Gas Shale Evaluation Techniques – Things to Think About

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Agenda

- Introduction
- Heterogeneous nature of shales
  - *Highly variable constituent content and distribution*
  - *Scales of measurement and analytical method*
- Data uncertainty
  - *GIP*
  - *Rw*
- Anisotropy
  - *Resistivity*
  - *Geomechanics*
- Summary

What is a Gas Shale?

Black shale

- There are 2 broad play types that currently fall under the “Gas Shale” umbrella
  - Black shale – “Barnett Like” - residual gas in a world class oil prone source rock that has cracked to gas
    - Woodford, Fayetteville, Marcellus, Muskwa, Haynesville, Eagle Ford
  - Gray shale –residual gas in moderate quality source rocks with interspersed silts
    - Mowry, Steele, Baxter, Hilliard, Lewis, Montney
  - Biogenic gas – produced by living organisms
    - Antrim

Gray shale

Would you analyze these the same way?

Black shale

- Black shale and gray shale are not behaving in the same way.
  - Trap, Seal, H, Phi, K, resource density
- Black shale
  - probably hydrophobic and hydrophilic parts of the pore system
- Gray shale
  - Probably mostly hydrophilic
  - Permeability jail issues?

Gray shale

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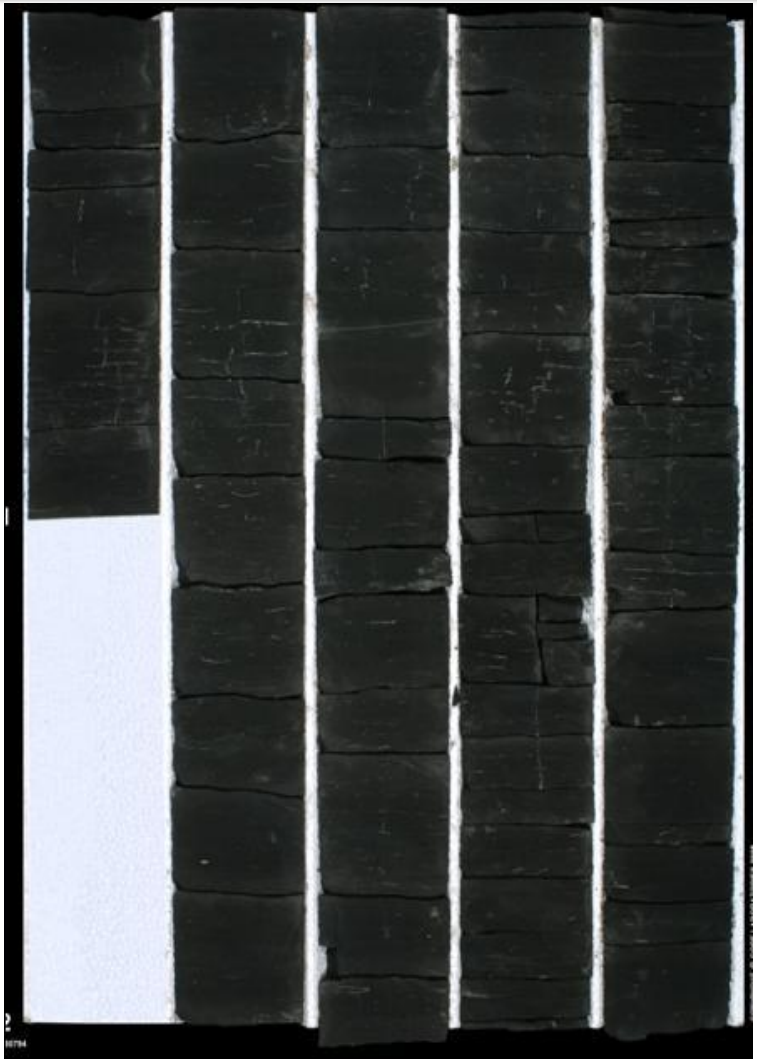
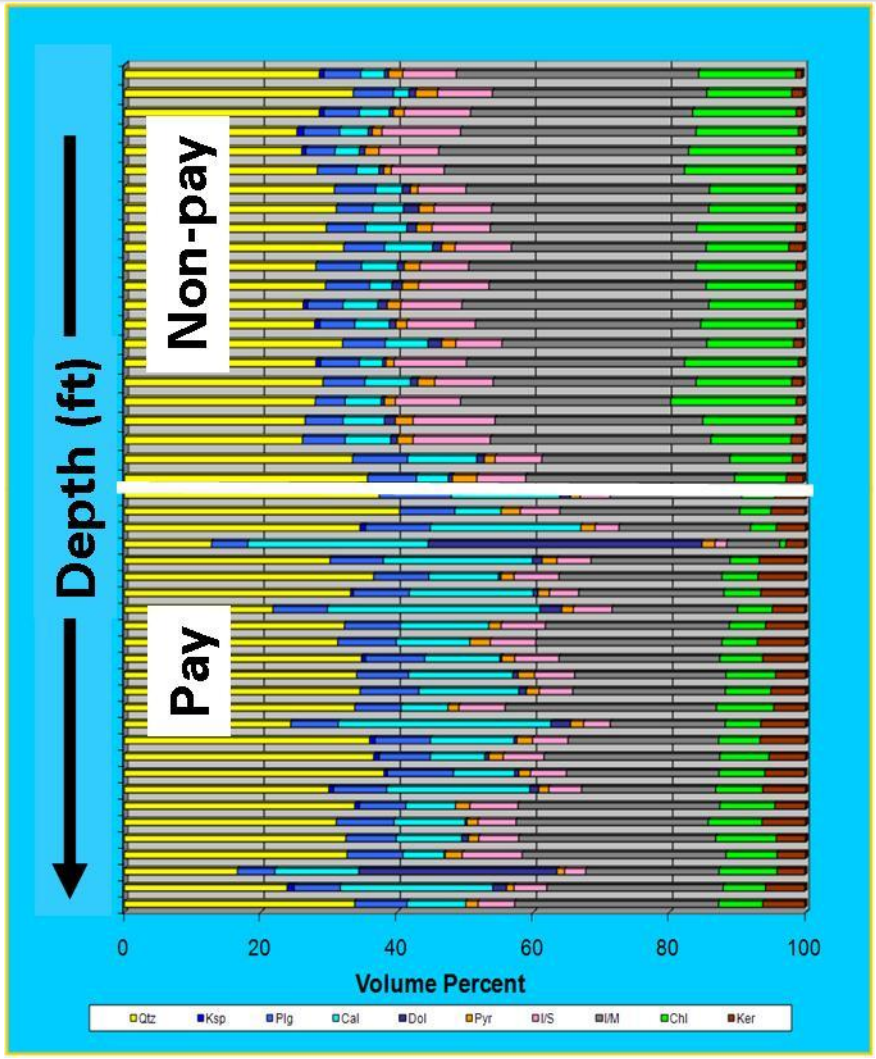
Shale ~ Heterogeneity

- Variable mineralogy
  - *Haynesville – roughly even split – quartz, calcite, clay*
  - *Eagle Ford – dominantly calcite with clay and minor quartz*
  - *Muskwa – dominantly quartz with clay and minor calcite*
- Laminated
  - *Mineralogy varies on the laminar scale*
  - *Organic content varies on the laminar scale*
- How to sample for log calibration?

