Reinventing Source Rocks as Reservoirs: **Shales and Imposters**

OCLASSH and RockAbuse Labs

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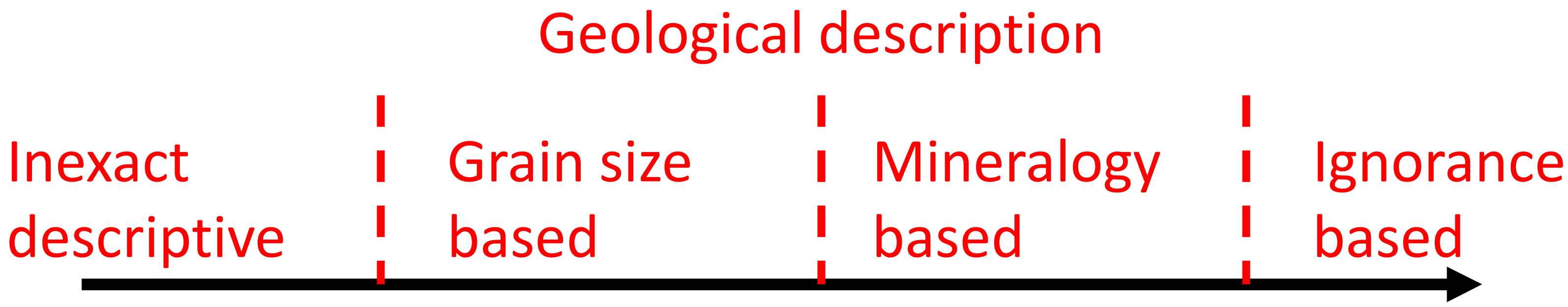
COLORADO SCHOOL OF MINES
EARTH ▲ ENERGY ▲ ENVIRONMENT

What is a shale?

Evolution of Shale Definitions



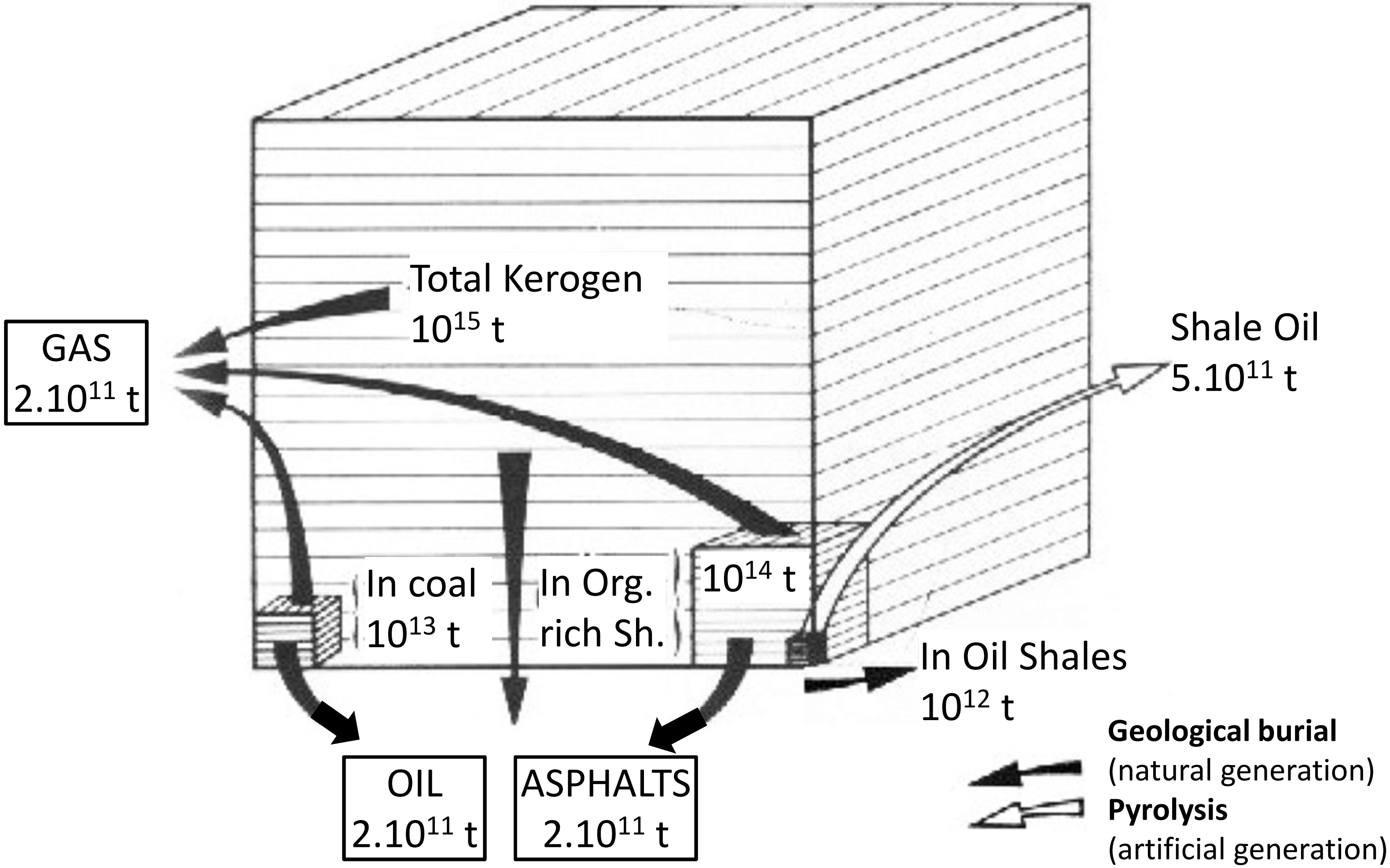
- Grain size description (before XRD)
- Mineralogic description (after XRD)
- Geologic Description
- Engineering (geomechanical) description
- Petroleum definition

What is Organic Matter / Kerogen

Kerogen

- Keros = wax; Introduction to geology debated
- Kerogene = generating wax
  - Used to describe kerosene produced from cannel coals
- OR
  - Used to describe the OM of a Scottish oil shale that produced a waxy oil upon distillation

Total Organic Budget



(From Vandenbroucke and Largeau, 2007; Durand, 1980)

What is Kerogen

- Defined by solubility:

  Organic Matter insoluble in organic solvents

- Defined by petroleum:

  Organic Matter capable of producing petroleum

- Extraction method alters kerogen properties: physical, compositional, and structural!

  Can be mixed with other insoluble OM: tar, asphaltene, bitumen!

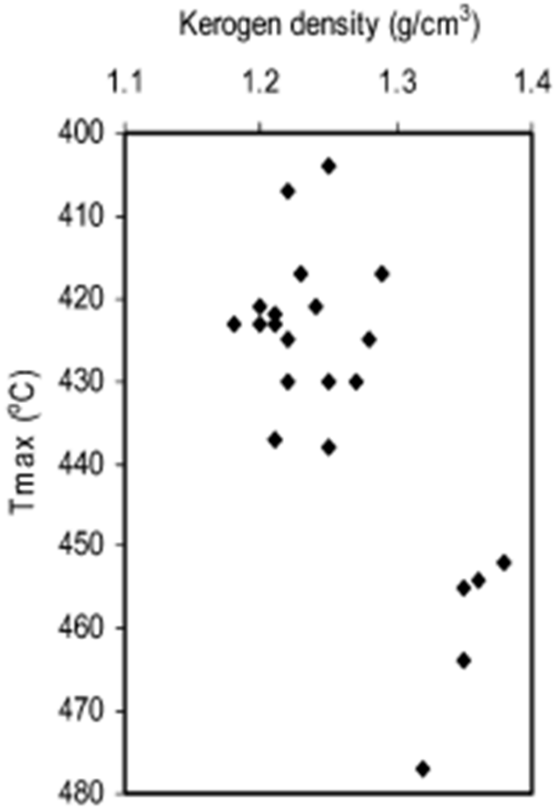
Measuring Porosity and Grain Density

Specific Gravity of Kerogen Types

Kerogen type	Sample maturity	HI (mg/gC)	Tmax (°C)	Specific gravity
II	End of diagenesis	532	414	0.814
II	Onset of oil window	439	438	0.995
II	Top of oil window	242	443	1.115
II	Wet gas window	22	479	1.518
III	Onset of oil window	250	435	1.295

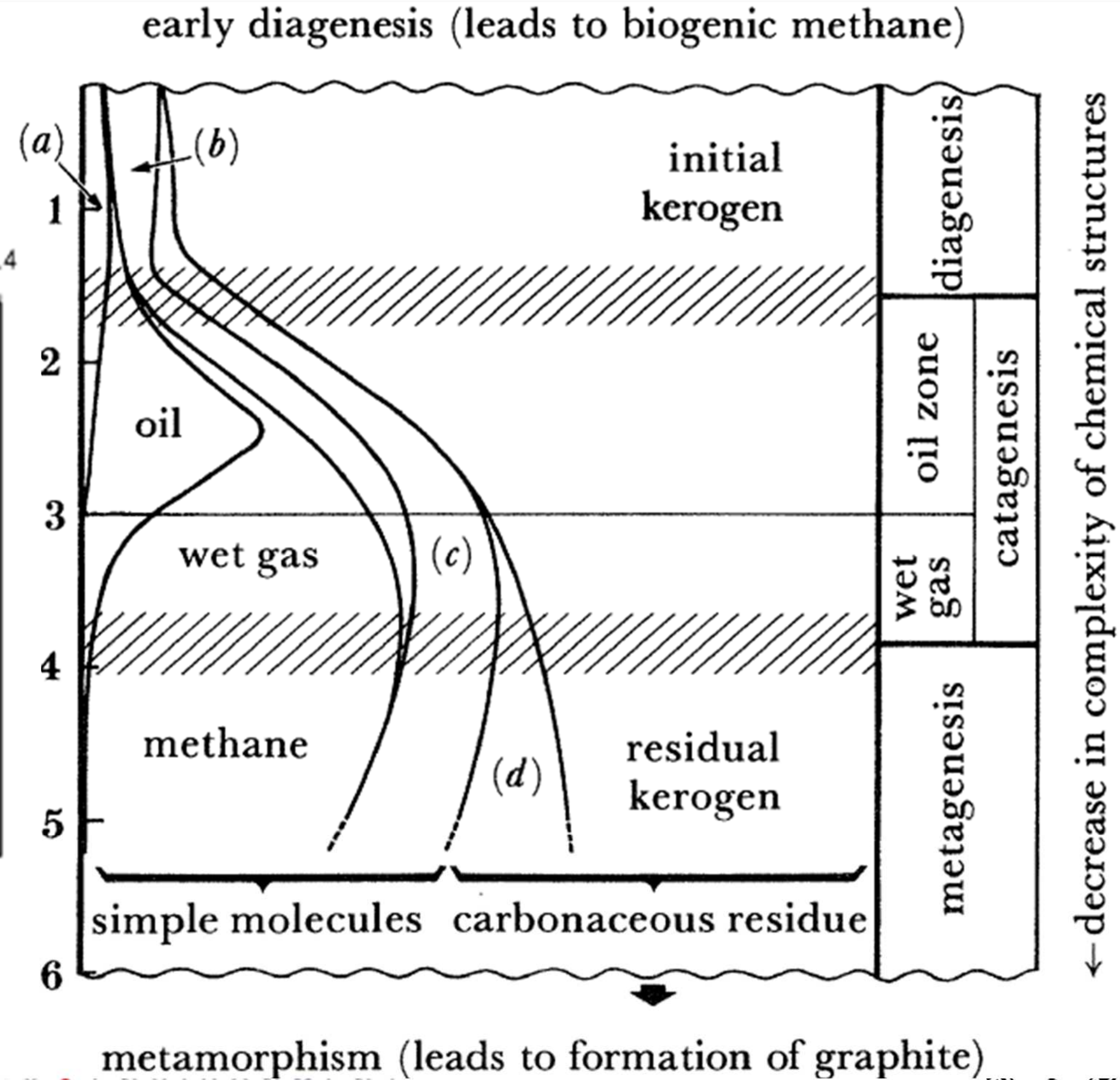
(From Vandenbroucke and Largeau, 2007)

