Impact of Geological Variation and Completion Type in the U.S. Bakken Oil Shale Play Using Decline Curve Analysis and Transient Flow Character*

Elliott V. Hough[1] and Thomas McClurg[1]

Search and Discovery Article #40857 (2011)
Posted December 19, 2011

*Adapted from oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

[1]ConocoPhillips, Houston, TX (evhough@conocophillips.com)

Abstract

A performance analysis study of production data from over 2,300 Bakken oil shale wells in North Dakota, U.S.A., was conducted and the results are correlated with significant geologic and completion type variations across the play. Historical rate-time data were analyzed to identify the transient flow character (wellbore storage, 1/2 slope, ¼ slope or pseudo radial flow) and matched using the Arps equation to estimate ultimate recoveries. Numerical modeling studies were also performed on individual and time-normalized average historical well production to validate reservoir model(s) that best fit the observed well transient production declines.

Differences in transient flow character were defined and mapped using Arps hyperbolic "b" values. Wells completed in areas with a high permeability non-shale Middle Bakken carrier bed, with vertical pressure support from the overlying Upper Bakken and the underlying Lower Bakken Shales, are readily identified and have a characteristic transient decline distinguished by a certain range of "b" values. In other areas, where the Middle Bakken is either much lower perm or not present, producing wells will exhibit a much different transient, shale-dominated, decline and are characterized by an entirely different "b" value.

Integrated analysis that ties well performance to the reservoir geology and completion type lead to much improved reservoir models that can be leveraged to focus development in play sweet spots and optimize completion and well spacing strategies.

References

Fetkovich, M.J., 1980, Decline Curve Analysis Using Type Curves: SPE 4629, SPE 48th Fall Meeting, Las Vegas, Nevada, USA, September 30-October 3, 1973, 28 p.

Rosato, N.D., C.O. Bennett, A.C. Reynolds, and R. Raghavan, 1982, Analysis of Short-Time Buildup Data for Finite-Conductivity Fractures: SPE 9890, 10 p.

Impact of Geological Variation and Completion Type in the U.S. Bakken Oil Shale Play Using Decline Curve Analysis and Transient Flow Character

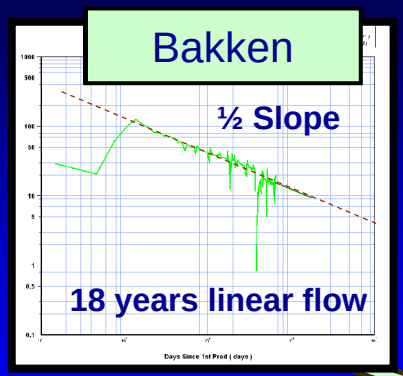
E.V. Hough, T.A. McClurg ConocoPhillips, Houston Texas

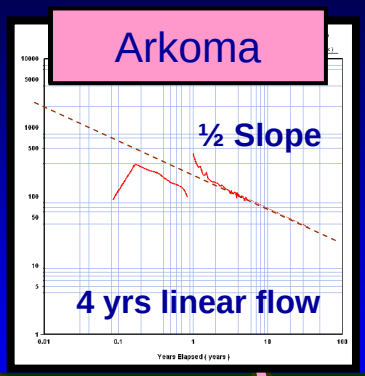
AAPG ICE
Milan, Italy
23-26 October 2011

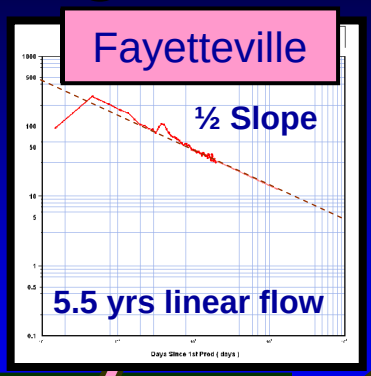
Key Points

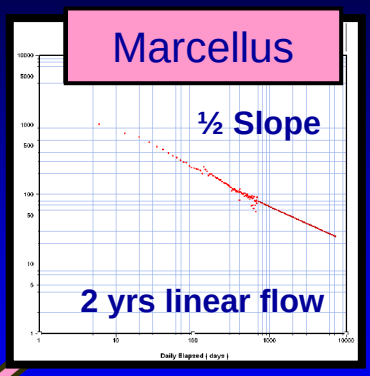
- Tied well performance for 3200 Bakken wells back to geology using Arps b-values
  - b< 0.5: Single layer in depletion (conventional reservoir)
  - b> 0.5 and < 1.0 : Multiple layers in depletion (conventional)
  - b > 1 : Transient formation linear flow into fractures (unconventional)
- Shales exhibit long duration linear flow (1/2 slope)
- Explained by ultra low nanodarcy perm matrix in contact with long planar fractures
- ½ slope can be matched empirically using Arps b=2
- Dual Perm system present when Arps b > 0.5
- b-values > 1.0 when production from nanodarcy perm rock
- Increasing completion size → increases EUR

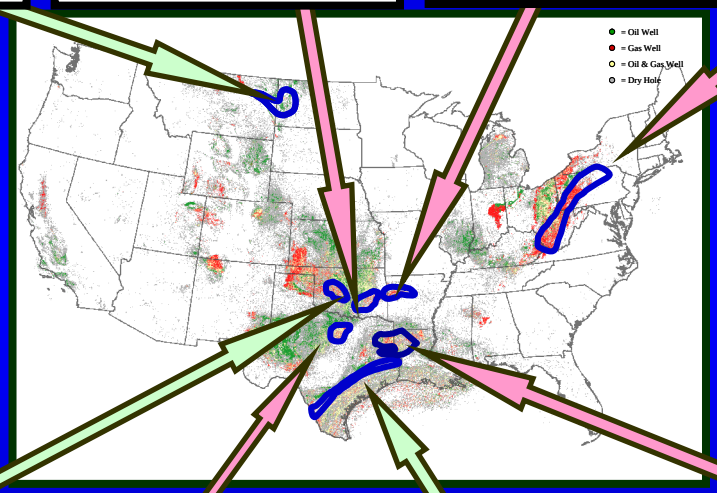
Shales Exhibit Long Duration Linear Flow



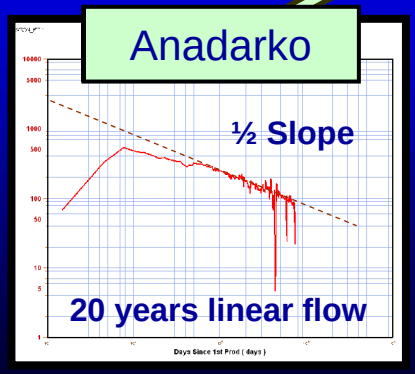


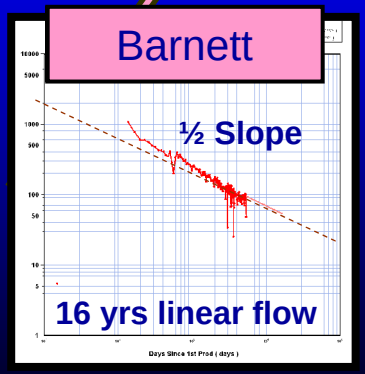


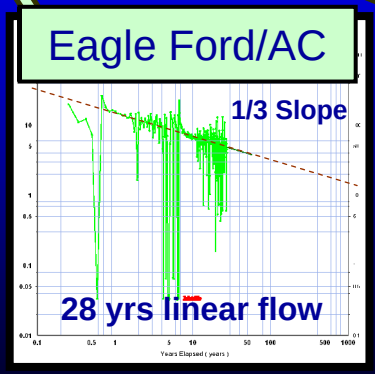


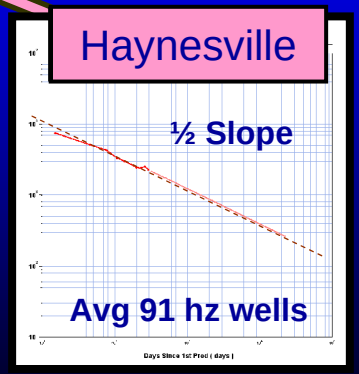


- Linear flow = Transient flow
- Long duration linear flow observed in + 90% of all L48 Shales
- Long duration Linear Flow means
  - Very low perm (nano darcy)
  - Long Induced fracture lengths





