Quick-Look Deterministic Approach for Evaluating Shale Distribution in Sandstone Reservoirs: Progress Report

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GCAGS Explore & Discover Article #00404[*]
http://www.gcags.org/exploreanddiscover/2018/00404_willis_et_al.pdf
Posted September 29, 2018.

[*]Article based on a full paper published in the *GCAGS Transactions* (see footnote reference below), which is available as part of the entire 2018 *GCAGS Transactions* volume via the GCAGS Bookstore at the Bureau of Economic Geology (www.beg.utexas.edu) or as an individual document via AAPG Datapages, Inc. (www.datapages.com), and delivered as an oral presentation at the 68th Annual GCAGS Convention and 65th Annual GCSSEPM Meeting in Shreveport, Louisiana, September 30–October 2, 2018.

ABSTRACT

Shale distribution in a sandstone reservoirs 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. We describe herein a brief progress report on the quantification of shale distribution types using quick-look deterministic graphical and mathematical analyses using total porosity versus shale volume, effective porosity versus shale volume, and density porosity versus neutron porosity. Use of conventional triple combination log data is capable of determining the range of distribution quantities (from most pessimistic to most optimistic in terms of reservoir quality), but additional data such as nuclear magnetic resonance, core, and triaxial resistivity log data can constrain these ranges to specific quantities. Determination of the laminar shale fraction determines the sandstone fraction; the dispersed shale fraction reduces the effective porosity of the sandstone fraction; and the structural shale fraction further reduces the useful porosity of the sandstone fraction.

Originally published as: Willis, J. J., D. S. McIntosh, Jr., G. J. Ferguson, J. W. Zwennes, J. Pasley, and G. M. Goettel, 2018, Quick-look deterministic approach for evaluating shale distribution in sandstone reservoirs: Progress report: Gulf Coast Association of Geological Societies Transactions, v. 68, p. 569–578.

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Overview

- **INTRODUCTION**
  - **PREVIOUS METHODOLOGY**
    - **REVISED METHODOLOGY**
      - **APPLICATION OF METHODOLOGY**
        - **ADDITIONAL TOOLS**
          - **CONCLUSIONS**

- Shale Distribution Types

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- 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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- Image Logs
- Resistivity Anisotropy

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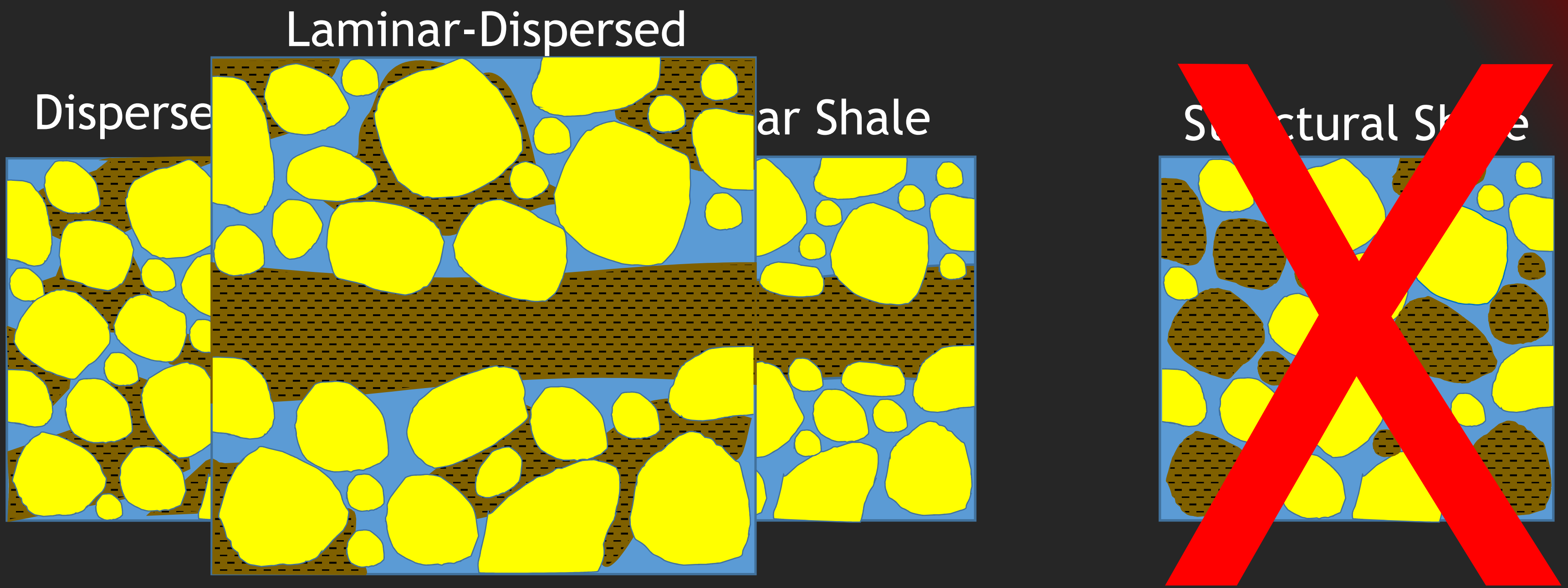
- **CONCLUSIONS**

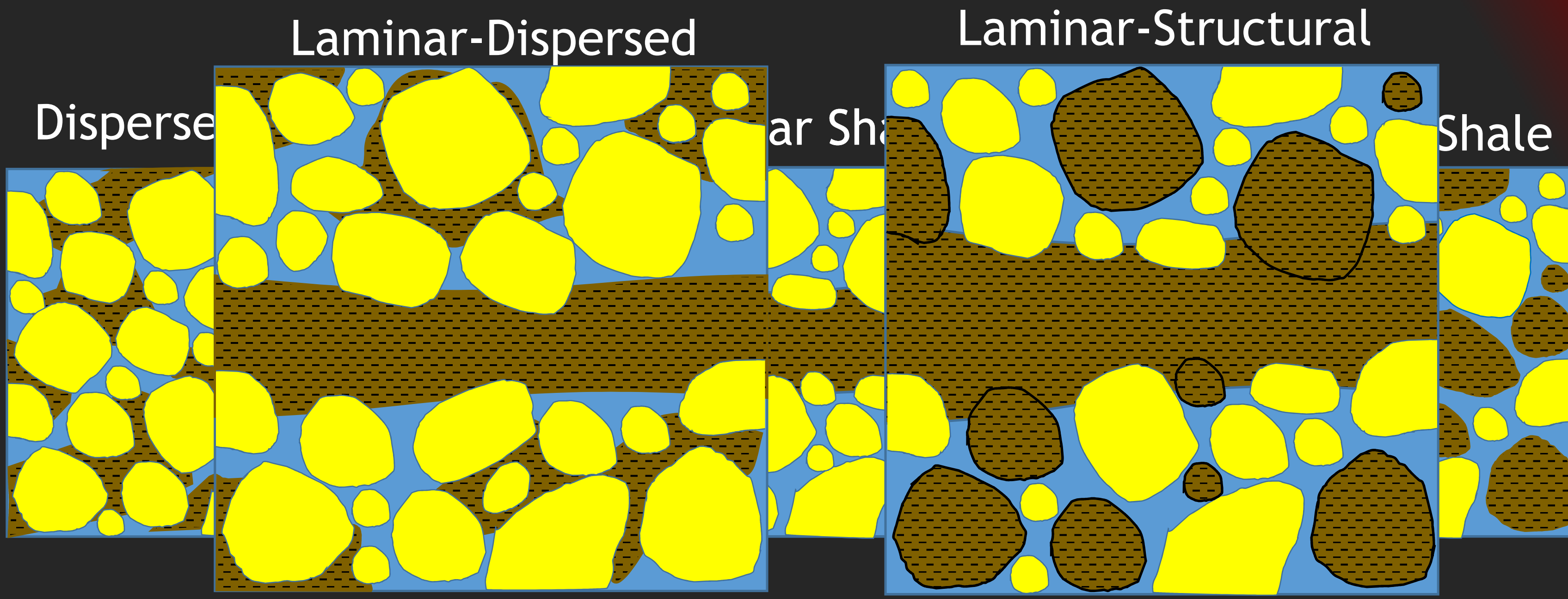
- We believe the previous methodologies are flawed.
- These 2 type distribution models may not fully describe the system, and represent the most optimistic scenario in terms of reservoir quality

Thomas & Stieber (1975)



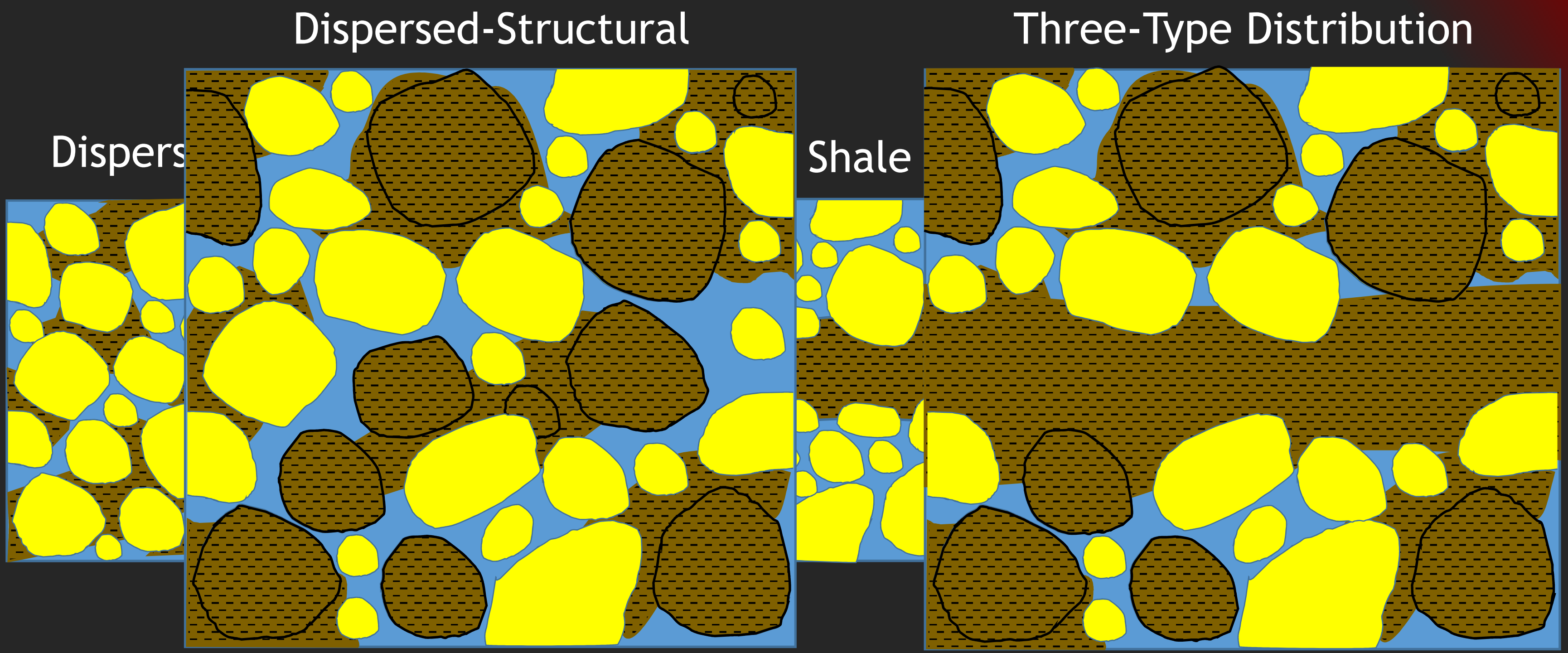
- Thomas and Stieber (1975) introduced the concept of shale distribution within a sand as dispersed, laminar, and structural, or any combination of the three.
- Simplified the quantification by assuming the amount of structural shale is too small to be significant, therefore ignoring it all together