Kerogen Maturation

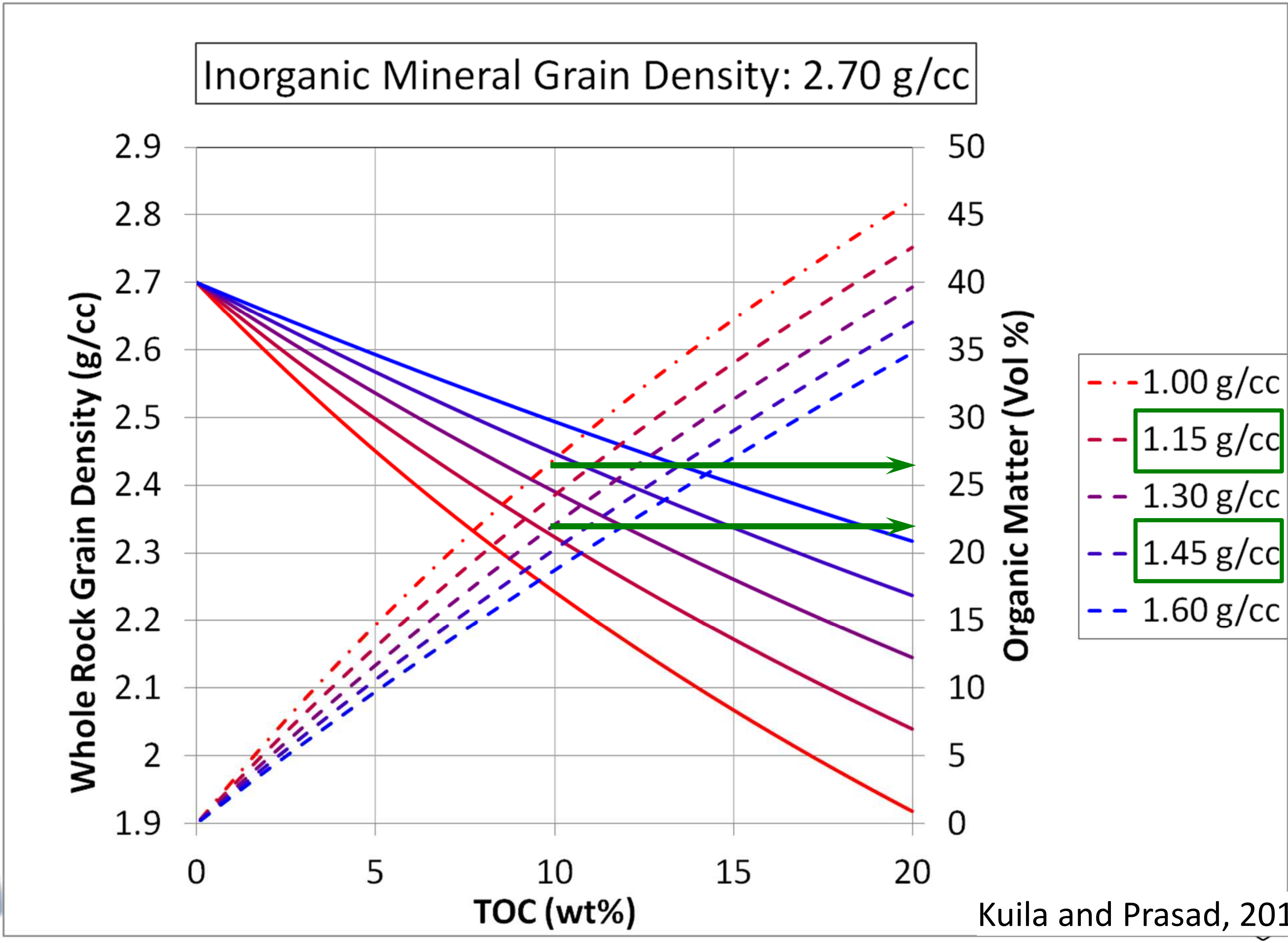


Okiongbo et. al. (2005)

Durand, 1985



Kerogen Density Variation

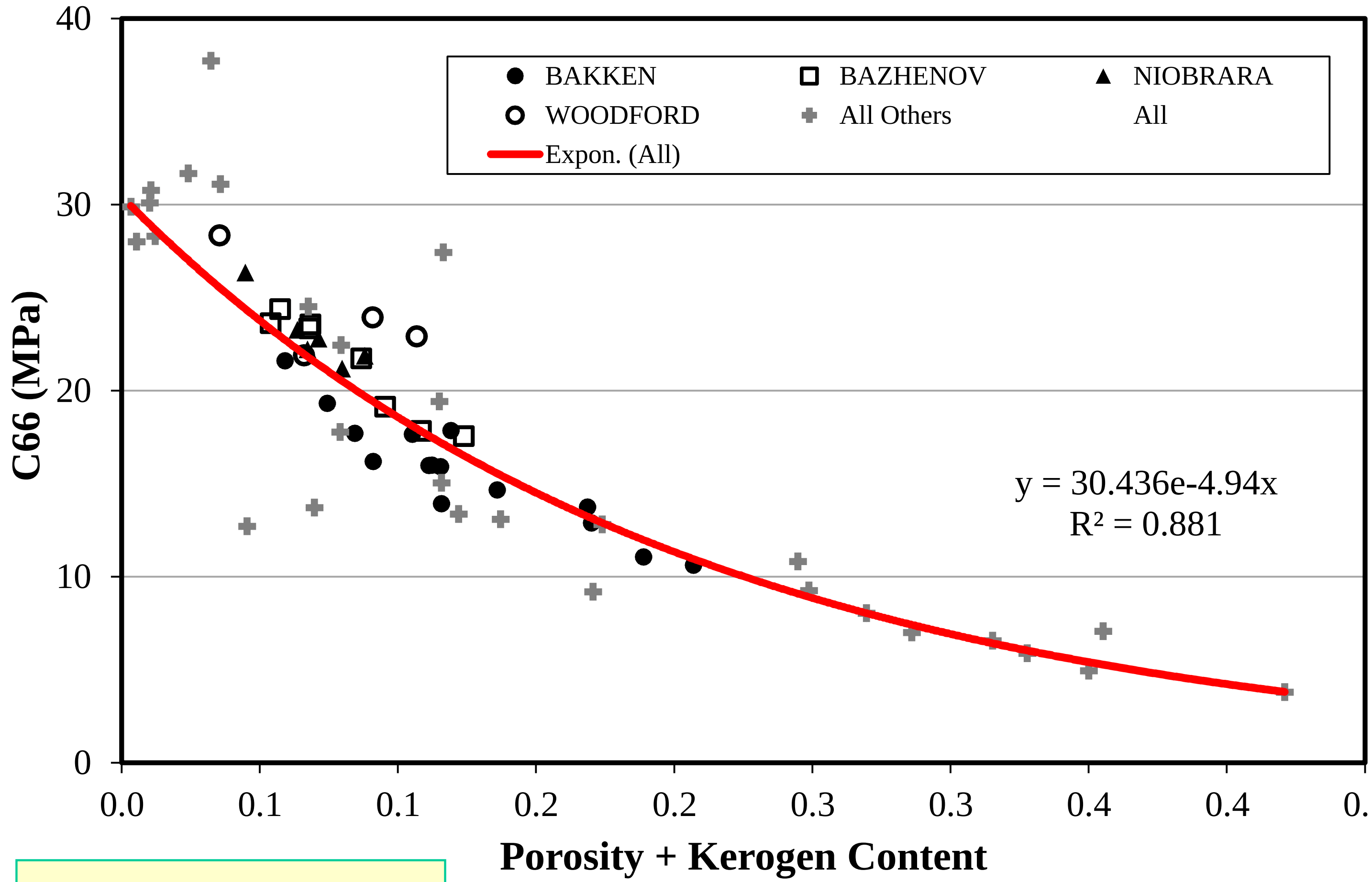


Kuila and Prasad, 2011

Measuring Grain Modulus

Modulus–Porosity–Kerogen Content

Reduce scatter in porosity – elastic modulus relation by accounting for pore-filling kerogen.

