Producing Gas-Oil Ratio Behavior of Multi-Fractured Horizontal Wells in Tight Oil Reservoirs

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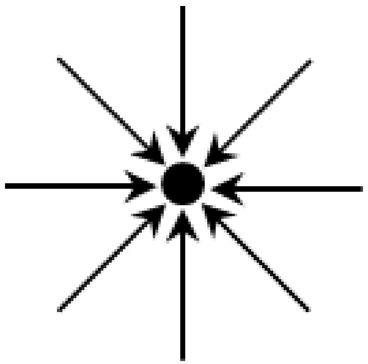
Overview

- SPE 184397 (Newfield)
- Framework for understanding GOR performance in unconventional black-oil solution gas-drive reservoirs
- Linear vs radial flow
- Four stages of GOR history
- Factors that affect GOR
- Practical observations and tools

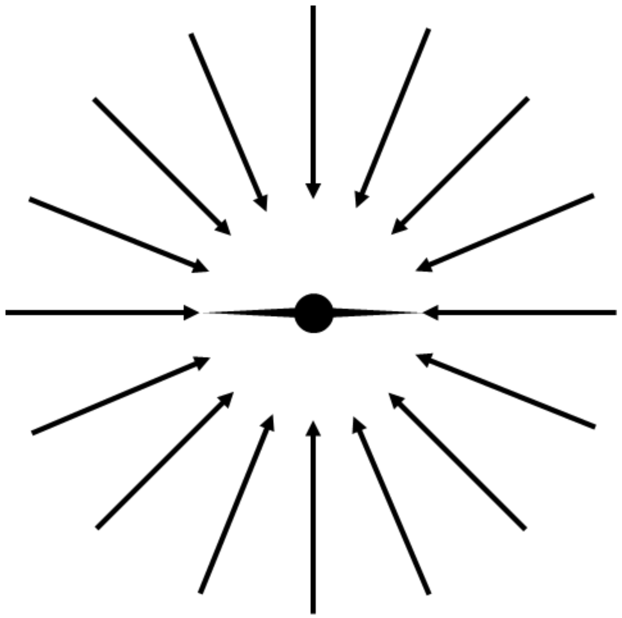
Conventional Reservoir

- “High” k (md)
- Vertical well
- Radial or psuedo-radial flow
- Pseudo-steady-state flow (BDF)

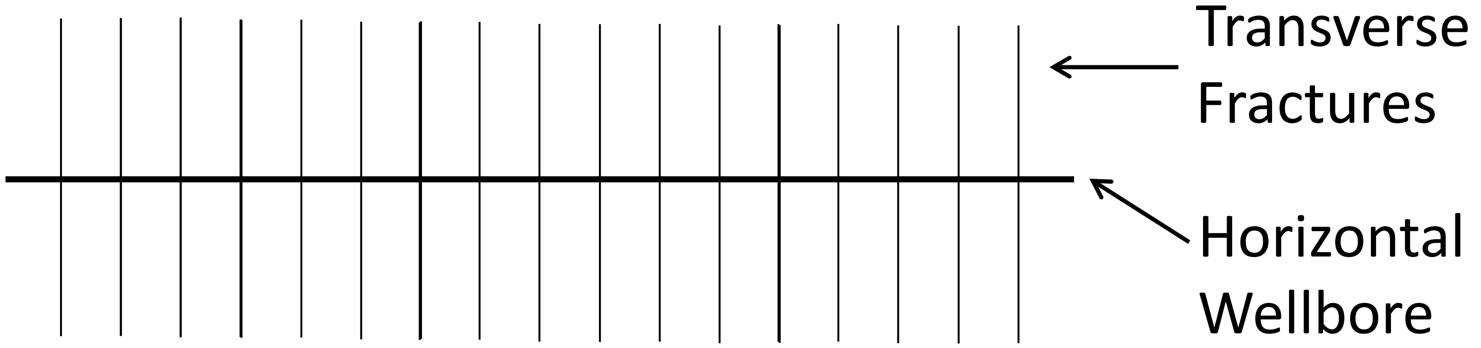
Radial

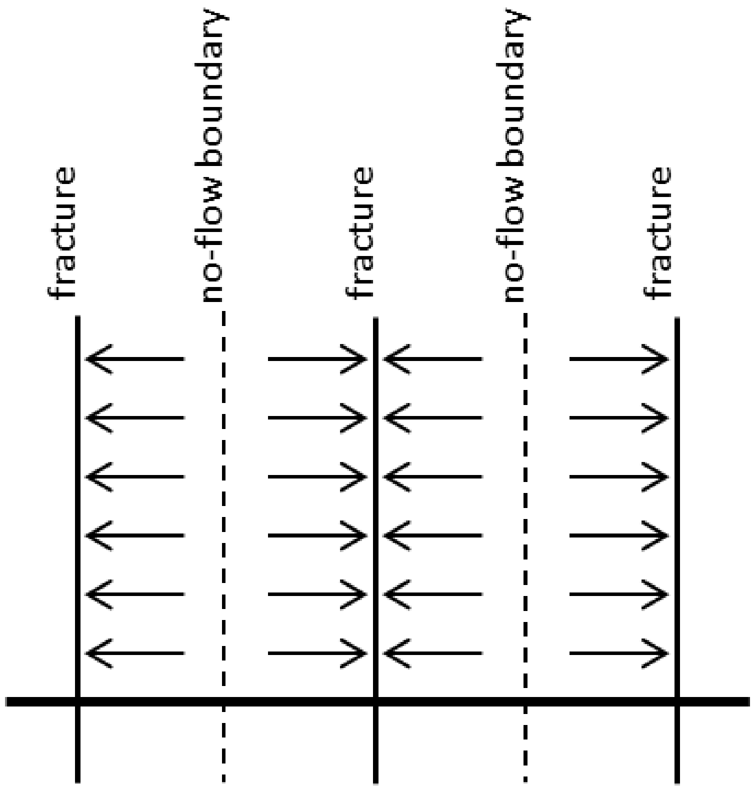


Pseudo-Radial



Unconventional Reservoir

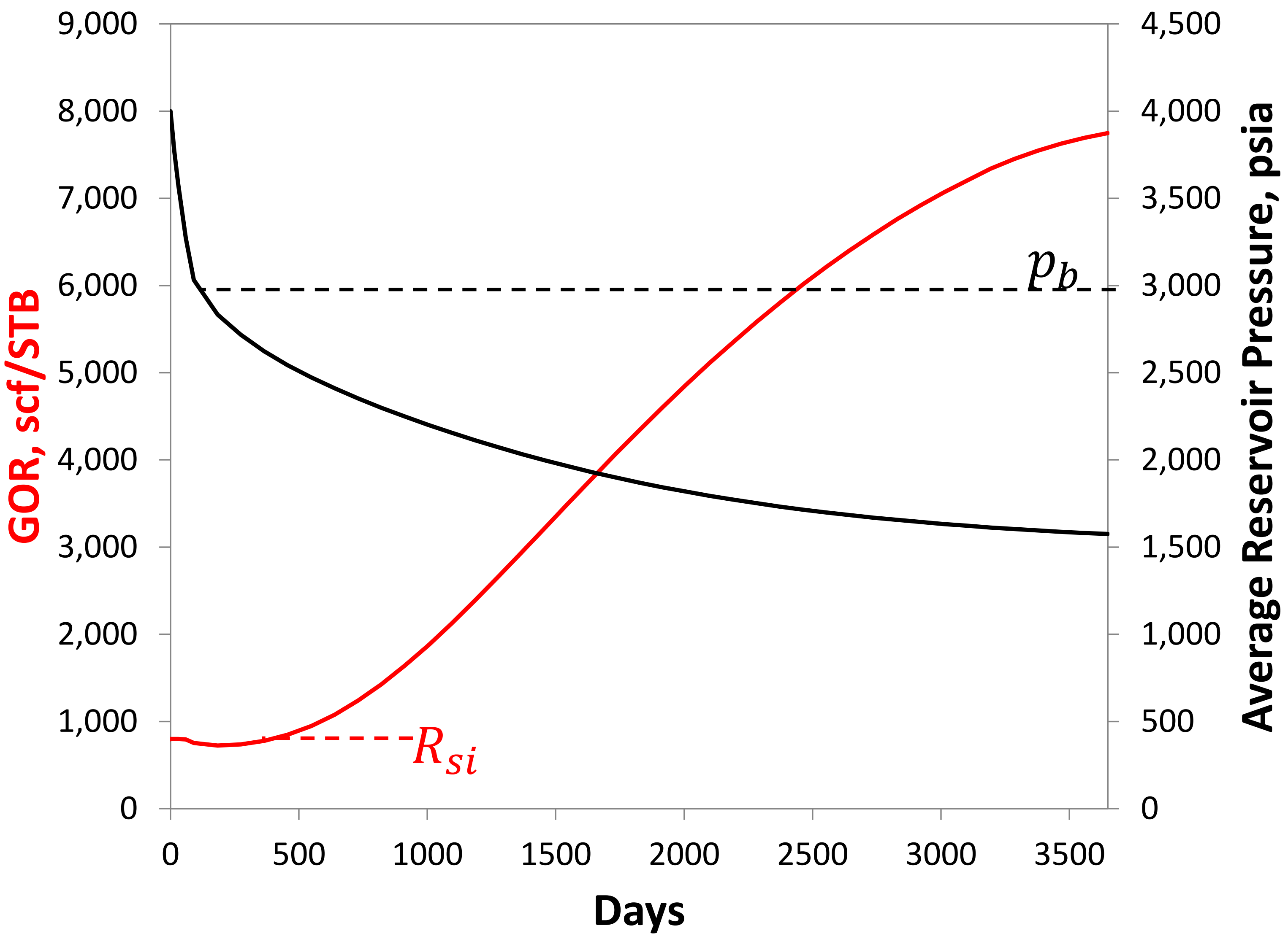




- Low k
- Linear Flow
- No flow from beyond frac tips
- Transient period can be long

