Quick-Look Technique for Quantifying Shale Distribution Types using Total Porosity versus Shale Volume Crossplots

James J. Willis[1,2], Duncan S. McIntosh, Jr.[3], Jesse W. Zwennes[2], and Gregory J. Ferguson[2]

[1]Odyssey International, LLC, 7190–C Cemetery Hwy., St. Martinville, Louisiana 70582

[2]School of Geosciences, University of Louisiana at Lafayette, Hamilton Hall, Rm. 323, 611 McKinley St., Lafayette, Louisiana 70503

[3]Formerly at University of Louisiana at Lafayette; currently at 5236 Perrier St., New Orleans, Louisiana 70115

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EXTENDED ABSTRACT

Shale distribution in a sandstone reservoir can be broadly described in terms of three components: shale laminations interlayered within the overall sandstone interval, dispersed shale within the overall sandstone pore network, and structural shale comprised of sand-sized particles of shale composition (e.g., Thomas and Stieber, 1975; Juhasz, 1986) (Fig. 1). Total porosity versus shale volume crossplots offer a tool for quantifying shale distribution components (Fig. 2). We expand upon previous work by describing a full three-component equation of total porosity based on the individual partial porosity contributions of each potential component—we plan to publish the full mathematical derivations in a separate publication and instead show here graphical representations of analysis. Due primarily to limitations of traditional triple-combination log data, previous studies focused on two-component models (either laminar-dispersed [Fig. 3] or laminar-structural [Fig. 4]), assuming the third component is entirely absent, and we ourselves describe an additional two-component model (dispersed-structural) [Fig. 5], which appears to be an especially relevant model in the cleanest reservoirs. Because the dispersed shale component plays a critical role in calculating effective sandstone porosity, a crucial parametric of reservoir quality, we considered the influence on dispersed shale volumetric calculations from two-component models when considering the potential presence of all three components in a reservoir sandstone. Importantly, we found that considering the potential occurrence of the third component in the previous dispersed-laminar or structural-laminar models resulted in an increase in the calculated dispersed shale volume (Figs. 6–8). Thus, previous studies, especially focused on the dispersed-laminar model, likely underestimated dispersed shale volume and therefore overestimated effective sandstone porosity—an optimistic rather than conservative result (Fig. 9). Rather, our methodology constrains the actual range in dispersed shale volume and thus the range in effective porosity when using triple-combination log data. Additional datasets (e.g., 3D resistivity, core, image logs, etc.) can help more fully quanti-

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Odyssey International, LLC
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Duncan S. McIntosh, Jr.
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Gregory J. Ferguson
University of Louisiana at Lafayette

Overview

- INTRODUCTION
- PREVIOUS METHODOLOGY
- PROPOSED METHODOLOGY
- APPLICATION OF PROPOSED METHODOLOGY
- FUTURE RECOMMENDATIONS
- CONCLUSIONS

- Shale Distribution Types

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- **CONCLUSIONS**

- Total Porosity versus Shale Volume Distribution Models
- Did not consider Dispersed-Structural Model, or Three-Type Distribution Model

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- Dispersed-Structural Model
- Three-Type Distribution Model

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- Case Studies

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- **CONCLUSIONS**

- ϕ_D vs. ϕ_N and $\phi_{effective}$ vs. Vsh Models
- Alternative Techniques

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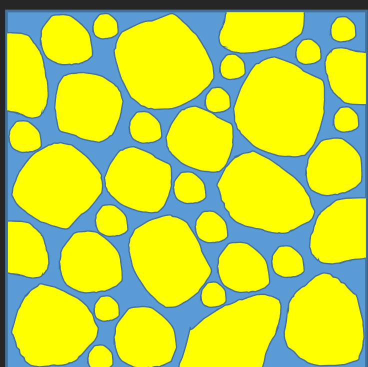
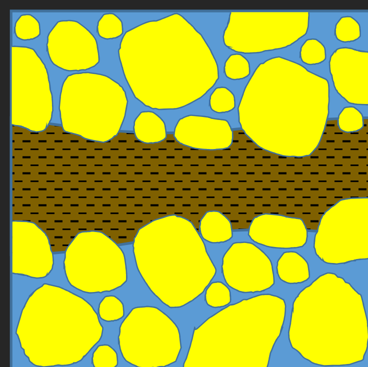
- CONCLUSIONS

- We believe the previous methodologies are flawed.
- These 2 type distribution models may not fully describe the system, and represent the most optimistic scenario in terms of reservoir quality

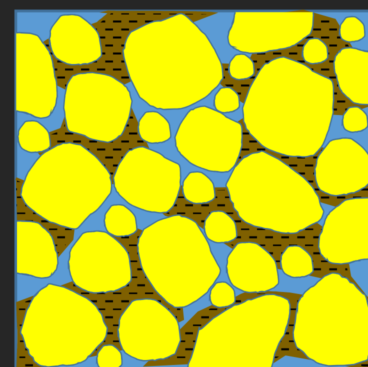
Shale Distribution Types



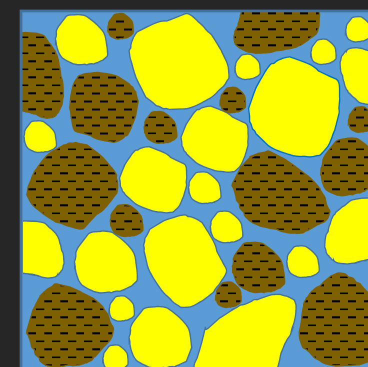
Clean Sandstone



Laminar Shale

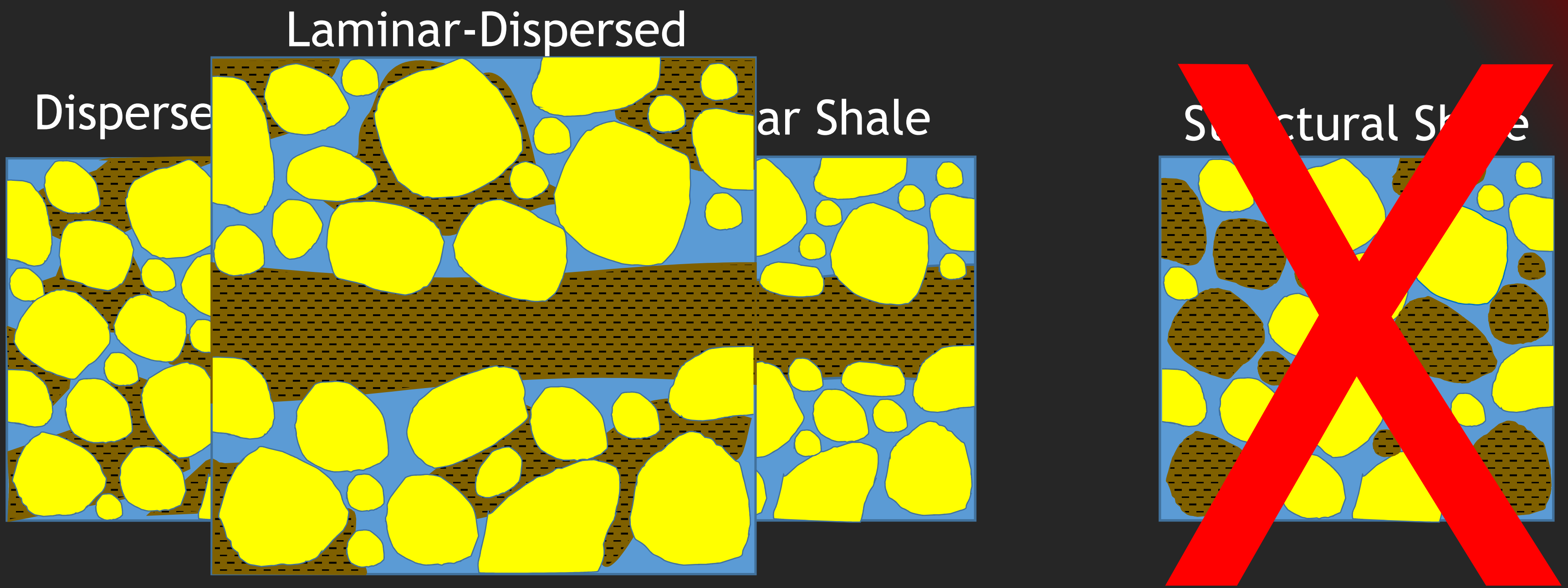


Dispersed Shale



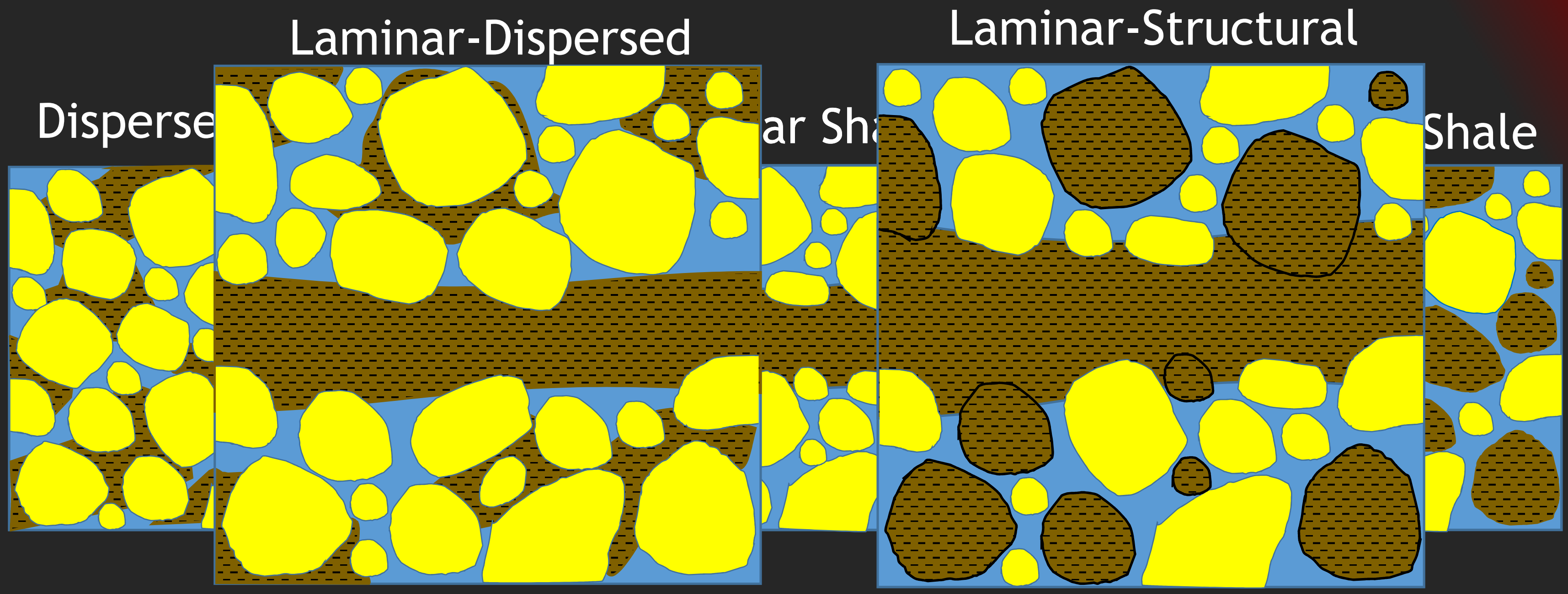
Structural Shale

Thomas & Stieber (1975)



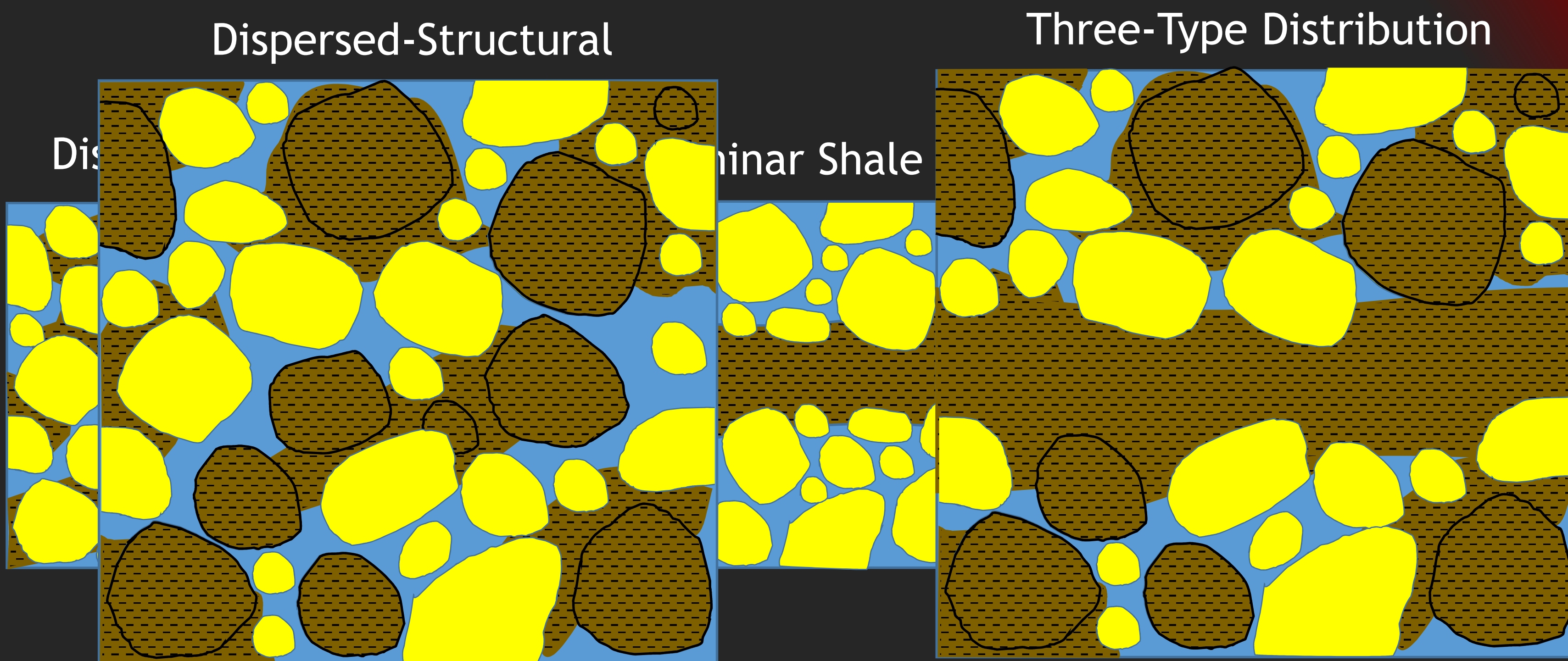
- Thomas and Stieber (1975) introduced the concept of shale distribution within a sand as dispersed, laminar, and structural, or any combination of the three.
- Simplified the quantification by assuming the amount of structural shale is too small to be significant, therefore ignoring it all together

Juhasz (1986)



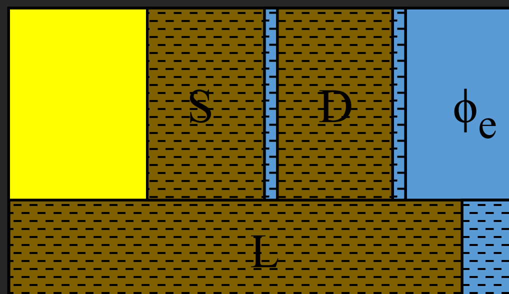
- Juhasz (1986) built upon the work of Thomas and Steiber (1975) and acknowledged the potential implications of structural shale.
- Expanded methodology to include mixture of laminar and structural shale

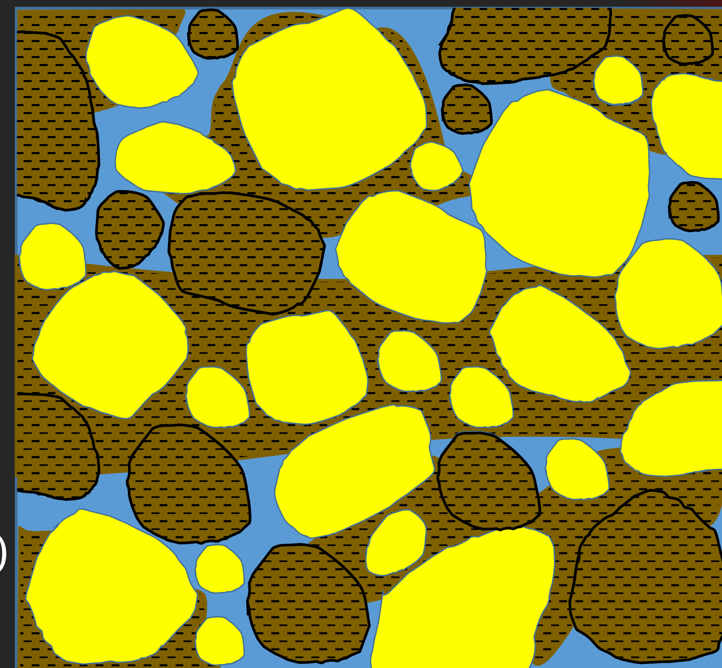
Proposed Methodology



- Previous deterministic methodologies did not consider the possibility of a Dispersed-Structural Distribution, or a Three-Type Distribution.
- Aquino-López et al. (2016) used a parametric inversion process with three homogenization levels to constrain the three distribution types—homogenization level 1 is the pore space that contains fluids and dispersed shale, level 2 is the sandstone that contains quartz and structural shale grains, and level 3 is the formation that contains sand and shale laminations.

