

A^{AV} A Petrophysical Study on Floyd Shale*

By

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Abstract

With shale plays becoming increasingly important source of natural gas, it has become all the more important to characterize shales. This paper attempts to improve the overall understanding of gas shales using laboratory based petrophysical measurements. A systematic petrophysical study on Floyd Shale samples from Black Warrior Basin, Alabama, was made on 27 suites of plugs, obtained from 100 feet of core from one well, using measurements of total organic carbon (TOC), quantitative mineralogy, native bulk and grain densities, effective porosity, velocity as a function of effective pressure, NMR spectroscopy, magnetic susceptibility, and SEM imaging. Except for the TOC measurements, all other measurements were made on samples from oriented plugs taken in 0, 90 & 45 degrees respectively to the symmetry axis. The TOC was less than 6% by weight and shows a weak trend of increasing with depth. The effective porosity ranges from 4 to 10%. The grain densities vary between 2.5 & 2.8 gm/cc, showing a general decreasing trend with depth. All samples have clay content more than 50 weight percent, and illite is the dominant clay mineral. Based of velocity measurements, transverse isotropic symmetry is seen in only 6 samples. NMR T2 distribution shows that the majority of the water was bound water.



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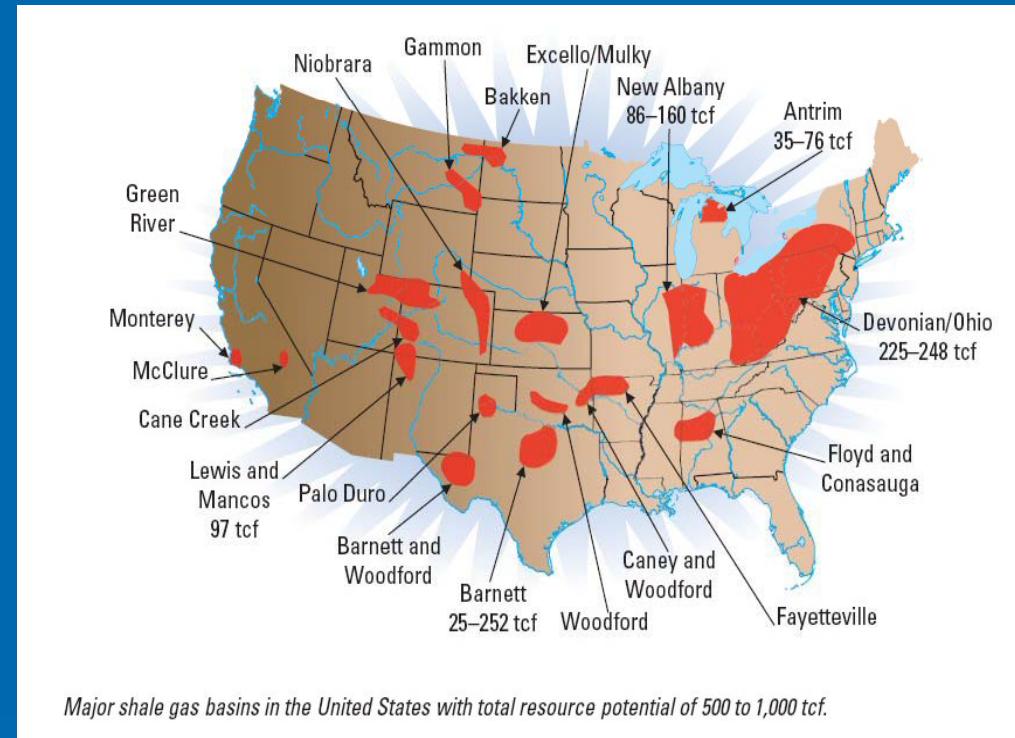
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Mewbourne School of Petroleum and Geological Engineering
The University of Oklahoma

Outline

- Introduction
- Petrophysical measurements
 - Techniques
 - Results
- Data Analysis
- Conclusions

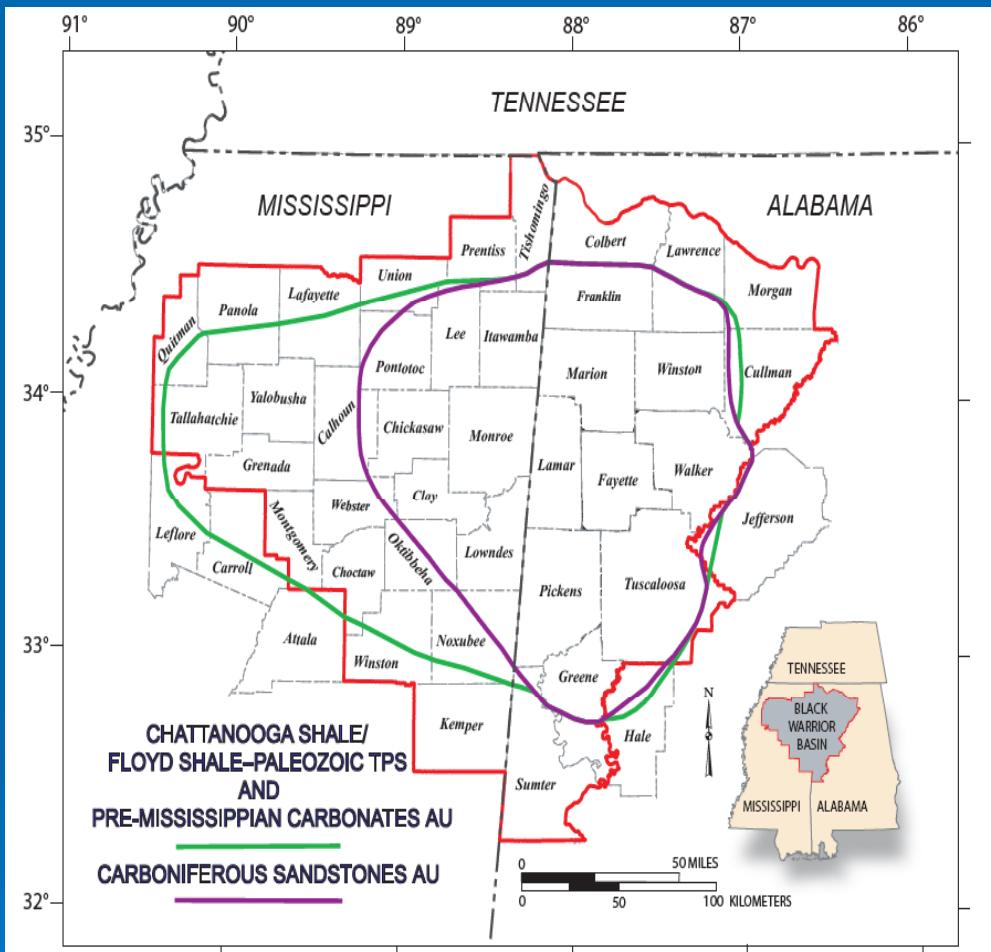
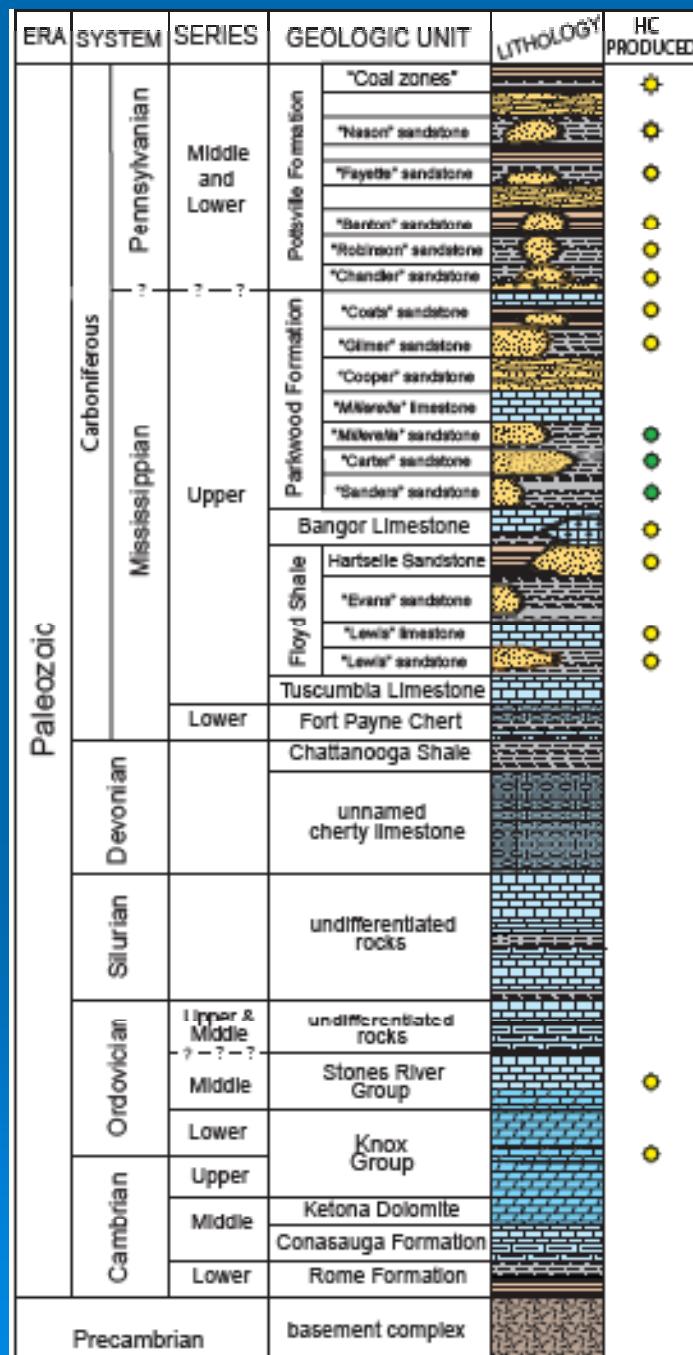
Importance

