Influence of Shale Distribution Types on the Effective Porosity of Sandstone Reservoirs

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ABSTRACT

Most previous work that analyzed the effect of the three distribution types of shale—dispersed, structural, and laminar—within a sandstone reservoir only considered quantification using either single-type distribution or either laminar-dispersed or laminar-structural two-type distribution models. Only recently has it been quantitatively analyzed for the third two-type distribution model, namely structural-dispersed, and the implications of three-type distribution by using a straightforward deterministic approach, involving total porosity versus shale volume graphical crossplot and mathematical analysis. We derived the relationships within an effective porosity versus shale volume system and tested the methodology using a case study with conventional triple-combination, as well as nuclear magnetic resonance log data. Results indicated in this case study that, although the dominant shale distribution type was laminar shale, the presence of dispersed shale reduced the sandstone-fraction effective porosity and the presence of structural shale further reduced the useful sandstone-fraction porosity, as opposed to a laminar-dispersed or laminar-structural model that would yield the most optimistic result.

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Overview

- Nature & Significance of Problem
- Shale Distribution Types: Previous Work and Methodologies
- Methodology
  - Volume of Shale and Effective Porosity
  - Quantification of Shale Distribution Types
- Case Study
  - Nuclear Magnetic Resonance Log
  - Crossplots
  - Ratio Analysis
- Conclusions

Nature & Significance of Problem

Why Do Shale Distribution Types Matter?

- Common methodology leads to reservoir potential being ***overestimated***

Nuclear Magnetic Resonance Logs… Why not just use triple-combo?

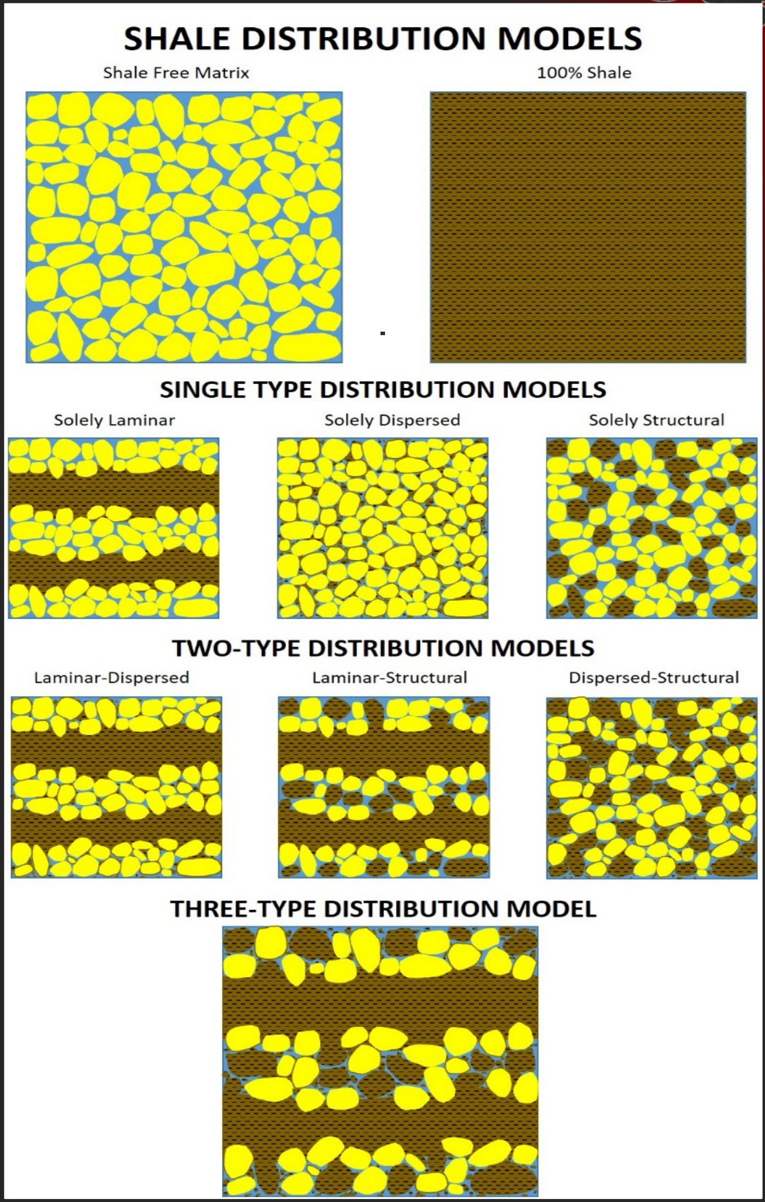
- Adding a new method of deriving volume of shale allows ***comparison*** of methodologies
- Adds potential for ***direct measurement*** of
  - Reservoir Fluids
  - Total & Effective Porosity
  - Clay Bound Water

Shale Distribution Types History

Thomas & Stieber (1975)
- Defined Laminar, Dispersed, & Structural Shale
- Acknowledged All Combinations
  - Ignored Structural Shale
- Used Total Porosity vs Vsh to Define Laminar-Dispersed System

Juhasz (1986)
- Used Total Porosity vs Vsh & Effective Porosity vs Vsh
- Quantified All Single-Type Models
- Quantified Two-Type Models
  - Laminar-Dispersed
  - Laminar-Structural

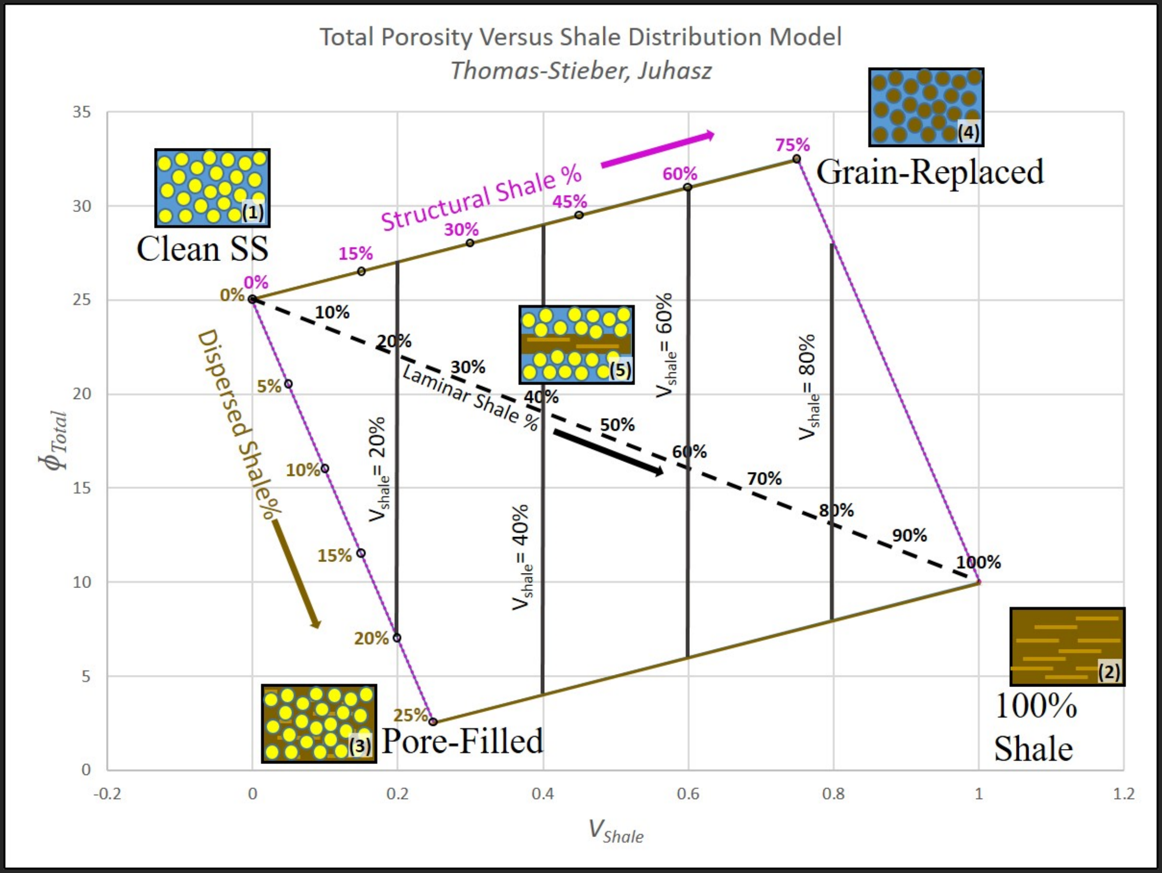
McIntosh (2017)
- Used Total Porosity vs Vsh
- Quantified Two-Type Model
  - Dispersed-Structural
- Quantified Three-Type Model in Two Scenarios
  - Three-Type: Dispersed-Required
  - Three-Type: Structural-Required