Effect of Shale Distribution on Total Porosity





$Vsh_{total} = 0$

$\phi_{total} = \phi_{ss_{clean}}$

$Vsh_{total} = Vsh_{laminar}$

$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh_L})$

$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed}$

$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh_L}) - Vsh_D + (Vsh_D * \phi_{sh_D})$

$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed} + Vsh_{structural}$

$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh_L}) - Vsh_D + (Vsh_D * \phi_{sh_D}) + (Vsh_S * \phi_{sh_S})$

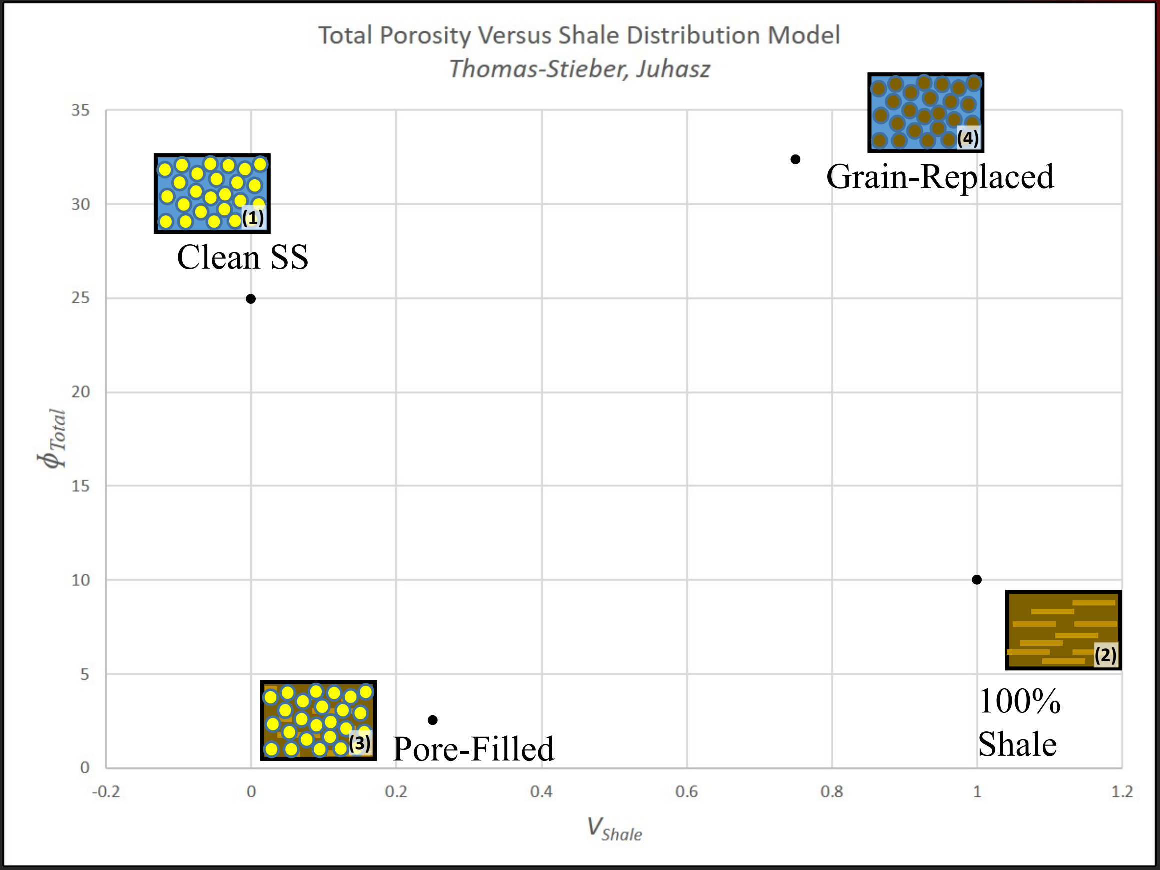
Total Porosity vs. Shale Volume Crossplot

1) Maximum Porosity in and Shale Free Matrix
   - $\phi_{total} = \phi_{ss_{clean}}$
   - Vsh= 0%

2) 100% Shale (No Matrix)
   - $\phi_{total} = \phi_{shale}$
   - Vsh = 100%

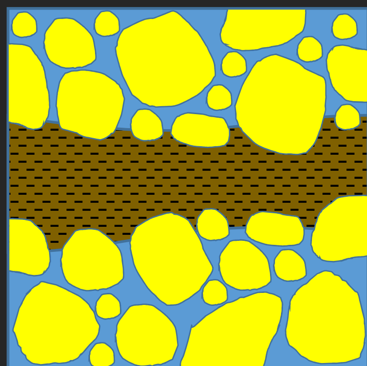
3) Matrix porosity occupied completely by Dispersed Shale
   - $\phi_{total} = \phi_{ss_{clean}} * \phi_{shale}$
   - $Vsh = \phi_{ss_{clean}}$

4) Matrix composed entirely of Structural Shale
   - $\phi_{total} = \phi_{ss_{clean}} + (V_{shale} * \phi_{shale})$
   - $Vsh = 1 - \phi_{ss_{clean}}$



Single-Type Distribution

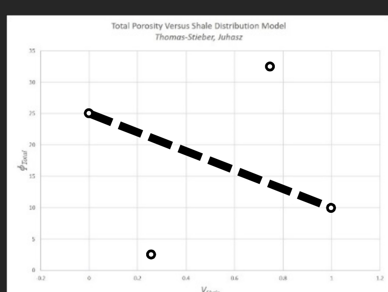
Laminar Shale



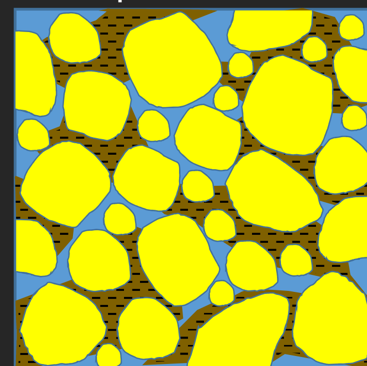
$$Vsh_{total} = Vsh_{laminar}$$

$$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh_L})$$

$$Vsh_L = \frac{\phi_{ss_{clean}} - \phi_{total}}{\phi_{ss_{clean}} - \phi_{sh}}$$



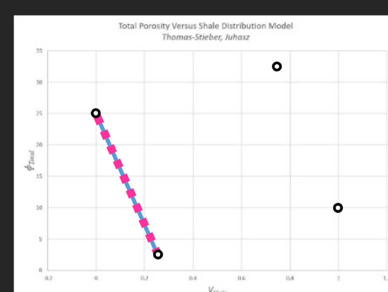
Dispersed Shale



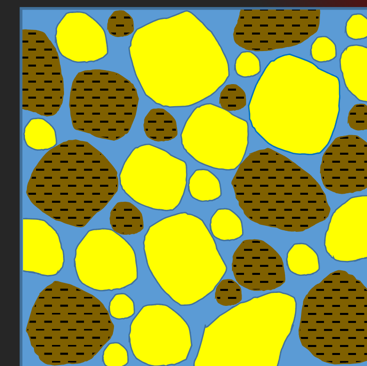
$$Vsh_{total} = Vsh_{dispersed}$$

$$\phi_{total} = \phi_{ss_{clean}} - Vsh_D + (Vsh_D * \phi_{sh_D})$$

$$Vsh_D = \frac{\phi_{ss_{clean}} - \phi_{total}}{1 - \phi_{sh}}$$



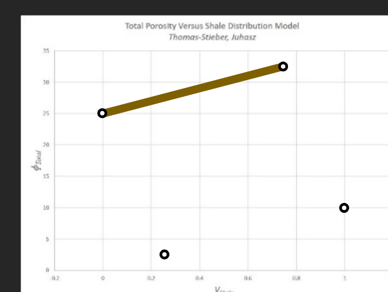
Structural Shale



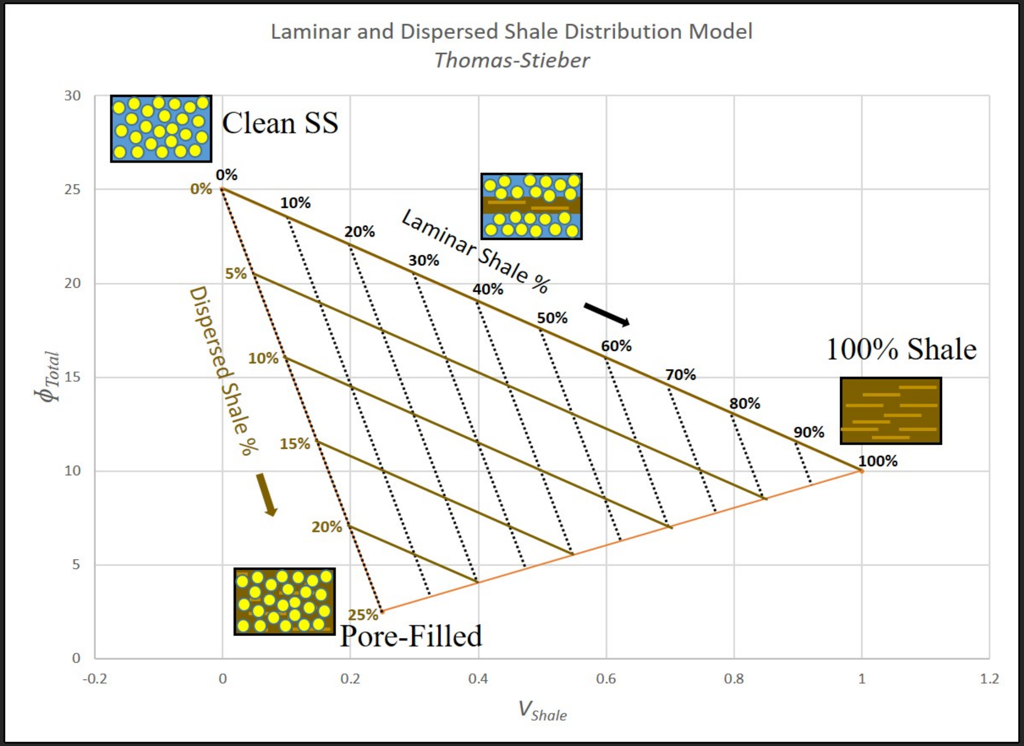
$$Vsh_{total} = Vsh_{structural}$$

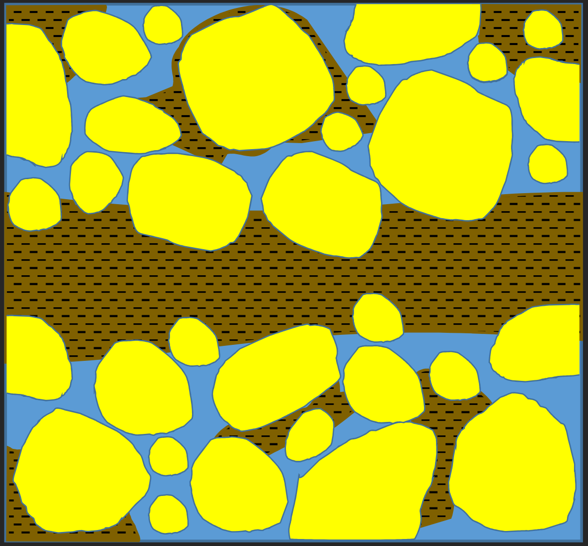
$$\phi_{total} = \phi_{ss_{clean}} + (Vsh_S * \phi_{sh_S})$$

$$Vsh_S = \frac{\phi_{total} - \phi_{ss_{clean}}}{\phi_{sh}}$$



2-Type Distribution Models





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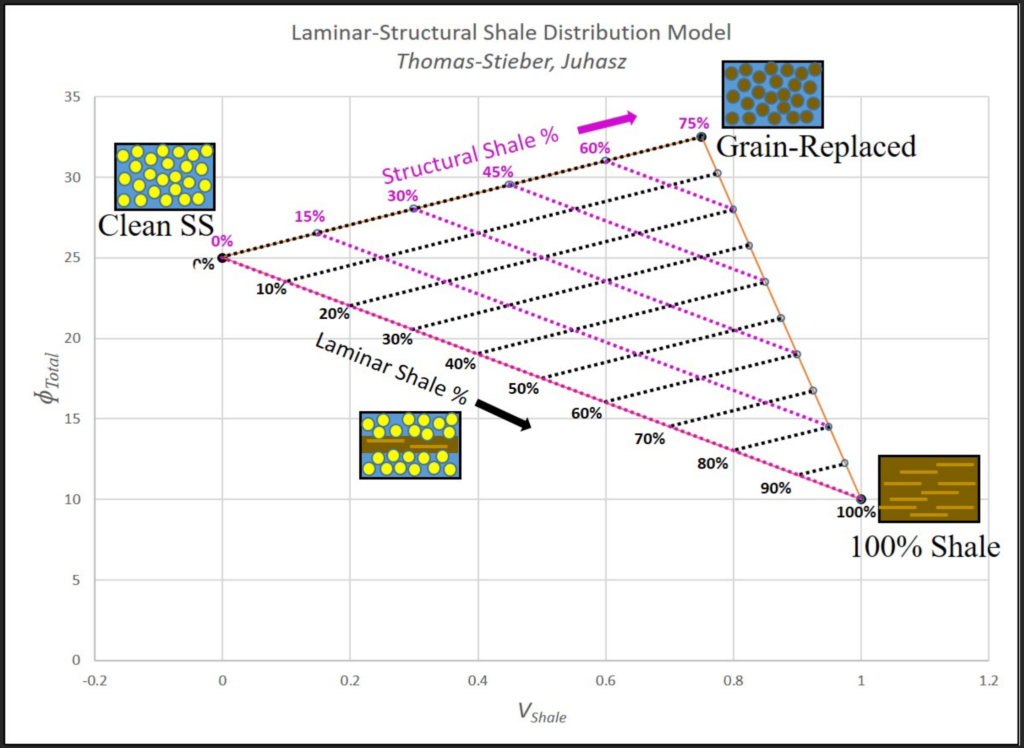

