Making Sense of Producing Gas-Oil Ratio in Unconventional Oil Reservoirs

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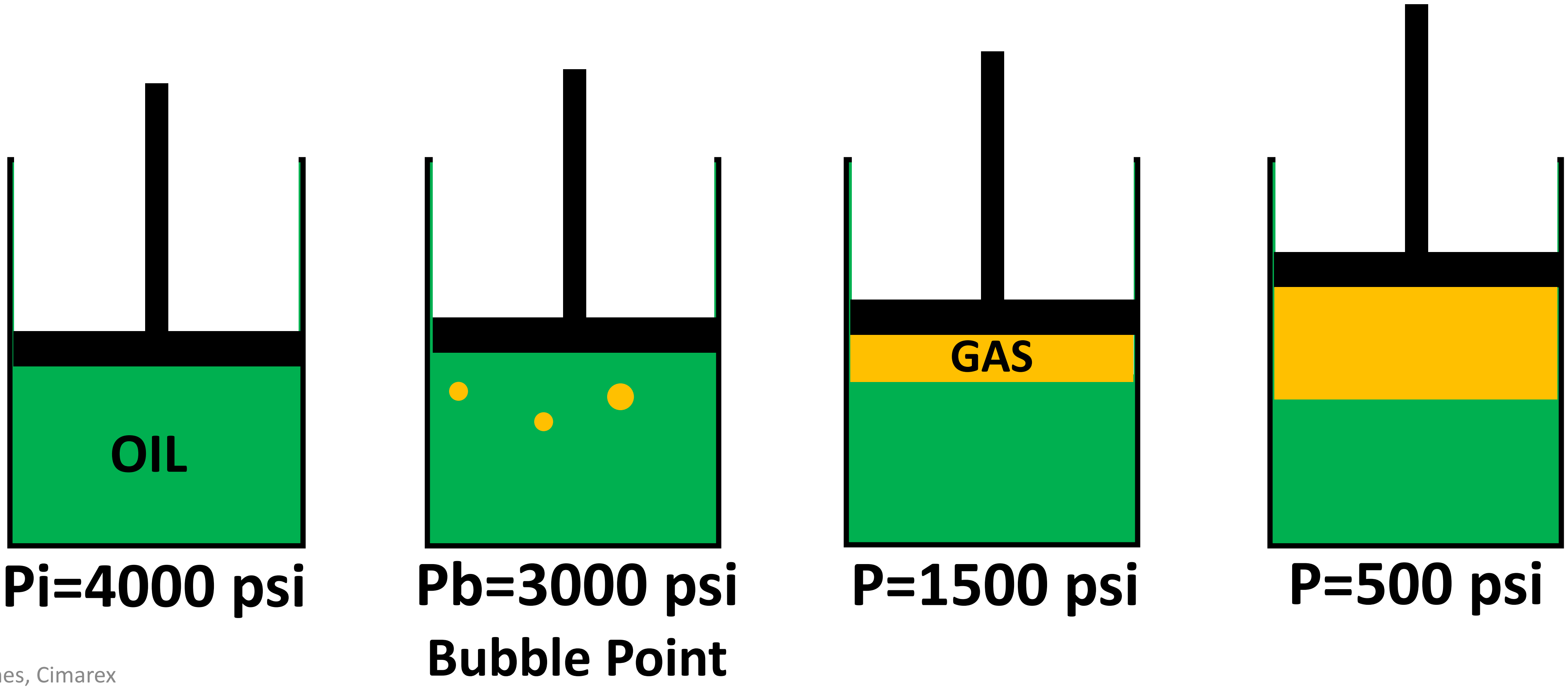
Overview

- Framework for understanding GOR performance in unconventional solution gas-drive reservoirs
- Linear vs radial flow
- Four stages of GOR history
- Factors that affect GOR
- Practical applications
- SPE 184397

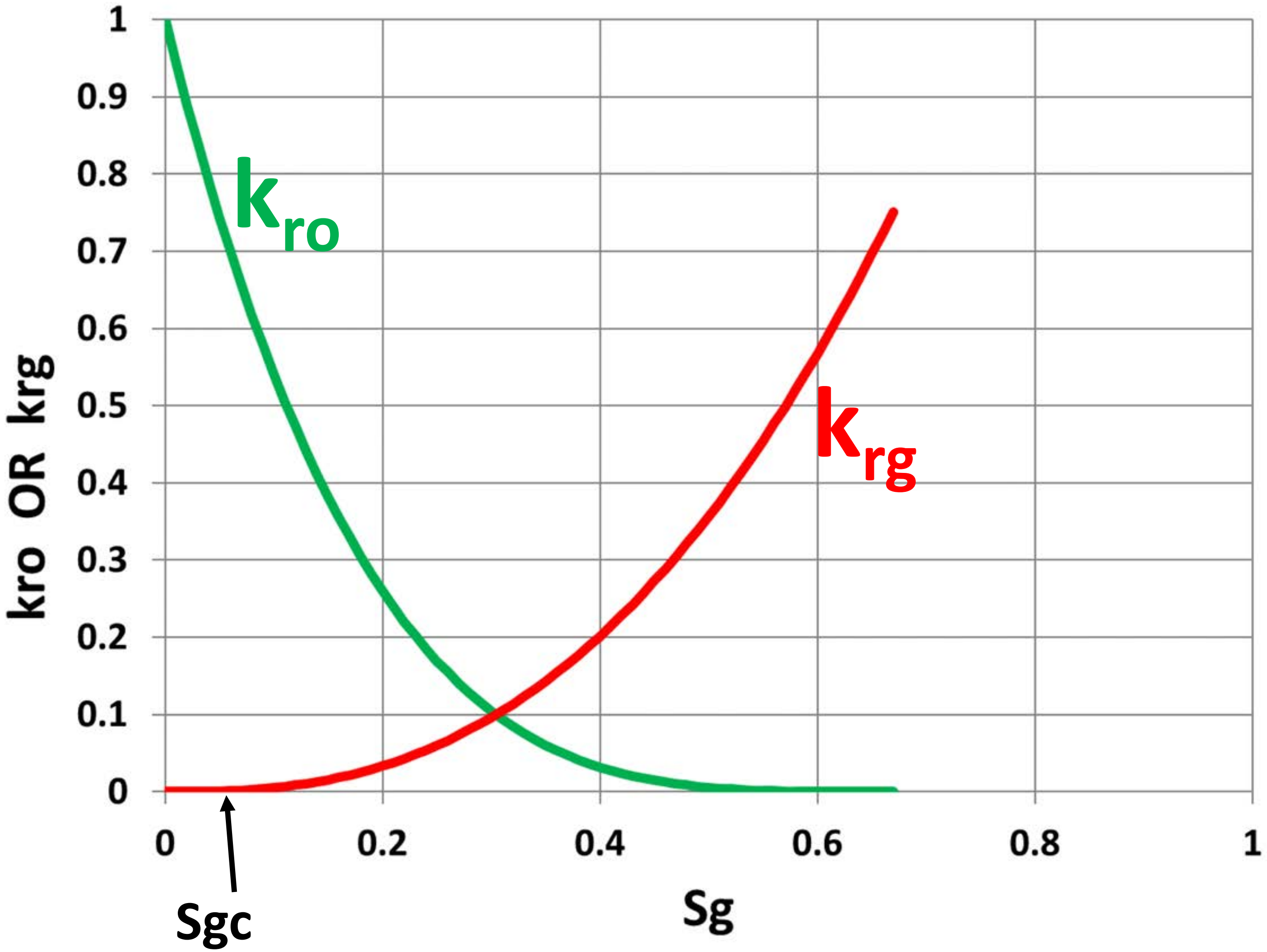
PVT of Oil Reservoirs

- Solution Gas Drive
- Rsi = dissolved gas at initial conditions, scf/stb



Gas-Oil Relative Permeability

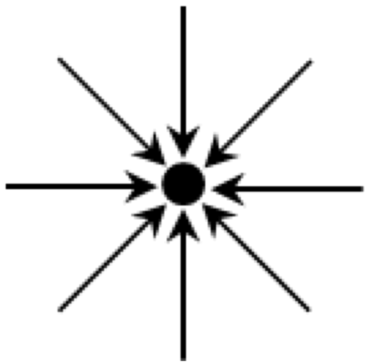
- Mobility = k / μ
- μ_o is 20-100x more than μ_g
- Sgc=Critical Gas Saturation
- As p⇩, Sg⇧, krg⇧ , kro⇩, **GOR⇧**



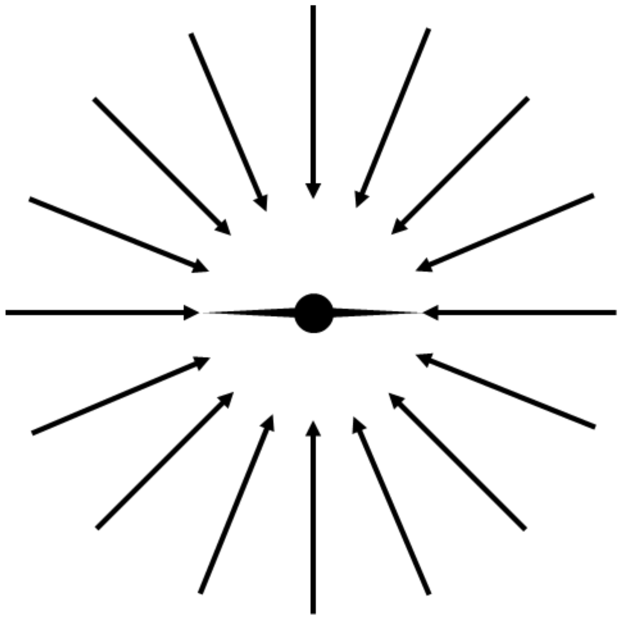
Conventional Reservoir

- "High" k (md)
- Vertical well
- Radial or psuedo-radial flow
- Rapid boundary-dominated flow (BDF)

