Characterize Shale Reservoir for Engineers*

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Abstract

There is no doubt that reservoir characterizations in different scales are critical in reservoir development and production optimization. Even through current technology and equipment reveal more and more details of core samples and enable geoscientists to understand the structure and elements of these samples, engineers from reservoir and production disciplines are still using traditional tools in reservoir simulation and well performance evaluation. For example, curve fitting technologies in rate forecast, which was originated in 1940s or earlier, are still being used in shale gas production forecast. This gap could be bridged via communication through different disciplines and calls for continuous research.

This presentation highlights on the importance of pore size distribution in shale gas reservoirs and their impacts on quantifying resource and production and some recent progresses in shale gas reservoir rate forecasting technologies. Furthermore, how to close the gap so that the data from scientists could be used by engineers will be proposed through topics that needs joint research of the industry and academia.

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Tolbert, B.T., and X. Wu, 2015, Quantifying Pore Size Distribution Effect on Gas in Place and Recovery Using SLD-PR EOS for Multiple-Components Shale Gas Reservoir: SPE Asia Pacific Unconventional Resources Conference and Exhibition, 9-11 November, Brisbane, Australia, SPE-176992-MS, 27 p.

Selected Website

Adsorption of Gases in Porous Media Using Grand Canonical Monte Carlo Simulations:
http://scienomics.com/Adsorption-of-gases-in-porous-media-using-Grand-Canonical-Monte-Carlo
Website accessed March 2016

Characterize Shale Reservoir for Engineers

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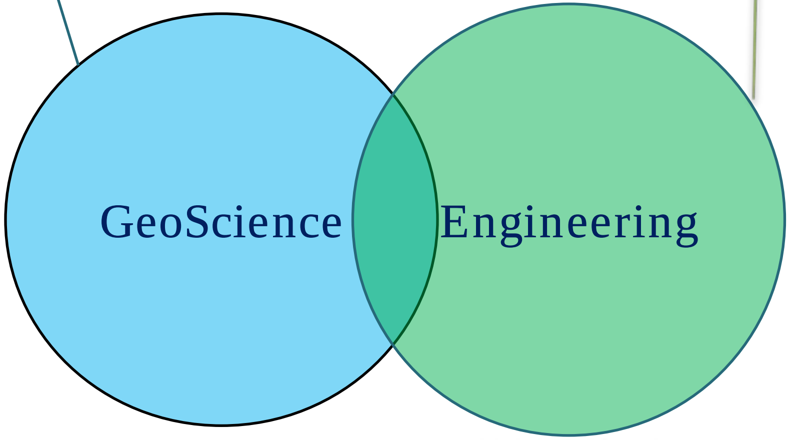
The Relationship Among Science, Engineering, and Technology

Objective: Understand the nature of subsurface

Study objects:
- Core
- Outcrops
- Solid/fluid samples
- …

Tool boxes:
- Seismic
- Elemental analysis
- Well logging
- …

Results:
- Reservoir structure
- Petrophysical characterization
- Where to place a well



http://www.zazzle.com/

Objective: Develop/design engineered process for asset production

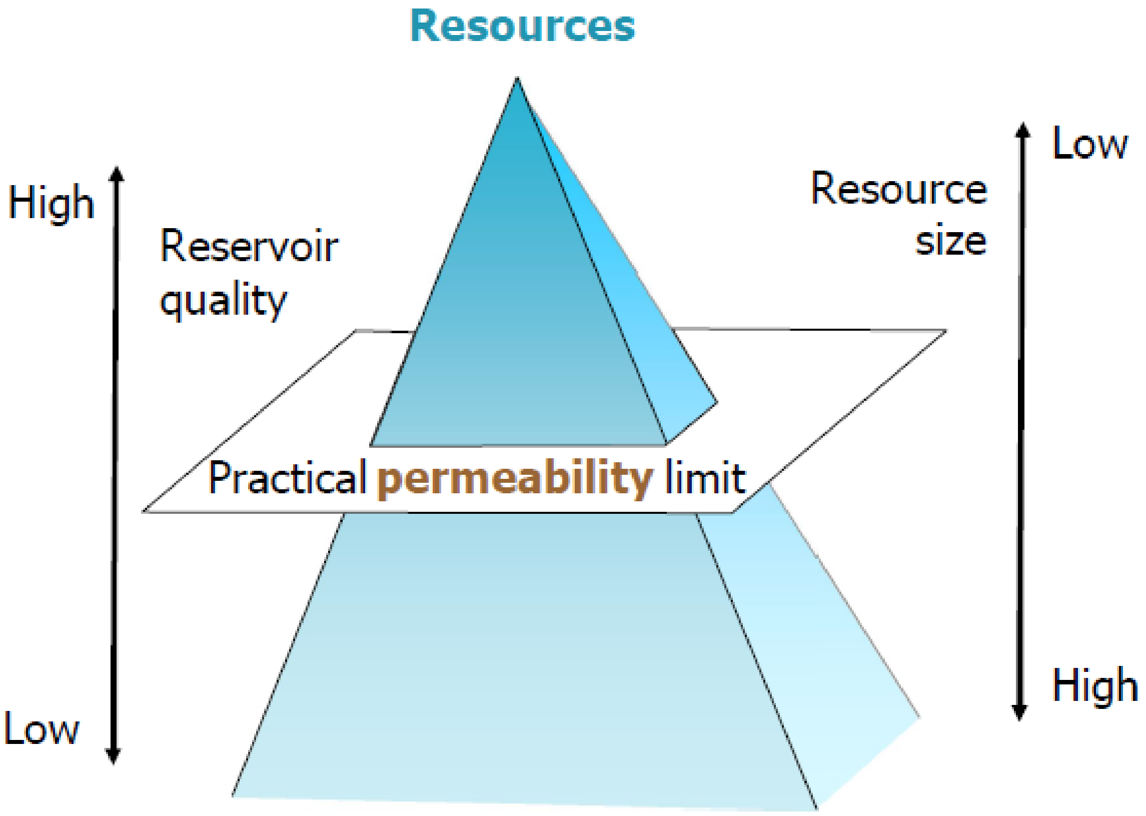
Study objects:
- Rock/fluid/steel
- STOIP
- Wells
- Permeability/porosity/saturations
- Pressure & rate
- Cost

Tool boxes:
- Production performance
- Reservoir simulation
- Decline curves
- Material balance

Results:
- Field development plan
- D & C
- Production strategy
- Economic performance

