Research Summary

PSEUDOTRANSIENT LINEAR FLOW ANALYSIS

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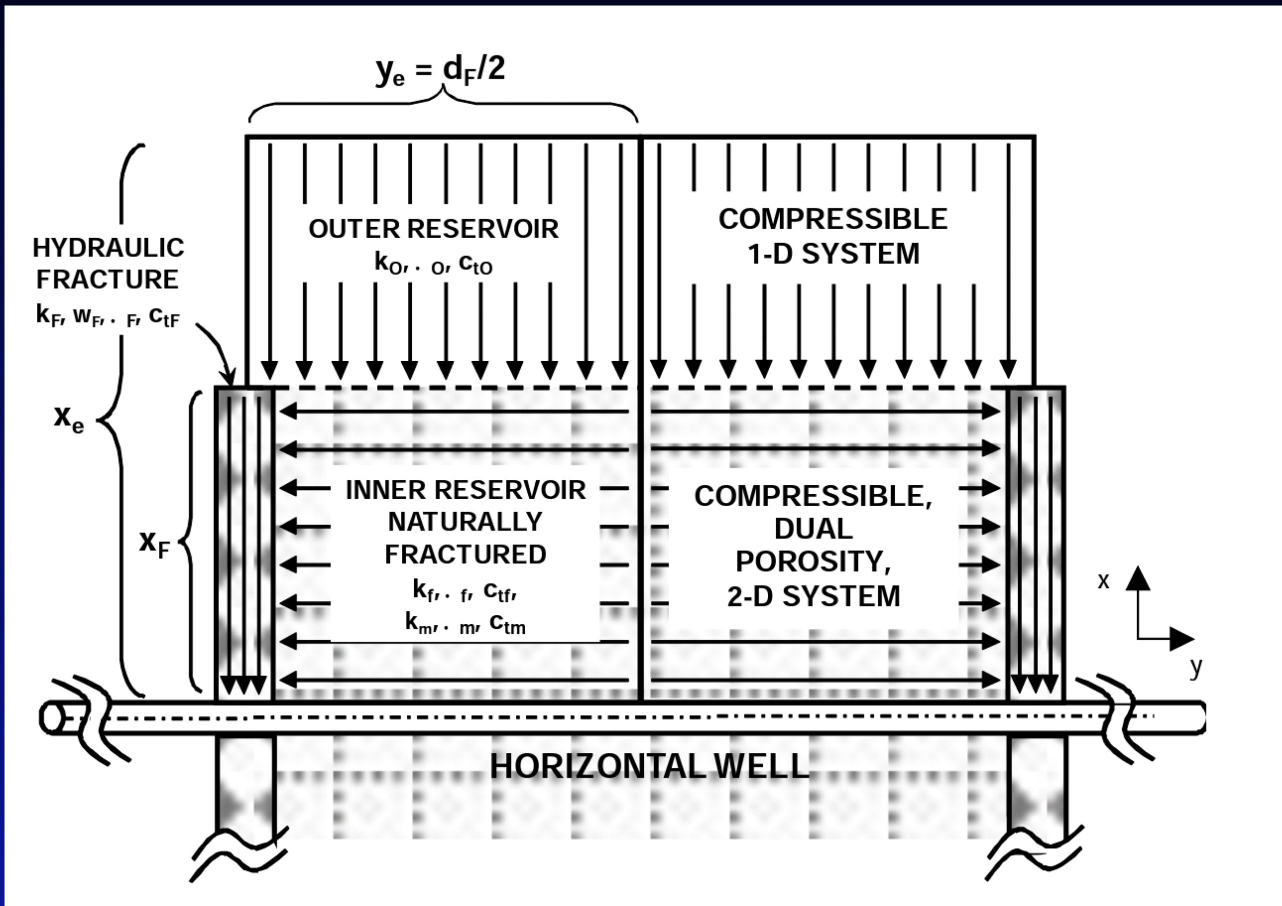
Trilinear Flow Model



HF: Hydraulic Fracture

NF: Natural Fracture

IM: Inner Matrix

OM: Outer Matrix

HW: Horizontal Well

Trilinear Flow Regimes (FR)