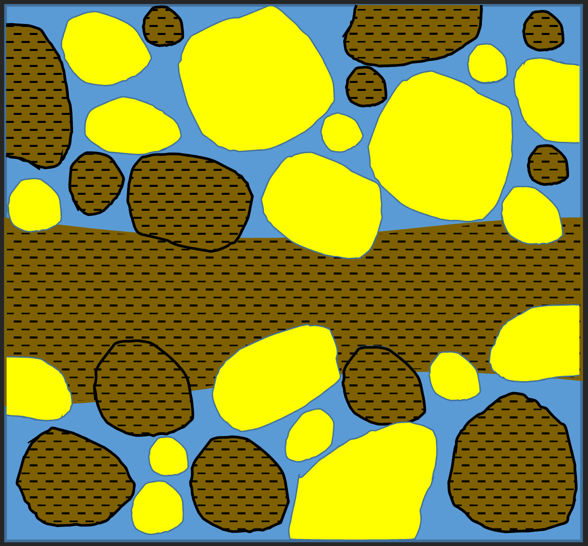

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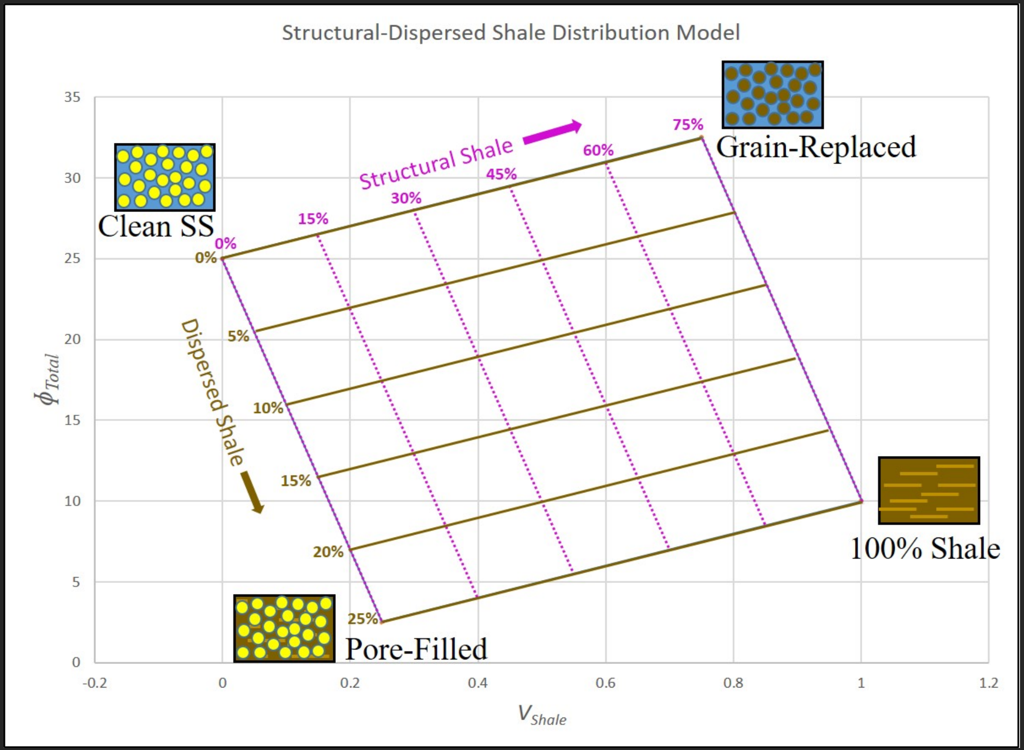

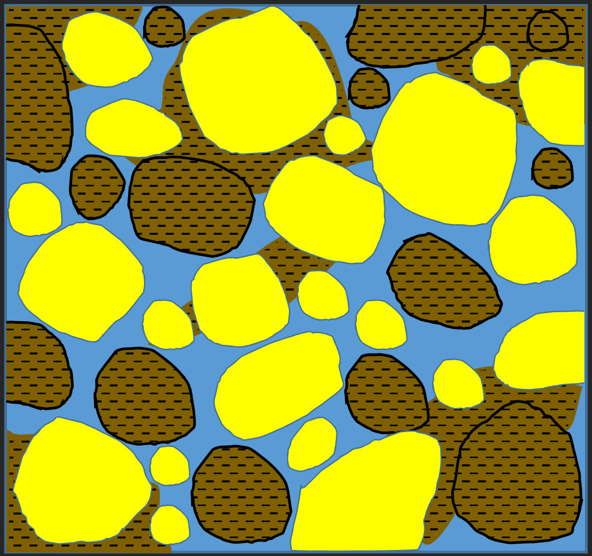

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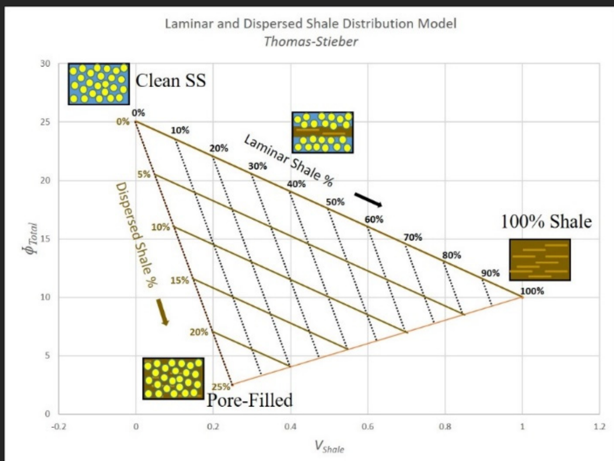
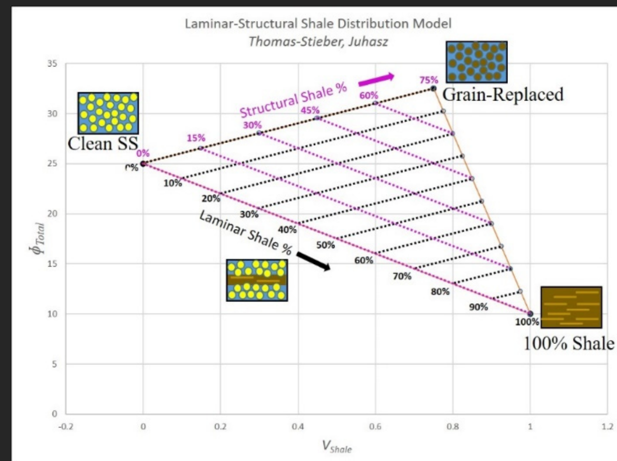
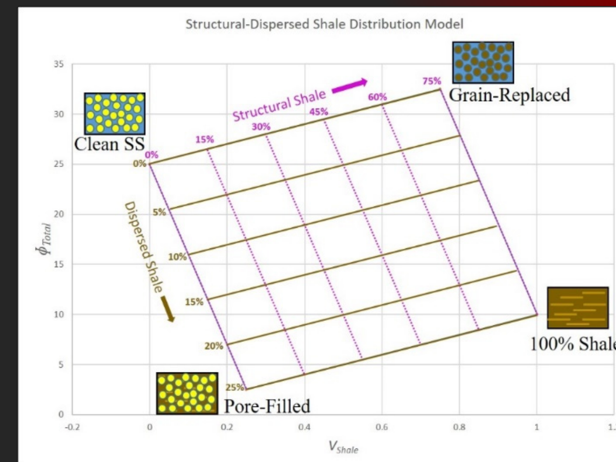


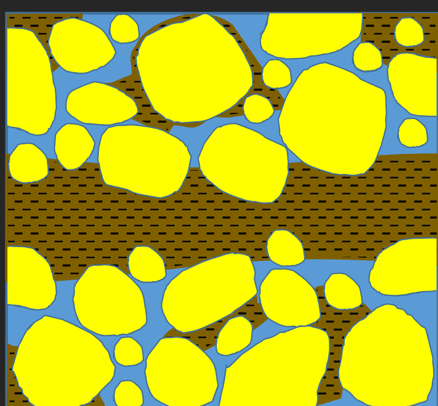


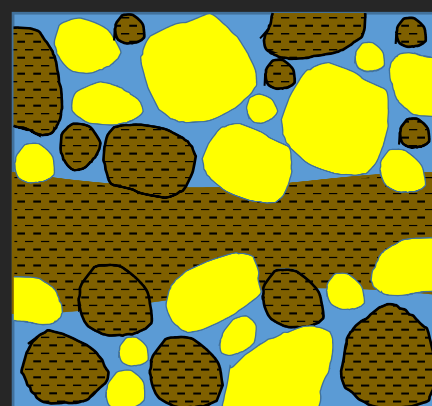


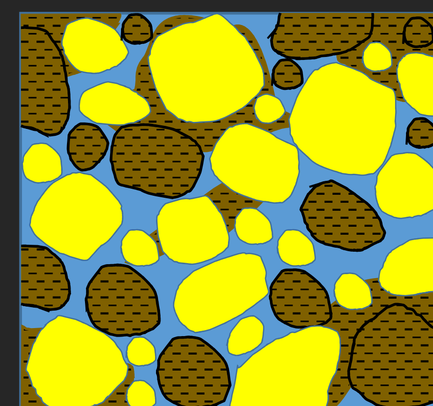
LAMINAR-DISPERSED

LAMINAR-STRUCTURAL MODEL

DISPERSED-STRUCTURAL MODEL







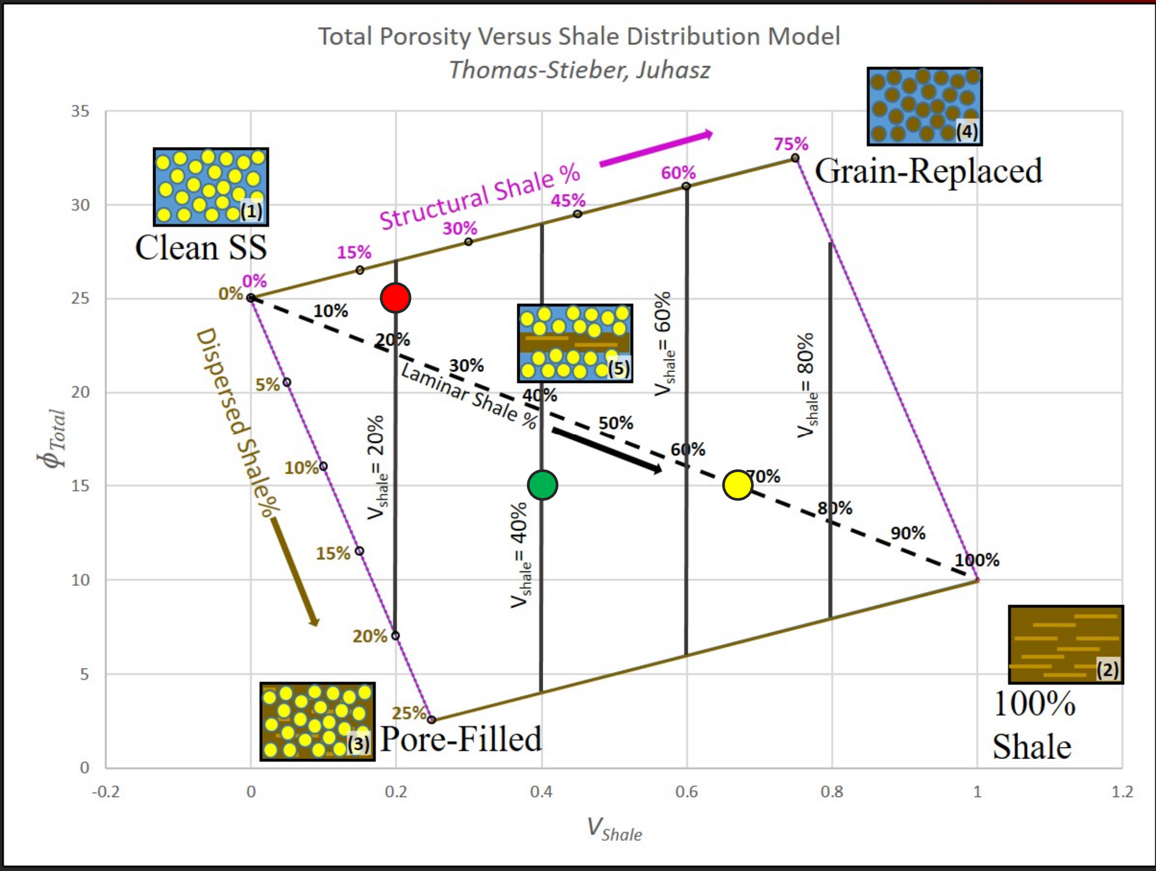
Existing Methodology

- Juhasz (1986)

- Points BELOW the laminar line invoke the LAMINAR-DISPERSED model. → GREEN POINT
  - BUT, the same input data may be described in the DISPERSED-STRUCTURAL model.
  - We now call this the "Dispersed-Required Field"

- Points ABOVE the laminar line invoke the LAMINAR-STRUCTURAL model. → RED POINT
  - BUT, the same input data may be described in the DISPERSED-STRUCTURAL model.
  - We now call this the "Structural-Required Field"

- Points ALONG the laminar line invoke the LAMINAR ONLY model. → YELLOW POINT
  - May not have any Dispersed or Structural but it could.



Quantifying Two-Type Distribution: Laminar/Dispersed Only

$$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed} + Vsh_{structural}$$

$$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) - Vsh_D + (Vsh_D * \phi_{Sh}) + (Vsh_L * \phi_{sh}) + (Vsh_S * \phi_{sh})$$

$$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed} + 0$$

$$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) - Vsh_D + (Vsh_L * \phi_{sh}) + (Vsh_D * \phi_{sh}) + 0$$

$$\boxed{Vsh_{dispersed} = Vsh_{total} - Vsh_{laminar}}$$

$$\phi_{total} = \phi_{sh} * (1 - Vsh_L) - (Vsh_T - Vsh_L) + (Vsh_T - Vsh_L) * \phi_{sh}) + (Vsh_L * \phi_{sh})$$

$$\boxed{Vsh_L = \frac{\phi_{ss_{clean}} - \phi_{total} + Vsh_T - (Vsh_T * \phi_{sh})}{1 - \phi_{ss_{clean}}}}$$

Quantifying Two-Type Distribution: Laminar/Dispersed Only

LAMINAR-DISPERSED CALCULATION

$$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed}$$
$$Vsh_{dispersed} = Vsh_{total} - Vsh_{laminar}$$
$$Vsh_L = \frac{\phi_{ss_{clean}} - \phi_{total} + Vsh_T - (Vsh_T * \phi_{Sh})}{1 - \phi_{ss_{clean}}}$$

LAMINAR-STRUCTURAL CALCULATION

$$Vsh_{total} = Vsh_{laminar} + Vsh_{structural}$$
$$Vsh_{structural} = Vsh_{total} - Vsh_{laminar}$$
$$Vsh_L = \frac{\phi_{ss_{clean}} - \phi_{total} + (Vsh_T * \phi_{Sh})}{\phi_{ss_{clean}}}$$

STRUCTURAL-DISPERSED CALCULATION

$$Vsh_{total} = Vsh_{dispersed} + Vsh_{structural}$$
$$Vsh_{structural} = Vsh_{total} - Vsh_{dispersed}$$
$$Vsh_D = \phi_{ss_{clean}} - \phi_{total} + (Vsh_T * \phi_{Sh})$$

Inconsistencies between Models

Laminar-Dispersed

$Vsh_L = $ 34%
$Vsh_D = $ 6%
$Vsh_S = $ 0%

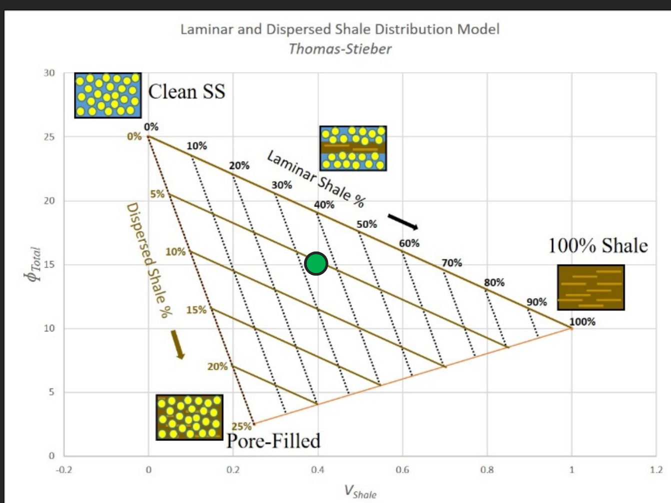
Green Point

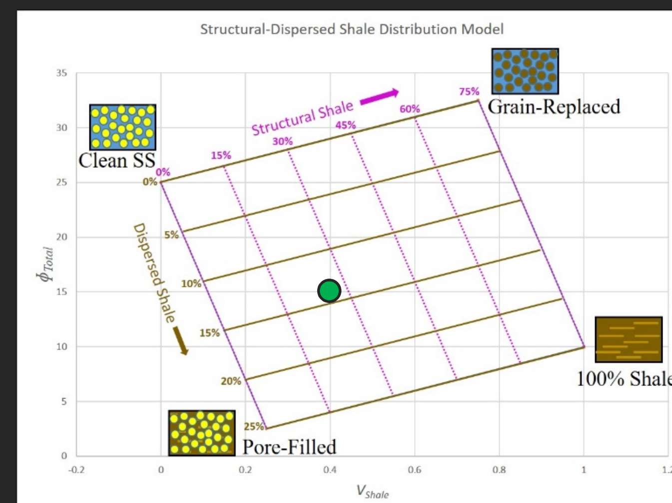
$Vsh_{total} = $ 40%

?