Juhasz (1986)



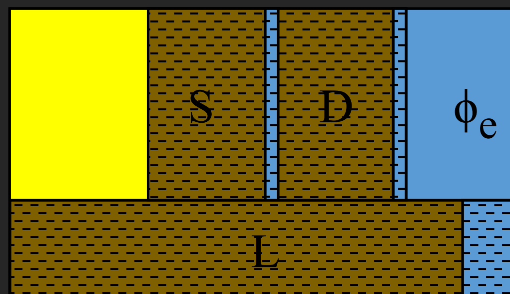
- Juhasz (1986) built upon the work of Thomas and Steiber (1975) and acknowledged the potential implications of structural shale.
- Expanded methodology to include mixture of laminar and structural shale

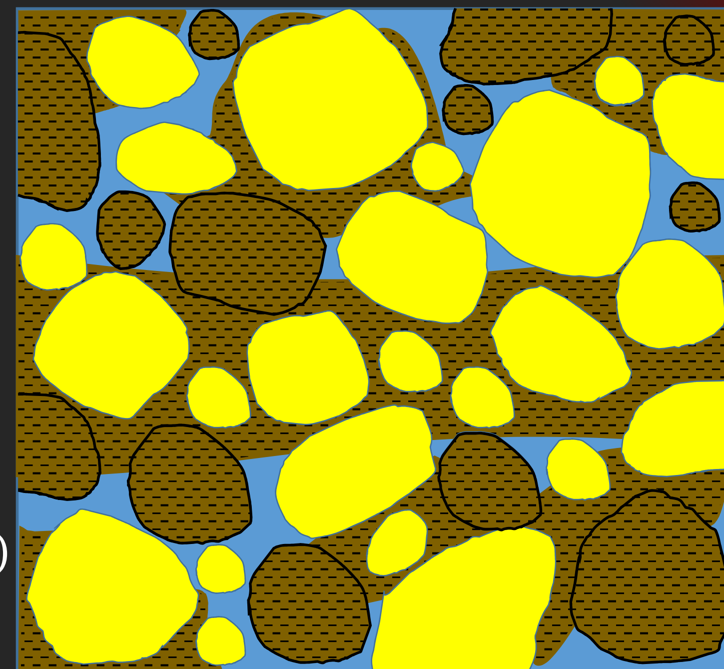
Revised Methodology



- 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.

Effect of Shale Distribution on Total Porosity





$Vsh_{total} = 0$

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

$Vsh_{total} = Vsh_{laminar}$

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

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

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

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

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

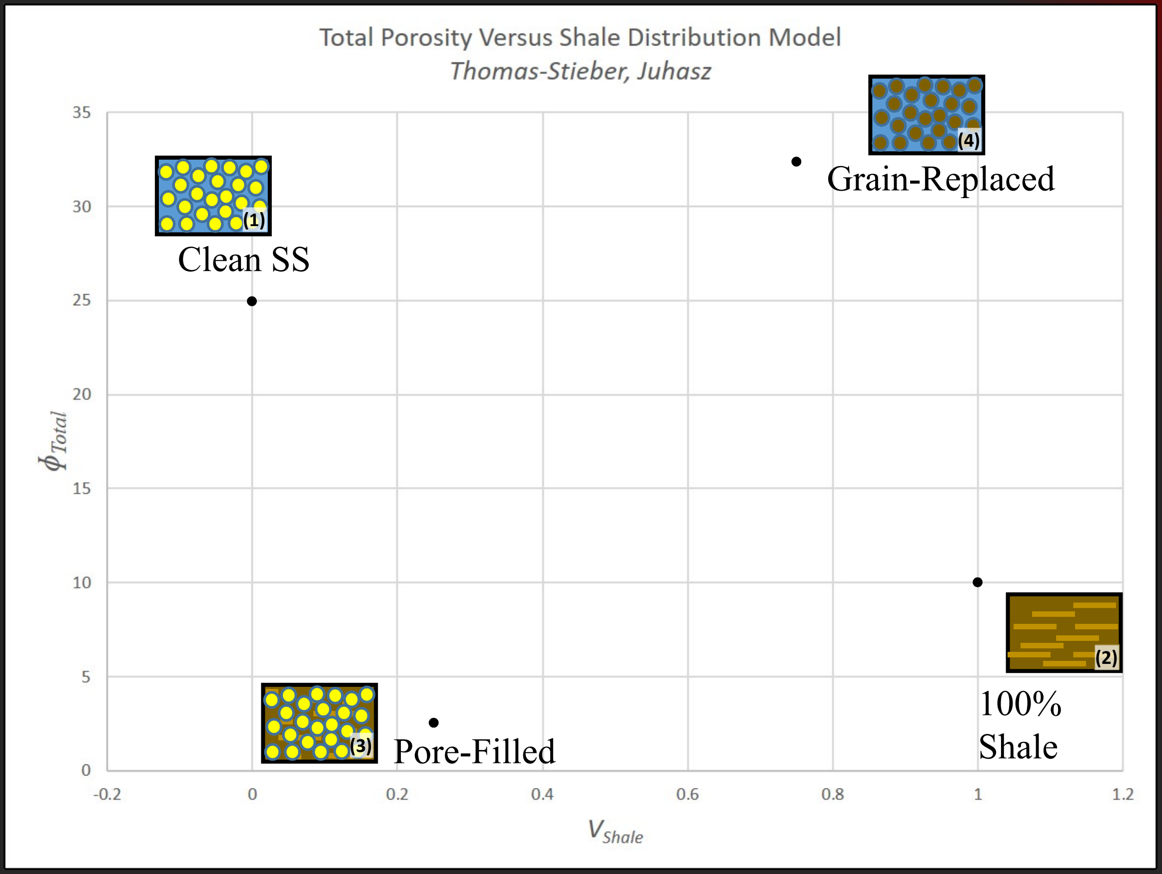
Total Porosity vs. Shale Volume Crossplot

1) Maximum Porosity in a 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
   - $\phi_{total} = \phi_{ss_{clean}} + (V_{shale} * \phi_{shale})$
   - $Vsh = 1 - \phi_{ss_{clean}}$



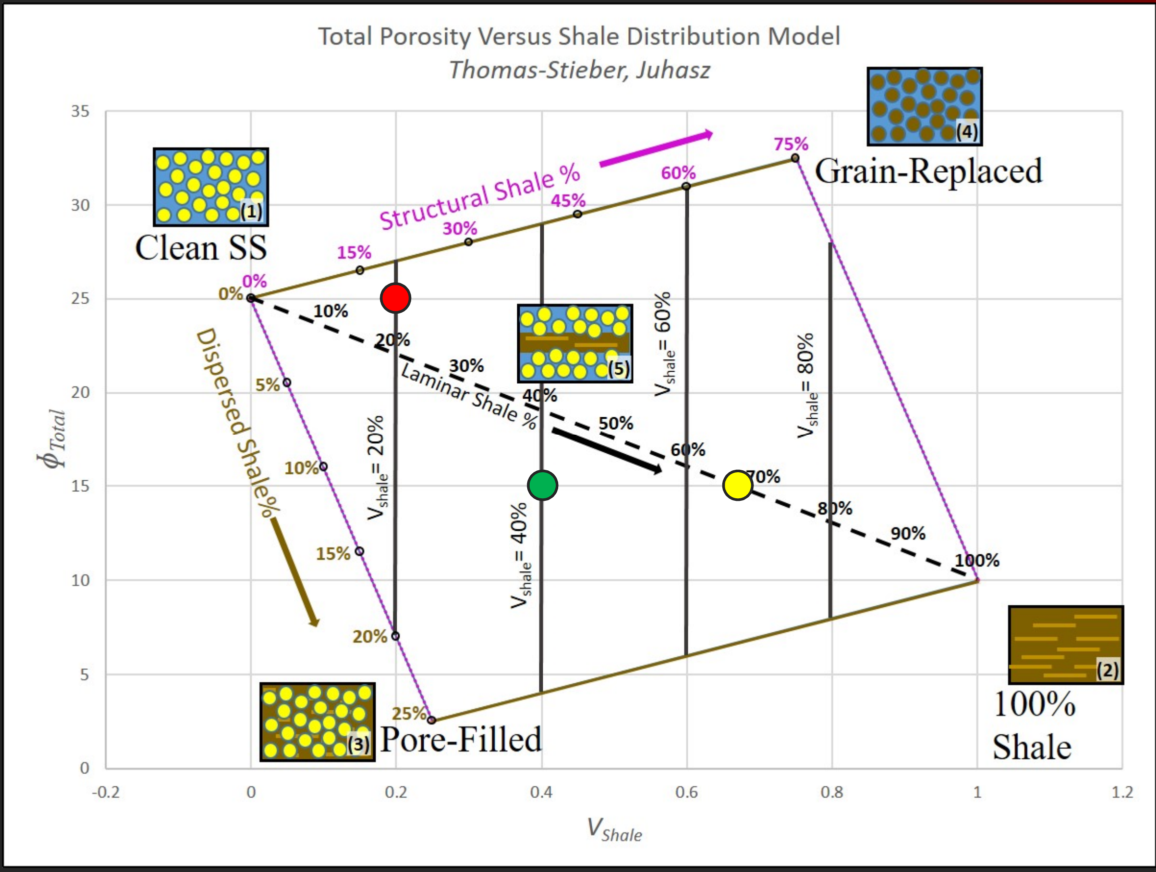
Existing Methodology

- 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.



