A Comprehensive Geochemical and Petrophysical Integration Study for the Permian Basin*

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Abstract

This project encompasses the integration of petrophysical and geochemical analyses of source rocks reservoirs of major importance in the Greater Permian Basin. As available, geochemical data have provided the ability to make maturity, richness and other source character interpretations and will be combined with important petrophysical properties of the shale intervals to predict multiple reservoir and mechanical proper-ties. These interpretations will provide the opportunity to sup-port economic, development and production decisions in the geologic workflow. Best practices for sampling shale intervals, wireline testing, database and interpretive processes will be investigated. Data compilation, project planning will be provided in the first phase of the study followed geochemical and petrophysical analysis of collected data. The final report will provide the following objectives:

1) Develop workflows for accurate pre-drill predictions of petrophysical parameters, organic richness, maturity modeling and geochemical analyses of the DJ Basin.
2) Integrate acquired data with established rock and fluids database. Acquire wireline log data, core and mud log data. Acquire geochemical rock and fluids data. Also, access any public seismic data, especially 3-D interpretation data.
3) Produce highly detailed reservoir quality and geochemical prediction maps. Perform detailed petrophysical analysis. Compare with core and mud log data. Incorporate geochemical data, primarily TOC.
a) TOC Prediction Maps
b) Vitrinite Reflectance Equivalence (VRE) Maps
c) Fluid Type and quality including Gas to Oil Ratio Prediction Maps
4) Map petrophysical reservoir property variation by formation including:
a) In place hydrocarbons
b) Fracture intensity
c) Mechanical properties (brittle vs. ductile) and compare with any available seismic interpretations
d) Petrophysical properties of the shale interval

e) Integrate petrophysics with geochemistry
5) Develop geochemical baselines and apply geochemical analyses to understand reservoir quality, reservoir fluid communication and compartmentalization specific to the basins studied.
6) Design safe and cost-efficient geochemical sampling techniques for acquiring the critical data types.
a) Data designed to support development and production decisions.
b) Develop criteria for sampling time and location best practices.
7) Establish best practices for managing geochemical data libraries to ensure their security, accessibility and future value.

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DIGITAL FORMATION

AAPG Launcher Program, Sept. 4 – 5, Houston, TX
Digital Formation, Denver, Colorado, 2014

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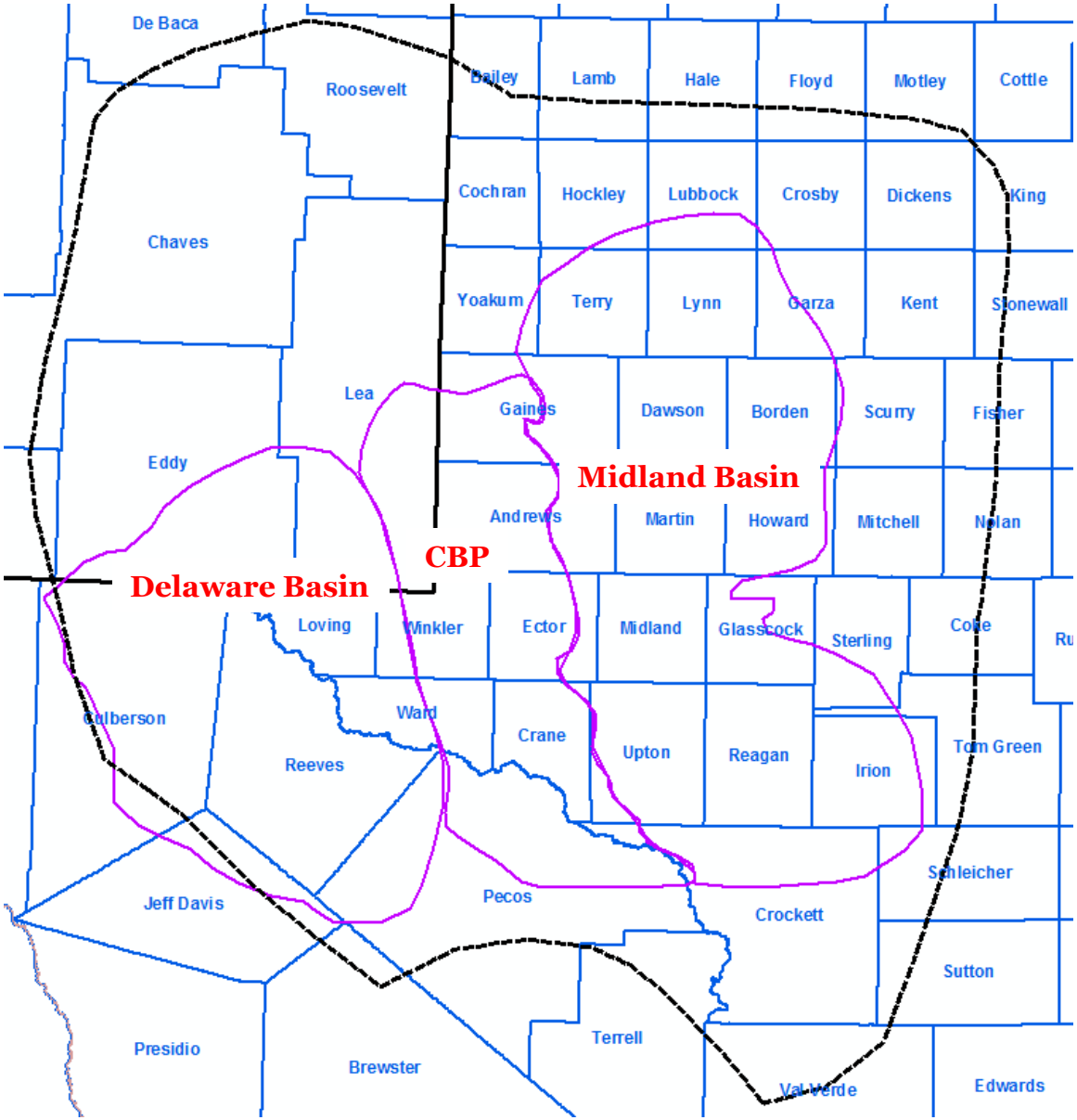
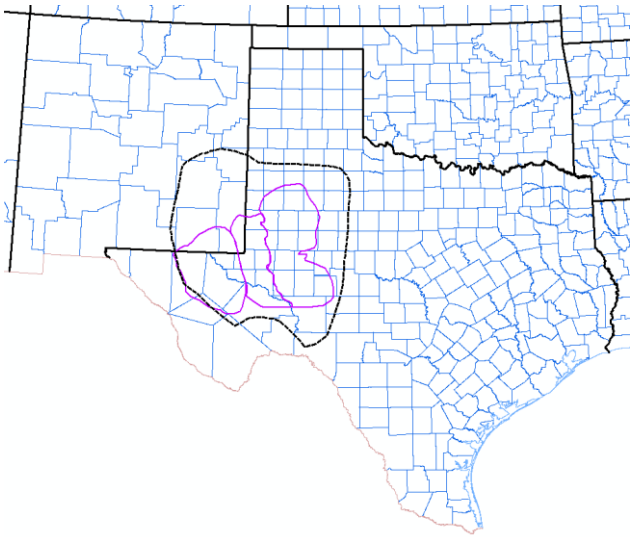
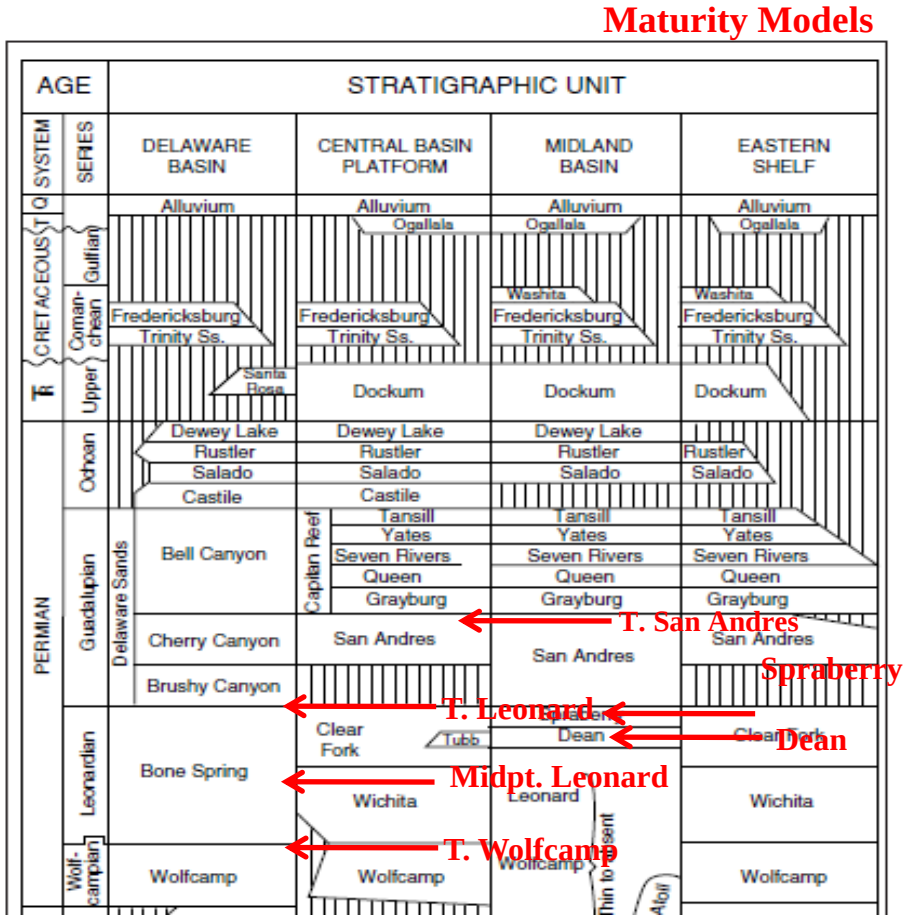
  - Unconventional reservoirs – integrated Geochemistry and Petrophysics

