Mixed Reservoir Wetting in Unconventional Reservoirs and Interpretation of Porosity/Resistivity Cross Plots, Derived From Triple-combo Log Data

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Outline

- Introduction
  - Unconventional reservoir model
  - Reservoir components
  - Summary of petrophysical model – unconventional reservoirs
- Statement of Theory
  - Four porosity components
  - Prior publications

Outline

- Procedures
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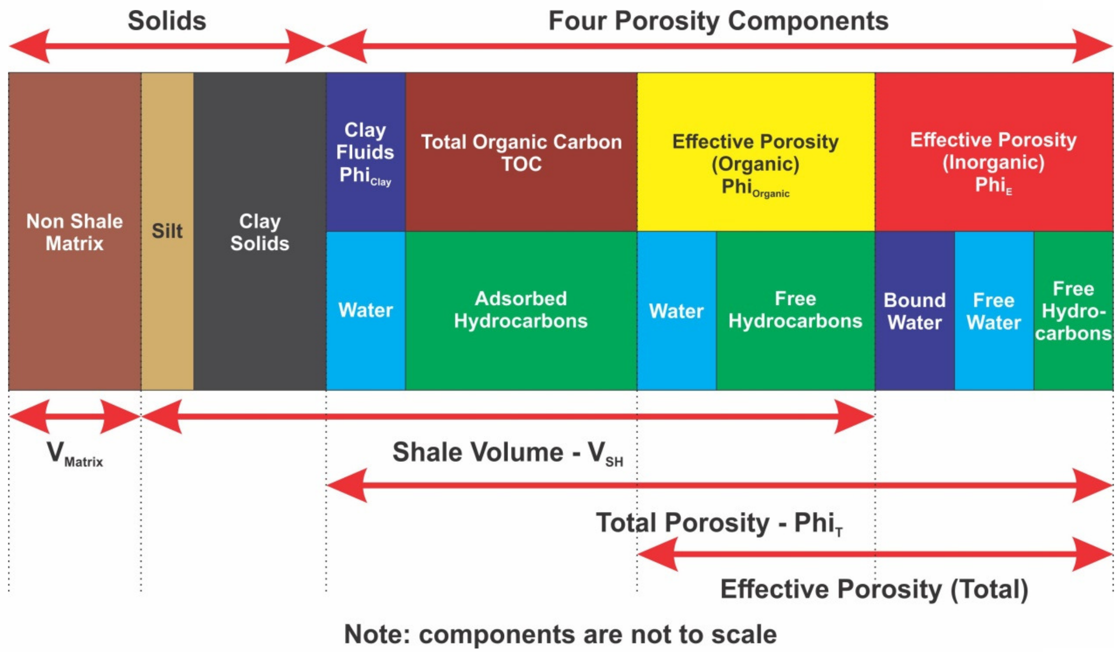
  - Standard petrophysical analysis
  - Subtract non-shale responses from density and neutron logs
  - Construct a shale-only density/neutron cross plot
  - Calculate effective porosity (organic)
  - Construct porosity/resistivity cross plots – clean formation and shale

Outline

- Mixed reservoir wetting interpretation
  - Archie cementation exponent ‘m’ and saturation exponent ‘n’ from porosity/resistivity comparisons
  - ‘m’ and ‘n’ values in clean formation, dominated by standard effective porosity (inorganic)
  - ‘m’ and ‘n’ values in shale, dominated by effective porosity (organic)
- Data Presentation
  - Bakken oil reservoir, North Dakota
  - Midland Basin (Wolfcamp) oil reservoir, Texas
- Conclusions
- References