- Clean Energy, Technology & Gas prices => Important Resource
- Better reservoir characterization of shale gas plays
- Fracture design & Fracture mapping through micro seismic



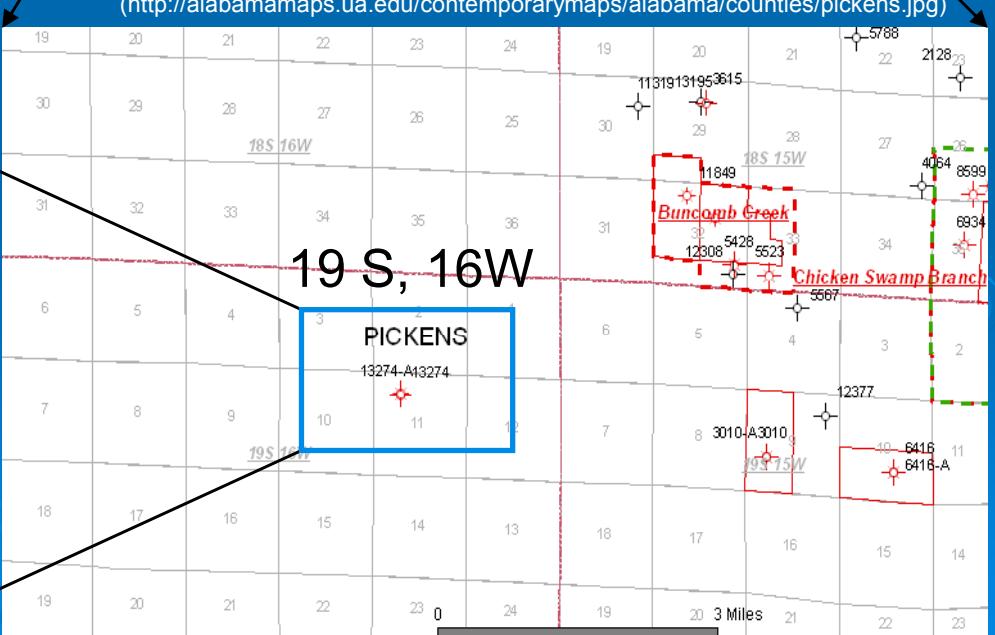
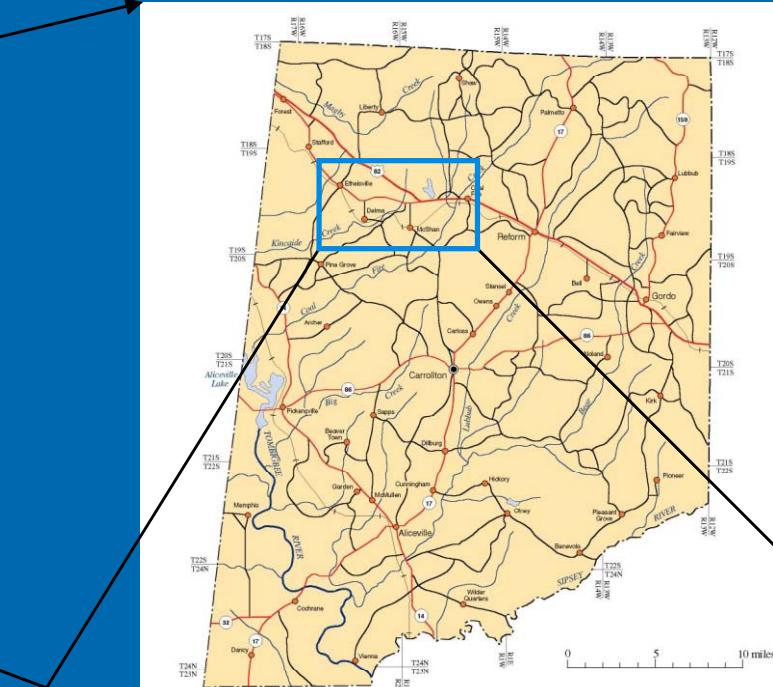
Schlumberger, Shale Gas white paper

Floyd Shale- A Brief Introduction



U.S. Geological Survey Digital Data Series DDS-69-I

Location map of study well



([http://www.ogb.state.al.us/website/map/viewer.htm?&ActiveLayer=1&QueryZoom=Yes&Query=\(PERMIT='13274-A'\)](http://www.ogb.state.al.us/website/map/viewer.htm?&ActiveLayer=1&QueryZoom=Yes&Query=(PERMIT='13274-A')))

Petrophysical Measurements

- Mineralogy
- Native Bulk & Grain Densities
- Helium Porosity
- Velocities (as a function of confining pressure)
- Circumferential Velocity Analysis

- Total Organic Carbon
- NMR
- SEM Imaging
- Magnetic Susceptibility
- High Pressure Mercury Injection

FTIR Mineralogy after removal of organic matter



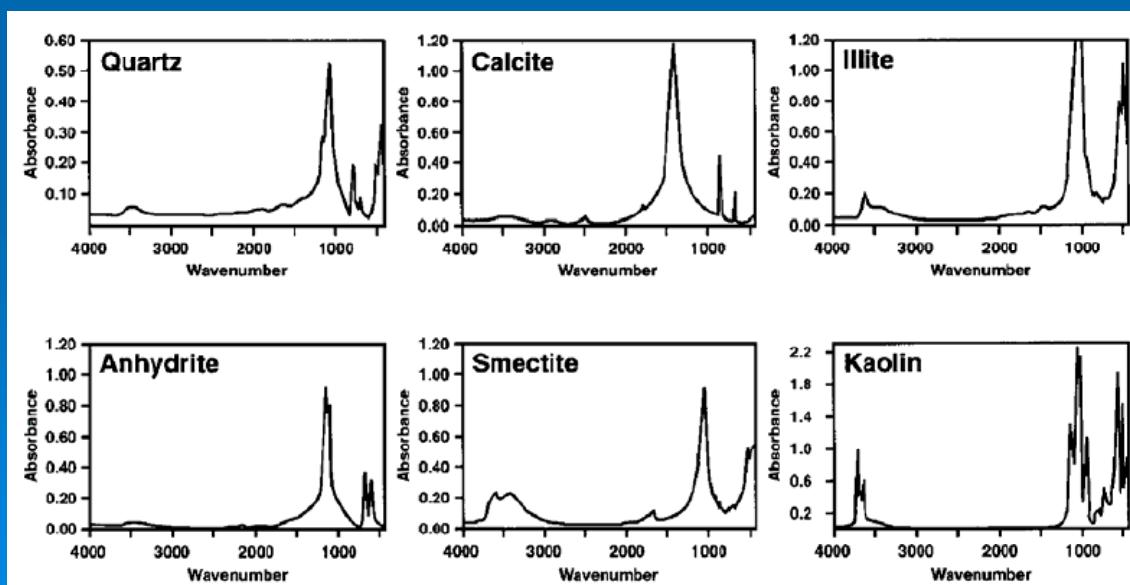
Quartz

Calcite, Dolomite, Siderite,
Aragonite

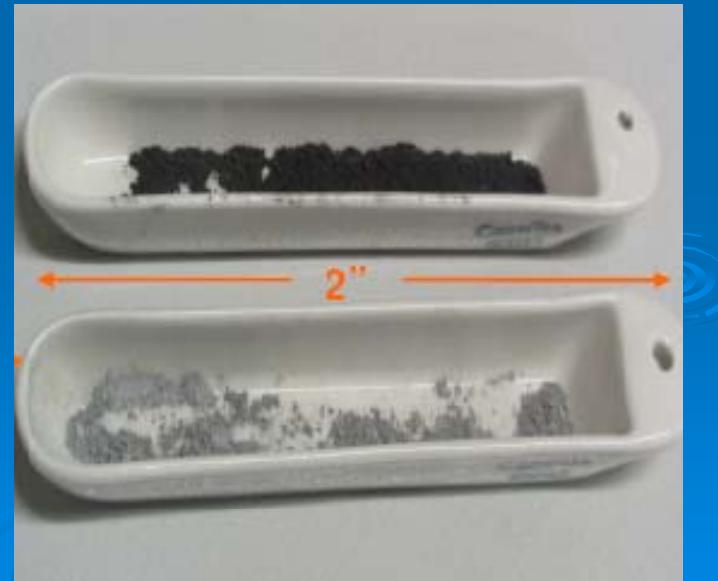
Illite, Smectite, Kaolinite,
Chlorite, Mixed Clays