Highly Variable Mineralogy XRD





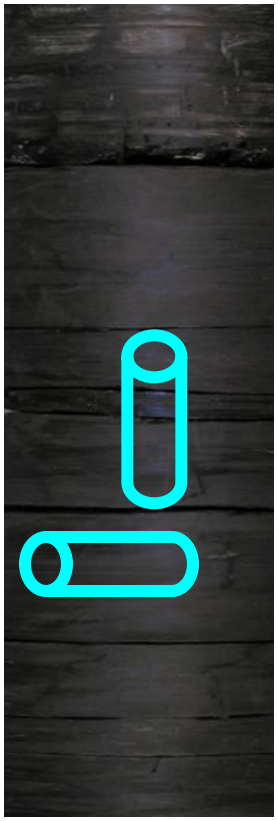
Log to core

Borehole

- Quartz
- Calcite
  - Dolomite
- Clays
  - Illite, smectite, chlorite
- Kerogen
- Pyrite
- Siderite
- Apatite
- Hole conditions
- Mud type

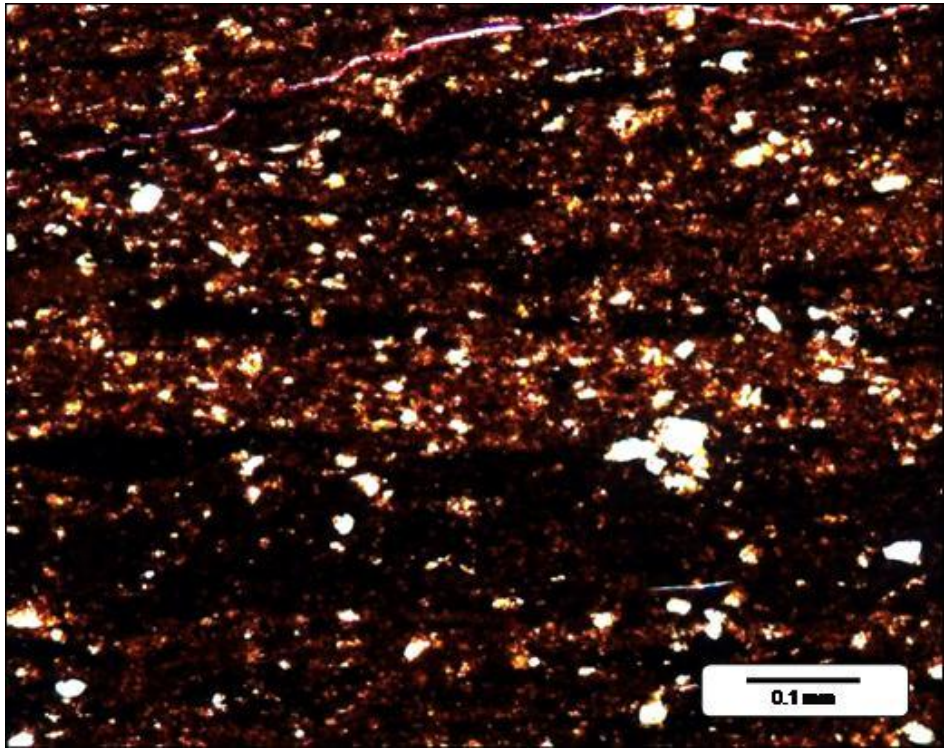
Core

Sampling variability – plug or puck?

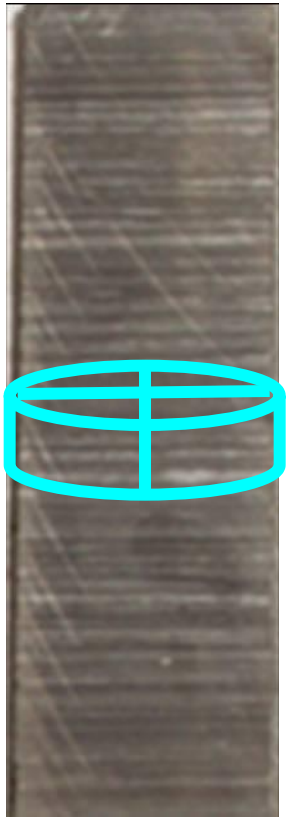


Black shale

1 ft



- Sample size
- Invasion
- Representative

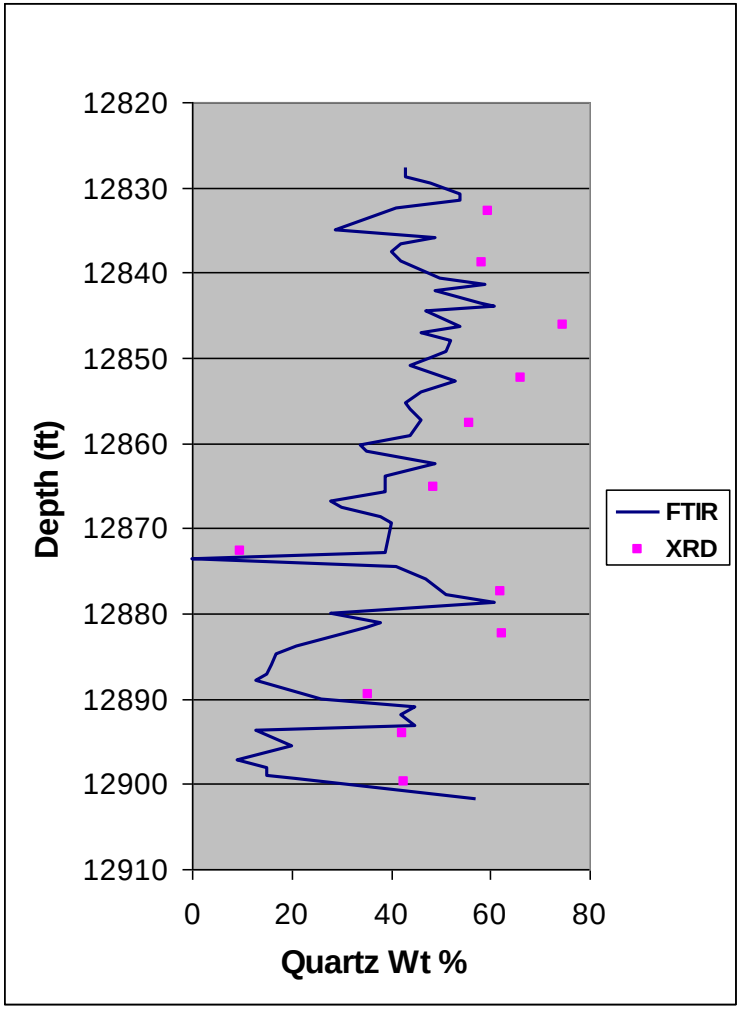


Gray shale

Mineralogy – XRD or FTIR?

