

# **AV The Importance of Pore Structural Heterogeneities for Shale Gas Reservoir Evaluation**

By

**Daniel J. Ross<sup>1</sup> and R. Marc Bustin<sup>1</sup>**

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<sup>1</sup>Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada ([dross@eos.ubc.ca](mailto:dross@eos.ubc.ca); [bustin@unixg.ubc.ca](mailto:bustin@unixg.ubc.ca))

## **Abstract**

Elucidating the controls upon gas capacities in fine-grained strata and accurately determining reservoir potential requires knowledge of shale physical structure. However, the intricate, heterogeneous pore network of shales is difficult to assess because pore-throats can be smaller than 2 nm. Shale gas reservoir evaluations rely upon scaling laboratory data to regional reservoir magnitudes, but failure to recognize nano-scale heterogeneities will lead to erroneous economic assessments.

Comparisons of Devonian-Mississippian (D-M) and Jurassic strata show that shale pore structure is a function of total organic carbon (TOC) content, mineralogy, and thermal maturation. Sorption experiments of D-M shales indicate greater micropore volumes of organic-rich shales than organic-lean shales, thus increasing methane sorption capacity with TOC. The ratio of sorbed gas to TOC is also dependent on thermal maturity. At higher maturation levels, internal surface areas are larger (per wt% TOC), illustrating the thermal maturity effect upon pore-wall chemistry. As such, over-mature D-M shales sorb more gas than Jurassic shales on a wt% TOC basis. Micropore volumes of low maturity Jurassic strata tend to be low, despite TOC contents >30 wt%, due to the structureless nature of matrix bituminite.

Inorganic material influences modal pore size, total porosity, and sorption characteristics of D-M shales. Highly mature Devonian shales are both silica- (biogenic) and TOC-rich (up to 85% quartz and 5 wt% TOC) and deemed excellent potential shale gas reservoirs because they are both fracable and gas-charged. However, quartz-rich Devonian shales display tight-rock characteristics, with poorly developed fabric, small median pore diameters, and low permeabilities. Hence potential 'frac-zones' will require an increased density of hydraulic fracture networks for optimum gas production.

# THE IMPORTANCE OF PORE STRUCTURAL HETEROGENEITIES FOR SHALE GAS RESERVOIR EVALUATION

Daniel Ross  
and  
R. Marc Bustin



# Pore structure

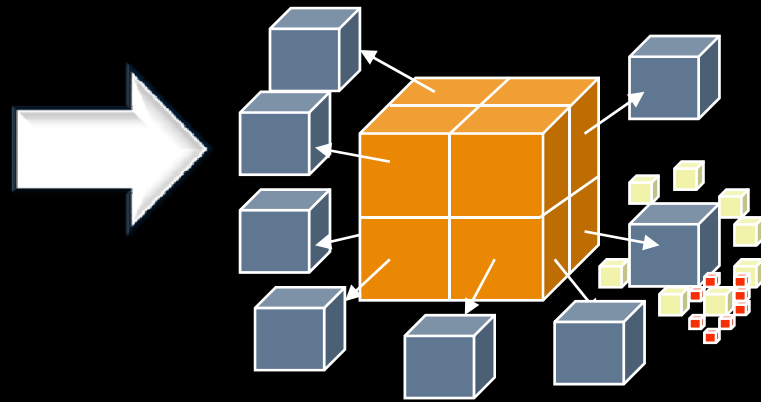
- What is pore structure?
- Why do we care?