Inconsistencies between Models

Laminar-Dispersed

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

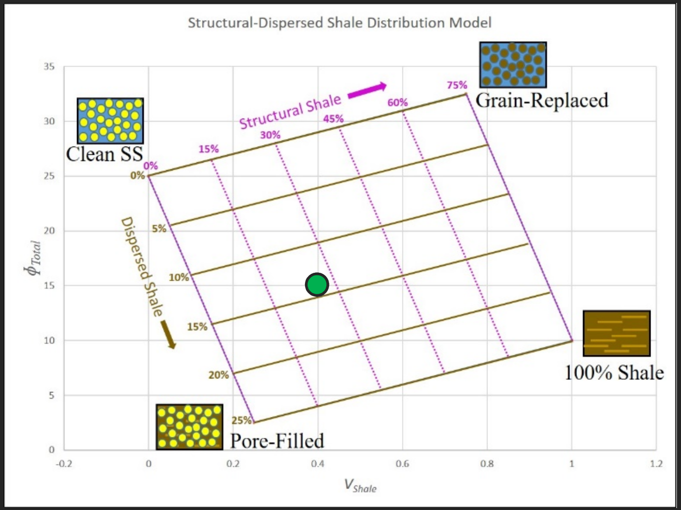
Green Point

$Vsh_{total} = 40\%$

?

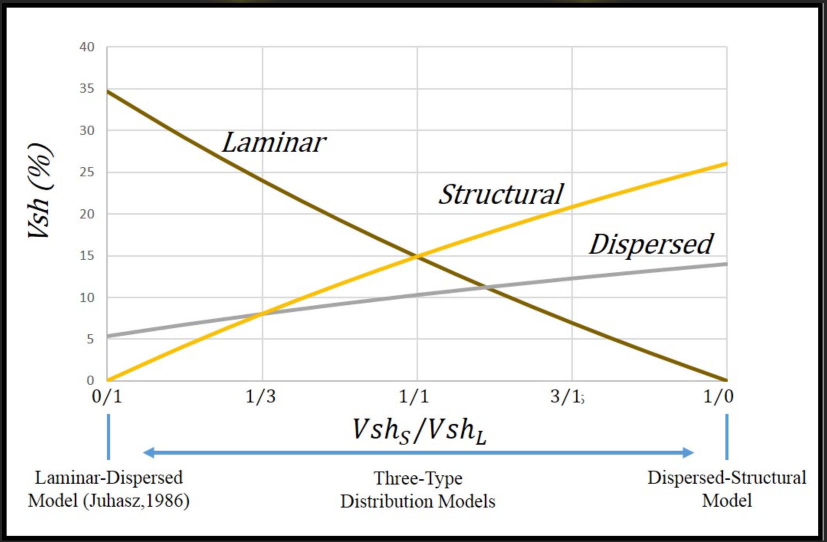
Dispersed-Structural

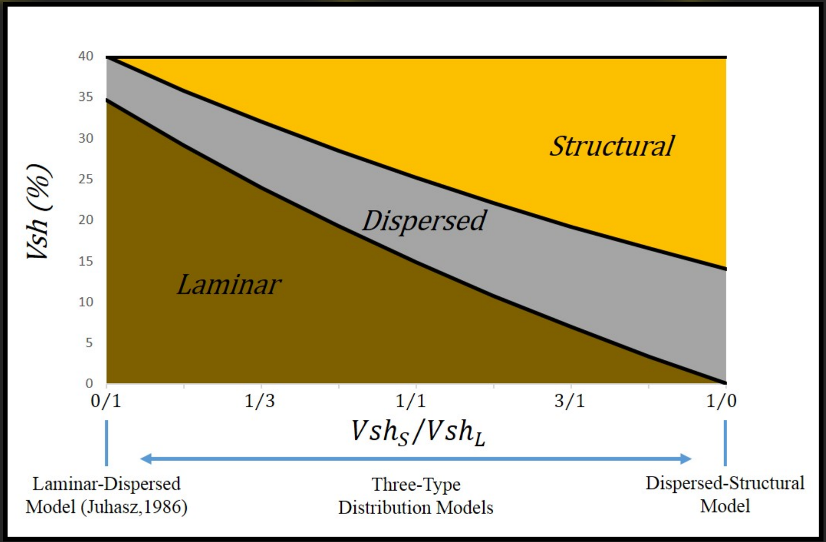
$Vsh_L = 0\%$
$Vsh_D = 14\%$
$Vsh_S = 26\%$



