Modeling Sonic Velocity in Carbonates Using Thin Sections*

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Abstract

The differential effective medium theory (DEM) is used to model high frequency (1MHz) laboratory velocity measurements of carbonates under dry and water-saturated conditions. Velocity-porosity data from laboratory experiments show that micropores have a strong softening effect on the sonic velocity of carbonates. Quantitative image analysis of 250 thin sections enables us to quantify the concentration of micropores and macropores, which forms the base of our rock physics modeling study. We model the effect of the varying stiffness of those two pore populations on velocity: (a) compliant micropores and (b) stiff macropores.

To verify the model results, we compare the elastic moduli derived from ultrasonic velocities and density information with elastic moduli obtained by DEM modeling of the same samples. This DEM model that uses measured input parameters from quantitative digital image analysis of the pore structure results in an excellent prediction of acoustic properties of carbonates. The velocity predictions also show significant improvement compared to velocity prediction using other empirical equations; e.g., the Wyllie times average equation. In addition, we show how a low rock stiffness identifies carbonates of low permeability, indicating the potential of improved reservoir characterization from acoustic data.

Modeling Sonic Velocity In Carbonates Using Thin Sections

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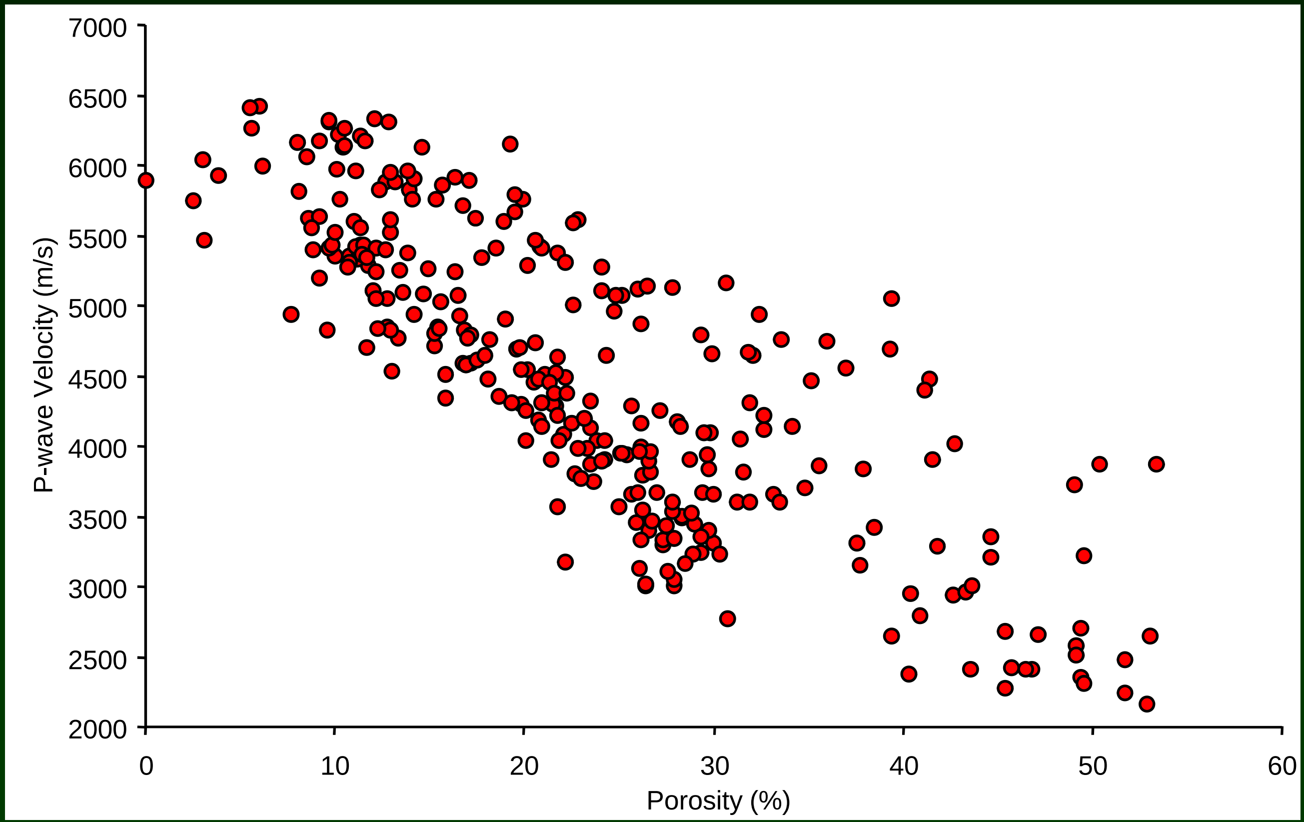
** University of Tromsø, Norway*

Key Points

- Laboratory data shows that compliant micropores have a strong softening effect on the sonic velocity of carbonates
- Macroporosity causes data scatter in velocity-porosity space
- Dual porosity DEM model that incorporates micro- and macroporosity predicts very well elastic properties.

DATASET

- 250 samples water saturated, 160 samples under dry conditions from CSL database
- Vp, Vs, porosity, density
- Mono-mineralogy: pure dolomite or calcite
- Wide range of pore and rock types captured with DIA