# What do we mean by pore structure?

- Pore size distribution
- Pore throat diameter

+

**Total pore volume**



Surface area increases exponentially with decrease in pore size

## How do we evaluate the pore structure?

### Meso-macroporosity (>2 nm):

– N<sub>2</sub> isotherms, Hg porosimetry → Measures really small pores

### Microporosity (<2nm):

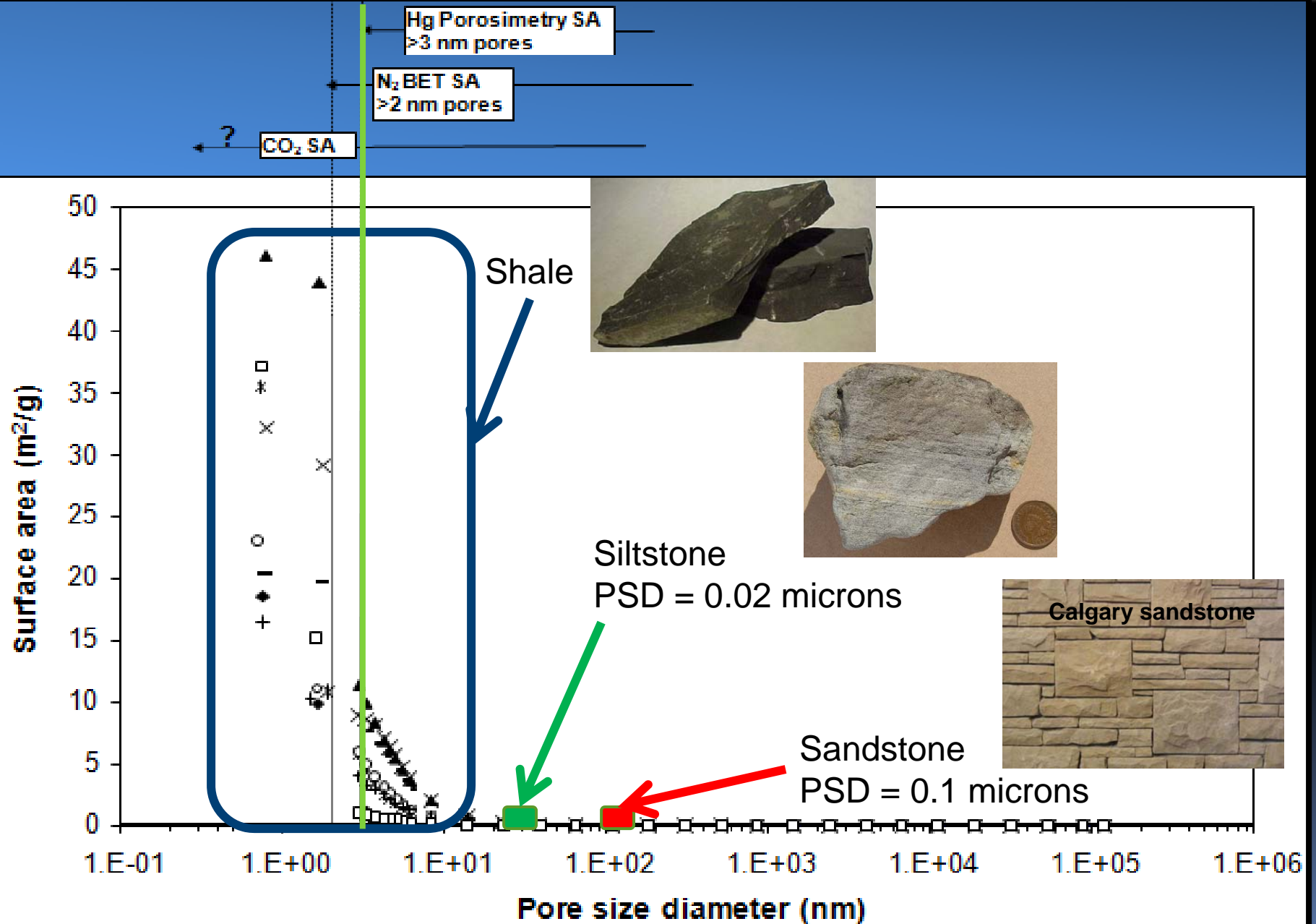
– CO<sub>2</sub> isotherms

→ Measures really really small pores

**Background**



# Surface area measurements



# Pore Structure

- What size of pores are we dealing with??
  - Micropores.....not micron-sized pores
  - Nanometre scale (can be  $<2$  nm diameter)