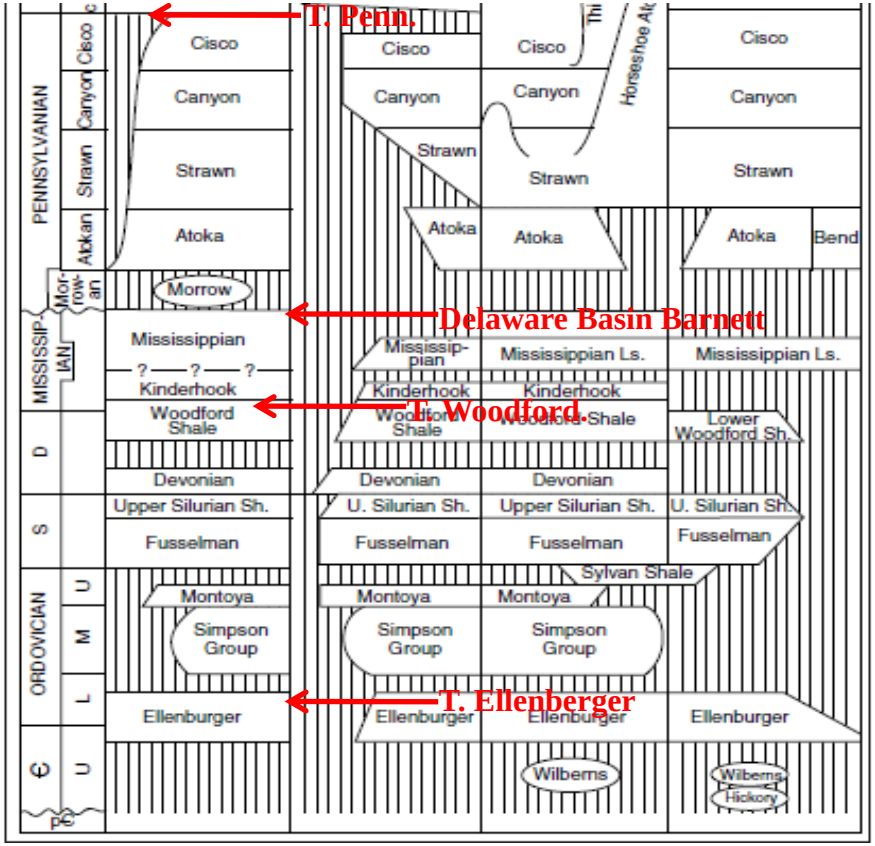
Permian Basin



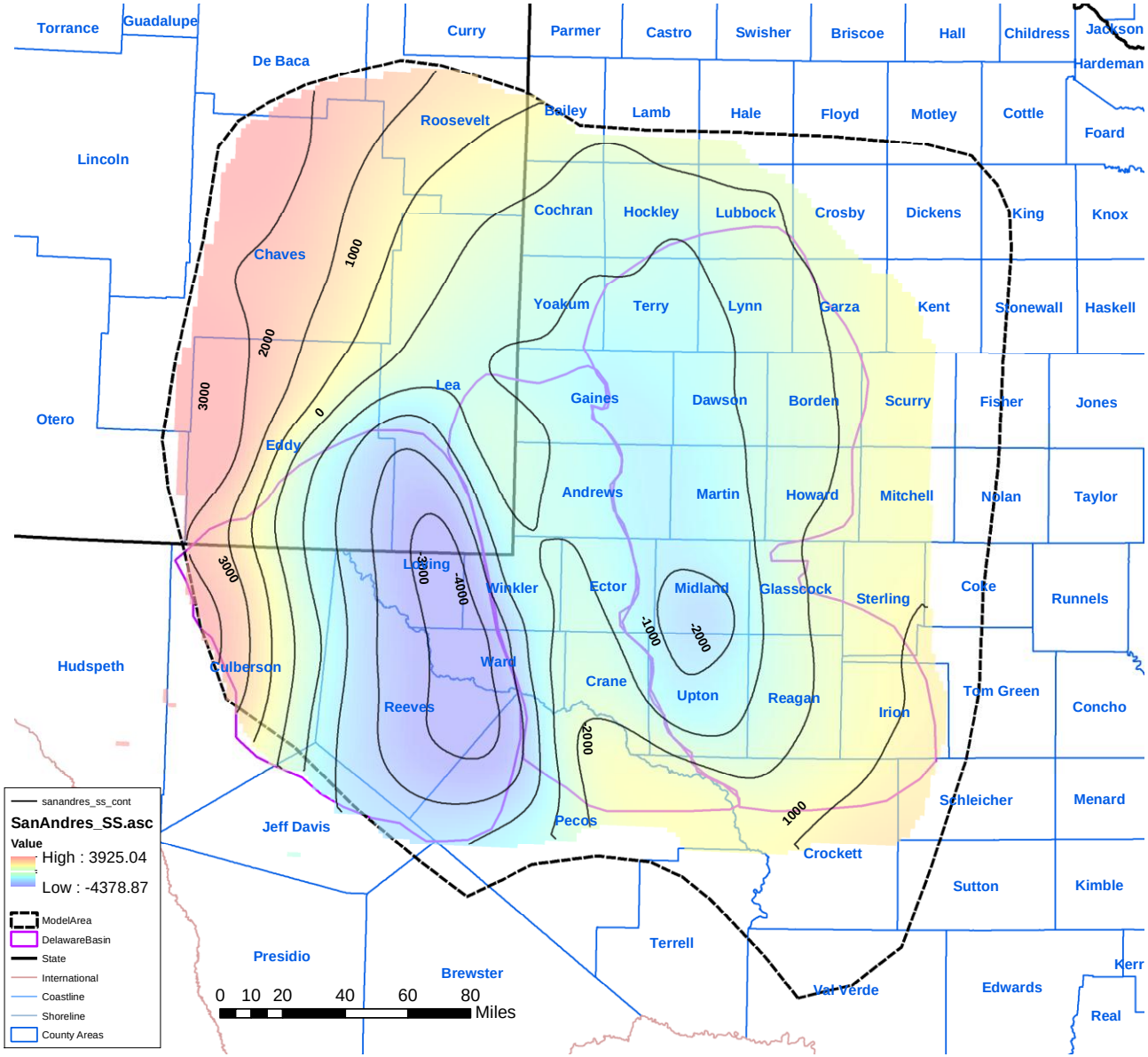


Permian Basin Stratigraphy (from USGS, 1995)

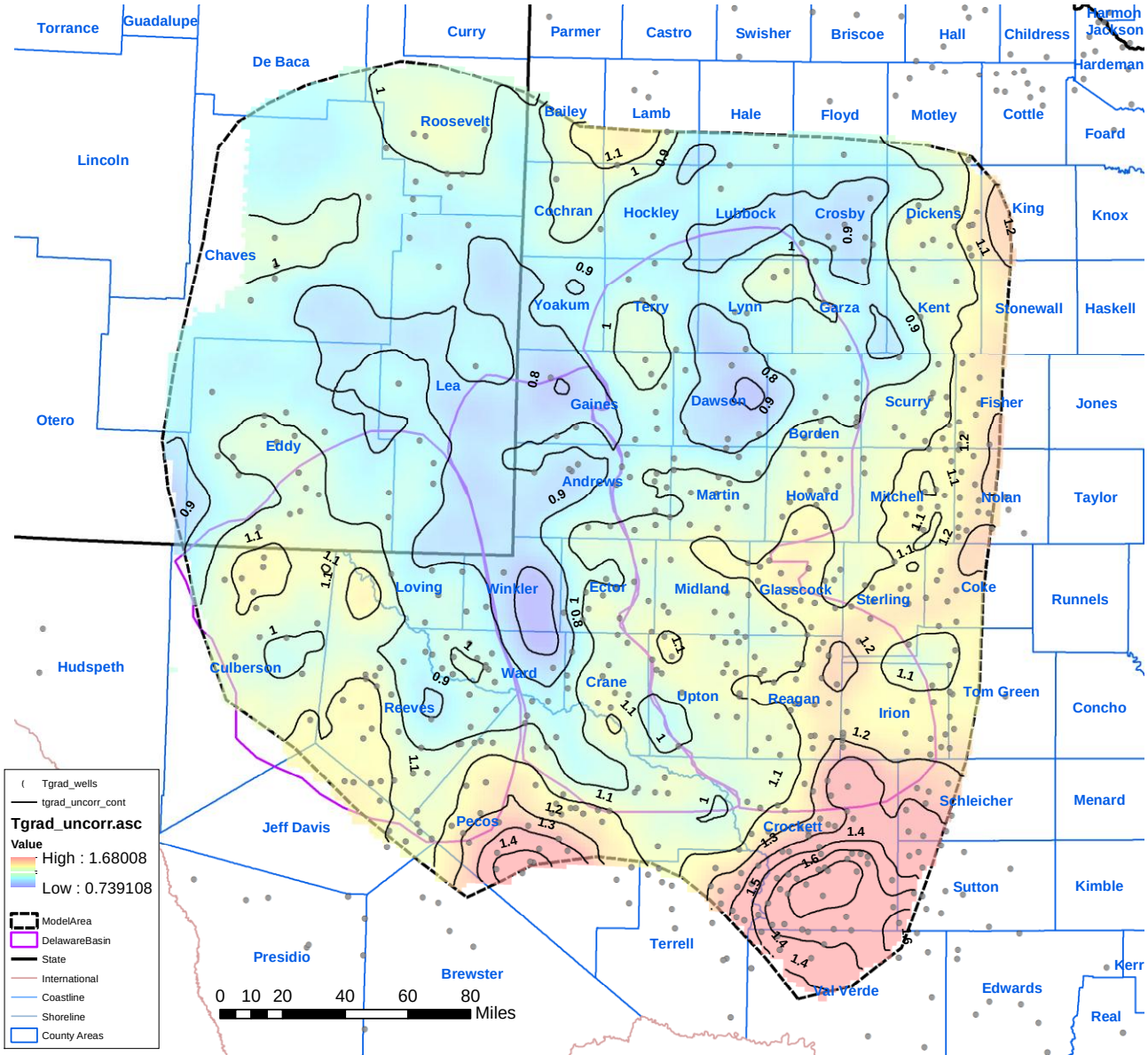


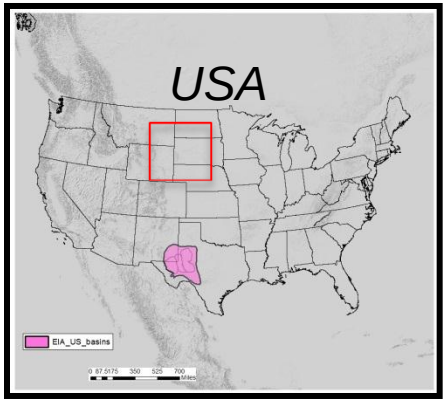


San Andres Structure



Temperature Gradient Uncorr. (F./100')