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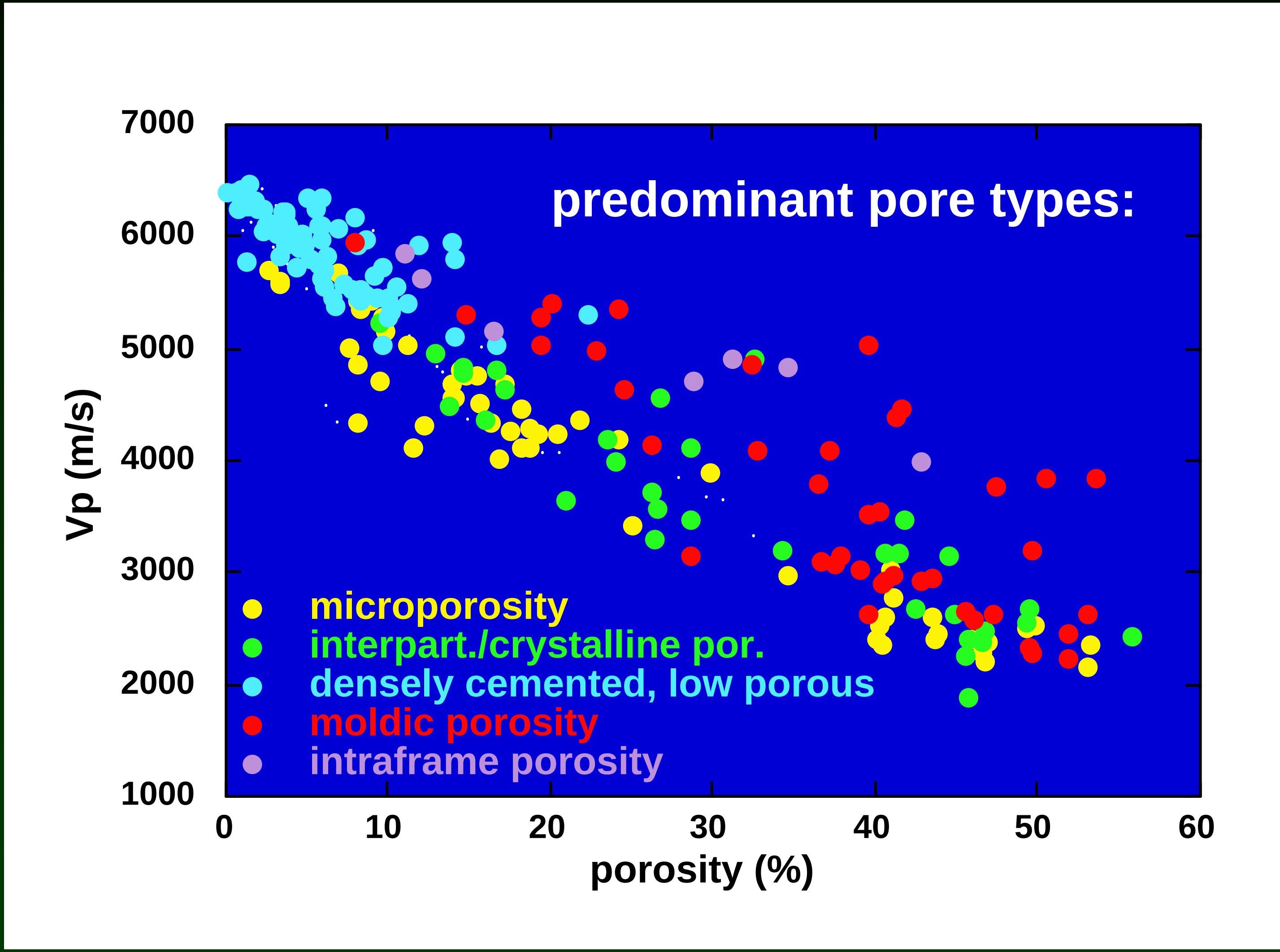
Pore Type Effects



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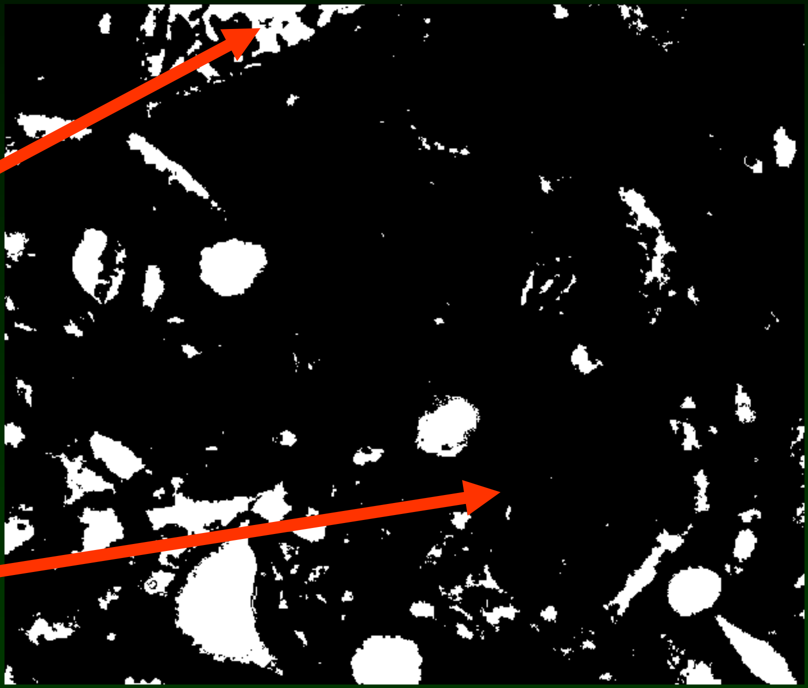
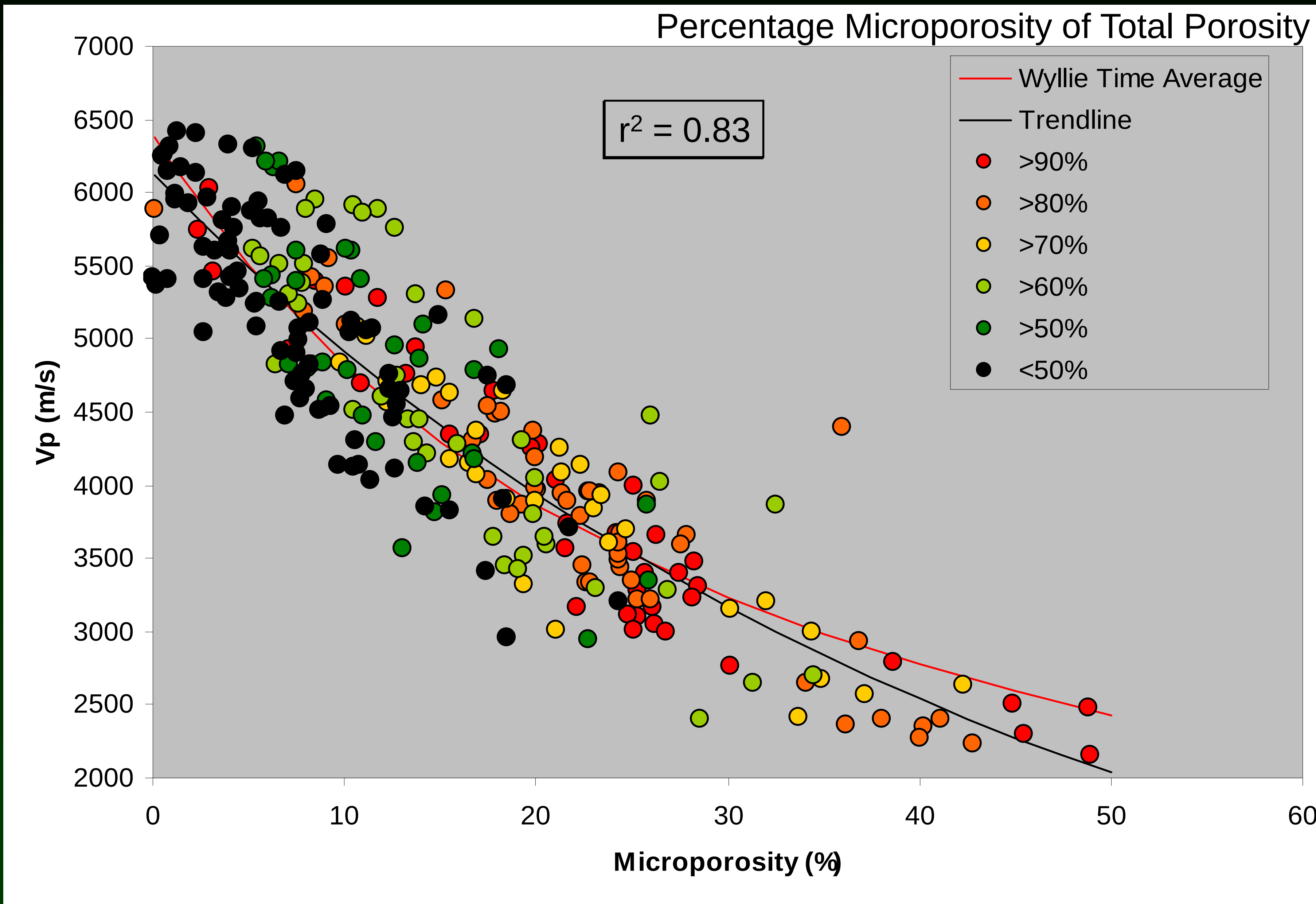
Porosity Definition