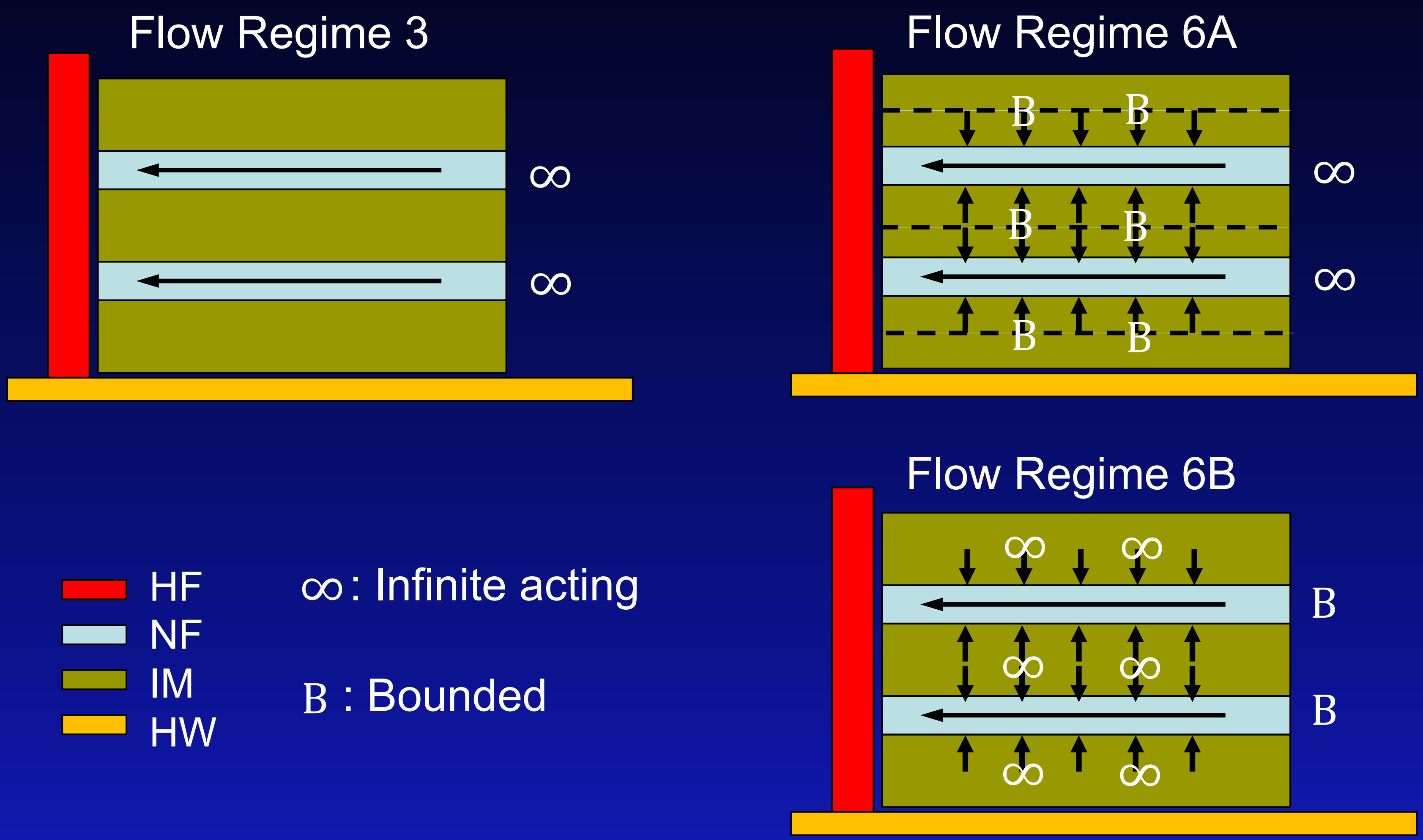
Early times (no contribution from IM)
- FR 1: HF linear flow
- FR 2: Early bilinear flow in HF & NF
- FR 3: Transient linear flow in NF only (no contribution from HF)

Intermediate times (transient contribution from IM)
- FR 4: Late bilinear flow in NF & IM
- FR 5: Trilinear flow in HF, NF & IM (highly unlikely)
- FR 6: Pseudotransient linear flow in NF & IM
  - FR 6A: Transient flow in NF and boundary dominated flow in IM (high λ')
  - FR 6B: Transient flow in IM and boundary-dominated flow in NF (low λ')

Late times (pseudosteady contribution from IM)
- Boundary dominated flow in NF & IM, no flow from OM
- Boundary dominated flow in NF & IM, and transient linear flow from OM
- Boundary dominated flow from HF, NF, IM, & OM

Flow Regimes 3 & 6

Transient dual-porosity slab model



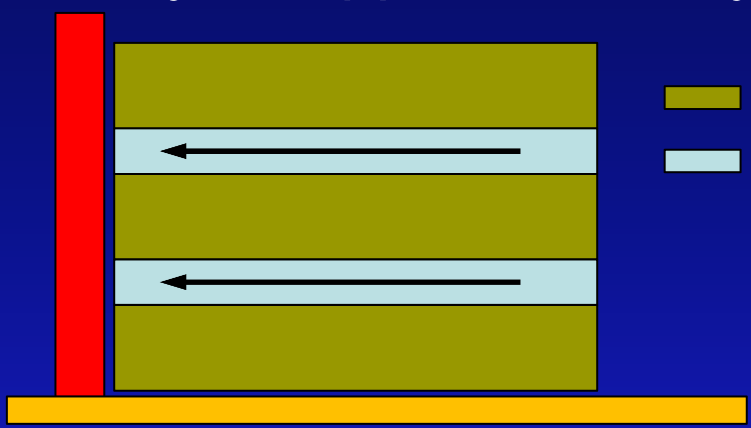
Flow Regimes 3 & 6

FR 3: Transient linear flow
FR 6: Pseudotransient linear flow

Condition for FR 6 (pseudotransient linear flow)

- Dual-porosity slab configuration
- May be too idealized for naturally fractured media