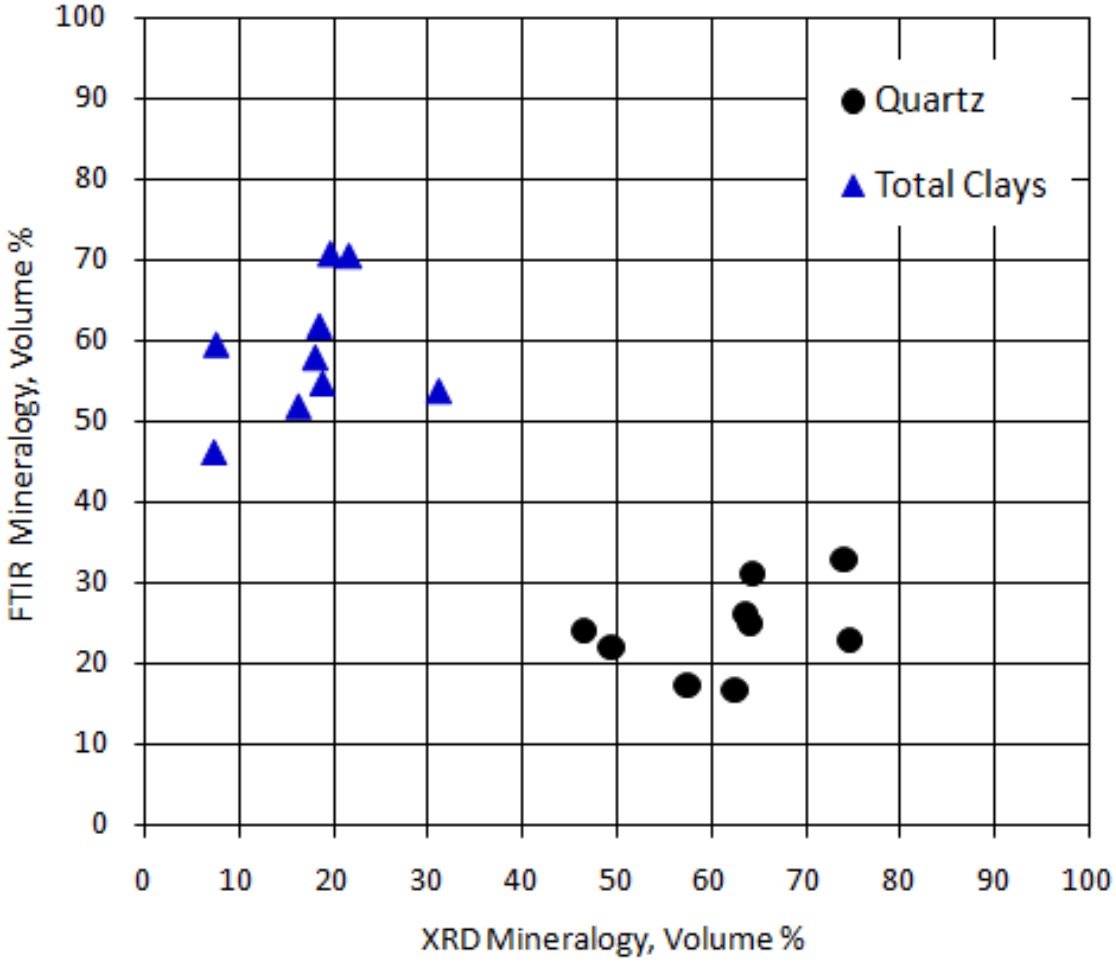
- What is the appropriate technique for mineralogy determination?
  - *Xray Diffraction (XRD – weight or volume %))*
  - *Fourier Transform Infrared Spectroscopy (FTIR)*
- Is sampling the same?
- Does it matter?
- Lets compare….

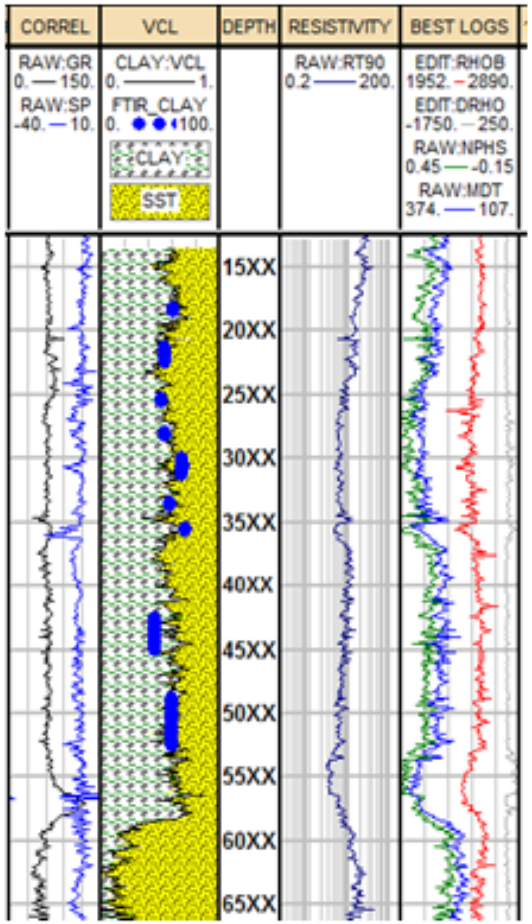
Quartz weight percent - Woodford



- FTIR Quartz Weight Percent
  - Sampled ~ every foot
- Wide spread in Quartz percentage
- XRD Quartz Weight Percent
  - Sampled ~ 10 feet
- What is the “correct” sampling protocol to match log resolution?