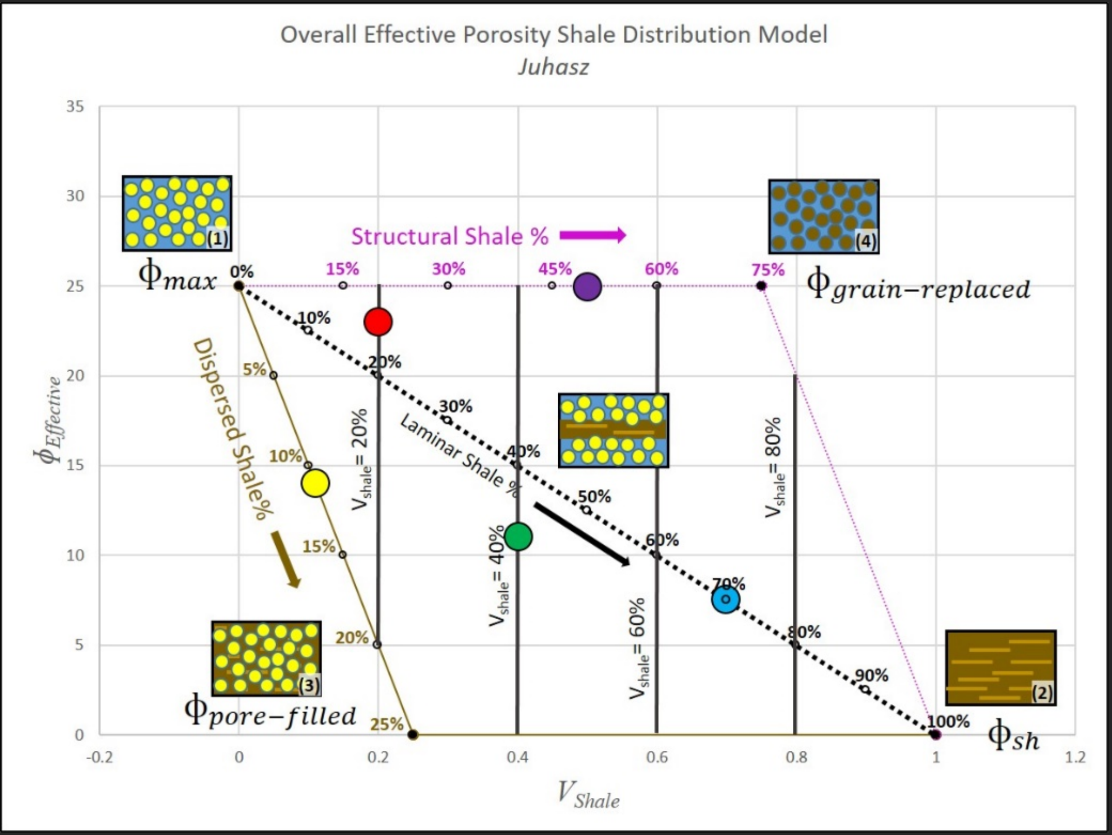
Total Porosity Rhombus

$$Vsh_T = Vsh_L + Vsh_D + Vsh_S$$

$$\Phi_{total} = \Phi_{SS}(1 - Vsh_L) - Vsh_D + \left(\Phi_{sh_D} * Vsh_D\right) + \left(\Phi_{sh_S} * Vsh_S\right) + \left(\Phi_{sh_L} * Vsh_L\right)$$



Effective Porosity Rhombus



$$Vsh_T = Vsh_L + Vsh_D + Vsh_S$$

$$\Phi_{effective} = \Phi_{total} - Vsh_T * \Phi_{sh}$$

$$\Phi_{effective} = \Phi_{SS}(1 - Vsh_L) - Vsh_D + (\Phi_{sh_D} * Vsh_D) + (\Phi_{sh_S} * Vsh_S) + (\Phi_{sh_L} * Vsh_L) - (\Phi_{sh_D} * Vsh_D) - (\Phi_{sh_S} * Vsh_S) - (\Phi_{sh_L} * Vsh_L)$$

