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New Pore-scale Considerations for Shale Gas in Place Calculations

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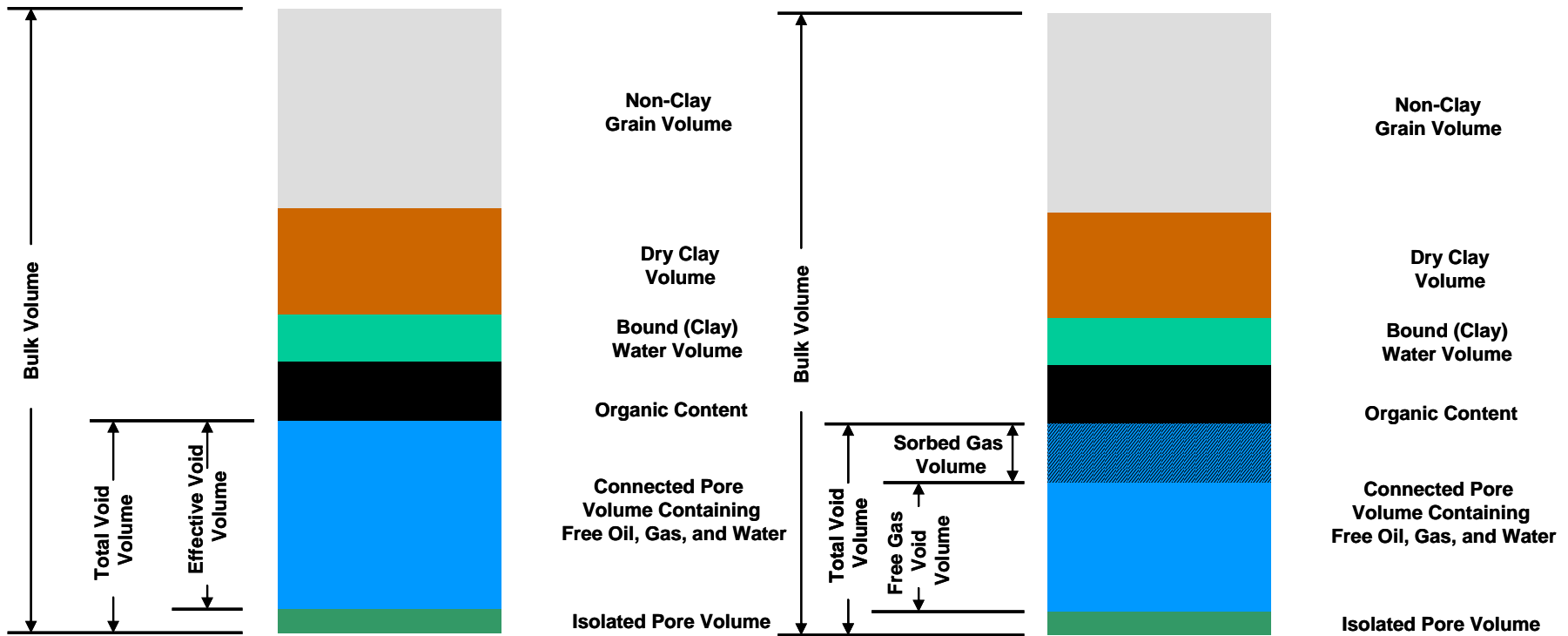
Overview

- Introduction
- Comparison of petrophysical models
- Physical evidence
 - Conceptual model
 - Sorbed phenomenon
 - SEM images of porosity in gas-shale
 - Movie of 3D model
 - Equation showing correction to free pore-space
- Sorbed phase density characterization
- Examples of effects
- Conclusion

Introduction

- With the current industry-wide calculation method for total gas volumes in organic shale reservoirs, the amount of gas storage has been overestimated.
- In this paper, that amount is quantified.
- In the past we have not accounted for the volume of measured free-space consumed by the sorbed gas component.
- By accounting for the volume consumed by the sorbed gas component, the space available for free gas is reduced.
- Examples show that this volume can be significant.