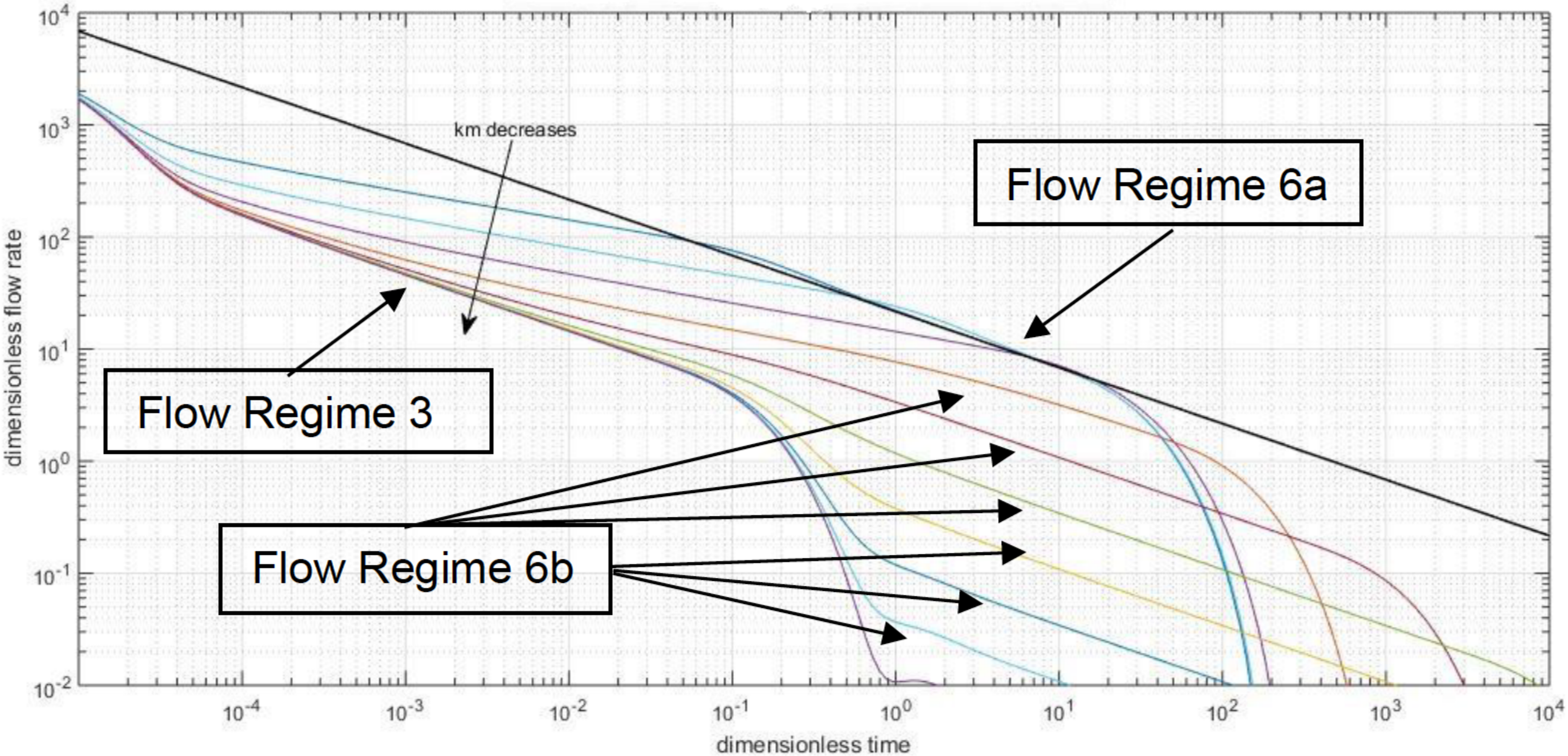
May be applicable in layered systems (dual-permeability)



Storage layer (shale)
Producing layer (fractured carbonate)

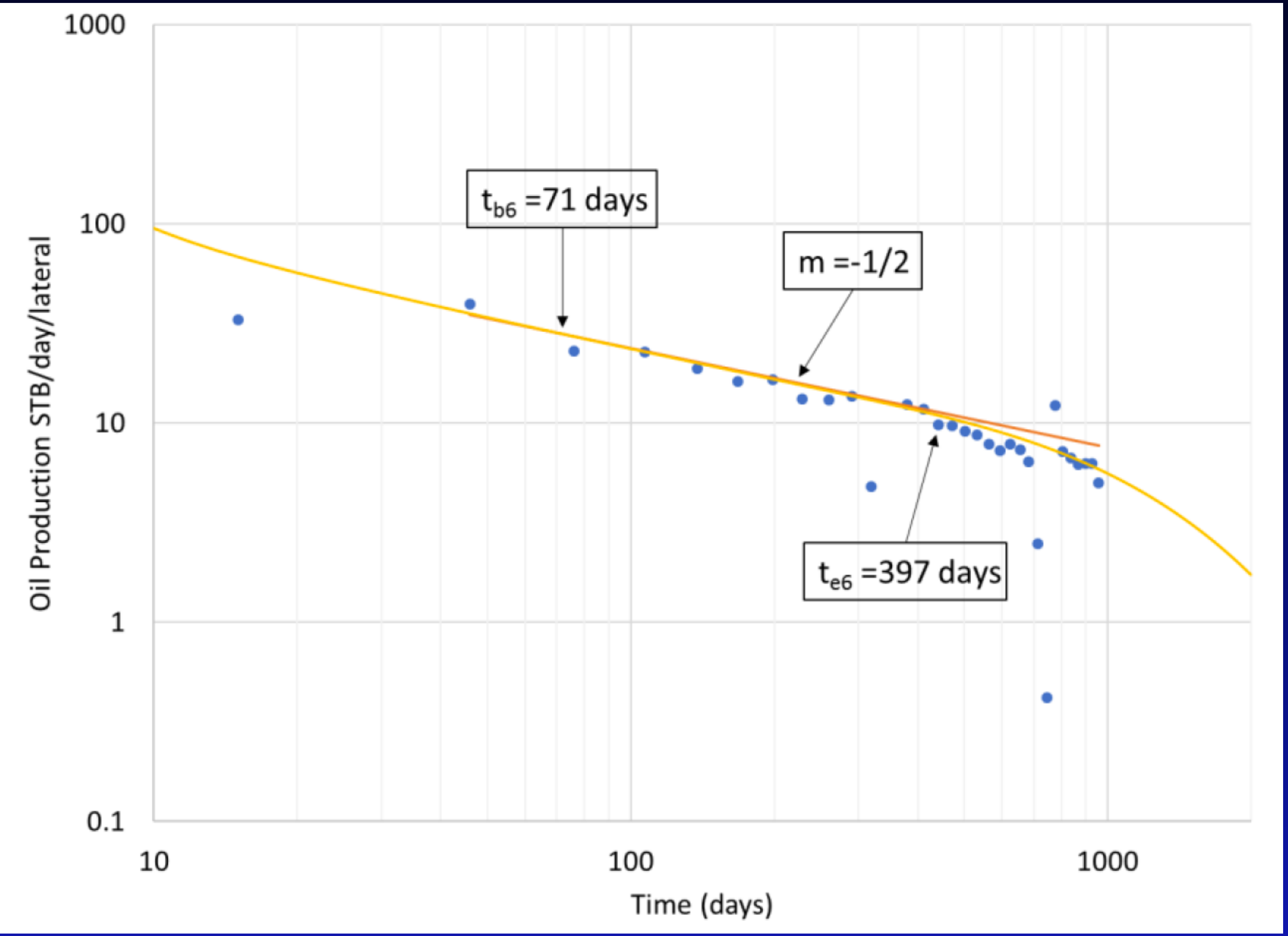
Eagle Ford, Bakken?