$$\Phi_{effective} = \Phi_{SS}(1 - Vsh_L) - Vsh_D$$

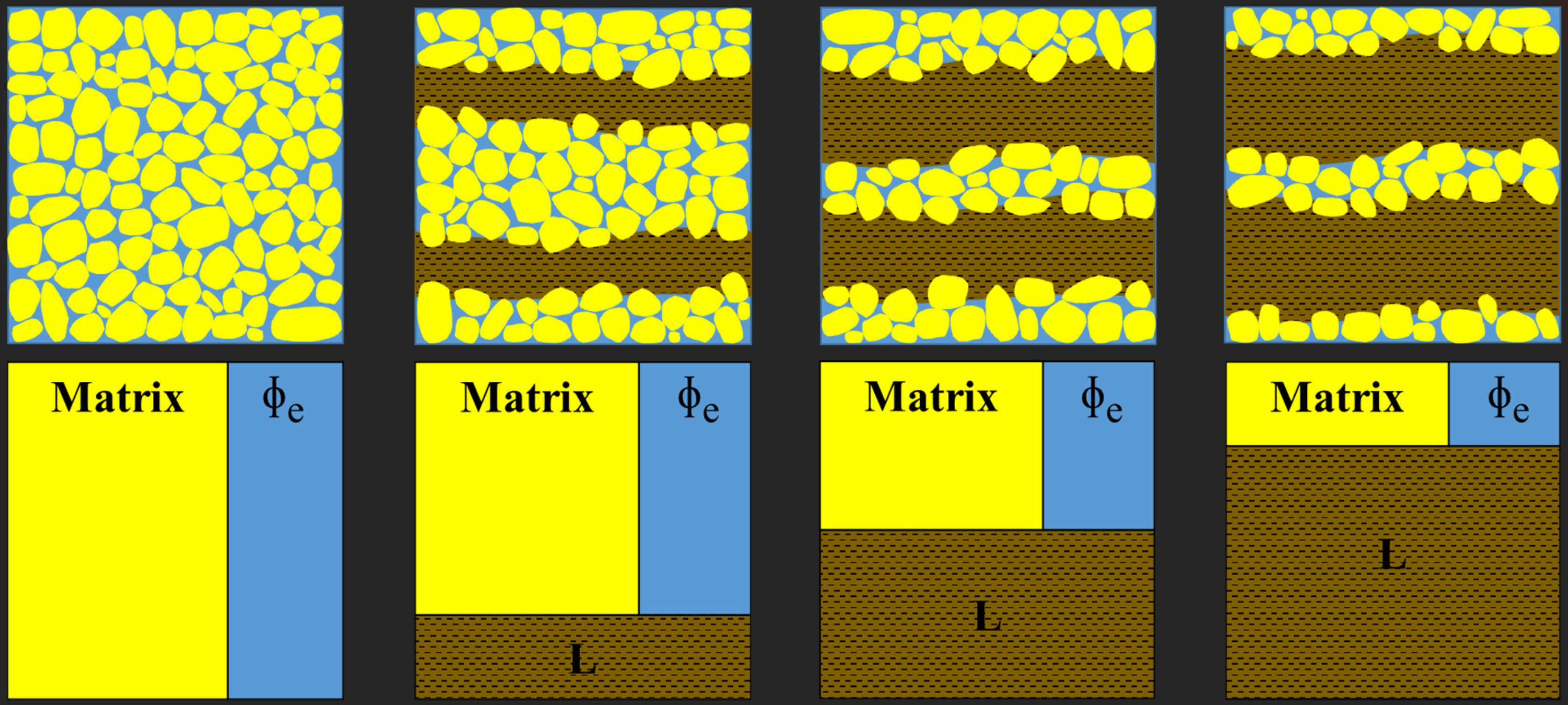
Single-Type Models

Laminar $Vsh_L = 1 - \frac{\Phi_{effective}}{\Phi_{SS}}$

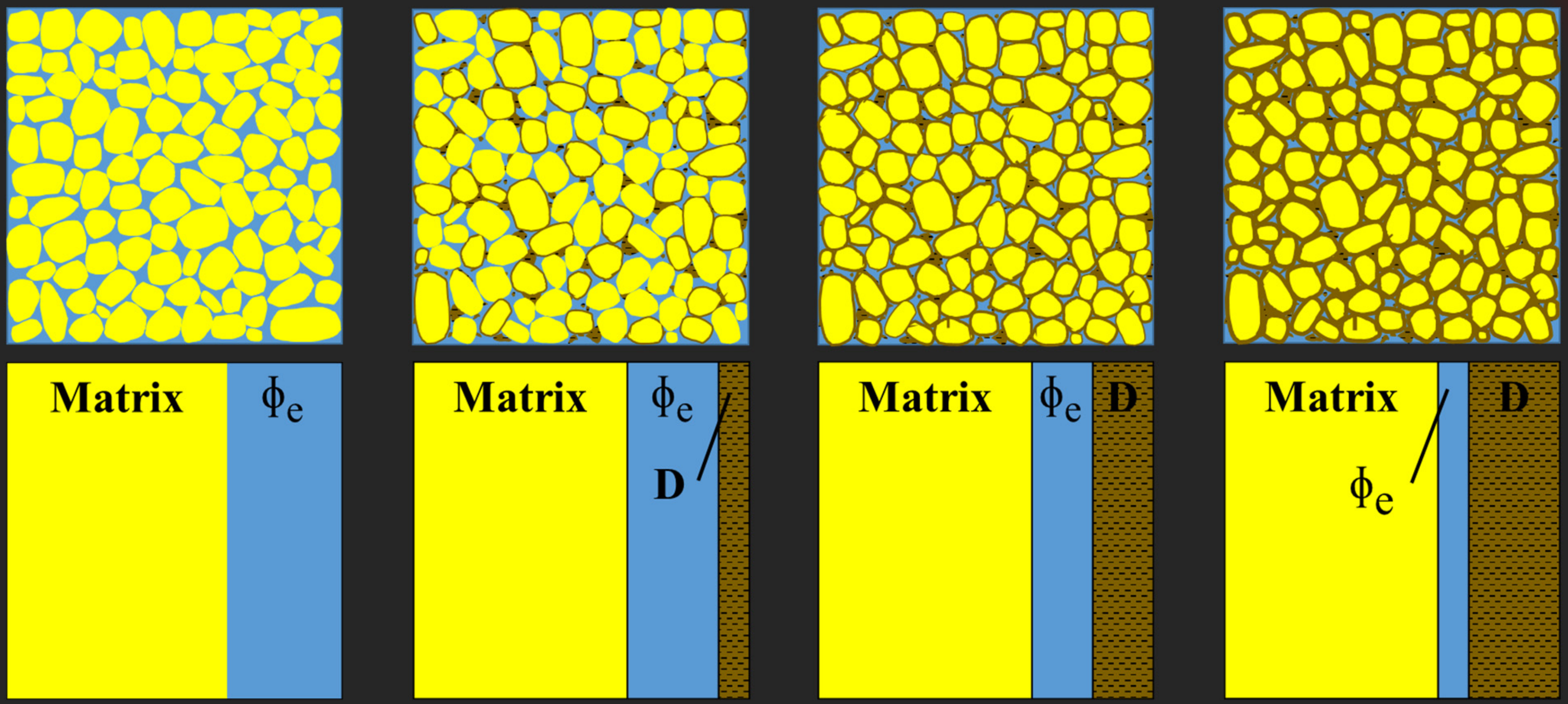
Dispersed $Vsh_D = \Phi_{SS} - \Phi_{effective}$