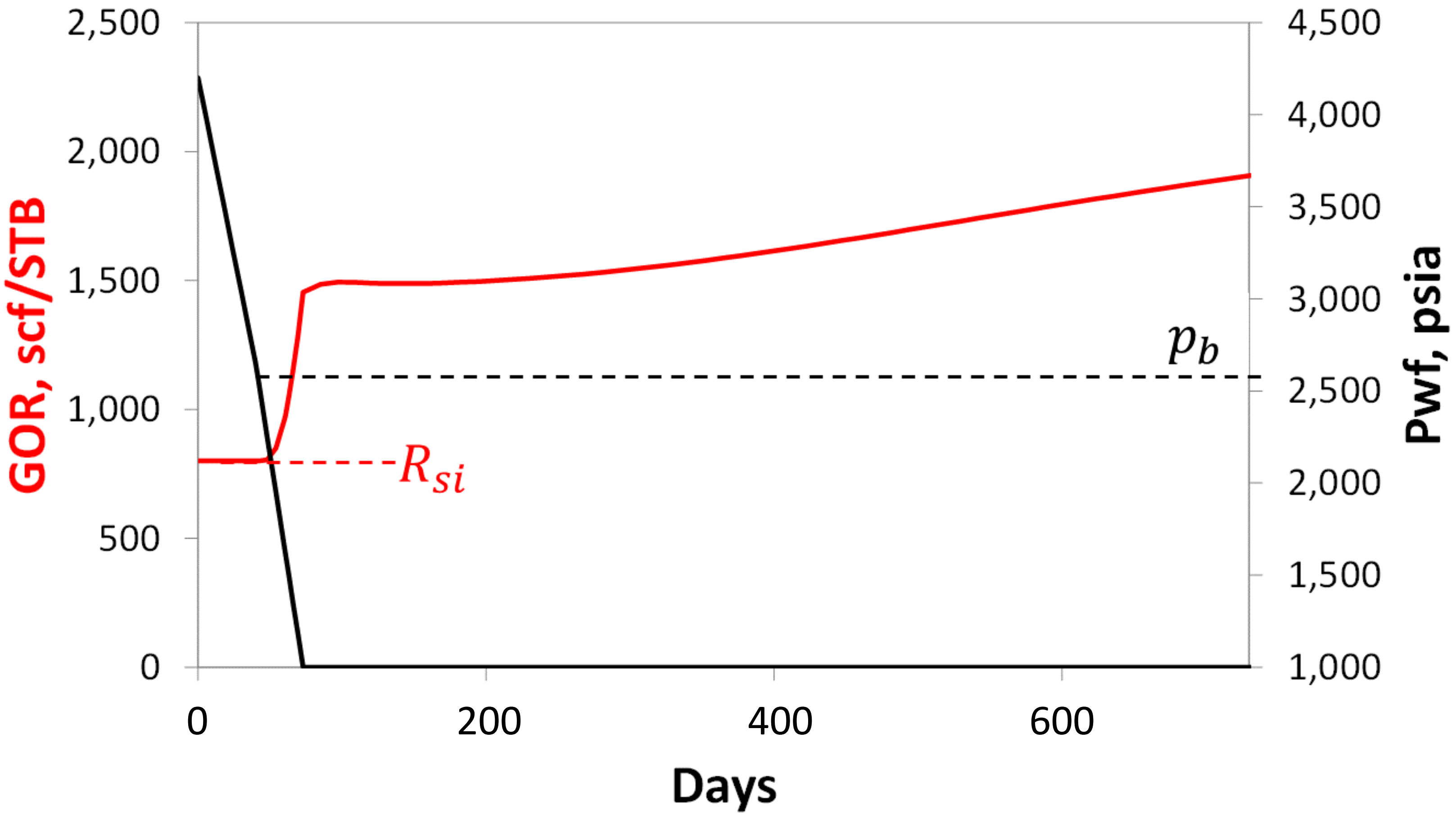
Conventional GOR History

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

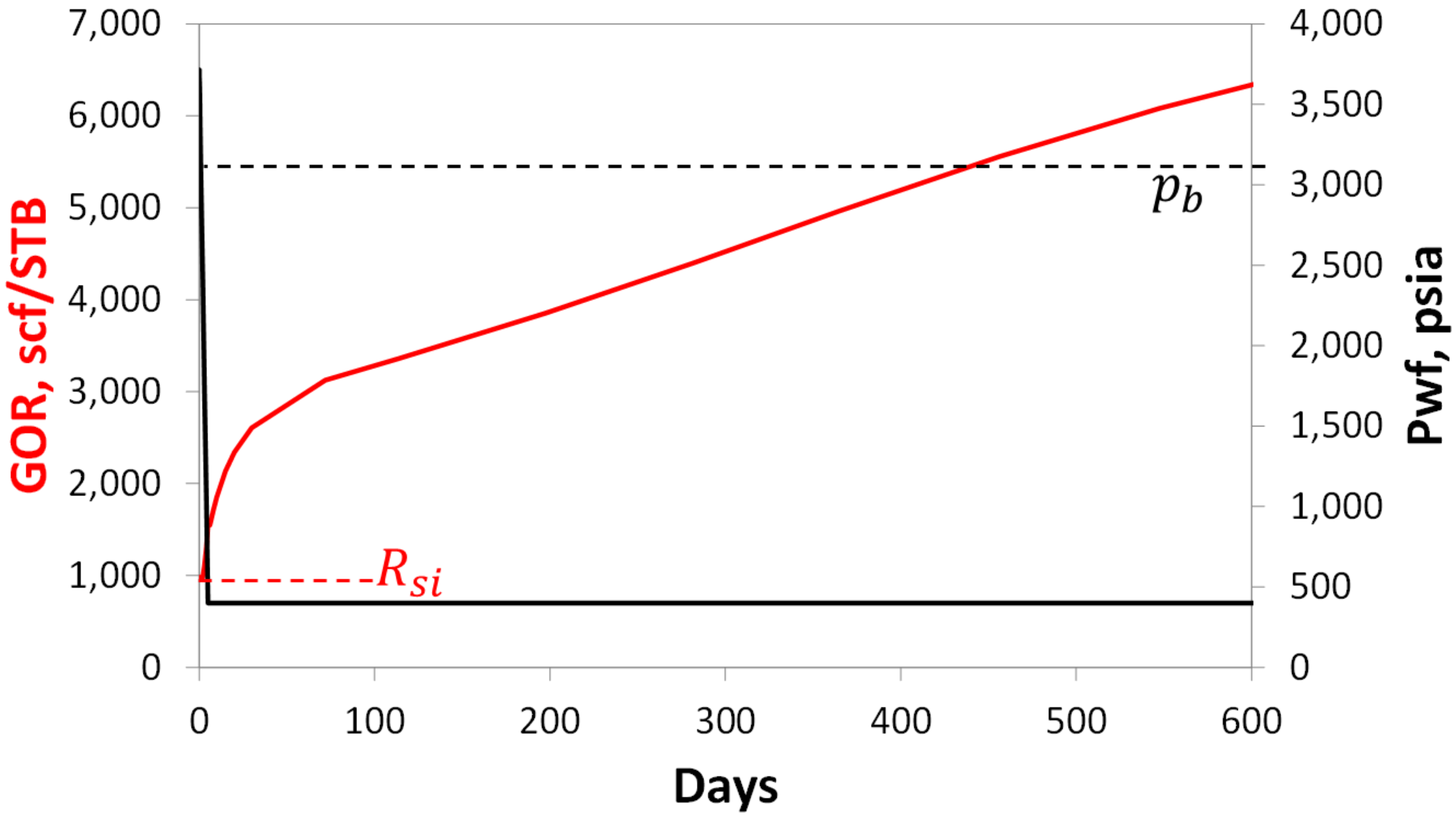


Unconventional GOR

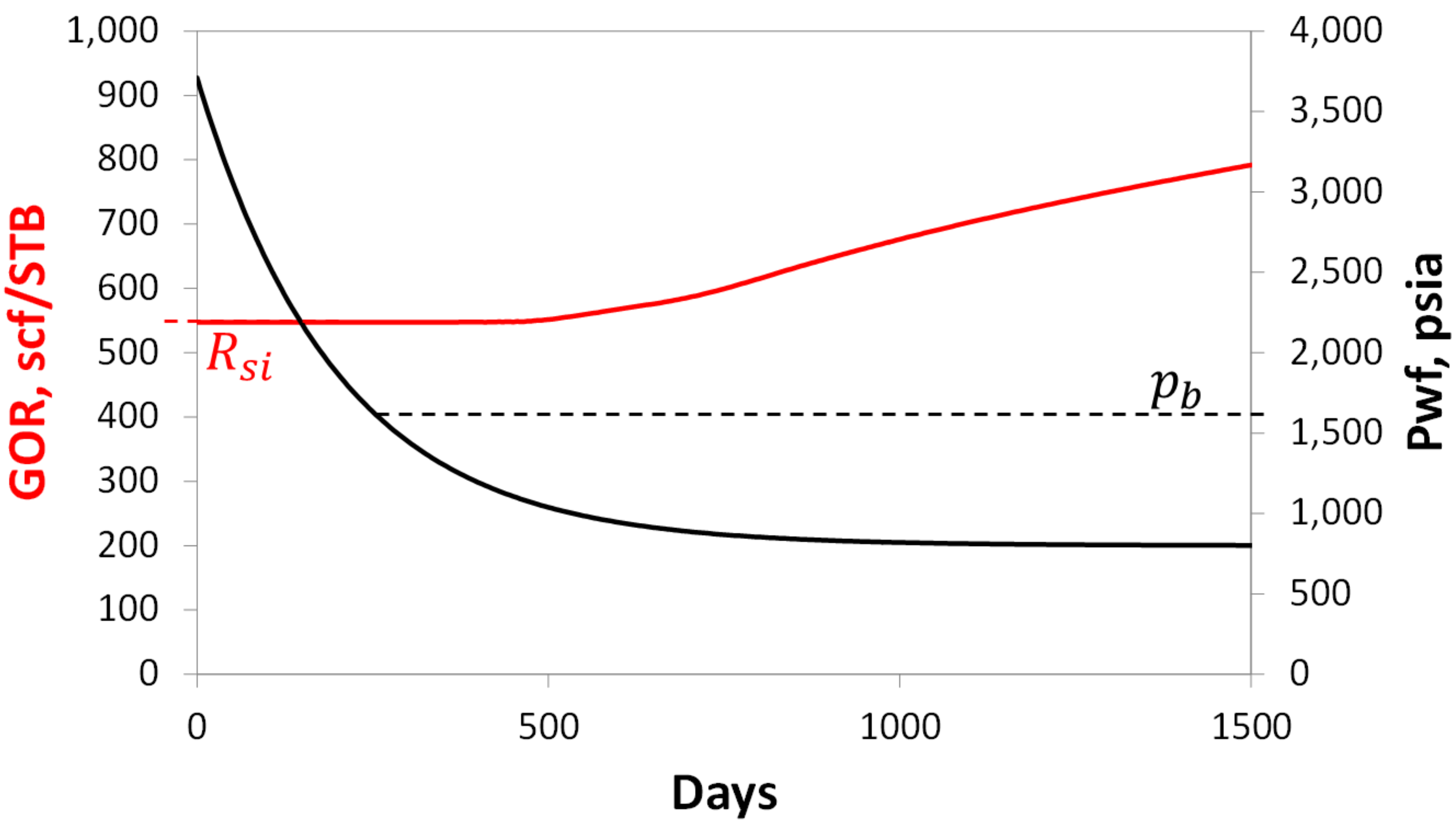
- Low k (nd)
- Horizontal well
- Multiple hydraulic fractures
- ***p_{wf}* strongly influences GOR**



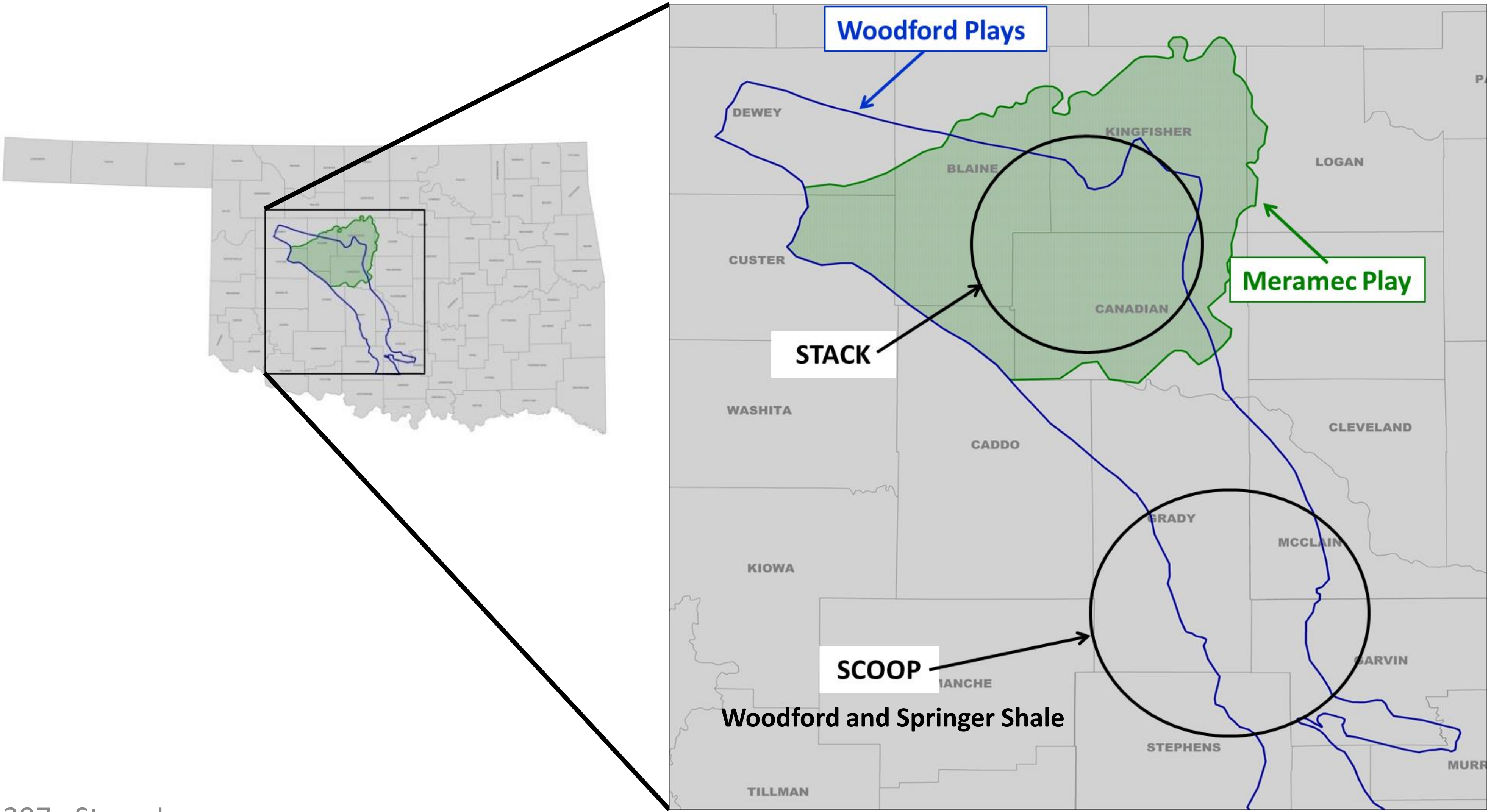
Unconventional GOR



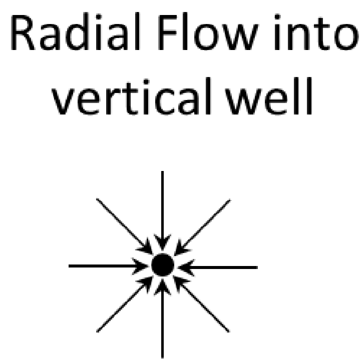
Unconventional GOR

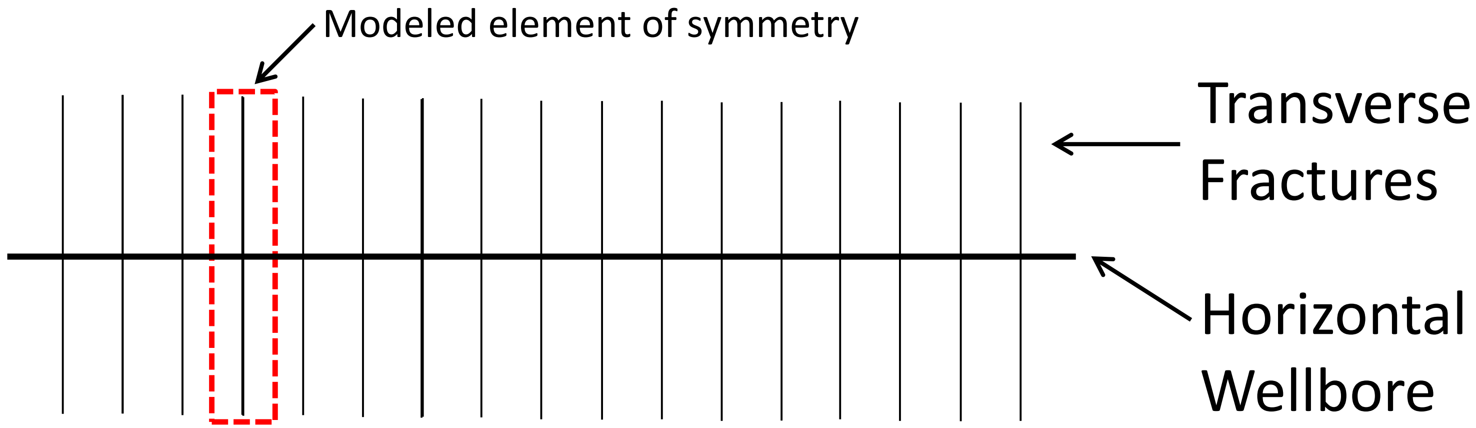


Field Examples



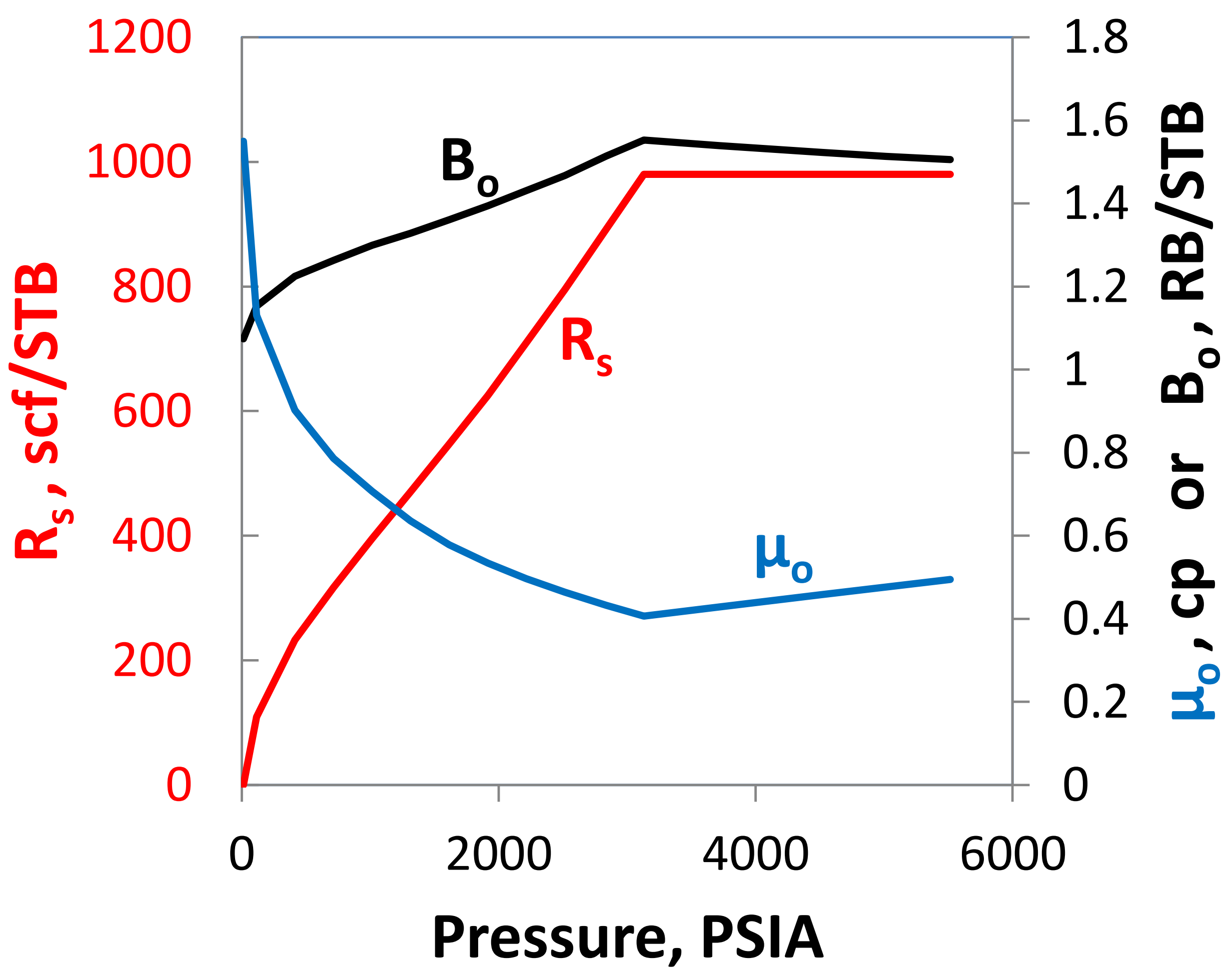
Simulation Models





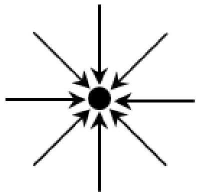
Model Parameters

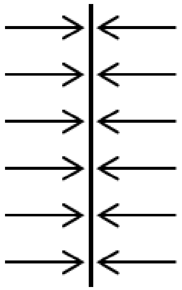
Initial pressure, Pi	3716	psia
Bubble Point pressure, Pb	3131	psia
API gravity	40	API
Tr	179	F
Rsi	980	scf/STB
Permeability, unless specified	200	nd
Swi	0	fraction
Soi	1	fraction
Sorg	0.4	fraction
Sgc	0.02	fraction
Corey oil exponent	2	
Corey gas exponent	2	
krg at max Sg	0.7	fraction
kro at max So	1	fraction
thickness, h	150	ft
Oil-filled porosity	0.03	fraction
xf, unless specified	325	ft

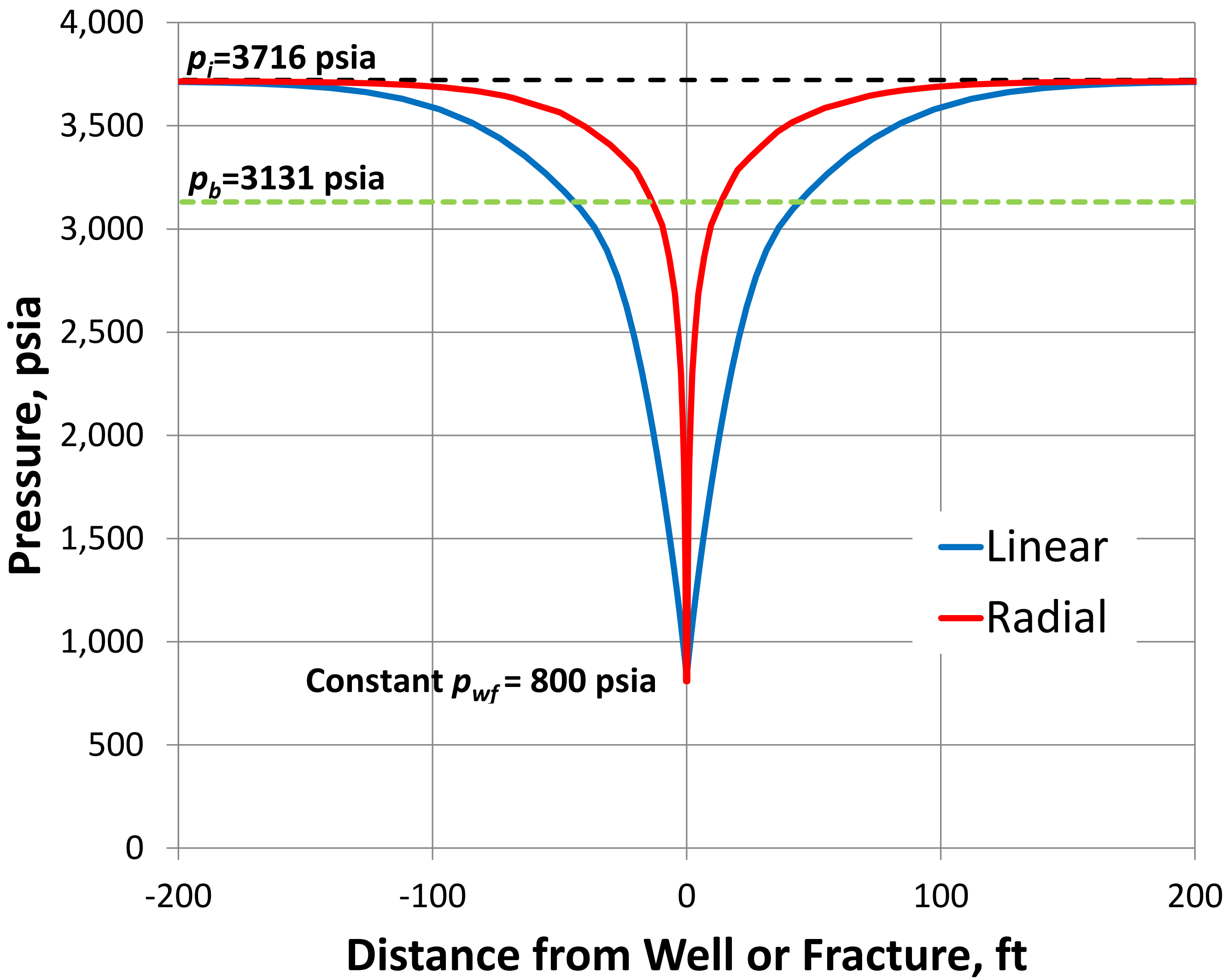


Linear vs. Radial Flow

- k=200 nd
- t=365 days, transient flow
- $p_{wf} < p_b$; 2-phase flow
- **Fundamentally different pressure profiles**