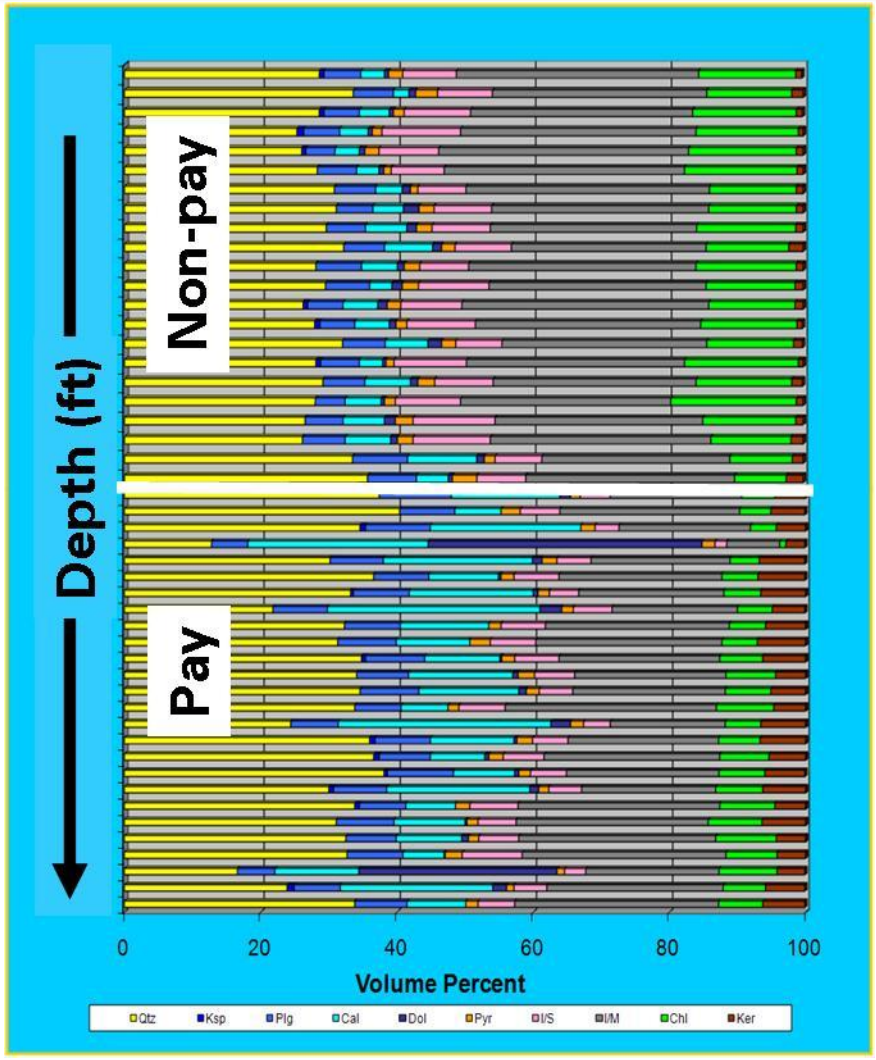
FTIR vs XRD mineral volume percent

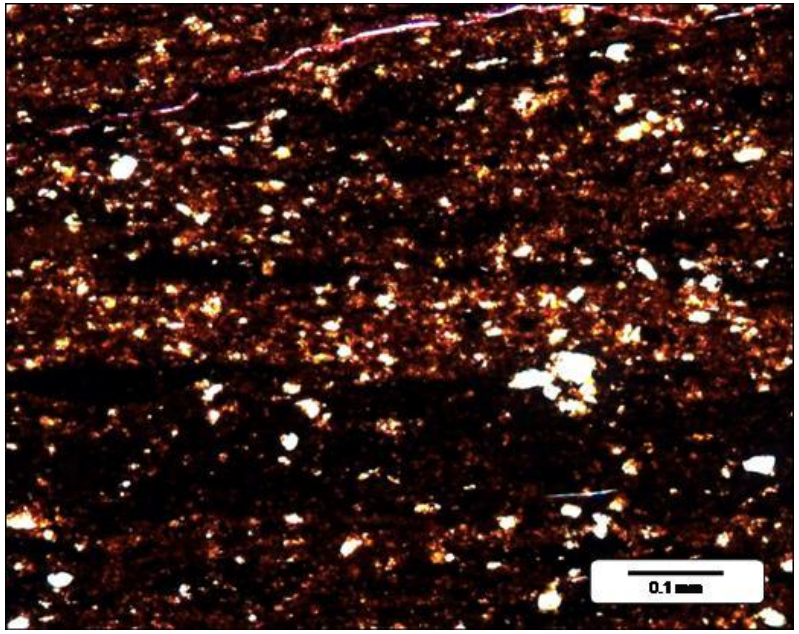




SPE -131768 PP

Where are the organics?