Structural $\Phi_{effective} = \Phi_{SS}$

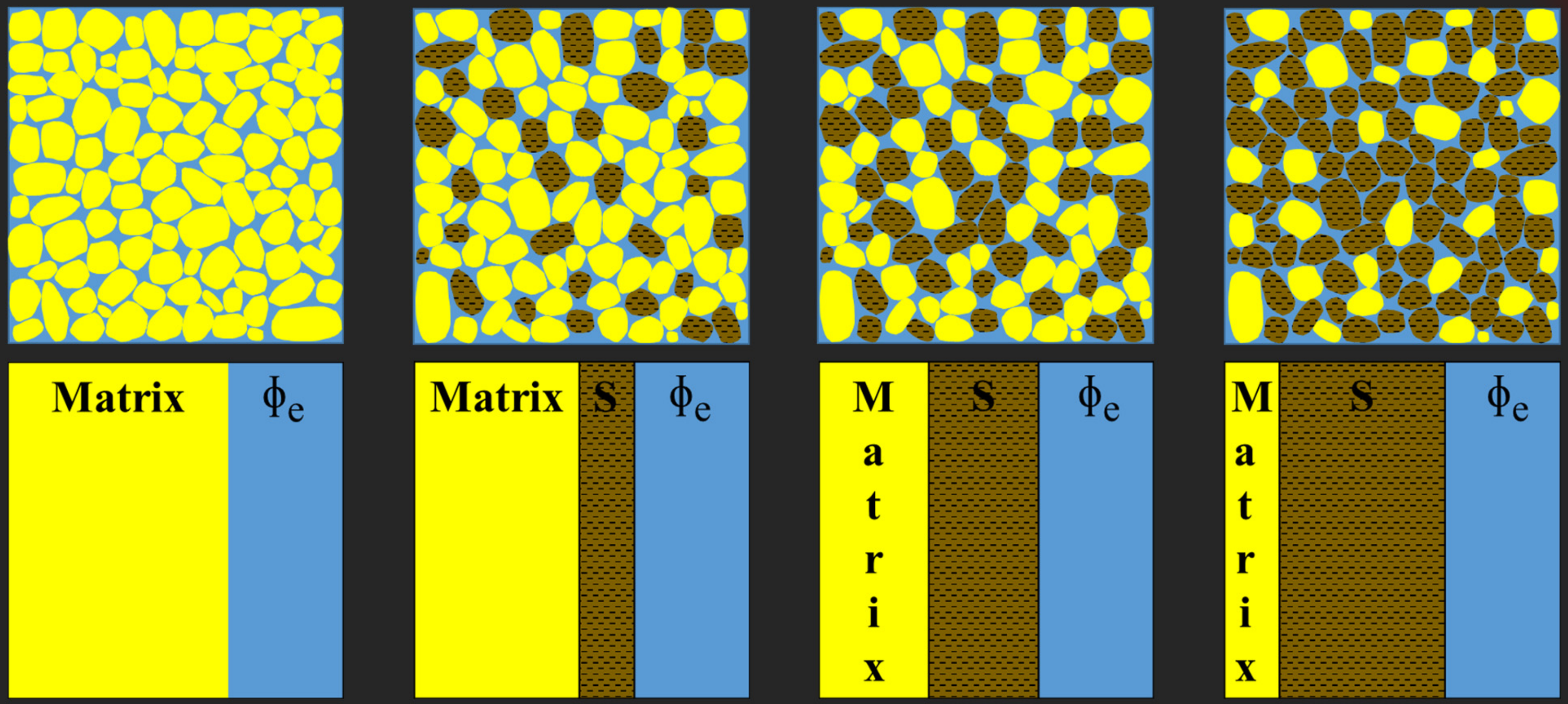
Increasing Laminar Shale



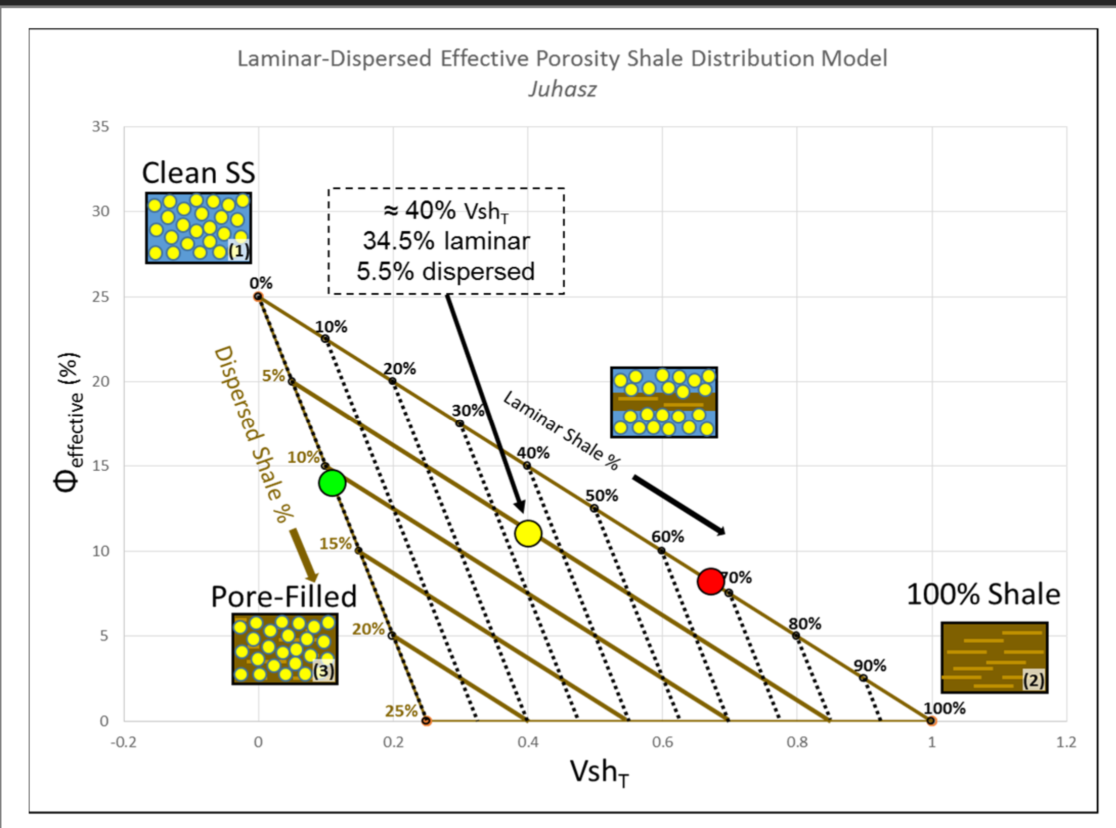
Increasing Dispersed Shale



Increasing Structural Shale



Laminar-Dispersed Model



$$Vsh_T = Vsh_L + Vsh_D + \cancel{Vsh_S}$$

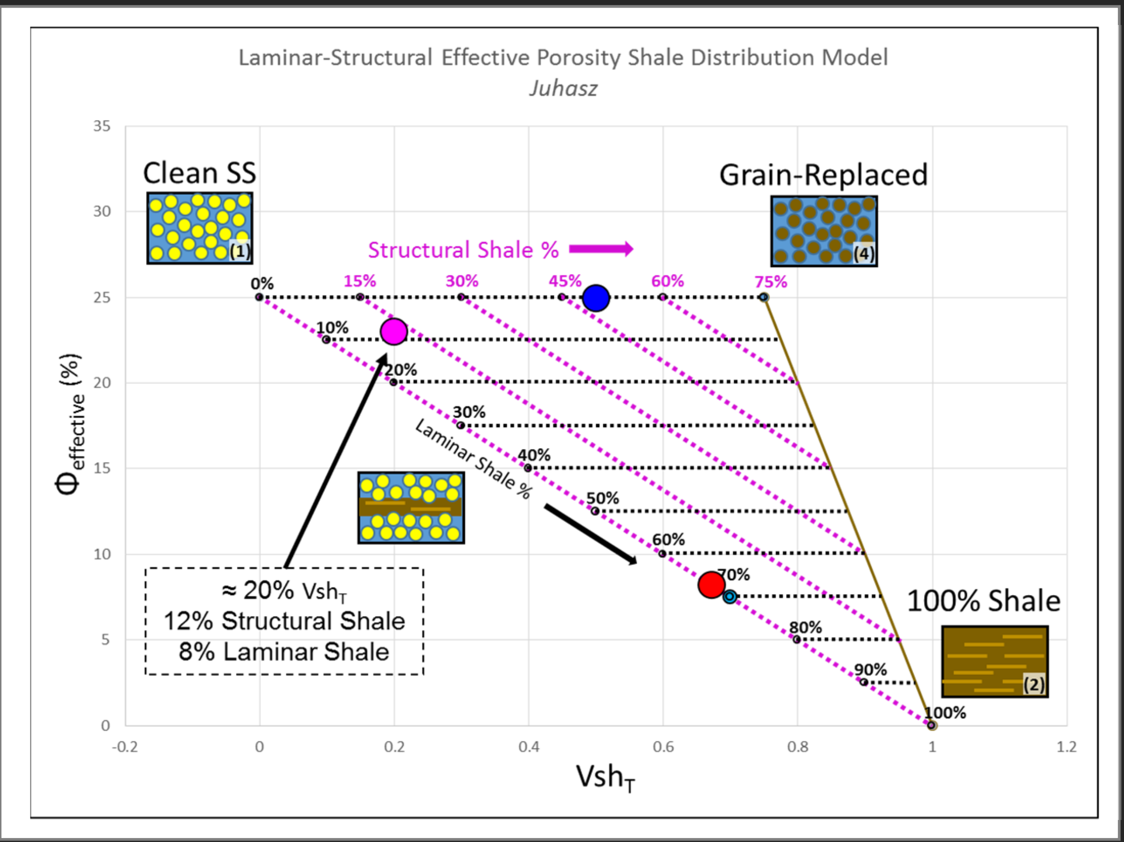
$$Vsh_D = Vsh_T - Vsh_L$$

$$\Phi_{effective} = \Phi_{ss}(1 - Vsh_L) - Vsh_D$$

$$\Phi_{effective} = \Phi_{ss}(1 - Vsh_L) - (Vsh_T - Vsh_L)$$

$$Vsh_L = \frac{\Phi_{effective} - \Phi_{ss} + Vsh_T}{1 - \Phi_{ss}}$$

Laminar-Structural Model



$$Vsh_T = Vsh_L + \cancel{Vsh_D} + Vsh_S$$

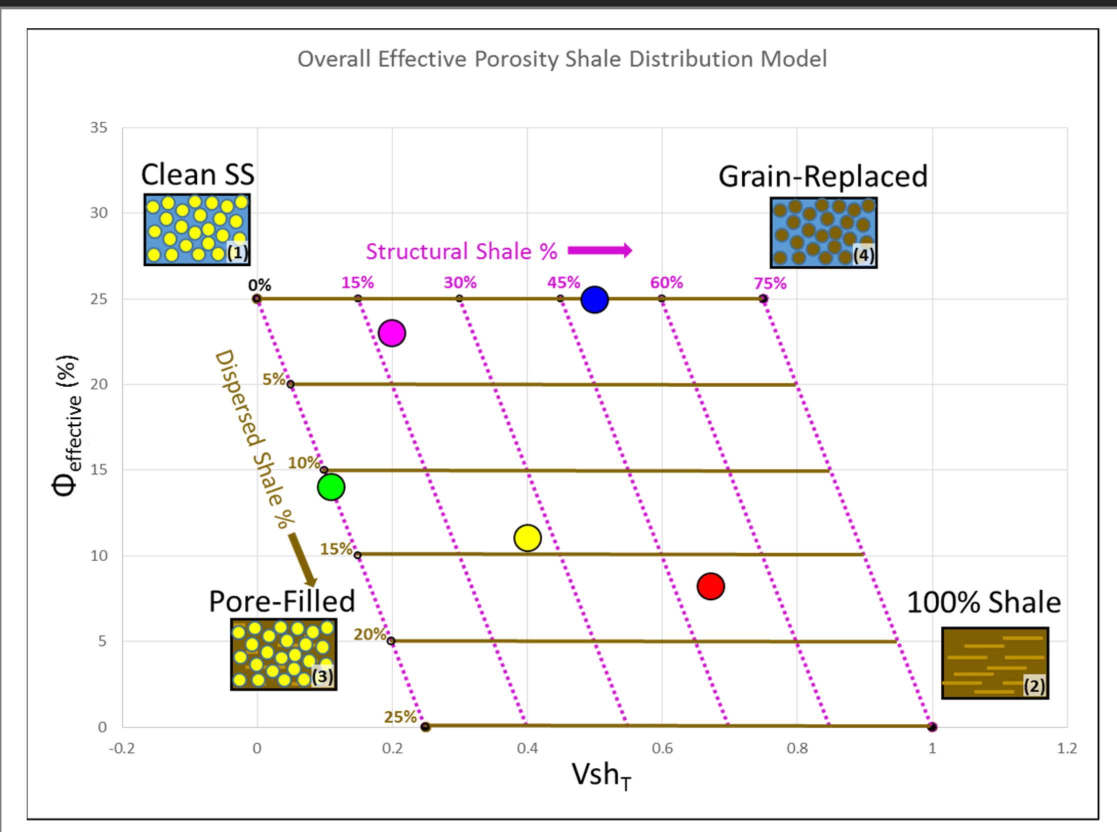
$$Vsh_L = Vsh_T - Vsh_S$$

$$\Phi_{effective} = \Phi_{ss}(1 - Vsh_L) - \cancel{Vsh_D}$$

$$\Phi_{effective} = \Phi_{ss}(1 - (Vsh_T - Vsh_S))$$