Ortho, Oligoclase & Albite

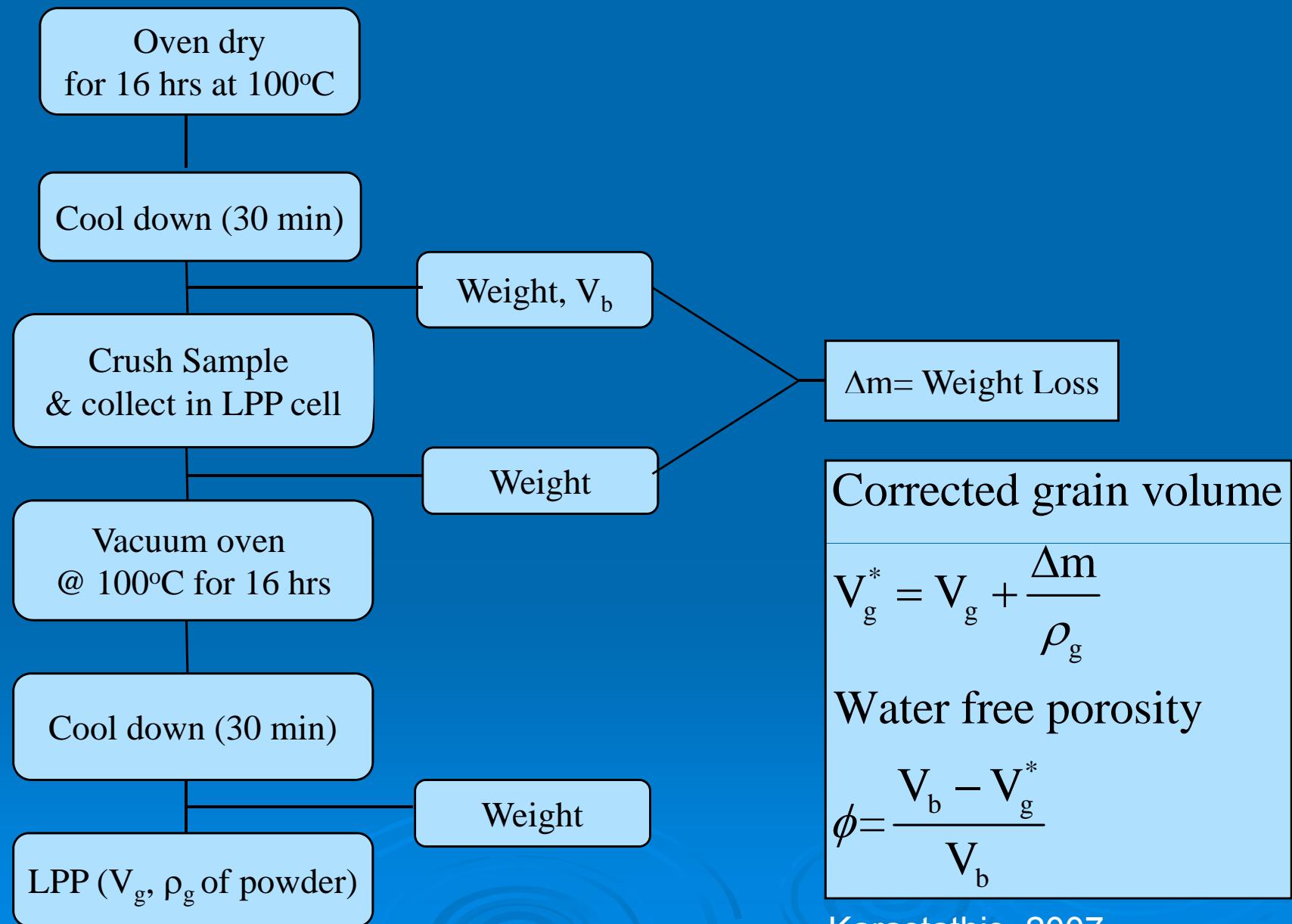
Pyrite, Apatite, Anhydrite



Sondergeld & Rai, 1993



Flow diagram for estimating Helium porosity



Velocity anisotropy measurement

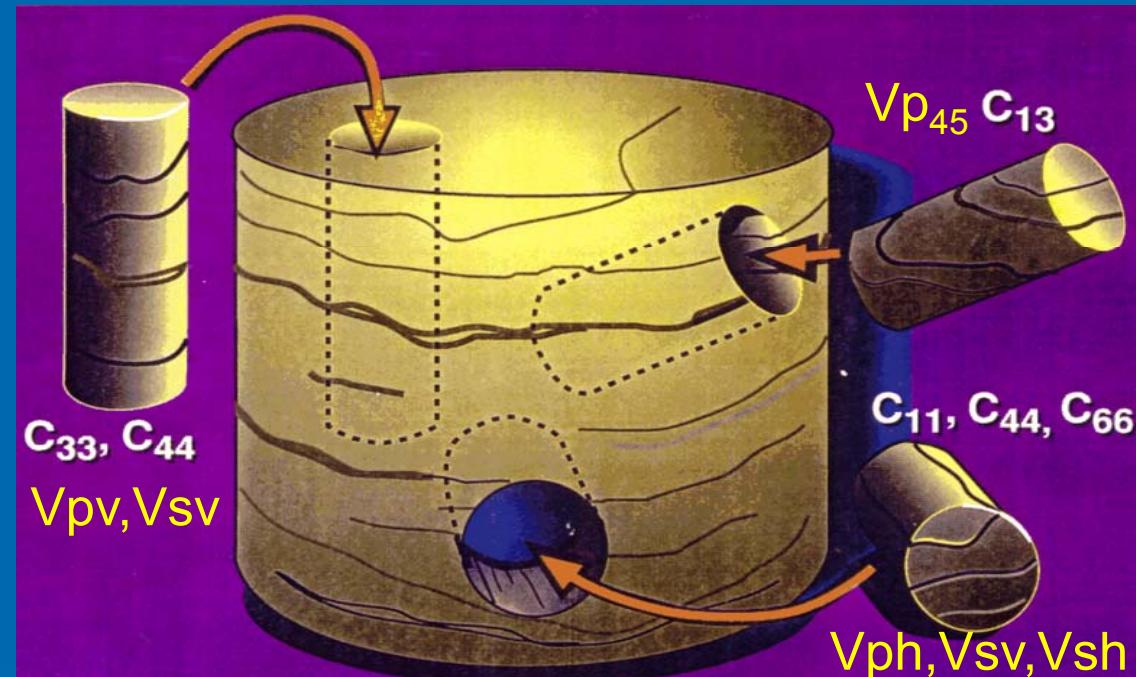
Basic Equations to calculate elastic constants:

$$C_{33} = \rho V_{pv}^2$$

$$C_{44} = \rho V_{sv}^2$$

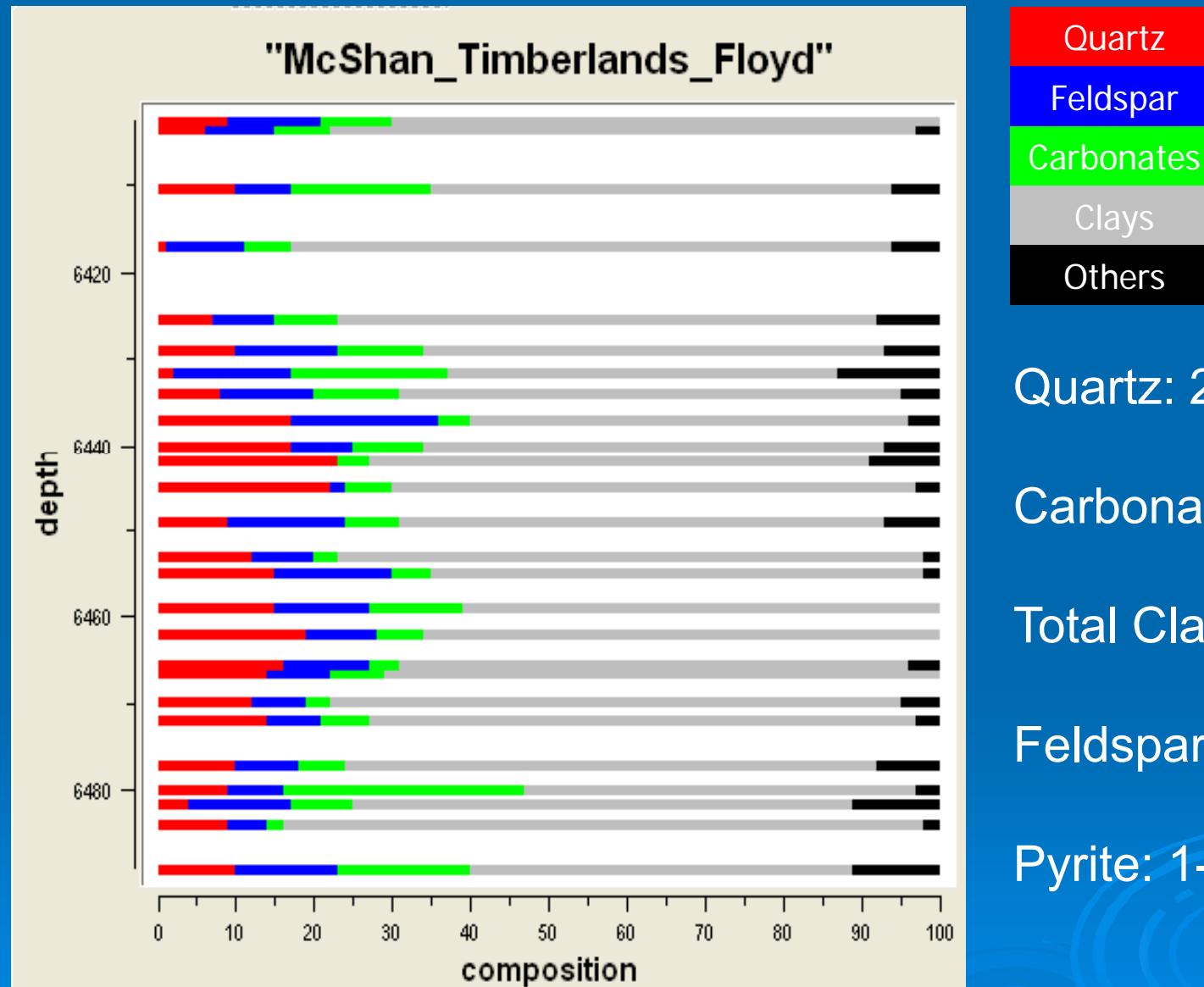
$$C_{11} = \rho V_{ph}^2$$

$$C_{66} = \rho V_{sh}^2$$

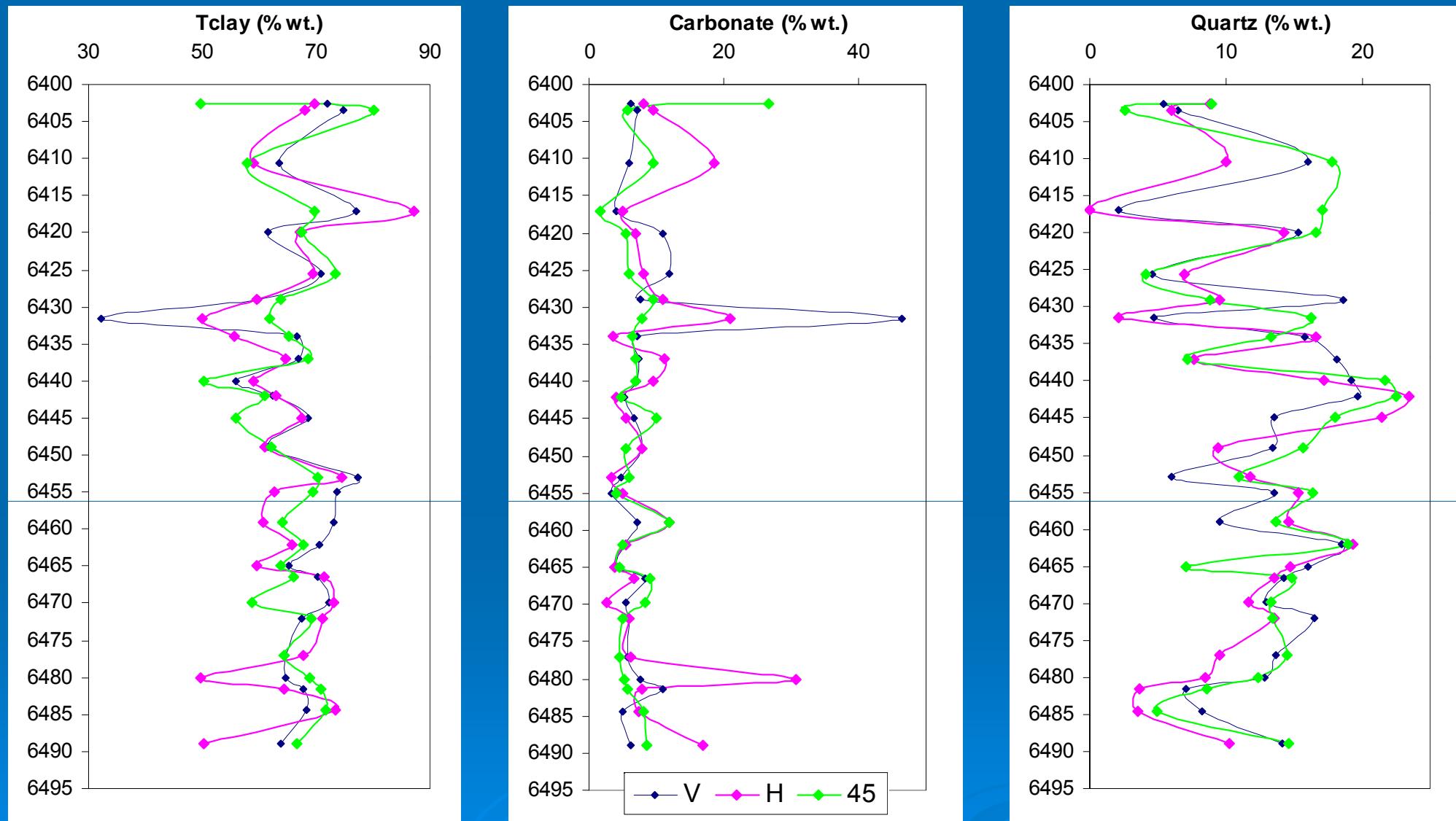


$$4\rho V_{p45}^2 = C_{11} + C_{33} + 2C_{44} + \left[(C_{11} - C_{33})^2 + 4(C_{13} + C_{44})^2 \right]^{1/2}$$

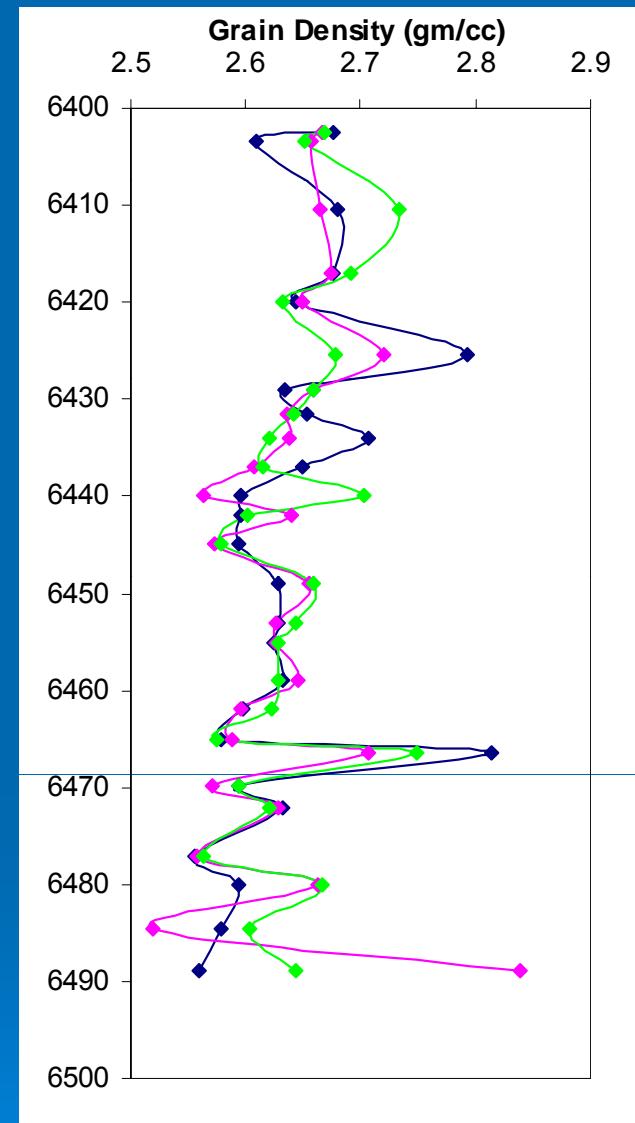
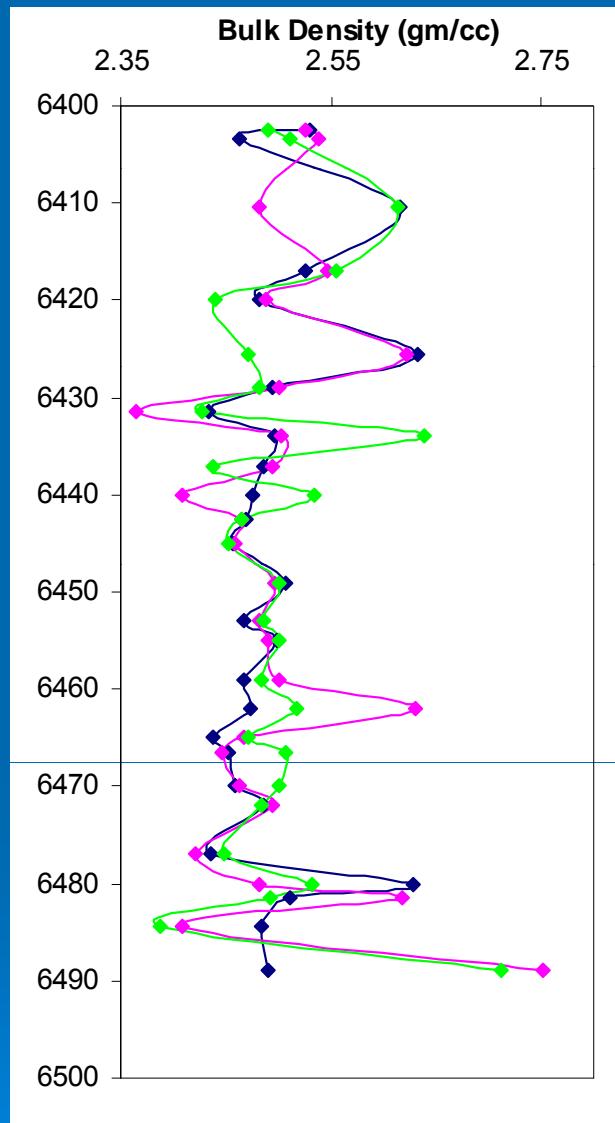
Mineralogy variation with Depth



