The Integration of Key Petrophysical and Geomechanical Play Drivers into Geological Attribute Mapping:
Getting Ahead of the Stampede*

Larry Brooks¹ and Randy Montalvo¹

Search and Discovery Article #40948 (2012)**
Posted June 11, 2012

*Adapted from oral presentation given at AAPG 2012 Southwest Section Meeting, Ft. Worth, Texas, 19-22 May 2012
**AAPG©2012 Serial rights given by author. For all other rights contact author directly.

¹Nu-Tech Alliance, Humble, TX (LBrooks@nutechenergy.com; Rmontalvo@nutechenergy.com)

Abstract

In unconventional and conventional plays alike, petrophysical attributes such as effective porosity (PHIE), permeability (k), brittleness, volume of clay (VCLAY), total organic carbon (TOC), adsorbed gas/original oil in place (OOIP), and water saturation (Sw) are key parameters that speak to the viability of entering into that play. Using abundantly available public well log data, high quality petrophysical attributes can be produced and subsequently mapped expeditiously. The ability to distribute these parameters in 2D mapping yields valuable insight to new and evolving plays.

In house data may be sparse and the ability for evaluating the play may not be recognized by conventional mapping (i.e. traditional structure, isopach maps, etc.). The power of using public data and proprietary petrophysical analysis gives the geoscientist an enviable suite of maps upon which critical decisions can be made. The final result is an accelerated advancement of learning and evaluation which will save time in the approval process, mobilization, leasing and E&P.
The Integration of Key Petrophysical and Geomechanical Play Drivers into Geologic Attribute Mapping: Getting Ahead of the Stampede

Larry Brooks & Randy Montalvo

NuTech Energy Alliance
The Integration of Key Petrophysical and Geomechanical Play Drivers into Geologic Attribute Mapping: Getting Ahead of the Stampede.

In unconventional and conventional plays alike, petrophysical attributes such as effective porosity (PHIE), permeability (k), brittleness, volume of clay (VCLAY), total organic carbon (TOC), adsorbed gas/original oil in place (OOIP), and water saturation (Sw) are key parameters that speak to the viability of entering into that play. Using abundantly available public well log data, high quality petrophysical attributes can be produced and subsequently mapped expeditiously. The ability to distribute these parameters in 2D mapping yields valuable insight to new and evolving plays.

In house data may be sparse and the ability for evaluating the play may not be recognized by conventional mapping (i.e. traditional structure, isopach maps, etc.). The power of using public data and proprietary petrophysical analysis gives the geoscientist an enviable suite of maps upon which critical decisions can be made. The final result is an accelerated advancement of learning and evaluation which will save time in the approval process, mobilization, leasing and E&P.
What are Some of the Initial Questions Before Entering into a Play?

- “Where do I purchase acreage?”
- “I’ve drilled a well-what zones will produce?”
- “How do I exploit the acreage I hold?”
- “Where are the fluid contacts?”
- “What are the characteristics of the pore size distribution?”
- “What are the reservoir volumes?”
- “Connectivity-how continuous are the reservoirs?”
- “Where are the sweet spots in the field?”
Answer: Integration of Petrophysics with Geologic Attribute Mapping

Where we start

- define project objectives
- data acquisition, screening, prepping

Petrophysical interpretation
- Cross-Sections

Where we end

- Respect for paleogeography
- Distribution of reservoir properties

MIDLAND BASIN

CENTRAL BASIN PLATFORM

OA

WEST TX

Mean Brittleness

Respect for
- data acquisition, screening, prepping

- Petrophysical interpretation
- Cross-Sections
Data Acquisition & Preparation
Define Project Objectives & Data Acquisition

Start with base map & define project objectives*
Define Project Objectives & Data Acquisition

Start with base map & define project objectives*

Proprietary log data provided
Define Project Objectives & Data Acquisition

Proprietary log data provided

Start with base map & define project objectives*

WEST TX

OR
Define Project Objectives & Data Acquisition

Start with base map & define project objectives*

Proprietary log data provided

Acquire public data

- **TGS** (6 M wells worldwide)
- **MJ Systems** (2 M wells)
- **State Databases** (ex: TX Railroad Commission)
- **IHS** (2.5 M wells)
- **International Databases**
Data Screening-Top Generation

Log data is carefully screened by a team of technicians & Petrophysicists.

Geologist evaluate if the zone of interest is present.