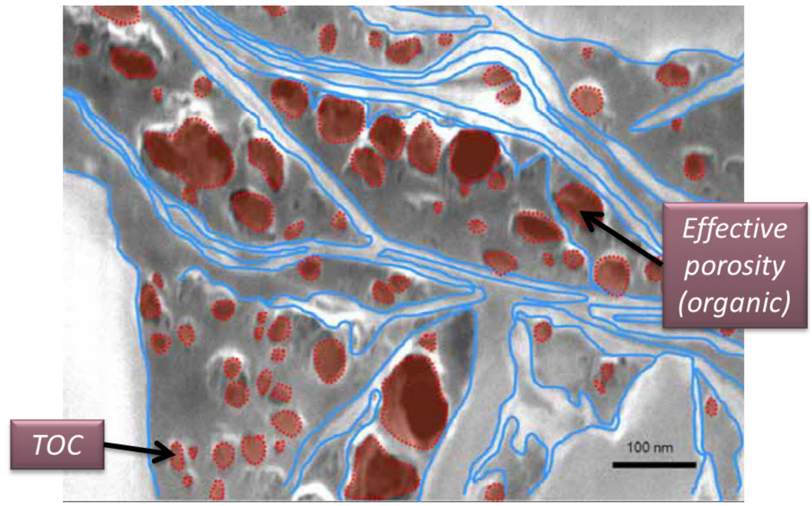
Introduction – Unconventional Reservoir Model



- For unconventional reservoirs, properties are quite different from conventional reservoirs, with unique petrophysical attributes. The shale component requires detailed analysis.
- This presentation addresses the analysis of the shale component using deterministic approaches involving triple-combo log suites.
- Particular emphasis is directed to differentiating electrical responses of the clean formation and shale.

Statement of Theory

- Glorioso, et al presented a model equivalent to the model presented here

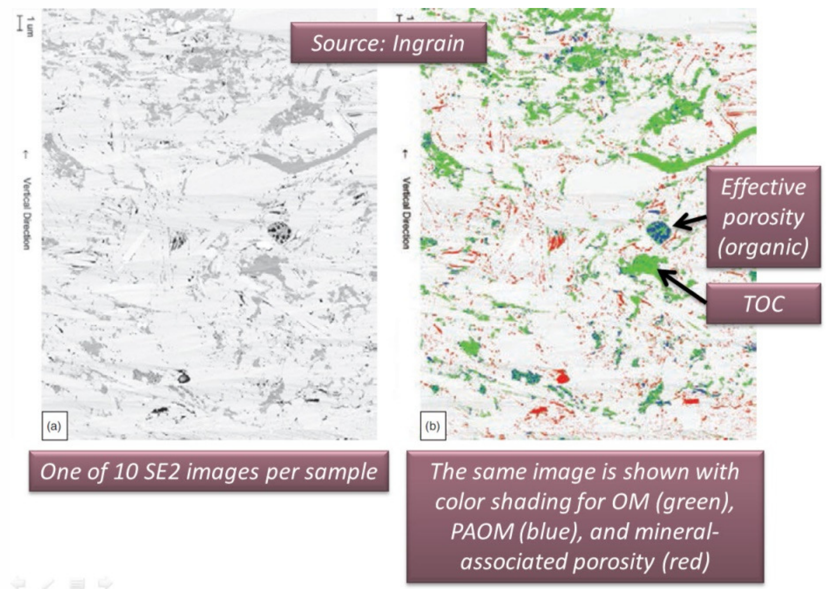


Fluid distribution in the porous system according to Passey; free gas (dark red) in kerogen pores, adsorbed gas in the kerogen pore wall (light red) and water (light blue) in the inorganic matrix that looks microfractured (Passey, 2010)