Radial

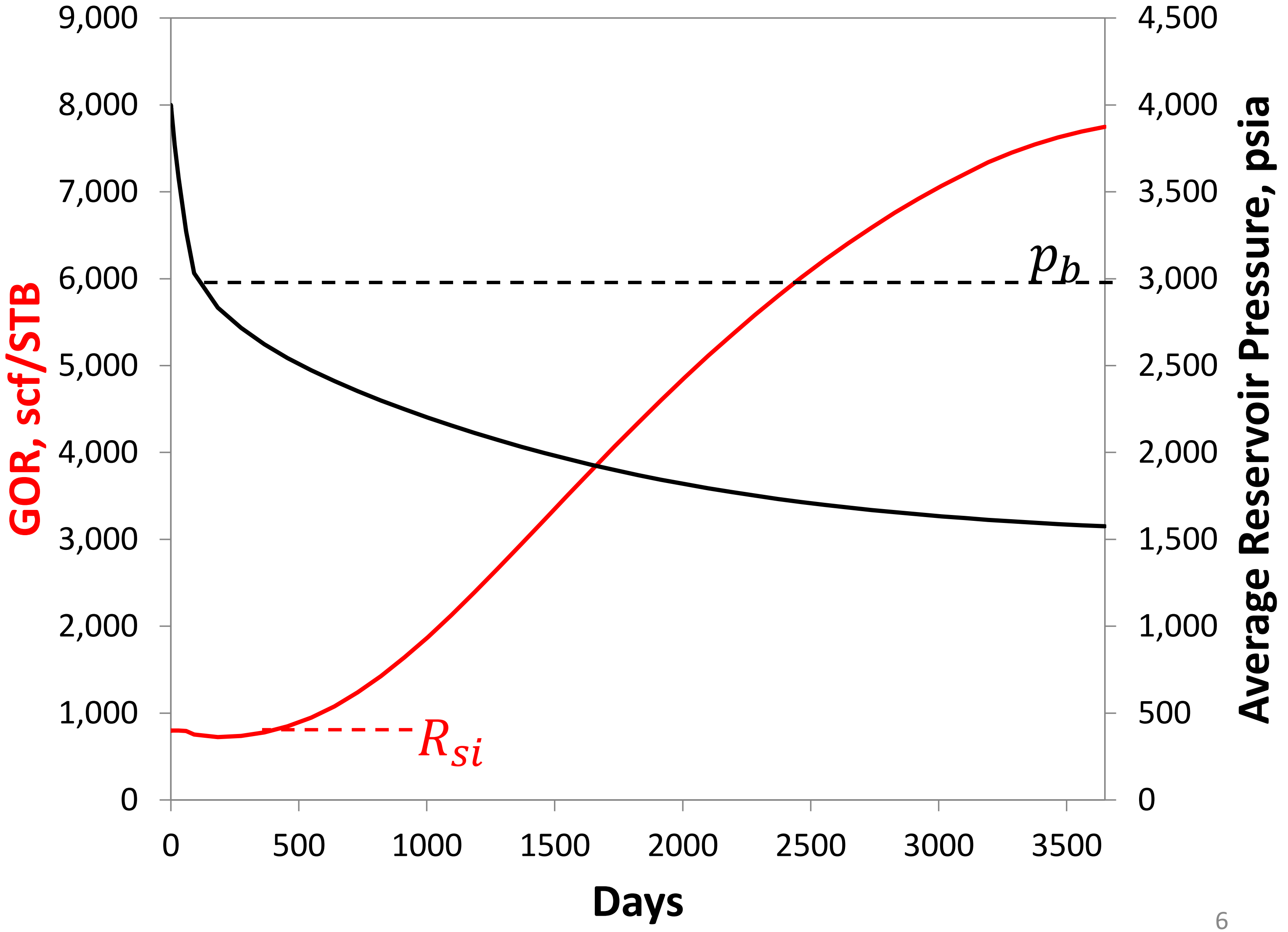


Pseudo-Radial

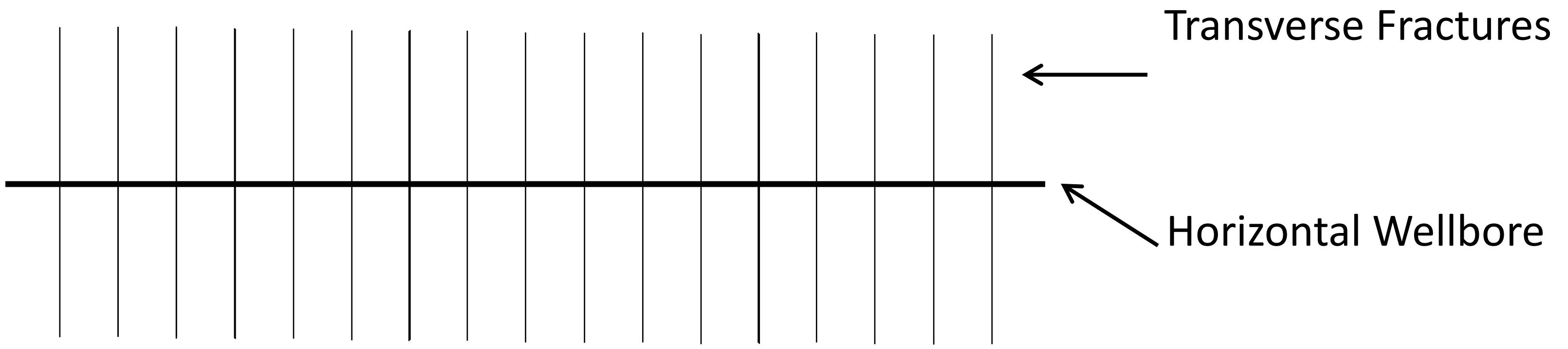


Conventional GOR History

- Radial flow, quick BDF
- **Average reservoir pressure controls GOR**
- Rising GOR indicates $\bar{p}_r$ has dropped below p_b

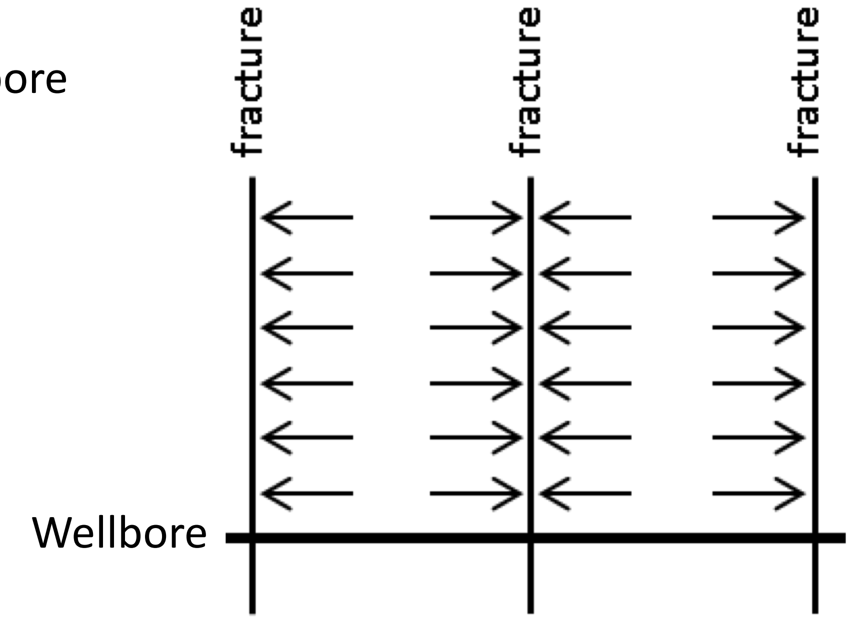


Unconventional Reservoir



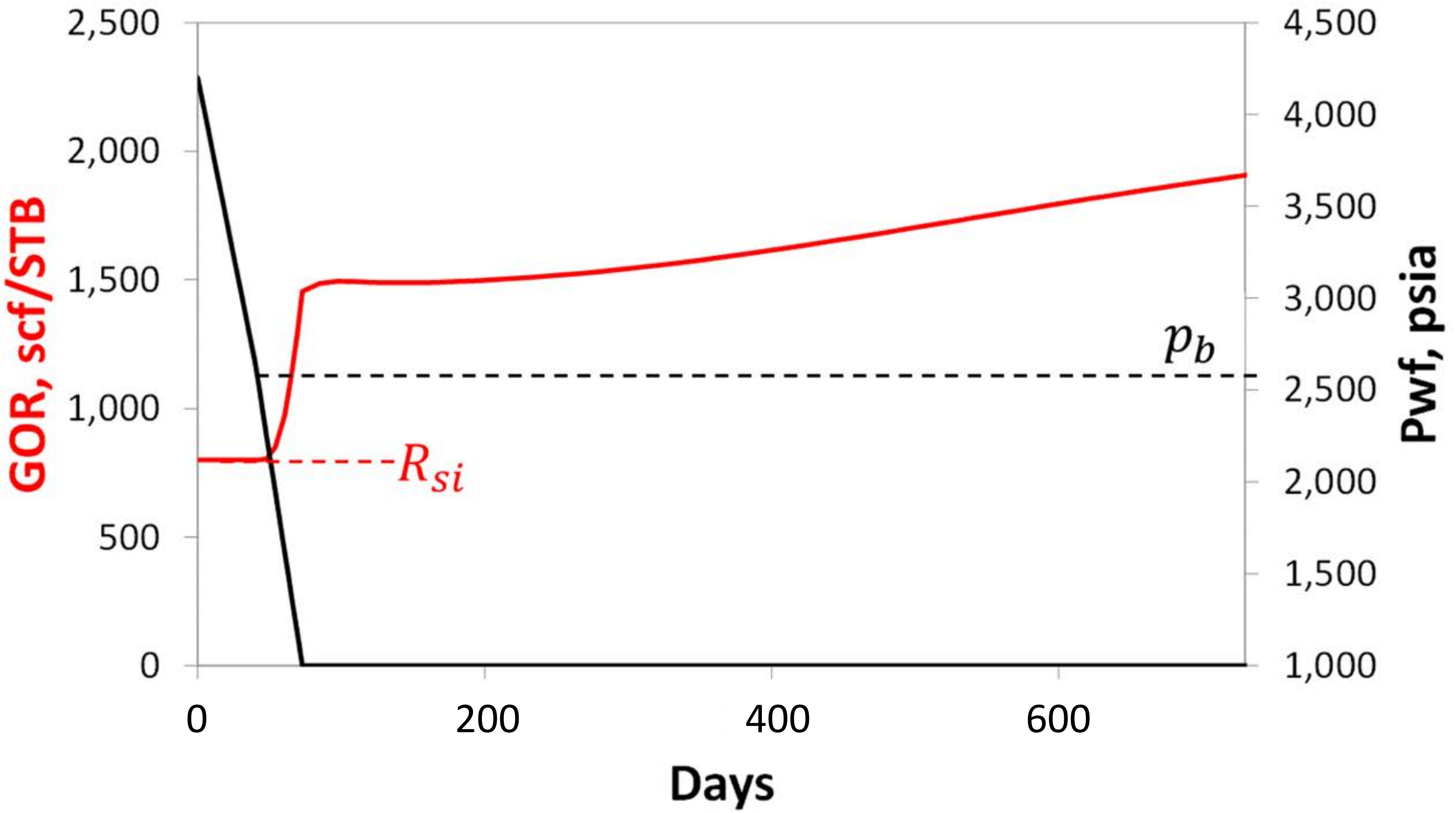
"Multi-Fractured Horizontal Well (MFHW)"

