• Study objectives
• Database preparation
• Overview of Barnett production
• Tarrant / Johnson County Area of Interest (AOI)
  – Drift Angle and Azimuth
  – Well bore undulation
• Bonus Slides – Building on Tuesday’s Sessions
• Conclusions
Study Objectives

• Document ongoing reservoir quality, well architecture, completion, stimulation studies

• Provide for data-driven discussion of best practices
Database Preparation

• Commercial data sets
  – Well history
  – Completion & stimulation practices
  – Monthly production
  – 3,300+ directional surveys

• Collected, reviewed, put into a database

• Quality Control Process
  – Statistical removal of outliers
  – Known limits & ratios examination
Overview of Barnett Production

• Development of Production proxies
  – Peak monthly gas rate
  – 3 & 12 month cum gas
  • 3 or 12 producing months cum beginning with peak month

7,310 wells, 2003-2009, \( R^2 = .94 \)
## Average Statistics for Barnett Horizontal Completions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Completion Year</th>
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<tbody>
<tr>
<td></td>
<td>2004</td>
</tr>
<tr>
<td>Number Completions</td>
<td>255</td>
</tr>
<tr>
<td>Perforated Length, ft</td>
<td>1793</td>
</tr>
<tr>
<td>Peak Monthly Gas, Mcf/mo</td>
<td>52098</td>
</tr>
<tr>
<td>1 year Cumulative Gas, MMcf/yr</td>
<td>378.3</td>
</tr>
<tr>
<td>1 year Cumulative Liquids, Bbl</td>
<td>2267</td>
</tr>
<tr>
<td>1 year Cumulative Water, Bbl</td>
<td>44050</td>
</tr>
<tr>
<td>Treatment Volume, Mgal</td>
<td>3849</td>
</tr>
<tr>
<td>Treatment Volume /perf ft, gal/ft</td>
<td>2206</td>
</tr>
<tr>
<td>Proppant Quantity, Mlbs</td>
<td>1141</td>
</tr>
<tr>
<td>Proppant Quantity /perf ft, lbs/ft</td>
<td>672</td>
</tr>
<tr>
<td>Number of Stages</td>
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</tr>
<tr>
<td>Peak Monthly Gas P10, MMcf/mo</td>
<td>17.0</td>
</tr>
<tr>
<td>Peak Monthly Gas P25, MMcf/mo</td>
<td>29.1</td>
</tr>
<tr>
<td>Peak Monthly Gas P50, MMcf/mo</td>
<td>45.6</td>
</tr>
<tr>
<td>Peak Monthly Gas P75, MMcf/mo</td>
<td>69.6</td>
</tr>
<tr>
<td>Peak Monthly Gas P90, MMcf/mo</td>
<td>93.1</td>
</tr>
</tbody>
</table>

* Limited Sample size

Table 1 – Statistical Data for Whole Field Barnett Horizontal Completions 2004 to 2009
Production Result Time Dependence

- Small energized fracs
- Cross link MHF
- First Horiz well
- $\mu$-seismic
- SWF
Longer Is Better (Until It’s Not)

Figure 4 - Peak Monthly Gas rate vs. Perforated Length
GIS Mapping: WGR

Figure 6 – Location Highest 10 percent 1 Year Water to Gas Ratio

Figure 7 – Location Lowest 10 Percent 1 Year Water to Gas Ratio
Lowest 10% vs Best 10% Barnett Horiz Producers

Figure 8 - Location of lowest 10 Percent of peak producers

Figure 9 - Location of top 10 Percent of peak producers
Most Barnett Wells Do Not Have a Good Sump

**Figure 5** – Representative Barnett wellbore path in the horizontal section.
Tarrant / Johnson County Area of Interest

Figure 11 – Location of the Top 10 Percent of peak producers and T/J AOI
Figure 12 – Peak Gas vs. Perfed Length
For 2329 wells in T/J AOI

Figure 13 – Peak gas per Perfed ft
For 2320 wells in T/J AOI
Peak Gas vs Azimuth

Figure 17 – Peak Gas vs. Horizontal Azimuth for all Barnett

Figure 18 – Peak Gas vs. Horizontal Azimuth for T/J AOI
Larger Treatments May Yield Increased Production

