A Comprehensive Deterministic Petrophysical Analysis Procedure for Reservoir Characterization: Conventional and Unconventional Reservoirs*

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Abstract

The past ten years, we have developed a number of petrophysical models for specific requirements: rock physics modeling create pseudo acoustic (both compressional and shear) curves, based on Gassmann and Krief geophysical models. The model allows for the estimate of acoustic data where no (or limited) acoustic data exists. From this modeling, mechanical properties can be made (Holmes et al., 2005a,b). Relative permeability modeling profiles of irreducible water saturation are compared with the actual water saturation (Holmes, 2009). Using the technique of Corey (1954) continuous profiles of relative and effective permabilities to both fluid phases can be created. Knowing viscosities of reservoir fluids water/hydrocarbon can be determined as continuous curves. Petrophysical Analysis of Unconventional Reservoirs Involves examination of the shale intervals independently of the clean formation. Additionally consideration of the total organic carbon (TOC) content of the reservoir is required. Quantitative calculations of free and adsorbed hydrocarbons need to be assessed for a complete analysis (Holmes et al., 2010, 2011, 2013). A technique (unpublished) to identify fractures was developed to estimate the presence of fractures, both open and healed-from standard open hole logs. Anonymously rapid rates of change with depth are attributed to fractures. If the trend is to higher porosity, open fractures are suggested. This paper presents how these various models can be combined including porosity, fluid saturation, shale volume, permeability, in-place and recoverable hydrocarbons, free hydrocarbons in the shale fraction, TOC and adsorbed hydrocarbons, profiles of relative and effective permabilities to the fluid phases, profile of water/hydrocarbon ratios, and brittle vs. ductile distinction. Examples from unconventional oil and gas reservoirs of North America are presented and include Niobrara, Bakken (oil), Western Canada, Barnett and Utica (gas).

References Cited

Corey, A.T., 1954, The interrelation between gas and oil relative permeabilities: Producers Monthly, v. 19/1, p. 38-41.

Holmes, M., A. Holmes, and D. Holmes, 2005a, Petrophysical Rock Physics Modeling: A Comparison of the Krief And Gassmann Equations, and Applications to Verifying And Estimating Compressional And Shear Velocities: SPWLA 46th Annual Logging Symposium, New Orleans, LA, June 26-29, 2005.

Holmes, M., A. Holmes, and D. Holmes, 2005b, Pressure Effects on Porosity-Log Responses Using Rock Physics Modeling: Implications on Geophysical and Engineering Models as Reservoir Pressure Decreases: SPE Annual Technical Conference and Exhibition, Dallas, TX, October 9-12, 2005.

Holmes, M., D. Holmes, and A. Holmes, 2009, Relationship Between Porosity and Water Saturation: Methodology to Distinguish Mobile from Capillary Bound Water: American Association of Petroleum Geologists Annual Convention & Exhibition, Denver, CO, June 2009.

Holmes, M., A. Holmes, and D. Holmes, 2010, A Petrophysical Method to Evaluate Irregularly Gas Saturated Tight Sands Which Have Variable Matrix Properties and Uncertain Water Salinities: American Association of Petroleum Geologists International Conference & Exhibition, Calgary, Alberta, Canada, September 2010.

Holmes, M., D. Holmes, and A. Holmes, 2011, A Petrophysical Model to Estimate Free Gas in Organic Shales: American Association of Petroleum Geologists Annual Convention and Exhibition, Houston, TX, April 2011.

Holmes, M., A. Holmes, and D. Holmes, 2013, A Petrophysical Model to Quantify Pyrite Volumes and to Adjust Resistivity Response to Account for Pyrite Conductivity: American Association of Petroleum Geologists Annual Convention and Exhibition, Pittsburgh, PA, May 19-22, 2013.

DIGITAL FORMATION

A Comprehensive Deterministic Petrophysical Analysis Procedure for Reservoir Characterization: Conventional and Unconventional Reservoirs

2014 RMS-AAPG Annual Meeting, July 20 – 22, Denver, CO

Presented by: Michael Holmes, Antony Holmes and Dominic Holmes Digital Formation, Denver, Colorado, 2014

Outline

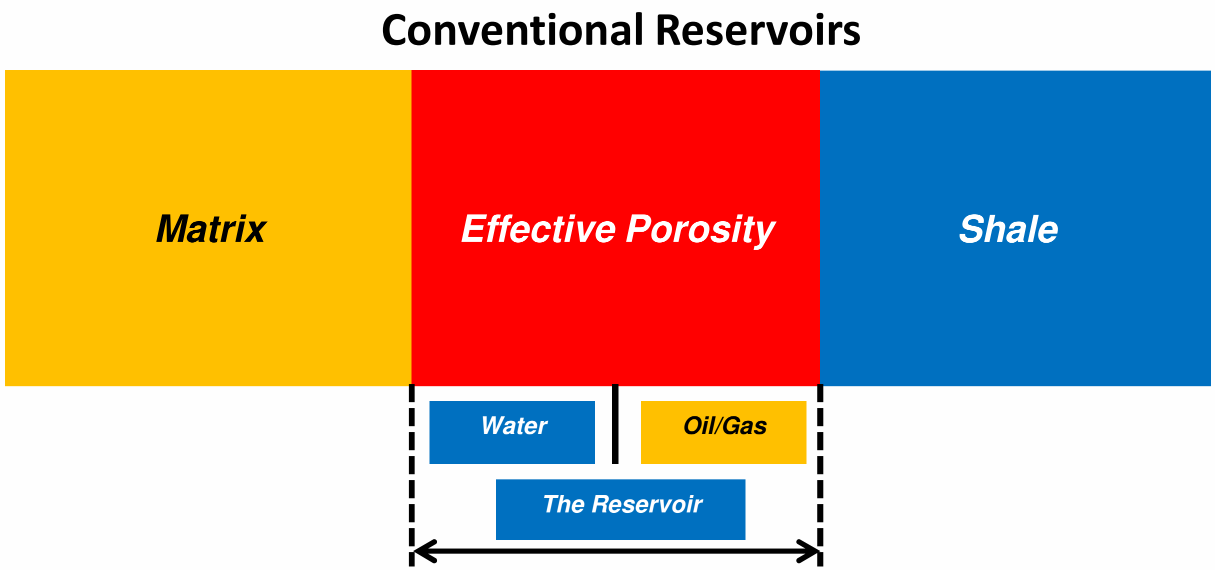
- Introduction
  - Conventional and Unconventional reservoir petrophysical models
- Procedures
  1. Standard shaley formation petrophysical model
  2. Unconventional reservoir petrophysical model
     - Four porosity components model
     - TOC calculations
     - Standard vs. shale only density/neutron comparisons
     - Free and adsorbed hydrocarbons

Outline

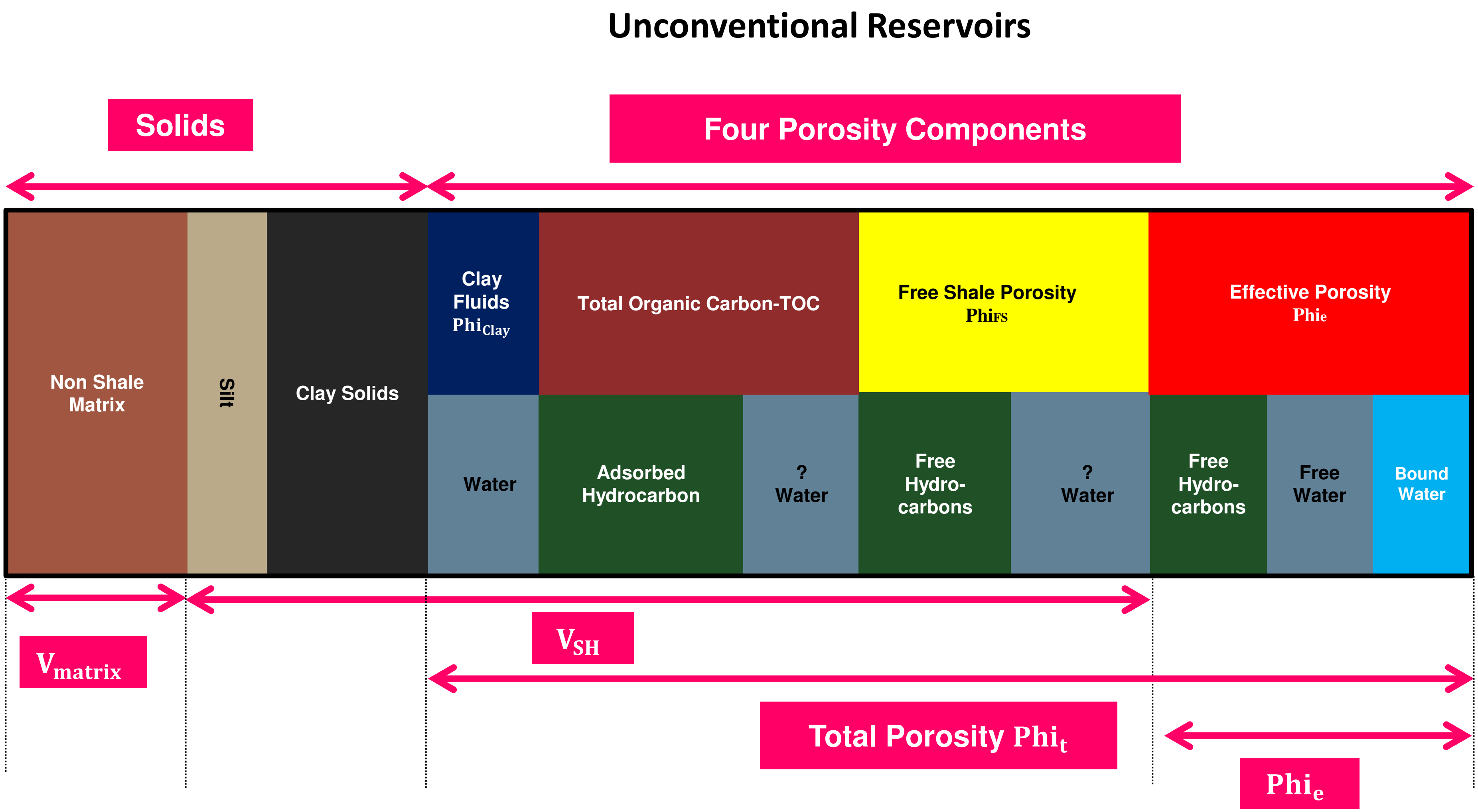
- Procedures Cont.
  3. Fracture analysis
  4. Relative permeability model
  5. Rock physics model and mechanical properties – brittle vs. ductile
  6. Comprehensive petrophysical model
- Examples
  - Niobrara, Colorado
  - Barnett Shale, Texas
  - Antrim Shale, Michigan
  - Shale Gas, Western Canada
  - Bakken, Montana
  - Tight Gas, Colorado