## Summary:

- Dealing with very small pores
- Put this knowledge into practice

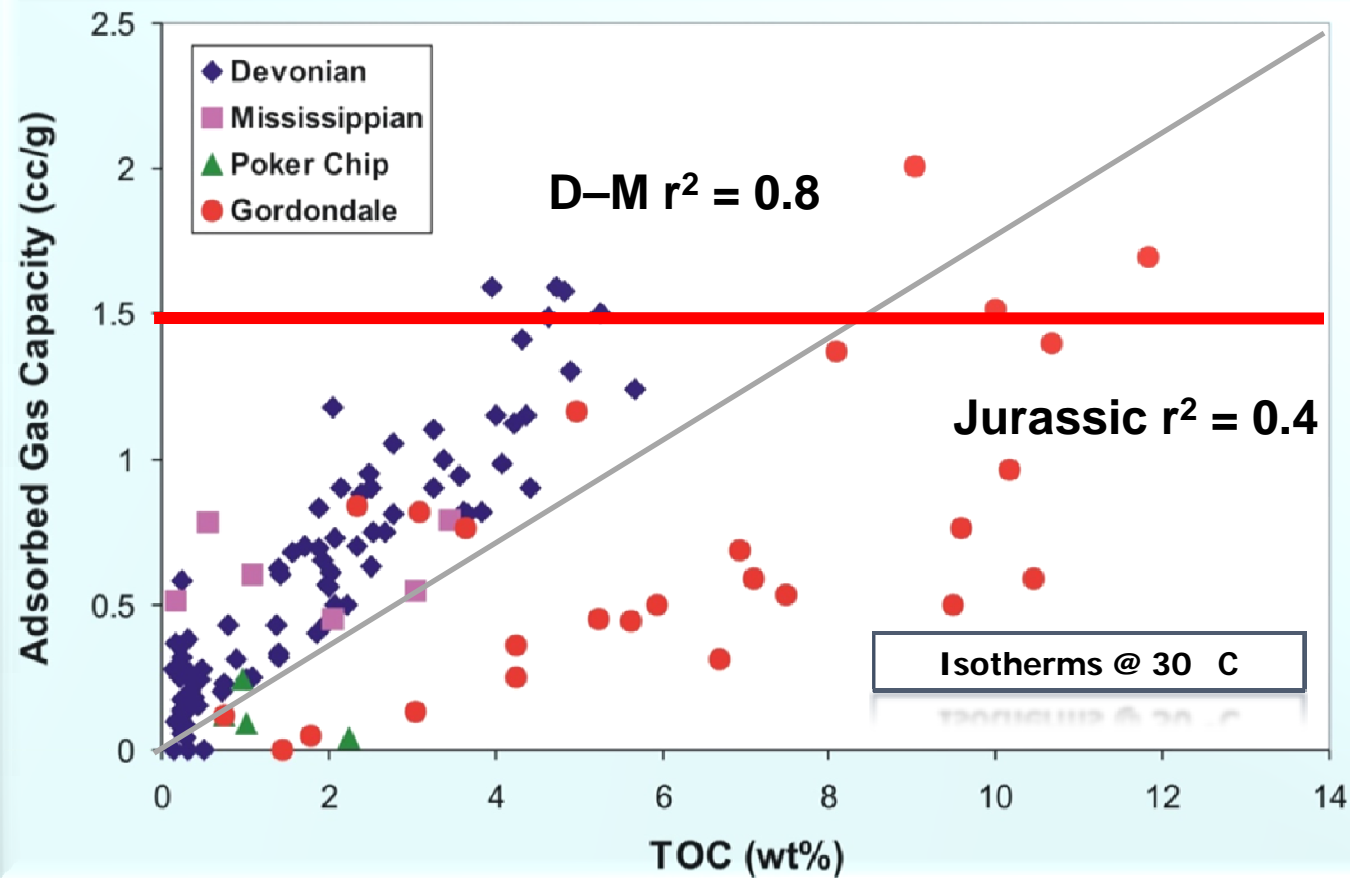


- Impact upon GIP

Why we care



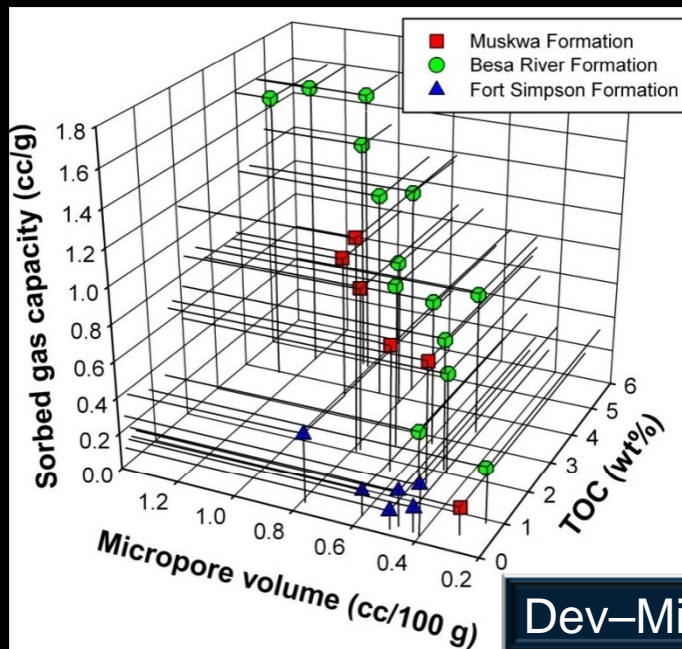
# GI P – gas sorption



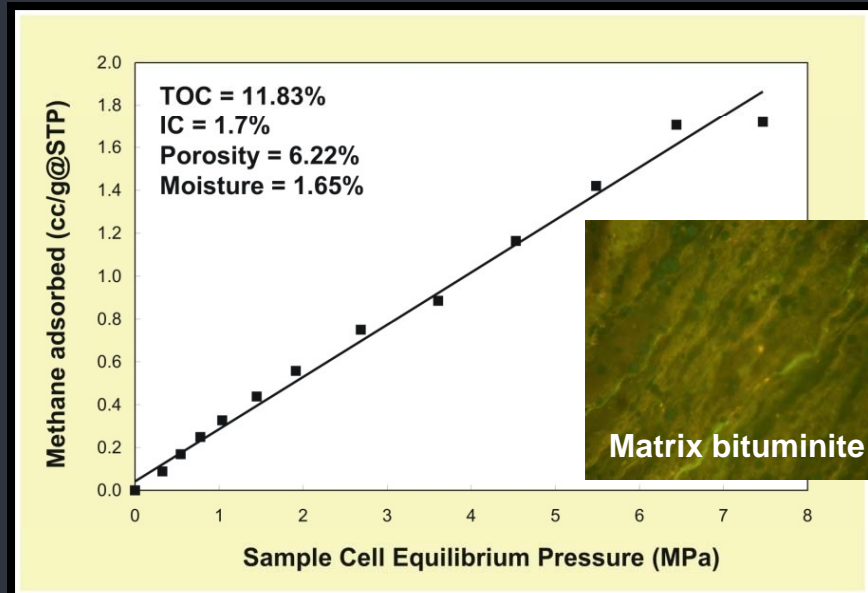
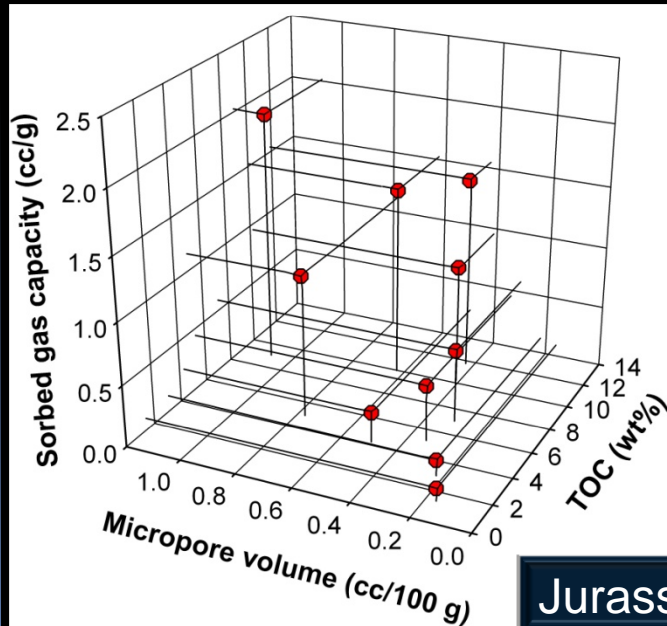
- Significant difference between sorbed gas to TOC ratios

**Gas-in-place: organics**

# Importance of micropores



- Organic matter in Devonian–Mississippian shales is microporous
- Jurassic shales: micropore volume can be invariant of TOC



- Linear correlation between sorption and pressure – component of solute gas.

**Gas-in-place: organics**

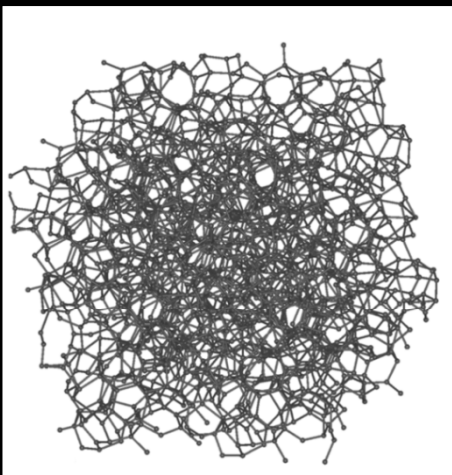
# Why the difference in OM pore structure?

**Jurassic**  
**VRo <2%**

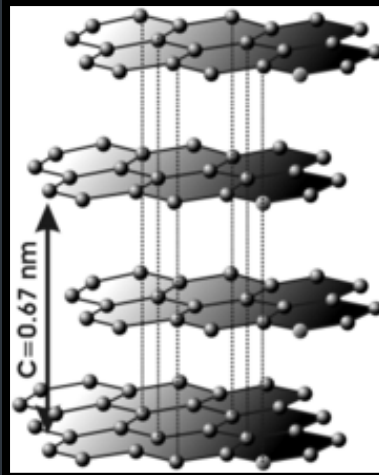
**Devonian**  
**VRo >2%**

Sample	TOC	IC	Surface area m <sup>2</sup> /g	Surface Area:TOC
<b>Jurassic</b>				
N2557-2	3.05	0.49	8.38	2.7
N230-1	7.09	3.77	11.45	1.6
N89-1	5.24	7.13	12.72	2.4
N49-2	10.00	2.64	23.44	2.3
N6080-1	4.25	0.26	18.53	4.4
N91-1	10.15	1.83	15.33	1.5
N376-1	1.44	8.10	6.21	4.3
N3793-1	9.00	2.7	40.3	4.5
N3773-2	4.97	1.15	28.78	5.8
<b>Devonian</b>				
BRS2563-5	2.77	0.14	21.87	7.9
BRS-C15-1331-5	3.97	0.23	46.99	11.8
BRS1331-6	4.72	0.211	44.67	9.5
BRS442-1	3.45	0.22	18.3	5.3
MS414-1	3.67	0.07	36.74	10.0
MS714-3	1.58	4.70	18.79	11.9
MS1416-1	2.14	0.79	28.98	13.5