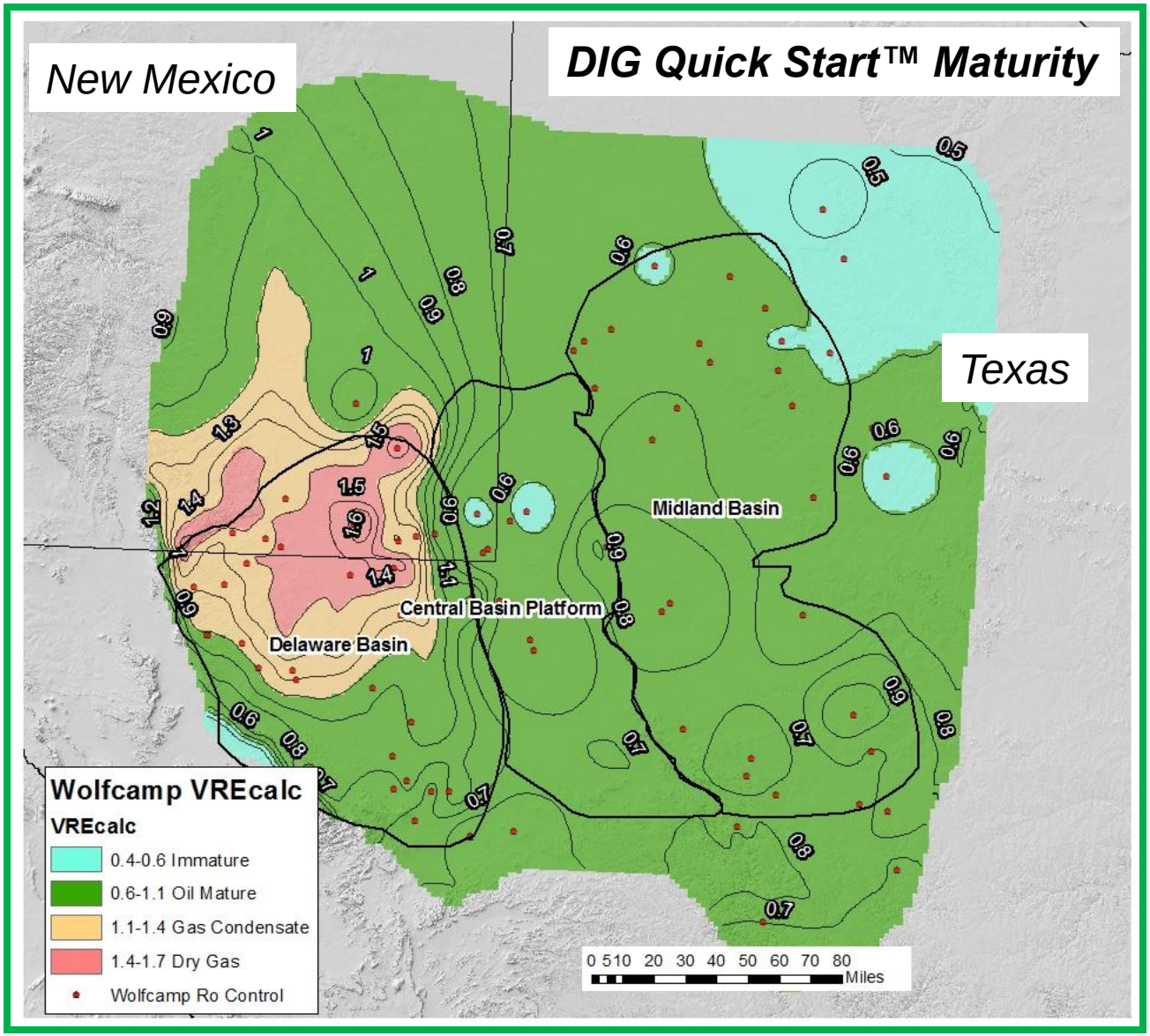
Top Wolfcamp Maturity

Integrating:

- Structure Maps
- Thermal History
- Rock Lithology
- Erosion
- Heat Flow Data
- Temperature Gradient
- Maturity Data

Make sure that your geological mechanisms are reasonable.

This is a Quick Start, not the end of the work!



Discussion

• The combination of variation in temperature gradient trends and erosion results in maturity trends which are significantly different than trends of present day structure in the Permian Basin.

• These modeled maturity maps tie the available calibration control quite well but it should be understood that the inputs such as temperature gradient, structure and estimated erosion have a range of uncertainty. These maps thus show regional trends and not fine detail over such a large area.

• The modeled maturity maps can be used to distinguish areas of oil Vs gas for various source intervals and can be used as a tool to generate new insitu oil and gas plays.

Conclusions

- **Regional Maturity Maps allow for comprehensive integration of geochemical data sets.**
  - **Speed and rigor are your objective.**
  - **Project planning will keep your effort on track.**
    - **What are your Objectives?**

<u>Products</u>

- **Quickly integrate existing knowledge base**
- **Comprehensive review of what is known and that which needs upgraded understanding.**
- **Make Integrated Interpretations**
- **Predict Risk Spatially**
- **Important Development decisions can benefit from spatial analysis.**

Petrophysical Modeling – Data Available (examples from San Andres)

- Pre 1970 log suite
  - Gamma Ray Neutron (neutron in counts)
    - Need to convert counts to porosity, which requires estimates of porosity in tight clean formation, and porosity in shales. Best to choose from nearby well with a modern neutron log.
  - Normal and lateral resistivity devices.
    - They can be used as a measurement of true resistivity. Resistivity modeling, based on GRI logic will correct (as far as possible) to give more accurate resistivity.
  - Standard petrophysical analysis of porosity and water saturation is possible. More advanced modeling cannot be done.

1970's Log Suite

- Gamma Ray Log
- Density log
- Neutron log – in porosity units
- Focused resistivity logs
- Acoustic compressional log
- Standard petrophysical analysis is easier to implement because neutron logs are in porosity units and resistivity logs give more accurate true resistivity. Additionally, lithologic data and direct gas indicators are available from density/neutron comparison.

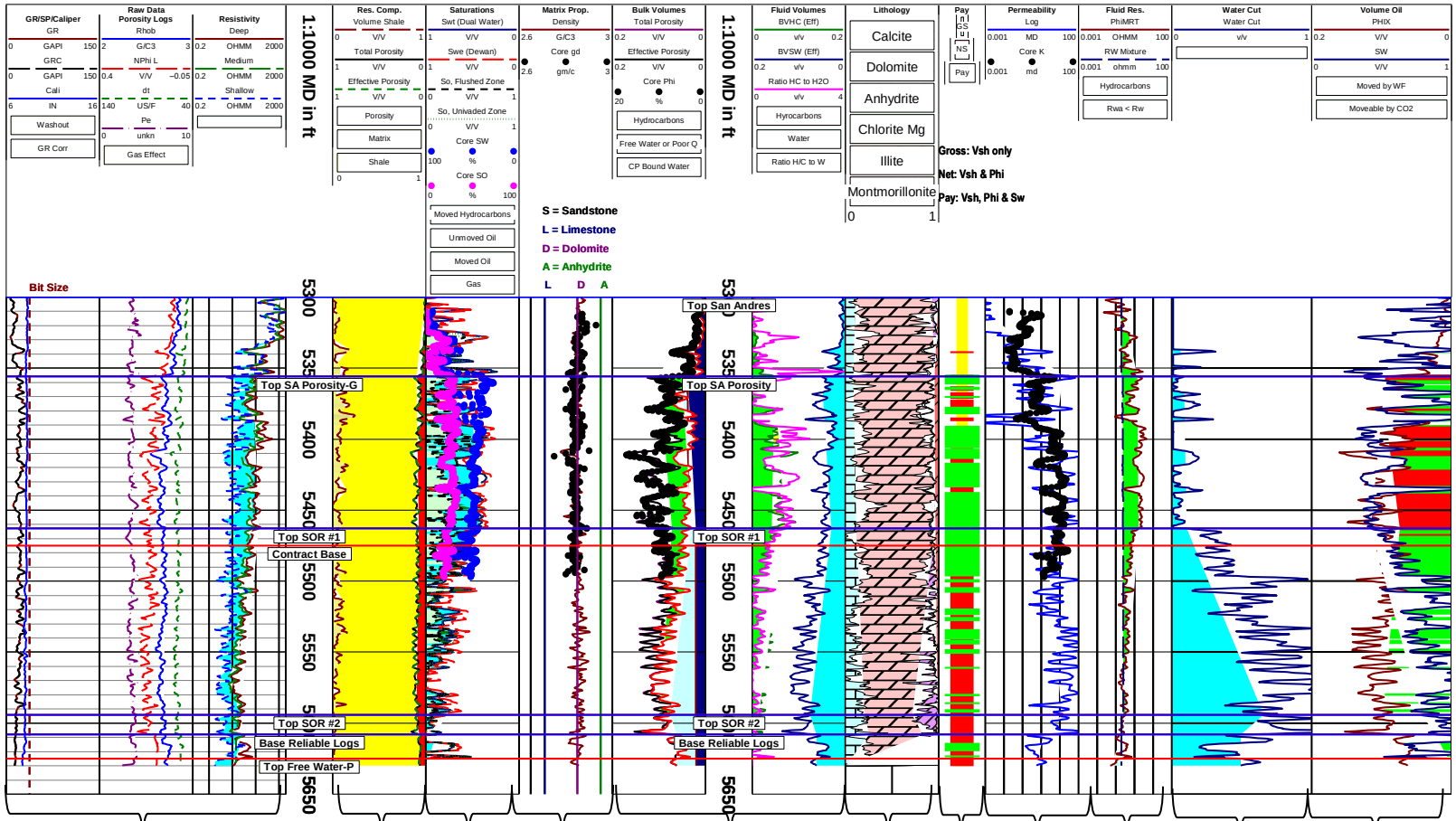
Modern Log Suites

- Addition of the Pe curve gives much more accurate lithology information, particularly in carbonate reservoirs
- If dipole sonic devices exist, accurate calculations of mechanical properties can be made. In the absence of acoustic data, good estimates of mechanical properties are available by running a rock physics model to generate pseudo curves.
- Nuclear magnetic resonance and image logs afford additional petrophysical models

Petrophysical Models

- In the following discussions an example from a modern San Andres well is used to illustrate procedures
- Similar models can be developed for all other formations