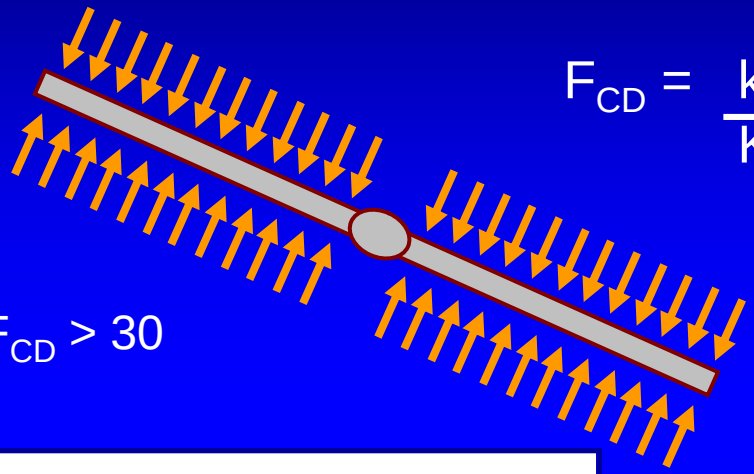




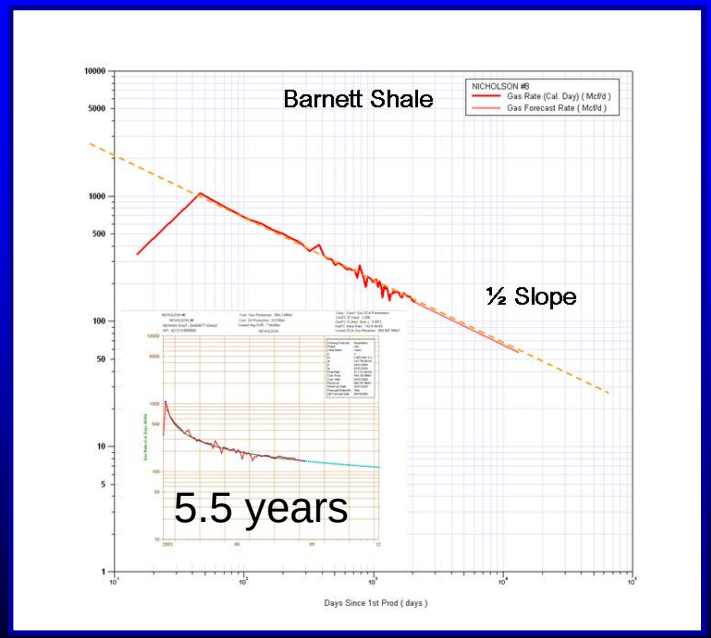
Linear Flow Types

½ Slope
Formation Linear Flow

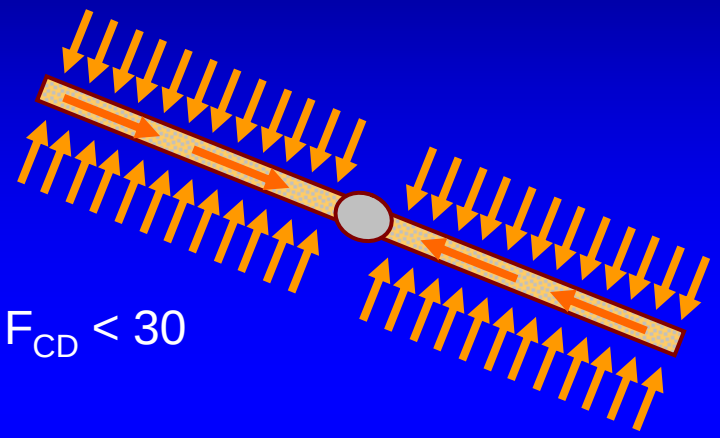
$$F_{CD} = \frac{k_f * w}{K * X_f}$$



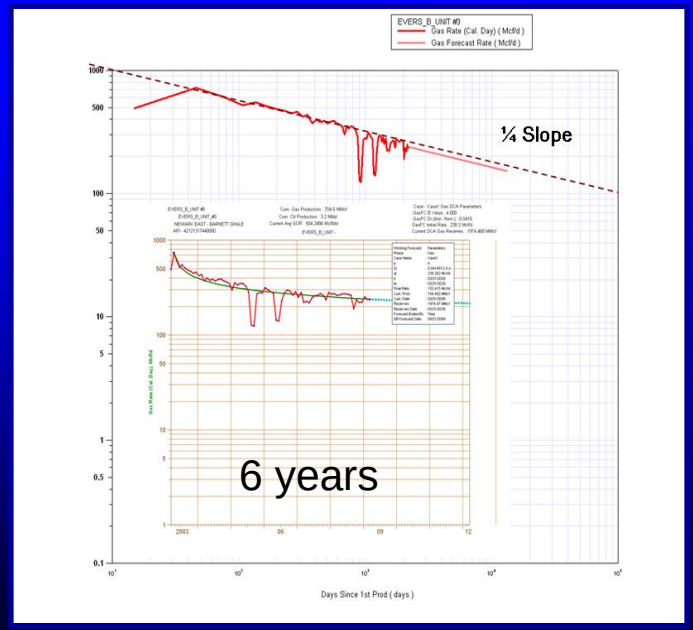
$F_{CD} > 30$



1/4 Slope
Bi-Linear Fracture Flow

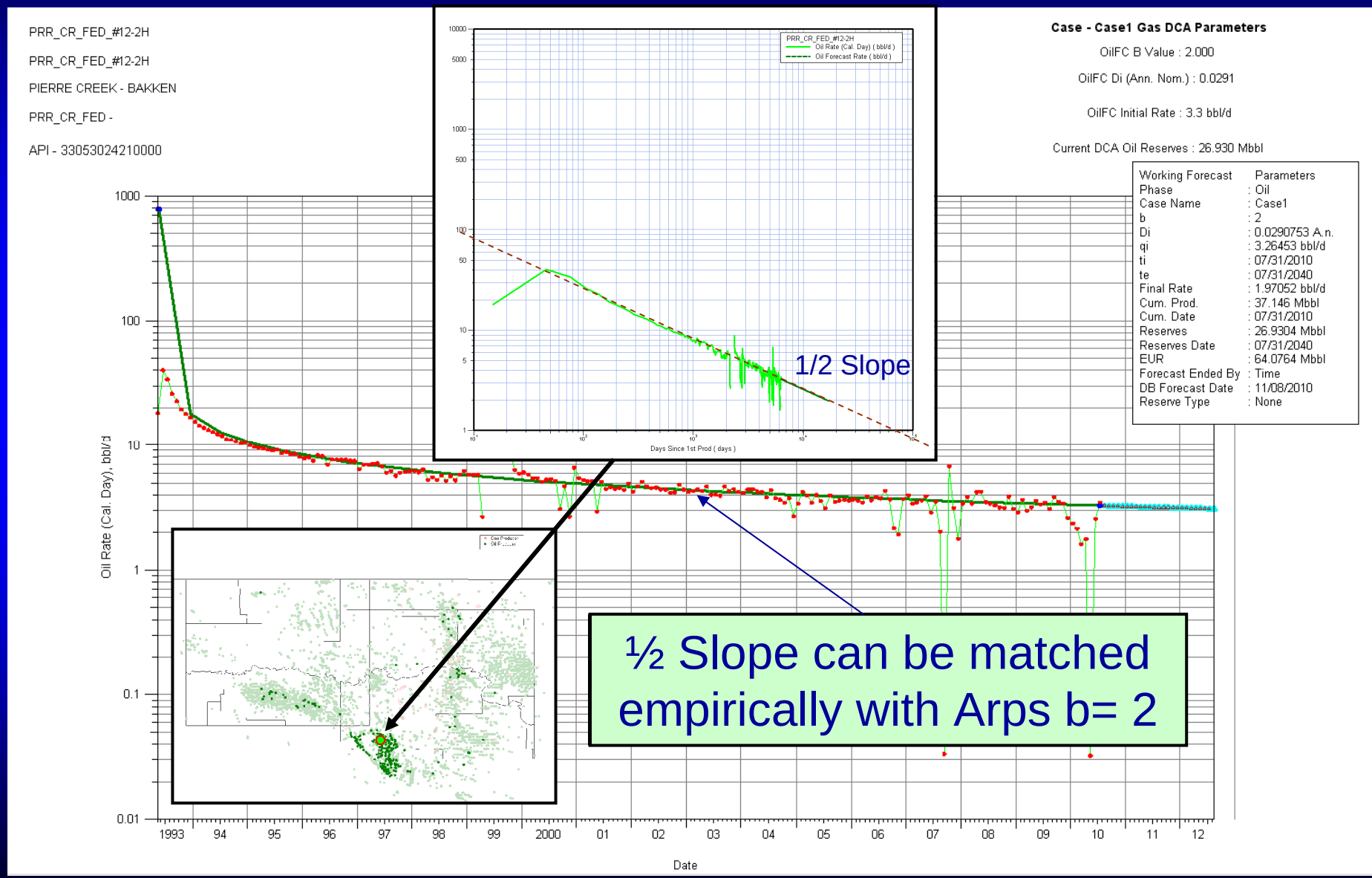


$F_{CD} < 30$

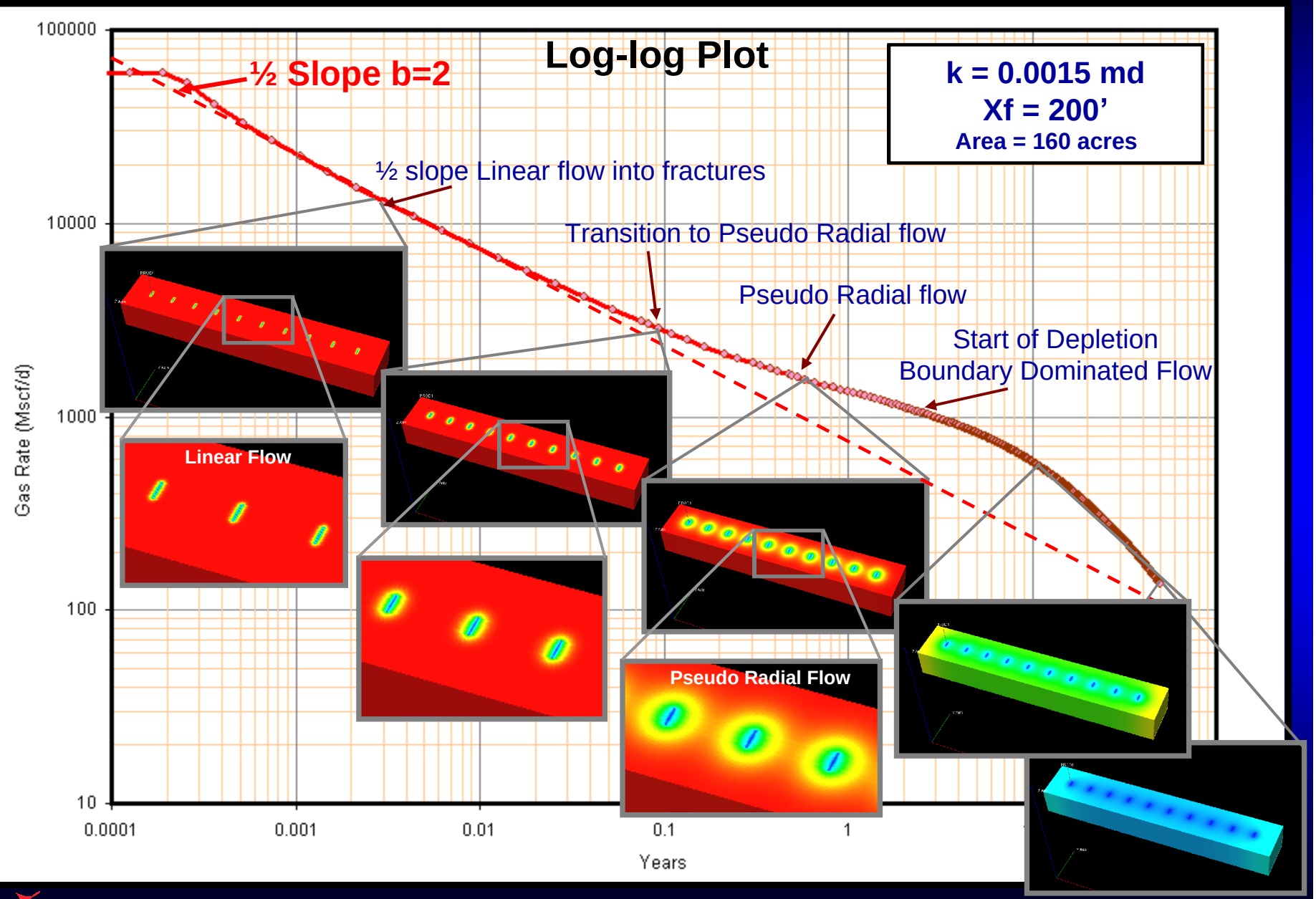


Bakken Example of Long Duration Linear Flow

17 Years on ½ Slope



Performance of very low perm fractured wells



Fetkovich Type Curve (SPE 4629)