Stratigraphic research & top generation by Geologists & Petrophysicists.
Data Preparation
### Depth shifting

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

![Graph showing data patterns](image-url)
Data Preparation

Depth shifting

SP Baseline
Data Preparation

Depth shifting

SP Baseline

Formation Temp Calculation (T)
Data Preparation

Depth shifting

Formation Temp Calculation (T)

SP Baseline

DPHI from RHOB (SS or LS matrix)
Data Preparation

Depth shifting

SP Baseline

Formation Temp Calculation (T)

DPHI from RHOB (SS or LS matrix)

SPHI from ∆T
Data Preparation

Formation Temp Calculation (T)

Depth shifting

SP Baseline

DPHI from RHOB (SS or LS matrix)

SPHI from ΔT

Neutron Matrix Conversions
Data Preparation

SP Baseline

Formation Temp Calculation (T)

Depth shifting

DPHI from RHOB (SS or LS matrix)

SPHI from ∆T

GR correction

Neutron Matrix Conversions

GR_CORR

GR

CALIPER
Data Preparation

Depth shifting

SP Baseline

Formation Temp Calculation ($T$)

$\Delta\phi_L$ from RHOB (SS or LS matrix)

$\phi_L$ from $\Delta T$

Neutron Matrix Conversions

GR correction

GR correction

RT-true resistivity corrections

ILD

RT

GRC

SFL

SP

 SP Baseline

$\phi_L$ from $\Delta T$

Neutron Matrix Conversions
Data Preparation

Depth shifting

Formation Temp Calculation (T)

SP Baseline

DPHI from RHOB (SS or LS matrix)

SPHI from ∆T

Neutron Matrix Conversions

RT-true resistivity corrections

GR correction

Neutron Matrix Conversions

GR CORR

CALIPER
Log data normalization is critical because:

- There are several historical logging companies
- Different vintages of logging tools—even within the same company
- There are differing degrees of calibration of logging tools as well as engineer experience

*before*

*after*
Petrophysics- Derivation of Play Drivers
Petrophysical Interpretation
Petrophysical Interpretation

Asquith & Krygowski, 2004

Arps, 1953

Petrophysical Interpretation

After preparation....

Correction of the Density

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Correction of the Density

VCLAY from several indicators

After preparation....

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

Correction of the Density

After preparation....

VCLAYs fed into proprietary models

VCLAYs from several indicators

*(Arps, 1953) *(Asquith & Krygowski, 2004)*
Petrophysical Interpretation

After preparation....

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

\[ R_w = \frac{R_o \times \phi^m}{\alpha} \]

Rwa calculation

*(Arps, 1953)  *(Asquith & Krygowski, 2004)*
Petrophysical Interpretation

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

\[ R_w = \frac{R_o \times \phi^m}{a} \]  

Rwa calculation

OR

\[ R_w = R_m + 0.131 \times 10^{0.57 \times \text{Poisson Ratio}} \]

\[ R_w = 0.5 \times R_m + 10^{0.57 \times \text{Poisson Ratio}} \]

Rw from SP

*(Arps, 1953)  *(Asquith & Krygowski, 2004)*
**Petrophysical Interpretation**

After preparation...

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

\[ R_w = \frac{R_o \times \phi^m}{a} \]

*Rwa calculation

OR

\[ R_w = R_{a1} + 0.131 \times 10^{\frac{1}{1-(\text{water saturation})}} \]

\[ = 0.5 \times R_{a1} + 10^{\frac{1}{1-(\text{water saturation})}} \]

*Rw from SP

OR

*Rw from DST or FT

*Pickett Plots

*Rw Catalogs

*Local reservoir history

*(Arps, 1953) *(Asquith & Krygowski, 2004)
**Petrophysical Interpretation**

After preparation:

- Correction of the Density
- VCLAY from several indicators
- VCLAYs fed into proprietary models
- Final VCLAY

**Rwa calculation**

\[ R_w = \frac{R_o \times \phi^n}{\alpha} \]

**OR**

\[ R_w = R_o + 0.131 \times 10^{\left(\frac{\text{ohmm} \times \text{m}}{\text{m}}\right)} \]

\[ -0.5 \times R_w + 10^{\left(\frac{\text{ohmm} \times \text{m}}{\text{m}}\right)} \]

**Rw from SP**

*Pickett Plots*
*Rw Catalogs*
*Local reservoir history*

Derive RWG

\[ RWG = R_2 \left( \frac{T_1 + k}{T_2 + k} \right) \]

*\( R_1 = \) Res. of solution @ T1\n*\( k = 6.77 \) when T1 & T2 in F*

*(Arps, 1953) (Asquith & Krygowski, 2004)*
Petrophysical Interpretation

After preparation....