Introduction

- Conventional vs. unconventional reservoir petrophysical models



Introduction

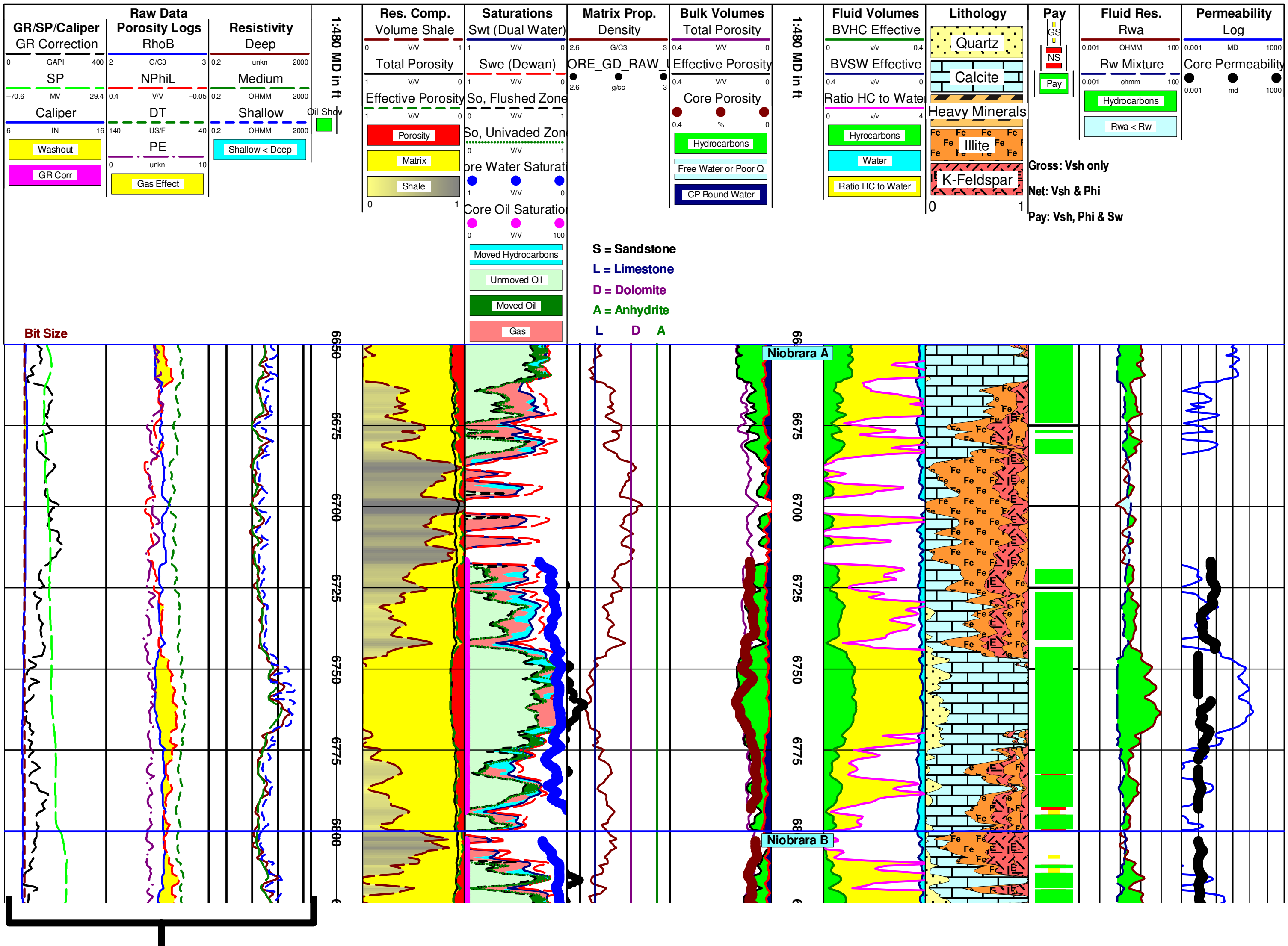


*Note: Components not to scale

Procedures

- In the following discussions an example from the Niobrara (Colorado) is used to illustrate procedures

Procedures 1 – Standard Shaley Formation Analysis



Raw Data

Shale Matrix Porosity

Fluids

Grain Density

Bulk Fluid Volumes

Lithology

Pay

RWA

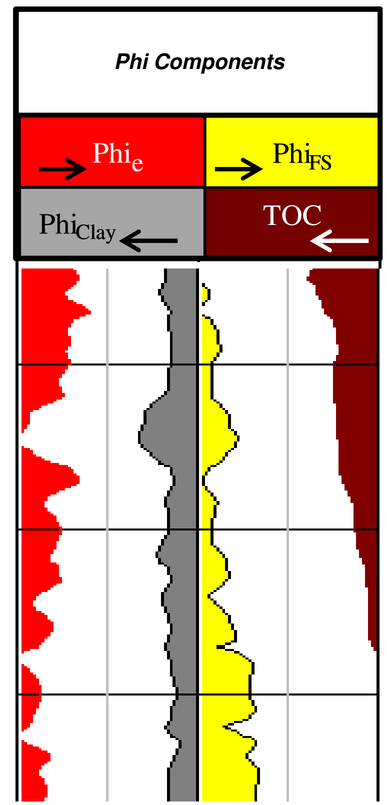
Perm

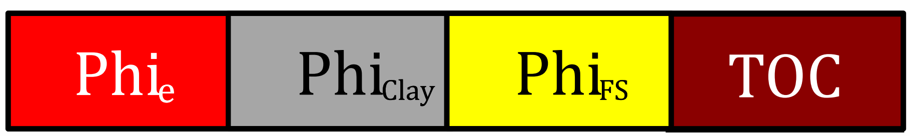
Core data symbols/heavy line

Procedure 2 – Unconventional Reservoir Petrophysical Model

Four Porosity Component Model

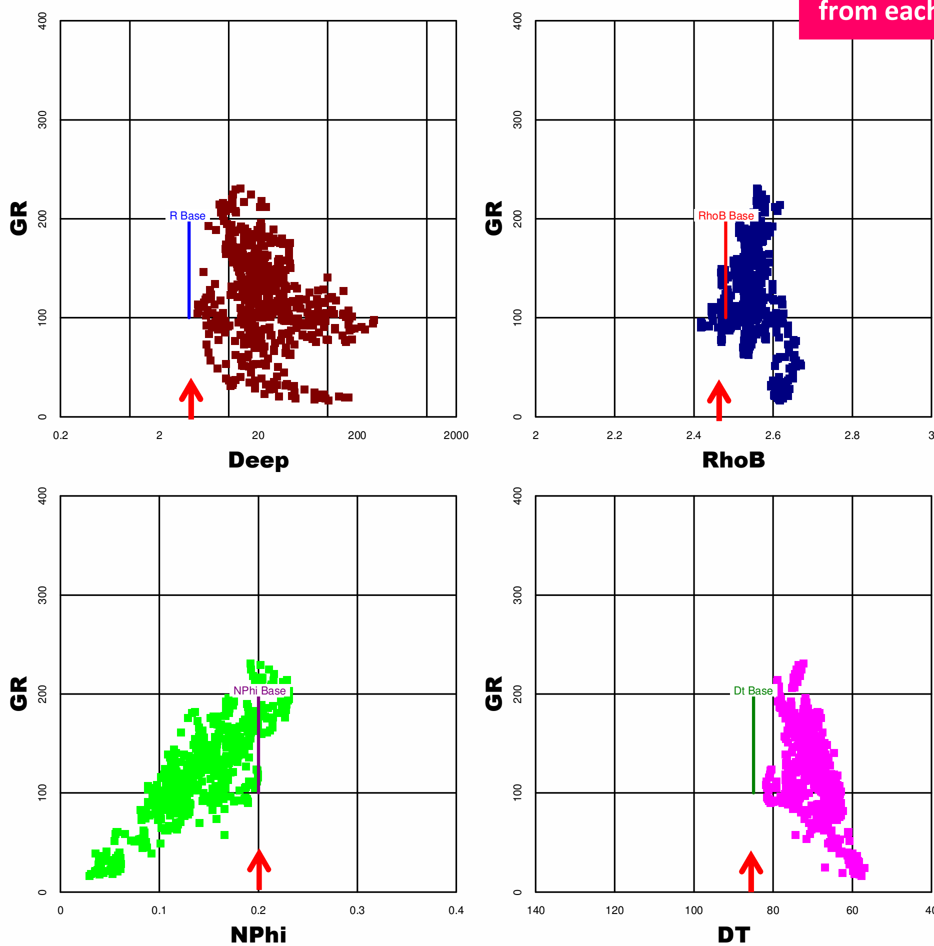
- The goal is to calculate the four porosity components from the unconventional reservoir model
  - Effective Porosity Phi_e
  - Total Organic Carbon TOC
  - Clay Porosity Phi_{Clay}
  - Free Shale Porosity Phi_{FS}





TOC Calculation

- TOC Passey et al

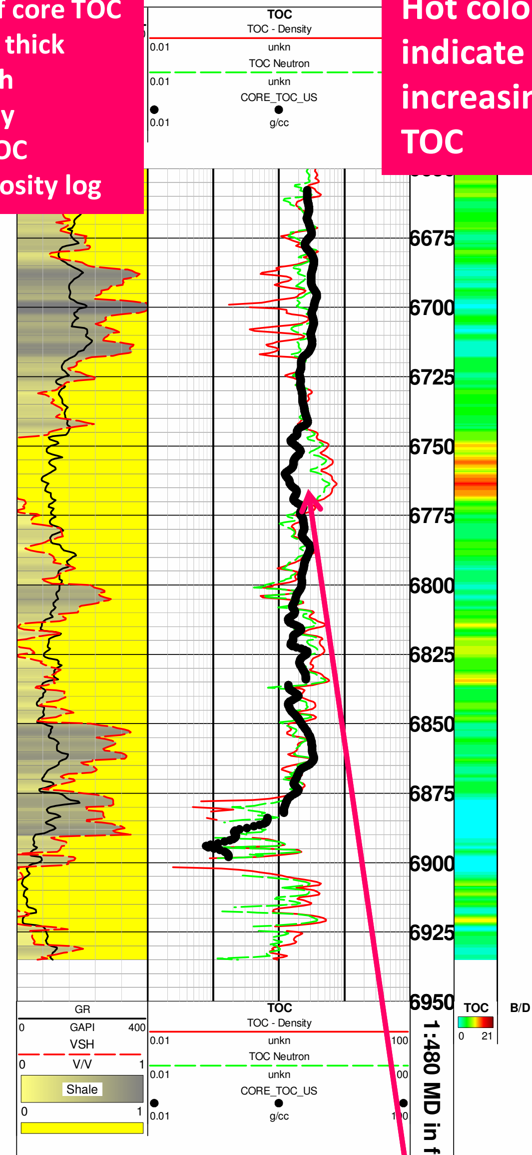


Responses in Organic – lean intervals

TOC = Total Organic Carbon

Comparison of core TOC (Illustrated by thick black line) with petrophysically determined TOC from each porosity log