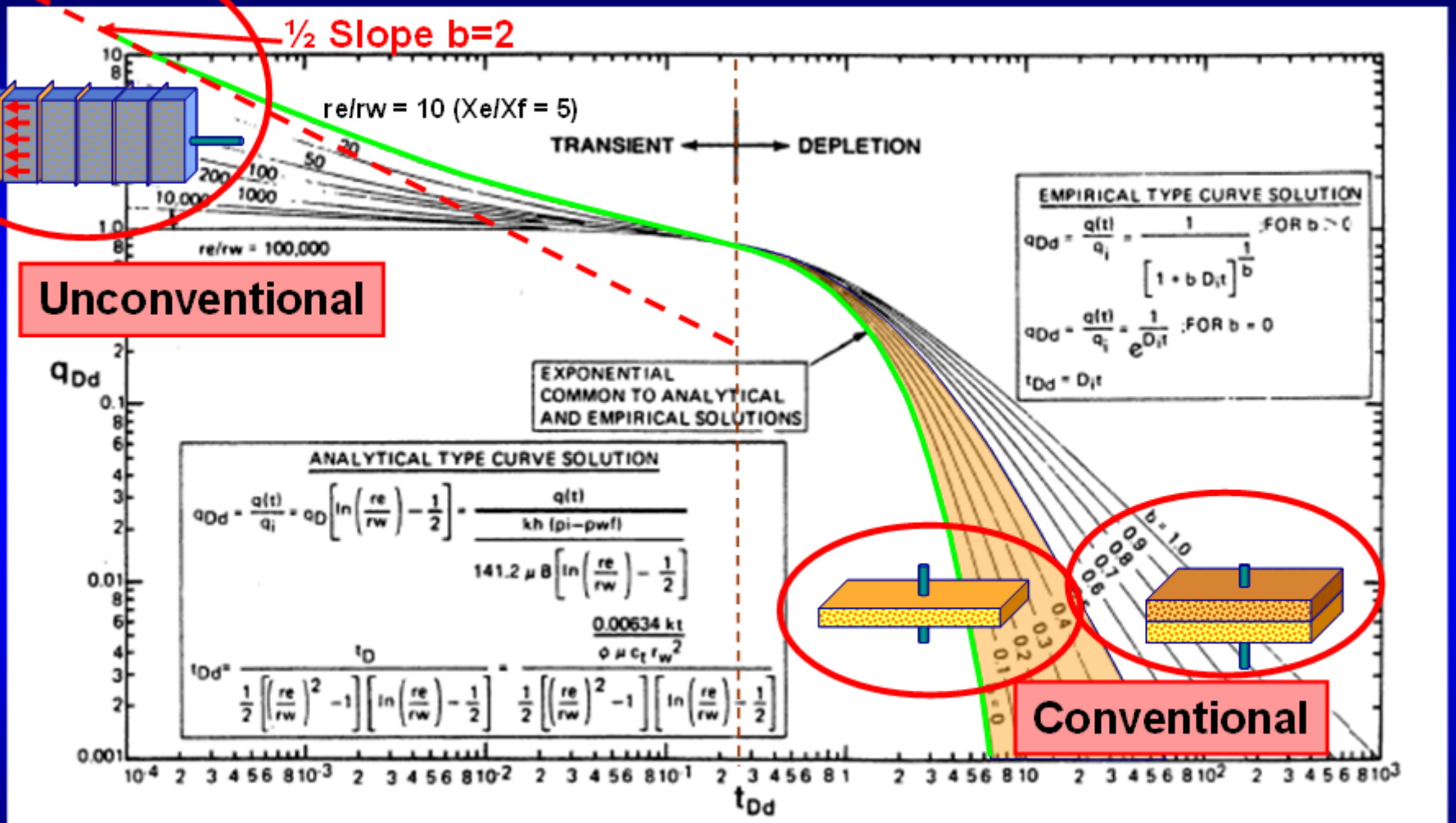
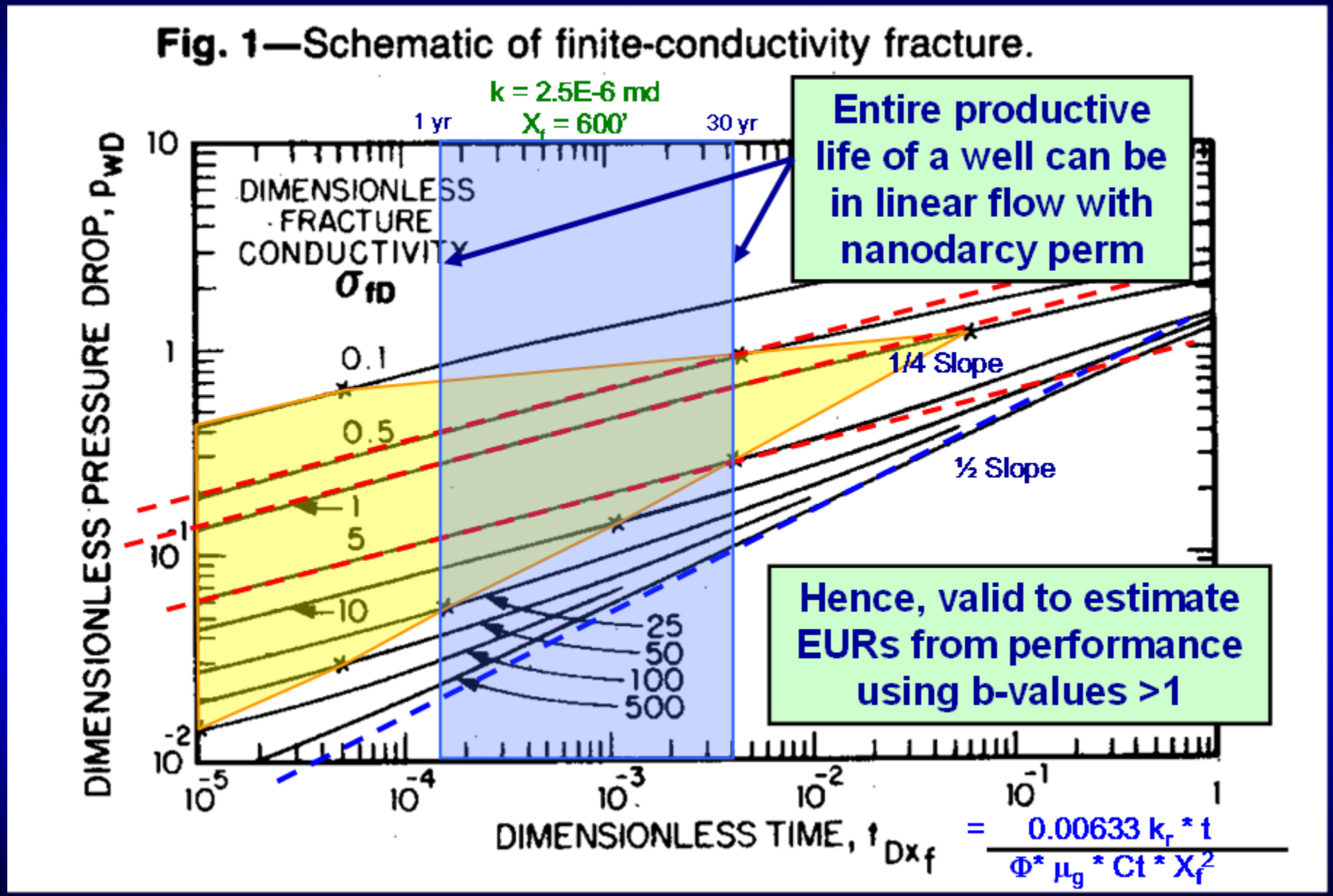


Fig. 1–Composite of analytic and empirical type curves (after Fetkovich[1]).

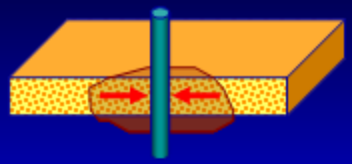
Constant Rate Log-Log Type Curve for Finite Conductivity Fractures

Rosato, Bennett, Reynolds and Raghavan 1982

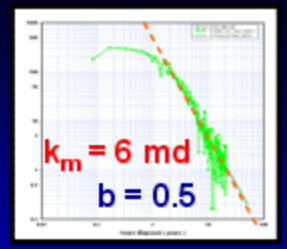


Reservoir Model b values

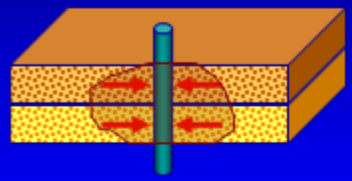
1. Conventional single layer depletion
   b = 0 to 0.5



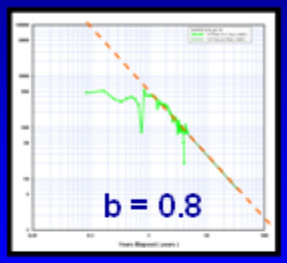
k > 0.1 mD



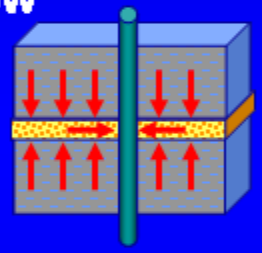
2. Conventional multi layered depletion
   b = 0.5 to 1.0

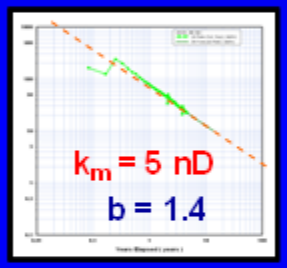


k = 0.1 mD
k = 1.0 mD
k_R = 10
V_R = 1

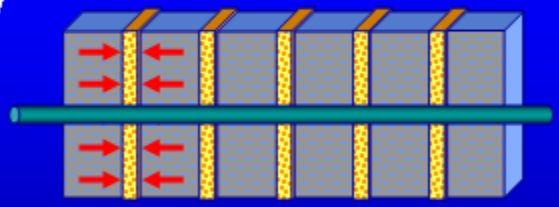


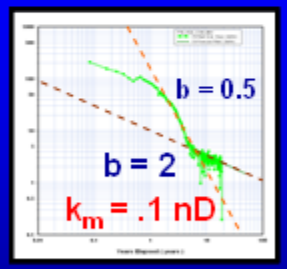
3. Carrier bed or fracture volume depletion and linear flow
   Moderate matrix perm (1-5 nD)
   b = 1.0 to 2
   then late time linear flow b = 2 to 4



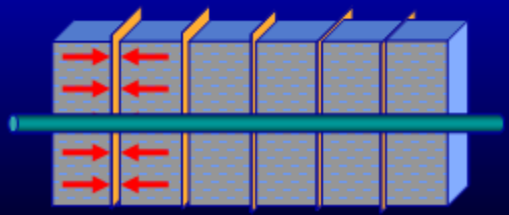


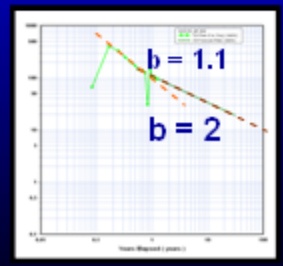
4. Fracture volume depletion and linear flow
   Sub nano darcy matrix perm
   b = 0.5 to 1
   then later time linear flow b = 2 to 4