*Increasing maturation*



Increasing  
maturation



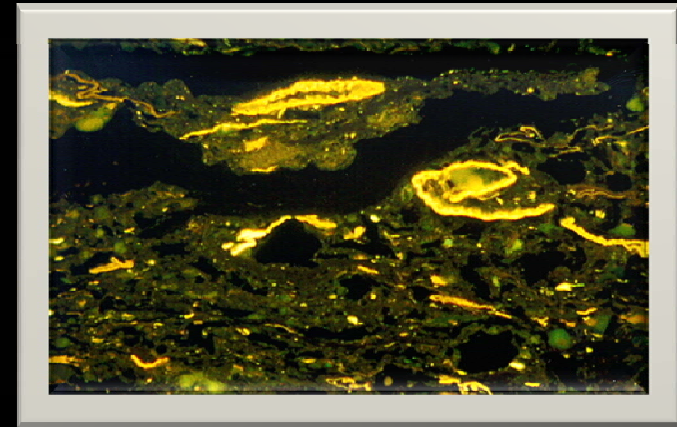
**Gas-in-place: organics**



# Shales as microporous materials

➤ We are dealing with heterogeneous microporous structures, influenced by:

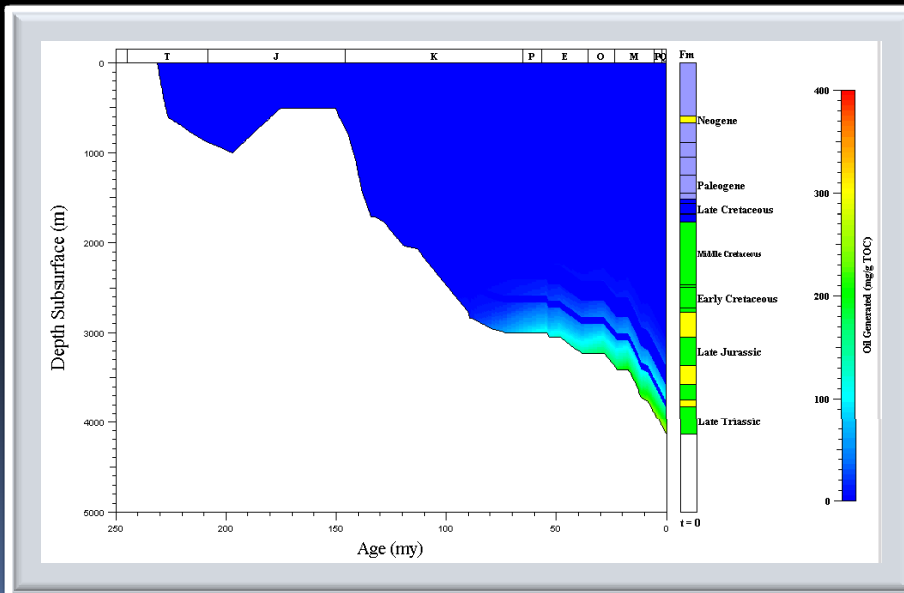
- organics
- thermal maturity/diagenesis
- inorganics



