Pitchfork Field Study

2012-2013

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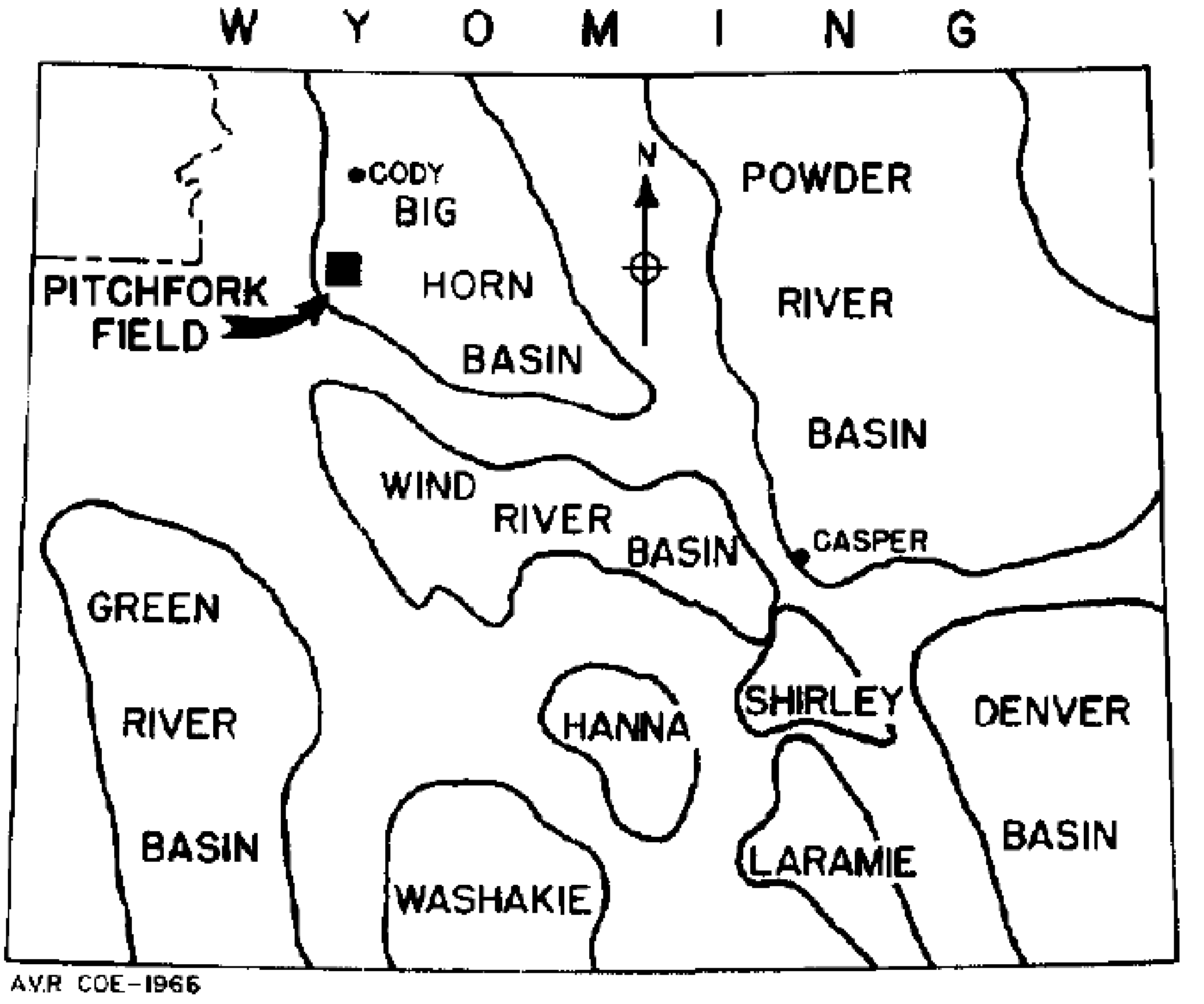
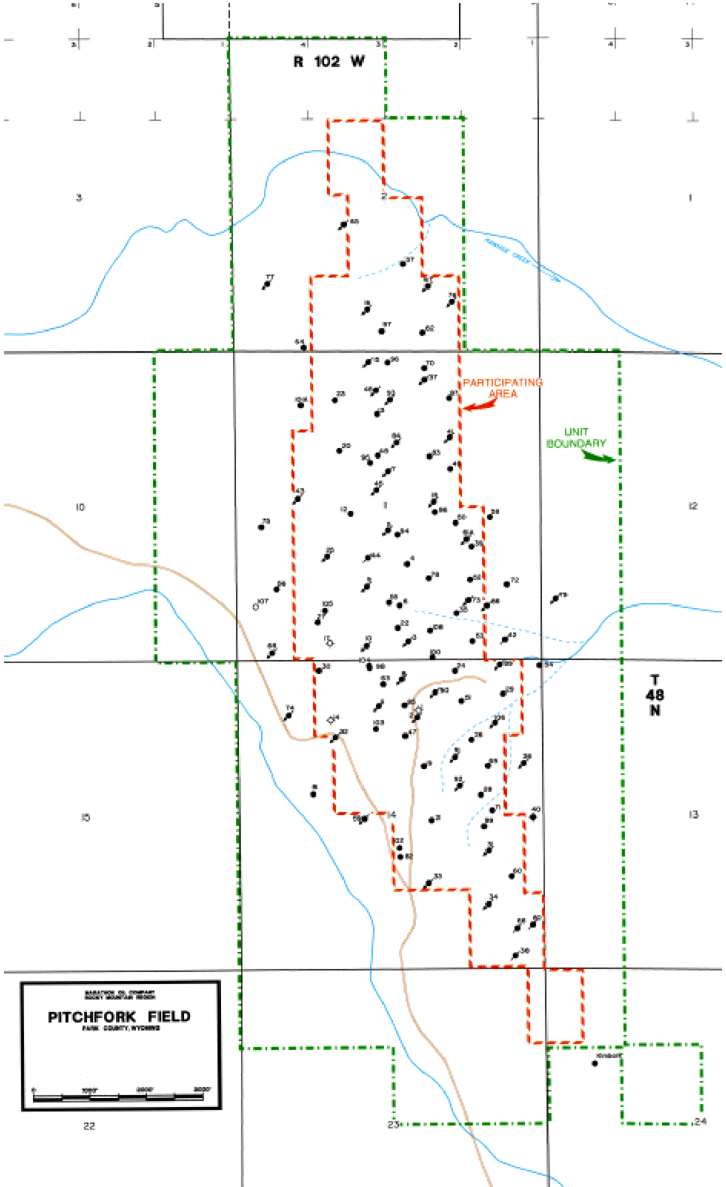
Pitchfork Field Location