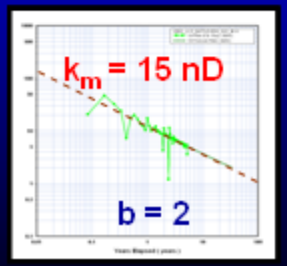


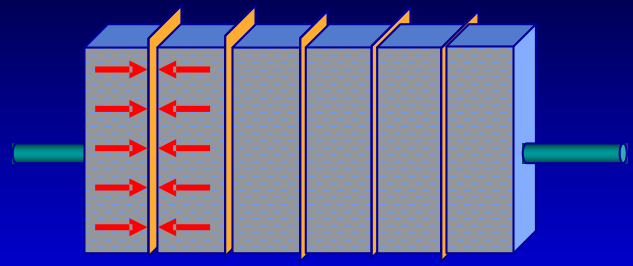


5. Formation linear flow with minor fracture volume depletion
   Good matrix perm > 5 nD
   linear flow b = 2









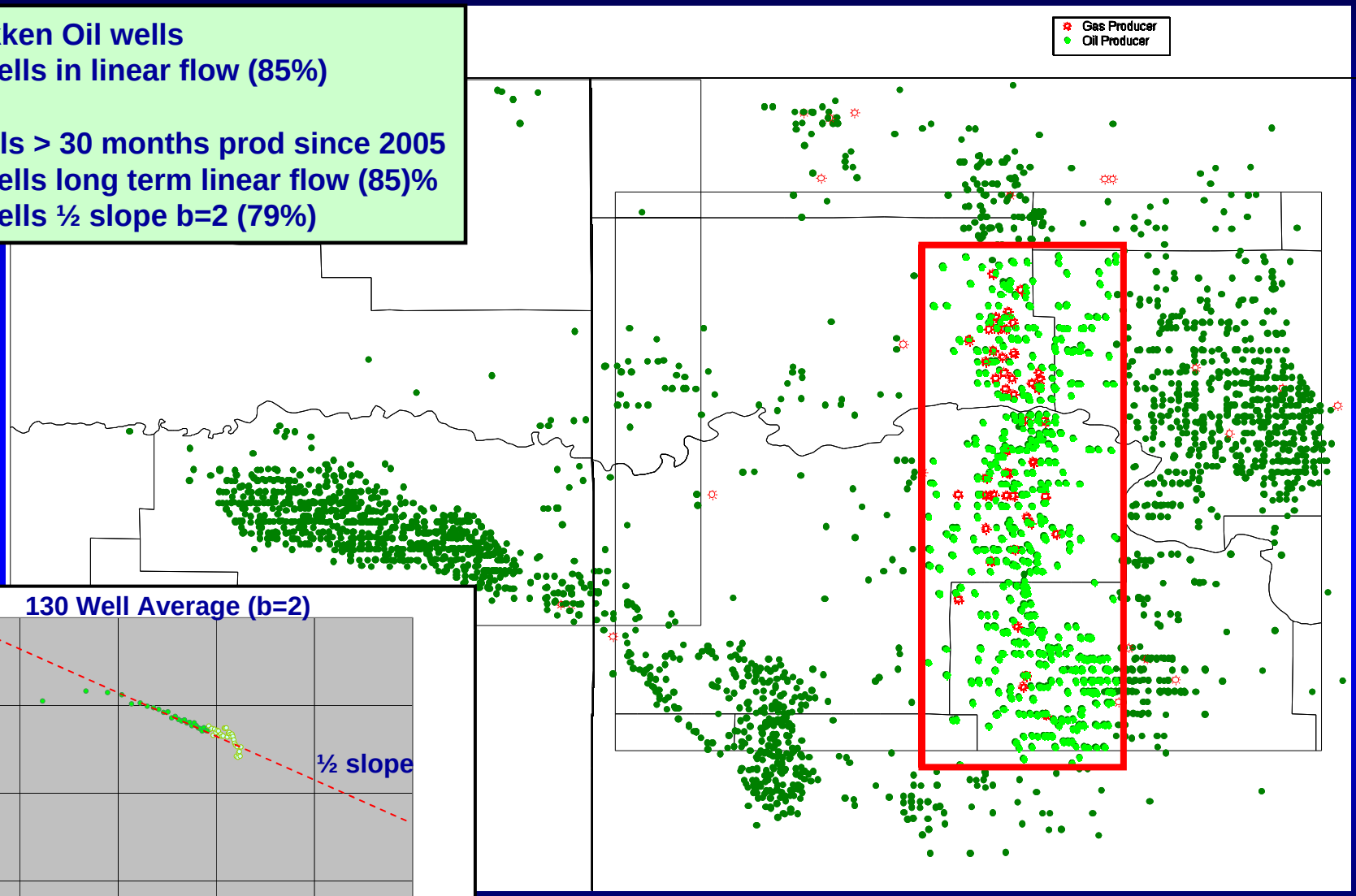
Modeling Long Term Linear Flow

½ Slope

Nesson Anticline Study Area

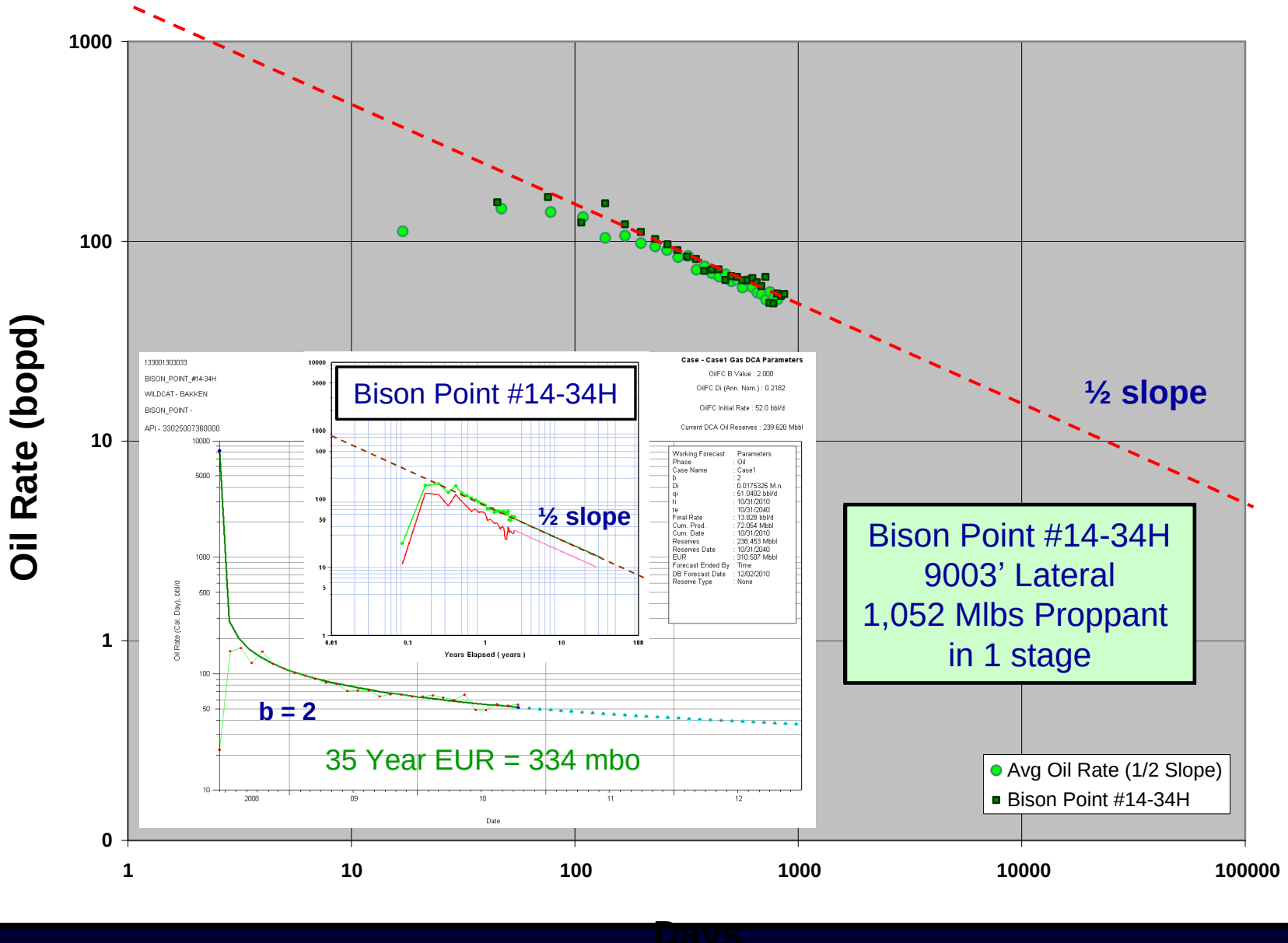
589 Bakken Oil wells
- **510 wells in linear flow (85%)**

