Abstract

The Woodford Shale in Oklahoma commonly is subdivided into Lower, Middle, and Upper members. Yet, based upon lithologic variability determined from core and/or well logs, the members can be further subdivided, particularly the productive Middle member. Subdivision is readily accomplished within the context of sequence stratigraphy (Slatt and Rodriguez, 2012): the Woodford comprises a 2nd order depositional sequence comprised of several 3rd (and most likely 4th) order (para)sequences. These intervals are verified by a combination of well and core descriptions, and more recently, by palynology (Molinares, in prep.). Such parasequences are correlative and mappable for considerable distances using well logs and 3D seismic (when calibrated with logs) (Amorocho, 2012).

Sequence stratigraphic intervals and their rock properties can be related to geomechanical (as well as geochemical) properties. Geomechanical characterization has led to development of the concept of brittle-ductile couplets, that can be correlated and mapped (Slatt and Abousleiman, 2011). Brittle strata tend to be enriched in biogenic quartz and/or carbonate material and ductile strata tend to be enriched in clays and organic matter.

Because depositional sequences and parasequences occur at a variety of geologic time scales, brittle-ductile couplets also occur at a variety of stratigraphic scales. Thus, there is a natural, predictable link between sequence stratigraphy and geomechanics. The recognition of such couplets can better target landing zones for horizontal drilling and artificial fracturing.

Selected References


Sequence stratigraphy of the Woodford Shale and applications to drilling and production

Roger M. Slatt and several students
Institute of Reservoir Characterization
University of Oklahoma
All well and outcrop locations are approximate
Shoreline moves seaward: shelf becomes exposed and eroded.

Falling sea level

Erosion Surface (sequence boundary-SB)

Shoreline moves landward

Rising sea level

Transgressive Surface of erosion (TSE)

Organic-rich condensed section

Progradation (regression) Shoreline moves seaward Rising sea level

SB/TSE Silty quartz/carbonate mls CS

“Lowstand systems tract”

“Transgressive systems tract”

“Regressive/Highstand systems tract”
Global (eustatic) cycle: *Intervals of geologic time*

- 2\(^{nd}\) order—10 -25 Ma
- 3\(^{rd}\) order-- - 1- 5 Ma
- 4\(^{th}\) order…. 0.1-0.5 Ma

Sequence Stratigraphy Model for resource shales
Woodford in McAlester Cemetary Quarry

Serna-Bernal, 2013

Modified from Slatt and Rodriguez, 2012

GAMMA RAY PARASEQUENCE
- Upward Decreasing GRP
- Upward Increasing GRP
- Constant GRP
- Sample

mfs: Maximum Flooding surface
SB: Sequence boundary
TSE: Trangressive surface of erosion
LST: Lowstand system tract
TST: Transgressive system tract
HST: Highstand system tract

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Age of Woodford = 388-359my = 29my = “2nd order sequence”. Several 3rd order (1-5my) sequences within 2nd order sequence.
An interval is classified (by drillers) to be:

**Ductile**
- A lot of pumping to break
- High fracture gradient

**Brittle**
- Not as much as the “ductile” intervals
- Lower fracture gradient

**Mineralogic affect on rock fracturability (brittleness)** (Wang and Gale, 2009)

\[
BI = \frac{(Q + Dol + Lm)}{(Q + Dol + Lm + Cl + TOC)}
\]

Where \( BI \) = brittleness index; \( Q \) = quartz; \( C l \) = clay; \( Dol \) = dolomite; \( Lm \) = limestone (calcite); \( TOC \) = Total organic carbon

**Geomechanical Measures of rock deformation**

**Brittle Rock** → **Ductile Rock**

- Decreasing stiffness: ability to propagate a fracture.
- Decreasing brittleness/increasingly ductile

Bustin et al., 2008
High frequency sequences and geomechanical properties

Young's modulus $\epsilon$ and Poisson's Ratio (PR) cross-over

$$(DT) \times (RHOB) = AI$$

Brittle

Ductile
Some applications, concepts, results
Green is target (oil) zone (relatively high silica)
Red is drilling hazard (relatively high clay content)

Well dipped into **Red (ductile)** and could not come back into **Green (brittle)**.
**Result:** Uneconomic well

**Brittle-Ductile Couplet**

Well landed low, but came back into **Green (brittle)** target zone and stayed.
**Result:** Very economic well

Killian, 2012
Woodford in 3D seismic area

10 GRP’s identified

<table>
<thead>
<tr>
<th>GR/SP</th>
<th>Res/Sonic</th>
<th>Density/Porosity</th>
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</thead>
<tbody>
<tr>
<td>TST</td>
<td>HST</td>
<td>2nd order cycles</td>
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<tr>
<td>3rd order cycles</td>
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</tbody>
</table>

Woodford in 3D seismic area

10 GRP’s identified

Amorocho, 2012

Cardona, 2013
Drilling opportunities??

TOC calculated using Passey method

Cardona, 2013
Apply natural fracture distribution to hydraulic fracturing?

- Hydraulic fractures propagate through brittle chert and ductile clay?
  - Proppant goes into both brittle chert and ductile clay
  - After fracturing, the fractures in chert remain open
  - But the ductile beds encase proppant and close?
Carbonate content also is of secondary importance. Therefore, layering is important to strength.
Why different initial production, Decline curves, and payouts??

Geologic factors?? How to Optimize these factors??