Field Background

- 1930: Discovery well drilled by Honolulu Corporation
- 1950s: Field developed by Husky Oil Corporation
- Currently Operated by Marathon Oil Corporation
- Well count
  - Total wells: 108
    - Production wells: 53
    - Injection wells: 32

Well Locations



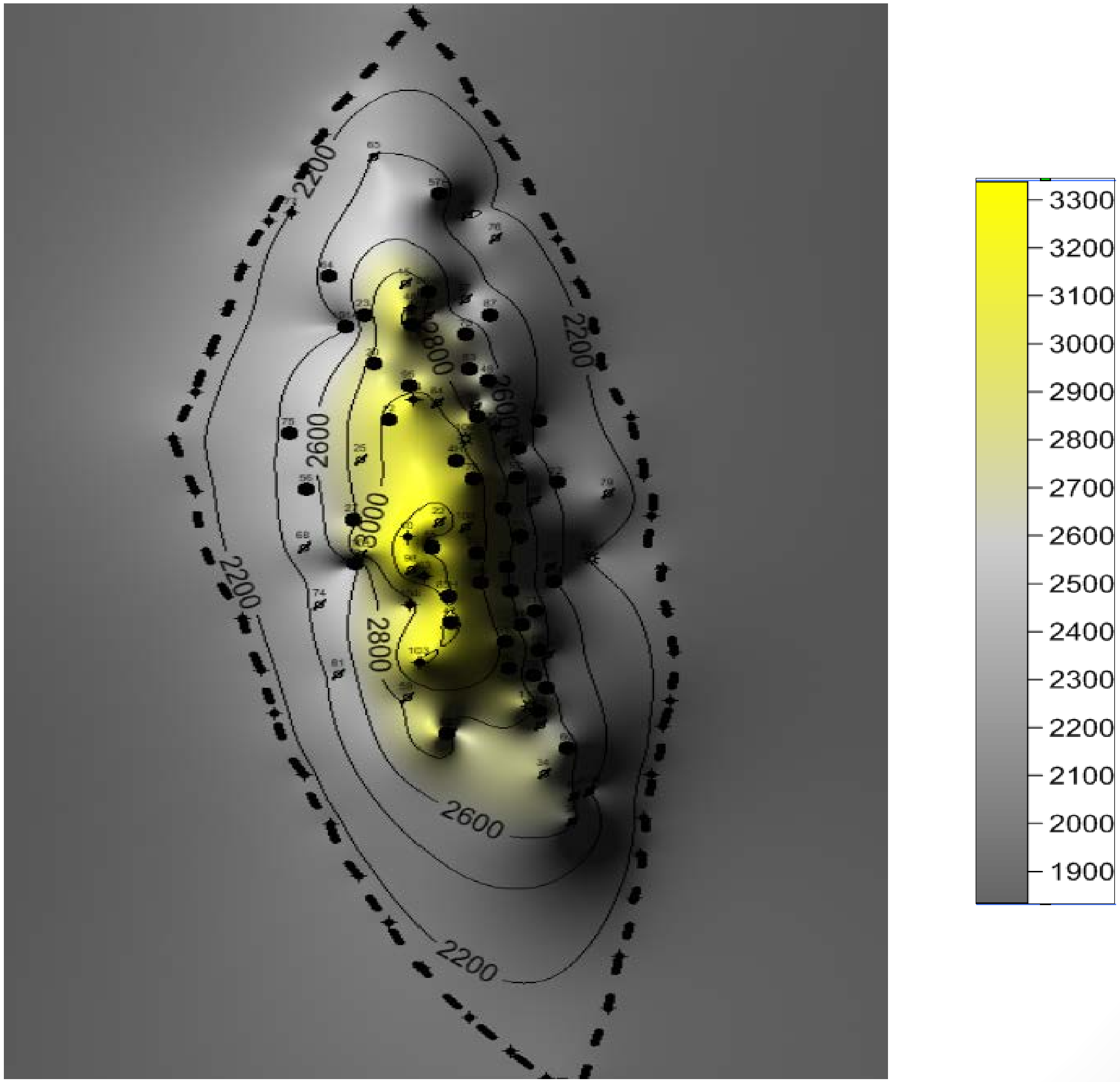
Tensleep Formation

- Primary producing zone
- Massive cross bedded sandstone formation
- Located below the Phosphoria and above the Amsden
- 2400-3200 feet structural depth throughout field
- Porosity
  - Average porosity 13 to 16%
  - Primary porosity is intergranular
  - Secondary porosity is fracture

Structure Mapping

- Well locations collected from Wyoming Oil and Gas Commission
- Surface locations converted from latitude to longitude to feet using software
- Top of the Tensleep formation found using available data and well logs
- Elevation – Tensleep Top Depth = Structural Depth