Mineralogical variation on plug scale

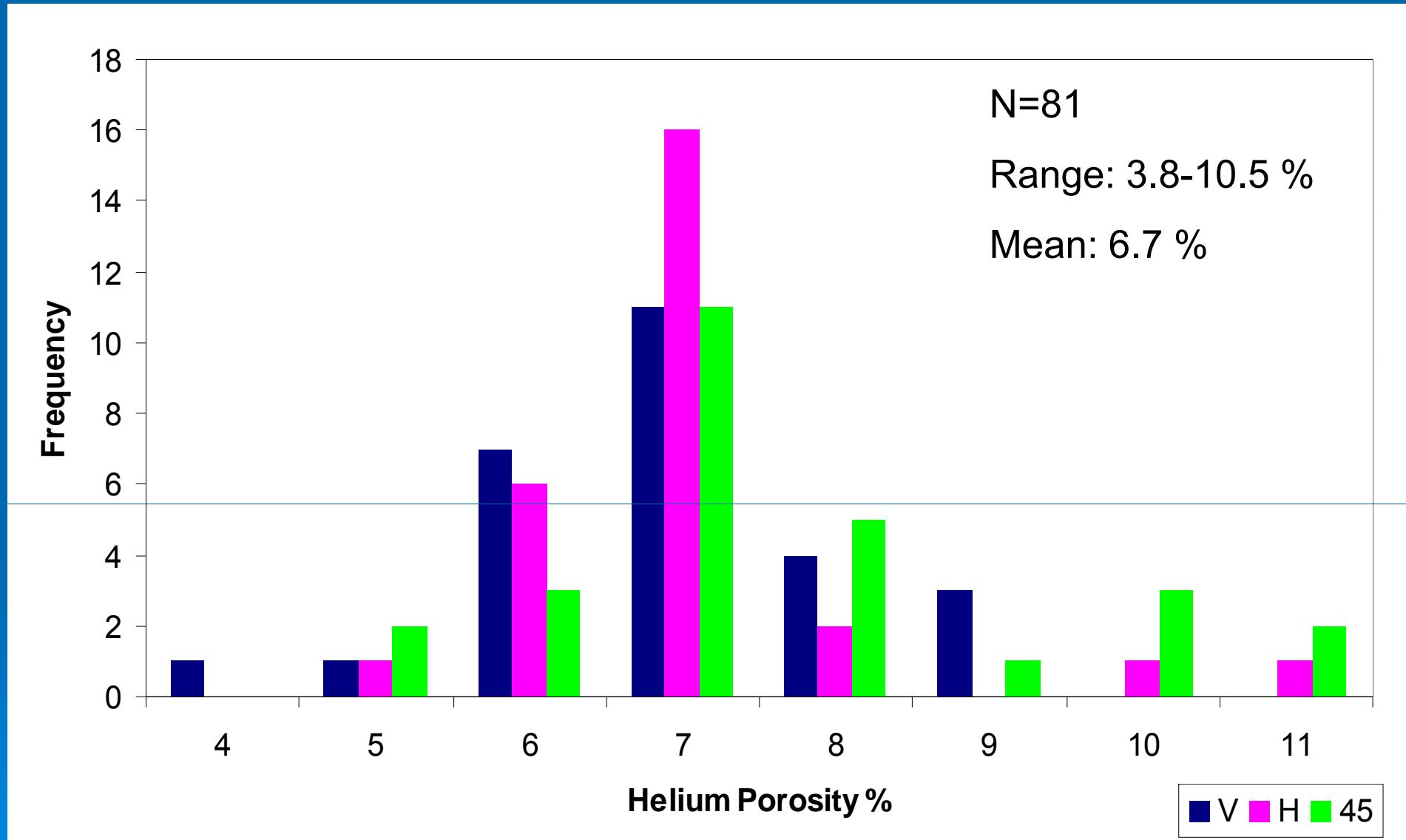


Variation of bulk & grain density

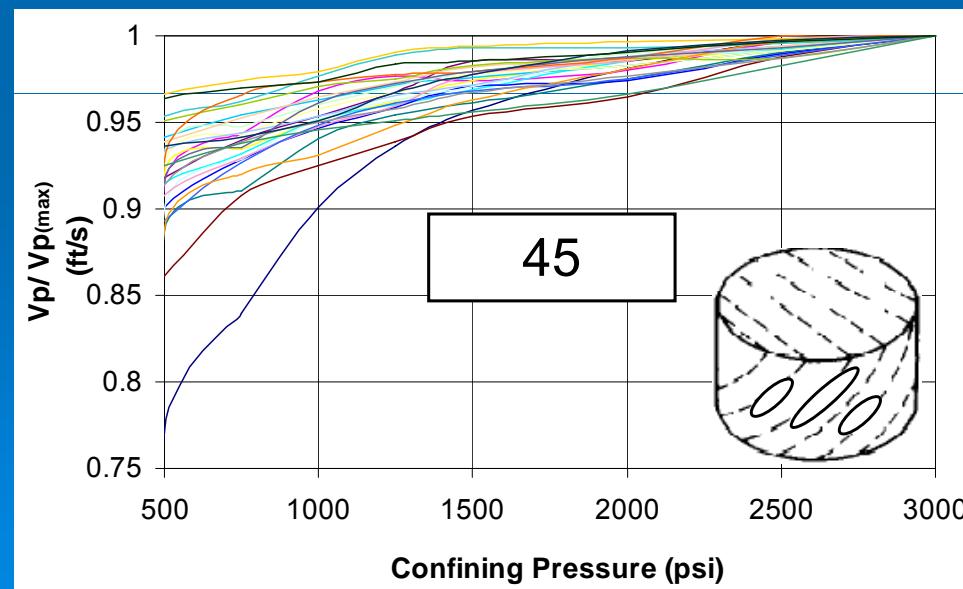
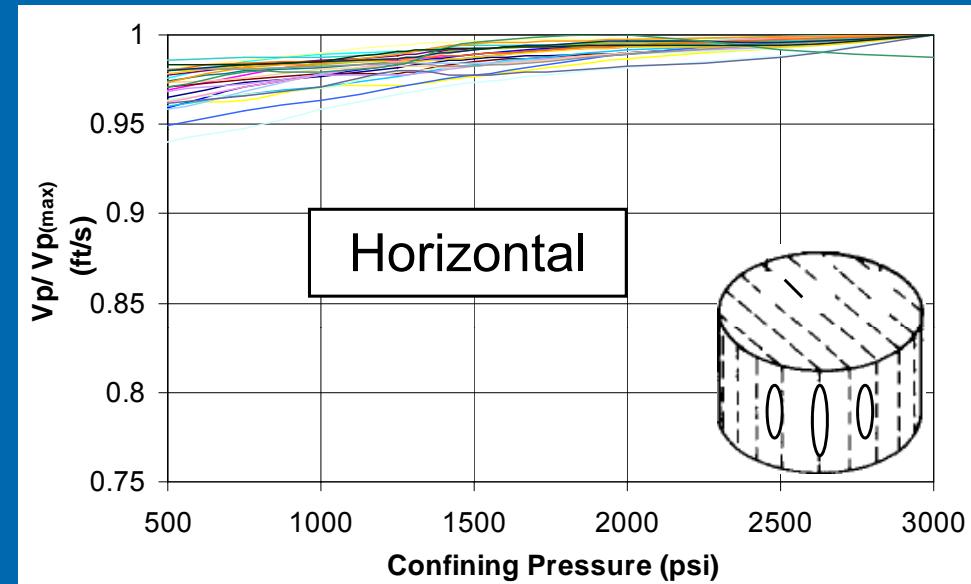
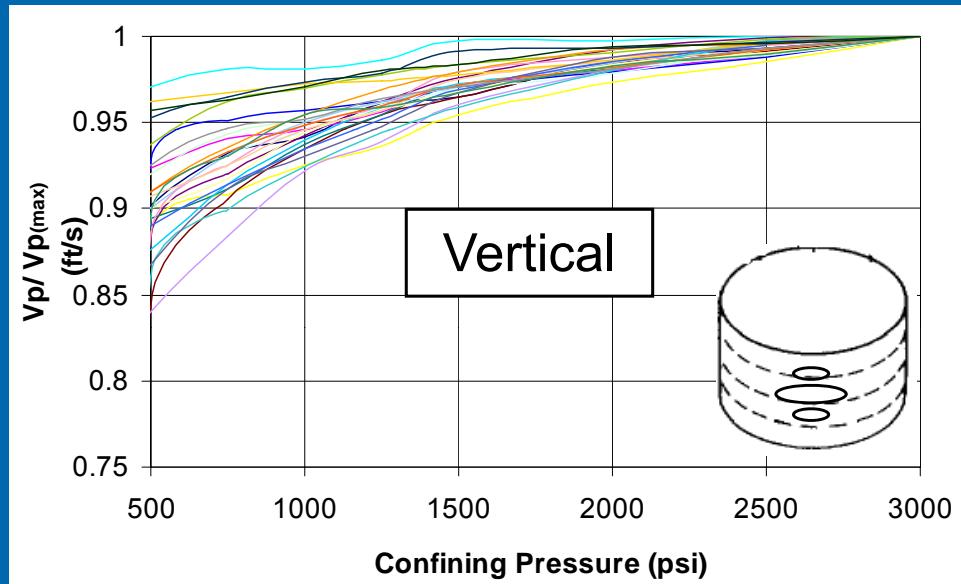


