Mechanical Properties of Mississippian Rocks*

Pouyan Ebrahimi[1], Priyank Jaiswai[1], Sandip Harimakar[1], and James Puckett[1]

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[1]Boone Pickens School of Geology, Oklahoma State University, Stillwater, OK (pouyan.ebrahimi@okstate.edu)

Abstract

The Mississippian carbonate reservoirs in the United States belong to the petroleum system of Devonian-Mississippian age. Although identified as a prolific hydrocarbon resource, they have proven difficult to develop. Mississippian carbonates are generally developed through lateral drilling and hydraulic fracturing. Field engineers have often observed that the rock's response to hydraulic fracturing varies greatly in the Mississippian reservoirs. Concepts that have worked successfully in siliciclastic or even shale reservoirs do not appear to be directly applicable to these systems. The exact dependencies of hydraulic fracturing response in the Mississippian are poorly constrained. Probable reasons include rapidly changing size and shapes of pores, facies-dependent intermittent transition from anisotropic to isotropic behavior, lithology driven heterogeneity, etc.

We have put a series of Mississippian rock samples under compression testing and observed their stress-strain relationship. The samples varied from chert-dominated to calcite-dominated compositions. Preliminary results indicate that massive carbonates can be more ductile than chert. However, chert-dominated samples appear to be readjusting their matrix over a larger range of strain rates between the inception and completion of rock failure. In the presence of fractures, strain rates between the inception and completion of rock failure have a very narrow range. In tripolites, fractures seem to be accumulating at the boundary of chert and limestone. The stress-strain charts can provide basic geomechanical parameters such as Young's modulus and Poission's Ratio which can then be related to the seismic velocities.

Mechanical Properties of Mississippian Rocks

P. Ebrahimi *, P. Jaiswal, S. Harimkar,
J. Puckette

* Pouyan.Ebrahimi@okstate.edu

Oklahoma State University

Mississippian Reservoirs Consortium

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Motivation

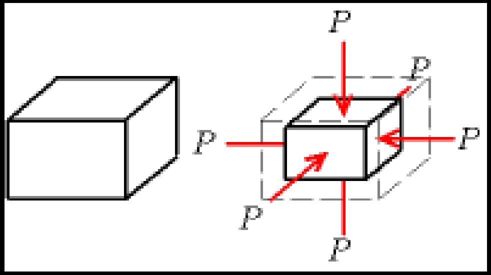
- Develop a rock physics model for Mississippian carbonate reservoir
  - Matrix
  - Fluid
  - Pore shapes
- Calibrate rock model with analytical results
  - Modulus (Bulk and Shear)
  - Porosity

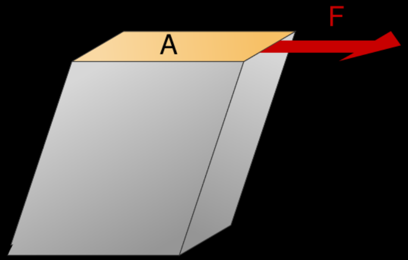
Presentation Summary

- Introduction to rock mechanical properties
- Preliminary results from lab measurements of Mississippian carbonate samples
- A case study on Quartz-rich Woodford Shale
  - ✓ Implications on exploration and development

