Improving Water Cut Predictions when drilling and completing infill wells in mature oil fields - a new formation evaluation approach

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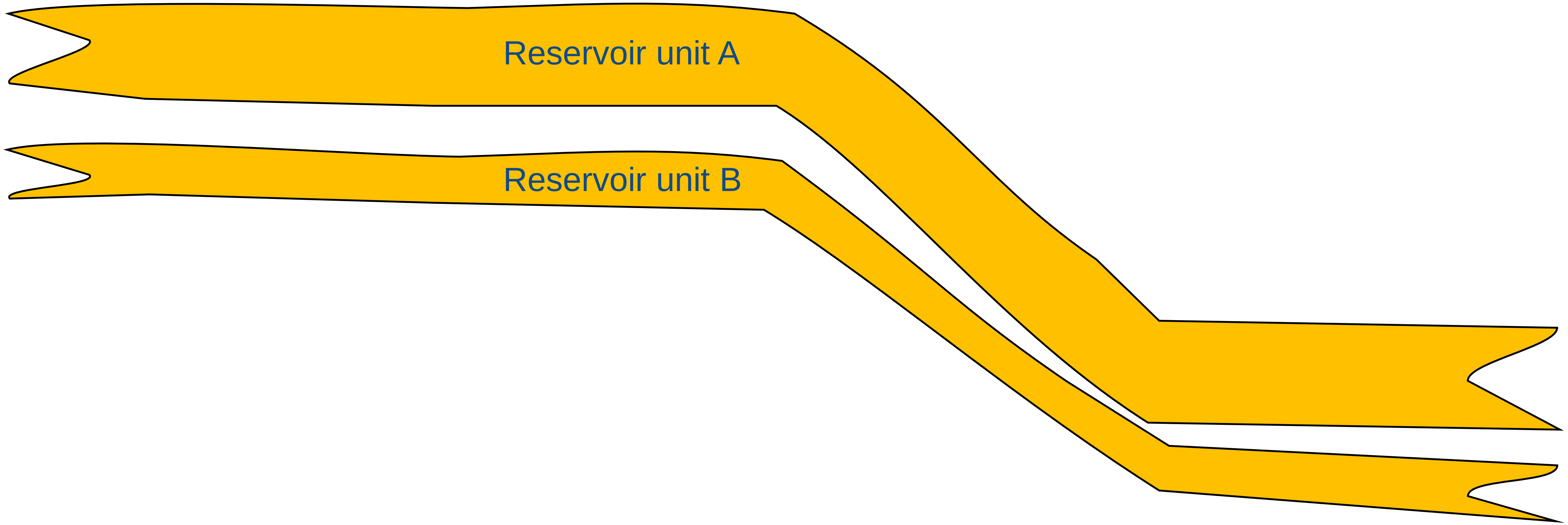
Overview

- **This presentation discusses formation evaluation of infill wells in mature oil fields...**
  …quantifying the volume of producible hydrocarbons, their expected rate of production and the associated water cut
- **The ideas are based on experience of doing this type of thing for a few years…**
  (35 infill wells in UK North Sea fields)
- **The focus is how to make robust decisions: with realistic expectations of oil rate and water cut**
- **The formation evaluation approach is also applicable to re-completing old wells.**

- ***Perhaps this is a common issue…***
  and other people have found similar or different solutions?

There is some petrophysics and reservoir engineering, hopefully appropriate for subsurface workers who are involved in this type of work.
Including : what can you do? …take-aways (labelled like this)

Pre-production formation evaluation – generally simpler



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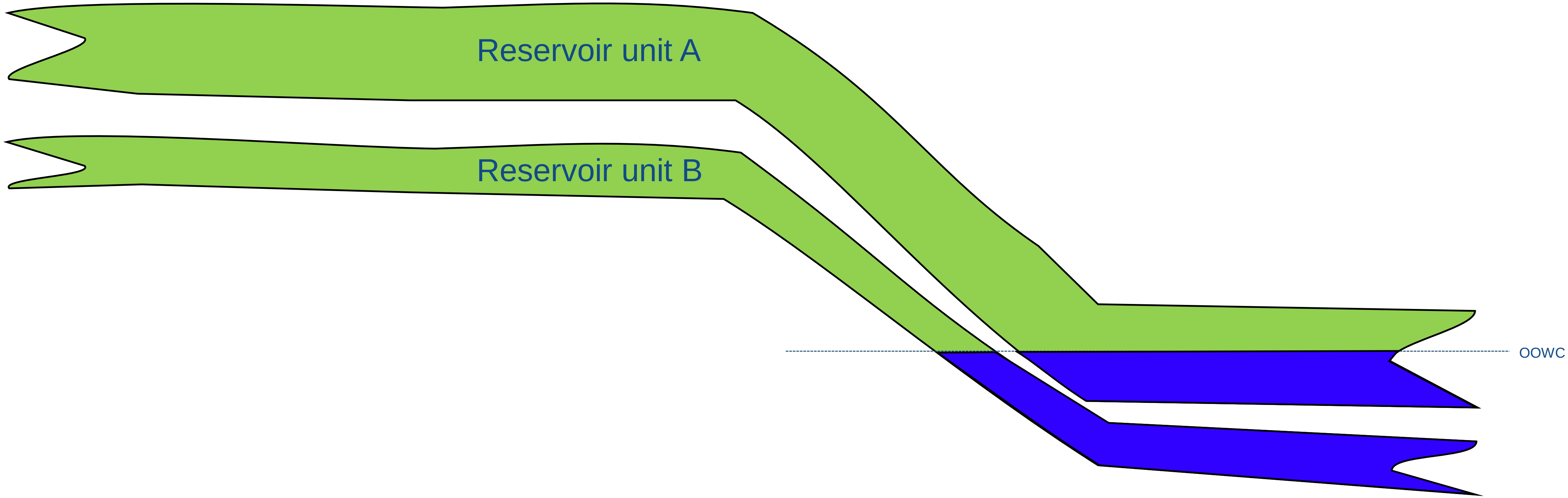

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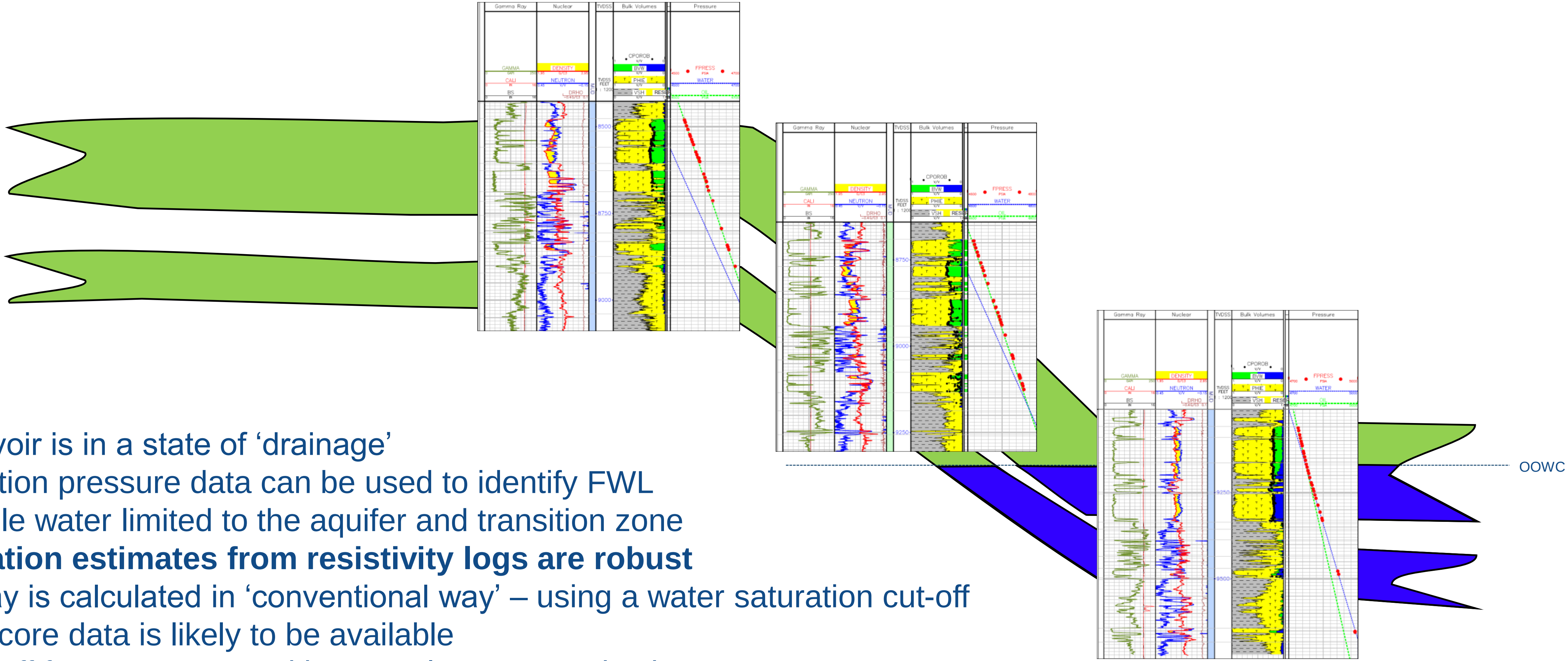
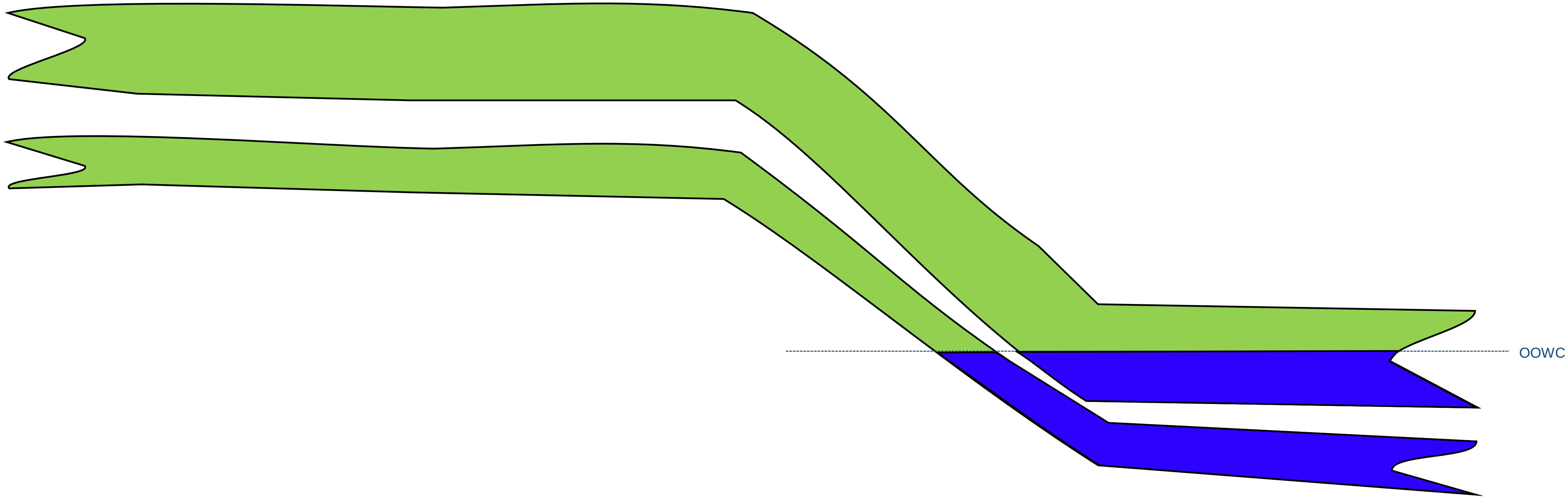