- ◆ Vertical
- ◆ Horizontal
- ◆ 45

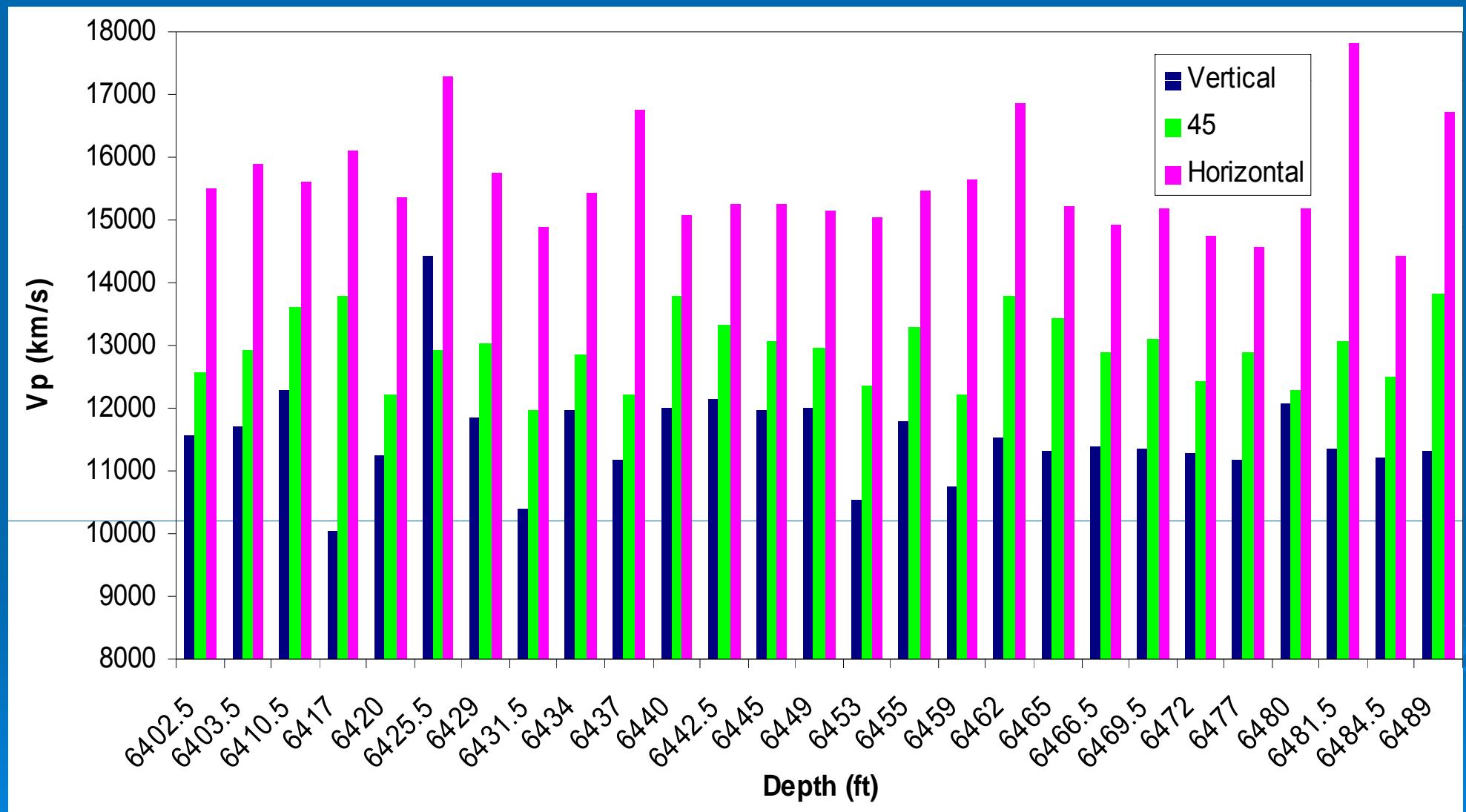
Helium Porosity Variation in Floyd Shale



Ultrasonic Velocity dependence on pressure



Velocity Anisotropy in Floyd



Transversely Isotropic behavior

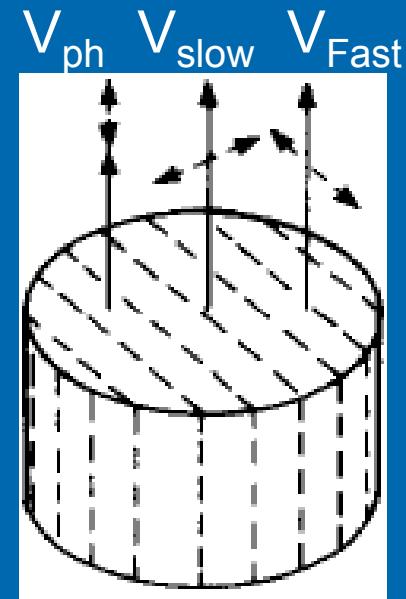
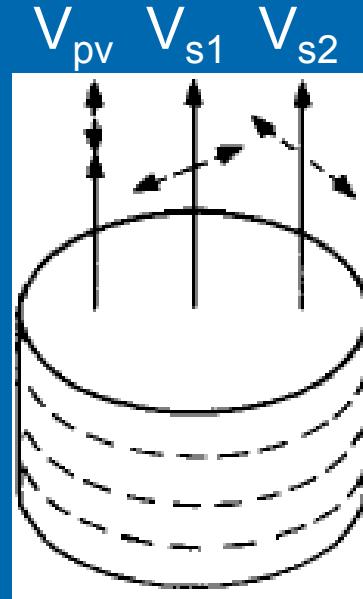
$$V_{s1} \approx V_{s2}$$