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%

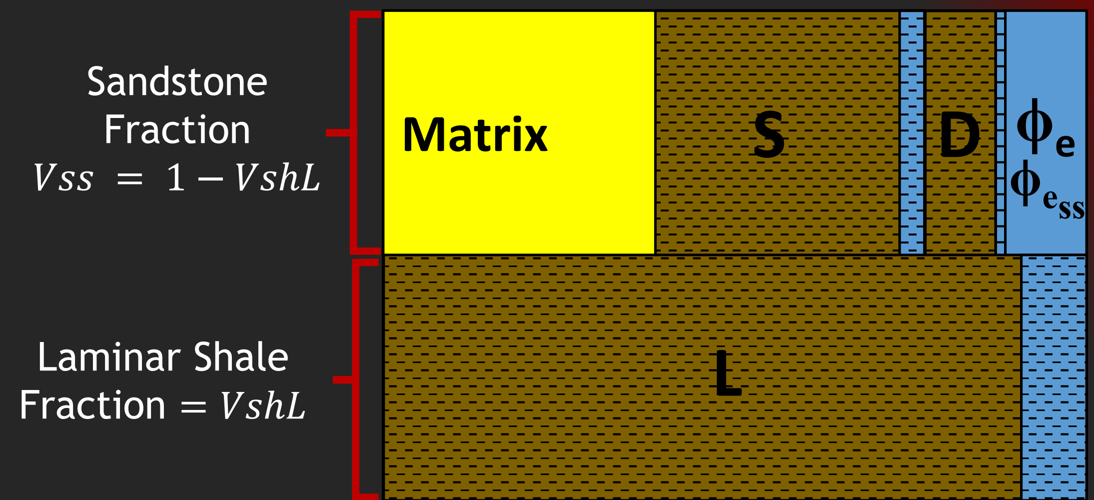




Effective Porosity

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

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

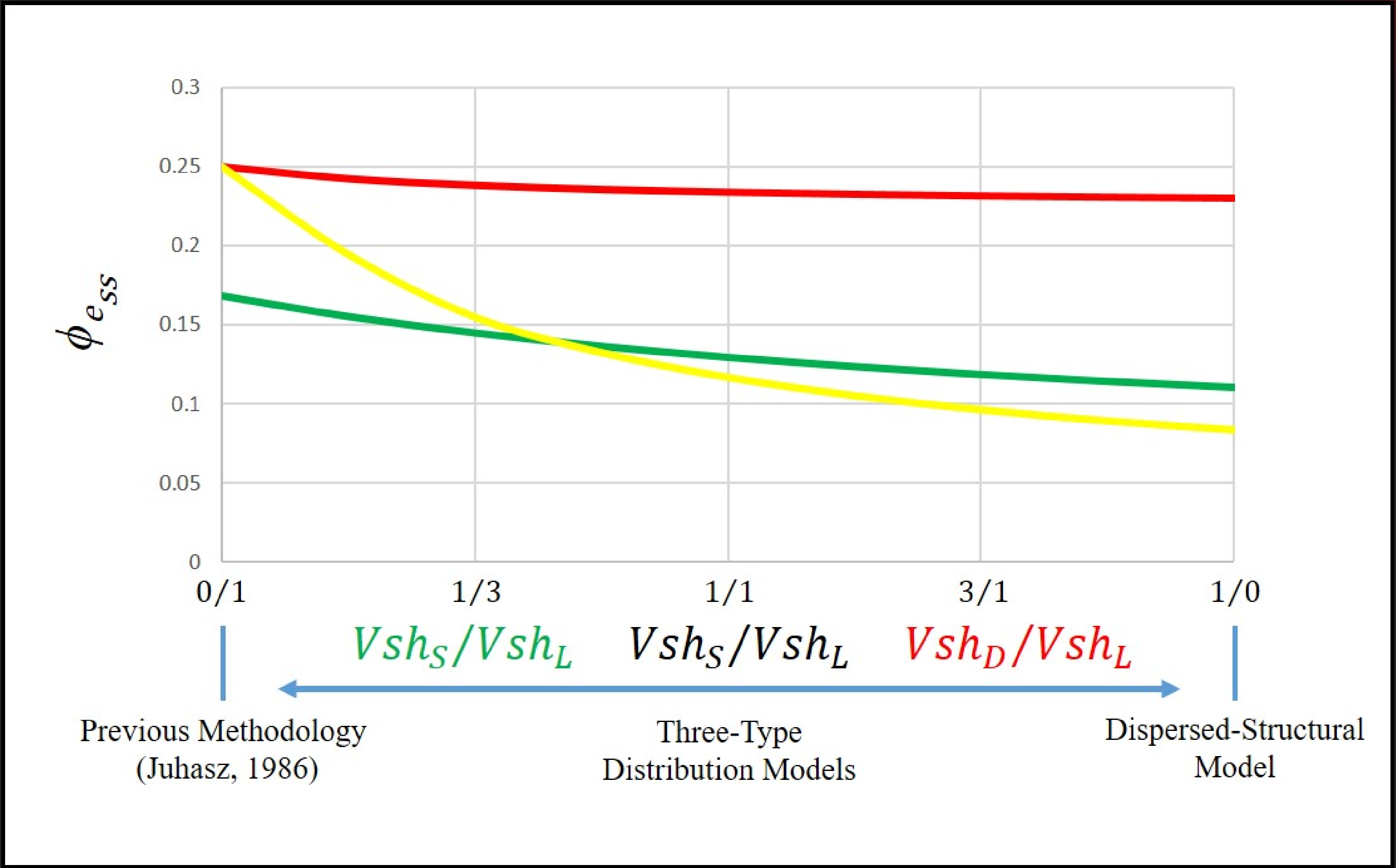


$$\phi_{e_{ss}} = \frac{\phi_e}{1 - Vsh_L}$$

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

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

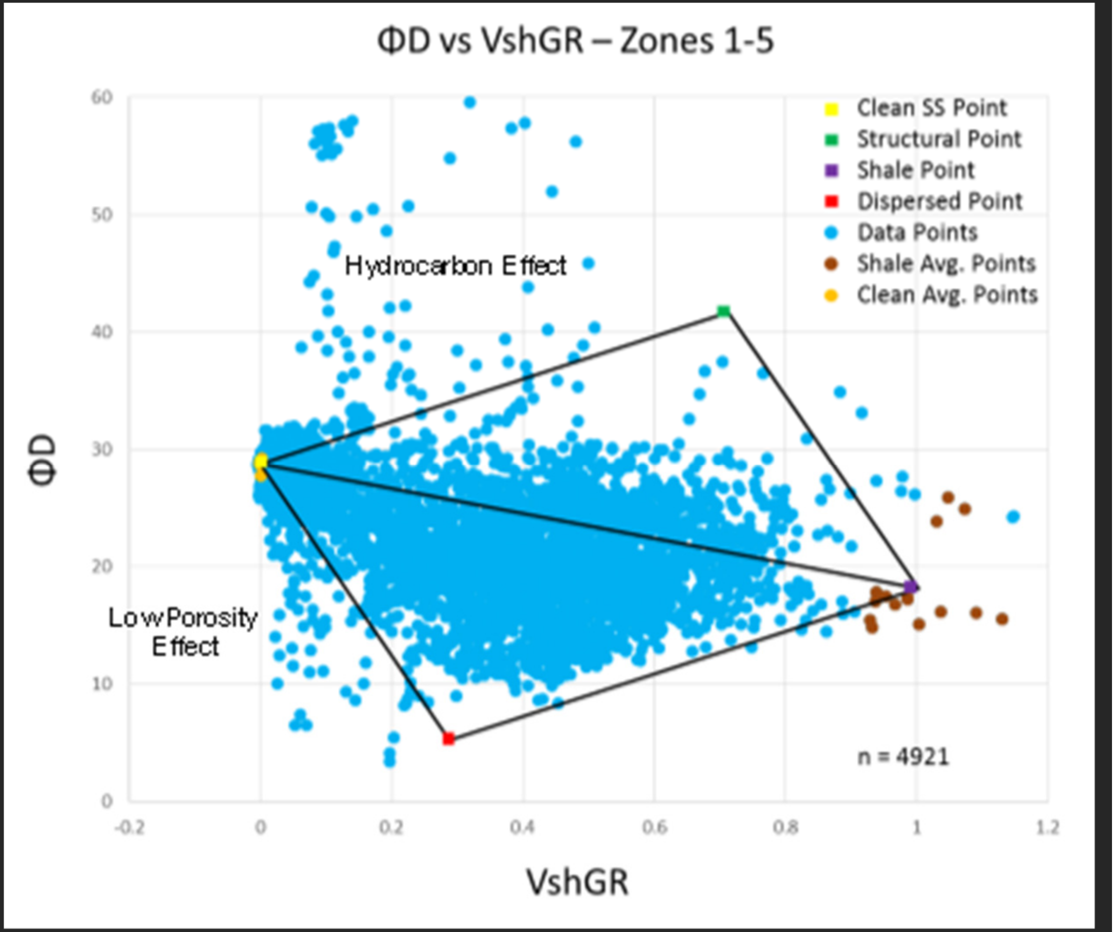
Shale Distribution Implications toward Effective Porosity

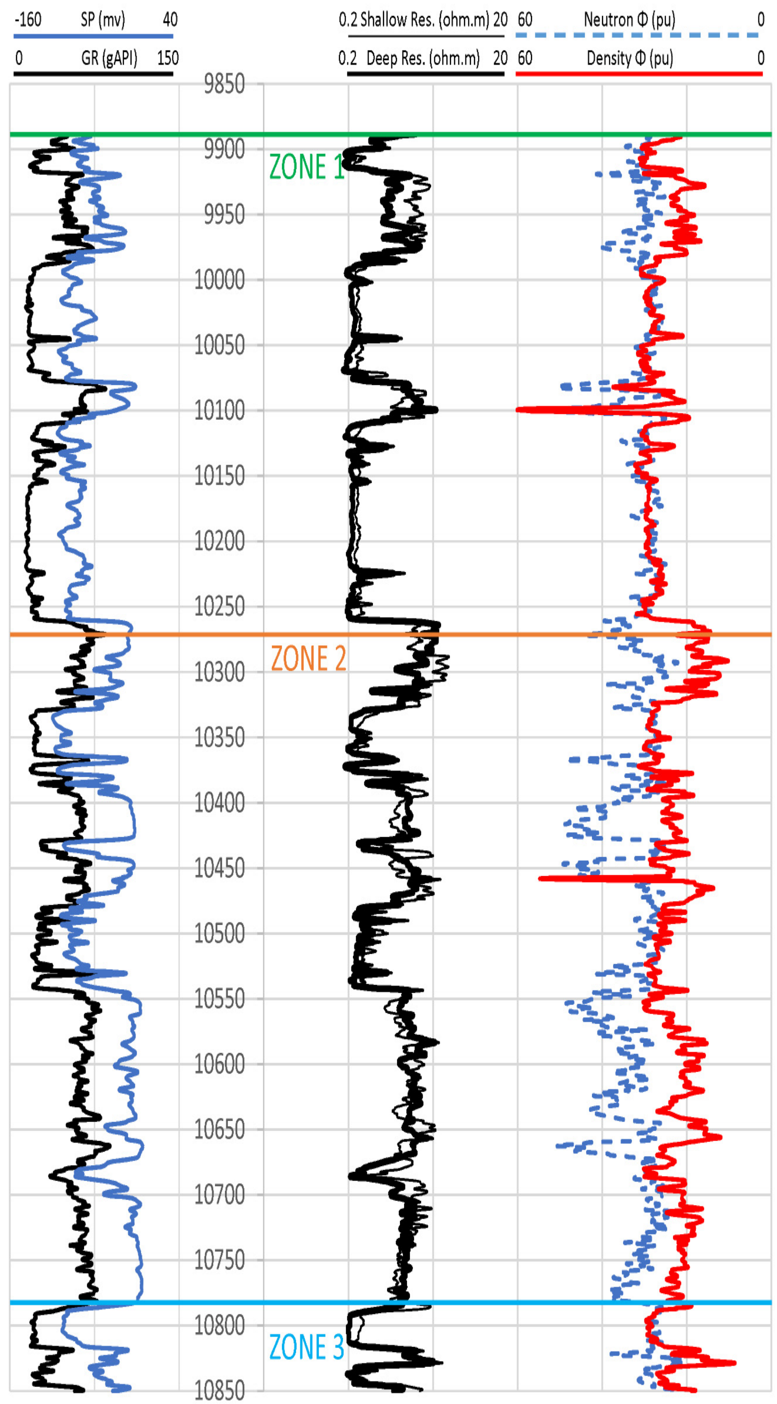


Application of Revised Methodology on Sandstone Case Studies

Case 1: Show Permission Denied
Case 2: Onshore Louisiana
Case 3: Deepwater GOM
Case 4: Onshore Louisiana

Case Study 2
Onshore Louisiana (Triple-Combo Log Data)





