A Multiscale Study of Fluid Flow in Mudrock Systems

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Mudrock Systems Research Laboratory
MSRL

Bureau of Economic Geology

Objective

Present a multiscale framework for shale to account for the distinct pore size distributions and transport properties in organic matter and inorganic minerals

$The value of a reservoir$

Oil & gas reserve

- Pores and porosity
  - SEM, AFM, MICP, NMR, N2 adsorption
- Gas-in-place
  - Pressurized gas in pores
  - Sorbed gas
  - Lost gas estimation
  - Adsorption of heavy components on pore walls

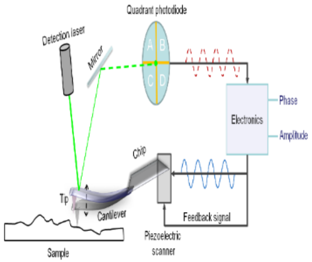
Oil & gas production, fracture fluid injection

- Effective gas permeability
  - Langmuir slip & Knudsen diffusion of gas flow
  - Gas perm measurement & models
- Liquid slip flow (water & HC)
- Fracture fluid loss

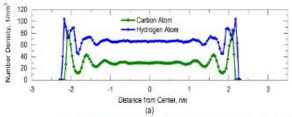
Subpore-to-core

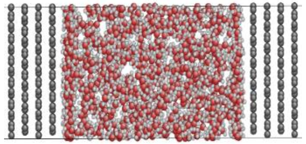
Subpore

Atomic force microscope (AFM) study for detailed study of fluid molecule interactions with pore inner walls



Molecular dynamics (MD) study of fluid molecules and pore inner walls

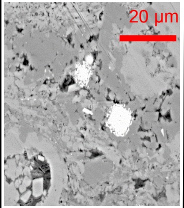




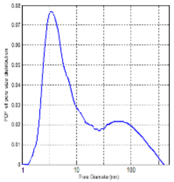
Metrology developed.

Pore

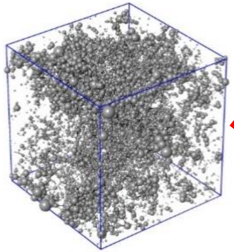
SEM study of organic, inorganic, and pores

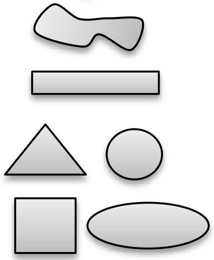


N2 adsorption data for pore size distribution



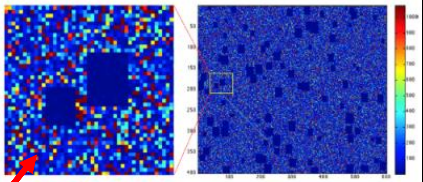
Pore network

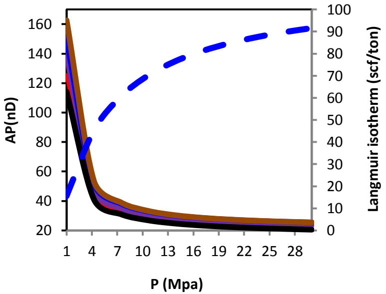




Network of pore networks

Stochastic permeability model to relate subpore interactions and information from SEM images, N2 adsorption, etc

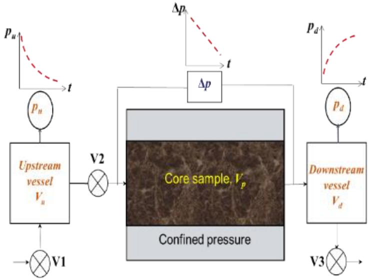




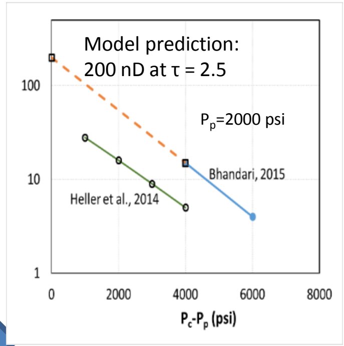
Model developed. New version with geomechanical effects.

Core plug

Pulse decay permeability measurements. Effect of effective stress



Many data at different confining stress was collected and used in model validation.



Core-to-simulation grid

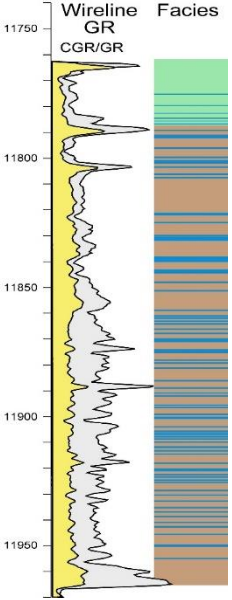
Core

Petrophysical properties such as porosity, permeability, mineral types and components collected from the retrieved core samples.

Geochem data needed to develop correlations for the wireline log.

Wireline log

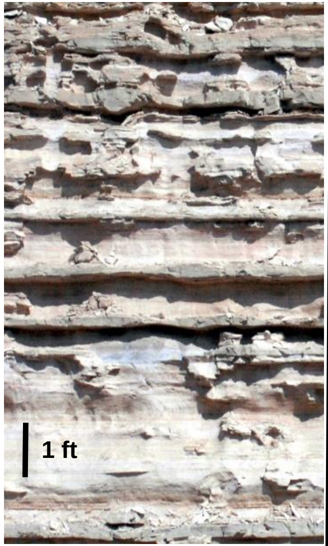
Develop correlation between core measurements and wireline logs.



Log data combines with core data to generate correlations.

Outcrop

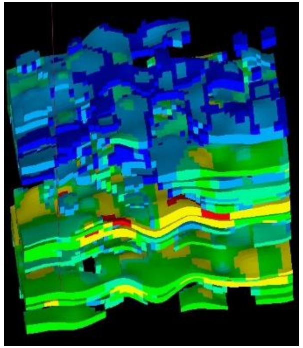
Outcrop study to develop two-dimensional geological models. Detailed study of facies, thin beds, ashes, extension of lenses, etc. Integrate with wire log data.