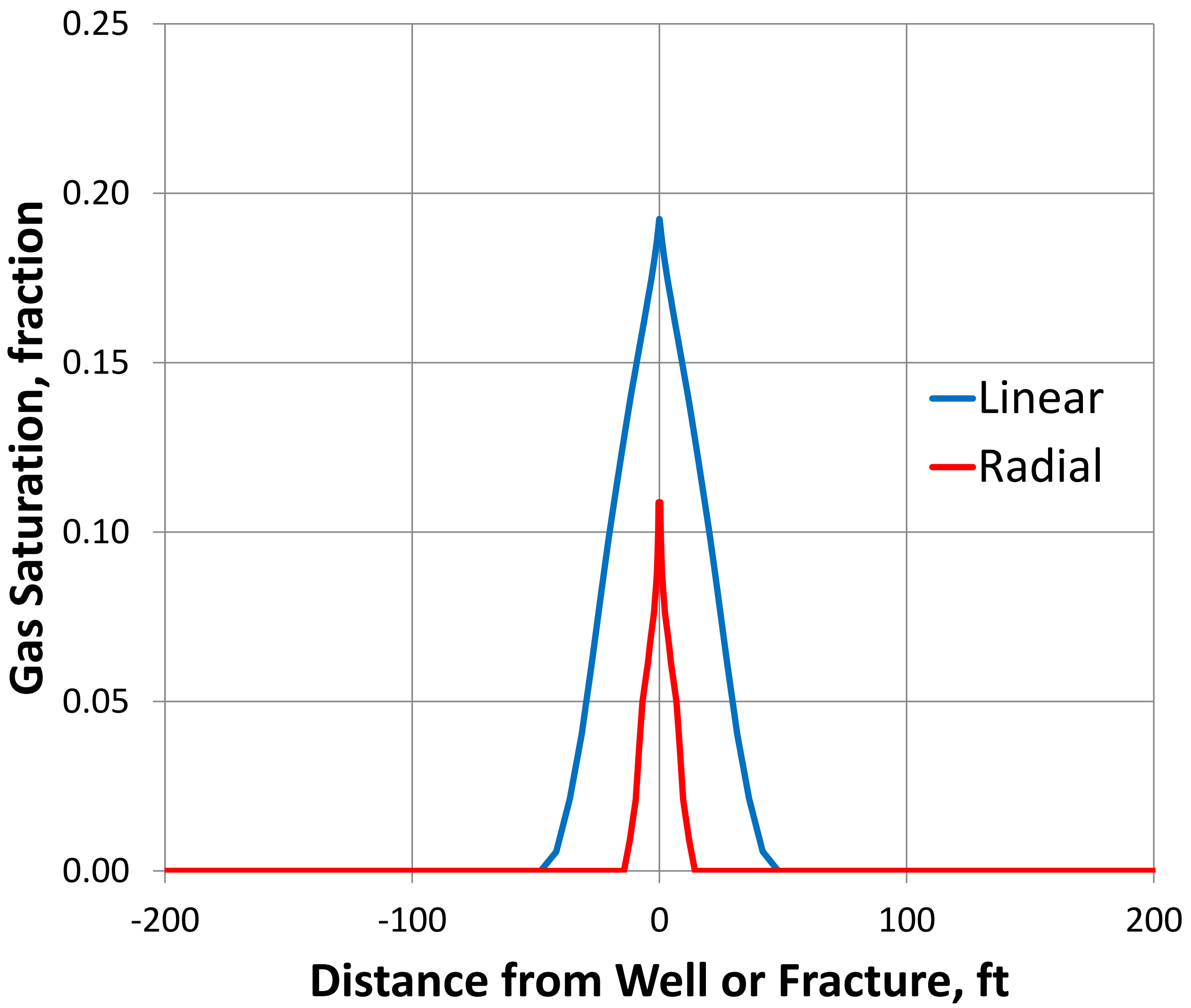






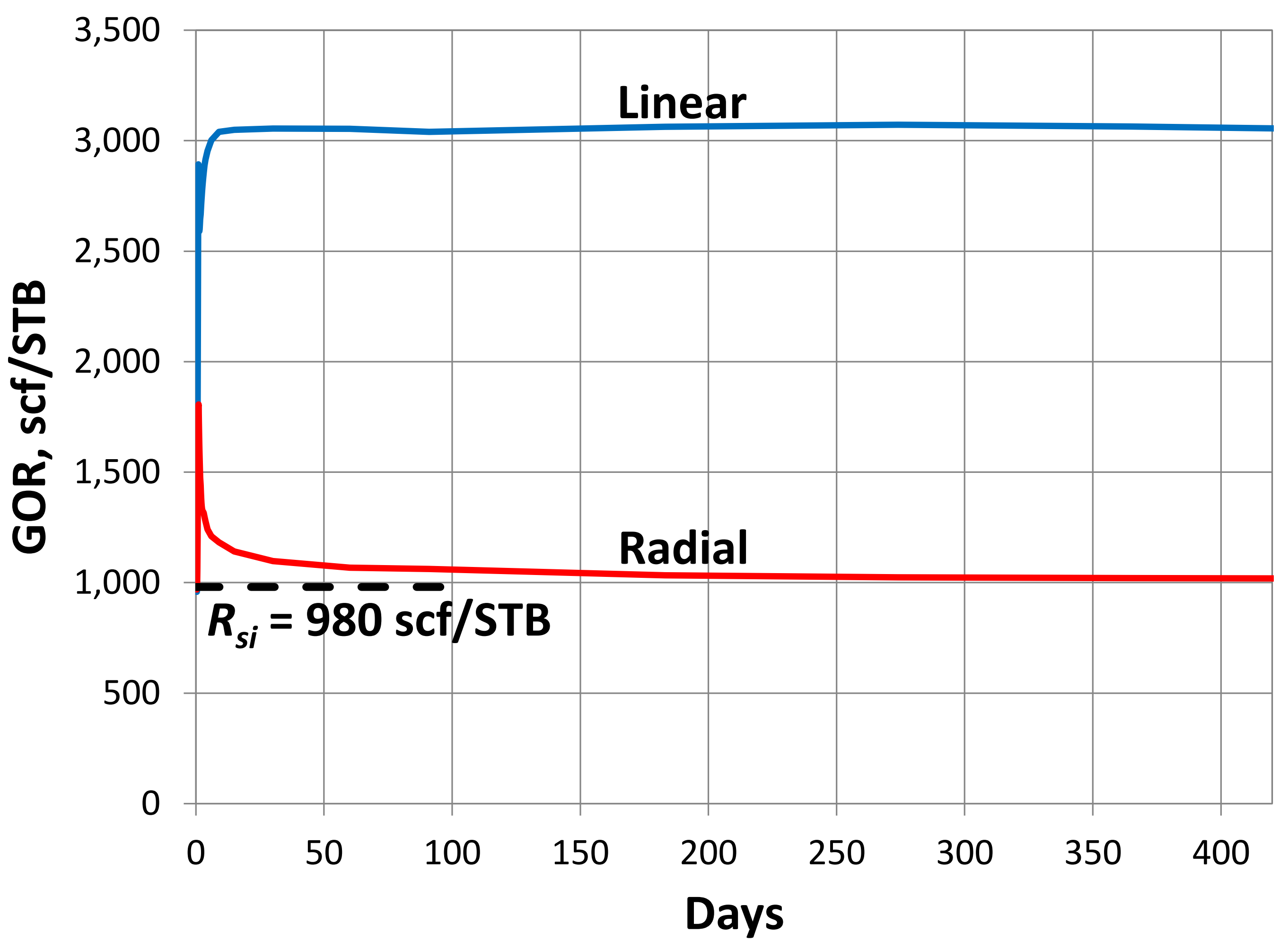
Linear vs. Radial Flow

- S_g profile, t=365 days
- Larger area of gas saturation for linear flow
- S_g at fracture is higher than at vertical well
- **Flowing GOR higher for linear than radial flow**