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

Rw calculation OR

*Rw from DST or FT
*Pickett Plots
*Rw Catalogs
*Local reservoir history

\[ R_w = \frac{R_o \times \phi^m}{\alpha} \]

\[ R_w = R_o + 0.131 \times 10^{-0.5 \times \frac{(1000/\rho_o)^{0.5}}{\gamma}} \]

\[ R_w = 0.5 \times R_w + 10^{-0.5 \times \frac{(1000/\rho_o)^{0.5}}{\gamma}} \]

Derive RWG

\[ RWG = R_2 \]

\[ R_1 = \text{Res. of solution @ T1} \]

\[ k = 6.77 \text{ when T1 & T2 in } F^\circ \]

TOC & VKER from custom models calibrated to core, XRD.

*(Arps, 1953) *(Asquith & Krygowski, 2004)
**Petrophysical Interpretation**

\[ R_w = \frac{R_o \times \phi^n}{\alpha} \]

Rwa calculation

**OR**

\[ R_w = R_{to} + 0.131 \times 10^{-\frac{(log(time/100))^2}{10}} - 0.5 \times R_{sw} + 10^{-\frac{(log(100/45))^2}{10}} \]

Rw from SP

*Rw from DST or FT*

*Pickett Plots*

*Rw Catalogs*

*Local reservoir history*

**Derive RWG**

\[ RWG = R_2 \left( \frac{T_1 + k}{T_2 + k} \right) \]

**TOC & VKER from custom models calibrated to core, XRD,**

**Deterministic Lithology models yields:**

VLS, VDOL, VSS, VHVY, PHIE, BVW, Sw

*(Arps, 1953) (Asquith & Krygowski, 2004)*
Petrophysical Interpretation

After preparation....

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

Rw calculation

OR

\[
R_w = R_p \times \phi^n
\]

\[
R_w = R_{w_s} + 0.131 \times 10^{ \left[ \frac{100 \times (\text{water content})}{100 \times \text{water content}} \right]}
\]

OR

*Rw from DST or FT
*Pickett Plots
*Rw Catalogs
*Local reservoir history

Derive RWG

\[
RWG = R_2 \left( \frac{T_1 + k}{T_2 + k} \right)
\]

R1= Res. of solution @ T1
k= 6.77 when T1 & T2 in °F

TOC & VKER from custom models calibrated to core, XRD,

Deterministic Lithology models yields: VLS, VDOL, VSS, VHVT, PHIE, BVW, Sw

Regional, field or formation specific textural models yields: BVI, PERMIABILITY & GRAIN SIZE

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

After preparation....

Correction of the Density

VCLAY from several indicators

VCLAYs fed into proprietary models

Final VCLAY

Rw calculation OR

Rw from SP OR

*Rw from DST or FT
*Pickett Plots
*Rw Catalogs
*Local reservoir history

Derive RWG

\[ \text{RWG} = \frac{R_2}{R_1 + \frac{k}{T_1 + k}} \]

\[ R_w = \frac{R_o \times \phi^m}{\alpha} \]

\[ R_w = R_w + 0.131 \times 10^{-\frac{\text{ln(wwf/vsh)}}{42}} - 0.5 \times R_w + 10^{-\frac{\text{ln(wwf/vsh)}}{42}} \]

TOC & VKER from custom models calibrated to core, XRD,

Deterministic Lithology models yields: VLS, VDOL, VSS, VHVY, PHIE, BVW, Sw

Regional, field or formation specific textural models yields: BVI, PERMIABILITY & GRAIN SIZE

Flags indicate the quality and productivity of zones

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

**Derive RWG**

\[
RWG = \frac{R_1 + k}{T_2 + k}
\]

- \( R_1 \) = Res. of solution @ T1
- \( k = 6.77 \) when T1 & T2 in °F

**Final VCLAY**

\[
R_w = \frac{R_o \times \phi^m}{\alpha}
\]

- \( R_w \) calculation
- OR

- \( R_w = R_o + 0.131 \times 10^{\frac{\text{API(Weight/gal)}}{501}} \)
- \( -0.5 \times R_w + 10^{\frac{\text{API(Weight/gal)}}{501}} \)

- \( R_w \) from SP
- OR

- **TOC & VKER from custom models calibrated to core, XRD,**

- **Regional, field or formation specific textural models yields:**
  - BVI, PERMIABILITY & GRAIN SIZE

**Production matched to models for continuous development**

- Flags indicate the quality and productivity of zones

*(Arps,1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

Correction of the Density

VCLAYs fed into proprietary models

Final VCLAY

After preparation....