Introduction
Elastic Moduli and Wave Velocity

Bulk Modulus (K) | **Shear modulus (G)**





$$K = -V\, dP/dV > 0$$

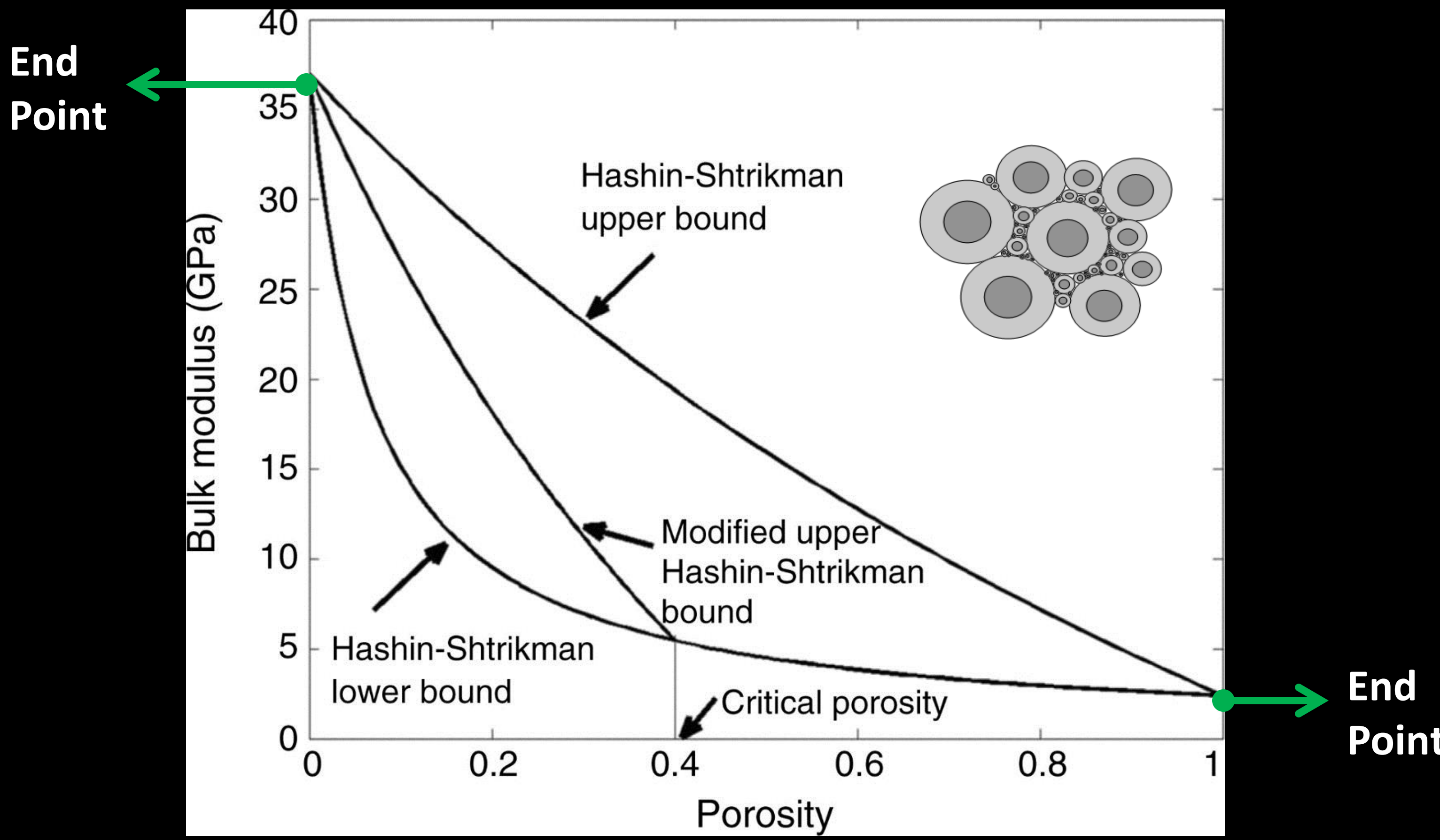
$$G = \frac{F/A}{\Delta x/l}$$

$$V_p = \sqrt{\frac{K + \frac{4}{3}G}{\rho}}$$