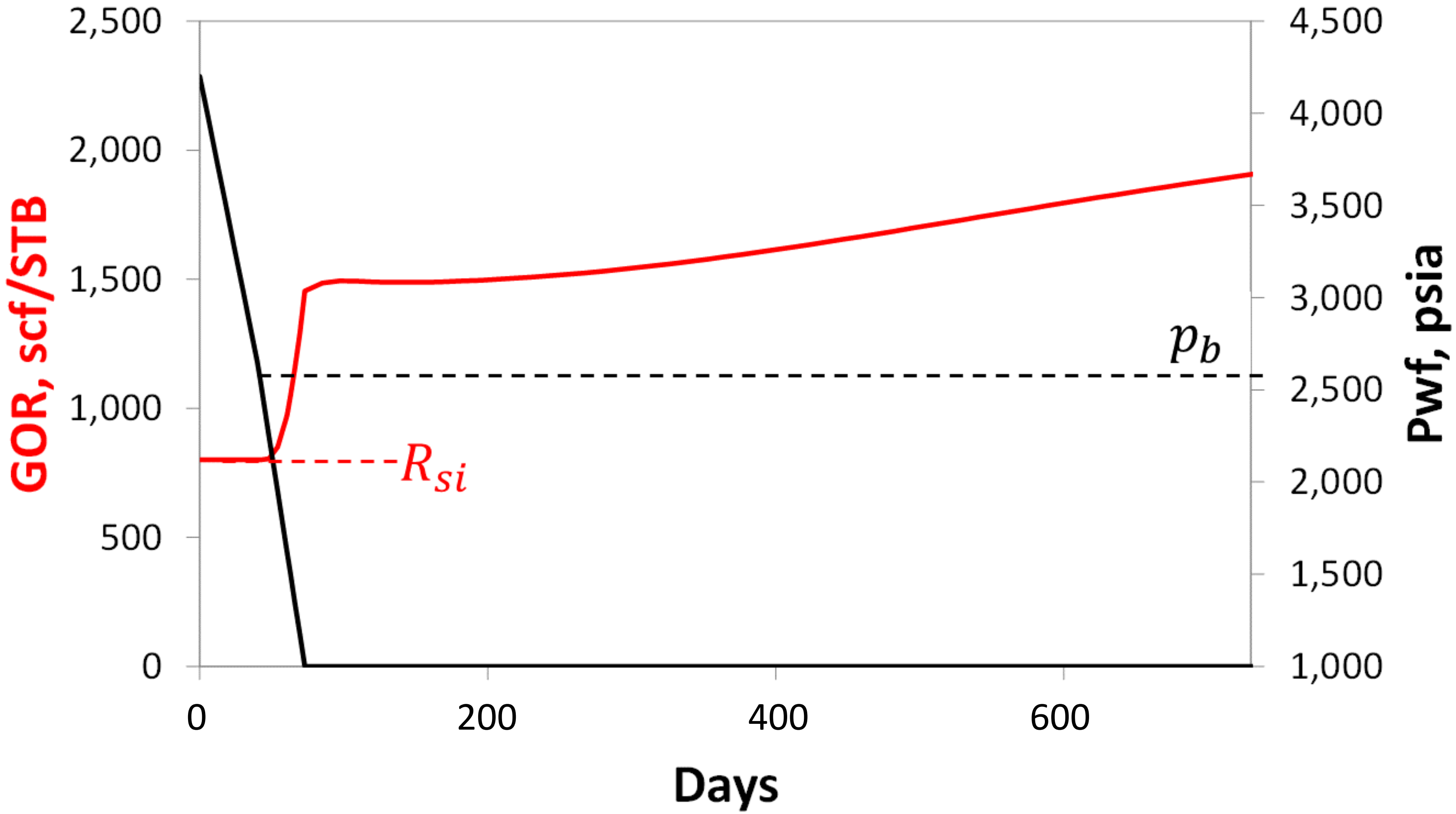


Linear vs. Radial Flow

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

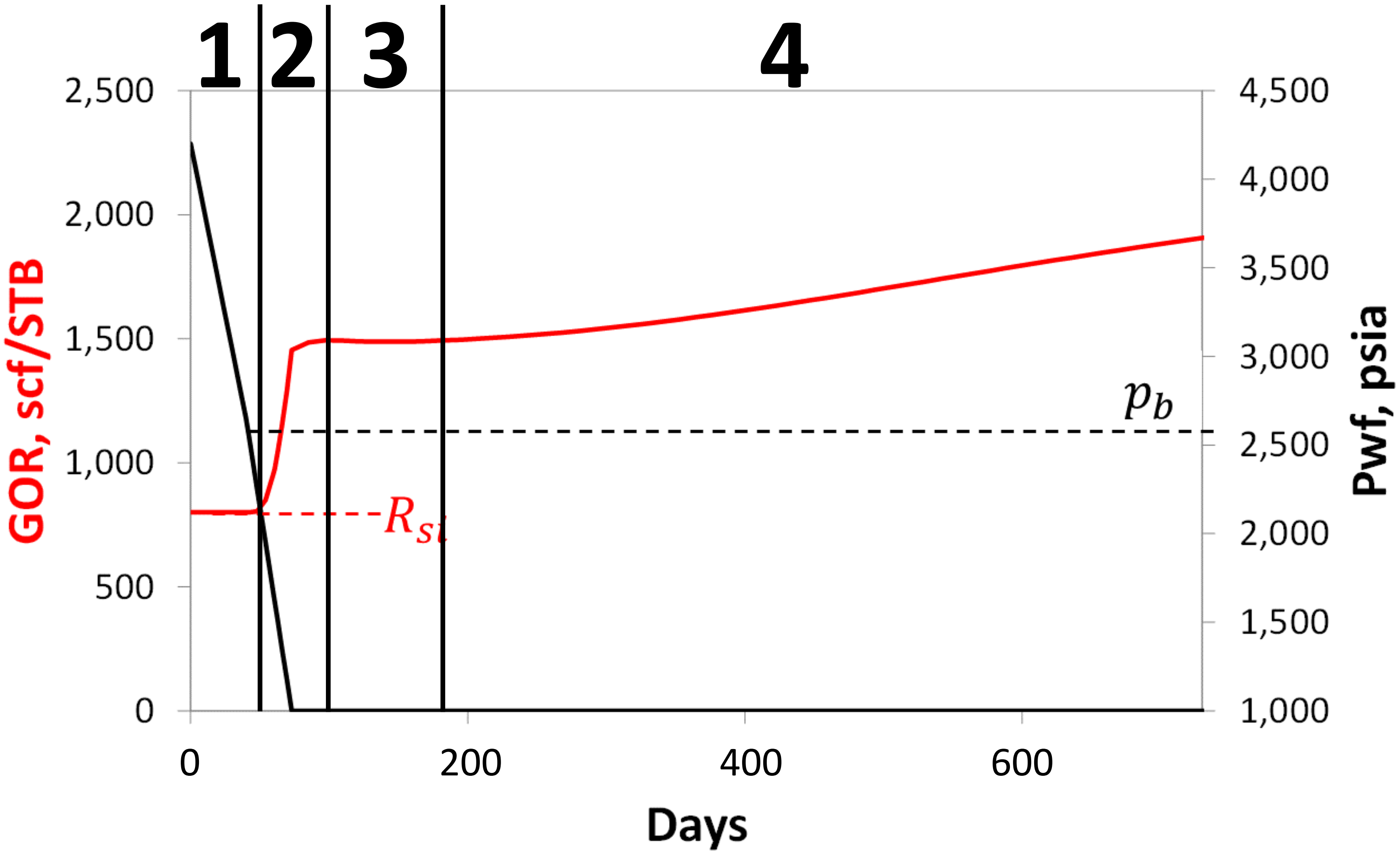


Idealized GOR History



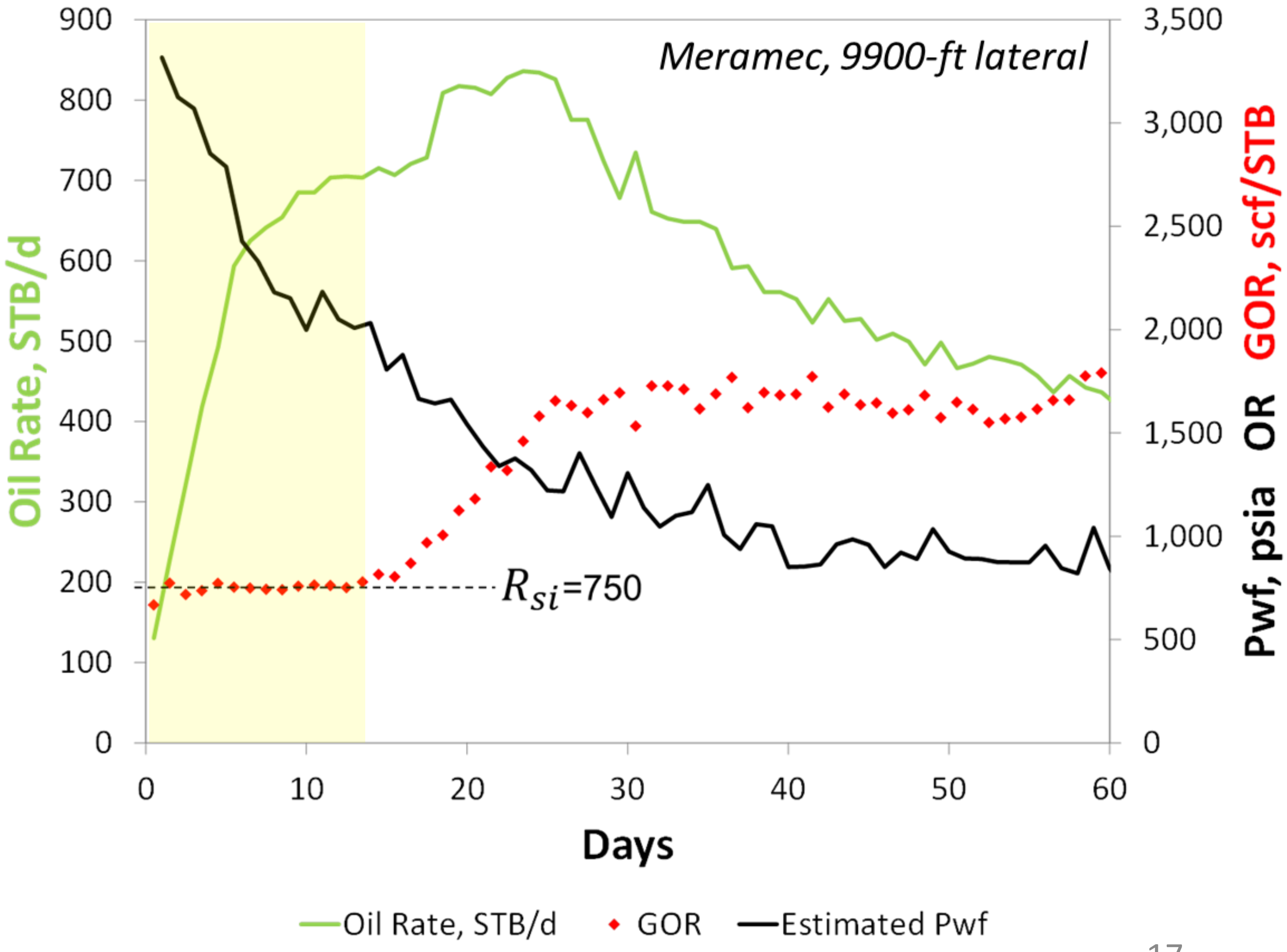
Four Stages

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



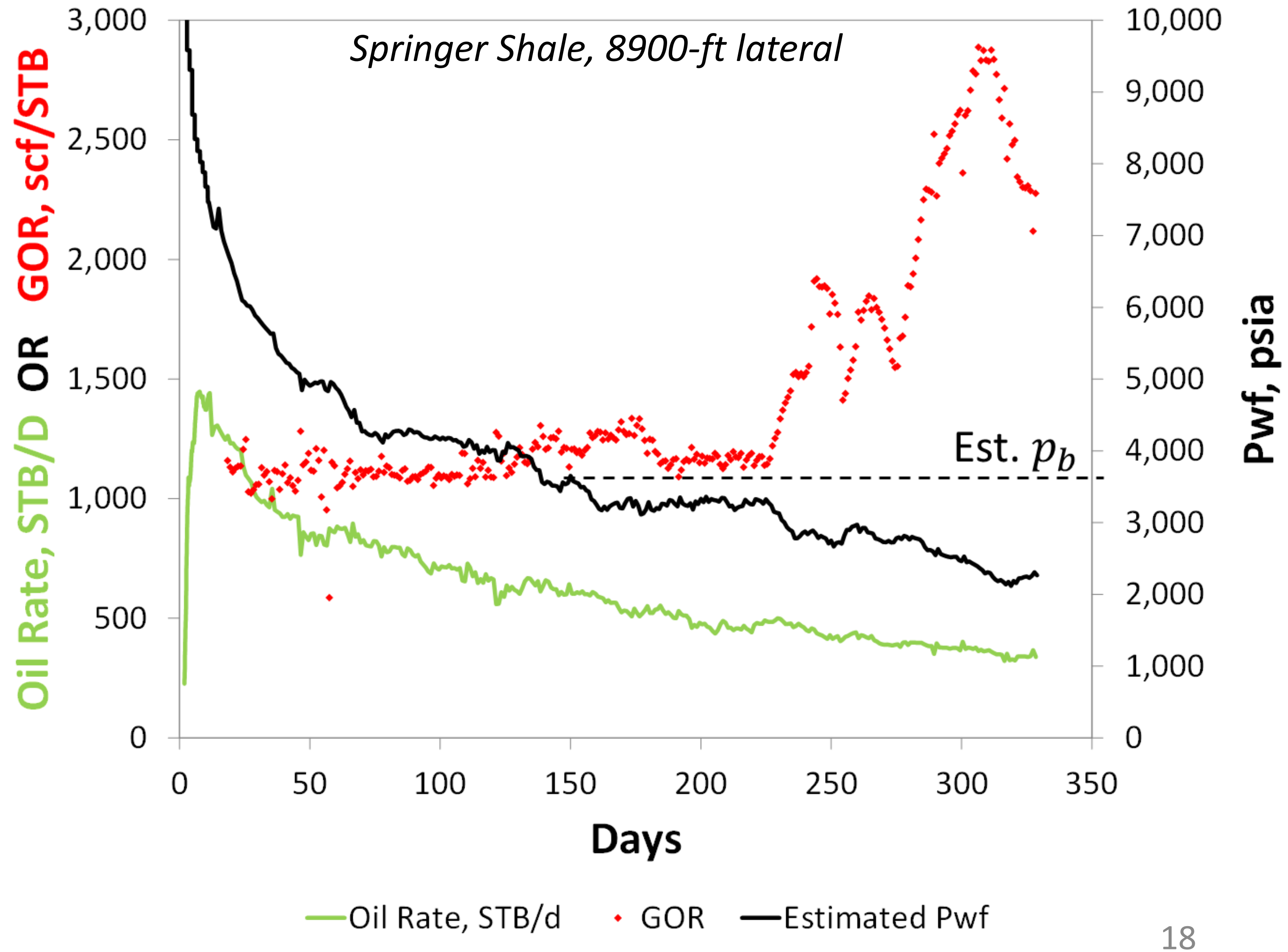
GOR = R_{si}

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



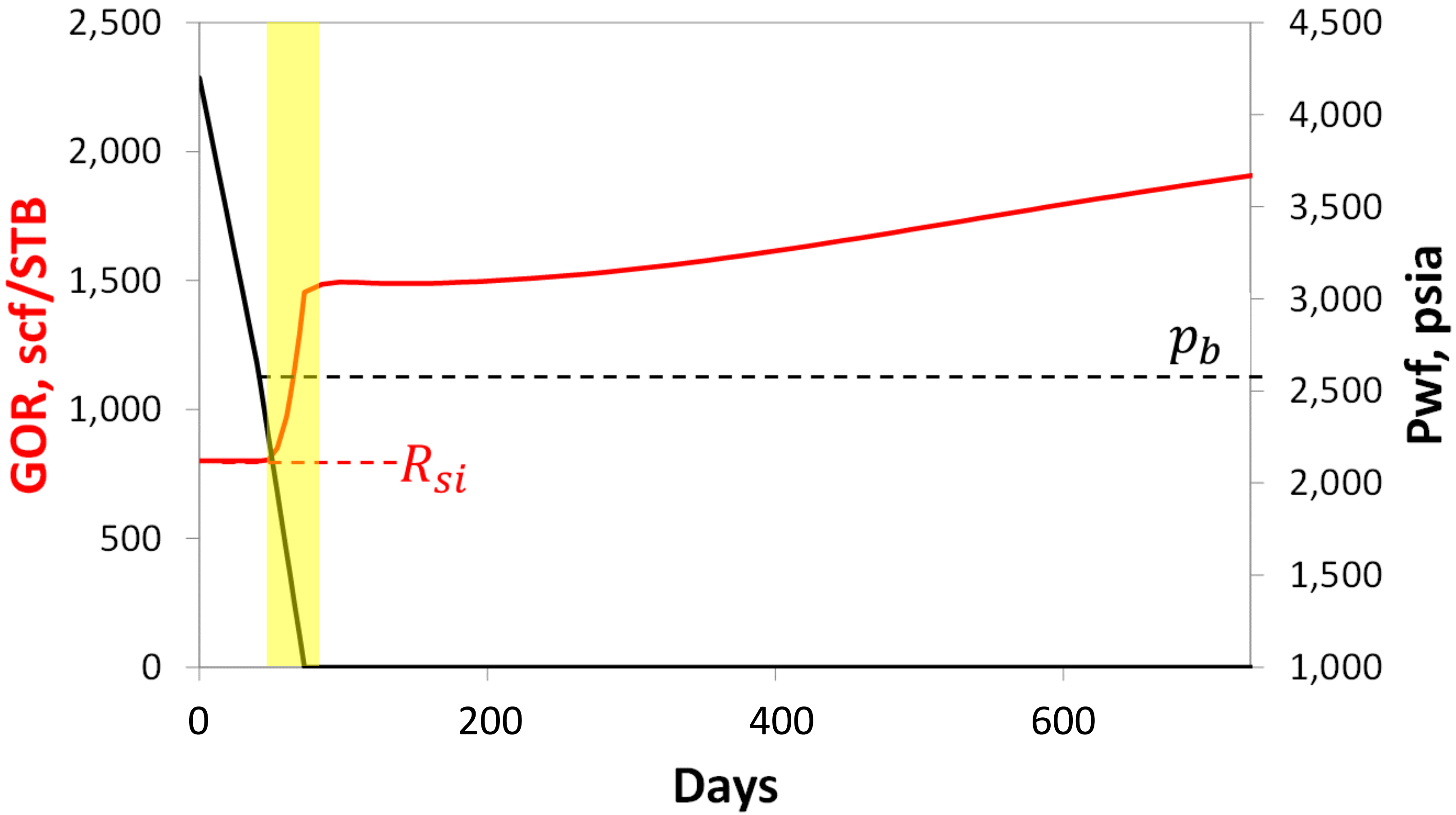
GOR = R_{si}

Example of long period of GOR=R_{si}



Rise due to $p_{wf} < p_b$

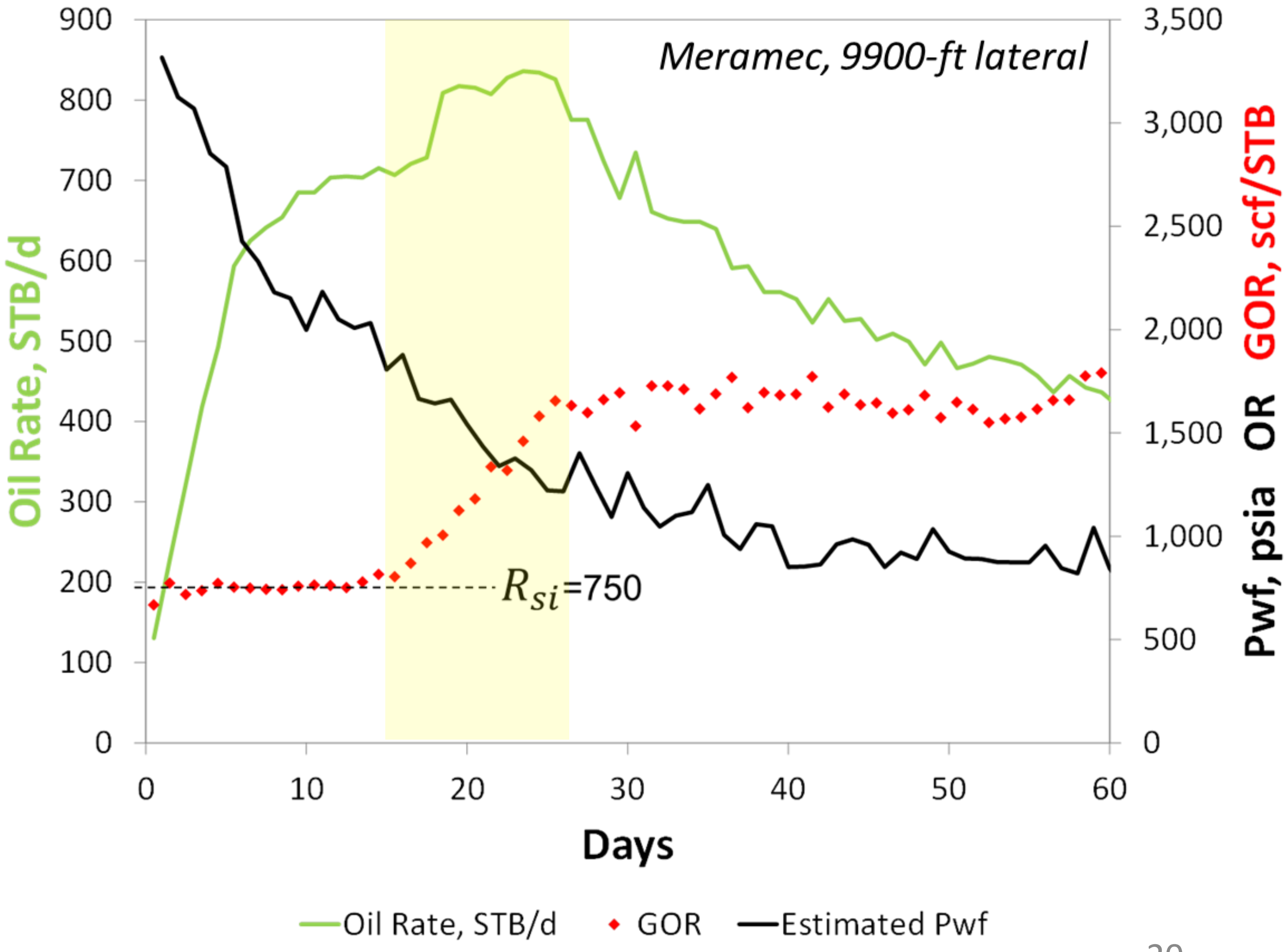
1. GOR = R_{si}
2. Rise due to $p_{wf} < p_b$