Reservoir is in a state of ‘drainage’
Formation pressure data can be used to identify FWL
Movable water limited to the aquifer and transition zone
Saturation estimates from resistivity logs are robust
Net Pay is calculated in ‘conventional way’ – using a water saturation cut-off
Some core data is likely to be available
Stand-off from OWC can mitigate early water production

Forecasts of oil production and water cut from new wells can generally be made with confidence, pre-production

Post-production formation evaluation – generally more challenging



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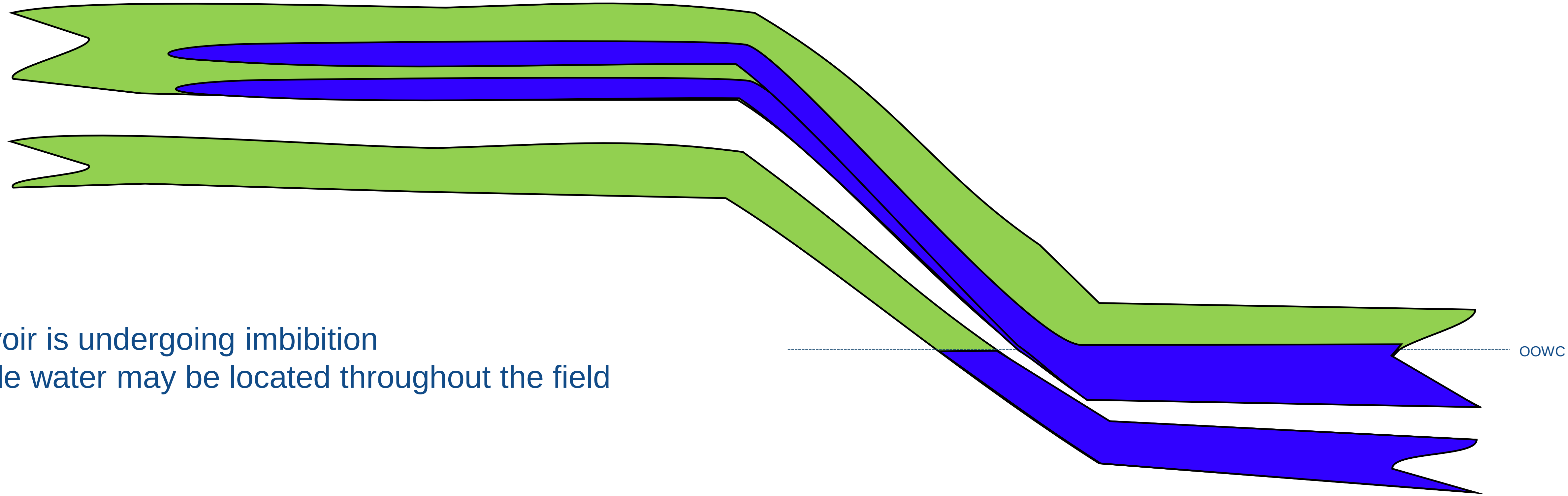
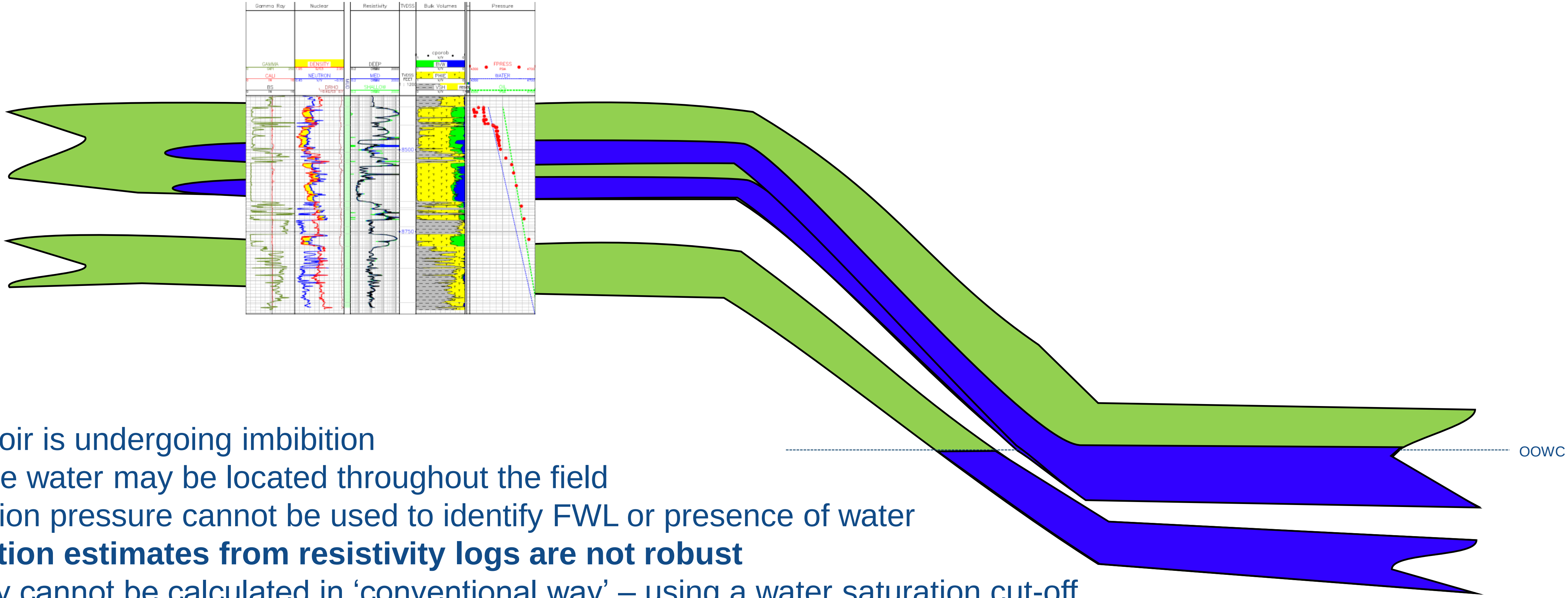


Reservoir is undergoing imbibition
Movable water may be located throughout the field

Post-production formation evaluation – generally more challenging



Reservoir is undergoing imbibition
Movable water may be located throughout the field
Formation pressure cannot be used to identify FWL or presence of water
Saturation estimates from resistivity logs are not robust
Net Pay cannot be calculated in ‘conventional way’ – using a water saturation cut-off
Mitigate of water production is challenged
Forecasts of water cut from new wells / re-completions are more uncertain

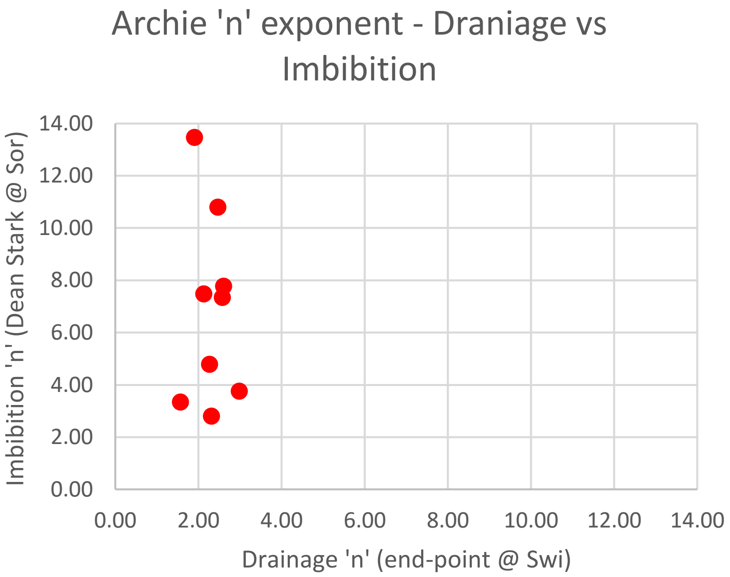
Conventional interpretation methods to estimate ‘Net Pay’ are not robust, a new formation evaluation mindset and approach is required

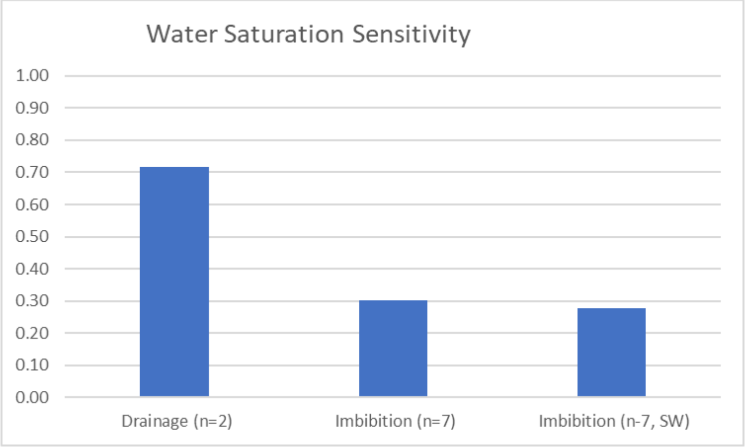
‘Challenging’ formation evaluation – post-production