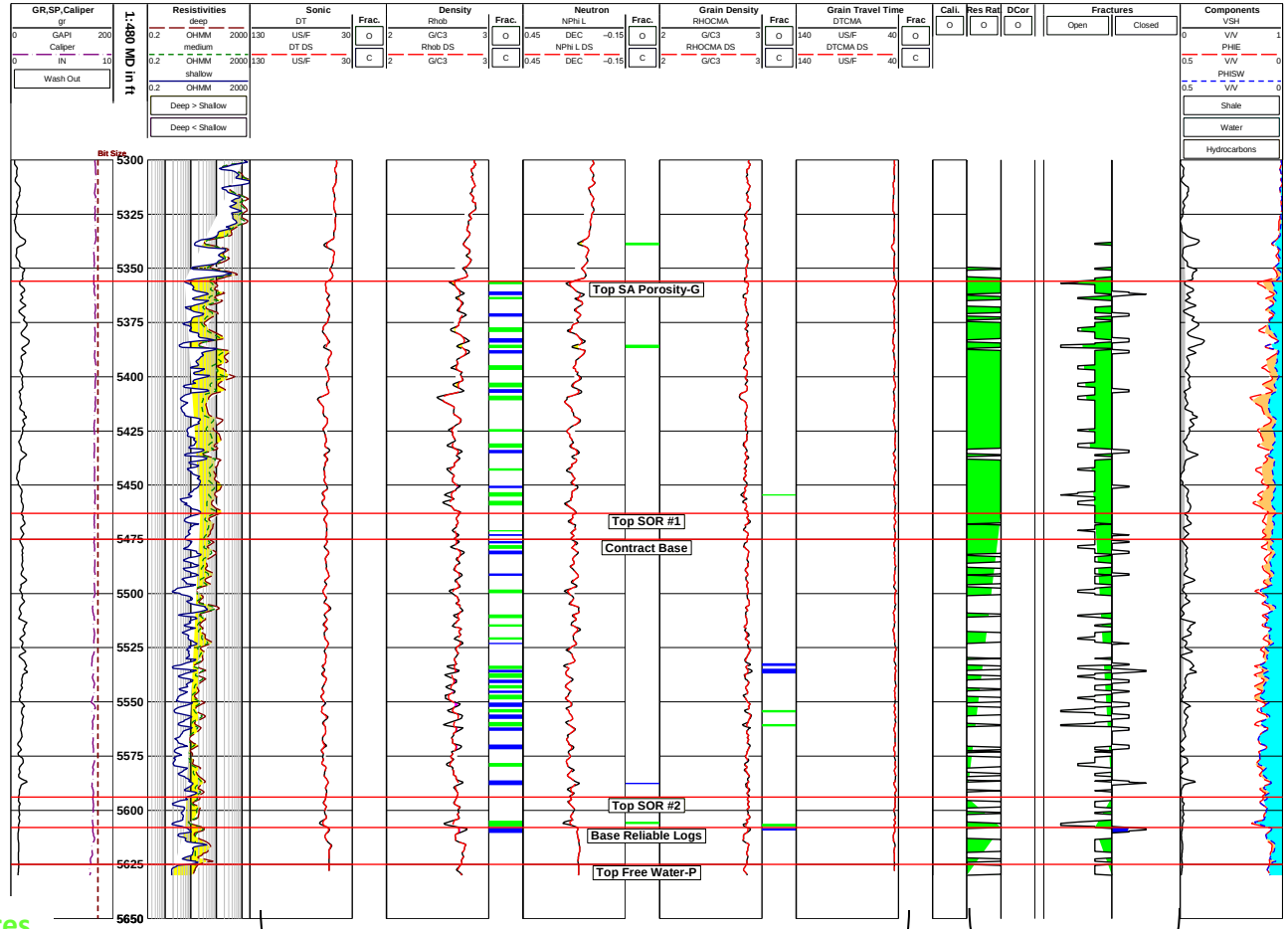
Standard Formation Analysis



Good comparison log/core

Fracture Analysis

- Based on rates of change of curve magnitude with depth. Rapid change to high porosity interpreted as an open fractures and to low porosity, as closed (cemented) fracture