2D outcrop information helps to extend 1D wireline data to develop stratigraphic models.

Multi-well

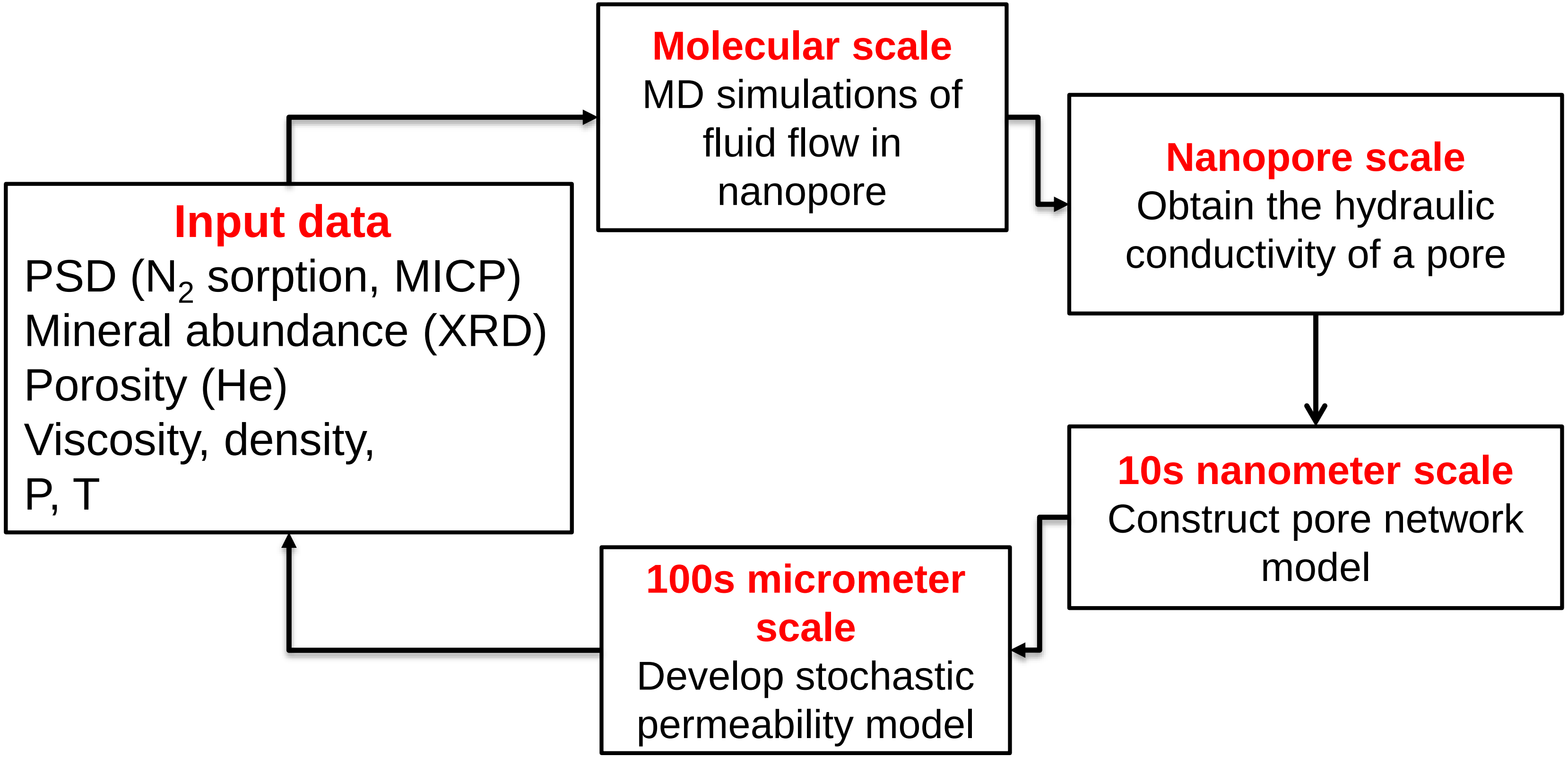
Development of an integrated methodology to create three-dimensional geologic and dynamic models.



2D to 3D based on log and outcrop knowledge.

We have developed the technology of multiscale research and have tested our approach for samples from different basins such as Eagle Ford.

Framework


Molecular scale
MD simulations of fluid flow in nanopore
Nanopore scale
Obtain the hydraulic conductivity of a pore
Input data
PSD (N_2 sorption, MICP)
Mineral abundance (XRD)
Porosity (He)
Viscosity, density,
P, T
10s nanometer scale
Construct pore network model
100s micrometer scale
Develop stochastic permeability model