Statement of Theory

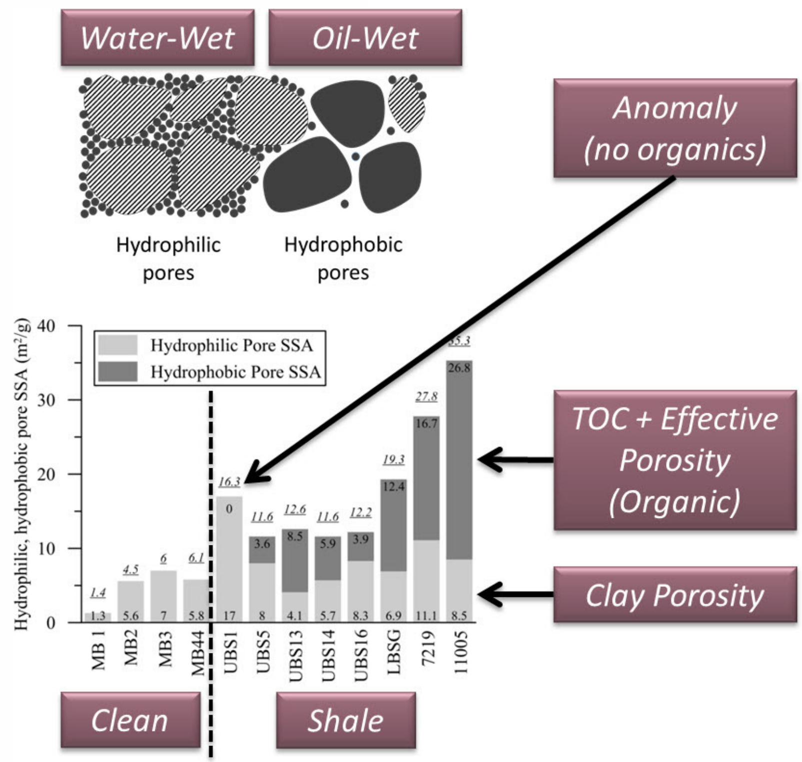
Walls, et al (2016) give an example from the Wolfcamp to recognize:

- Mineral associated porosity
- Organic matter (OM)
- Porosity associated with organic matter (PAOM)

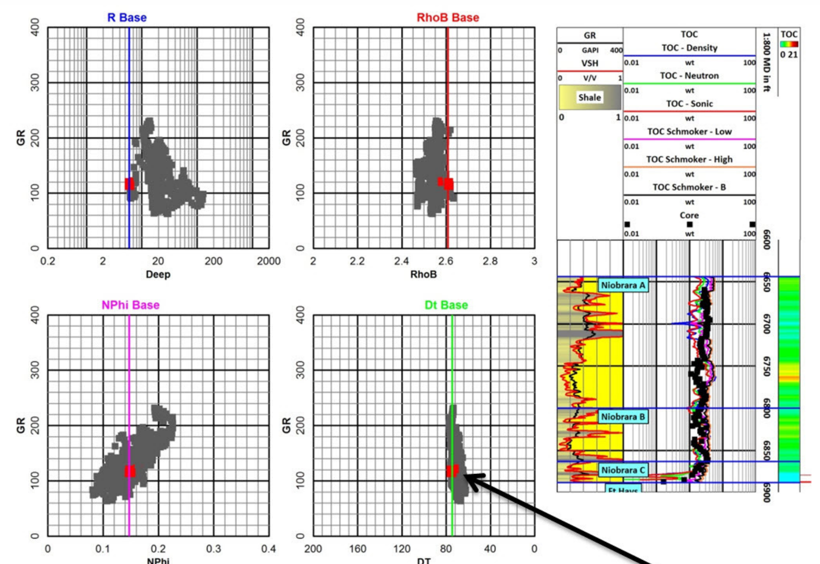


Statement of Theory

- Kumar (2015) shows a distinction between water-wet clean formation and oil-wet shale formation from the Bakken. The analysis involved preferential sorption of fluids, which depends on the polarity of the rock surfaces.



