Seismic Expression of Shale Reservoirs
Opportunities for Technology Improvement

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Outline

Review of workflows useful in the Barnett Shale
- Volumetric attributes
- Basement control of faulting and collapse
- Velocity anisotropy analysis
- Azimuthal AVO analysis
- Improved lateral resolution through innovative migration

Some flash images of preliminary application of these techniques to the Woodford Shale
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Post-stack time migration

(Aktepe et al., 2008)
Pre-stack time migration

(Aktepe et al., 2008)
Post-stack depth migration

(Aktepe et al., 2008)
Pre-stack depth migration

(Aktepe et al., 2008)
Structural components of the Fort Worth Basin

Magnetic tilt derivative map

(Pollastro, 2007)
(Baruch et al., 2009)
Understanding the Ellenburger karstified topography

(Baruch, 2009)
Time-Structure Maps of Shale Sequencies

With fault interpretation

Faults and Fracture distribution within a Paleocave Collapse

Ellenburger Group

GRPS 1

GRPS 2-3

Lower Barnett Shale or GRPS 4

Upper Barnett Shale

Time (ms)

(Baruch, 2009)
Ant Tracking over Variance

Ellenburger Group

Upper Barnett Shale

Lower Barnett Shale

Seismic Amplitude

Ant Tracking over Variance (Baruch, 2009)
Variance

Ant Tracking over Variance

Rose Diagram

Most Positive Curvature

Ant Tracking over Most Positive Curvature

Rose Diagram

(Baruch, 2009)
Curvature on Viola Limestone

Most-positive curvature, $k_{pos}$

Most-negative curvature, $k_{neg}$

Image enhancement of $k_{pos}$

$k_{pos}$ and image enhancement

(Perez, 2009)
Curvature lineaments at each horizon

(Perez, 2009)
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Induced fractures versus expected ultimate recovery (E.U.R.)

Micro-Seismic studies suggest that large E.U.R. depends on creation (by hydrofractures) of large network of multi-azimuth vertical fractures.

(Simon, 2005)
Drilling-induced fractures show that the main present-day stress field is N45E.

Most pre-existing natural fractures are oriented N50W.

(Simon, 2005)
Azimuthal velocity anisotropy vs. induced fractures (Fort Worth Basin, Texas, USA)

Poor well (fractures parallel) (Simon, 2005)
Azimuthal velocity anisotropy vs. induced fractures (Fort Worth Basin, Texas, USA)

Good well (orthogonal fracture sets)

(Simon, 2005)
Azimuthal velocity anisotropy vs. most positive curvature (Fort Worth Basin, Texas, USA)
Curvature and microseismic?

Minimum Stress Direction Map of Microseismic events

(Awasekien, 2009)
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Azimuthal AVO:

~ 75 Square miles
16 receiver lines, 98 channels each,
21,750 SPs (290 / sq mi)
29,100 Rcvr Stns (388 /sq mi)
30 fold

Acquisition parameters

6 sectors
250 ft offset classes
sector fold of 20
110 by 110 ft bins
13% empty bins

6 SP’s – 110 ft interval
880 ft line interval

Spider plots

(Roende et al., 2008)
Stacked azimuth sector gathers

Anisotropy indicators

Data aligns

Data Jitters

(Roende et al., 2008)
6 Migrated Sectors:

NOTE differences in amplitude and imaging

Anisotropy indicators

(Roende et al., 2008)
6 Migrated Sectors:

NOTE differences in amplitude and imaging

(Roende et al., 2008)
Prestack azimuth sectors

Anisotropy in

0.6 ms

0.8 ms

1000 ft

~8 ms
AVOZ analysis

\[ R(i, \phi) = I + \left[ G_{iso} + G_{aniso} \cos^2(\phi - \theta) \right] \sin^2(i) \]

(Rüger, 1996)

Non-linear equation: \( I, G_{iso}, G_{aniso}, \theta \) are the unknowns

\( \theta \) is the source-receiver azimuth

\[ R(i, \phi) = I + [W_{11} \cos^2 \theta + 2W_{12} \cos \theta \sin \theta + W_{22} \sin^2 \theta] \sin^2 i \]

(Jenner, 2002)

Linear equation: \( W_{11}, W_{12}, W_{22}, I \) are the unknowns

(AVOZ analysis) (Roende et al., 2008)
AVOZ Resulting maps

(Roende et al., 2008)
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Coherence applied to Azimuthally-Limited Volumes

All-azimuth volume

Limited-azimuth volume

Time slices at 1.514 s

(Chorpa, 2005)
Azimuthal Binning to Better Image Fractures

Kirchhoff migration

(Perez, 20
Azimuthal Binning:
Source-receiver azimuth = NW-SE

(Perez and Marfurt, 2008)
Azimuthal Binning:
Source-receiver azimuth = NNE-SSW

(Perez and Marfurt, 2008)
Conventional Azimuthal Binning

Data slices at $t = 1.24\ s$

(Perez and Marfurt, 2008)
New Azimuthal Binning

Data slices at $t = 1.24 \text{ s}$
Conventional Azimuthal Binning

(Perez and Marfurt, 2008)
New Azimuthal Binning

(Perez and Marfurt, 2008)
Conventional Azimuthal Binning

Kneg slices at $t = 1.36$ s

(Perez and Marfurt, 2008)
New Azimuthal Binning

Kneg slices at $t = 1.24$ s

(Perez and Marfurt, 2008)
Can we predict ‘fracability’ from $\lambda$-$\mu$ cross plots of shales?

(Goodway et al., 2007)
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Natural fractures in the Woodford Shale (Wyche shale pit, OK)
Summary

In the core area of the Fort Worth Basin:
- Large fractures and karst can be readily identified by using 3D wide-azimuth seismic volumes; these features often result in production of water from the Ellenberger.
- Mapping fractures and karst can be facilitated by coherence and curvature.
- Fractures at the target area correlate to those in the Basement.
- Minor fractures are almost always healed and have been shown to be correlated to paleo-deformation. Induced fractures preferentially follow the direction of maximum horizontal stress.

In other areas:
- Production (EUR) appears to be enhanced by natural fractures seen in curvature.

Further development is needed in:
- Correlating surface seismic AVO and AVOA to core and EUR for a wider suite of shale reservoirs.
- Improving resolution of anisotropy velocity analysis.