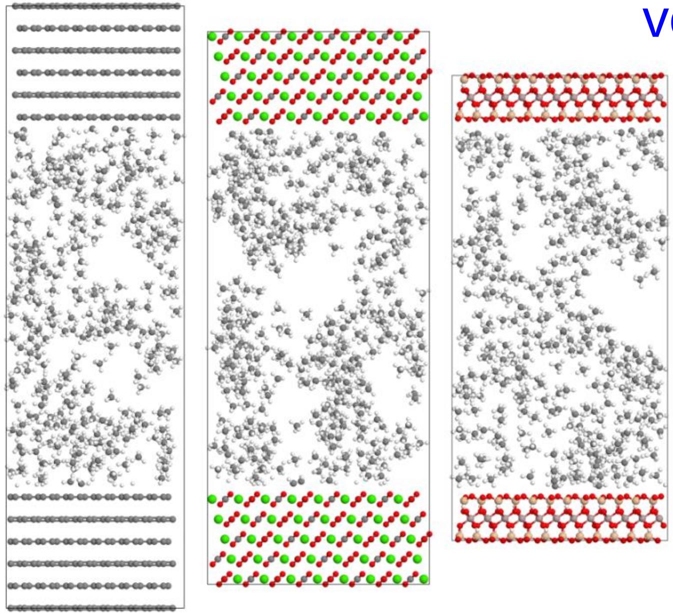
Exploring the Flow Behavior Using MD

CH_4 | adsorption | slip length

Solid model → Liquid model → EMD → NEMD → Flow characterization

velocity profile

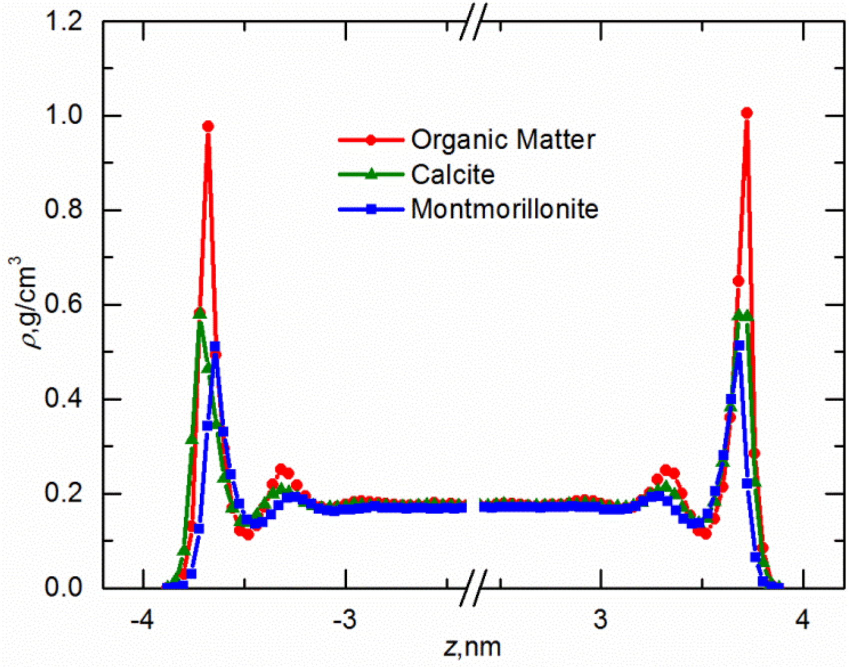
- OM
- calcite
- montmorillonite

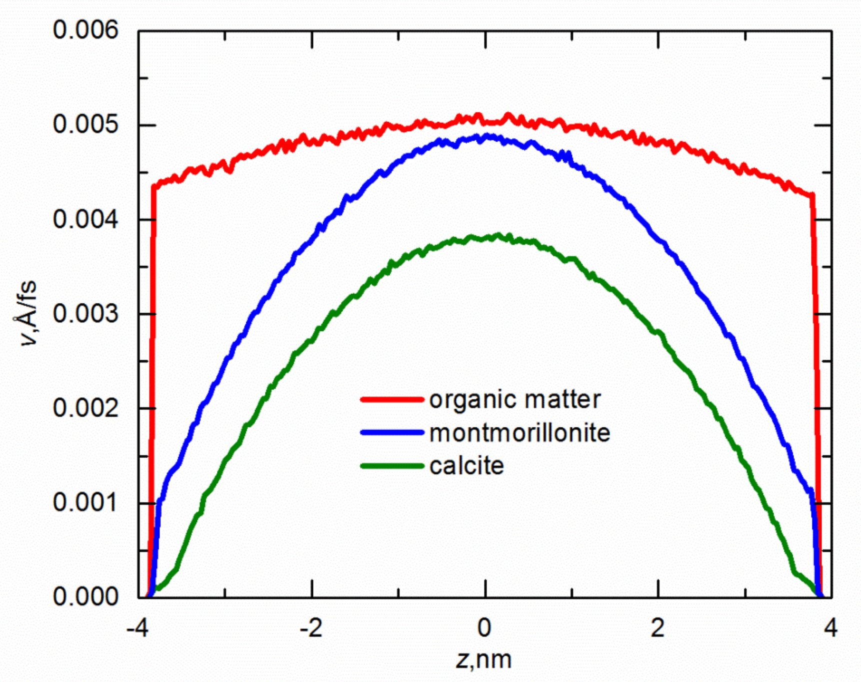


T=386 K, P=39.5 MPa

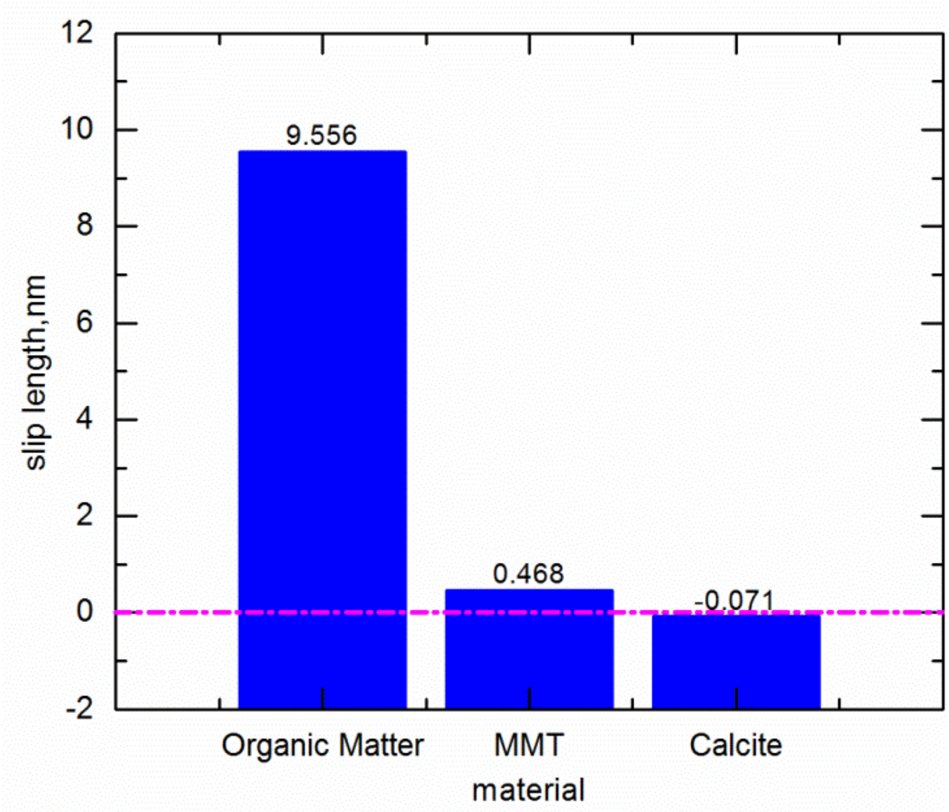
Slit aperture：3.44 nm

