# A Workflow to Assess Multi-Staged Horizontal Well Plays

**SPE Back to Basics Seminar**

**2014-05-21**

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# Question

- What metrics are you using to assess your horizontal wells ?
  - Initial production rate at a certain time in days ?
    - IP30, IP60 …
  - Cumulative production at a certain time ?
    - Cum 1 yr, Cum 2yr …
  - Other

# Introduction

- Multi-Stage Horizontal Fracture Challenges
  1. Developing Type Curves
  2. Effectiveness of Current Fracture Stimulation Strategy
     1. Identifying successful plays
     2. Identifying successful companies
     3. What makes a good well ?
        - Sweet spot
        - Stimulation
     4. Optimal treatment selection

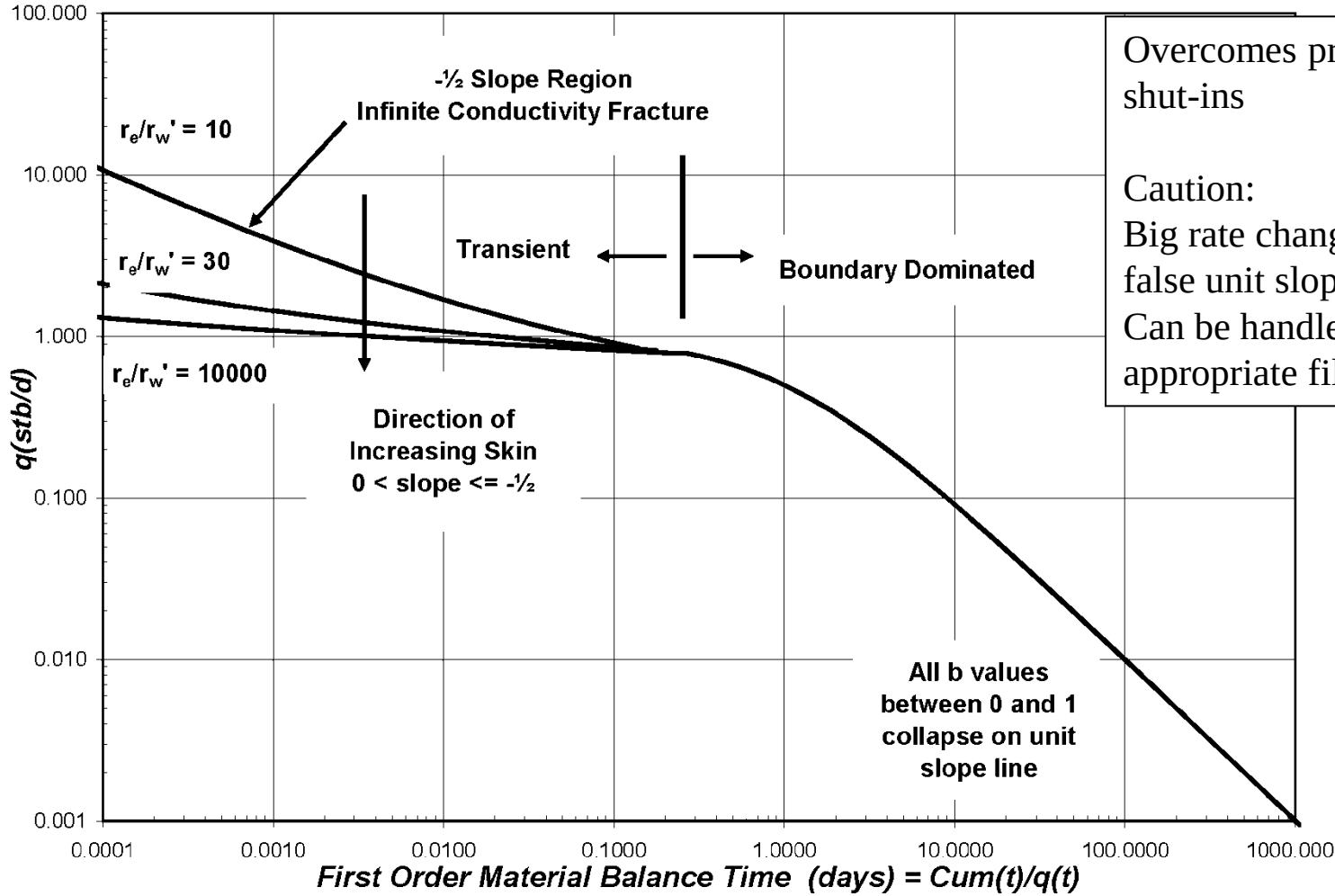
# Approach

- Illustrated by case studies
  - Viking Plato
  - Montney Gas
    - 2 case studies

# Important Concept - Flow Regimes

- What are they ?
  - Early (transient)
    - Drainage area increasing
  - Late (bounded)
    - Drainage area fixed
- Vertical and horizontal wells
  - What are the important flow regimes
    - Radial flow (transient)
    - Linear flow (transient)
    - Bounded flow
  - They have a mathematical signature

# Modified Fetkovich Plot or Blasingame Type Curve



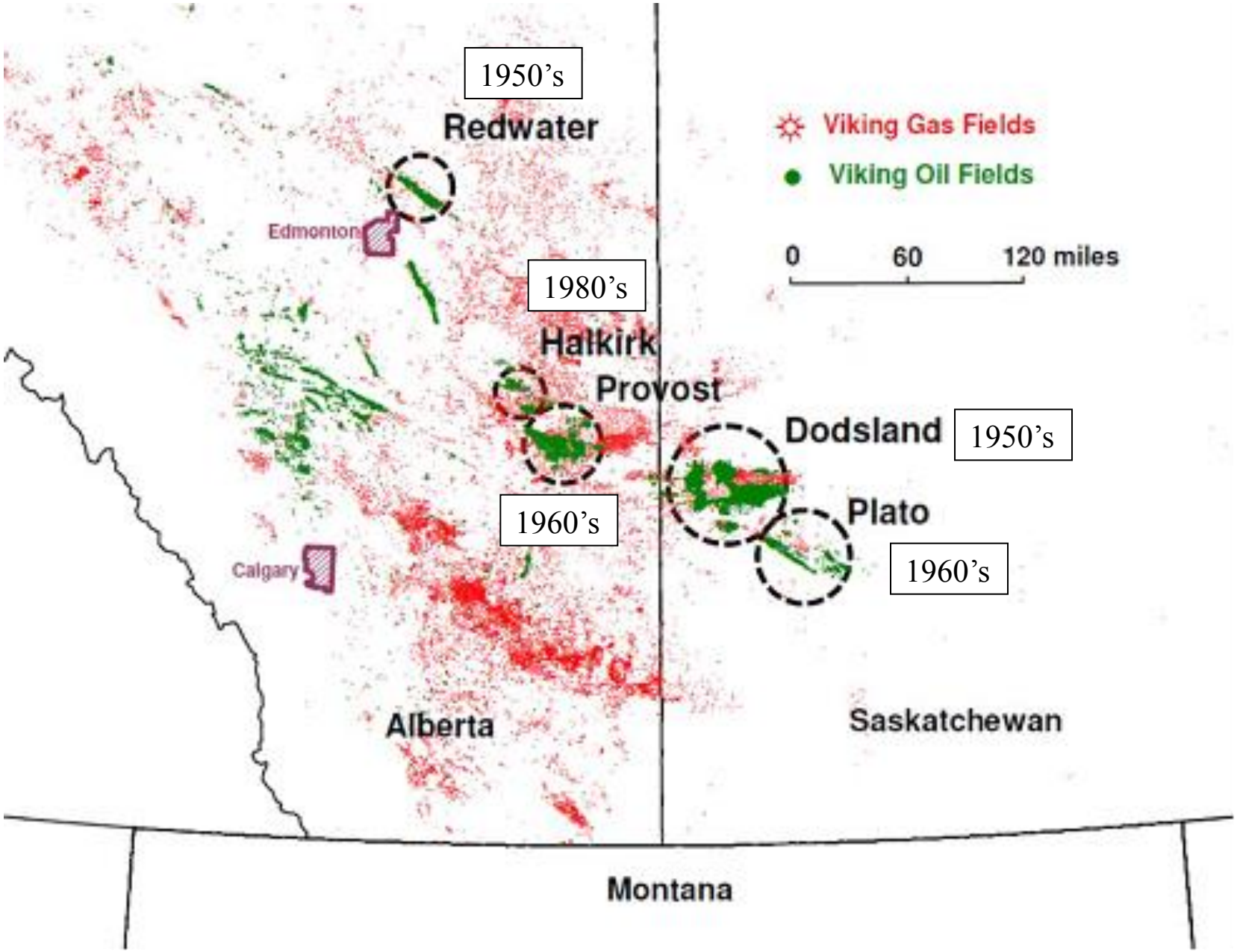

Overcomes problem of shut-ins

Caution:
Big rate changes will give false unit slopes
Can be handled by appropriate filtering

If $p_{wf}$ changes with time replace with $q/(p_i-p_{wf}) = q/\Delta p$

# Case 1 - SPE 162813
# Viking - Oil

- Widespread across Alberta and Saskatchewan
  - 5 fields focused on
- Cretaceous age
- Deposited in transitional to marine environment
  - Direction of shoreline was NW/SE
- thinly-laminated, bioturbated, clastic (sand/silt/shale)



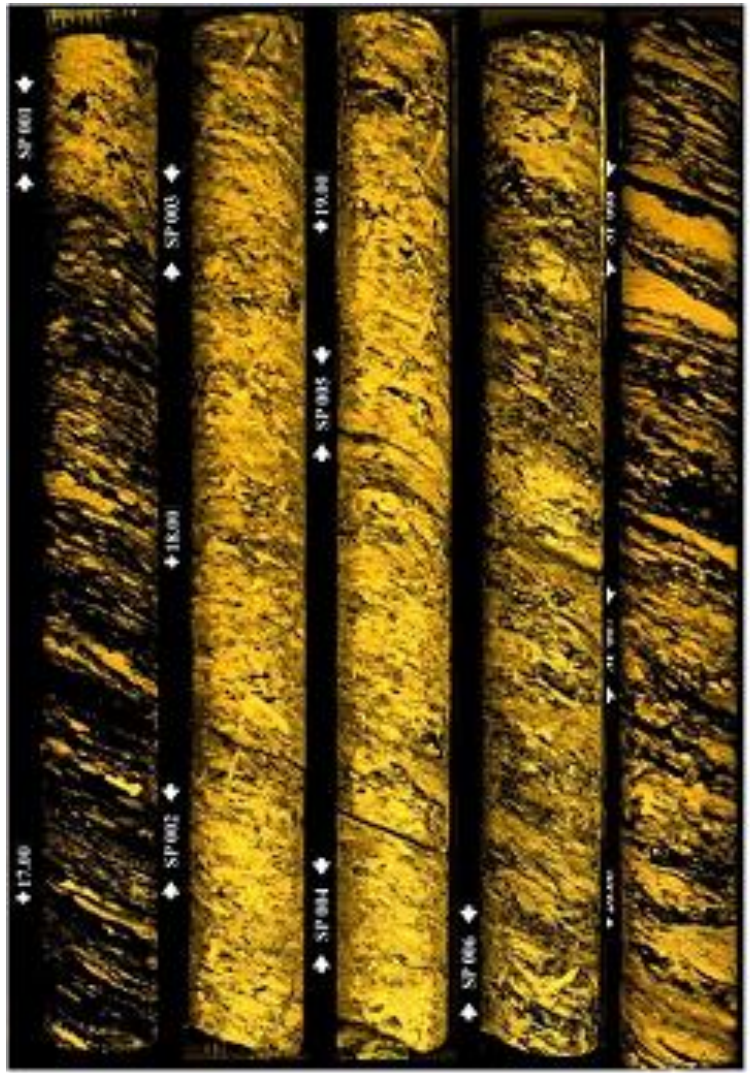

Viking Formation Western Canada

# Production History

- Production began:
  - Redwater + Greater Dodsland in 1950's
  - Provost in early 1960's
  - Plato in late 1960's
  - Halkirk in early 1980's
- Wells predominantly vertical
  - Hydraulically fractured (sometimes repeatedly)
  - Starting in 2006 horizontal multi-stage fracturing started
    - 1100 such wells
- Some attempts at waterflooding
  - Mostly unsuccessful

# Reservoir Properties

- Pi ≈ 6.2 MPa
- Reservoir Temperature 28 – 30 $^{o}$C
- Depth ≈ 700 m
- Low GOR ? (reporting issue in Saskatchewan)
- Soft friable rocks
  - Difficulties fracturing through even thin ‘barriers’
- Swelling clays
- Paraffin based waxy light crude (37 to 39 API)
  - Cloud point ≈ 23 $^{o}$C



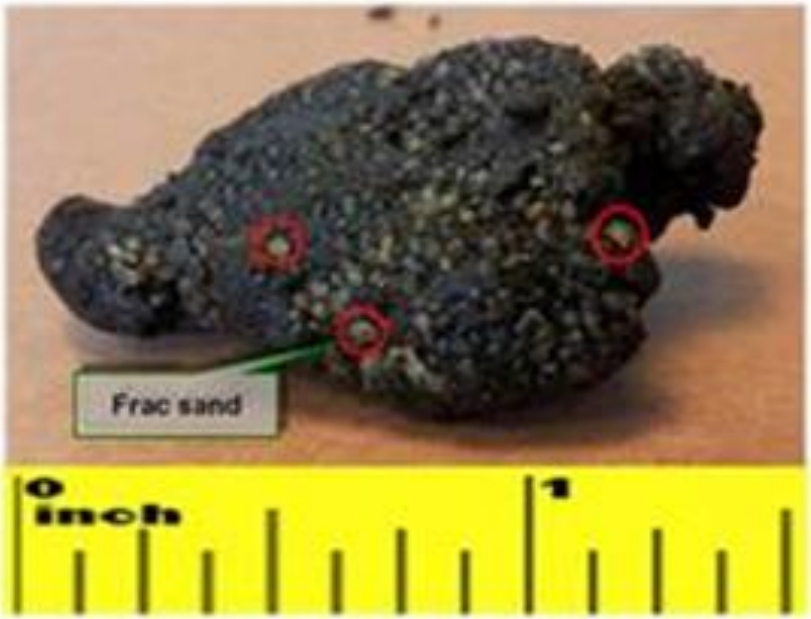
- Discontinuous and compartmentalized interbedded sands and shales
- Thinly laminated and bioturbated ('lam scram')

Viking Net Pay Determination (UV Digital Processing)

Core put into fresh water

Currently using high concentrations of KCL as clay stabilizer

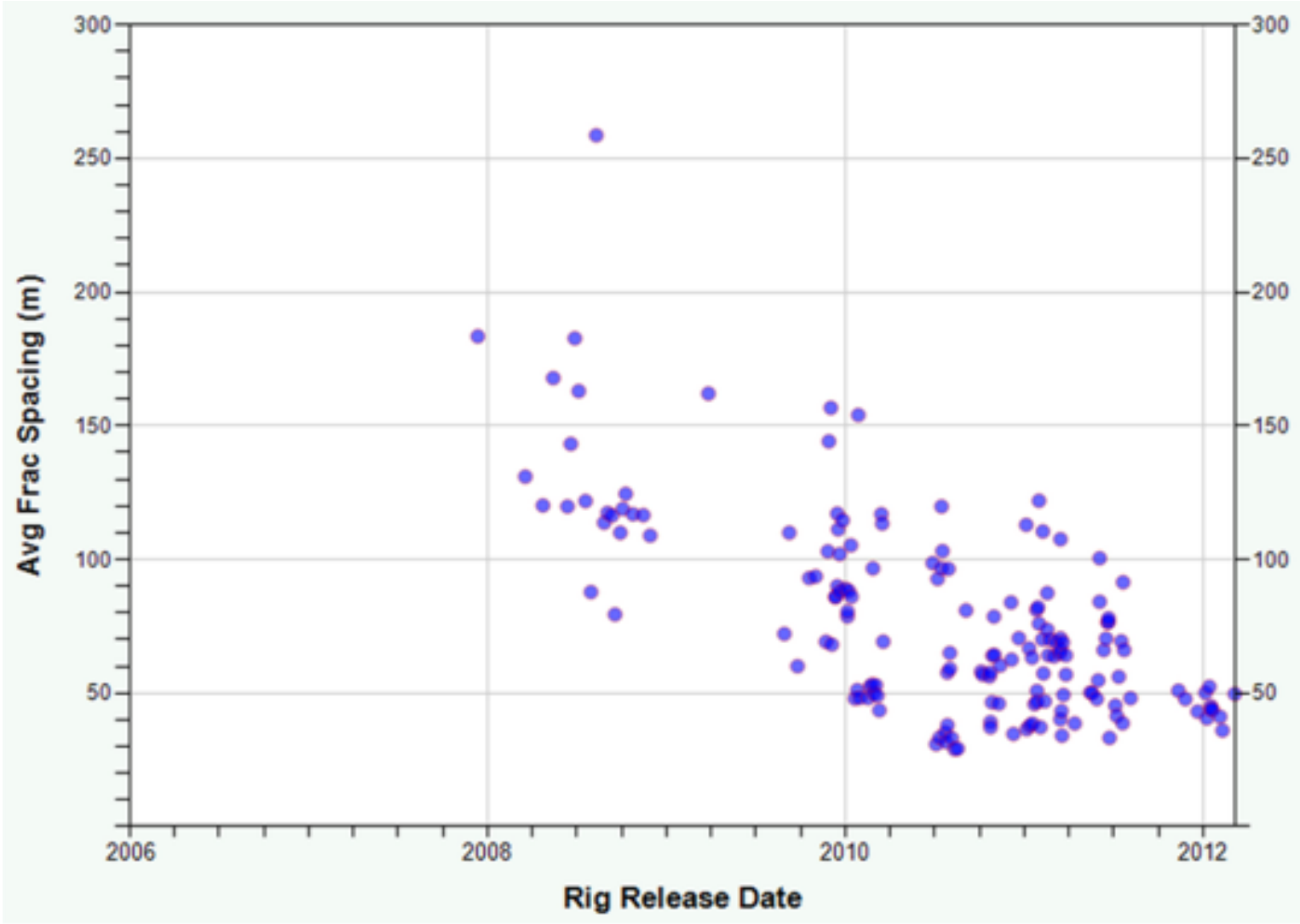
Swelling Clays/Fines Migration




Fear of wax deposition in perforations has lead to hot water treatments in the area