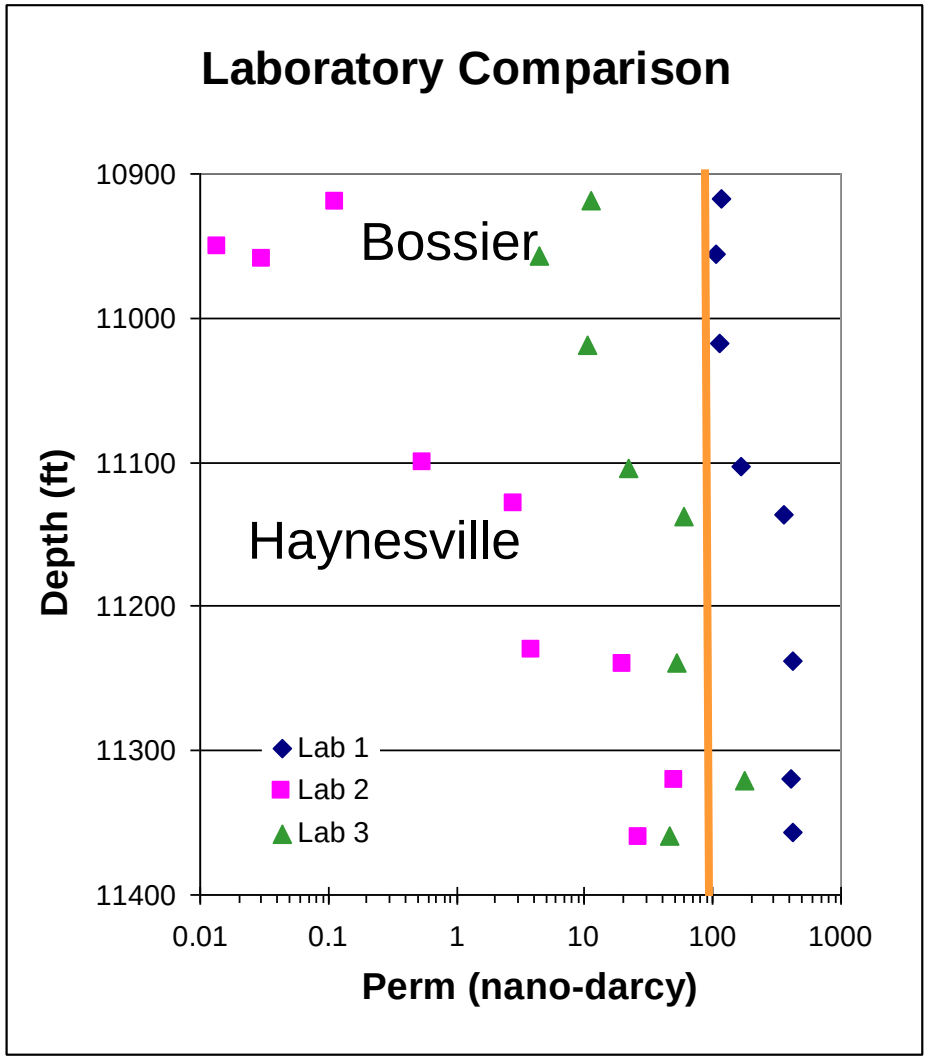


Organics are not typically randomly distributed

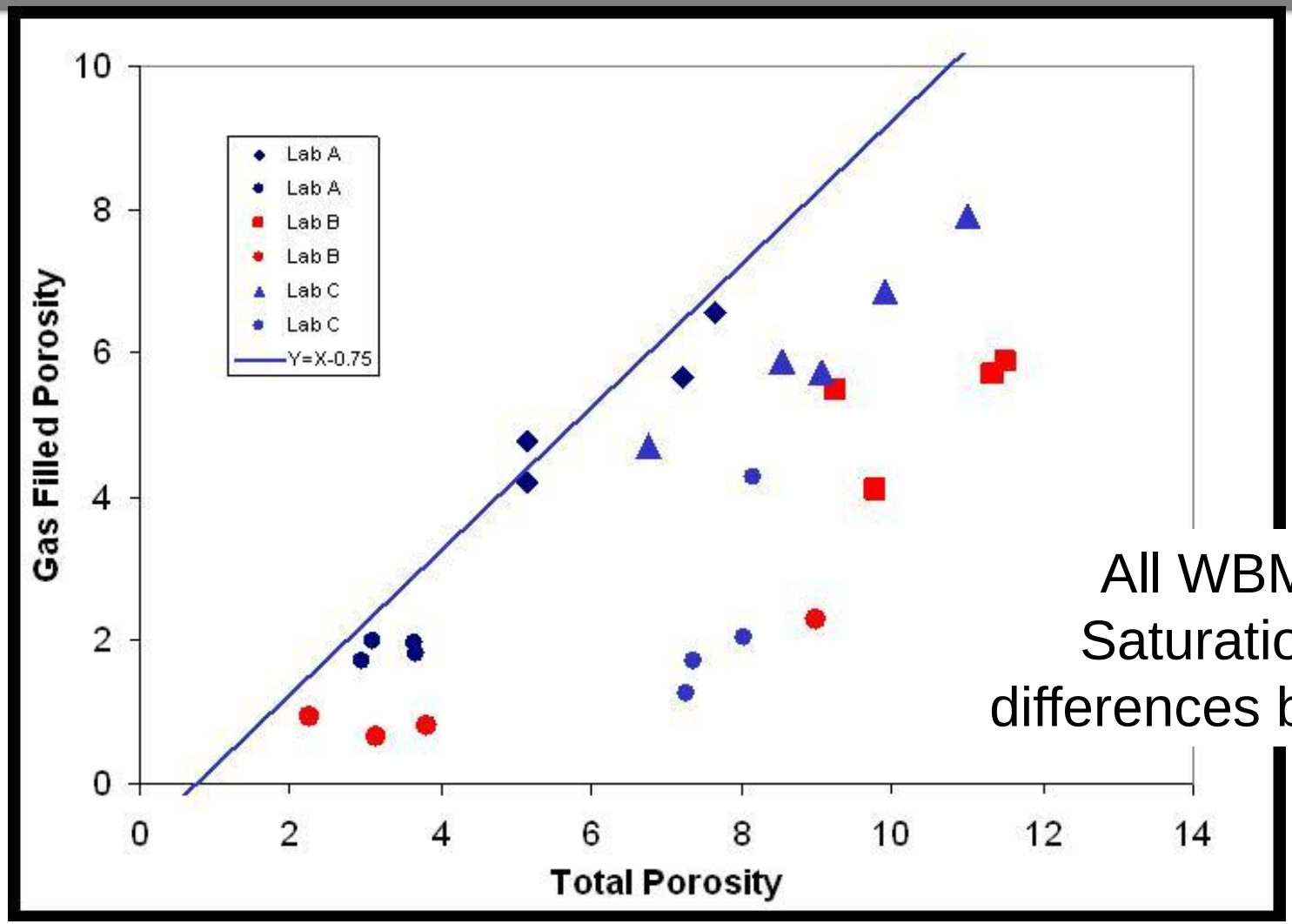
Differences in core data - various labs

100 nD is often quoted as a gas flow cutoff for gas shales

If true;
- Lab 1 The entire interval will flow gas.
- Lab 2 No gas flow
- Lab 3 Minor gas flow



Differences in core data - various labs



All WBM Saturation differences by lab

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- Anisotropy
  - *Resistivity*
  - *Geomechanics*
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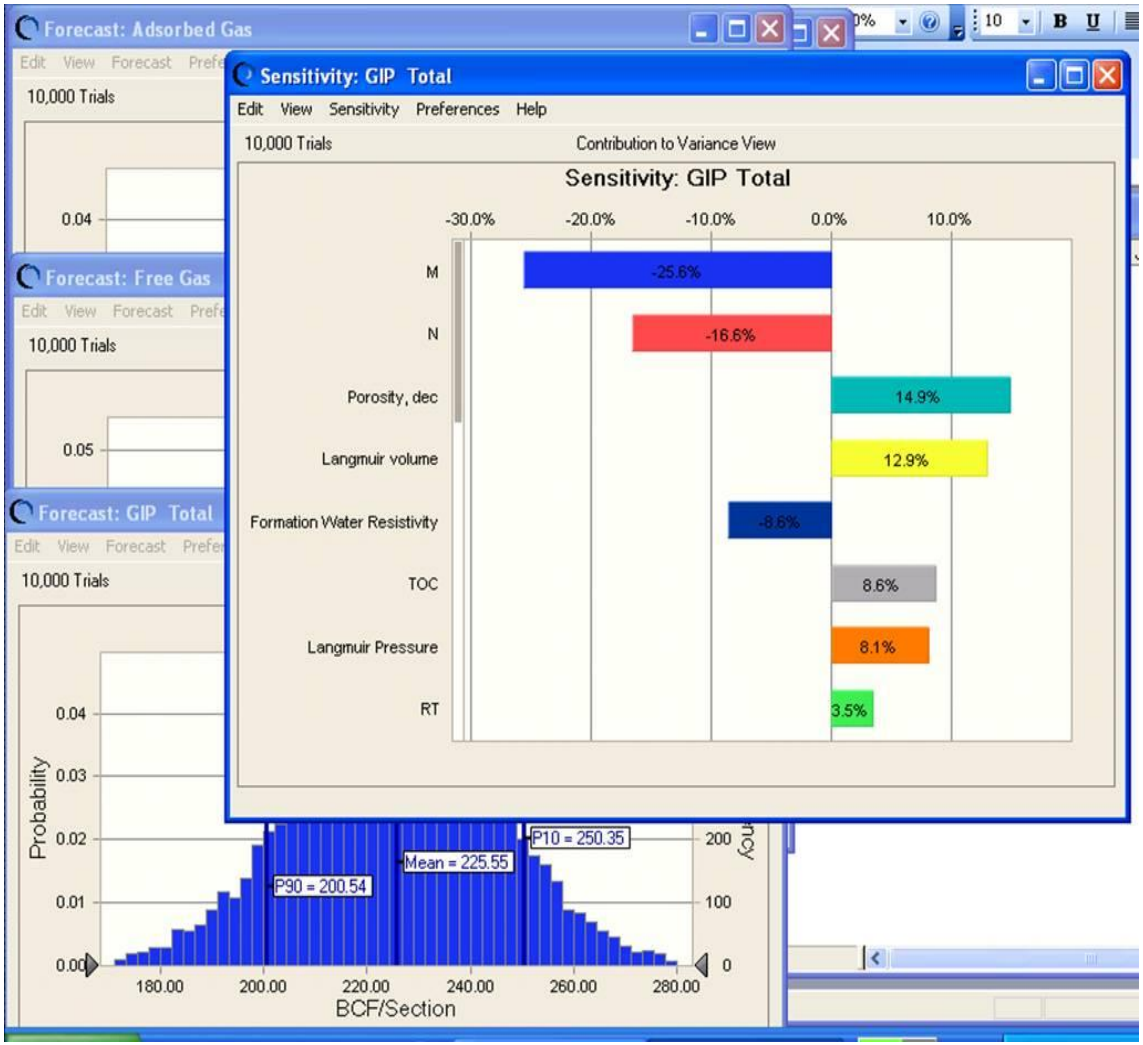
Gas in place sensitivity