Flow Regimes 3 & 6



Field Example: Eagle Ford well

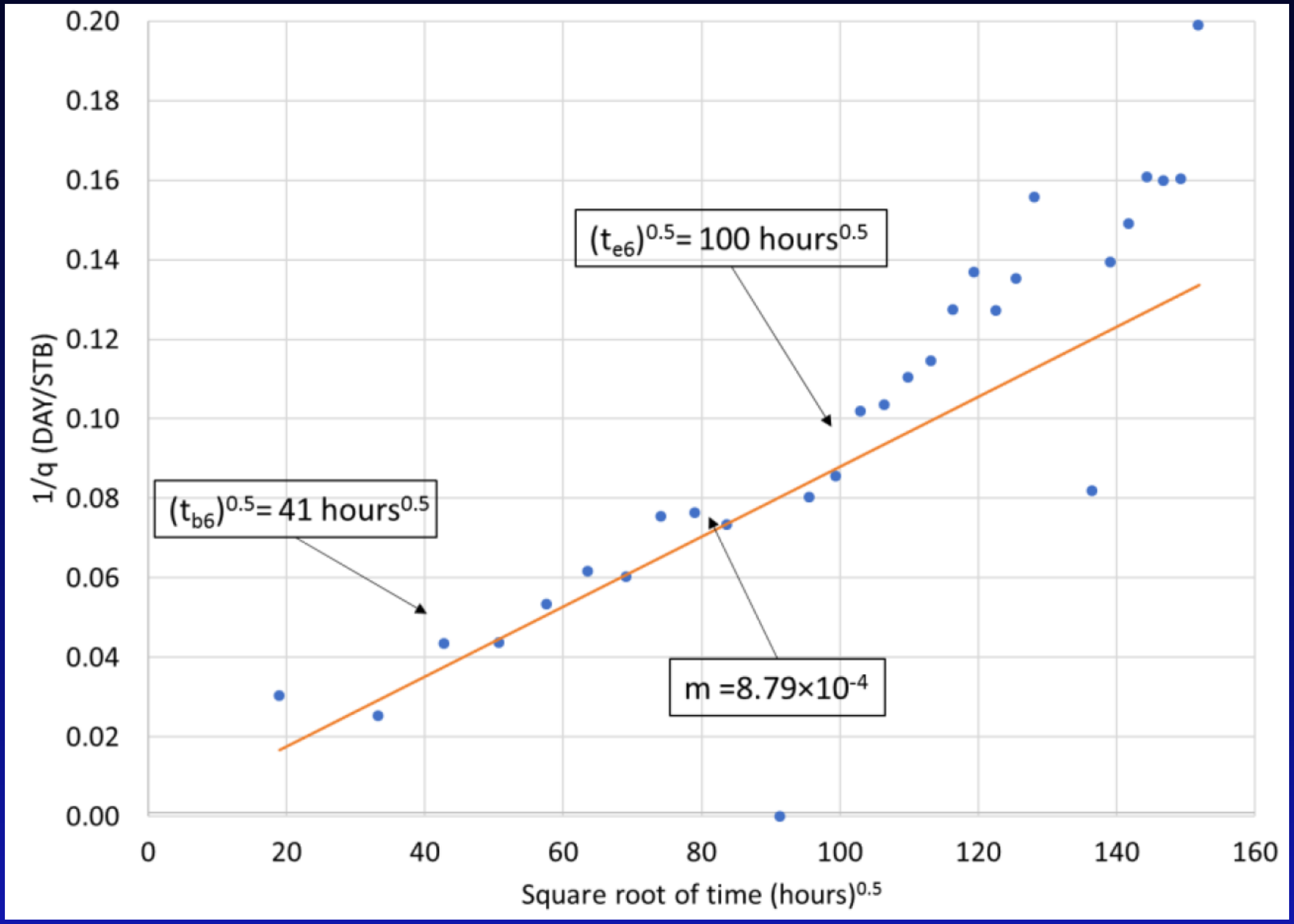
Log-log diagnostic plot



Identify linear flow trend and mark up the start and end times

Field Example: Eagle Ford well

Cartesian (square-root-of-time) plot

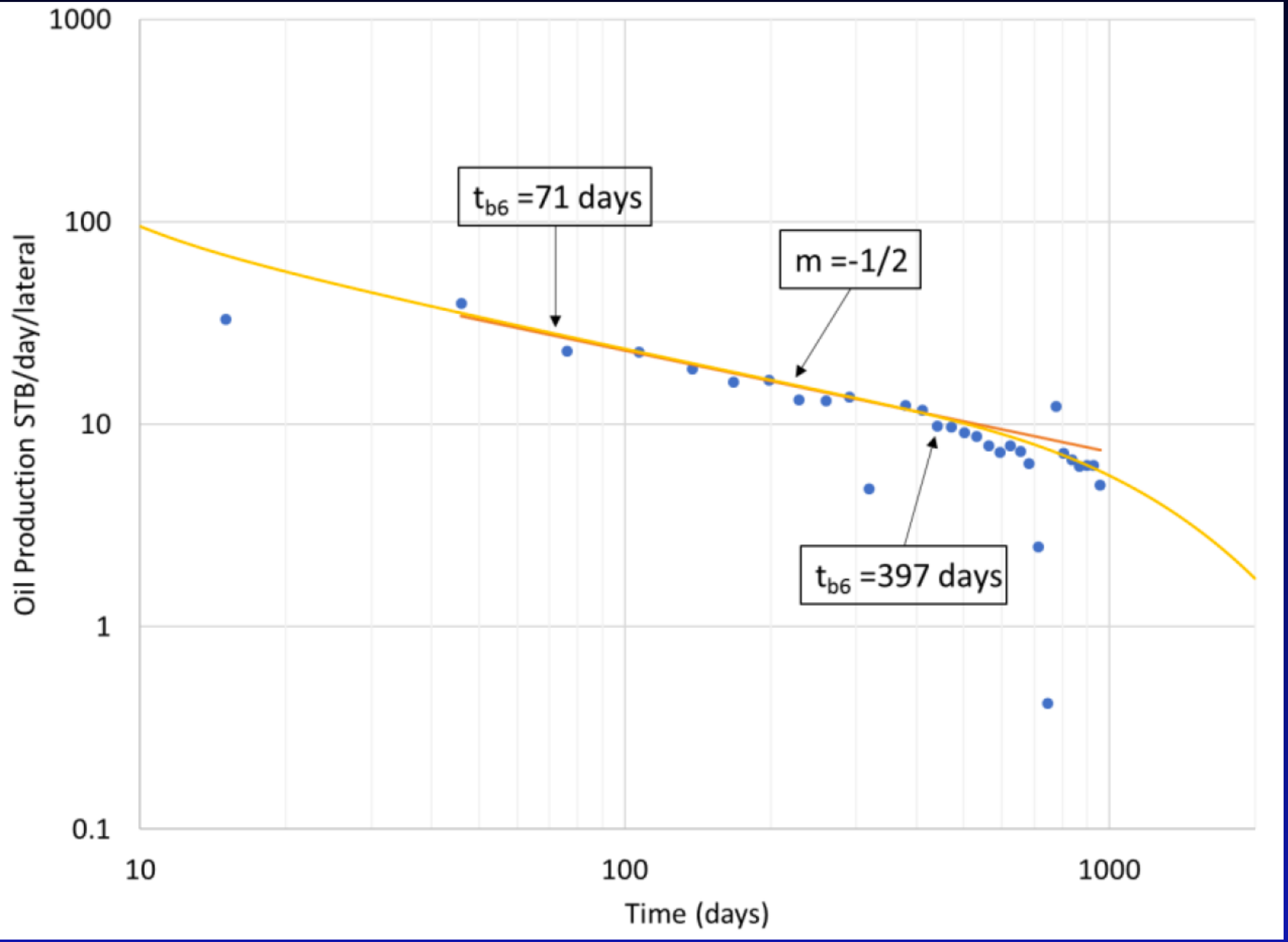


Assume FR 6B

Use the equations for the slope of the straight line and the start & end of linear flow to obtain matrix properties, k_m and $(\phi c)_m$.

Field Example: Eagle Ford well

Model match of the data



If fracture properties are known, match data with model for verification

Else, use matrix properties in regression to obtain fracture properties

Check the existence condition of FR 6B for consistency

Field Example: Eagle Ford well

Equations used in the analysis

$$k_m = \left[\frac{0.7980 \mu h_m}{m\, n_F\, x_F\, n_f \left(y_e - \frac{w_F}{2}\right) \Delta p}\right] \sqrt{\frac{180.13}{t_{e6}}}$$ Slope

$$t_{b6b} = 42{,}230 \left(y_e - \frac{w_F}{2}\right)^4 \frac{k_m\, c_m\, \phi_m\, \mu}{k_f^2 h_f^2}$$ Start of FR 6B if it follows bilinear flow