$$Vsh_S = \frac{\Phi effective}{\Phi ss} - Vsh_T - 1$$

Dispersed-Structural Model



$$Vsh_T = \cancel{Vsh_L} + Vsh_D + Vsh_S$$

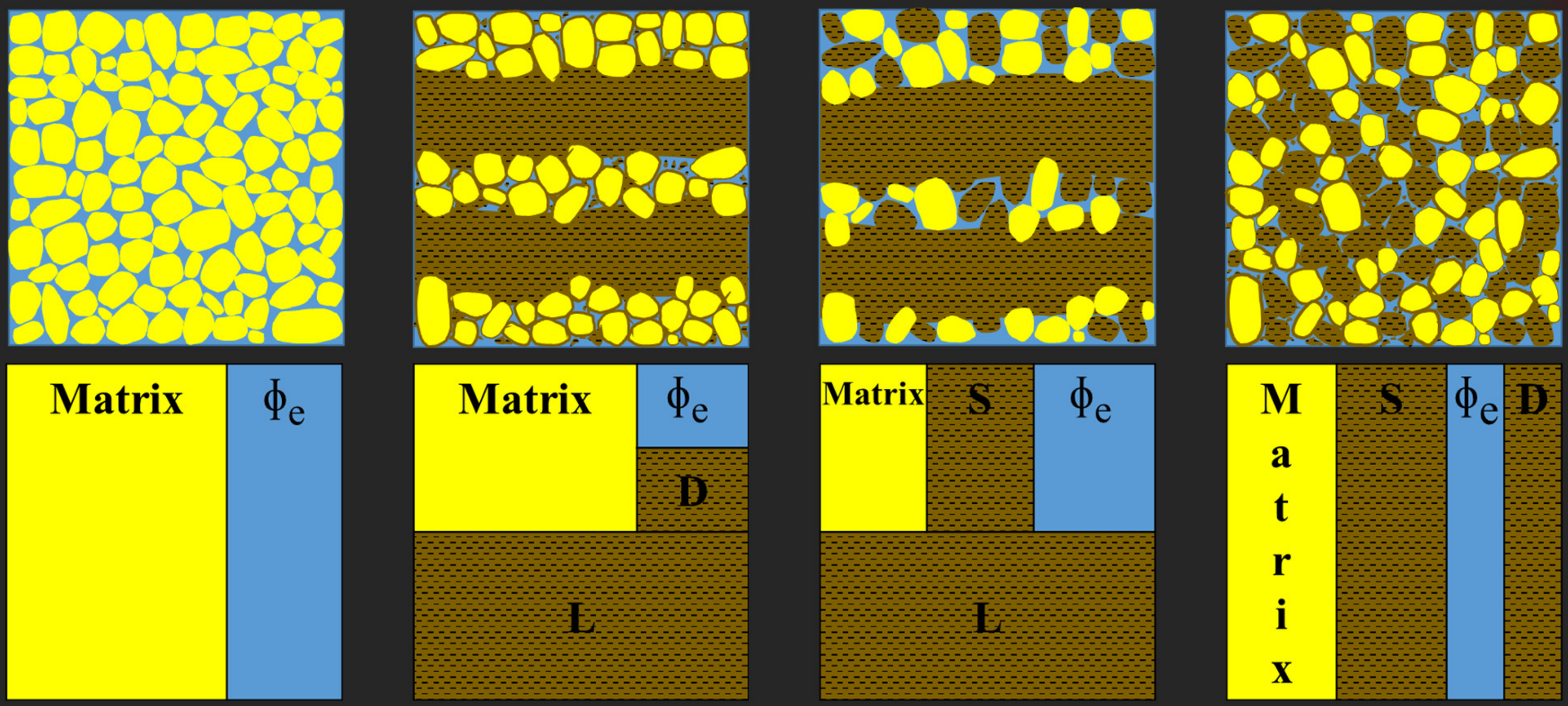
$$Vsh_D = Vsh_S - Vsh_T$$

$$\Phi_{effective} = \Phi_{ss}(1 - \cancel{Vsh_L}) - Vsh_D$$

$$\Phi_{effective} = \Phi_{ss} - (Vsh_S - Vsh_T)$$

$$Vsh_S = Vsh_T + \Phi_{ss} - \Phi_{effective}$$

Two-Type Models



Three-Type System Example: Dispersed-Required

$$Vsh_T = Vsh_L + Vsh_D + Vsh_S$$

$$R = \frac{Vsh_S}{Vsh_L}$$

$$Vsh_S = R * Vsh_L$$

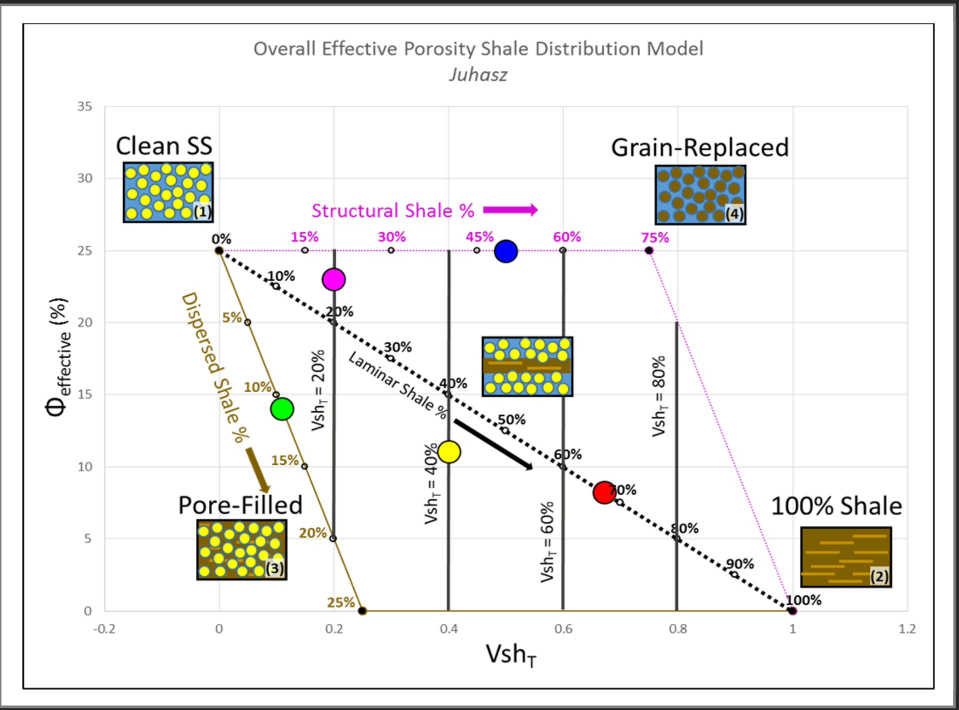
$$Vsh_T = Vsh_L + Vsh_D + R * Vsh_L$$

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

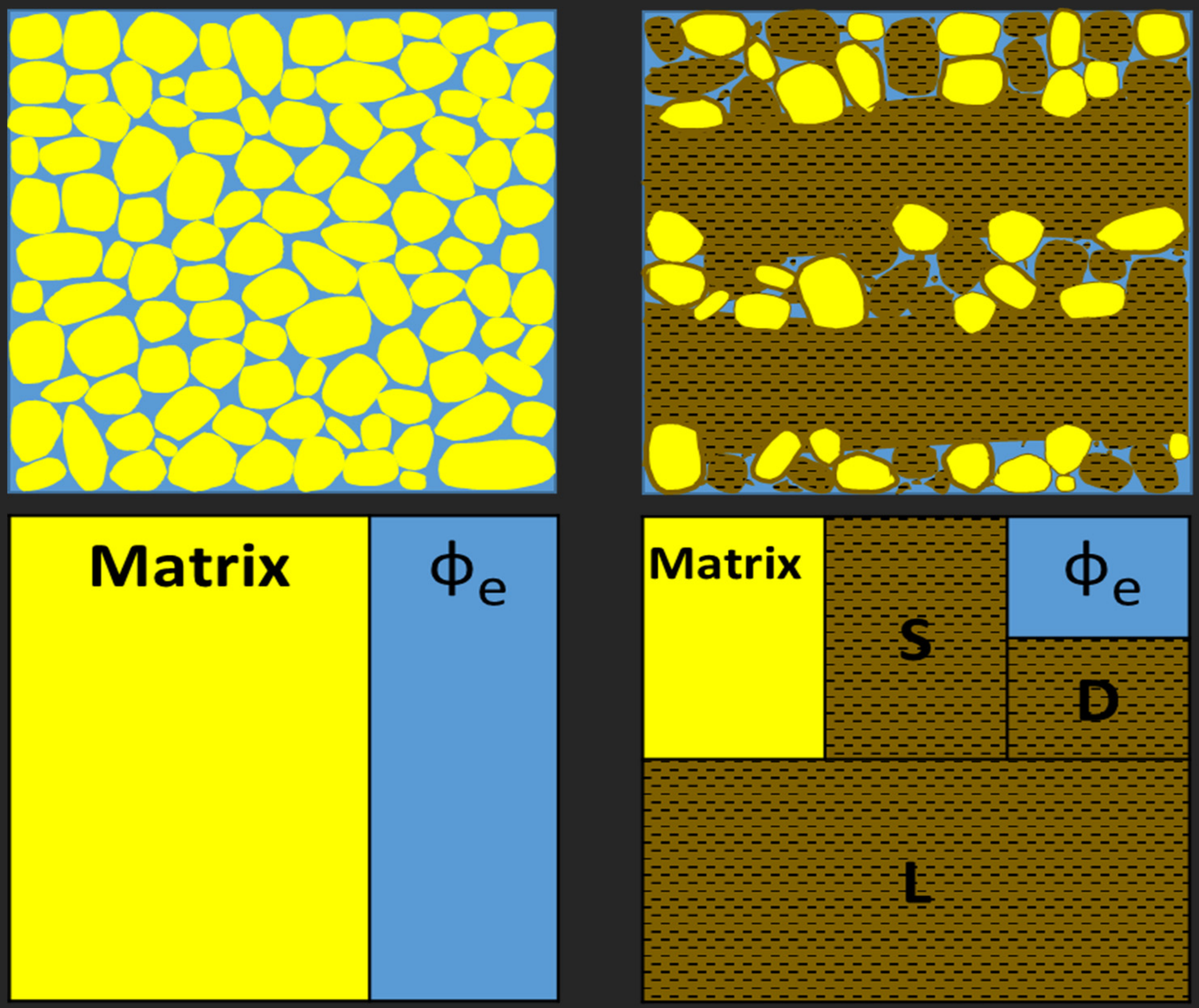
$$\Phi_{effective} = \Phi_{ss}(1 - Vsh_L) - Vsh_D$$

$$\Phi_{effective} = \Phi_{ss}\left(1 - \frac{Vsh_T - Vsh_D}{1+R}\right) - Vsh_D$$

