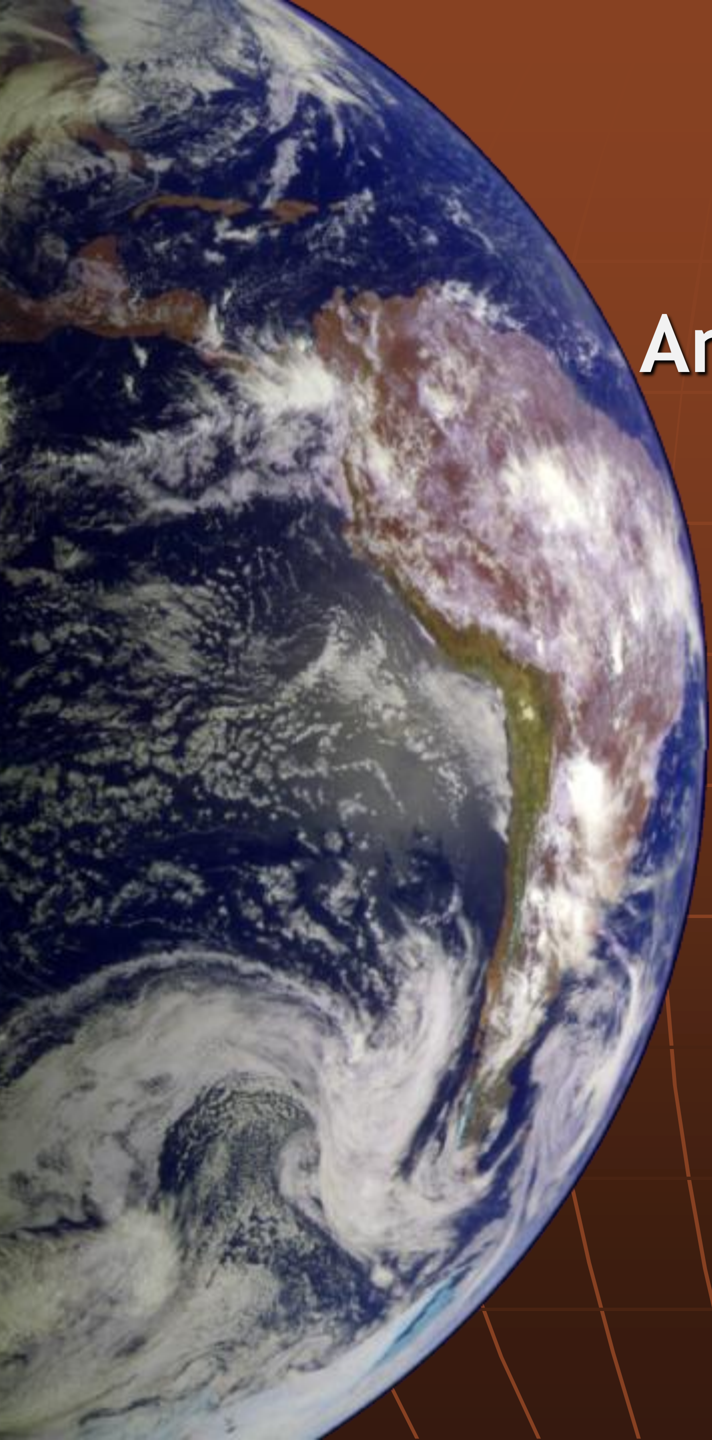

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Characterization of Seismic Anisotropy of the Marcellus Shale from Borehole Data

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Ph.D. Aspirant

Advisor : Dr. Robert Tatham

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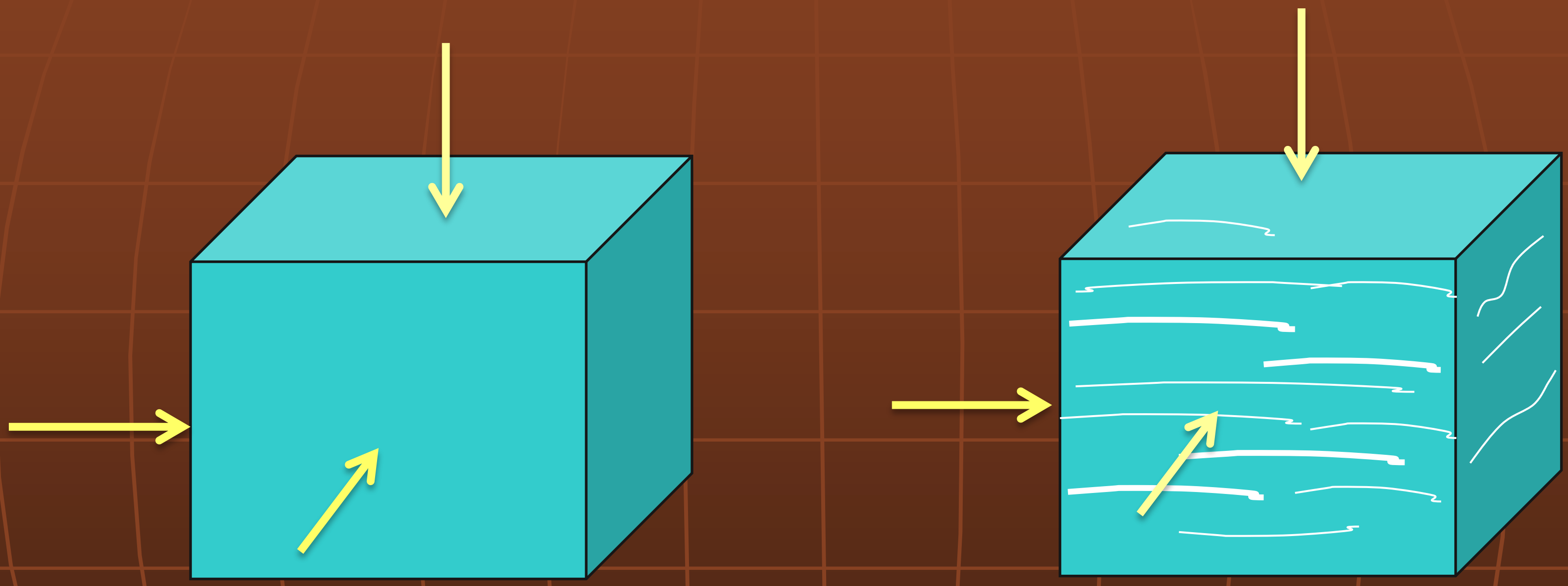
Talk Outline