Procedures – TOC Calculations



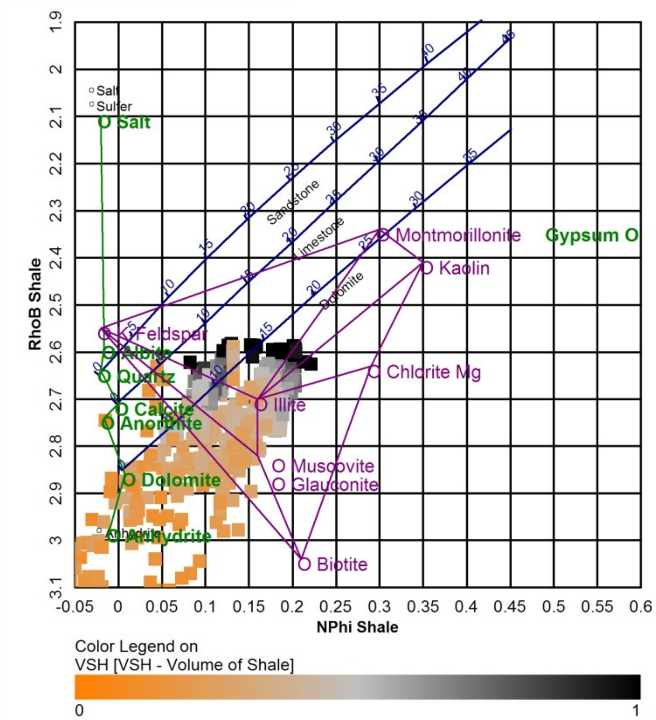
Montage as input to Passey, et al ΔlogR technique and TOC calculations from both Passey and Schmoker

Base values are the organic lean responses (red data points)

- Two procedures are available:
  - Passey et al, 1990
  - Schmoker, 1989
- The ΔlogR technique of Passey et al, is used to differentiate between organic rich and organic lean shales
- The calculation of TOC (in weight percent) can be made for any available porosity log
- Input of LOM or Ro is required (measurement of thermal maturity). This is best determined from calibration with core or cuttings measurements, or from a knowledge of thermal maturity of the reservoir.
- Schmoker relates TOC to density response, recognizing TOC has a significantly lower density than most of the other reservoir components
- TOC needs to be converted from weight percent to volume percent. The density of TOC has a range of 1.1 – 1.8 g/cc.

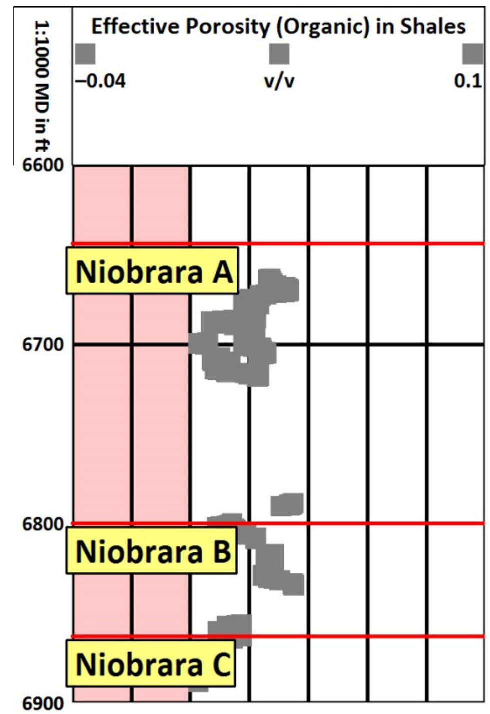
Procedures – Subtract Non-Shale Responses from the Density and Neutron Logs

- The non-shale components are:
  - Effective porosity (inorganic) – account for fluid content
  - Matrix Volume
  - Total Organic Carbon – as a volume fraction
- Determine porosity from the shale only density/neutron cross plot
- Calculate clay porosity as the product of cross plot porosity and V_{SH}