$$V_s = \sqrt{\frac{G}{\rho}}$$

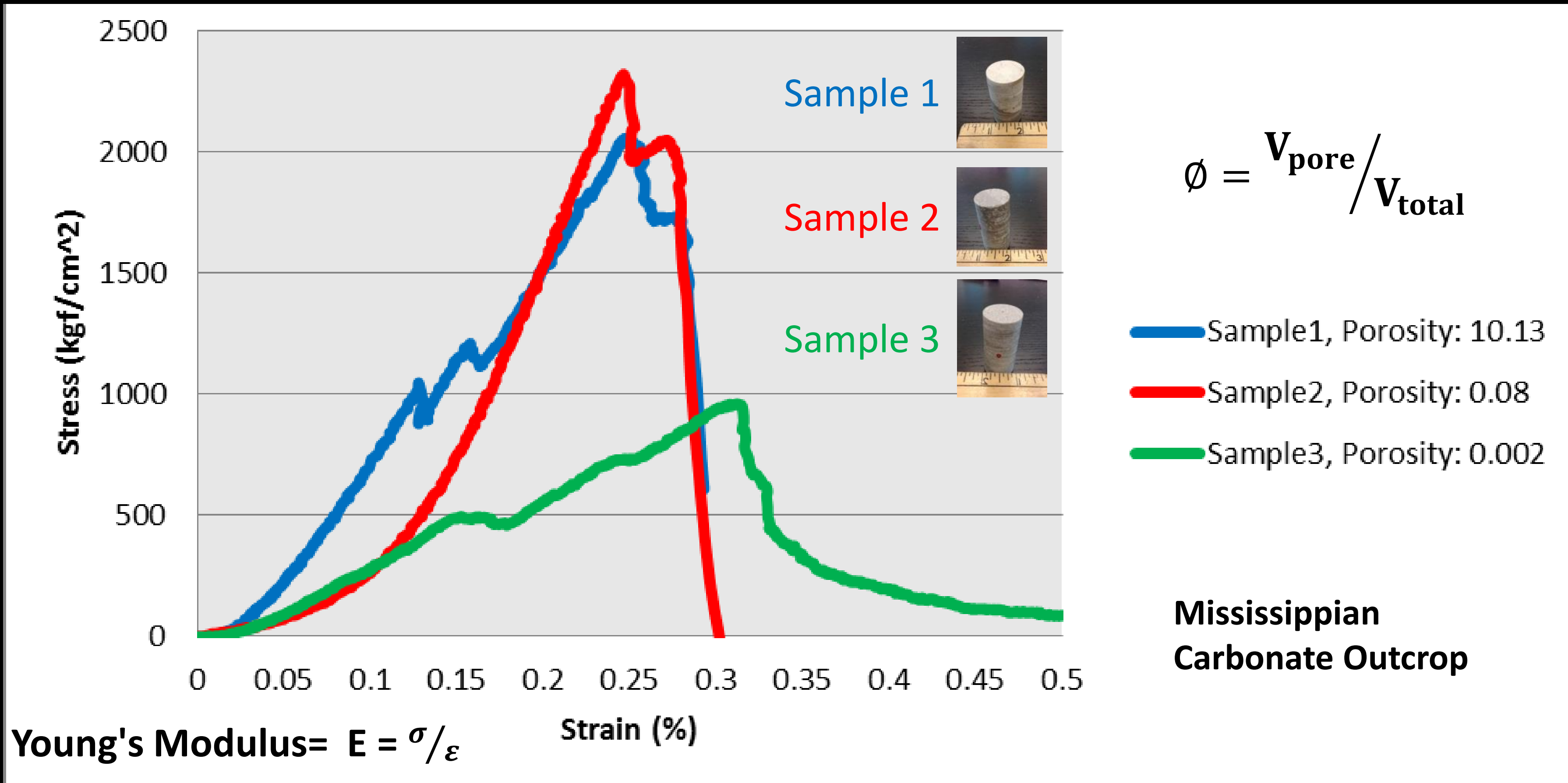
Poisson's Ratio, $\mathrm{PR} = \frac{1}{2} \times \frac{(Vp/Vs)^2 - 2}{(Vp/Vs)^2 - 1} = \frac{1}{2} \times \frac{K/G - 2/3}{K/G - 1/3}$