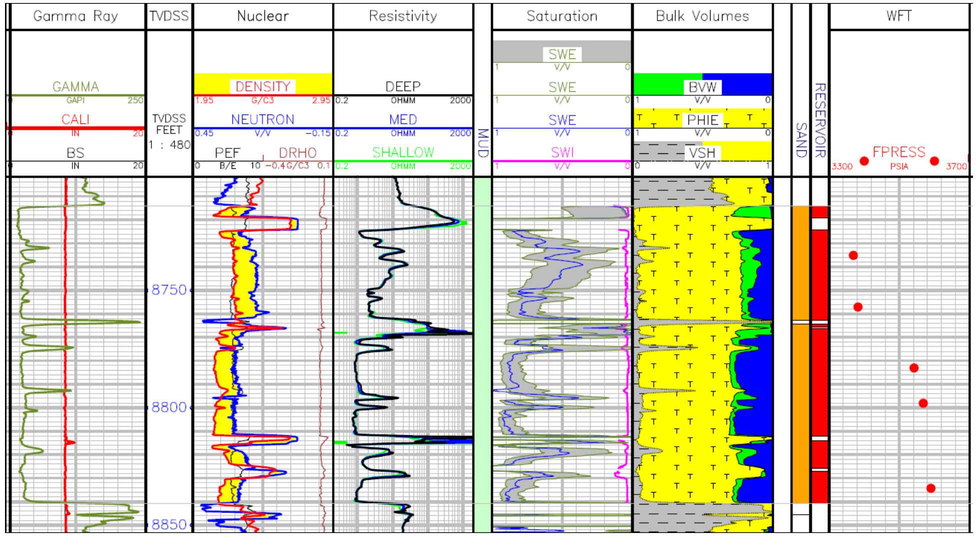
- **Why are water saturation estimates not robust during imbibition?**
- **2 reasons:**

1. **Salinity**
2. **Archie ‘n’**

$$S_w = \left[\frac{a\,R_w}{\Phi^m\,R_t}\right]^{1/n}$$

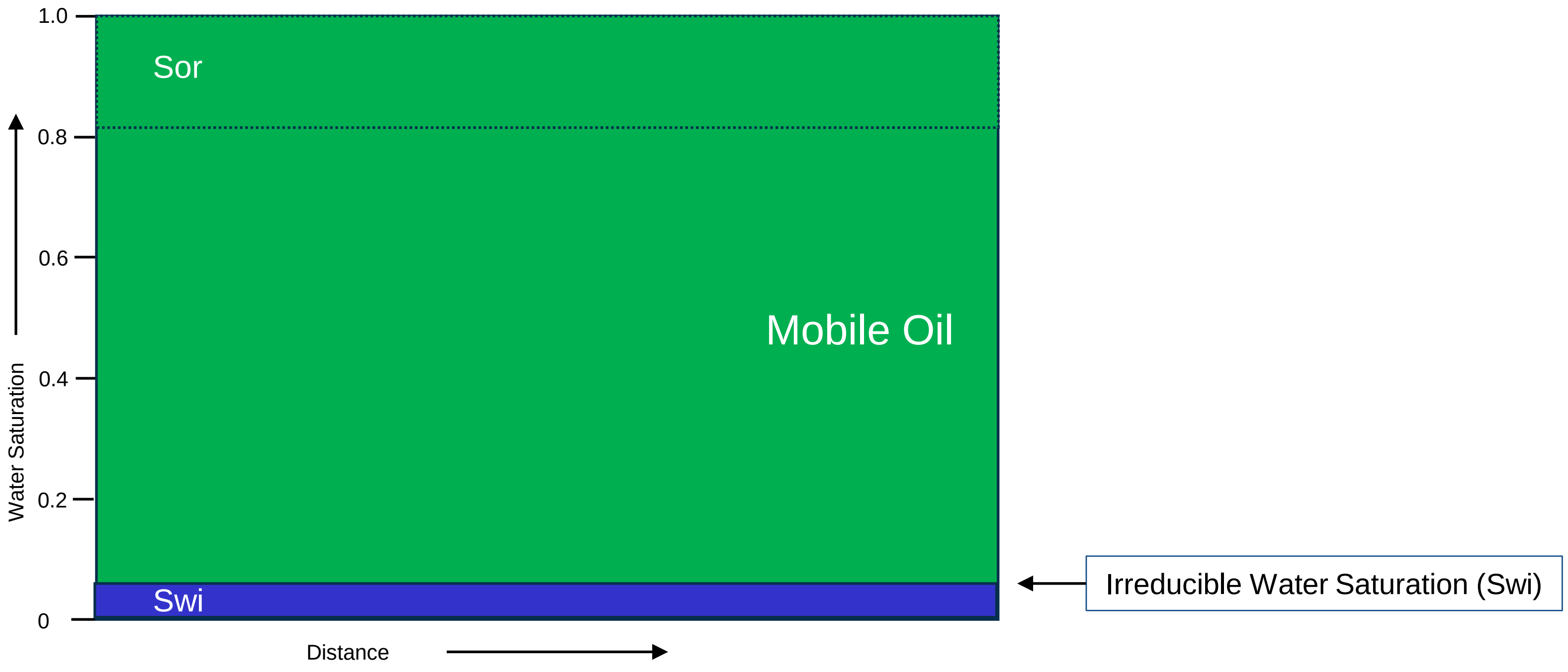






Don’t trust the water saturation when you have evidence of imbibition, it will be misleading
This doesn’t affect the intervals that are obviously still unswept
Make several saturation scenarios for varying salinity and varying Archie ‘n’

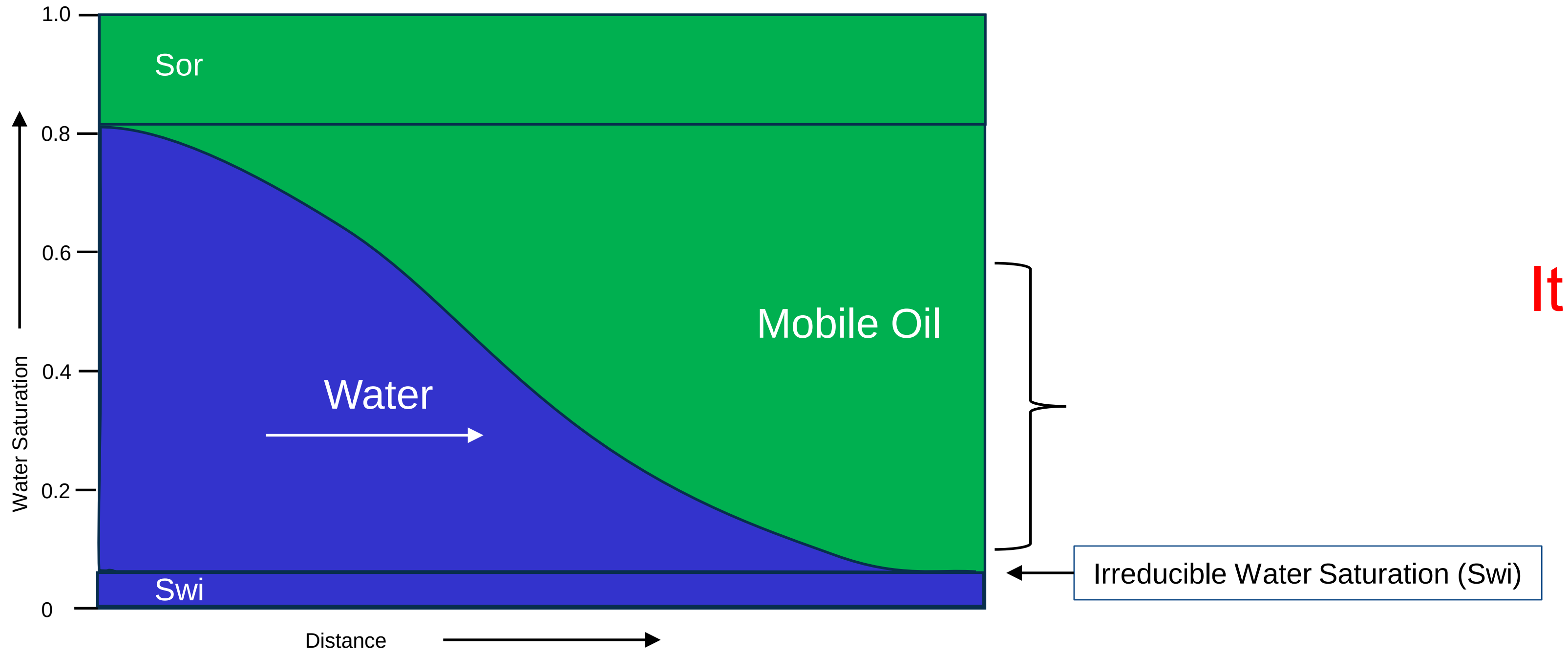
Water flood front behaviour in an oil reservoir…



Adapted from Donaldson, in Wettability, 2008

In the oil reservoir
away from the transition zone

Water flood front behaviour in an oil reservoir…



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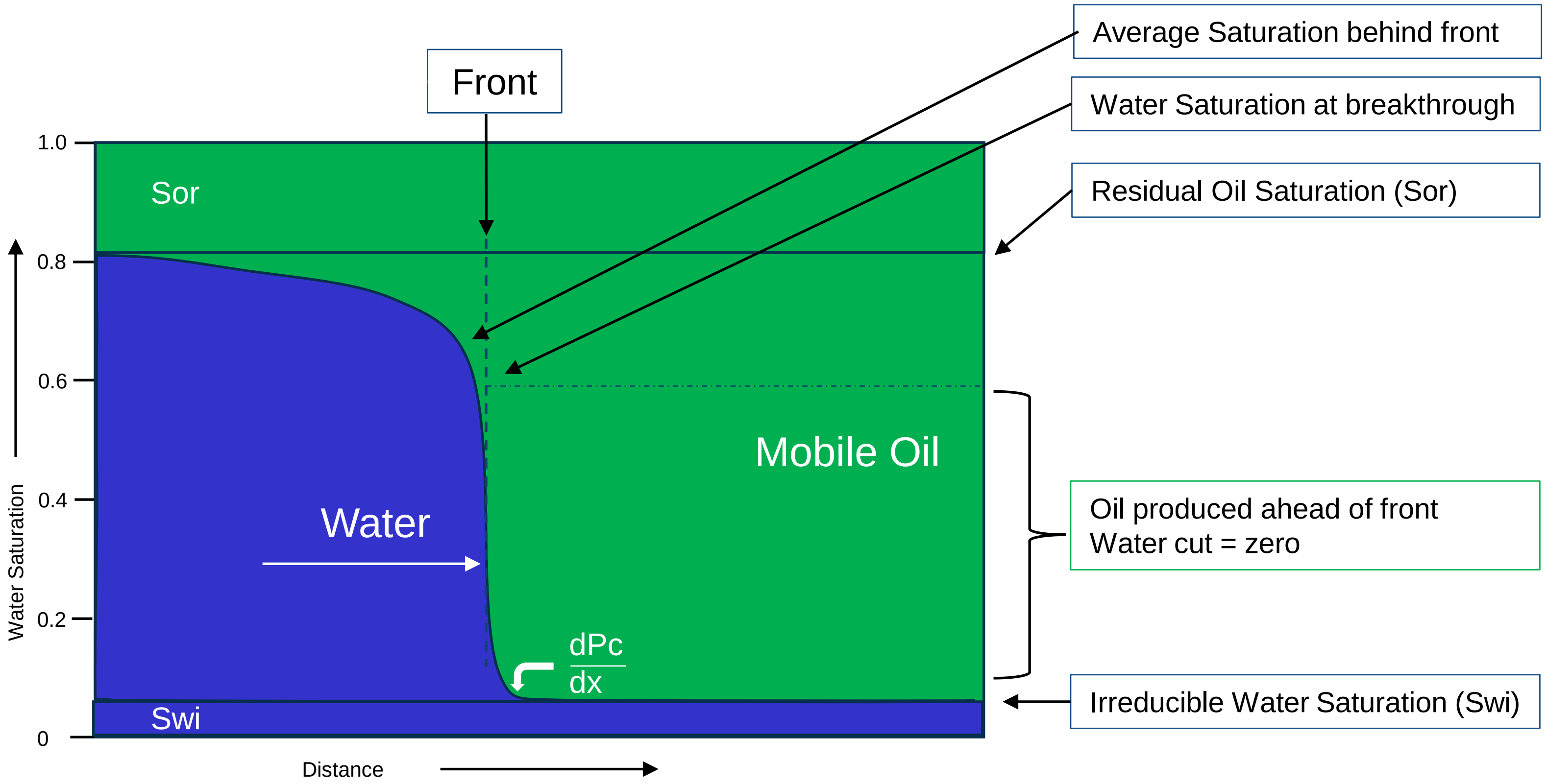
It doesn't happen like this