164 Wells > 30 months prod since 2005
- **140 wells long term linear flow (85)%**
- **130 wells ½ slope b=2 (79%)**

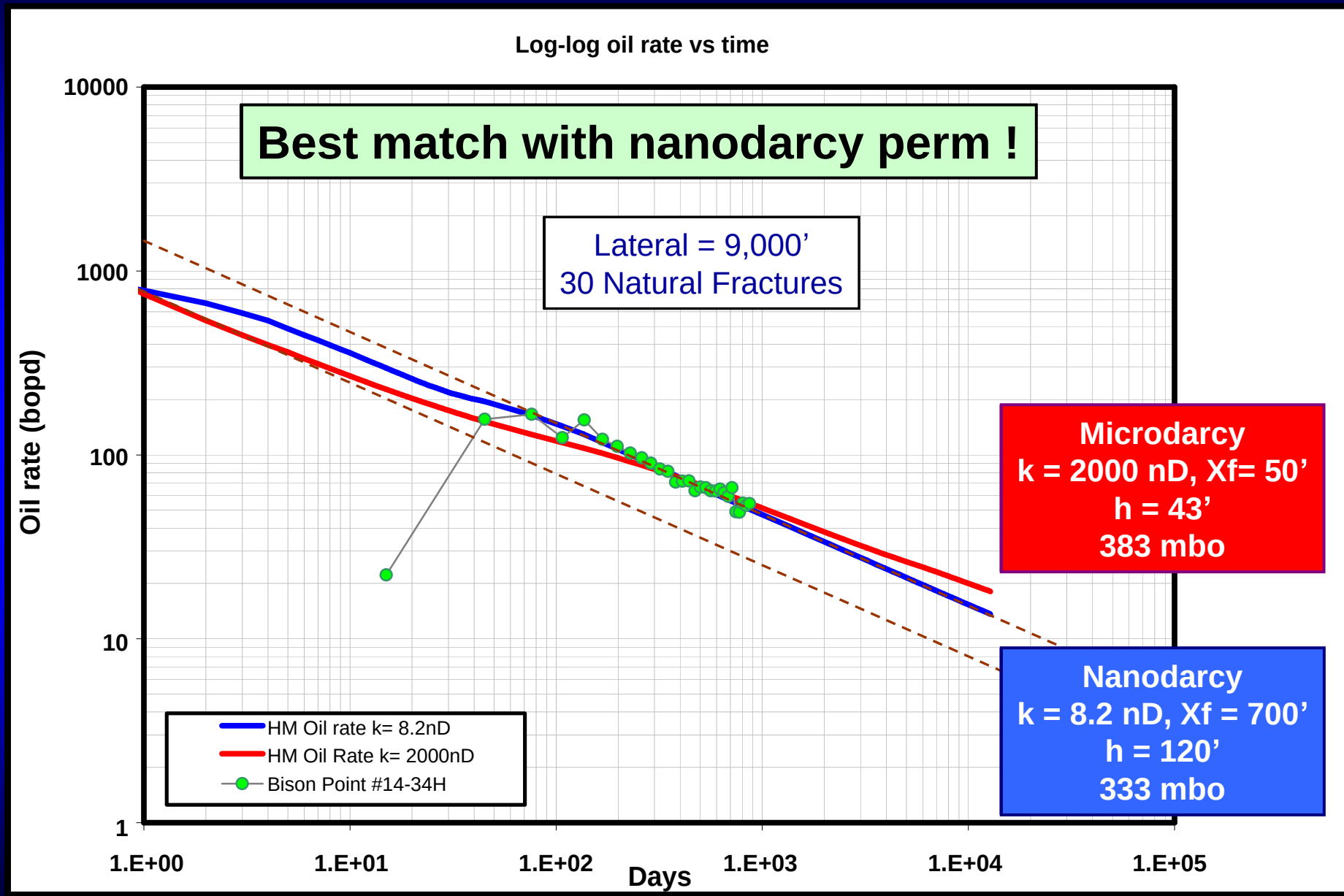


ConocoPhillips

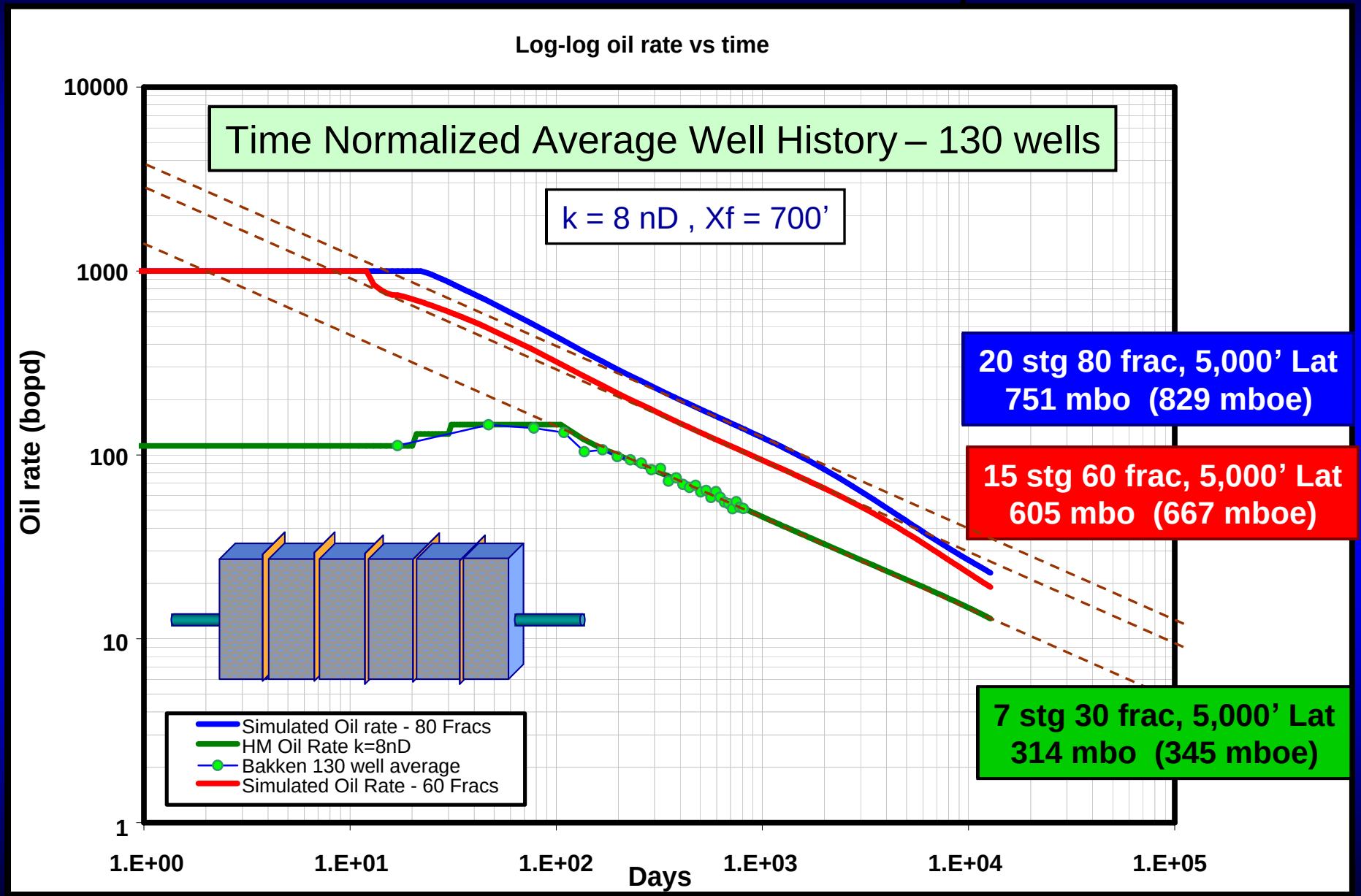
Time Normalized Average Well History – 130 wells

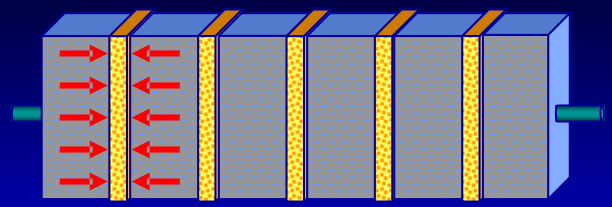


History Match of Bison Point #14-34H



EUR & Rate Increase with Completion Size

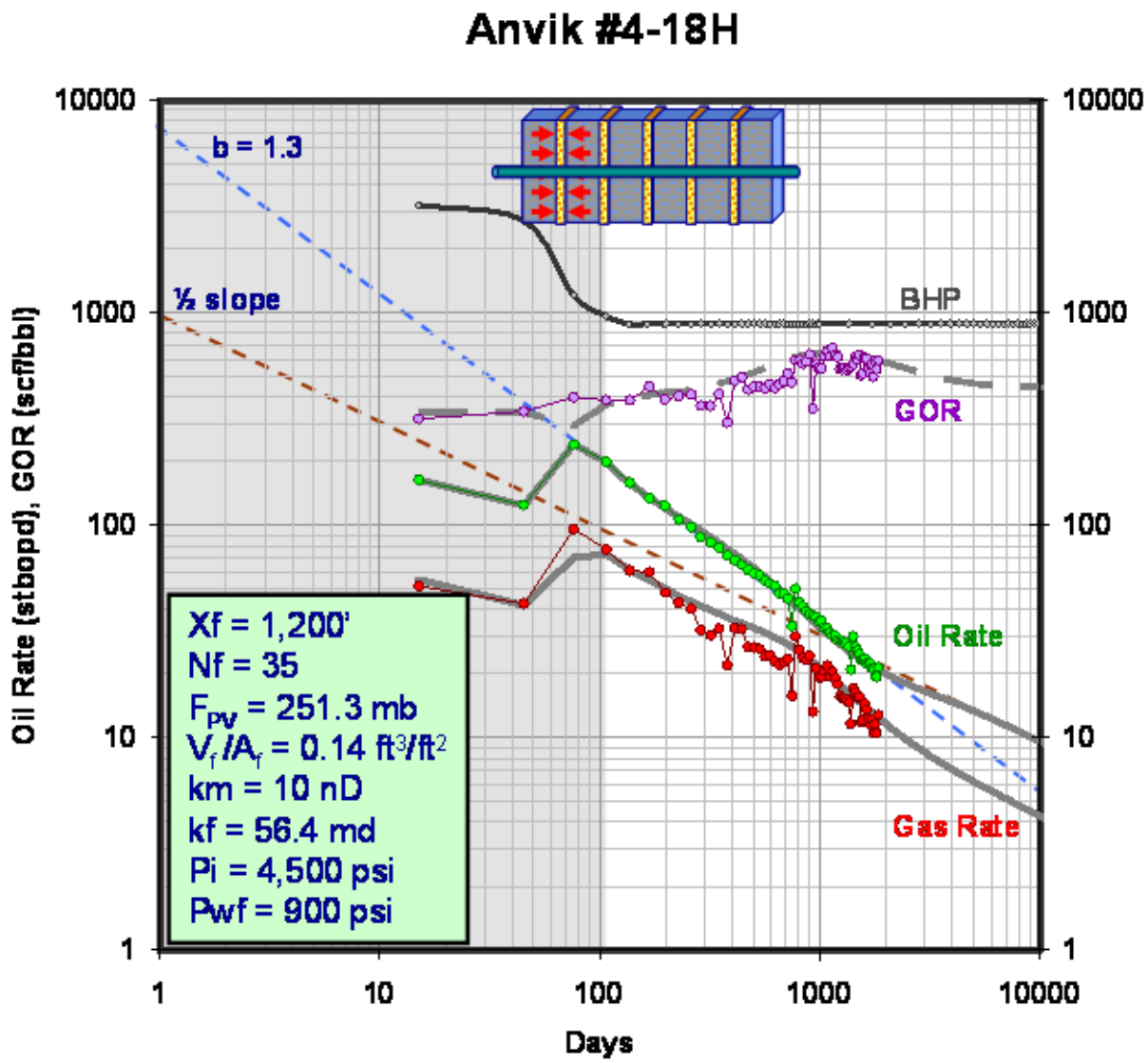


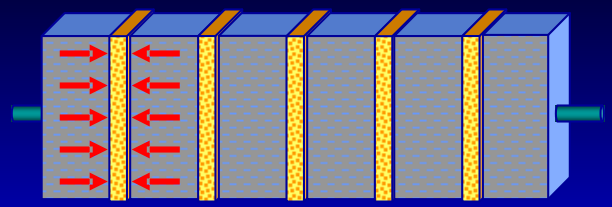


Dual Perm system
b – values between 1 and 2

High perm depletion volume (fractures) connected to nanoperm matrix volume in long term linear flow