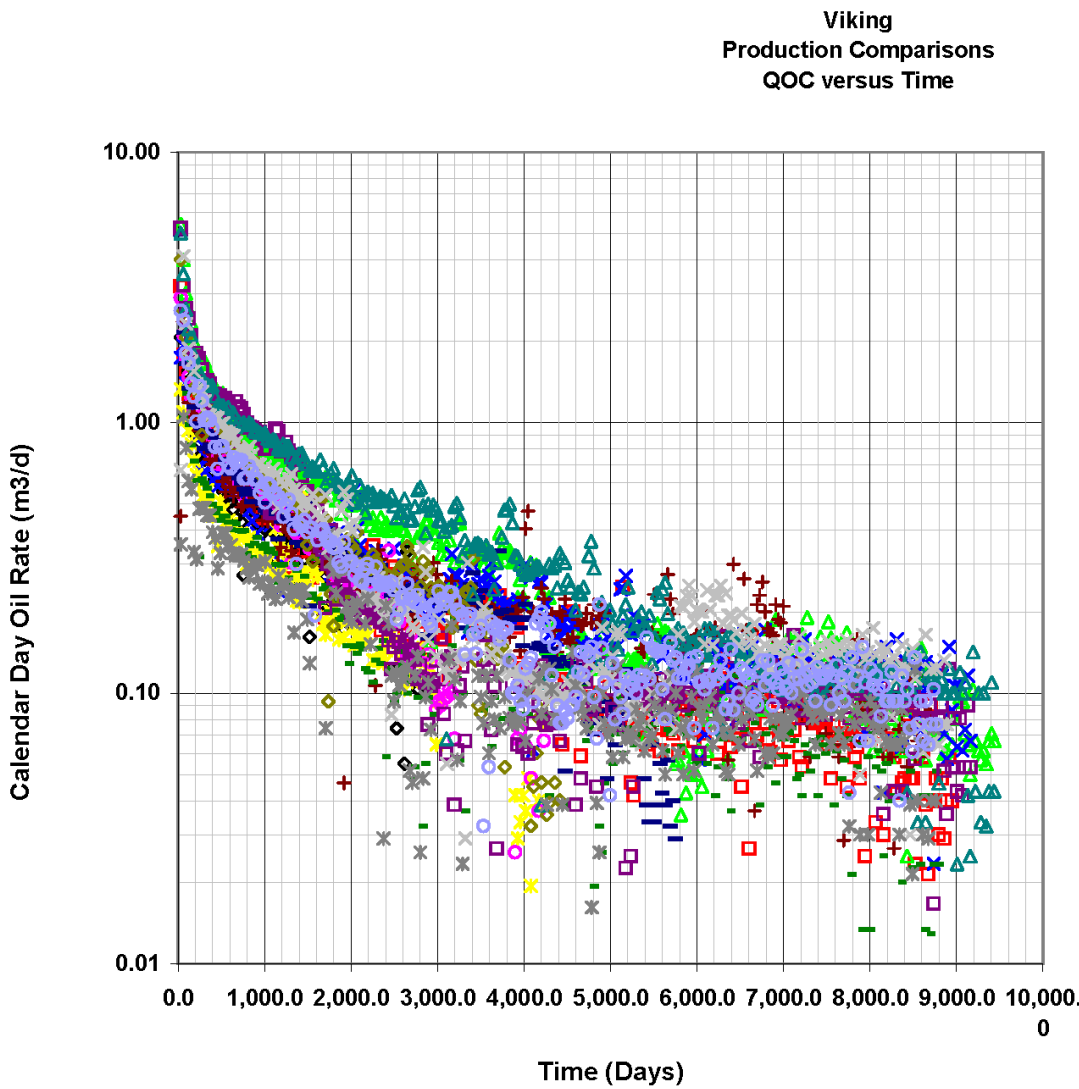
Wax Deposition

# Fracture Treatment Stage Spacing versus Date



# Production Analysis/Forecasting

- Start with Vertical Wells
  - Flow Regime Identification
  - Time to end of transient flow (start bounded flow)
    - What type of transient flow
  - Do we get more reserves when we infill drill ?
  - Type curve for reserves determination
    - Methodology
- Horizontal Wells
  - Repeat vertical well workflow



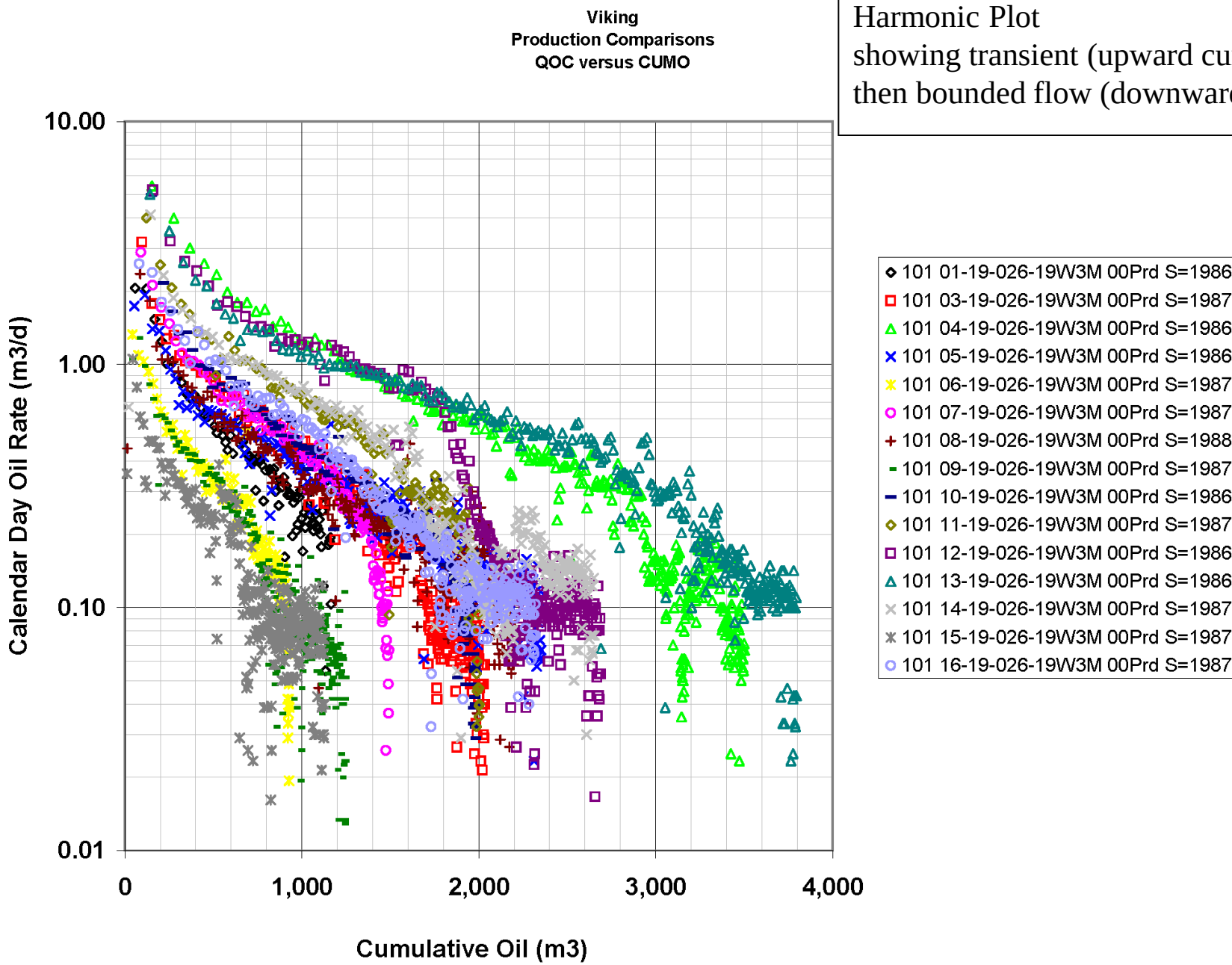

Traditional semi-log plot seen everywhere
No ability to identify reservoir behavior (early or late time flow regimes

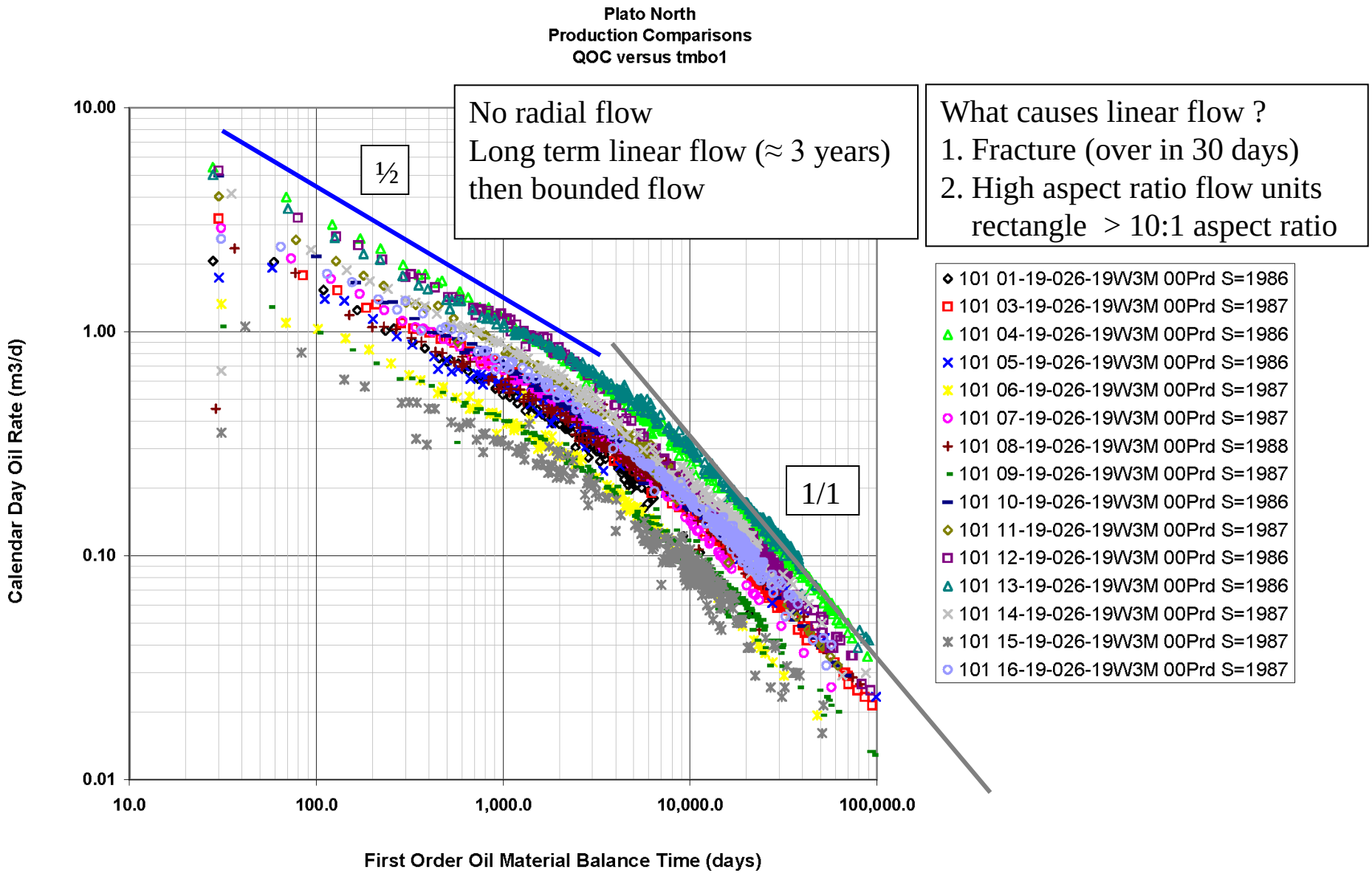
101 01-19-026-19W3M 00Prd S=1986
101 03-19-026-19W3M 00Prd S=1987
101 04-19-026-19W3M 00Prd S=1986
101 05-19-026-19W3M 00Prd S=1986
101 06-19-026-19W3M 00Prd S=1987
101 07-19-026-19W3M 00Prd S=1987
101 08-19-026-19W3M 00Prd S=1988
101 09-19-026-19W3M 00Prd S=1987
101 10-19-026-19W3M 00Prd S=1986
101 11-19-026-19W3M 00Prd S=1987
101 12-19-026-19W3M 00Prd S=1986
101 13-19-026-19W3M 00Prd S=1986
101 14-19-026-19W3M 00Prd S=1987
101 15-19-026-19W3M 00Prd S=1987
101 16-19-026-19W3M 00Prd S=1987

All Wells Hydraulically Fractured

Oil Production for Vertical North Plato Wells within one Section (Wells start in 1986 and 1987)

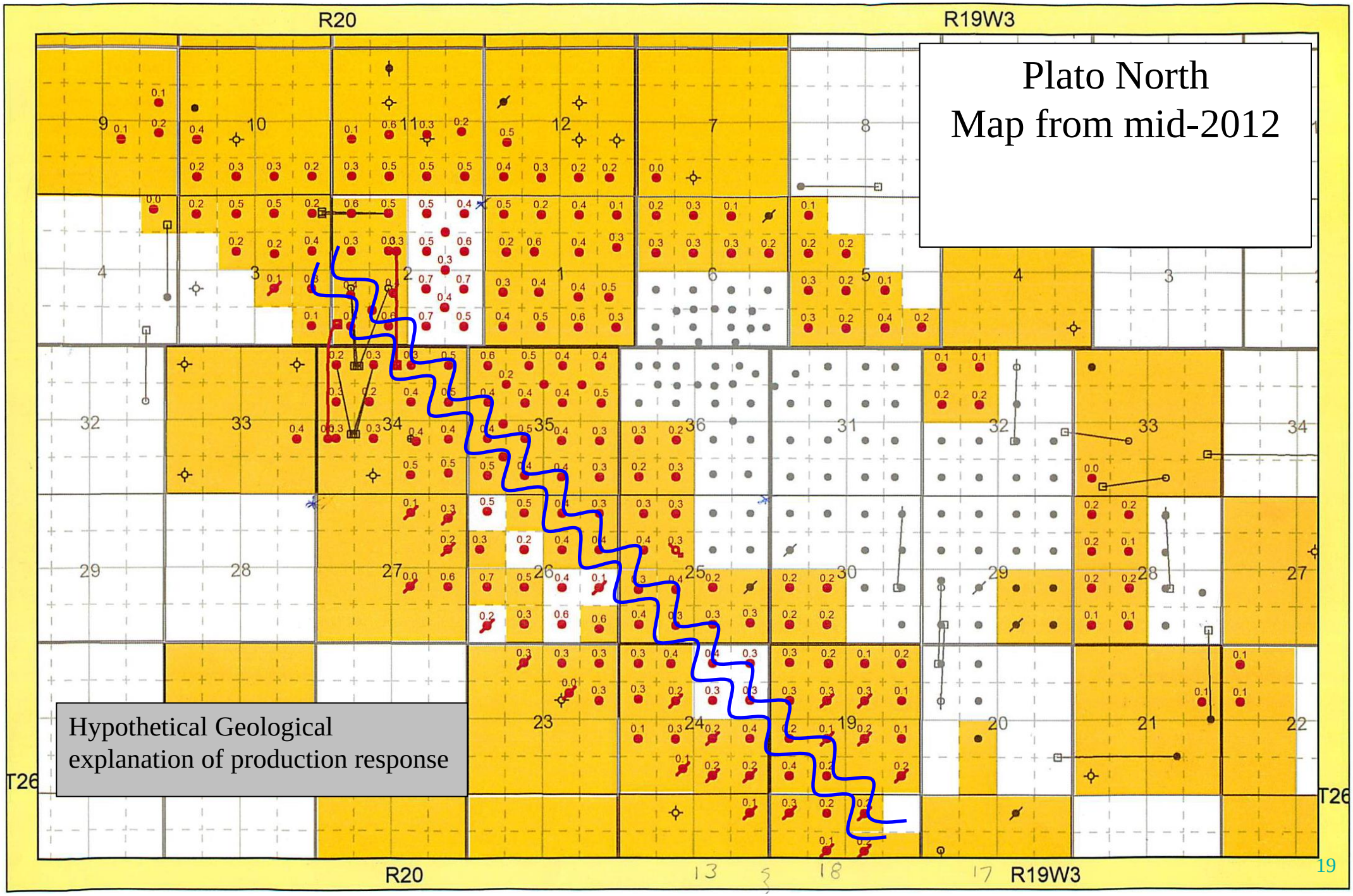
Harmonic Plot
showing transient (upward curvature)
then bounded flow (downward curvature)