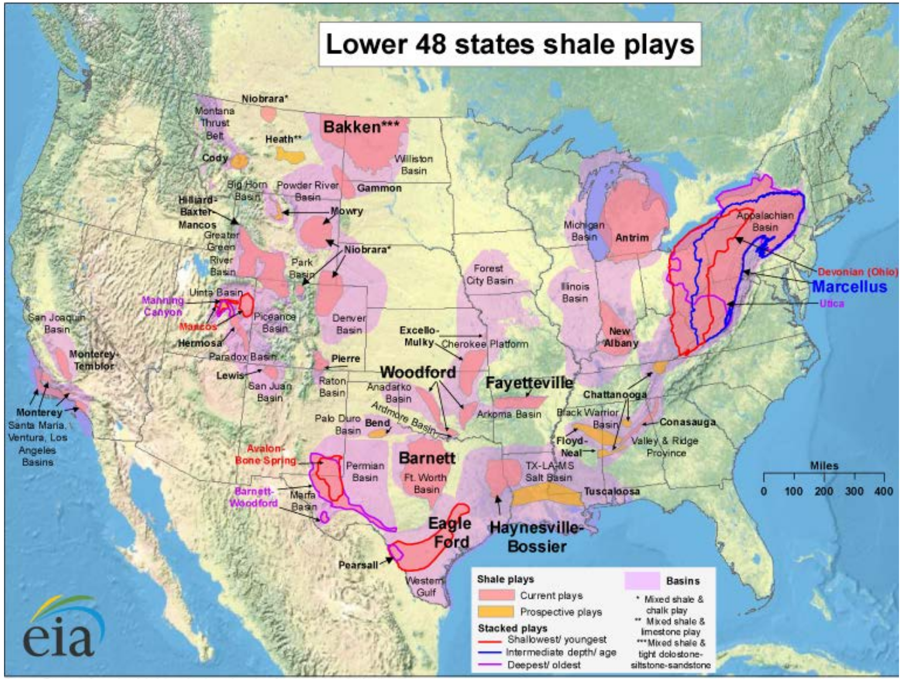
Outline

1. Shale reservoir characterization
2. How much hydrocarbon in the pores?
3. Production performance
4. Closing Remarks

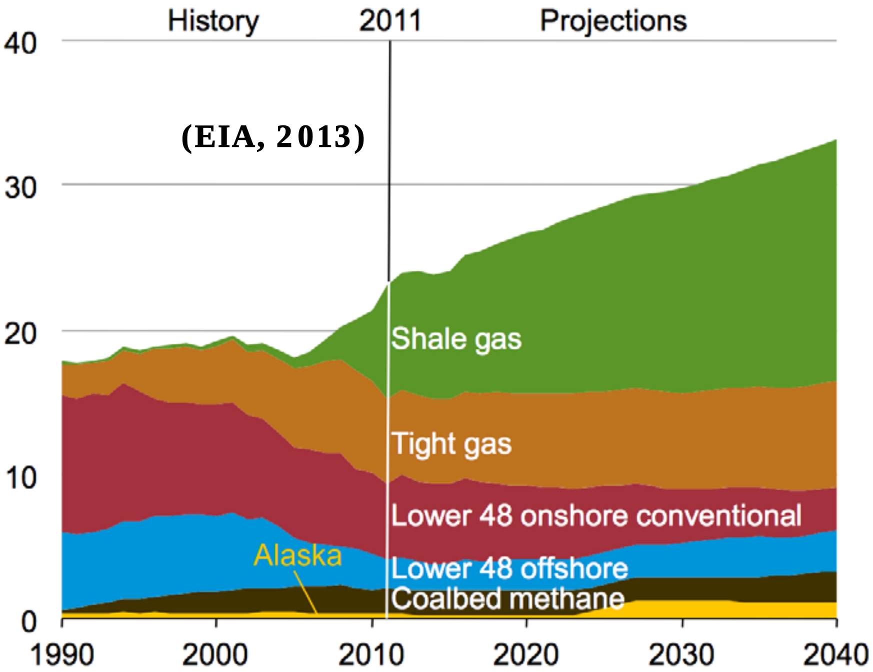


After USGS 2005

Status and Projection of Unconventional Assets in USA



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

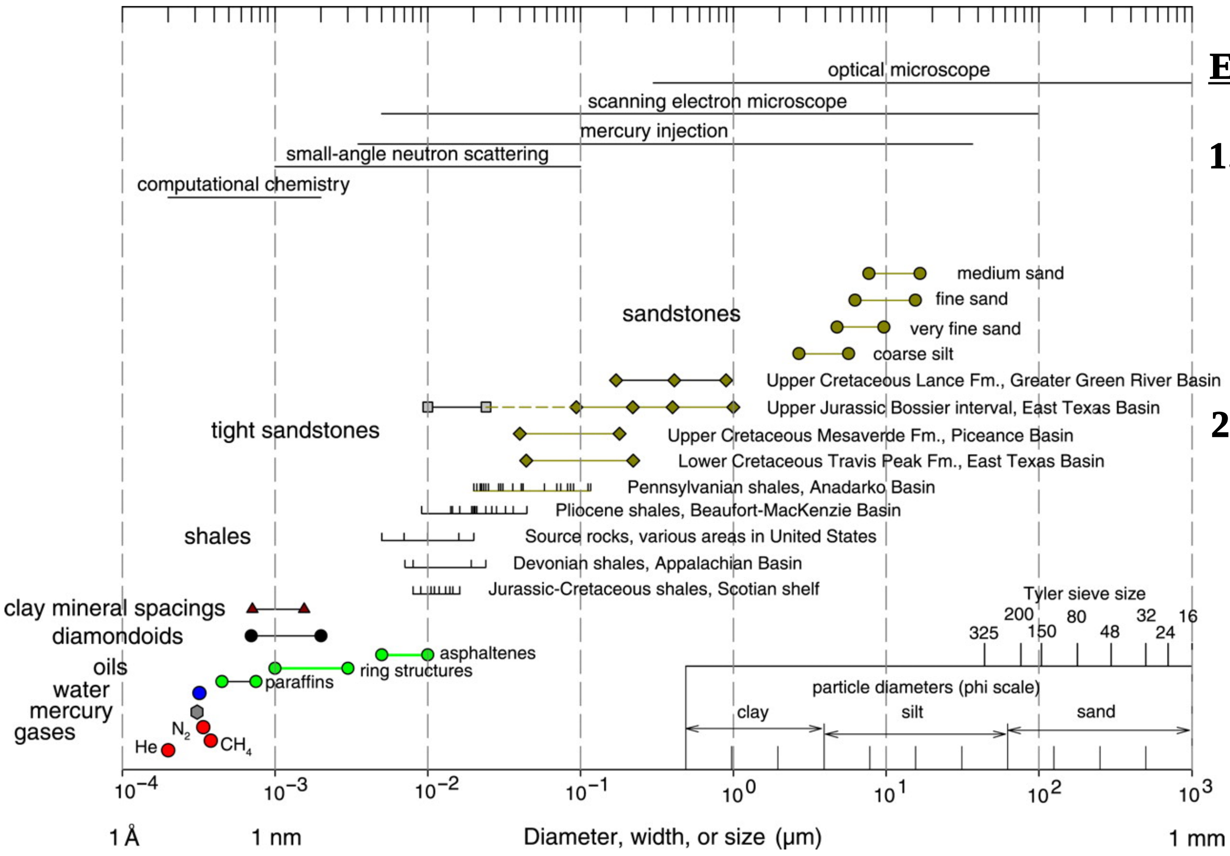


(EIA, 2013)

- Typically large areas
- Relatively thin (± 15m) to quite thick (300m+)
- Low porosity, low permeability, requires fracing
- Vertically and laterally complex

Pore Size in Rocks: Nelson Pore/Molecule Size Chart

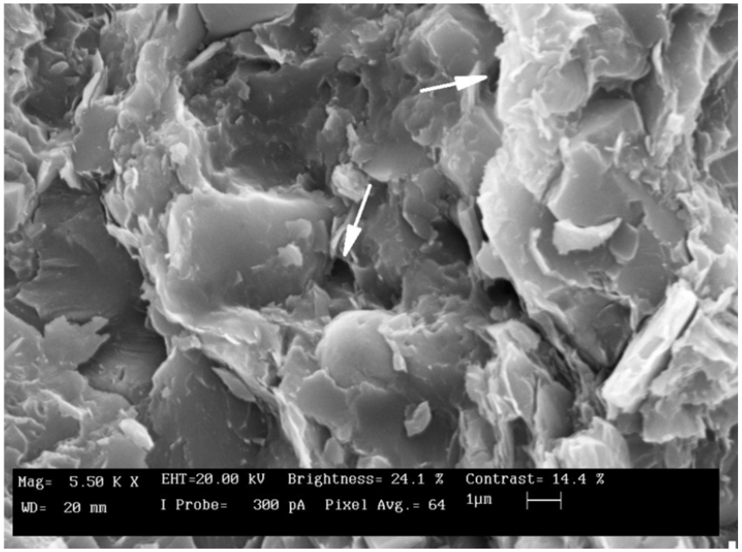
Source: Nelson, 2009, AAPG Bulletin

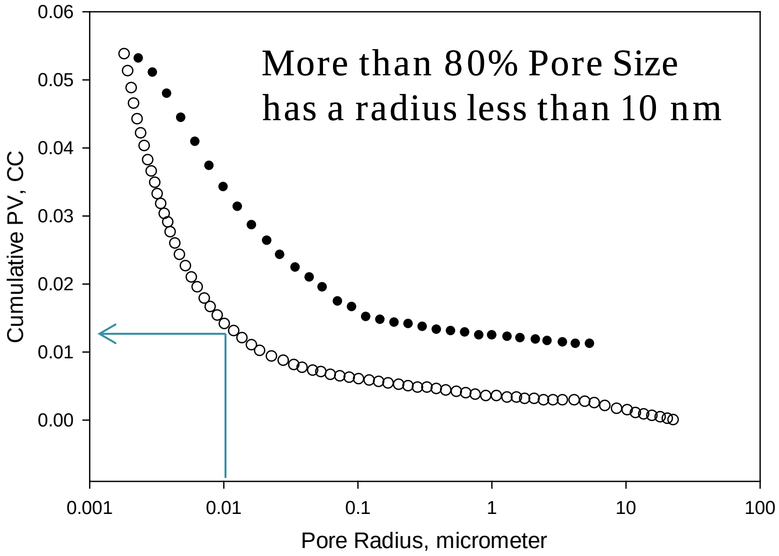


Engineer cares:

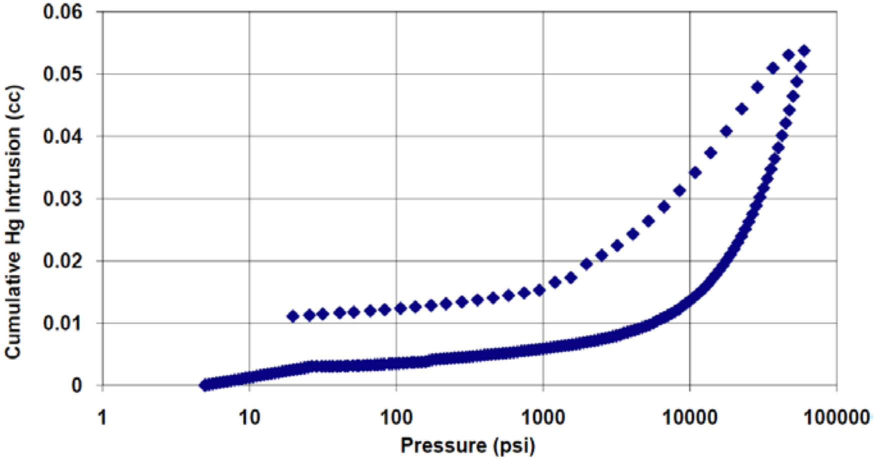
1. **How does the fluid store?**
   - In the organic matter?
   - Adsorbed?
2. **How does the fluid flow?**
   - Darcy's flow?
   - Dispersion?
   - Knudsen flow?

PSD for Tight Formation (Shale)

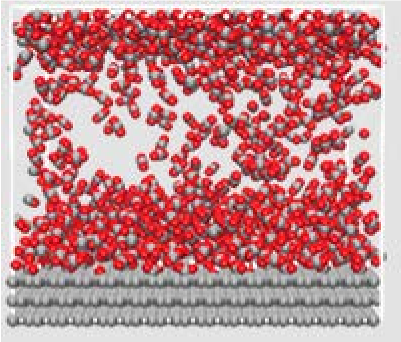




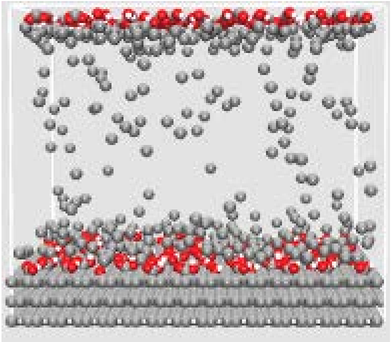
More than 80% Pore Size has a radius less than 10 nm



CO2



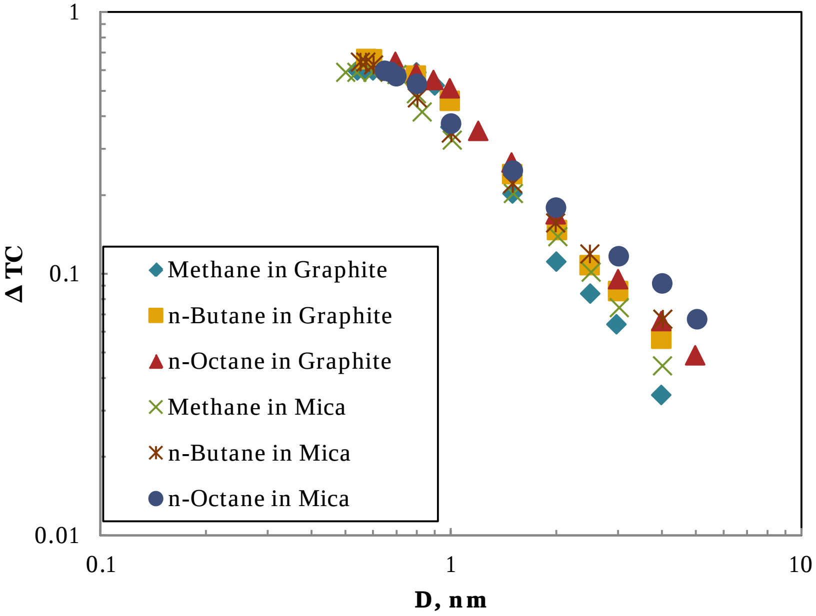
CH4



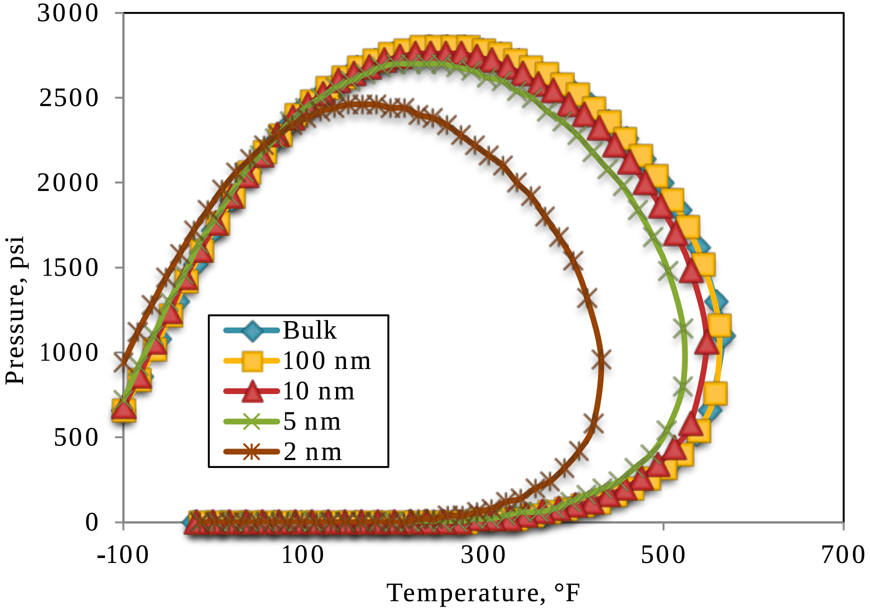
http://scienomics.com/Adsorption-of-gases-in-porous-media-using-Grand-Canonical-Monte-Carlo