- Seismic Anisotropy : Theoretical Basics
- Dipole Sonic Tool
- Anisotropy Characterization
  - The Marcellus Shale Data
  - VTI Analysis
    - Backus Average
  - HTI Analysis
    - Fracture Modeling
- Conclusion
- Future Work

Seismic Anisotropy



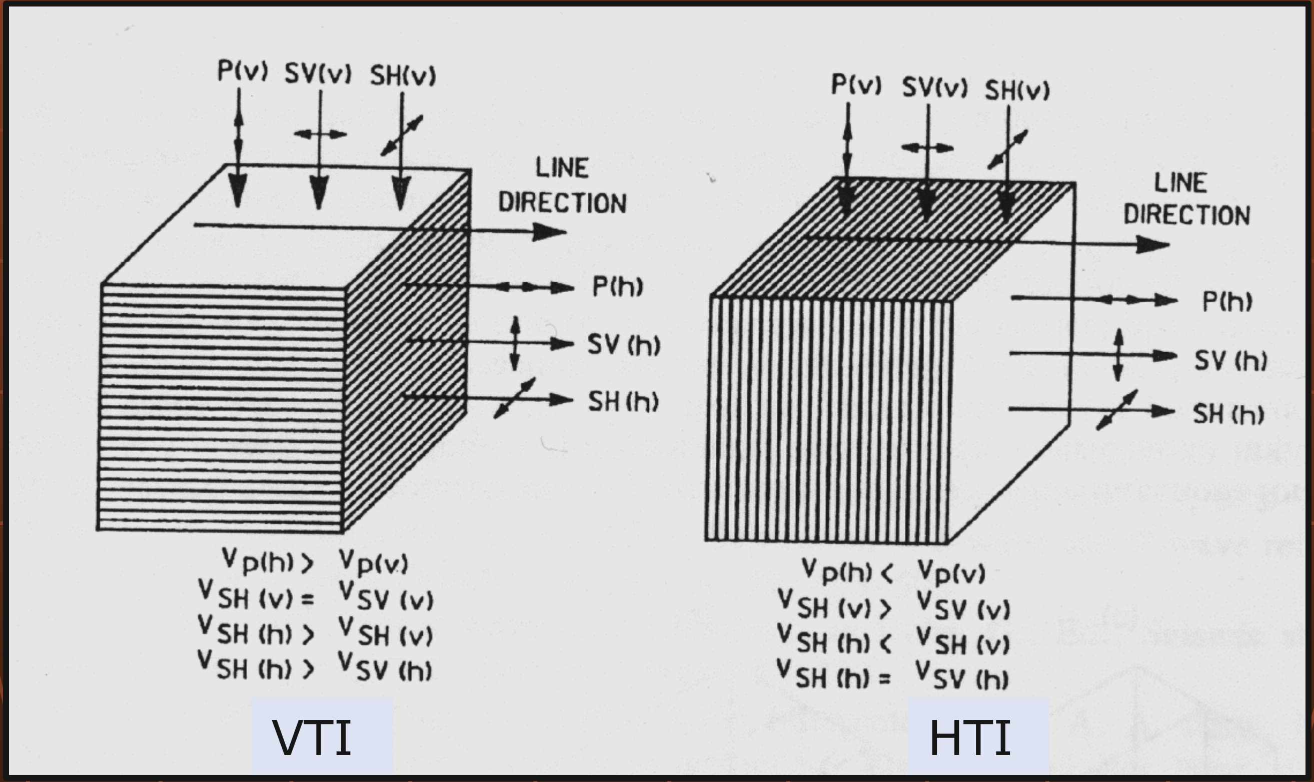
Isotropic

Anisotropic

Velocities are same in all directions

Velocities are **NOT** same in all directions

Simple Anisotropic System



Tatham & McCormack, 1991

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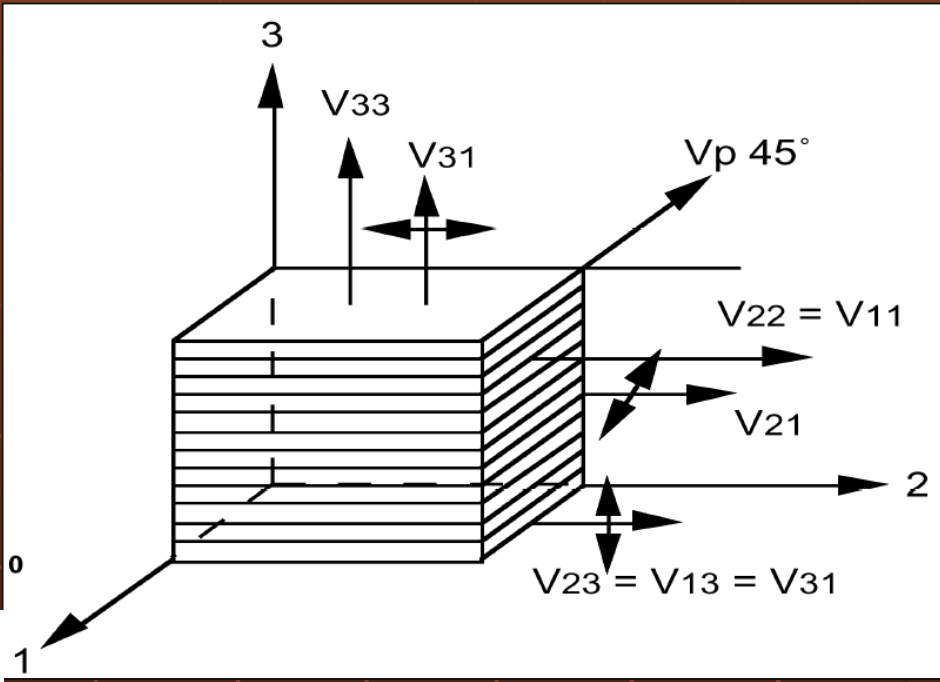
Transverse Isotropy Tensor