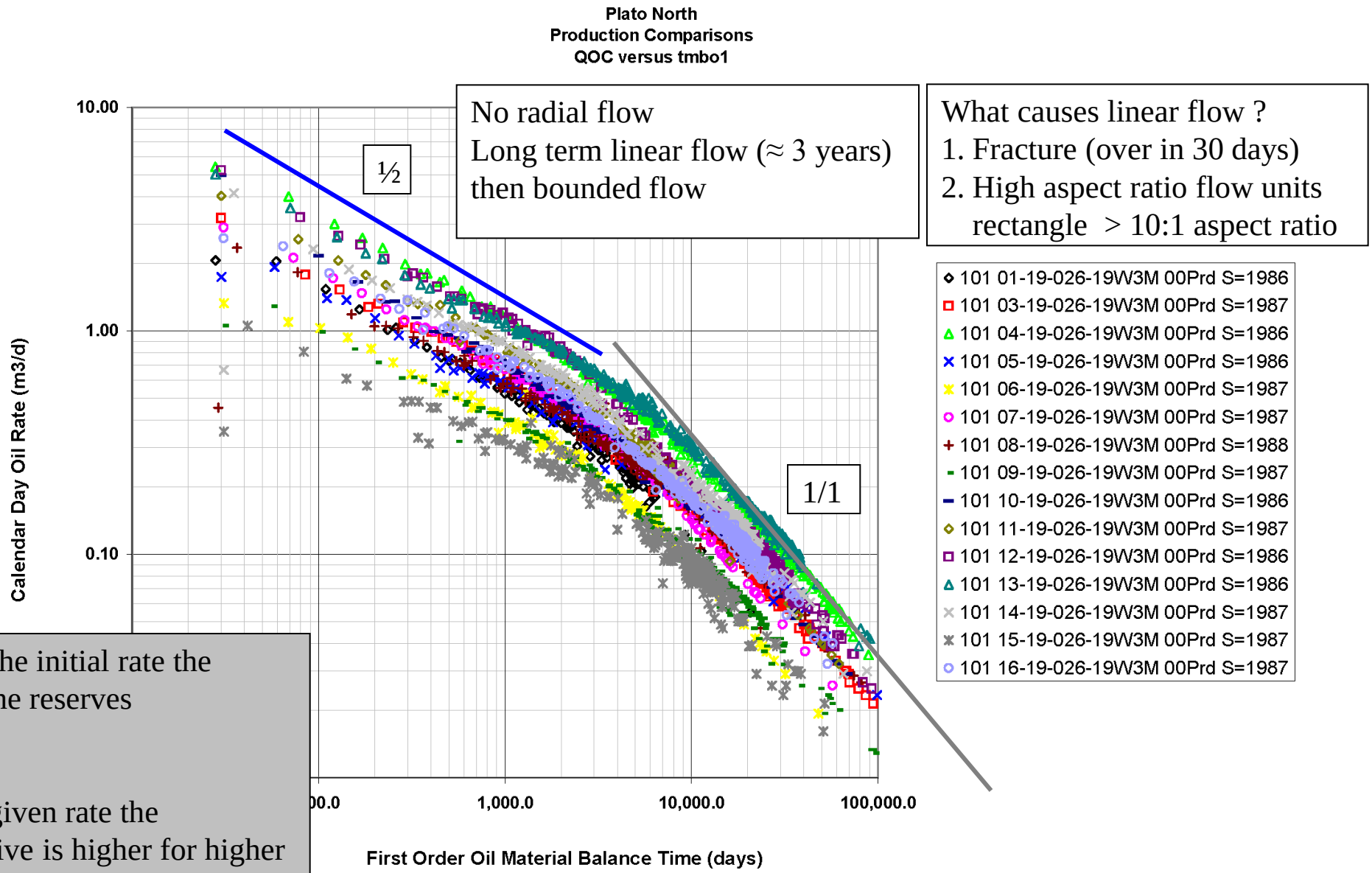





First Order Material Balance Time = Cum(t)/q(t)

Modified Fetkovich Plot - Vertical North Plato Wells


Plato North
Map from mid-2012
Hypothetical Geological
explanation of production response
R20
R19W3
T26
13
18
17




No radial flow
Long term linear flow (≈ 3 years) then bounded flow

What causes linear flow ?
1. Fracture (over in 30 days)
2. High aspect ratio flow units rectangle > 10:1 aspect ratio

Higher the initial rate the higher the reserves

Why ?
At any given rate the cumulative is higher for higher initial rate wells

Order Material Balance Time = Cum(t)/q(t)

Modified Fetkovich Plot - Vertical North Plato Wells

# Type Curve (1)
# Old Ideas

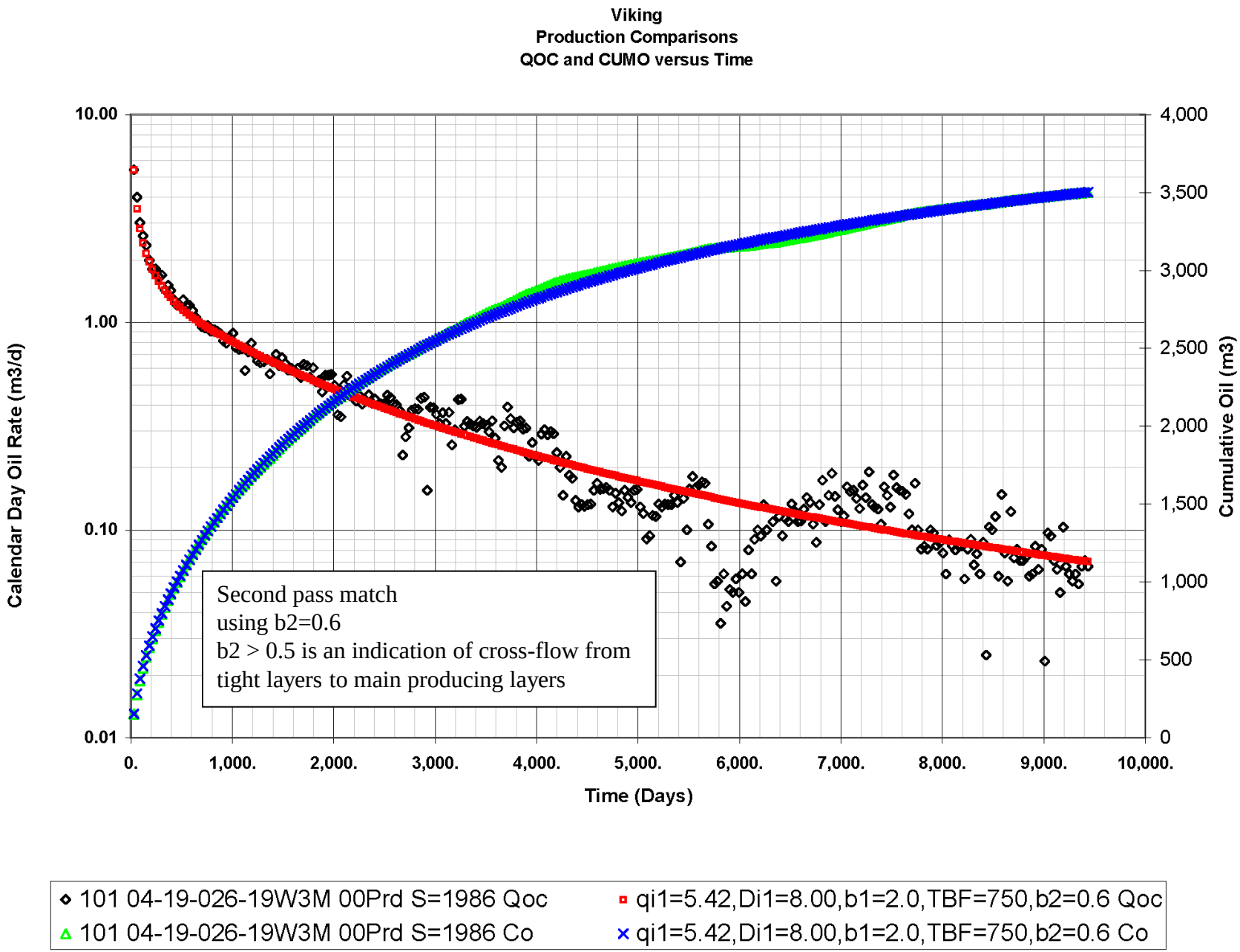
- Old ideas
  - Never allow b>1
  - Arbitrarily curve fit data

# Type Curve (2a)
# My Recommendation

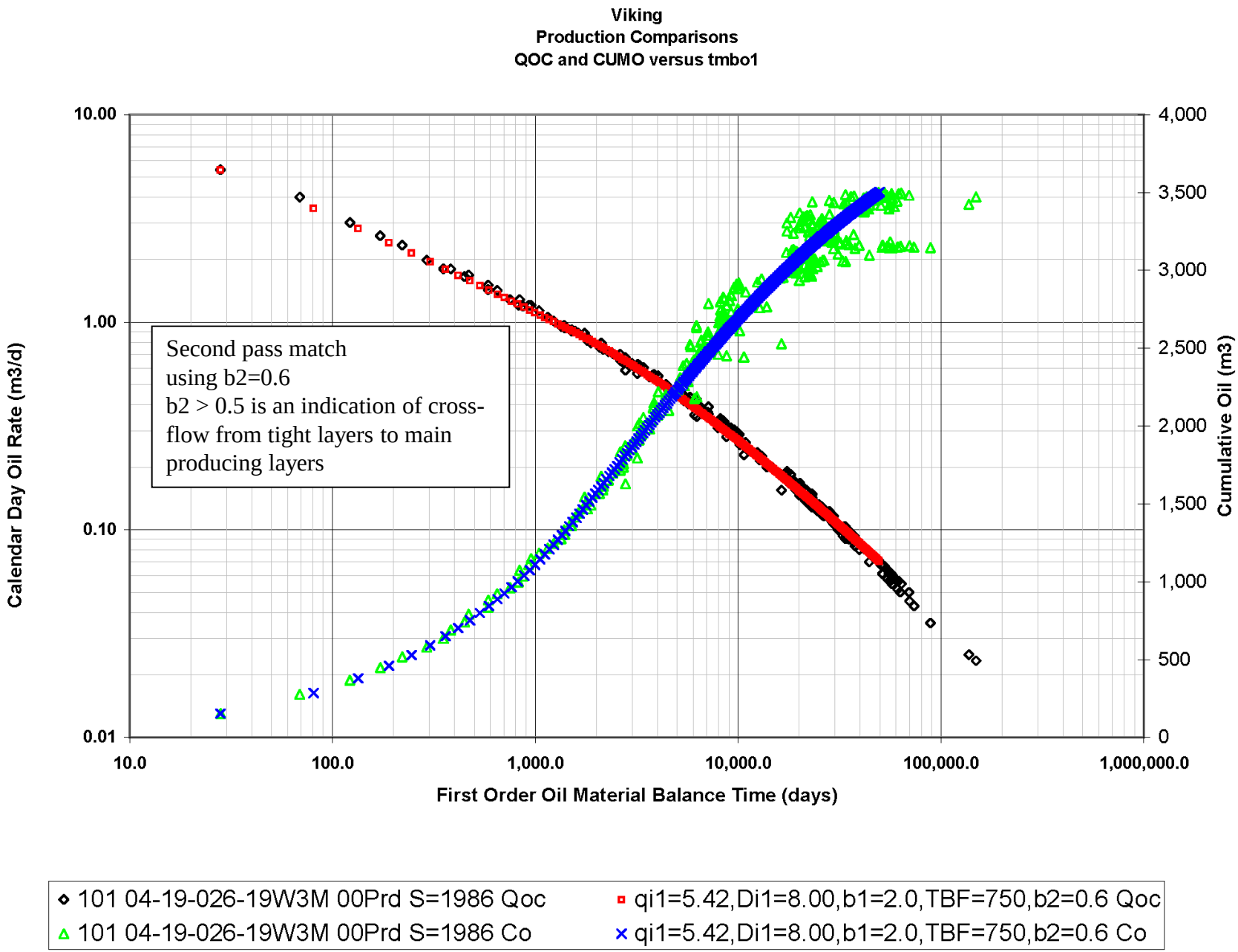
- Physics based type curves
  - Composite decline curves
    - Three Stems
    - Available in most software

# Type Curve (2b)
# My Recommendation

- Stem 1 - Transient Flow
  - b >1 is indication of transient behavior
  - b = 2 is linear flow
  - time to end of transient flow = end of b > 1
- Stem 2 - Bounded Flow
  - b for solution gas drive (single layer)
    - b = 0.3 Fetkovich
    - 0.4 < b <0.5 Ahmed and McKinney
  - b for solution gas drive (multiple layer)
    - 0.5 < b <1.0 Fetkovich
  - It is my recommendation not to regress on b but to assign b after careful consideration
- Stem 3 - Terminal Decline (exponential decline)
  - How do you pick it?
  - Typically around 6% per year



