Abstract

Successful completions in the shale of the Barnett Formation require a combination of high quality geology and geophysics in association with high technology drilling and completion engineering. Large areas of the Barnett play contain challenging conditions that make economic completions more difficult. These challenges can be geological (faulting and karsting), geophysical (gas effects and velocities), and engineering (Barnett thickness and lack of frac barriers). Thus, the majority of the play area has more difficulties to overcome than in the core area (sweet spots) and requires the use of higher technology with respect to the geosciences and engineering. Success is not simply a matter of drilling a large number of wells into a uniform resource (as mistakenly applied to the Barnett), but one must both avoid drilling marginally or non-economic wells and drill more wells with significantly higher economic returns.

Important aspects related to the geology and geophysics for the drilling of successful Barnett gas wells are:
- Prediction and avoidance of Ellenberger karsts and both large- and small-scale faults that provide vertical conduits for water.
- Ability to define an objective zone within the Barnett and to maintain penetration within that zone.
- Ability to define “lateral” facies changes within the Barnett that may require different frac techniques from one zone to another.
- Improved frac designs to better contact the Barnett more efficiently.
- Anticipate conduits between wells to reduce problem communication.

We use detailed structural analysis and multi-attribute interpretation of 3D seismic data to aid in the drilling program. Karsts and major tectonic faults, both development hazards, are easily seen in dip-steered Similarity and Curvature attributes. The mid range of the Most Negative Curvature attribute shows a fine network of anomalies that can be correlated to natural fracture trends and small faults and that these are activated and accessed by fracture stimulation during well completions. Comparing micro-seismic fracture monitoring and visualization of the seismic-derived structural attribute volumes shows a clear relationship that allow us to predict reservoir presence as well as hazards. Clearly this is a broad multidisciplinary workflow that requires expertise from area of Geology, Geophysics, and Engineering that is somewhat unique to the play.
References


Structural Attribute Analysis
Used in Barnett Resource Development, Fort Worth Basin, Texas

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ACKNOWLEDGEMENTS

• Rimrock Energy
• Basin Geology
• Geologic Hazards
• Completion Issues
• Geophysical Techniques
• Applications
• Fracing the Barnett
• Further efforts
• Conclusions
Basin Geology

- Stratigraphy
- Structure
- Barnett Thickness
- Maturation
- Composition of Barnett
Generalized Subsurface Stratigraphic Section

From Montgomery, et al, 2005
BARNETT STRATIGRAPHIC CROSS SECTION

DATUM: TOP BARNETT

Approximate length of section = 9 miles
**Top of Barnett Structure Contour Map**

C.I. = 500 feet

The Barnett in the Fort Worth Basin dips from west to east towards the Ouachita Thrust Belt and northeast to the Muenster Arch. Dips are approximately 1° to 2°.
**Barnett Isopach Map**

**C.I. = 25 and 100 feet**

The Barnett thins from less than 100 feet to the west to over 700 feet in front of the Ouachita Thrust Belt to the northeast.
Ro’s are high enough throughout the Fort Worth Basin area for gas generation.

1.3 Ro Values
Composition of the Barnett

- 35-50% quartz
- <35% clay
- <15% carbonate
- <15% other
- Original TOC >10%

High TOC and high quartz content provides an ideal situation for porosity filled free gas within the shale as well as sorbed gas that will be produced late in the production history of the well after the free gas is produced early in the well’s history.

From Montgomery et al, 2005
Geologic Hazards

• Faults
  • Large (> 100 feet of throw)
  • Small (< 100 feet of throw to ~5 feet)

• Fracture zones connecting into the Ellenberger

• Ellenberger karsts and collapse features
  • Problems
    – Faulting affects placement of horizontals bringing the Ellenberger closer to the wellbore
    – Small faults and fracture zones taking fracs and bringing water into the wellbores
    – Karsts affecting placements of horizontals
Completion Issues

- Faults bringing the horizontal wellbore close to the top of the Ellenberger
- Small faults and fracture zones taking fracs that bring water from the Ellenberger into the wellbore
- Inconsistency in effective fracing along the wellbore within the Barnett, especially when using the same techniques in every frac
Geophysical Techniques

- Similarity
- Curvature
SIMILARITY

• Similarity measures the lateral seismic reflection variation and highlights discontinuities, i.e., faulting, facies changes, major fractures, etc.
FIG. 1. Curvature in two dimensions. Note that curvature is defined as the inverse of the radius of a circle that is tangent to the surface at any point and that, by convention, positive curvature is concave downward and negative curvature is concave upwards. (After Roberts, 2001).
Types of Curvature

- Based on PSTM
- Requires Dip and Azimuth Cube (Dip Steering)

1) Dip Curvature
2) Strike Curvature
3) Minimum Curvature
4) Maximum Curvature
5) Most Negative Curvature *
6) Most Positive Curvature *
7) Mean Curvature
8) Gaussian Curvature
9) Contour Curvature

(* “most useful in delineating faults, fractures, flexures and folds.” Al-Dossary and Marfurt, 2006, Geophysics)
APPLICATIONS

Three examples

• 1. Core/Tier 1 – Deepest and thickest Barnett
• 2. Tier 2 – Intermediate depth and thickness of Barnett
• 3. Tier 3 – Shallowest and thinnest Barnett
Areas of seismic examples to be presented

**Similarity**
- Core/Tier 1
- Tier 2
- Tier 3

**Neg. Curvature**
- Core/Tier 1
- Tier 2
- Tier 3

**Barnett Isopach Map**

*C.I. = 25 and 100 feet*
SIMILARITY IN THE THREE SEISMIC AREAS
Core/Tier 1 Similarity