The water saturation in the reservoir doesn't change in a gradual way

Water flood front behaviour in an oil reservoir…



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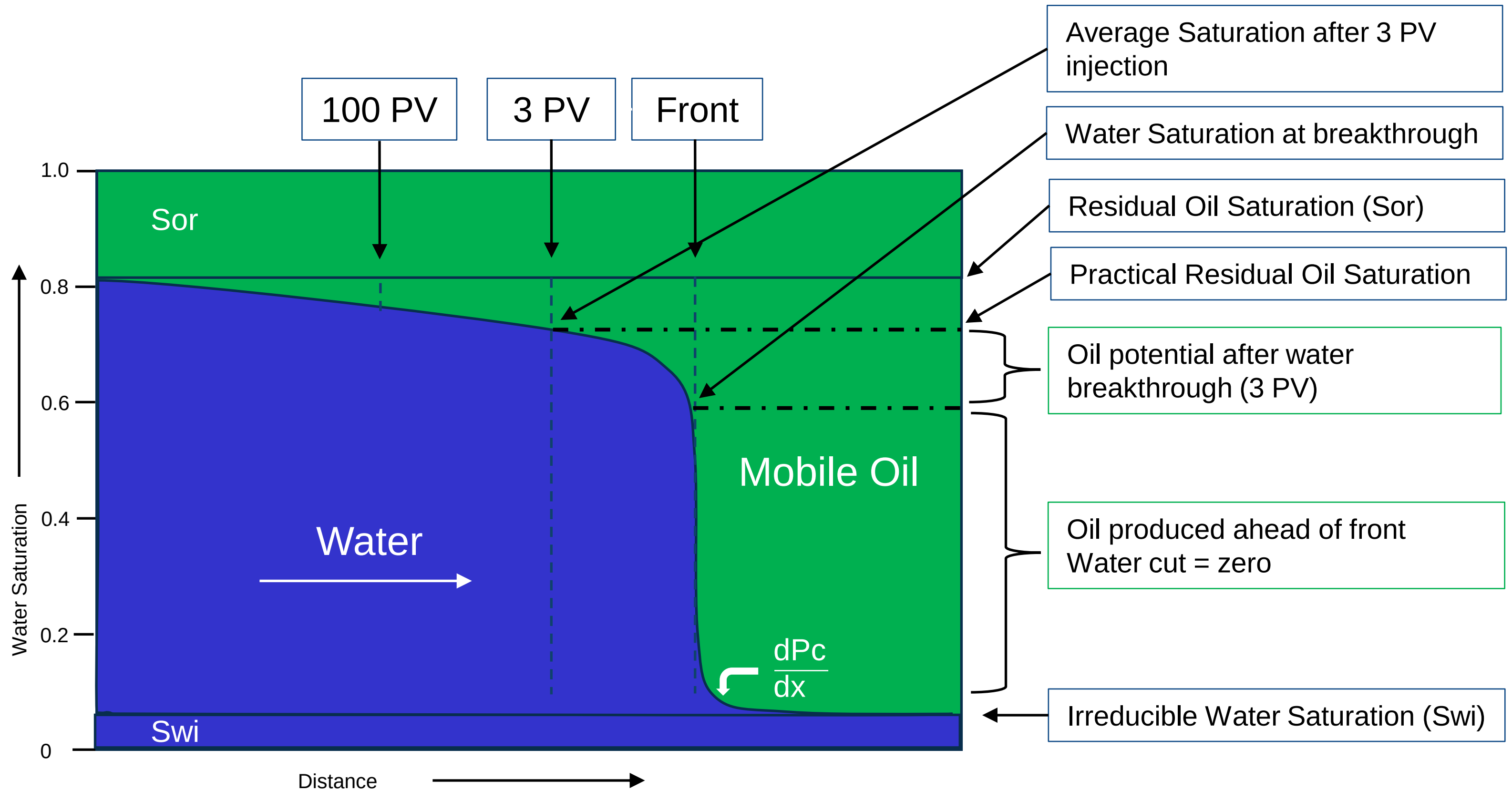
In the oil reservoir
when the water flood front arrives

The water saturation in the reservoir doesn't change in a gradual way

Water flood front behaviour in an oil reservoir…



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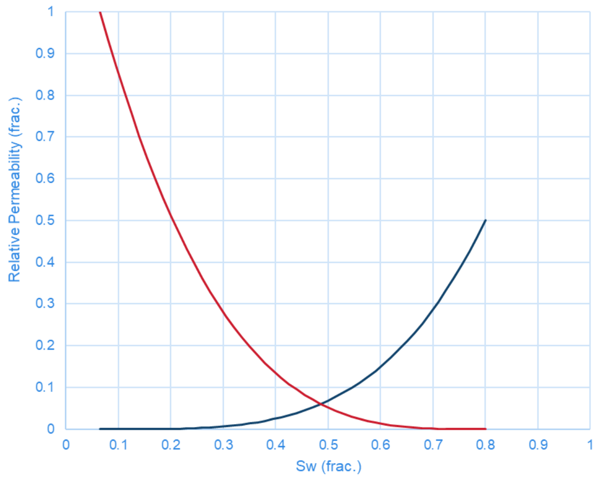
In the oil reservoir
when the water flood front arrives

The water saturation in the reservoir doesn't change in a gradual way
A water flood front (shock front) moves through the reservoir, pushing the majority of the oil ahead of it. There is a dramatic change in water saturation when the flood front arrives at a point
There is a limited 'tail' of oil production produced after the arrival of the flood front

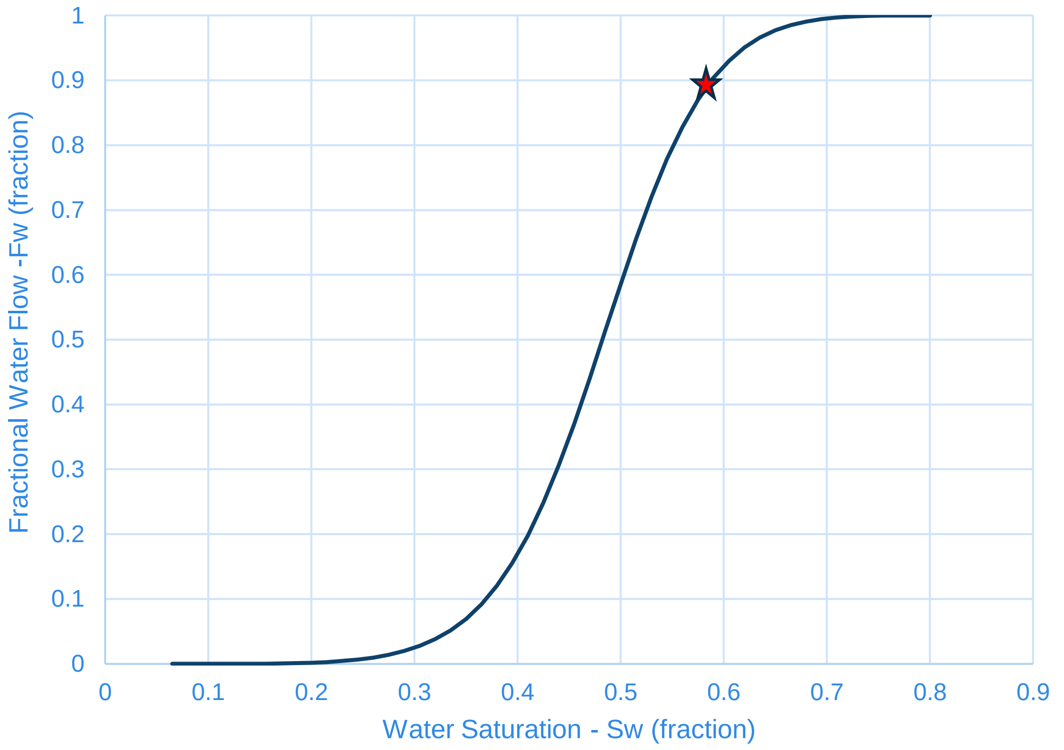
What can be done?
Fractional flow analysis…



Fractional flow* analysis

Welge analysis 1952

$$f_w = \frac{1}{1 + \frac{k_{ro}}{k_{rw}} \cdot \frac{\mu_w}{\mu_o}}$$



Buckley, S.E. and Leverett, M.C.: “Mechanism of Fluid Displacement in Sand,” Trans., AIME (1942)146,107.
Welge, H.J.: “A Simplified Method for Computing Oil Recovery by Gas or Water Drive,” Trans., AIME (1952)195,91
Dake, L.P.: “The Practice of Reservoir Enginnering,” Elsevier (Revised Edition) 2001.