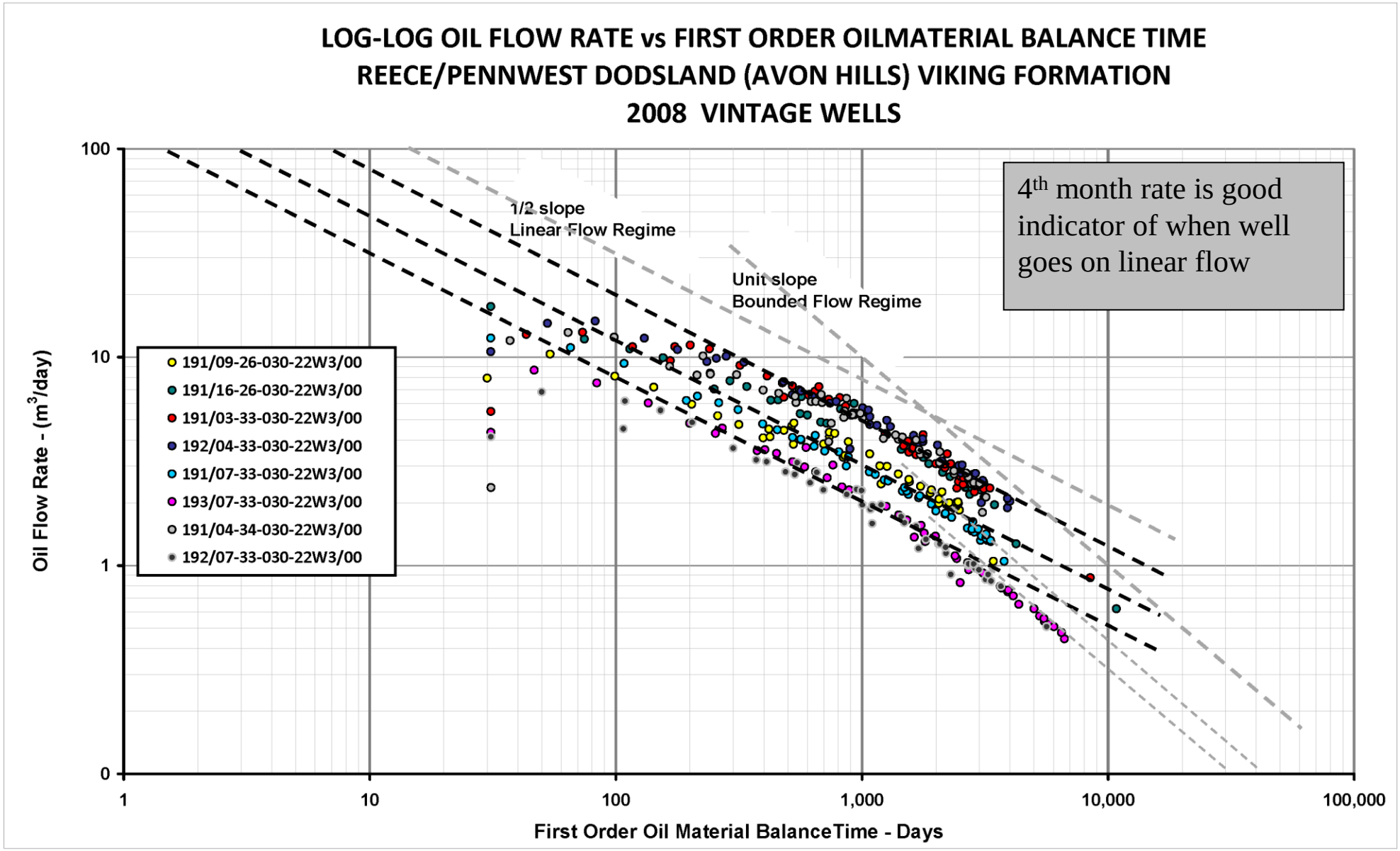

Semi-Log Rate/Time – Type Curve Match 2 where late time b=0.6



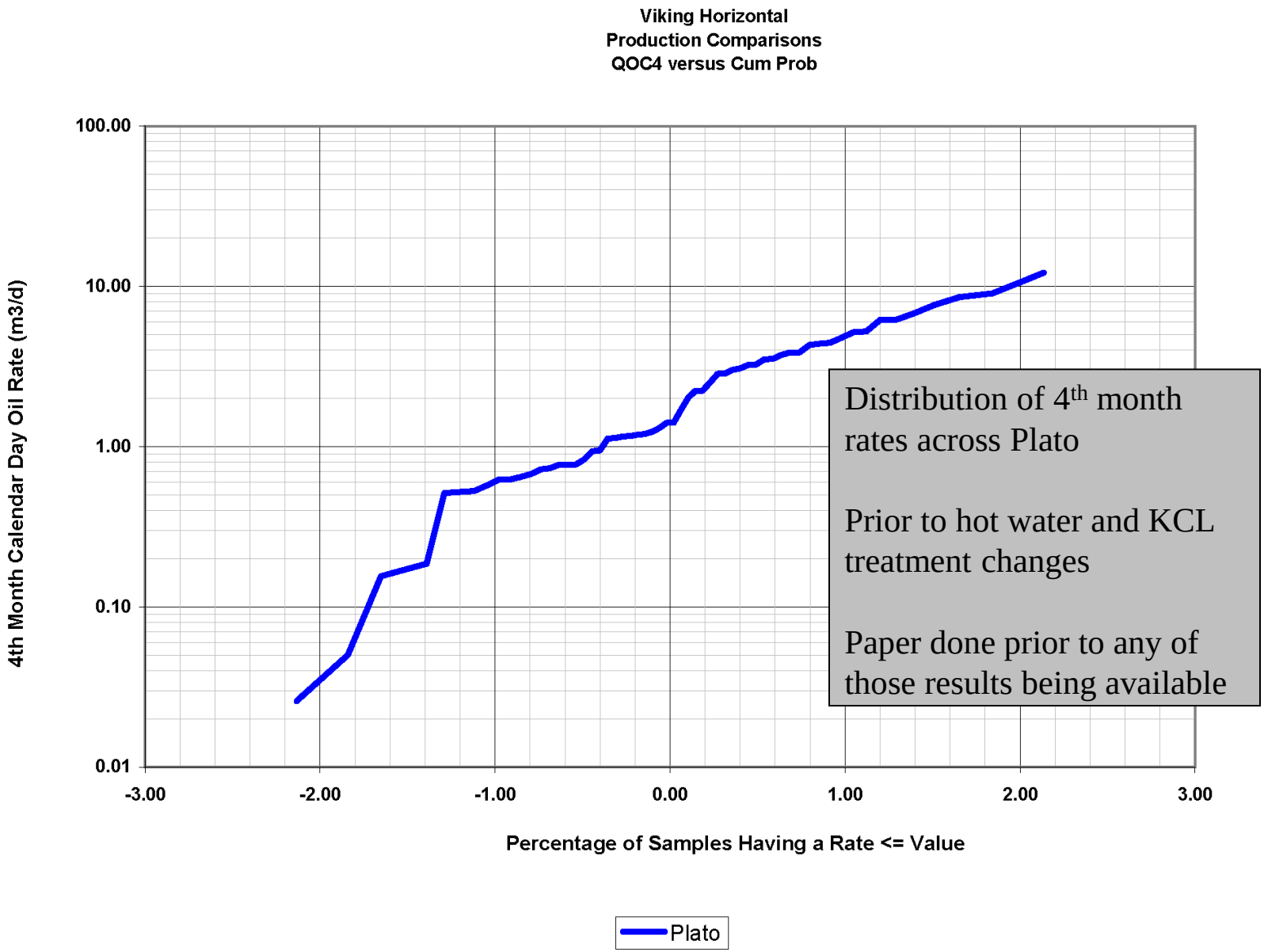

Fetkovich Plot – Type Curve Match 2 where late time b=0.6

# Horizontal Wells

# Horizontal Wells with Longest Production History



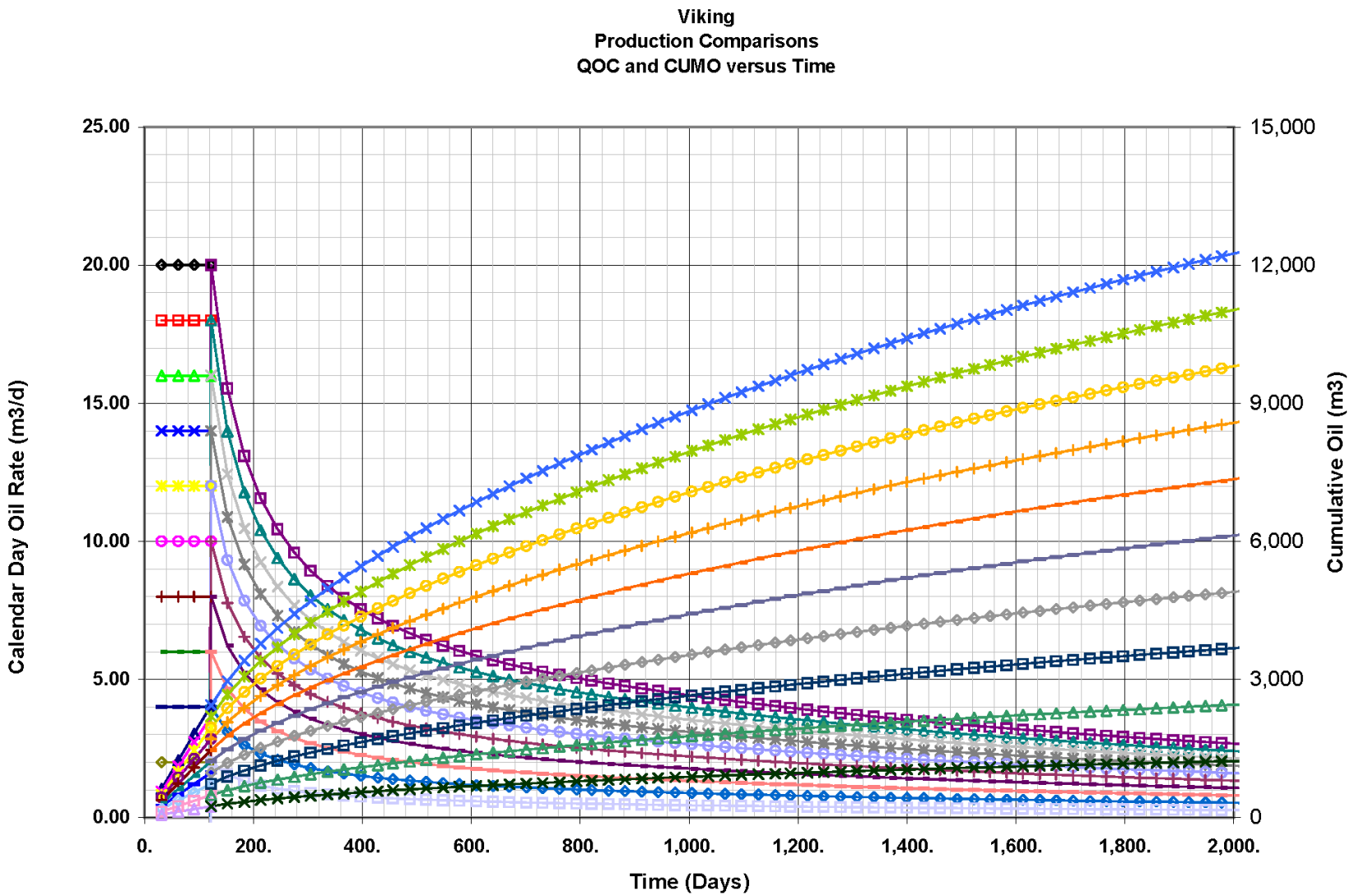

Early Dodsland Horizontal Multi-Stage Fractured Wells




Distribution of 4th month rates across Plato

Prior to hot water and KCL treatment changes

Paper done prior to any of those results being available

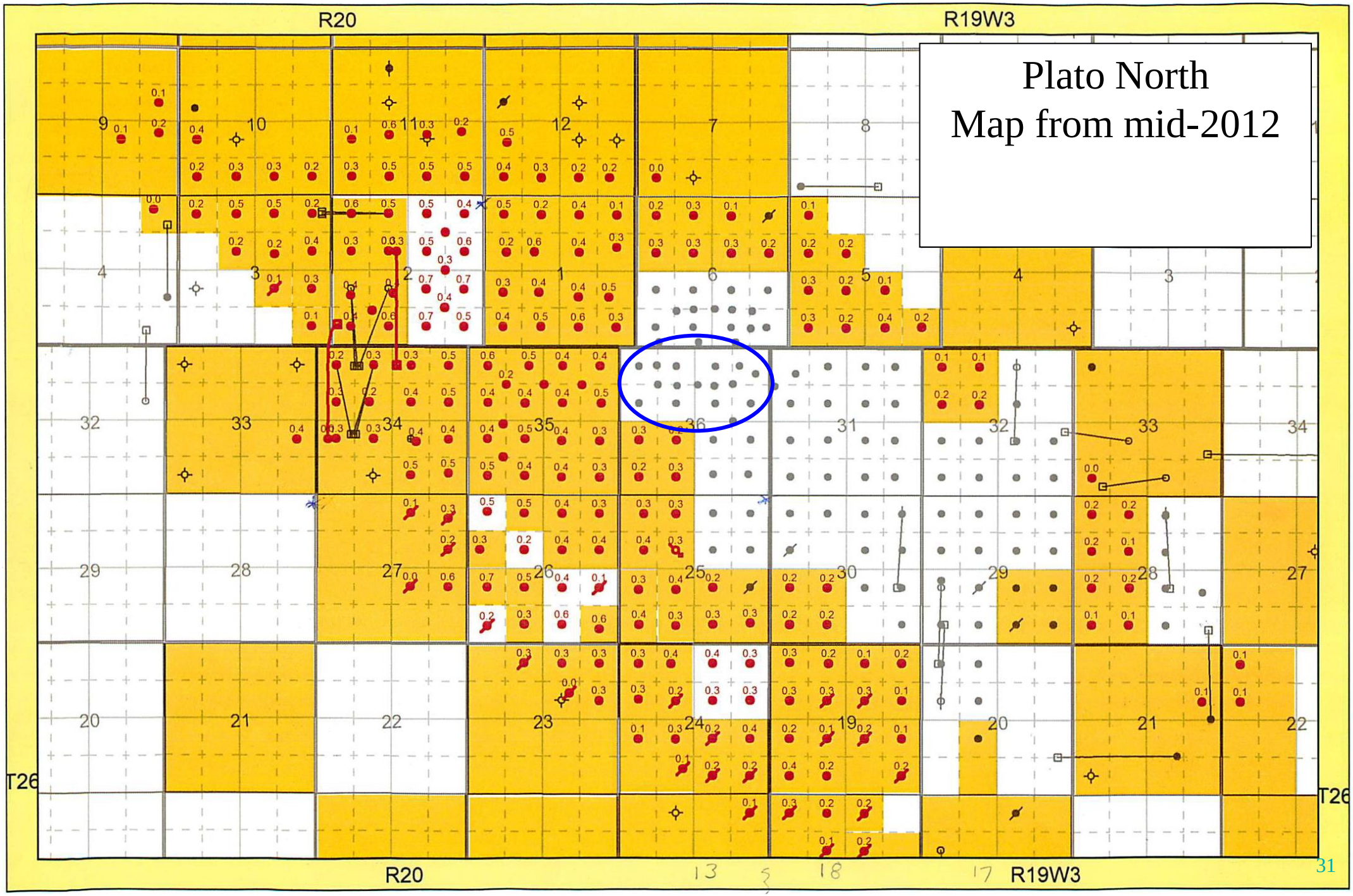


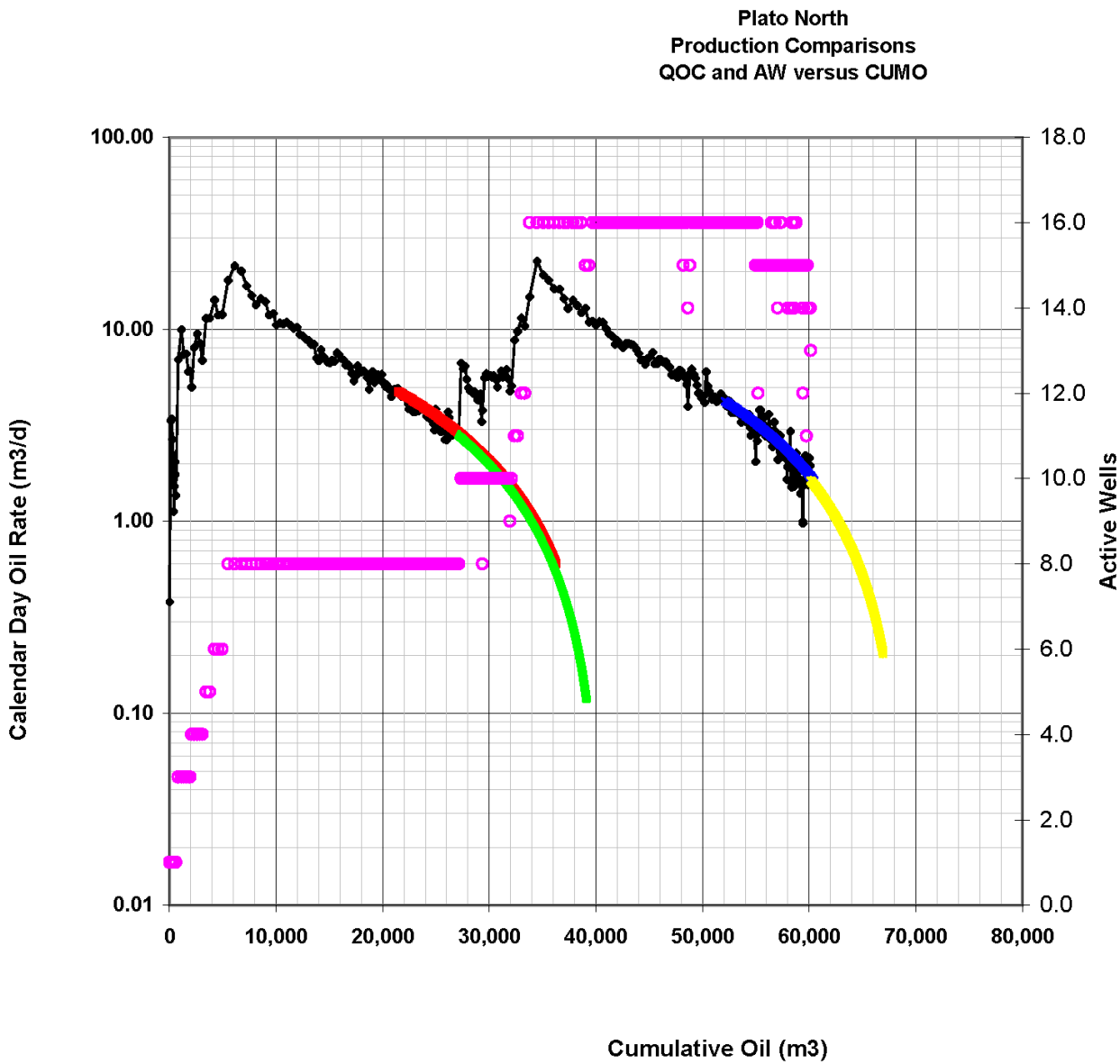

Range of initial rates

4 months flat rate then linear flow (b1=2.0). At time =850 days bounded flow (b2=0.7)

# Infill Drilling

- Did infill drilling vertical wells add reserves ?
- Find areas with highest well counts
  - Two half sections with the equivalent of 32 wells per section


Plato North
Map from mid-2012
R20
R19W3
T26
R20
R19W3
T26



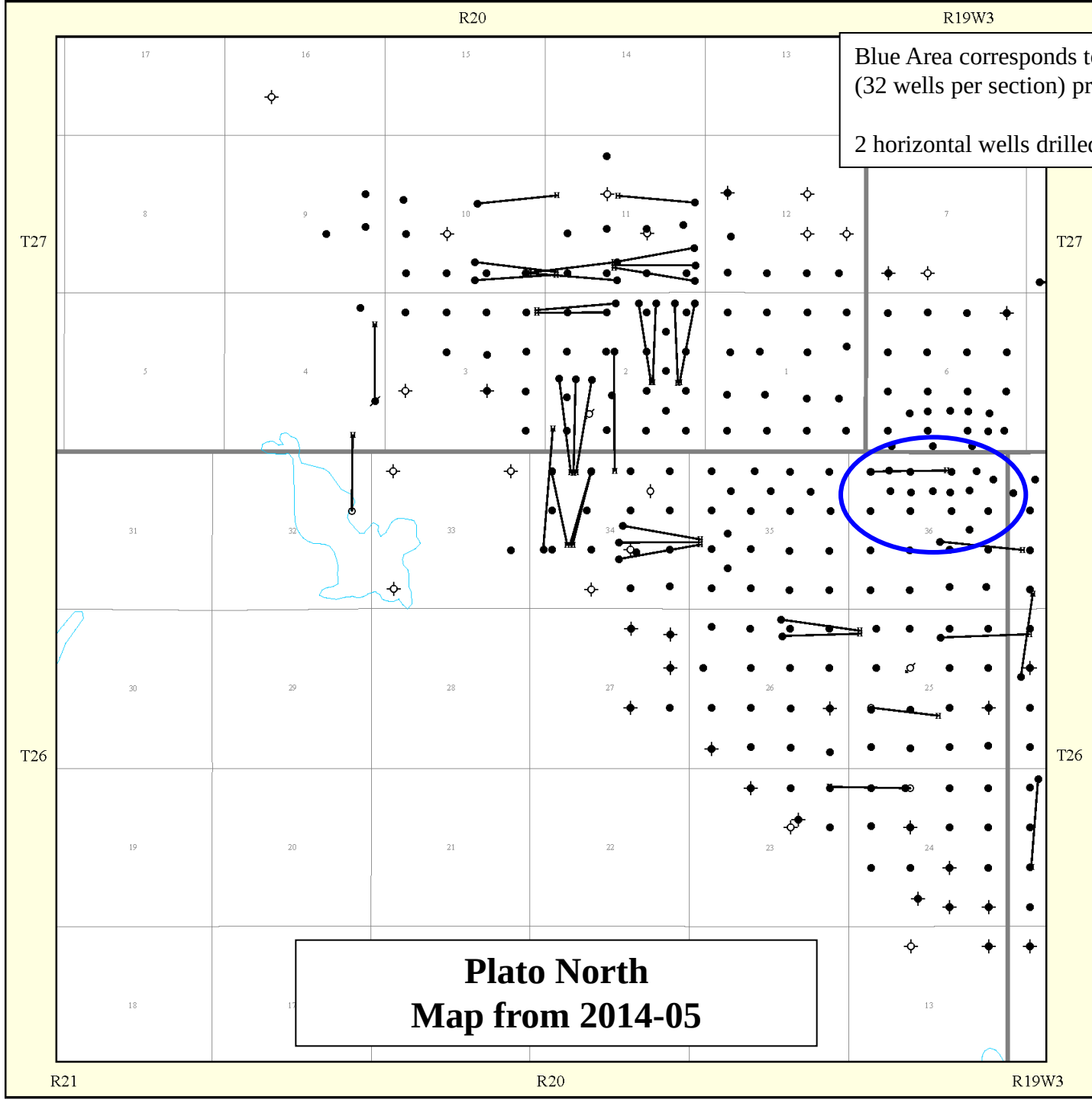

16 Wells per ½ Section

More Reserves ?
Very clearly 'yes' from
Group semi-log rate-cum plot
(The Harmonic Plot)