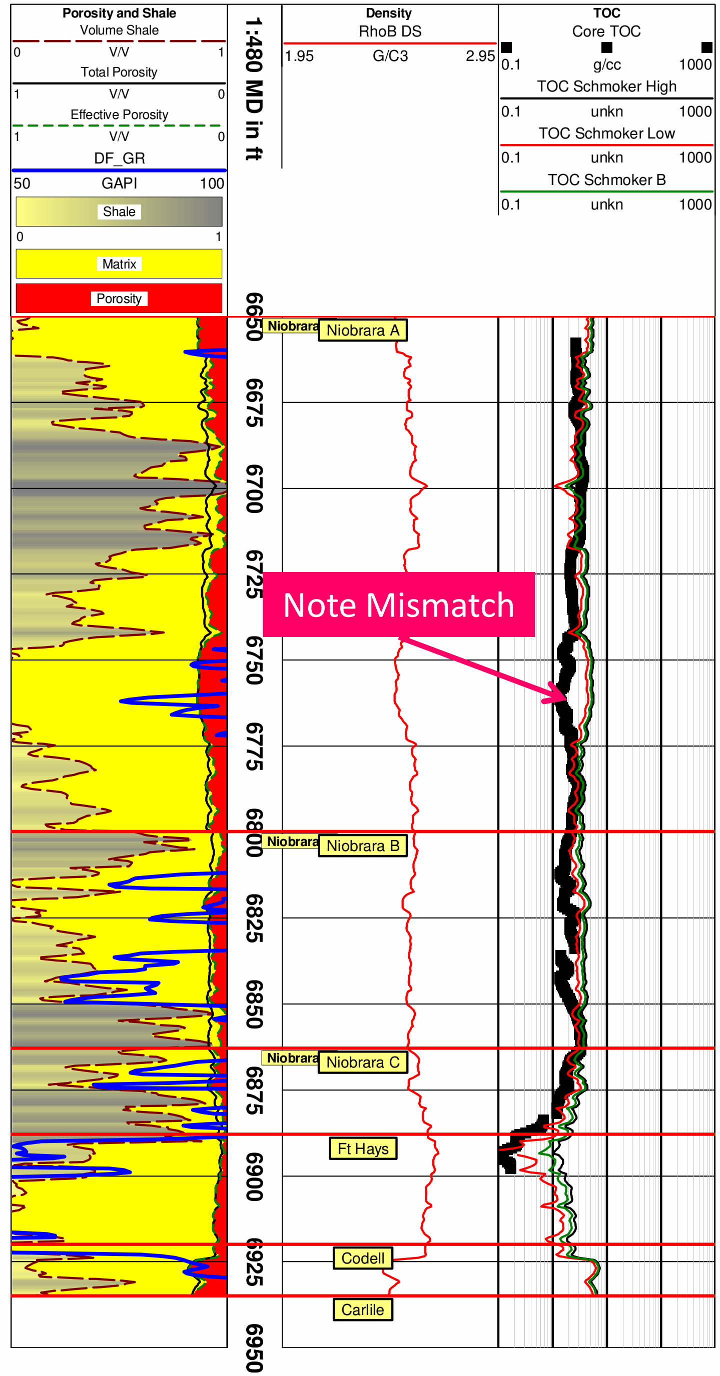
Hot colors indicate increasing TOC



Note Mismatch

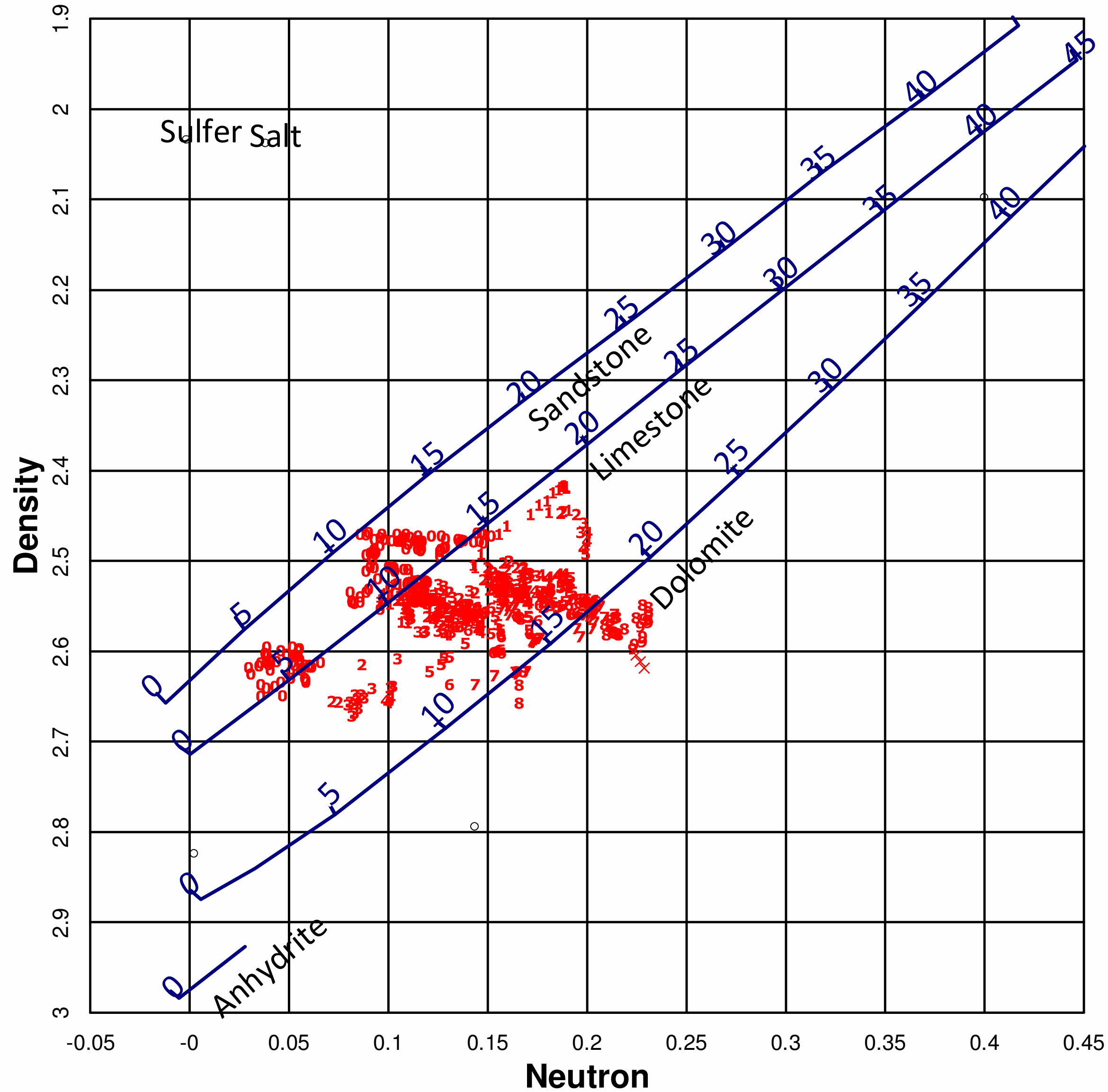
TOC Calculation

- TOC Schmoker
- Schmoker has three different correlations of RhoB with TOC
- Schmoker high Appalachian correlation
- Schmoker low Appalachian correlation
- Schmoker Williston Basin Bakken



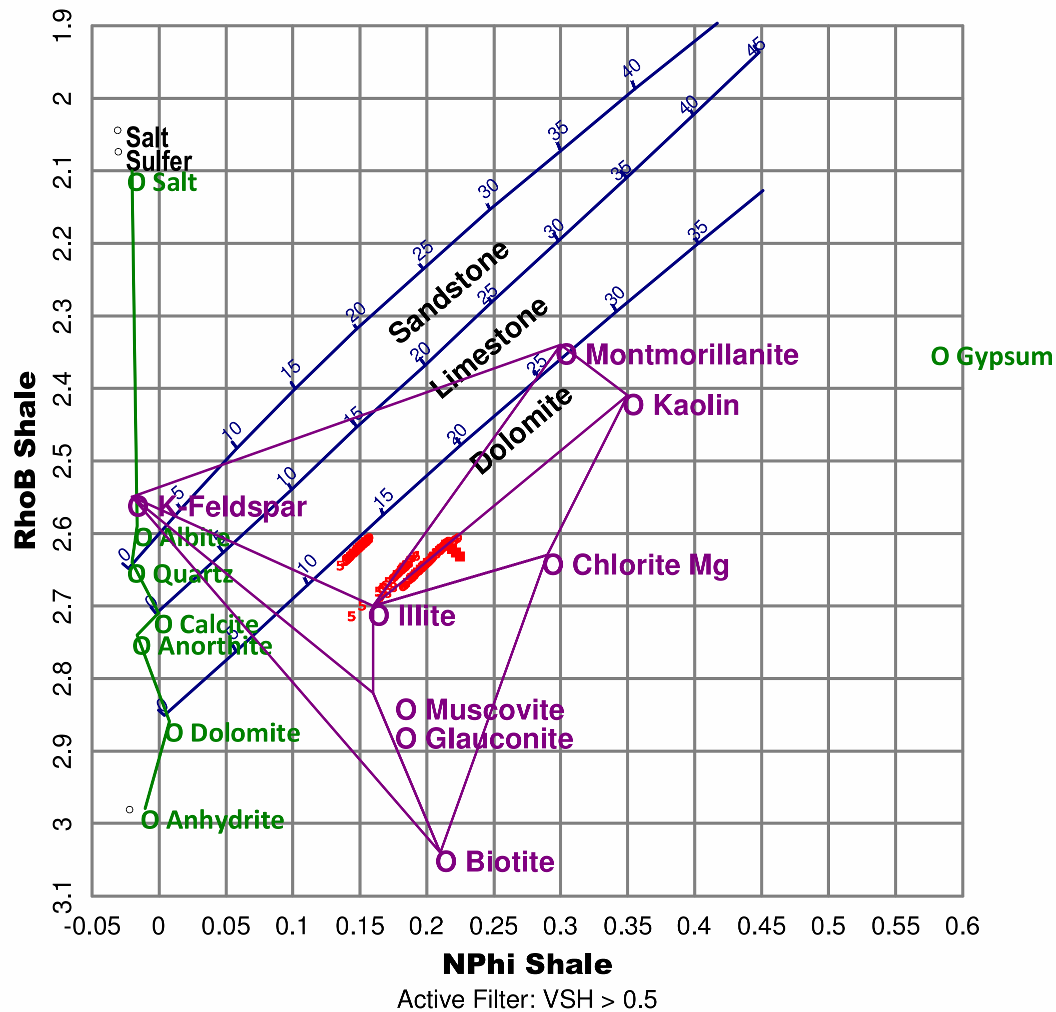
Standard vs. Shale Only Density/Neutron Cross Plots

Standard



Standard vs. Shale Oil Density/Neutron Cross Plots

Shale Only

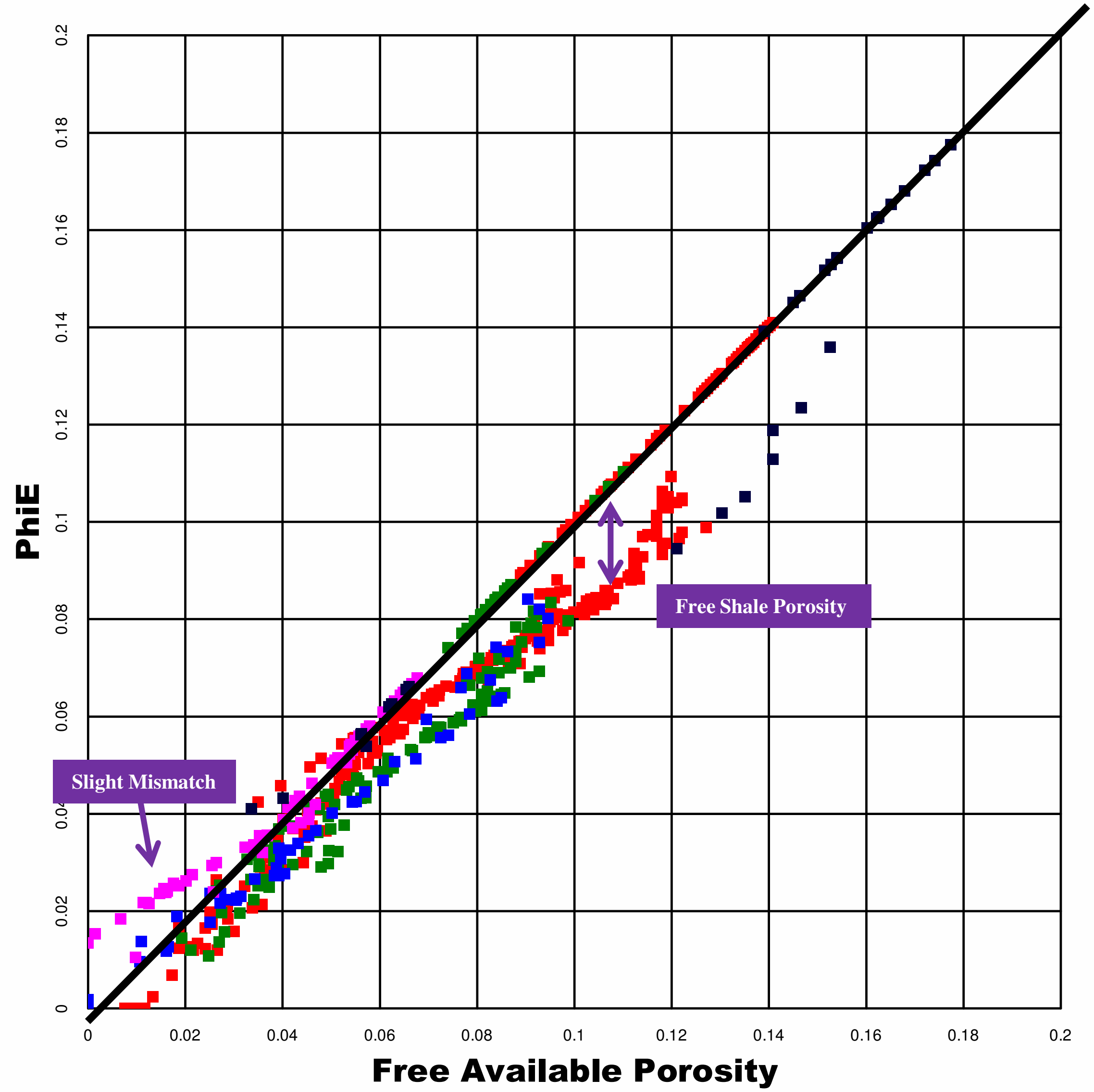


Calculate

Clay Porosity = Cross Plot Porosity X V_{SH}

Free Shale Porosity = Total Porosity – (Effective Porosity + TOC Volume + Clay Porosity)