Voigt notation for VTI system

C11	C11 – 2C66	C13	0	0	0
C11 – 2C66	C11	C13	0	0	0
C13	C13	C33	0	0	0
0	0	0	C44	0	0
0	0	0	0	C44	0
0	0	0	0	0	C66



Voigt notation for HTI system

C11	C13	C13	0	0	0
C13	C33	C33 – 2C44	0	0	0
C13	C33 – 2C44	C33	0	0	0
0	0	0	C44	0	0
0	0	0	0	C66	0
0	0	0	0	0	C66

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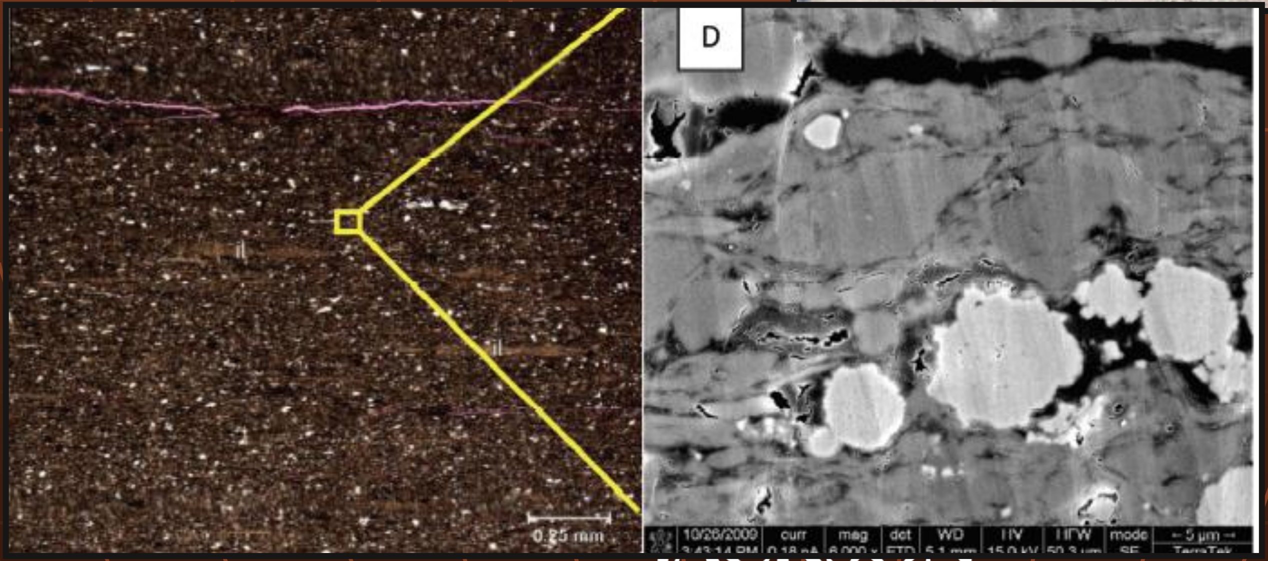
Anisotropy in the Marcellus Shale

Outcrop

- Fractures
- Bedding parallel cracks/ layering

Engelder, 2009

Thin Section and SEM image



Milner, 2010

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Anisotropy Characterization

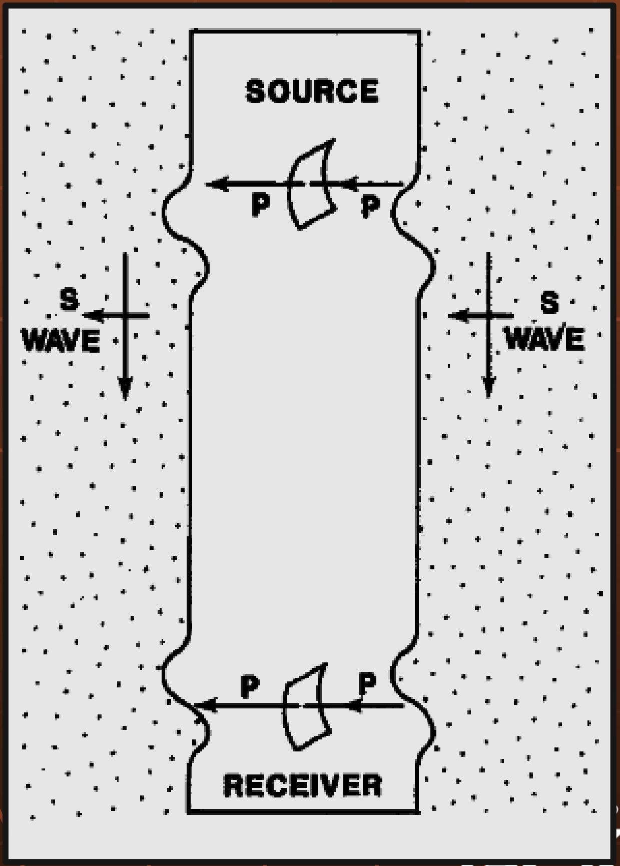
- Lab Measurement data
- Borehole Sonic data
- Surface Seismic data