$$\epsilon = \frac{C_{11} - C_{33}}{2C_{33}}$$

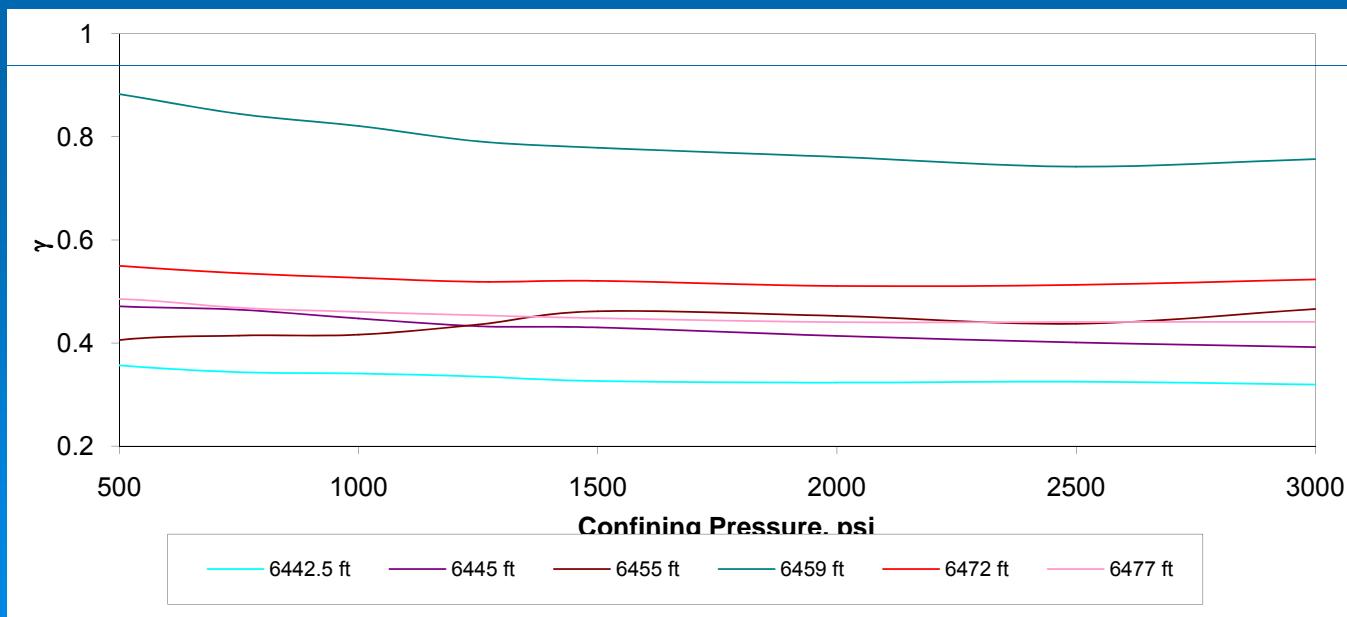
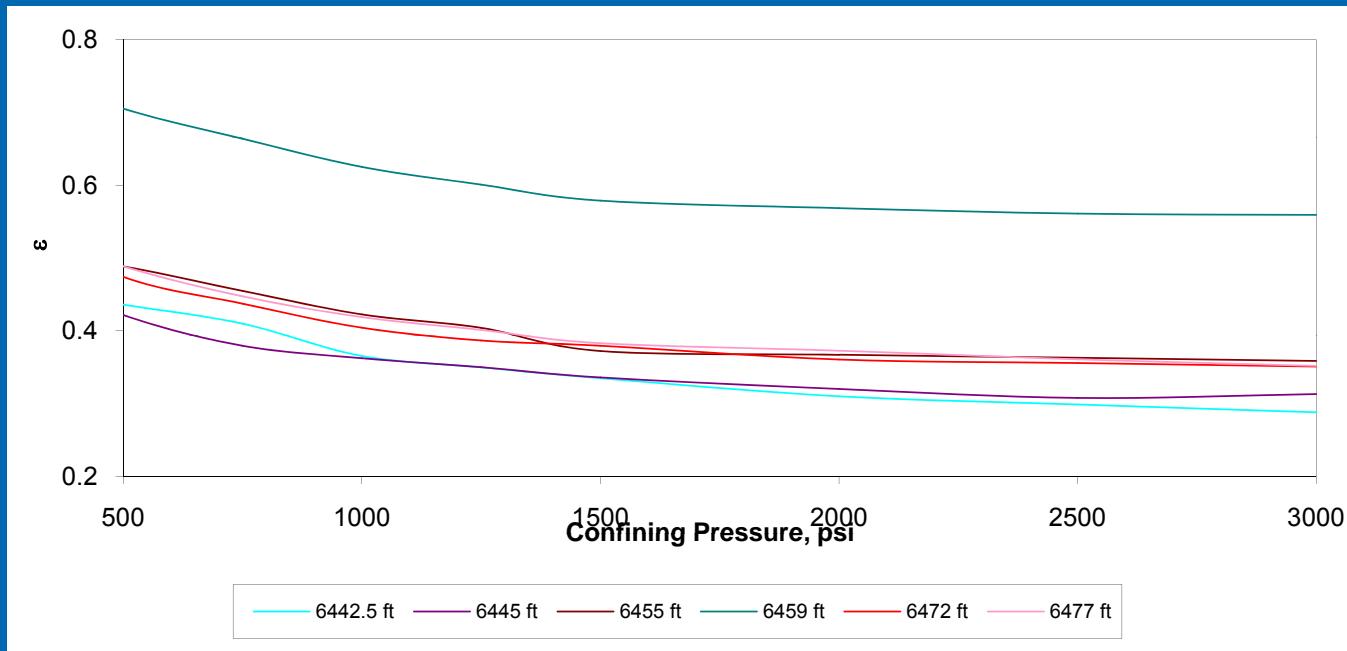
$$\gamma = \frac{C_{66} - C_{44}}{2C_{44}}$$

$$\delta = \frac{(C_{13} + C_{44})^2 - (C_{33} - C_{44})^2}{2C_{33}(C_{33} - C_{44})}$$

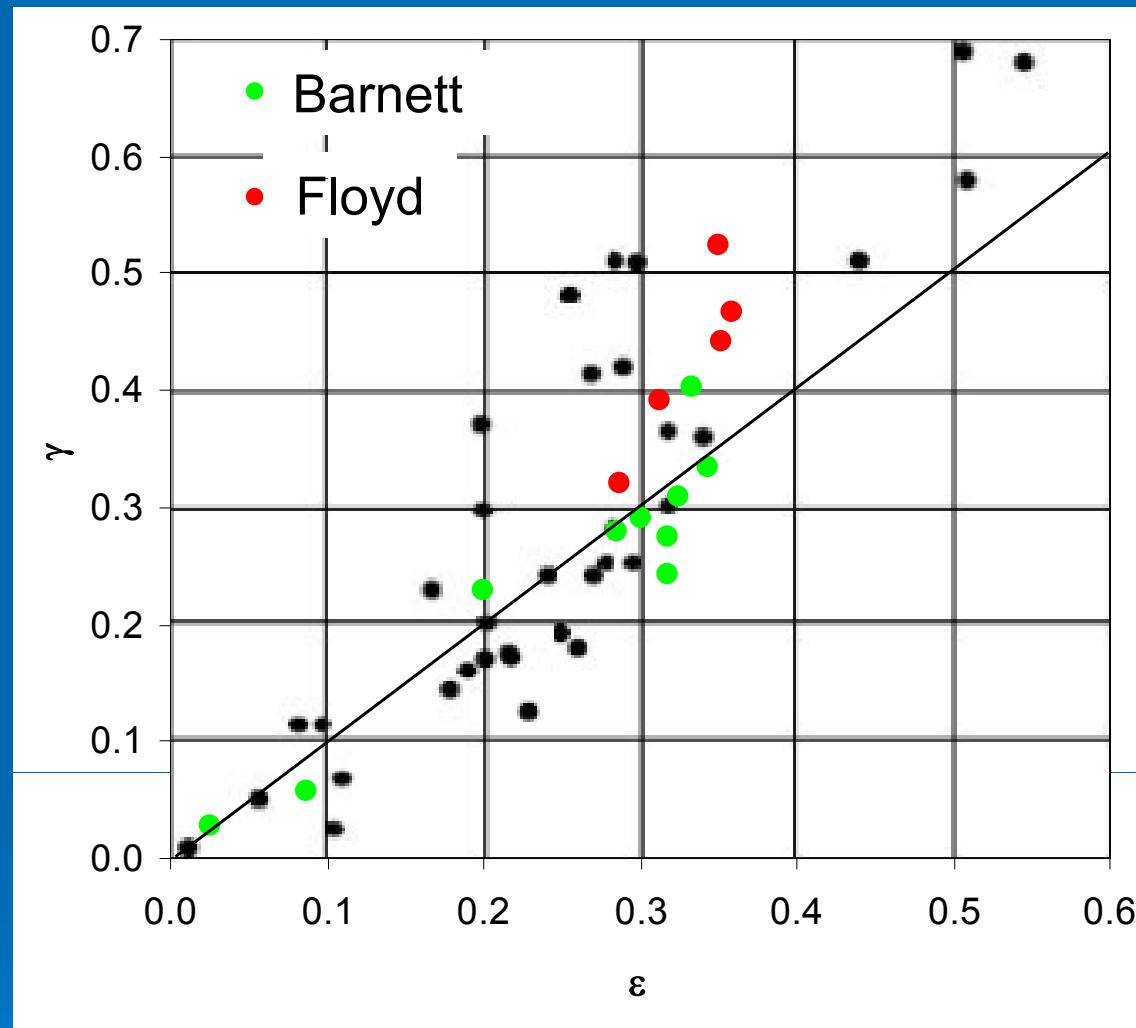
(Thomsen, 1986)



