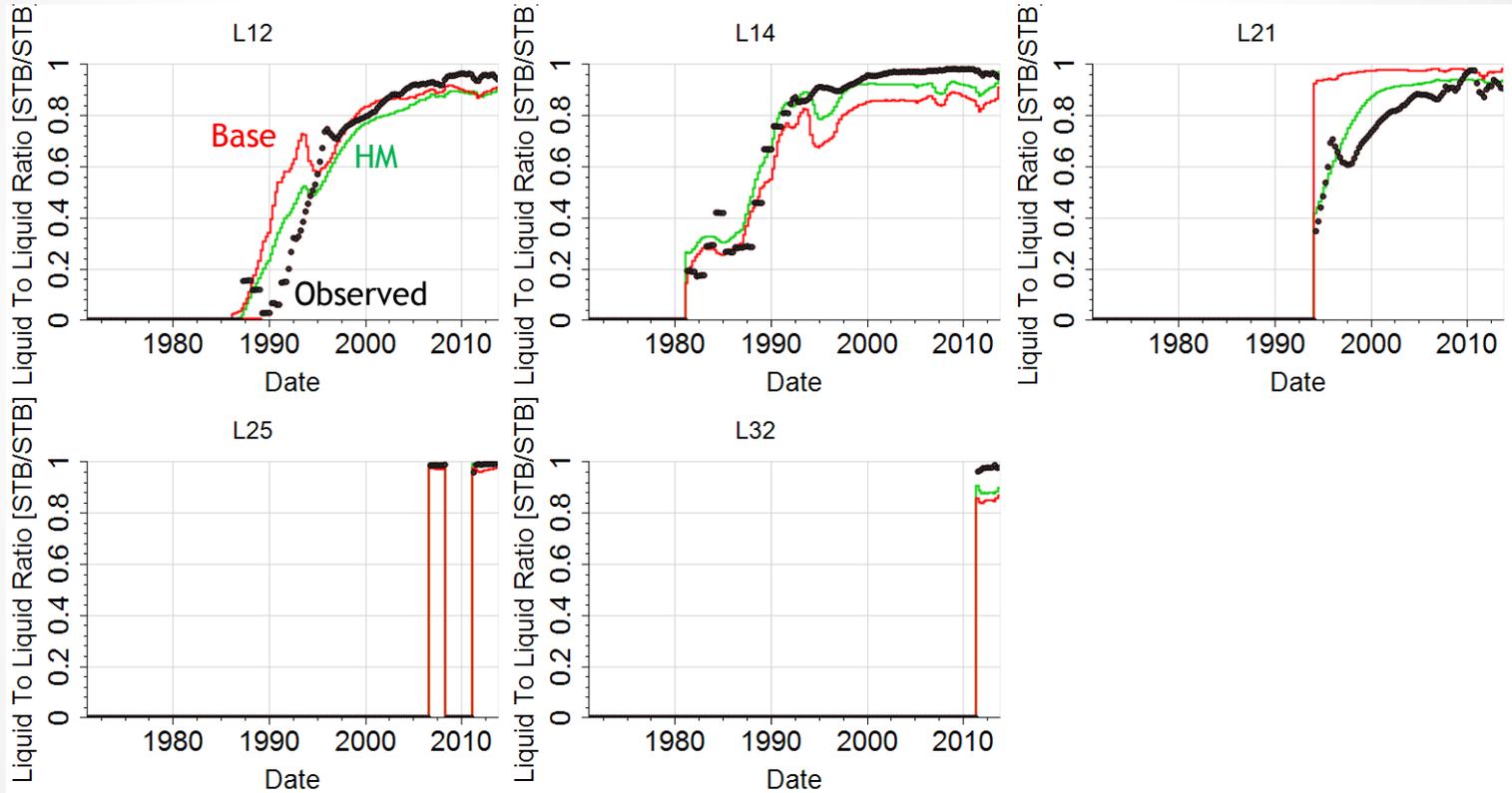
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Waterflood Match: Water-cut