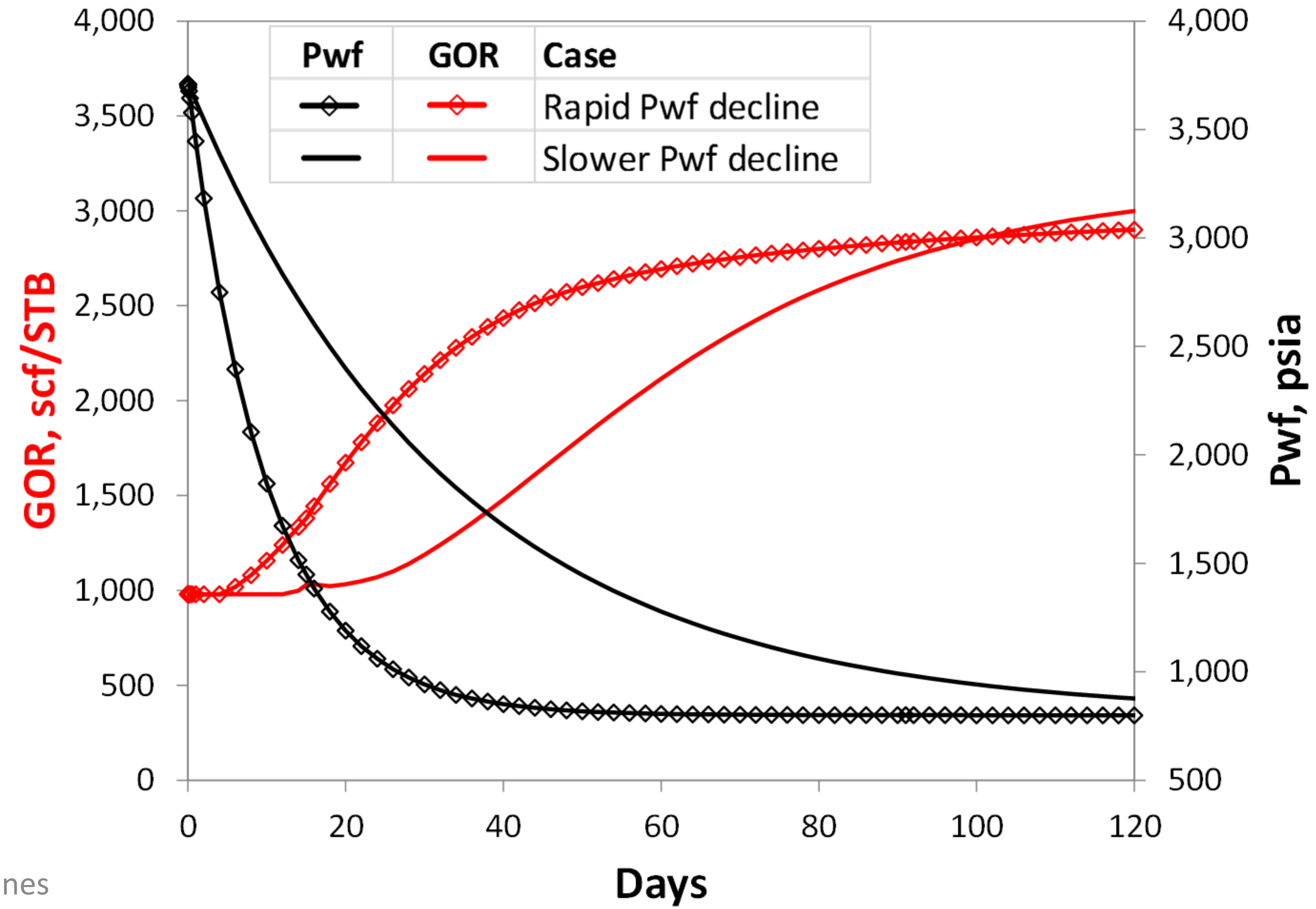
Rise due to $p_{wf} < p_b$

<u>Shape controlled by:</u>

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

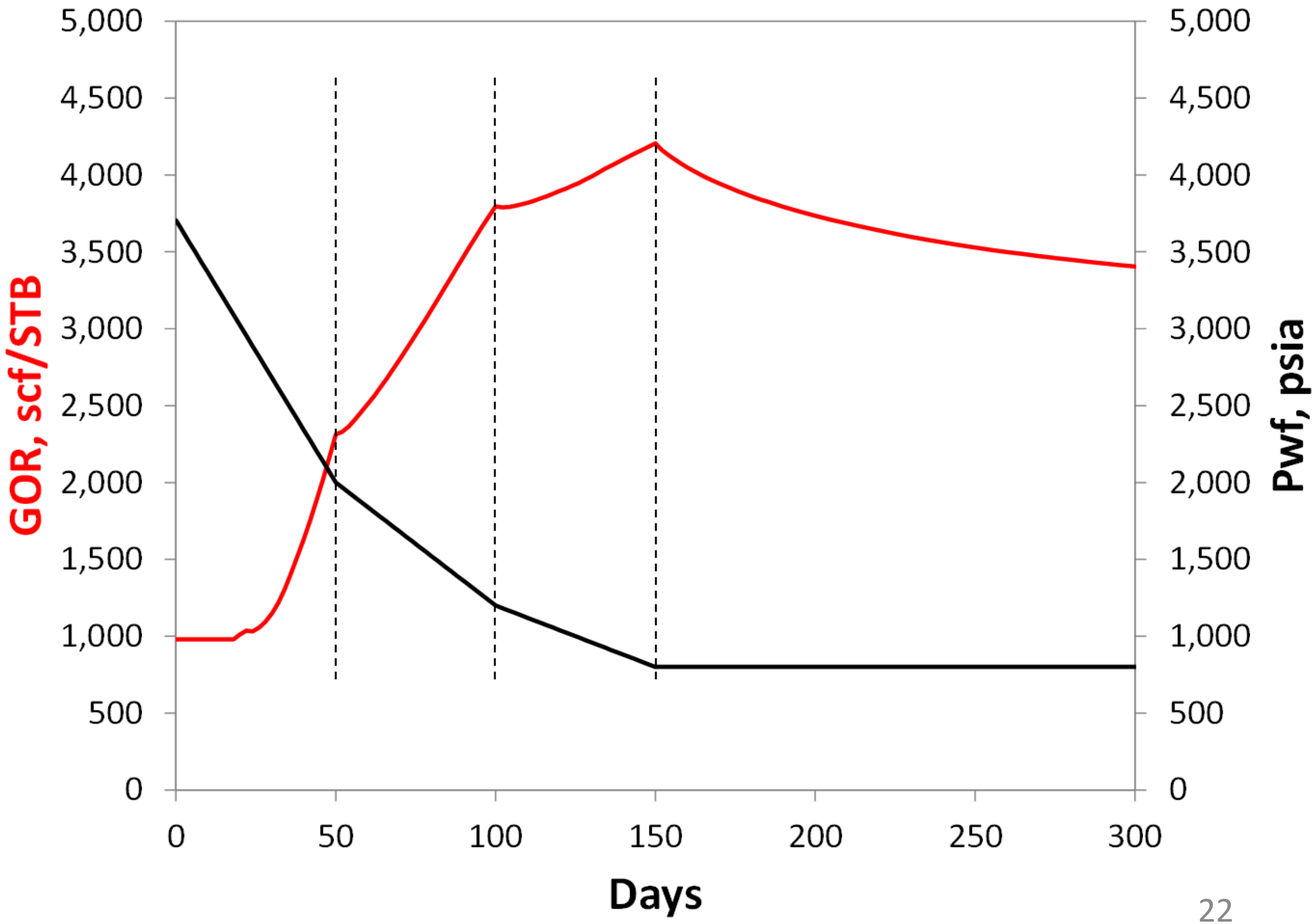


Rise due to $p_{wf} < p_b$: $\mathrm{p_{wf}}$ Schedule



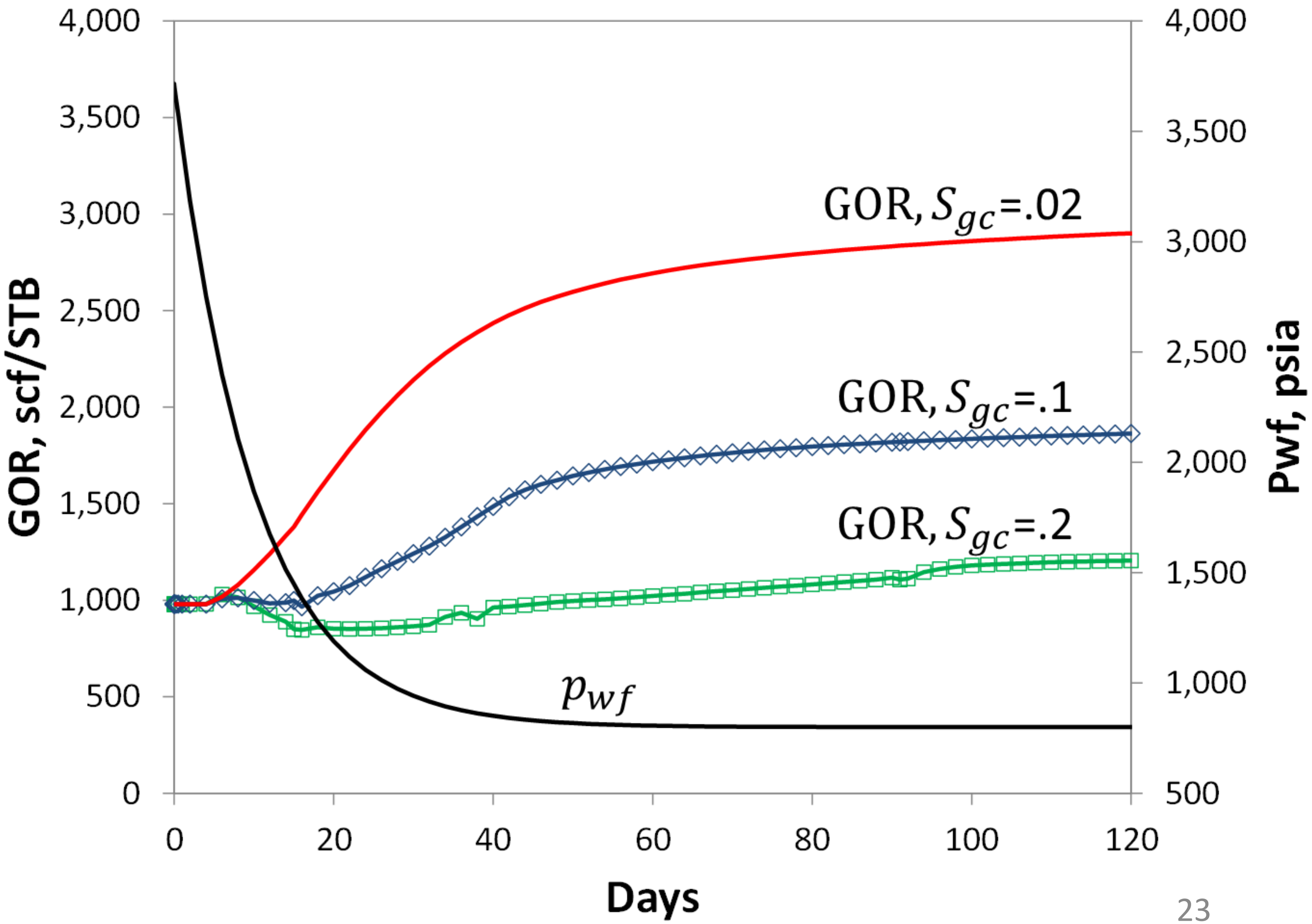
Rise due to $p_{wf} < p_b$: P_{wf} Schedule

Dependence on P_{wf} not limited to transient flow



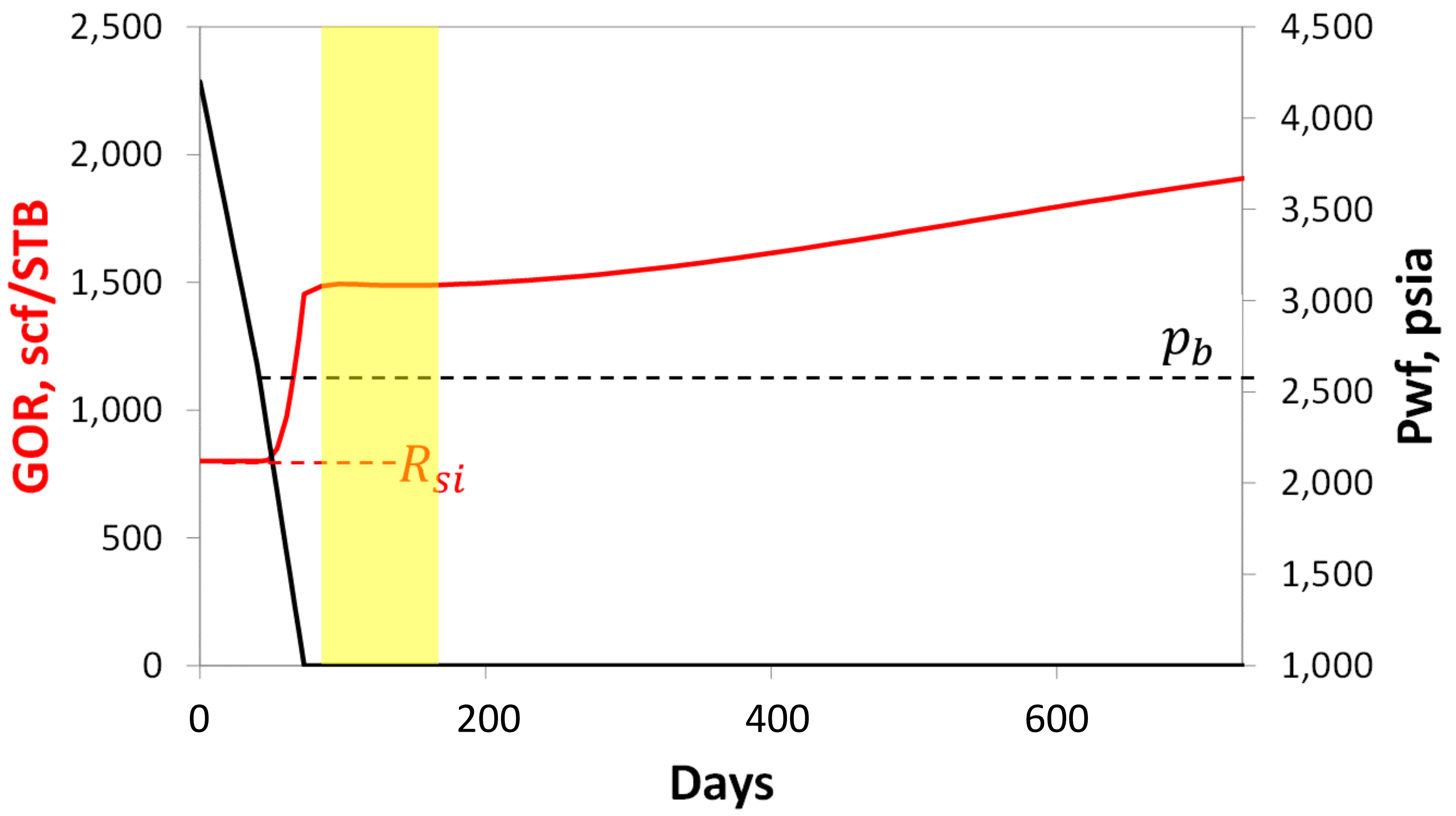
Rise due to $p_{wf} < p_b$: Relative Permeability

- Corey exponents and endpoints
- ***S_{gc}* has largest effect**
- “Pore-proximity effects” may be important in some rocks



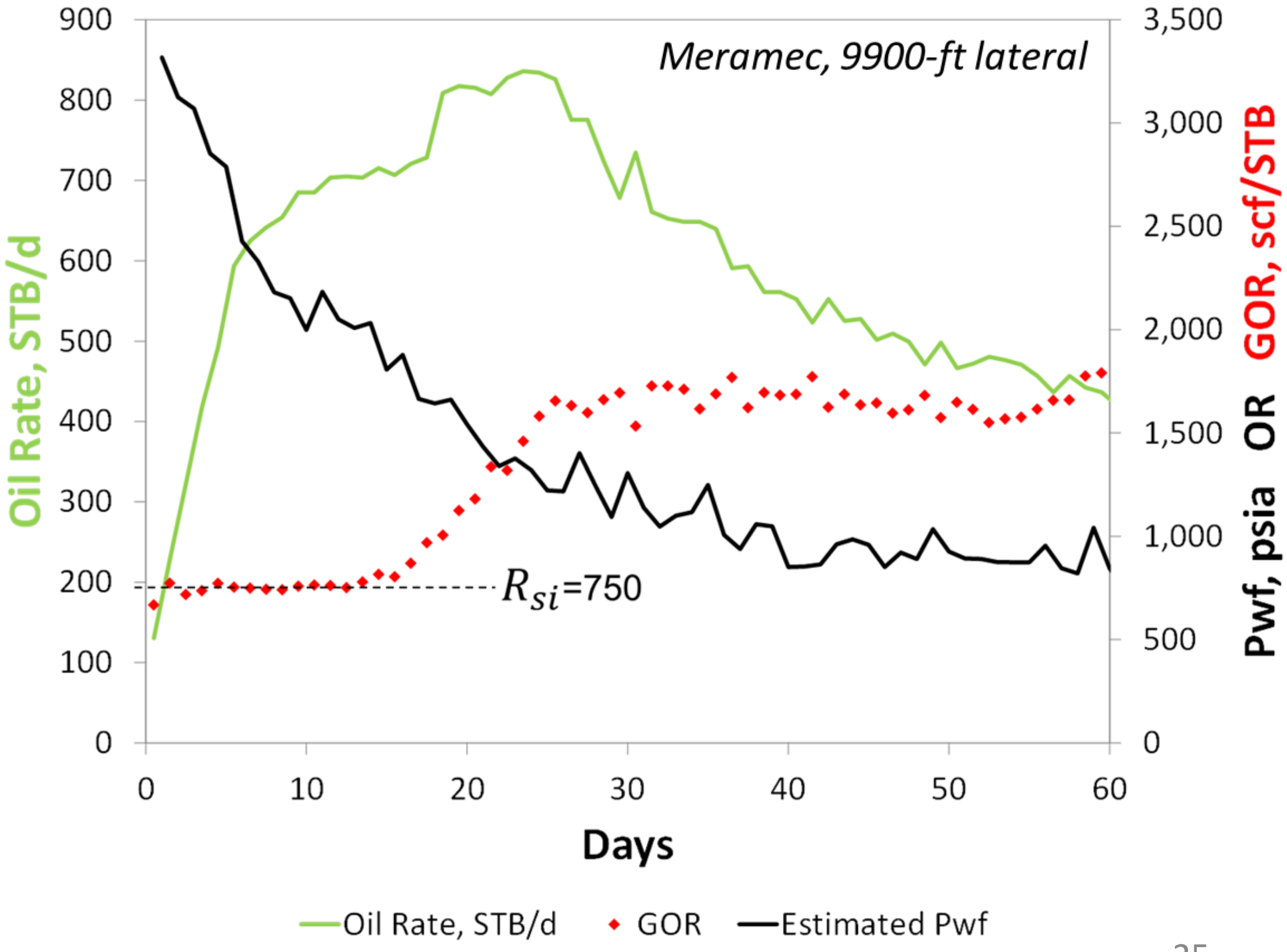
Transient GOR Plateau

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



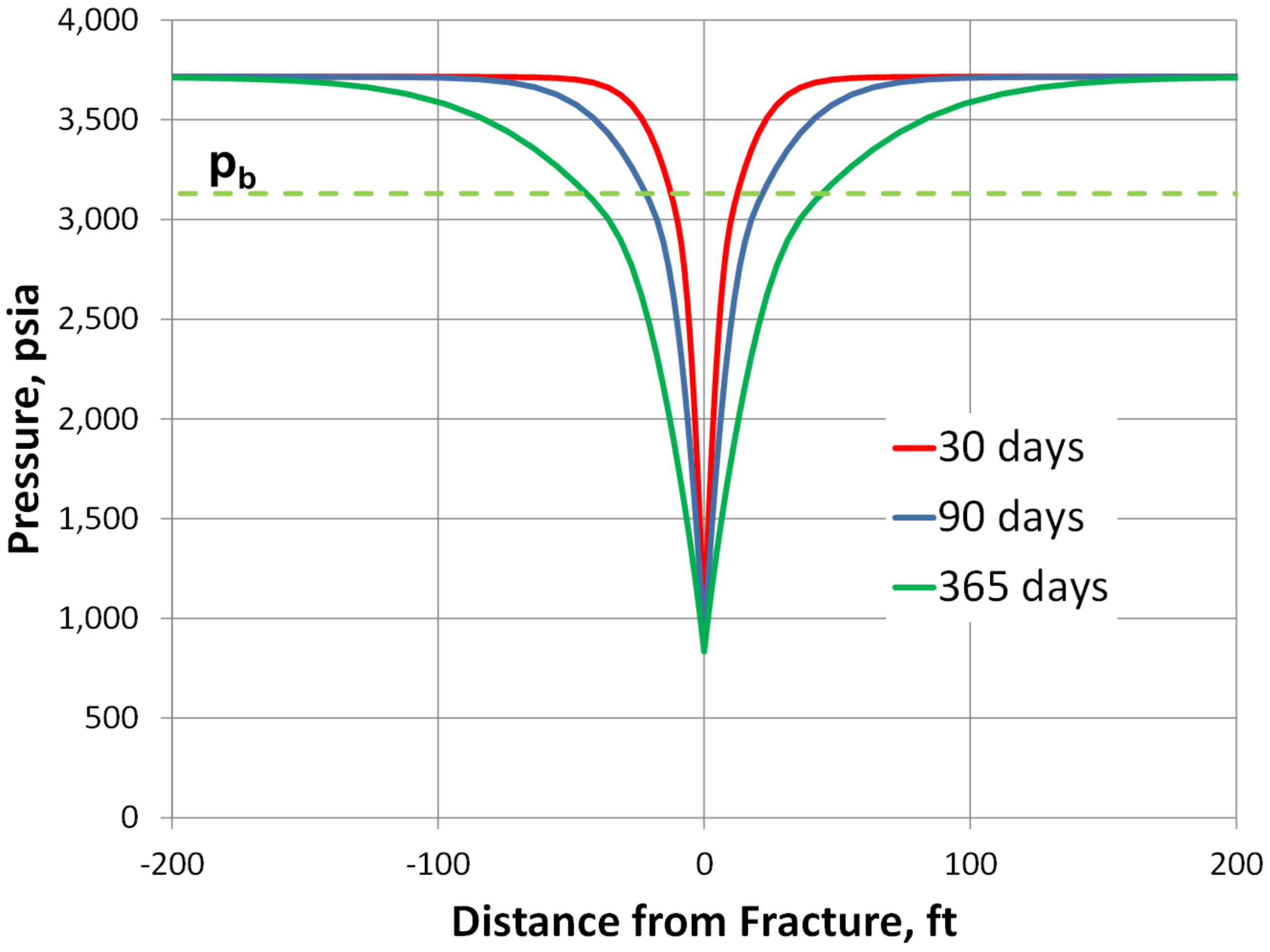
Transient GOR Plateau

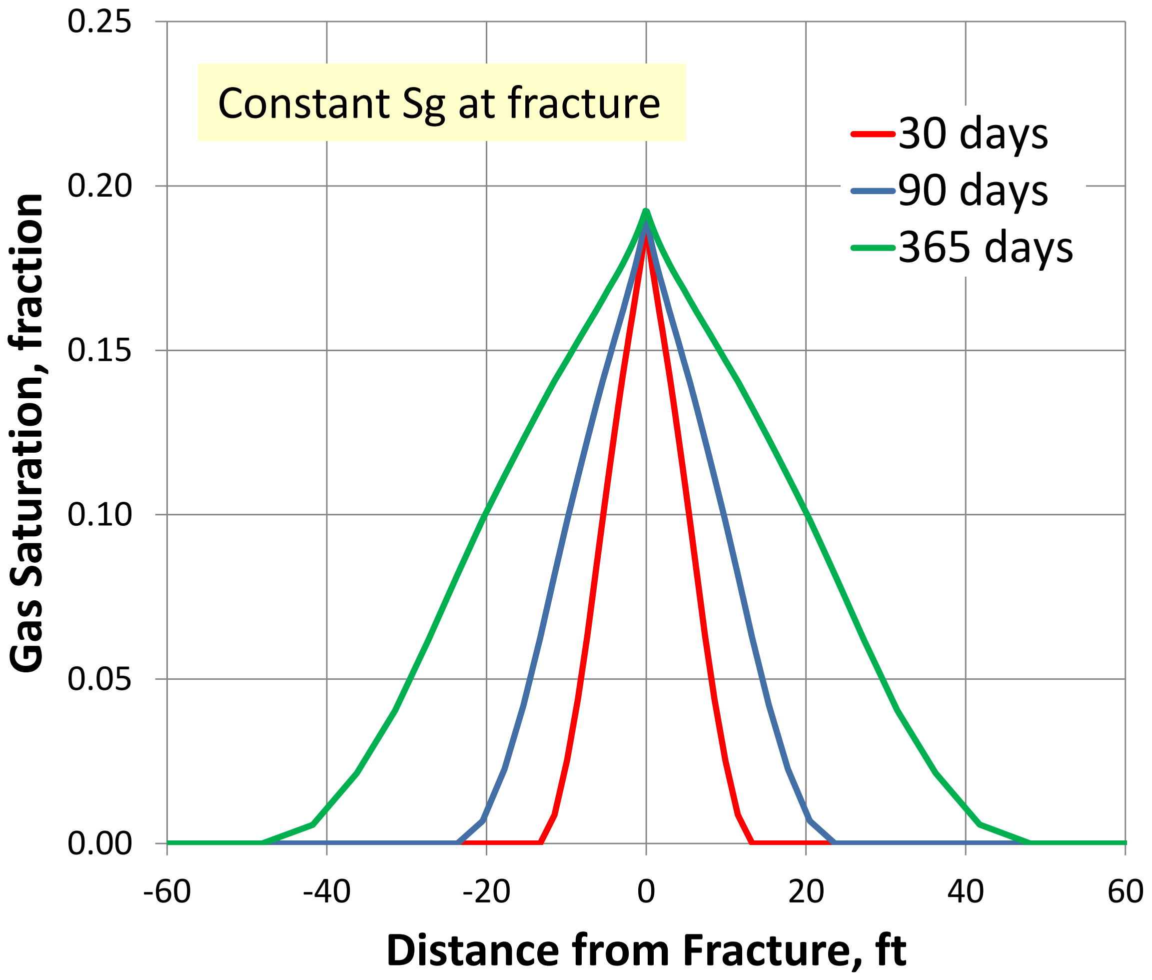
- Requires constant p_{wf}
- Result of **constant average pressure and saturations in distance of investigation (DOI)**