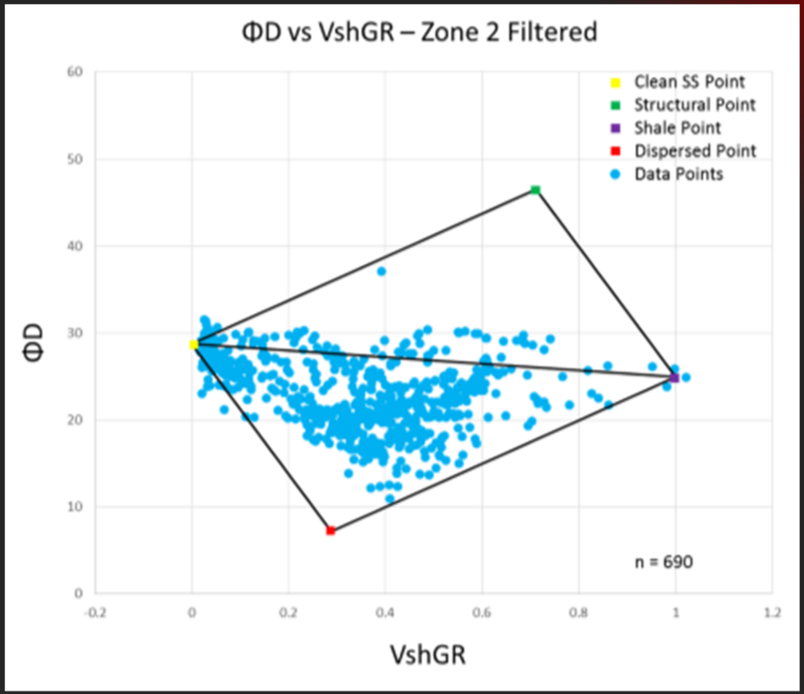
ϕ_d vs. V_{sh-gr}

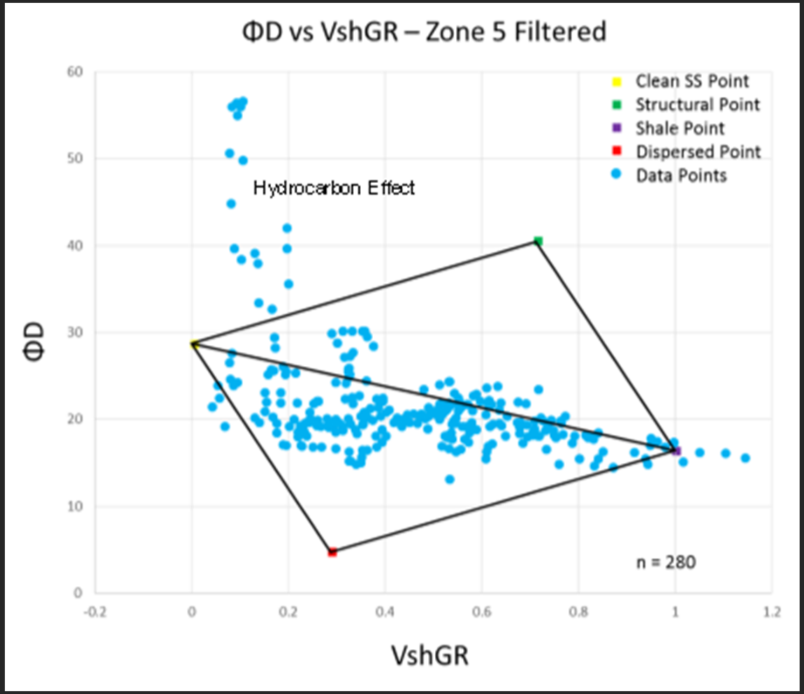
<u>(TOP) Zones 1-4</u>

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

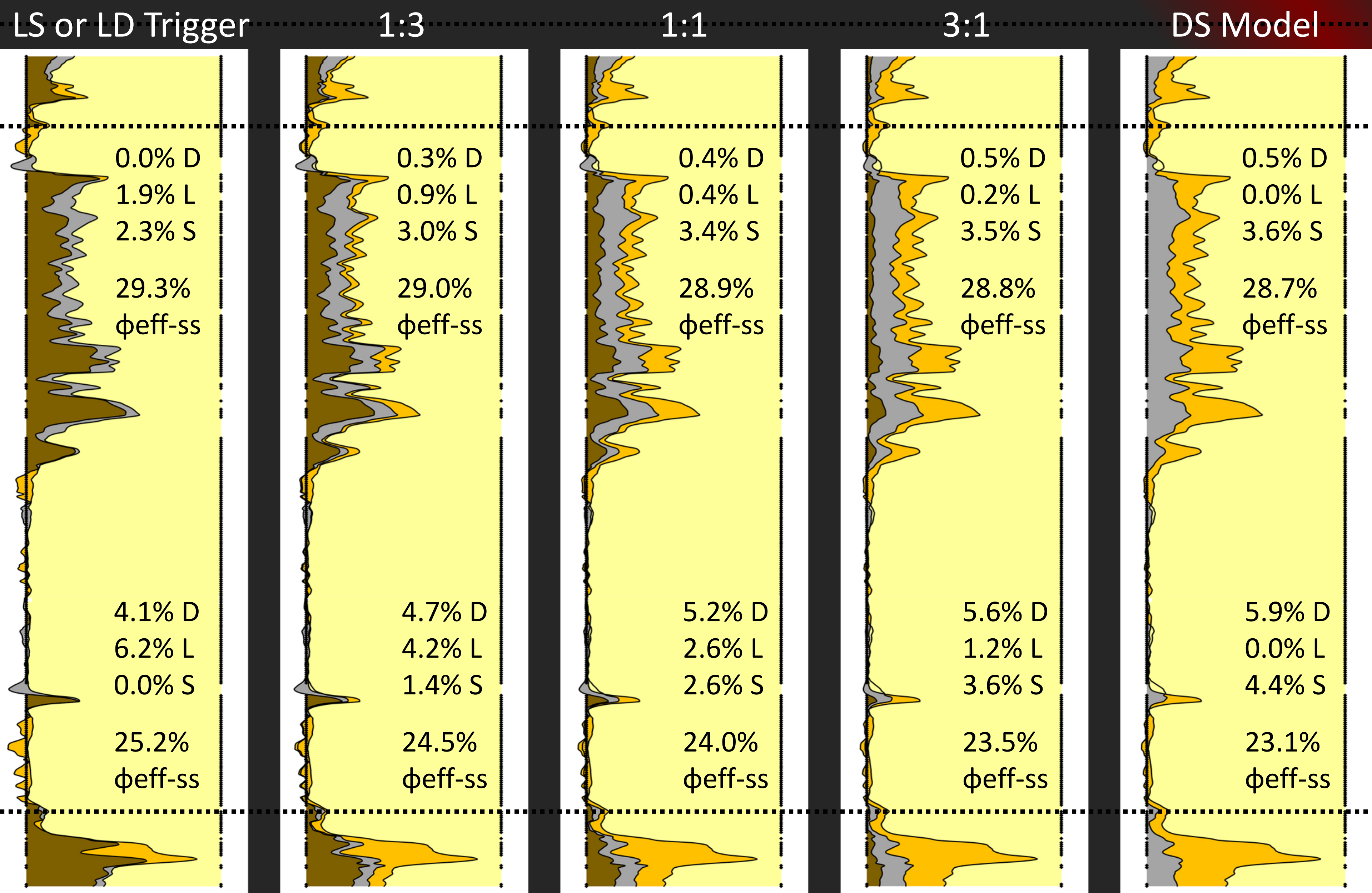
<u>(BOTTOM) (Zone 5)</u>

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

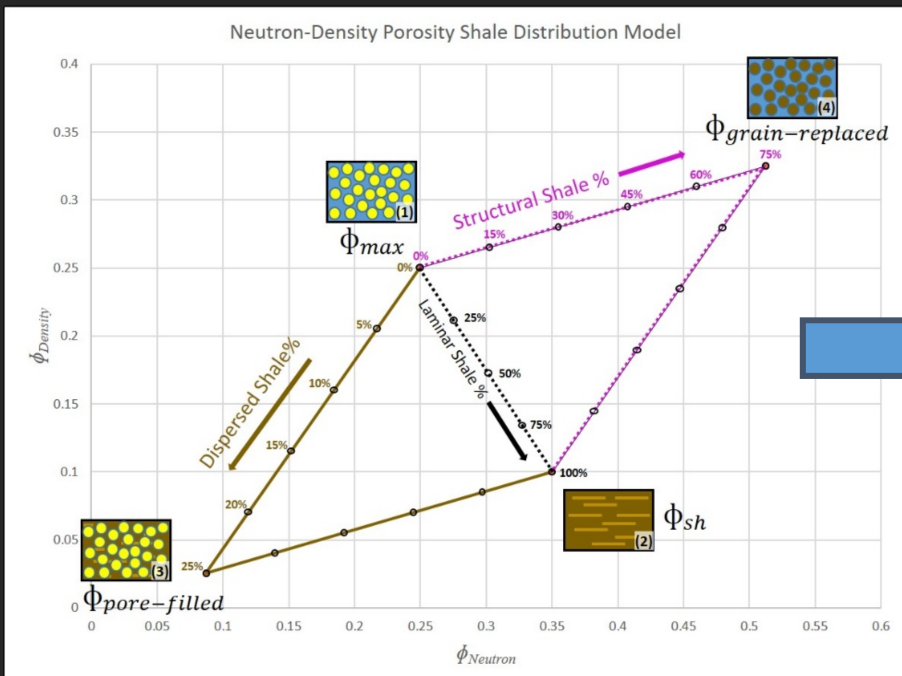




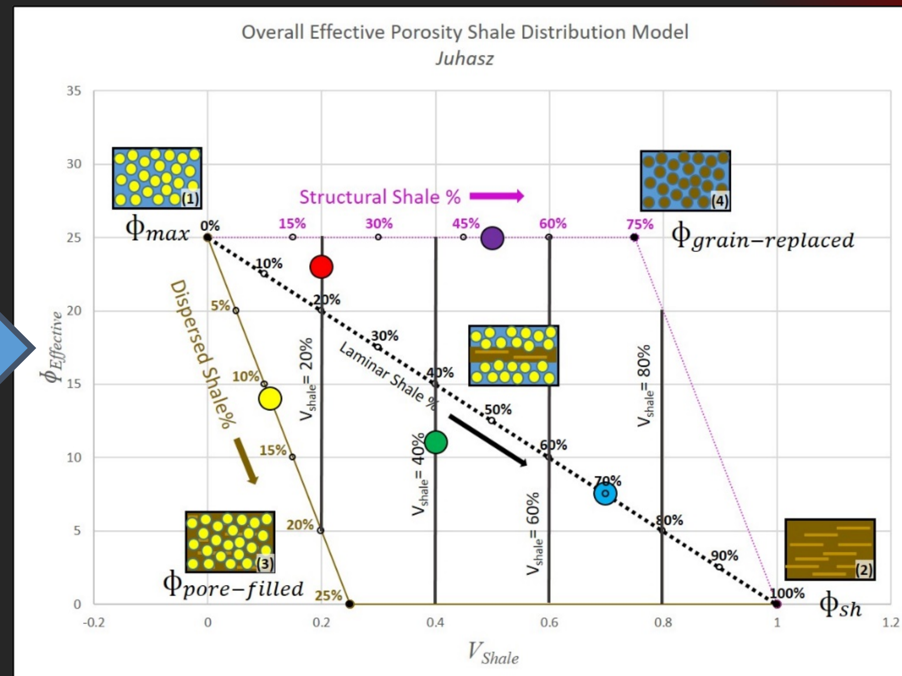
Ratio Analysis and Effective Porosity