b = 1.3

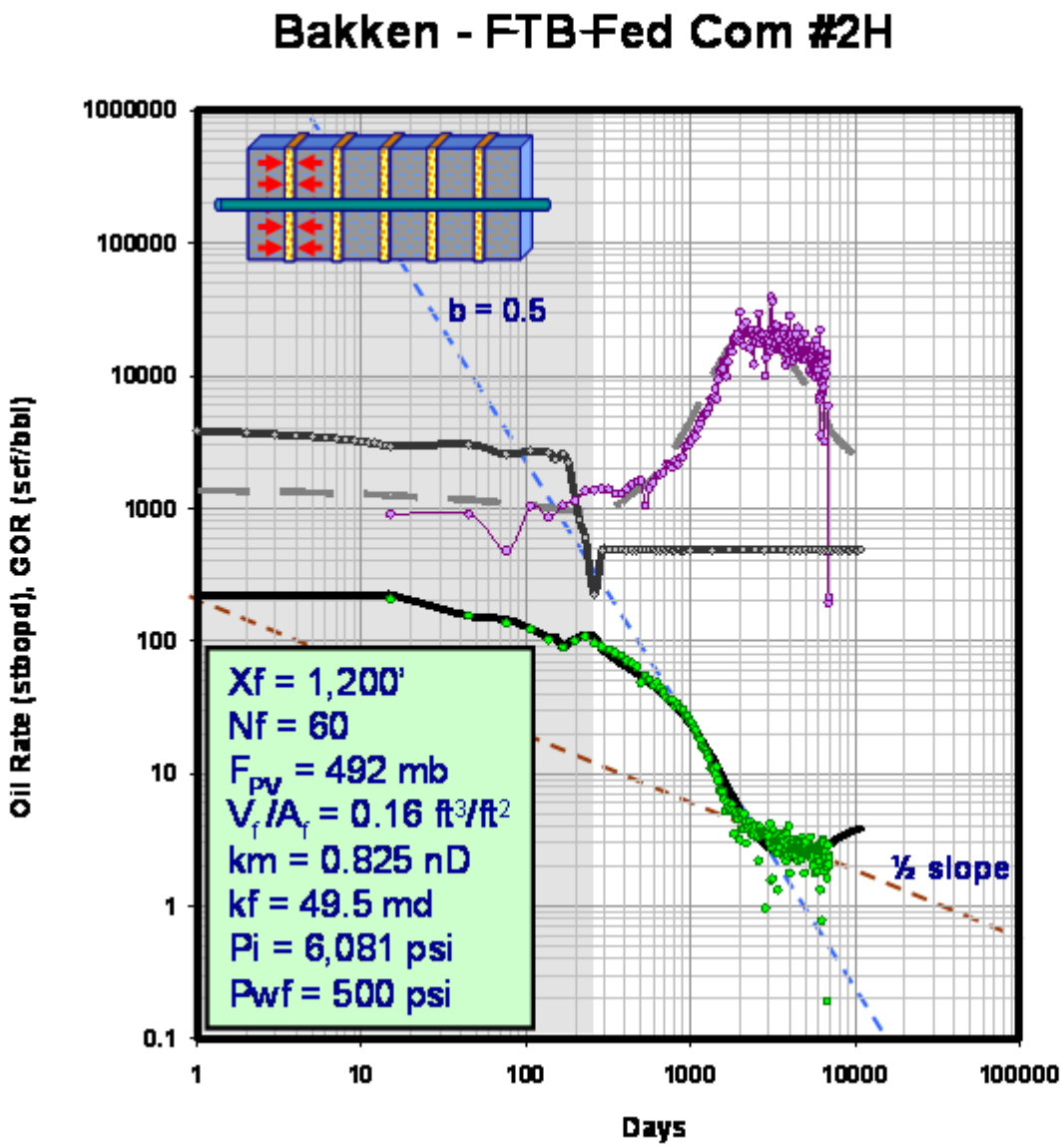

Anvik #4-18H
b = 1.3
½ slope
BHP
GOR
Oil Rate
Gas Rate
Xf = 1,200'
Nf = 35
F_{pv} = 251.3 mb
V_f/A_f = 0.14 ft³/ft²
km = 10 nD
kf = 56.4 md
Pi = 4,500 psi
Pwf = 900 psi
Oil Rate (stbopd), GOR (scf/bbl)
Days
10000
1000
100
10
1
1
10
100
1000
10000



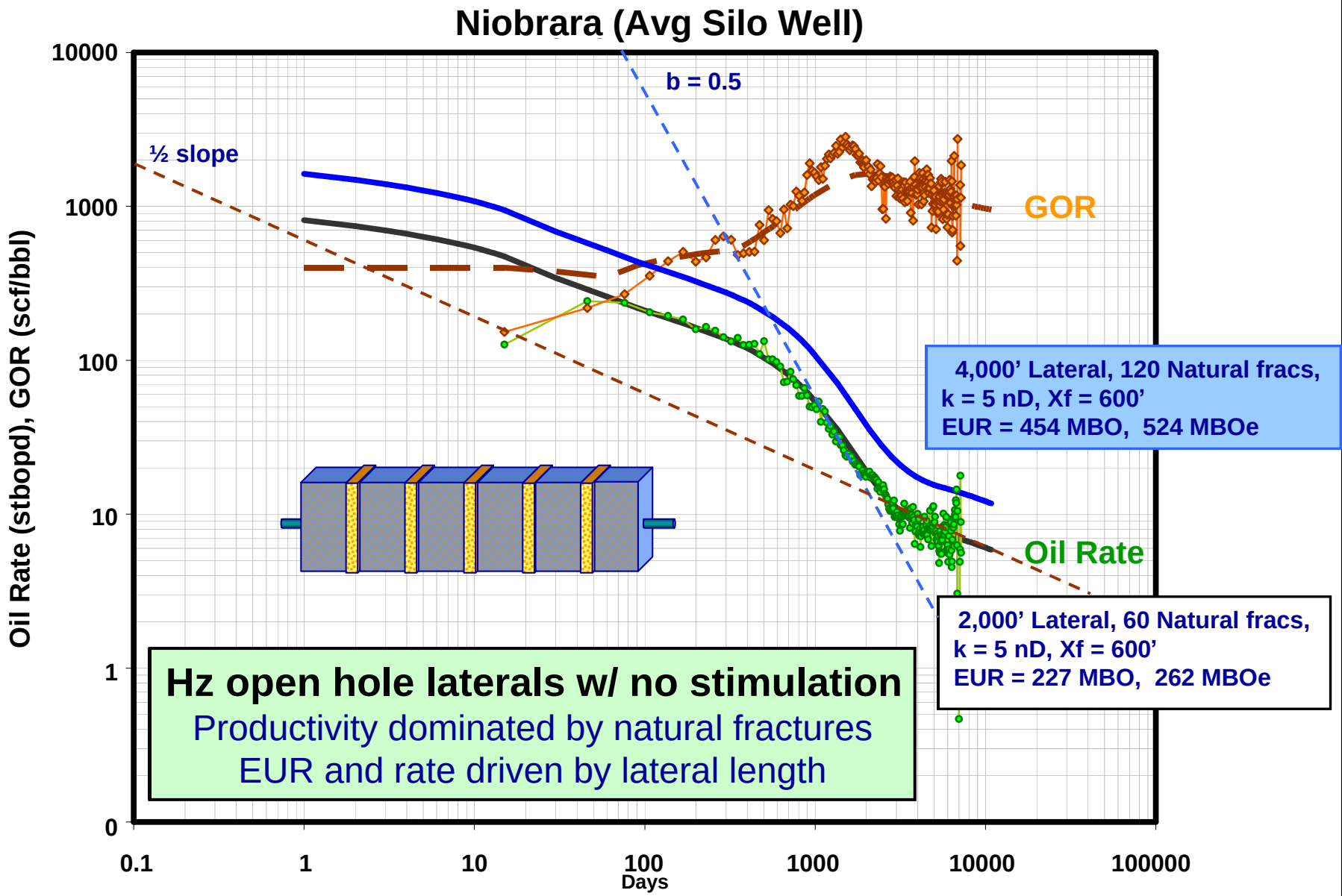
When fracture depletion dominates… Early b-values less than 1.0

Nanoperm and sub nanoperm matrix connected to high perm high pore volume natural fractures