$$Vsh_D = \frac{\Phi_{ss}(1+R-Vsh_T) - \Phi_{effective}(1+R)}{1+R-\Phi_{ss}}$$



Shale Distribution Type Effect on Matrix & Effective Porosity



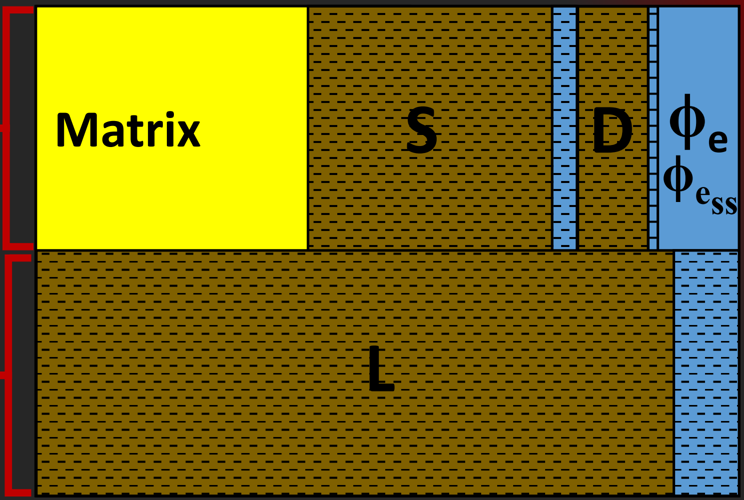
Sandstone Fraction Effective Porosity

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

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

Sandstone Fraction $Vss = 1 - VshL$

Laminar Shale Fraction $= VshL$



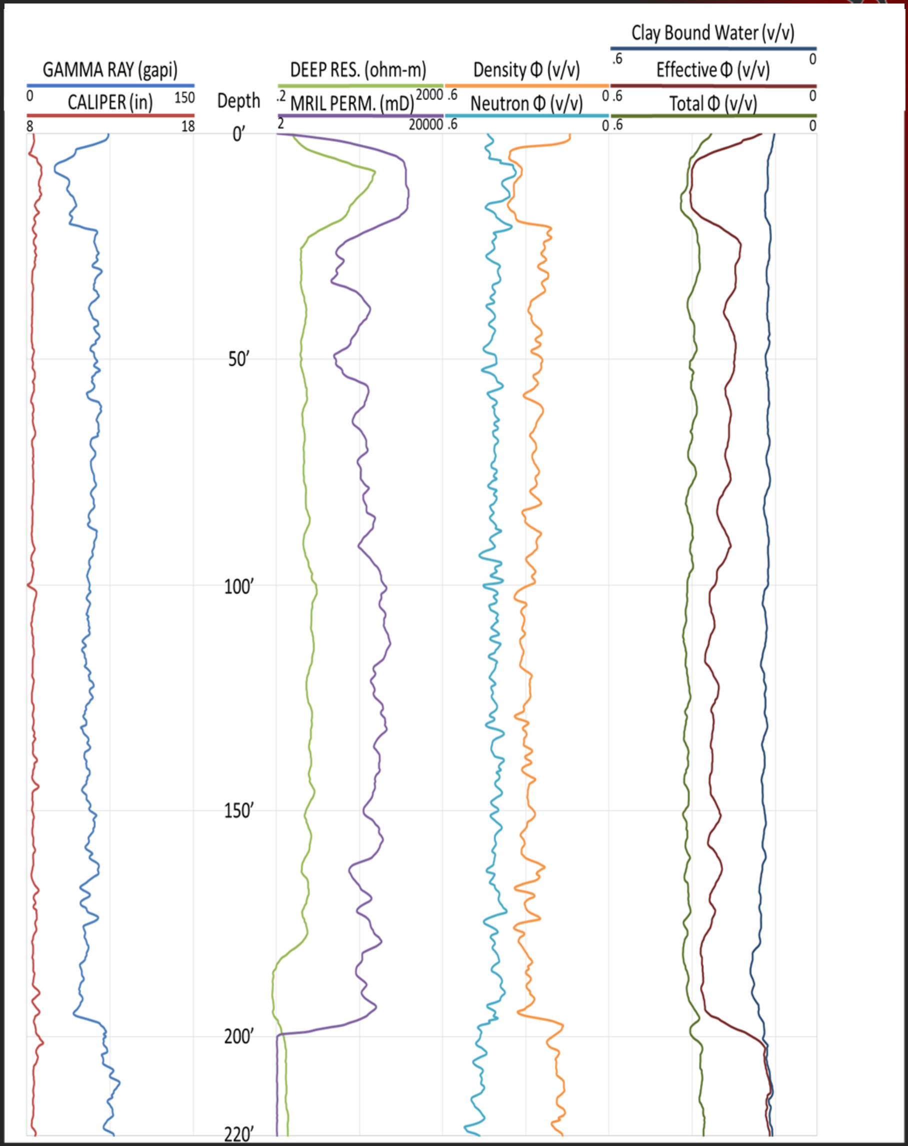
$$\phi_{e_{ss}} = \frac{\phi_e}{1 - Vsh_L}$$

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

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

Case Study

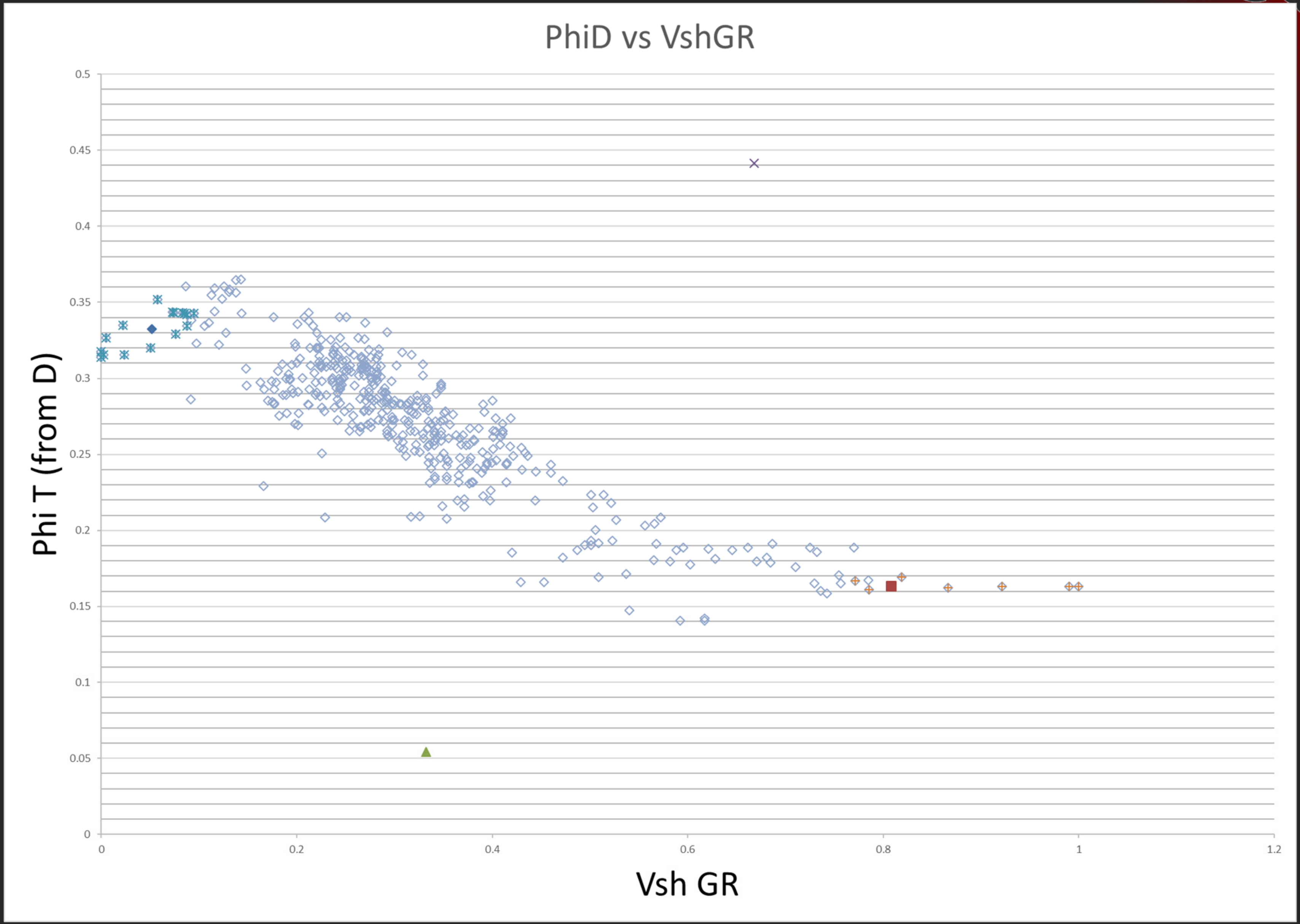
- 222’ logged section, mostly hydrocarbon bearing from GOM
  - Triple Combo Log
    - Φ_{total} vs Vsh_{GR}
    - $\Phi_{effective}$ (from Φ_D vs Vsh_{GR})
    - $\Phi_{effective}$ (from Φ_{ND} vs Vsh_{GR})
  - Nuclear Magnetic Resonance Log
    - Φ_{total} vs Vsh_{CBW}
    - $\Phi_{effective}$ vs Vsh_{CBW}