- Try to match core data, but what core data…..
- XRD or FTIR?
- Dean Stark or retort?
- Sieve crushed samples or no
- “as received” analysis or no
- Oil based or water based mud

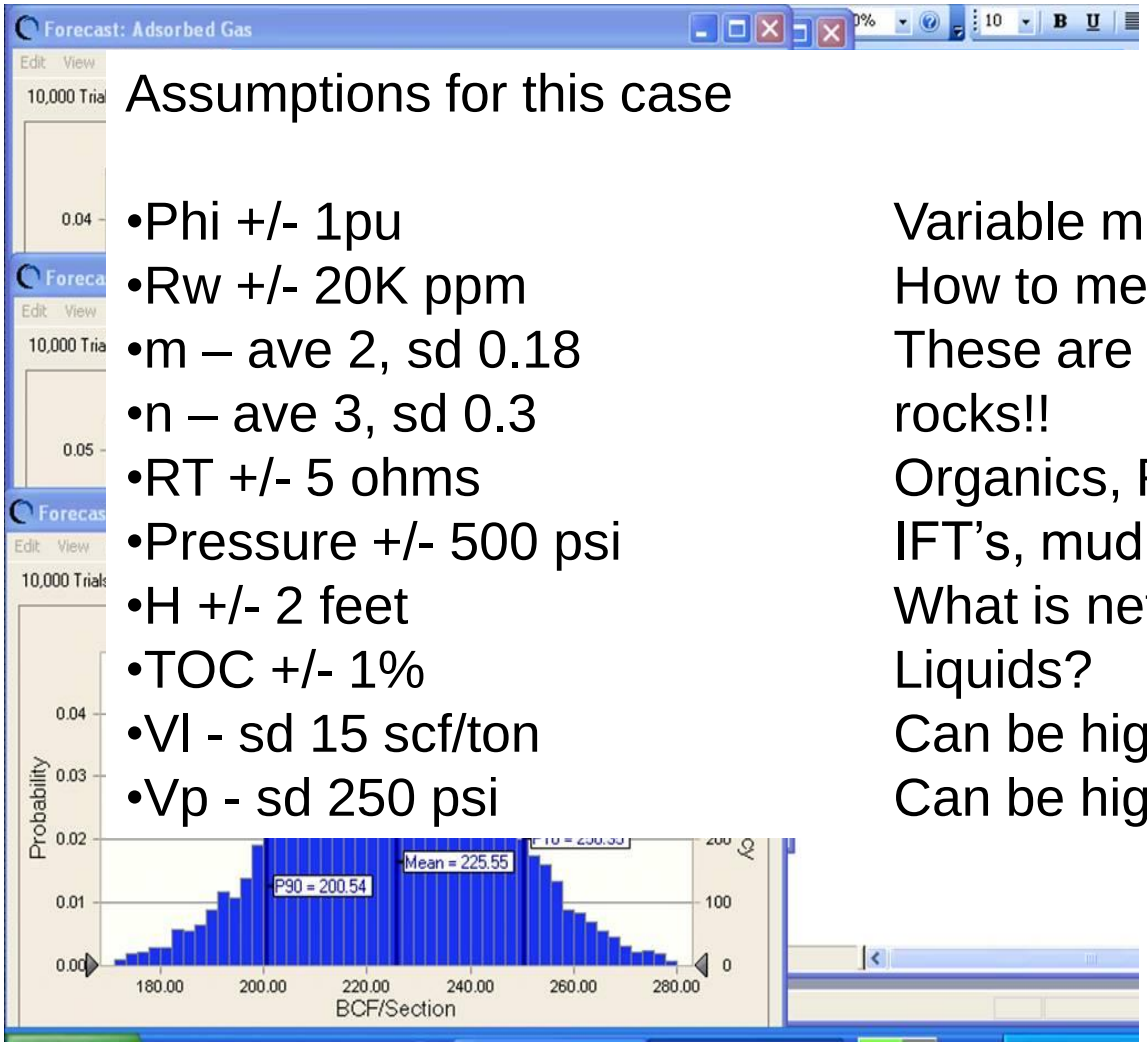
Gas in place sensitivity - RT based solution



Assumptions for this case

- Phi +/- 1pu
- Rw +/- 20K ppm
- m – ave 2, sd 0.18
- n – ave 3, sd 0.3
- RT +/- 5 ohms
- Pressure +/- 500 psi
- H +/- 2 feet
- TOC +/- 1%
- Vl - sd 15 scf/ton
- Vp - sd 250 psi

Gas in place sensitivity - RT based solution



Assumptions for this case

•Phi +/- 1pu	Variable mineralogy, method, lab
•Rw +/- 20K ppm	How to measure, constant?
•m – ave 2, sd 0.18	These are NOT Archie
•n – ave 3, sd 0.3	rocks!!
•RT +/- 5 ohms	Organics, Ro, conductive minerals
•Pressure +/- 500 psi	IFT's, mud weights?
•H +/- 2 feet	What is net?
•TOC +/- 1%	Liquids?
•Vl - sd 15 scf/ton	Can be highly variable
•Vp - sd 250 psi	Can be highly variable

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Focus on Rw uncertainty

- How much water is there?
- Where is the water?
- What is the electrical pathway through the water?
- What is the water resistivity in gas shales?
  - *Is the water resistivity constant?*
  - *GRI – noted highly variable Rw – GRI-95/0496*
  - *Can we get an idea from flowback salinity?*
    - In two of our producing shale areas the flowback water has up to 10X increase in salinity
  - *Any direct evidence?*