- Macroporosity:
  - All pores connected vertically through thin section, resulting in pore diameter >= 30µm
- Microporosity:
  - Macroporosity from DIA substracted from porosity measured on plug





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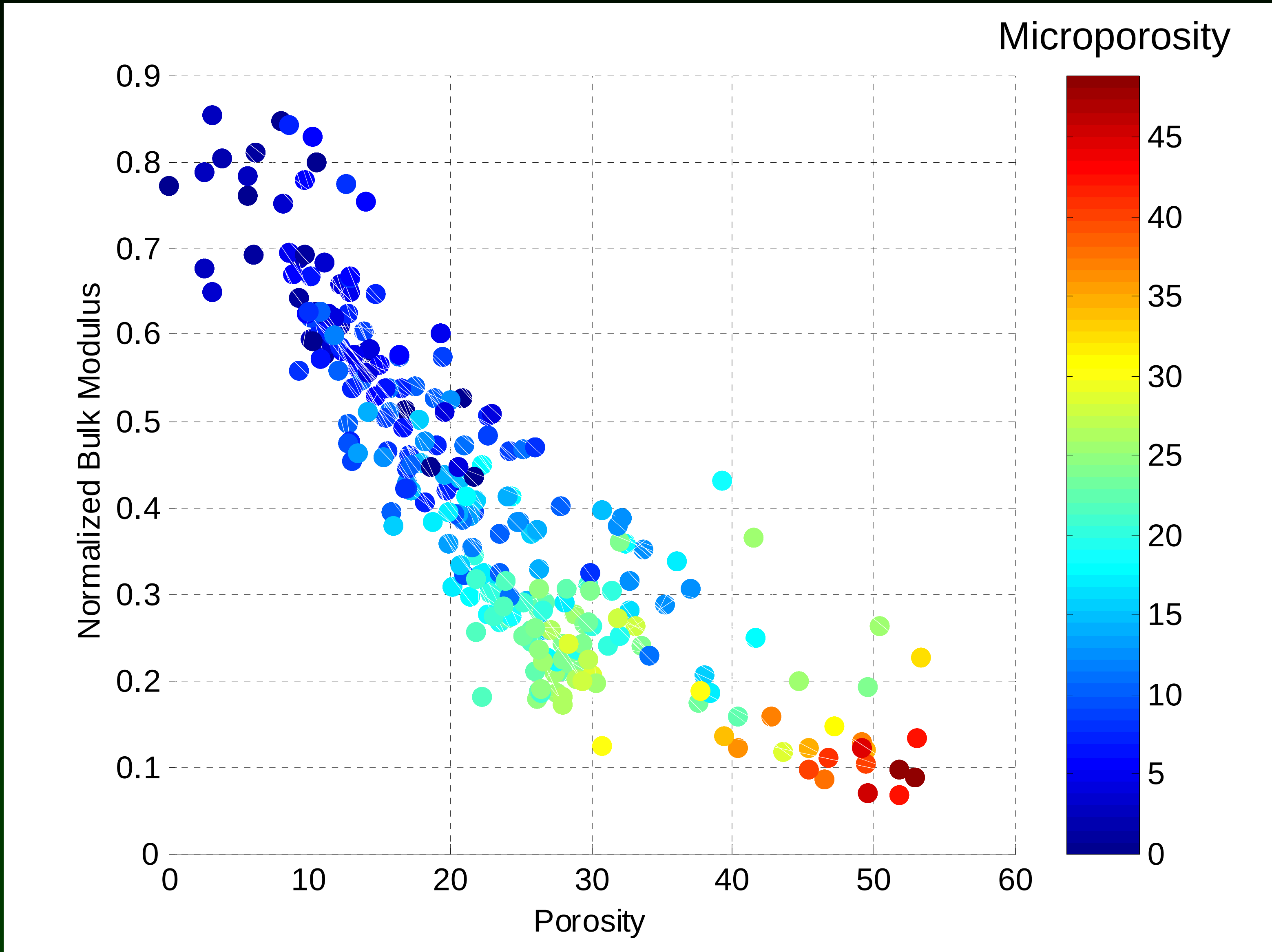
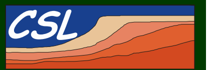
Effect of microporosity: decrease in rock stiffness