Dispersed-Structural

$Vsh_L = $ 0%
$Vsh_D = $ 14%
$Vsh_S = $ 26%





Quantifying Shale Distribution: Dispersed-Required System

$$Vsh_{total} = Vsh_{laminar} + Vsh_{dispersed} + Vsh_{structural}$$

$$\boxed{R = Vsh_S / Vsh_L \rightarrow R * Vsh_L = Vsh_S}$$

$$Vsh_T = Vsh_L + Vsh_D + (R * Vsh_L)$$

$$\boxed{Vsh_L = \frac{Vsh_T - Vsh_D}{1 + R}}$$

$$Vsh_T = \left(\frac{Vsh_T - Vsh_D}{1 + R}\right) + Vsh_D + (R * Vsh_L)$$

$$\phi_{total} = \phi_{ss_{clean}} * \left(1 - \left(\frac{Vsh_T - Vsh_D}{1 + R}\right)\right) - Vsh_D + \left(\phi_{sh}\left(\frac{Vsh_T - Vsh_D}{1 + R}\right)\right) + (Vsh_D * \phi_{sh}) + \left(R * \phi_{sh}\left(\frac{Vsh_T - Vsh_D}{1 + R}\right)\right)$$

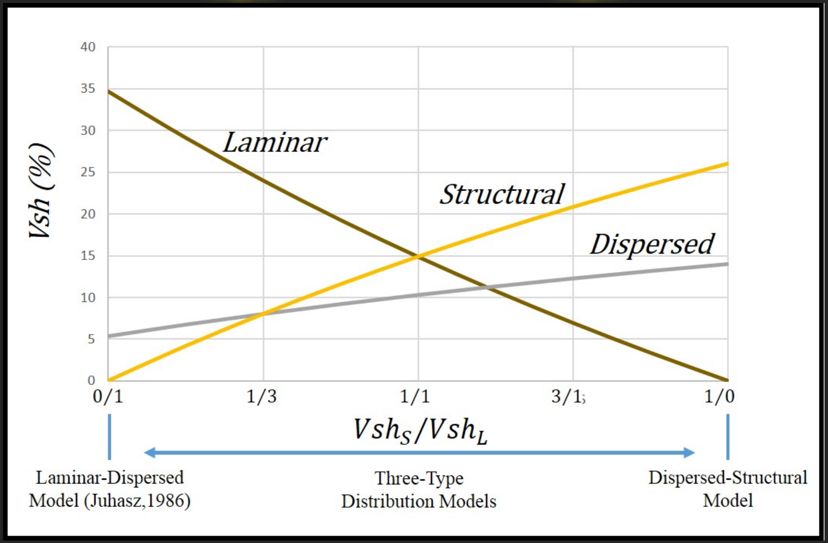
$$\boxed{Vsh_D = \frac{\phi_{total} - \phi_{ss} + \dfrac{\phi_{ss} * Vsh_T}{(1 + R) - Vsh_T * \phi_{sh}}}{\dfrac{\phi_{sh}}{(1 + R) - 1}}}$$

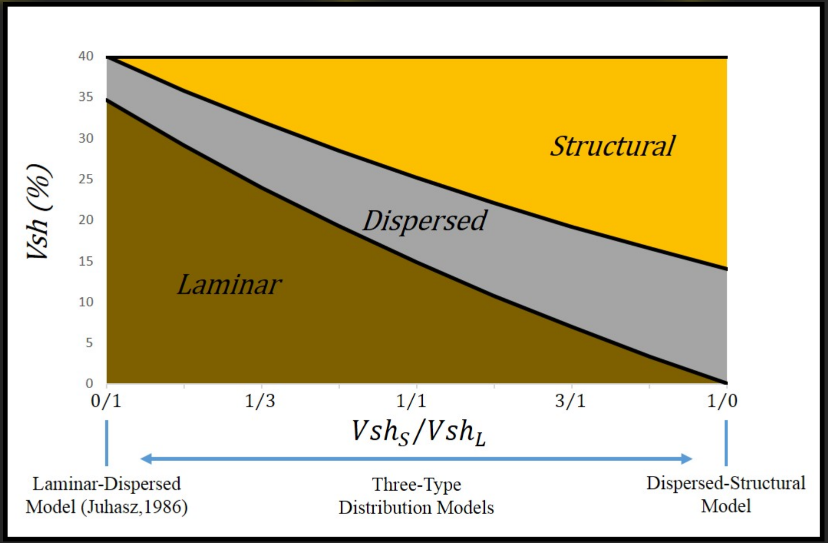
Quantifying Shale Distribution: Dispersed-Required System

$Vsh_S/Vsh_L = R$	$Vsh_S = R * Vsh_L$
$Vsh_S/Vsh_L = 0/1$	$Vsh_S = \frac{0}{1} * Vsh_L$
$Vsh_S/Vsh_L = 1/3$	$Vsh_S = \frac{1}{3} * Vsh_L$
$Vsh_S/Vsh_L = 1/1$	$Vsh_S = \frac{1}{1} * Vsh_L$
$Vsh_S/Vsh_L = 3/1$	$Vsh_S = \frac{3}{1} * Vsh_L$
$Vsh_S/Vsh_L = 1/0$	$Vsh_S = \frac{1}{0} * Vsh_L$

Implications of 3-Type Distribution Model

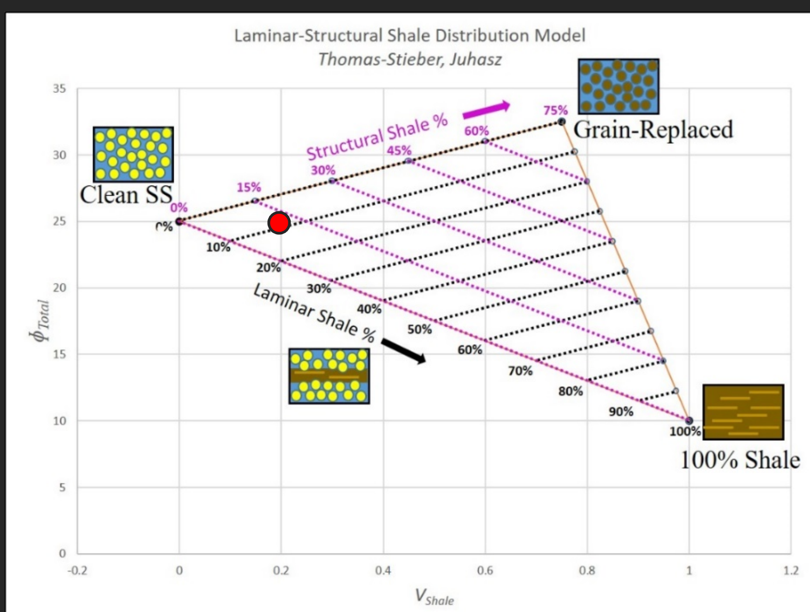
	Laminar-Dispersed Model			$Vsh_S:Vsh_L$ = 1:3 Model			$Vsh_S:Vsh_L$ = 1:1 Model			$Vsh_S:Vsh_L$ = 3:1 Model			Dispersed-Structural Model		
Vsh	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S
%	34%	6%	0	24%	8%	8%	15%	10%	15%	7%	12%	21%	0	14%	26%

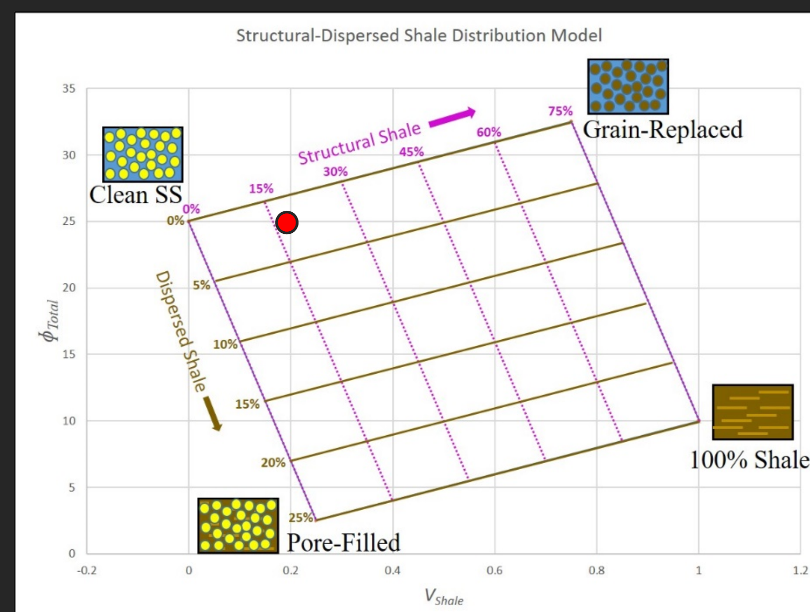




Implications of 3-Type Distribution Model

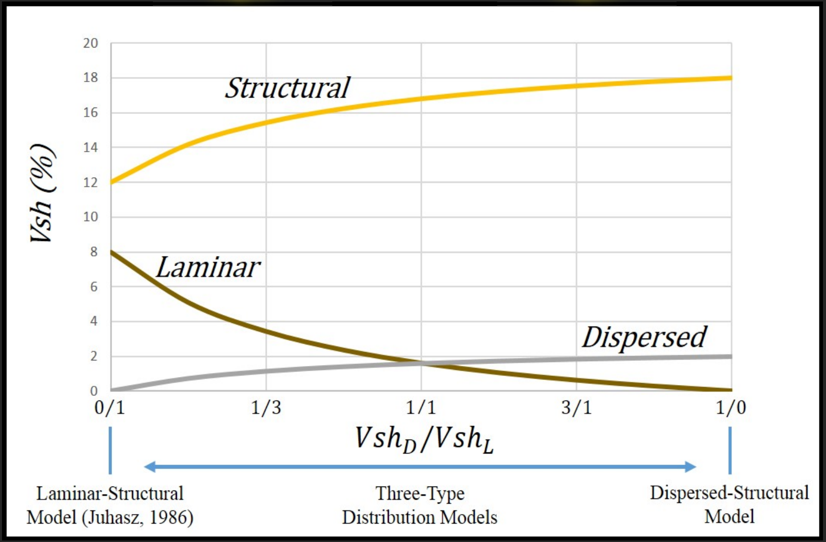
	Laminar-Structural Model			Vsh_D:Vsh_L = 1:3 Model			Vsh_D:Vsh_L = 1:1 Model			Vsh_D:Vsh_L = 3:1 Model			Dispersed-Structural Model		
Vsh	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S
20.0 %	8.0%	0.0%	12.0 %	3.4%	1.2%	15.4 %	1.6%	1.6%	16.8 %	0.6%	1.9%	17.5 %	0.0%	2.0%	18.0 %

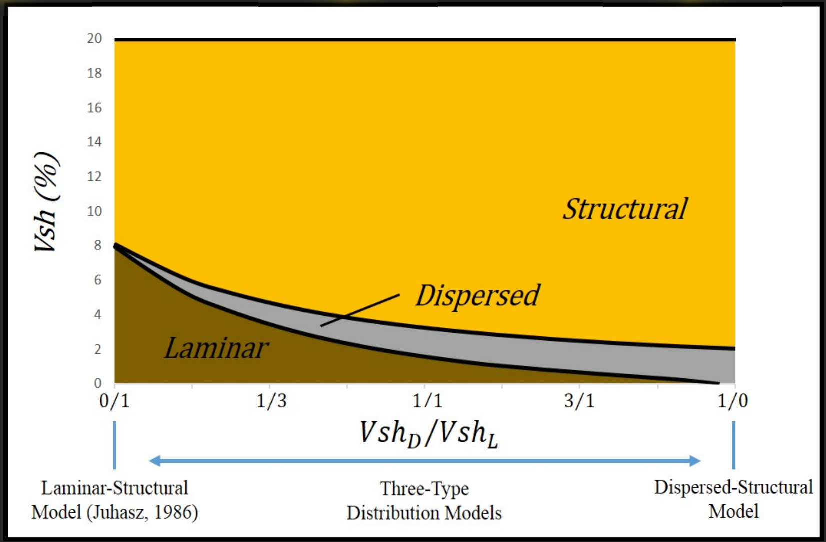




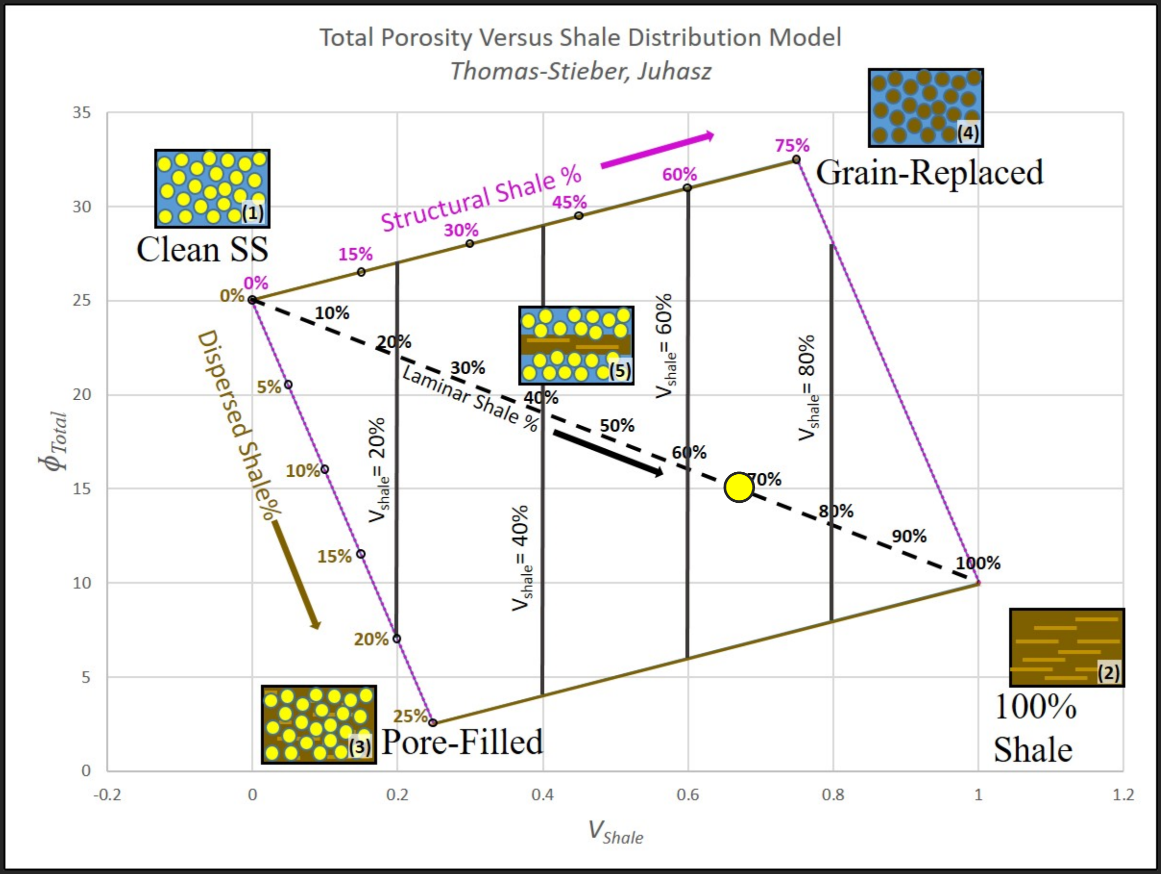
Implications of 3-Type Distribution Model