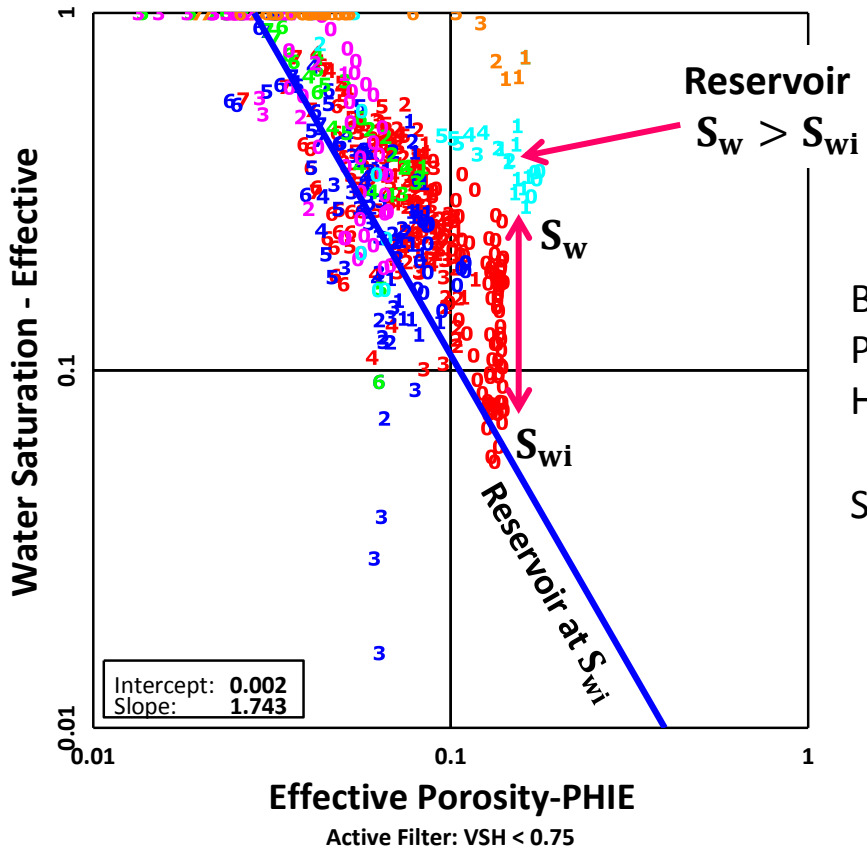
Green = Open Fractures

Blue = Closed Fractures

Individual Log Responses

Stacked Data

Procedure 4 – Relative Permeability Model



Buckles Relation

Phie X S_{wi} = Constant

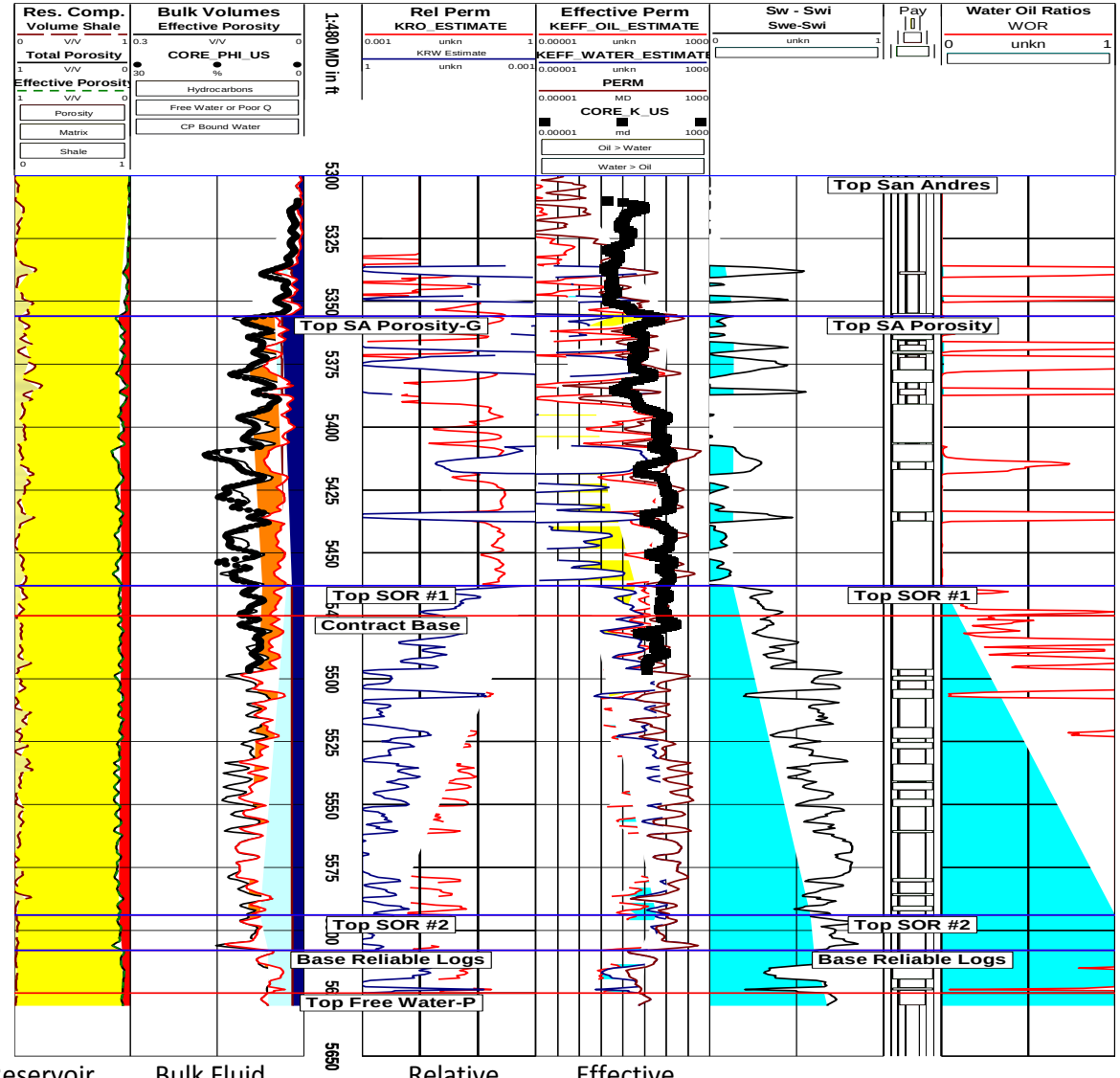
Holmes Adaptation

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

Slope = Q

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

Relative Permeability



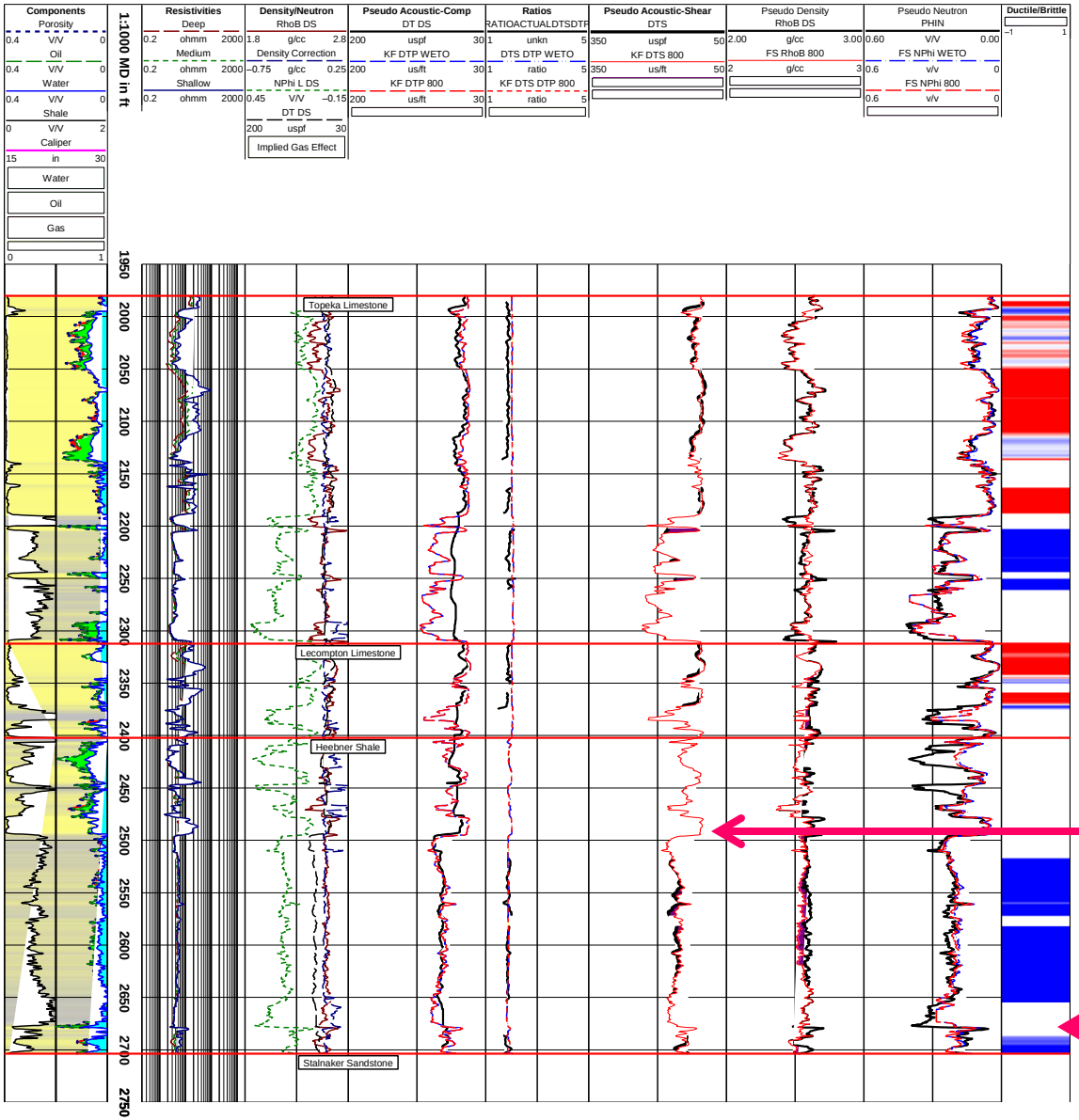
Reservoir Components | Bulk Fluid Volumes | Relative Permeability | Effective Permeability | Sw – Swi | Water Cut

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 San Andres example shows pseudo curves based on the Krief geophysical model (Dipole Sonic not run).

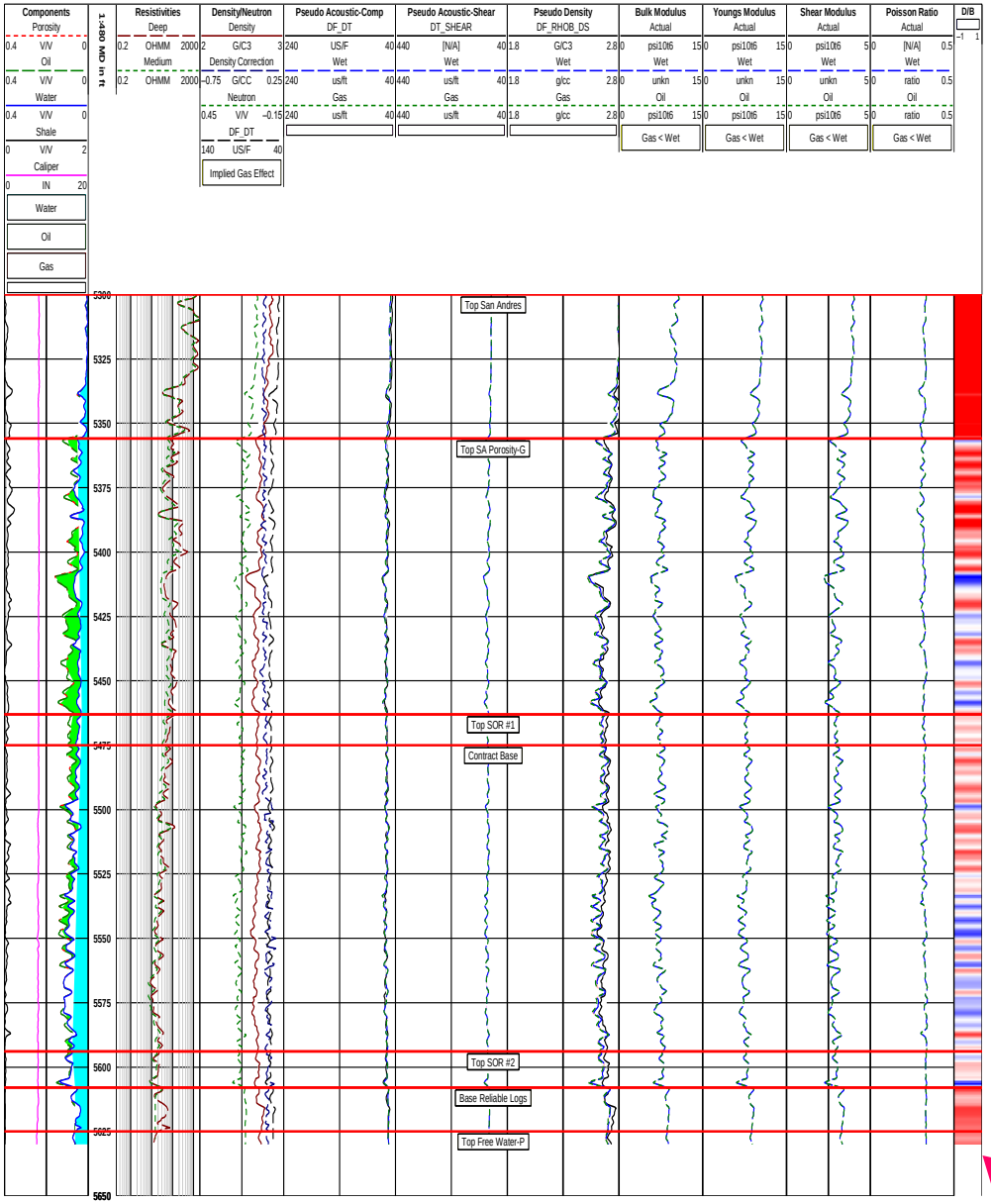
Dipole Sonic Example from Kansas



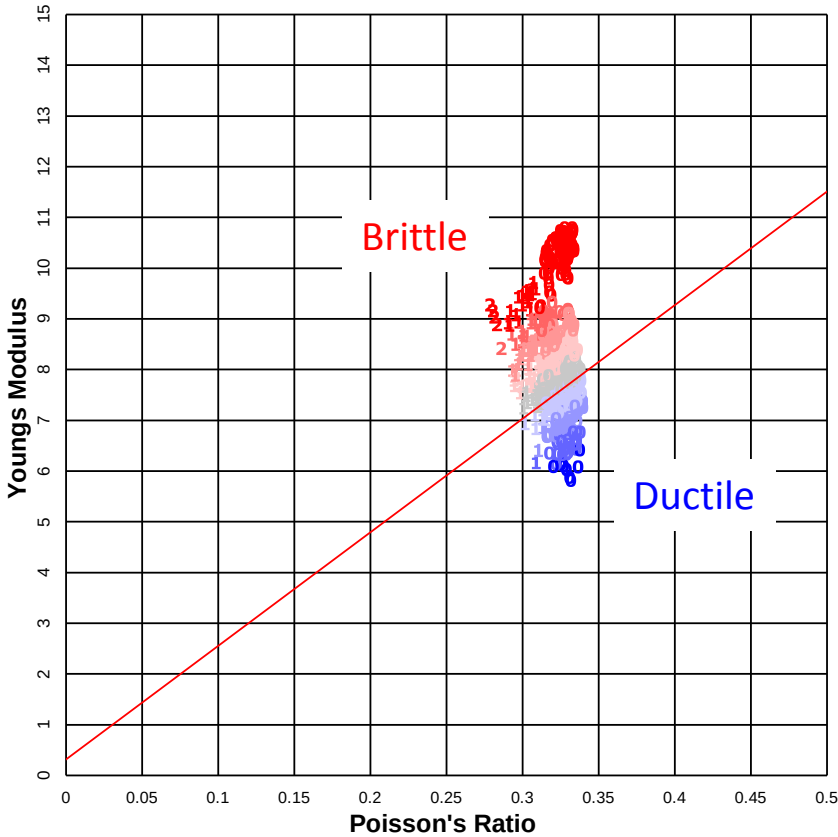
Missing DT Shear

Cannot Compute ductile/brittle when DT Shear is Missing – use pseudo logs to fill in missing DT shear