Transform ND Crossplot to ND Effective Porosity versus ND Vsh



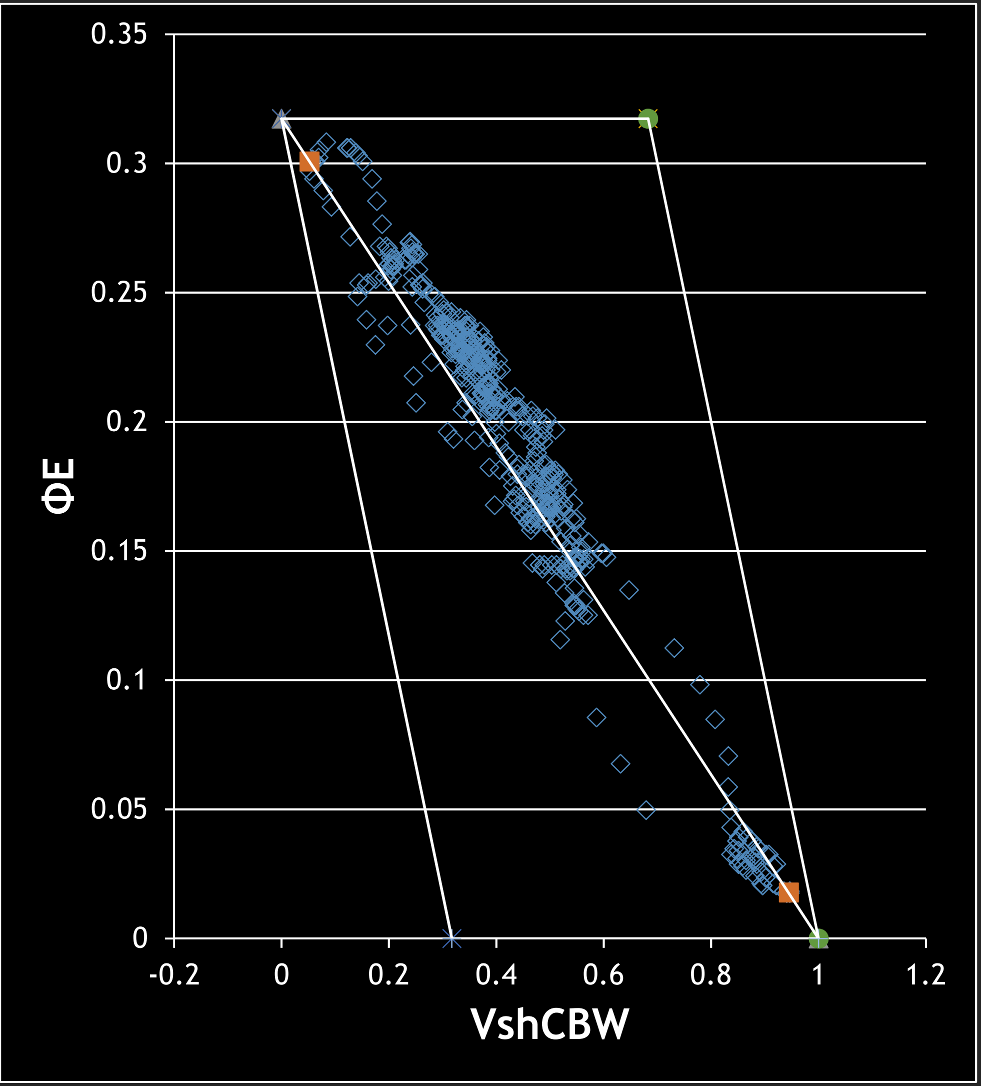
Density Porosity versus Neutron Porosity

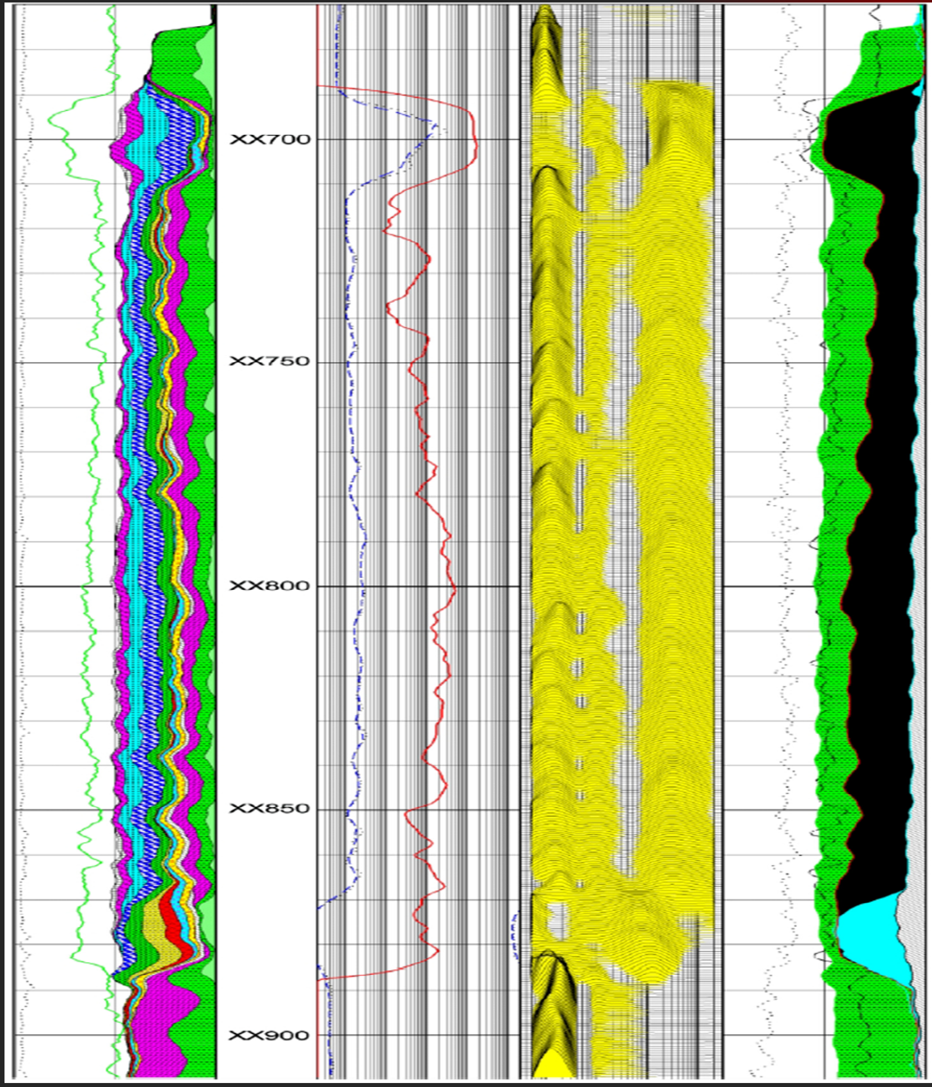


ND Effective Porosity versus ND Volume of Shale

- Allows comparison to other source data on same crossplot (e.g., NMR-derived effective porosity versus Vsh CBW.

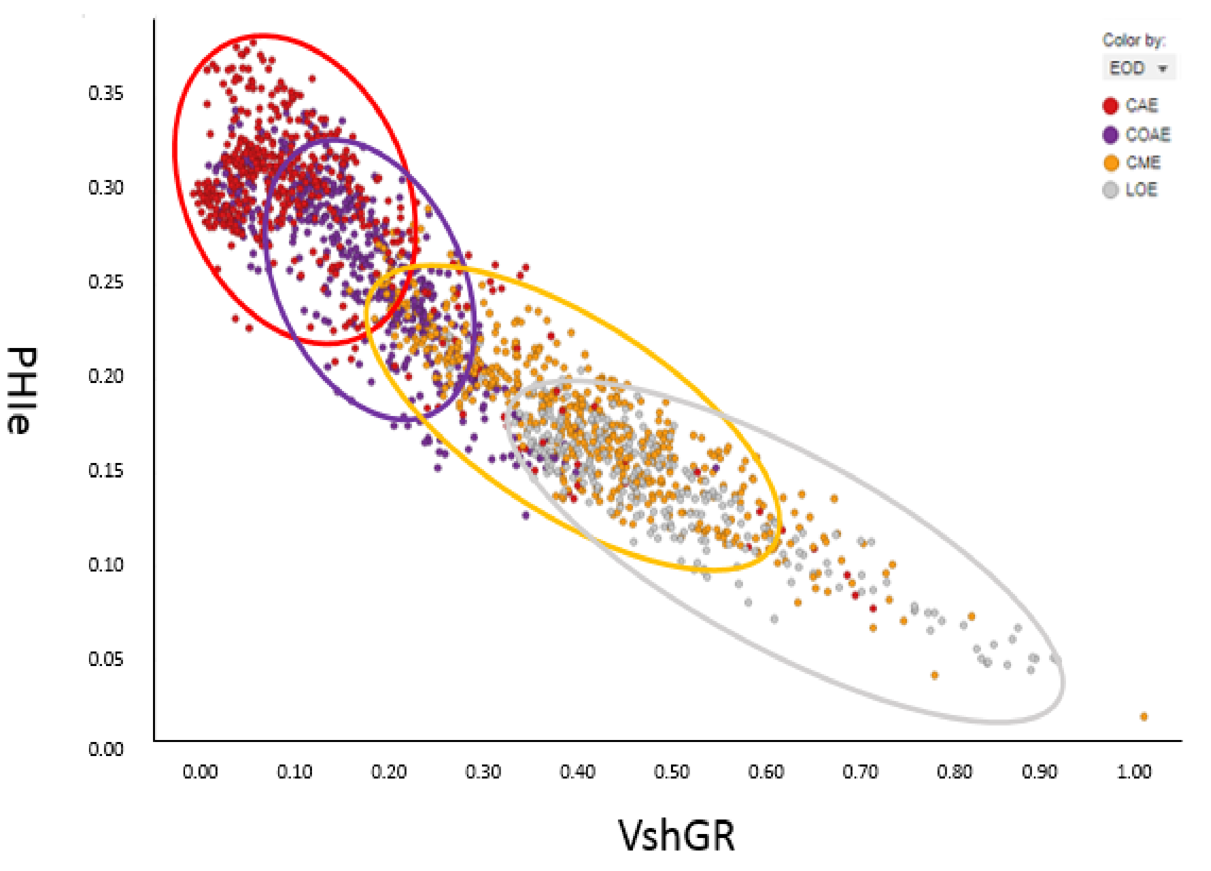
Case Study 2
Deepwater GOM (includes NMR)