Comparison of Petrophysical Models



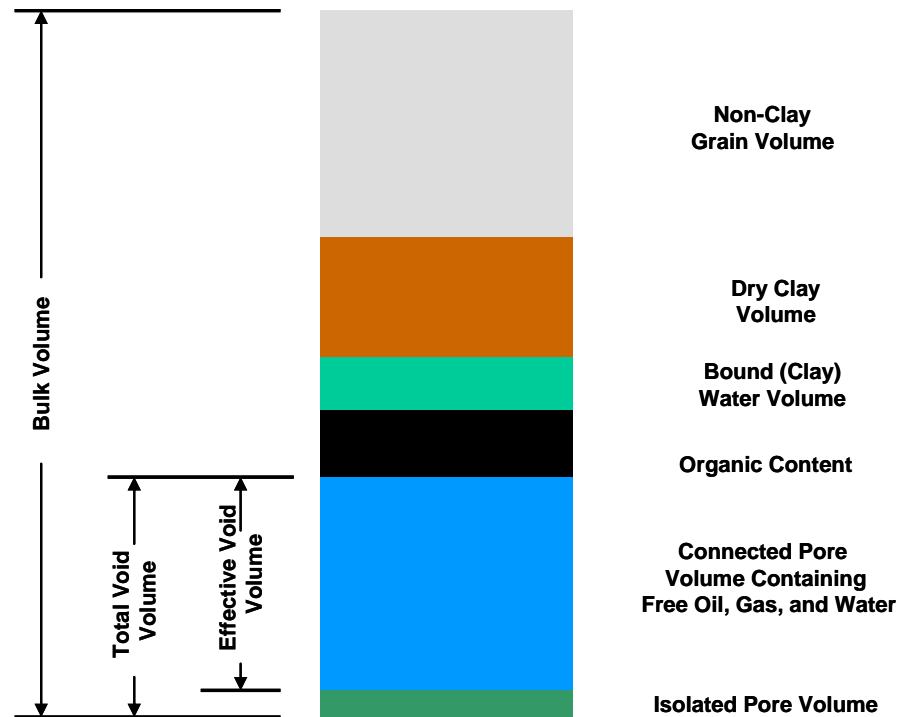
Old Petrophysical Model

- Old petrophysical model
 - Provided basis for calculating volumes.
 - Assumed free gas porosity and organics were independent.
 - Bulk volume determined from mercury displacement (V_b).
 - Grain volume determined from helium pycnometry (V_g).

$$\phi S_g = (V_v/V_b)(V_g/V_v) = V_g/V_b$$

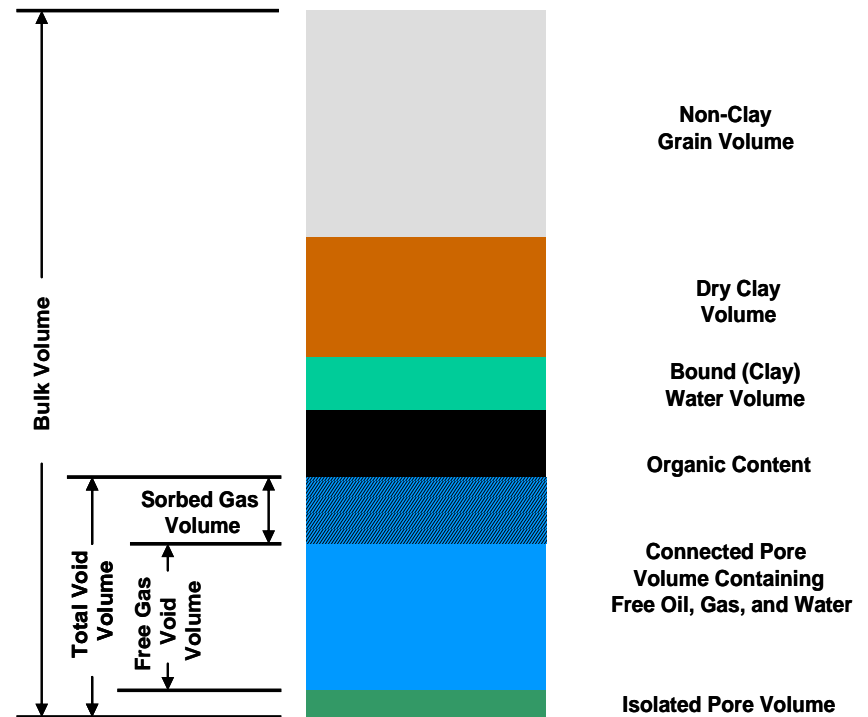
$$\phi S_{ge} = (V_{ve}/V_b)(V_g/V_{ve}) = V_g/V_b$$