Velocities from Borehole Sonic Data

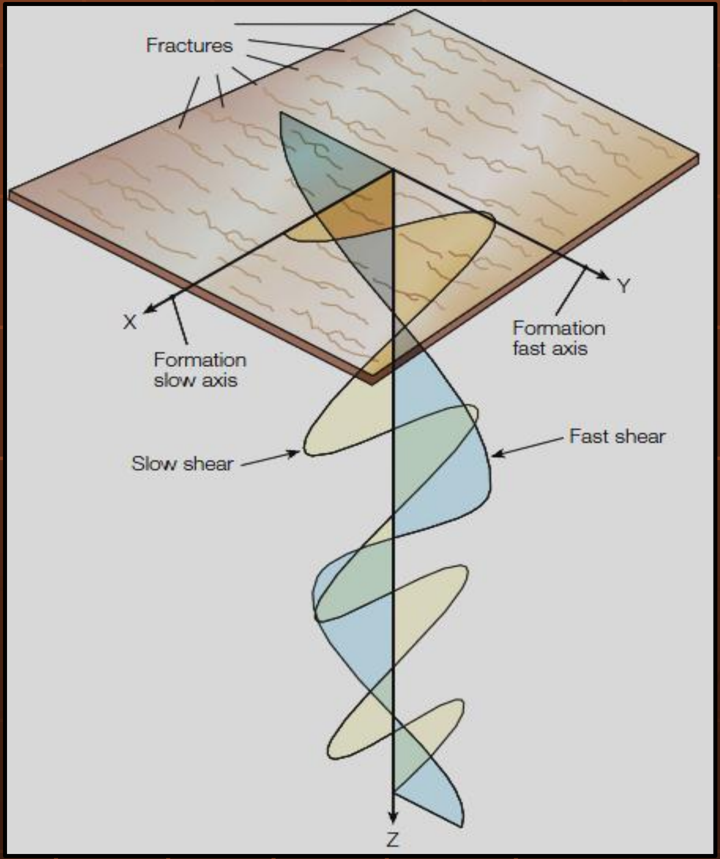
- Compressional and Shear slowness
  Monopole Source (7-20kHz)--Vp(0°), Vs(0°)
- Shear Slowness Fast and Slow
  Dipole Source (2-4kHz)—Vs_1,Vs_2
- Stoneley Slowness
  Horizontal Shear wave slowness

Dipole Sonic Tool

Shear Slowness Fast and Slow
Dipole Source (2-4kHz)—Vs1,Vs2
-> Estimate of C_{44}, C_{55}



Zemanek et al, 1991



Brie et al, 1998

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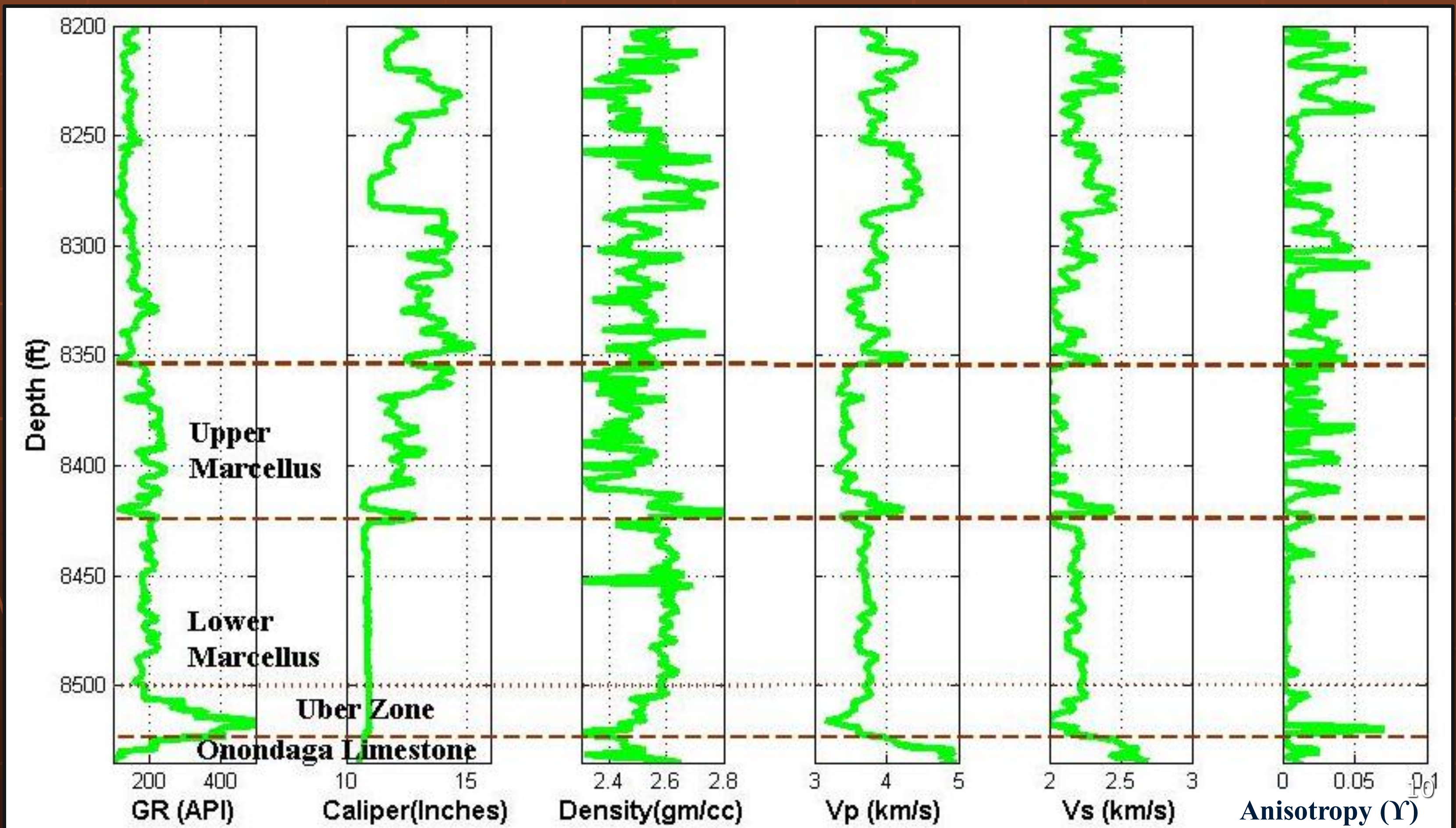
The Marcellus Shale

Middle Devonian marine organic shale extensive in New York, Pennsylvania, Ohio and West Virginia