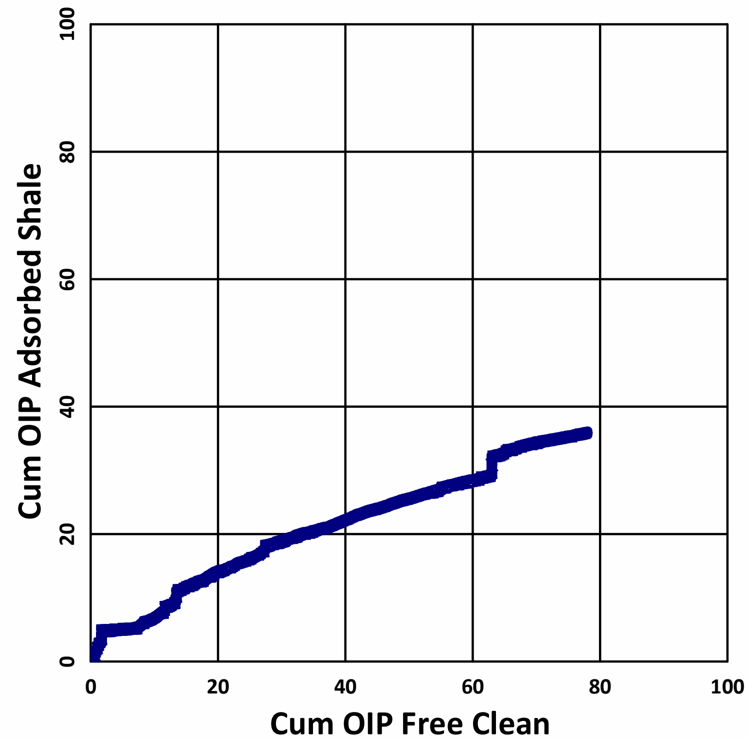
Phie Vs. Free Available Porosity



Free Available Porosity = Effective Porosity + Free Shale Porosity

Free vs. Adsorbed Hydrocarbons

- Free hydrocarbons are located in the free available porosity element, and are calculated using standard approaches
- Publications on calculating adsorbed hydrocarbon volumes are sparse. Empirical relations are:

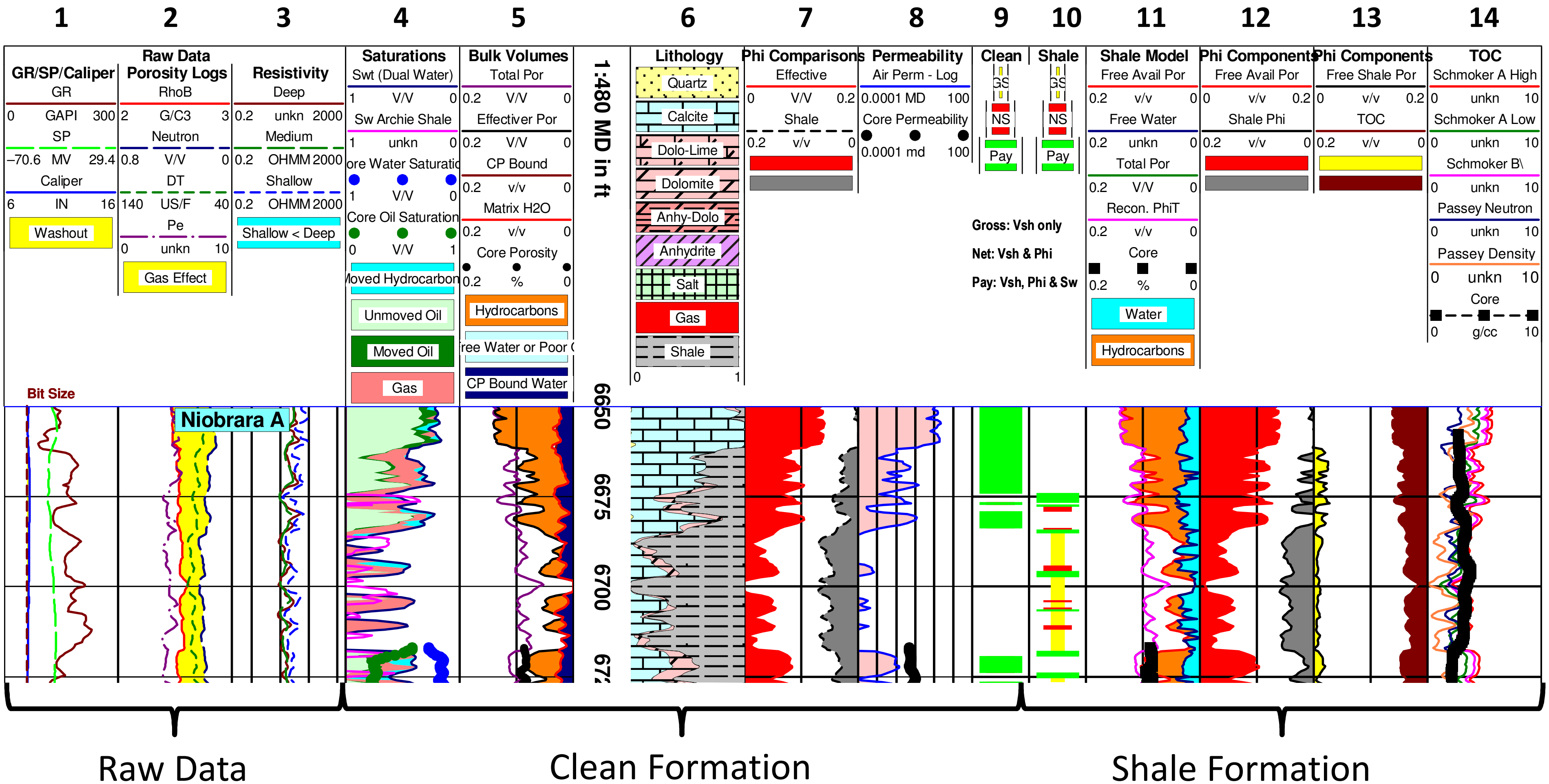


Gas – Published Relation
Adsorbed G.I.P. (SCF) = 1359.7 X Area X Thickness X RhoB X (16 X TOC)

Oil – Suggested Relation
Adsorbed O.I.P. (Bbl) = S2 X 0.0007 X RhoB X h X Area X 7758

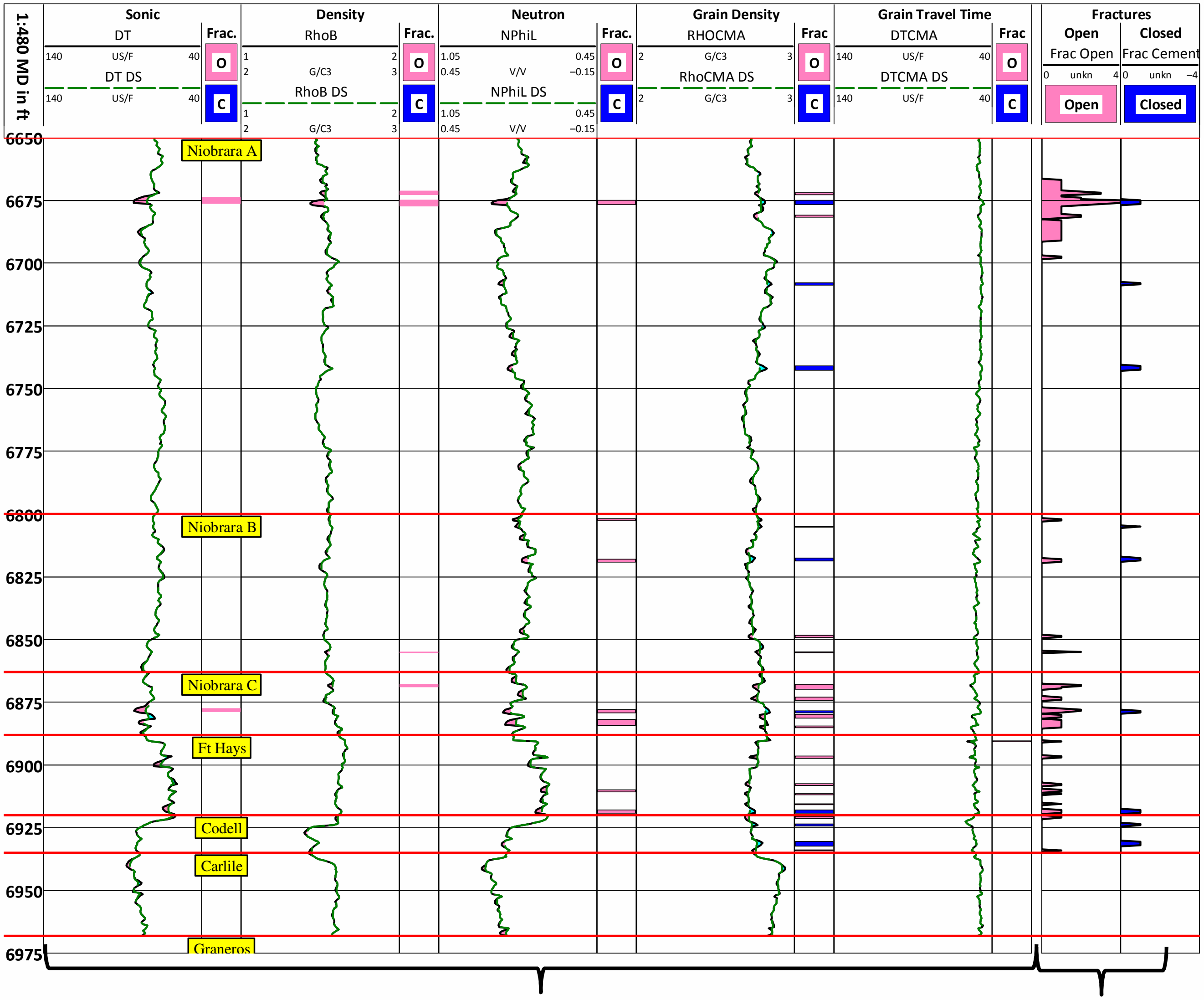
S2 = Hydrocarbons generated by thermal cracking