SPE131771, Sondergeld et al. 2010, Barnett gas shale

PSD Changes Fluid Properties

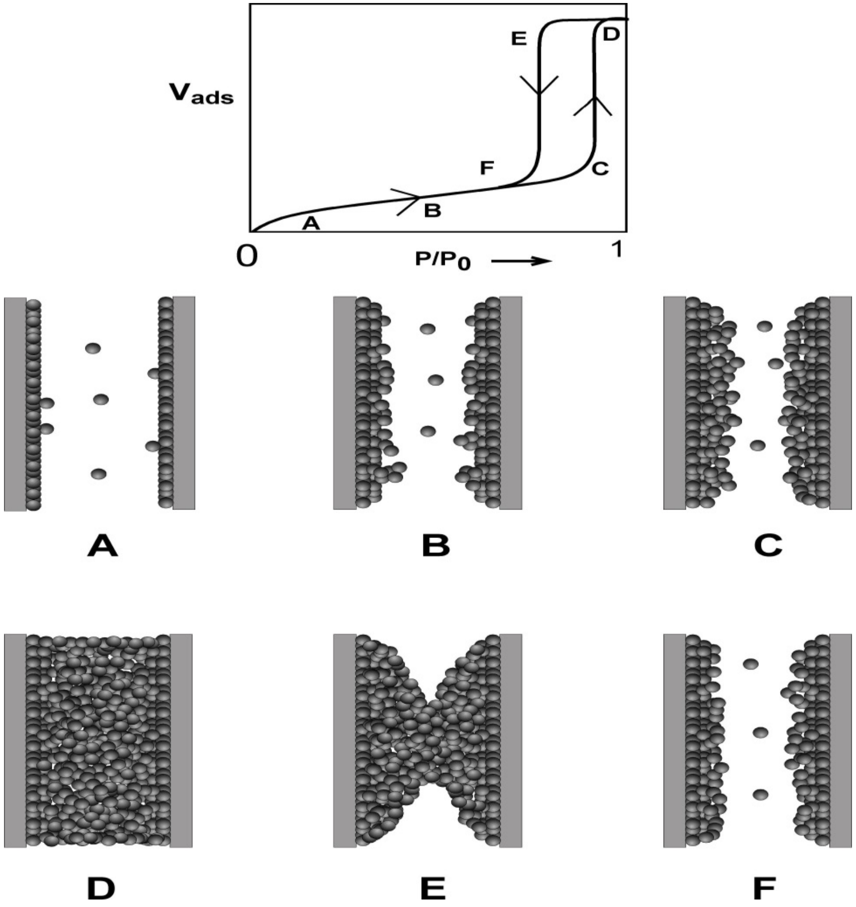


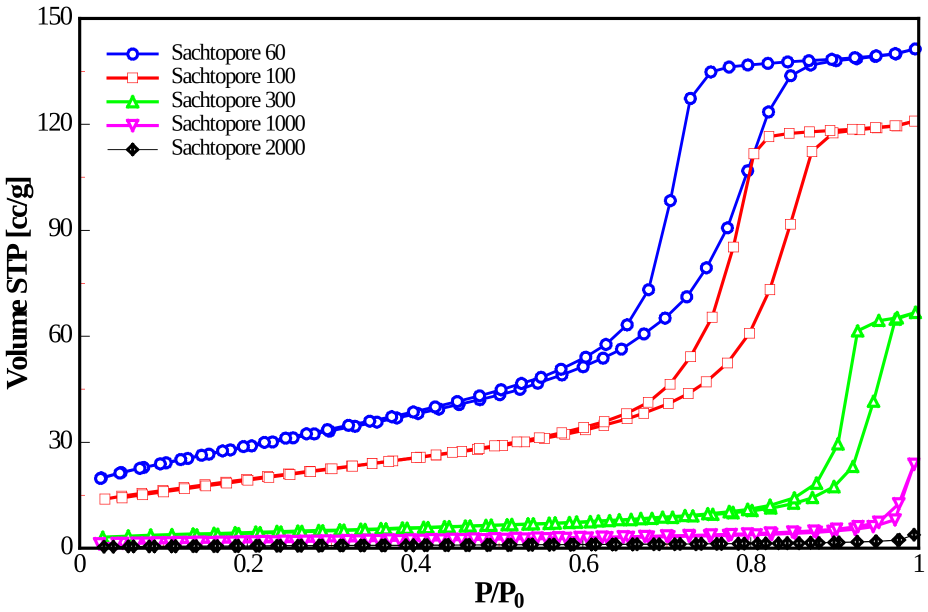
Pore size impact on critical temperature (Singh et al. 2009)



Two-phase envelopes of a C1/nC4/C10 mixture in different pore sizes (Ma, 2014)

Sorption, Pore Condensation and Hysteresis Behavior of a Fluid in a Single Cylindrical Mesopore





From: M Thommes, “ Physical adsorption characterization of ordered and amorphous mesoporous materials”, Nanoporous Materials- Science and Engineering” (edited by Max Lu, X.S Zhao), Imperial College Press, Chapter 11, 317-364 (2004)

Method to Study Adsorption Effect in Shale

Empirical Models

+ Easy to use

− Limited Scope

- Langmuir
- Brunauer-Emmet-Teller (BET) model

Theoretical Models

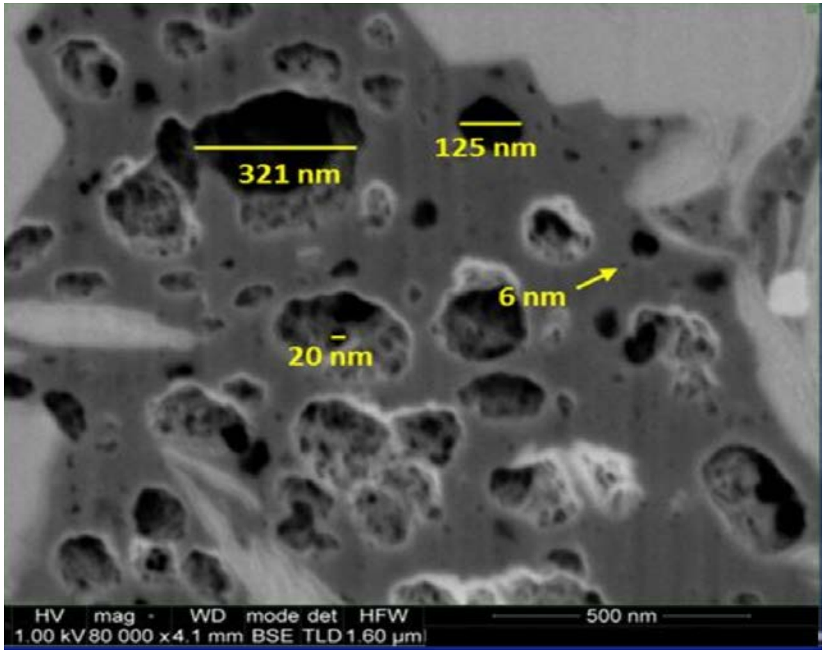
+ Theoretically Sound

− Computationally intensive

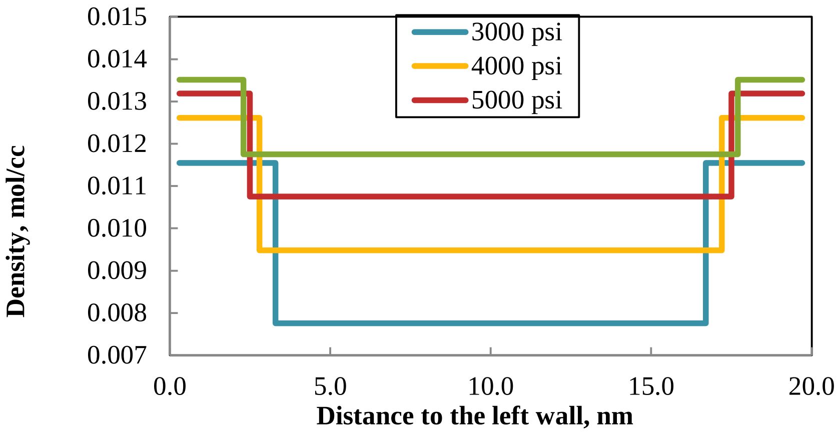
- Molecular Dynamic Simulations (MDS)
- Grand Canonical Monte Carlo Simulations (GCMC)

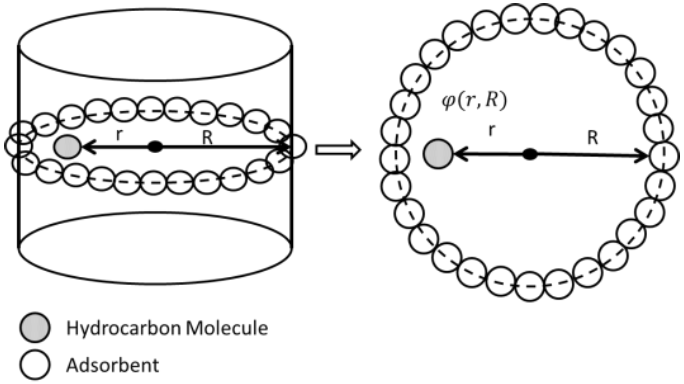
Simplified Local Density Model (SLD)