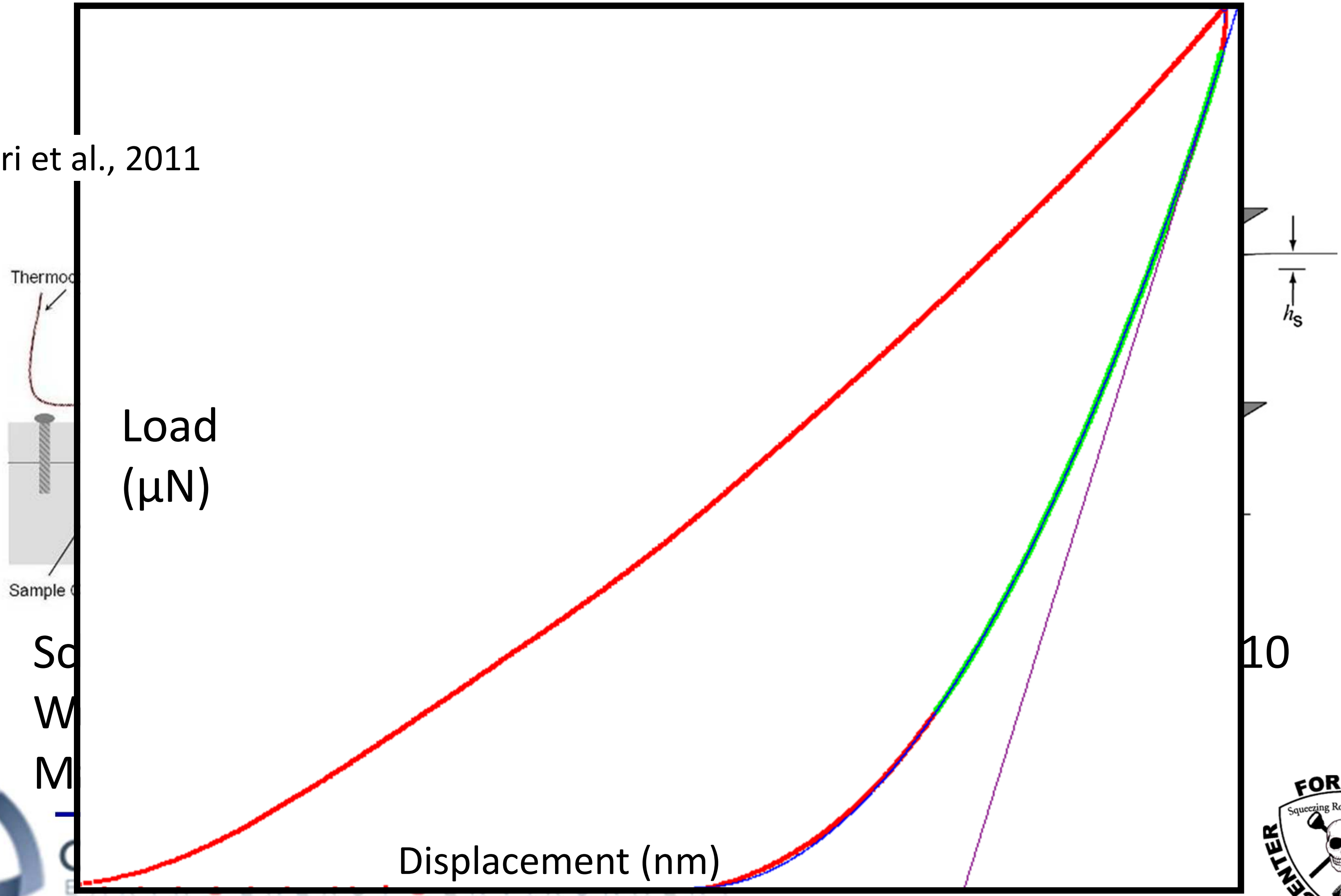


$KC\_{\Phi} = \Phi + 0.4\ KC$

Data from Vernik and Liu, 1997; in Prasad et. al 2010

Nanoindentation - Elastic Properties

Zargari et al., 2011



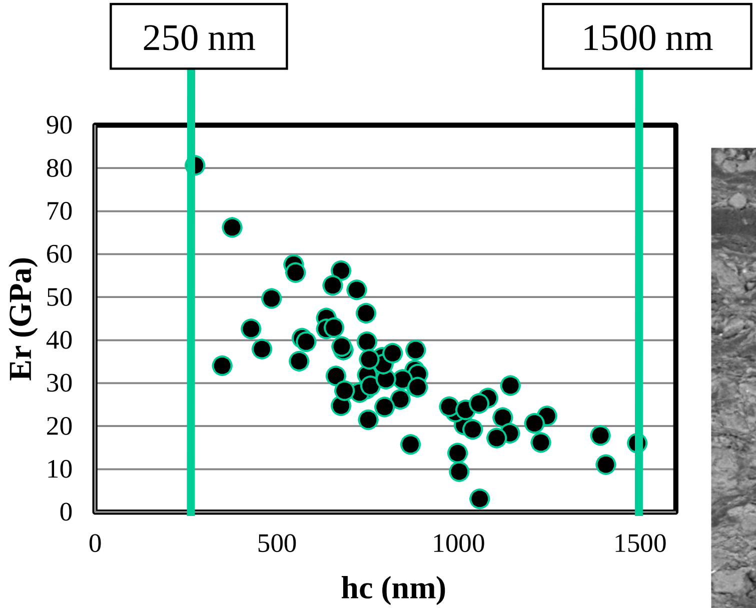
Sc ... 10

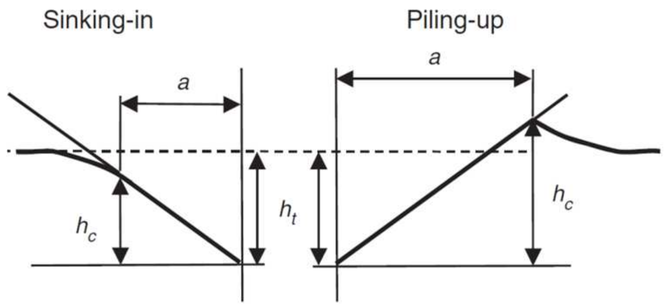
W

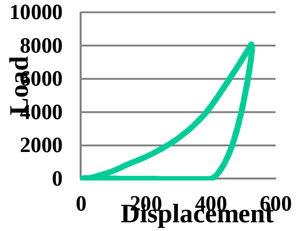
M

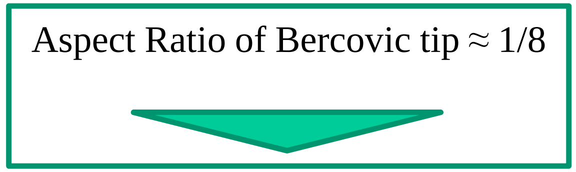
Nanoindentation Sensing Dimensions in a Load Control Test

Zargari et al., 2011

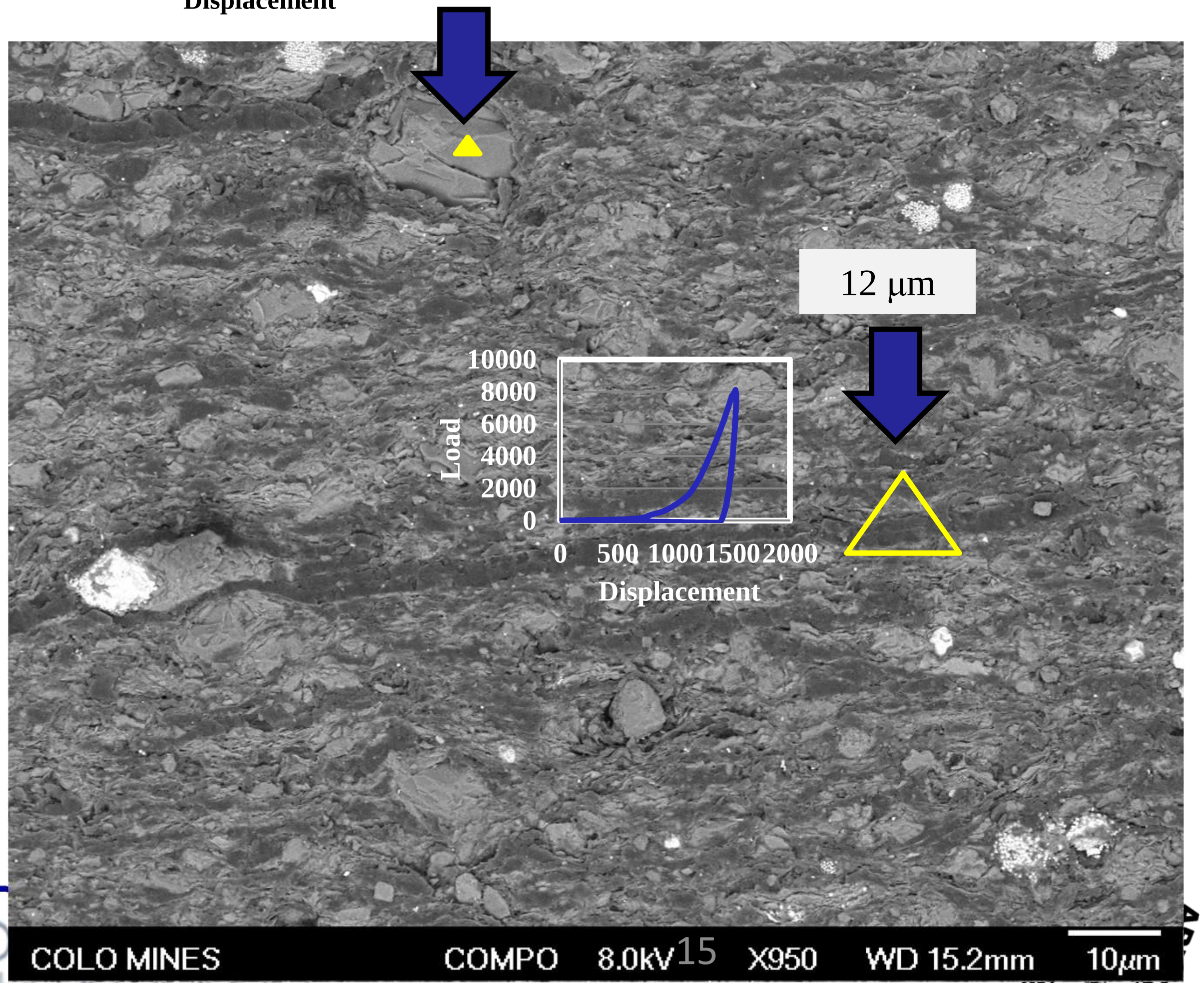




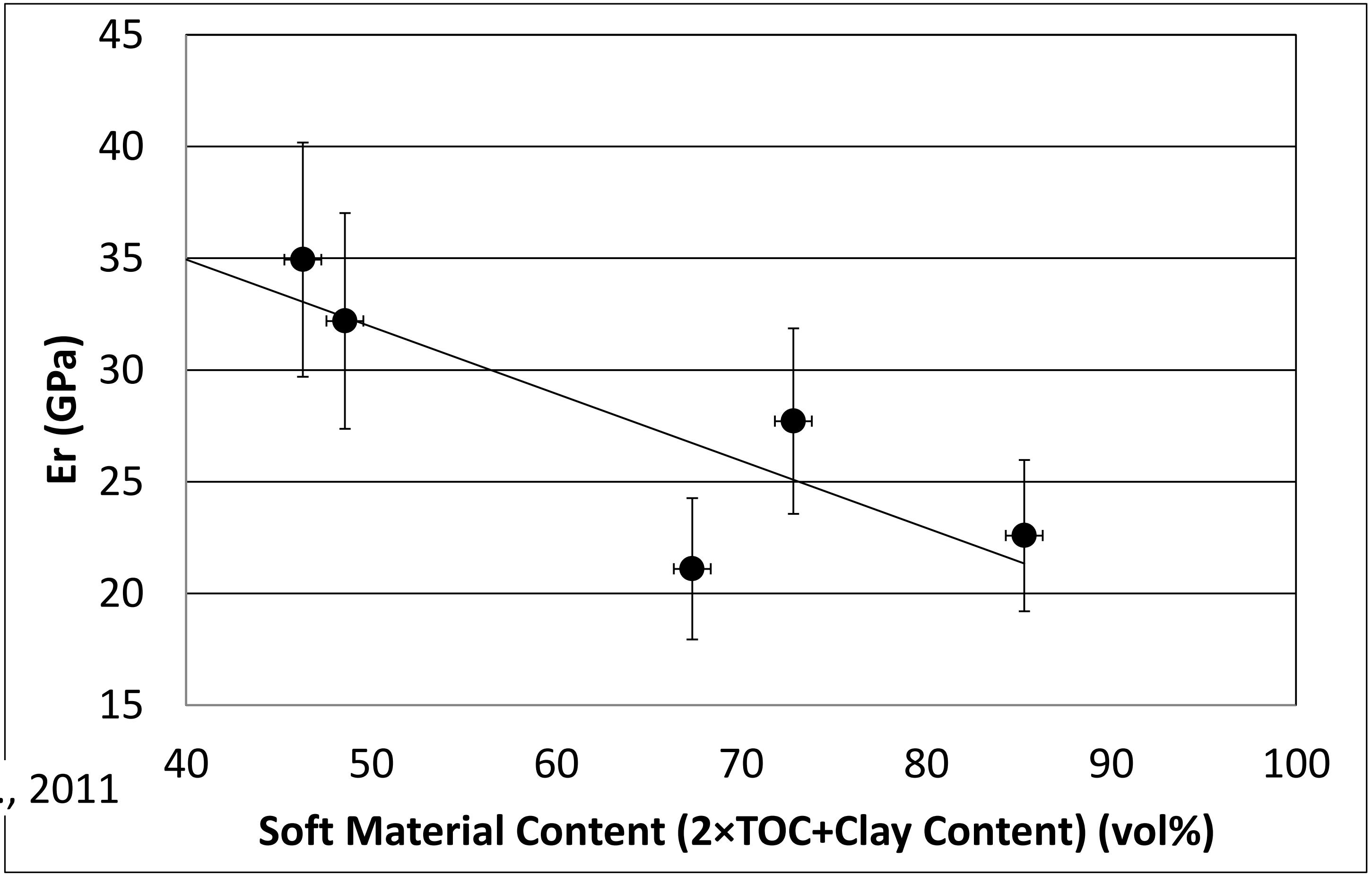




2 μm



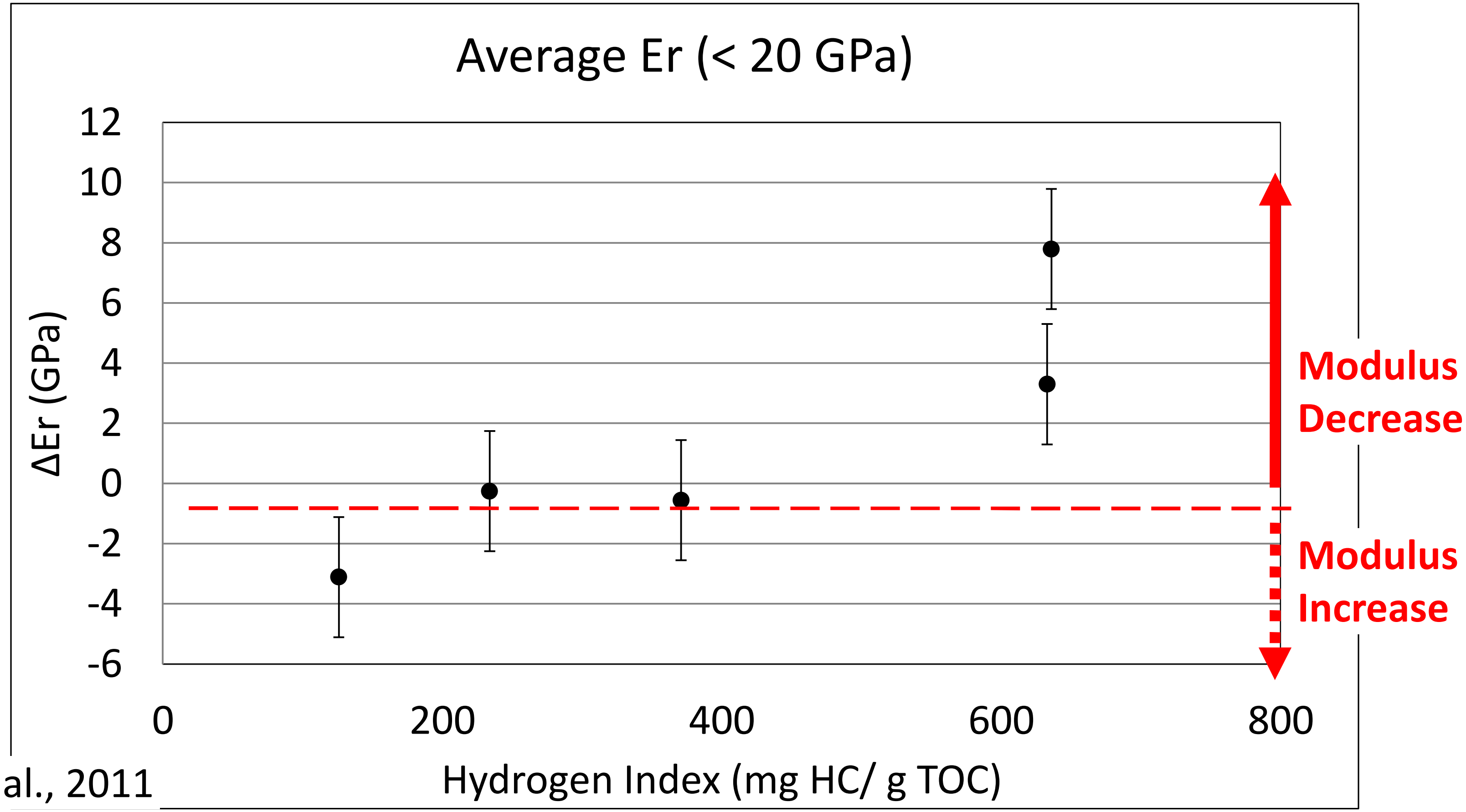
Average of Young's Modulus vs. Soft Material Content – ***Natural Samples***