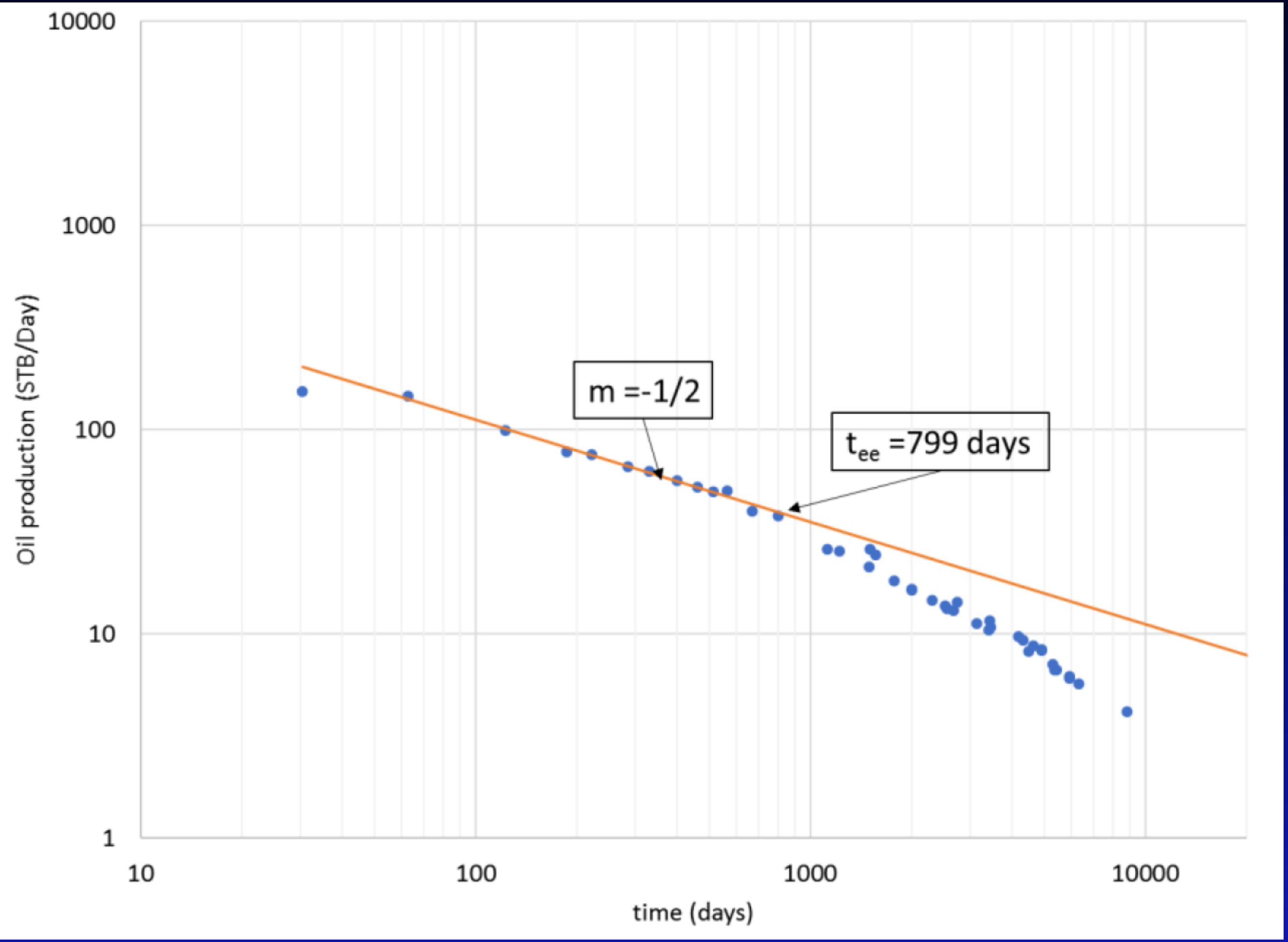
$$t_{b6b} = \frac{1.35\times10^5 \left(y_e - \frac{w_F}{2}\right)^2 c_f\, \phi_f\, \mu}{k_f}$$ Start of FR 6B if no bilinear flow

$$t_{e6b} = \frac{180.13\, h_m^2\, c_m\, \phi_m\, \mu}{k_m}$$ End of FR 6B

$$\frac{\left(h_f\, c_f\, \phi_f + h_m\, c_m\, \phi_m\right) k_f\, h_f}{k_m\, c_m\, \phi_m \left(y_e - \frac{w_F}{2}\right)^2} > 4$$ Existence condition of FR 6B