Late Time Linear

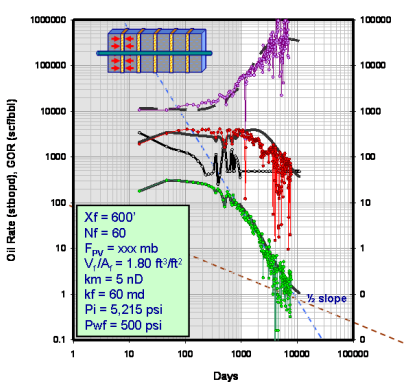


Late Time Linear

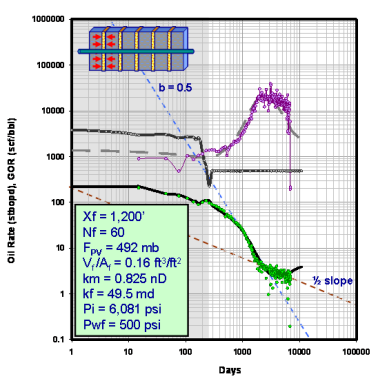


Matching Dual Perm b-values

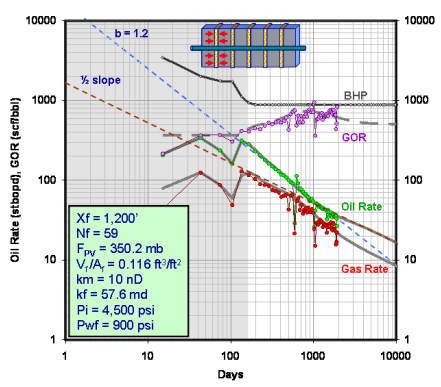
b = 0.5



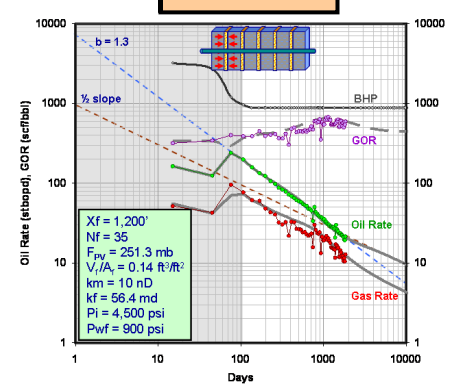
Late Time Linear



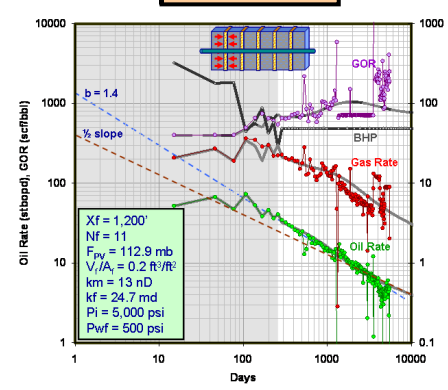
b = 1.2



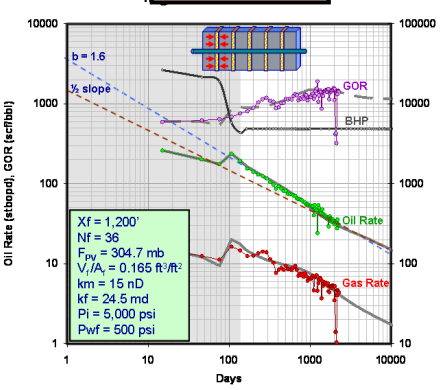
b = 1.3



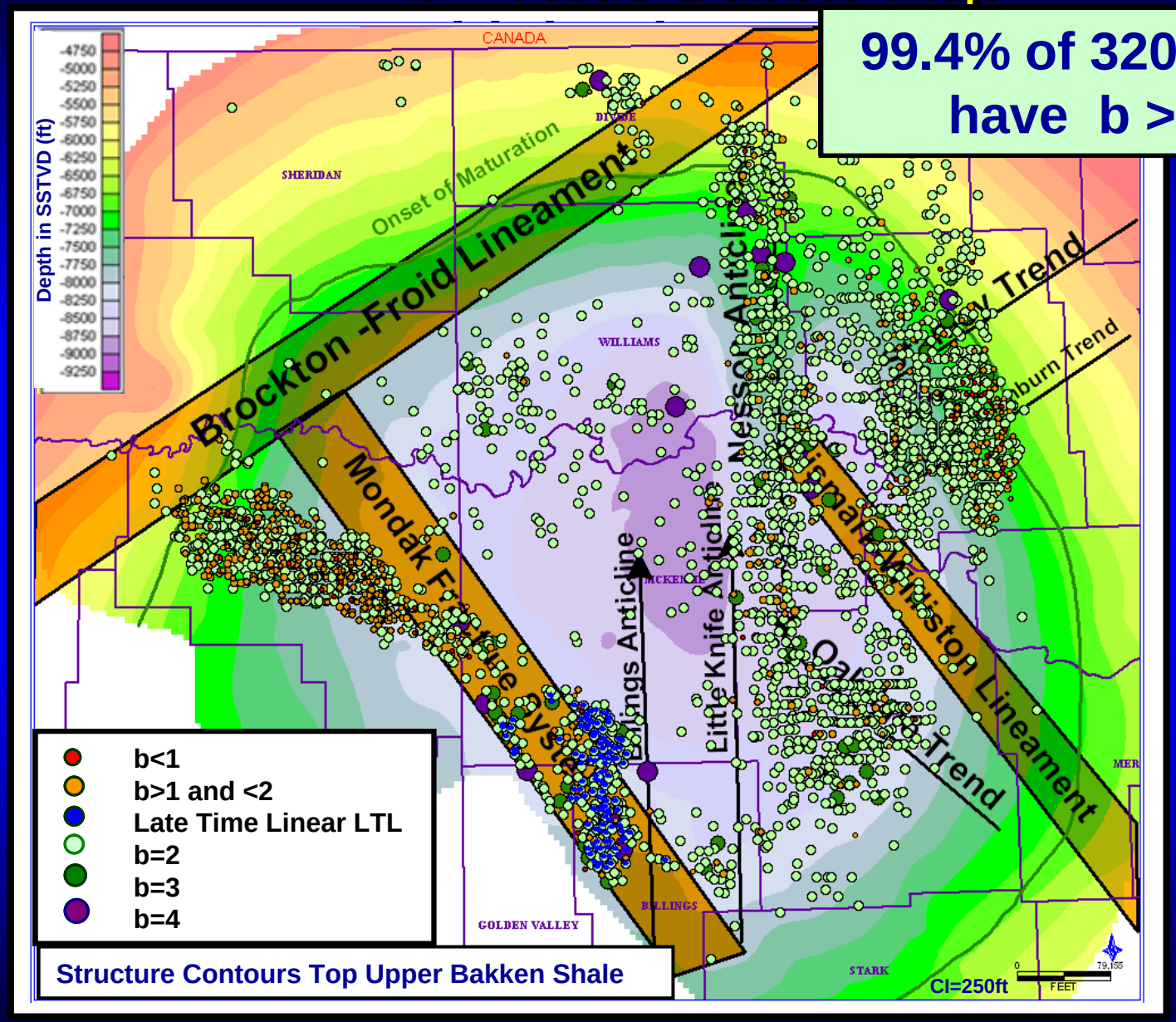
b = 1.4



b = 1.6



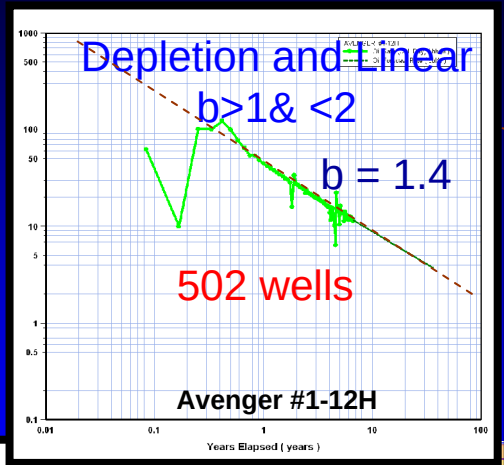
b - Value Bubble Map

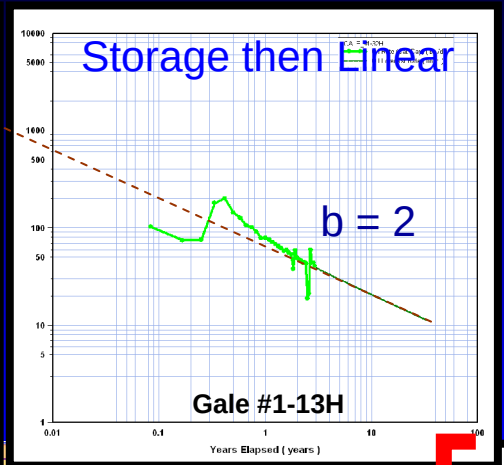


Structural features from Gerhard 1987

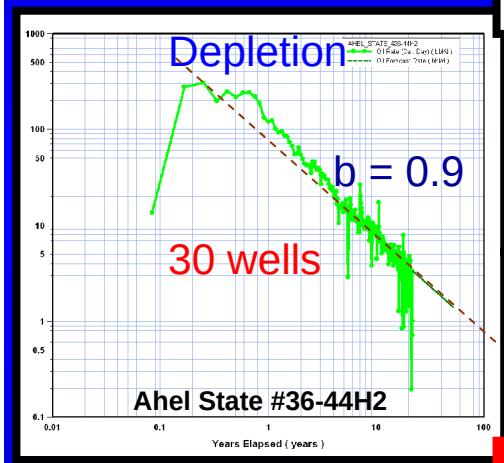
Bakken Well Performance Characteristics

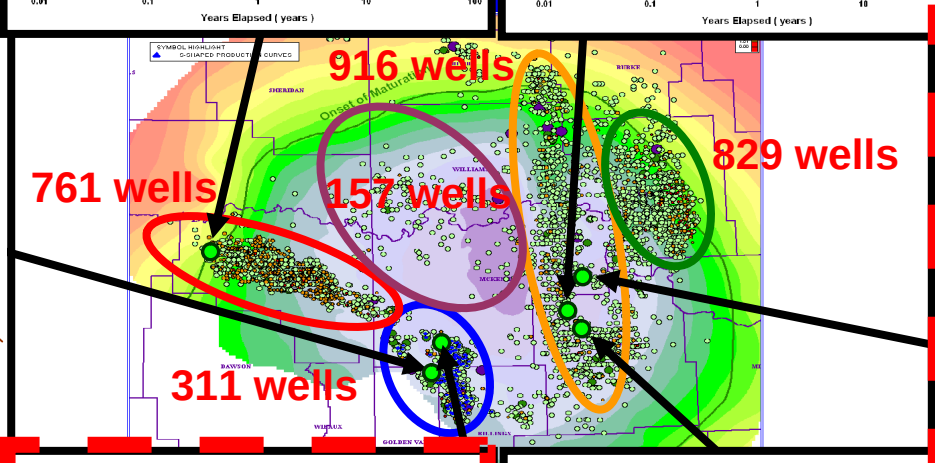
Elm Coulee Area
761 Wells
464 wells b=2
15 wells b=3
5 wells b=4
260 wells b>1 &<2
5 wells b<1

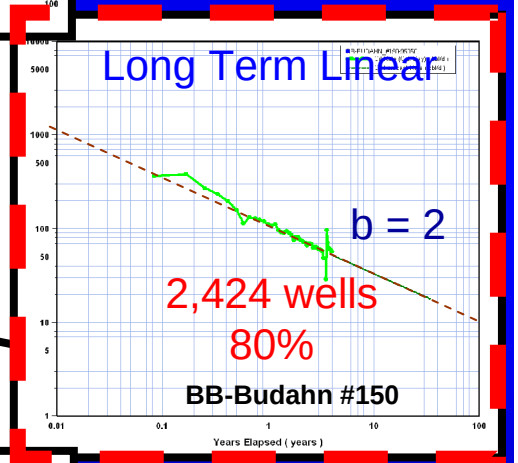




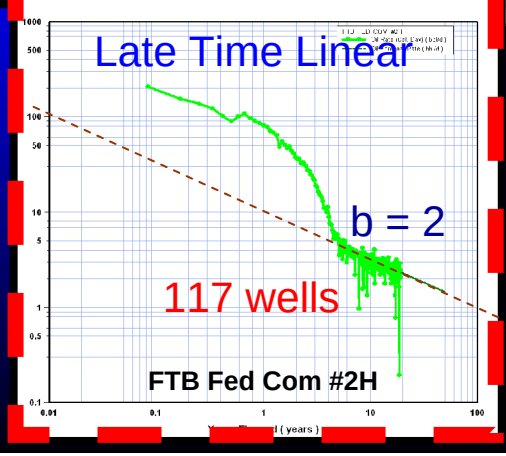
Sanish Area
829 wells
691 wells b=2
17 wells b=3
1 wells b=4
120 wells b>1 &<2
7 wells b<1