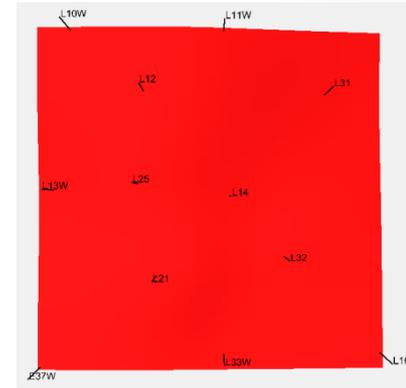
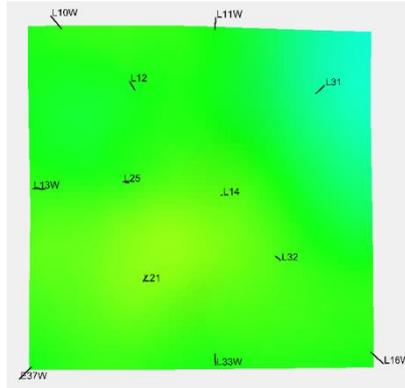
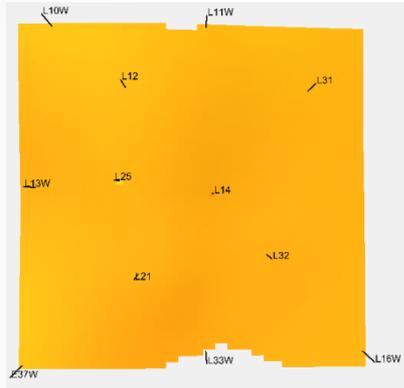
Waterflood Match: Permeability change

Layer - 4

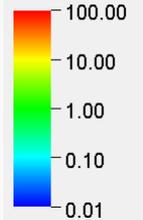
Layer - 7

Layer - 8

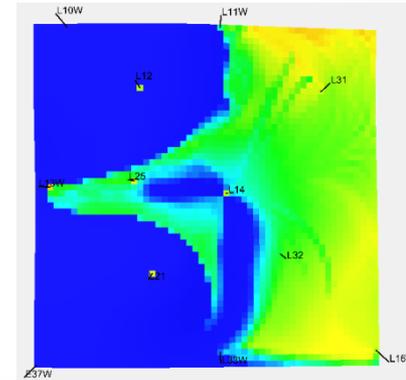
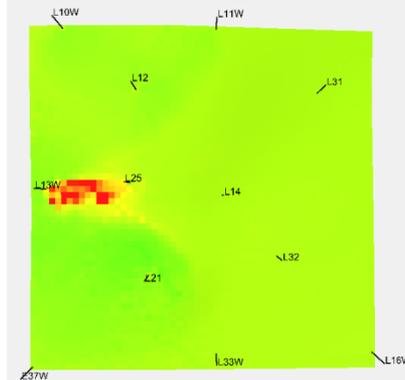
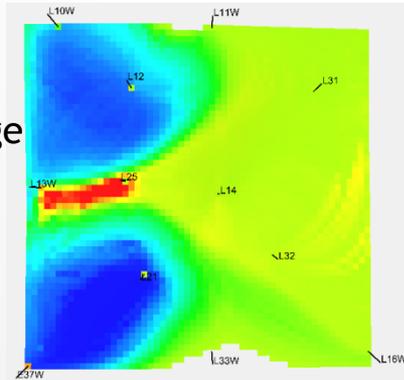
Base PermX



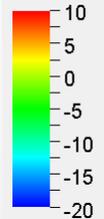
PERMXBASE



PermX Change



PERMXDIFF



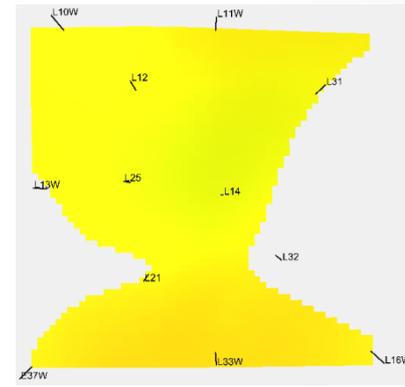
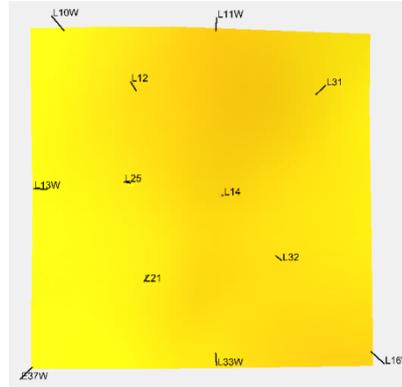
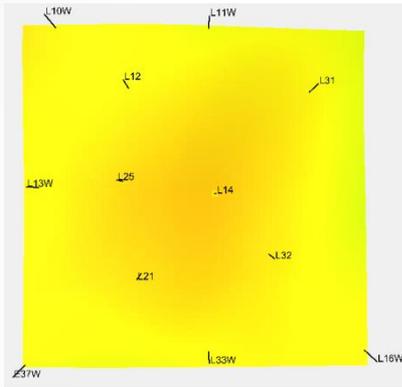
Waterflood Match: Permeability change