Production matched to models for continuous development

Flags indicate the quality and productivity of zones

Regional, field or formation specific textural models yields: BVI, PERMEABILITY & GRAIN SIZE

Derive RWG

Rw calculation

OR

Rw from SP

OR

*Rw from DST or FT
*Pickett Plots
*Rw Catalogs
*Local reservoir history

TOC & VKER from custom models calibrated to core, XRD,

Deterministic Lithology models yields: VLS, VOIOL, VSS, VHV, PHIE, BVW, Sw

*(Arps, 1953) *(Asquith & Krygowski, 2004)
Petrophysical Interpretation

Recap...

- From the petrophysical analysis, the play drivers we derive are: VCLAY, RWG, TOC, VKER, LITHOLOGY, PHIE, BVW, BVI, SW, & PERMIABILITY
Gas in Place/Oil in Place

Calculation of gas in place and oil in place...
Gas in Place/Oil in Place

Establish the relationship between gases adsorbed to solids

*Langmuir’s Equation:

\[ \theta = \frac{K \cdot C}{1 + K \cdot C} \]

\( \theta \) = fractional coverage of the surface
\( C \) = gas pressure concentration
\( K \) = Langmuir adsorption constant

Gas in Place/Oil in Place

Calculation of gas in place and oil in place...

Establish the relationship between gasses adsorbed to solids

Langmuir’s Equation:

\[
\theta = \frac{K \cdot C}{1 + K \cdot C}
\]

\(\theta\) = fractional coverage of the surface
\(C\) = gas pressure concentration
\(K\) = Langmuir adsorption constant

Calculate Original Oil in Place & Original Gas in Place

\[\text{OOIP} = 7758 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot DA\]

\[\text{OGIP} = 43560 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot [(0.43 \cdot \text{depth})/14.7] \cdot DA\]

where:
\(\text{OOIP}\) = original oil-in-place
\(\text{OGIP}\) = original gas-in-place
\(\Phi\) = porosity
\(h\) = reservoir thickness
\(DA\) = drainage area
\(\text{depth}\) = depth of reservoir
7758 = barrels of oil in an acre-foot
43560 = cubic feet of gas in an acre-foot
0.43 = pressure gradient [normal]
**Gas in Place/Oil in Place**

**Calculation of gas in place and oil in place...**

**Establish the relationship between gasses adsorbed to solids**

*Langmuir’s Equation:*

\[ \theta = \frac{K \cdot C}{1 + K \cdot C} \]

\( \theta \) = fractional coverage of the surface  
\( C \) = gas pressure concentration  
\( K \) = Langmuir adsorption constant

**Calculate Original Oil in Place & Original Gas in Place**

\[ \text{OOIP} = 7758 \cdot \Phi \cdot (1.0 - \text{Sw}) \cdot h \cdot DA \]

\[ \text{OGIP} = 43560 \cdot \Phi \cdot (1.0 - \text{Sw}) \cdot h \cdot \left[ (0.43 \cdot \text{depth}) / 14.7 \right] \cdot DA \]

**where:**

- OOIP = original oil-in-place  
- OGIP = original gas-in-place  
- \( \Phi \) = porosity  
- \( h \) = reservoir thickness  
- DA = drainage area  
- depth = depth of reservoir  
- 7758 = barrels of oil in an acre-foot  
- 43560 = cubic feet of gas in an acre-foot  
- 0.43 = pressure gradient [normal]

Gas in Place/Oil in Place

**Calculation of gas in place and oil in place...**

**Establish the relationship between gasses adsorbed to solids**

**Langmuir’s Equation:**

\[ \theta = \frac{K \times C}{1 + K \times C} \]

\( \theta \) = fractional coverage of the surface  
\( C \) = gas pressure concentration  
\( K \) = Langmuir adsorption constant

**Lower 48 States Shale Plays**

**Inputs entered into basin specific models**

*Vertical wells only

**Calculate Original Oil in Place & Original Gas in Place**

\[ \text{OOIP} = 7758 \times \Phi \times (1.0 - Sw) \times h \times DA \]

\[ \text{OGIP} = 43560 \times \Phi \times (1.0 - Sw) \times h \times \left[ \frac{(0.43 \times \text{depth})}{14.7} \right] \times DA \]

where:

- \( \text{OOIP} \) = original oil-in-place  
- \( \text{OGIP} \) = original gas-in-place  
- \( \Phi \) = porosity  
- \( h \) = reservoir thickness  
- \( DA \) = drainage area  
- depth = depth of reservoir  
- 7758 = barrels of oil in an acre-foot  
- 43560 = cubic feet of gas in an acre-foot  
- 0.43 = pressure gradient [normal]

Gas in Place/Oil in Place

Establish the relationship between gasses adsorbed to solids

Langmuir’s Equation:

\[ \theta = \frac{K \cdot C}{1 + K \cdot C} \]

- \( \theta \): fractional coverage of the surface
- \( C \): gas pressure concentration
- \( K \): Langmuir adsorption constant

Yields

Lower 48 States Shale Plays

Inputs entered into basin specific models

*Vertical wells only

Calculate Original Oil in Place & Original Gas in Place

\[ \text{OOIP} = 7758 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot DA \]

\[ \text{OGIP} = 43560 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot \left( \frac{(0.43 \cdot \text{depth})}{14.7} \right) \cdot DA \]

where:
- \( \text{OOIP} \): original oil-in-place
- \( \text{OGIP} \): original gas-in-place
- \( \Phi \): porosity
- \( h \): reservoir thickness
- \( DA \): drainage area
- \( \text{depth} \): depth of reservoir
- 7758 = barrels of oil in an acre-foot
- 43560 = cubic feet of gas in an acre-foot
- 0.43 = pressure gradient [normal]

Calculation of gas in place and oil in place...

**Establish the relationship between gasses adsorbed to solids**

**Langmuir’s Equation:**

\[ \theta = \frac{K \cdot C}{1 + K \cdot C} \]

- \( \theta \): fractional coverage of the surface
- \( C \): gas pressure concentration
- \( K \): Langmuir adsorption constant

*Establish the relationship between gasses adsorbed to solids*

*Yields*

**Inputs entered into basin specific models**

*Vertical wells only*

**Calculate Original Oil in Place & Original Gas in Place**

- OOIP = \( 7758 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot DA \)
- OGIP = \( 43560 \cdot \Phi \cdot (1.0 - Sw) \cdot h \cdot \left[(0.43 \times \text{depth})/14.7\right] \times DA \)

where:

- OOIP = original oil-in-place
- OGIP = original gas-in-place
- \( \Phi \) = porosity
- \( h \) = reservoir thickness
- DA = drainage area
- depth = depth of reservoir
- 7758 = barrels of oil in an acre-foot
- 43560 = cubic feet of gas in an acre-foot
- 0.43 = pressure gradient [normal]

*Yields*

Finally, derivation of some final Petrophysical play drivers.....
Play Drivers from Engineering Summary

Finally, derivation of some final Petrophysical play drivers....

<table>
<thead>
<tr>
<th>DEPTH FT</th>
<th>CROSSTMT</th>
<th>PHIT</th>
<th>RANK</th>
<th>DAV</th>
<th>PVNE</th>
<th>2V</th>
<th>PERMISHMT</th>
<th>PERMISOFT</th>
<th>TOC</th>
<th>QEC</th>
<th>MMDD</th>
<th>OFF</th>
<th>123</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.37</td>
<td>0.059</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.9508</td>
<td>3.94</td>
<td>0.042</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.36</td>
<td>0.052</td>
<td>0.32</td>
<td>0.0012</td>
<td>0.846</td>
<td>52.952</td>
<td>3.24</td>
<td>0.018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.37</td>
<td>0.059</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>9.255</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.35</td>
<td>0.052</td>
<td>0.63</td>
<td>0.002</td>
<td>0.846</td>
<td>52.952</td>
<td>1.00</td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.35</td>
<td>0.052</td>
<td>0.63</td>
<td>0.002</td>
<td>0.846</td>
<td>52.952</td>
<td>0.32</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.33</td>
<td>0.052</td>
<td>0.63</td>
<td>0.002</td>
<td>0.846</td>
<td>52.952</td>
<td>0.32</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.33</td>
<td>0.052</td>
<td>0.63</td>
<td>0.002</td>
<td>0.846</td>
<td>52.952</td>
<td>0.32</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.33</td>
<td>0.052</td>
<td>0.63</td>
<td>0.002</td>
<td>0.846</td>
<td>52.952</td>
<td>0.32</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.054</td>
<td>0.61</td>
<td>0.0009</td>
<td>0.846</td>
<td>52.952</td>
<td>0.43</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cumulative permeability over specific formation
### Play Drivers from Engineering Summary

Finally, derivation of some final Petrophysical play drivers.