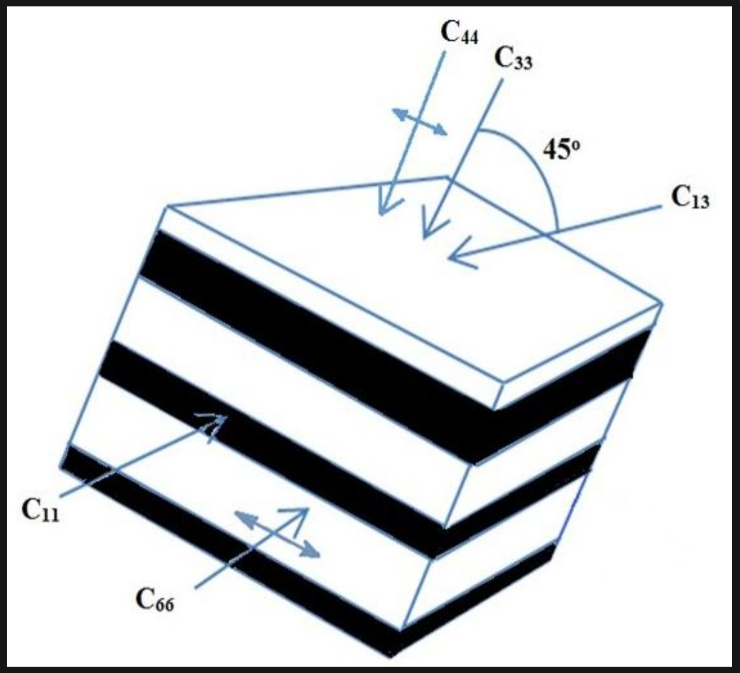


Estimation of VTI Anisotropic parameter from Dipole log

- For VTI, Thomsen (1986) parameters

$$\varepsilon = (C_{11} - C_{33})/2C_{33}$$
$$\gamma = (C_{66} - C_{44})/2C_{44}$$
$$\delta = (C_{13} + C_{44})^2 - (C_{33} - C_{44})^2/2C_{33}(C_{33} - C_{44})$$

- $C_{33}=\rho(Vp(0^o))^2$
- $C_{44}=C_{55}=\rho(Vs(0^o))^2$
- $C_{66}=\rho(Vs(90^o))^2$
- ➢ $C_{11}=?$, $C_{13}=?$, $\varepsilon=?$, $\delta=?$

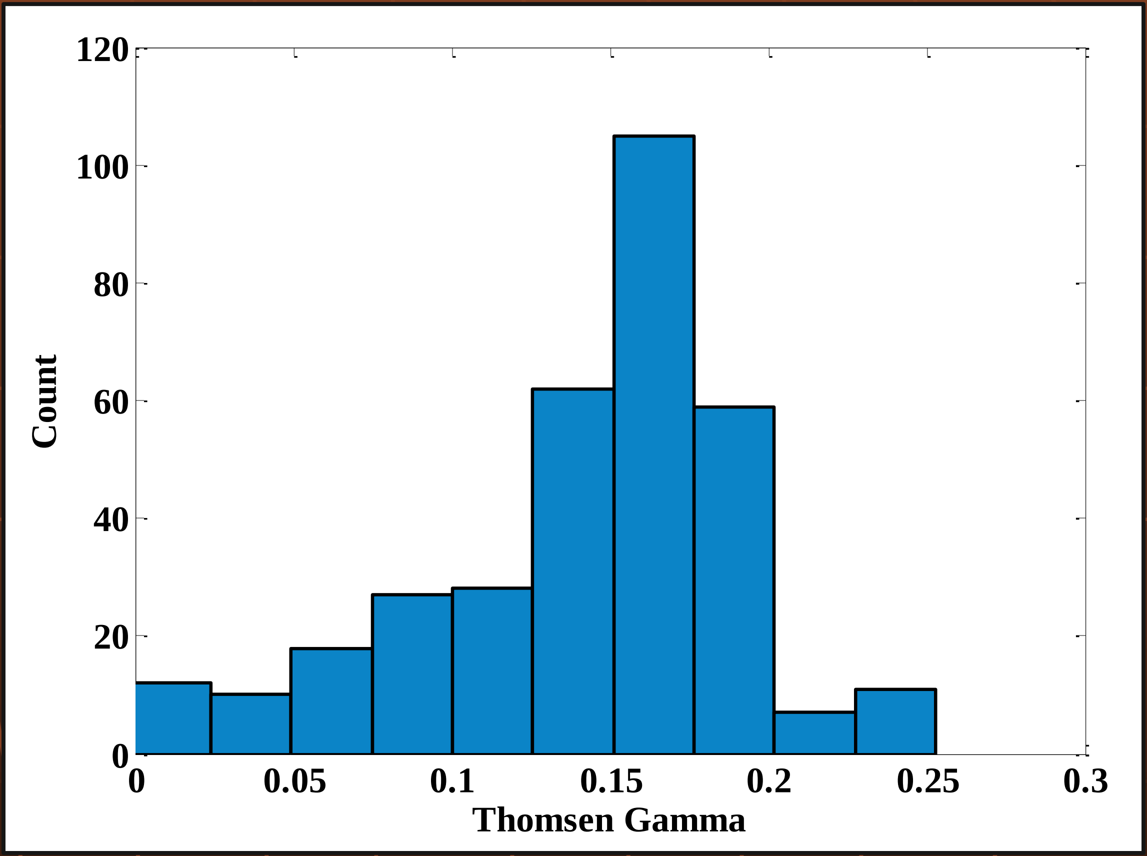


Thomsen (1986) ϒ from Monopole log

$$\gamma = (C_{66} - C_{44})/2C_{44}$$

C44--Vertical monopole shear slowness

C66--Horizontal shear slowness from stoneley slowness



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VTI Anisotropy at Seismic Scale

- Upscaling

  Seismic frequency--~order of 10's, like 50 Hz
  Borehole monopole frequency--~ 5-10kHz
  Borehole dipole frequency -- ~ 2 kHz