Local Density Calculation with PR-EOS

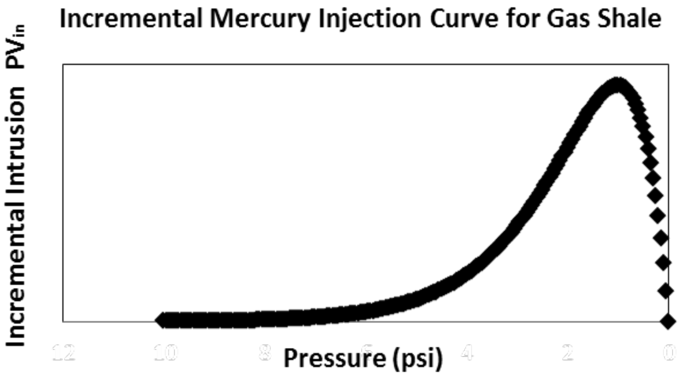


SEM image of organic contents from a shale sample (Curtis et al., 2010)

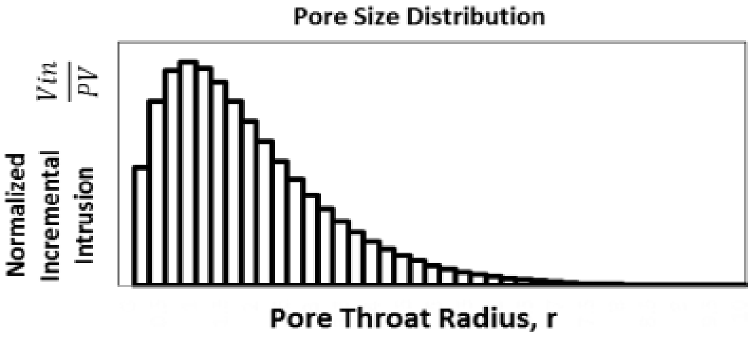




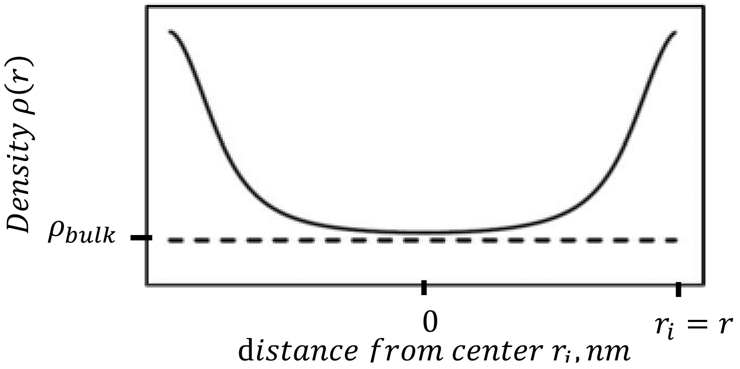
SLD-PR EOS and MICP Workflow



- **Acquire incremental intrusion curve from core samples**



- **Construct pore size distribution from Young's equations**



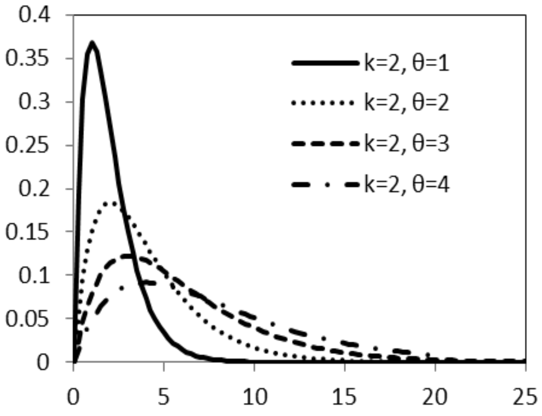
- **Apply SLD-Peng-Robinson algorithm for each pore size radius**
- **Determine average adsorbed phase density**

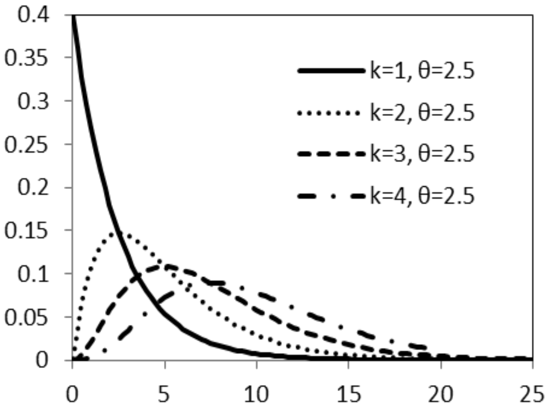
$$OGIP = \text{Free Gas Volume } (G_f) + \text{Adsorbed Gas Volume } (G_{ads})$$

$$\textbf{SLD-PR OGIP} = \underbrace{\boxed{\varnothing_{inorganic}}}_{G_f = f(Bulk\ Density)} + \underbrace{\boxed{\varnothing_{organic}}}_{G_{ads} = f(Adsorbed\ Density)}$$

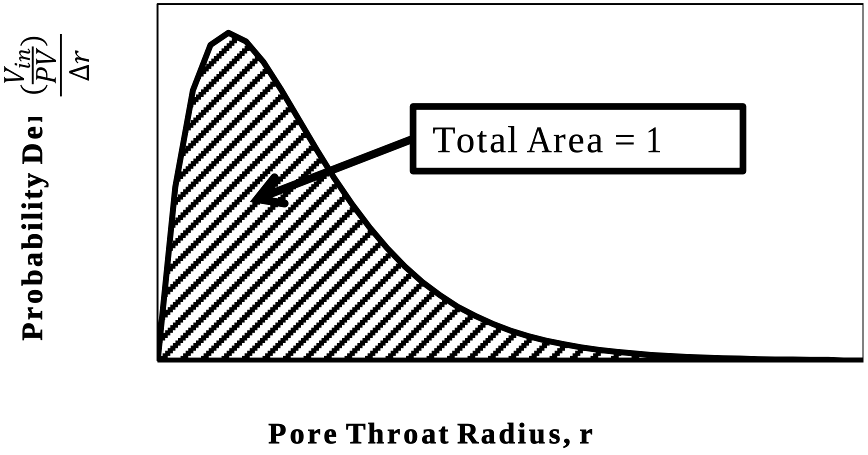
- **Determine OGIP**

Multicomponent OGIP Esimation





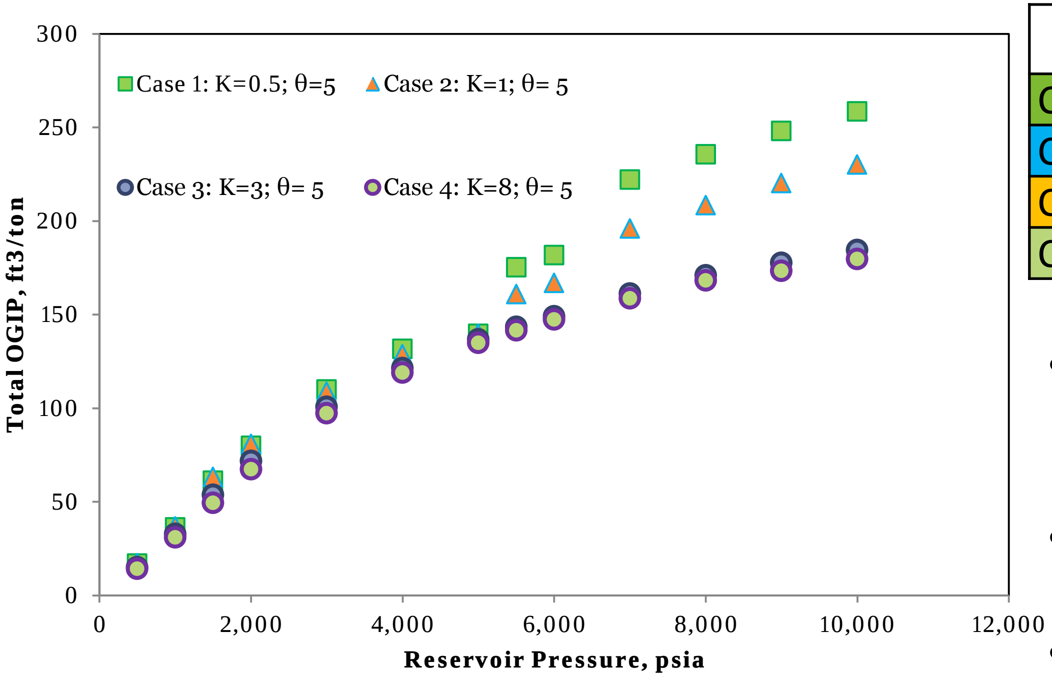
Component	**Bulk Composition (Z_i)**
C_1	61.9%
C_2	14.1%
C_3	8.4%
C_4	4.4%
C_5	2.3%
C_6	9.0%