Density and velocity profiles





Slip lengths in different nanoslits

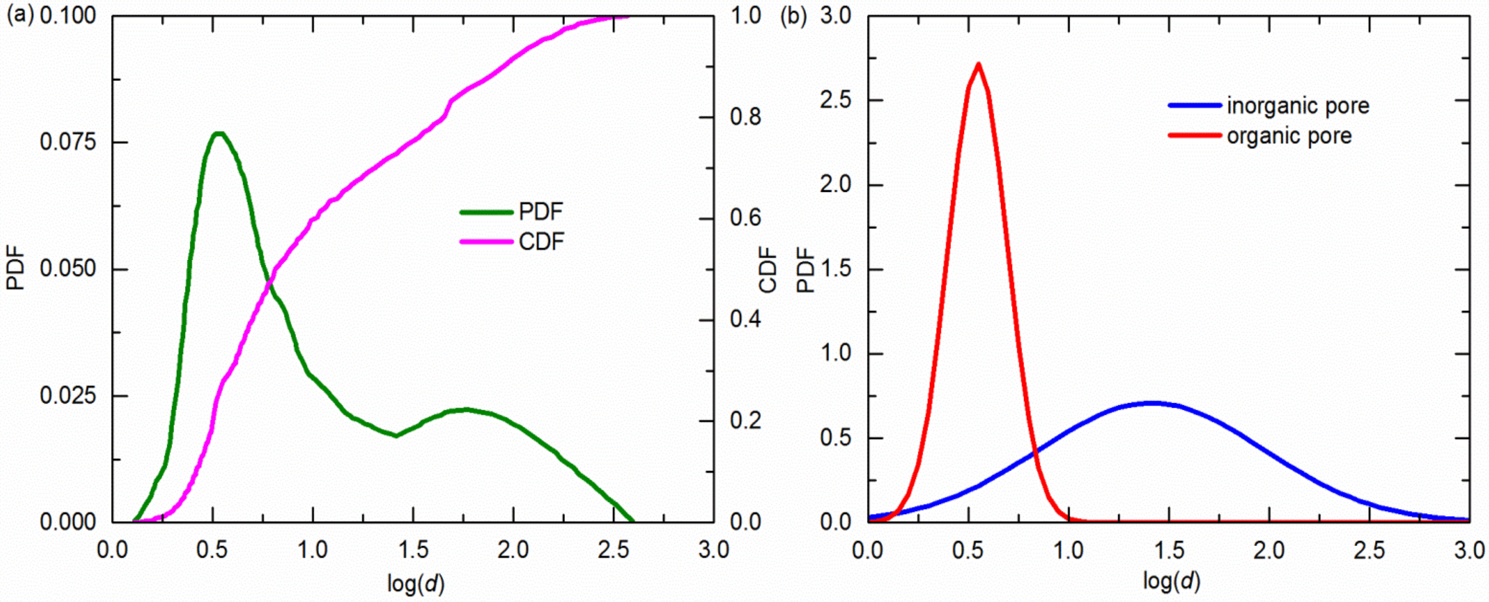


Estimating the Apparent Permeability Using PNM

$$P\left(R<r\right)=\sum_{i=1}^{N}P\left(F_i\right)P\left(R<r\middle|F_i\right)$$

$$P\left(R<r\middle|F_i\right)=N\left(\mu_i,\sigma_i\right)$$

$$OBF=\sum_{k=1}^{N_{\text{data}}}\left(P_{\text{data}}\left(R<r\right)-P_{\text{model}}\left(R<r\right)\right)^2$$