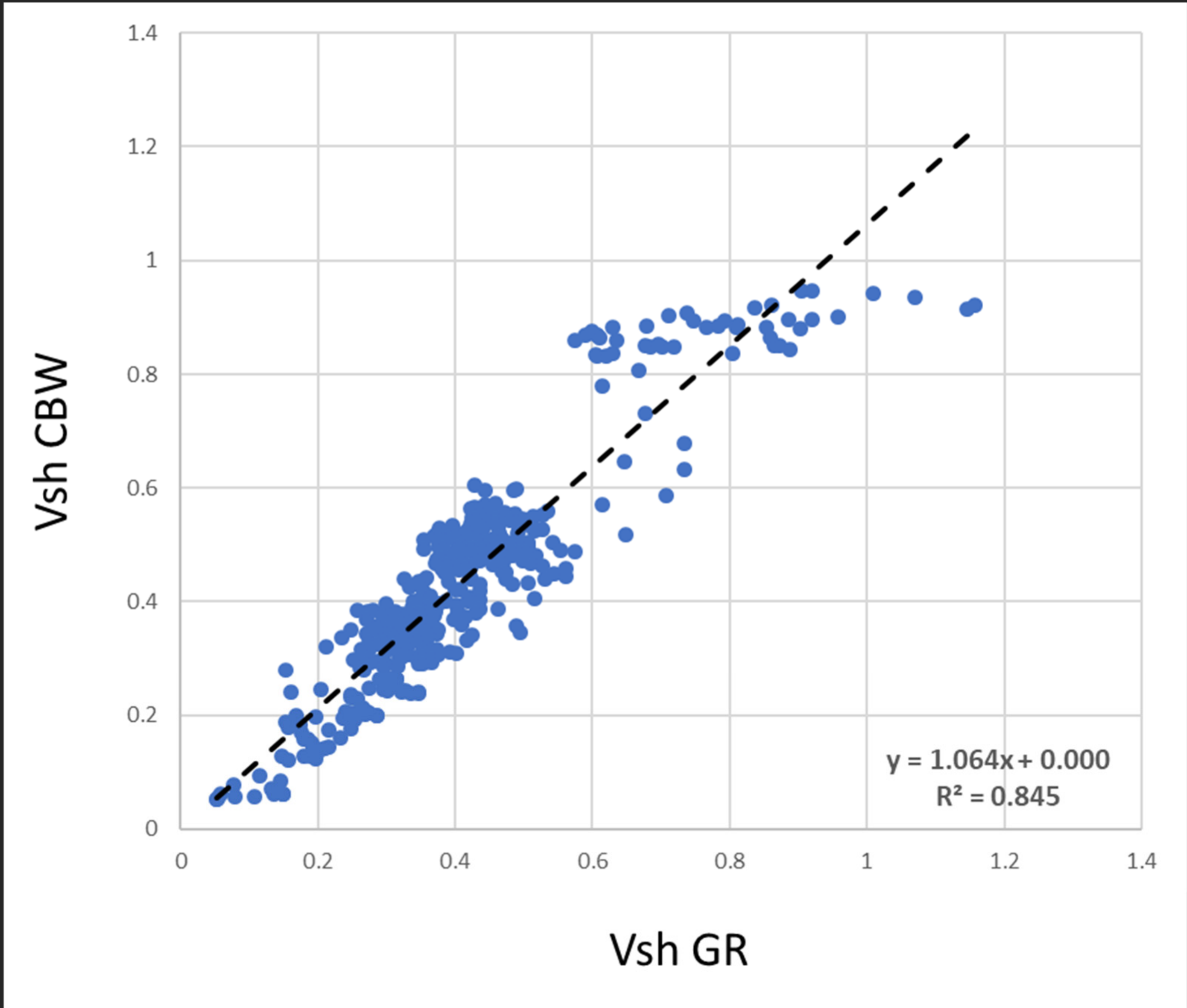
Establishing Rhombus Points

- Triple Combo
  - Derived Vsh_{GR} & $\Phi_{effective}$
- Nuclear Magnetic Resonance
  - Derived Vsh_{CBW}
- Determined “Clean” & “Shale” intervals to be used for Endmembers
  - Clean zone still had CBW & Shale Zone still had $\Phi_{effective}$
  - Scaling Factor applied to Vsh_{GR} & Vsh_{CBW}
  - Resulting laminar line was projected to x- & y- crossings
- Calculate Dispersed Point & Structural Point from Results