	Laminar-Structural Model			Vsh_D:Vsh_L = 1:3 Model			Vsh_D:Vsh_L = 1:1 Model			Vsh_D:Vsh_L = 3:1 Model			Dispersed-Structural Model		
Vsh	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S
20.0 %	8.0%	0.0%	12.0 %	3.4%	1.2%	15.4 %	1.6%	1.6%	16.8 %	0.6%	1.9%	17.5 %	0.0%	2.0%	18.0 %



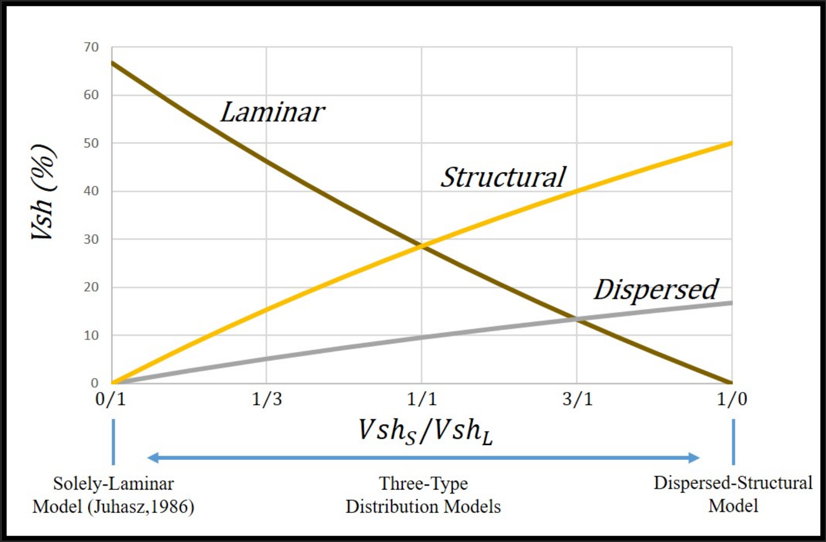


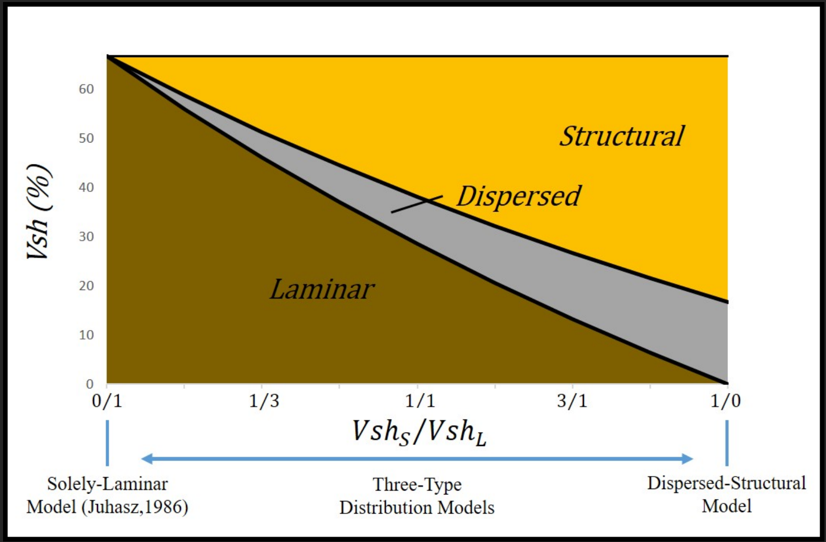
Implications of 3-Type Distribution Model



Implications of 3-Type Distribution Model

	Laminar Line Model			$Vsh_S:Vsh_L$ = 1:3 Model			$Vsh_S:Vsh_L$ = 1:1 Model			$Vsh_S:Vsh_L$ = 3:1 Model			Dispersed-Structural Model		
Vsh	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S	Vsh_L	Vsh_D	Vsh_S
66.7 %	66.7 %	0.0%	0.0%	46.2 %	5.1%	15.4 %	28.6 %	9.5%	28.6 %	13.3 %	13.3 %	40.0 %	0.0%	16.7 %	50.0 %





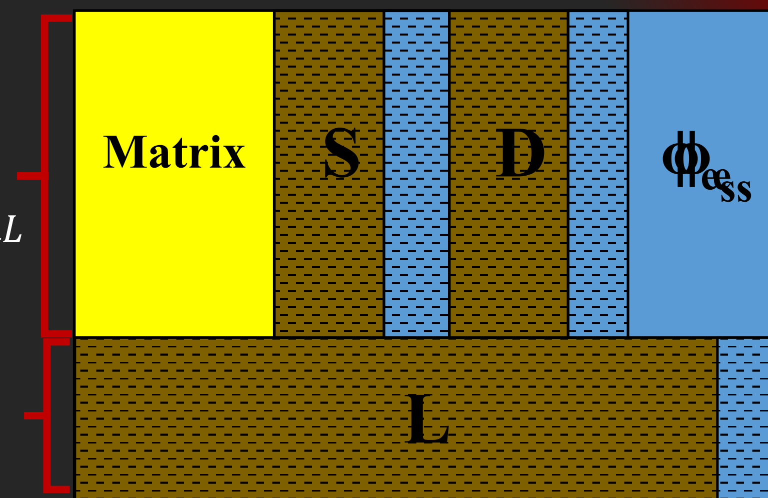
Effective Porosity

$$\phi_{total} = \phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh}) - Vsh_D + (Vsh_D * \phi_{sh}) + (Vsh_S * \phi_{sh})$$

$$\phi_{effective} = \phi_{total} - (Vsh_T * \phi_{sh})$$

Sandstone Fraction $(V_{ss}) = 1 - VshL$

Laminar Shale Fraction $= VshL$

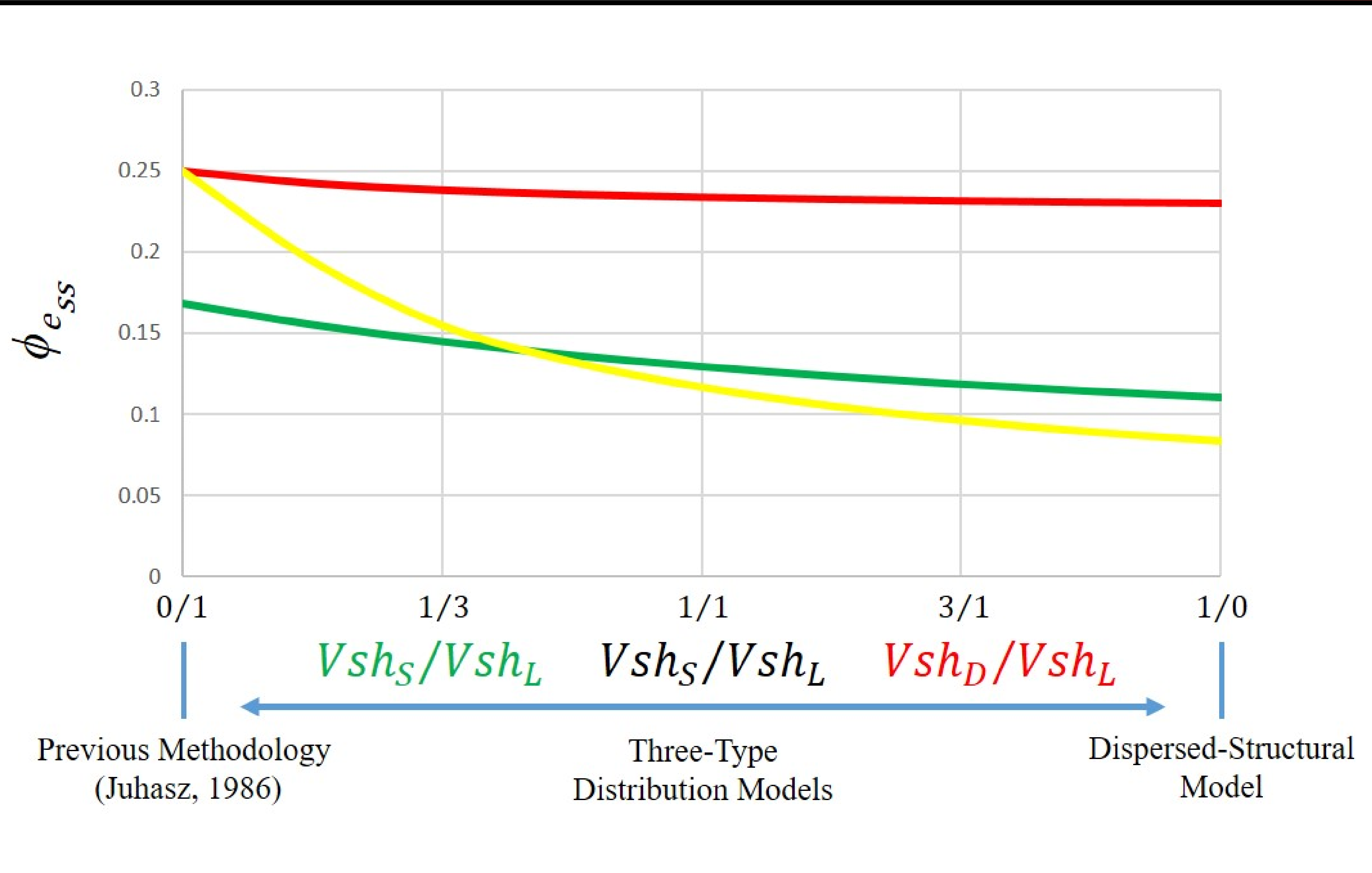


$$\phi_{e_{ss}} = \frac{\phi_e}{1 - Vsh_L}$$

$$\phi_{e_{ss}} = \frac{\phi_{ss_{clean}} * (1 - Vsh_L) + (Vsh_L * \phi_{sh}) - Vsh_D + (Vsh_D * \phi_{sh}) + (Vsh_S * \phi_{sh}) - (Vsh_L * \phi_{sh}) - (Vsh_D * \phi_{sh}) - (Vsh_S * \phi_{sh})}{1 - Vsh_L}$$

$$\boxed{\phi_{e_{ss}} = \phi_{ss_{clean}} - \frac{Vsh_D}{(1 - Vsh_L)}}$$

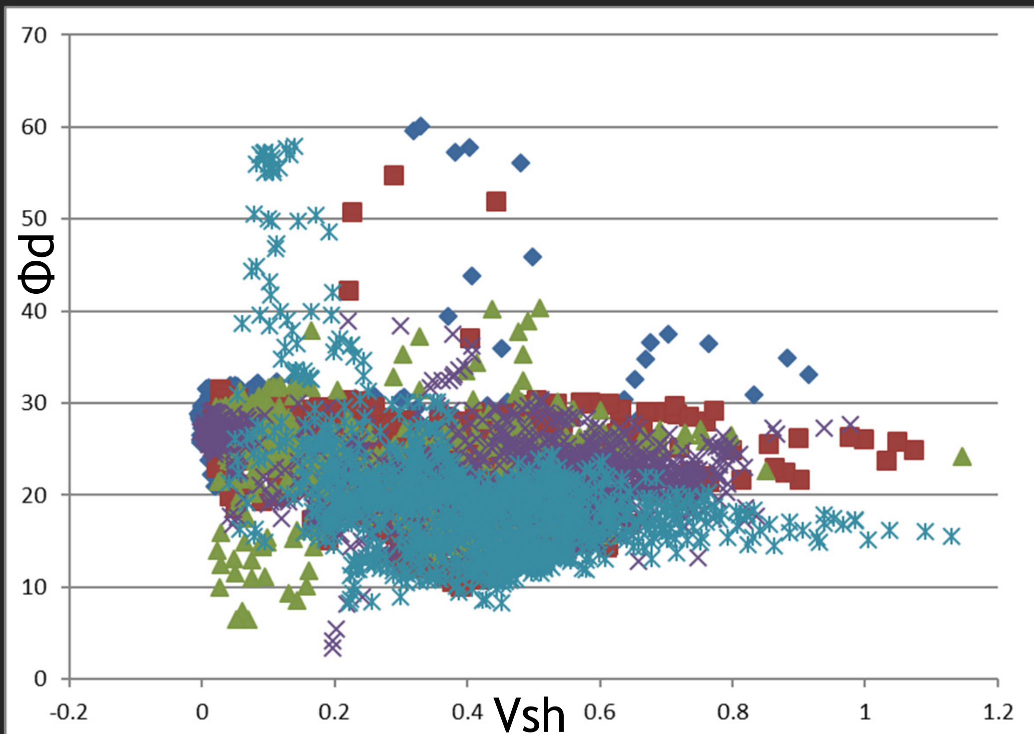
Shale Distribution Implications toward Effective Porosity