Procedure 2 – Unconventional Reservoir Petrophysical Model



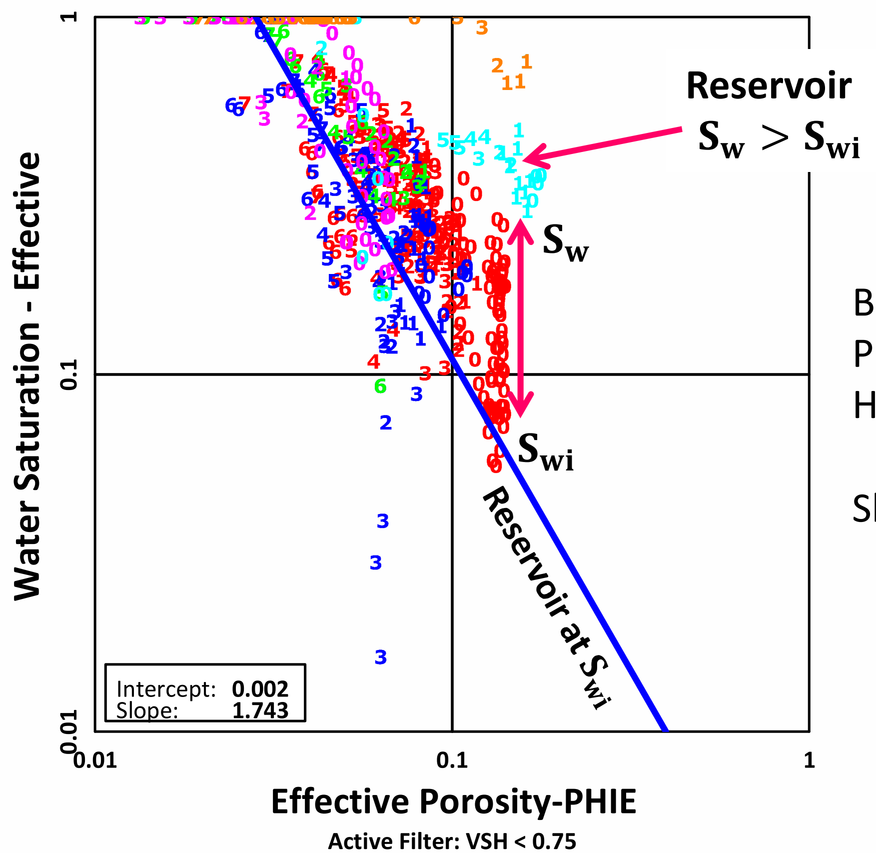
1	Gr, SP	4	Saturations	7	Porosity Comparison	10	Pay Flag	13	Porosity Comparison
2	Porosity	5	Bulk Volumes	8	Permeability	11	Bulk Volume	14	TOC Comparison
3	Resistivity	6	Lithology	9	Fractures	12	Porosity Comparisons		

Procedure 3 – Fracture Analysis



Pink O = Open Fractures – ? Low stress
Blue C = Closed Fractures – ? High stess

Procedure 4 – Relative Permeability Model



Buckles Relation

Phie X S_{wi} = Constant

Holmes Adaptation

$\text{Phie}^{Q} \times S_{wi} = \text{Constant}$

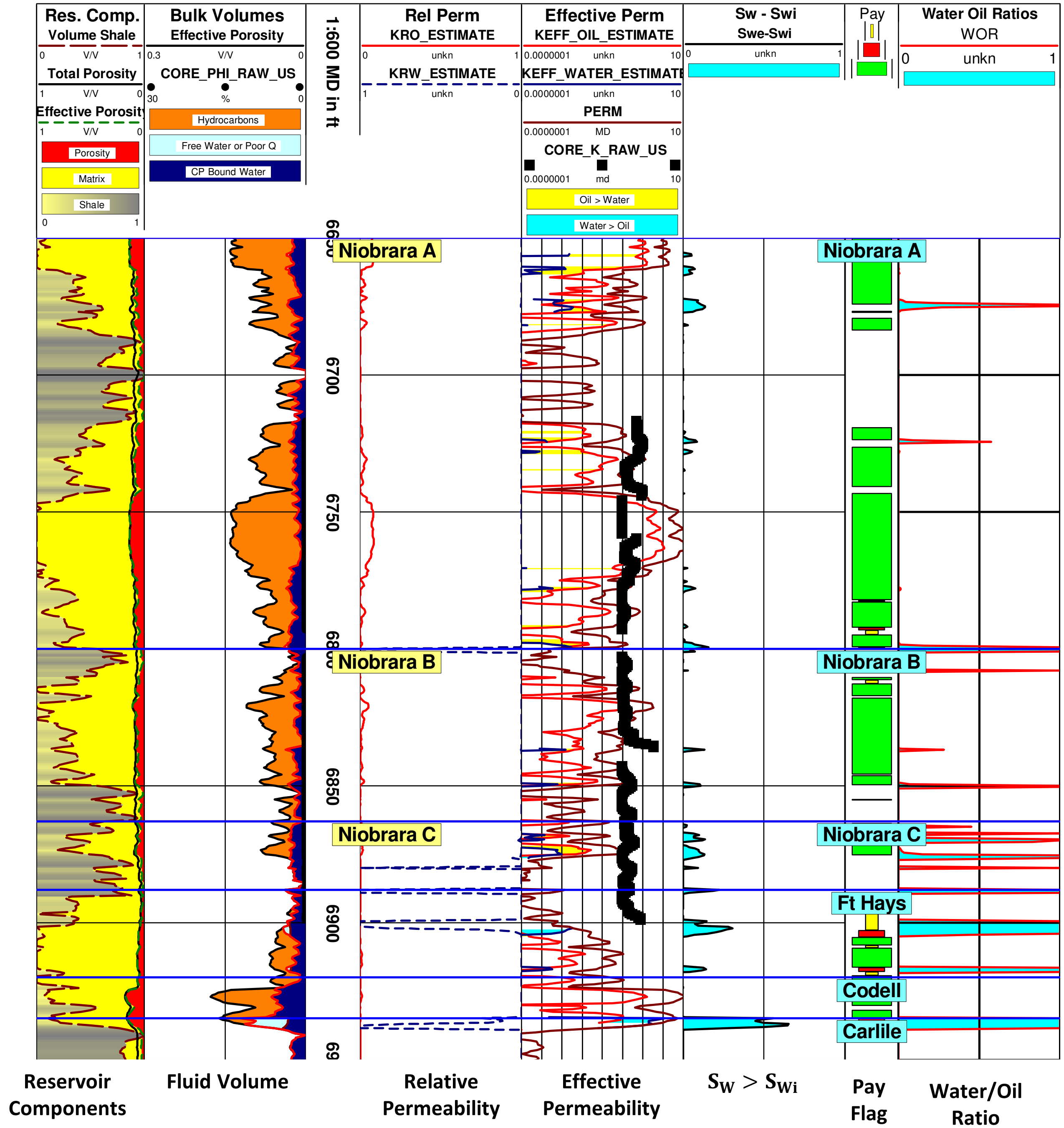
Slope = Q

- Solve the Corey relation
  - $S_{we} = \dfrac{S_w - S_{wi}}{1 - S_{wi}}$
  - $K_{rw} = {S_{we}}^4$ Water
  - $K_{rh} = (1 - S_{we})^2 (1 - {S_{we}}^2)$ Hydrocarbons