Harmonic Plot for North Half of Section 36-026-20 W3M, North Plato Pool

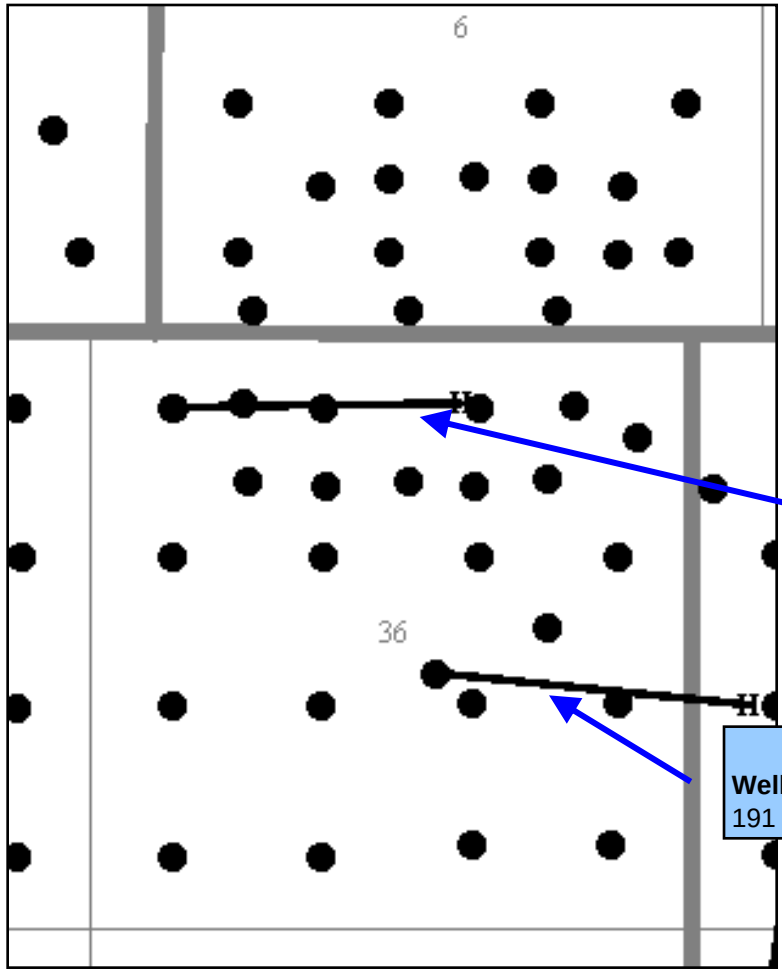
# Infill Drilling Horizontal Wells 2014 Update

- Same region as last map
- Number of horizontal wells drilled into area




Blue Area corresponds to 16 wells per ½ section (32 wells per section) previously reviewed

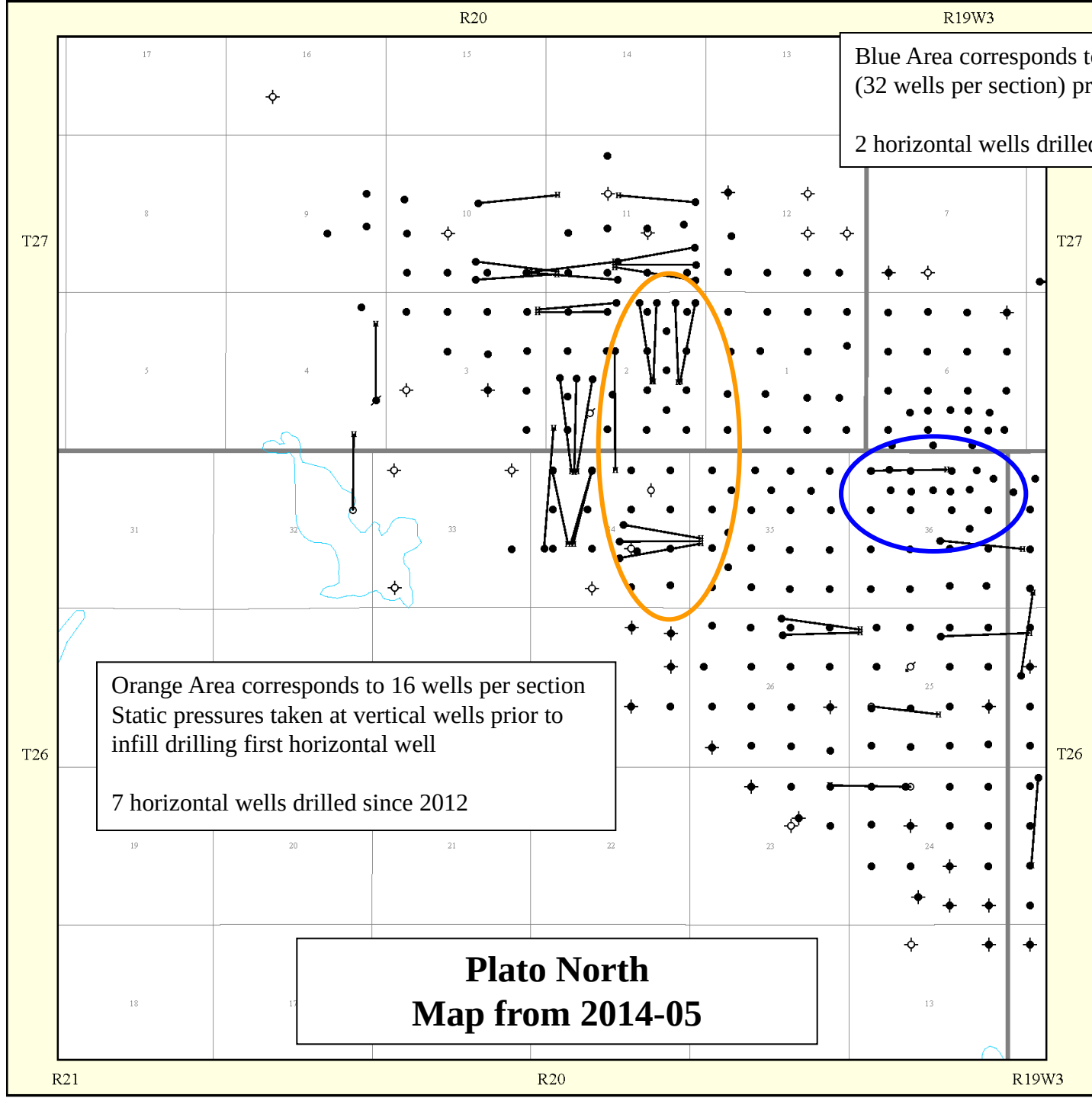
2 horizontal wells drilled since 2012




No production data yet

| Well Name | Qo (4th Month) m3/d | Better Than % of Wells |
|---|---|---|
| 191 07-36-026-20W3M 00Prd | 4.43 | 81.7 |

**Section 36-029-19 W3M**
**Blue Region**




Blue Area corresponds to 16 wells per ½ section (32 wells per section) previously reviewed

2 horizontal wells drilled since 2012

Orange Area corresponds to 16 wells per section
Static pressures taken at vertical wells prior to infill drilling first horizontal well

7 horizontal wells drilled since 2012

**Plato North**
**Map from 2014-05**

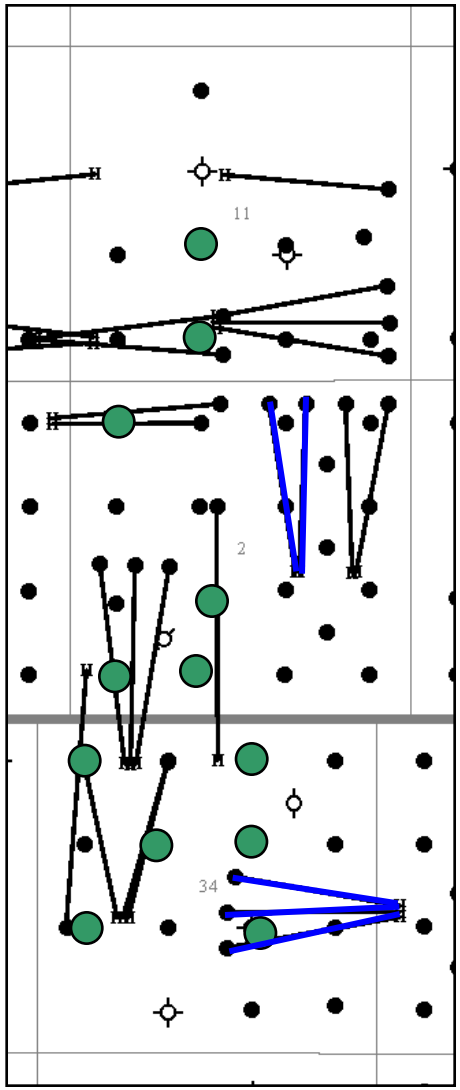
Most vertical wells drilled in 1980's
3 wells drilled between 1990 and 1992

Small amount of water injection at 03-02

Pool initial pressure = 6200 kPa
Pressures taken at producing wells in March 2012 (in green) Pavg = 1367 kPa

3 wells around injection well Pavg =1451 kPa

First horizontal well initial pressure ~ 4500 kPa
**Strong indicator of upside potential**




Horizontal wells in blue have available production data

| Well Name | Qo (4th Month) m3/d | Better Than % of Wells |
|---|---|---|
| 191 15-02-027-20W3M 00Prd | 6.40 | 90.7 |
| 192 15-02-027-20W3M 00Prd | 7.35 | 92.9 |
| 191 10-34-026-20W3M 00Prd | 4.87 | 84.0 |
| 192 07-34-026-20W3M 00Prd | 9.34 | 96.9 |
| 191 07-34-026-20W3M 00Prd | 7.07 | 92.4 |