Linear Flow



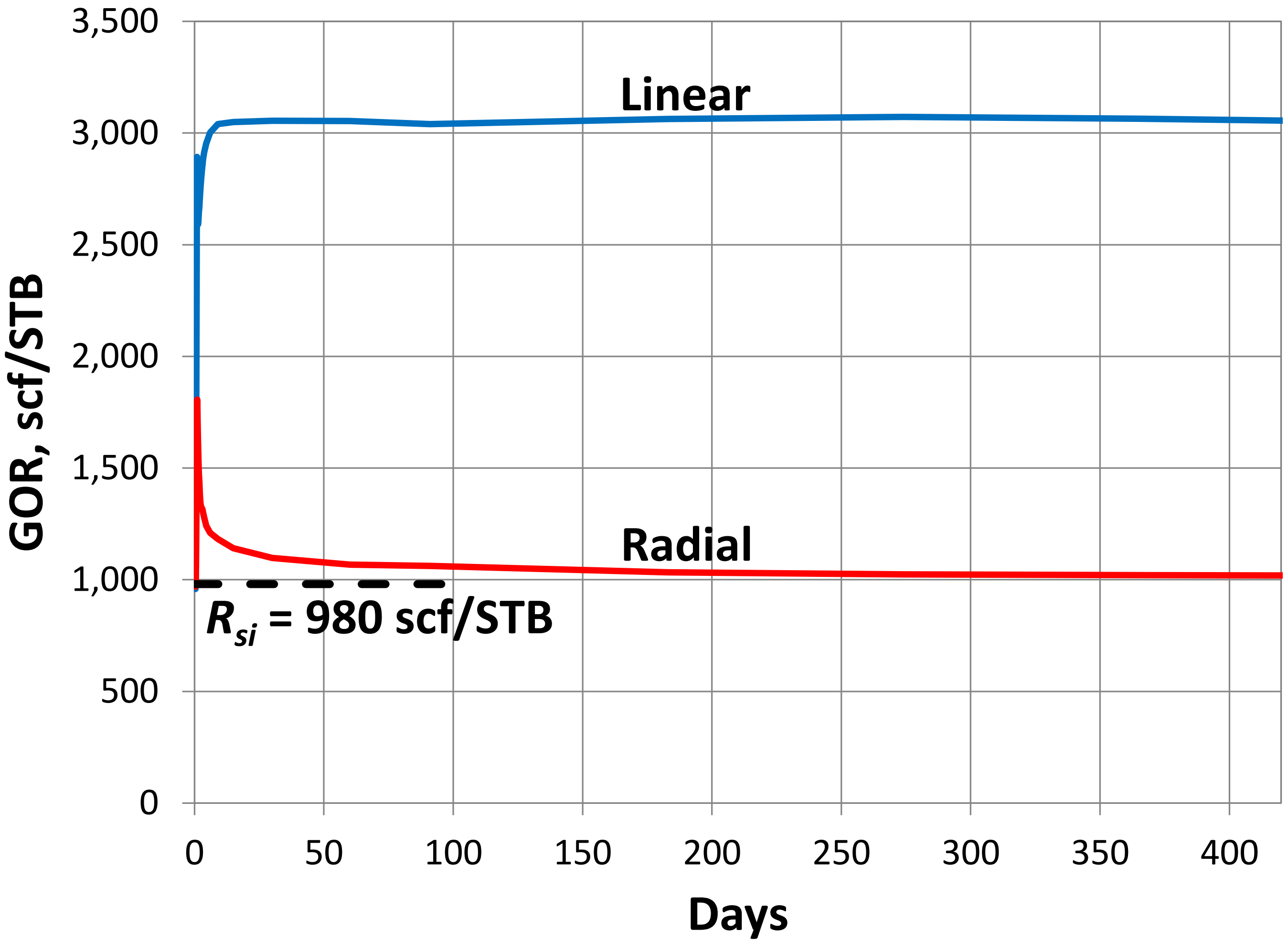
Unconventional GOR

- Low k (nd)
- Linear flow
- p_{wf} = BHFP
- **p_{wf} strongly influences GOR**

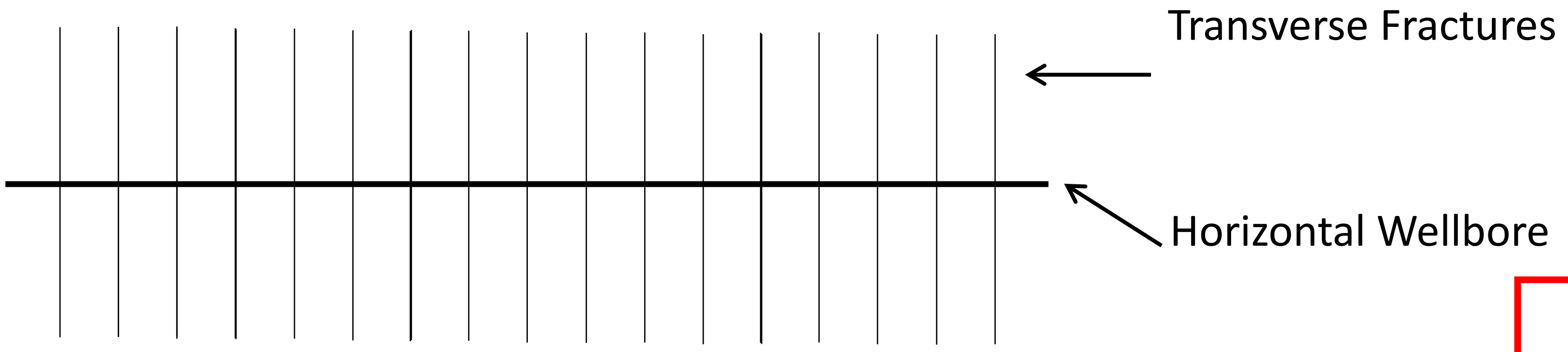


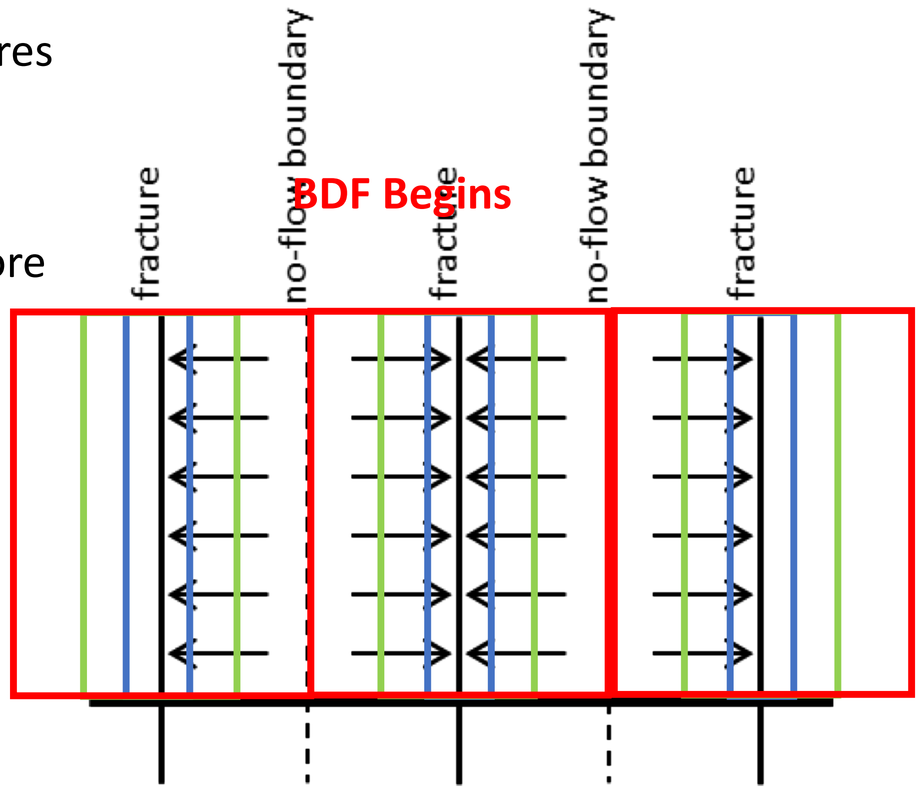
Linear vs. Radial Flow

- Constant GOR in transient flow
- Constant p_{wf}
- **Producing GOR is higher for linear than radial flow**



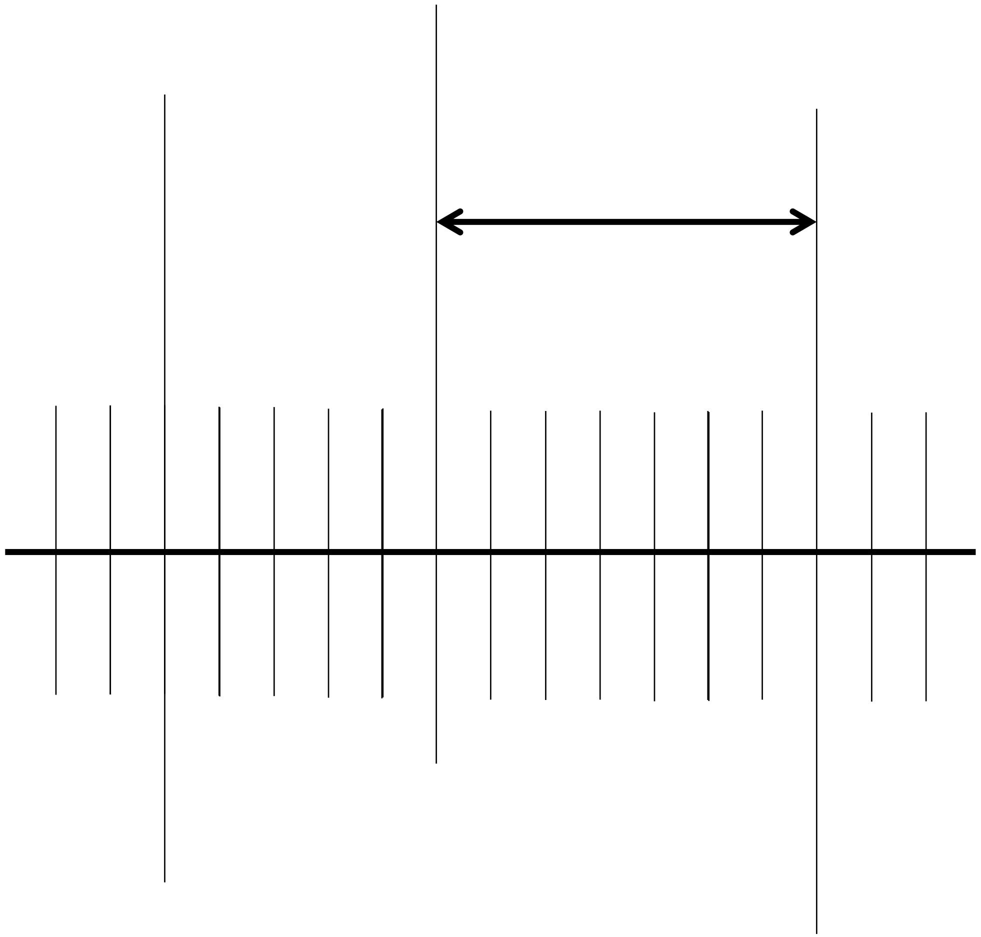
Transient vs. Boundary-Dominated Flow



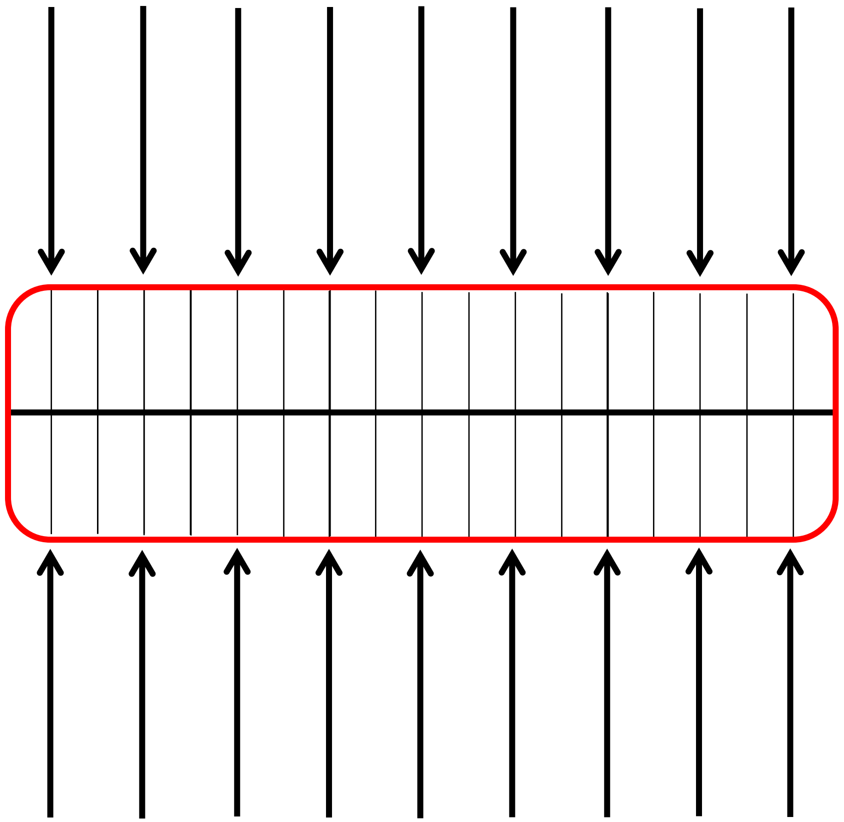


- Transient time depends on k and fracture spacing
- Assumes no flow beyond frac tips