Layer - 10

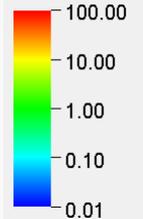
Layer - 16

Layer - 19

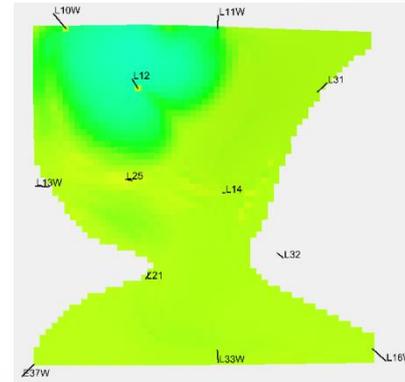
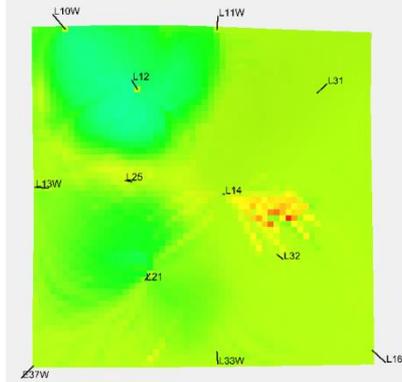
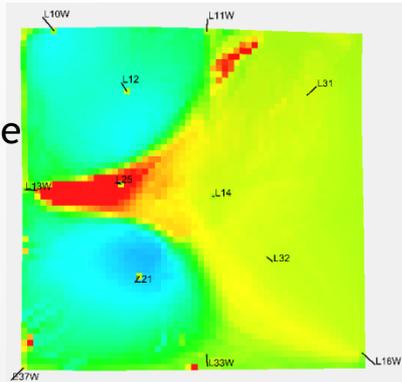
Base PermX



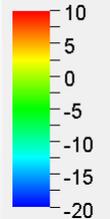
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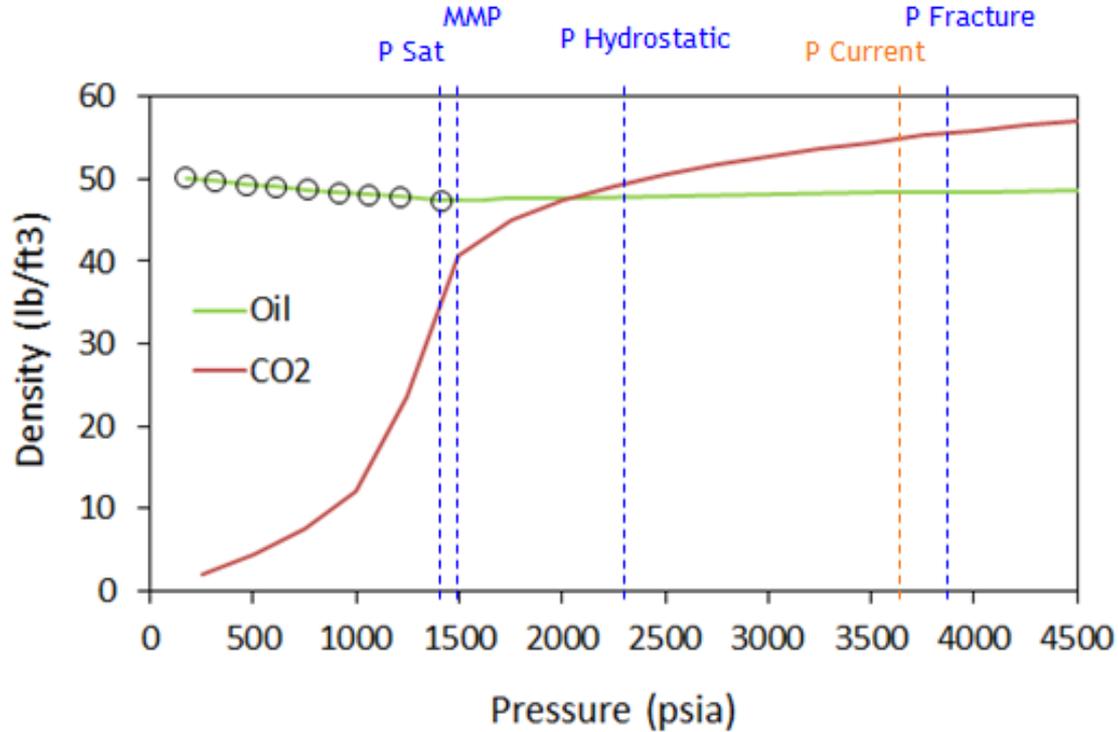
PermX Change