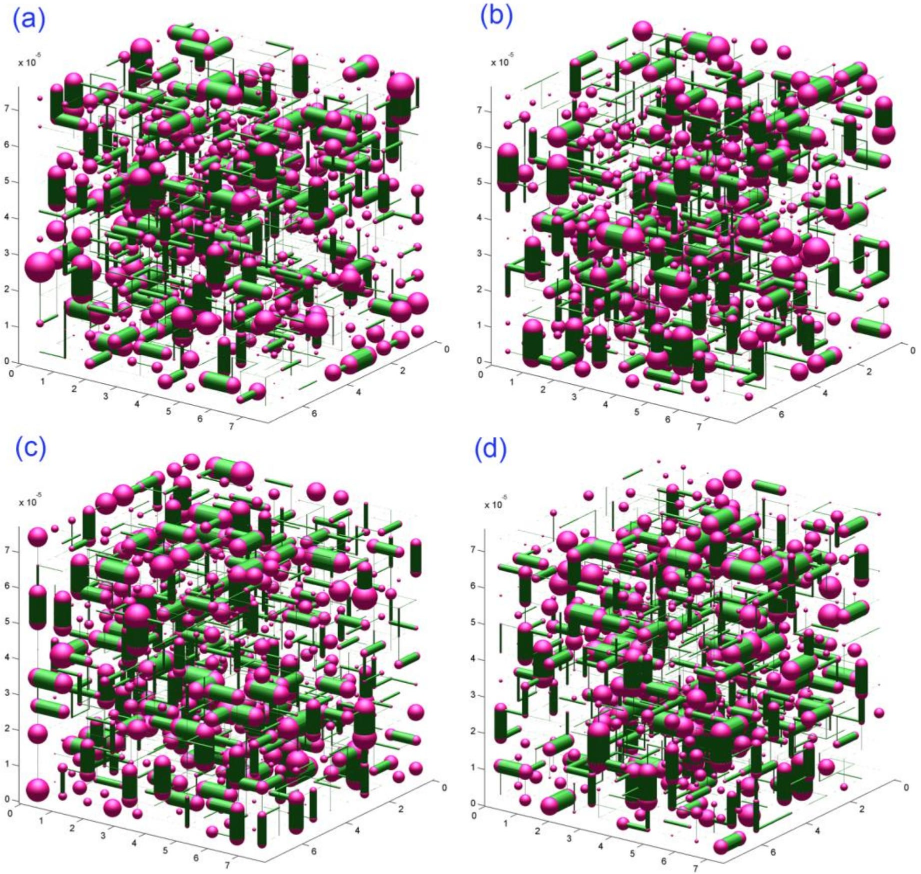


Shale pore network model

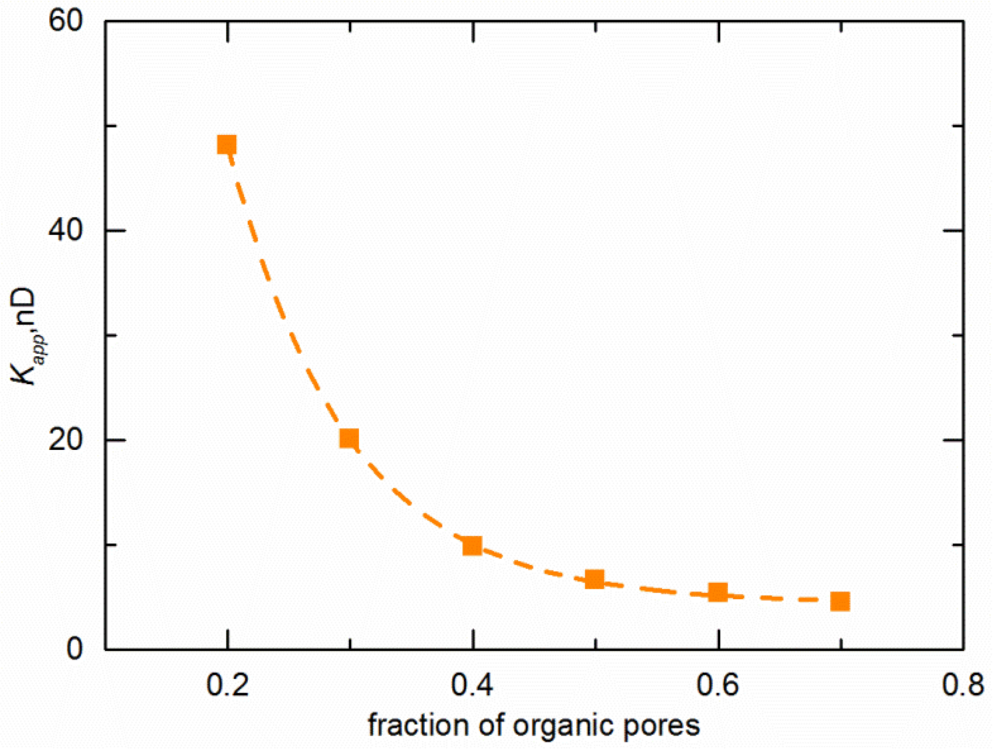
Pore type	μ	σ	fraction
OM	0.5474	0.1469	0.4094
IM	1.4124	0.5622	0.5906