$$G_f = 32.0368 \frac{\phi(1 - S_w)}{\rho_b B_g}$$



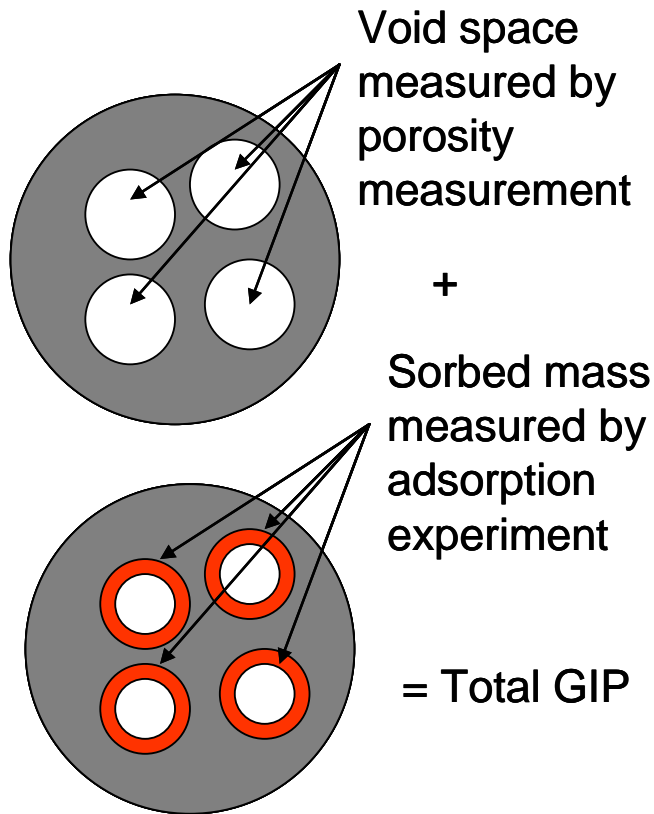
New petrophysical model

- Porosity for free-gas and volume consumed by sorbed gas is interconnected.
- Evidence has existed in the method used to measure adsorption isotherms.
 - Un-corrected (raw) isotherms bend downward.
 - Sorbed volume must be accounted for in order to correct for this phenomenon.
 - This correction is called the Gibbs correction.