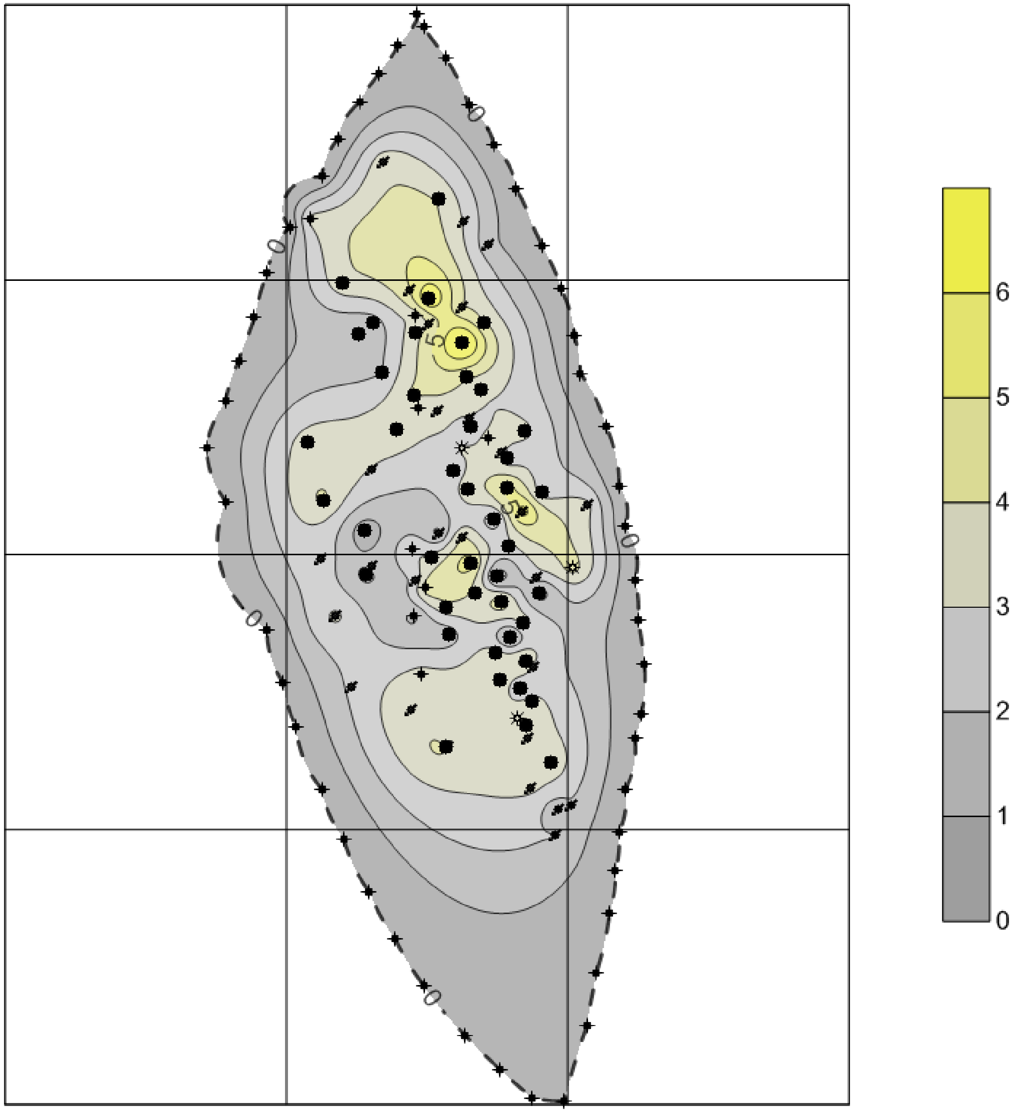
Tensleep Structure Map



Reservoir Parameters

- Selected 30 wells for log analysis
- Calculate using log values
  - Porosity
    - 16.3% average
  - Water saturation
    - 32% average

Original Oil in Place Plot



Original Oil in Place

$$\text{OOIP} = \frac{h\phi(1-S_w)}{5.61458\, B_o}$$

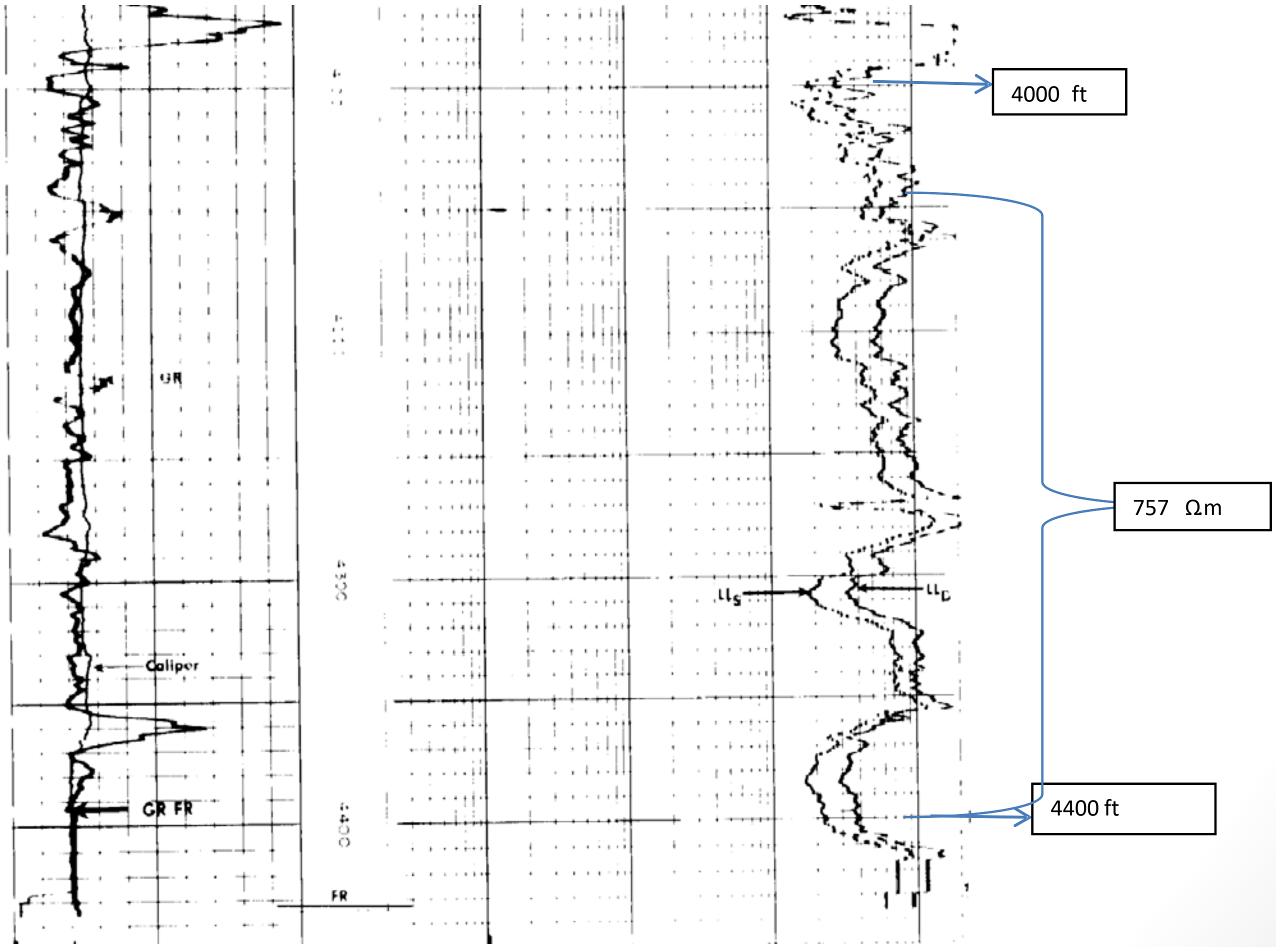
- OOIP using volumetric: 209 MMSTB
- Oil recovered to date: 56 MMSTB

True Resistivity

- R_t obtained from the dual lateral log for each well
  - Used to calculate water saturation
  - Used to create Hingle and Pickett Plots