Field Example: Niobrara well

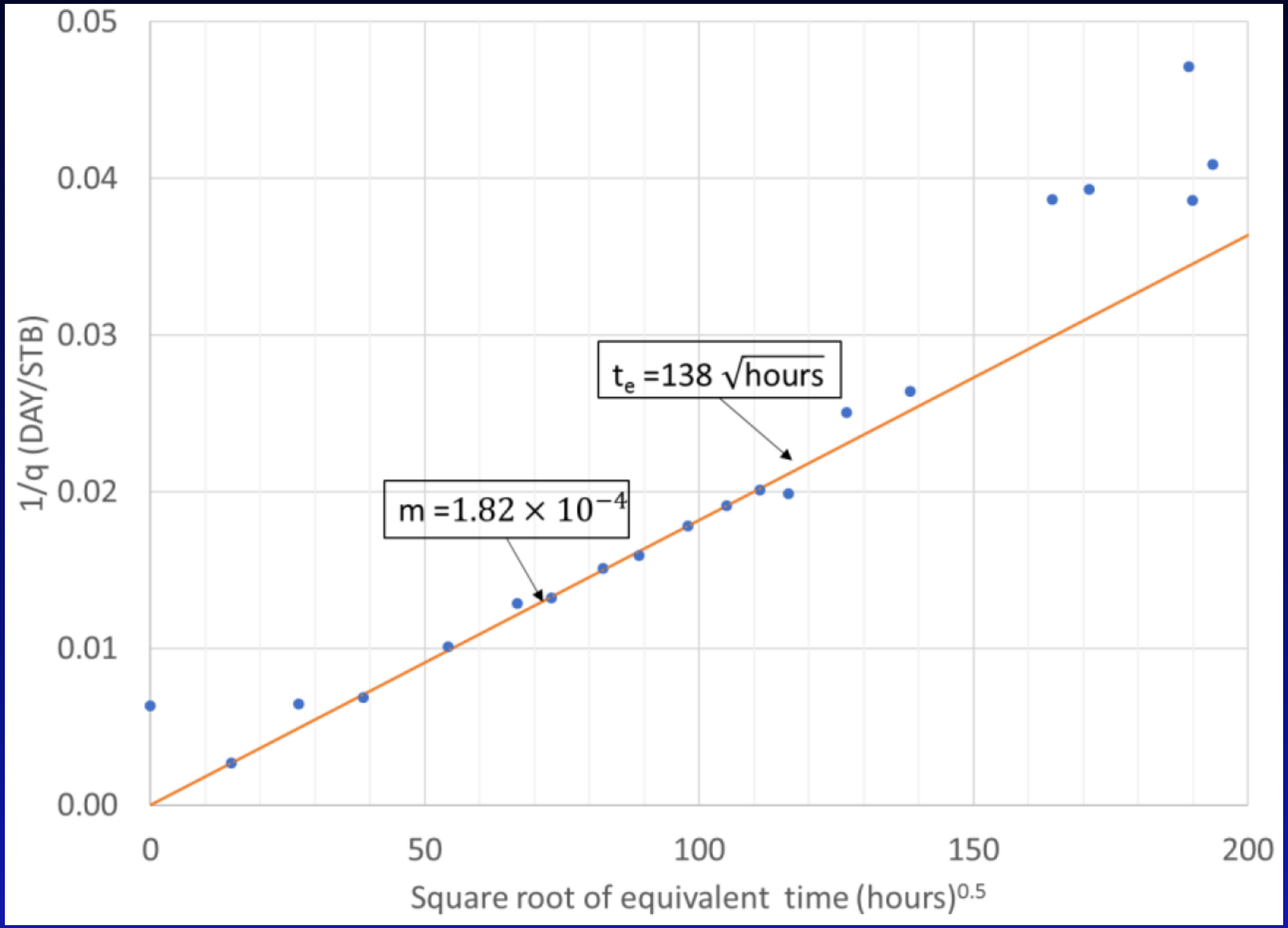
Log-log diagnostic plot



Identify linear flow trend and mark up the end time (start time is not clear)

Field Example: Niobrara well

Cartesian (square-root-of-time) plot



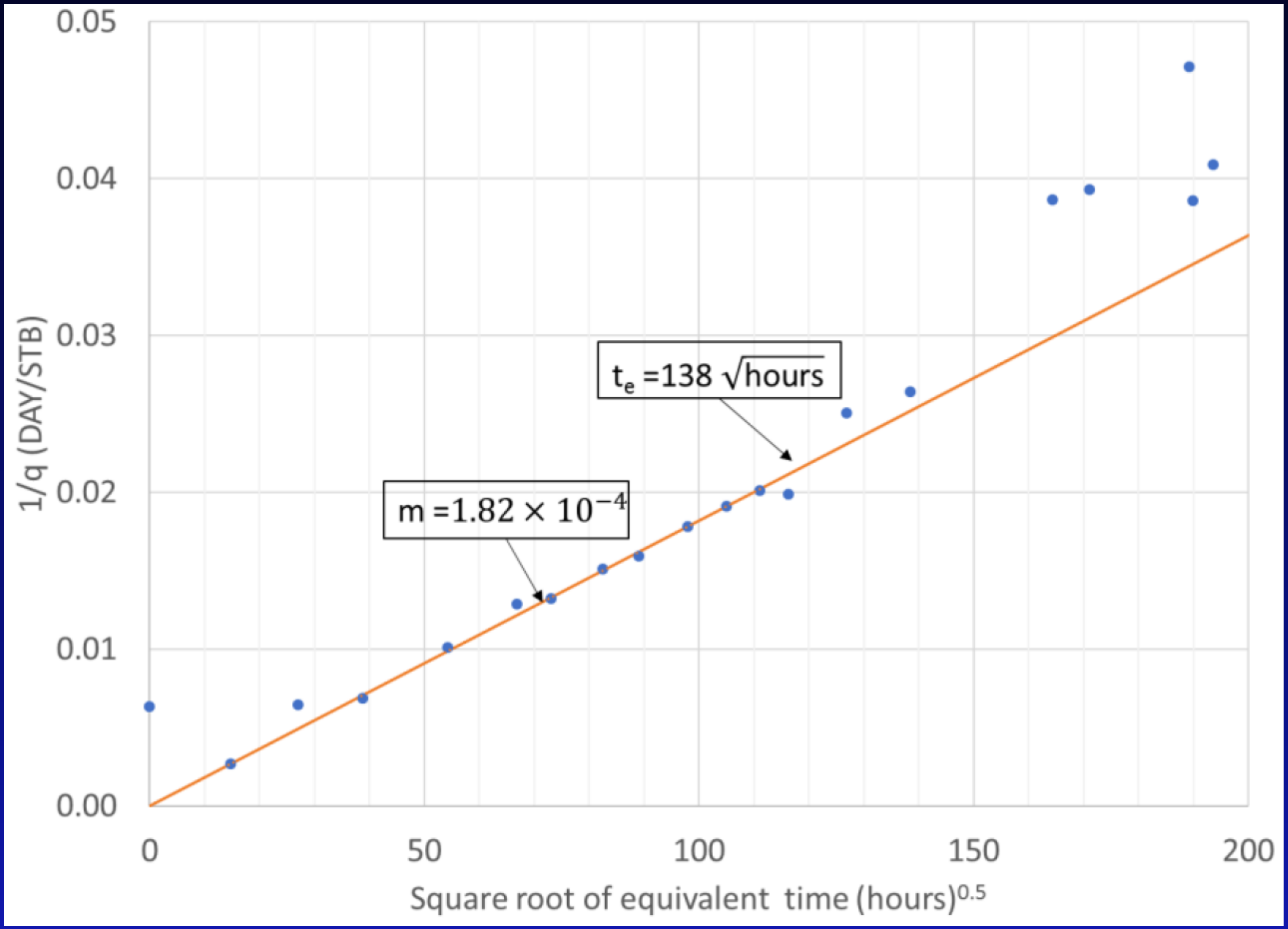
Assume FR 3

Use the equations for the slope of the straight line and the end of linear flow to obtain fracture properties, k_f and $(\phi c)_f$