Longer Transient Period

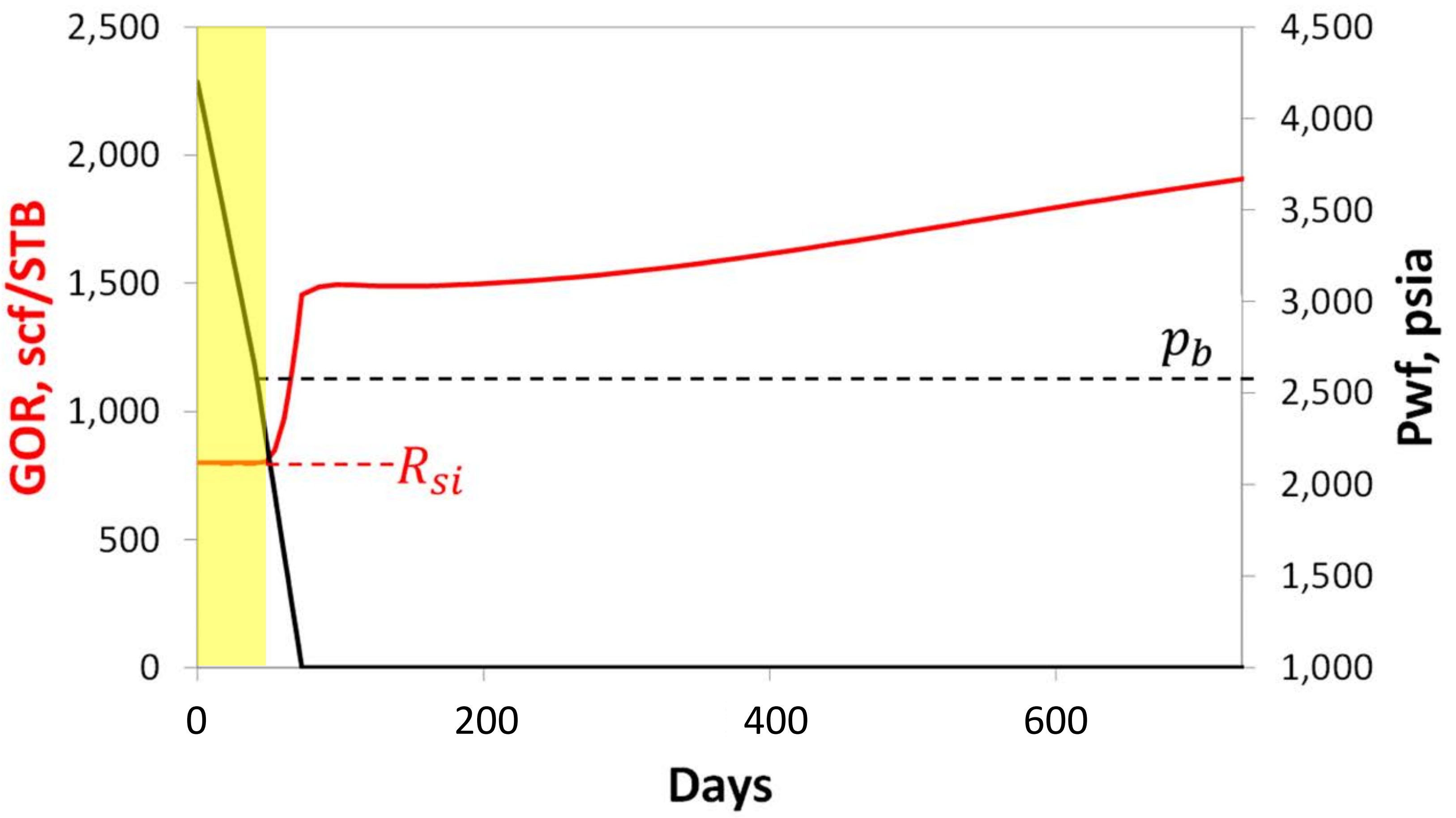


Compound Linear Flow



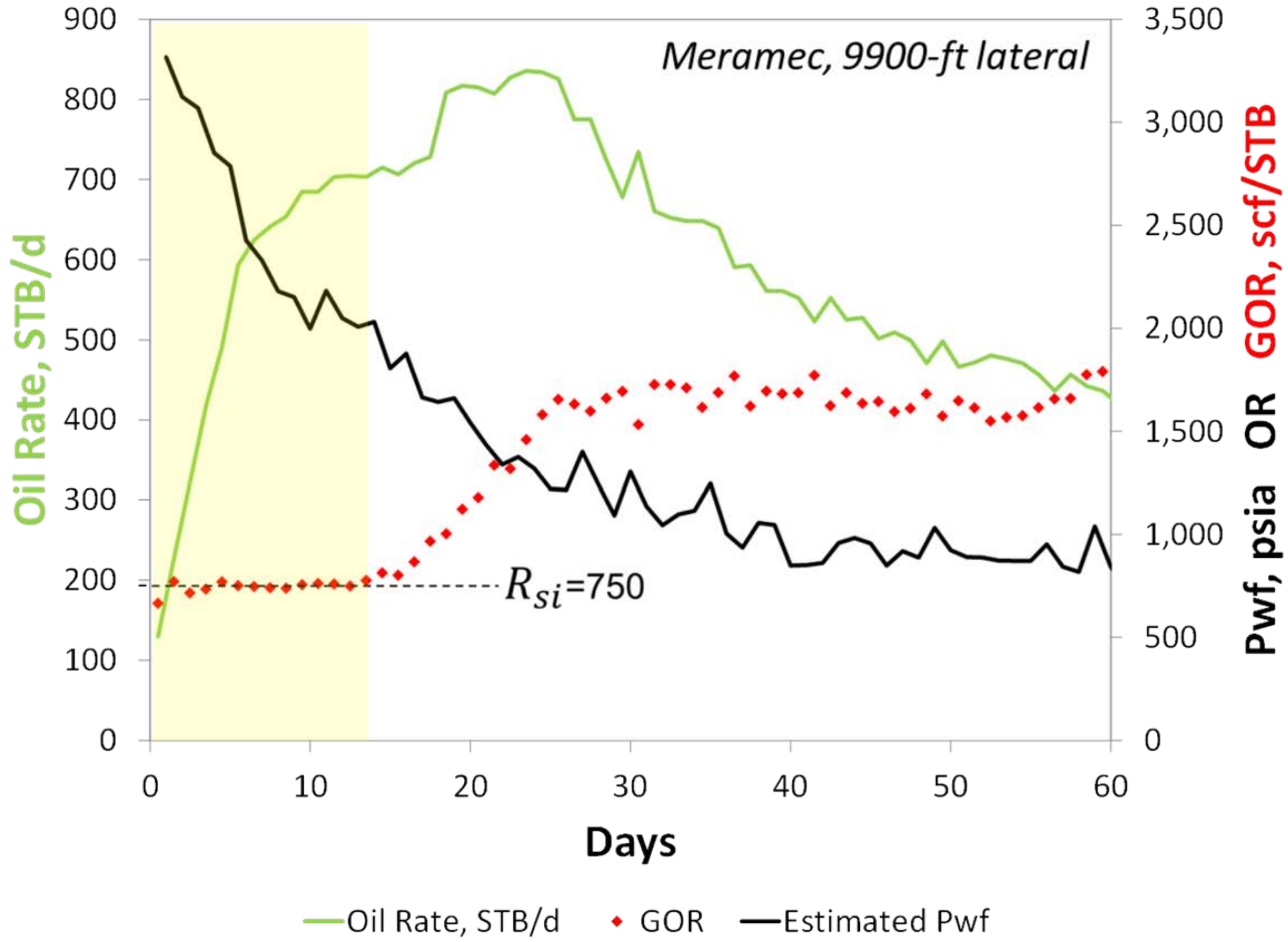
Four Stages of GOR Performance in MFHW

1. GOR = R_{si} while $p_{wf} > p_b$



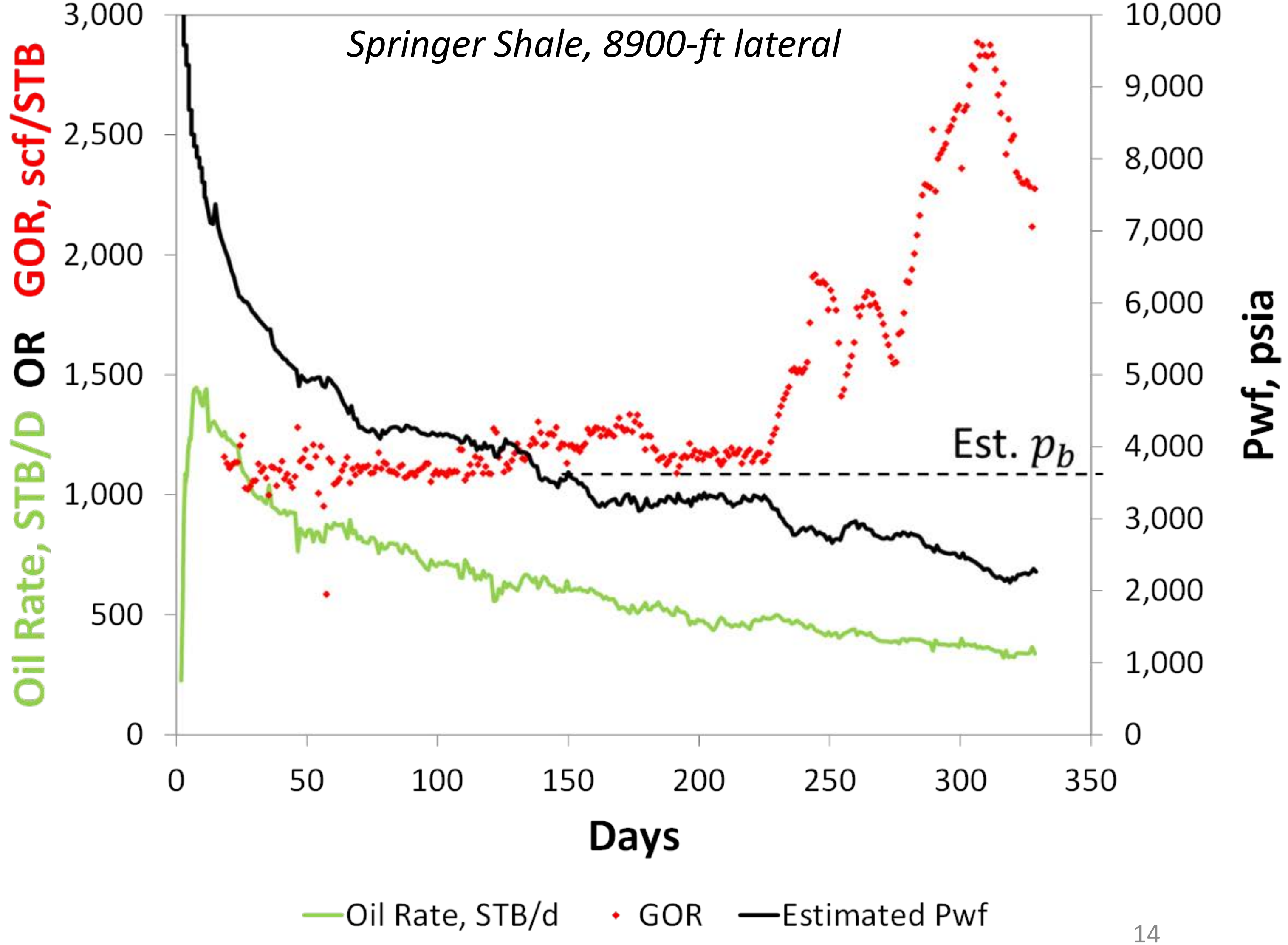
GOR = R_{si}

- $p_{wf} > p_b$
- Important to correctly estimate R_{si}
- Take PVT samples here
- Can be very short, or long