Mechanical Properties – San Andres Example



Young's Modulus Vs. Poisson's Ratio

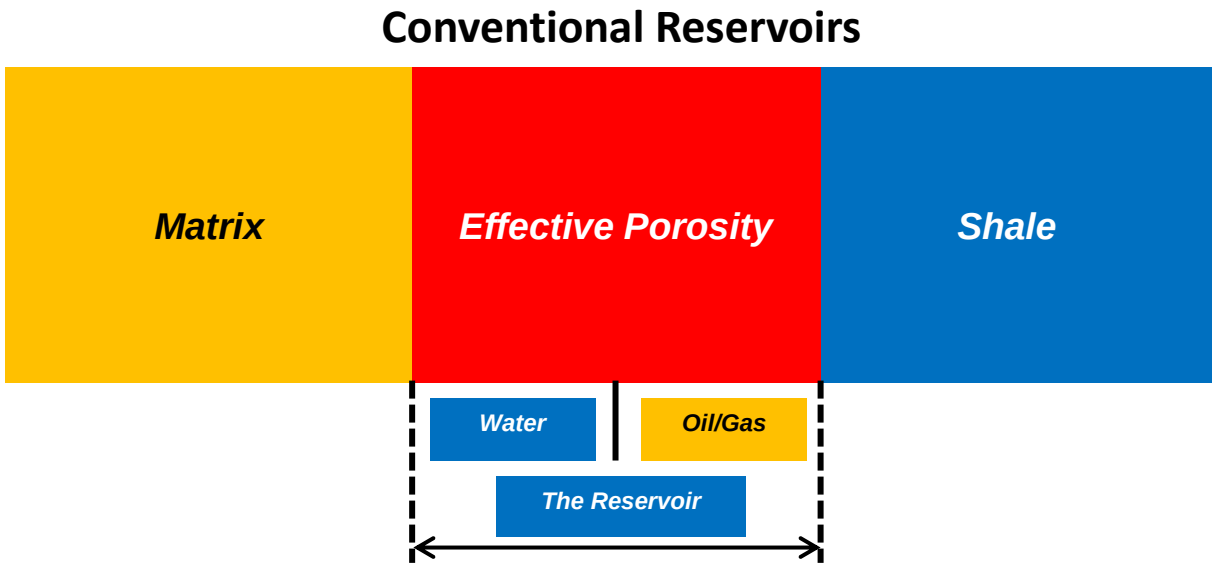


Red = Brittle

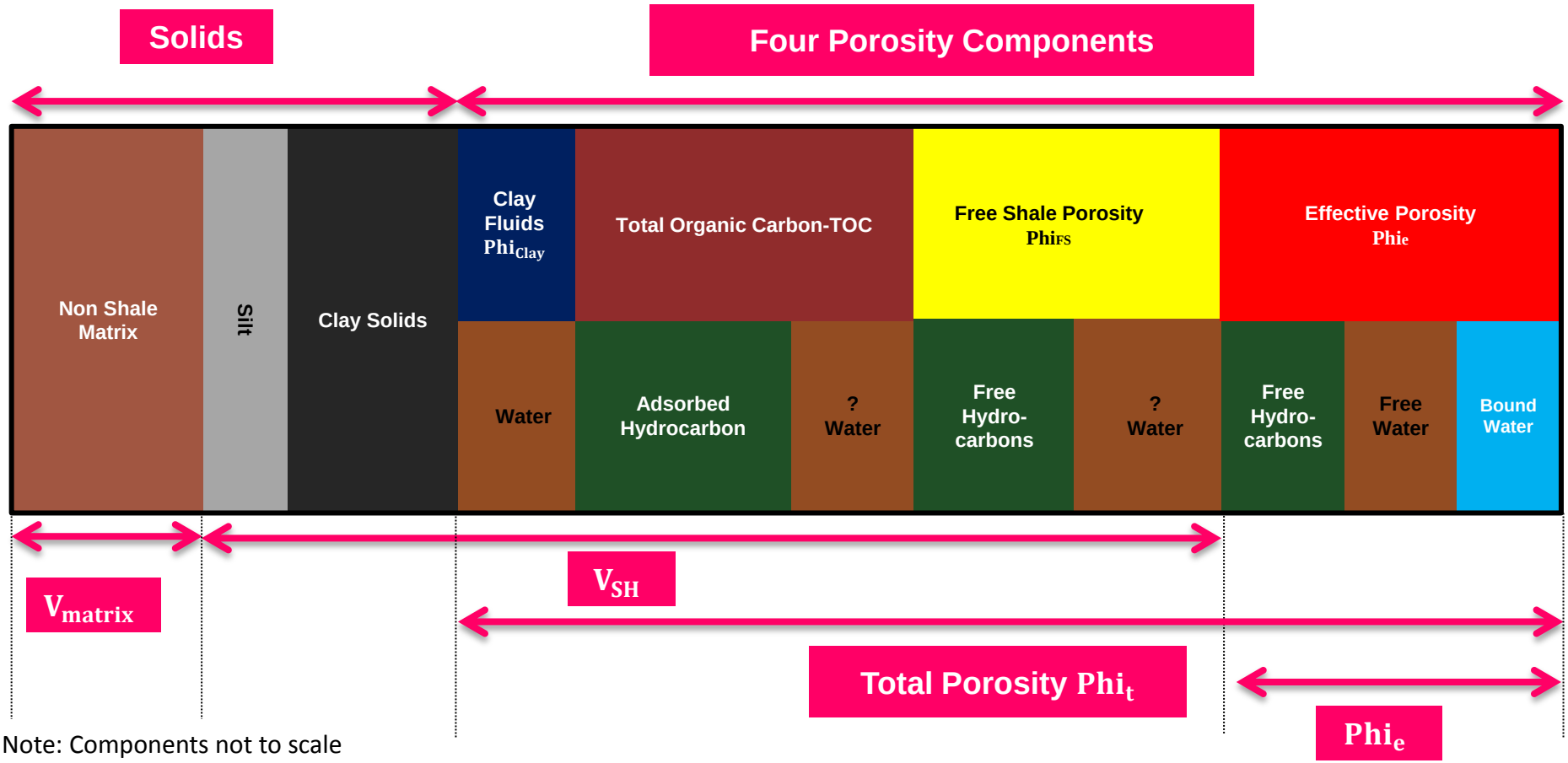
Blue = Ductile

Unconventional Reservoirs

- Conventional vs. unconventional reservoir petrophysical models



Unconventional Reservoirs

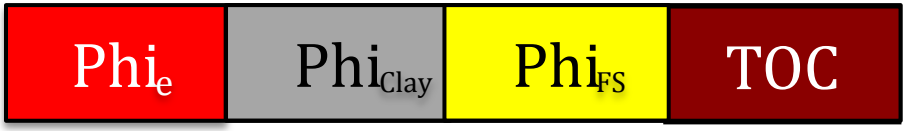


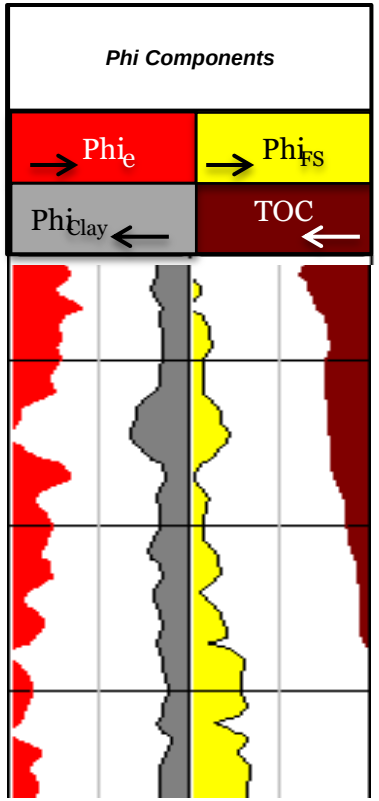
*Note: Components not to scale

- Integrates Geochemistry with Petrophysics
  - TOC Component
  - Reservoir Wetting
    - Maturity
    - Clay Mineralogy

Four Porosity Component Model

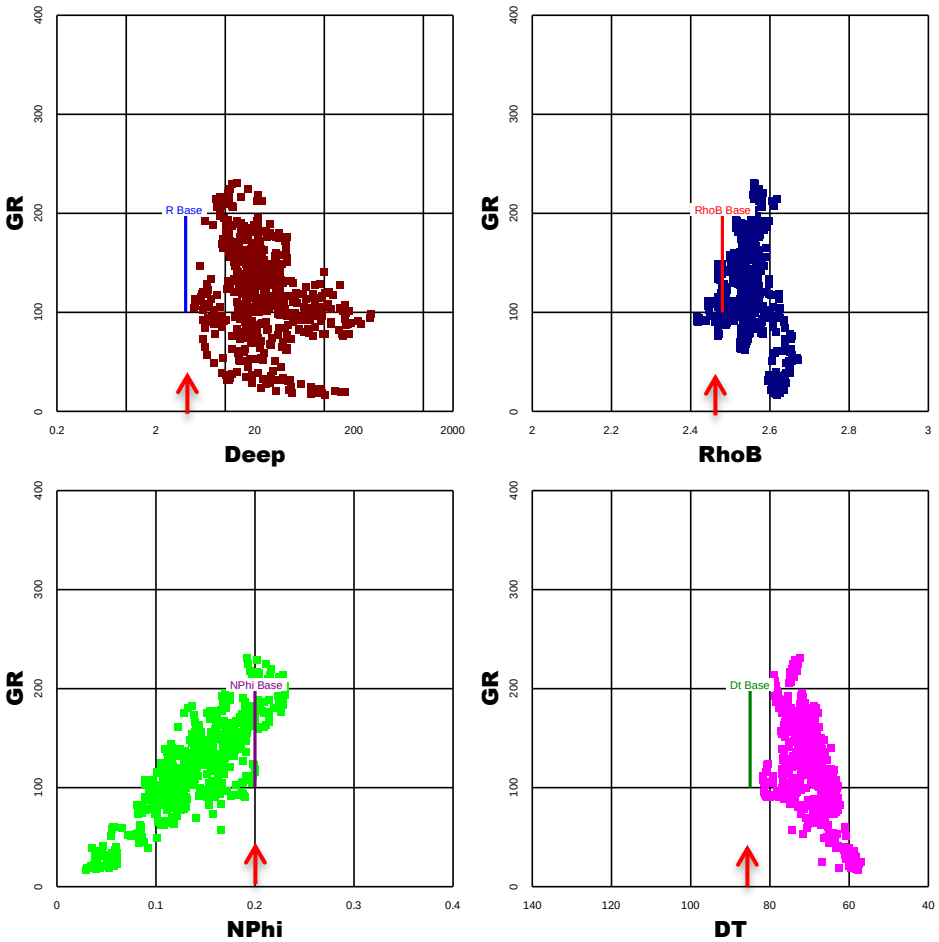
- The goal is to calculate the four porosity components from the unconventional reservoir model
  - Effective Porosity Phi_e
  - Total Organic Carbon TOC
  - Clay Porosity Phi_{Clay}
  - Free Shale Porosity Phi_{FS}