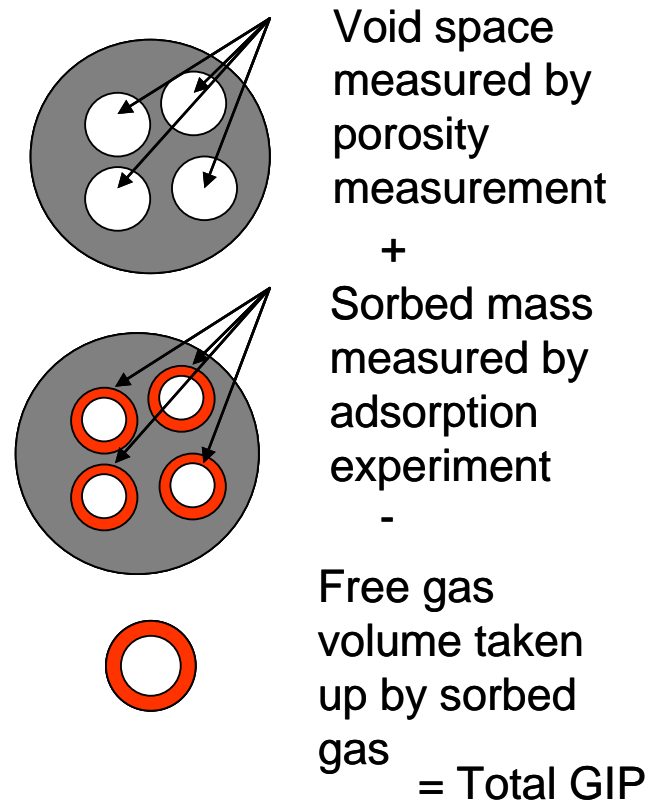


Simplified conceptual model

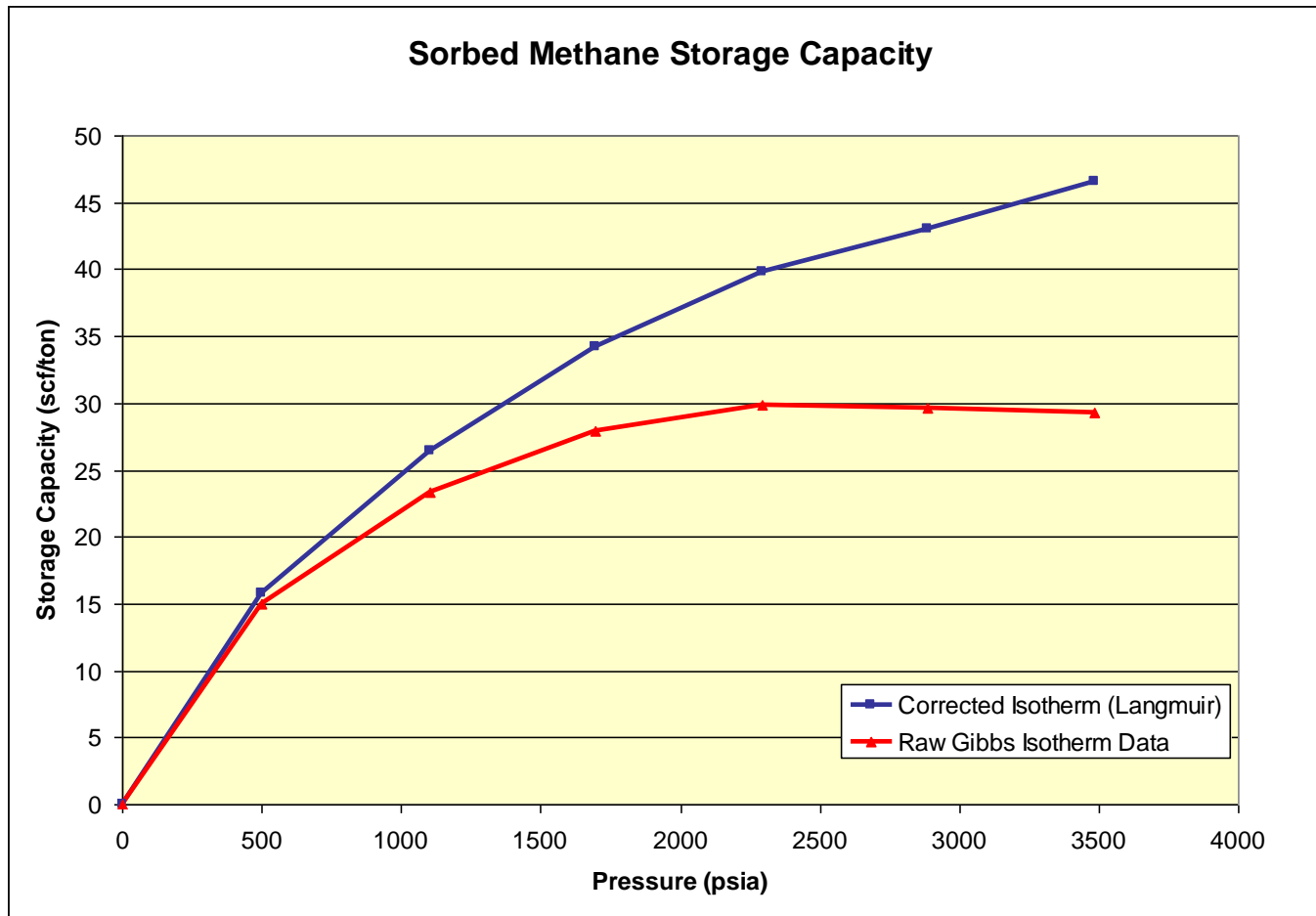