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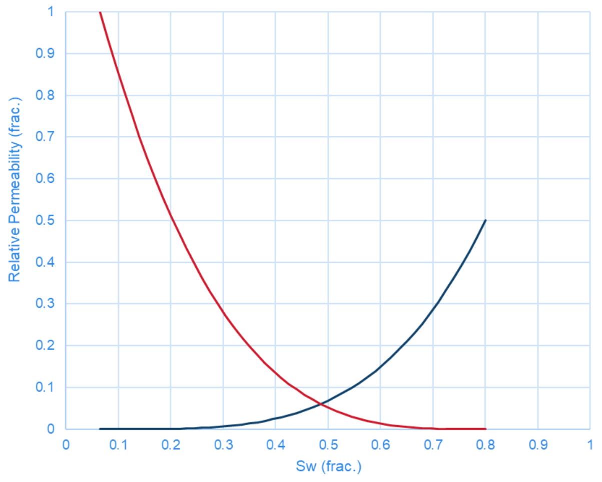

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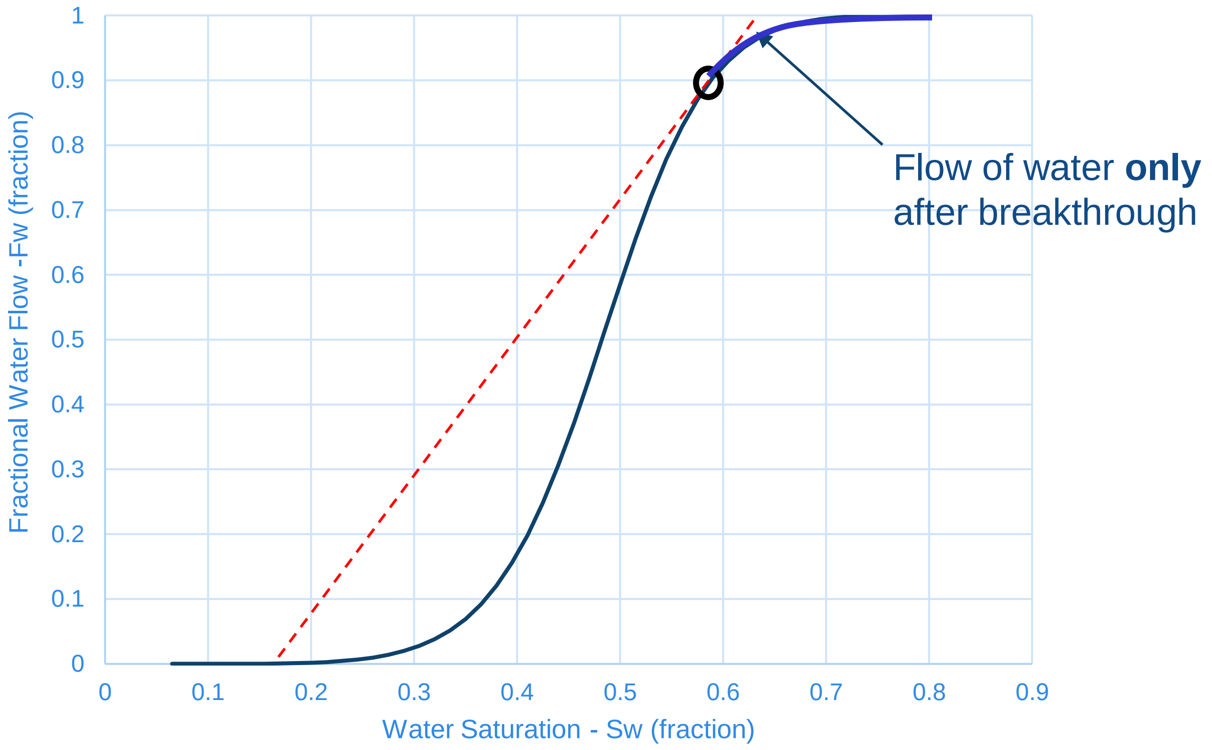

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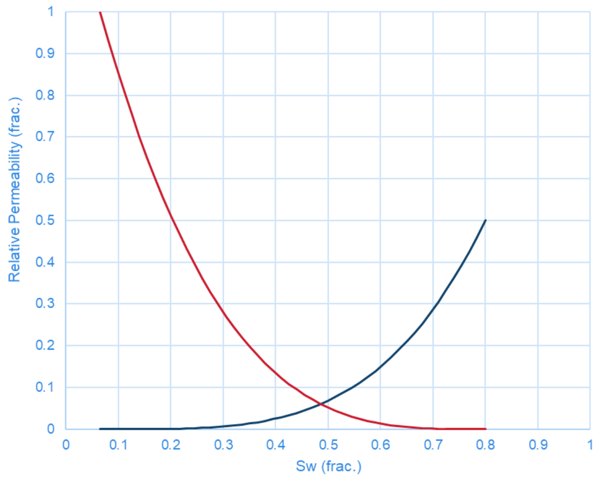

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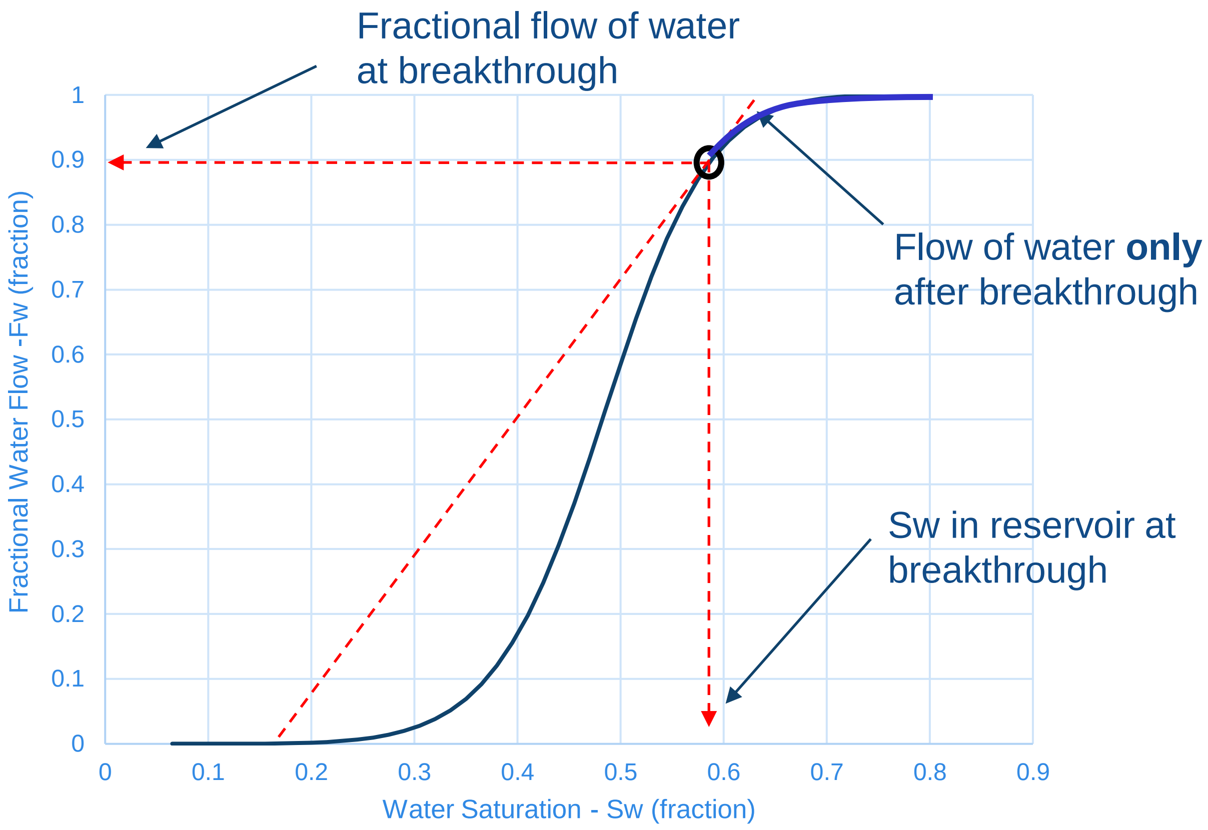

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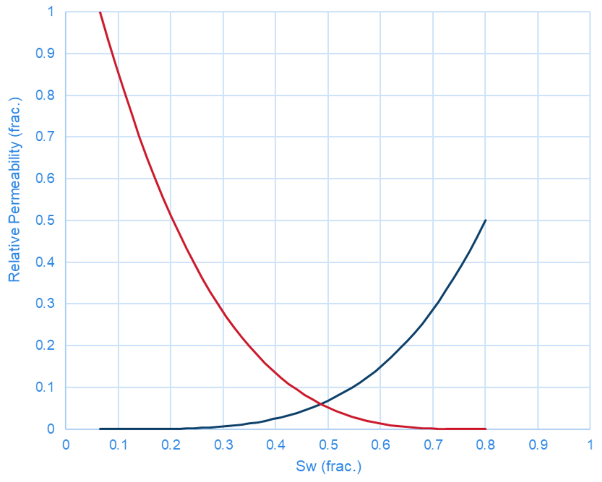

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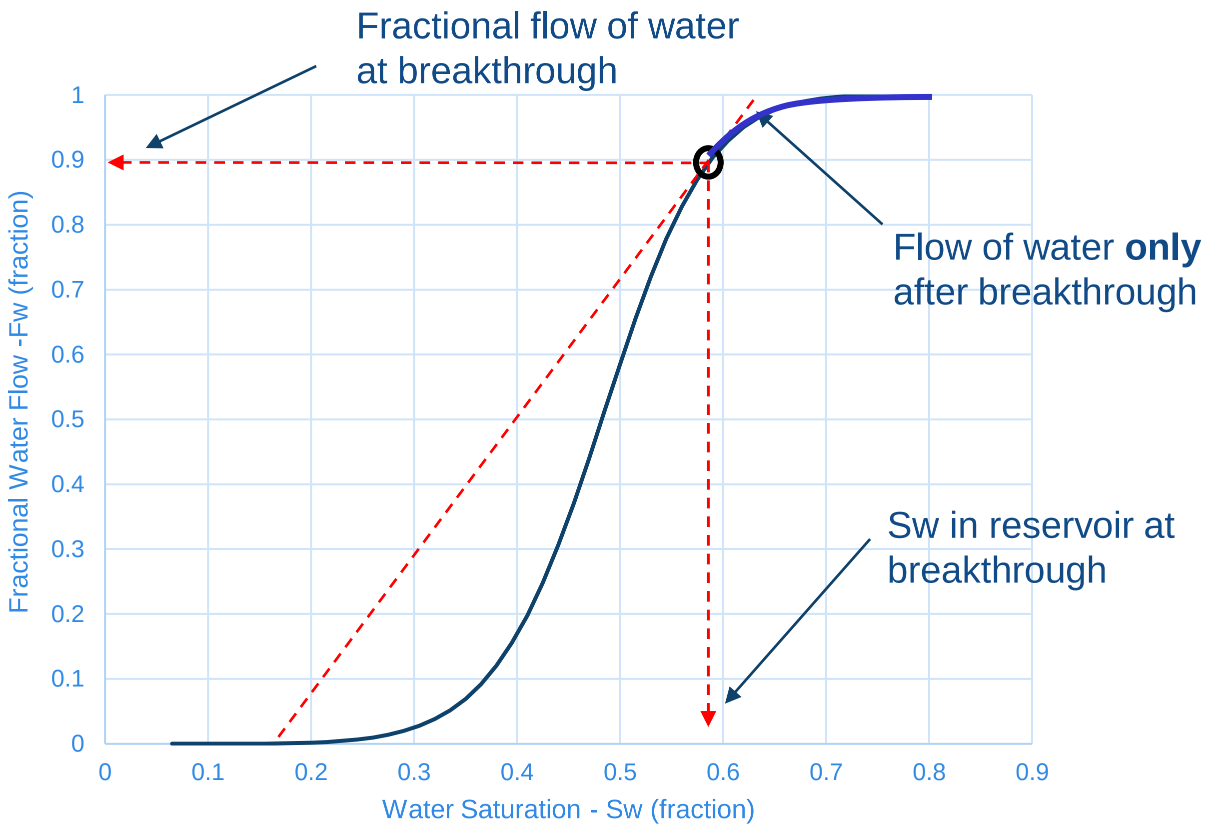