Fraction of each kinds of pores

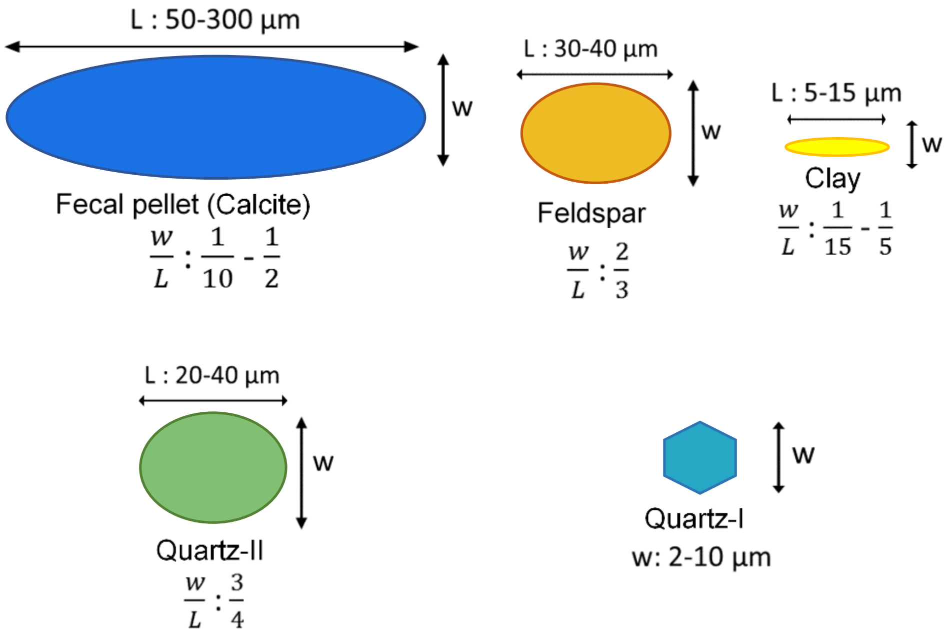
$$C_i = P\left(F_2\right)\alpha_i$$



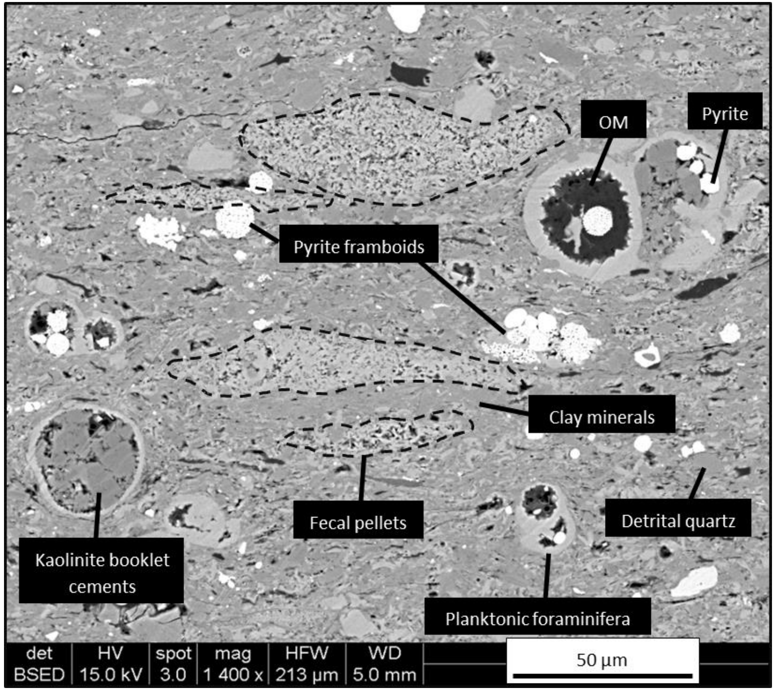
Apparent permeability versus fraction of organic pores