Transient GOR Plateau

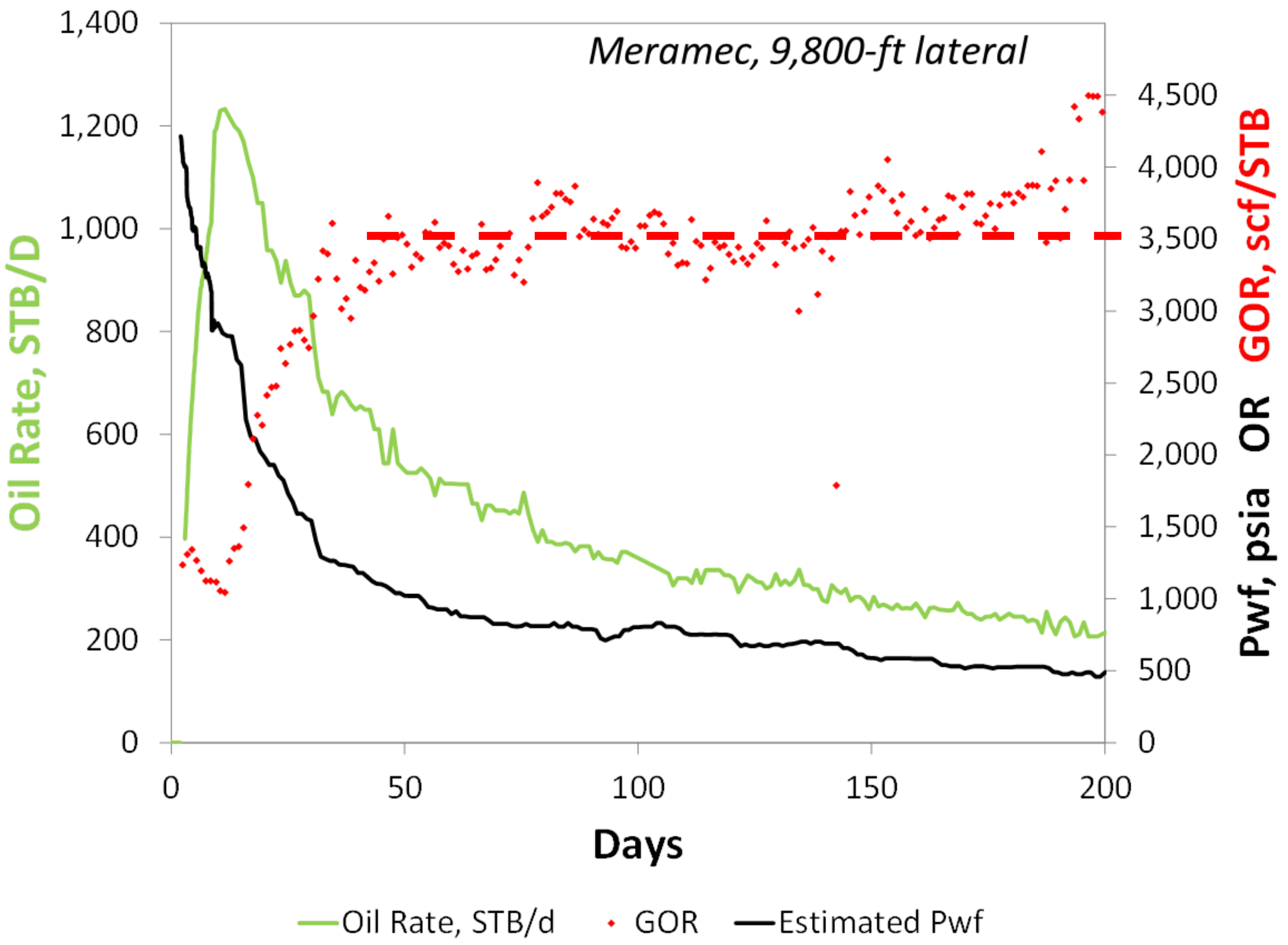
Constant average pressure and saturations in DOI **for constant p_{wf}**





Transient GOR Plateau

- Higher R_{si} → higher plateau
- Characteristic level in an area
- Plateau may not always occur
  - Gradual p_{wf} decline
  - Low conductivity, long x_f
  - Short transient period



GOR Rise during BDF

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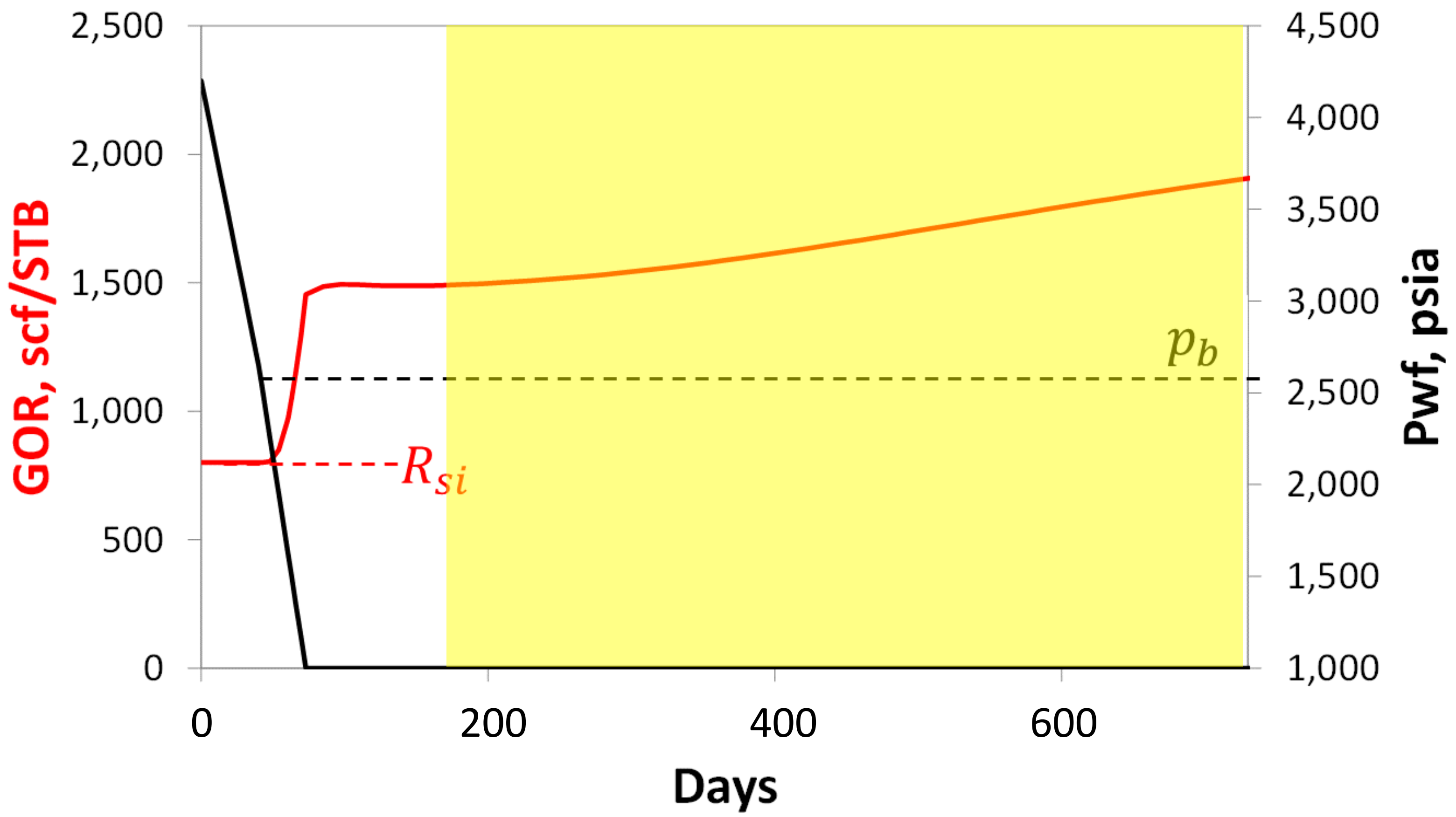
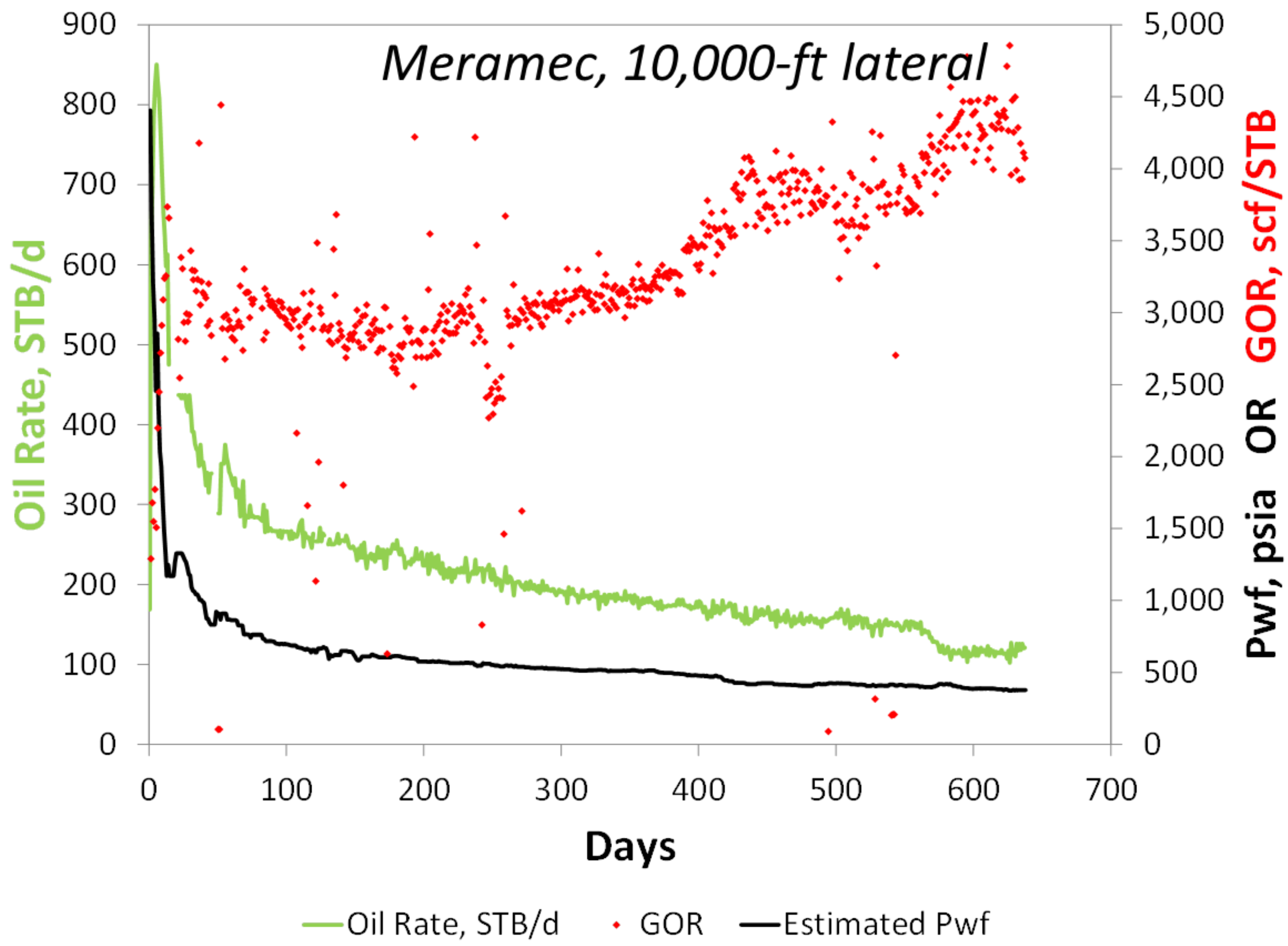
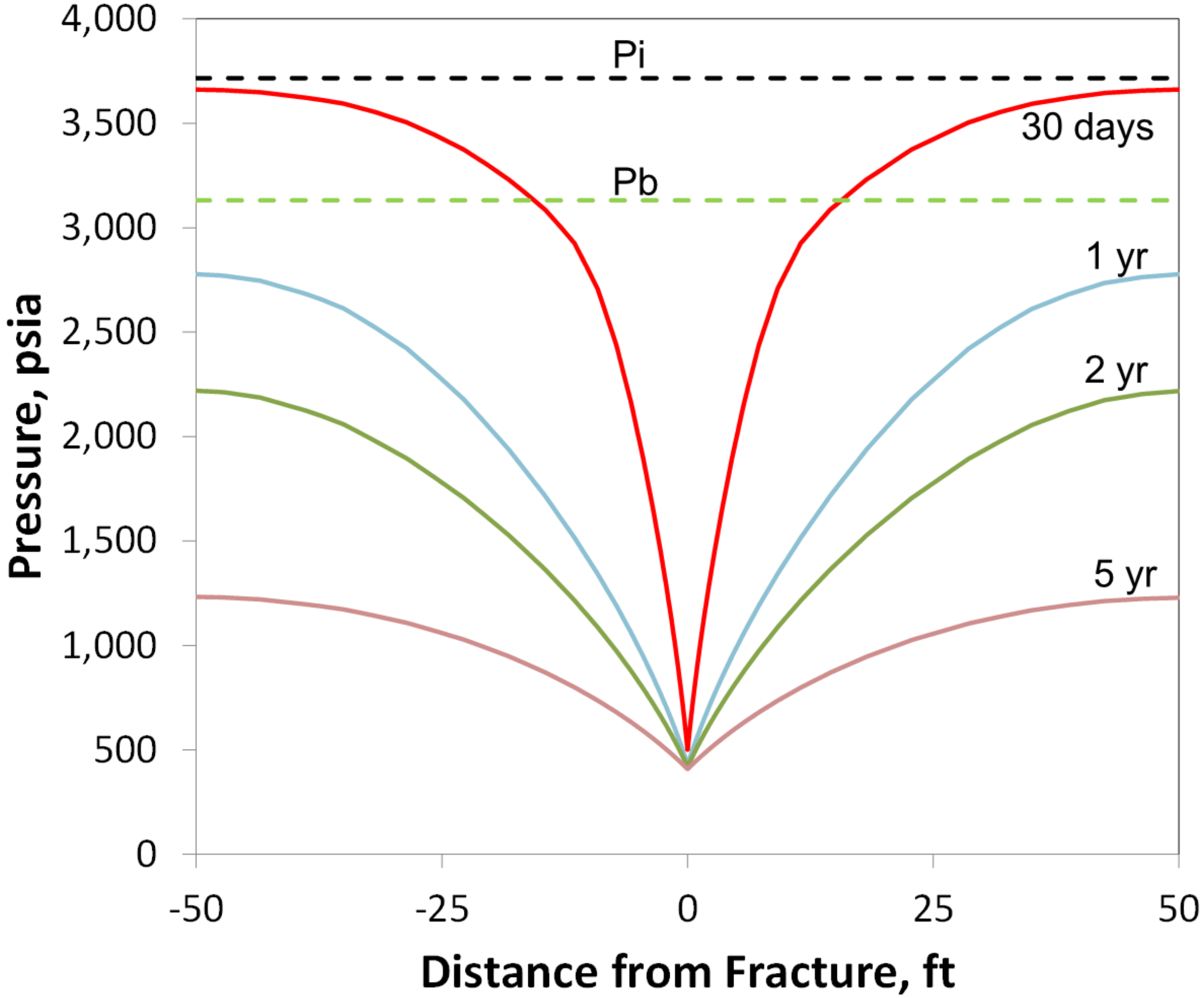
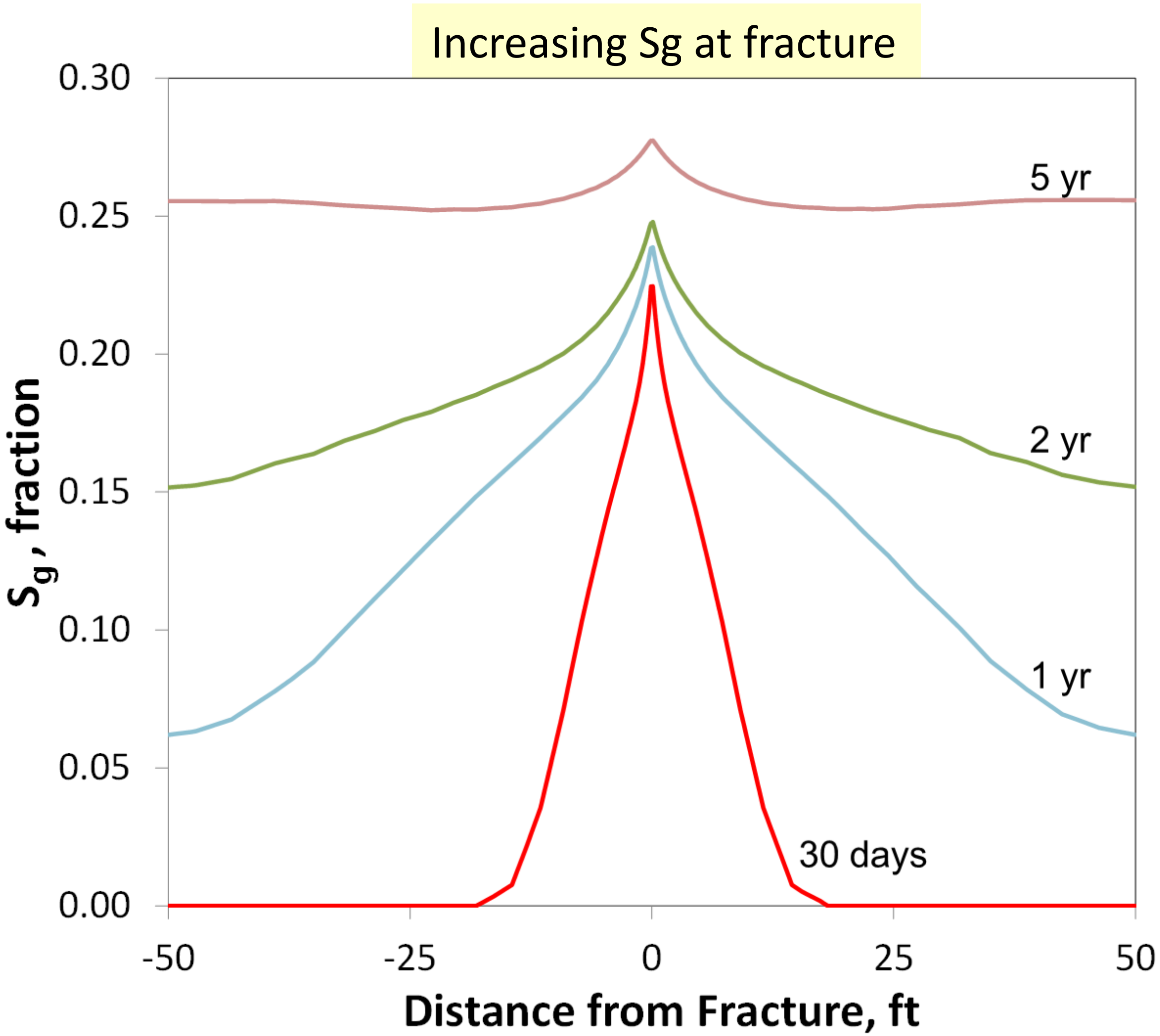