Relative Permeability Example

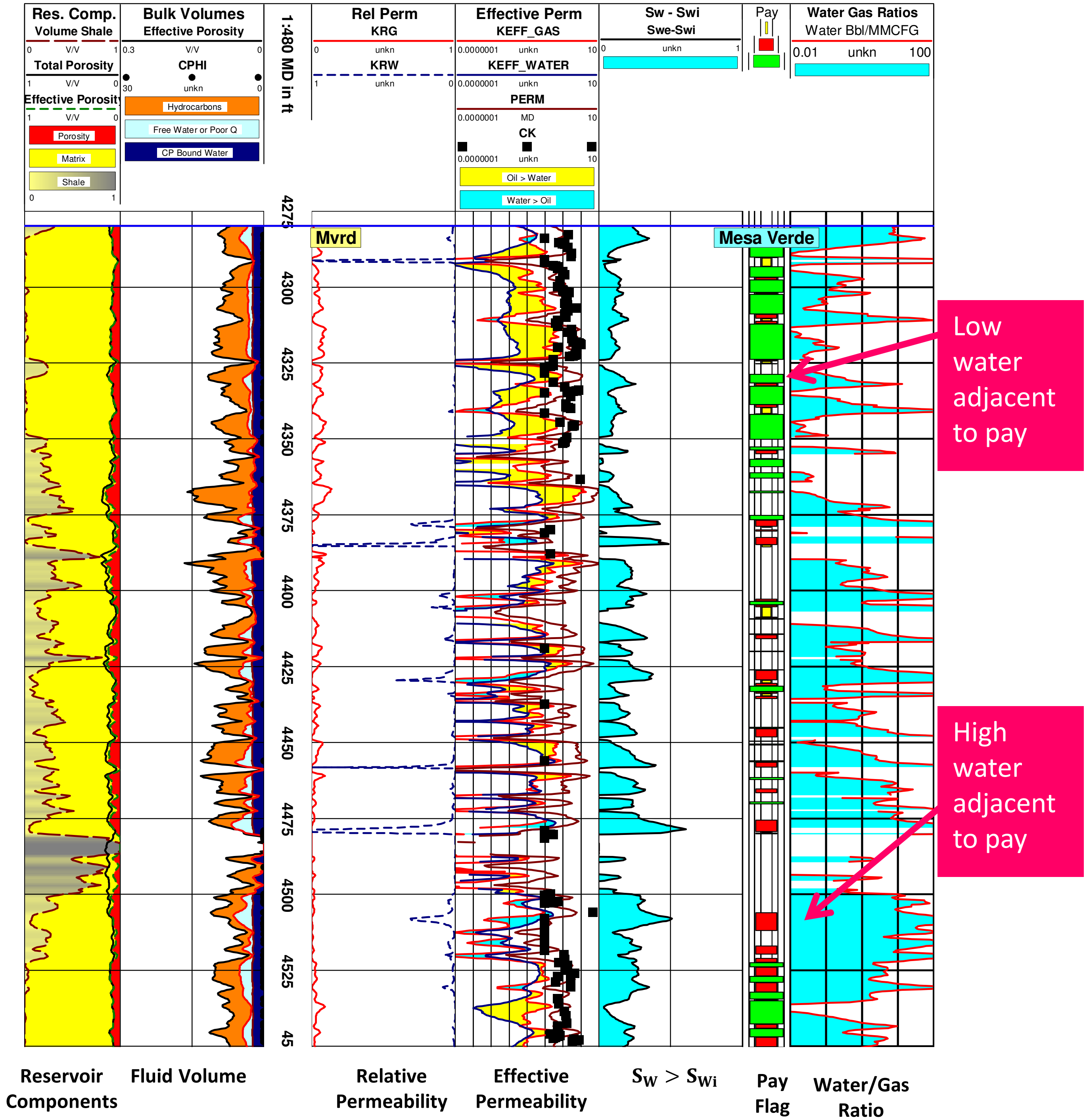
Oil Well

$$KEFF = K_r \times Perm$$



Relative Permeability Example

Gas Well



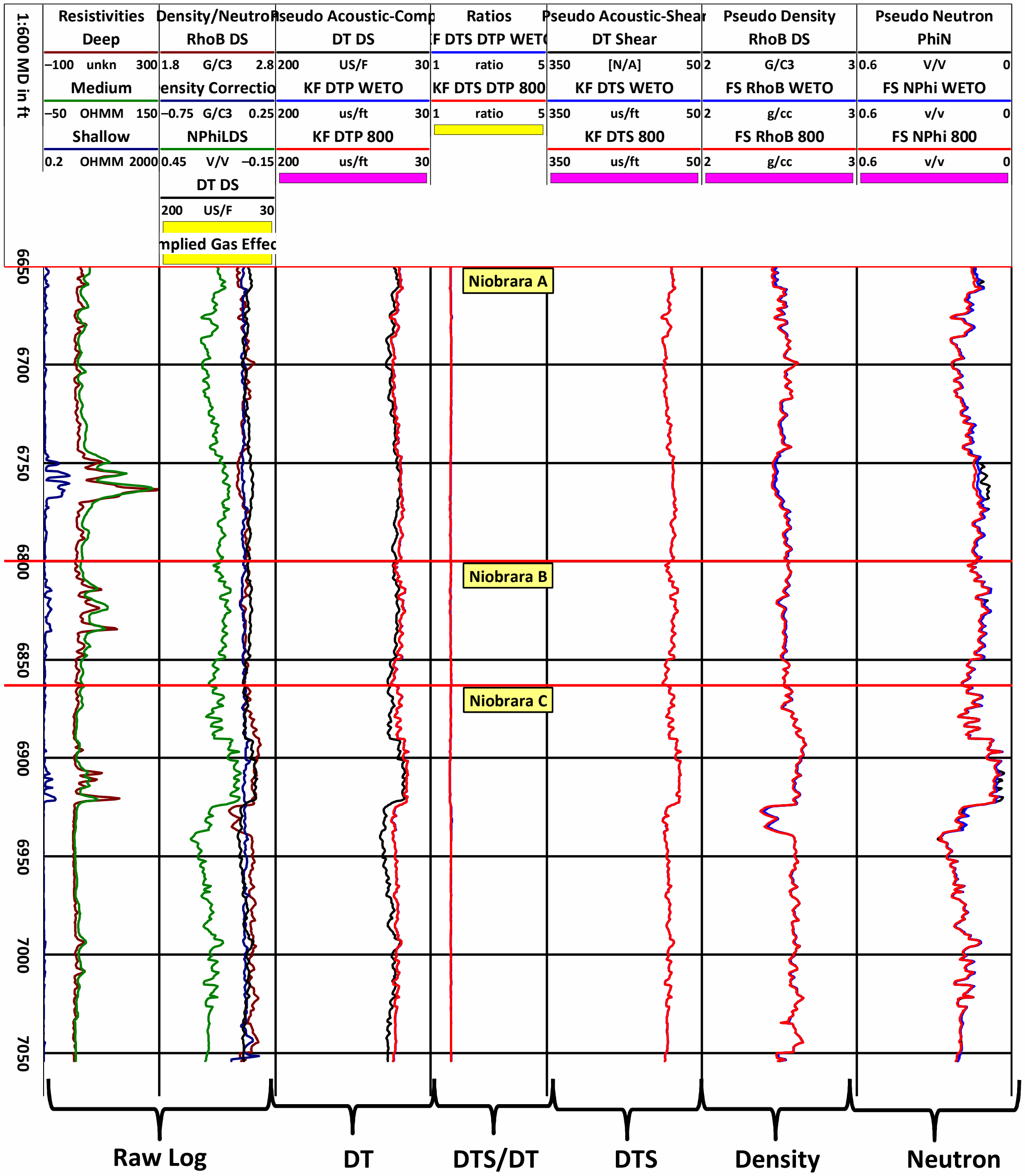
Procedure 5 – Rock Physics Model and Mechanical Properties – Brittle vs. Ductile

- To calculate mechanical properties, the following measurements are required
  - Acoustic compressional
  - Acoustic shear
  - Density

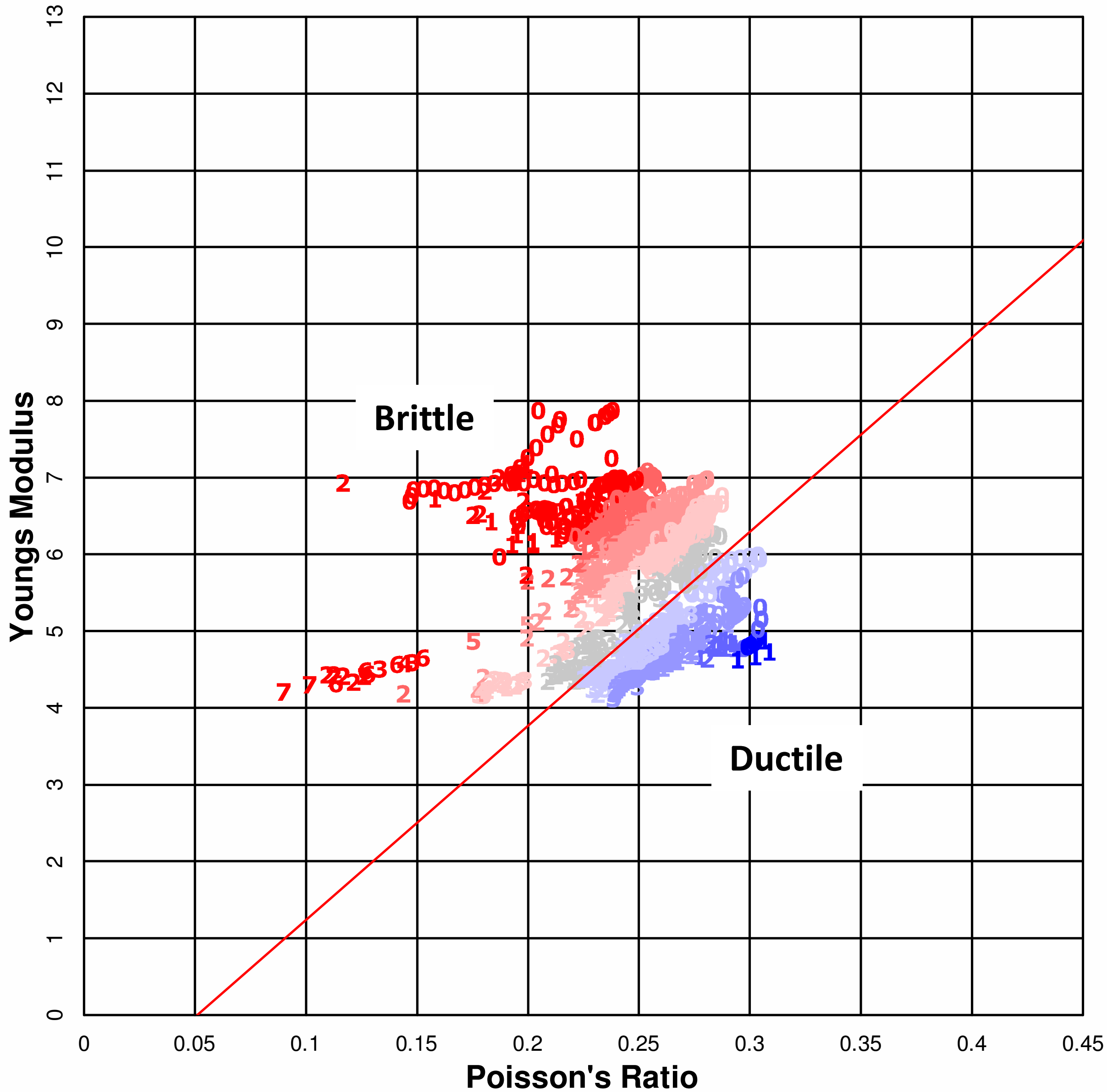
  } Dipole Sonic

- Often acoustic shear is not available but can be estimated from other logs. The example shows pseudo curves based on the Krief geophysical model (Dipole Sonic not run in the Niobrara example).