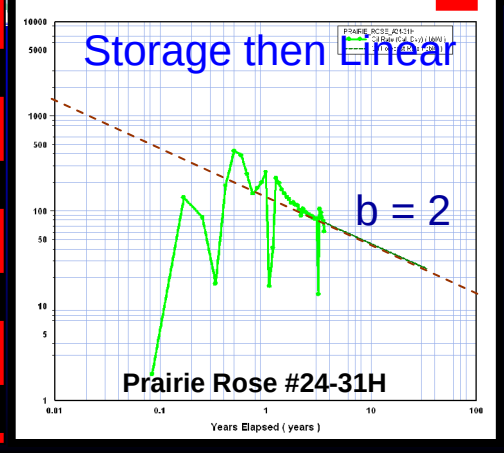






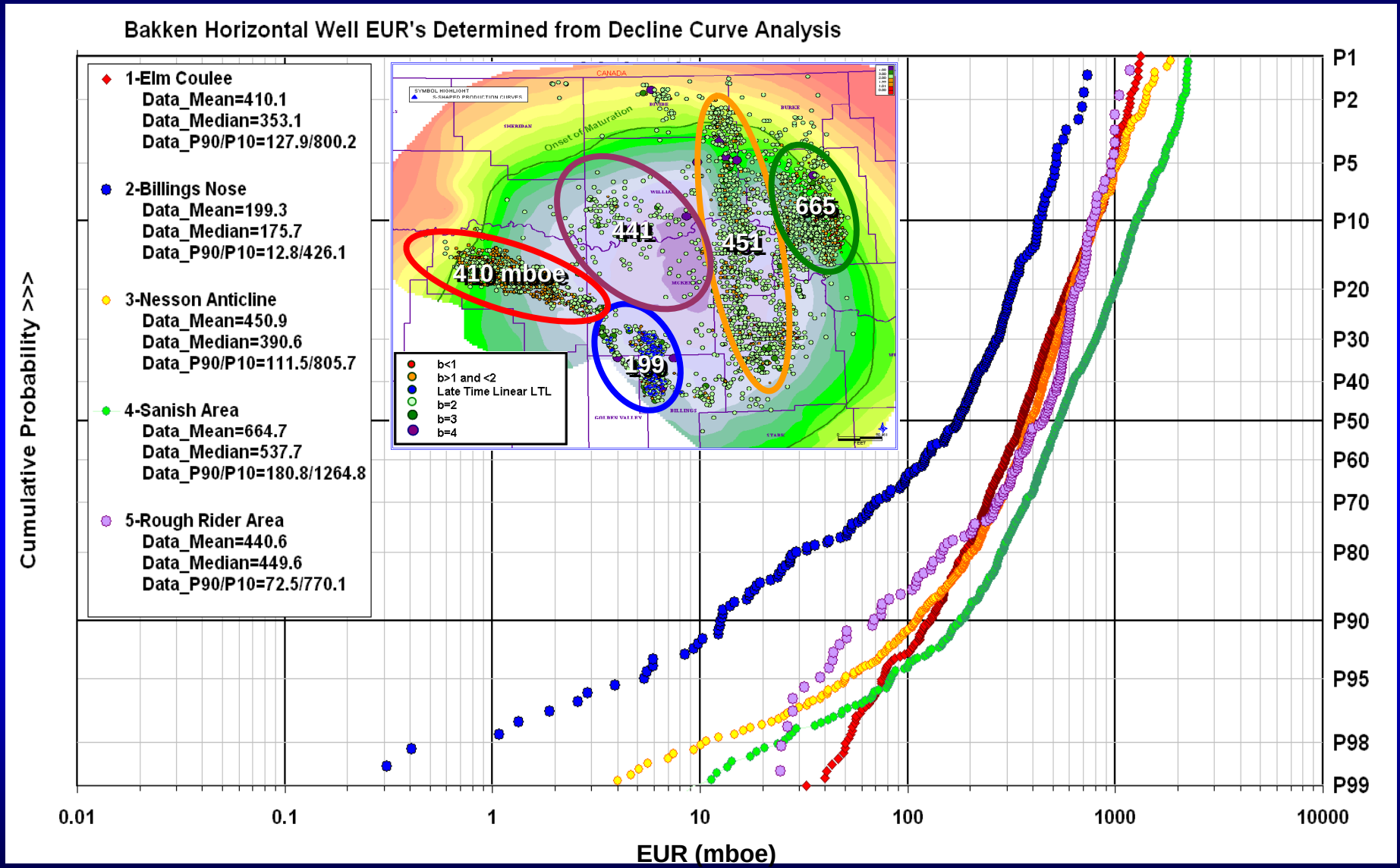
Billings Nose Area
311 wells
138 wells b=2
117 wells LTL
13 wells b=3
4 wells b=4
27 wells b>1 &<2





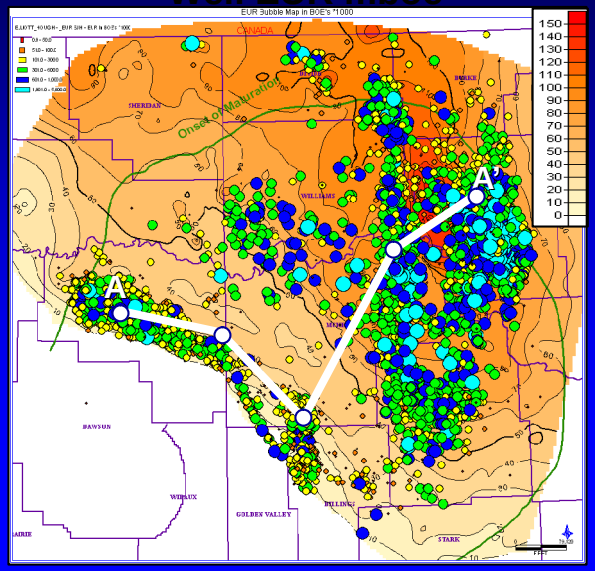
Nesson Anticline
916 wells
795 wells b=2
31 wells b=3
6 wells b=4
84 wells b>1 &<2
6 wells b<1

Bakken EUR Distributions (mboe)

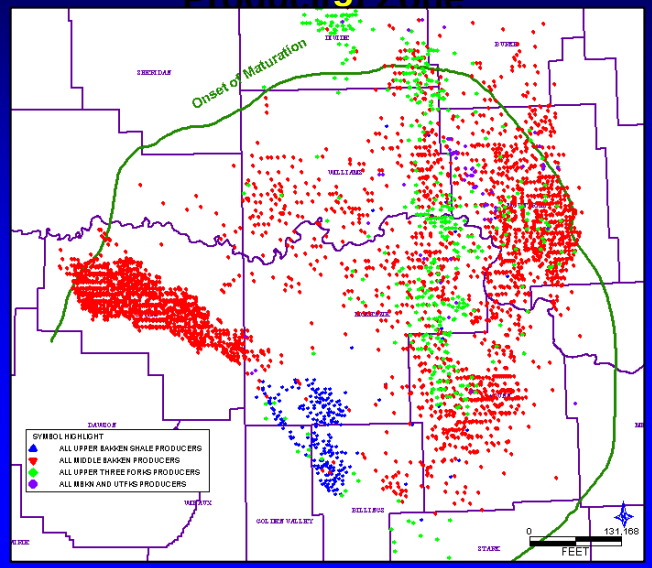


Bakken Stratigraphic Cross Section

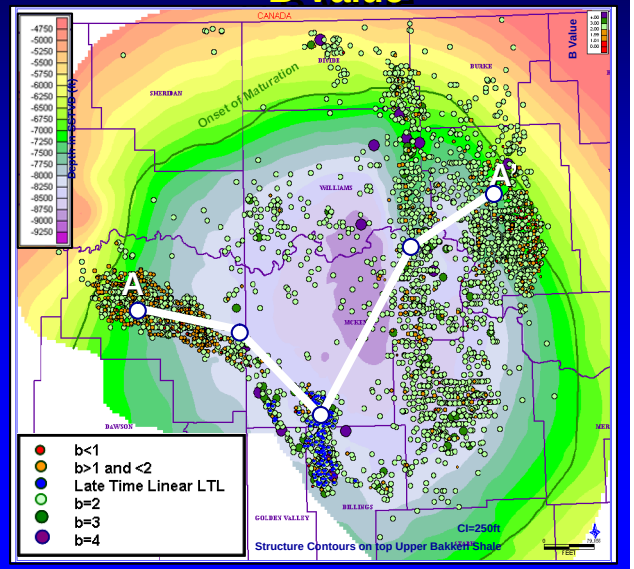
Well EUR mboe



Producing Zone



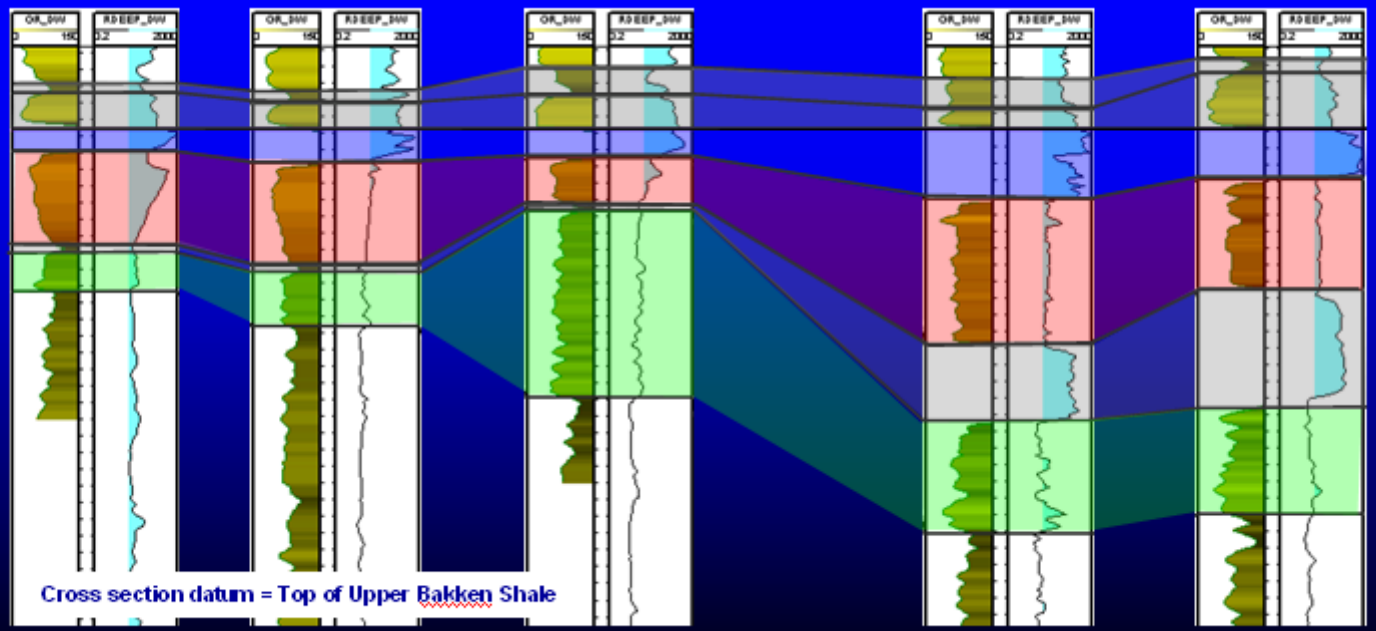
B Value



Carrington
Scallion
Upper Bakken Shale

Middle Bakken

Lower Bakken Shale
Upper Three Forks



ConocoPhillips

Summary

- Bakken wells exhibit long duration linear flow
- Best explained with ultra low nano darcy matrix in contact with long planar fracs
- Fractures provide enough high perm PV to give dual perm rate decline behavior
- When b-values ~ 2.0
  - Better or more surface area contact with nano darcy matrix perm
- When b-values in 0.5 to 1.5 range,
  - more influence from fracture pore volume, less influx from matrix
  - less surface area contact with matrix relative to total fracture pore volume
- In late time, ultra low perm matrix will dominate and decline will flatten to a b = 2
  - 1/2 slope on a log log plot
- Increasing completion size, pumping more water and sand in more stages to create more planar fractures:
  - Increases surface area contact with nano darcy perm matrix
  - Creates more high perm pore volume associated with both propped and natural fractures improving early time well performance
  - Combining to achieve higher well rates and higher EUR's