Porosity vs. Moduli : general



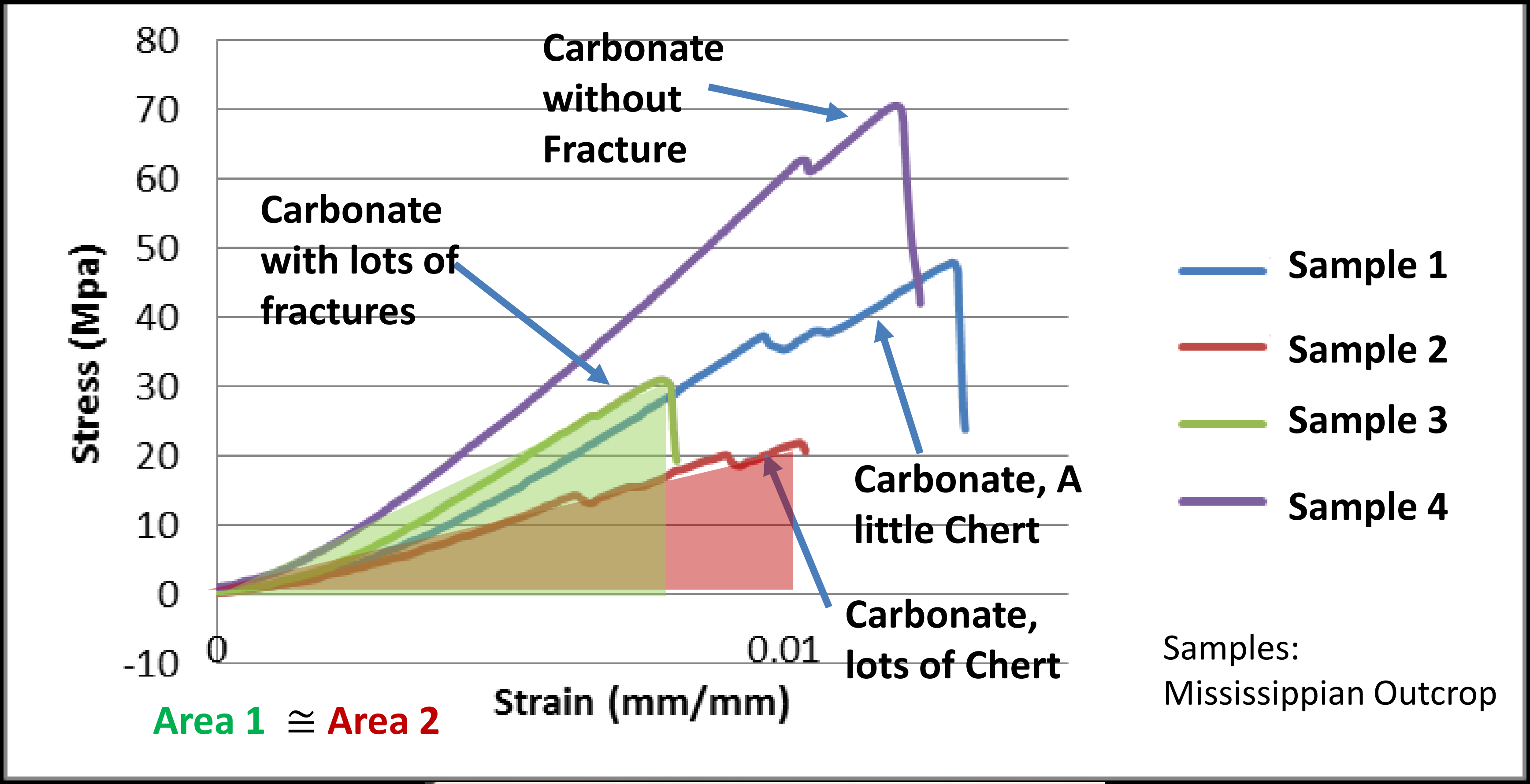
Critical Porosity: Porosity above which grain-to-grain contact is lost and hence shear strength vanishes.

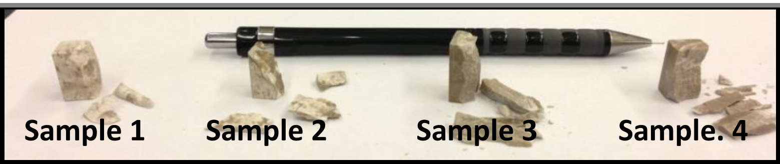
Porosity vs. Moduli : Miss. Carb.



Porosity-moduli relation in the Mississippian Carbonates does not obey the conventional wisdom.

Mineralogy & Fractures vs. Moduli.





Toughness: ability to absorb mechanical (or kinetic) energy up to failure.

