U.S. Shale Gas
From Resources and Reserves to Carbon Isotope Anomalies

John B. Curtis
Potential Gas Agency
Colorado School of Mines
Major U.S. Basins and Shale Plays c. 2007
(Where are the Haynesville and Marcellus???)
Shale Gas Annual Production and Energy Information Administration (EIA) Forecast

Annual Production, Bcf

CUM
EIA Projection

EnCana
U.S. Shale Gas Annual Production from Five Classic Plays to 2007

Modified and updated from Hill and Nelson, 2000
Targeted Research – $150 Million
Acquisitions – >$8 Billion

Source: Trollart.com – Ray Troll
Resource Development – >$15 Billion
Hydrocarbons From Shale – Never Say Die

Growth in Barnett Shale - Ft. Worth Basin

- Gas Production
- Well Count

Annual Production, Bcf

Producing Wells

Exploration Considerations

- Natural fractures - Friend or Foe?
- Facies changes - greater permeability
- Kerogen type - I, II, IIS, III
- Microbial or thermogenic gas?
- Thermal maturation history
- MWD - especially w/ gas isotopes
Geochemical Properties of Gas Shales

Modified from Hill and Nelson, 2000
Evolution of Antrim Shale Gas

<table>
<thead>
<tr>
<th>PALEozoIC</th>
<th>MESOzoIC</th>
<th>CENO.</th>
<th>PETROLEUM SYSTEM EVENT</th>
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<tbody>
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<td>C</td>
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<tr>
<td><strong>Deposition</strong></td>
<td>Fracturing due to HC maturation &amp; regional loading/unloading</td>
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<td>Source rock</td>
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<td>Reservoir rock</td>
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<td>Seal rock</td>
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<td>Overburden</td>
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<td>Trap formation</td>
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<td>Generation-migration-accumulation</td>
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<td>Preservation time</td>
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<td>Critical moment</td>
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(Modified from original work by Ira Pasternack)
Some Elements of a Successful Shale Gas Play

- Organic Richness
- Maturation
- Gas-In-Place
- Permeability
- Pore Pressure
- Brittleness
- Mineralogy
- Thickness

Productivity
Potential Supply of Natural Gas in the United States

Report of the Potential Gas Committee
(December 31, 2008)
Proved Reserves vs Resources

- Known gas reservoirs
- Existing economic conditions
- Existing operating conditions
- Discovered
- Undiscovered
- Effects of technology
- Effects of economics

POTENTIAL GAS AGENCY
COLORADO SCHOOL OF MINES
Regional Resource Assessment

Data source: Potential Gas Committee (2009)

Traditional 1,673.4 Tcf
Coalbed 163.0 Tcf
Total U.S. 1,836.4 Tcf

Rocky Mountain
374.4
51.9

North Central
24.0
16.6

Mid-Continent
274.9
7.5

Atlantic
353.5
17.3

Gulf Coast
455.2
3.4

Pacific
51.3
2.6

ALASKA
193.8
57.0
PGC Resource Assessments, 1990-2008

Total Potential Gas Resources (mean values)

Data source: Potential Gas Committee (2009)
Possible Constraints on Future Gas Supply

- Resource Base
- Environmental Concerns
- Gas Price
- Skilled Workforce
- Regulatory & Land Issues
- Pipeline Capacity
- Technology
- Rig Availability

Sufficient Supply to Meet Demand
Gas Character Anomalies Found in Highly Productive Shale Gas Wells

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²Colorado School of Mines, Golden, Colorado USA
Presentation Outline

• **Background:** carbon isotope fractionation; gas wetness and wellsite sample collection during drilling;

• I. *Ethane isotope “rollover,”* suggestive of in situ gas cracking and more productive wells;

• II. *Mud gas isotope “reversals,”* indicative of overpressured shales;

• III. *Permeability markers* from differences in methane isotopic composition between mud (free) and cuttings (adsorbed) gases.
Background

![Diagram of Carbon Isotopes and Methane Structure](image)

- **$^{12}\text{C}$**: 6 protons, 6 neutrons
- **$^{13}\text{C}$**: 6 protons, 7 neutrons

Natural abundance:
- $^{12}\text{C}$: 98.93%
- $^{13}\text{C}$: 1.07%

**Methane**

+1 additional neutron
Dry Gas and Wet Gas Compositions

Typical "background" bacterial or low-maturity thermogenic distribution

Typical "reservoir" mature thermogenic distribution

Dry gas

Methane

Wet gas

Ethane  Propane  Butanes  Pentanes  Hexanes+

Retention time

Response
Wellsite Sampling for Gas Isotopes

- IsoTube for mud gases
- IsoJar for cuttings gases
Mud Gas and Cuttings Sampling
Changes in Carbon Isotope Ratios with Thermal Maturation (after M. Schoell)
I. Barnett Shale Ethane Isotope “Rollover”

Normal increasing maturity trend

Ethane isotope reversals in mature eastern Barnett gases

C₂ isotope “rollover”
Barnett Ethane Isotope “Rollover”

Normal maturity trend
Ethane isotope reversal
Wells without isotope “rollover” are never the best producers.