GOR Rise during BDF



GOR Rise during BDF



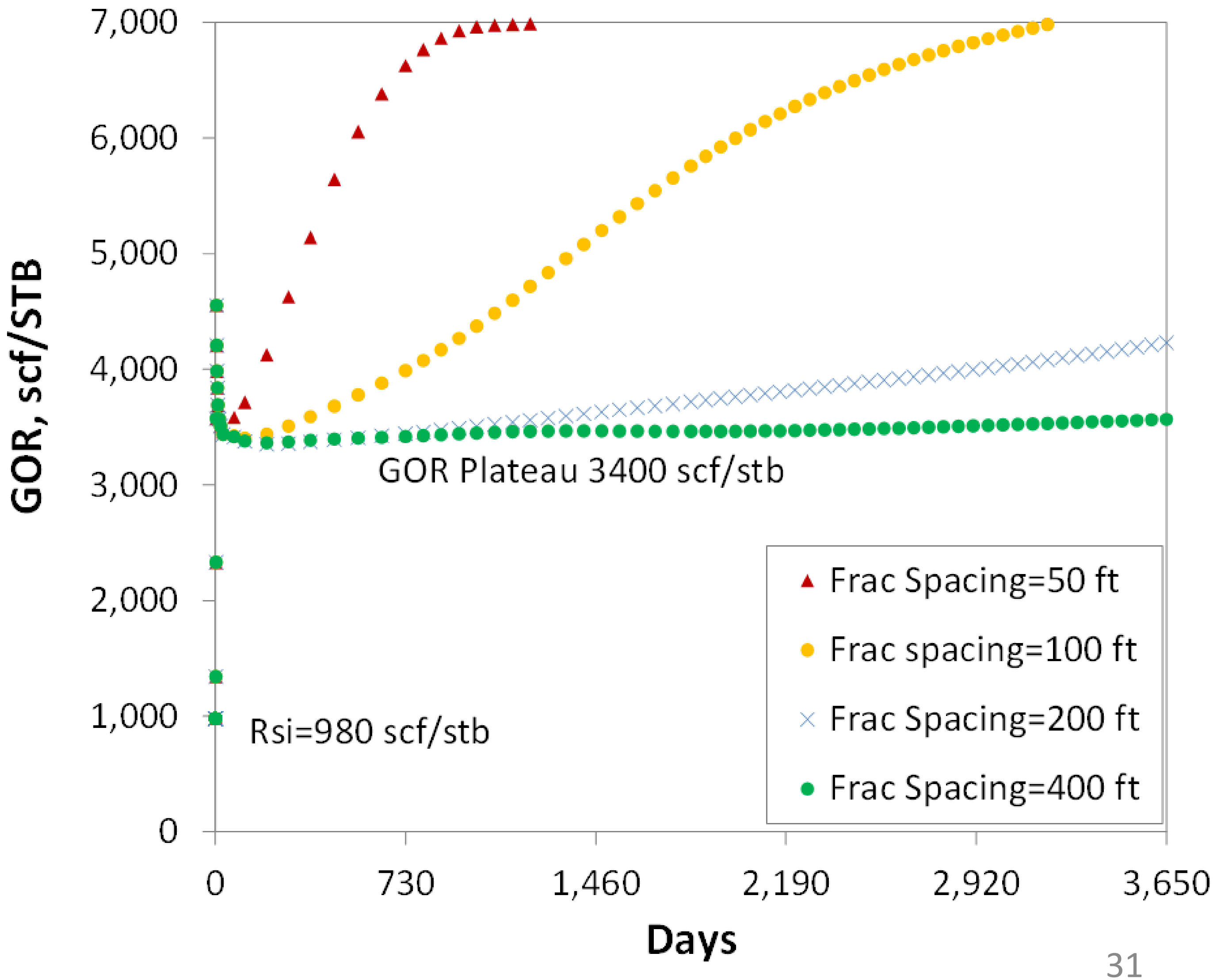


GOR Rise during BDF

Frac Spacing

- Closest frac spacing has quickest GOR rise
- Rise begins at plateau level, if visible
- Rate of GOR rise depends on **efficiency of access to drainage volume**

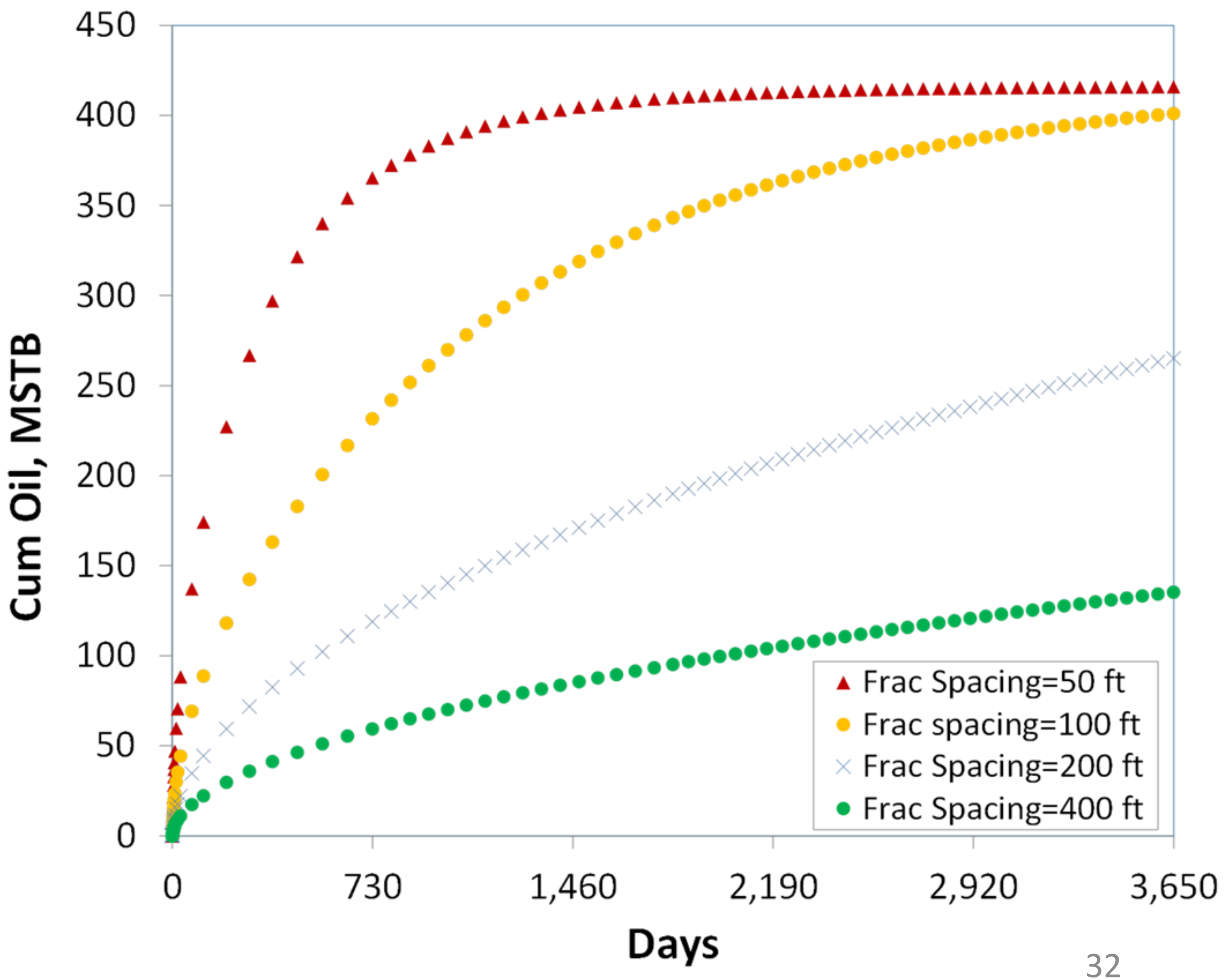
k=300 nd



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

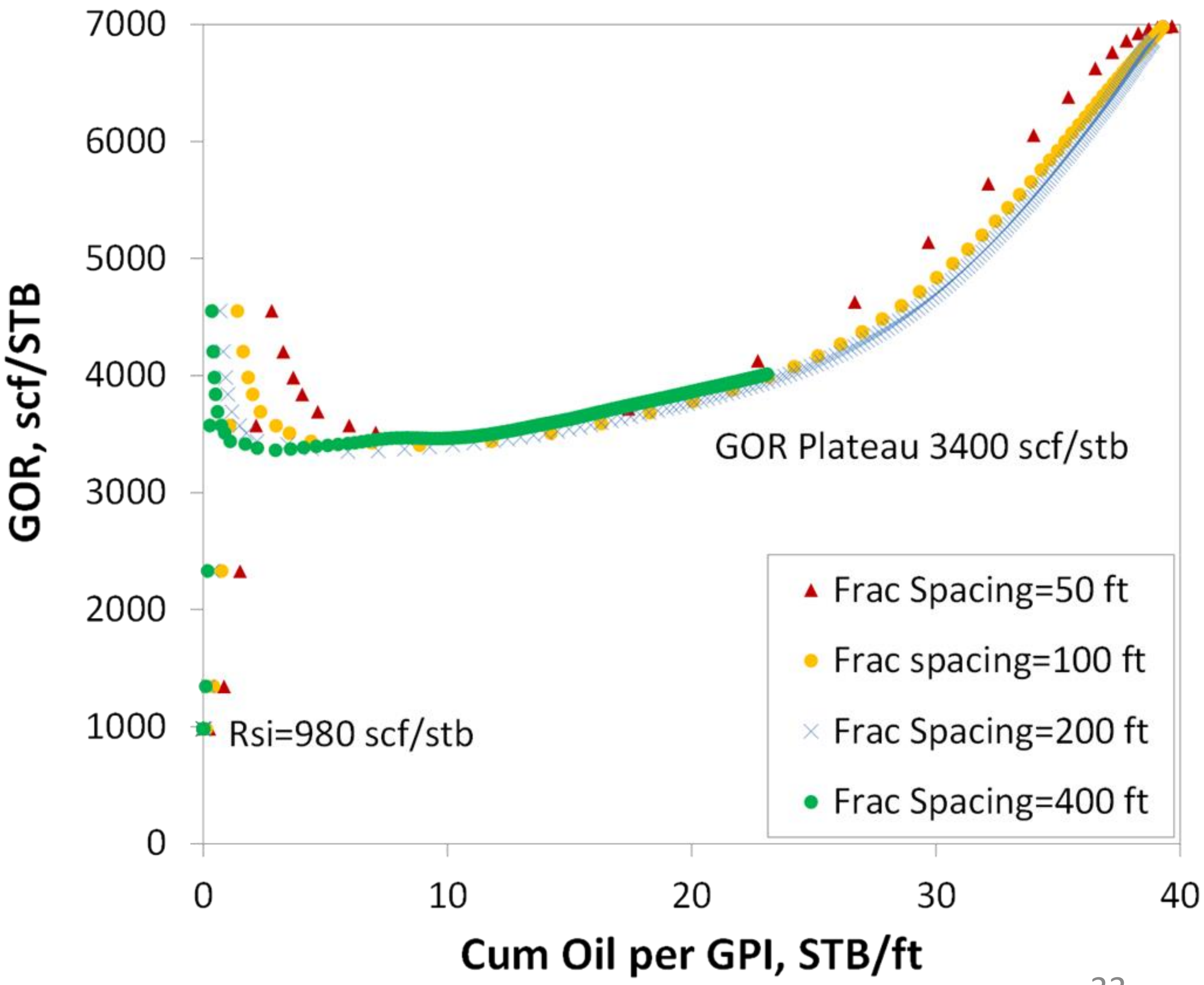


k=300 nd

GOR Rise during BDF

Frac Spacing

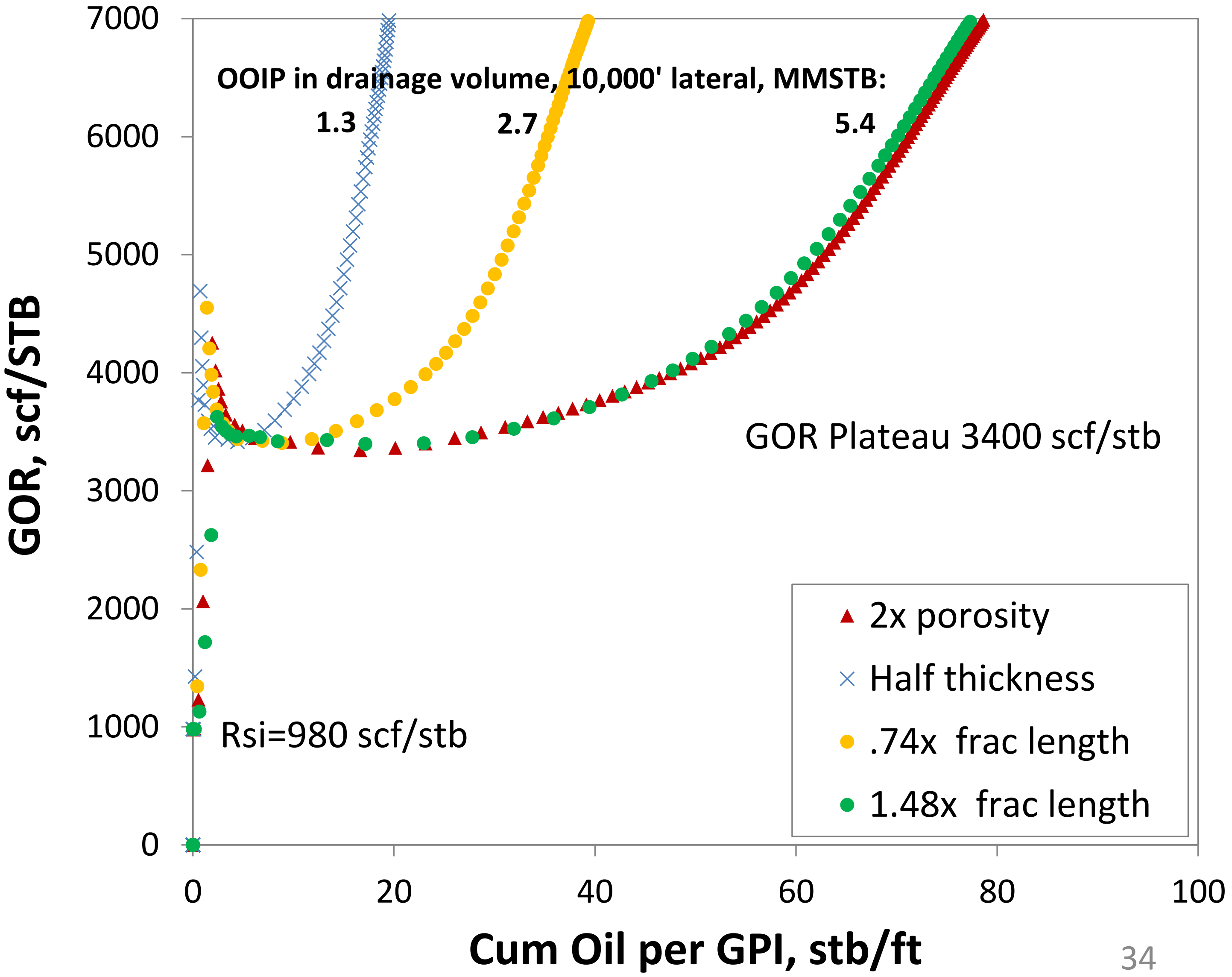
- **GOR vs. cum oil per ft. of lateral**
- Assumes same minimum p_{wf}
- Same OOIP



k = 300 nd

GOR Rise during BDF

- GOR rise correlates with OOIP
- Estimating OOIP requires rel perms and PVT
- Infill pilots