**Map from 2014-05**
**Orange Area +**

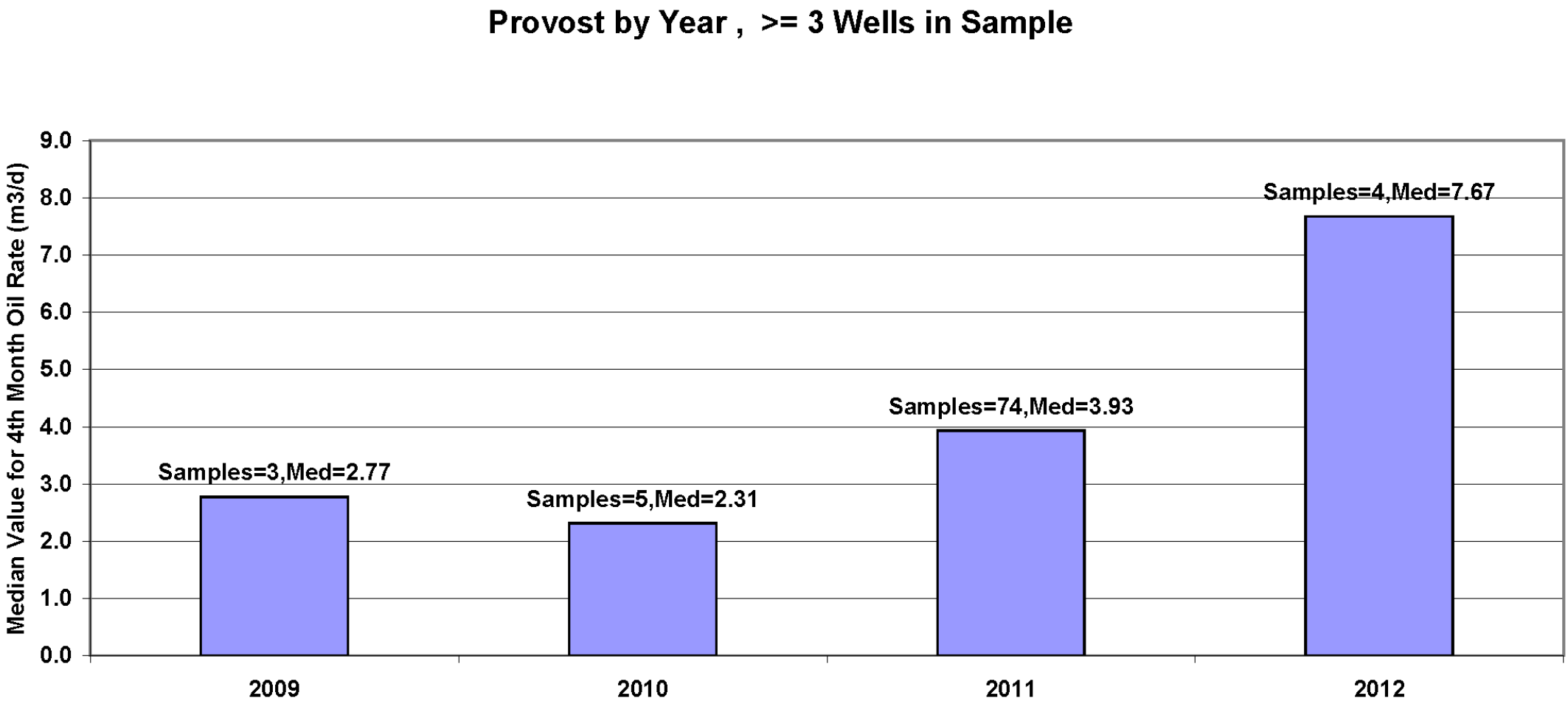
# High Rate Wells

1. Better quality reservoir
2. Better completion technology

- How do you tell ?
  - 5 plots are recommended for a preliminary diagnosis

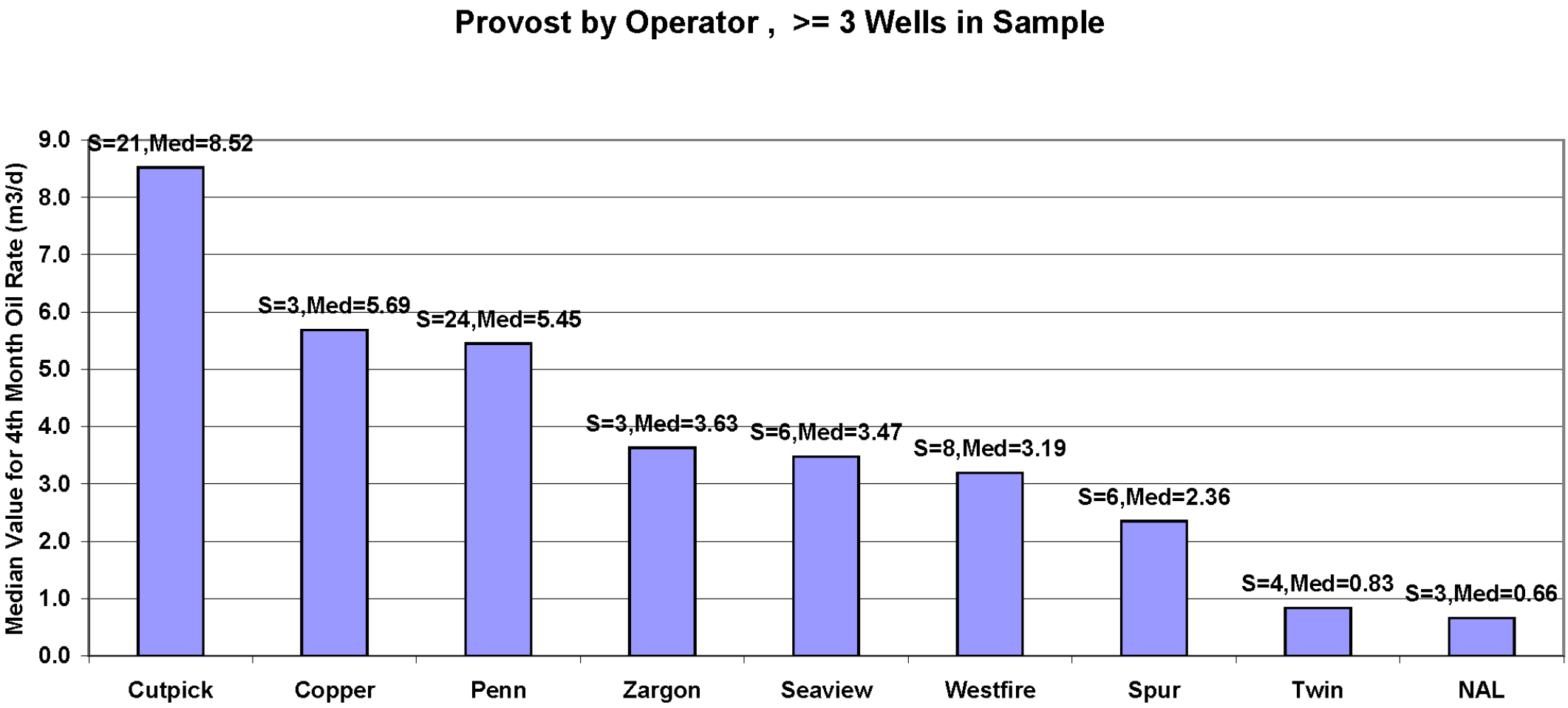
# Provost

# Production Statistic is 4th month Oil Rate



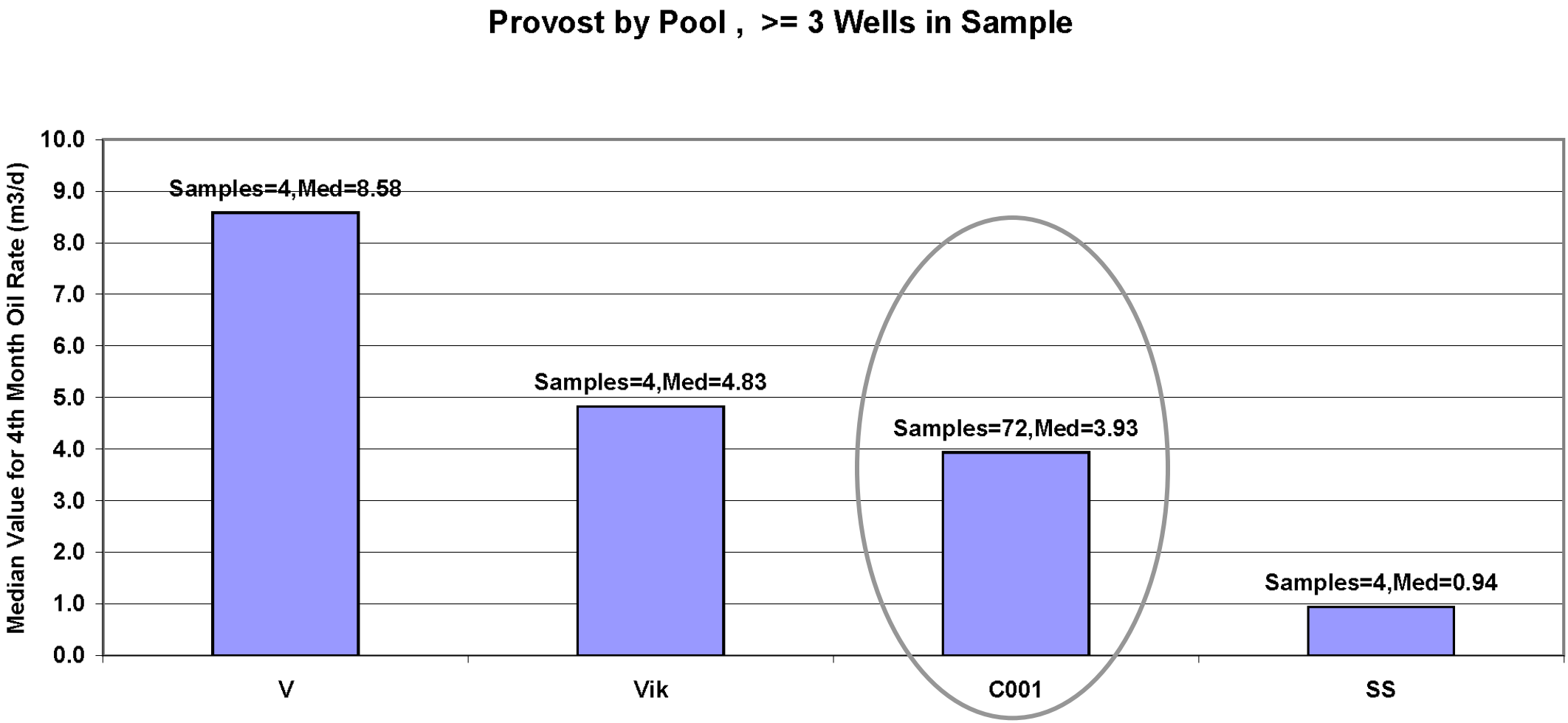

**Rate going up with time**
**Better areas or better technology ?**

# Production Statistic is 4th month Oil Rate



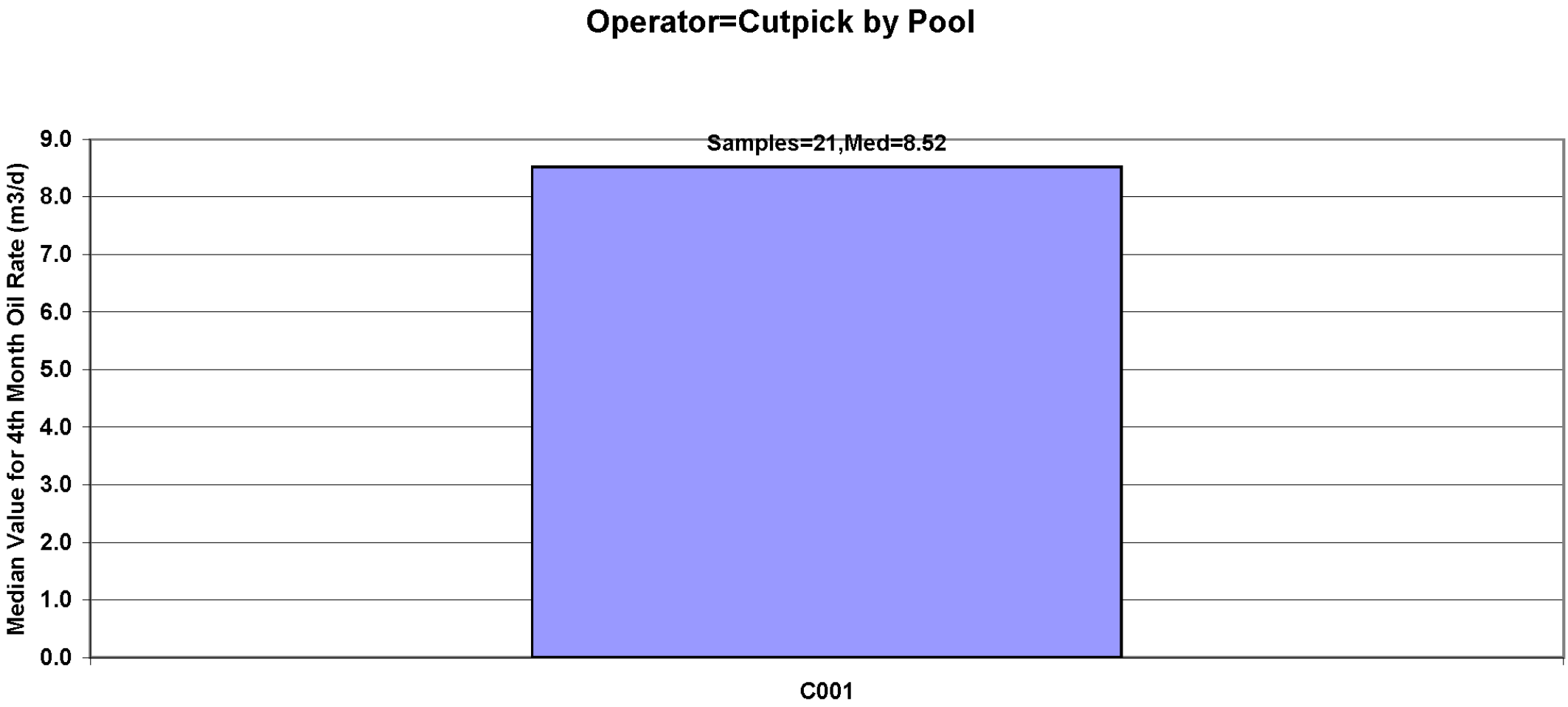

**Cutpick is the best operator by far**

# Production Statistic is 4th month Oil Rate



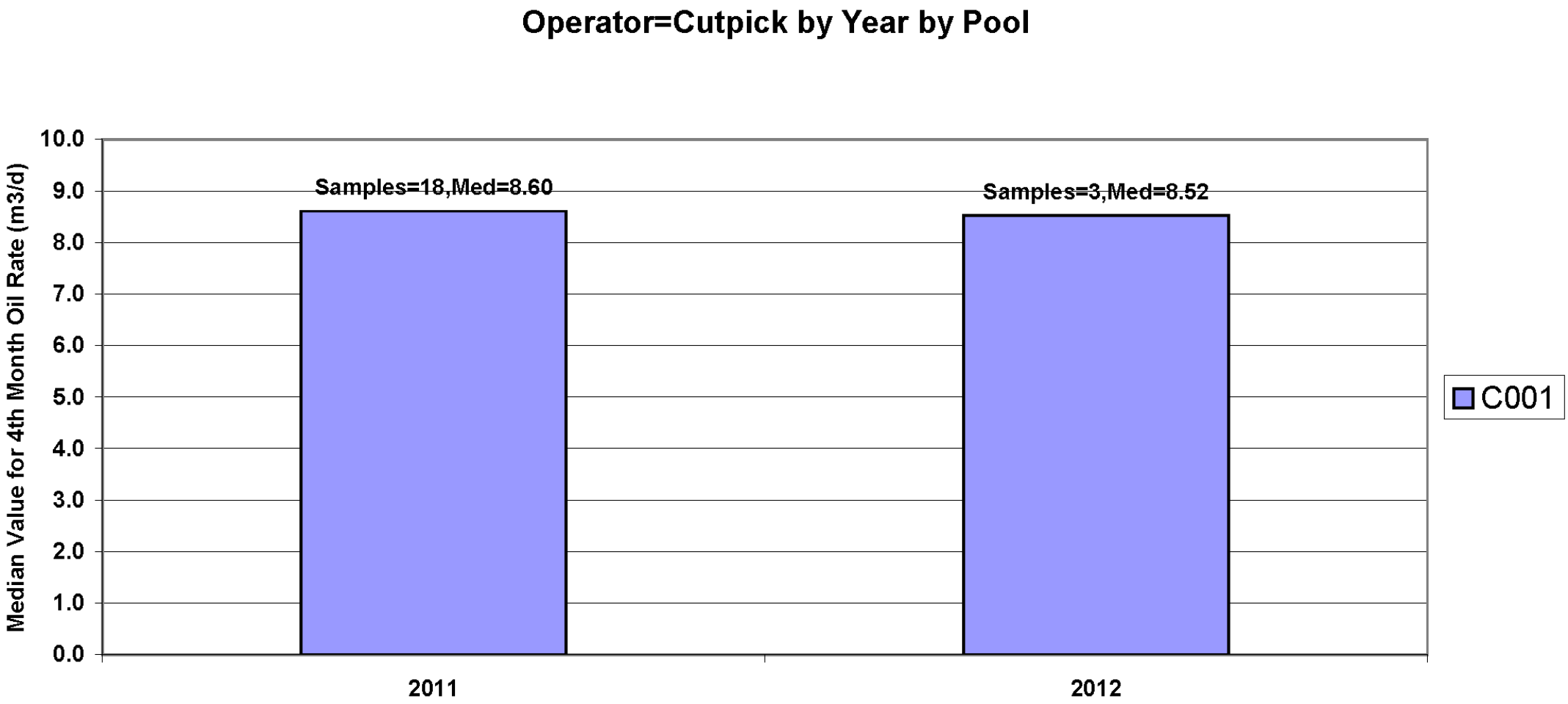

**Note the C001 pool is the 3rd best pool with 72 wells**

# Production Statistic is 4th month Oil Rate

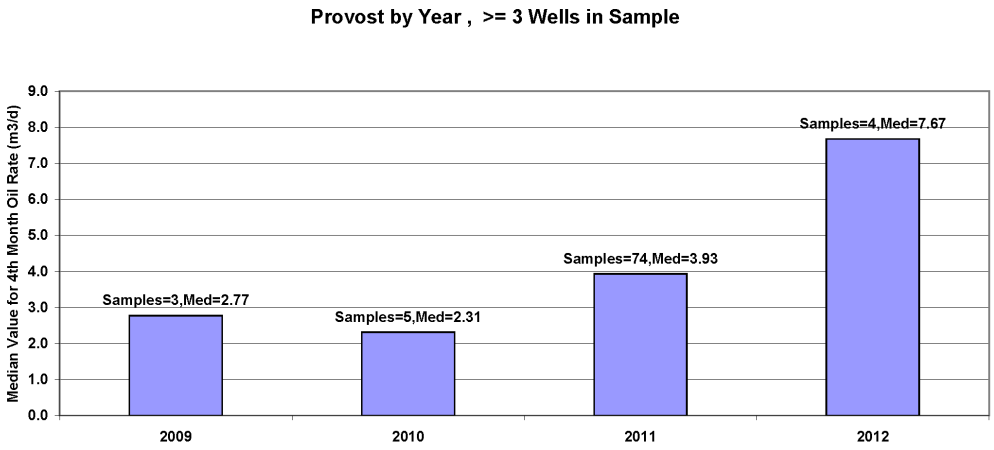


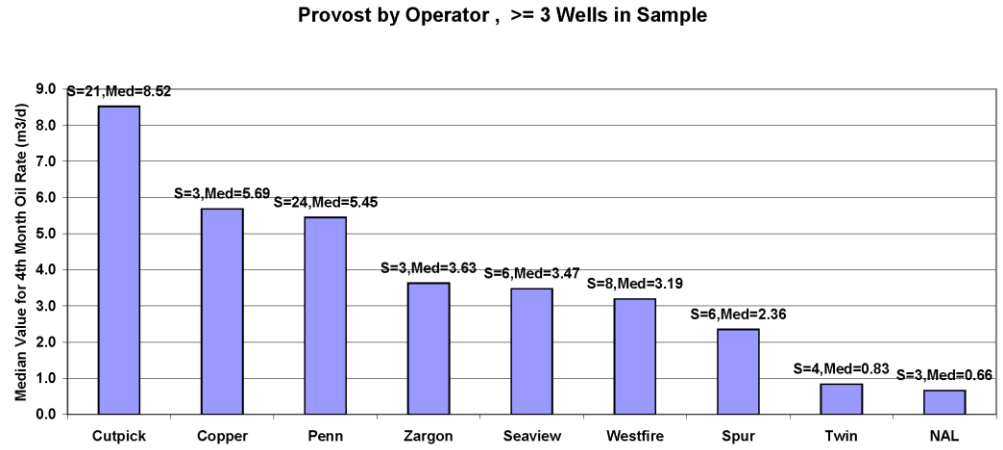

**Cutpick is exclusively in the 3rd best pool**
**Total Samples = 72, Med=3.93 m3/d**
**Infer that Cutpick has better completion technology**

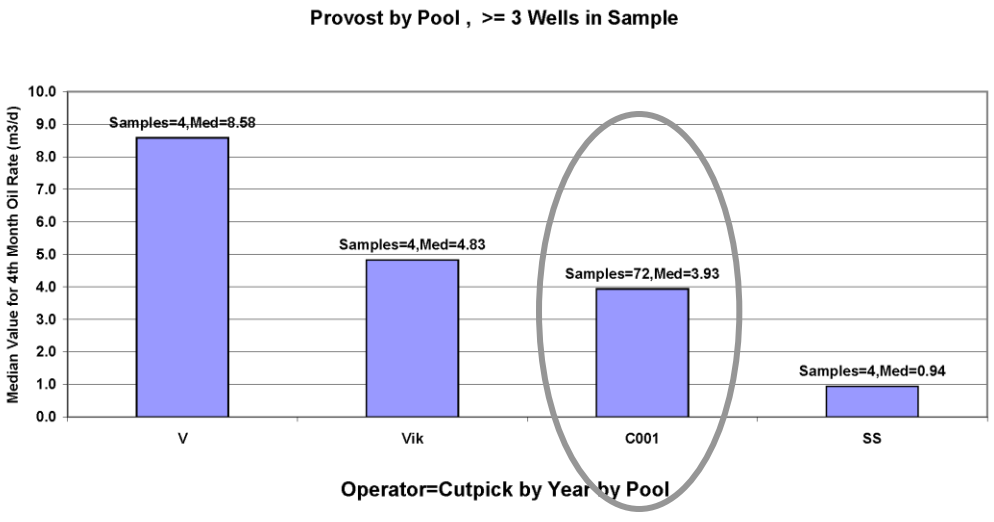
# Production Statistic is 4th month Oil Rate

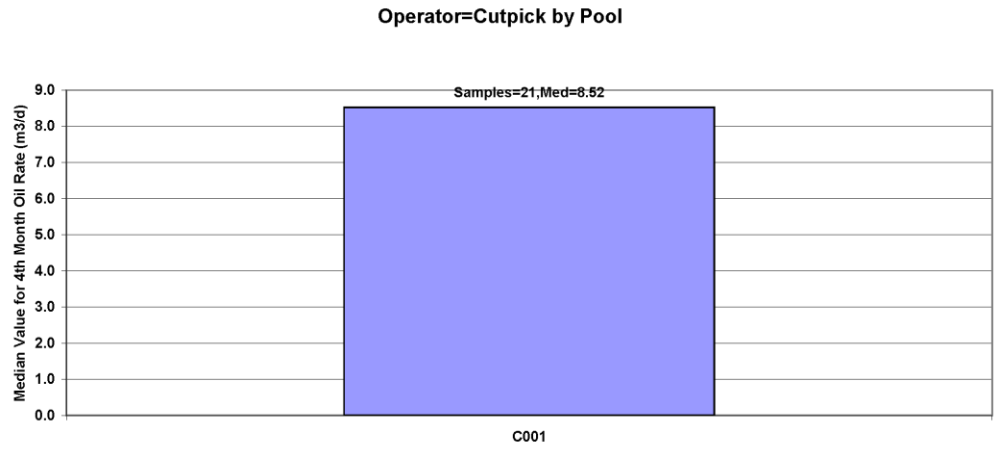



**Cutpick figured out how to complete wells right away**
**Found out that principals had prior experience in Viking with other companies**

