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?

- 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

Black shale

Gray shale
Would you analyze these the same way?

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?
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Summary
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?**
New Perspectives on Shale
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?

- Sample size
- Invasion
- Representative

Black shale

Gray shale

New Perspectives on Shale
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

- FTIR Pyrite Weight Percent
  - Sampled ~ every foot
  - Wide spread in Pyrite percentage
- XRD Pyrite Weight Percent
  - Sampled ~ 10 feet
  - Habit - nodules, replacement or disseminated?

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New Perspectives on Shale
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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Summary
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%
- Vi - sd 15 scf/ton
- Vp - sd 250 psi
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%
• Vi - sd 15 scf/ton
• Vp - sd 250 psi

Variable mineralogy, method, lab
How to measure, constant?
These are NOT Archie rocks!!
Organics, Ro, conductive minerals
IFT’s, mud weights?
What is net?
Liquids?
Can be highly variable
Can be highly variable

New Perspectives on Shale
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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?*
### Table 1-6 Summary of Formation Water Salinity Measurements from Core Analyses – GRI-95/0496

<table>
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<th>No. Samples</th>
<th>Average</th>
<th>Range</th>
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</table>

Salinity (1,000 ppm NaCl)

**Rw Variability from GRI work**
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
Focus on $R_w$ uncertainty

- If one uses a variable $R_w$ model, how do you get predictive?
  - Areal changes and/or vertical changes?
- Do orders of magnitude ranges of $R_w$ make sense?
SW – What model to use?

- 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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Summary
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.
- Good data, misfit is less than the cutoff
- High and low anisotropy
- Anisotropy not consistent
- Low formation dip
- $R_v > R_h$ in this section
- AT90 close to $R_h$
this formation - flat beds
Resistivity Anisotropy affects SW

Horizontal Resistivity
- 10 Ohms

Input Values:
- $\Phi = 0.06$
- $m = 1.5, \ n = 2$
- $R_w = 0.048 \ \Omega \cdot m$
  (75degF)
- $FT = 300 \ \text{degF}$

SW Vertical Well
- $Sw = 26\%$

Archie water saturation for a gas shale

Need a different model for vertical and horizontal wells

Vertical Resistivity
- 50 Ohms

SW Horizontal Well
- $Sw = 12\%$
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Data uncertainty
  - *GIP*
  - *Rw*

Anisotropy
  - *Resistivity*
  - *Geomechanics*

Summary
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

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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

- Resistivity 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?