True Resistivity

Pitchfork 57H



Water Saturation

- Archie's Equation

$$S_w = \left[\left(\frac{a}{\phi^m}\right)\left(\frac{R_w}{R_t}\right)\right]^{1/n}$$

- Clean sand formation
  - R_w= 1.7 ohm-m
  - a = 1
  - m = 2
  - n = 2

Pickett Plot

$$S_w{}^n = \frac{a}{\phi^m}\left(\frac{R_w}{R_t}\right) = \frac{aR_w}{\phi^m R_t}$$

$F=\phi^{-m}$, $R_o=R_w*F$ and $R_t=R_o*S_w{}^{-n}$

$$\log(R_t) = \log(aR_w) - \mathrm{m}\log(\phi) - \mathrm{n}\log(S_w)$$

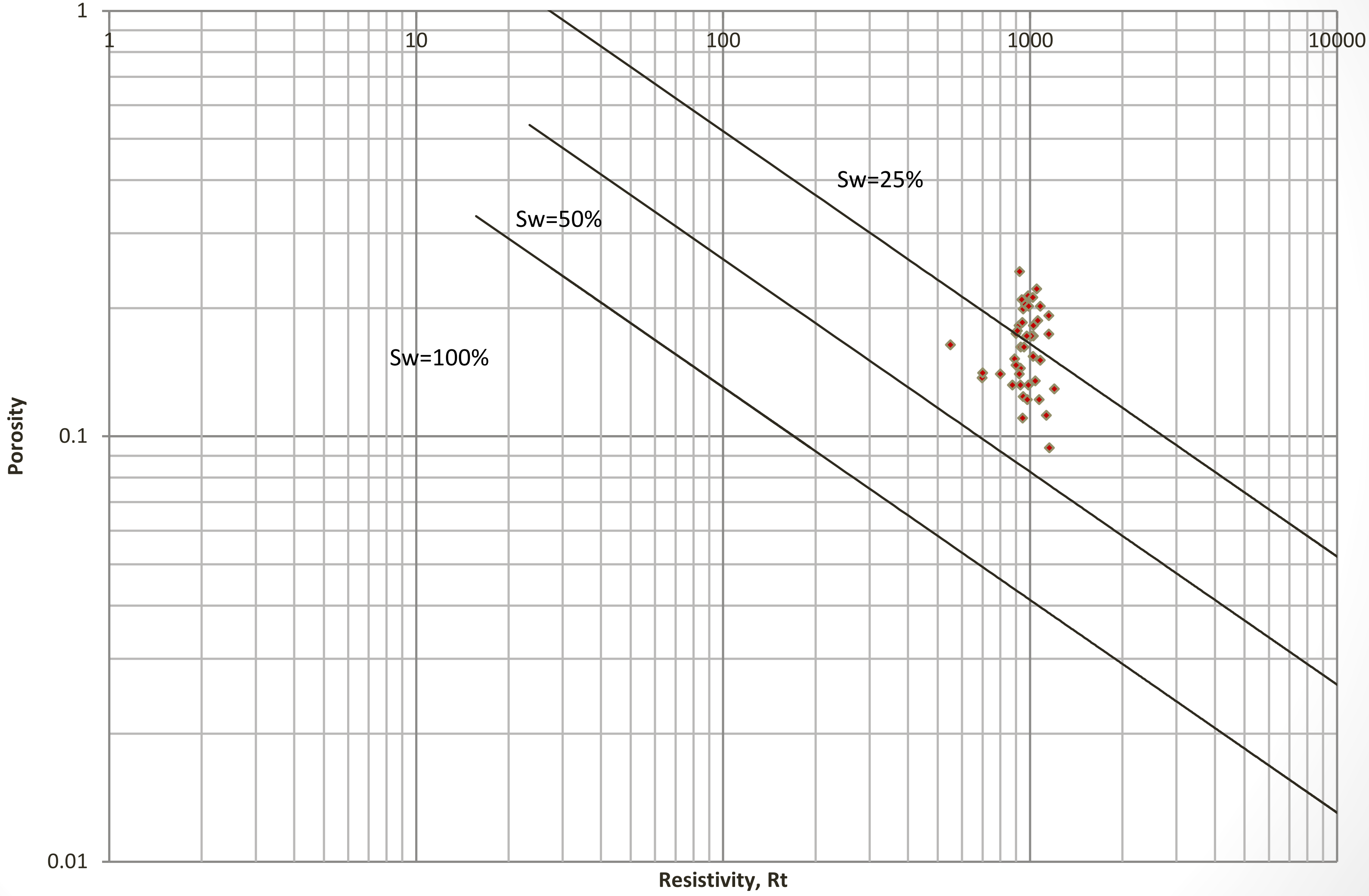
$$\log(R_o) = -\mathrm{m}\log(\phi) - \mathrm{n}\log(R_t)$$

$$\mathrm{I} = \frac{R_t}{R_o} = \frac{1}{S_w{}^n}$$

Where aR_w is constant

S_w is constant for a given $\log(R_t)$ versus $\log(\phi)$ trend

Pickett Plot



Hingle Plot

$$S_w{}^n = \frac{a}{\phi^m}\left(\frac{R_w}{R_t}\right) = \frac{aR_w}{\phi^m R_t}$$

Arranging in y=mx form gives:

$$\left(\frac{1}{R_t}\right)^{\frac{1}{m}} = \left(\frac{1}{aR_{wt}}\right)^{\frac{1}{m}} (\phi) S_w{}^{\frac{n}{m}}$$

Assumptions:

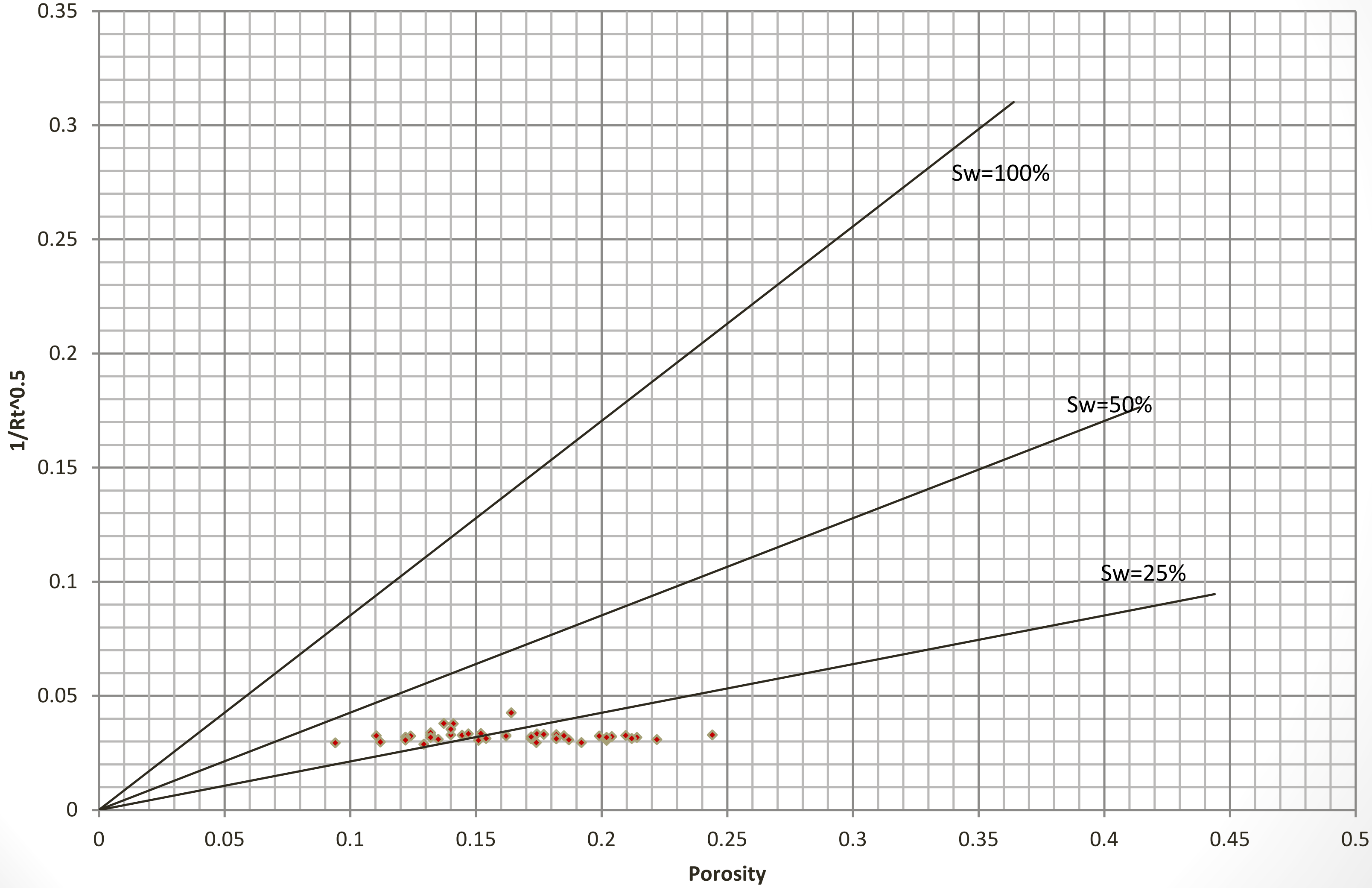
a = 1
m = 2
n = 2

Plotting function:

$$\left(\frac{1}{R_t}\right)^{\frac{1}{2}} \text{ versus } \phi$$

$$Slope = \frac{S_w}{R_w{}^{\frac{1}{2}}}$$

Hingle Plot

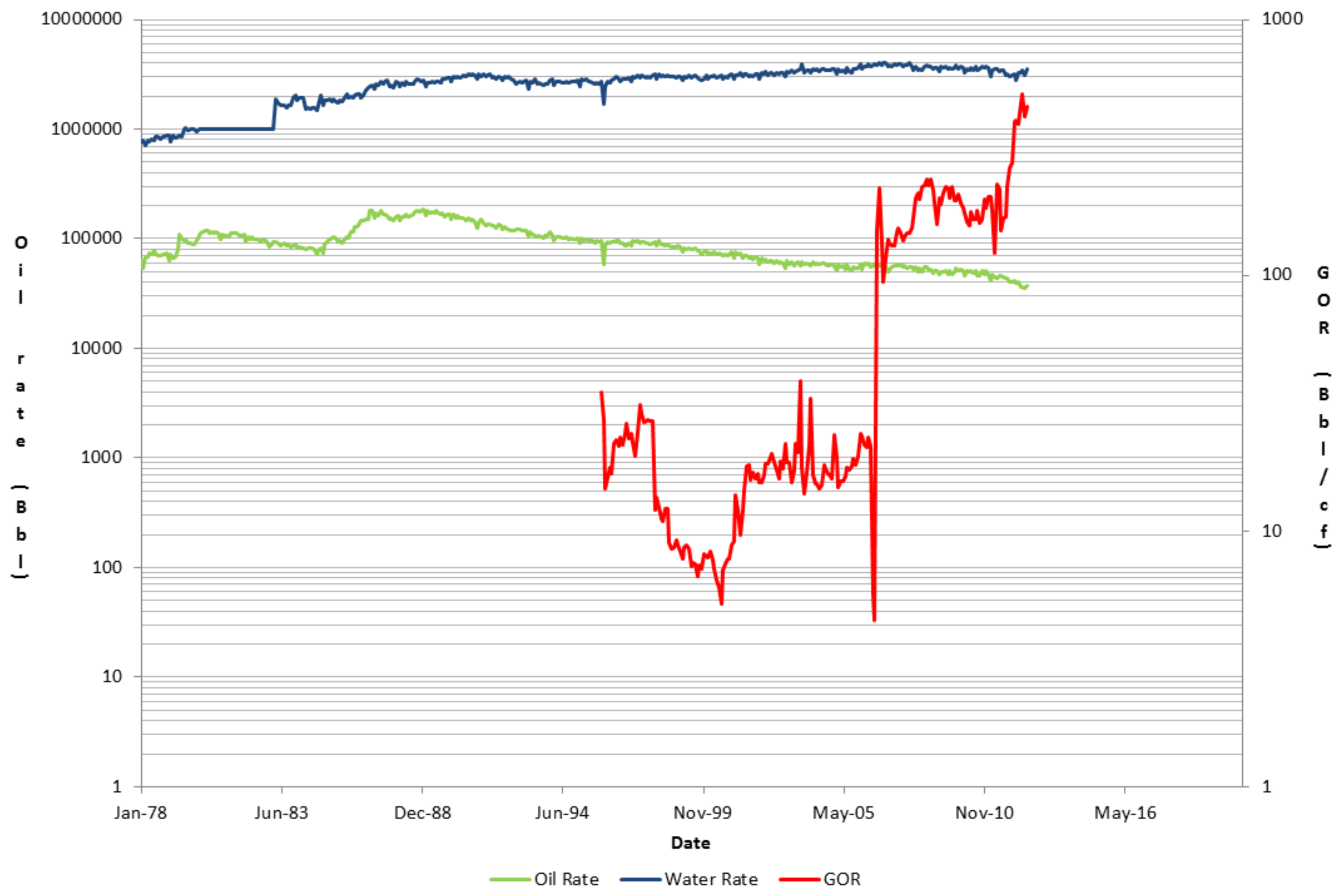


0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1/Rt^0.5
Sw=100%
Sw=50%
Sw=25%
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Porosity