<table>
<thead>
<tr>
<th>DEPTH FT</th>
<th>CROSST RT PAYFT</th>
<th>RANK</th>
<th>CLAY</th>
<th>PHIE</th>
<th>SW</th>
<th>PERMSH</th>
<th>HydPorFT</th>
<th>PERMSHT</th>
<th>TOC</th>
<th>OIP</th>
<th>MMBO/Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>DEC</td>
<td>DEC</td>
<td>DEC</td>
<td>uD</td>
<td>POR-FT</td>
<td>uD-FT</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

**Cumulative permeability over specific formation**

**Total cumulative hydrocarbon porosity-feet (kh) over specific formation**

**Total cumulative permeability-feet (kh) over specific formation**

---

### Zone Summaries

<table>
<thead>
<tr>
<th>DEPTH FT</th>
<th>GROSS FT PAYFT</th>
<th>RANK</th>
<th>CLAY</th>
<th>PHIE</th>
<th>SW</th>
<th>PERMSH</th>
<th>HydPorFT</th>
<th>PERMSHT</th>
<th>TOC</th>
<th>OIP</th>
<th>MMBO/Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>DEC</td>
<td>DEC</td>
<td>DEC</td>
<td>uD</td>
<td>POR-FT</td>
<td>uD-FT</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>formation 1</td>
<td>139</td>
<td>94</td>
<td>2.5</td>
<td>0.336</td>
<td>0.073</td>
<td>0.585</td>
<td>0.407</td>
<td>4.526</td>
<td>56.5355</td>
<td>2.210</td>
<td>17.287</td>
</tr>
<tr>
<td>formation 2</td>
<td>517</td>
<td>254</td>
<td>2.7</td>
<td>0.262</td>
<td>0.068</td>
<td>0.658</td>
<td>0.273</td>
<td>13.225</td>
<td>140.9915</td>
<td>1.848</td>
<td>50.508</td>
</tr>
<tr>
<td>formation 3</td>
<td>877</td>
<td>317</td>
<td>2.7</td>
<td>0.232</td>
<td>0.053</td>
<td>0.692</td>
<td>0.188</td>
<td>16.269</td>
<td>164.892</td>
<td>1.963</td>
<td>62.138</td>
</tr>
<tr>
<td>formation 4</td>
<td>1860</td>
<td>1324</td>
<td>2.2</td>
<td>0.216</td>
<td>0.070</td>
<td>0.437</td>
<td>1.018</td>
<td>82.876</td>
<td>1893.452</td>
<td>2.253</td>
<td>316.536</td>
</tr>
<tr>
<td>formation 5</td>
<td>362</td>
<td>195</td>
<td>2.8</td>
<td>0.314</td>
<td>0.068</td>
<td>0.615</td>
<td>0.163</td>
<td>11.046</td>
<td>59.1641</td>
<td>0.712</td>
<td>42.188</td>
</tr>
</tbody>
</table>

**TOT**          | **TOT**        | **AVGX** | **AVGX** | **AVGX** | **AVGX** | **AVGX** | **AVGX** | **AVGX** | **AVGX** | **AVGX** |

---

*Note: The table provides detailed petrophysical data for various zones, including depth, gross pay, rank, clay, phie, sw, permeability, hydrocarbon porosity, total organic carbon, and original oil in place (OIP) in million barrels per acre foot (MMBO/Sec).*

*Image Source: NuTech Energy Alliance*
Next, the petrophysical solutions drive the GeoTextural log properties...

*(Davis & Reynolds, 1996)*
GeoTextural Play Drivers: Brittlness & Competency

Next, the petrophysical solutions drive the GeoTextural log properties...

* (Davis & Reynolds, 1996)

Delta-T Compressional & Delta-T Shear wave modeled if not acquired
Next, the petrophysical solutions drive the GeoTextural log properties...

Next, the petrophysical solutions drive the GeoTextural log properties...