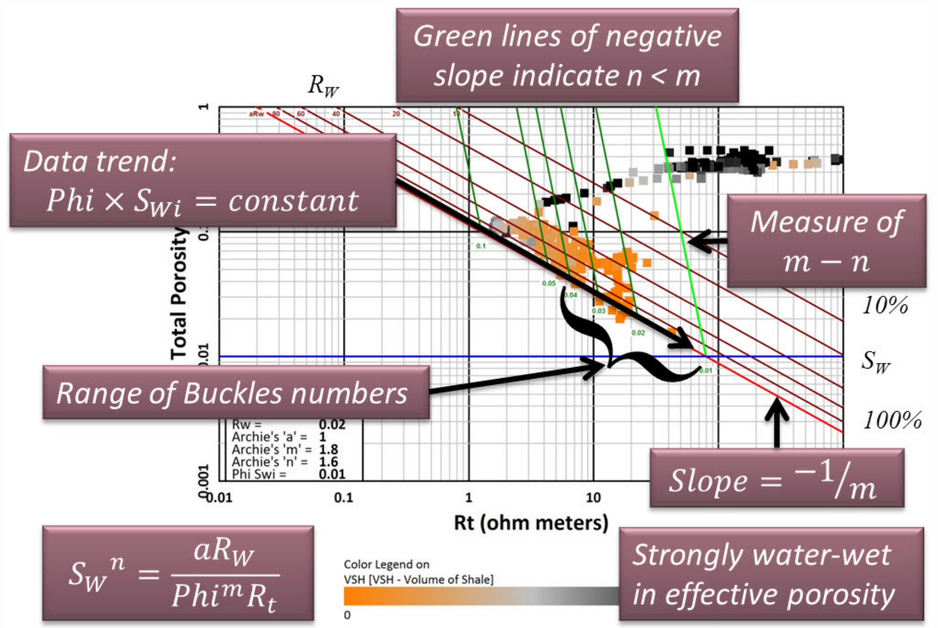
Procedures – Calculate Organic Porosity

- Effective Porosity (Organic) = Total Porosity – Effective Porosity (inorganic) – Clay Porosity – TOC Volume
- Clearly effective porosity (organic) is zero or greater. If negative values are calculated it might be a consequence of incorrect estimates of shale volume of TOC and/or an incorrect assumption of TOC weight percent. Additionally, there may be an incorrect weight to volume conversion for TOC.
- A depth plot of effective porosity (organic) will help in the interpretation – data cannot fall in the pink shaded region

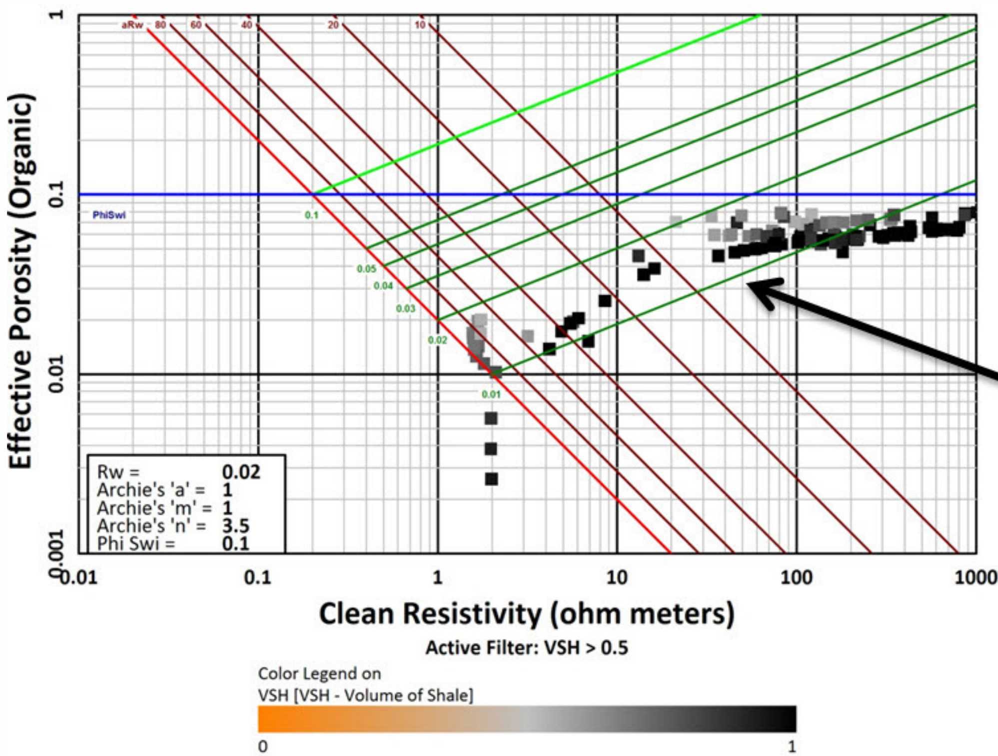


Construct Porosity/Resistivity Cross Plots – Clean Formation

- Green line is a measure of the difference between cementation exponent (m) and saturation exponent (n). Negative slope is n<m, positive slope n>m, and vertical m=n.