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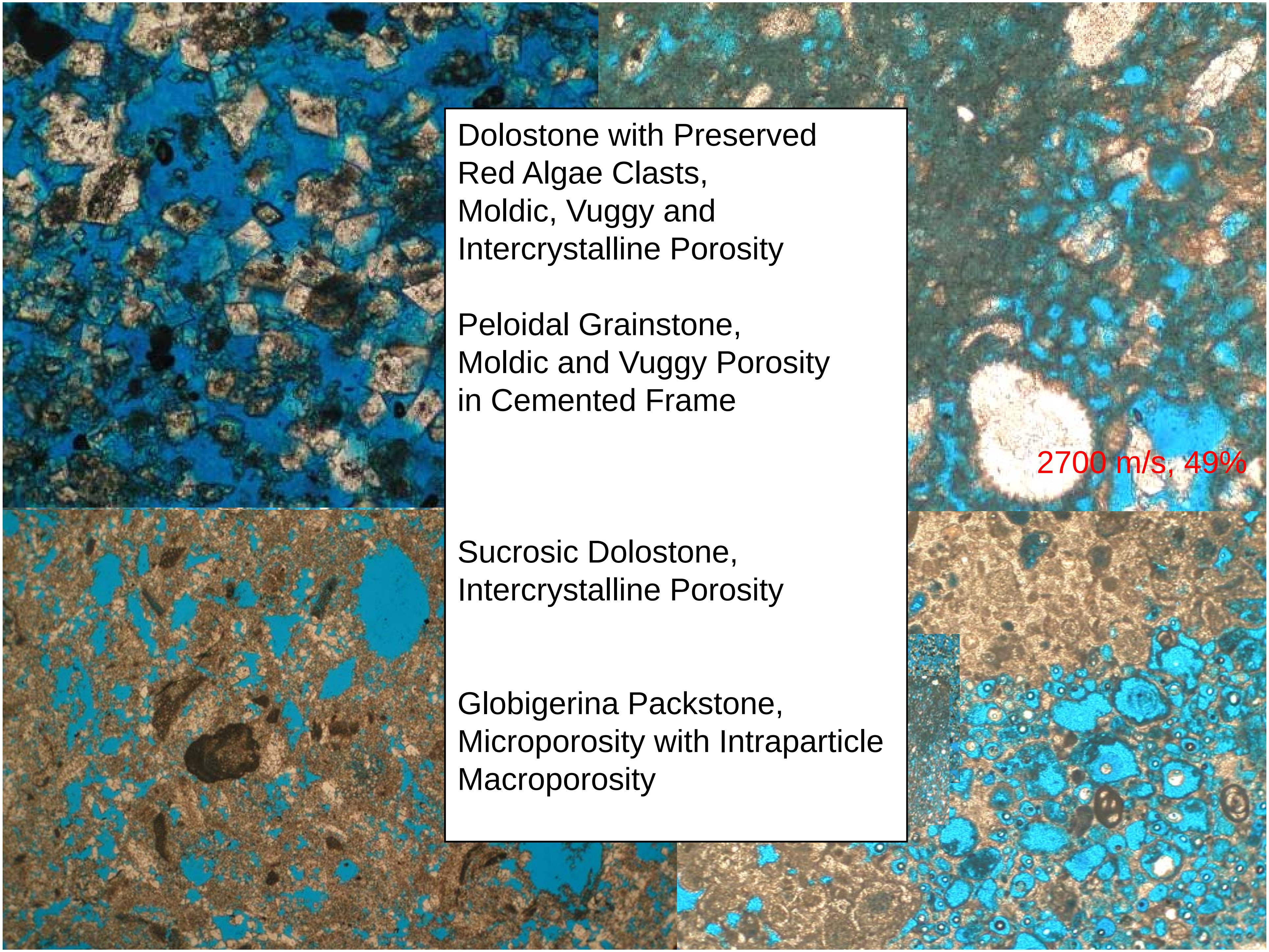
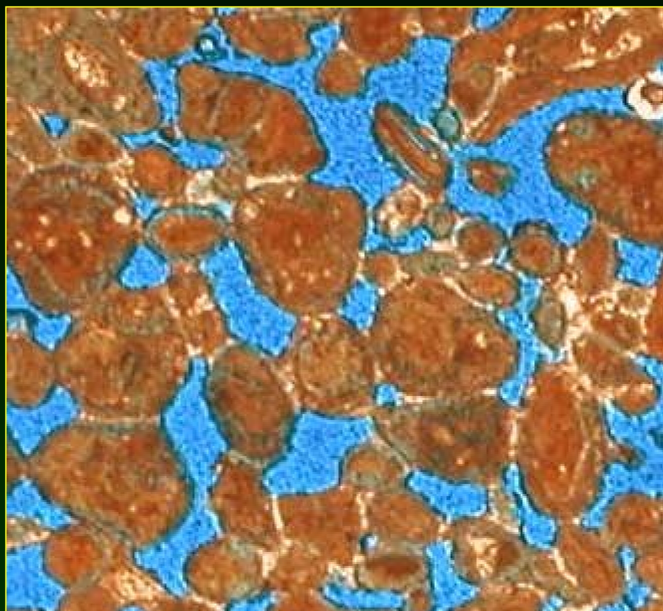