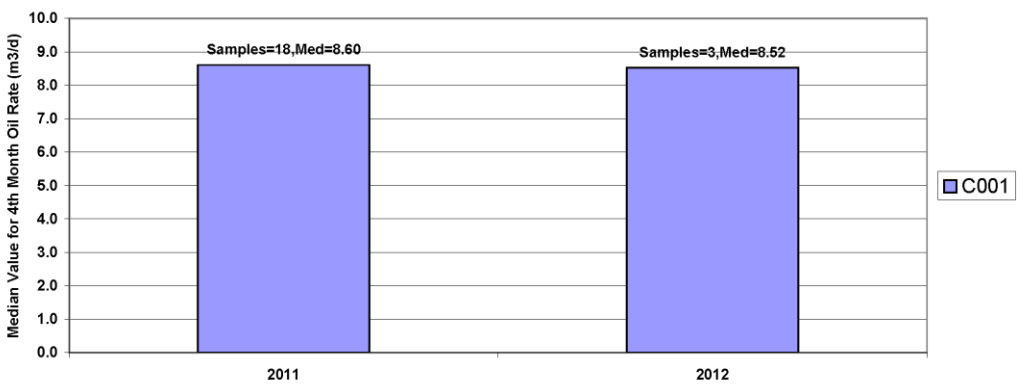



**Recommended Dashboard Plot**




**One statistically significant pool**
**C001 – Cutpick Med=8.52, All Med=3.93**

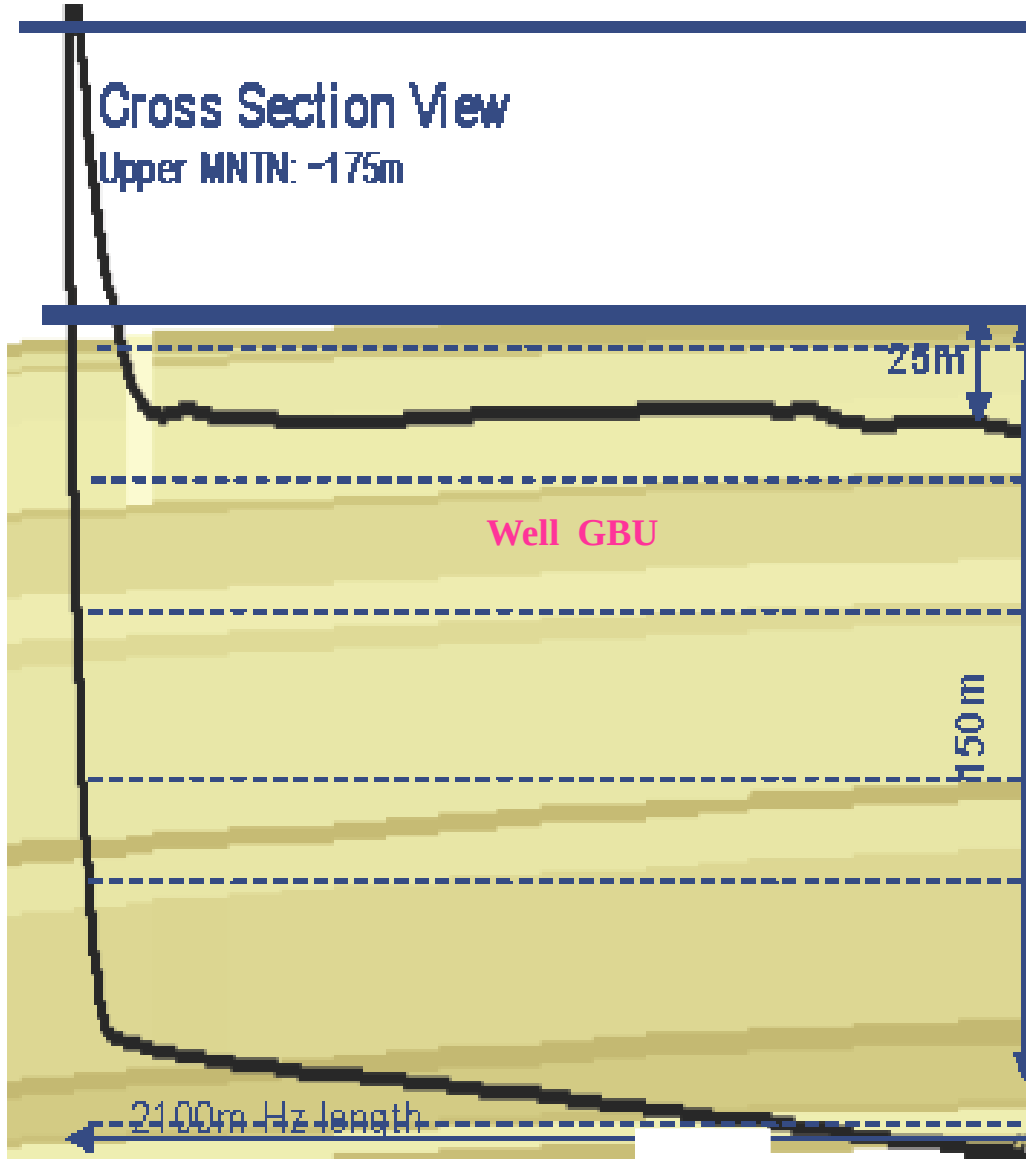
# Case 1 - Conclusions

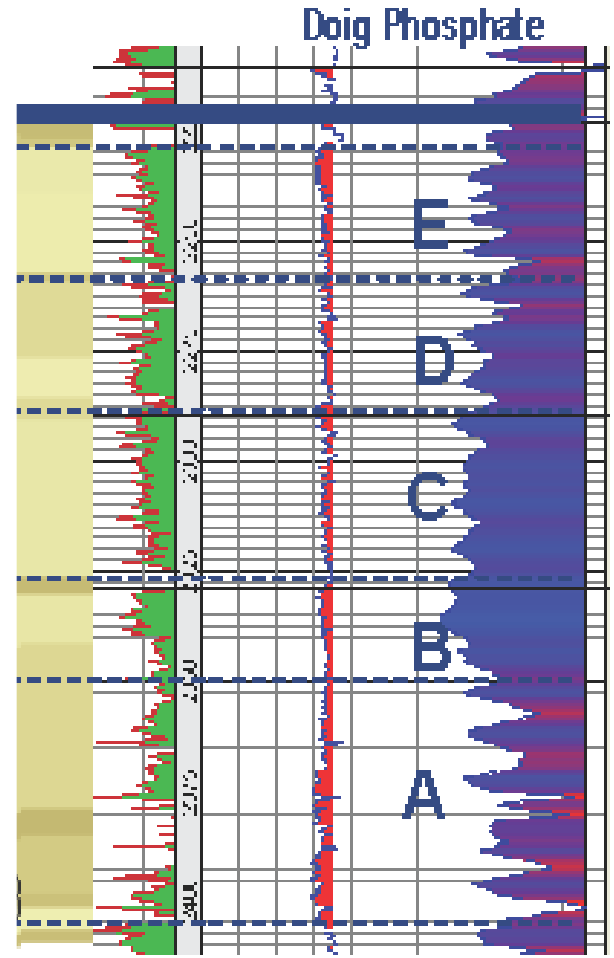
- Have shown
  - Type Curve development
  - Infill drilling analysis (vertical and horizontal) and post mortem
  - Identification of successful plays
  - Identification of successful companies

- But …
  - How do you compare various treatment strategies?

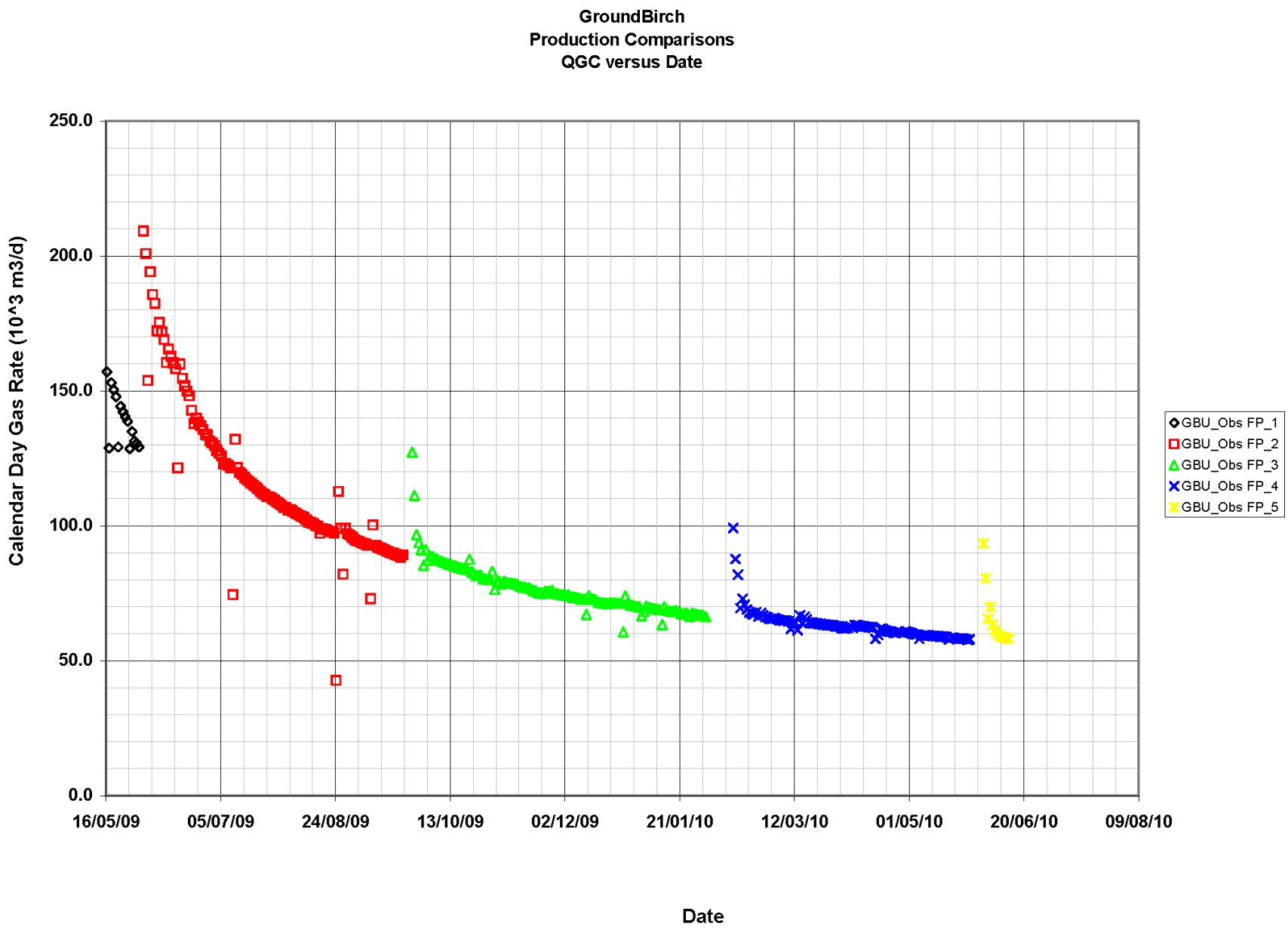
# Case 2 - SPE 149331
# Montney Gas

- Groundbirch area (gas)
  - Zone thickness 28.5 meters
  - Big slick water job
  - 67 tonnes per stage
  - 12 of 17 stages assumed to be flowing (based on PLT)
- Trying to determine via numerical simulation
  - Permeability
  - Fracture half length – $x_f$
  - Fracture Conductivity