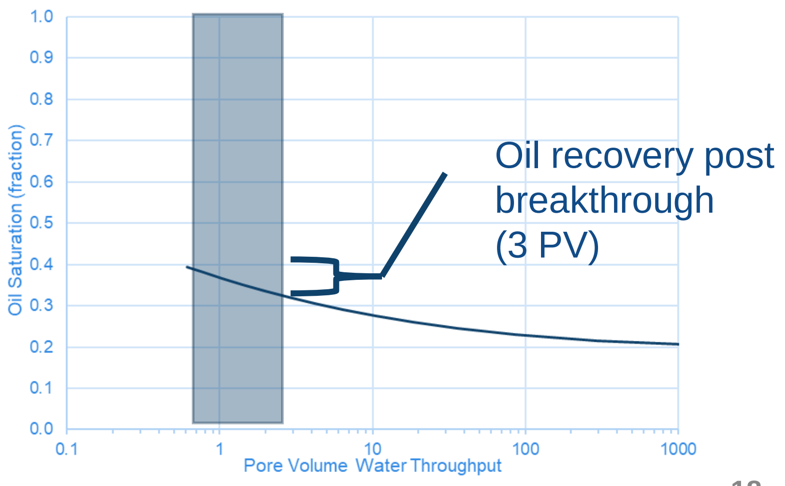

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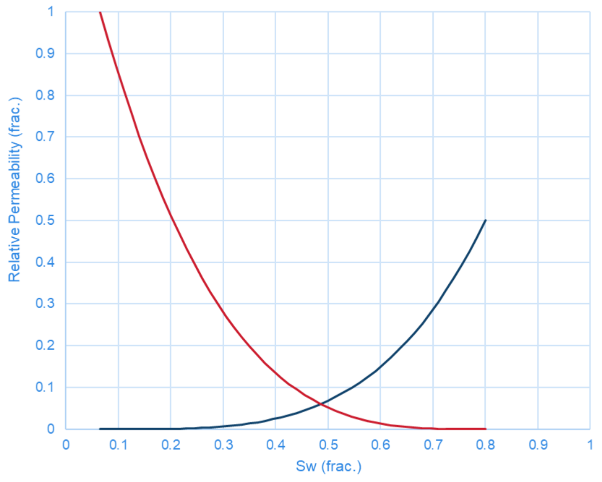

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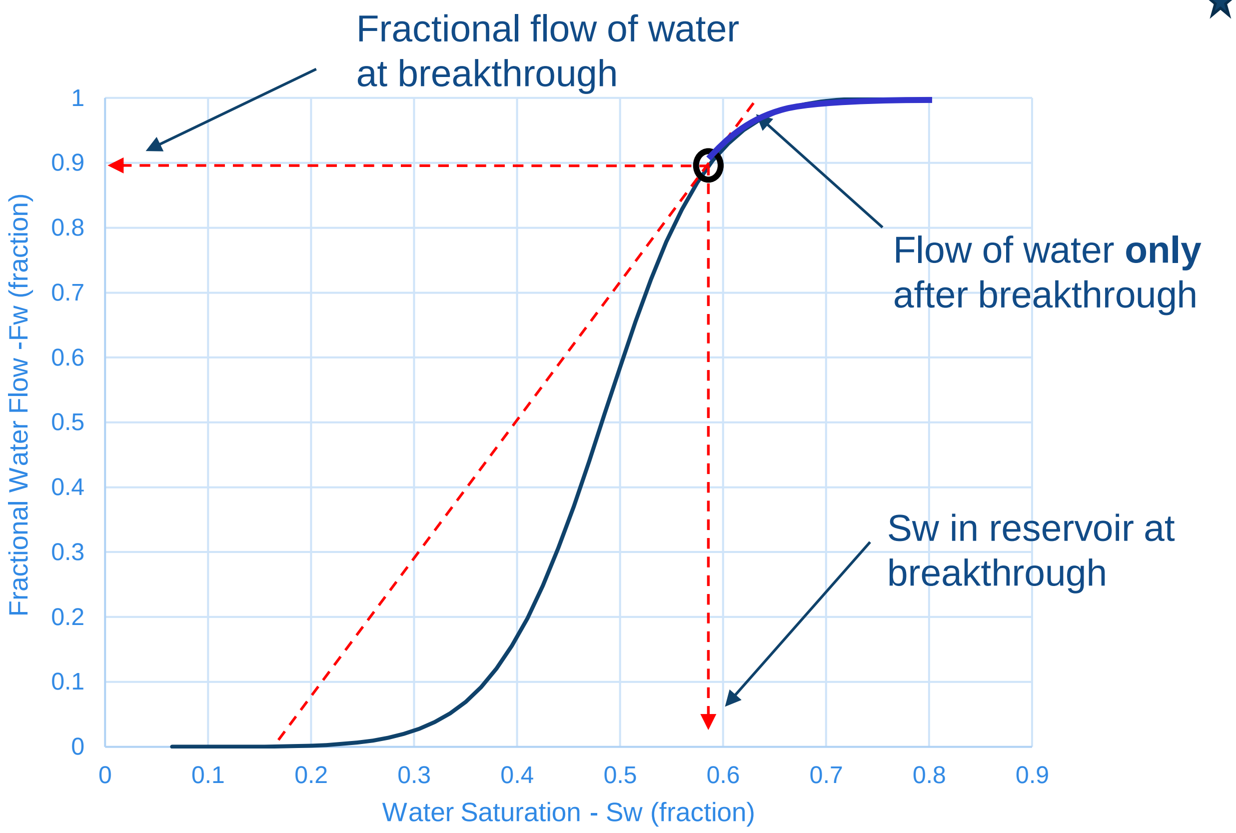
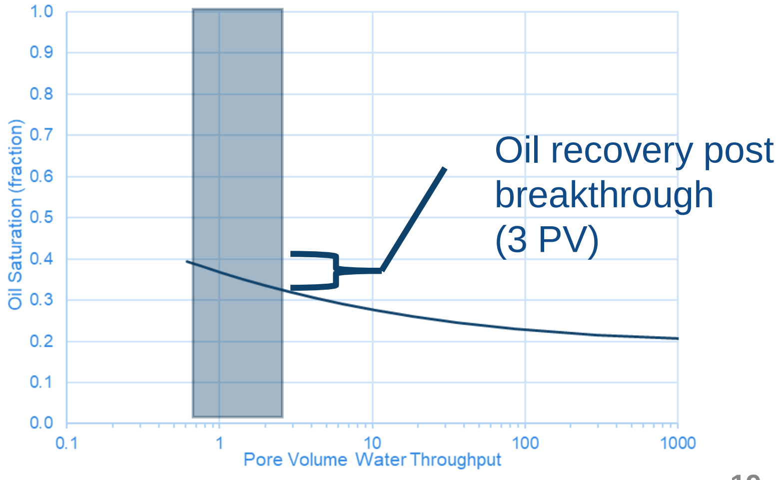
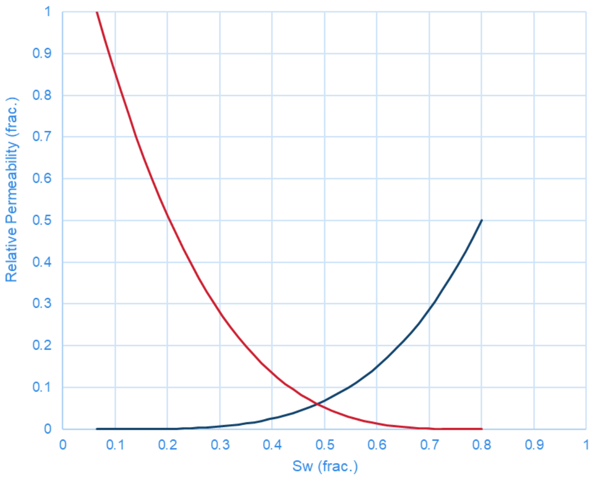




Implication:

- Sw > ~ 0.55 at breakthrough
- Fw ~ 0.9 after breakthrough
- Only 5 to 10 s.u. of oil is produced post breakthrough

What can be done?
Fractional flow analysis…



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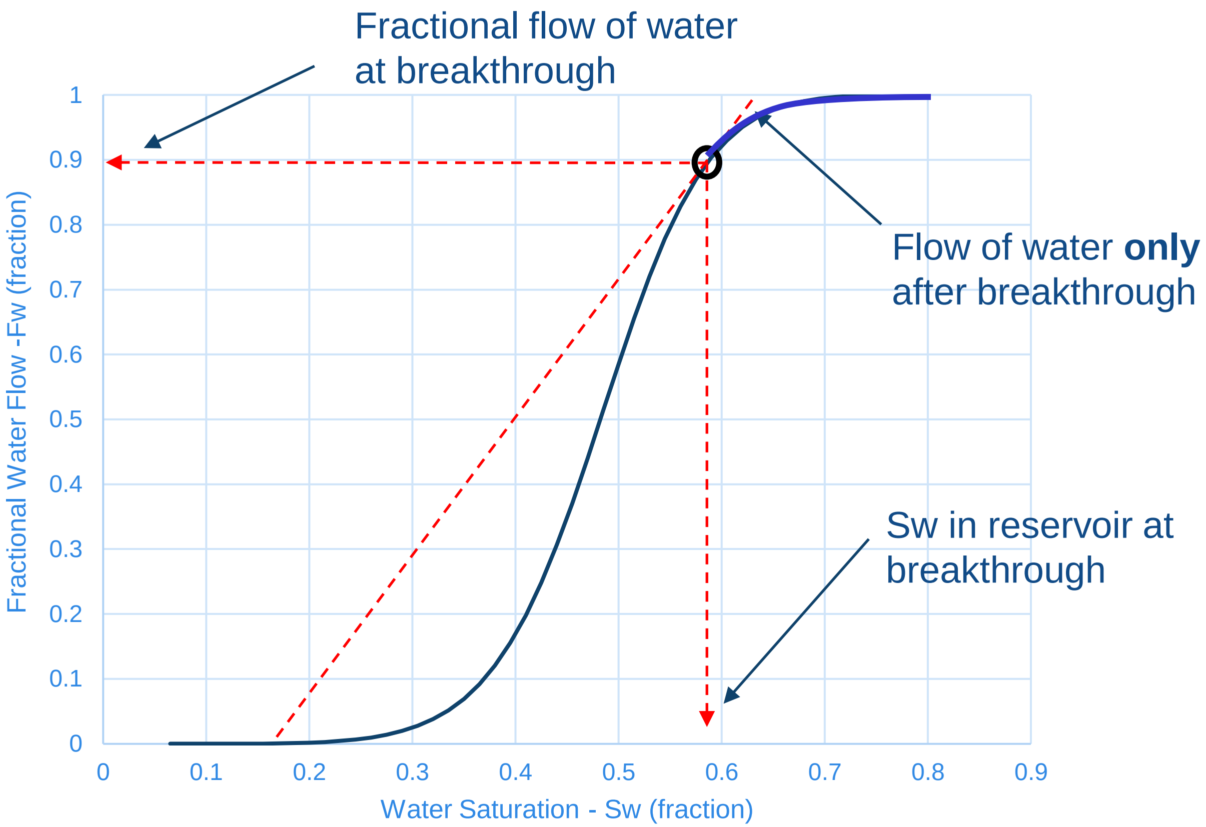