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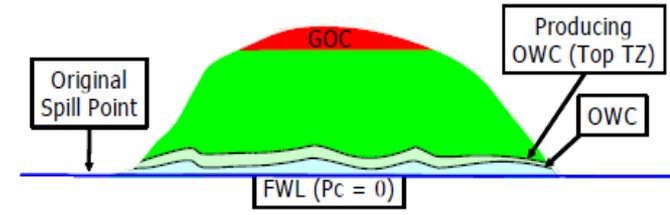


Reservoir Pressure on higher side !

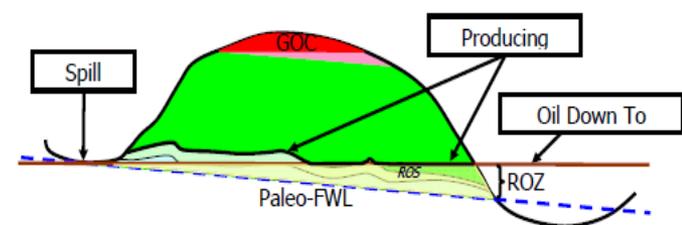


Reservoir Setup

- 2 zones because of structural tilting / seal breach event:
 - MPZ (Main Pay Zone)
 - Primary & Secondary recovery
 - ROZ (Residual Oil Zone)
 - Large amount of immobile oil (20-40%)



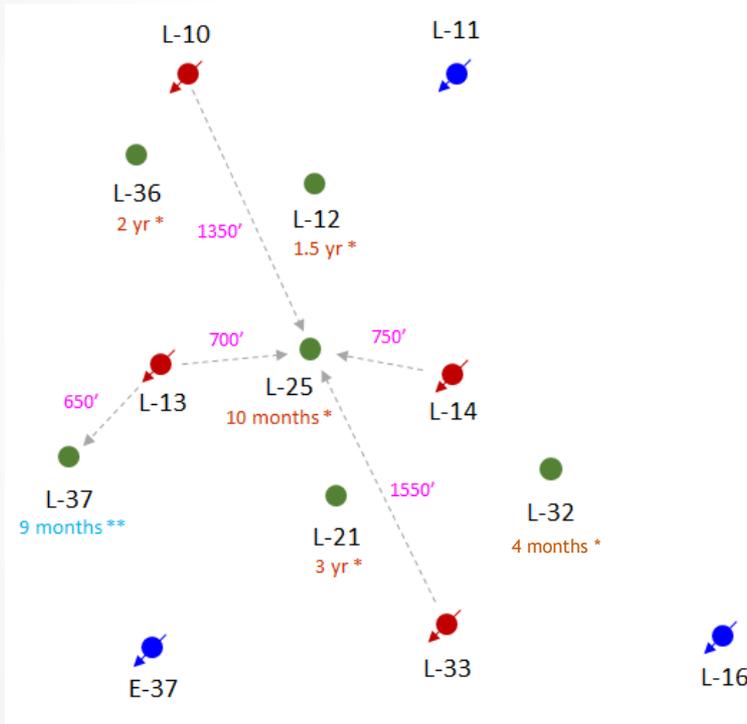
Original oil accumulation



Effects of structural tilting / seal breach

Zones differ in fluid composition

Well Connectivity



** from start of CO₂ injection: Oct-13
 ** from start of CO₂ injection in L-13: Jan-16