Dolostone with Preserved Red Algae Clasts, Moldic, Vuggy and Intercrystalline Porosity
Peloidal Grainstone, Moldic and Vuggy Porosity in Cemented Frame
2700 m/s, 49%
Sucrosic Dolostone, Intercrystalline Porosity
Globigerina Packstone, Microporosity with Intraparticle Macroporosity

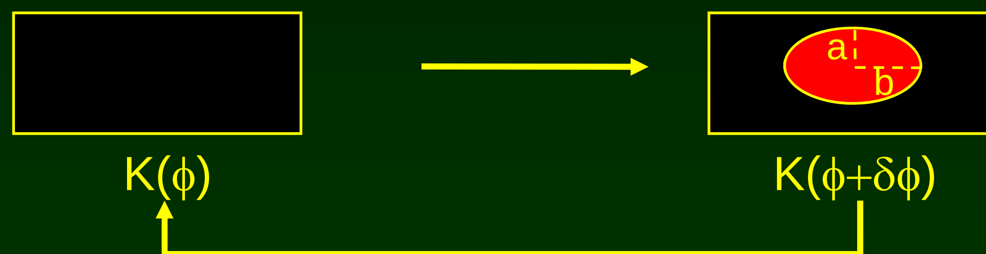
Differential Effective Medium (DEM) Model



Pore Space (1)
Solid Frame (2)
Contact Area (3)

Differential effective medium theory: Iterative procedure to add pores of specific pore shape or associated pore stiffness to the rock

Aspect ratio = a/b



Differential Effective media modeling to estimate elastic moduli of the rock:

- volume fractions of various phases (mineral, porosity)
- elastic moduli of various phases (mineral, porosity)
- geometrical details of how phases are arranged in form of aspect ratio

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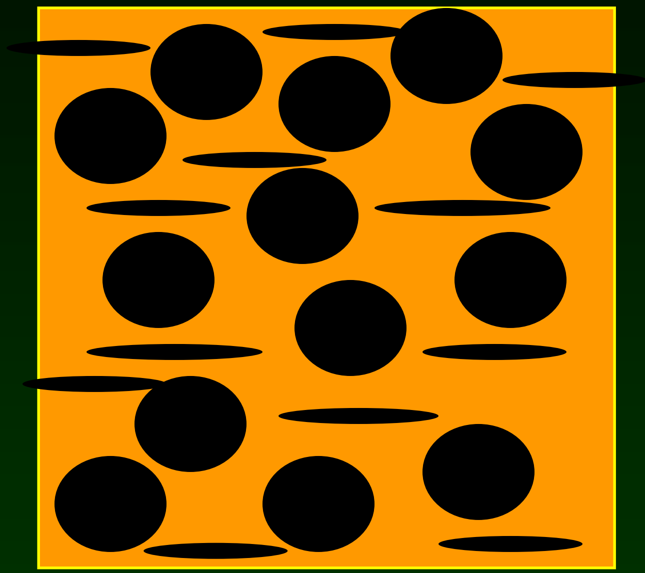
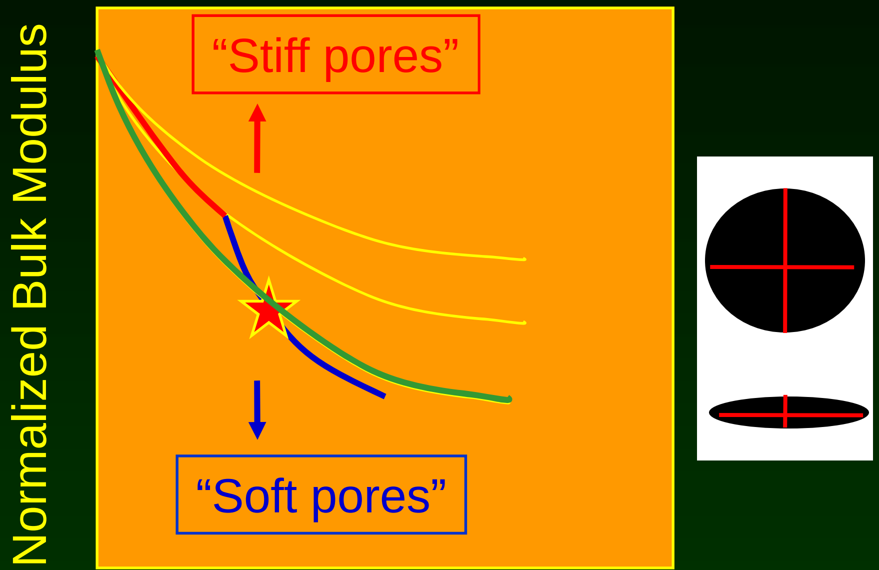
DEM Model

Simplified Rock Model



Rock Stiffness



Input Parameters:

- ***Pore fraction (amount of pores with a specific pore shape/size)***
- ***Pore stiffness (modeled by aspect ratio)***

Approach for Multipore Systems – Different Aspect Ratio for Different Pore Size Fractions

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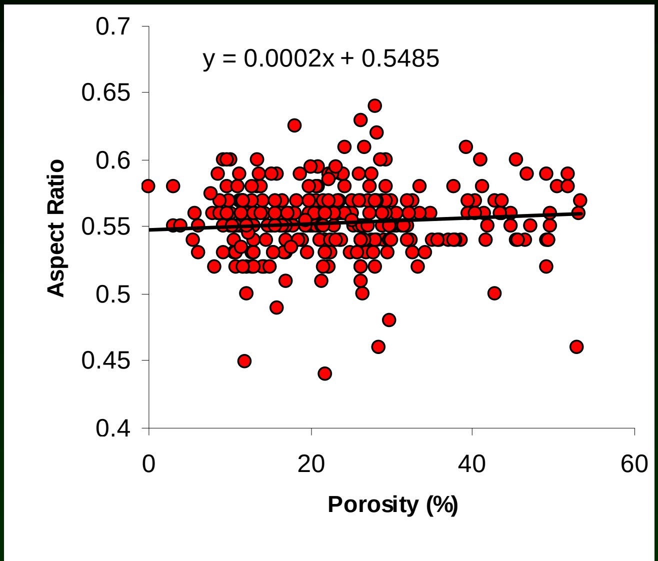
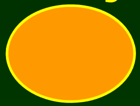
New Dual Porosity DEM Model