- Backus (1962) Average

  a. Upscaling at seismic wavelength
  b. Full VTI tensor
  c. Estimation of Ɛ, γ, and δ

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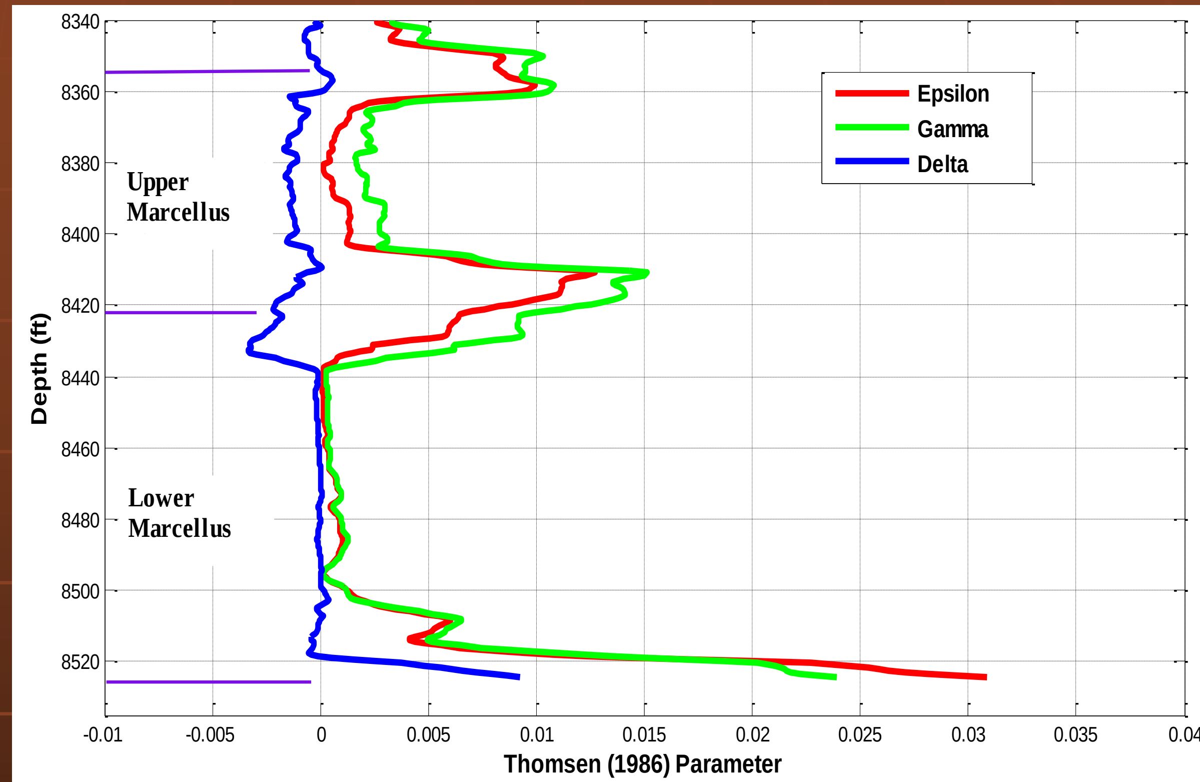
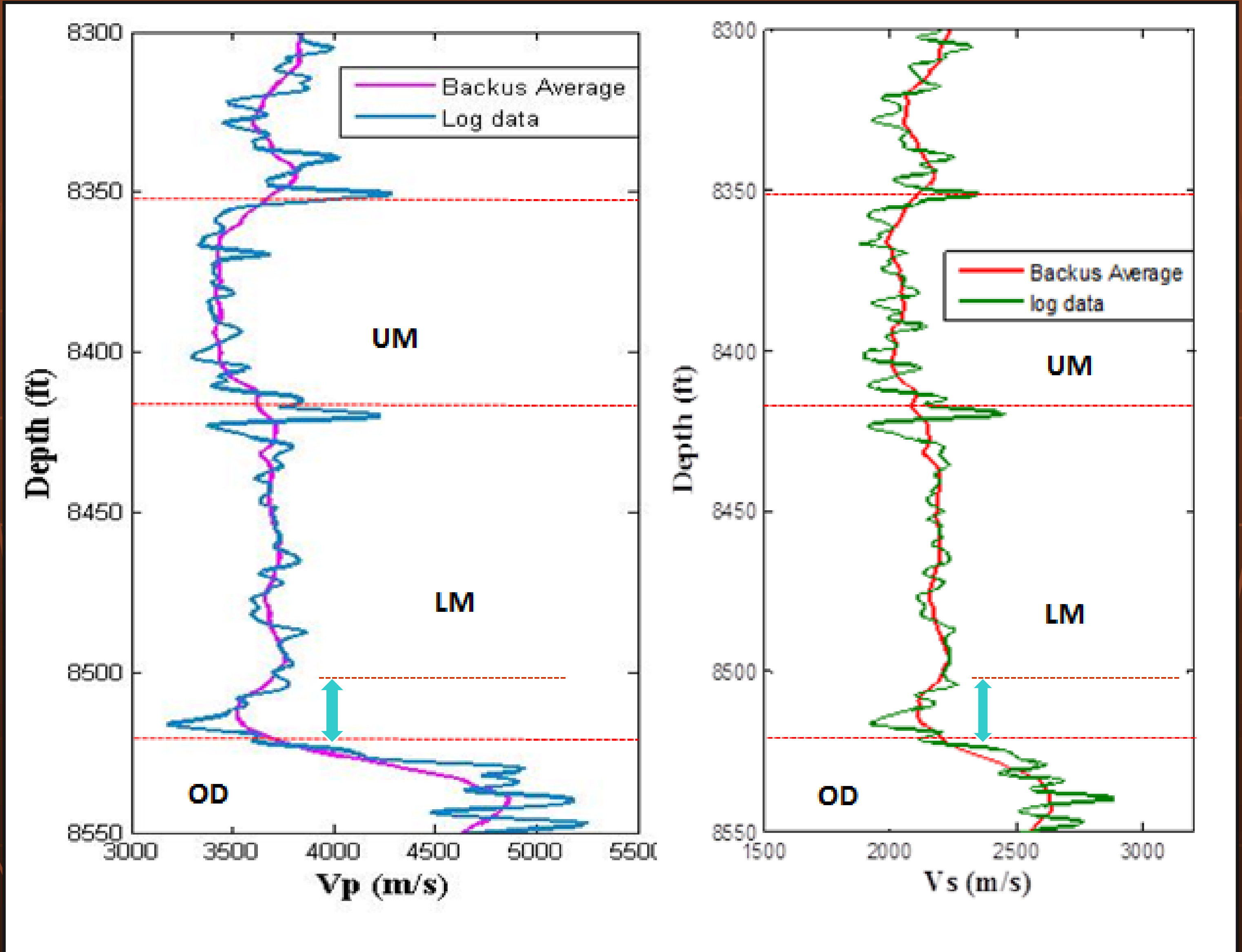
Thomsen parameters from Backus (1962)