Variation of Thomsen's anisotropy parameters with confining pressure



ε - γ Crossplot for the TI samples



Shale data includes Jones and Wang (1981), Vernik and Nur (1992), Hornby (1994), Johnston and Christensen (1995), Wang (2002) and Karastathis (2007)

Visual fractures in Floyd shale



6425 ft



6445.5 ft



6451.5 ft



6472 ft

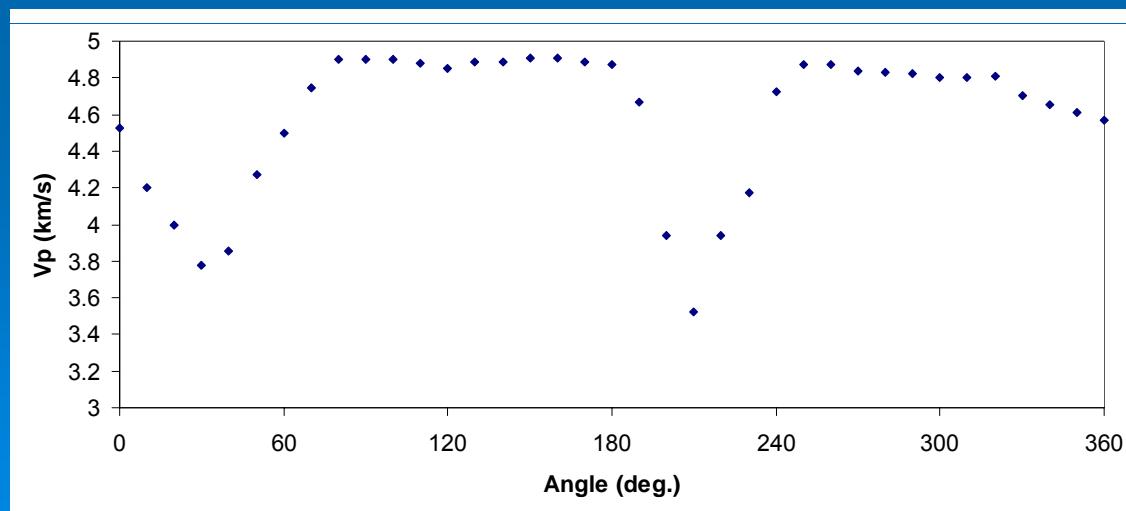
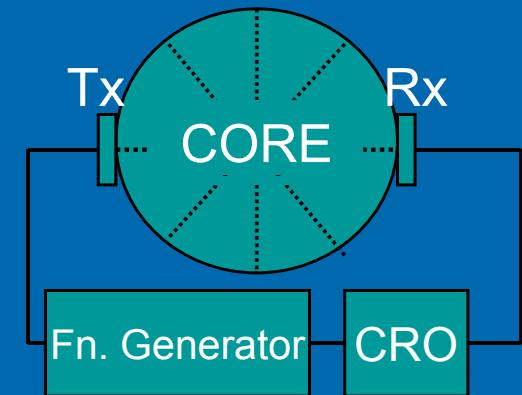
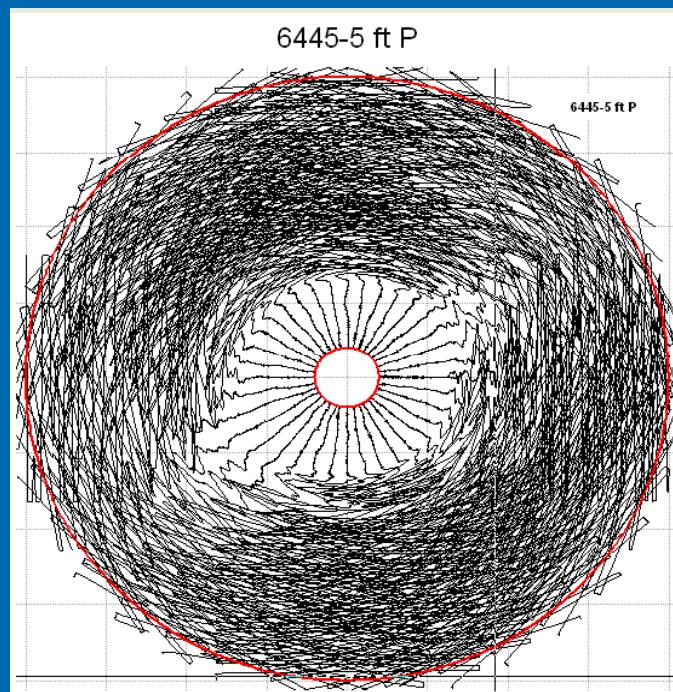


6474 ft

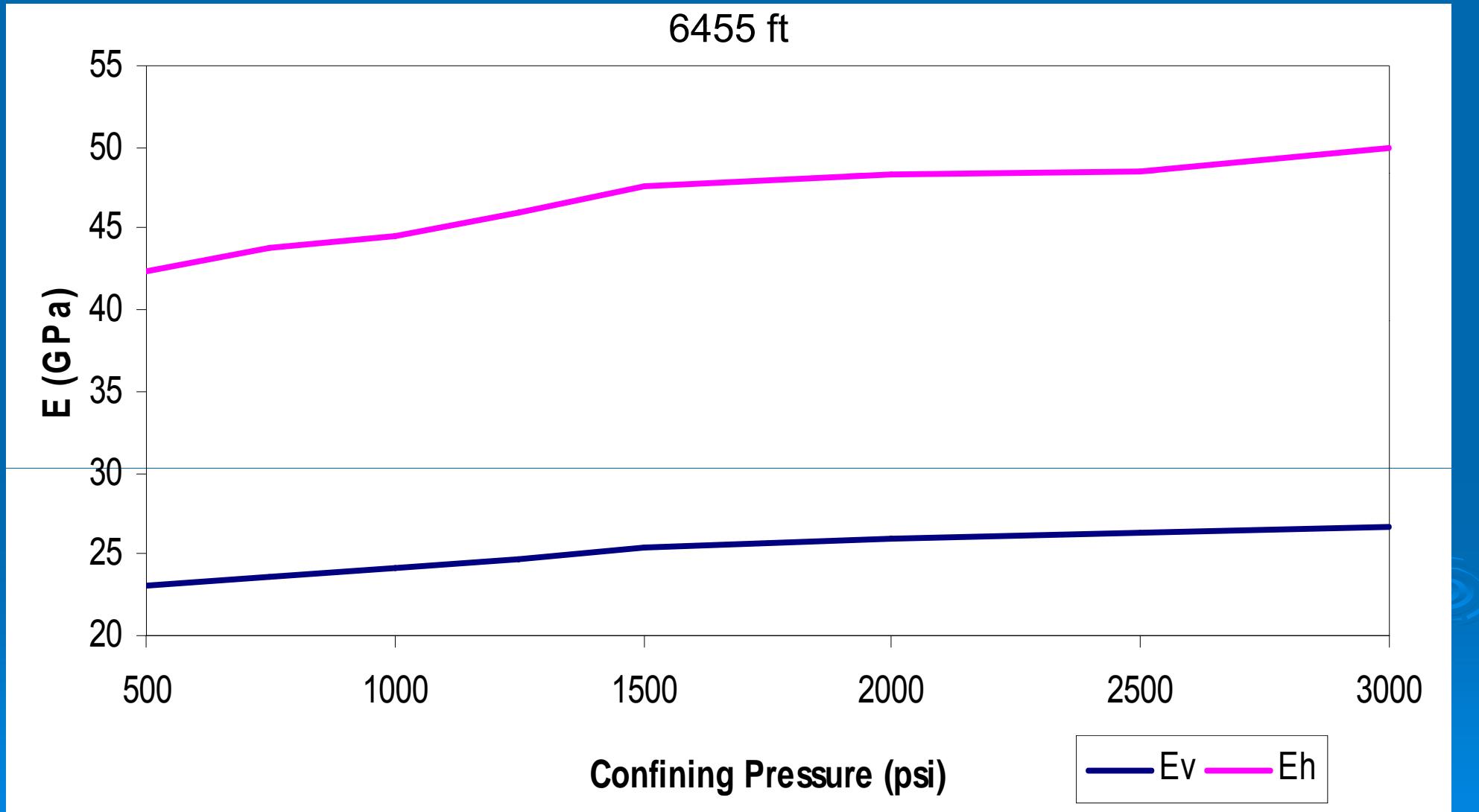


6488 ft

Circumferential Velocity Analysis



Variation of mechanical properties with confining pressure



Conclusions

- All suites exhibit velocity anisotropy
- Only 6 suites exhibit TI symmetry. The absence of TI symmetry can be explained due to local heterogeneity and presence of a fracture network
- Mineralogy variation with depth indicates heterogeneity

Acknowledgements

- Wagner & Brown
- Gary Stowe & Bruce Spears

References

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Questions ??