GOR = R_{si}

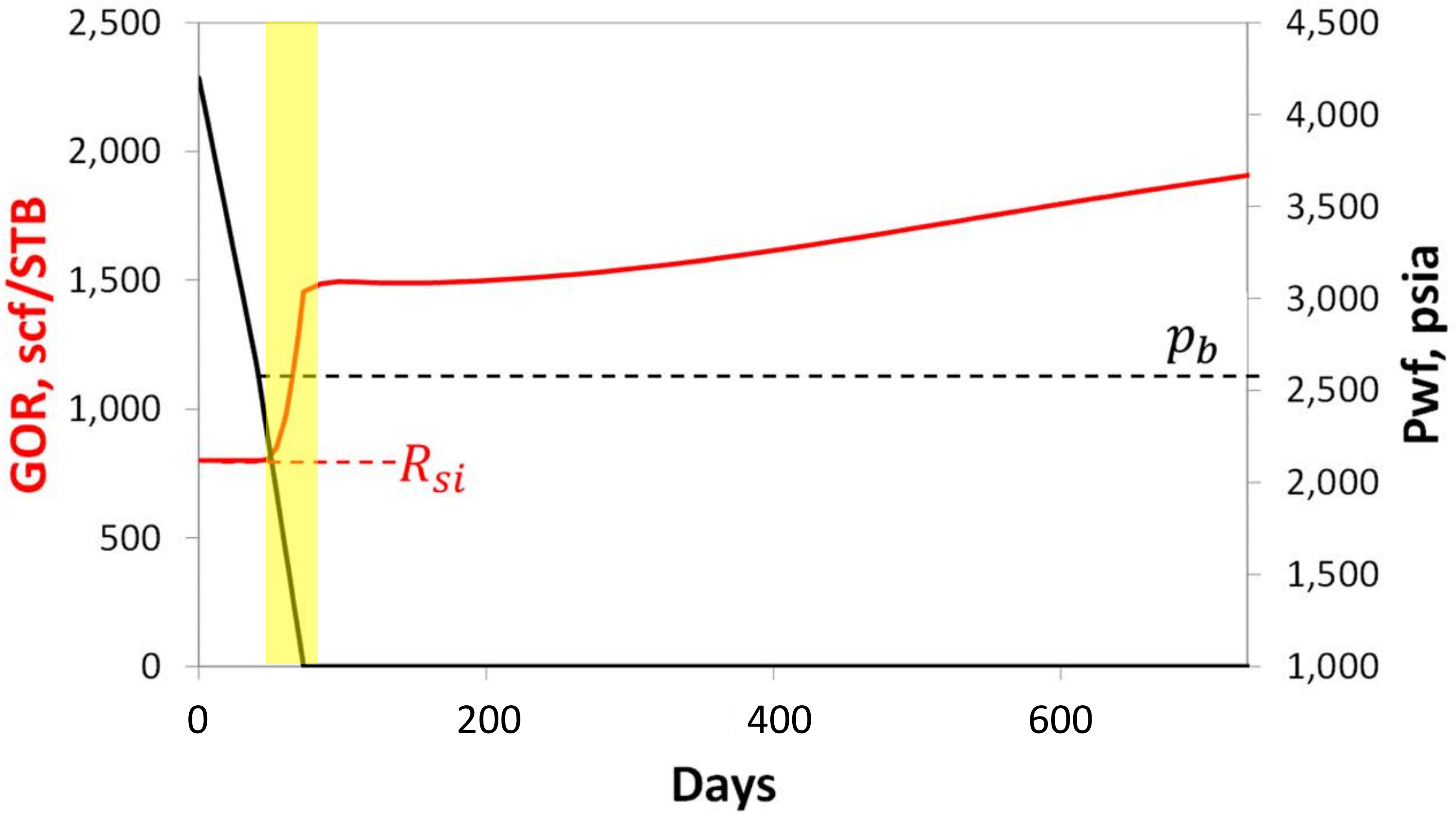
Example of long period of GOR=R_{si}



Four Stages

1. GOR = R_{si}
2. Rise due to $p_{wf} < p_b$

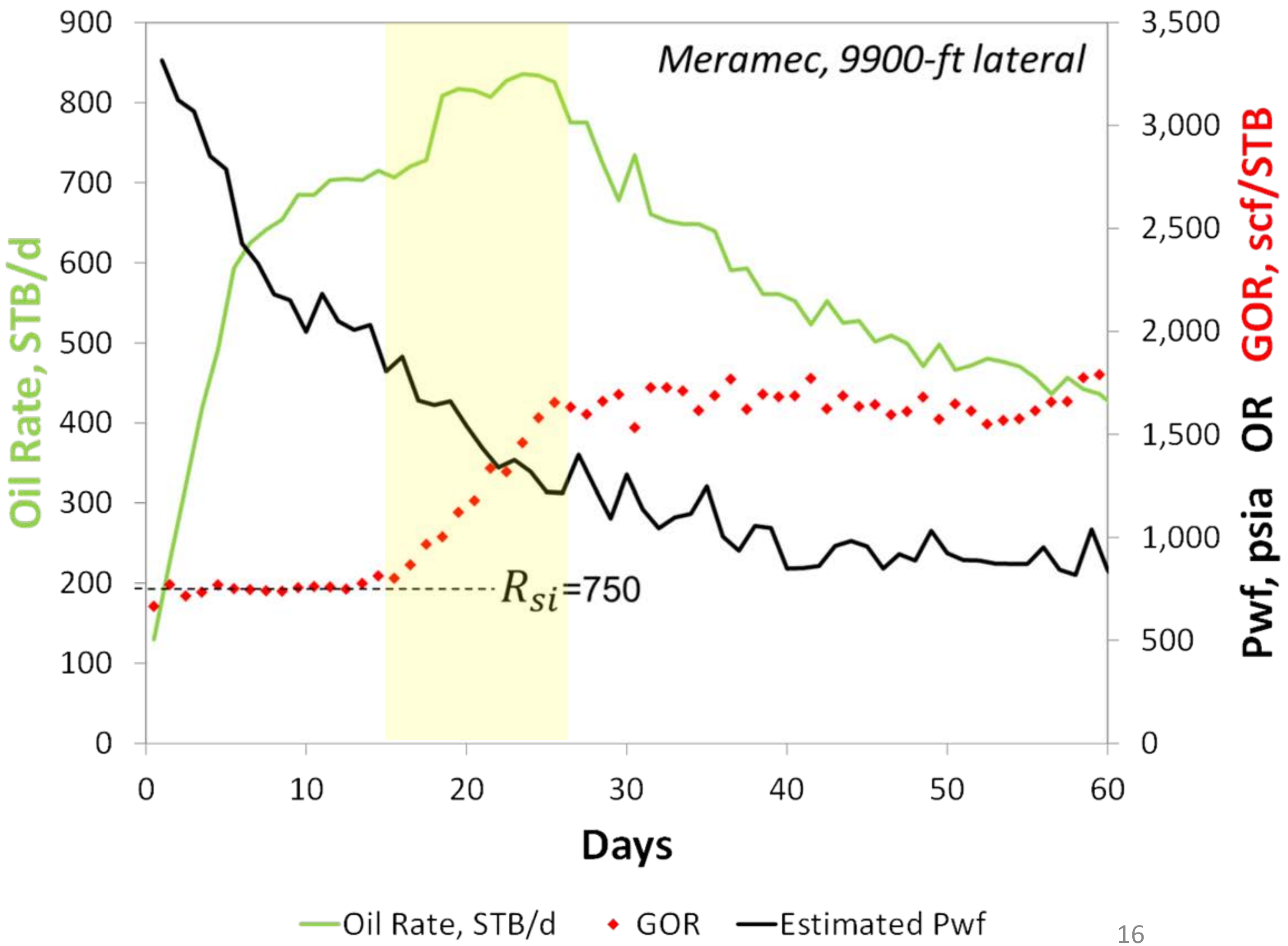
During transient flow, for a given reservoir and completion, GOR is controlled by pwf.



Rise due to $p_{wf} < p_b$

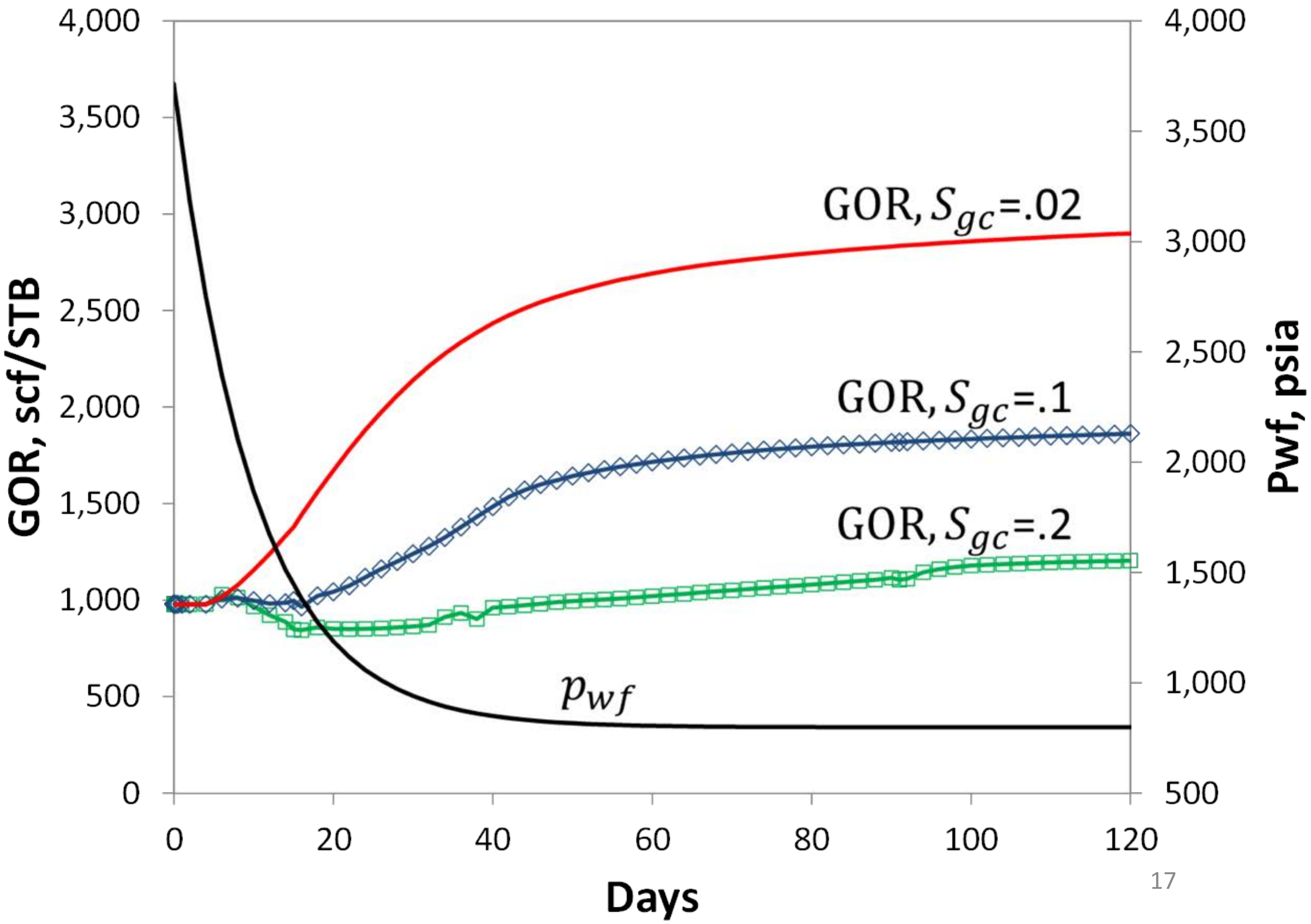
<u>Shape controlled by:</u>

- p_{wf} schedule
- Rel perm, especially S_{gc}
- Finite frac conductivity
- Frac length



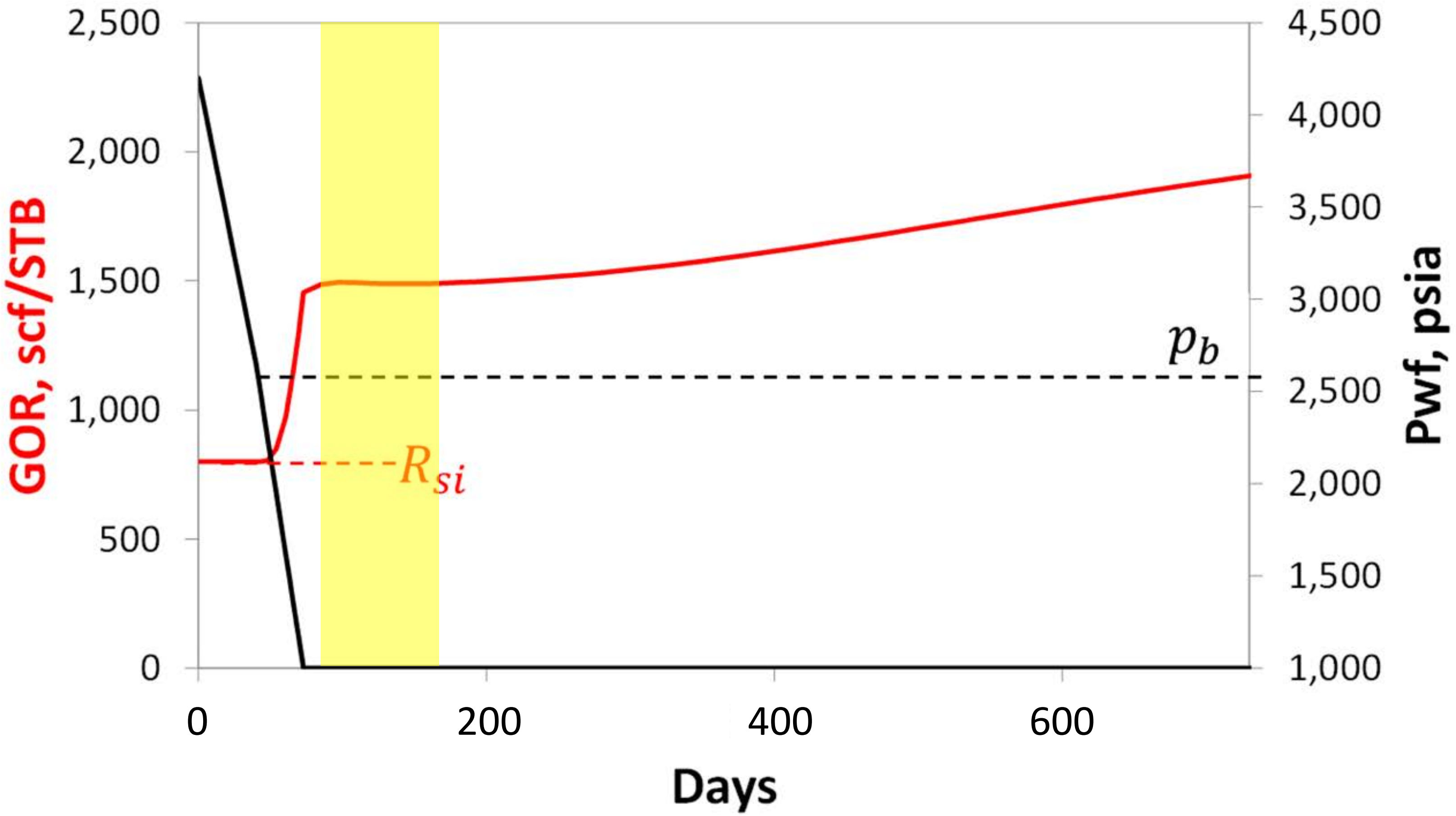
Rise due to $p_{wf} < p_b$: Relative Permeability

- Corey exponents and endpoints
- **S_{gc} has largest effect**
- Suppressed bubble point causes similar effect