Zargari et al., 2011

2×TOC+Clay Content

Change in Modulus after Pyrolysis



Zargari et al., 2011

$$\Delta E_r = E_r^{\text{(before pyrolysis)}} - E_r^{\text{(after pyrolysis)}}$$

Small scale properties

- PORES
  - Pore size distributions
  - Surface areas
  - Pore shapes
  - Adsorption effects
  - Tortuosity
  - S/A: Surface area to grain volume

- MATRIX
  - Grain size; Mineralogy
  - Modulus
  - Contact zones
  - Hardness
  - 'Frac-able'
  - Impedance

Large scale properties

- PORES
  - Porosity
  - Permeability
  - Fluid mobility
  - Gas Storage
- MATRIX
  - Velocity
  - Attenuation
  - Impedance
  - Fracture growth

CORES
LOGS
SEISMIC

Links Between Laboratory and Field

Approaches

- Descriptive
- Empirical
- Theoretical …first principles based
- Practical Approach!

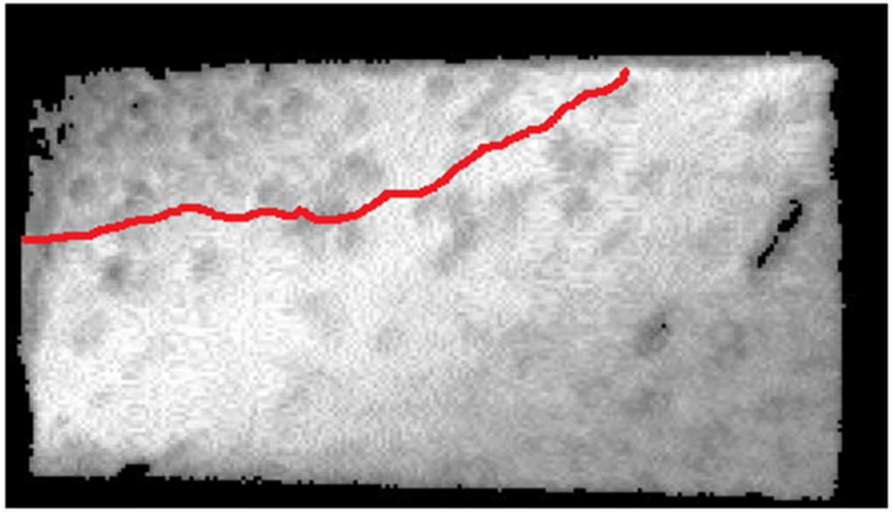
Descriptive Approach

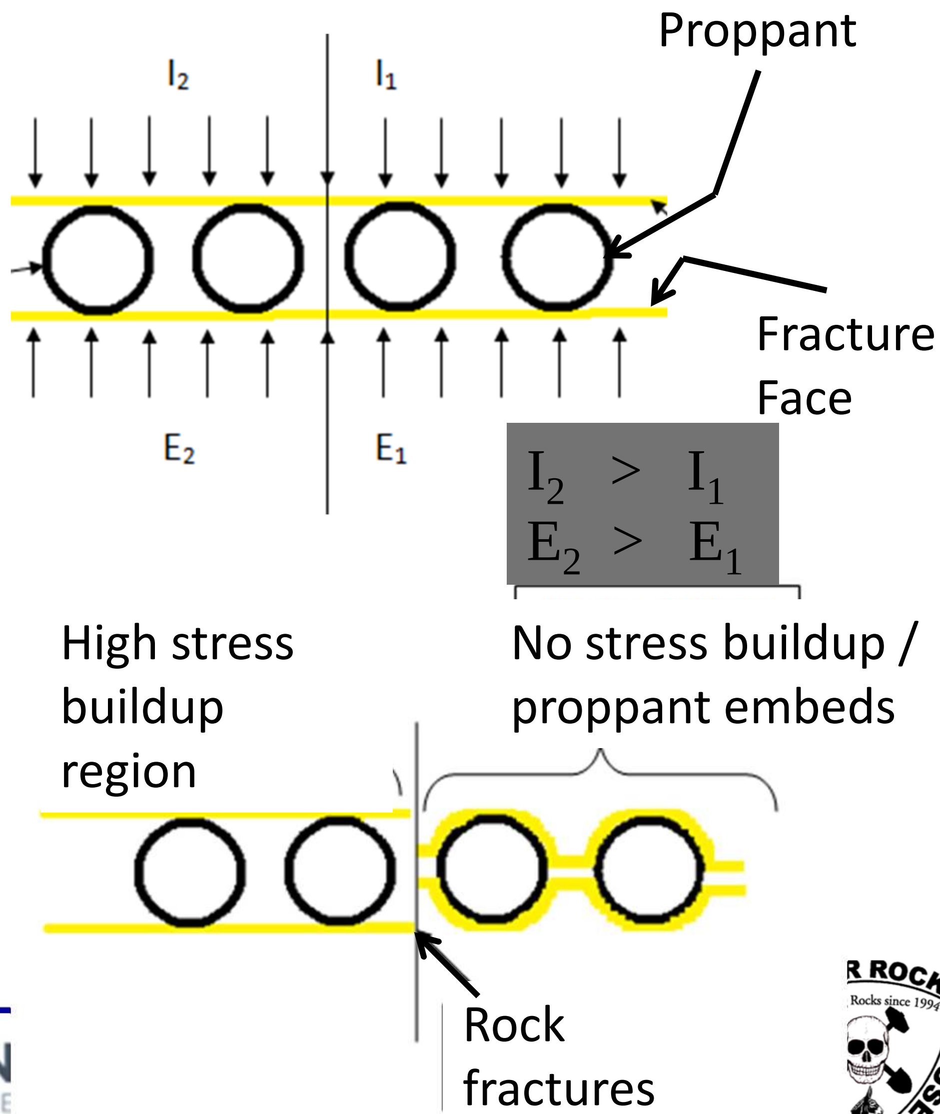
- Observe some physical phenomena
- Observe microstructural properties