- Assumption:
  - Macropores: stiff pores
  - Micropores: compliant pores



- Input Parameters for Dual Porosity DEM Model:
  - Macroporosity fraction and fixed minimum aspect ratio: 0.5 
  - Microporosity fraction and best fit aspect ratio from sensitivity study: 0.1 

Workflow for Dual DEM model

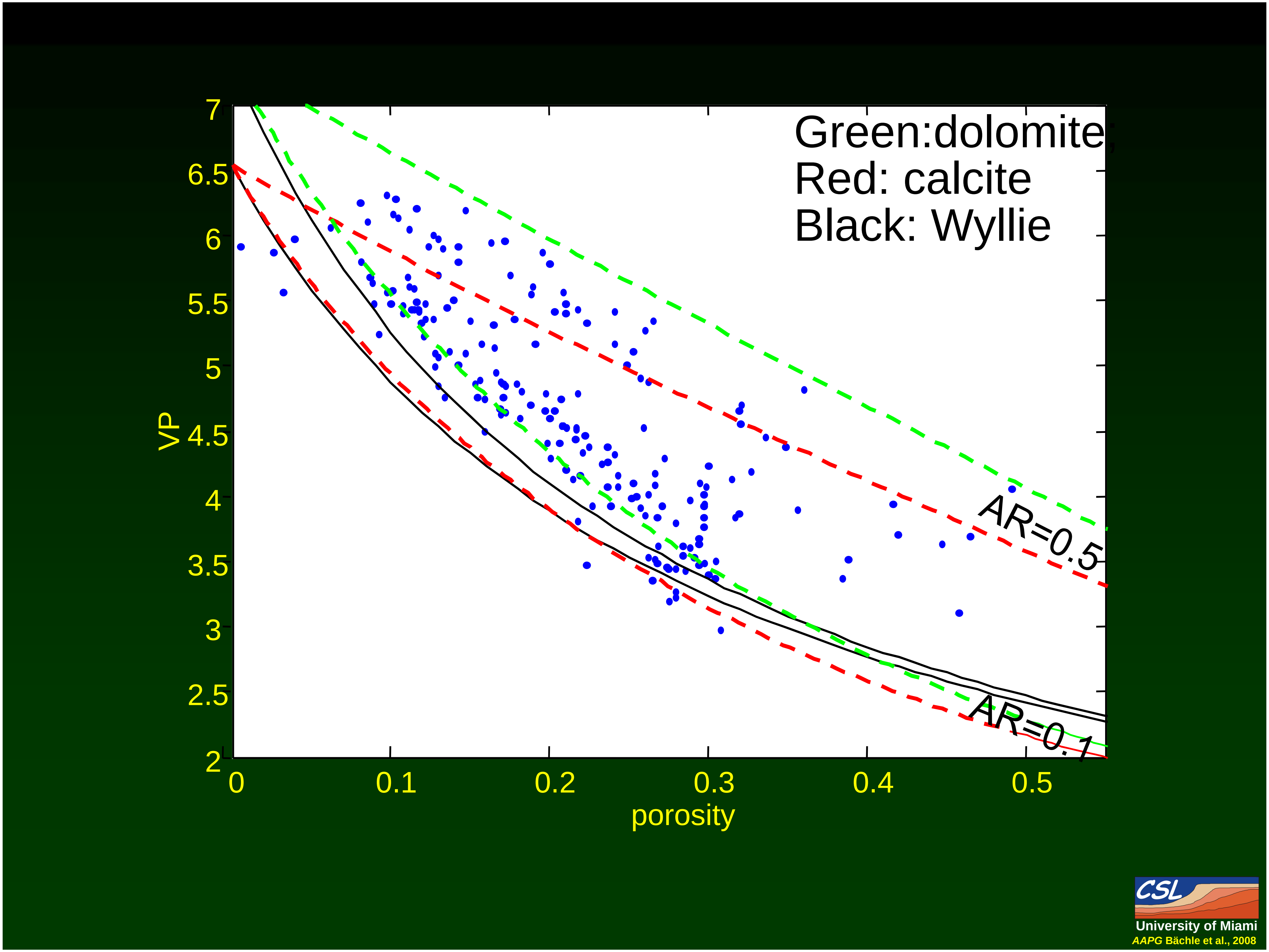
(1) Quantitative image analysis on thin sections:

(a) Fraction of macroporosity and microporosity

(b) Average aspect ratio of macroporosity

(2) Determine average aspect ratio of microporosity by best fit multiple model runs using different aspect ratios of microporosity fraction

(3) Use fraction of macroporosity and microporosity to model both, shear and bulk moduli (and velocity) from thin sections