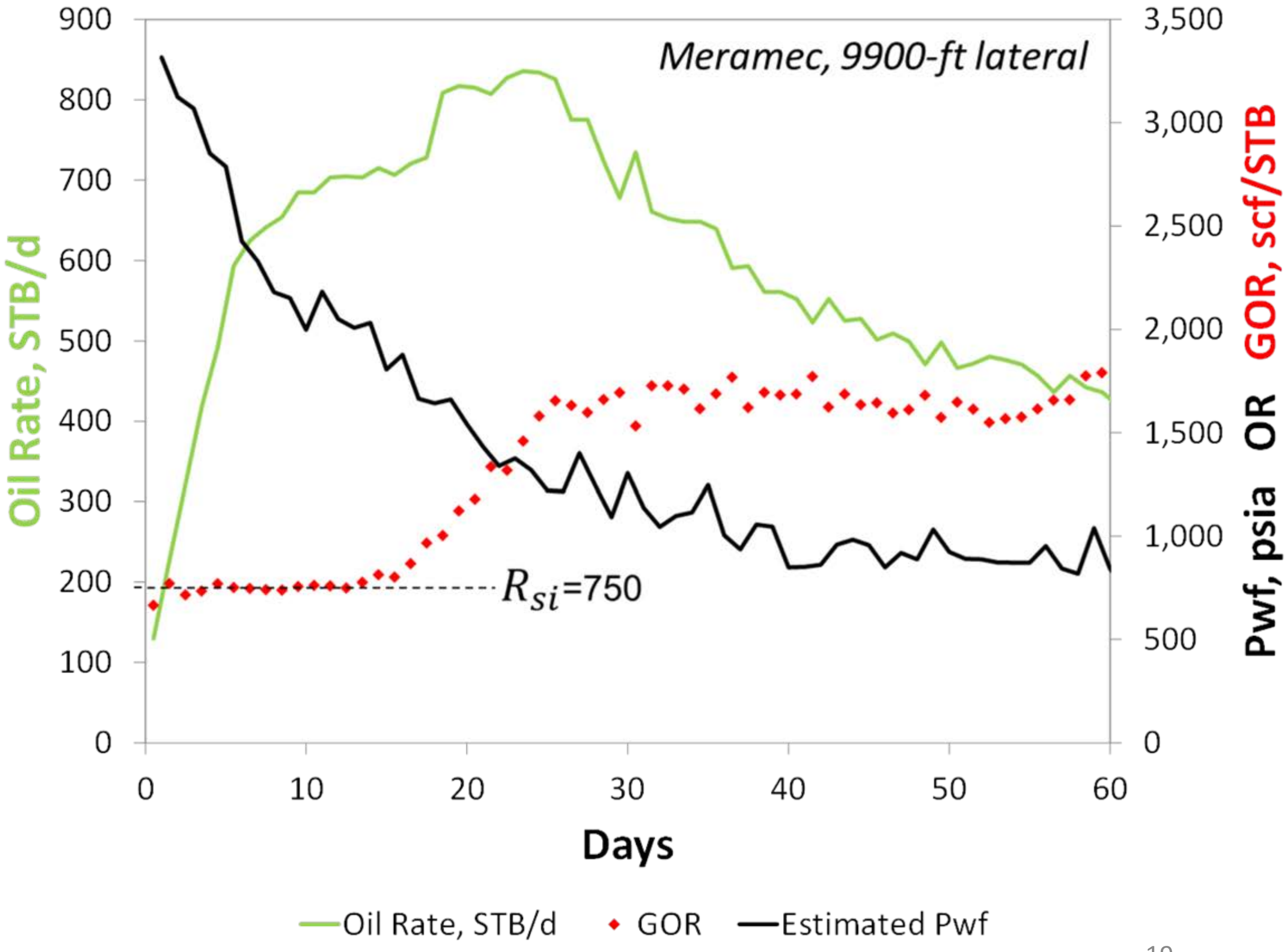
Four Stages

1. GOR = R_{si}
2. Rise due to $p_{wf} < p_b$
3. Transient plateau during constant p_{wf}



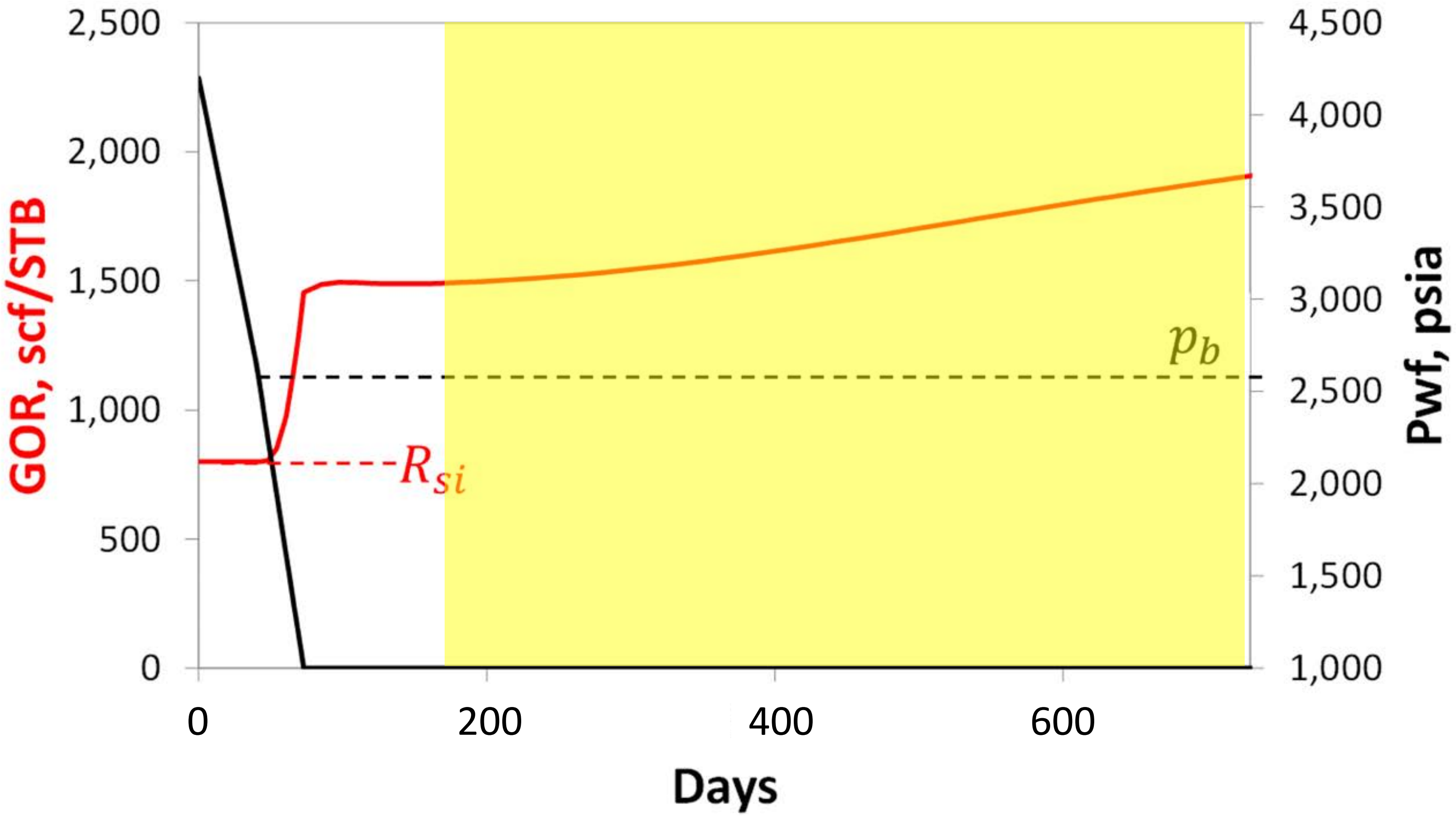
Transient GOR Plateau

- Requires constant p_{wf}
- Result of constant average pressure and saturations in distance of investigation (DOI)

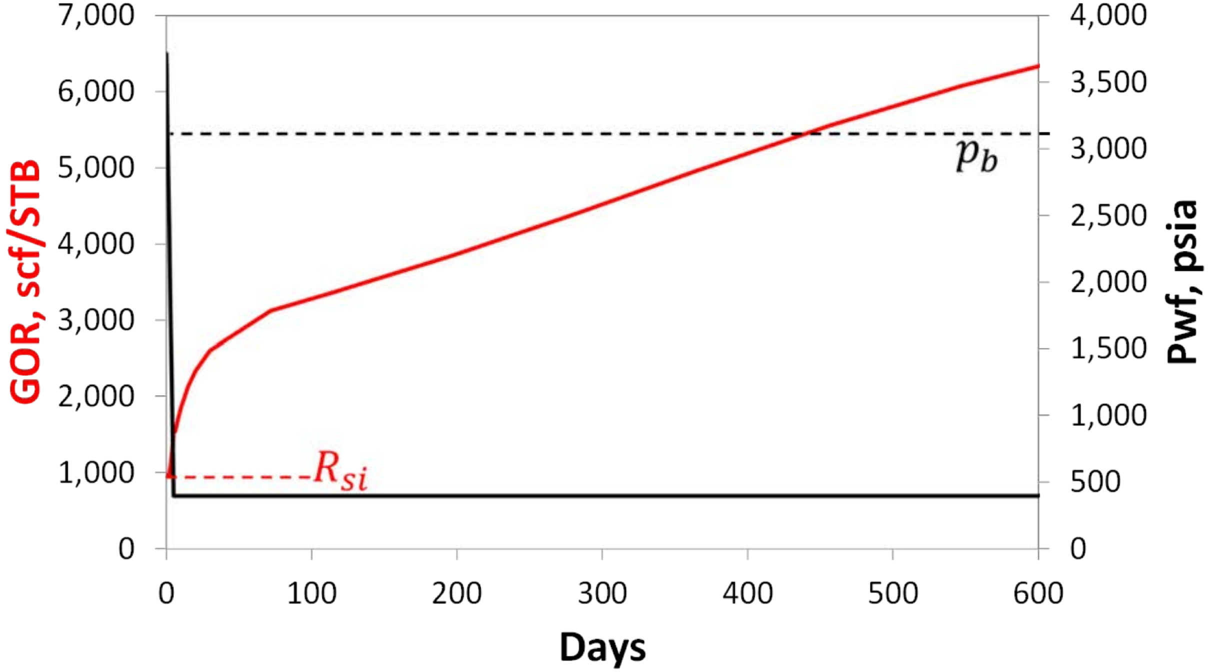


Four Stages

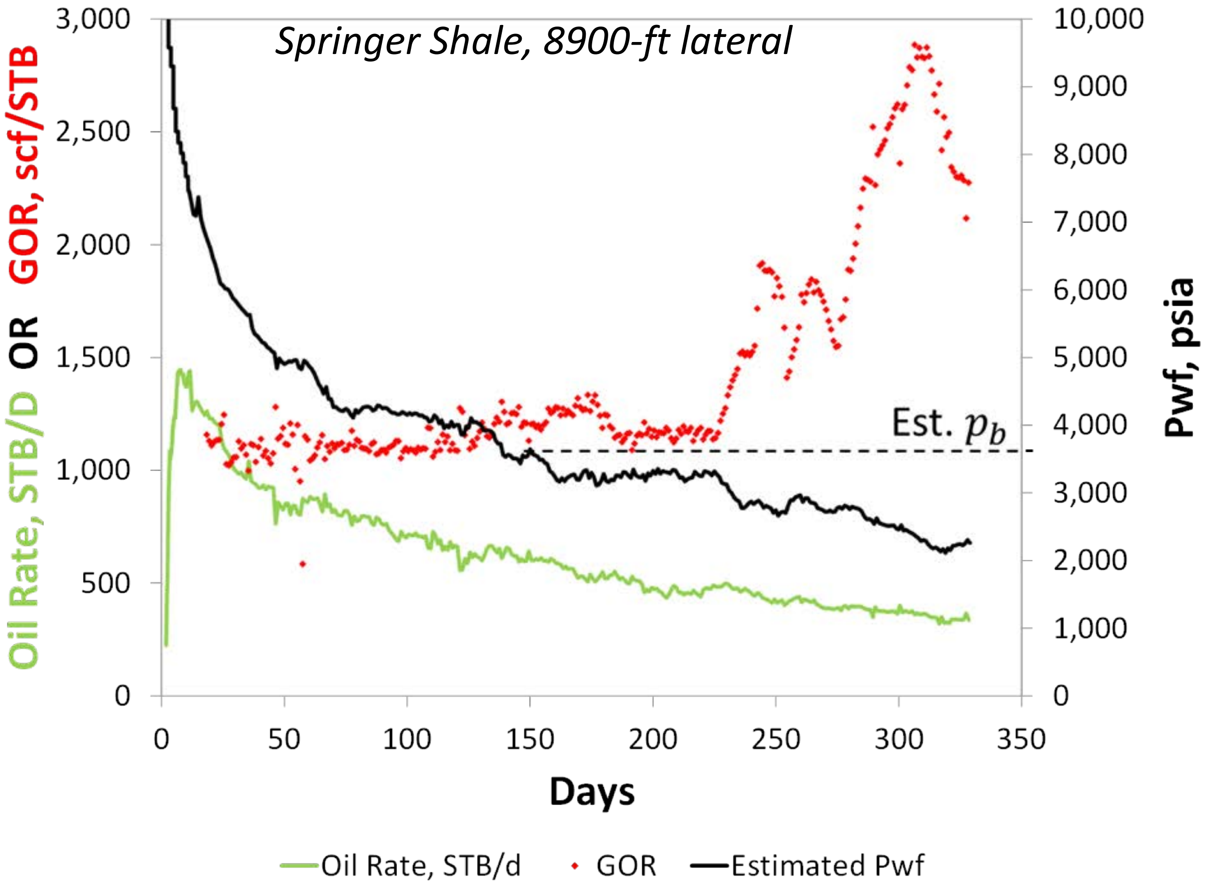
1. GOR = R_{si}
2. Rise due to $p_{wf} < p_b$
3. Transient plateau
4. Rise during BDF