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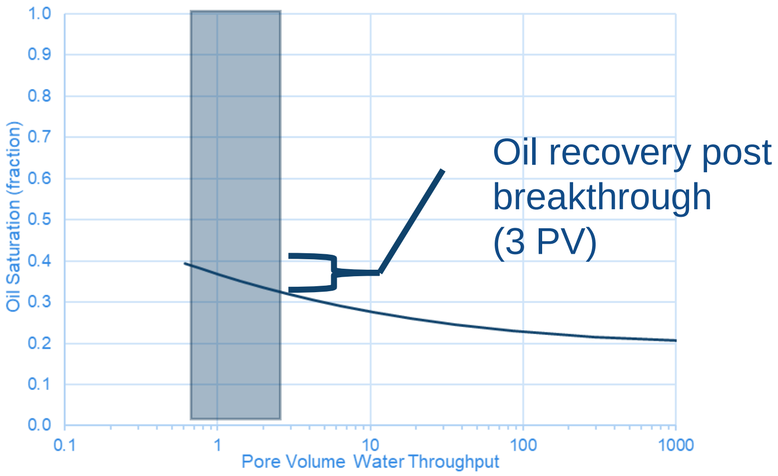


Run fractional flow (Welge) analysis using your SCAL data to understand the Sw at breakthrough, the Fw at breakthrough, and the remaining oil potential (to 3 PV) after breakthrough

How can we use this?

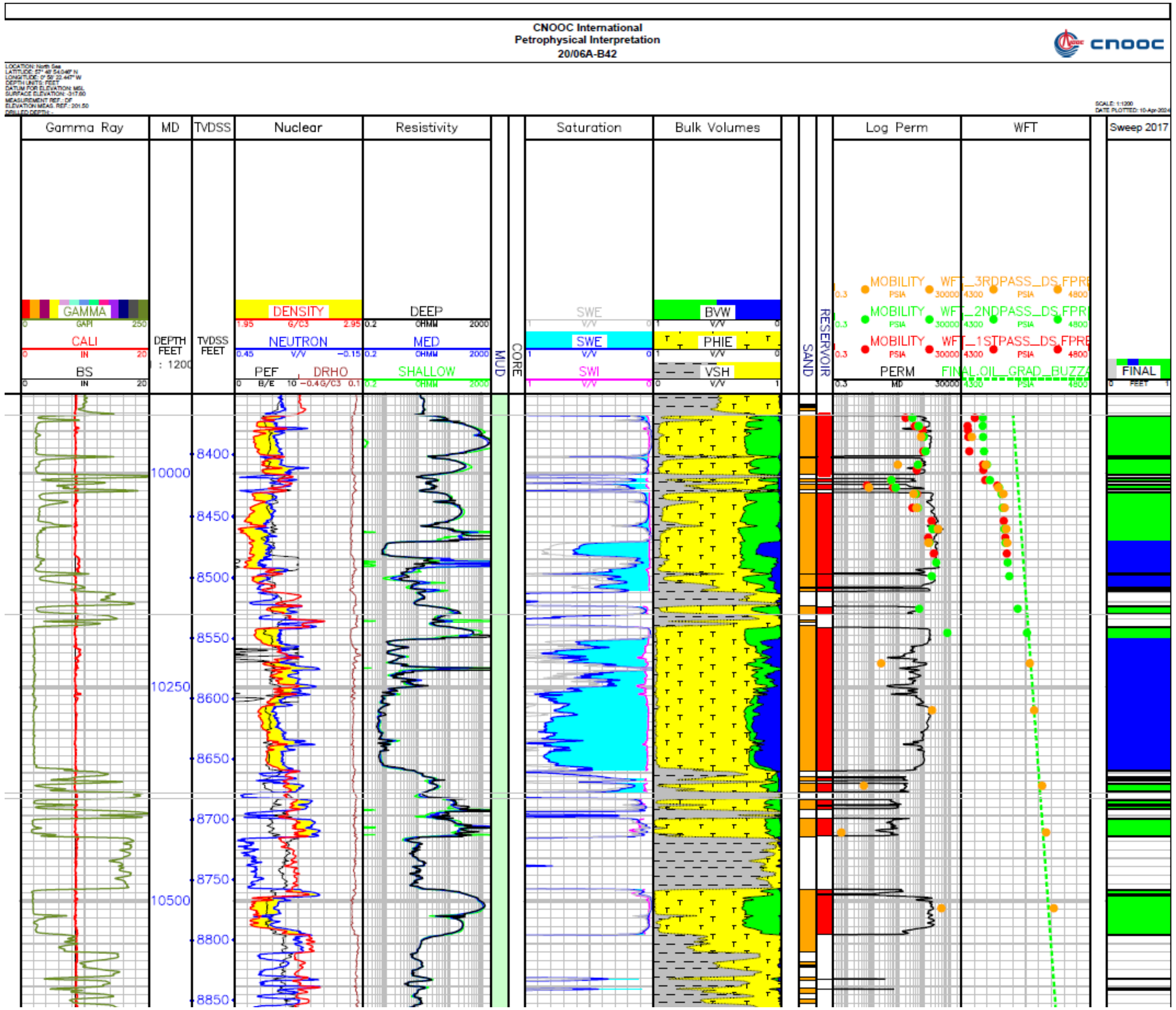
- If evidence shows the flood front has arrived then it is possible to determine the value of the remaining oil in that part of the reservoir.
- E.g. Saturation >0.55, fractional flow of oil < 10%, then the remaining potential is 0.05 s.u.
- Does this work for your development situation / facility? Do you want to produce oil at >90% water cut?
- This can inform a decision to complete this type of interval (or not)

- Ensure your formation evaluation workflow clearly indicates intervals that are unswept, and intervals where the flood front has arrived. Treat them separately.

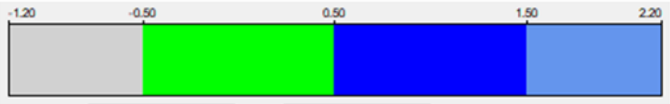
Use realistic assumptions from fractional flow analysis to determine the value (if any) of oil production from a zone that has seen the arrival of the flood front
Decide if completing this type of interval makes sense for your development

Make sure the formation evaluation workflow clearly identifies zones that are still unswept, and zones where the water flood front has arrived. **Treat them separately**

Sweep flag



SWEEP LEGEND:



SWEEP UNCERTAIN (-1) NO SWEEP (0)

SWEEP (1) AQUIFER (2)

NO SWEEP (0)

Defined as an interval where
Sw ≈ Swi,
with no evidence of the arrival of the water flood front

SWEEP (1)

Defined as an interval where
Sw > Swi
with good evidence of the arrival of the water flood front

Make sure the formation evaluation workflow clearly identifies zones that are still unswept, and zones where the water flood front has arrived. **Treat them separately**

Sweep flag

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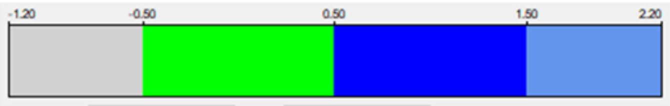

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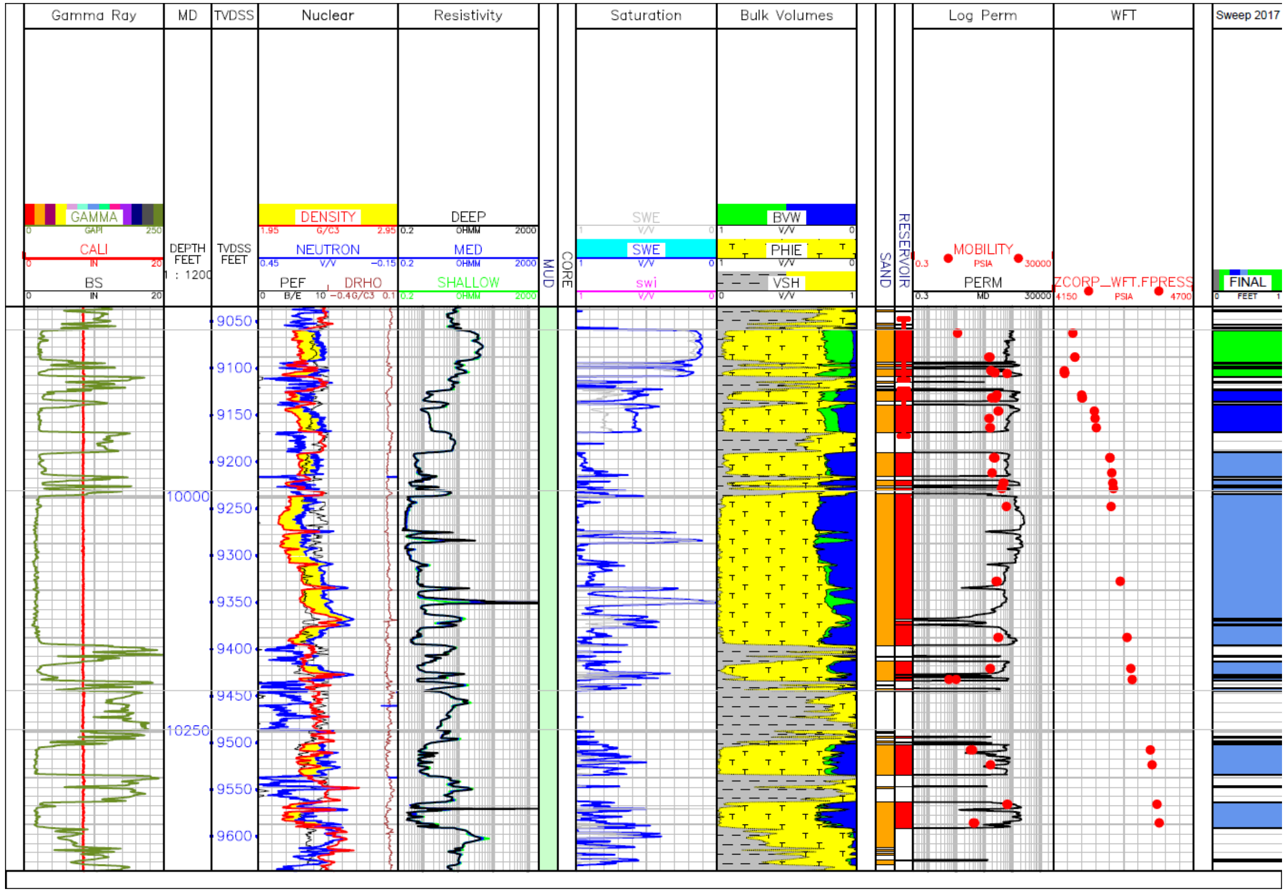