Initial Analysis Example

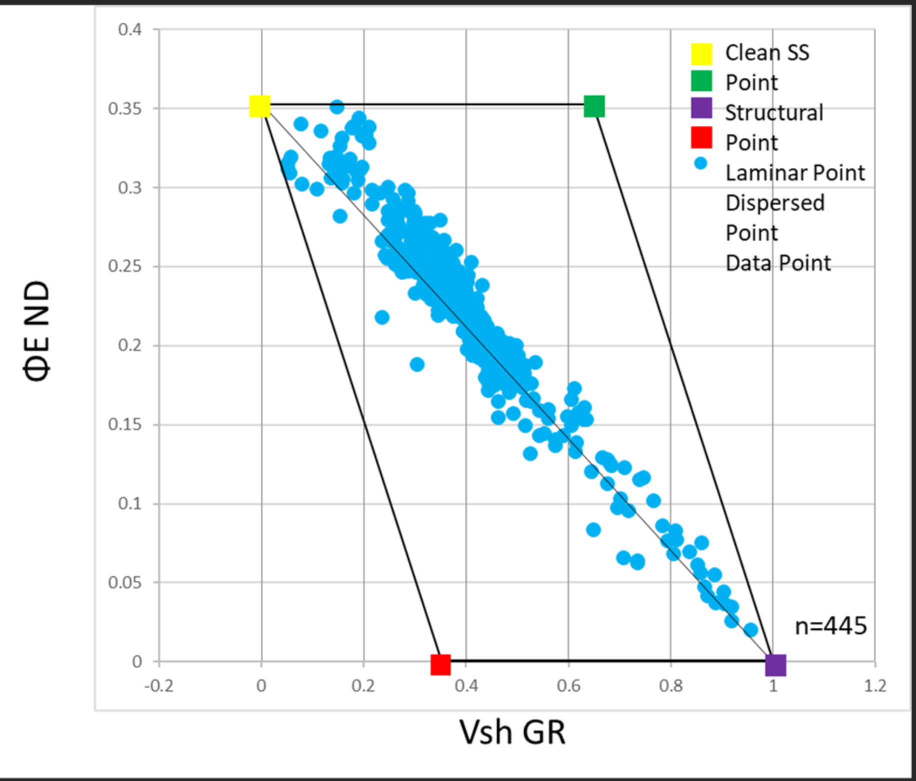


Comparison of Corrected Vsh_{GR} & Vsh_{CBW}

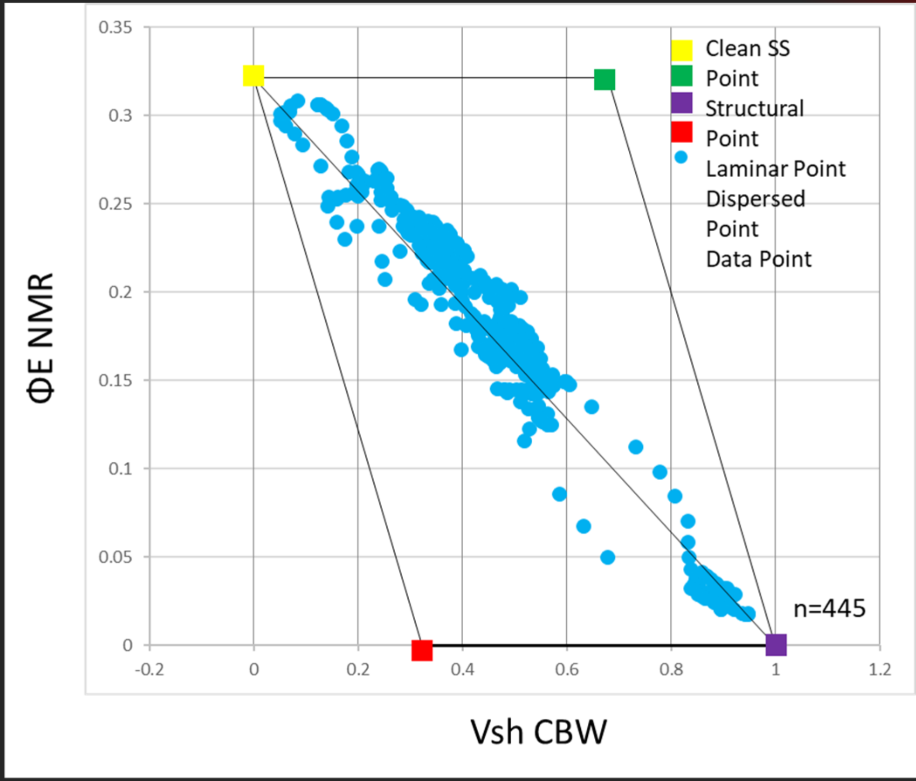


Final Effective Porosity vs. Vsh Crossplots

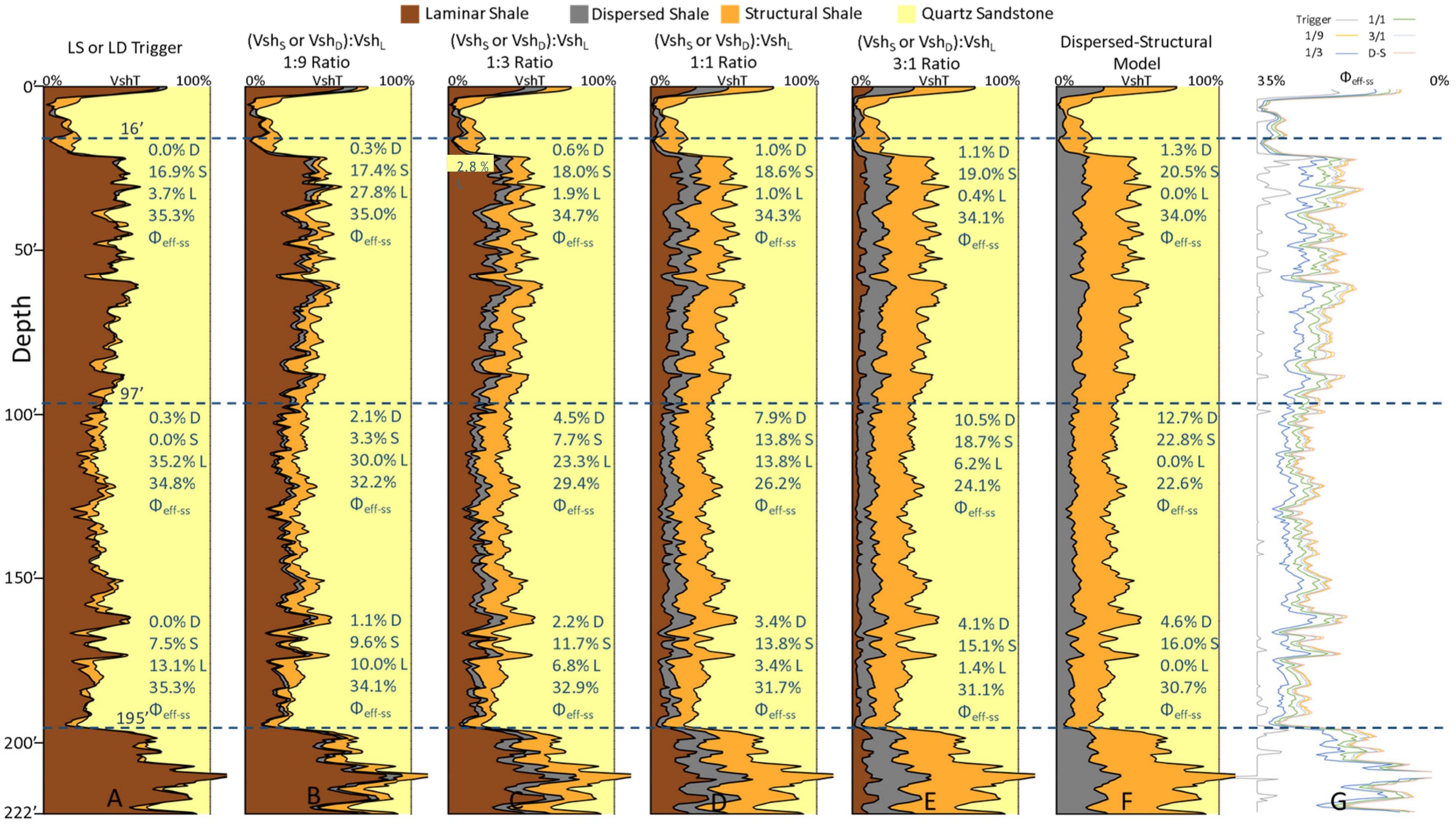
$\Phi_{effective}$ (ND) vs. Vsh_{GR}



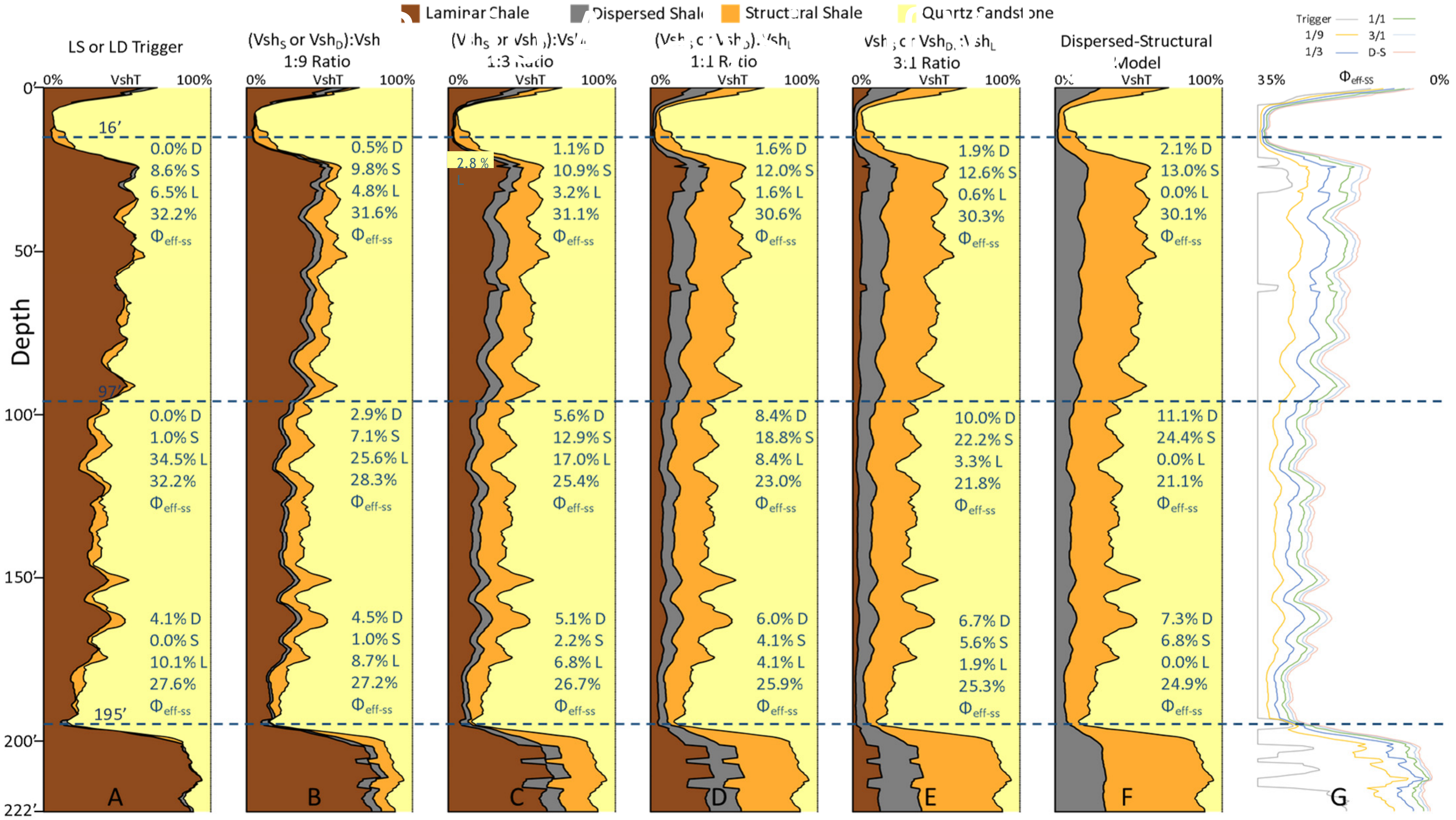
$\Phi_{effective}$ (NMR) vs. Vsh_{CBW}



Shale Distribution Analysis
Triple-Combination Log Based



Shale Distribution Analysis
NMR Log Based



Conclusions

- Use of $\Phi_{eff\text{-}ND}$ corrects for differential measurement of shale and hydrocarbon effects
  - Commonly used $\Phi_{total\text{-}D}$ or $\Phi_{total\text{-}ND}$ does not correct for shale and hydrocarbons → $\Phi_{total\text{-}D}$ errs with hydrocarbons and $\Phi_{total\text{-}ND}$ errs as Vsh increases
  - Better to use $\Phi_{eff\text{-}ND}$ and thus Effective Porosity vs. Vsh analysis
- NMR_{log} adds a valid & independent measure of Vsh_T, Φ_{total}, & $\Phi_{effective}$
- Triple Combination Log and NMR_{log} largely agree in case study
  - Overall laminar trend suggested
  - Both suggest dominance of structural shale over dispersed shale in the log run
- $\Phi_{effective}$ is vital for producibility of a reservoir & previous methodology overestimates and is thus *overly optimistic*
  - Our methodology demonstrates a range of values rather than a single optimistic value