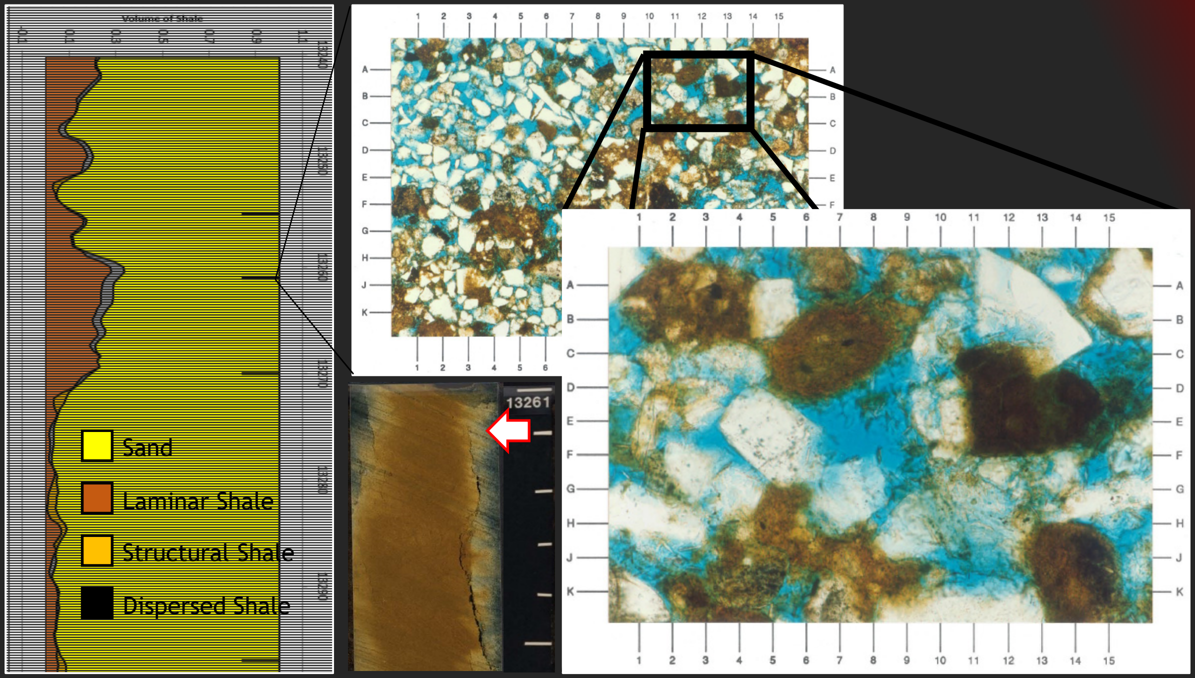
Case Study 3
Deepwater GOM (includes core)

- Utilized VshT curve shape to evaluate well location within a deepwater system
- Utilized this system to evaluate well positions relative to channel-axis
- When these interpretations were plotted on the Φe vs VshT Rhombus, a clear distinction of EOD type can be distinguished
  - Red: Axis
  - Purple: Off-Axis
  - Gold: Margin
  - Grey: Levee



Three-Type Models in Cored Intervals

- Thin sections were used and compared to the Trigger Model (black ticks on the right represent thin section depths)
- The Trigger Model predicts that shale in this interval is Laminar-Dispersed with no Structural shale present
- Yet thin section clearly shows some Structural shale



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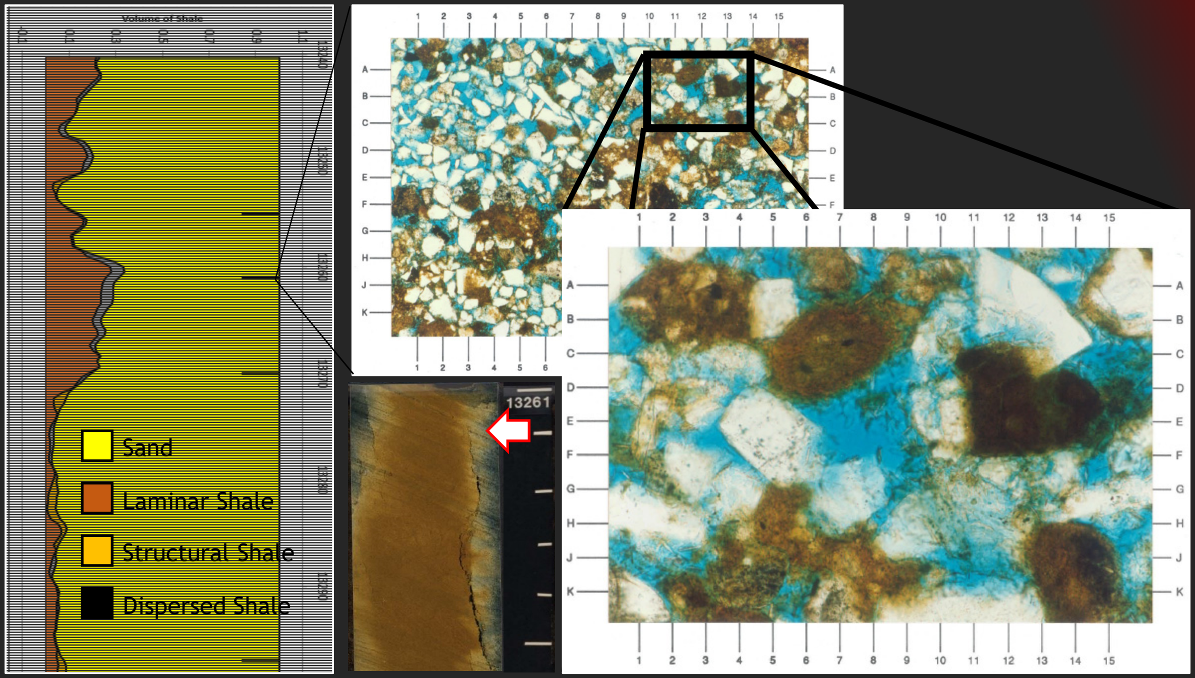
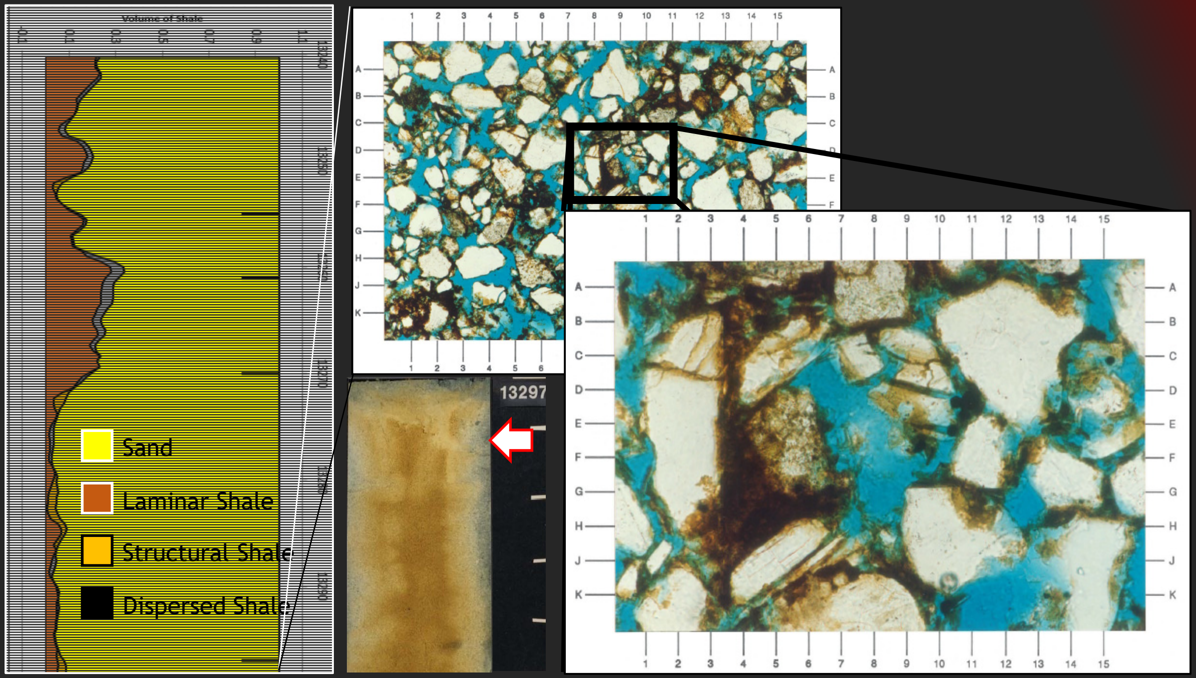


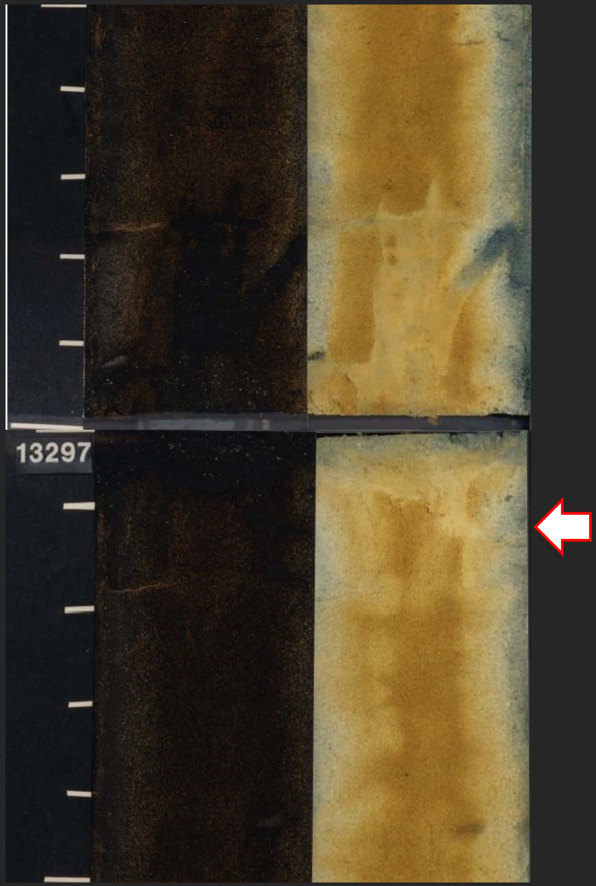
Three-Type Models in Cored Intervals

- Thin sections were used and compared to the Trigger Model (black ticks on the right represent thin section depths)
- The Trigger Model predicts that shale in this interval is Laminar-Structural with no Dispersed shale present
- Yet, thin section shows some Dispersed shale