NO SWEEP (0)

Defined as an interval where Sw ≈ Swi, with no evidence of the arrival of the water flood front

SWEEP (1)

Defined as an interval where Sw > Swi with good evidence of the arrival of the water flood front

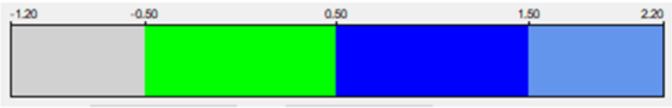
AQUIFER (2)

Defined as an interval below original OWC

Make sure the formation evaluation workflow clearly identifies zones that are still unswept, and zones where the water flood front has arrived. **Treat them separately**

Sweep flag

SWEEP LEGEND:



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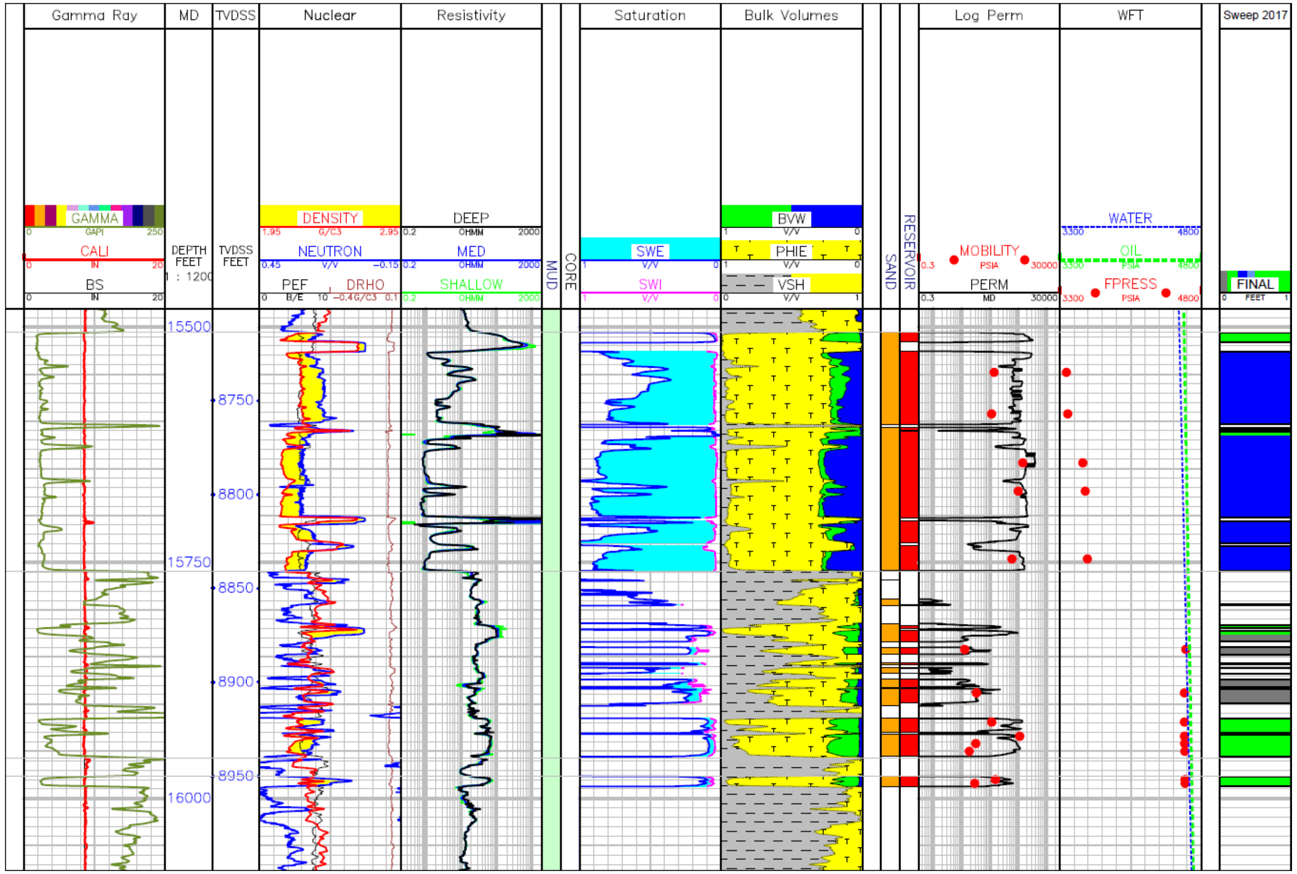

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SWEEP (1) — Defined as an interval where Sw > Swi with good evidence of the arrival of the water flood front

SWEEP UNCERTAIN (-1) — Defined as an interval where no robust interpretation can be made

Make sure the formation evaluation workflow clearly identifies zones that are still unswept, and zones where the water flood front has arrived. **Treat them separately**

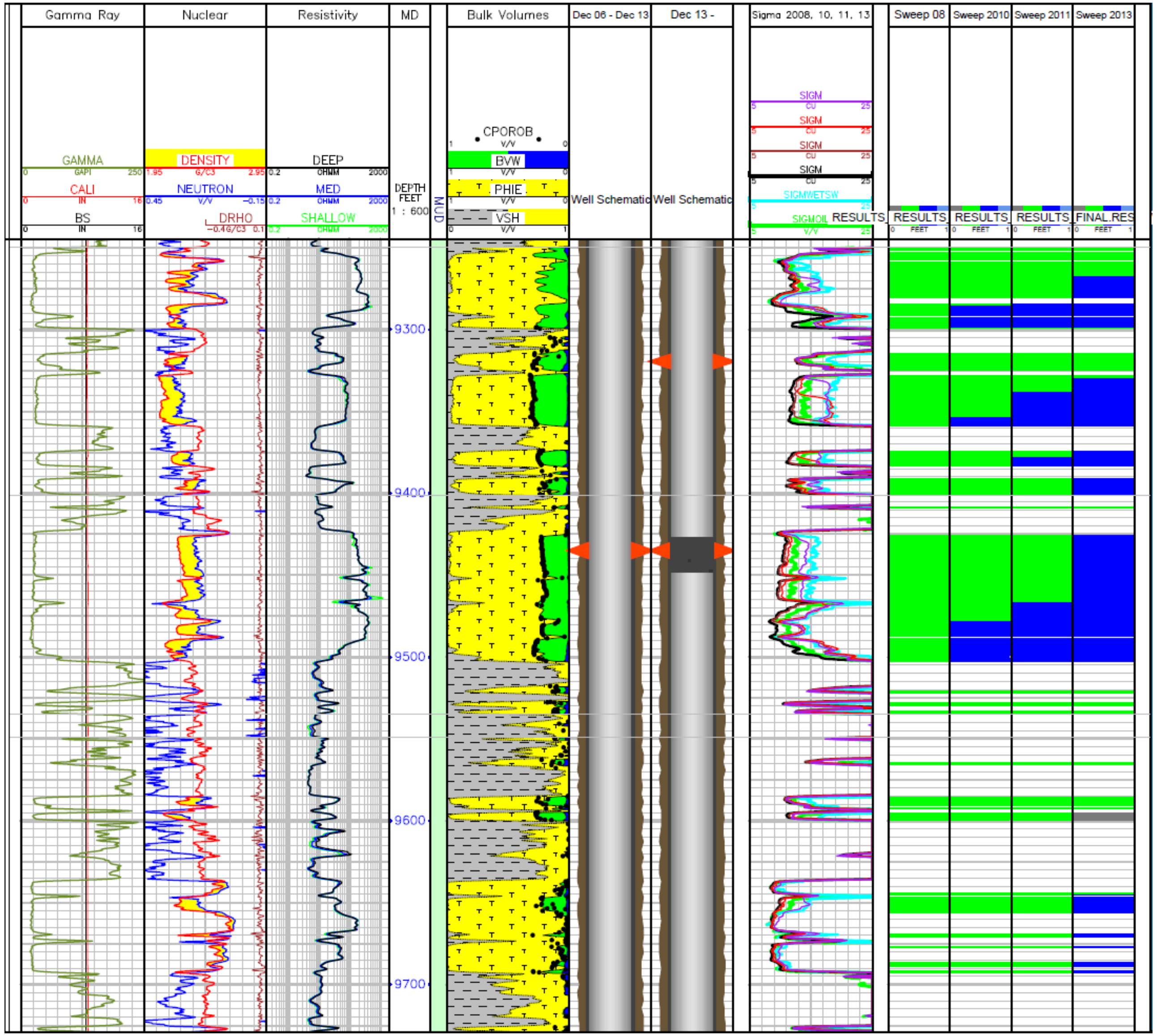
Summary

- Understand the limitations / uncertainty associated with water saturation estimates in a reservoir where imbibition has taken place
- Complete fractional flow analysis to determine realistic assumptions for :
  - Water saturation at breakthrough of the flood front
  - Fractional flow of oil at breakthrough of the flood front
  - Remaining oil potential following breakthrough of flood front (to 3 PV)
- Using these assumptions determine if production from this type of interval is of value for your development if encountered when drilling infill wells

- When evaluating new wells, ensure the formation evaluation clearly identifies intervals that are unswept and intervals where the water flood front has arrived
- Don’t be misled by water saturation estimates in intervals where the flood front has arrived

- Treat these intervals separately, and this approach can inform robust completion decisions and production forecasts

Cased hole Sweep flag (E.g. from RST)



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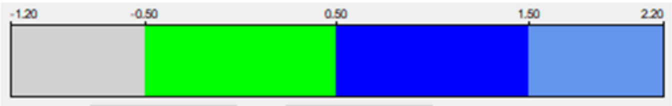

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Thanks

Thank you to the Buzzard Co-Venture partnership for permission to publish this presentation…

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THANK YOU