Rock Physics Model and Mechanical Properties

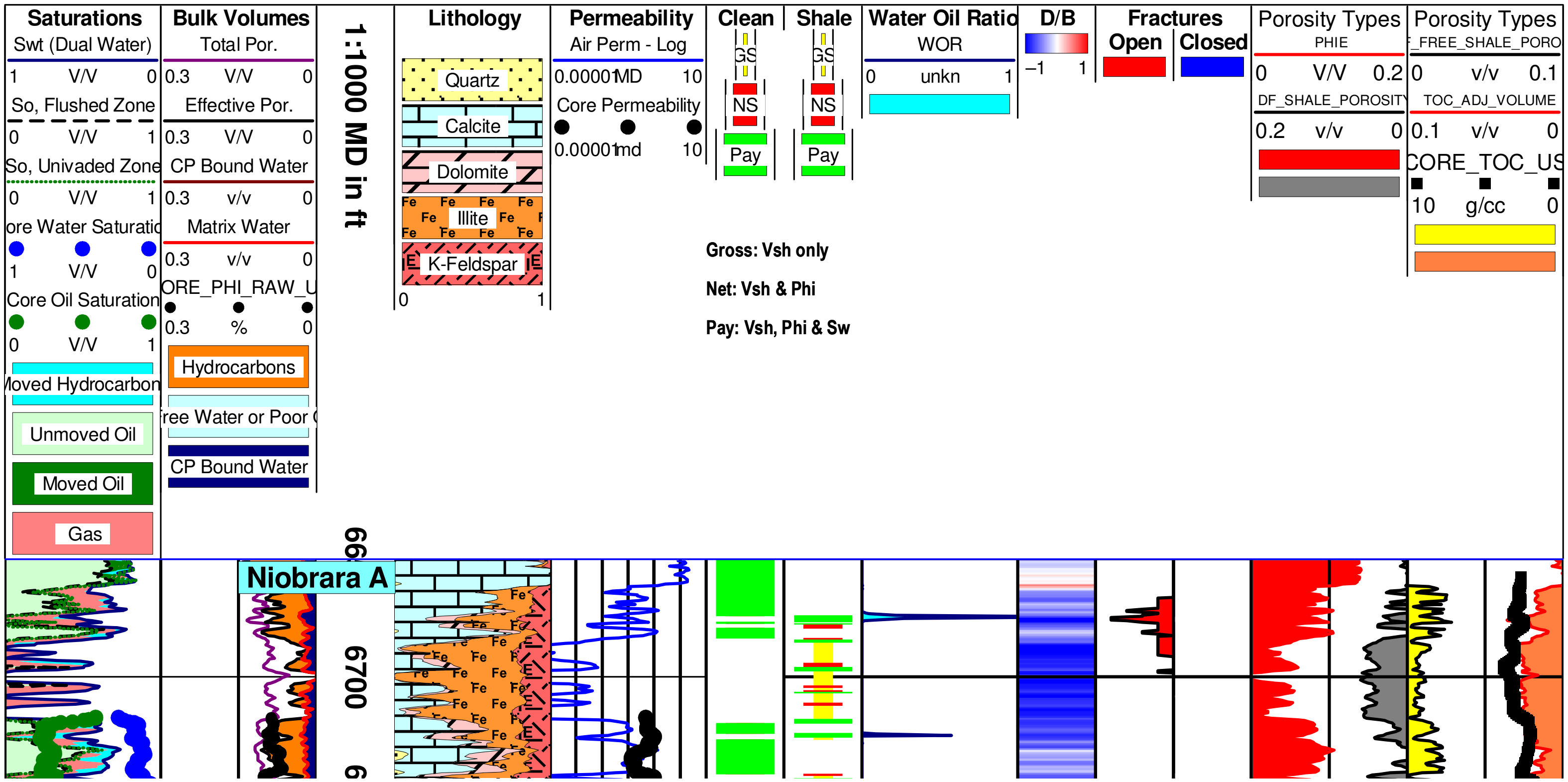


Young's Modules vs. Poisson's Ratio



Procedure 6 – Comprehensive Petrophysical Model

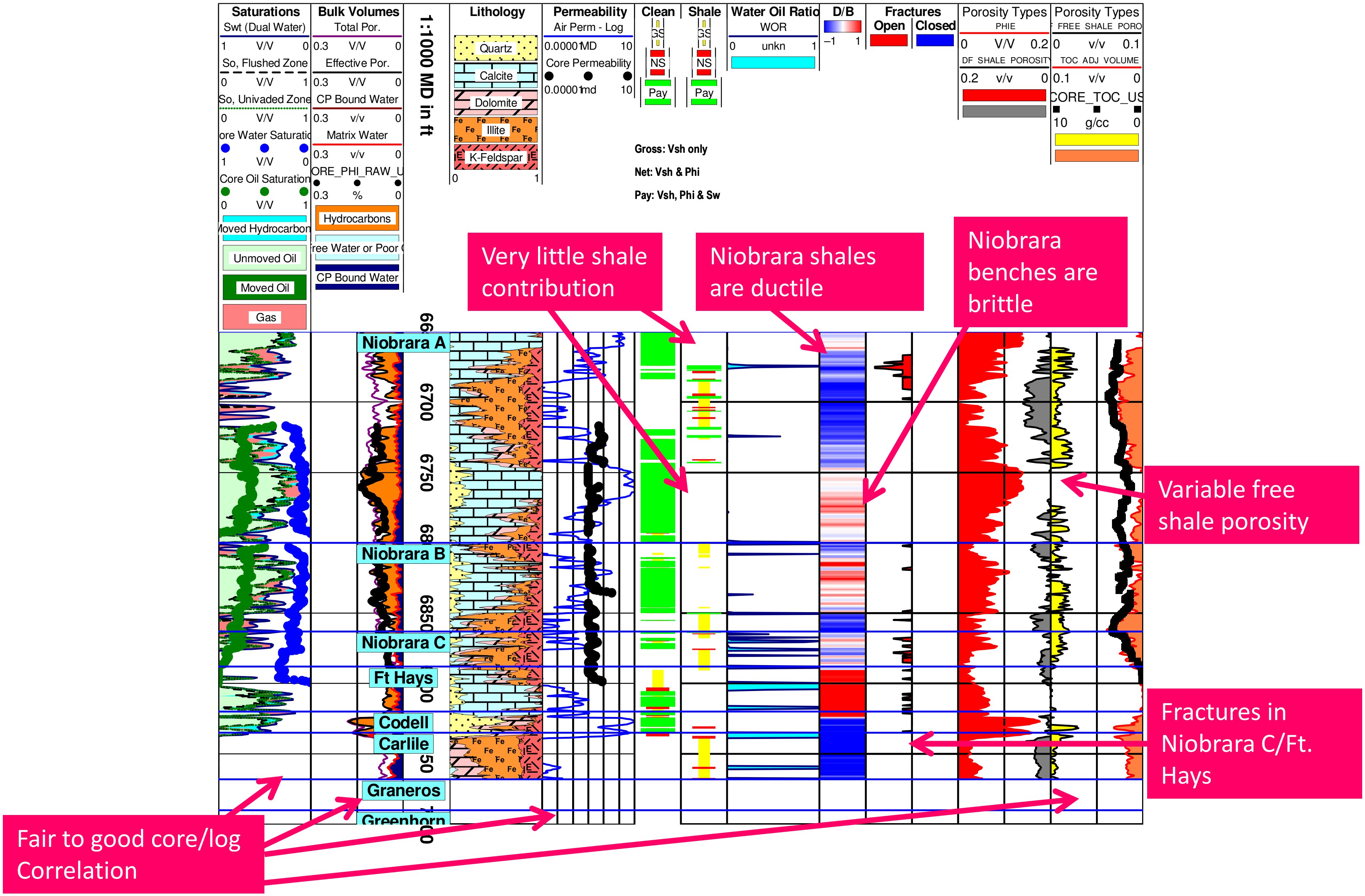
A Standard Template is Used for All Examples



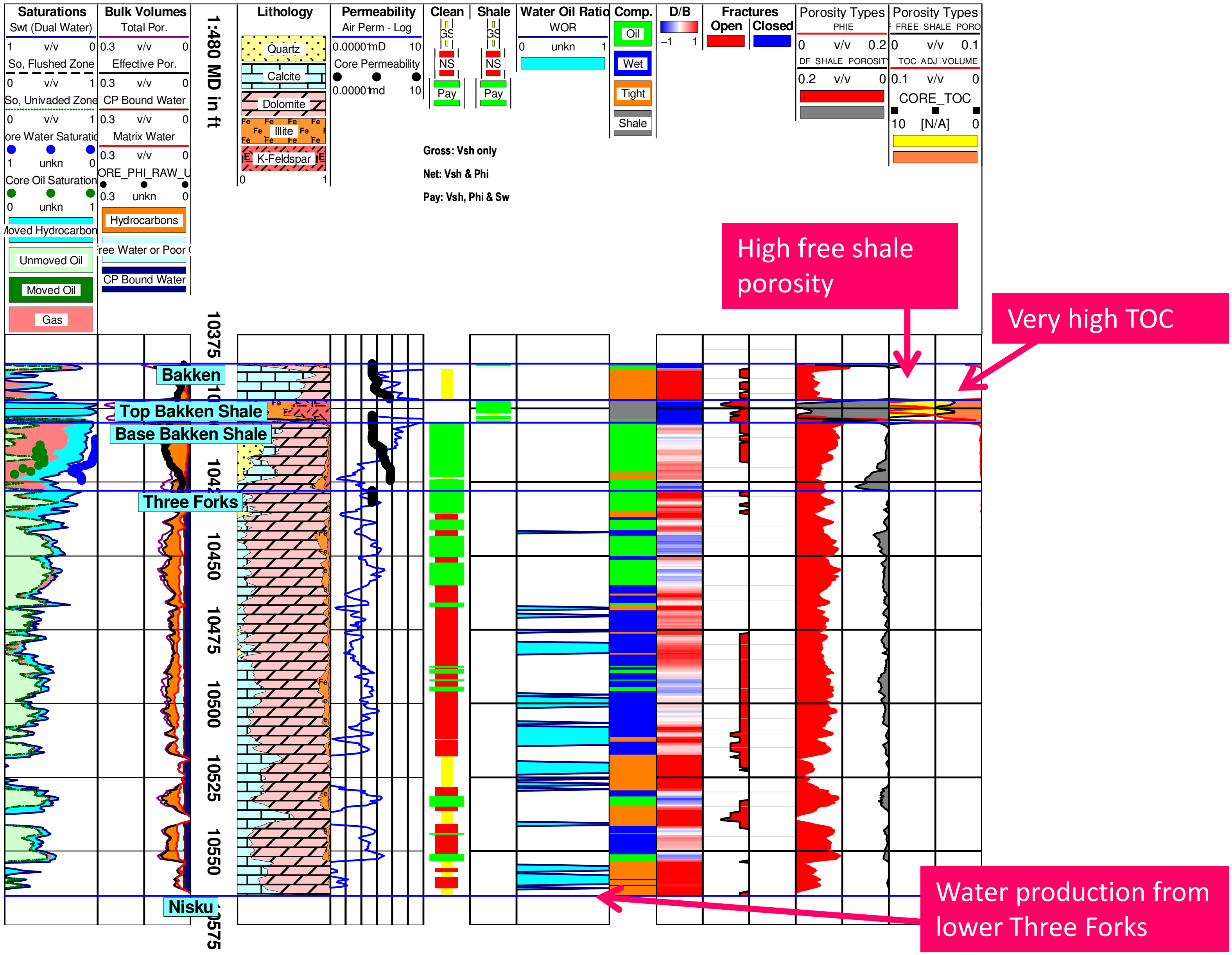
1 2 3 4 5 6 7 8 9 10 11

1. Fluid Saturation
2. Bulk Volume – non shale fraction
3. Lithology
4. Permeability
5. Pay Flag – Clean Formation
   Yellow = Gross "Sand"
   Red = Net "Sand"
   Green = Pay
6. Pay Flag – Shale
   Yellow = Gross "Sand"
   Red = Net "Sand"
   Green = Pay
7. Water/Oil Ratio – Oil Reservoirs
   Water Bbl per MMCF – Gas Reservoir
8. Estimates of Fractures
9. Fractures
10. Porosity Types – Phie and shale porosity
11. Porosity Types – Free Shale Porosity and TOC