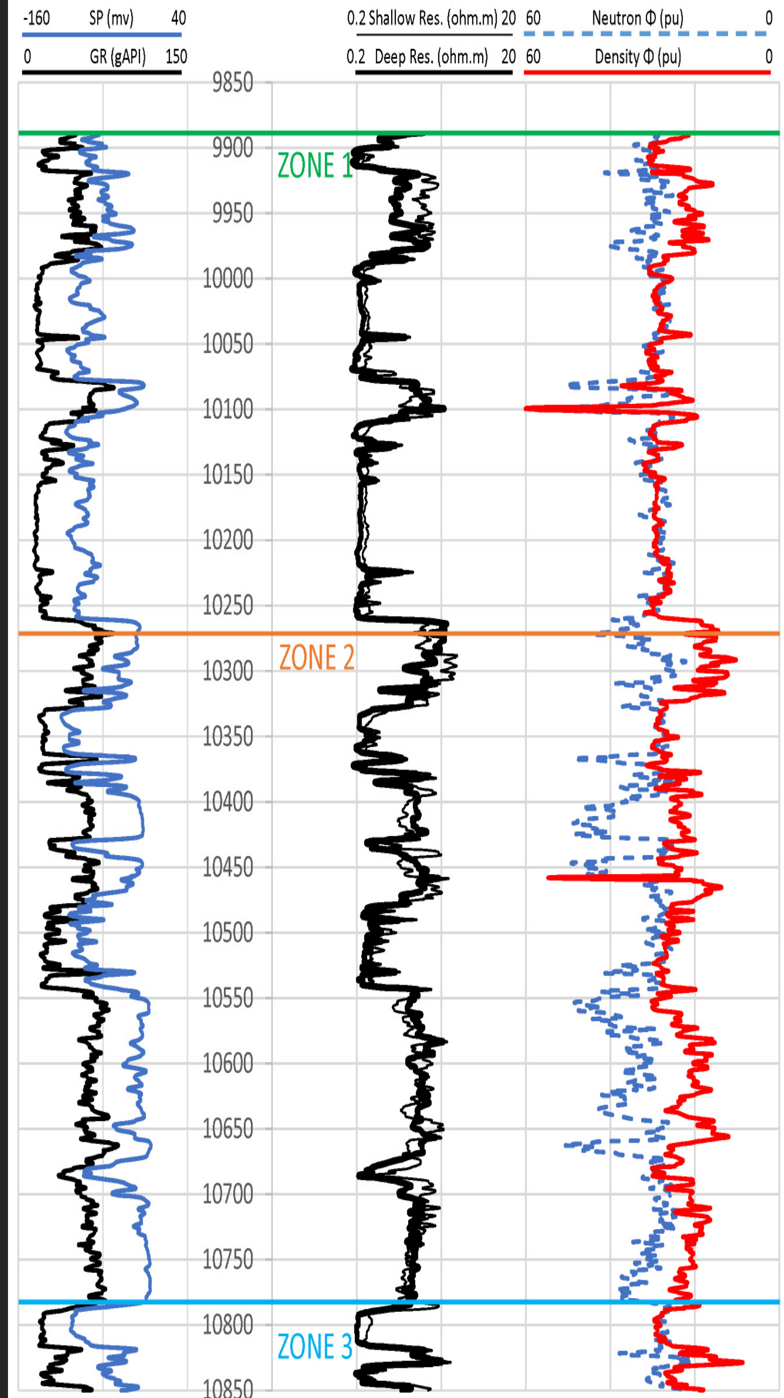


Application of Revised Methodology on Sandstone Case Studies

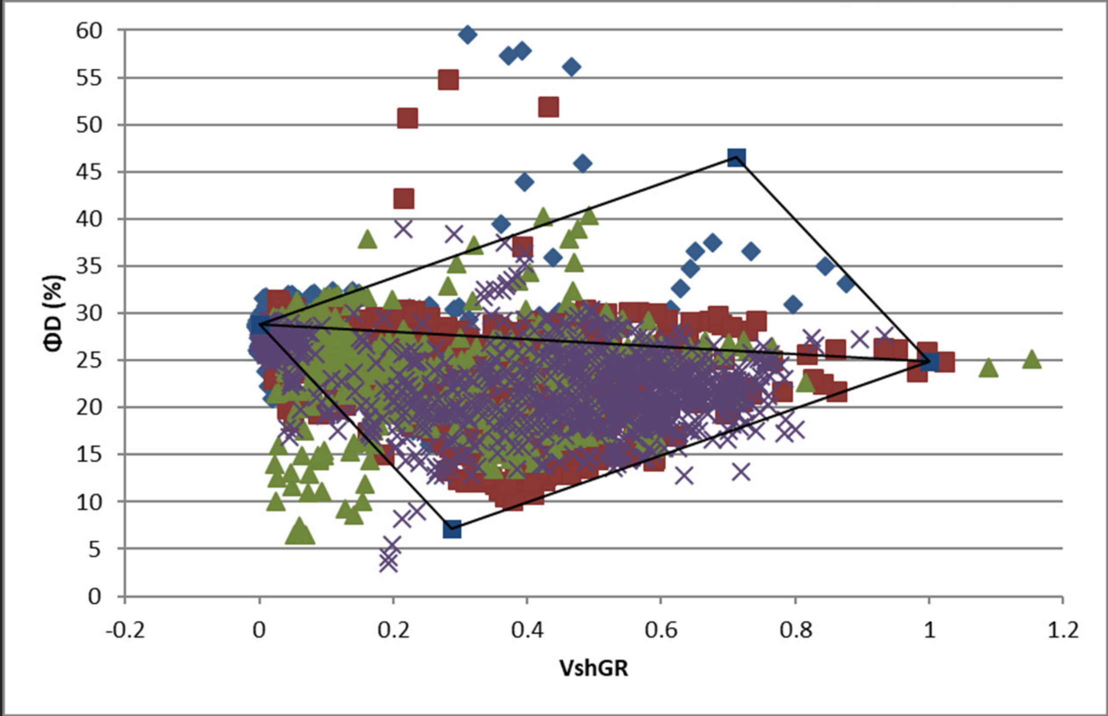
Case 1: Show Permission Denied
Case 2: Onshore Louisiana
Case 3: Deepwater GOM

Case Study 2
Onshore Louisiana



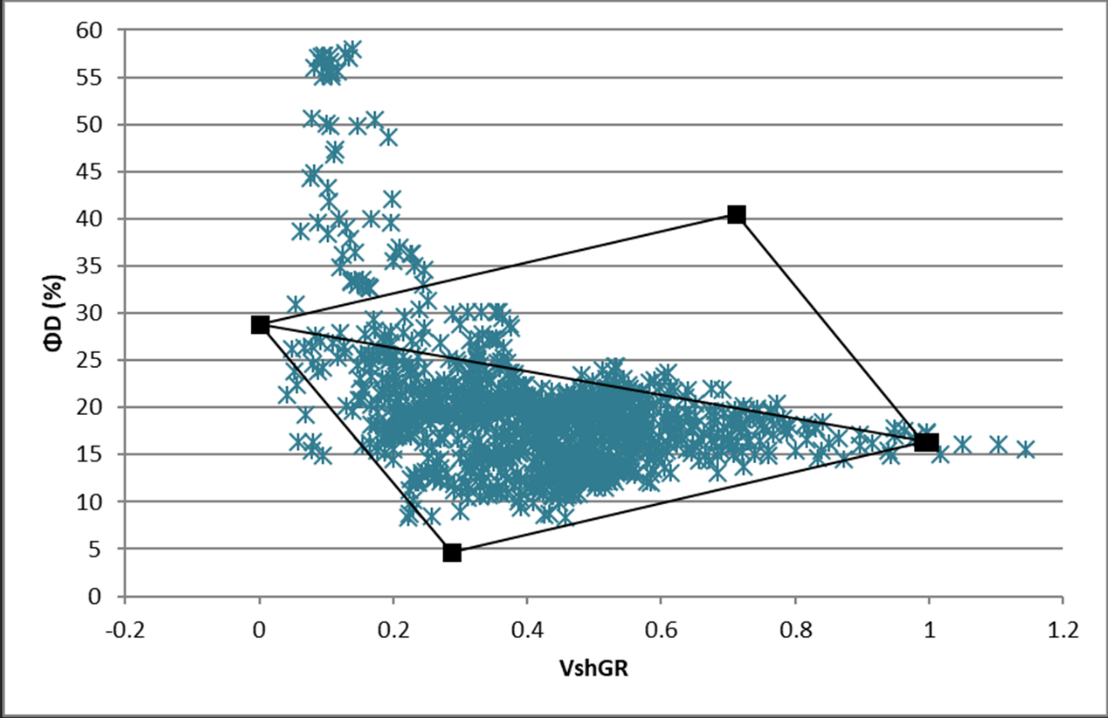


ϕ_d vs. $V_{sh\text{-}gr}$



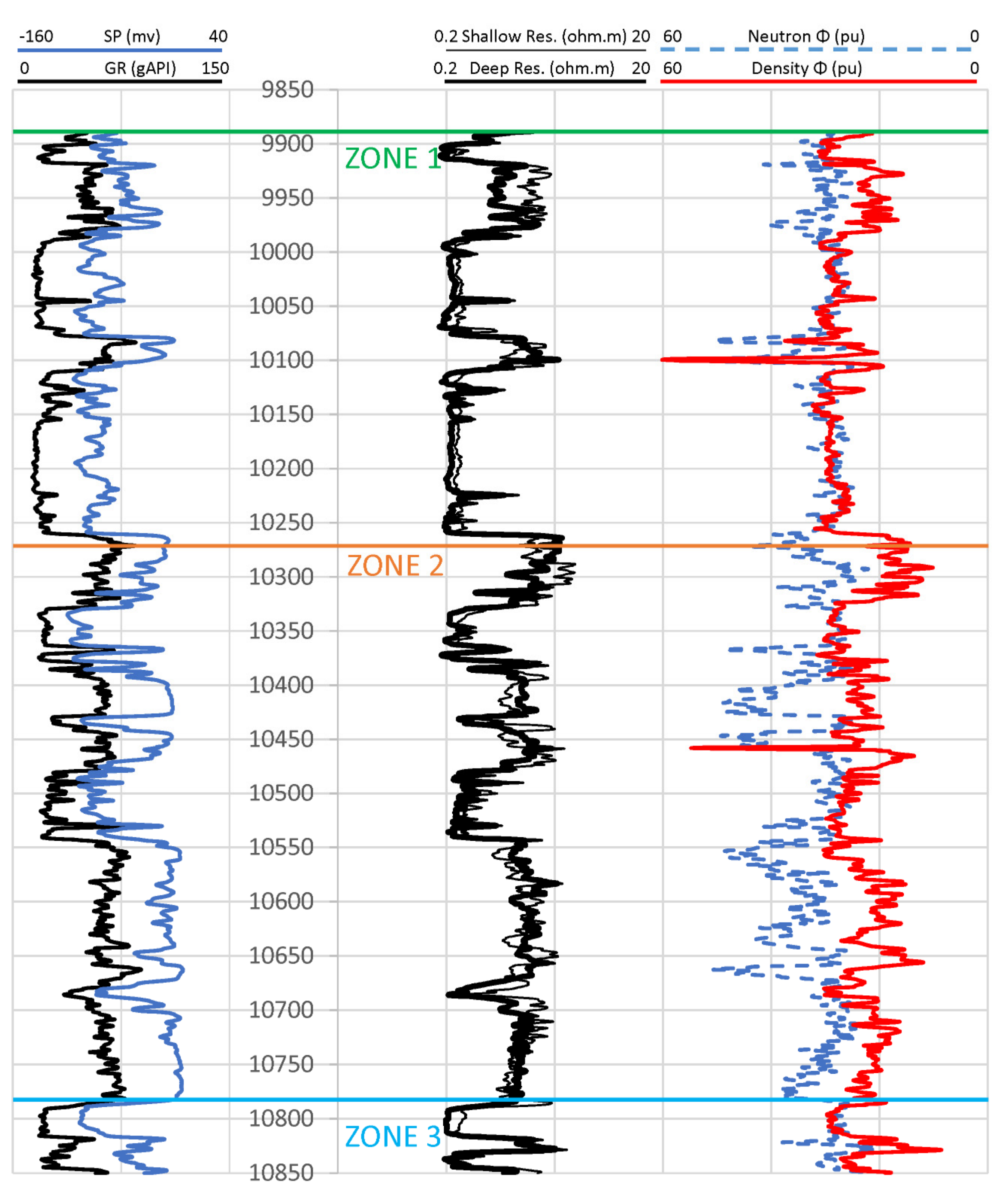
(TOP) Zones 1-3

Shale Point has higher porosity and GR versus original zone 1-5 average

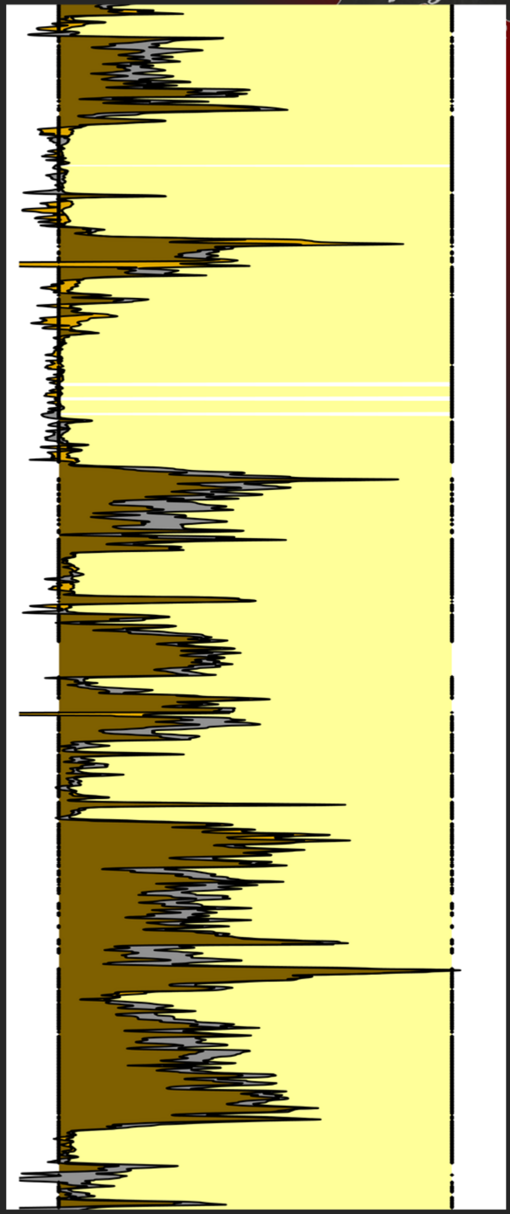


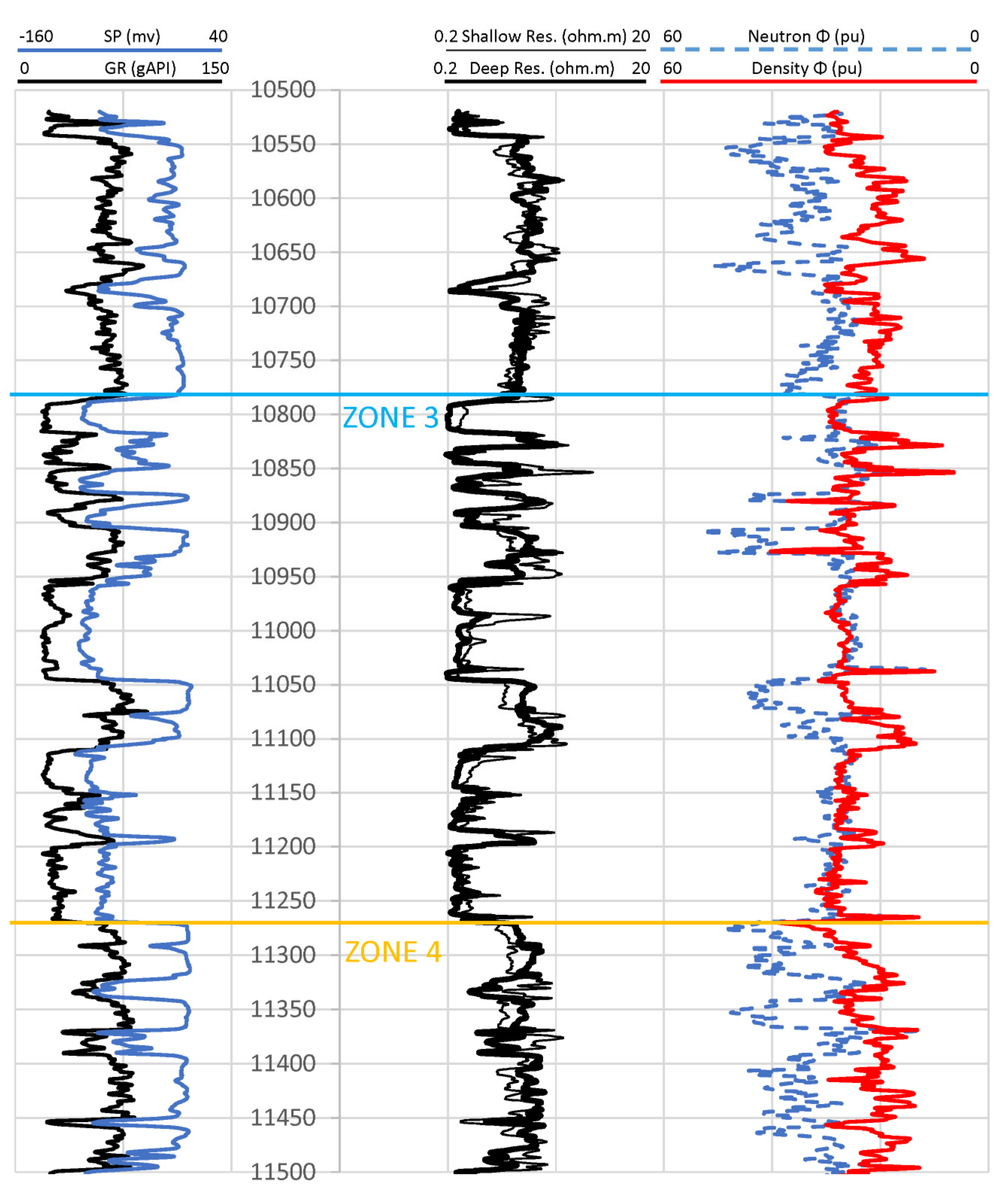
(BOTTOM) (Zone 5)

Shale Point has lower porosity and GR versus original 1-5 average.