Construct Porosity/Resistivity Cross Plots – Shale



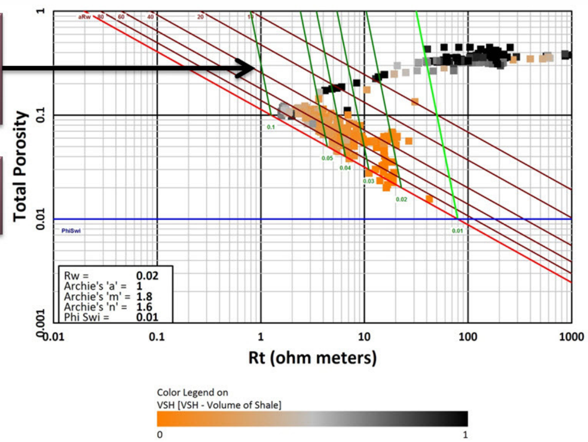
Green lines show a positive slope indicating n > m

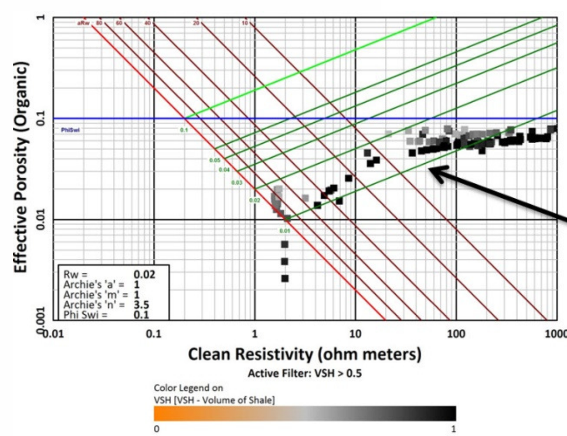
m = 1.0 (linear flow paths)
n = 3.5 (oil-wet)

Bakken Oil Reservoir, North Dakota

Green lines show a negative slope indicating n < m

m = 1.8
n = 1.6 (water-wet)