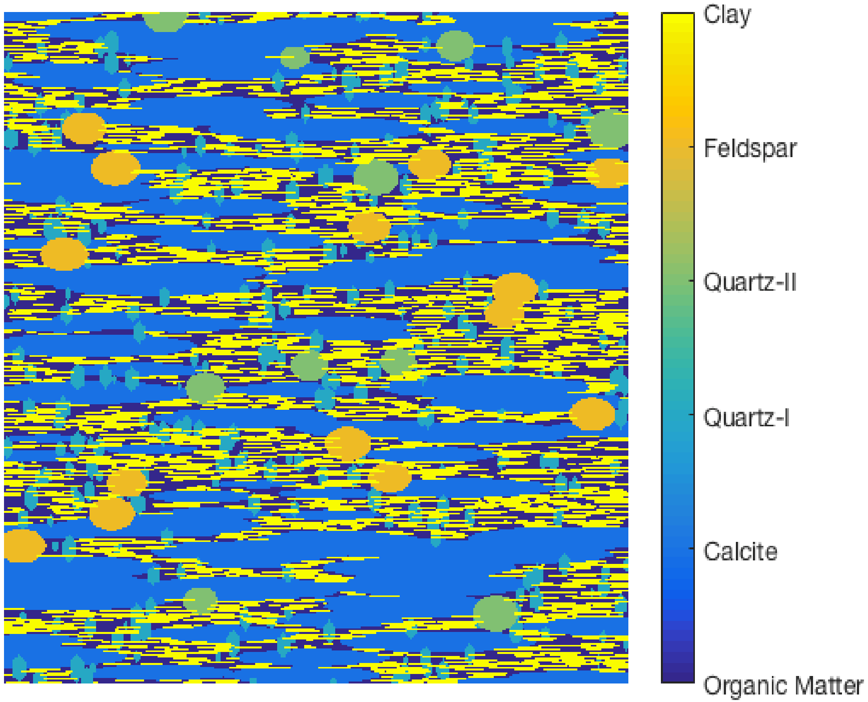


Size and shape of different mineral types in Eagle Ford



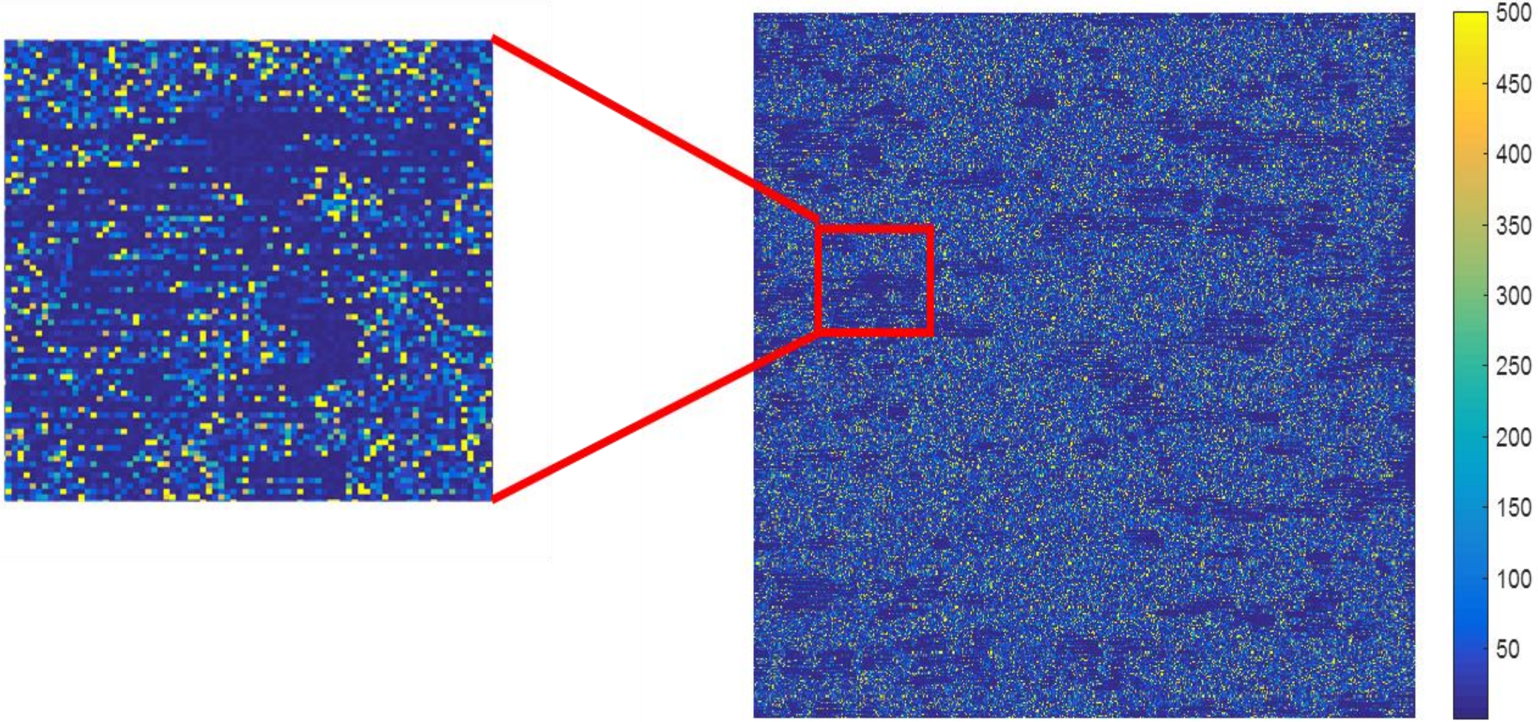
Problem Statement





Naraghi et al., 2018

An example of a realization



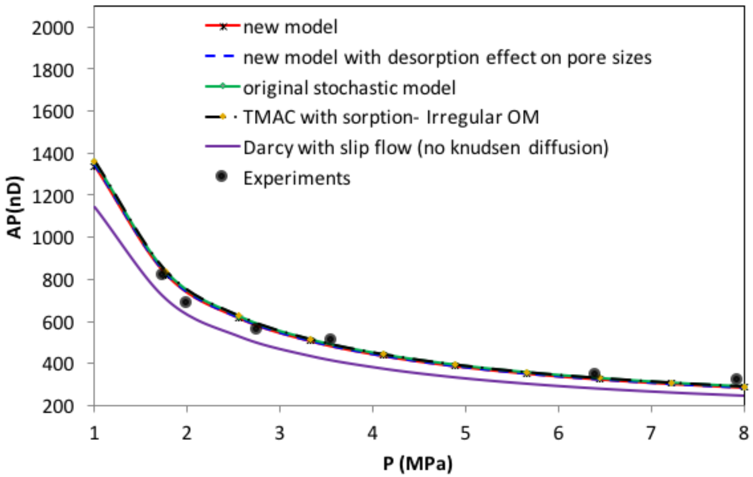
Pressure field

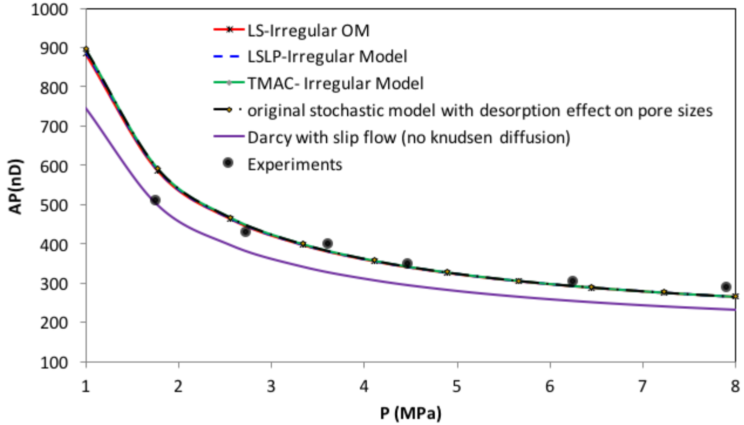
Validation→ In-house experiments

Experiment	Condition	Sample Size	Data courtesy	Results
Nitrogen sorption	Clean sample	Powder	Dr. T. Zhang (UT-Austin)	Pore size distribution
Helium porosity measurement	As received sample		Dr. A. R. Bhandari (UT-Austin)	Porosity
Pulse Decay	As received sample	Core plug	Dr. A. R. Bhandari (UT-Austin)	Permeability
In-house Setup	Confined Stress (27.6 MPa) with Methane	Powder	Dr. T. Zhang (UT-Austin)	Langmuir isotherm

	Permeability (nD)
Experiment	15
Stochastic model	27.6
Singh and Javadpour (2015)	40