Petrophysical Properties for OGIP Determination

Parameters	**Values**	**Units**
Total Porosity, ϕT	5.5%	
Kerogen Porosity (organic)	3.5%	
InOrganic Porosity	2.0%	
Water Saturation, Sw	25%	
Rock density	2.5	g/cm3

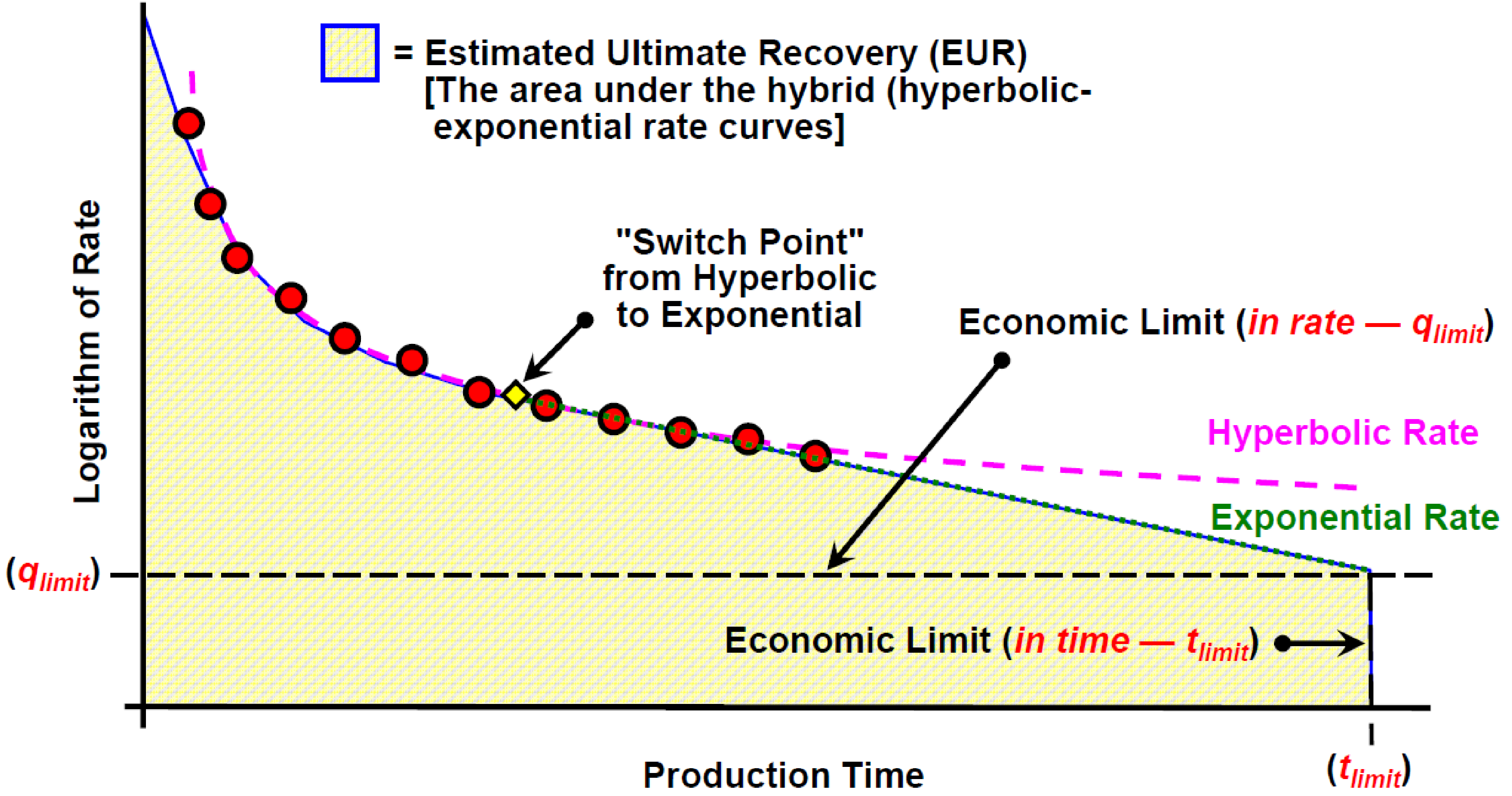
Sensitivity Study (OGIP)



Case	**μ, nm**	**Micro**	**Meso**	**Macro**
Case 1	2.5	47%	53%	0%
Case 2	5	18%	81%	1%
Case 3	15	0%	87%	12%
Case 4	40	0%	13%	87%

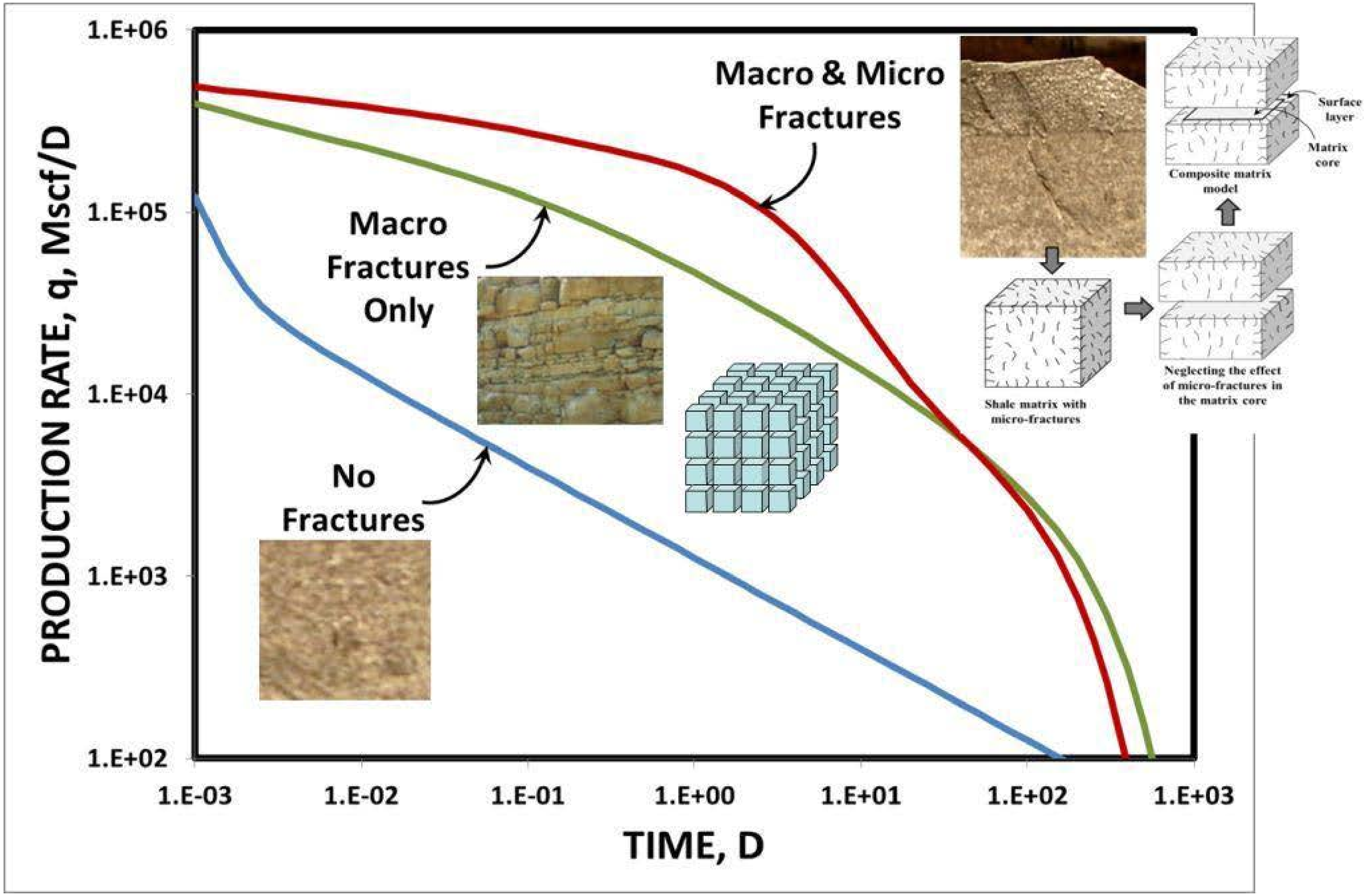
- At high pressures, more small pores correlate to more gas in place
- At low pressures, OGIP estimates are similar
- Neglecting pore size distribution can yield over 40% errors in OGIP values