-160 SP (mv) 40
0 GR (gAPI) 150
0.2 Shallow Res. (ohm.m) 20
0.2 Deep Res. (ohm.m) 20
60 Neutron Φ (pu) 0
60 Density Φ (pu) 0
9850
9900
9950
10000
10050
10100
10150
10200
10250
10300
10350
10400
10450
10500
10550
10600
10650
10700
10750
10800
10850
ZONE 1
ZONE 2
ZONE 3

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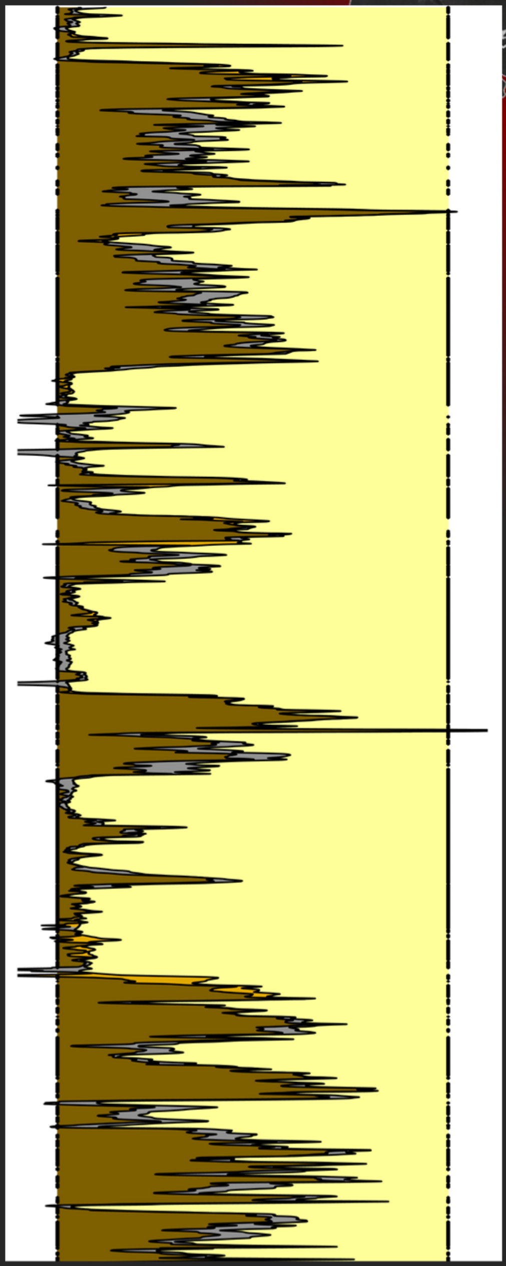
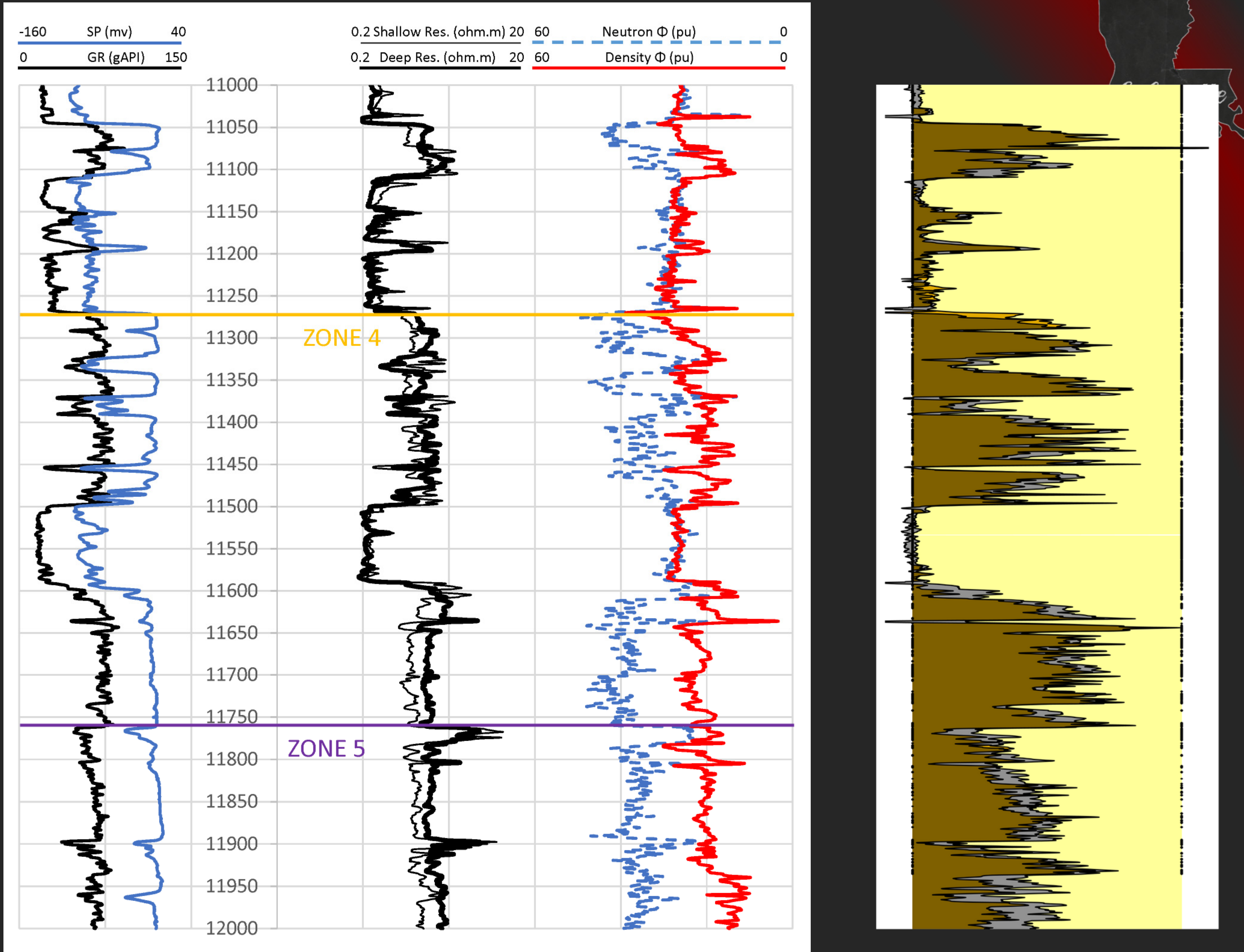
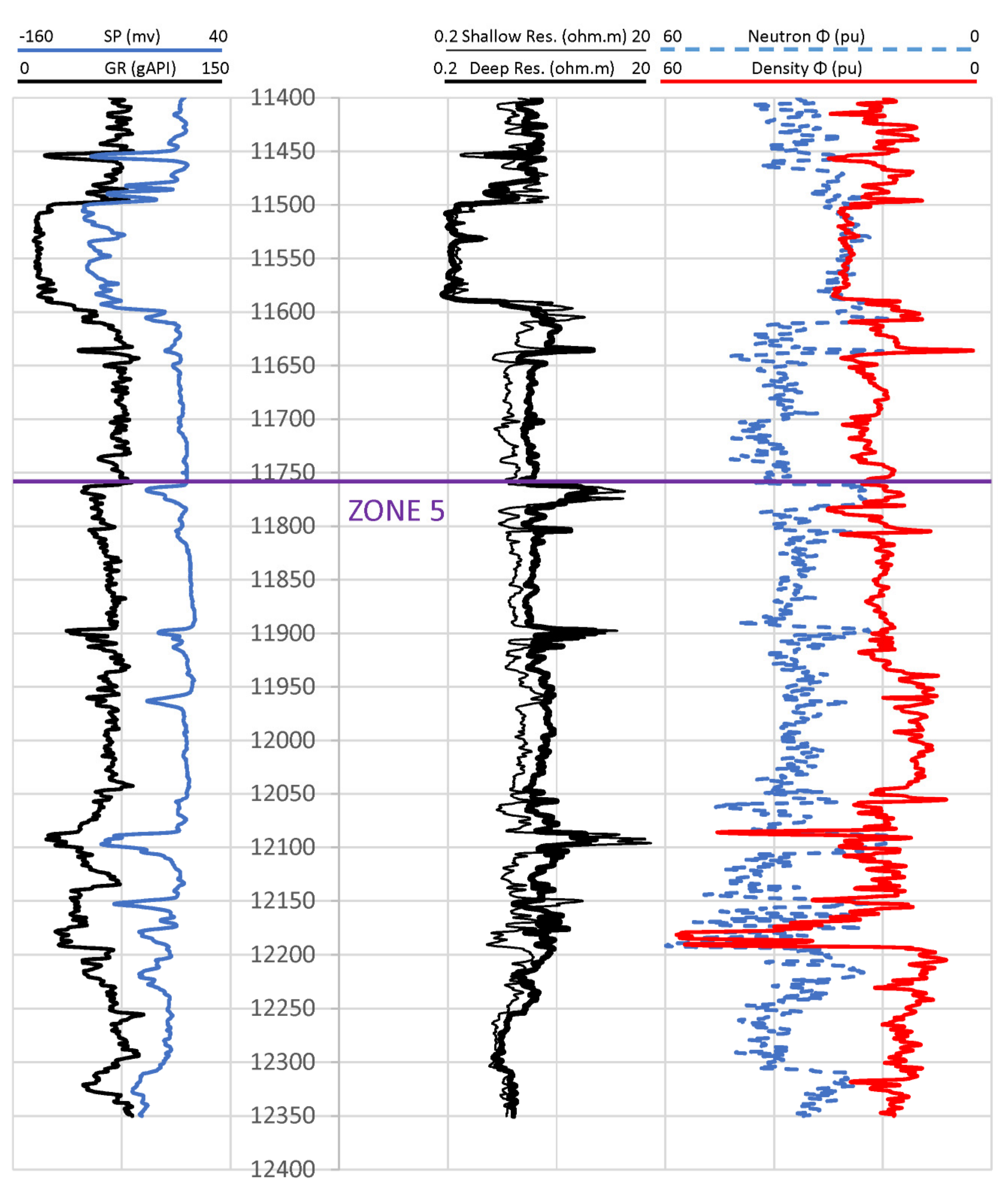
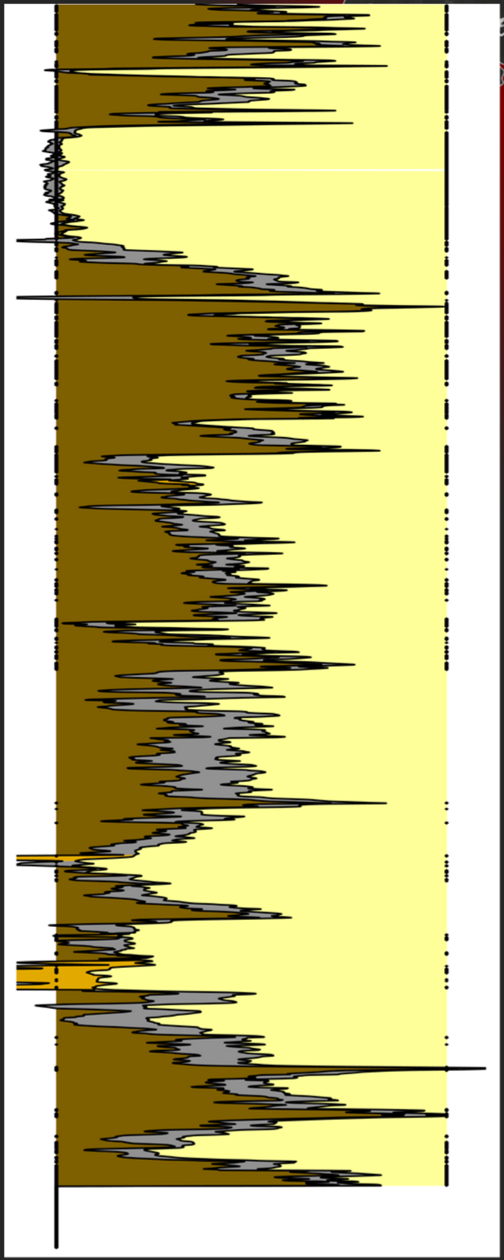
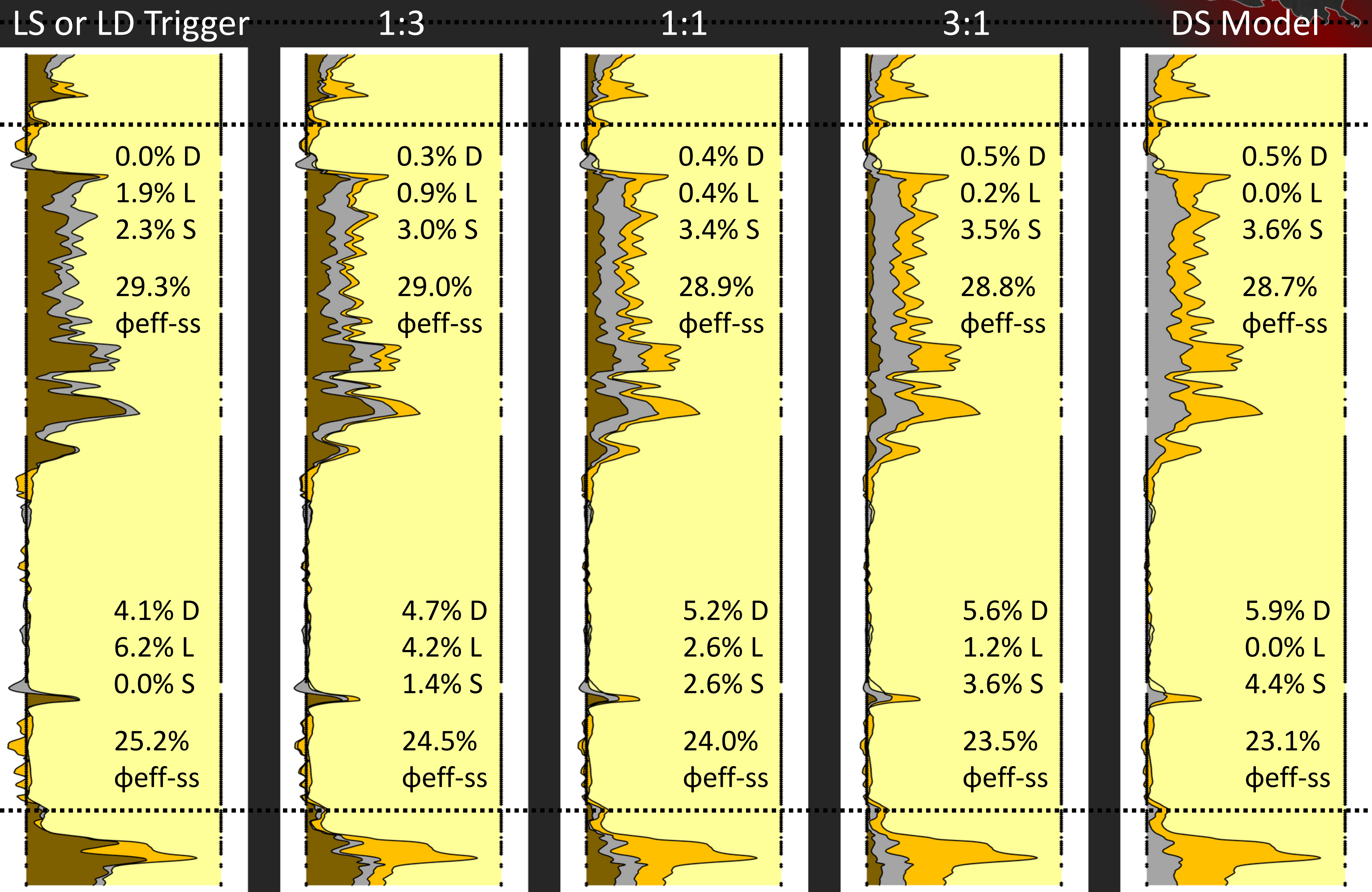
0 GR (gAPI) 150
0.2 Shallow Res. (ohm.m) 20
0.2 Deep Res. (ohm.m) 20
60 Neutron Φ (pu) 0
60 Density Φ (pu) 0
10500
10550
10600
10650
10700
10750
10800
10850
10900
10950
11000
11050
11100
11150
11200
11250
11300
11350
11400
11450
11500
ZONE 3
ZONE 4