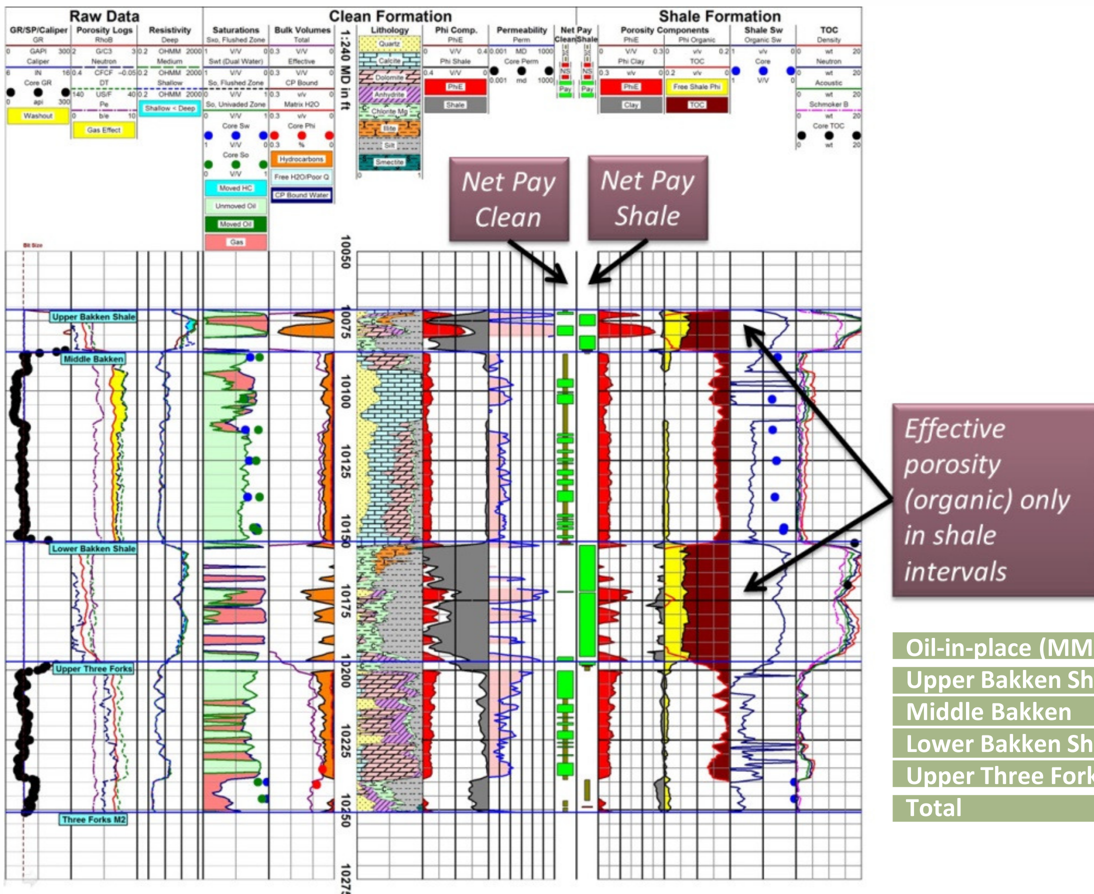




Green lines show a positive slope indicating n > m

m = 1.0 (linear flow paths)
n = 3.5 (oil-wet)

Bakken Oil Reservoir, North Dakota



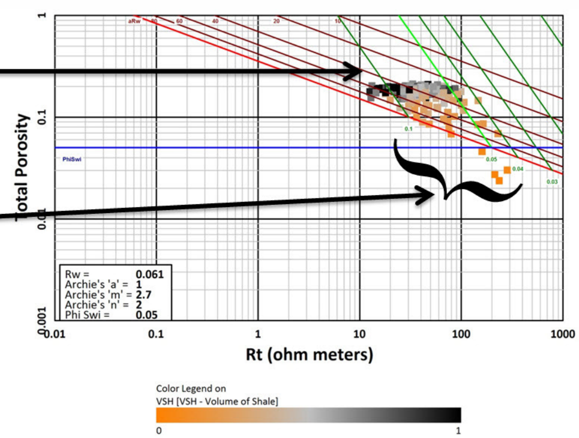
Oil-in-place (MMBO)	Clean	Shale	Ratio Clean : Shale
Upper Bakken Shale	3,573	1,593	2.24
Middle Bakken	3,836	0	-
Lower Bakken Shale	1,065	7,366	0.14
Upper Three Forks	4,706	120	39.2
Total	13,180	9,079	1.45

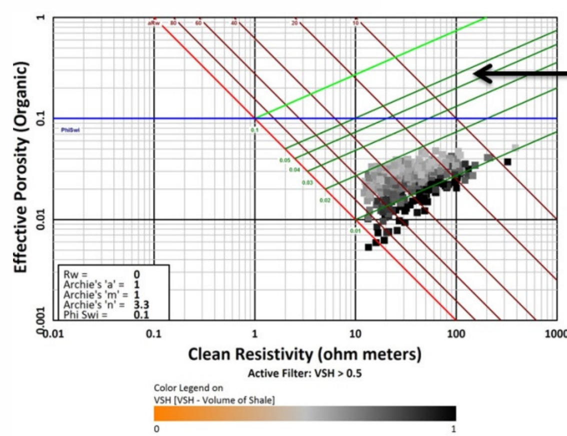
Midland Basin (Wolfcamp) Oil Reservoir, Texas

Green lines show a negative slope indicating n < m

Possible range of Buckles numbers from 0.01 to 0.03 (see also below)

m=2.7
n=2.0 (water-wet)