Verify the existence condition of FR 3

Field Example: Niobrara well

Cartesian (square-root-of-time) plot



Repeat the analysis assuming FR 6A & FR 6B

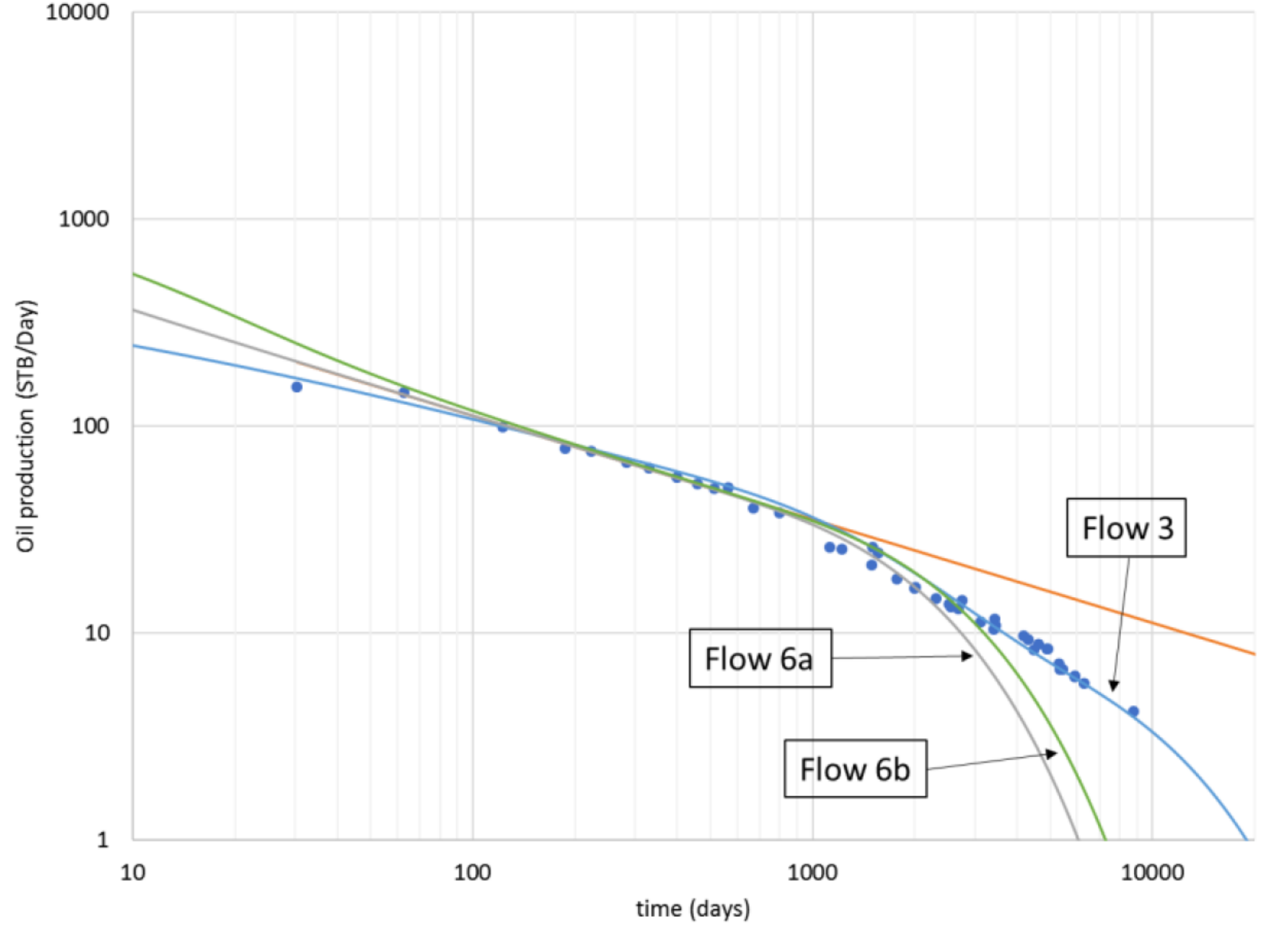
FR 6A: Estimate matrix properties, k_m and $(\phi c)_m$

FR 6B: Estimate fracture properties, k_f and $(\phi c)_f$

Verify the existence of FR 6A & FR 6B (existence of FR 6A is not verified)

Field Example: Niobrara well

Model match of the data



Using the data obtained from all three analyses, match the data with the model

Only FR 3 yields an acceptable match

Conclusions

In unconventional plays where producing layers are interbedded by tight storage layers (shale), pseudotransient linear flow may develop at intermediate times

It is essential to distinguish between transient (FR 3) and pseudotransient (FR 6) linear flows for the accuracy of the analysis

Analysis procedure outlined in this presentation helps identify the correct linear flow and consistently analyze the data

Further details are provided in the PhD dissertation of Wisam Assiri (2017)