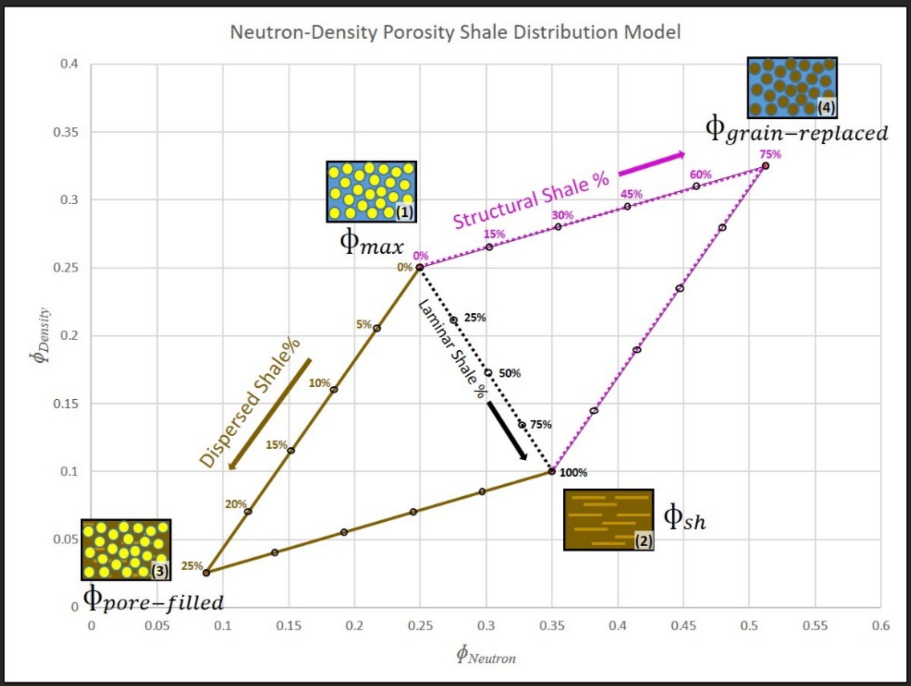

-160 SP (mv) 40
0 GR (gAPI) 150
0.2 Shallow Res. (ohm.m) 20
0.2 Deep Res. (ohm.m) 20
60 Neutron Φ (pu) 0
60 Density Φ (pu) 0
11000
11050
11100
11150
11200
11250
11300
11350
11400
11450
11500
11550
11600
11650
11700
11750
11800
11850
11900
11950
12000
ZONE 4
ZONE 5


-160 SP (mv) 40
0 GR (gAPI) 150
0.2 Shallow Res. (ohm.m) 20
0.2 Deep Res. (ohm.m) 20
60 Neutron Φ (pu) 0
60 Density Φ (pu) 0
11400
11450
11500
11550
11600
11650
11700
11750
ZONE 5
11800
11850
11900
11950
12000
12050
12100
12150
12200
12250
12300
12350
12400


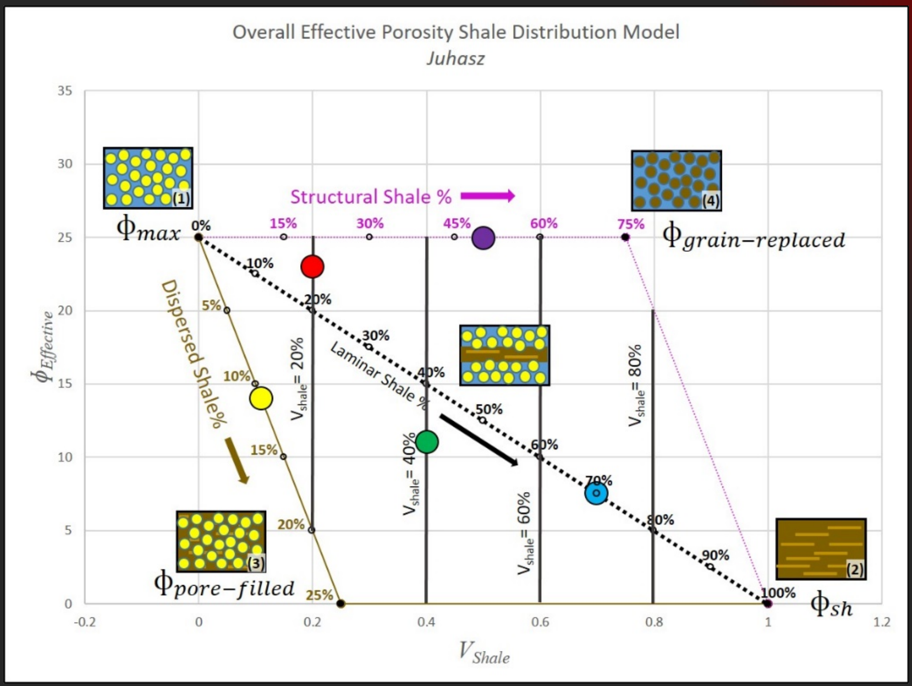
Ratio Analysis and Effective Porosity



Ongoing Research

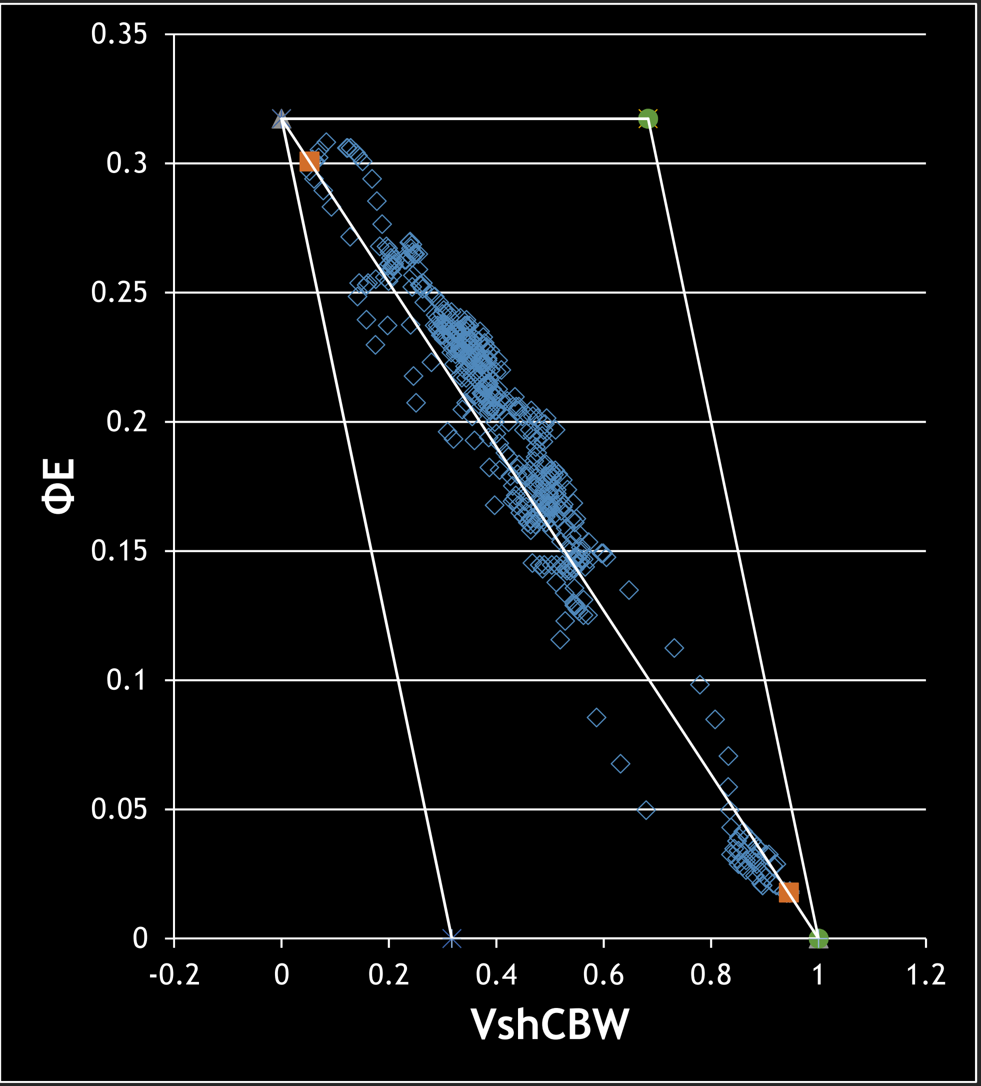


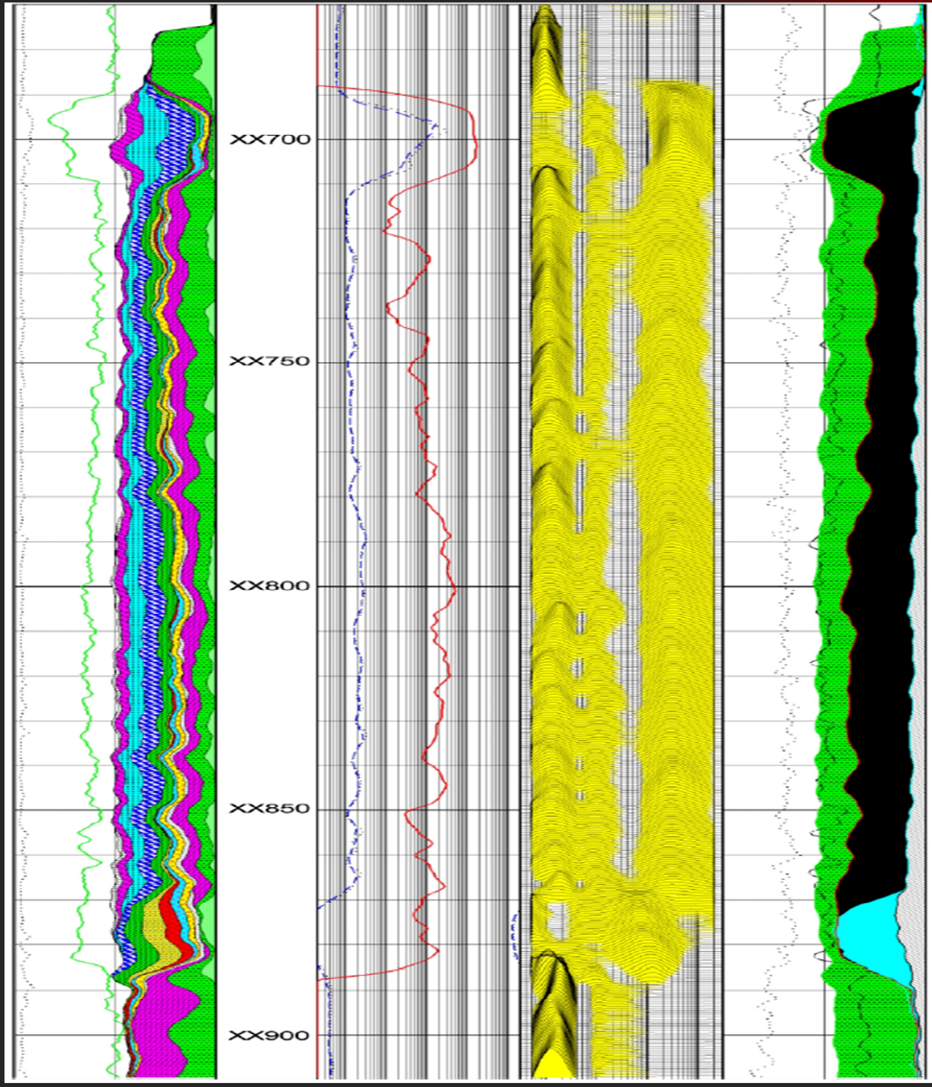
Density Porosity versus Volume of Shale



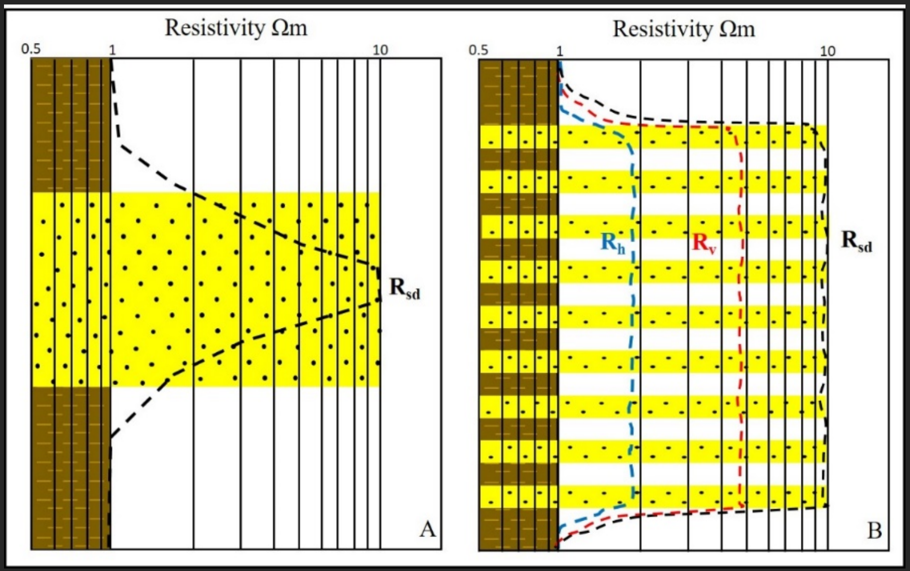
Effective Porosity versus Volume of Shale

NMR Case Study Deepwater GOM





Additional Techniques



3D Resistivity

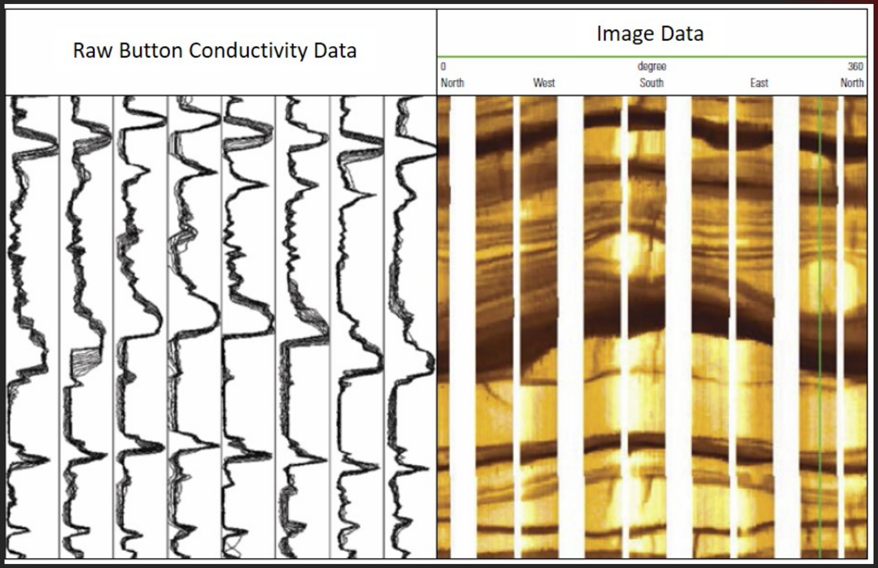


Image Logs

Summary

Juhasz’s (1986) method provides one endmember for shale volumetrics and interpretation, and that endmember just so happens to be the most optimistic with respect to reservoir quality.

Using triple-combo data with our method, we can quickly provide the range of possible scenarios, from most optimistic to most pessimistic.

As additional datasets are added, the range can be more accurately constrained.