Old Methodology



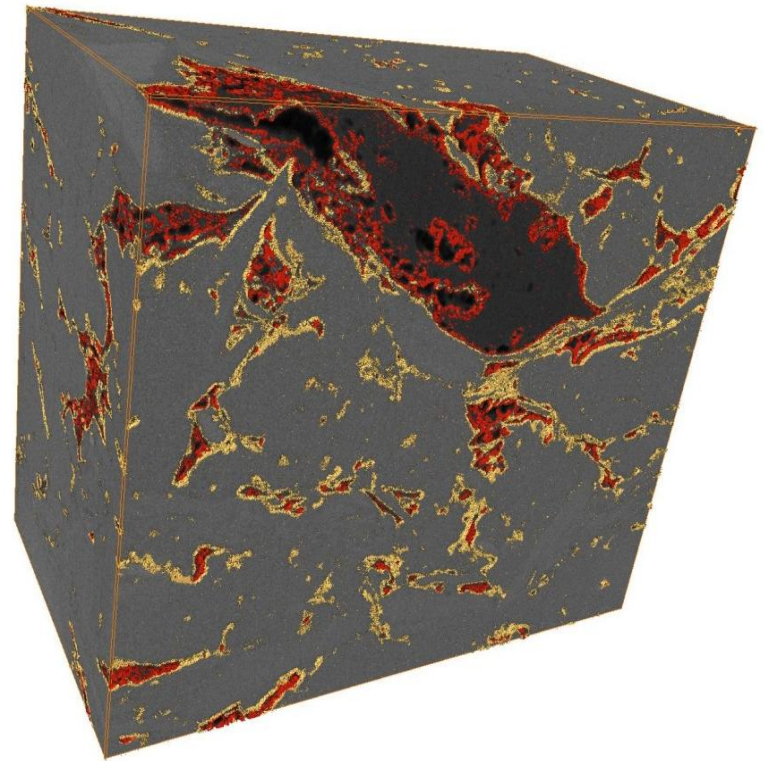
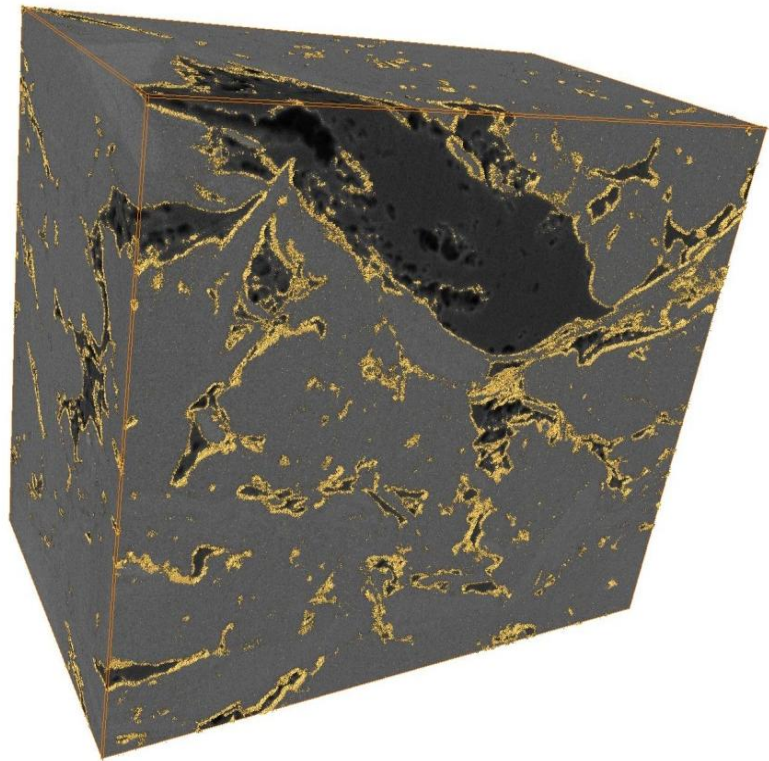
New Methodology