+

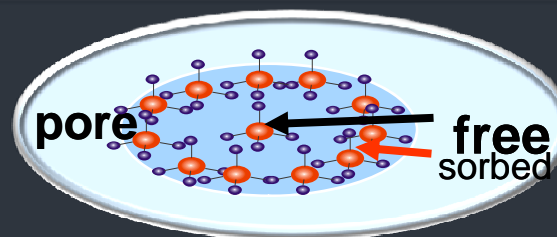


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# Quartz and $\emptyset$

$\emptyset =$



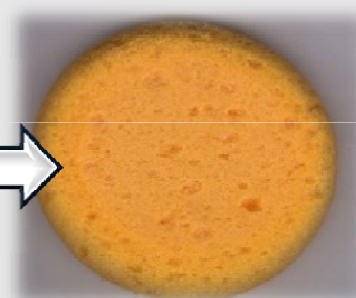
## Fracturing potential



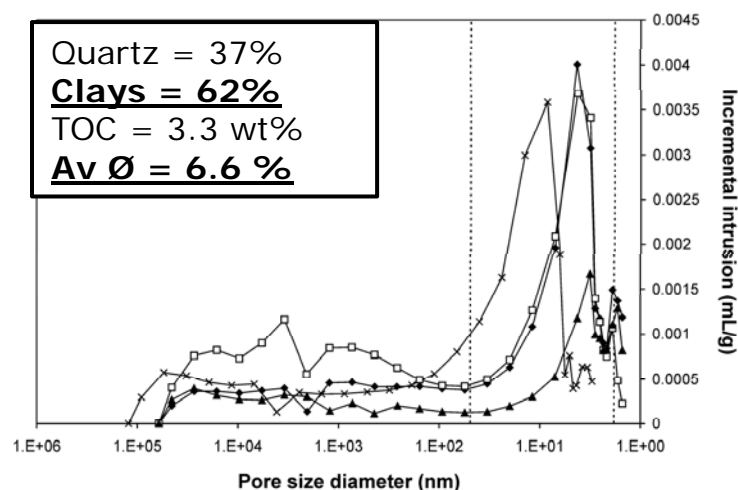
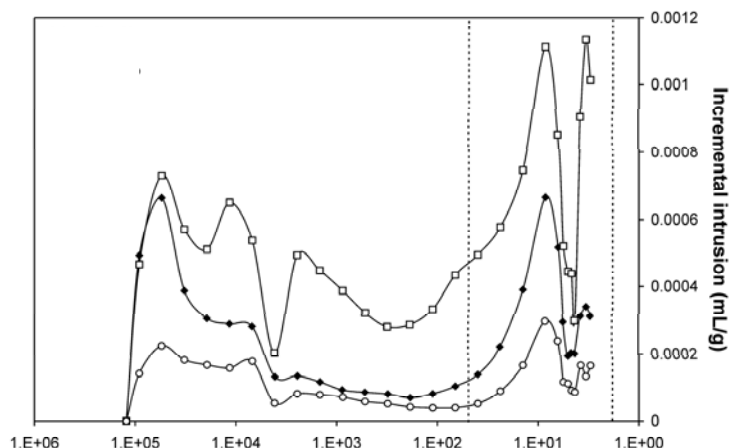
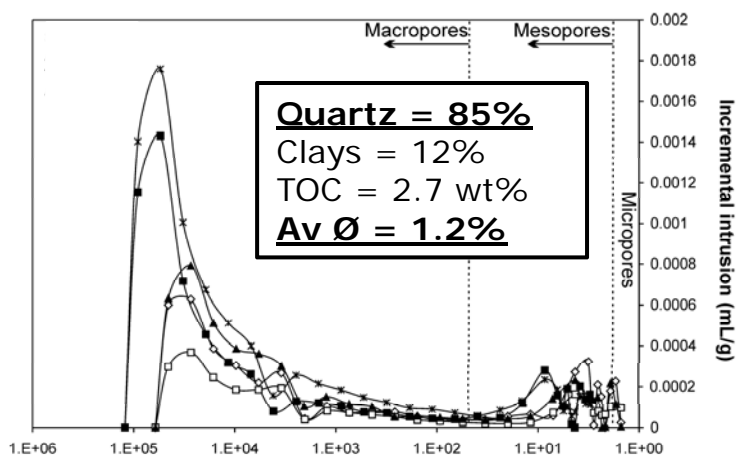
Quartz-rich



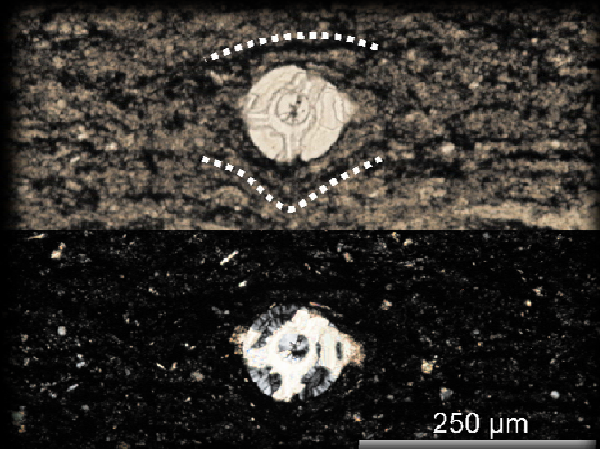
Clay-rich



Gas-in-place: inorganics



# Silica-source



Entactiniid radiolarian, Family Entactinaria  
(Carter, *pers. comm.*)

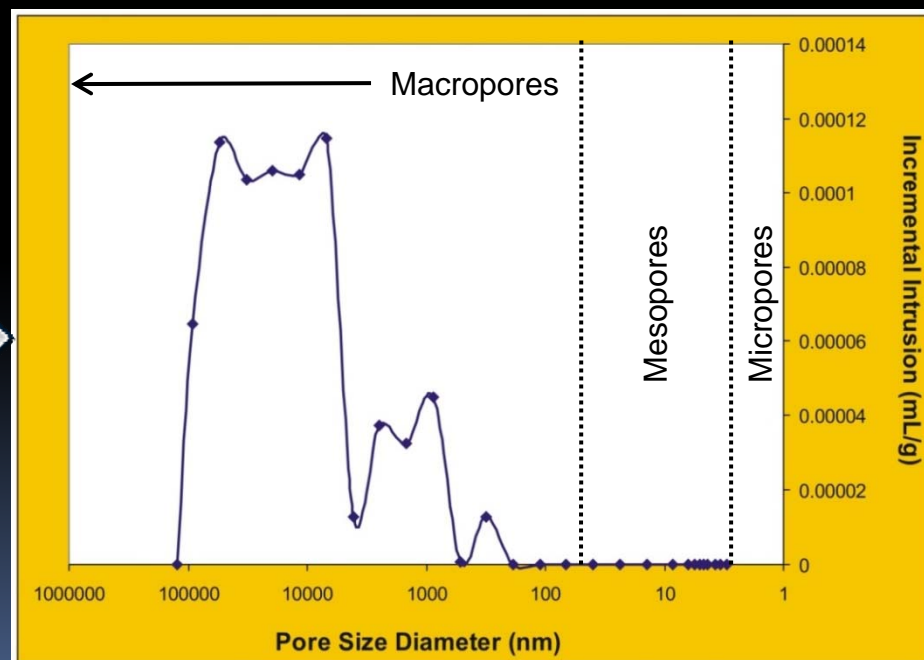
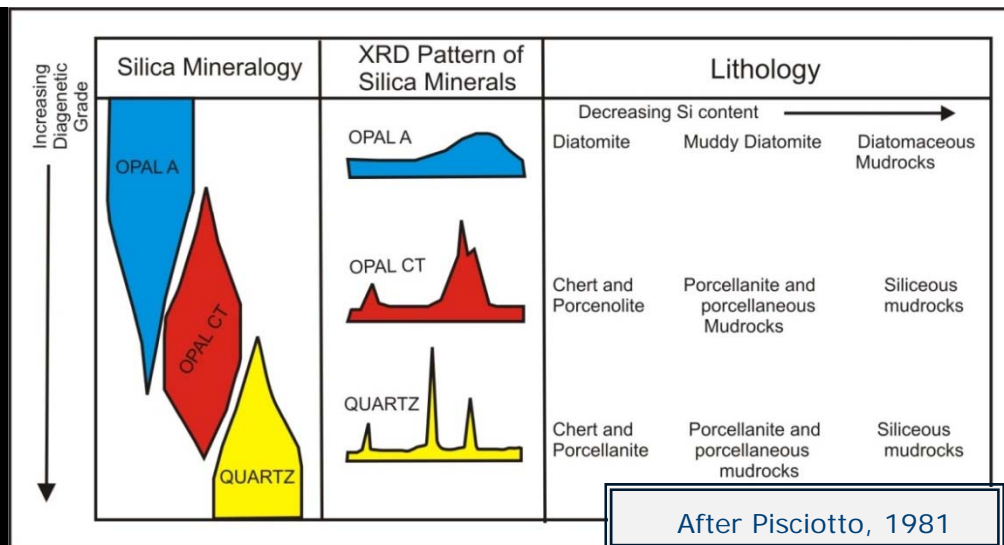
## Chert