- Explain Physical Phenomena with Microstructure

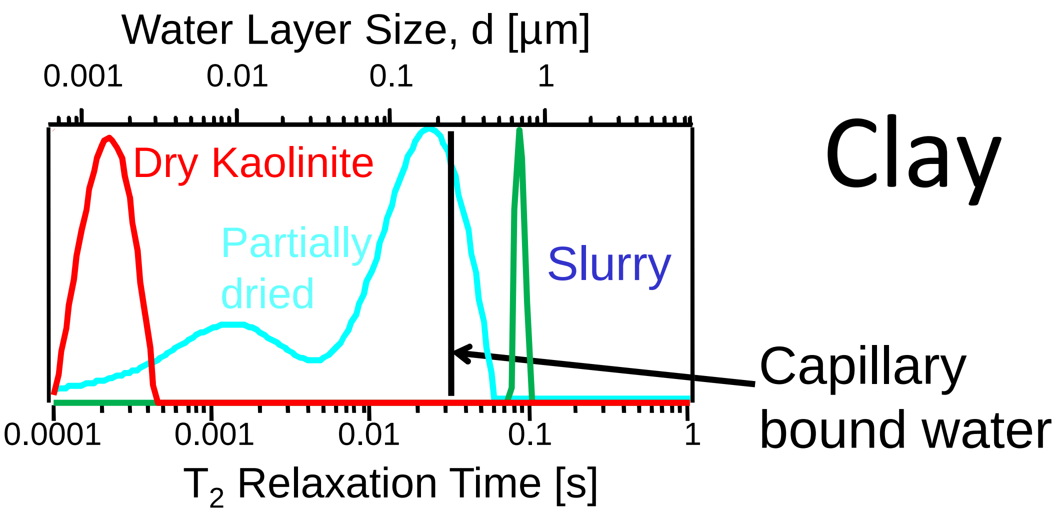
Middle Bakken

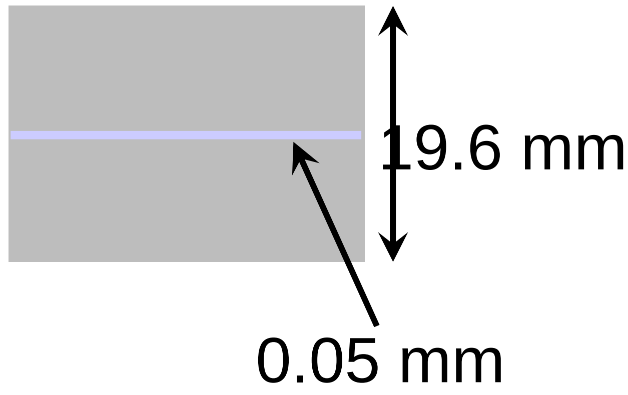
Akrad et al., 2011

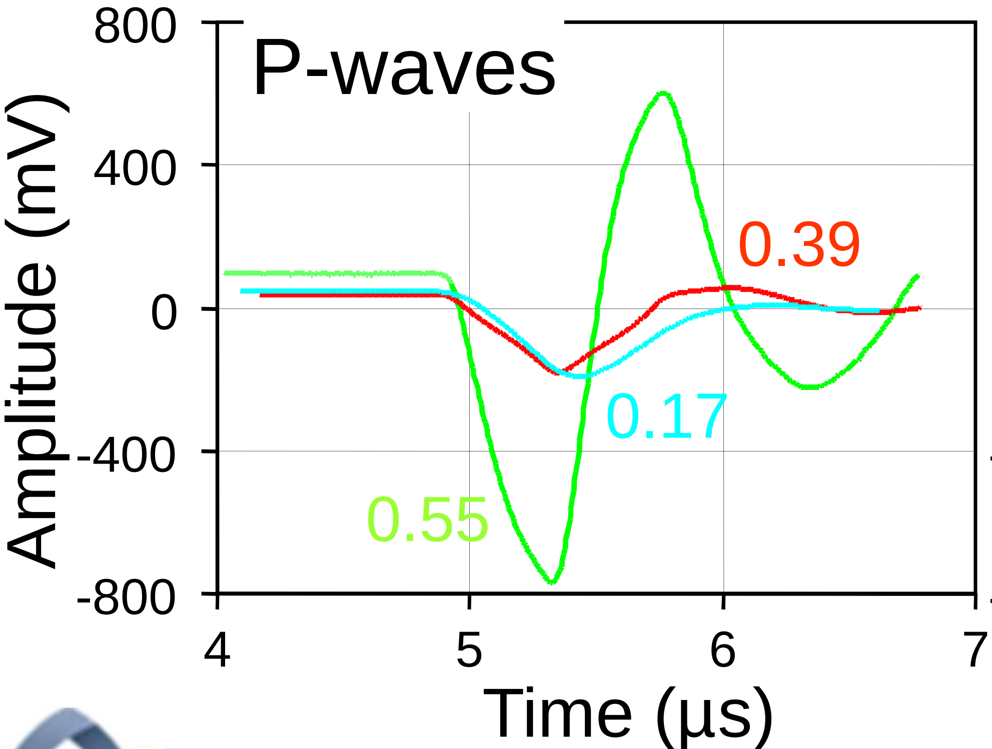


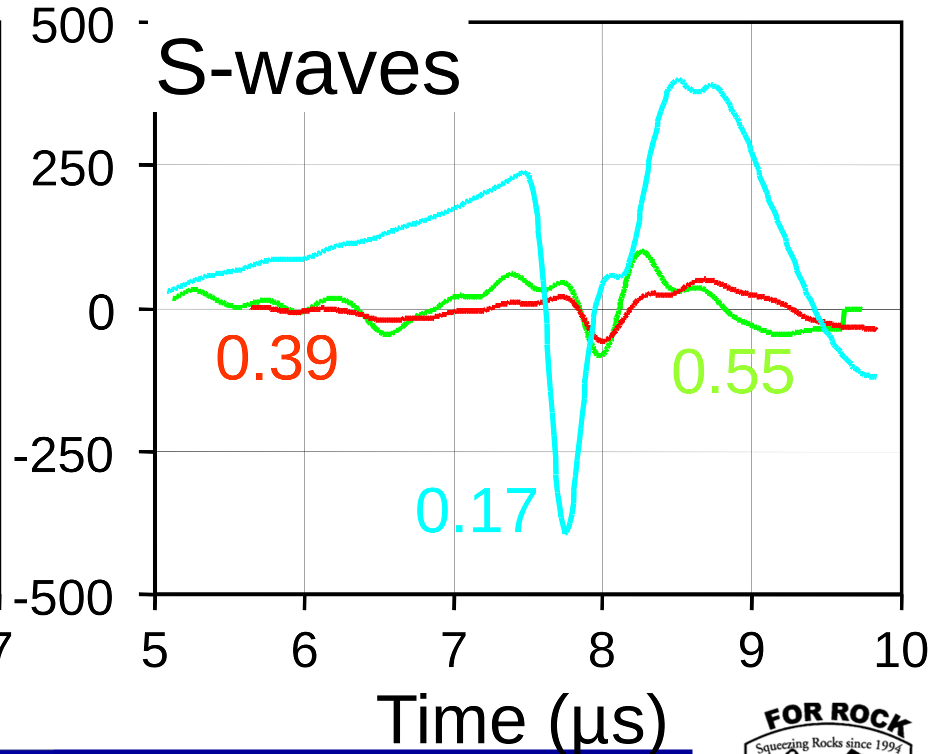


Clay









Wet clay layer dampens; Drying clay cements

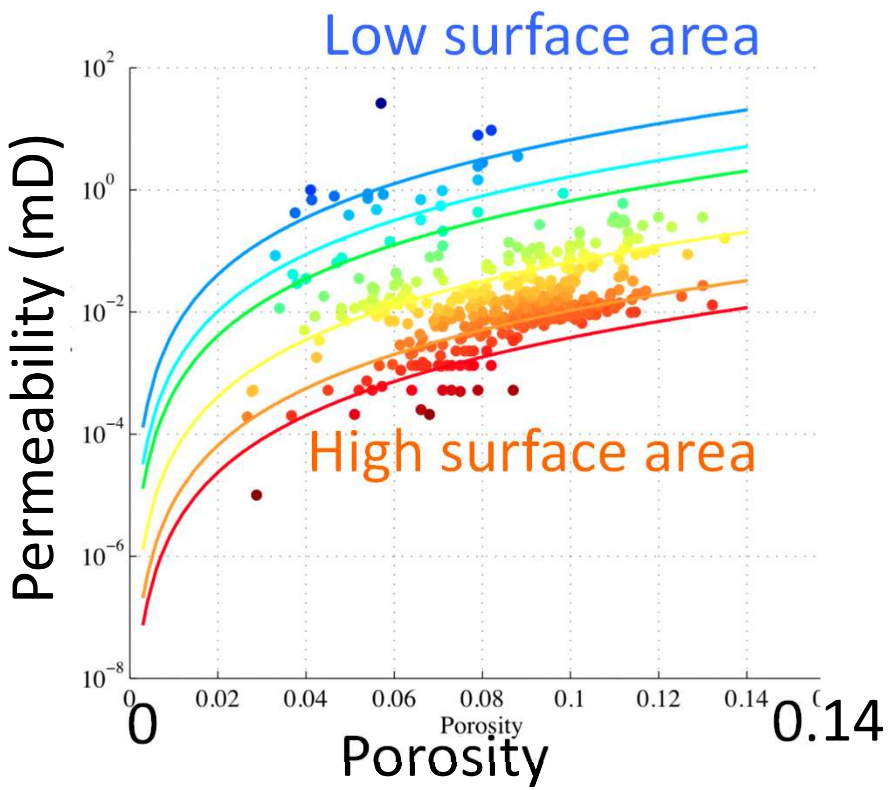
Empirical Approach

- Measure some physical properties
- Derive empirical fits between different properties

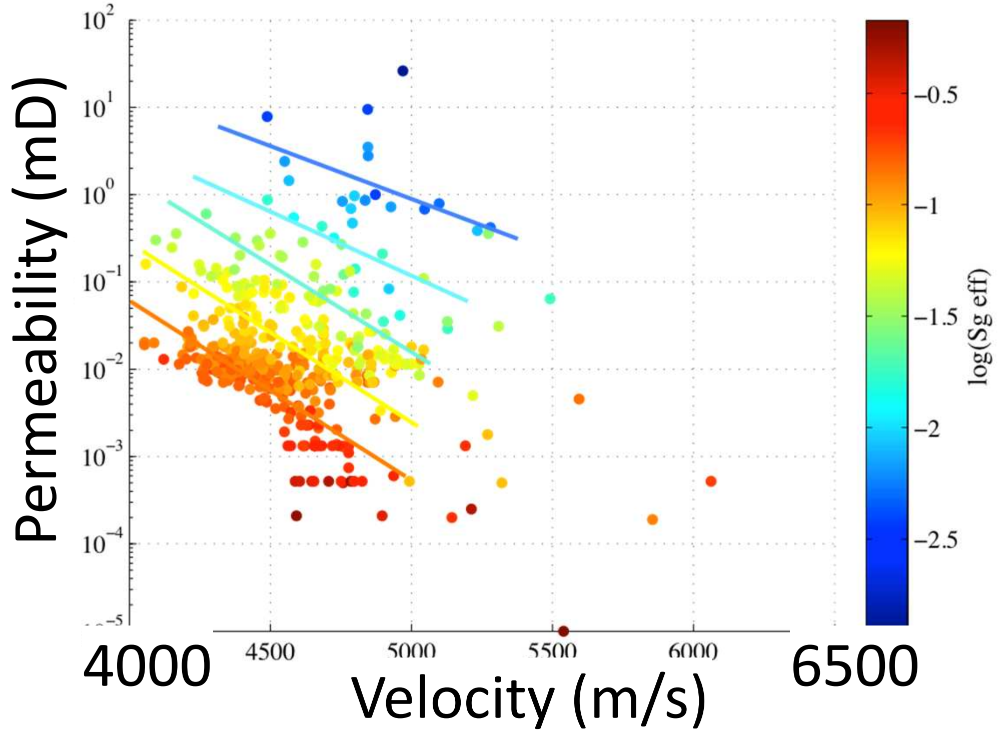
- Use correlations to relate / predict / bin data

Porosity- Permeability-Velocity Relationship

Castillo, 2011

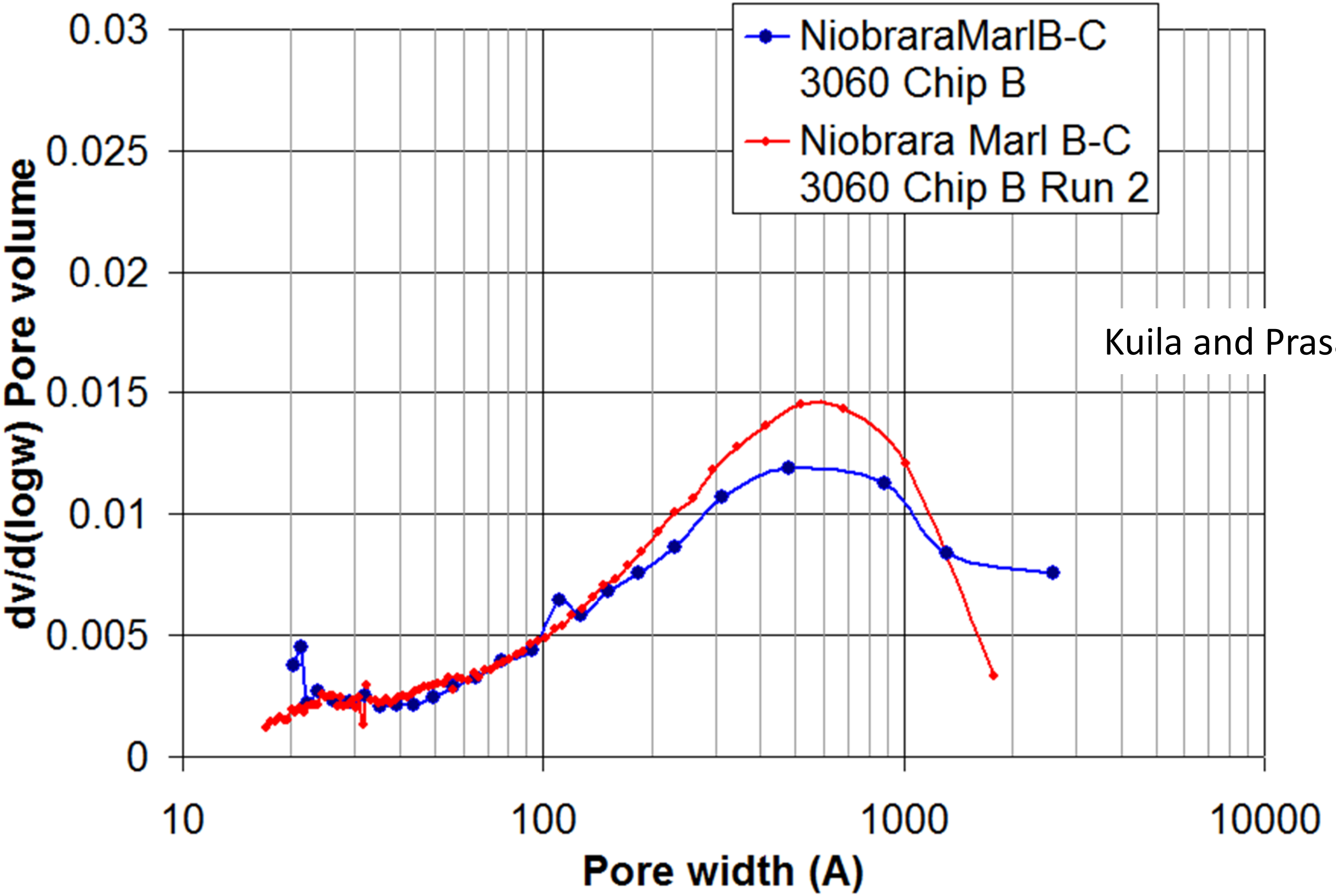


(a) K vs. ϕ Segg color-coded.



(b) K vs. Vp Segg color-coded.