Comparison of Plots

- Water saturations found from
  - Pickett Plot
    - 20 - 45%
  - Hingle Plot
    - 22 - 48%

Production



10000000
1000000
100000
10000
1000
100
10
1
Oil rate (Bbl)
1000
100
10
1
GOR (Bbl/cf)
Jan-78
Jun-83
Dec-88
Jun-94
Nov-99
May-05
Nov-10
May-16
Date
Oil Rate
Water Rate
GOR

Decline Analysis

- Hyperbolic model

$$q' = \frac{q_i}{(1 + n(t)(d_i))^{\frac{1}{2}}}$$

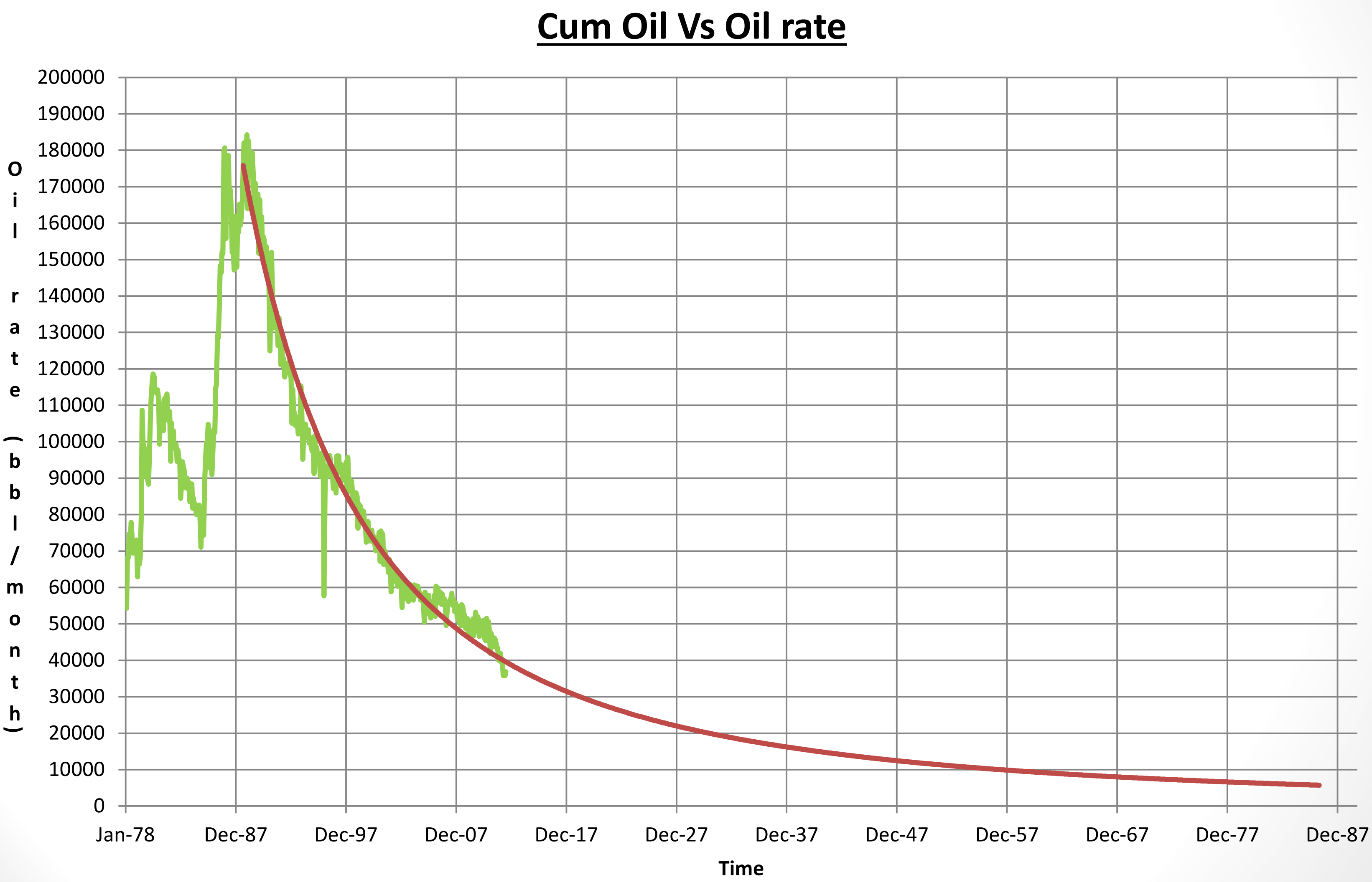
$$Q_t = \frac{{q_i}^n}{(1-n)(di)}(qi^{1-n} - {q_t}^{1-n})$$

  - Where
    - q_i = inital flow rate (bbl/d)
    - d_i = inital decline rate (1/t)
    - n = hyperbolic decline exponent (n= 0.5)
    - Q_t = cumulative production (bbls)
    - q' = hyperbolic production rate at time t, (bbl/d)
    - q_t = production rate at time t (bbl/d)