TOC Calculation

- TOC Passey et al

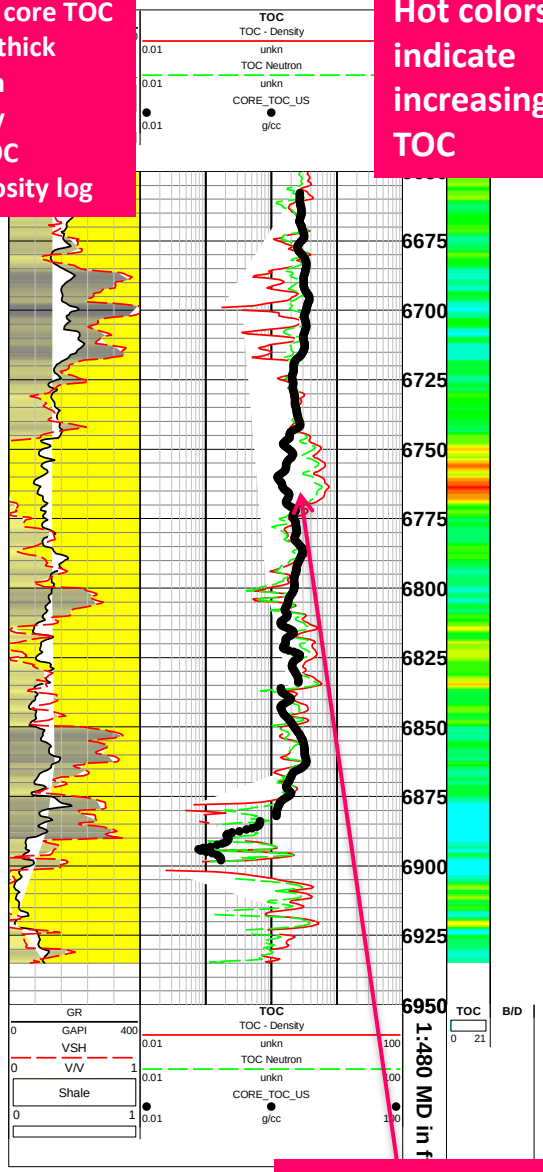


Responses in Organic – lean intervals ↑

TOC = Total Organic Carbon

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

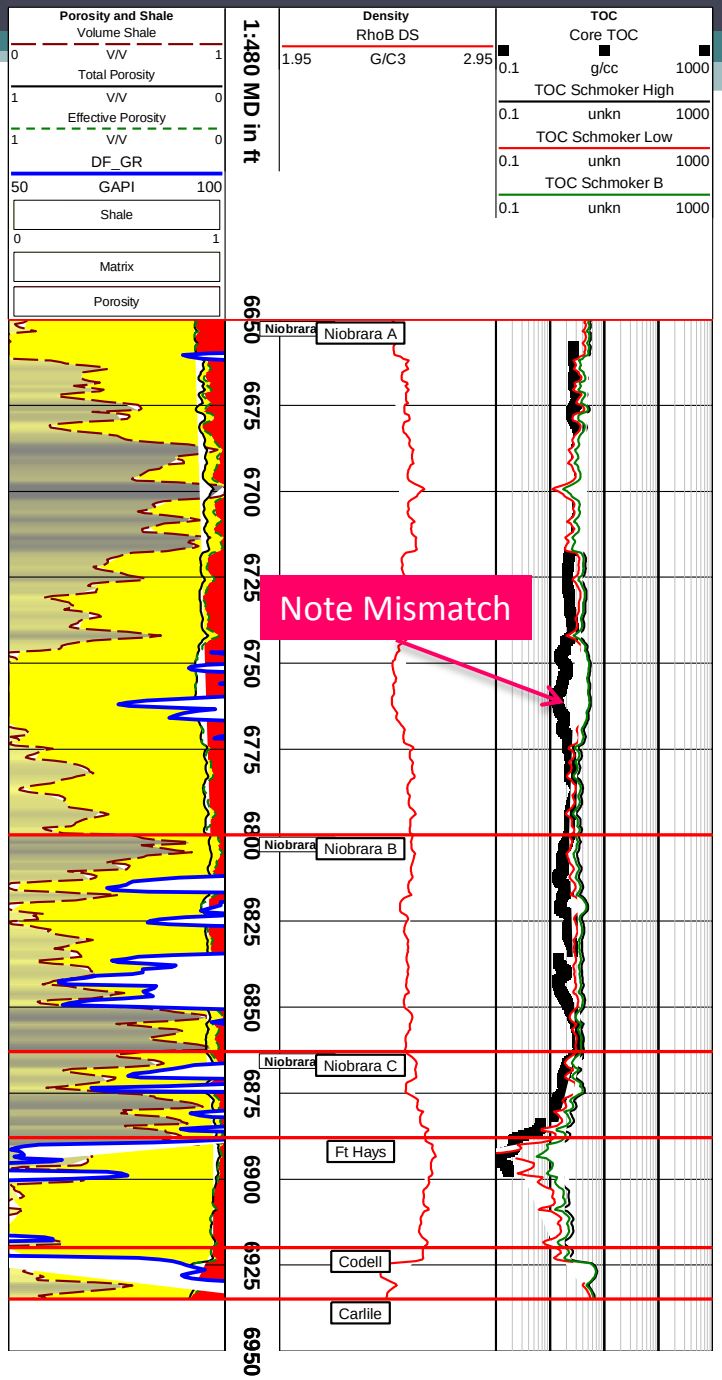
Hot colors indicate increasing TOC



Note Mismatch

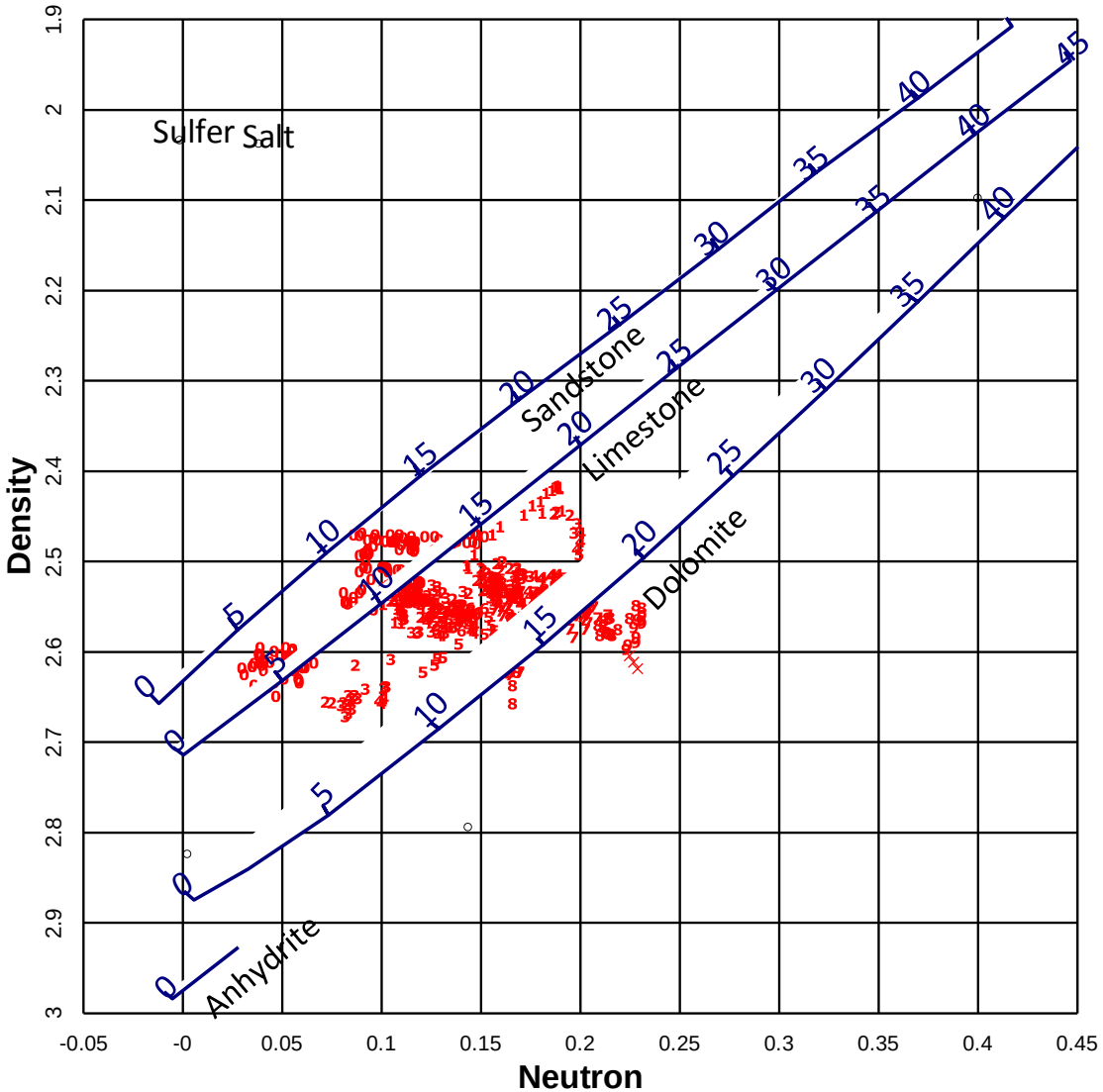
TOC Calculation

- 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

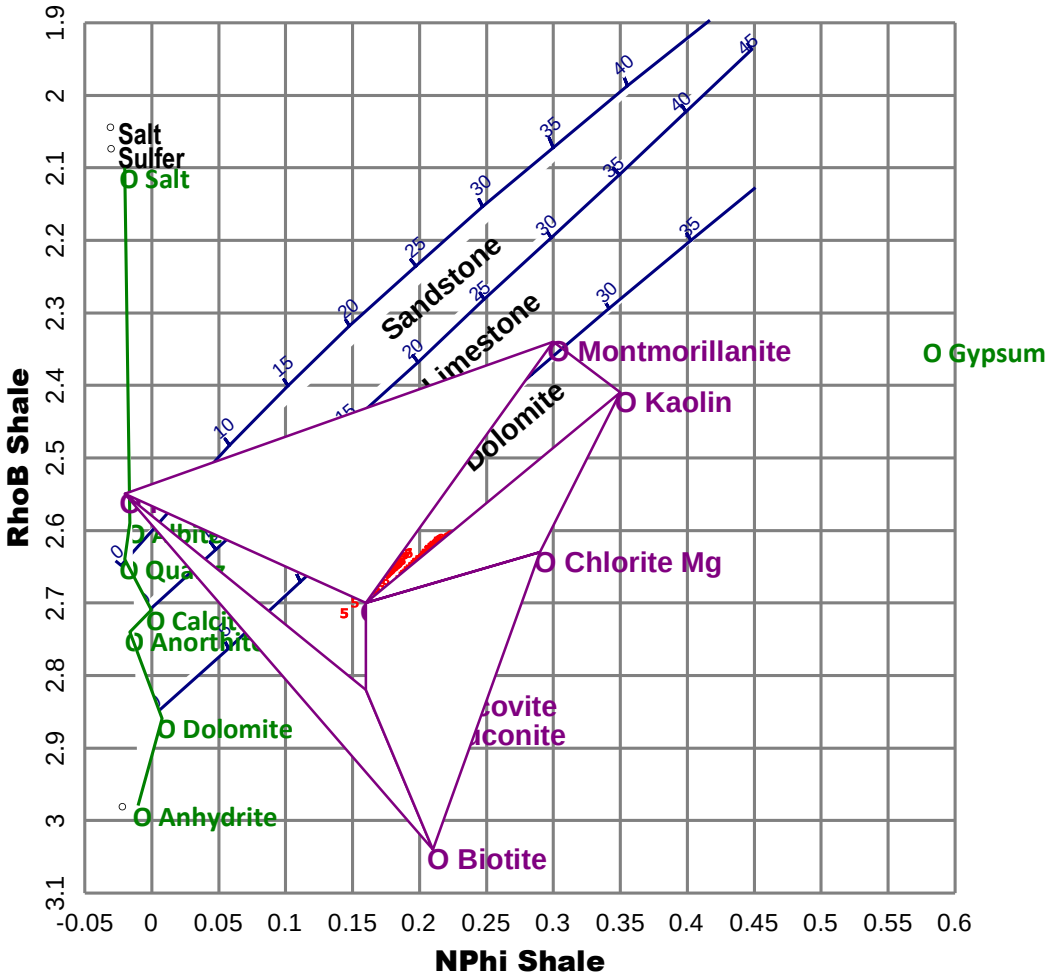
Standard



Standard vs. Shale Oil Density/Neutron Cross Plots

Shale Only

Plot gives indication of clay mineral species. Application to reservoir wetting – montmorillanite = oil wet? Illite = water wet?