Production Performance-Common Approach



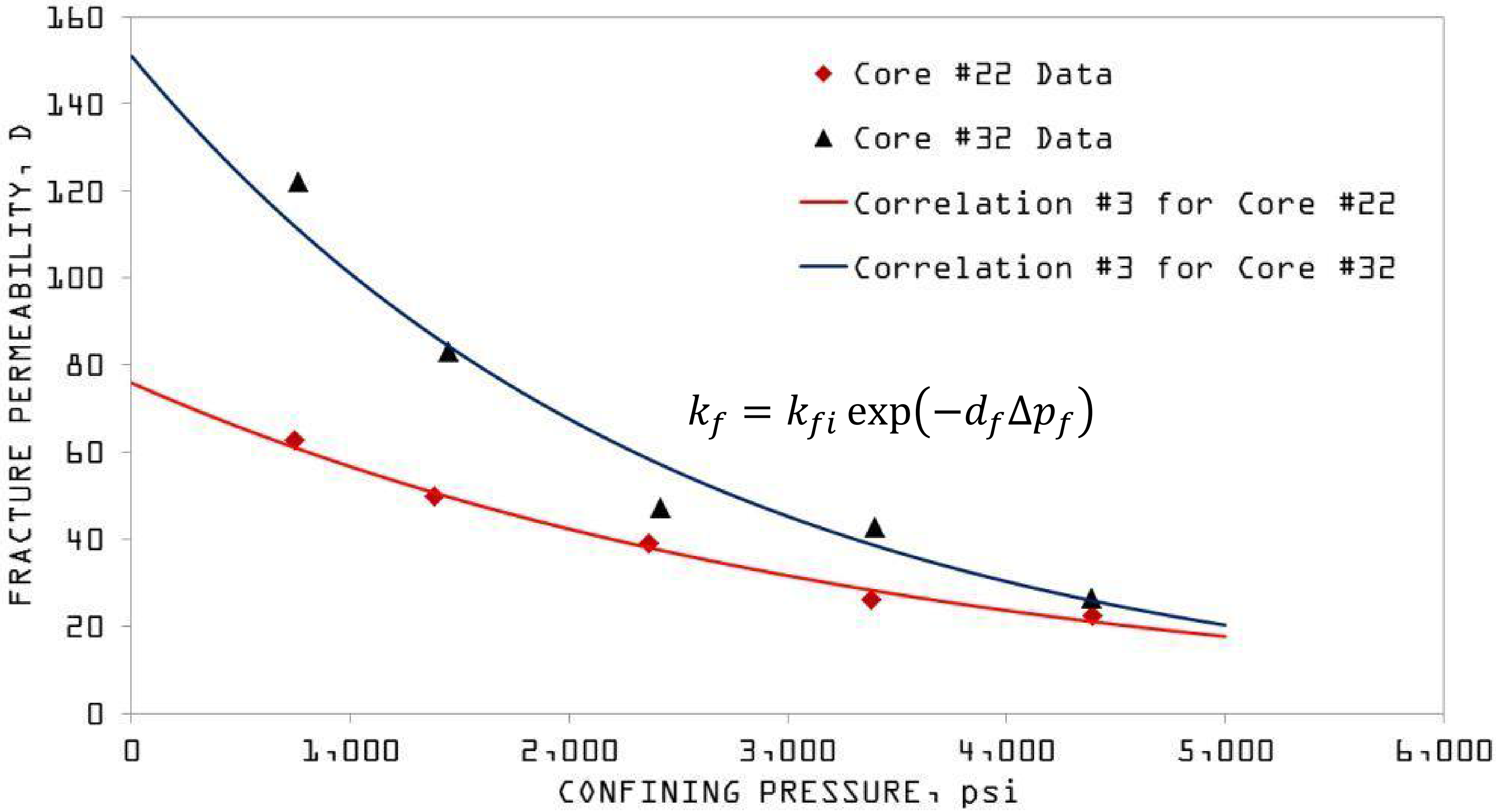
Blasingame,2011

Miscrofactures in Shale



Shale-Matrix model with microfractures(Apaydin et al., 2011)

Pressure-Dependent Fracture Permeability



$$k_f = k_{fi} \exp\left(-d_f \Delta p_f\right)$$

Cho, 2011

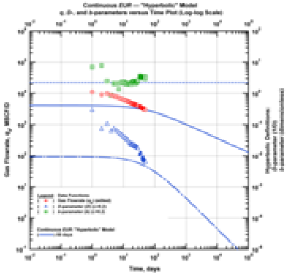
Predicting EUR from Production Data

Analyze All Intervals Using the Hyperbolic Relation

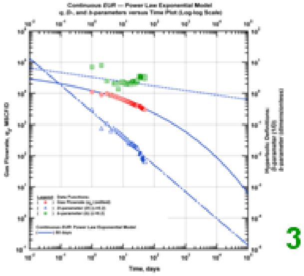
Analyze All Intervals Using the Power-Law Exponential Relation