Variations



- p_b very near p_i
- BDF begins early



- $p_{wf} > p_b$ for a long time
- BDF begins prior to $p_{wf} < p_b$

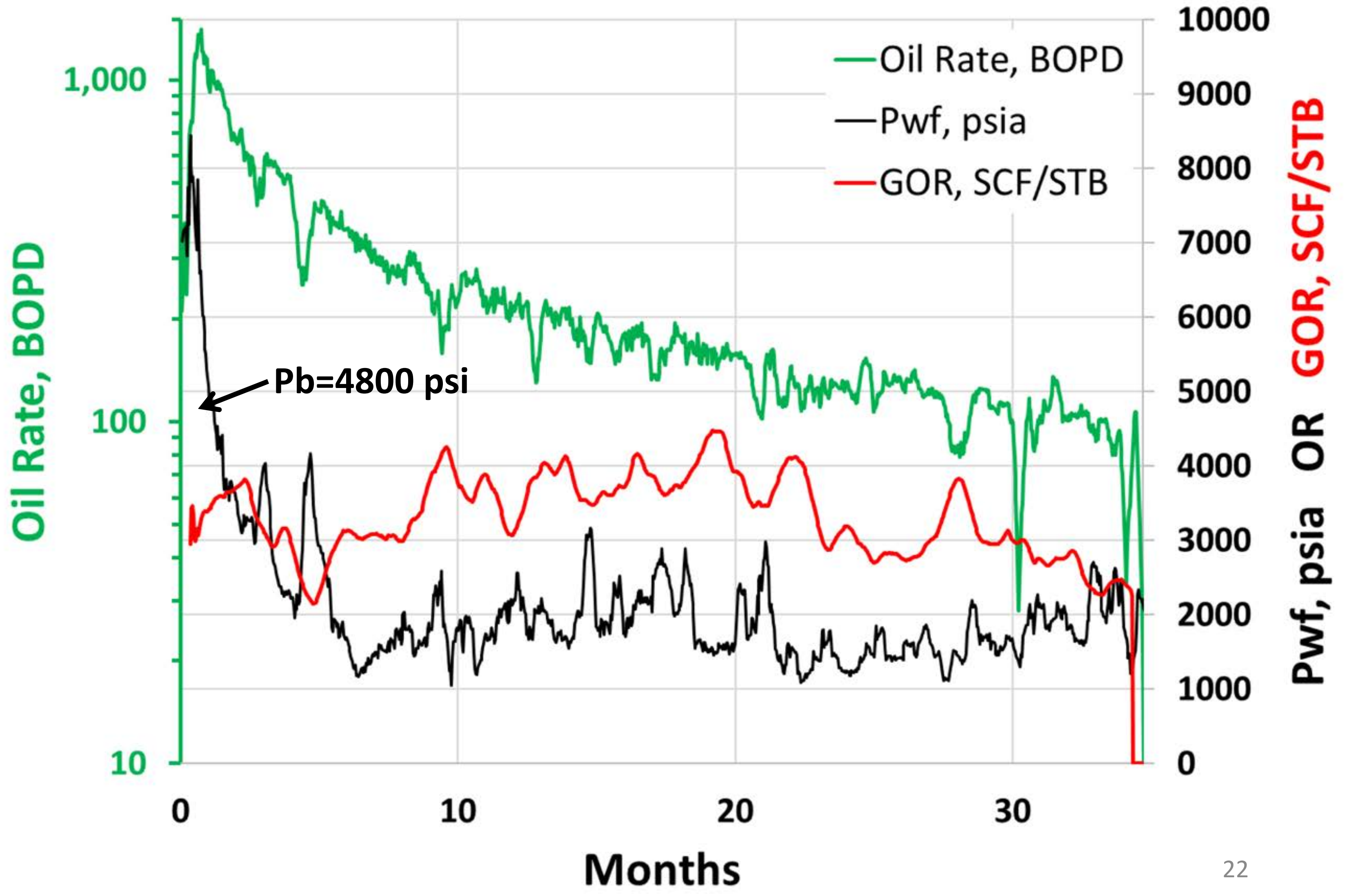
Difficult to Explain

- ***GOR constant while Pwf is well below Pb***

- Bubble point known from PVT
- High Sgc?
- Low frac conductivity?

- Depressed Pb due to "nanopore proximity" effects?

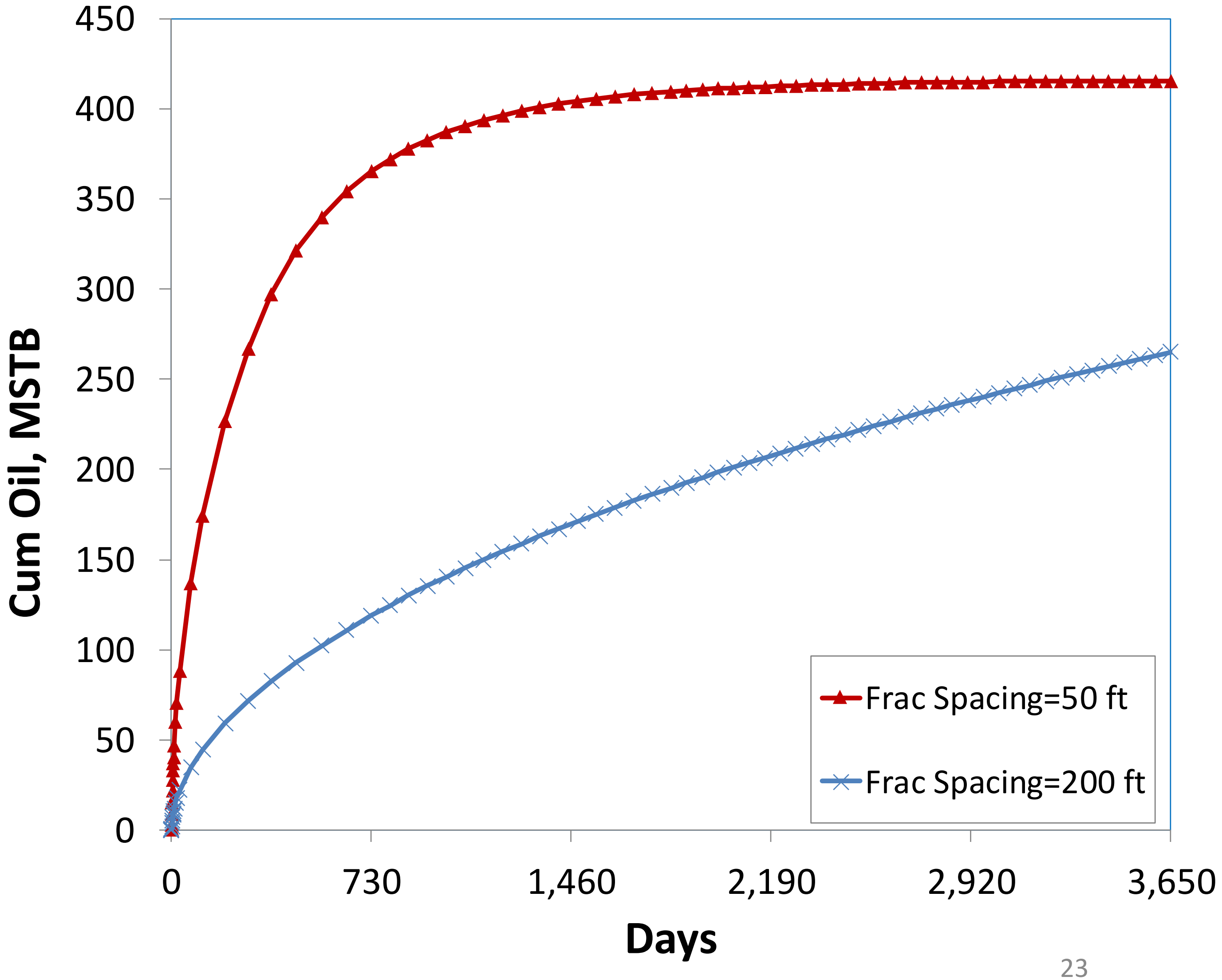
- Not linear flow due to natural fractures?



GOR Rise during BDF

Frac Spacing

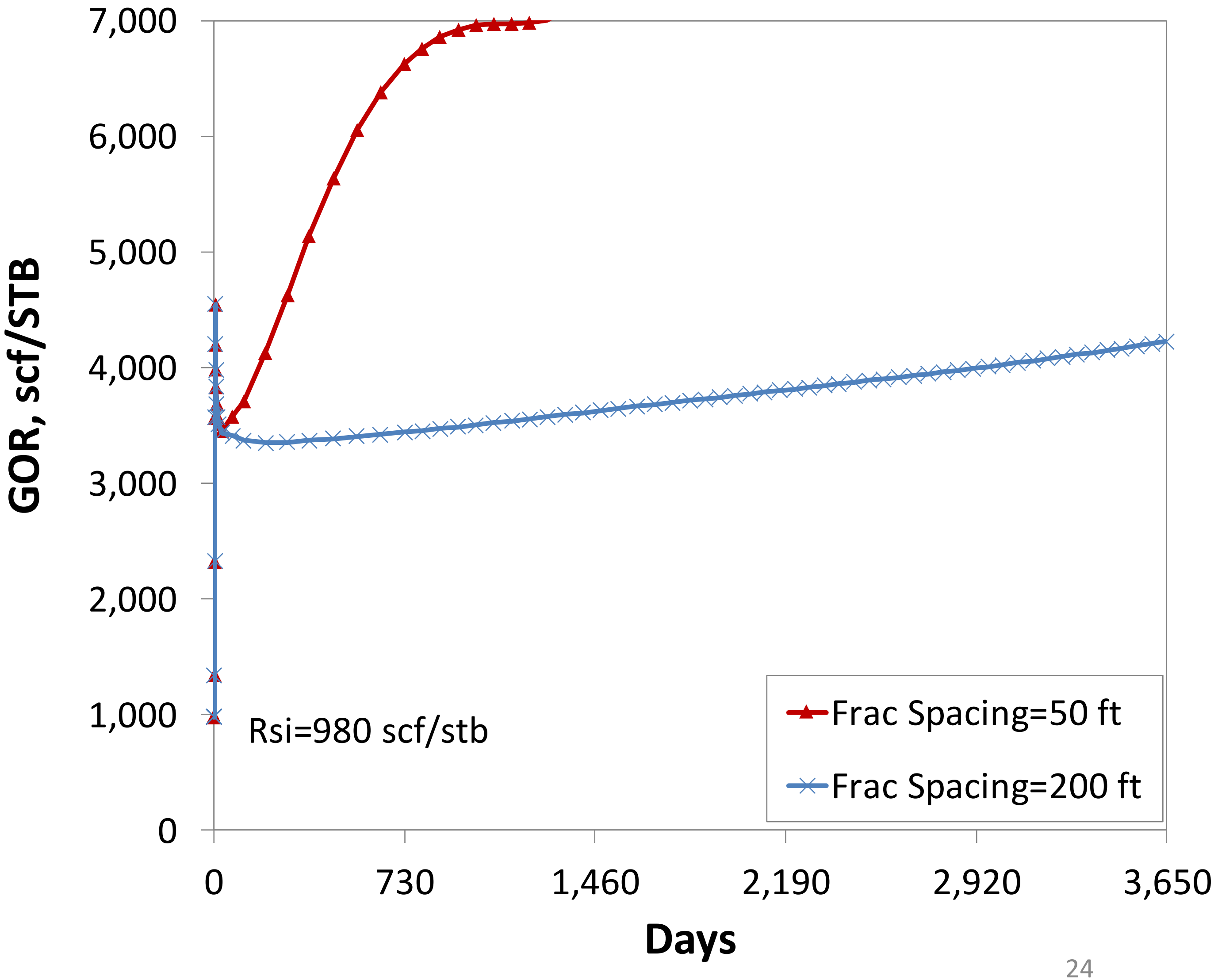
- Cum oil for 10,000 ft lateral
- 200 fracs for 50-ft spacing
- 25 fracs for 400-ft spacing
- Same p_{wf} schedule



k=300 nd

GOR Rise during BDF

- Closest frac spacing has quickest GOR rise
- Rate of GOR rise depends on **efficiency of access to drainage volume**