GeoTextural Play Drivers: Brittleness & Competency

* \[ E = \frac{\Delta \sigma}{\Delta \varepsilon} \]

* \[ \sigma = \text{Axial stress} \]

* \[ \varepsilon = \text{Axial strain} \]

Young's Modulus

* \[ v = \frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{axial}}} \]

Poisson's Ratio

Derivation of elastic properties

Delta-T Compressional & Delta-T Shear wave modeled if not acquired

*(Davis & Reynolds, 1996)*
Next, the petrophysical solutions drive the GeoTextural log properties...

\[ E = \frac{\Delta \sigma}{\Delta \varepsilon} \]

Young's Modulus

\[ \nu = \frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{axial}}} \]

Poisson's Ratio

Delta-T Compressional & Delta-T Shear wave modeled if not acquired

Derivation of elastic properties

\[ \text{In-situ stress indicates the minimum least principle stress of the formation} \]

\[ \text{Closure stress gradient} \]

*Validated & calibrated to injection tests & fracture treatments

*(Davis & Reynolds, 1996)
Next, the petrophysical solutions drive the GeoTextural log properties...

**GeoTextural Play Drivers: Brittleness & Competency**

Young's Modulus:

\[ E = \frac{\Delta \sigma}{\Delta \varepsilon} \]

where:
- \( \sigma \) = Axial stress
- \( \varepsilon \) = Axial strain

Poisson's Ratio:

\[ \nu = \frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{axial}}} \]

Derivation of elastic properties:

- Delta-T Compressional & Delta-T Shear wave modeled if not acquired

In-situ stress indicates the minimum least principle stress of the formation.

Closure stress gradient.

Brittleness coefficient (%): *Validated & calibrated to injection tests & fracture treatments

*(Davis & Reynolds, 1996)*
GeoTextural Play Drivers: Brittleness & Competency

Next, the petrophysical solutions drive the GeoTextural log properties... 

**E = \frac{\Delta \sigma}{\Delta \varepsilon}**

*Young’s Modulus*

* \sigma = Axial stress  
* \varepsilon = Axial strain

**V = \frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{axial}}}**

*Poisson’s Ratio*

Derivation of elastic properties

In-situ stress indicates the minimum least principle stress of the formation

Closure stress gradient

Brittleness coefficient (%)

Compatability = E / stress

*In terms of mechanical strength, the resistance to either erosion or deformation.*

*Validated & calibrated to injection tests & fracture treatments

*(Davis & Reynolds, 1996)*
GeoTextural Interpretation

Recap...

- The petrophysical analysis drives the GeoTextural results and the play drivers we derive are: Brittleness & Competency
Recap...

- The petrophysical analysis drives the GeoTextural results and the play drivers we derive are: Brittleness & Competency
GeoTextural Interpretation

Recap...

- The petrophysical analysis drives the GeoTextural results and the play drivers we derive are: **Brittleness & Competency**
Geologic Attribute Mapping
Data Collection & Conditioning
Data Collection & Conditioning

Petrophysical drivers collected

Geomechanical properties collected

Listing of data
Data Collection & Conditioning

Petrophysical drivers collected

Geomechanical properties collected

Petrophysical play drivers are further conditioned into mappable attributes (EX: accumulations, net cutoffs & averages)

Listing of data

<table>
<thead>
<tr>
<th>Zone</th>
<th>Summary</th>
<th>DEPTH FT</th>
<th>RDCDF</th>
<th>PAYFT</th>
<th>RANK</th>
<th>CLAY</th>
<th>PORE</th>
<th>SW</th>
<th>PERM</th>
<th>RHOF</th>
<th>TOC</th>
<th>CIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOLFCAMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>formation 1</td>
<td></td>
<td>133</td>
<td>36</td>
<td>0.033</td>
<td>0.073</td>
<td>0.568</td>
<td>0.040</td>
<td>0.457</td>
<td>4.578</td>
<td>56.5355</td>
<td>2.10</td>
<td>17.247</td>
</tr>
<tr>
<td>formation 2</td>
<td></td>
<td>547</td>
<td>254</td>
<td>2.7</td>
<td>0.262</td>
<td>0.131</td>
<td>0.058</td>
<td>0.009</td>
<td>53.305</td>
<td>148.5915</td>
<td>1949</td>
<td>52.506</td>
</tr>
<tr>
<td>formation 3</td>
<td></td>
<td>177</td>
<td>177</td>
<td>2.7</td>
<td>0.002</td>
<td>0.035</td>
<td>0.532</td>
<td>0.100</td>
<td>76.203</td>
<td>194.092</td>
<td>1903</td>
<td>62.109</td>
</tr>
<tr>
<td>formation 4</td>
<td></td>
<td>1600</td>
<td>1324</td>
<td>2.2</td>
<td>0.270</td>
<td>0.070</td>
<td>0.952</td>
<td>0.016</td>
<td>62.076</td>
<td>1893.452</td>
<td>2.253</td>
<td>376.530</td>
</tr>
<tr>
<td>formation 5</td>
<td></td>
<td>302</td>
<td>105</td>
<td>2.3</td>
<td>0.032</td>
<td>0.080</td>
<td>0.012</td>
<td>0.103</td>
<td>11.046</td>
<td>53.9141</td>
<td>0.755</td>
<td>47.189</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOT</th>
<th>TOT</th>
<th>AVGX</th>
<th>AVGX</th>
<th>AVGX</th>
<th>AVGX</th>
<th>CUM</th>
<th>CUM</th>
<th>AVGX</th>
<th>CUM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data Collection & Conditioning