Figure 16 – Peak Mo Gas vs. Stimulation Fluid Volume In T/J AOI after removing top 25 pct 1 yr WGR, R=0.56
Peak Gas vs Drift Angle

Figure 19 – Peak Gas vs. Drift Angle for all Barnett (3297 wells)

Figure 20 – Peak Gas vs. Drift Angle for T/J AOI (933 wells)
Figure 23 – Peak Monthly Gas for Varying Horizontal Well Lengths as a Function of Absolute Feet of Undulation, Wells in the T/J AOI
Conclusions

• Success of the geographical approach.
• Horizontal lengths greater than 3500-4500 feet are less efficient.
• More successful Barnett wells are drilled on +- 140 / 320 degree azimuths.
  – This is not the preferred azimuth for all Barnett locations!
• Best Barnett producers are drilled nearly flat.
• Barnett wells are distributed evenly toe-up / toe-down.
• Undulations in T/J AOI do not measurably reduce productivity during early well life.
Strong mineralogy variations

Montney  Haynesville  Eagle Ford  Marcellus  Barnett
Key Reservoir Parameters

- **Brittle Rock** – Helps maximize extent of induced fracture network
  (Brittle Rock will fracture like glass = better SRV)
- **Stress Regime** – Relates to pattern orientation and well spacing
- **Over-pressure**
- **Local Lithology Variations**
- **Faults, Karsts, Water**
- **Organic Content**
- **Micro-porosity**
- **Thermal Maturity** ($R_o$) – >Mature = Dry Gas <Mature = Wet Gas

Relates to well productivity

Total Porosity increases at higher TOC

Relates to gas in place

TOC decreases at higher $R_o$
Critical Production Drivers: Reservoir Quality

- **GIP**
  
  \[ G_i = \frac{AhFS_g}{B_{gi}} \]

  - **Bg = 0.0283 ZT/p**

- **Deliverability**

  \[ q \approx \frac{2\pi kh(P_{res} - P_{wf})}{u[\ln(r_e / r_w) + S]} \]
Permeability (the second most abused number in the oil patch)

- Matrix K \(10^{-7}\) to \(10^{-9}\) D widely quoted
- Natural fractures controversial
  - Mainly sealed by calcite in Brnt and other gas shales
  - May be open or closed in Bakken, Monterey
- Three data points
  - Gas molecule movement may only be on the order of 10 feet in the lifetime of a well, first modeled by Dr. Mohan Kelcar, Univ. of Tulsa
  - Dr. Chunlou Li, Baker Hughes, modeled 1.5 – 10 feet/year over 1 – 1000 nD perm range
  - Nexen unconventional team modeled 1 m/year
- Implies that complex hydraulic fracturing is a requirement
Thickness

- H is a critical driver in Brnt reservoir quality
  - Both for rate and storage
### Resource Shale Plays

#### Pressure Gradient Comparisons

<table>
<thead>
<tr>
<th>Play</th>
<th>Gradient</th>
<th>Pressure</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Big Sandy Low Pressure</strong></td>
<td>.1 - .2</td>
<td>900#</td>
<td>4,500’</td>
</tr>
<tr>
<td><strong>Transitional Pressure</strong></td>
<td>.2 - .35</td>
<td>1,800#</td>
<td>6,000’</td>
</tr>
<tr>
<td><strong>Core Areas</strong></td>
<td>.4 - .60?</td>
<td>4,000#</td>
<td>7,550’</td>
</tr>
<tr>
<td><strong>Barnett</strong></td>
<td>.53</td>
<td>4,000#</td>
<td>7,550’</td>
</tr>
<tr>
<td><strong>Fayetteville</strong></td>
<td>.43</td>
<td>1,000#</td>
<td>2,400’</td>
</tr>
<tr>
<td><strong>Woodford</strong></td>
<td>.44</td>
<td>3,270#</td>
<td>7,500’</td>
</tr>
<tr>
<td><strong>Haynesville</strong></td>
<td>.92</td>
<td>12,500#</td>
<td>13,500’</td>
</tr>
</tbody>
</table>

*Wrightstone 2008*
Mobility is a Critical Driving Issue

![Graph showing the relationship between permeability and mobility for different shale formations.](image-url)
Drainage Radius ($R_e$)

- Is what you touch with the frac
- See slide 14
- The most abused number in the oil patch, IMHO
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Acknowledgements

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Thank You!