Pore-size distribution



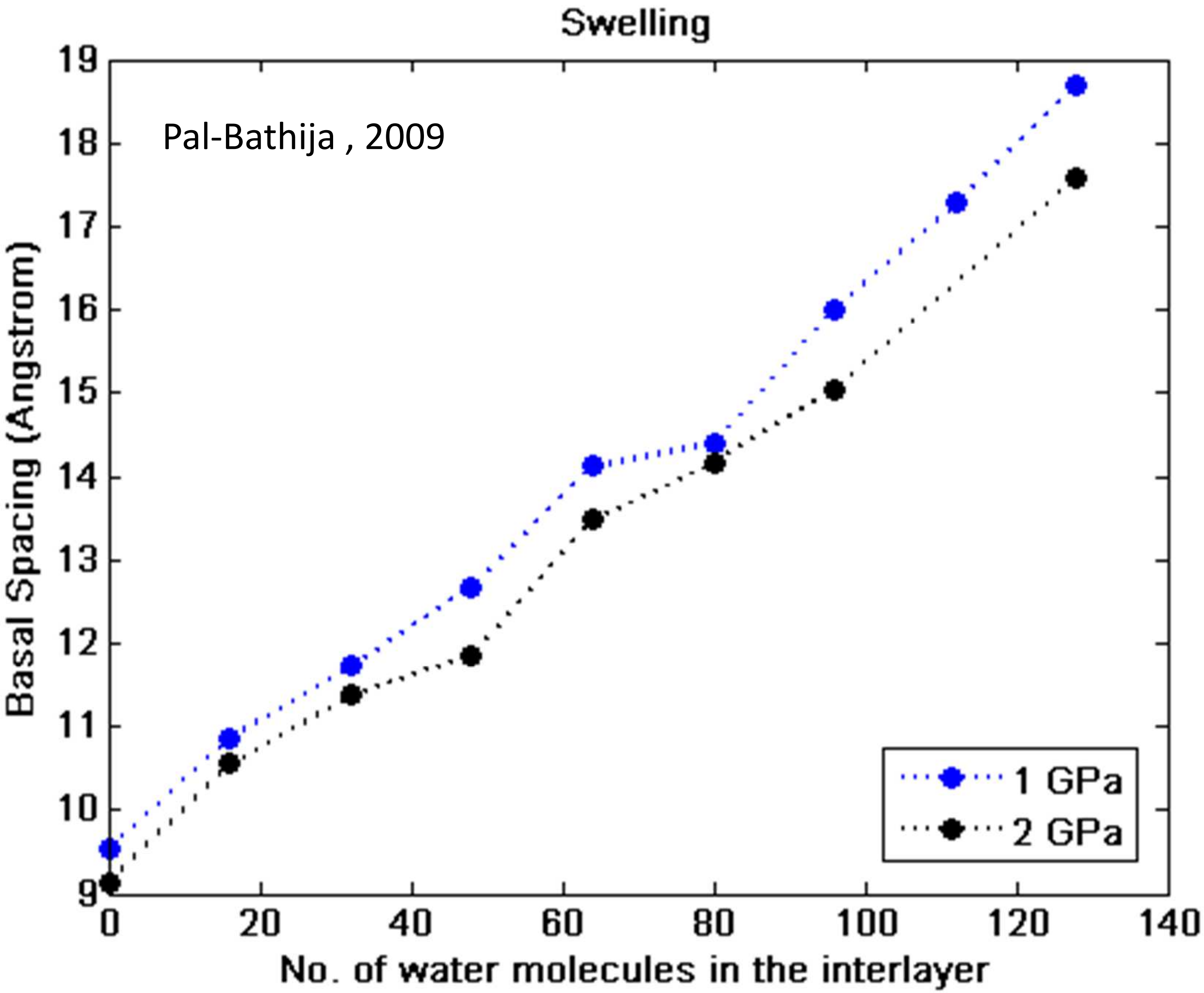
Kuila and Prasad, 2011

Theoretical …first principles based

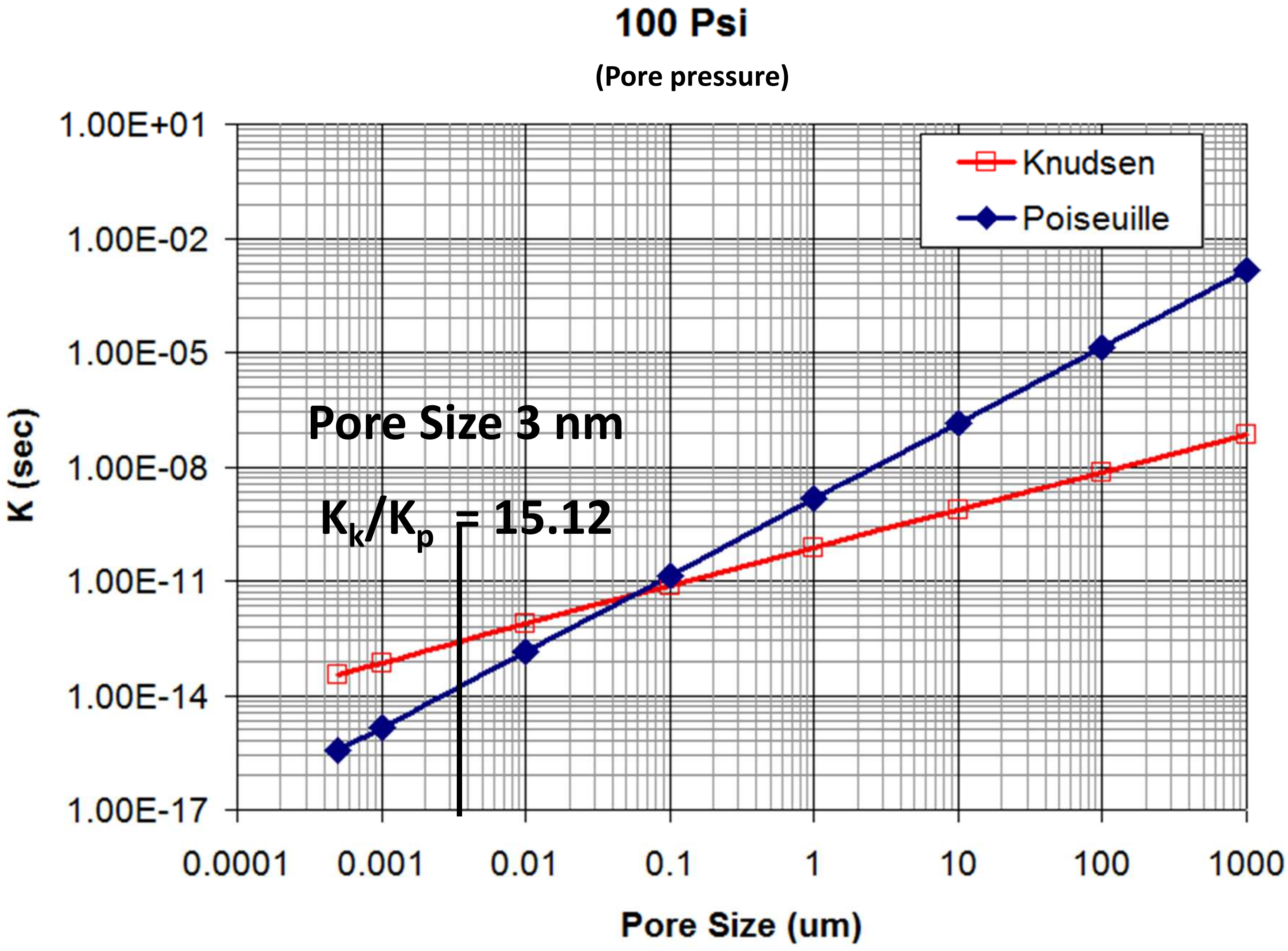
- Create a theoretical model based on first principles
- Collect input parameters – (if necessary, use empirical correlations to derive inputs)