Adsorption isotherm evidence - Gibbs correction



SEM evidence of large portion of porosity within the kerogen



Free pore-space correction

$$G_f = 32.0368 \frac{\phi(1 - S_w) - \phi_a}{\rho_b B_g}$$

$$\phi_a = 1.318 \times 10^{-6} \hat{M} \frac{\rho_b}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right)$$

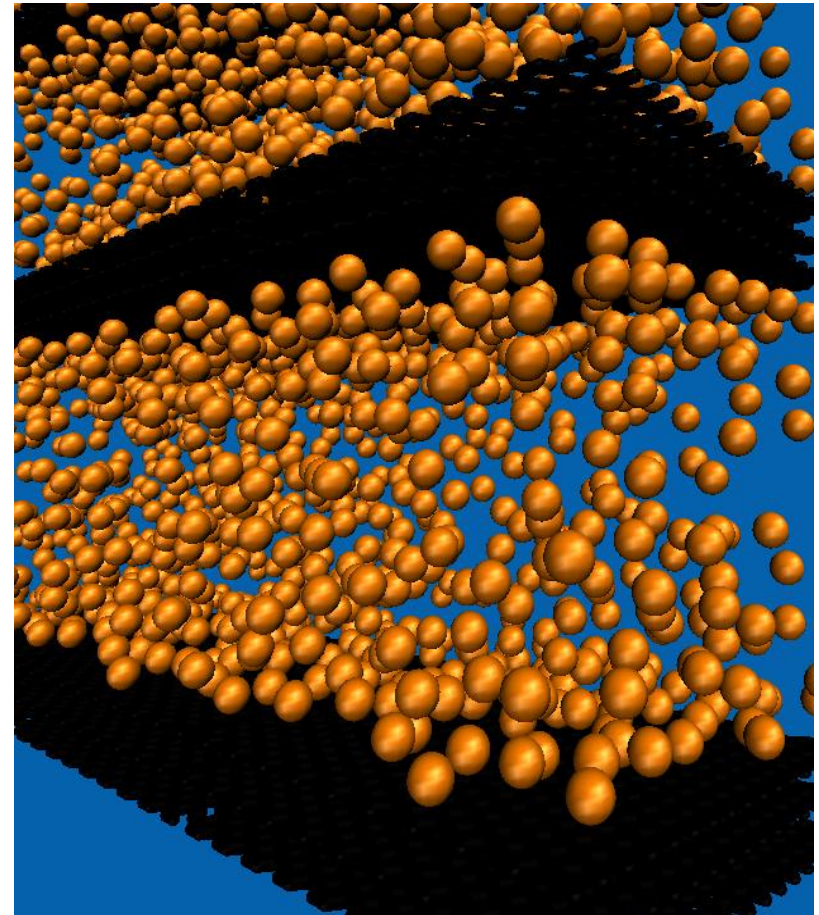
$$G_f = \frac{32.0368}{B_g} \left[\frac{\phi(1 - S_w)}{\rho_b} - \frac{1.318 \times 10^{-6} \hat{M}}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right) \right]$$

Sorbed phase density

- Previously published work all centers around 0.375-0.4233 g/cm³ for sorbed methane density.
 - Dubinin (1960) suggested adsorbate density related to van der Waals co-volume constant b .
 - Haydel and Kobayashi (1976) reproduced co-volume constant value experimentally.
 - Menon (1968) suggested the value was the liquid density.
 - Other authors have had different theories, but all are within the range of 0.375-0.4233 g/cm³.
- Sorbed phase densities when fluid is above the critical temperature are difficult.
 - Difficult to separate the gas from the sorbed phase.