Porosity = 0.2 %

BET N<sub>2</sub> Surface area = 0.4 m<sup>2</sup>/g

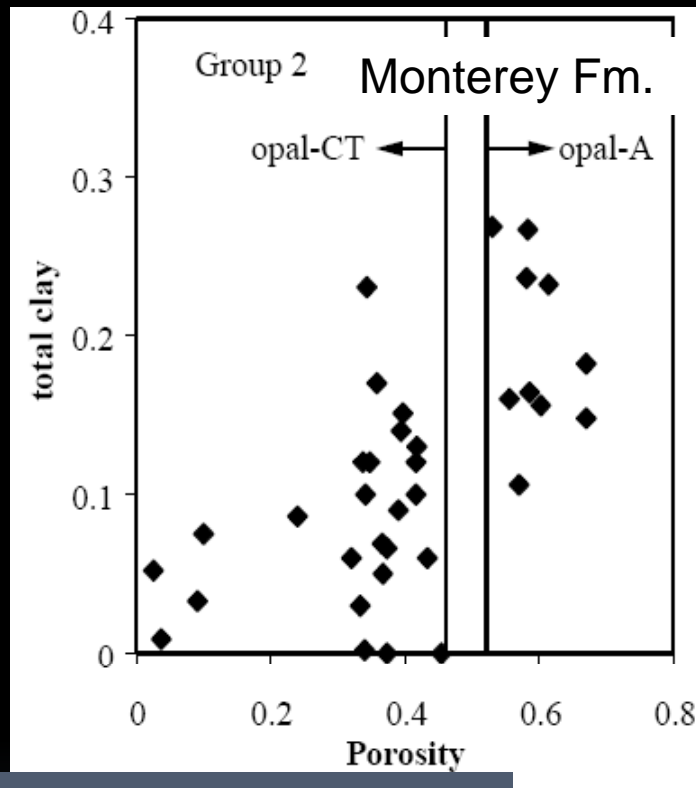
CO<sub>2</sub> Surface area = 3.1 m<sup>2</sup>/g



**Gas-in-place: inorganics**



# Diatomaceous analogs

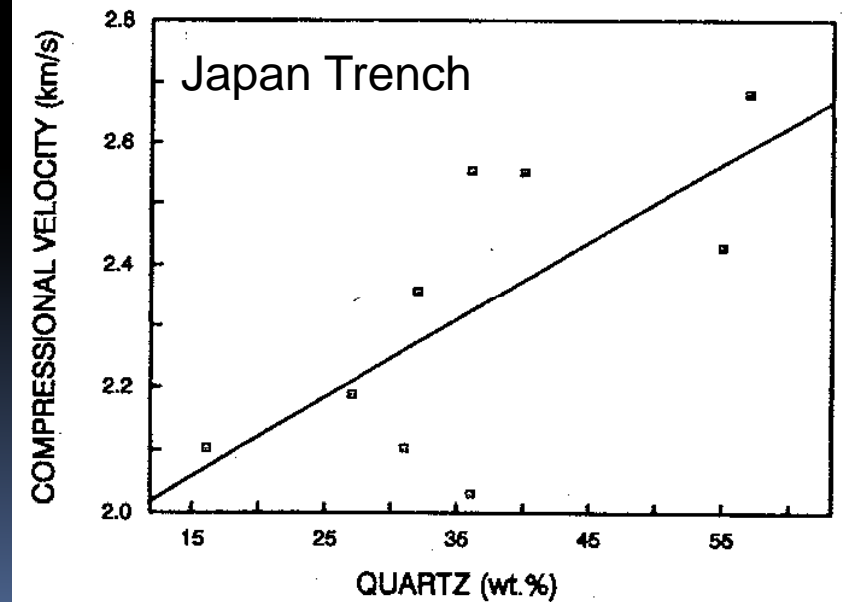


Chaika & Dvorkin, 2000

- Abrupt porosity reduction due to opal-A to opal CT transition
- The higher the clay content, the larger the total porosities

Opal-A to Opal CT to Quartz

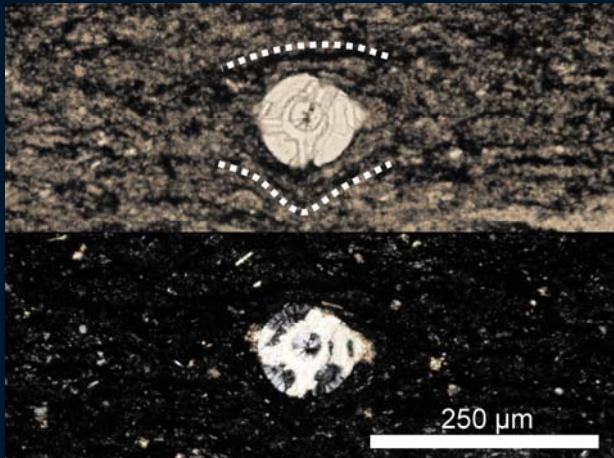
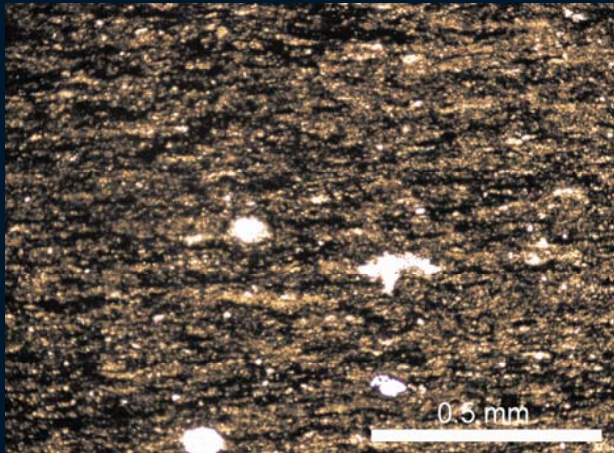
- “Distinct changes in microfabric, porosity distribution and sonic velocity”