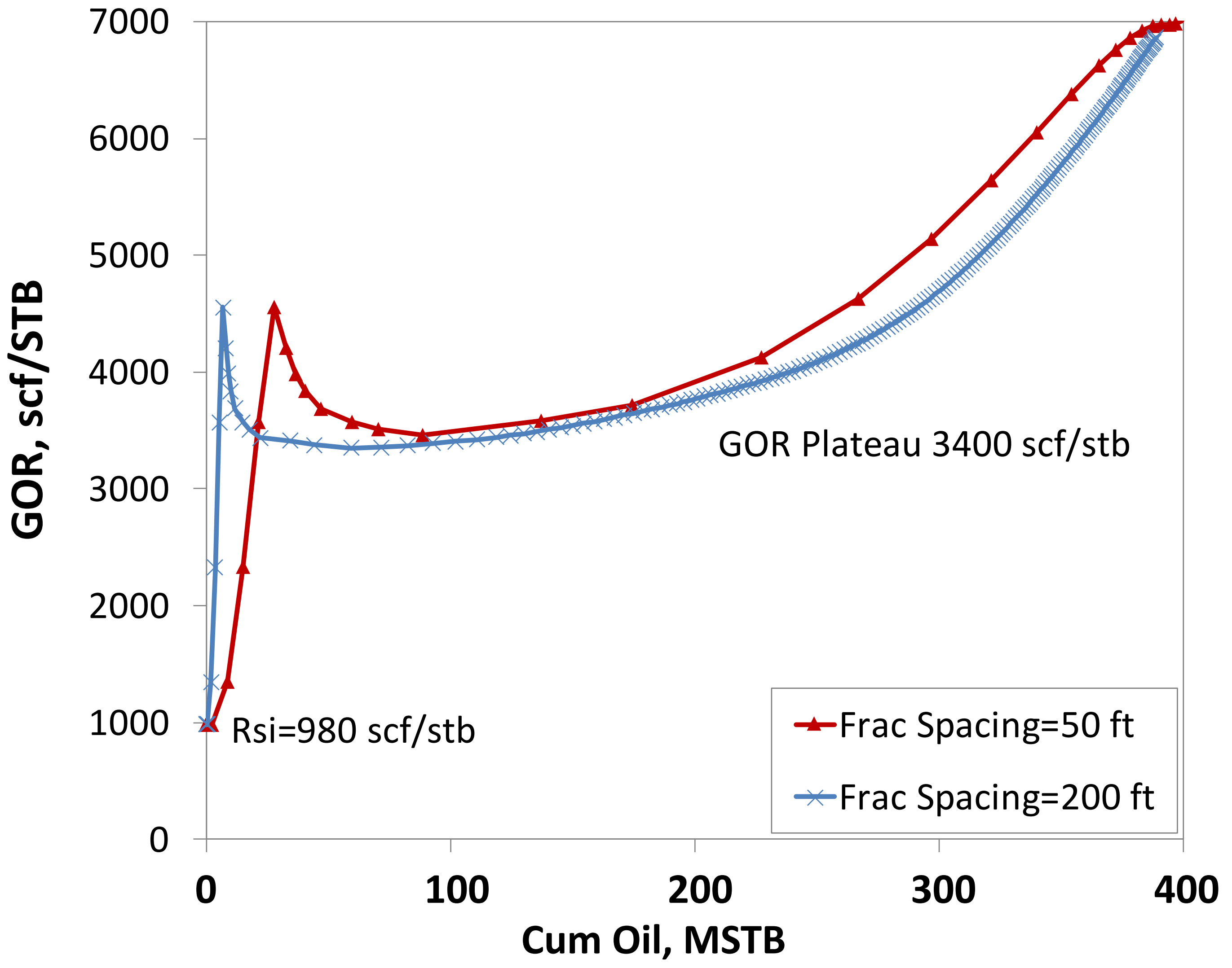


k=300 nd

GOR Rise during BDF

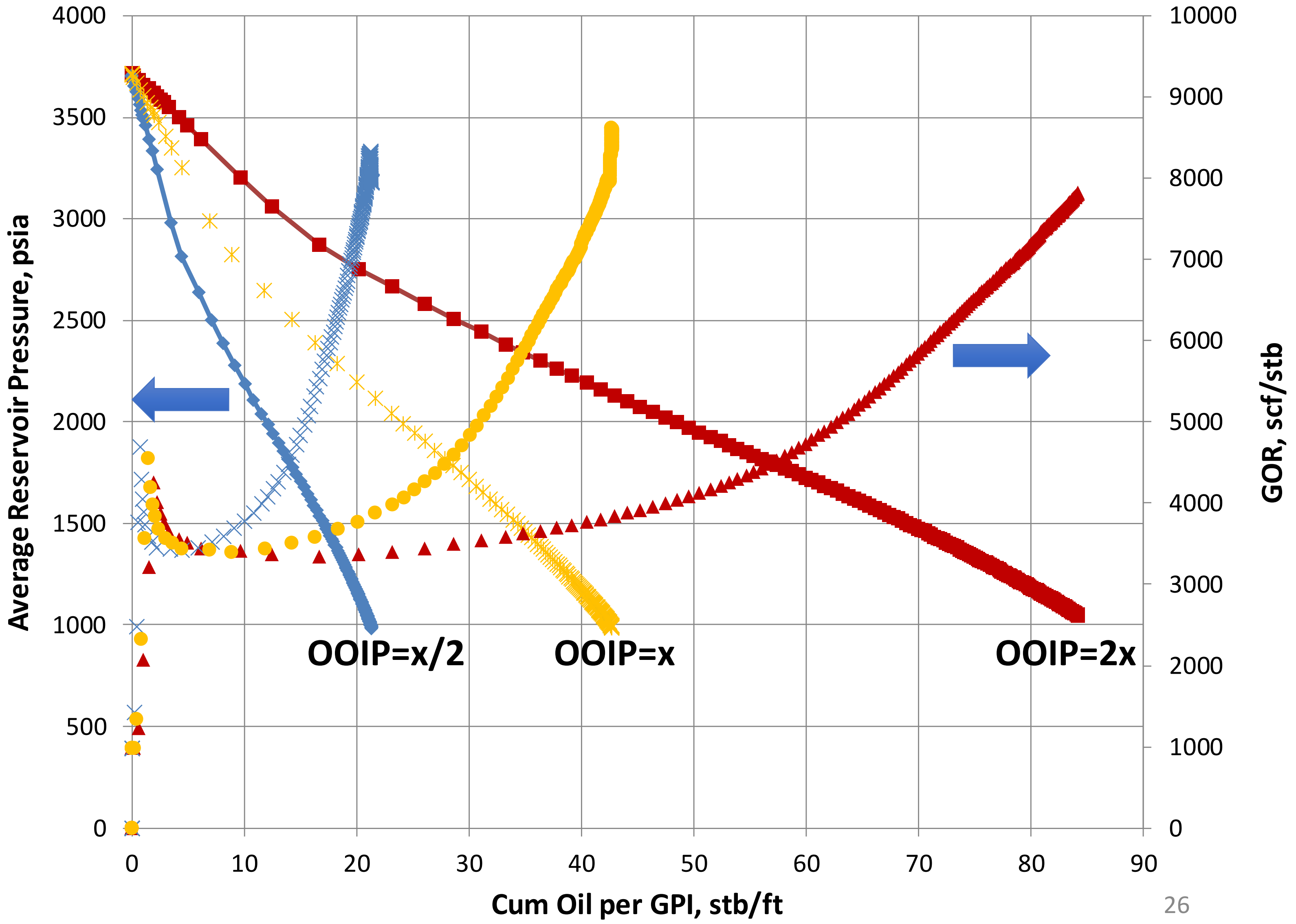
- **Plot GOR vs. cum oil**
- Same OOIP

k = 300 nd

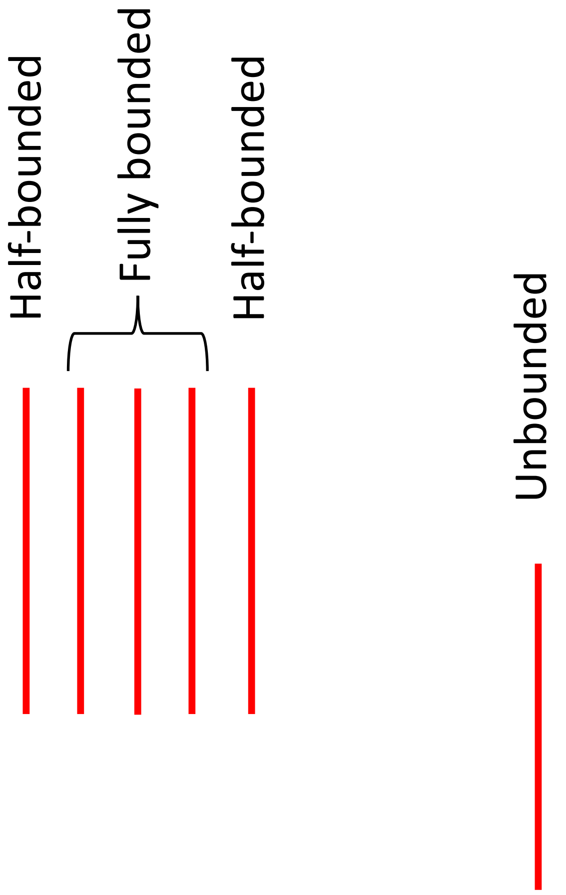


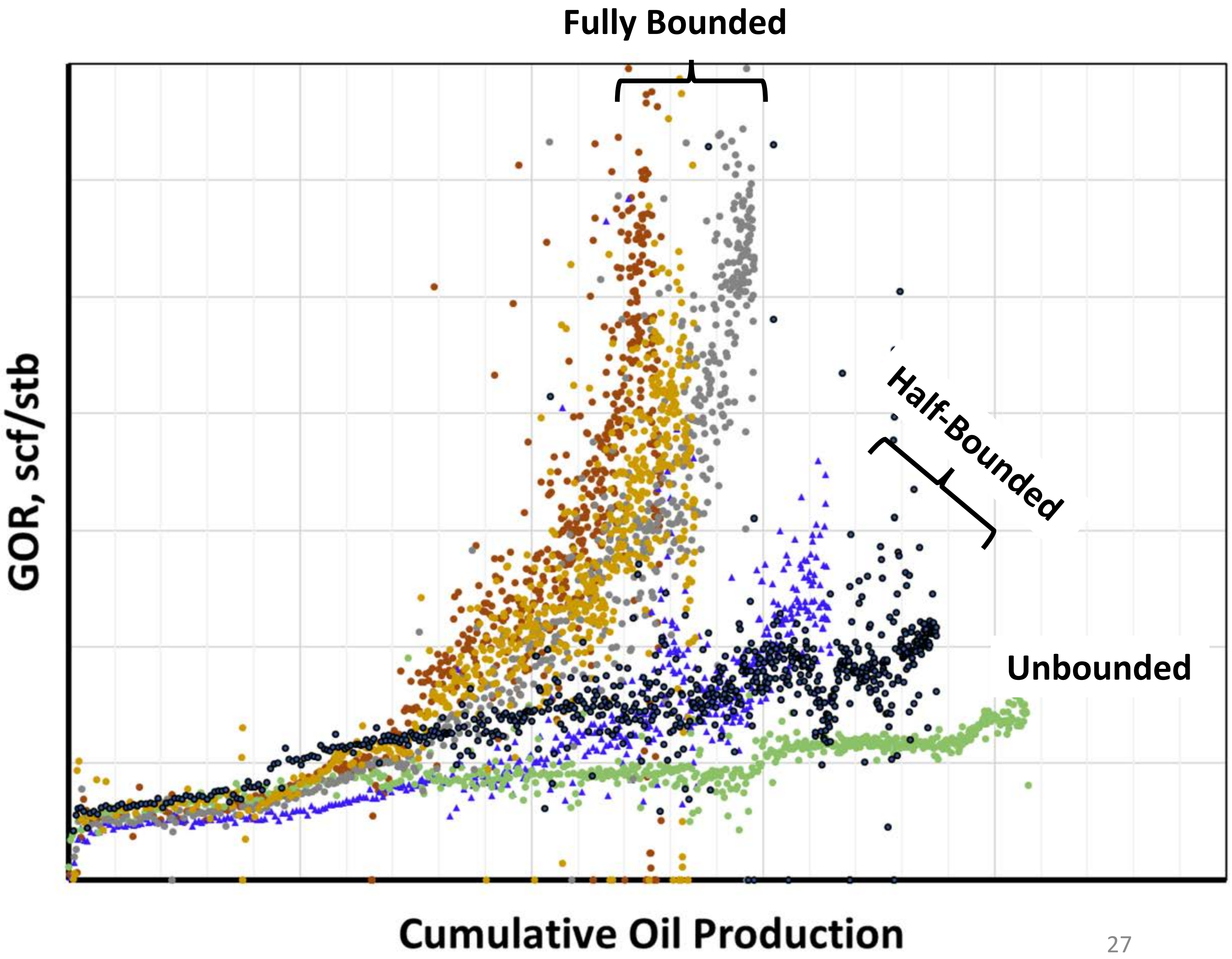
GOR rise in BDF correlates with OOIP

- Three model cases varying only OOIP
- **For same PVT, Pi, rel perms, and pwf schedule**
- GOR is indicator of p_r and therefore OOIP



Effect of Drainage Volume





Conclusions

- GOR depends strongly on p_{wf}
- Four idealized stages of GOR history
- Several factors cause deviation
- Identify R_{si} and flow regime (transient or BDF) to interpret history
- GOR in BDF is function of cumulative oil production
- GOR rises at cum oil proportional to drainage volume
- SPE 184397

Questions ?

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