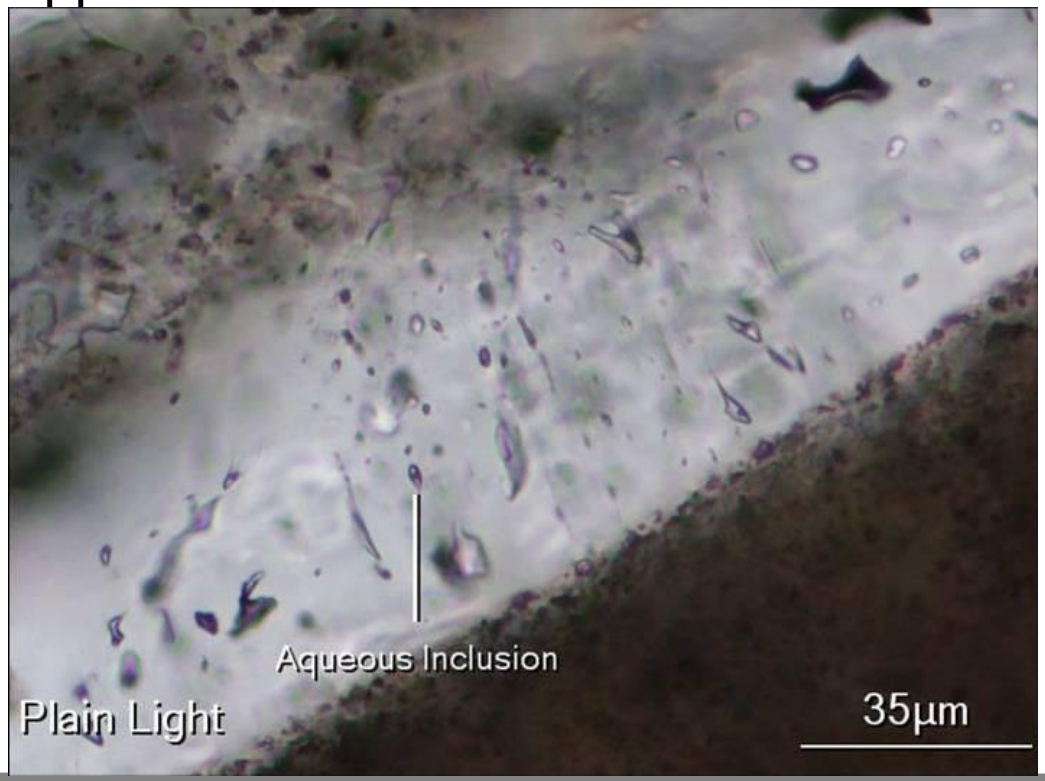
Rw Variability from GRI work

		Salinity (1.000 ppm NaCl)	
	No. Samples	**Average**	**Range**
CSW No. 2			
Lower Huron	10	49	12 to 102
CSW No. **4A**			
Cleveland	2	71	57 to 85
Lower Huron	13	72	32 to 114
CSW No. 5			
Lower Huron	7	71	41 to 92
Java	3	192	161 to 210
CSW **No. 1A**			
Middle Huron	9	136	85 to 222
Lower Huron	6	48	19 to 90

Table 1-6 Summary of Formation Water Salinity Measurements from Core Analyses – GRI-95/0496

Aqueous Fluid Inclusions

- As cements grow, part of the fluid becomes trapped as inclusions
- Fluid temperature and salinity of the fluid can be determined.
- ~ 188K to 254K ppm chlorides

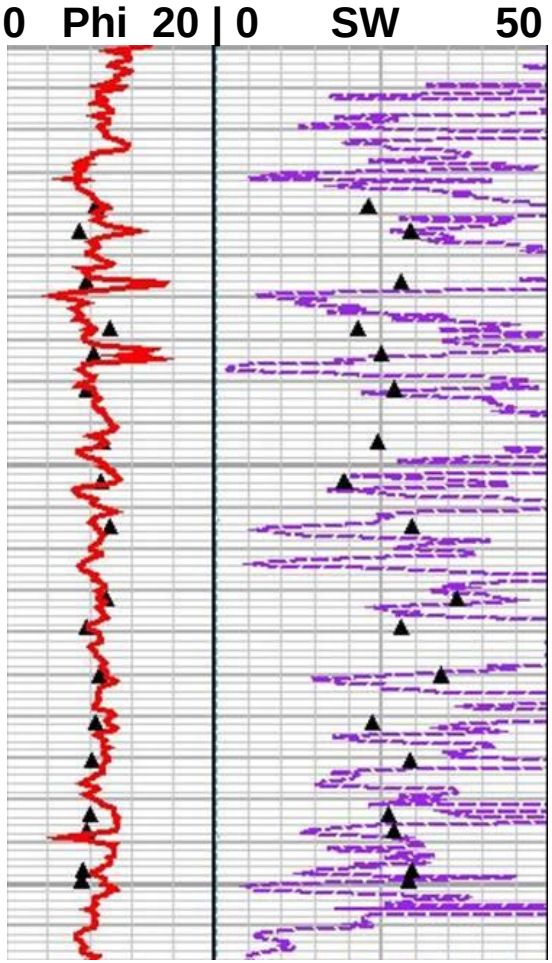


Fluid Inclusion Technologies, Inc

Focus on Rw uncertainty

- If one uses a variable Rw model, how do you get predictive?
  - *Areal changes and/or vertical changes?*
- Do orders of magnitude ranges of Rw make sense?

SW – What model to use?



▲ Core - GRI

- Observed SW variability from a vendor solution
- RT based solution
- Porosity solution looks reasonable
- Does this SW variation make sense?
- Don’t see this type of variation in core data
- What if I use a different model?
- How hard do I have to drive inputs to converge?