Molecular dynamics simulation

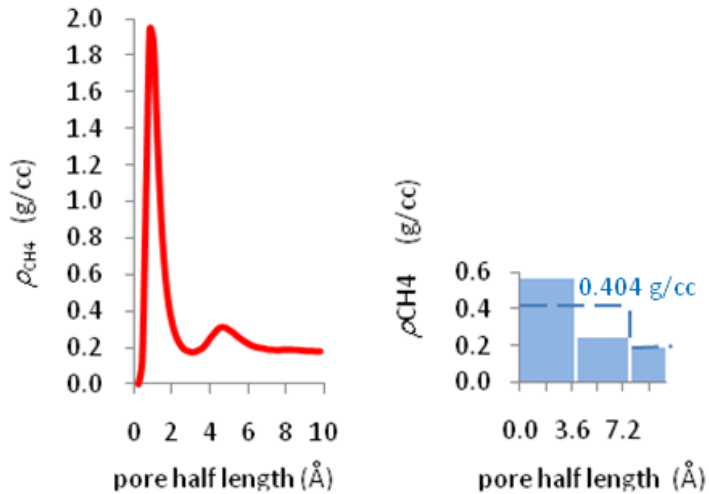
- We took a molecular dynamics simulation approach
 - Utilizes principals of Newtonian mechanics.
 - Models fluid-solid, fluid-fluid interactions at pressure and temperature to determine values that are difficult to find experimentally.
 - Study effects on sorbed phase density
 - pore-size
 - temperature



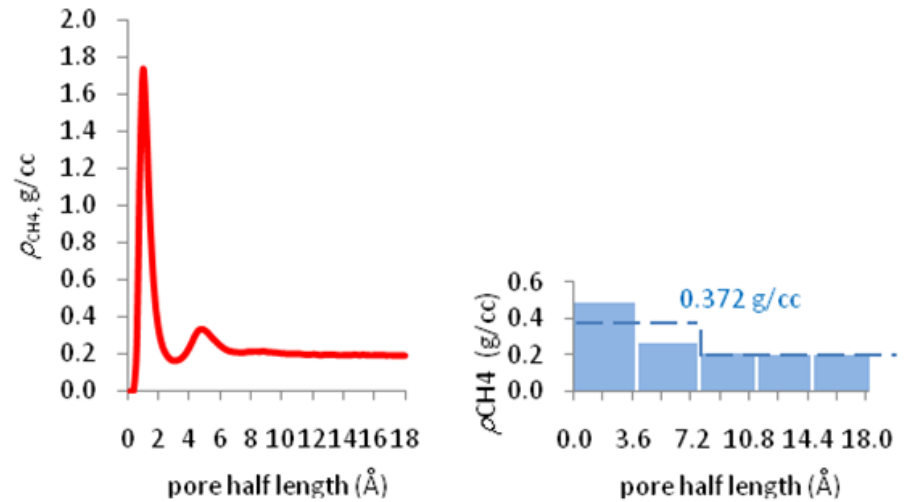
Molecular simulation cell consisting of graphite walls and OPLS-UA methane