- Used sum of the deviations squared and nonlinear regression

$$\sum (q - q')^2$$

Decline Analysis



Hubbert's Model

$$Q_t = \frac{Q_{max}}{1+ae^{-bt}}$$

$$q_t = \frac{Q_{max}abe^{-bt}}{(1+ae^{-bt})^2}$$

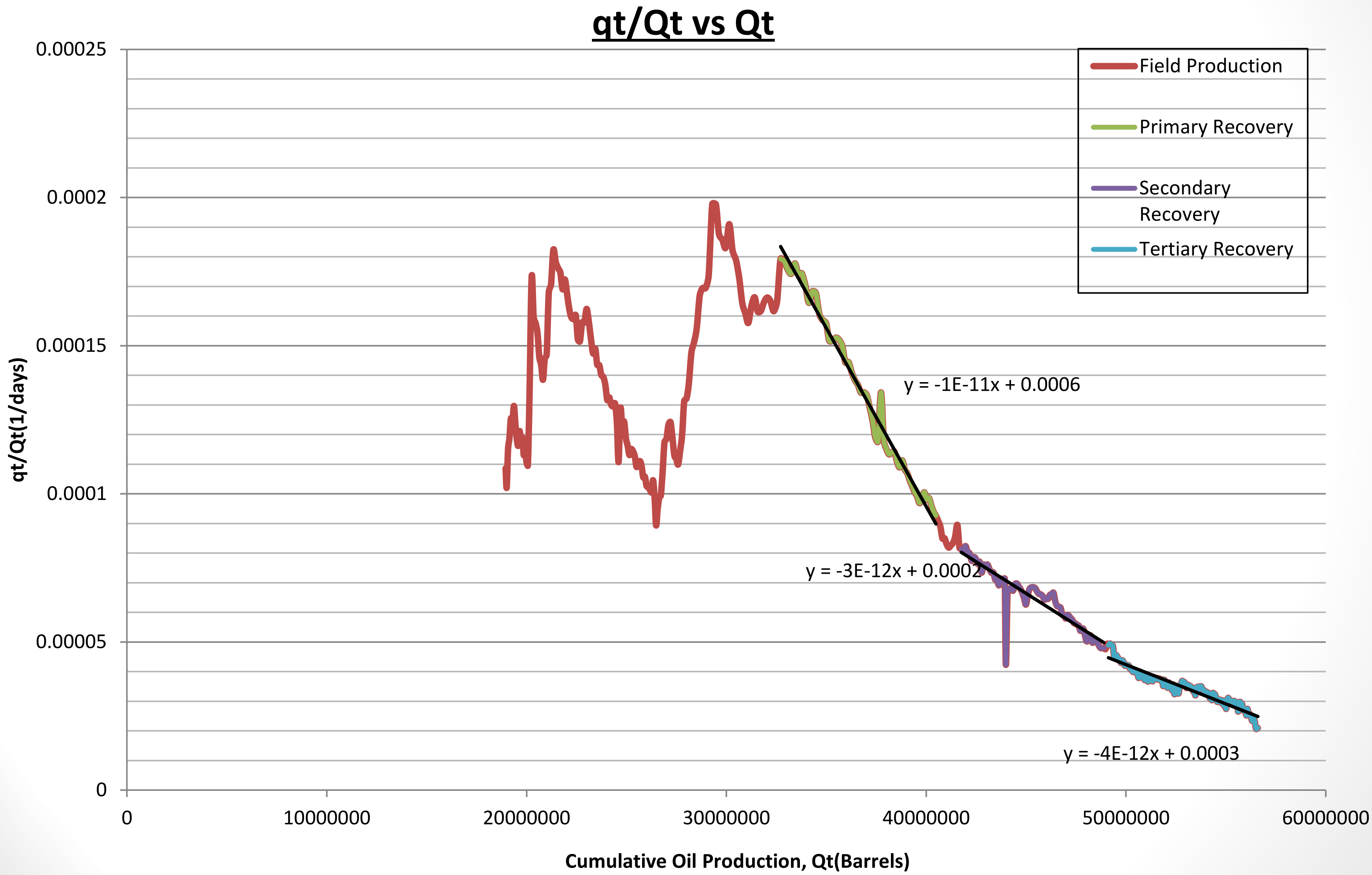
$$\frac{q_t}{Q_t} = b - b\frac{Q_t}{Q_{max}}$$