MAJOR FAULT

Clean areas indicate lack of geologic hazards

KARSTS
Tier 2 Similarity

Clean areas indicate lack of geologic hazards

SMALL FAULT

KARST

KARST
Clean areas indicate lack of geologic hazards
SIMILARITY

- Defines large faults and the extent of the fault complexity
- Defines smaller faults that more conventional seismic may not define
- Defines small and large karst features well
- Is very quiet when there are no geologic hazards present
MOST NEGATIVE CURVATURE IN THE THREE SEISMIC AREAS
Core/Tier 1 Most Neg. Curvature

MAJOR FAULT

Structural Grains

KARSTS
Tier 2 Most Neg. Curvature

Structural Grains

SMALL FAULT

KARST

KARST
Lateral changes within the Barnett and Maximum Negative Curvature

• Color variations in the Most Negative Curvature processing may indicate lateral changes in the Barnett that may indicate better targets for more effective frac design that “rubblizes” the Barnett creating better permeability to access more of the gas contained in the shales.
Tier 3, Good Well

Note this profile orientation is reversed to the conventional seismic.

Well Path
Target Zone

4250' TVD Marker (yellow line)
Ellenberger
Barnett target (between red lines)
Duffer

Perf zones

Gamma Ray vs. Measured Depth
Tier 3, Good Well 1

- Barnett Thickness ~150 feet
- # of faults: 4  Min Throw 2’  Max Throw 84’  Ave. 24.5’
- # of Perfs: 9
  # of Perfs ___ ft from faults: <300’  <200’  <100’  <50’
  5  4  3  3
- Vert. Dist. of Perfs from Ellenberger: <50’-0  <75’- 8  <100’-8
- GAS SHOWS:  Min.  Max.  Ave.
  90  1,300  350
- Ave. Prod.  445 mcf/d  45 bw/d  738 Days
- Total Frac Fluid Used  43,617 BW
- Total Water Produced  33,308 BW (76%)
- Cum. Prod.  328,202 MCF,  33,308 BW  .1 bw/mcf
Good wells have both excellent reservoir and connectivity.
Tier 3, Poor Well

Marble Falls

Ellenburger
Tier 3, Poor Well

Note this profile orientation is reversed to the conventional seismic.
Tier 3, Poor Well

- Barnett Thickness ~140 feet
- # of faults 4  Min Throw 2’  Max Throw 36’  Ave. 18.25’
- # of Perfs 8
  # of Perfs ___ ft from faults  <300’  <200’  <100’  <50’
  9  7  1  1
- Vert. Dist. of Perfs from Ellenberger  <50’-4  <75’-8  <100’-8
- GAS SHOWS:   Min.  Max.  Ave.
  0  3,100  1,700
- Ave. Prod.  174 mcf/d  797 bw/d  110 Days
- Total Frac Fluid Used  46,205 BW
- Total Water Produced  87,285 BW (189%)

Cum. Prod. 19,009 MCF, 87,285 BW, 4.6 bw/mcf
Poor wells have no apparent reservoir
FRACING THE BARNETT
Most Neg. Curvature and Fracing

• Tying the Most Negative Curvature to the fracing results in wells can give an indication of the efficiency of fracs and may lead to more efficient fracing techniques. Two examples follow. Fracs seem to be better in one shade of the colors and is less effective in another shade of colors.
Complex Fracturing – the Key to Shale Contact

Microseismic spread usually an indication of increasing complexity and contact area.

What are the undisturbed areas?

From King, et al, 2009
Tier 2, 12 stage frac on Most Negative Curvature
Tier 3, 8 stage frac on Most Negative Curvature
Tier 3, 8 stage frac well profile
Tier 3, 8 stage frac Pinnacle Data

Lower breakout occurred at half way point in stage 8 and we tried to spread the frac. At the sharp pressure rise, several low points were noted. We reduced pressure immediately and only one other low point was seen in the area.
Neg. Curvature can be a “Karst killer”

Note several karsts and possible karsts
MOST NEG. CURVATURE

- Defines large faults and the extent of the fault complexity
- Better defines smaller faults that more conventional seismic may miss
- Defines small and large karst features well
- Defines structural grains that may allow better orientation of horizontal wells
- Perhaps indicates zones of fracturing that allows modification of fracs to avoid fracing downward into the Ellenberger
- May indicate lateral changes within the Barnett that affects the fracing of wells
FURTHER EFFORTS

• Better understand the color variations of the similarity and negative curvature data related to the variations in Barnett rock properties laterally and vertically.

• Better understand the color variations of the similarity and negative curvature data to better identify fracture zones to avoid fracing down into the water-bearing Ellenberger.

• Need more understanding of the orientation of horizontal wellbores related to the structural grains shown in the negative curvature as to what orientation allows more efficient fracing and rubblizing of the objective Barnett.
CONCLUSIONS:
These processing techniques of 3D data in the Fort Worth Basin:

• Are effective throughout the Barnett gas productive area of the Fort Worth Basin
• Identify large and small geologic hazards.
• Identify lateral changes in the Barnett
• Provide better control for horizontal orientation
• Provide insight into improving frac efficiency along single well bores
• Show that cookie cutter frac techniques applied in the same manner throughout the basin, and even along the same well bore, do not work.
• **MOST IMPORTANTLY, INCREASE THE CHANCES OF DRILLING A LARGER PERCENTAGE OF GOOD WELLS AND DRILLING FEWER POOR, NON-ECONOMIC WELLS RESULTING IN HIGHER ECONOMIC RATES OF RETURN.**
AN DEIREADH
THE END

TAPADH LEIBH, GLÉ MHOR, A H-UILEDUINE
THANK YOU, VERY MUCH EVERYONE

MADAINN MHATH
GOOD MORNING

Garaidh agus Tim
Gary and Tim