Green:dolomite;
Red: calcite
Black: Wyllie
AR=0.5
AR=0.1
VP
porosity
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
0
0.1
0.2
0.3
0.4
0.5
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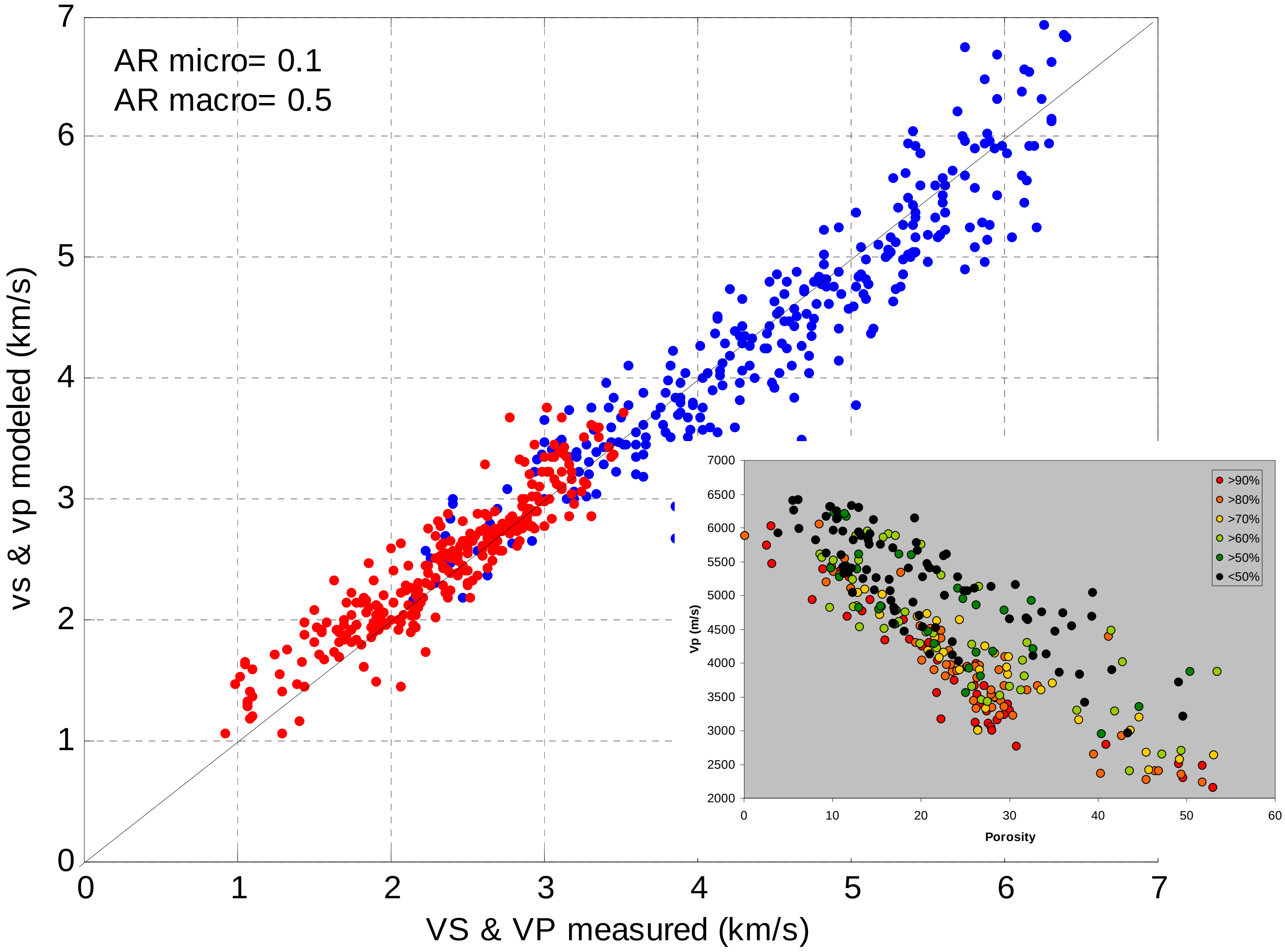

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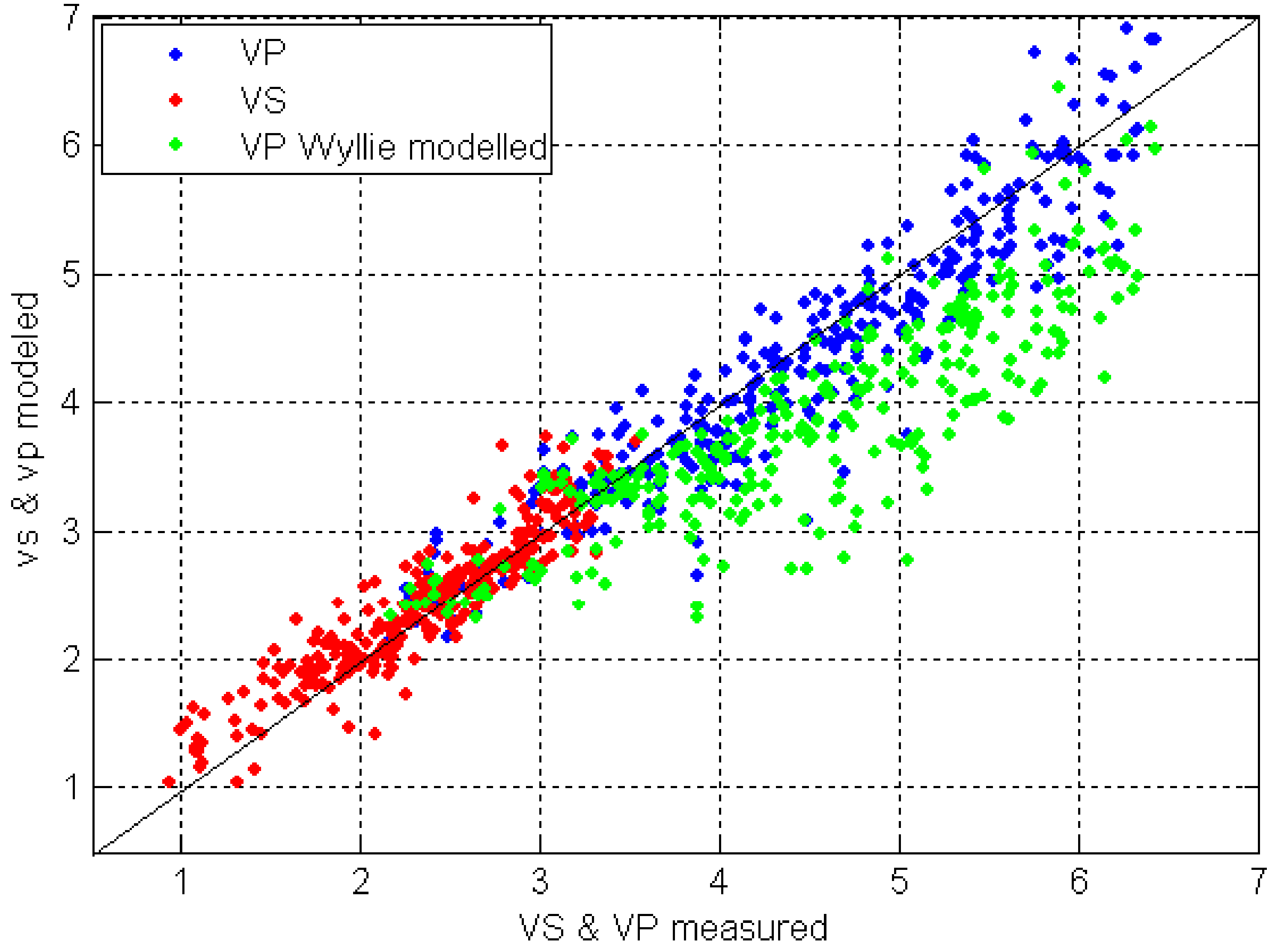