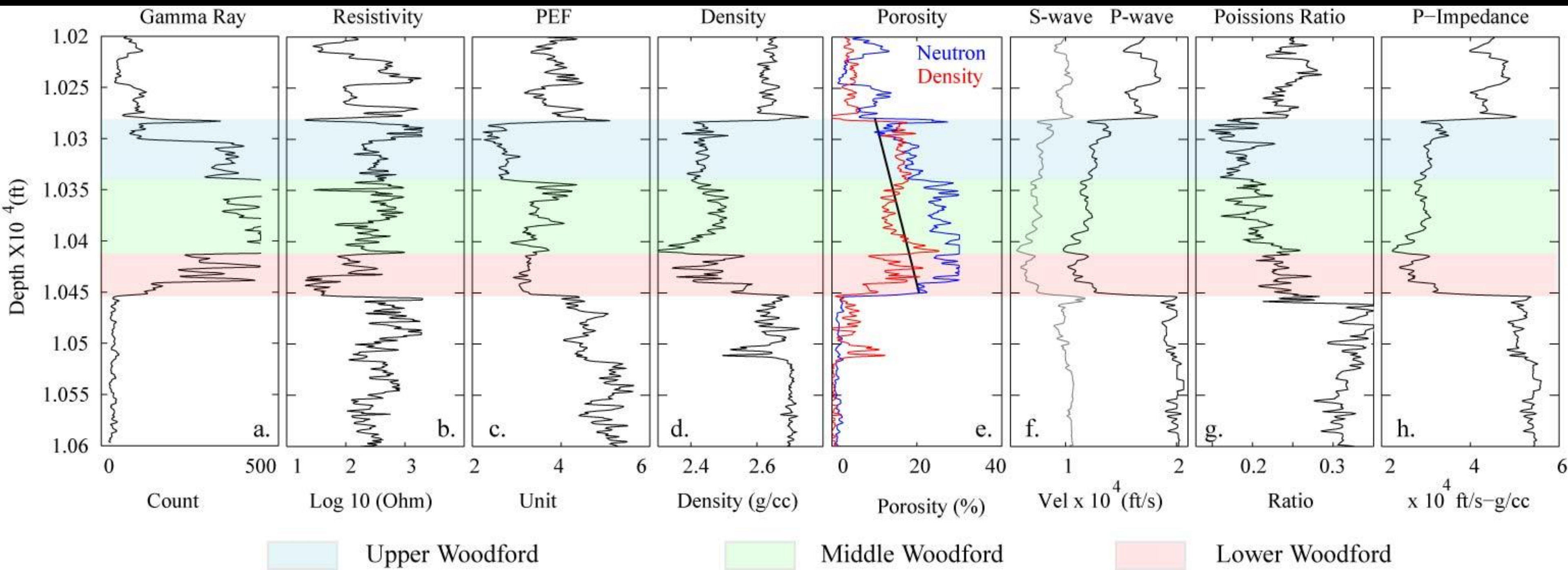
- Area below stress-strain graph will present toughness.
- Effect of fracture on sample 3 is almost the same as effect of Chert in sample 2

Thoughts…

- Mississippian carbonates rocks may not follow the conventional rock physics wisdom
  – Porosity may not have direct relation to moduli
  – Mineralogy may not have direct relation to moduli
  – Seismic attributes may not be interpretable as in Siliciclastics
- Pre-existing fractures seem to have strong effect on rock weakness
  – Sub-seismic resolution
  – Need for S-wave survey?

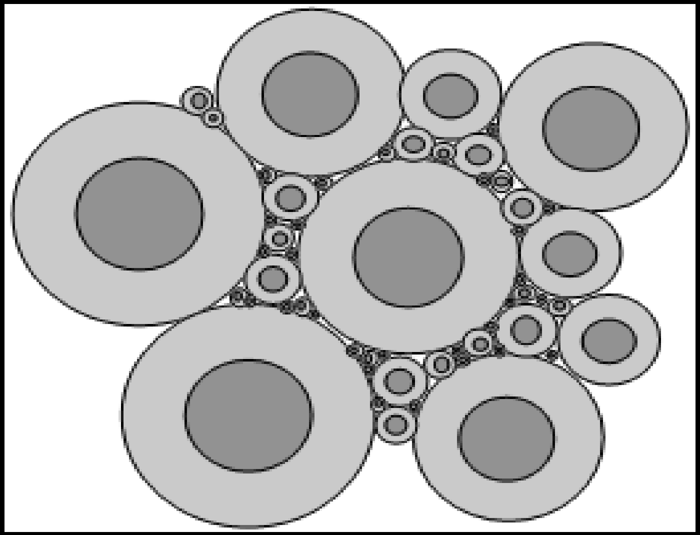
An example of connecting surface seismic with rock properties using rock physics modeling

- Woodford Shale
  - Full log suit (including shear sonic).