Averaging Length= 20 ft



	ε	ϒ	δ
Upper Marcellus	0.0052	0.0071	-0.0012
Lower Marcellus	0.0029	0.0033	-0.0001
[illegible]	[illegible]	[illegible]	[illegible]

Upscaled Velocities using Backus (1962)

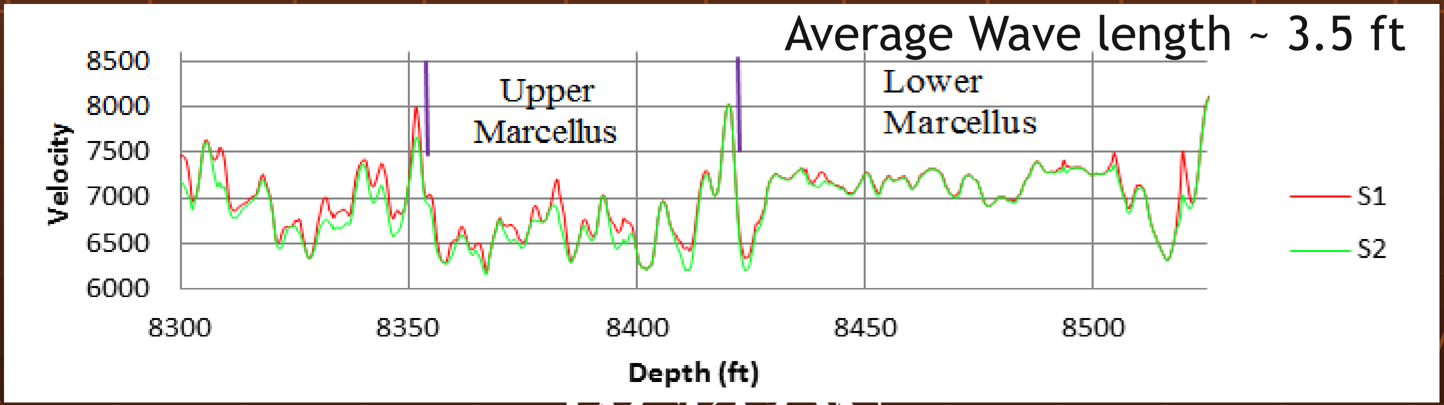


HTI Anisotropy

Voigt notation for stiffness tensor of HTI system

$$
\begin{bmatrix}
C11 & C13 & C13 & 0 & 0 & 0 \\
C13 & C33 & C33-2C44 & 0 & 0 & 0 \\
C13 & C33-2C44 & C33 & 0 & 0 & 0 \\
0 & 0 & 0 & C44 & 0 & 0 \\
0 & 0 & 0 & 0 & C66 & 0 \\
0 & 0 & 0 & 0 & 0 & C66
\end{bmatrix}
$$

- $C_{44}=\rho(Vs2)^2$
- $C_{66}=C_{55}=\rho(Vs1)^2$



Fracture Modeling

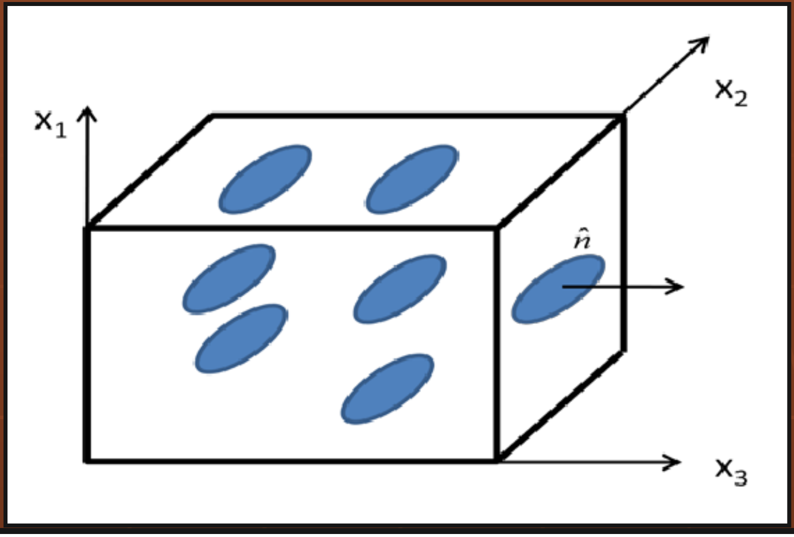
Hudson (1982) for isolated penny shaped cracks,