RMSE Dual porosity DEM: 392 m/s

RMSE Wyllie times average velocity: 841 m/s

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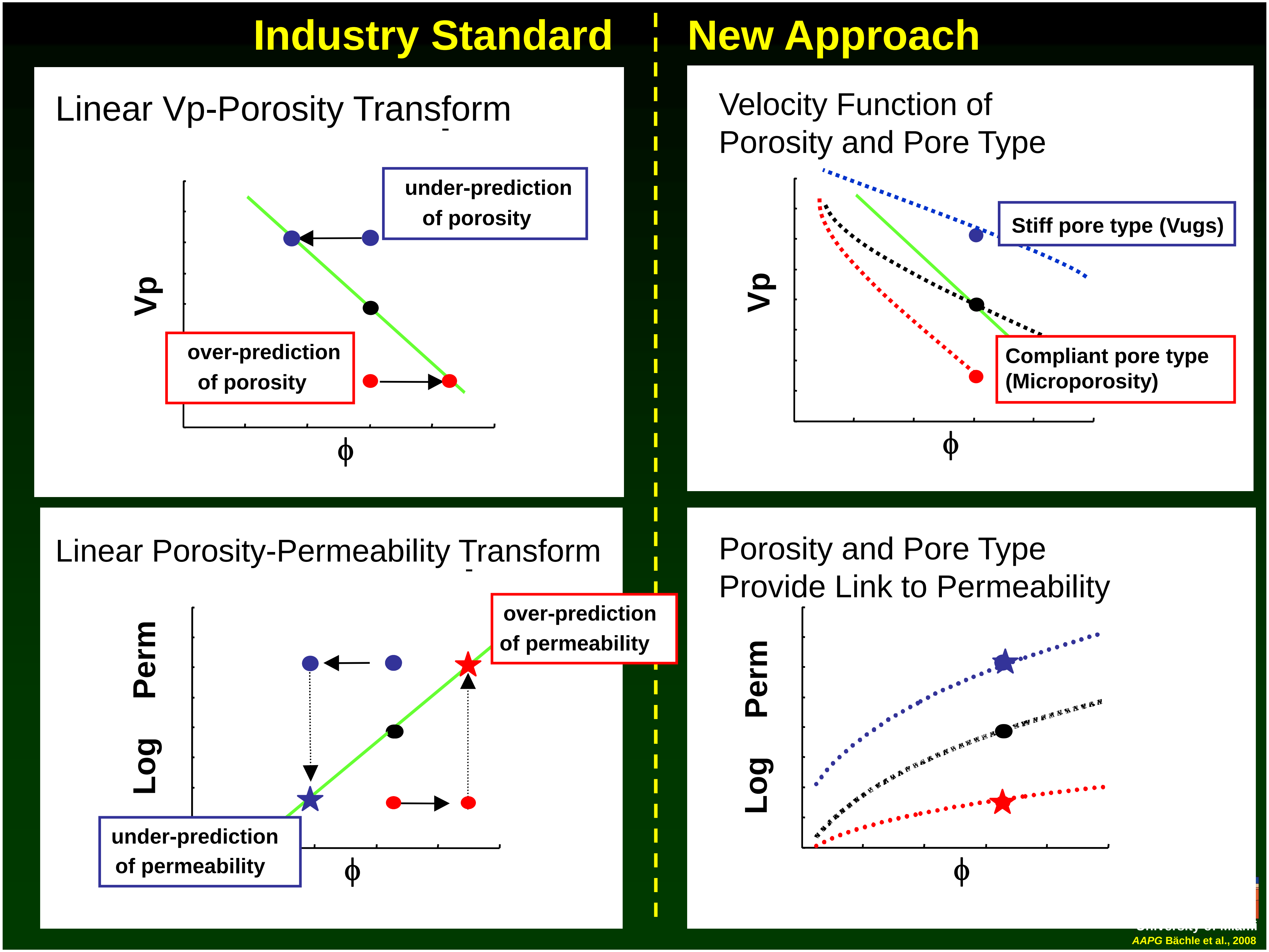
Industry Standard
New Approach
Linear Vp-Porosity Transform
under-prediction of porosity
over-prediction of porosity
Vp
ϕ
Velocity Function of Porosity and Pore Type
Stiff pore type (Vugs)
Compliant pore type (Microporosity)
Vp
ϕ
Linear Porosity-Permeability Transform
over-prediction of permeability
under-prediction of permeability
Log Perm
ϕ
Porosity and Pore Type Provide Link to Permeability
Log Perm
ϕ
AAPG Bächle et al., 2008

Conclusions

- Laboratory data shows that compliant micropores have a strong softening effect on the sonic velocity
- Digital image analysis of thin sections provides pore structure descriptions (fraction of micro- and macroporosity)
- Dual porosity DEM model incorporates micro- and macroporosity and enables Vs and Vp predictions

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and

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