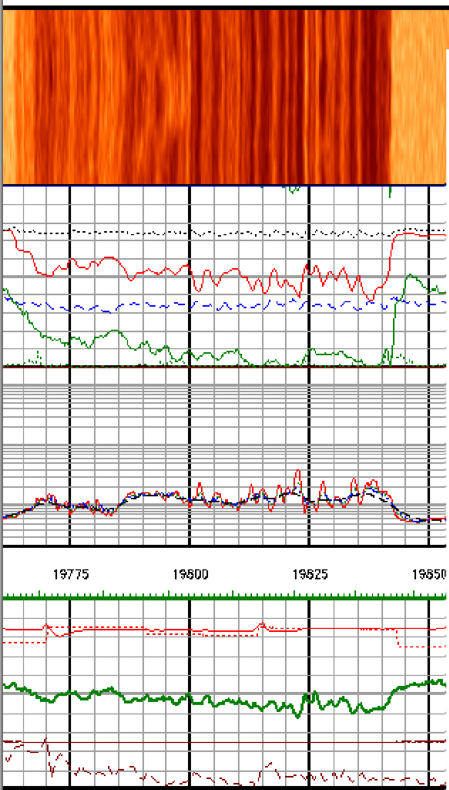
Three-Type Models in Cored Intervals

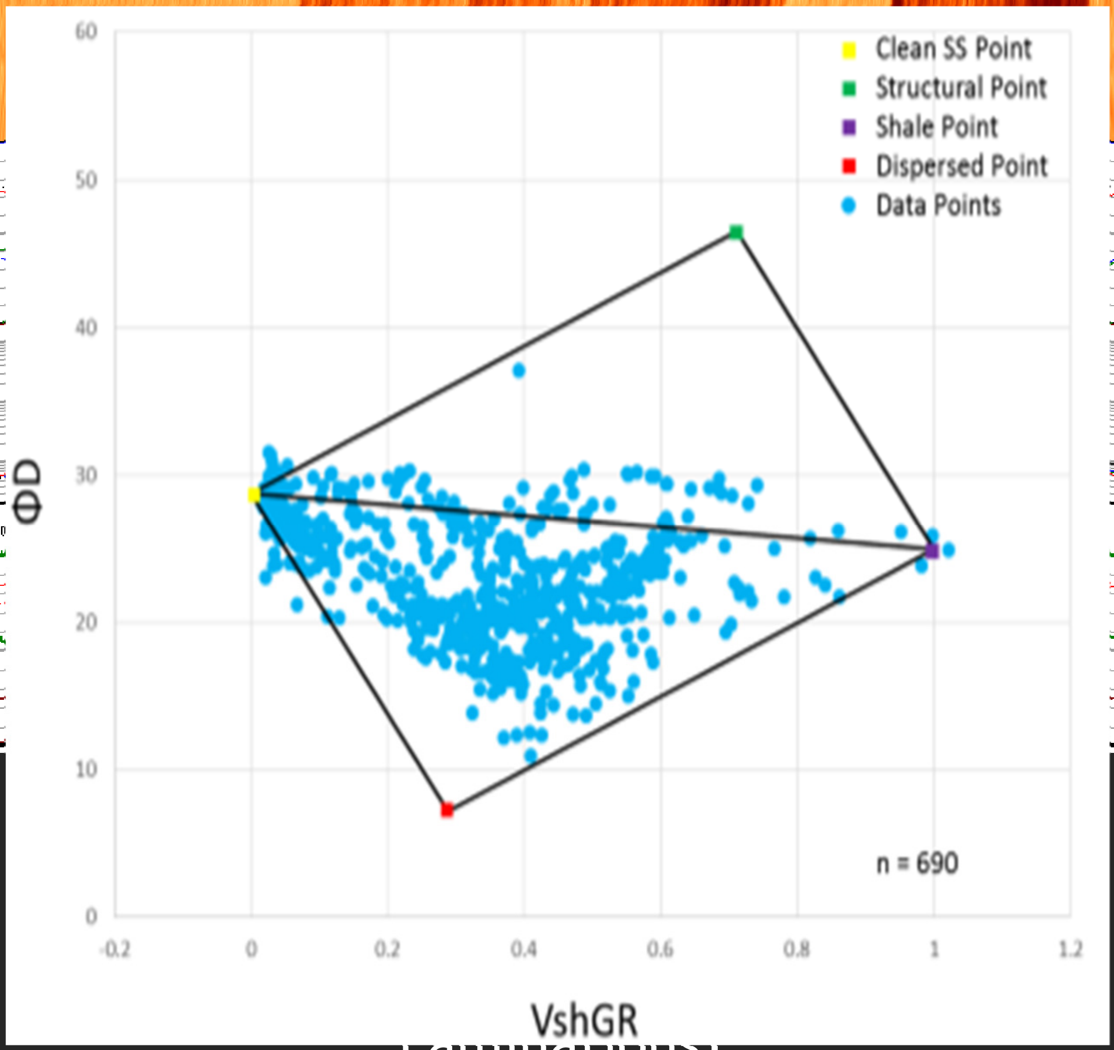
- Trigger model predicted Laminar shale in Massive Sands.
- Yet, Core showed no laminations.
- Dispersed-Structural model applies.

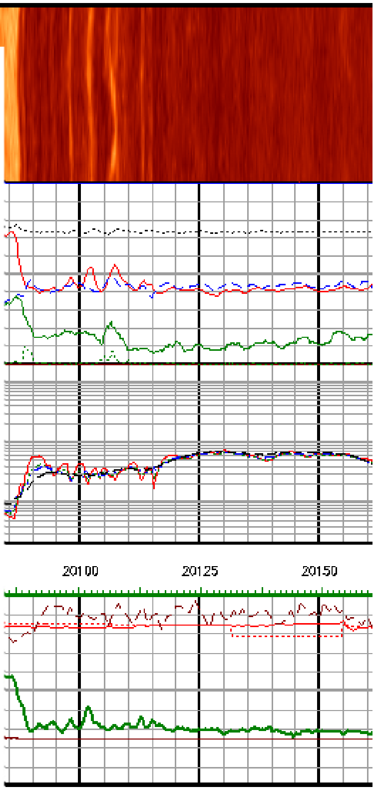


Model	Φe-ss
Trigger	33.0%
1:9	32.5%
1:3	32.0%
1:1	31.6%
3:1	31.3%
DS	31.1%

Additional Tools
Image Log Integration





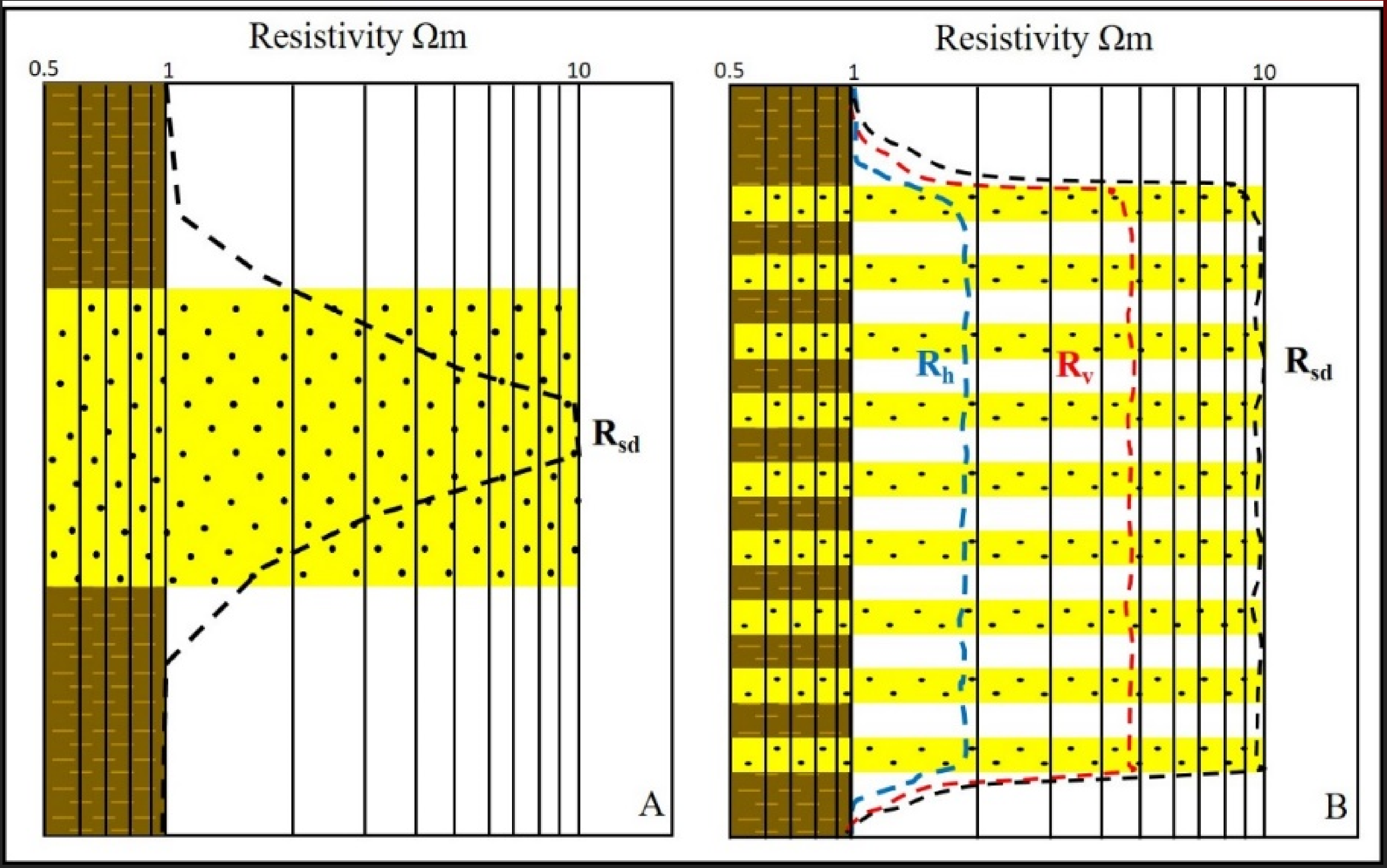


Laminated Sequence

Laminations)

Clean Massive Sand

Additional Tools
Resistivity Anisotropy



Able to independently constrain laminar shale volume

Summary

Earlier deterministic approaches 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.

→ Our plan is to release open-access software to perform this analysis.