Molecular dynamics calculated density profiles - damped oscillations

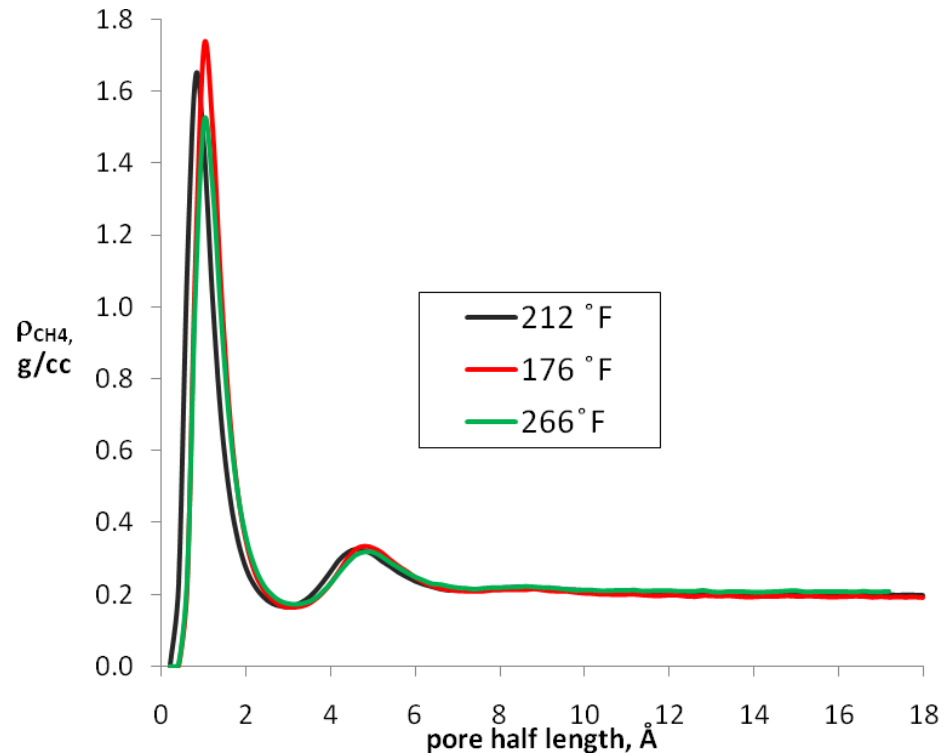
1.95 nm width pore



3.6 nm width pore



Sorbed phase density as a function of temperature



Example of effects

- Typical gas shale

	<u>Shale A:</u> <u>(low sorption capacity)</u>	<u>Shale B:</u> <u>(high sorption capacity)</u>
ϕ	0.06	0.06
S_w	0.35	0.35
S_o	0.0	0.0
B_g	0.0046	0.0046
\hat{M}	20 lb/lb-mol	20 lb/lb-mol
G_{sL}	50 scf/ton	120 scf/ton
p	4000 psia	4000 psia
T	180 °F	180 °F
p_L	1150 psia	1800 psia
ρ_b	2.5 g/cm ³	2.5 g/cm ³
ρ_s	0.37 g/cm ³	0.37 g/cm ³

- Shale A shows a decrease of 14.2% of free gas and 11.6% of total gas*
- Shale B shows a decrease of 30.2% of free gas and 17.1% of total gas*
- * Compared to old industry standard calculation methods

Conclusions and Future Work

- The disregard of the volume that is consumed by the sorbed phase in gas shale leads to inadvertently high values of total gas-in-place due to double counting of the volume available for free gas.
- Evidence of a finite volume consumed by the sorbed phase has been around a long time. It has been used to correct raw isotherm data.
- The sorbed phase mass is determined in the sorbed gas experiment. Properly characterizing the sorbed phase density is critical in accounting for the volume consumed by the sorbed phase mass.
- A new method is shown to properly account for this volume and remove it from the space available for free gas.
- Future work in publishing compositional effects on sorbed gas quantities, taking the Langmuir isotherm portion of the equation and substituting a multi-component isotherm model.

$$G_f = \frac{32.0368}{B_g} \left[\frac{\phi(1-S_w)}{\rho_b} - \frac{1.318 \times 10^{-6} \hat{M}}{\rho_s} \left(G_{sL} \frac{p}{p + p_L} \right) \right]$$