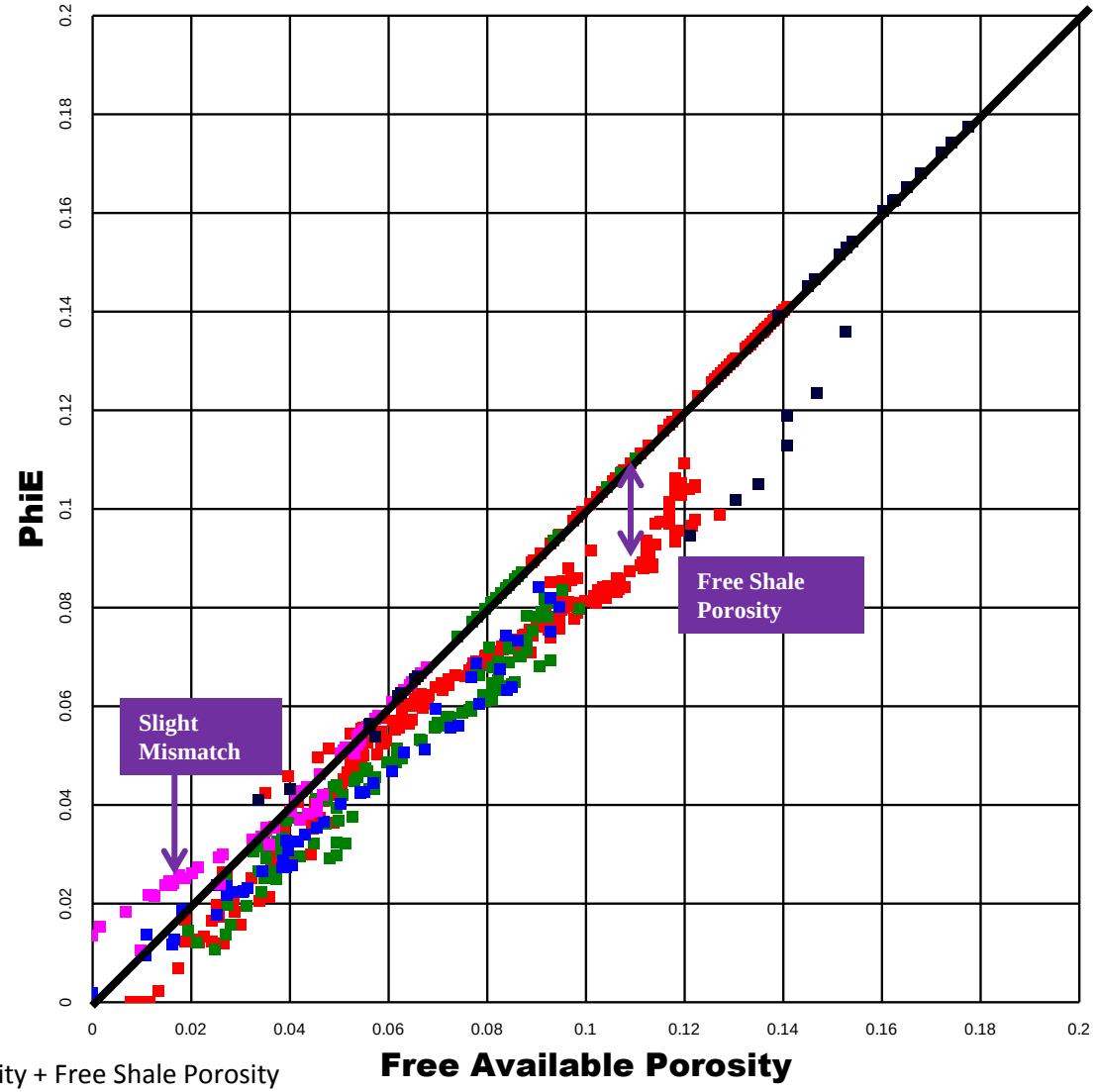


Calculate

Clay Porosity = Cross Plot Porosity X V_{SH}

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

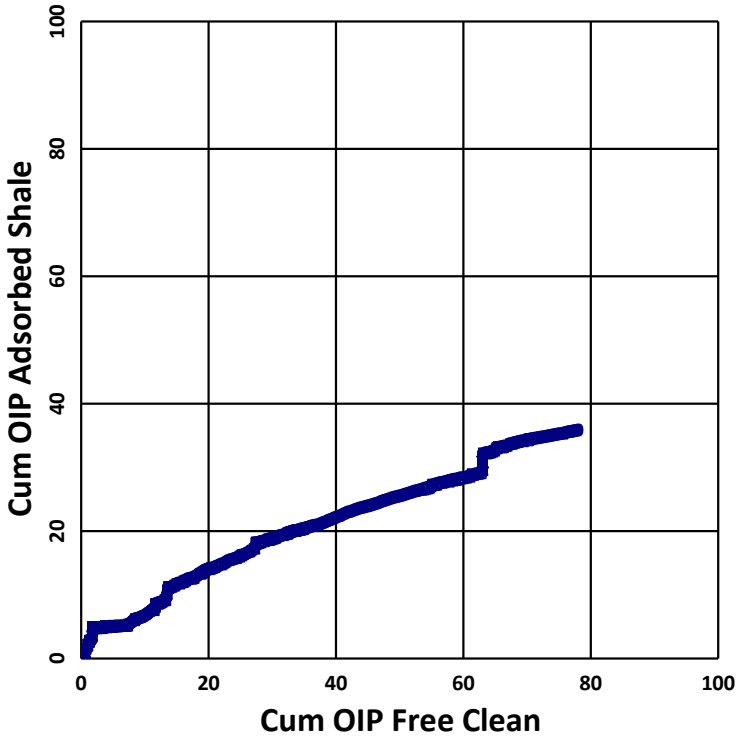
Phie Vs. Free Available Porosity



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

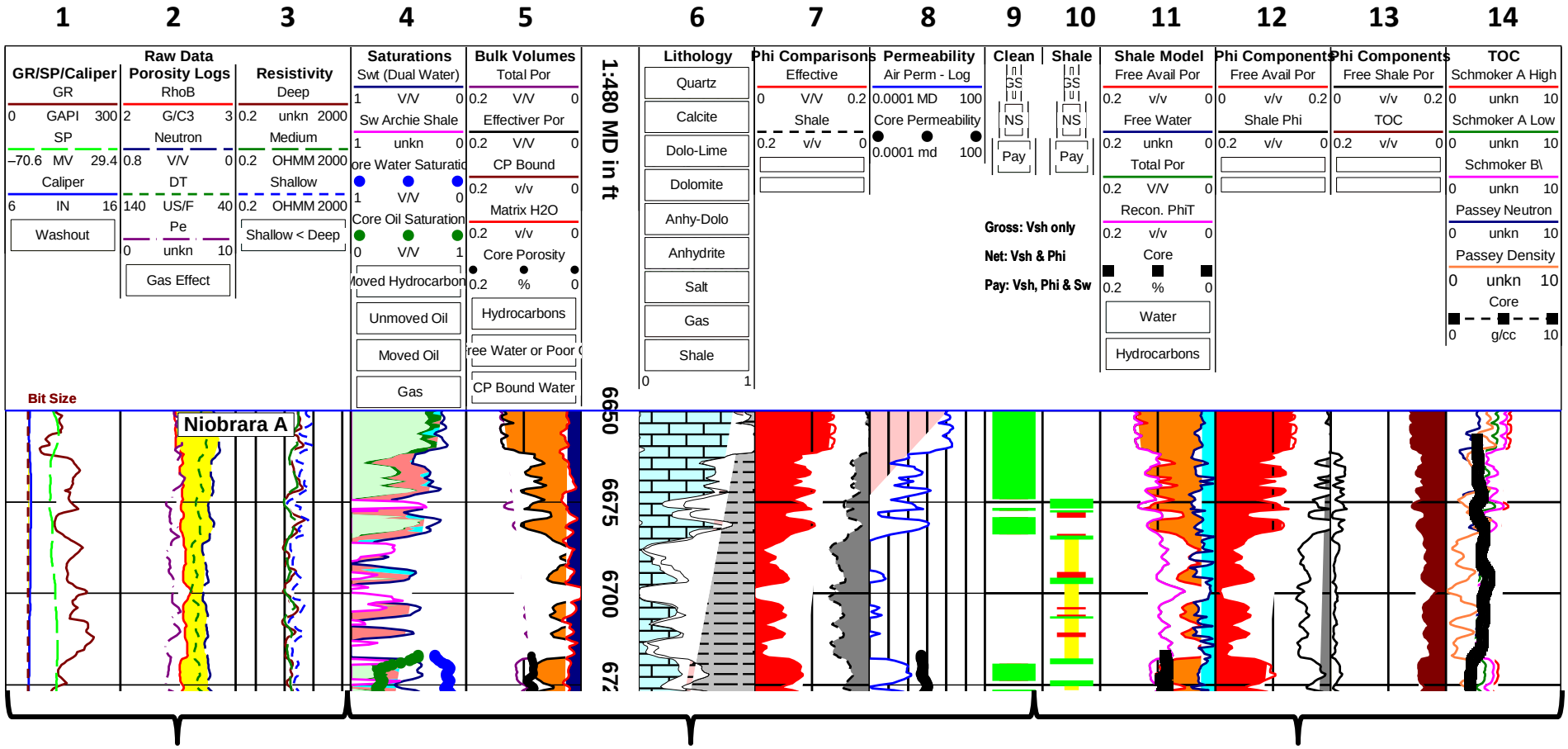
Adsorbed G.I.P. (SCF) = 1359.7 X Area X Thickness X RhoB X (16 X TOC)

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

Unconventional Reservoir Model – Niobrara, Colorado



1	Gr, SP	4	Saturations	7	Porosity Components	10	Pay Flag – Shale	13	Porosity Components
2	Porosity	5	Bulk Volume Fluids	8	Permeability	11	Bulk Volume Fluids	14	TOC Comparison – Cores/logs
3	Resistivity	6	Lithology	9	Pay Flag – Clean	12	Porosity Components		

Thank You
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