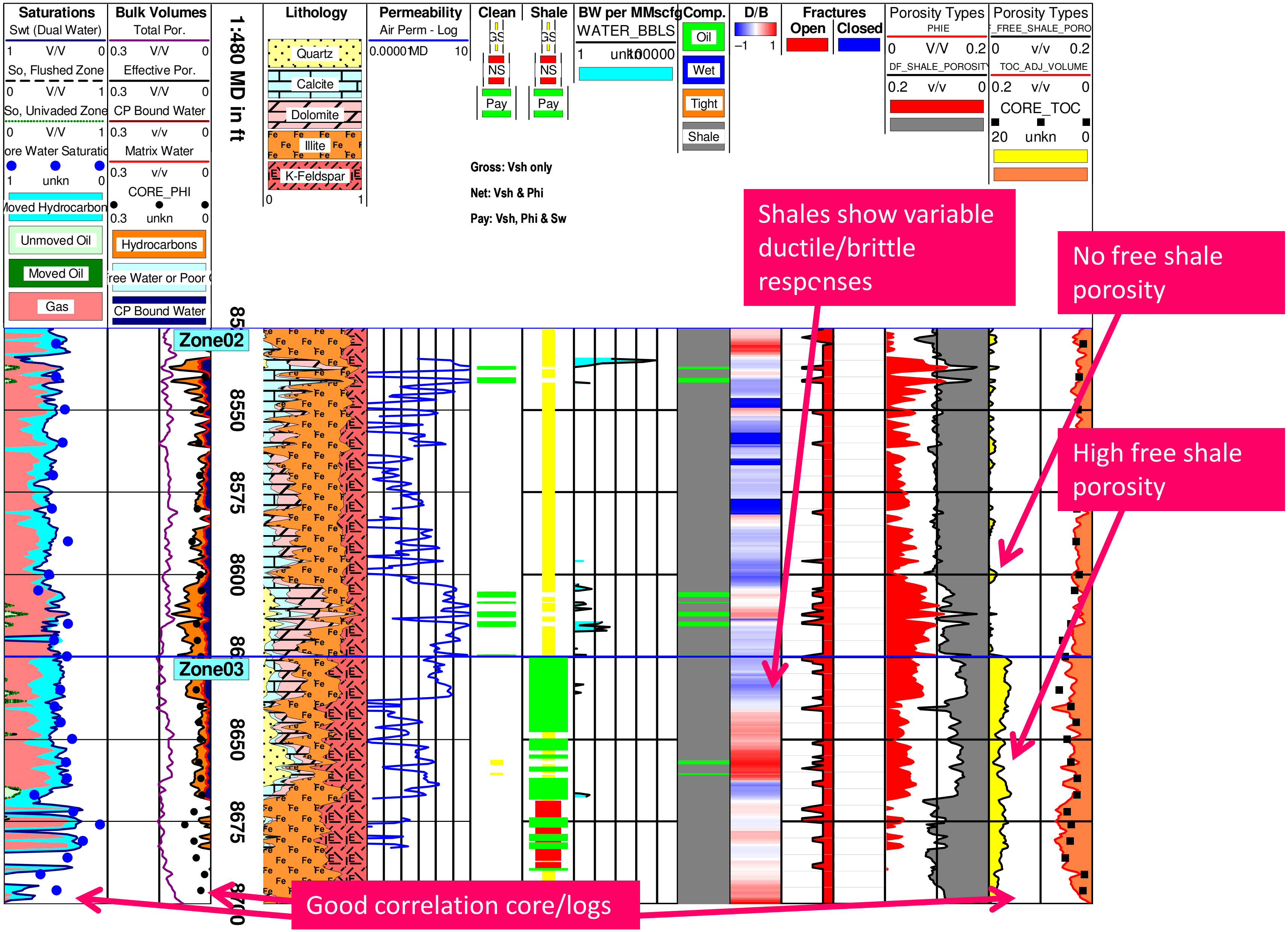
Niobrara, Colorado – Oil



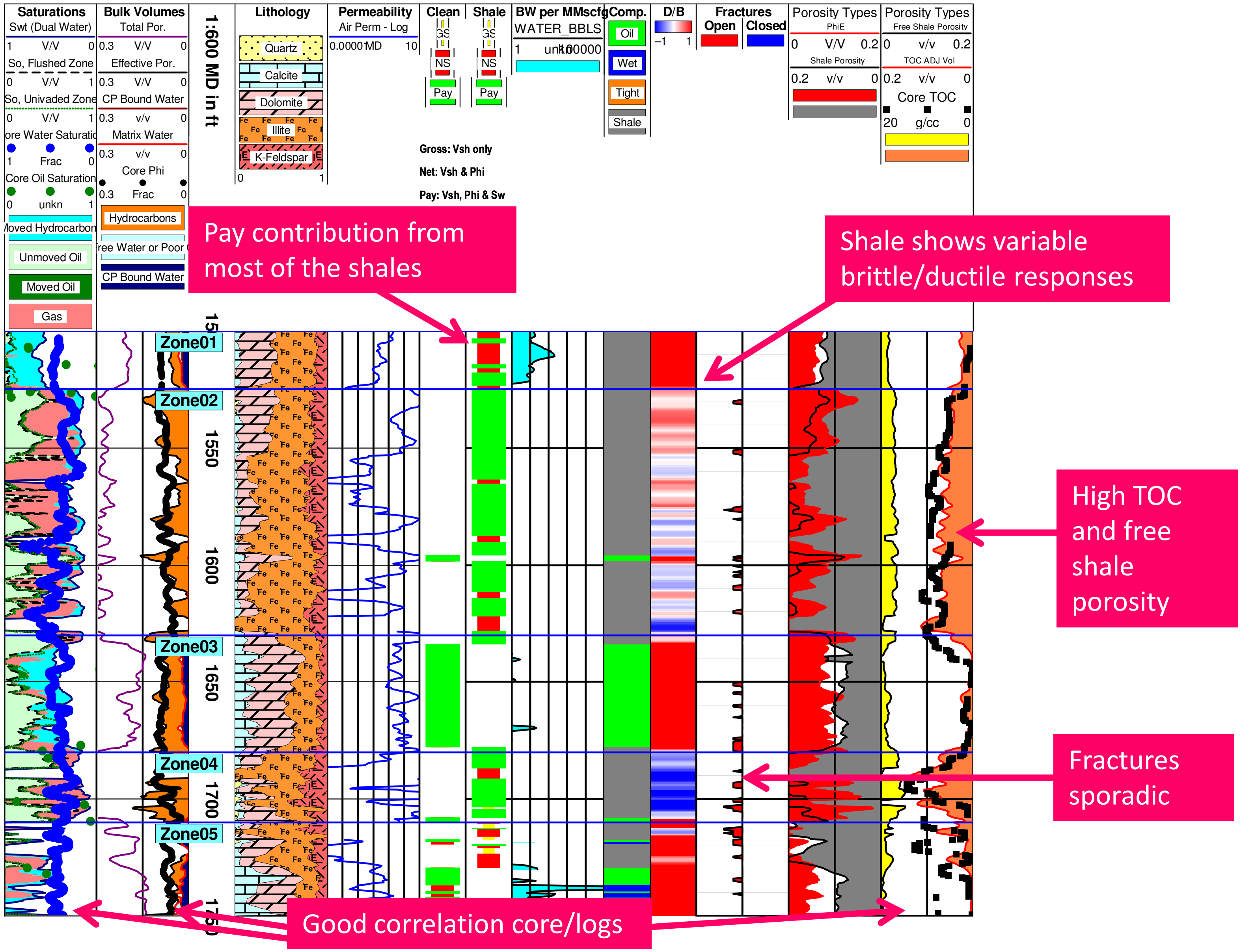
Bakken, Montana – Oil



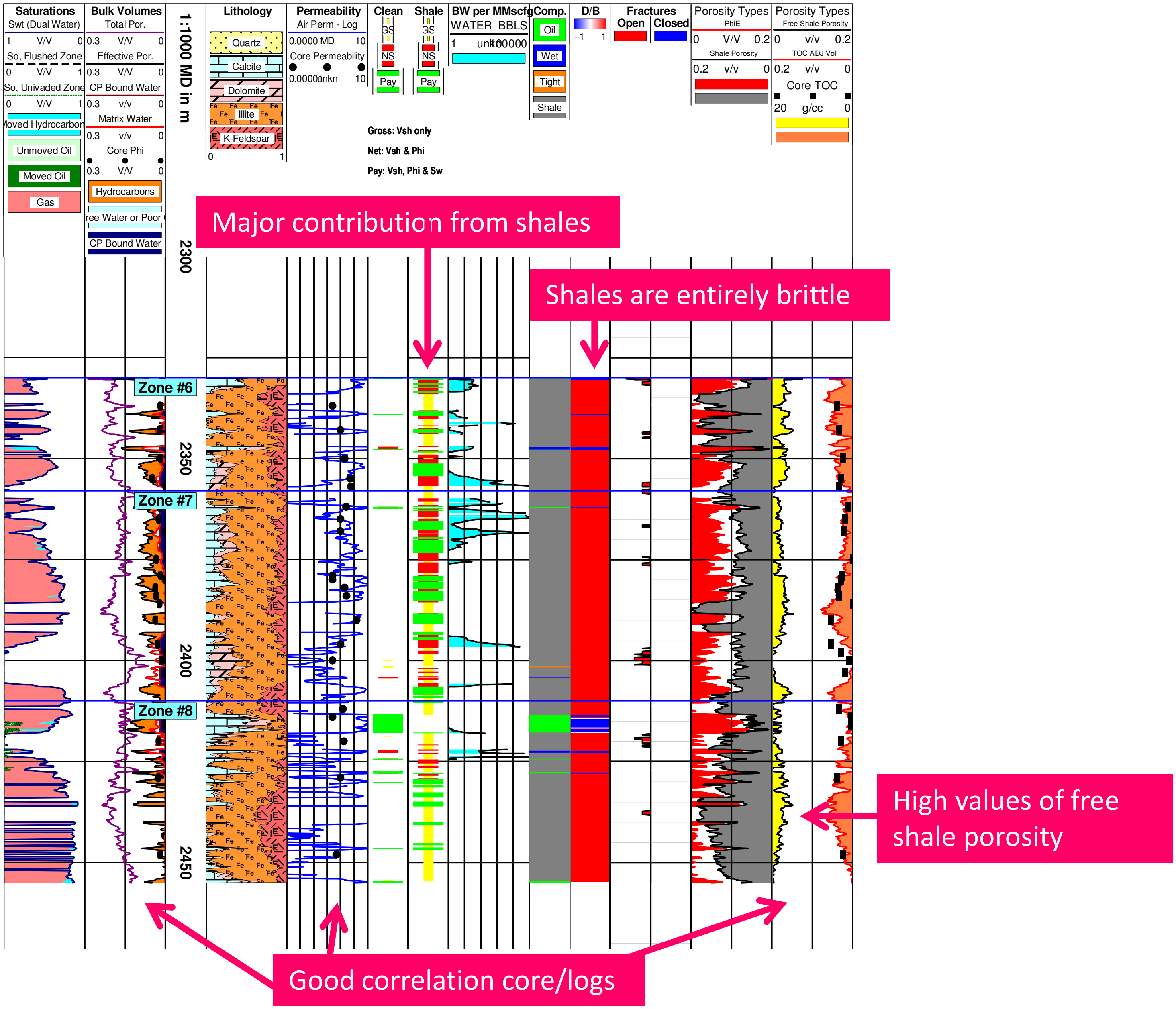
Barnett, Texas – Shale Gas



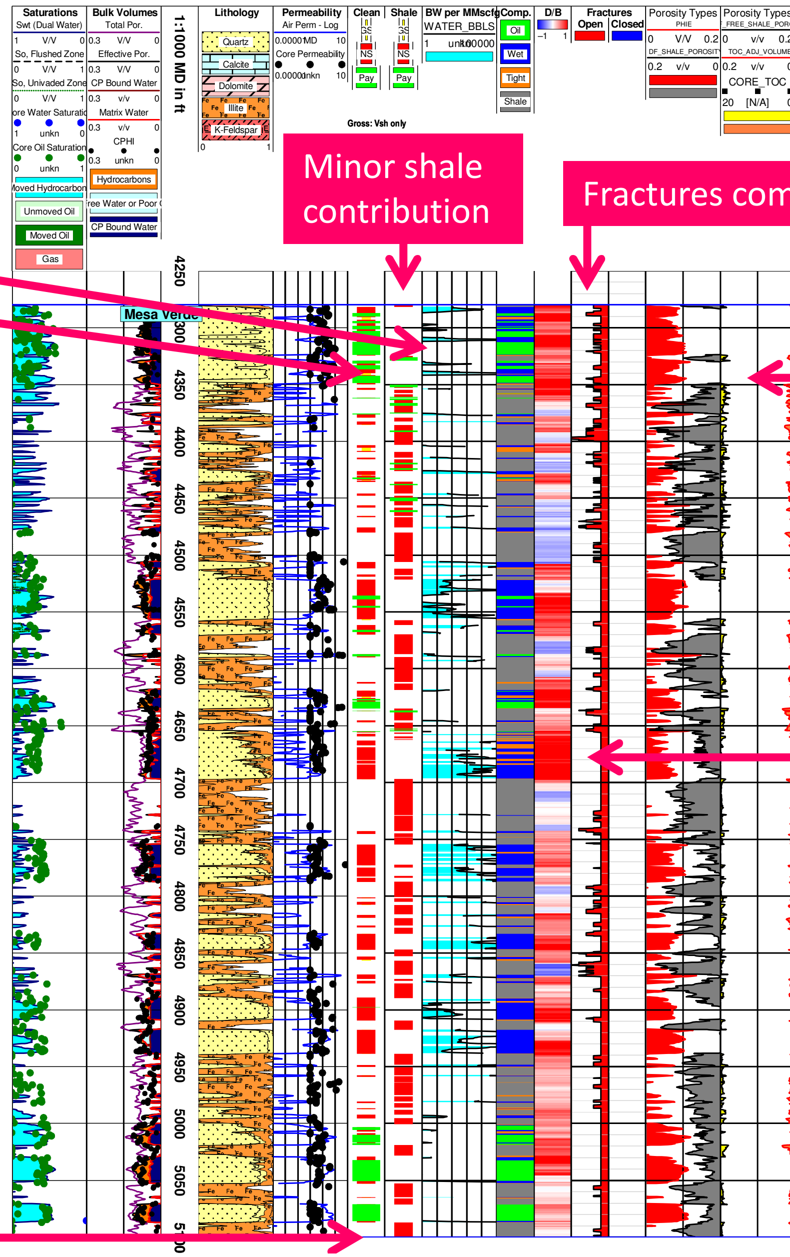
Antrim, Michigan – Shale Gas



Western Canada – Shale Gas



Piceance Basin, Colorado – Tight Gas



Water production close to pay intervals

Minor shale contribution

Fractures common

Very low TOC and free shale porosity

Sand intervals are brittle

Pay intervals mostly water-free

References

- Michael Holmes, Antony Holmes, and Dominic Holmes “A Petrophysicial Model to Estimate Free Gas in Organic Shales”, Presented at the AAPG Annual Convention and Exhibition, Houston Texas, 10-13 April, 2011.
- Michael Holmes, Antony Holmes, and Dominic Holmes “A Petrophysical Model for Shale Reservoirs to Distinguish Macro Porosity, Micro Porosity, and TOC”, Presented at the 2012 AAPG ACE, Long Beach, California, April 22-25.
- Holmes, Michael, et al. "Pressure Effects on Porosity-Log Responses Using Rock Physics Modeling: Implications on Geophysical and Engineering Models as Reservoir Pressure Decreases." Prepared for the SPE Annual Technical Conference and Exhibition held in Dallas, Texas, USA, 9-12 October (2005).
- Michael Holmes, Antony Holmes, and Dominic Holmes “Petrophysical Rock Physics Modeling: A Comparison of the Krief And Gassmann Equations, and Applications to Verifying And Estimating Compressional And Shear Velocities” presentation at the SPWLA 46th Annual Logging Symposium held in New Orleans, Louisiana, United States, June 26-29, 2005
- James W. Schmoker “Use of Formation-Density Logs to Determine Organic-Carbon Content in Devonian Shales of the Western Appalachian Basin and an Additional Example Based on the Bakken Formation of the Williston Basin”, Petroleum Geology of the Black Shale Eastern North America 1989.
- Q.R. Passey, S. Creaney, J.B. Kulla, F.J. Moretti, and J.D. Stroud “A Practical Model for Organic Richness from Porosity and Resistivity Logs”, AAPG 1990.

Questions?

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