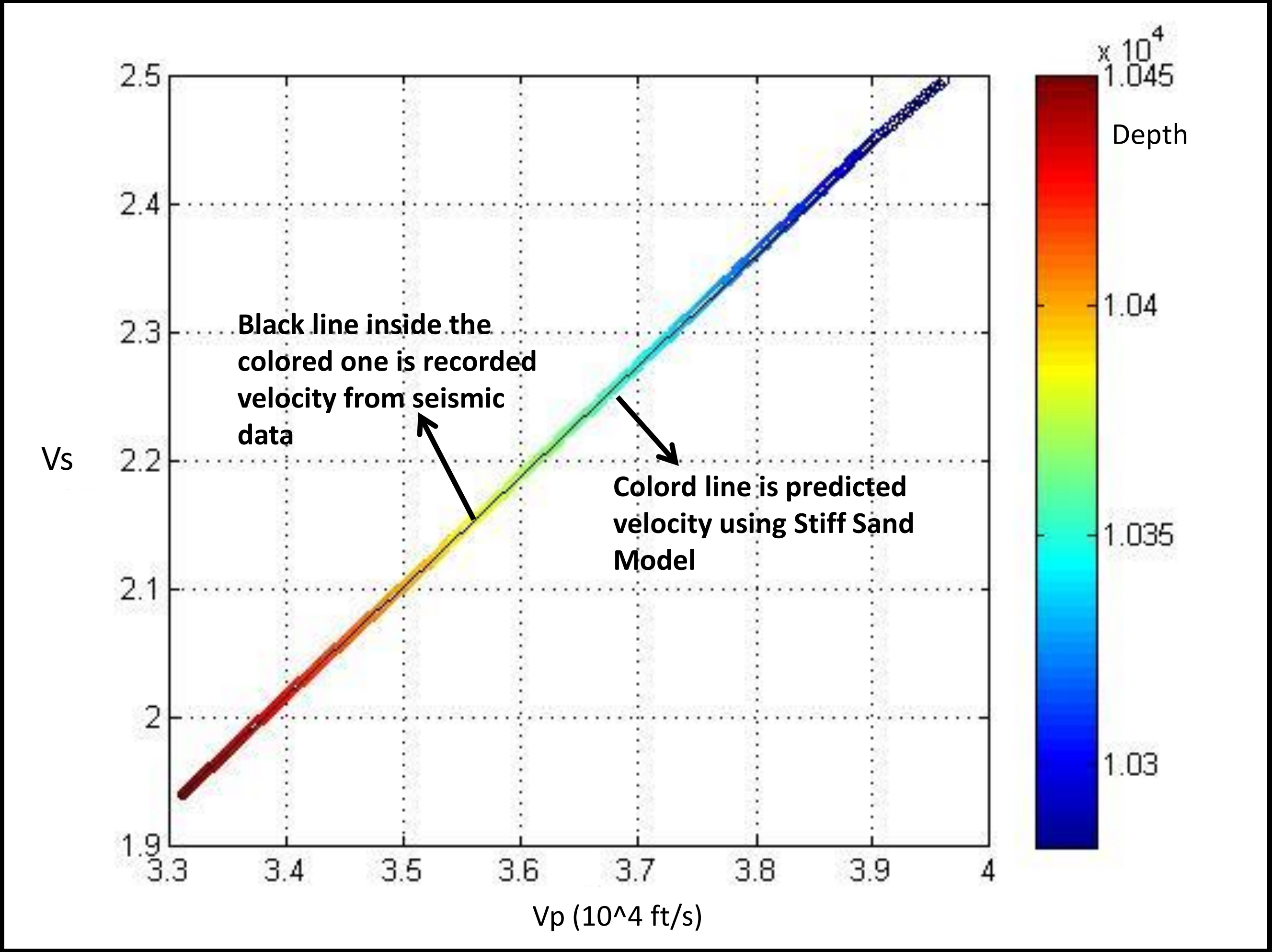


Stiff Sand Model

- Maximum possible moduli for a given porosity
- Compact, low-porosity rocks.
- Woodford
  - Matrix: Quartz, Illite, & Calcite
  - Fluid: Brine, gas
  - OM : both ways



Predicted Velocity Using Rock Physics (Stiff Sand Model)



	Silica	Clay	Calcite	Org	Sgas	Phi	Critical Phi
Top	0.7648	0.2202	0.0150	0.1000	0.3900	0.1490	0.4000
Base	0.1967	0.7634	0.0399	0.3991	0.3003	0.1715	0.5580

Conclusions : Woodford Case Study

- Higher Quartz in upper Woodford compared to middle or lower units
- Moderate (1-5%) calcite
- Model porosity consistent with density porosity
- Moderate OM (1 – 5%)
  - When OM in part of pore fluid, fluid-filled porosity is ~50% of the density porosity

Going Forward

- Similar rock model development is intended for the Mississippian Carbonates

- Effect of pore-shapes on elastic velocities need to be analyzed

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