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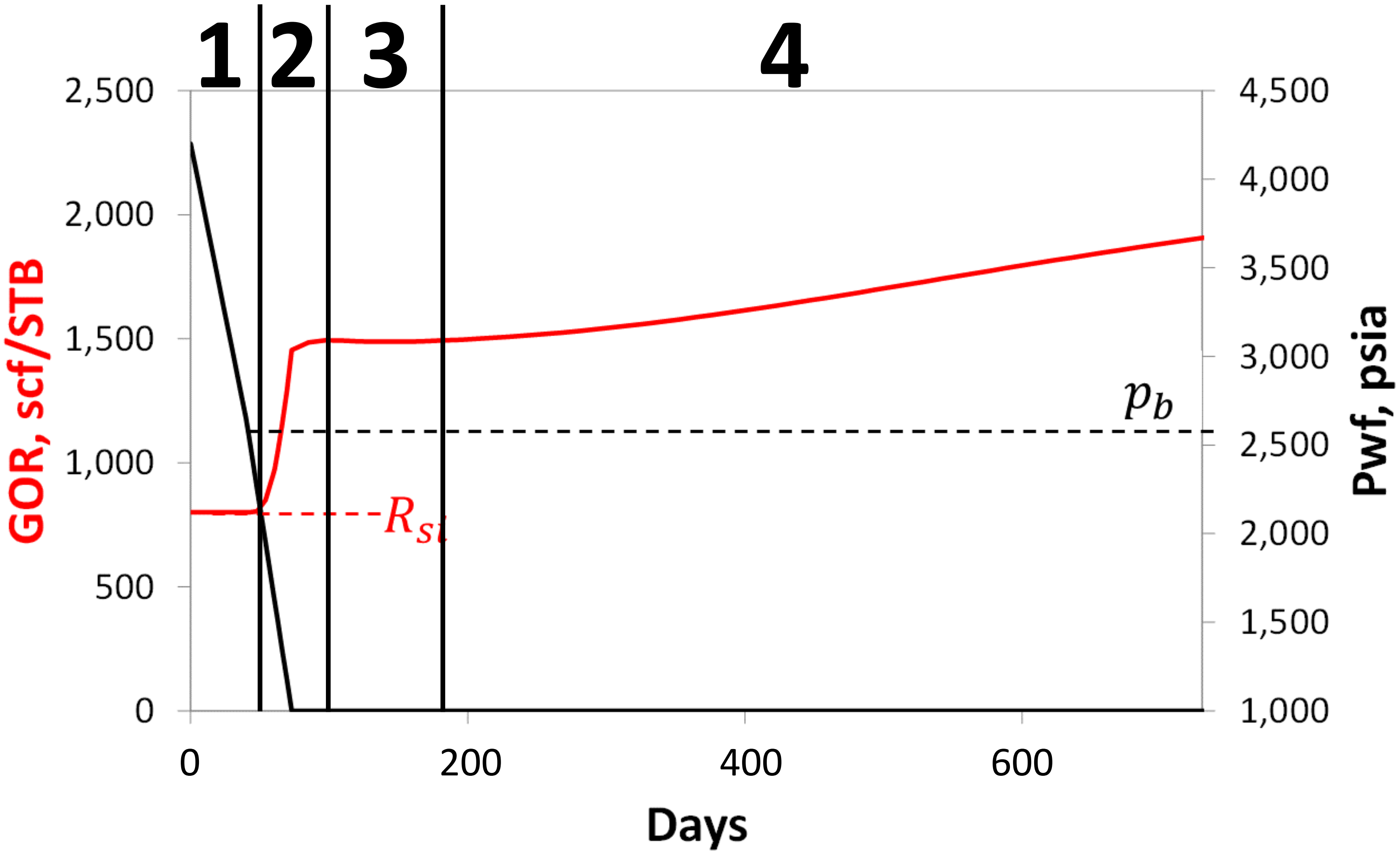
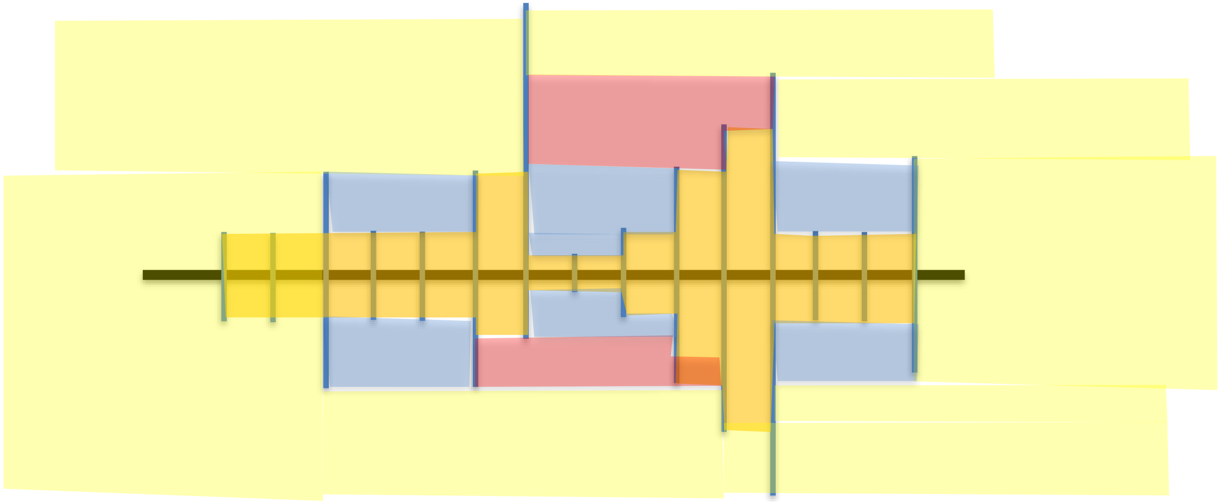
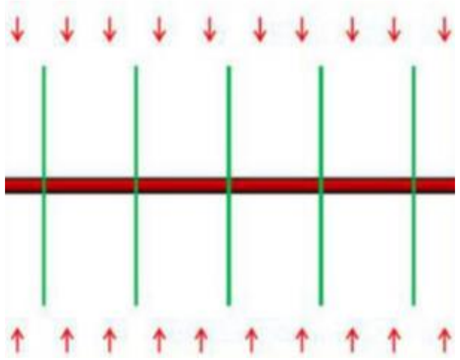


Other Factors

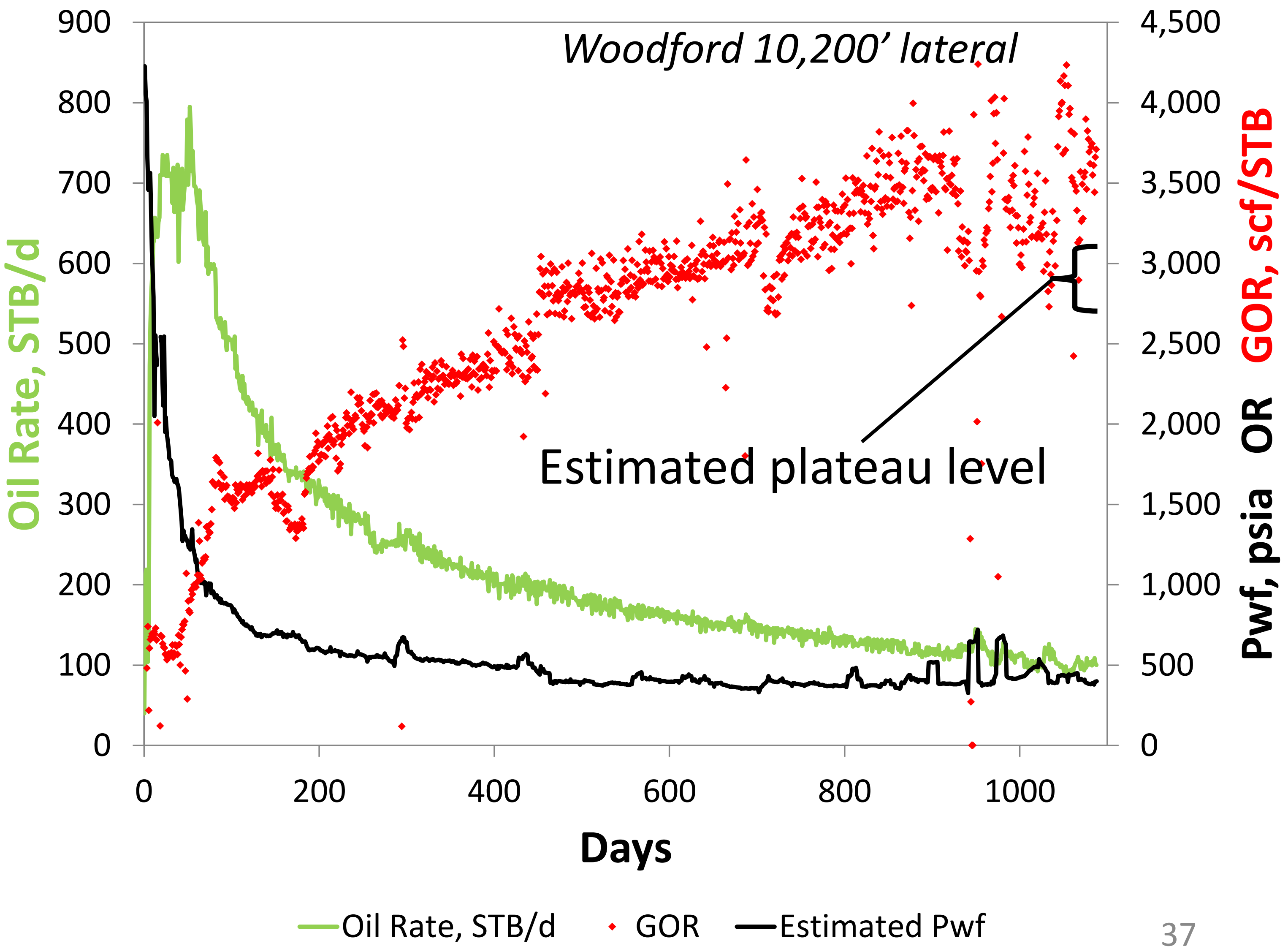


- Well is sum of many parts
- Non-uniform frac lengths
- Non-uniform frac spacing
- Non-uniform frac height
- Layering
- Different flow regimes in parts of drainage volume
- Compound linear flow



“Non-ideal” Behavior: Woodford

- Low-conductivity fractures delay initial GOR rise
- Depletion starts in different areas at different times



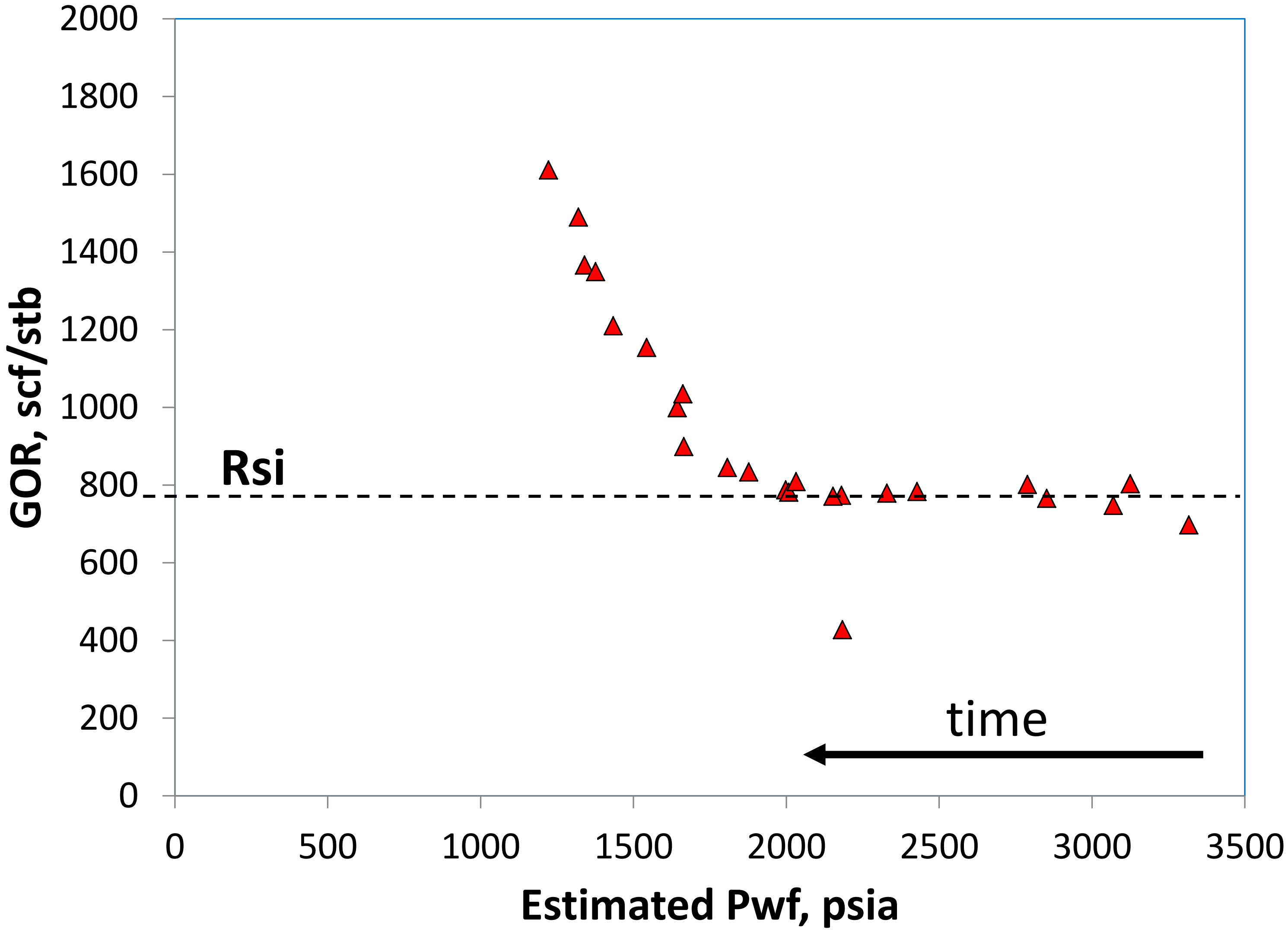
Key Data for Understanding GOR

- PVT Characterization – R_{si} and p_b
- Initial reservoir pressure
- p_{wf} estimates or measurements

- Estimating R_{si}
- Estimate plateau with simulation

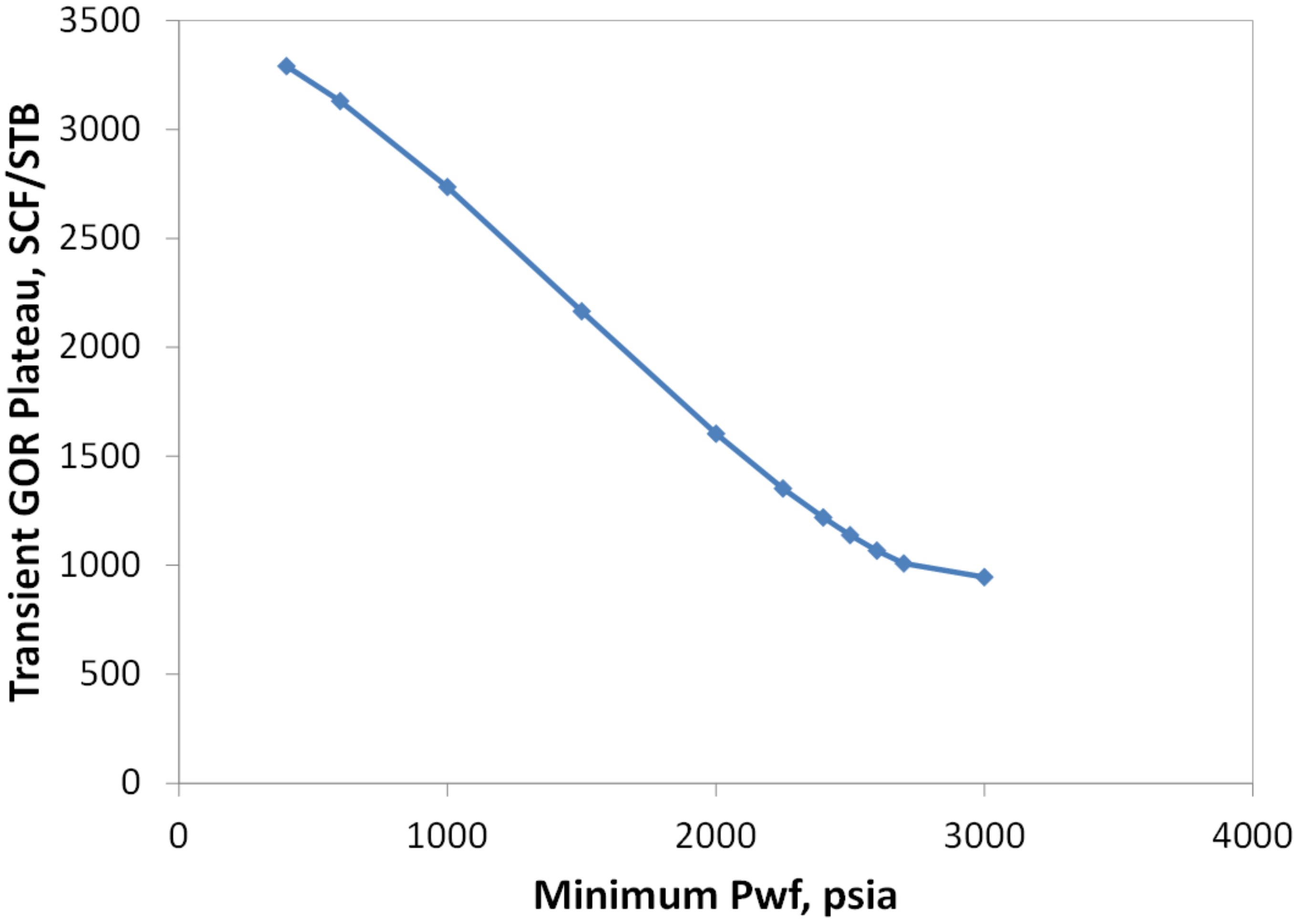
Key Data for Understanding GOR

R_{si} estimate



Key Data for Understanding GOR

- Identify **transient GOR plateau** level at range of constant p_{wf}
- Simulation with good PVT, high conductivity, long transient



Observations

- Many Meramec wells have recognizable transient GOR plateau
- Transient plateau often not evident in Woodford wells
- Lab PVT can be used directly in both Woodford and Meramec – no suppression of bubble point observed
- Meramec has low S_{gc} , 0-5%

Conclusions

- Linear flow causes dependence of GOR on p_{wf}
- Four idealized stages of GOR history are identified
- Several factors cause deviation
- Identify R_{si} and transient GOR plateau level to interpret history
- GOR in BDF is function of cumulative oil production

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