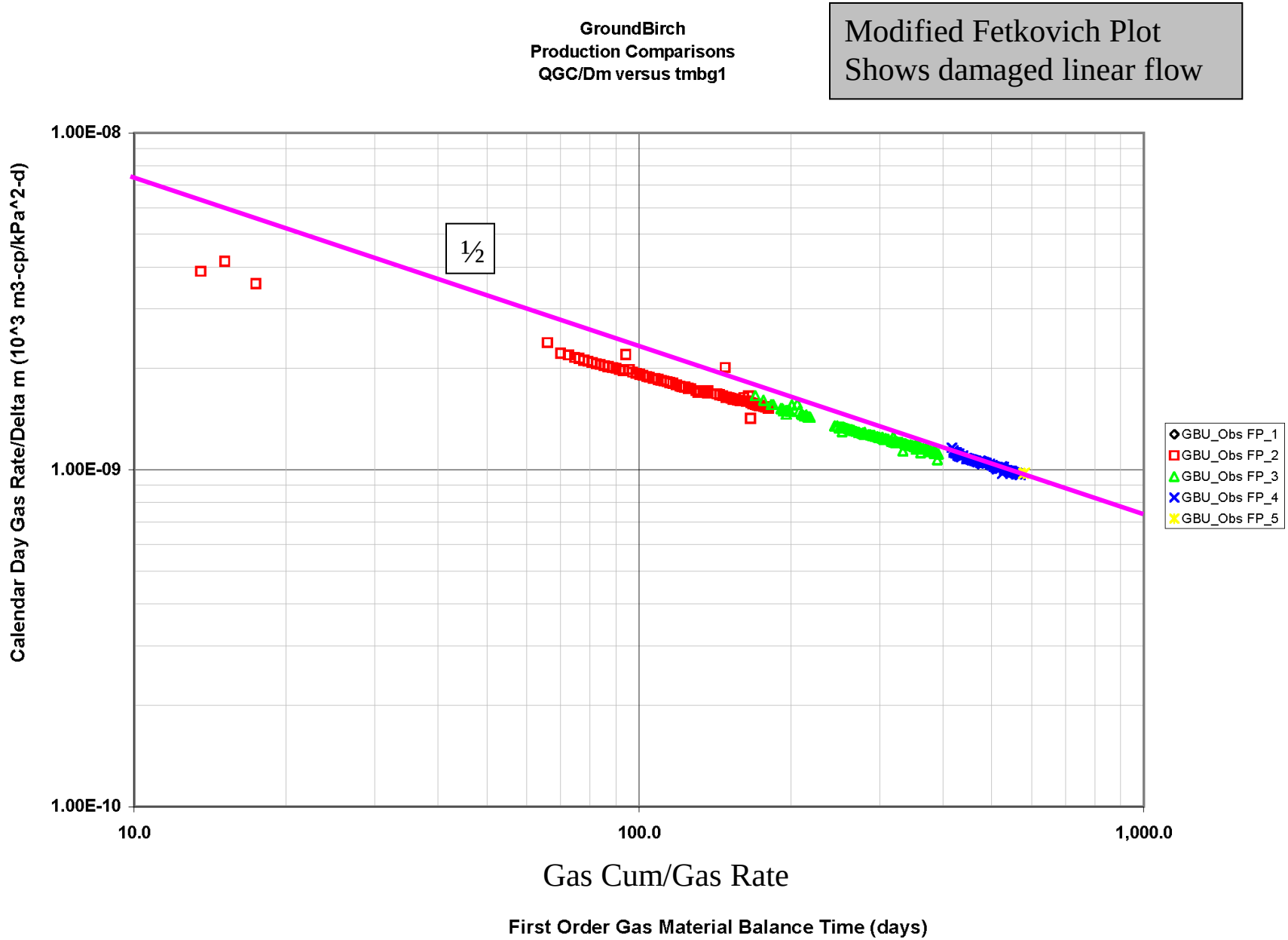

Cross Section View
Upper MNTN: ~175m
25m
Well GBU
150m
2100m Hz length

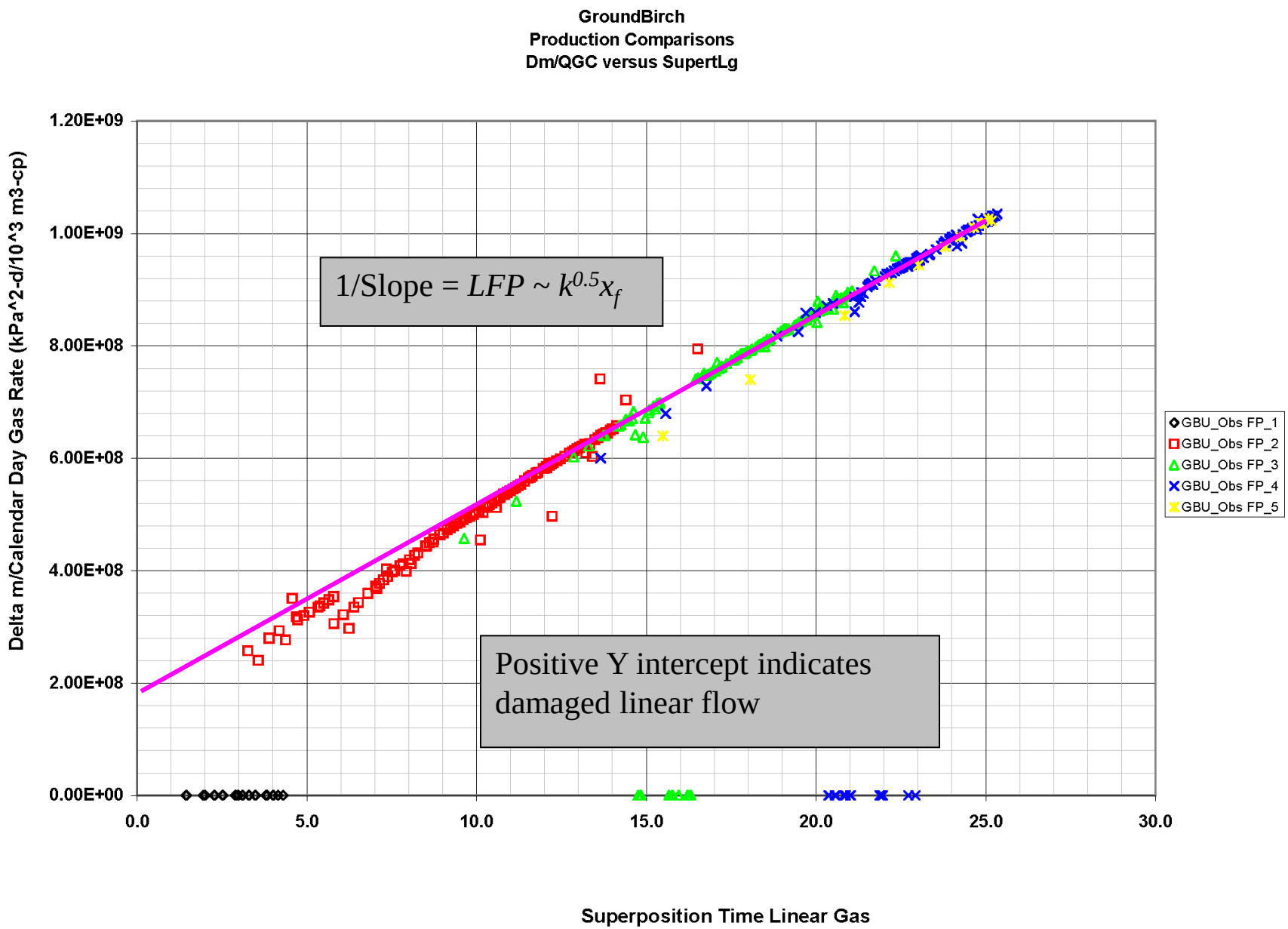

Doig Phosphate
E
D
C
B
A

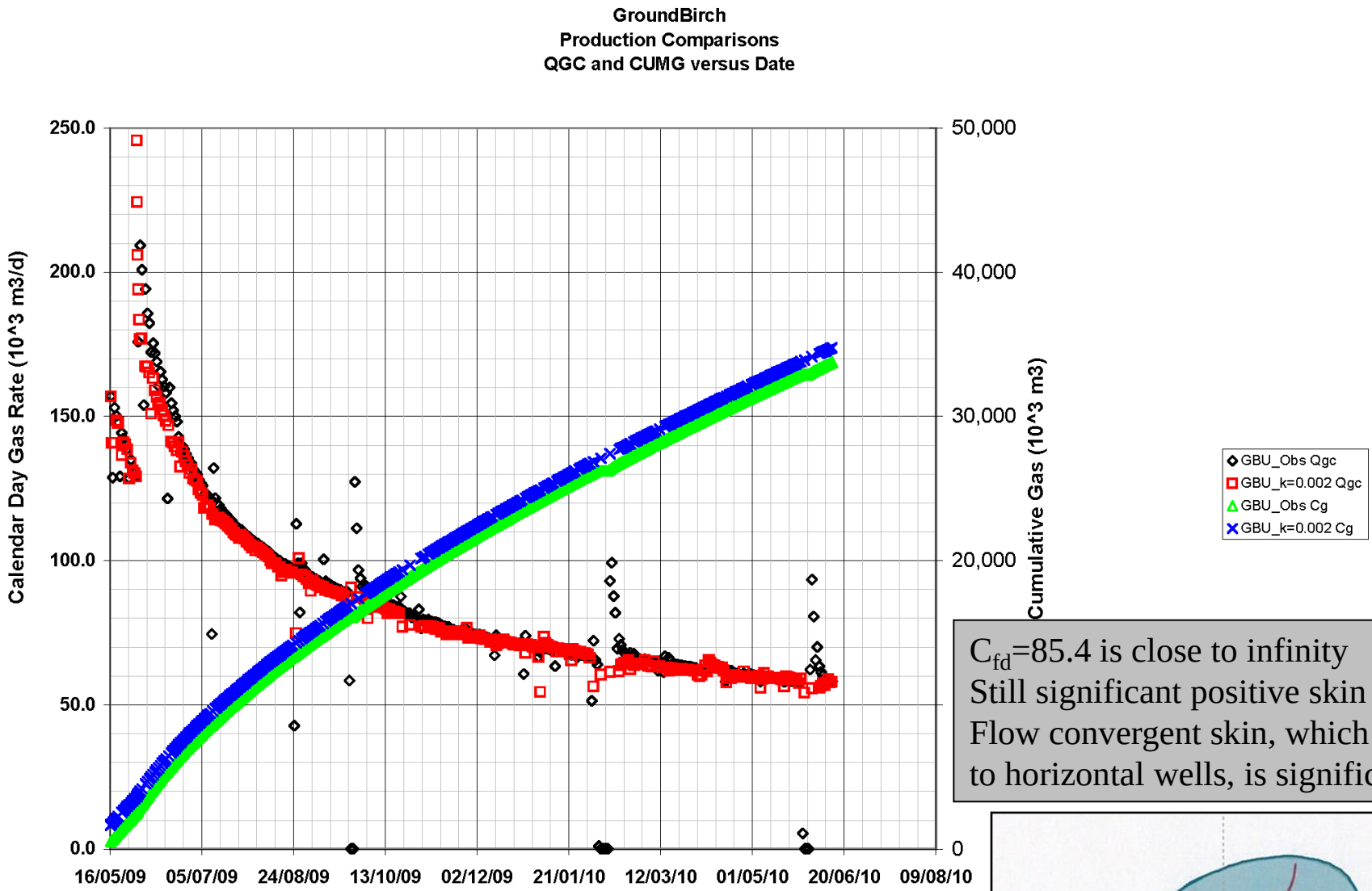
Well GBL


GroundBirch
Production Comparisons
QGC versus Date
Calendar Day Gas Rate (10^3 m3/d)
250.0
200.0
150.0
100.0
50.0
0.0
16/05/09
05/07/09
24/08/09
13/10/09
02/12/09
21/01/10
12/03/10
01/05/10
20/06/10
09/08/10
Date
GBU_Obs FP_1
GBU_Obs FP_2
GBU_Obs FP_3
GBU_Obs FP_4
GBU_Obs FP_5

Modified Fetkovich Plot
Shows damaged linear flow



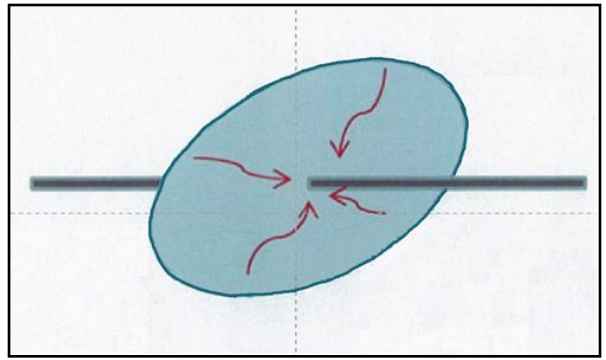

GroundBirch
Production Comparisons
Dm/QGC versus SupertLg
Delta m/Calendar Day Gas Rate (kPa^2-d/10^3 m3-cp)
1.20E+09
1.00E+09
8.00E+08
6.00E+08
4.00E+08
2.00E+08
0.00E+00
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Superposition Time Linear Gas
1/Slope = $LFP \sim k^{0.5}x_f$
Positive Y intercept indicates damaged linear flow
GBU_Obs FP_1
GBU_Obs FP_2
GBU_Obs FP_3
GBU_Obs FP_4
GBU_Obs FP_5




$C_{fd}$=85.4 is close to infinity
Still significant positive skin on well
Flow convergent skin, which is unique to horizontal wells, is significant

| Property | Value | Units |
|---|---|---|
| Reservoir Permeability | 2.0 | μ-D |
| Fracture Half Length (xf) | 58 | m |
| Proppant Permeability | 3900 | md |
| Propped Width | 0.254 | cm |
| Propped Conductivity | 9.9 | md-m |
| Cfd | 85.4 | |

**Table 3: Modified Properties from the Initial Input Values for the Constant Permeability Match**



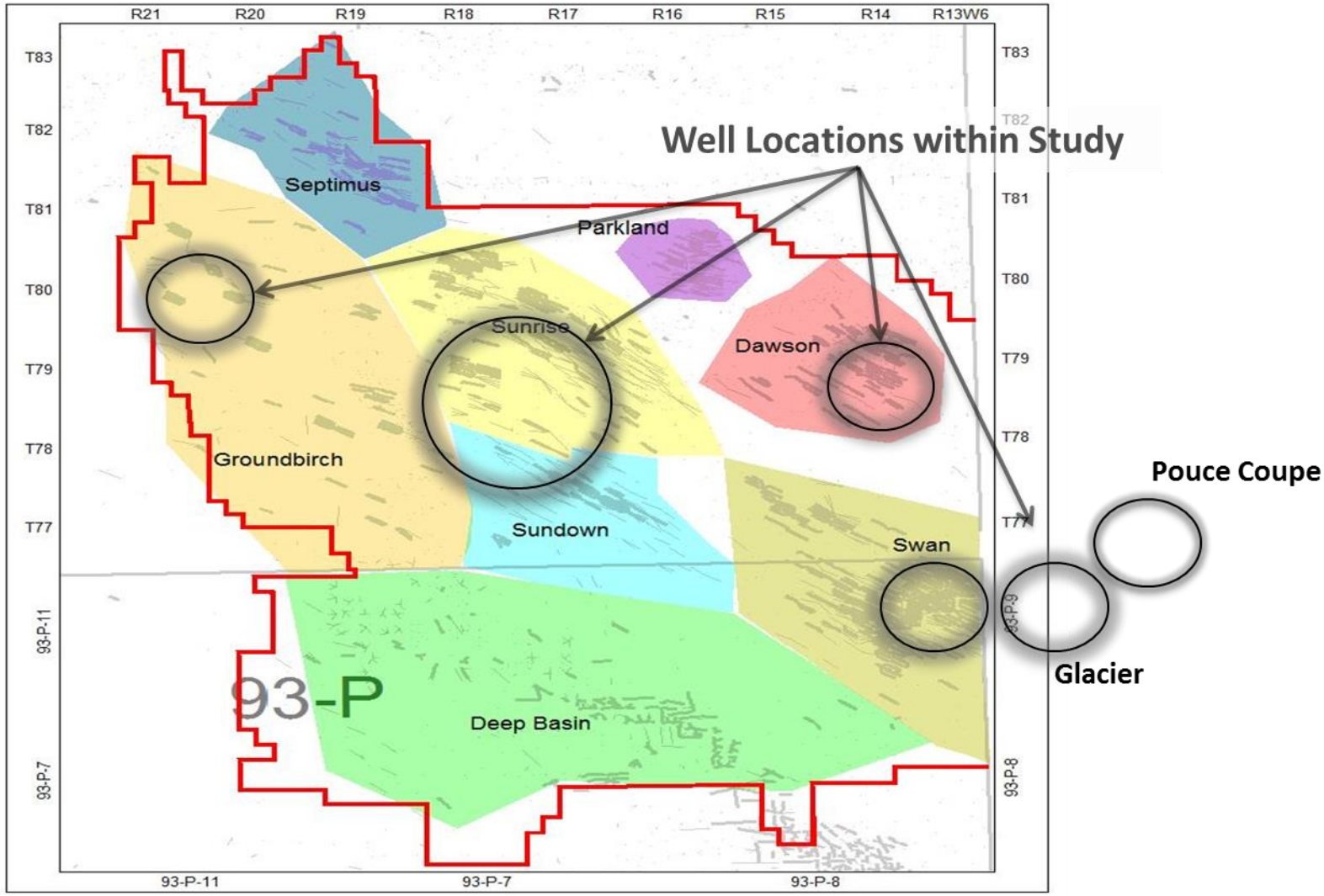
# Case 2 - SPE 149331 Montney Gas Conclusions

- Even though $C_{fd}$ is 'infinite' there is still considerable positive skin
- Positive skin due to 'flow convergence' within fracture to perforations
  - Prevalent in thicker formations
  - Further improving fracture conductivity would reduce 'flow convergence' skin

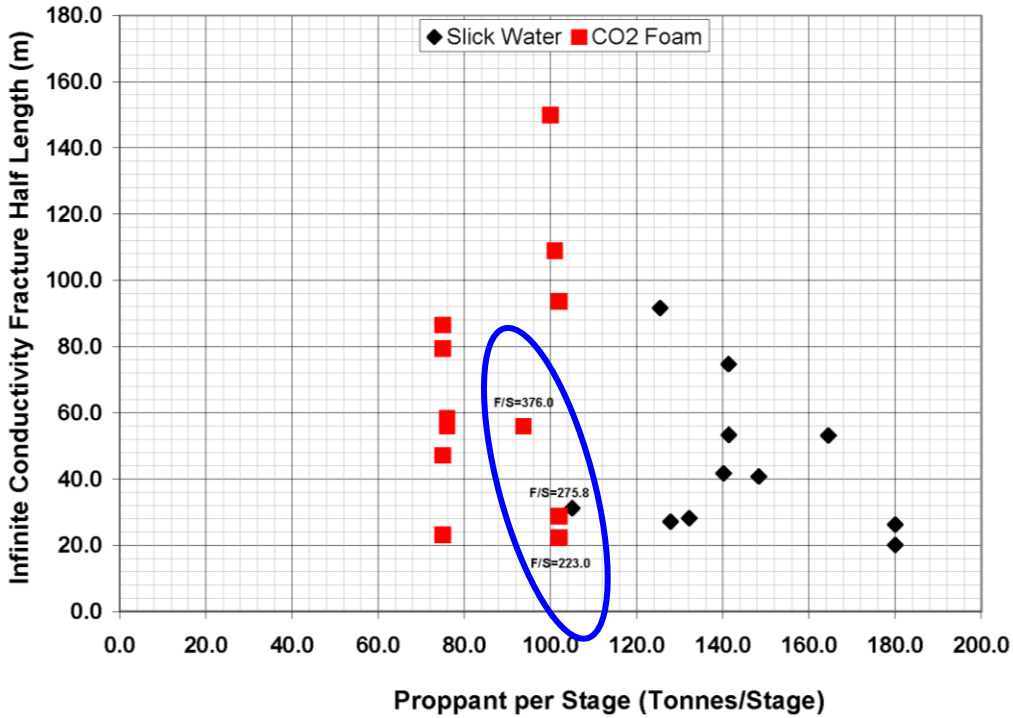
# Case 3 - SPE 168632
# Montney Gas
# Comparing Slickwater to CO2 Foam

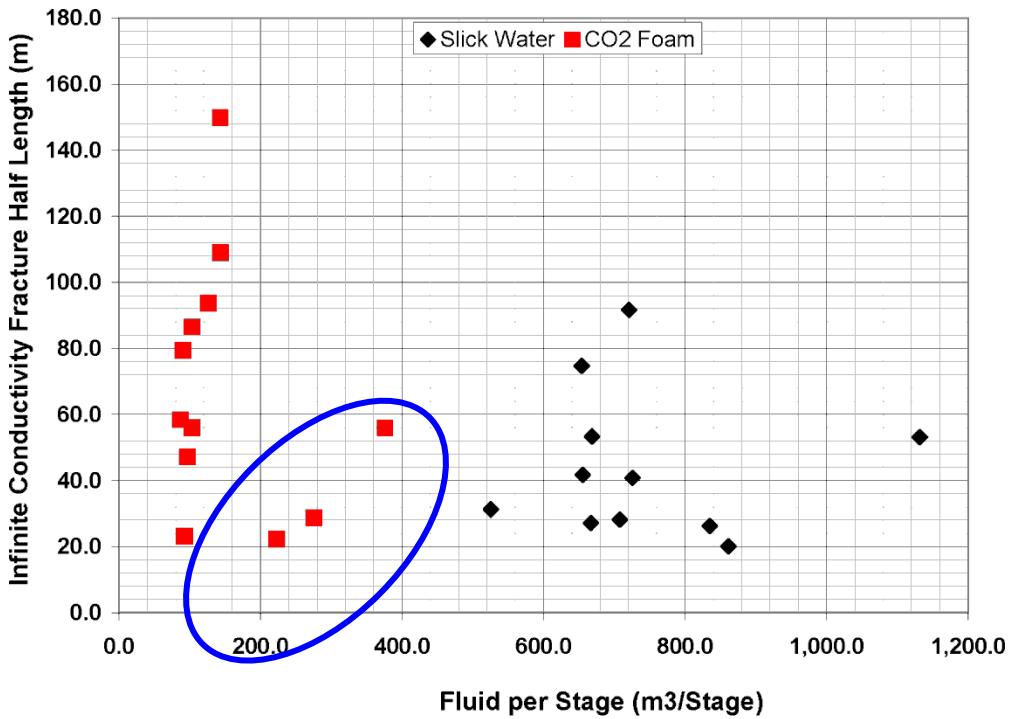
- RTA study (50 wells)
- Determine fracture properties + reservoir permeability
- Slick water treatments
  - Low viscosity treatments
  - Create more complex fracturing (SRV)
- Foam base treatments
  - Lower water usage
  - High viscosity
  - Better proppant carrying capacity
  - Potential for higher fracture propped width and conductivity

# Study Overview – Heritage Area



# Montney Heritage Area
# Comparing Slickwater to CO2 Foam




CO2 foam gives superior fracture properties with less proppant as compared to slickwater

For CO2 foam, more proppant per stage at high proppant concentration has positive effect

CO2 foam gives superior fracture properties with less fluid as compared to slickwater

For CO2 foam, more fluid per stage (lower overall proppant concentration) has negative effect

# Case 3 - SPE 168632 Montney Gas Conclusions

- Different fracturing processes can be compared
  - Effect of reservoir permeability removed
- CO2 foam fracture fluids are superior to slickwater