- Compare model with data and recompute

Molecular simulation results



Modeling Flow in Shales



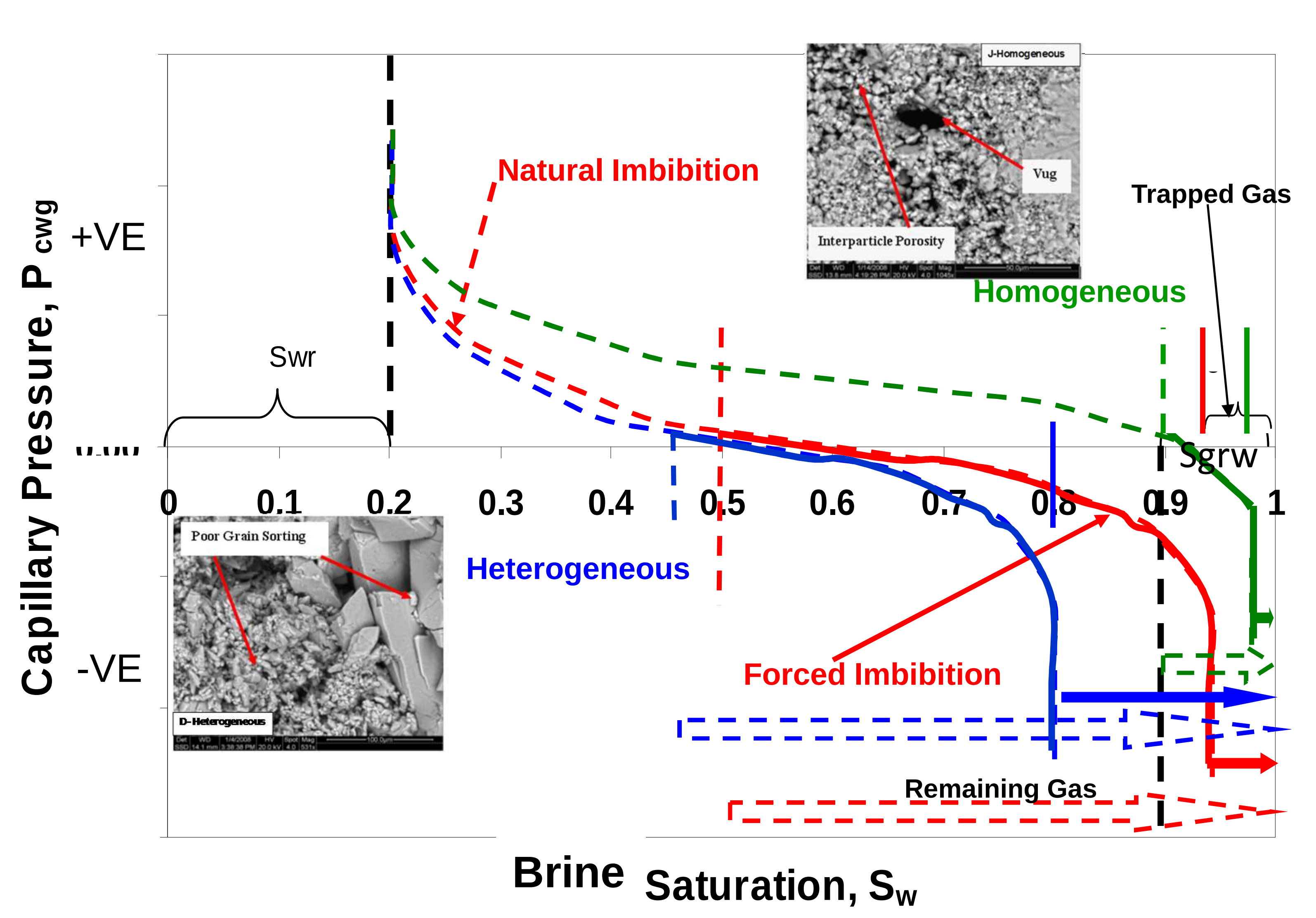
Kuila and Prasad, 2011

Practical Approach

- Make some observations
- Collect some sample data

- Use combination of models and analog data to model reservoir properties

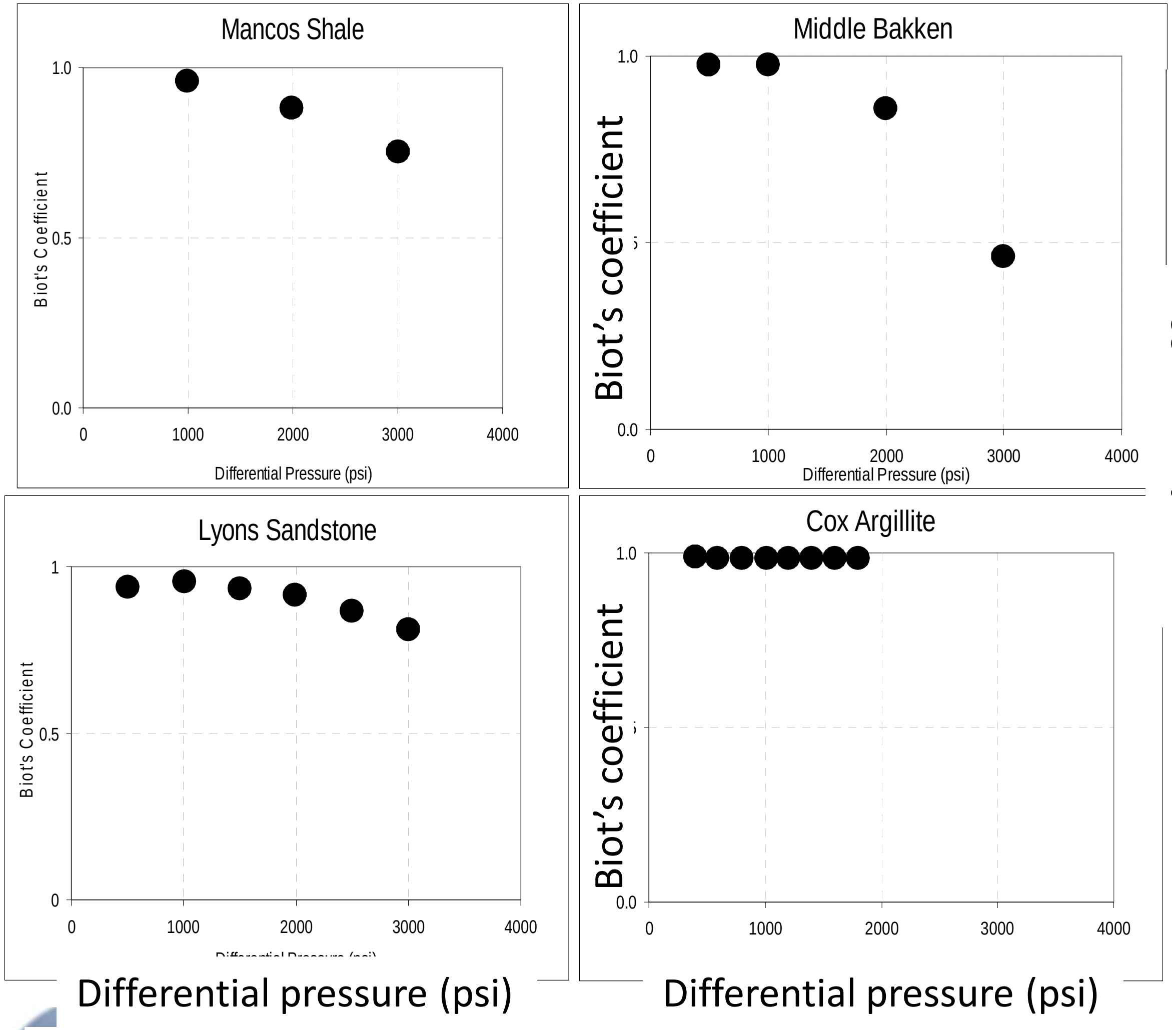
Heterogeneity and Residual Fluids



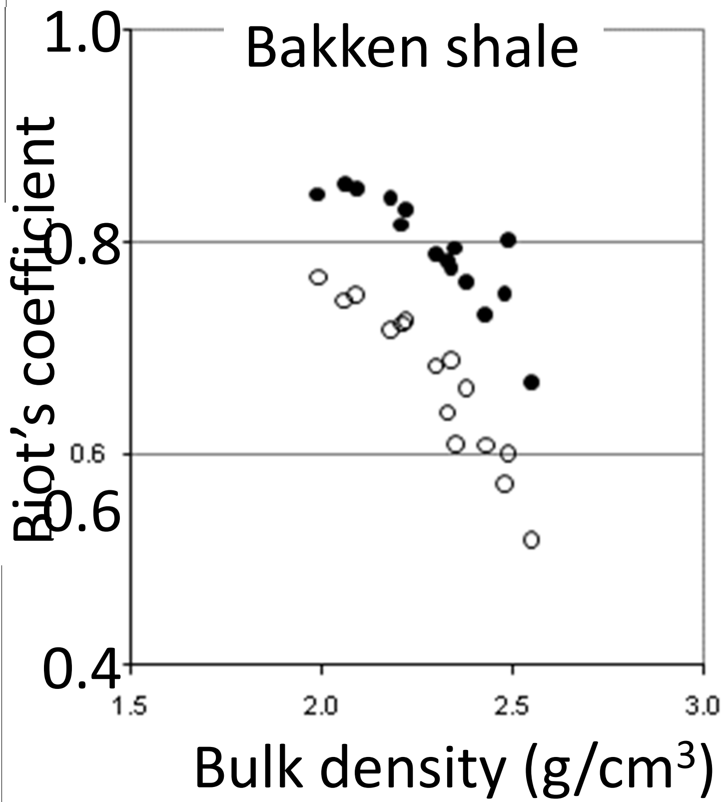
Sharma et al., 2011

Links Between Laboratory and Field

Biot's coefficient

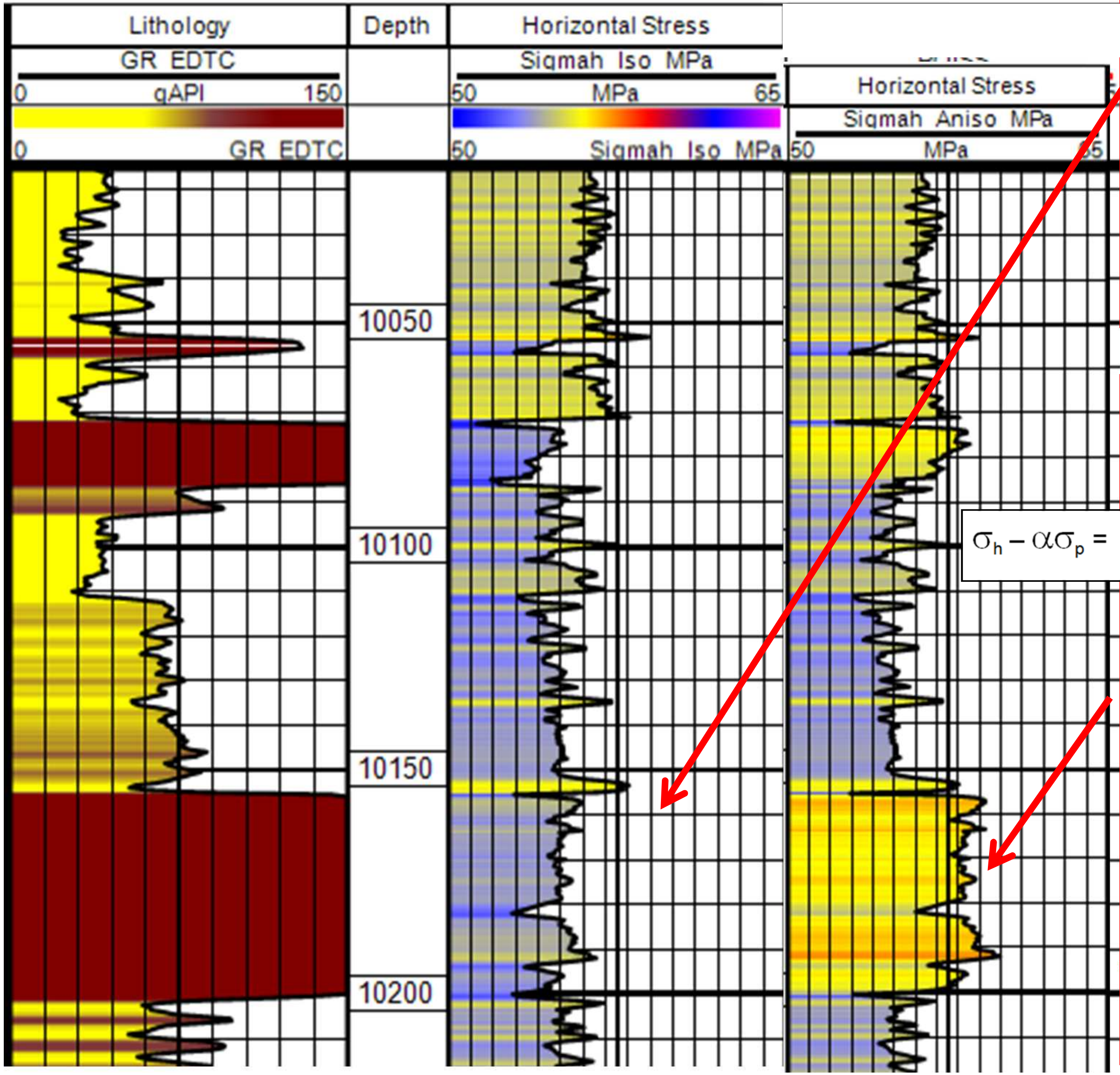


Sarker et al., (2010): Biot's coefficient calculated from specific storage measurements



Prasad et al., 2010: Biot's coefficient calculated from acoustic measurements

Stress and Anisotropy



ISOTROPIC CASE

Presuming no tectonic stresses and Biot coefficient ≈ 1 and applying isotropic in situ stress equation → Almost constant horizontal stress throughout upper, middle, and lower Bakken → Fractures are not contained in middle Bakken.

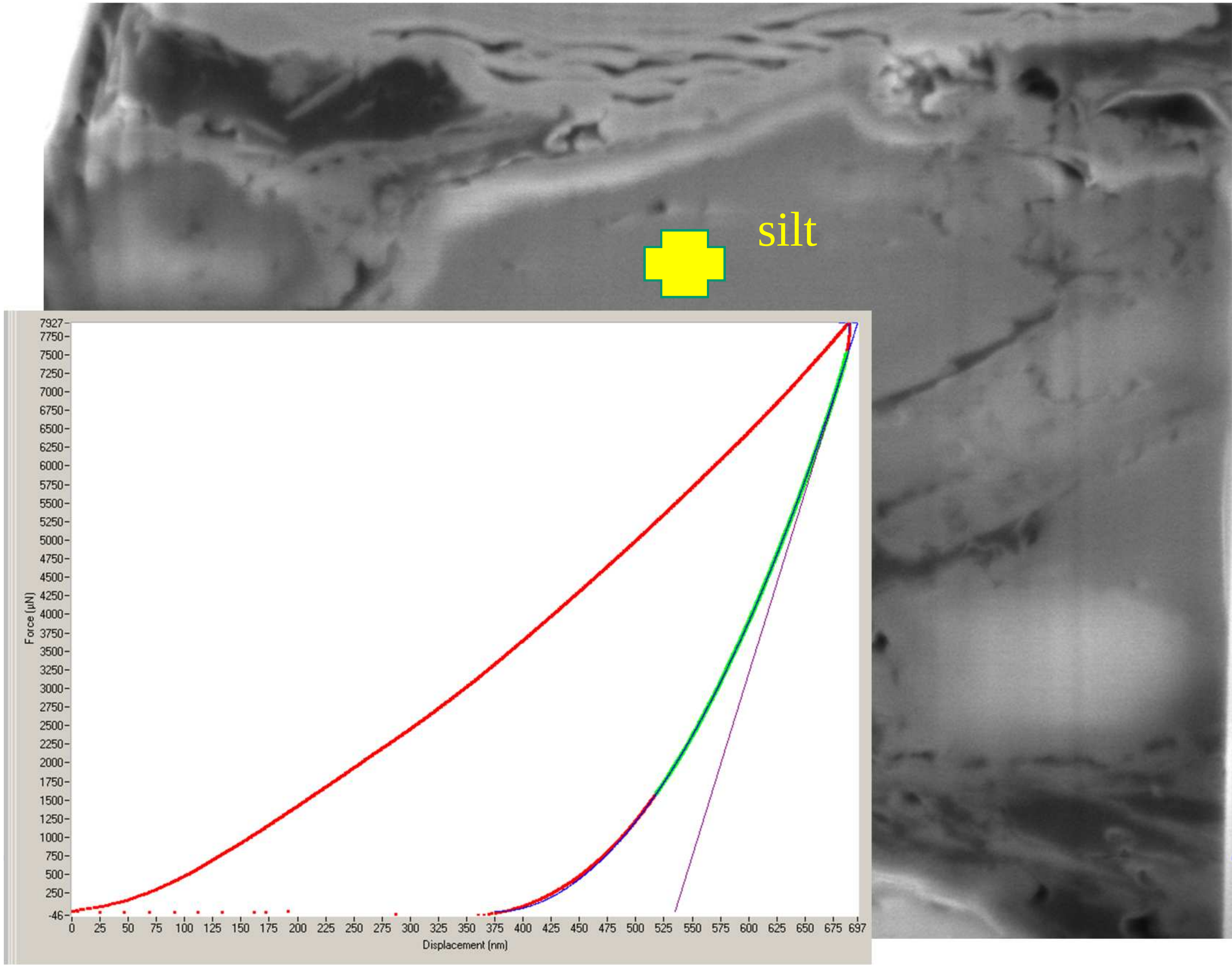
ANISOTROPIC CASE

Anisotropic conditions → Horizontal stress different:

$$\sigma_h - \alpha\sigma_p = \frac{E_h}{E_v}\frac{\nu_v}{1-\nu_h}(\sigma_v - \alpha\sigma_p) + \text{Tectonic Stresses}$$

(Young's modulus: E_h horizontal, E_v vertical; Poisson's ratio: σ_h horizontal, σ_v vertical). The variation between E_v and E_h gives a different horizontal stress profile. Increased σ_h in the upper and lower Bakken imply that they will be more effective in hydrofracture containment.