Find Lower Limit Using q_g vs. G_p Straight Line Extrapolation

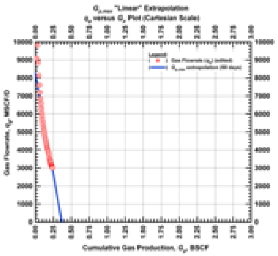
50 days



***EUR* = 6.04 BSCF**

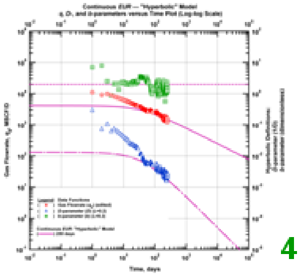


***EUR* = 3.10 BSCF**

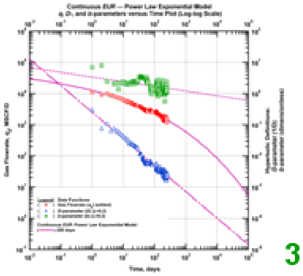


$G_{p,max}$ = 0.37 BSCF

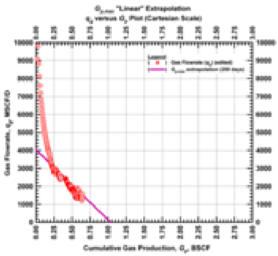
250 days



***EUR* = 4.92 BSCF**



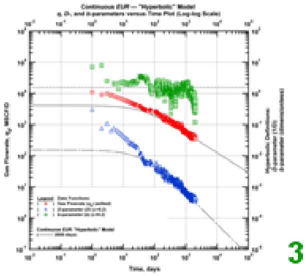
***EUR* = 3.09 BSCF**



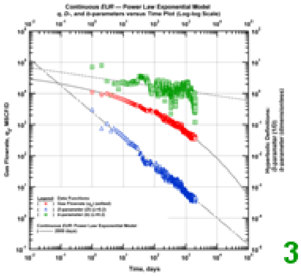
$G_{p,max}$ = 1.03 BSCF

⋮

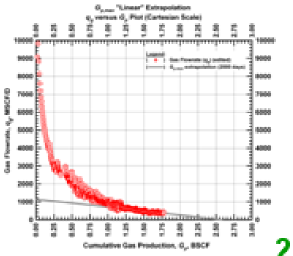
2000 days



***EUR* = 3.10 BSCF**



***EUR* = 3.05 BSCF**

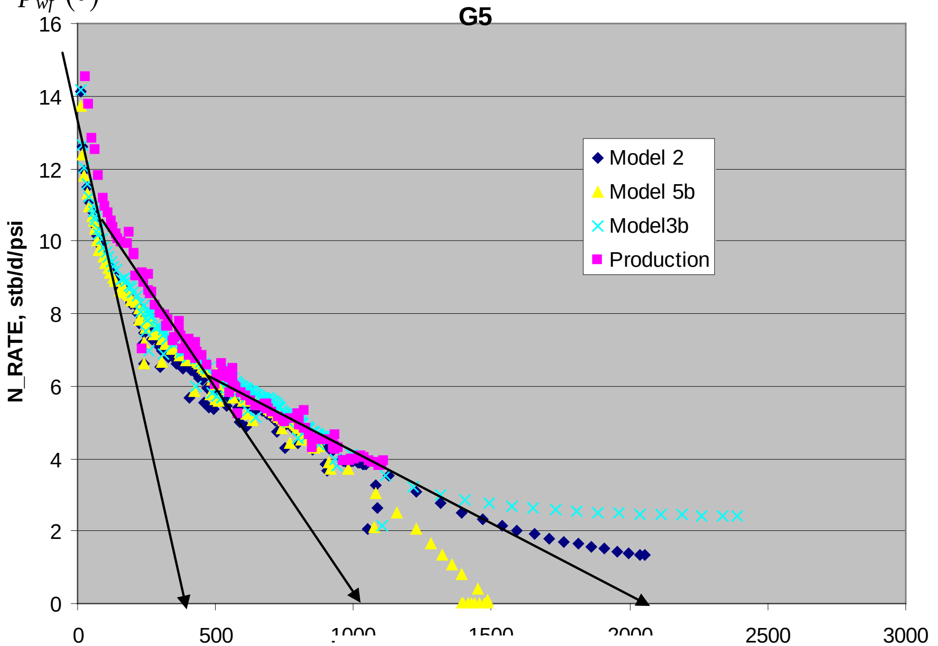


$G_{p,max}$ = 2.58 BSCF

Currie et al., 2010

Method 2: Concept of Reservoir Storage

$$\frac{q(t)}{p_i - p_{wf}(t)}$$



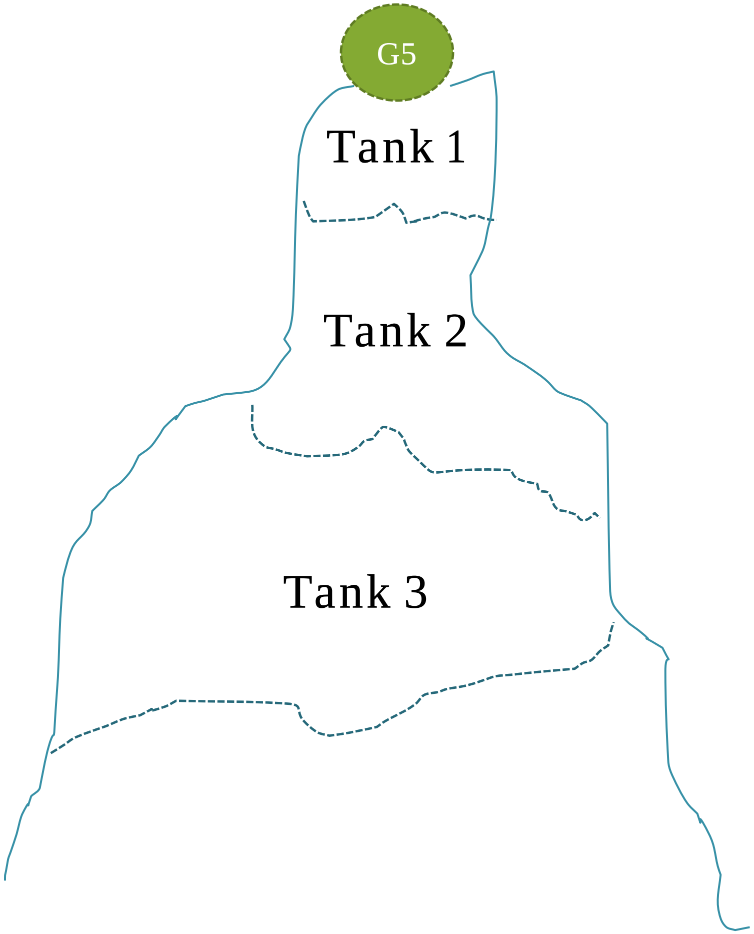
N_COP, stb/psi

$$\frac{N_p}{p_i - p_{wf}(t)}$$

Tank 1 Vol

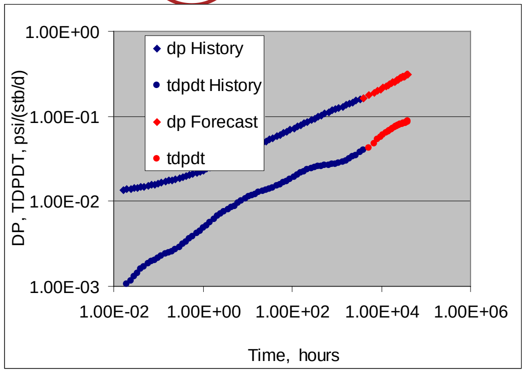
Tank 2 Vol

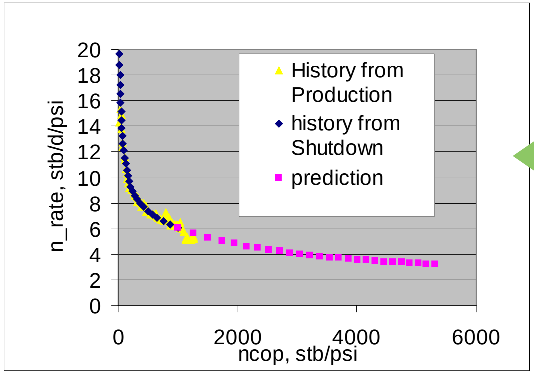
Tank 3 Vol

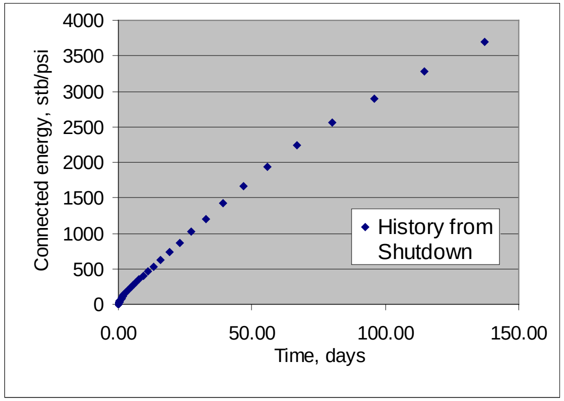


Framework for well performance characterization & prediction

- Rate forecasting
- Startup simulation
- Short-term production optimization
- Represent well performance from complex models







- Well performance diagnosis
- Rate forecasting

- Estimate reservoir pressure
- Facilitate history match
- Evaluate skin variation

Closing Remarks

- Engineers care about (1) how much fluids are in place; (2) how fast can they be produced.
- Rocks with the same pore volume do not necessarily the same OGIP with the same pressure.
- Production forecast:
  - More data and better models
  - Flow mechanisms are NOT clear! New methods are required
  - Reservoir storage model looks promising!