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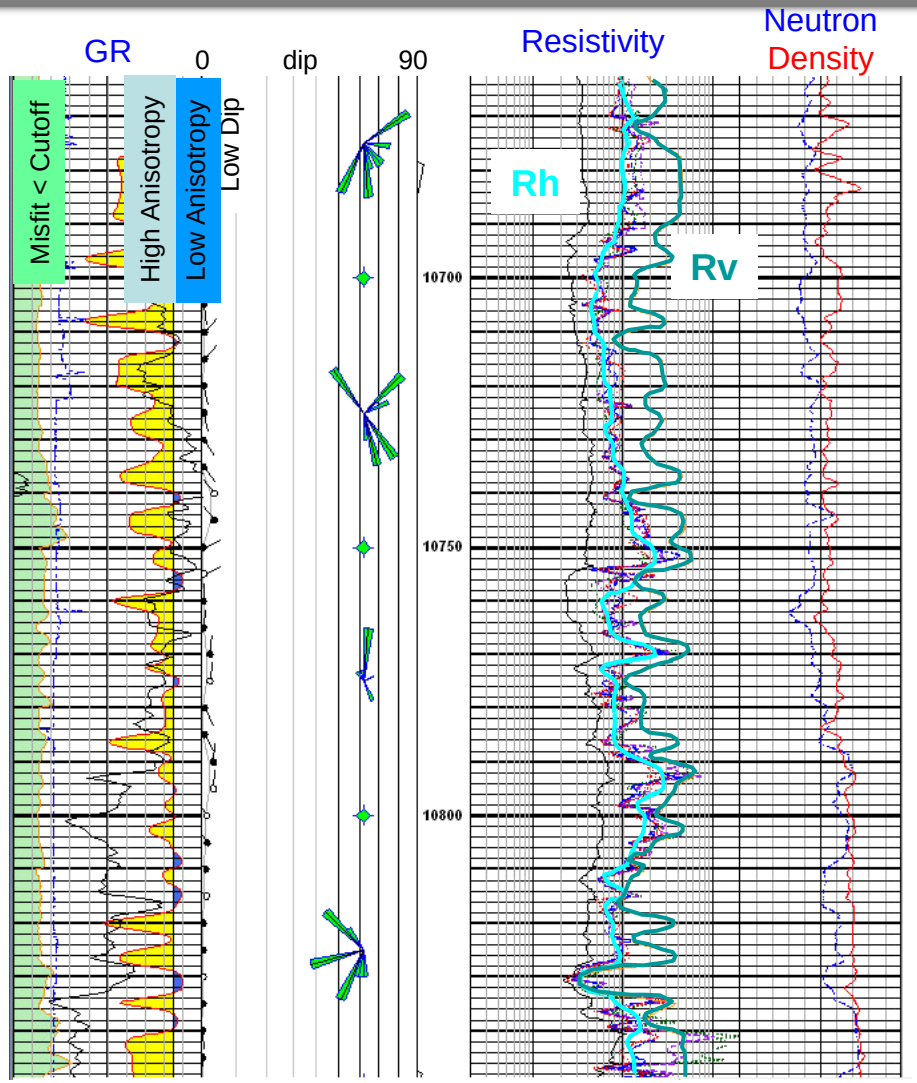
RT Anisotropy

- The basic Resistivity tool “sees” a combination of Rh and Rv.
  - *Different tools have different physics*
  - *Different hardware arrangements*
- How different are the Rh and the Rv in gas shales?
- Is the RT closer to Rh or Rv or ?
- Is the processing for Rv – Rh applicable to gas shales?
  - *Processing typically assumes a bimodal system – sand and shale*
- What difference does it make in SW calculation?
- May not want to use an RT based saturation model calibrated in a vertical well for your horizontal wells.

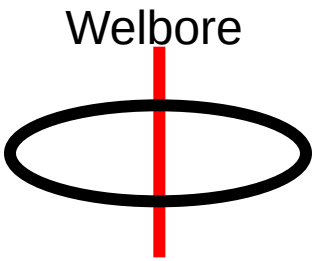
RT Anisotropy



- Good data, misfit is less than the cutoff
- High and low anisotropy
- Anisotropy not consistent
- Low formation dip
- Rv > Rh in this section
- AT90 close to Rh

this formation - flat beds

Resistivity Anisotropy affects SW



Horizontal Resistivity

10 Ohms

SW Vertical Well

Sw = 26%

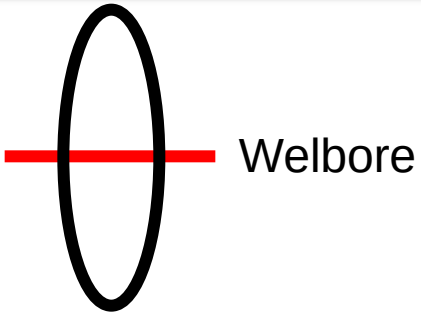
Input Values:

Φ = 0.06

m = 1.5, n = 2

Rw = 0.048 Ω-m (75degF)

FT = 300 degF



Vertical Resistivity

50 Ohms

SW Horizontal Well

Sw = 12%

Archie water saturation for a gas shale

Need a different model for vertical and horizontal wells

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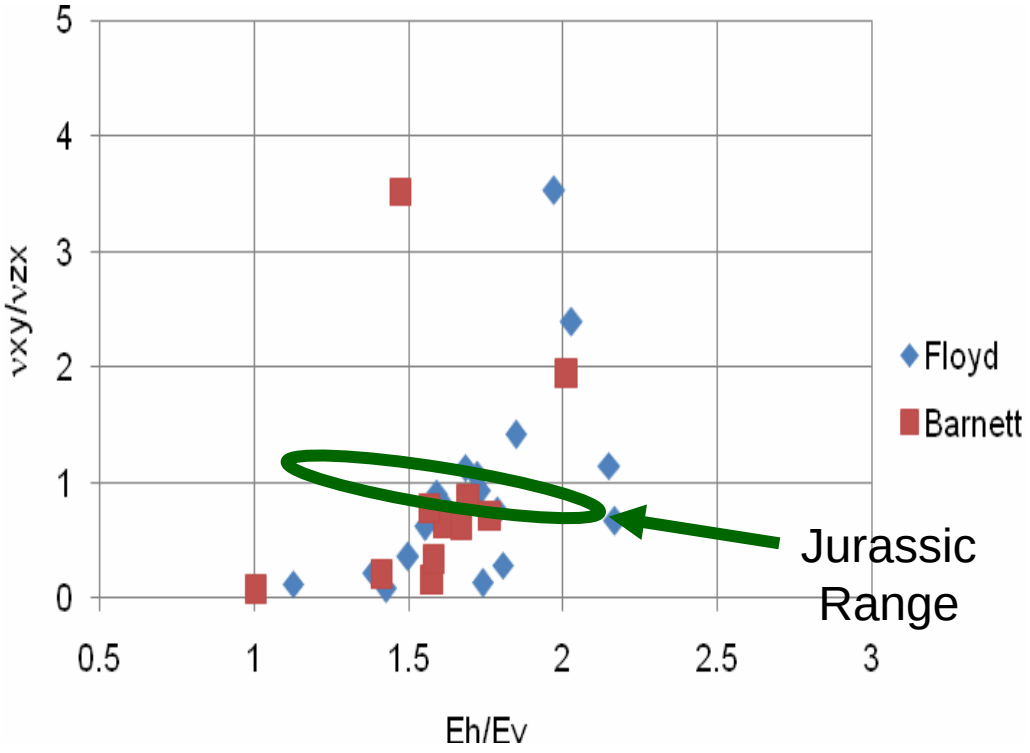
Geomechanical Anisotropy

- Observed anisotropy in Young's Modulus and Poisson's Ratio from vertical and horizontal samples
- YM horizontal ~ 2X YM Vertical
- Same observation in Jurassic gas shales
- What about azimuthal anisotropy?



The majority of measurements on Devonian shales display strong anisotropy and a strong variation in anisotropy
SPE 131768 PP

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Summary

- Gas shales are heterogeneous
- A gas shale, is not a gas shale, is not a gas shale…
- What are the correct laboratory protocols
  - *What is the correct sample size for log calibration*
  - *What are the correct measurement techniques*
- What are the largest sources of GIP uncertainty
  - *Resisitvity or non-resistivity based SW?*
  - *Pressure*
  - *Langmuir volume and pressure*
- Gas shales may have high water salinity
- Gas shales have anisotropy in resistivity, and acoustic/geomechanical properties

Thank You.....

Questions?