Co-locate FiB-SEM & Nanoindent



8 x 8 µm

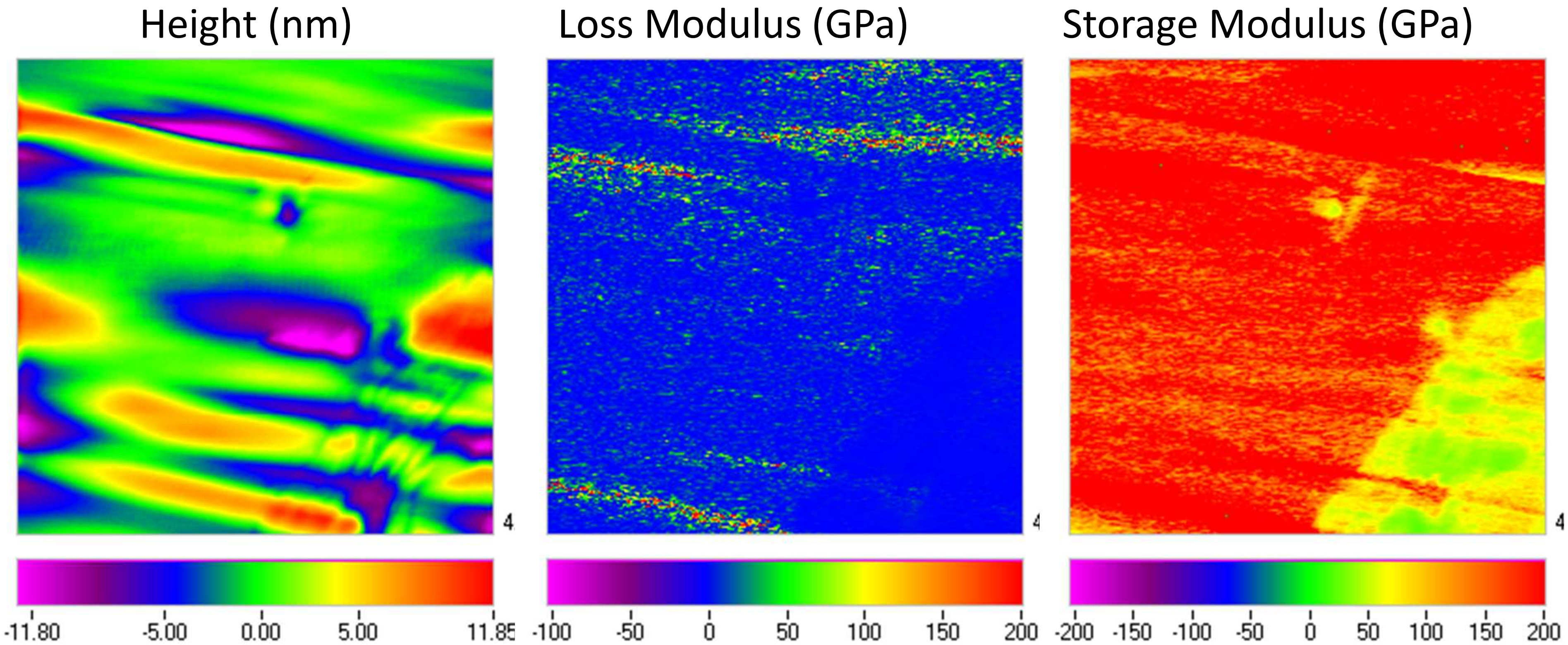
In collaboration with
Brian Gorman

Next Steps: Modulus Mapping

FiB polished
Bakken shale

4.4 µm x 4.4 µm

- Note the modulus contrast between grains



In collaboration with Corinne Packard

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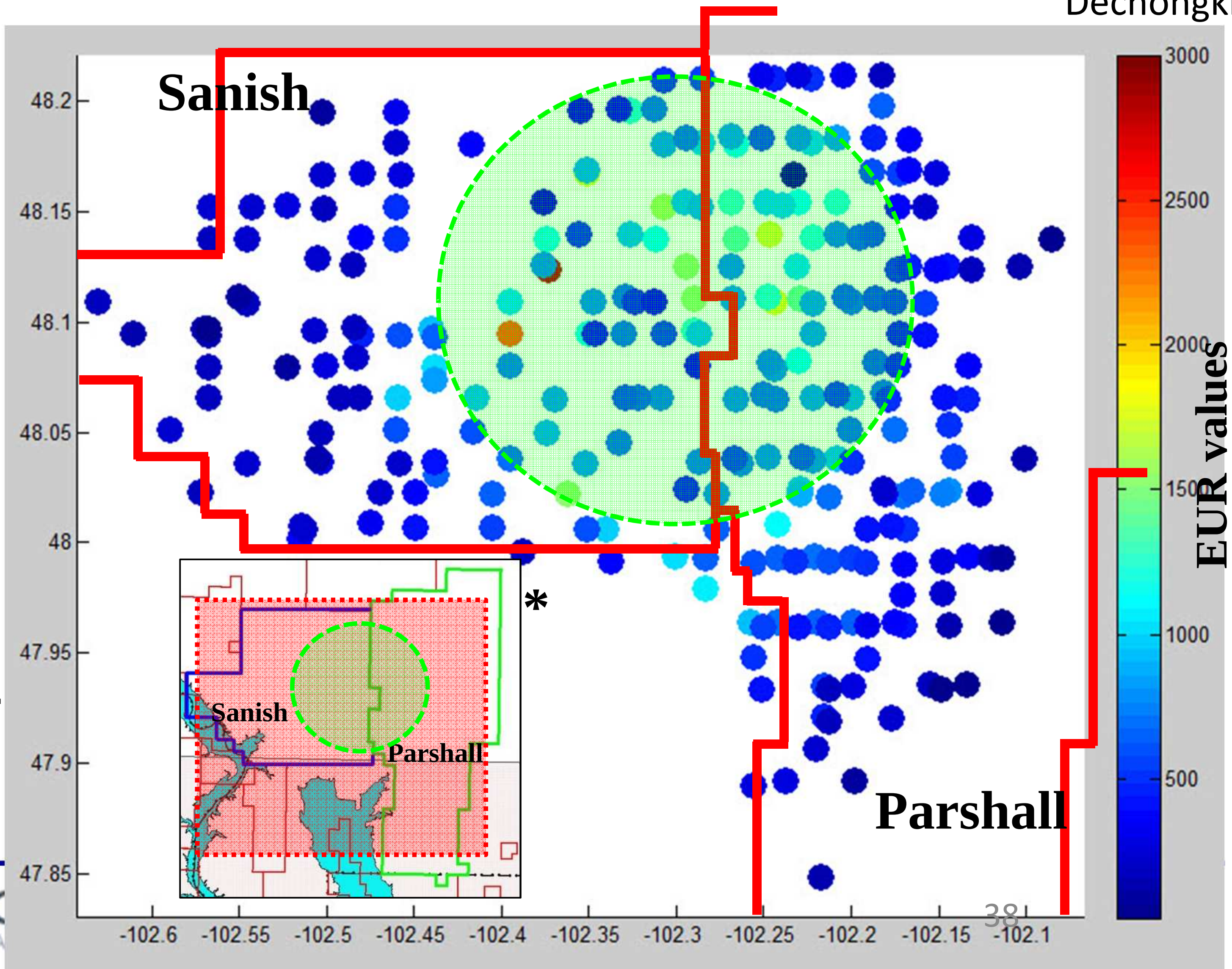
Squeezing Rocks since 1994

Results(cont)–EUR of Sanish & Parshall fields

Dechongkit, 2011



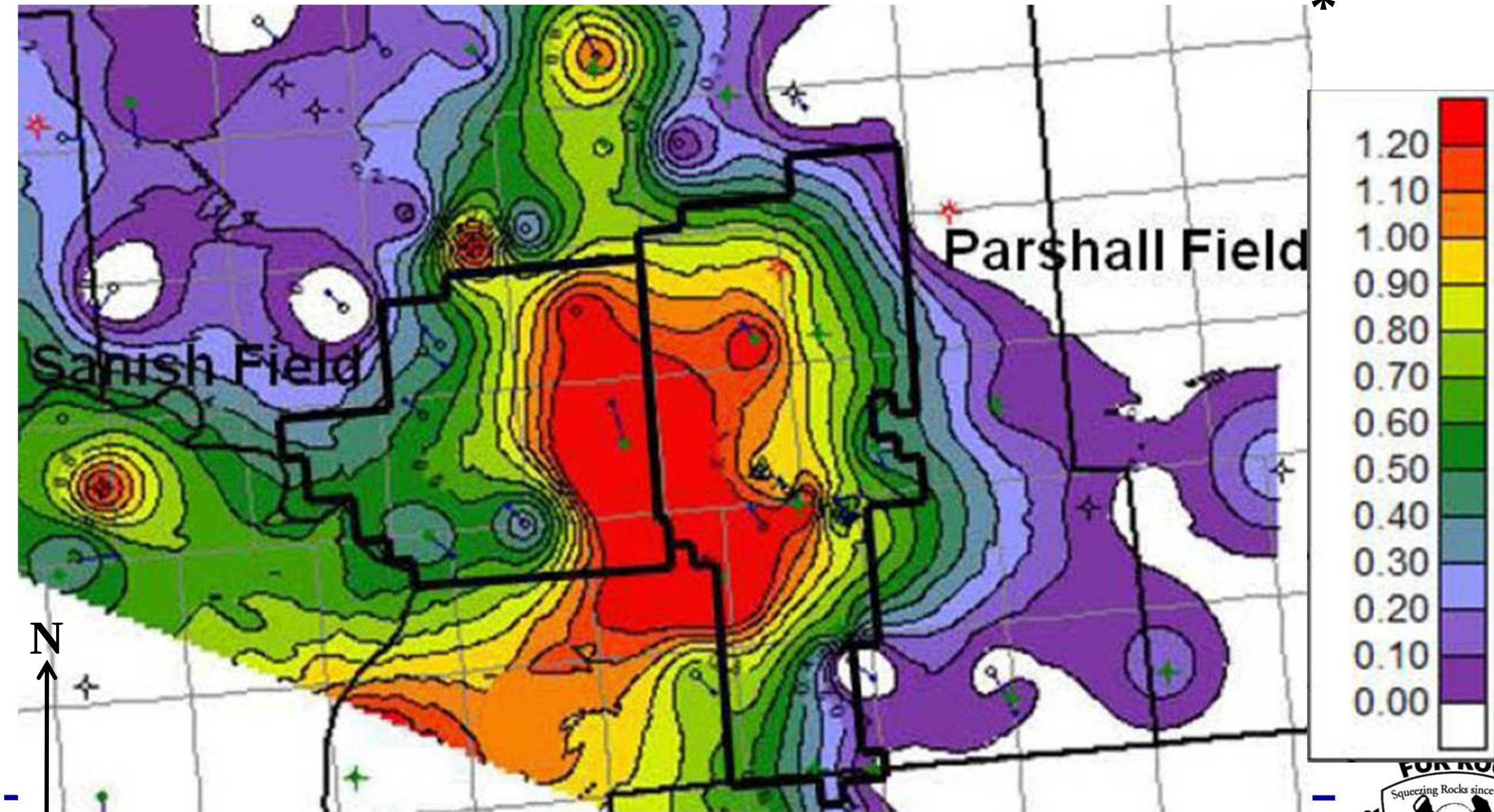
* *GIS map server in NDIC website*

Results(cont)–EUR of Sanish & Parshall fields

$$HCPV = h\phi(1 - S_{wi})$$

Dechongkit, 2011

*



* *Simenson (2010)*

Results (cont) – EUR summary

Dechongkit, 2011