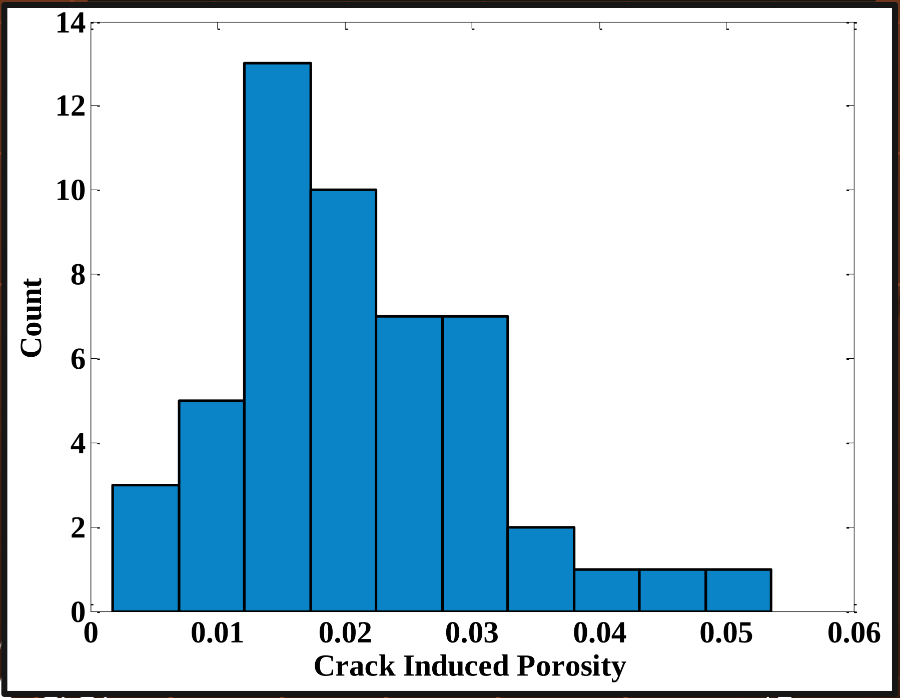
$$c_{ij}^{eff} = c_{ij}^{0} + c_{ij}^{1} + c_{ij}^{2}$$

Aspect ratio : 0.07 - 0.15

Crack density : 0.005-0.09

First Order correction for dry cracks





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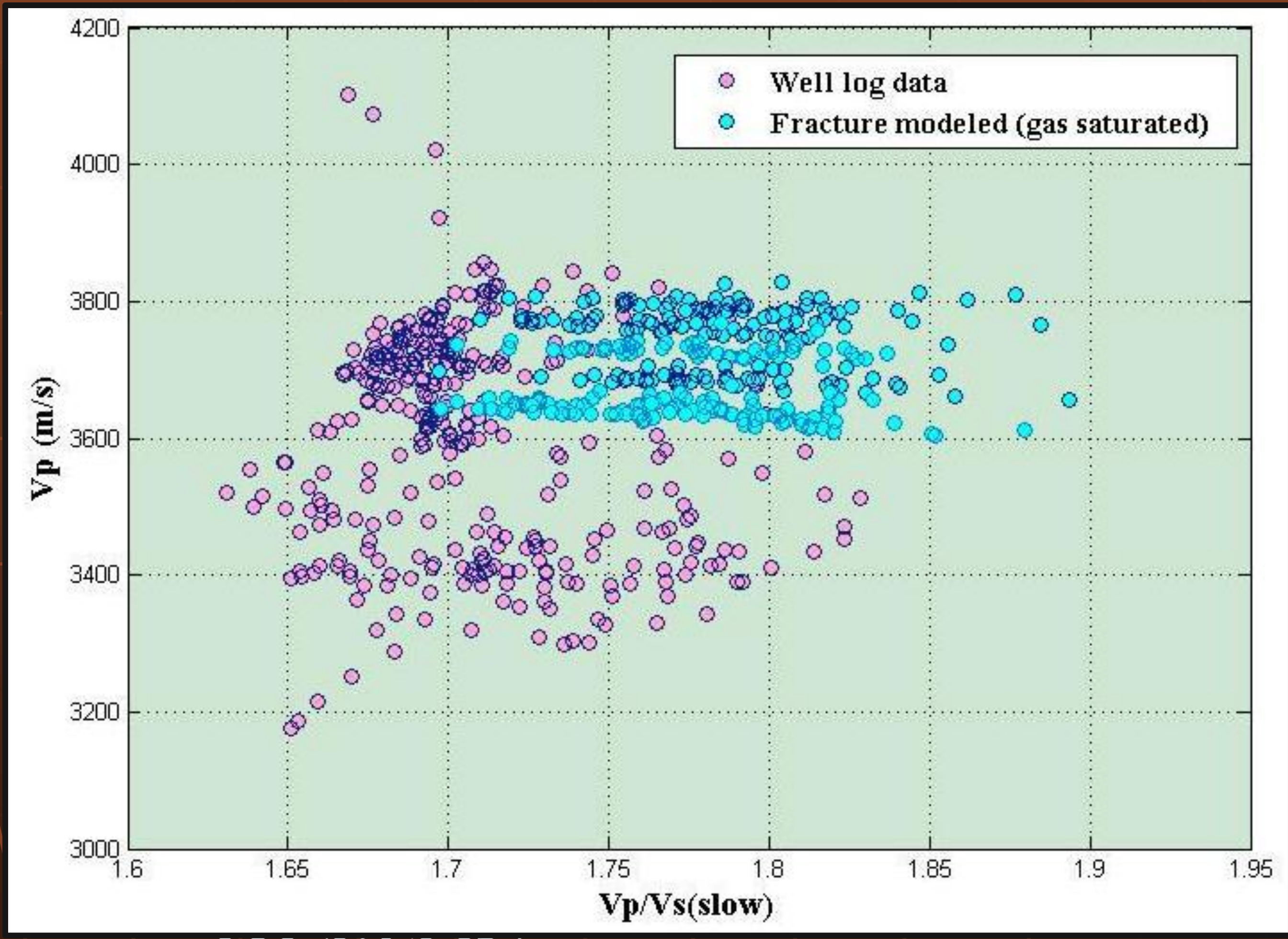
Fracture Modeling Results

Dry cracks are substituted with Gas, Using Gassmann (1951)



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Conclusion

- The Marcellus shale is complex in terms of anisotropy.
- The Marcellus Shale is very weakly VTI at seismic frequency.
- The Marcellus shale may be fractured.
- More complex model like Orthorhombic consideration may give better result.

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Future Work

- AVOZ
- Orthorhombic model
- Orientation distribution function with Organic porosity consideration
- Calibration and tie with core and surface seismic data

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