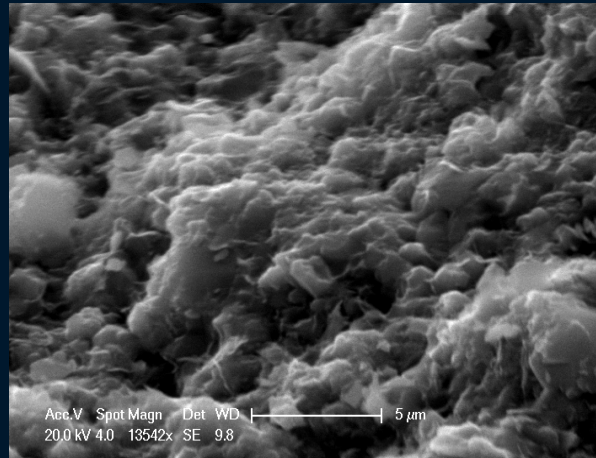
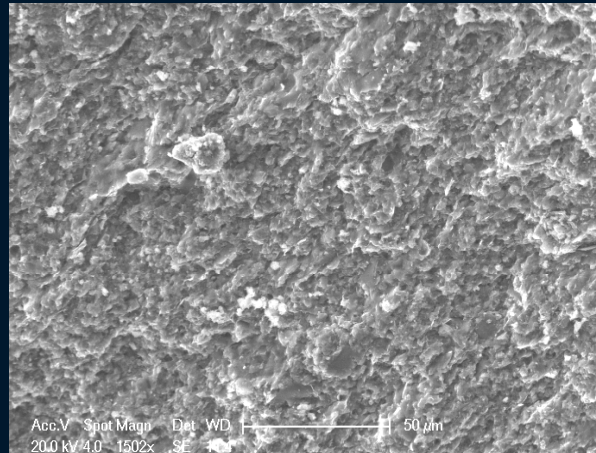
# Fabric analysis I

## Image analysis of quartz-rich shales

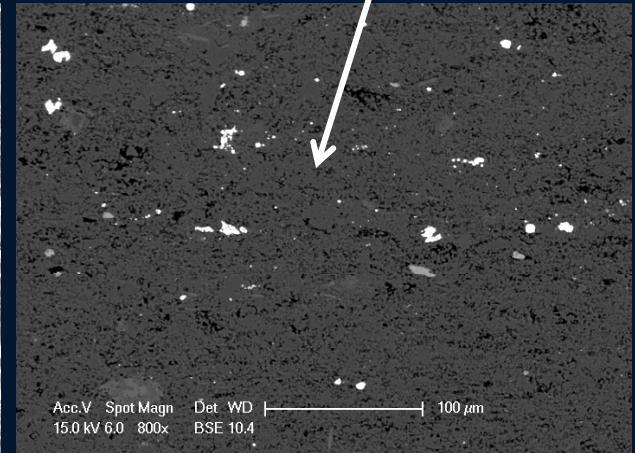
T/S



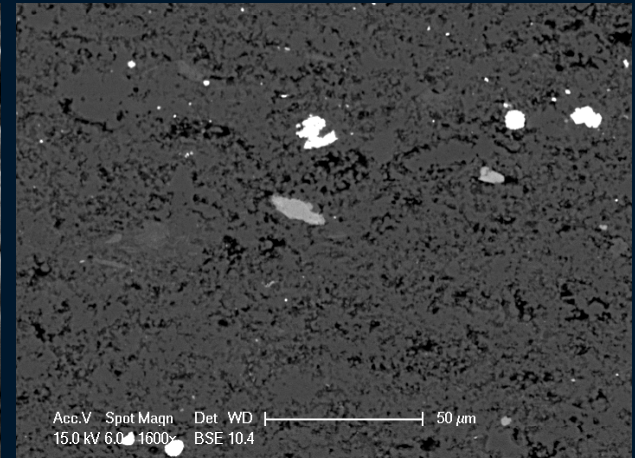
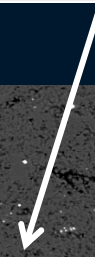
SEM



BSEM



Lack of fabric/grain-on-grain contacts



➤ Implications for fluid-flow properties

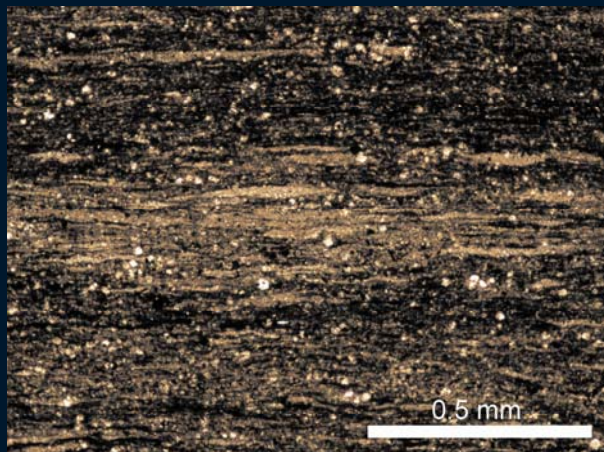
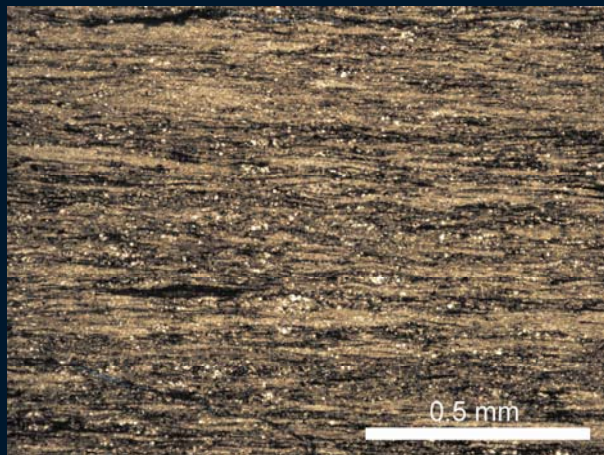
**Gas-in-place: inorganics**