Poorly producing “rollover” wells are often earlier completions. Low TOC and rock properties are also important issues.
Summary - Ethane Isotope “Rollover”

- Ethane (and propane) isotope “rollover” occurs in increasingly high-maturity shale-gas wells.
- Behavior is also observed in numerous other gas shales in other basins.
- These wells appear to be among the most productive shale-gas wells:
  - In situ cracking increases the number of smaller molecules, increasing fluid pressure.
  - Organic material becomes more brittle, leading to increased kerogen porosity and permeability.
II. Mud Gas Ethane Isotope “Reversals”

Haynesville Example

- Bossier / Cotton Valley
- Haynesville

- “normal” maturity isotopic trend

- Top of overpressure
East Texas/North La. Oil Distribution
A clear isotopic difference exists between methane from mud gases (black squares) and methane from headspace gases (red squares).

- **Mud gas** ~ Free / solution / lost gas
- **Headspace gas** ~ Adsorbed gas

Larger differences between IsoTube and IsoJar isotopes correlate with increased permeability.
Well Log Evidence for Porosity/Permeability Detection from Shale Gas Isotopes

Zones of maximum porosity / permeability
Shale Gas Analyses as Permeability Markers – Poorer Permeability

Poorer permeability: Gas eventually evolving off cuttings has more free gas, making methane isotopes more negative.

Methane Carbon Isotope

Headspace Gas

Mud Gas

Free Gas (more negative isotopes)

Adsorbed Gas (more positive isotopes)
Shale Gas Analyses as Permeability Markers – Better Permeability

Better permeability: Gas eventually evolving off cuttings is mostly adsorbed gas.

Methane Carbon Isotope

Headspace Gas - IsoJars
Mud Gas - IsoTubes

Free Gas (more negative isotopes)
Adsorbed Gas (more positive isotopes)
Conclusions

• Shale-gas well performance can be correlated to gas character anomalies seen in produced, mud and headspace gas isotopic analyses:
  – Ethane and propane isotope “rollovers” indicate in situ cracking at high maturities.
  – Ethane isotope “reversals” within a single well demonstrate overpressure/effective seals.
  – Mud (free) and headspace (adsorbed) methane isotopic signatures can be used as permeability markers.
Potential Gas Agency
## Regional Resource Assessment Summary

<table>
<thead>
<tr>
<th>PGC Area</th>
<th>Traditional Resources (Mean, Tcf)</th>
<th>Coalbed Gas Resources (M.L., Tcf)</th>
<th>Total Pot. Resources (Tcf)</th>
<th>Region’s Proportion of Total L48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf Coast</td>
<td>455.2</td>
<td>3.4</td>
<td>458.5</td>
<td>28.1%</td>
</tr>
<tr>
<td>Rocky Mountain</td>
<td>374.4</td>
<td>51.9</td>
<td>426.3</td>
<td>26.1%</td>
</tr>
<tr>
<td>Atlantic</td>
<td>353.5</td>
<td>17.3</td>
<td>370.8</td>
<td>22.7%</td>
</tr>
<tr>
<td>Mid-Continent</td>
<td>274.9</td>
<td>7.5</td>
<td>282.4</td>
<td>17.3%</td>
</tr>
<tr>
<td>Pacific</td>
<td>51.3</td>
<td>2.6</td>
<td>53.8</td>
<td>3.3%</td>
</tr>
<tr>
<td>North Central</td>
<td>24.0</td>
<td>16.6</td>
<td>40.6</td>
<td>2.5%</td>
</tr>
<tr>
<td><strong>Total Lower 48</strong></td>
<td><strong>1,484.9</strong></td>
<td><strong>99.2</strong></td>
<td><strong>1,632.5</strong></td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>193.8</td>
<td>57.0</td>
<td>250.8</td>
<td></td>
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<tr>
<td><strong>Total U.S. (means)</strong></td>
<td><strong>1,673.4</strong></td>
<td><strong>163.0</strong></td>
<td><strong>1,836.4</strong></td>
<td></td>
</tr>
</tbody>
</table>

Data source: Potential Gas Committee (2009)

* Separately aggregated total, not arithmetically additive.
PGC Resource Assessment 2008

Total Traditional Resources (mean values) by category

- Probable (existing fields): 441.4 Tcf
- Possible (new fields): 736.9 Tcf
- Speculative (frontier): 500.7 Tcf
- Total: 1,673.4 Tcf

Data source: Potential Gas Committee (2009)
PGC Resource Assessment 2008

Total Coalbed Gas Resources (mean values) by category

- Probable (existing fields): 14.2 Tcf
- Possible (new fields): 49.8 Tcf
- Speculative (frontier): 98.9 Tcf
- Total: 163.0 Tcf

Data source: Potential Gas Committee (2009)