$$\frac{Q_{max}}{Q_t} - 1 = ae^{-bt}$$

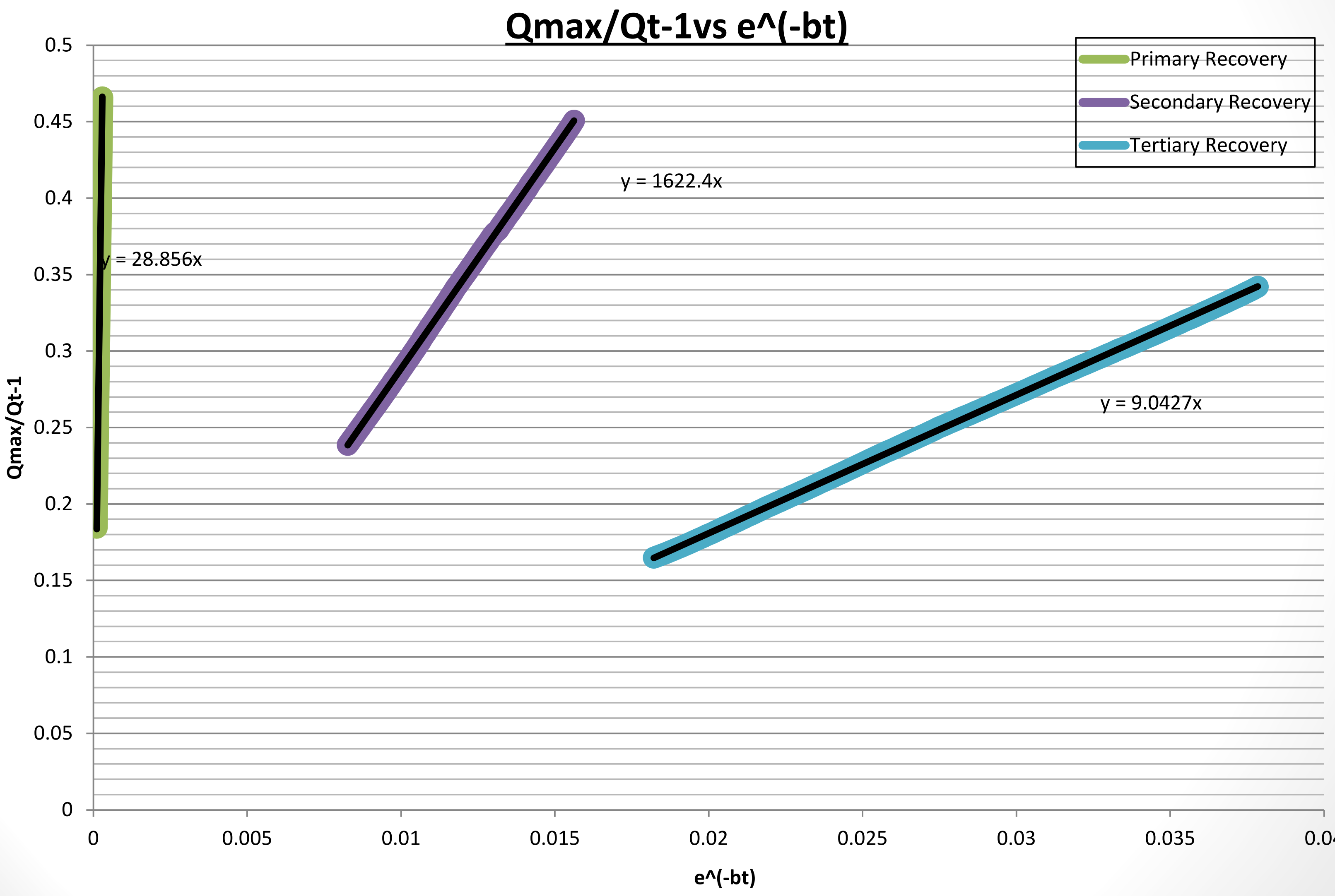
Where

- Q_t = cumulative production at time (t), barrels
- q_t = production rate at time (t), barrels/day
- Q_{max} = ultimate cumulative production, barrels
- a = growth or decline coefficient, dimensionless
- b = growth or decline exponent where dimensions are the reciprocal of time, e.g. 1/day

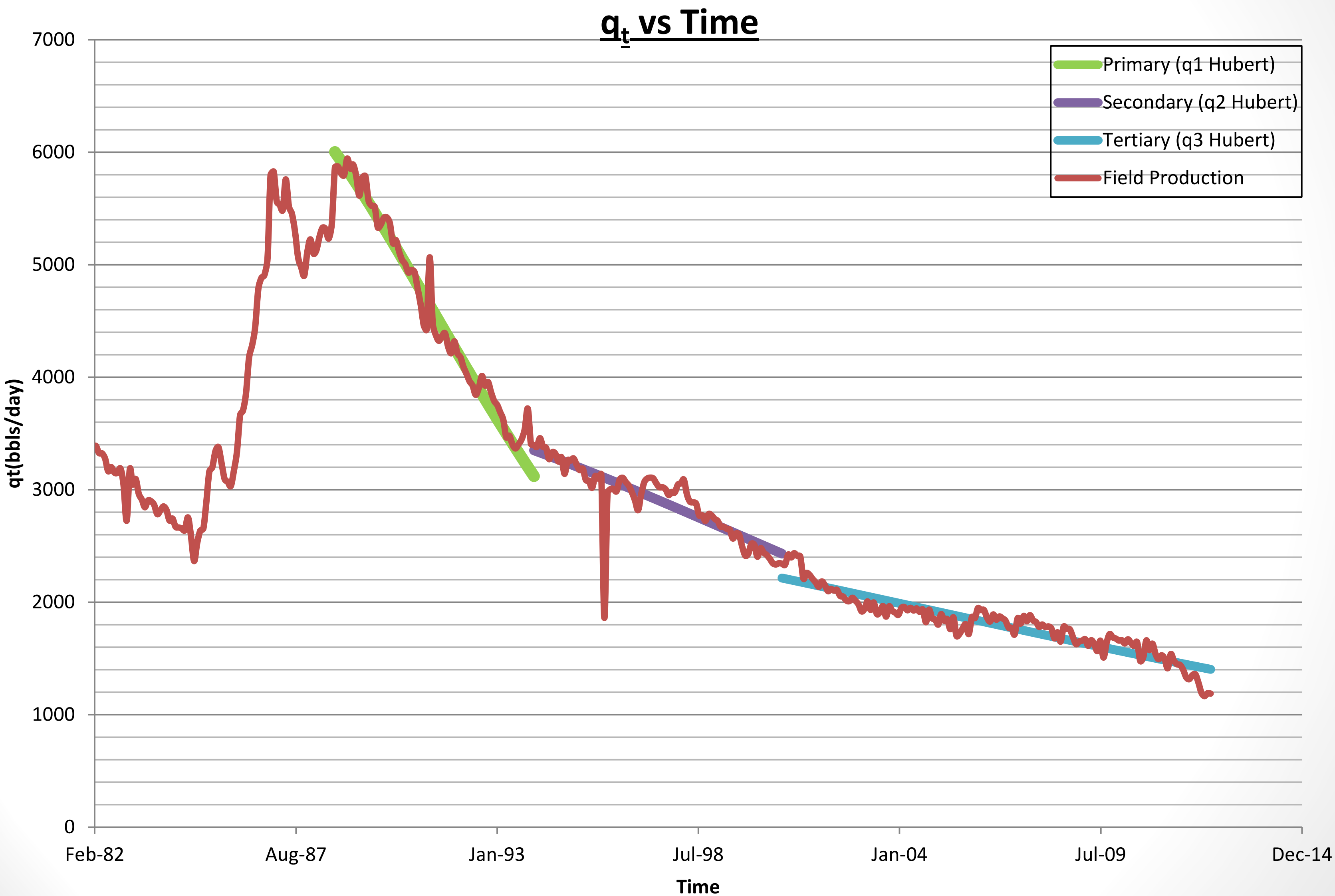
Hubbert's Model



Hubbert's Model



Hubbert's Model



Hubbert's Calculated Parameters

Calculated Huberts parameters								
Primary	**Qmax1=**	47946711.32	bbls	**b1=**	0.000577409	1/day	**a1=**	1622.40
Secondary	**Qmax2=**	60578899.43	bbls	**b2=**	0.000258308	1/day	**a2=**	28.86
Tertiary	**Qmax3=**	65922621.60	bbls	**b3=**	0.000175482	1/day	**a3=**	9.04

Hubbert's vs Hyperbolic

- Original Oil in Place: 209 MMSTB
- Total Oil Recovered to Date: 56 MMSTB

Hubbert

Total Recoverable: 65 MMSTB

Recovery Factor: 31.1%

Hyperbolic

Total Recoverable: 69.8 MMSTB

Recovery Factor: 33.9%

Economics of Additional EOR Options

- Alkaline Polymer Surfactant Flooding
  - Less than $2.00 per barrel injected
  - $2.50-$8.00 per incremental barrels of oil produced
  - Water flood infrastructure already in place

- Miscible CO_2 Flooding
  - Approximately $0.50 per Mcf injected
  - $6.00-$10.00 per incremental barrels of oil produced
  - Located near CO_2 sources

- ASP Flooding most viable option due to costs of operation and infrastructure

Conclusion

- Multiple models were used to confirm water saturation, total recovery factor and recoverable oil all of which produced similar results

- All calculated parameters were found to be similar to literature about the Pitchfork Field and Tensleep Formation

- Current gas flood operation is economic with polymer flooding being a potential future EOR option