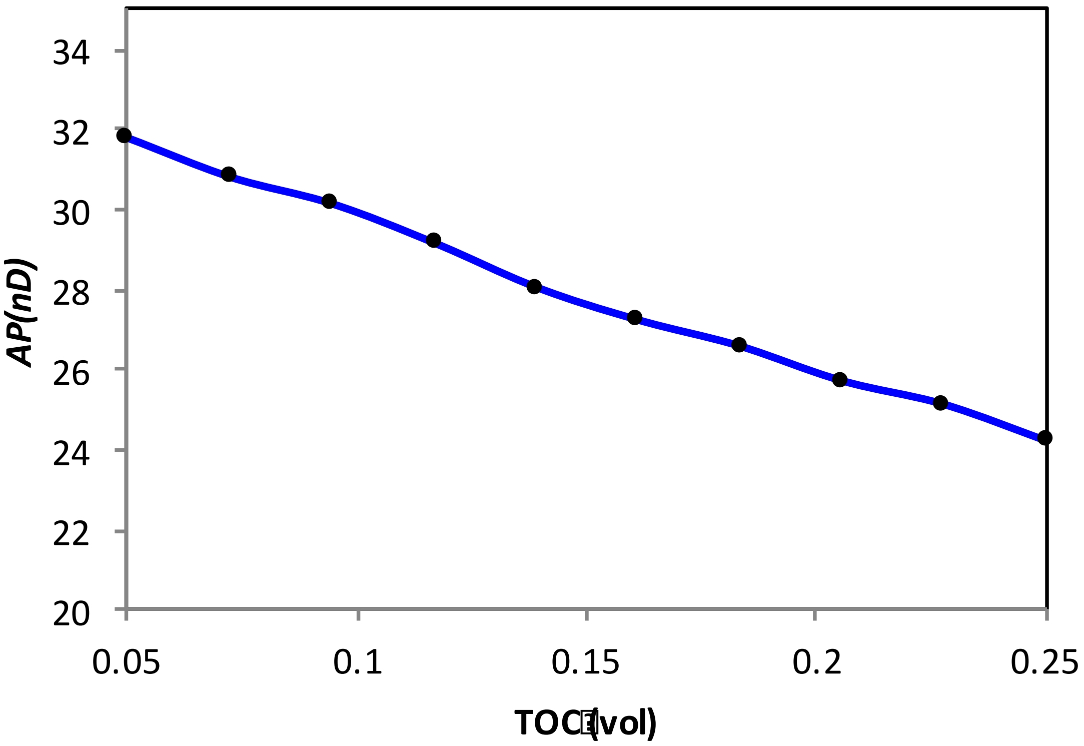
Validation → Literature Data



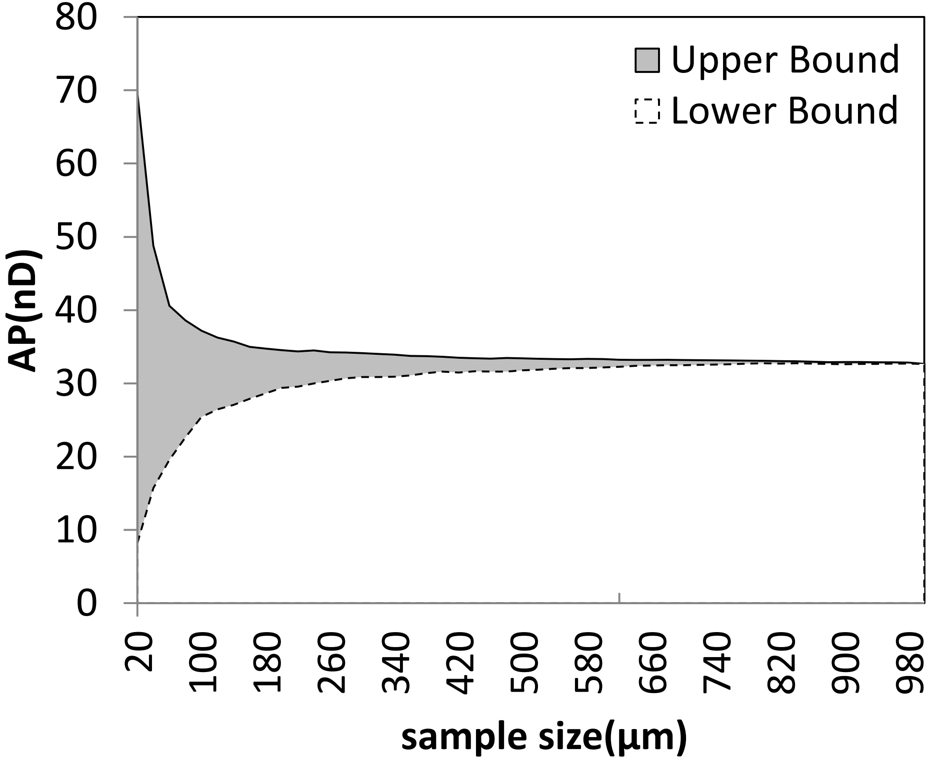


Experimental data:
Letham 2011

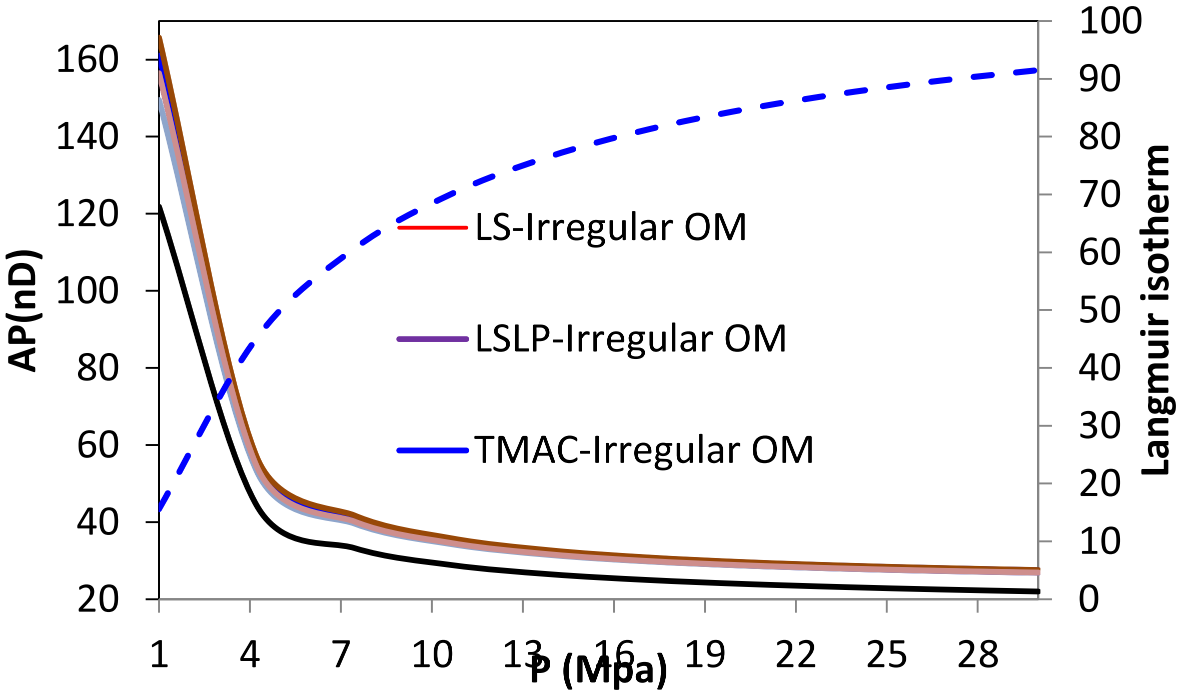
Effect of TOC



Effect of sample size



Sorption effect on permeability



Summary and Conclusion

- We present a multiscale framework to simulate gas flow through shales and estimate the apparent permeability.
- The transport behavior of gas in an organic nanopore is different from that within inorganic minerals.
- At high pressures, gas transport through shale nanopores can be fairly characterized by the slip-corrected Poiseuille equation.
- Apparent permeability in shale systems is more sensitive to the size distribution of pores within inorganic matrix than those associated with kerogen.

Acknowledgements

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Thank You!

Comments and Questions?

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