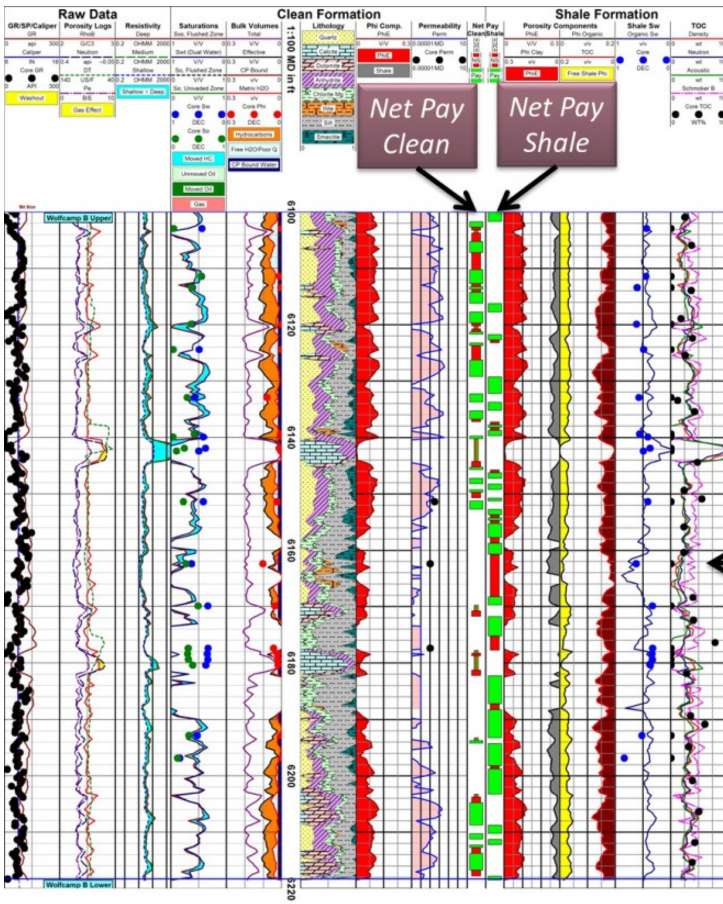




Green lines show a positive slope indicating n > m

m=1.0 (linear flow paths)
n=3.3 (oil-wet)

Midland Basin (Wolfcamp) Oil Reservoir, Texas



Good agreement between core and log TOC

Oil-in-place (MMBO)	Clean	Shale	Ratio Clean : Shale
Wolfcamp B Upper	7,763	18,579	0.29

Conclusions

- Two sets of porosity/resistivity cross plots are constructed:
  - **Standard total porosity vs. resistivity**: This is interpreted to define Archie parameters cementation exponent ‘m’ and saturation exponent ‘n’. From the value of ‘n’ it is possible to determine reservoir wetting. Low values (mostly less than 2) indicate a water-wet system. In the examples presented here, both are water-wet.
  - **Organic porosity vs. resistivity**: All examples show consistently low values of cementation exponent ‘m’, suggesting linear flow paths for this porosity segment. They also show higher values of the saturation exponent ‘n’ (sometimes much higher) than for the clean porosity responses, suggesting an oil-wet condition.

Conclusions

- It is proposed that the organic porosity component is generated during the thermal maturation process, as oil is generated and expelled from the organic material. Consequently, the newly generated pore system will be exposed to oil at inception, and is likely to be oil-wet.
- The very low values of cementation exponent ‘m’ would suggest that as the porosity system is forming, it is accompanied by the creation of linear flow paths.

Conclusions

- As far as we are aware, this is a novel approach and provides quantitative data as to which fraction of the reservoir is water-wet and which is oil-wet.
- Since it can be applied to any well with a triple-combo logging suite, the methodology has widespread application and should provide a much better understanding of reservoir behavior from an engineering viewpoint.
- Further refinement is planned by examining a data set with cores to compare log calculations with core analyses directed to measuring pore wettability.

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