Petrophysical drivers collected

Petrophysical play drivers are further conditioned into mappable attributes (EX: accumulations, net cutoffs & averages)

Geomechanical properties collected

FINAL MAPPABLE ATTRIBUTES:

- Net PHIE-ft (> 7.5%)
- Net Permeability-ft (> 100 uD-ft)
- Mean Brittleness (dimensionless)
- Mean VCLAY (%)
- Net TOC (%) (> 2%)
- Summation of OIP (MMBO/SEC)

Listing of data
Cross-Sections
Cross-Sections

Revisiting the original base map, cross-sections are developed that will give us an inference of the strike and dip of the study area.
Cross-Sections

Revisiting the original base map, cross-sections are developed that will give us an inference of the strike and dip of the study area.

Cross-sections are generated along strike and dip from the petrophysical interpretations.

Lubbock

Crosby

Dip 1

Stk 1

Stk 2

Dip 1

Stk 1' Dstk 2'
Research & Respect for the Paleogeography

*(Modified from Dutton et al., 2005) *(Modified from Blakey, 2011)
Research & Respect for the Paleogeography

Extensive research helps to define basin outlines, structural features, depositional systems, and facies changes.

* (Modified from Dutton et al., 2005) * (Modified from Blakey, 2011)
Research & Respect for the Paleogeography

**Permian Basin**

Extensive research helps to define basin outlines, structural features, depositional systems, and facies changes.

Respect for the paleogeography helps to drive the contoured attribute maps of the study area.

*Modified from Dutton et al., 2005*  *Modified from Blakey, 2011*
Finally...
MAPPING

- Final mappable attributes are distributed over the study area.
- Contoured maps are generated in accordance with basin structure, facies relationships, depositional systems and paleogeography.
Finally...

- Final mappable attributes are distributed over the study area.
- Contoured maps are generated in accordance with basin structure, facies relationships, depositional systems and paleogeography.
• Evaluating the final maps of the study area answers our initial questions before entering into the play.
Evaluating the final maps of the study area answers our initial questions before entering into the play.
A proper methodology is crucial to gathering petrophysical attributes that can be mapped with respect to the paleogeography and depositional systems. Employing this methodology can allow for an advanced “reconnaissance” of an area and help to answer some initial questions before entering into a play.

Typical data sets are sparse on petrophysical and geomechanical (textural) data. The ability to utilize public data systems and apply petrophysical processing can significantly decrease the time expended on in-house petrophysics. Utilizing public data systems also greatly expands the interpretation and confidence of any given play.

With the integration of petrophysics and attribute mapping, one can evaluate large areas for play viability, understand the regional aspect of the unconventional play and delineate the smaller conventional anomaly. Mapping the petrophysical attributes gained from region specific models gives the geoscientist conceptual proof and delivers an enhanced data set within the area of interest.

The ability for an experienced team to integrate petrophysics with geologic attribute mapping can justify the economic aspects of play analysis. The ability to execute this process expeditiously will lead to successful leasing of acreage ahead of the stampede.
References


George Asquith, Geology 5325: Petrophysics. Lubbock, TX: Texas Tech University, Fall 2005


Halliburton, Log Interpretation Charts, GEN-5: Resistivity-Salinity-Temperature Conversions of NaCl Solutions.

http://www.eia.gov/pub/othr_gas/analysa_publications/maps/maps.htm


Ron Blakey, “Paleogeographic Images of North America”, Northern Arizona University,
http://www.personal.umich.edu/~sperrin/geo/paleogeo.html


http://www.tgs.com/ContentBlock.aspx?id=2374