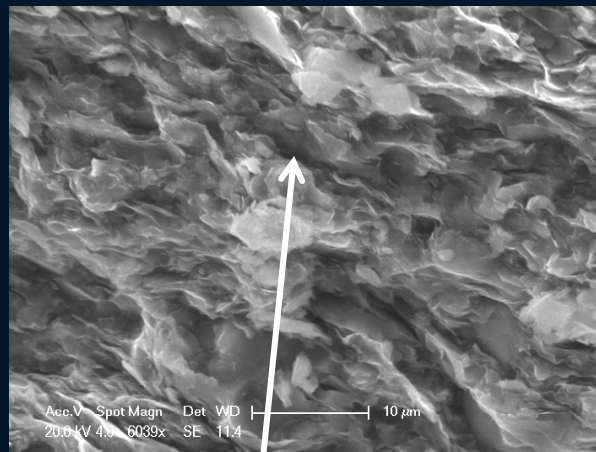
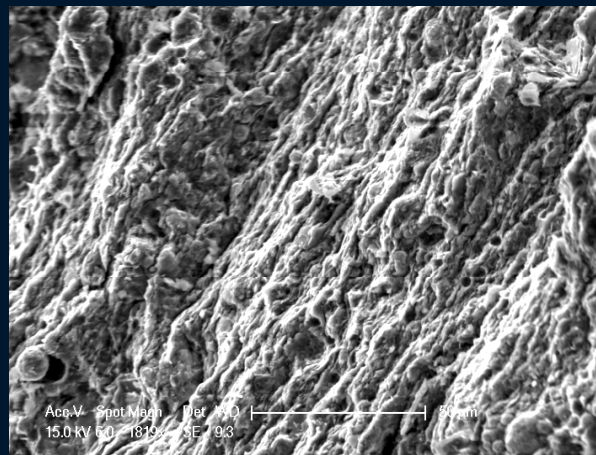
# Fabric analysis II

## Image analysis of illite-rich shales

T/S

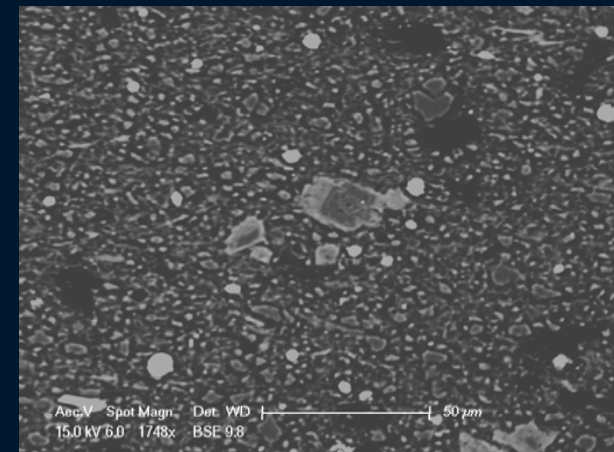
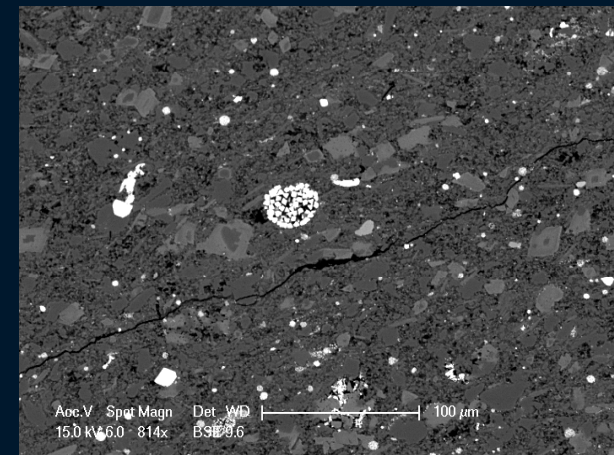


SEM



Porosity between parallel aligned clay plates

BSEM



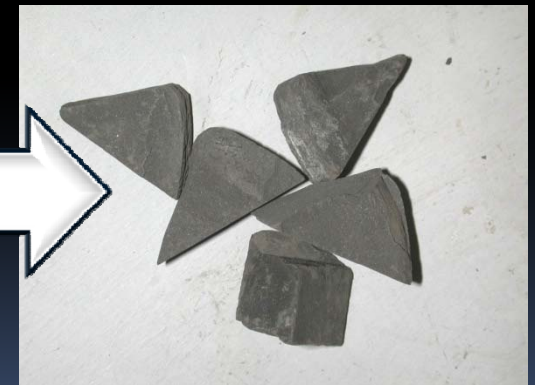
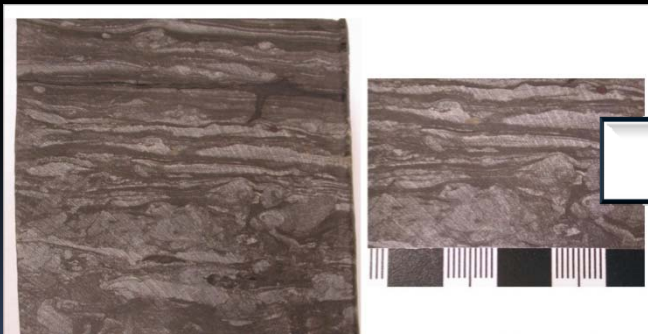
Gas-in-place: inorganics

# Conclusions

- True gas shales are extremely heterogenous



- Only part of the 'shale gas' realm.....not all shales are created equal



- Have to look at shales at completely different scale than what we are used to

# Acknowledgements

- NSERC research grant (R.M. Bustin)
- CBM Solutions

## **References**

Chaika, C. and J. Dvorkin, 2000, Porosity reduction during diagenesis of diatomaceous rocks: AAPG Bulletin, v. 84/8, p. 1173-1184.

Pisciotta, K.A., 1981, Diagenetic trends in the siliceous facies of the Monterey Shale in the Santa Maria region, California: Sedimentology, v. 28/4, p. 547-571.