Abstract

Outcrop studies used in conjunction with coring and logging of reservoir rocks are widely used to characterize complex stratigraphic variability while minimizing cost compared with obtaining these data from exploratory wells. To increase knowledge base in the Woodford Shale in the western portion of the Arkoma Basin of southeastern Oklahoma, an OU-Devon-Schlumberger project cored 200 ft. of Woodford section behind an active quarry and ran an extensive logging suite to its basal contact with the Hunton Limestone. Preliminary results indicate that numerous macroscopic features visible in whole core - such as phosphate and pyrite nodules, near-vertical healed fractures, and pulses of silica-rich layers - appear in image log data, and where present in sufficient proportions and thicknesses, these can also be resolved on conventional logs. This is especially true when distinguishing between the stratigraphic sections of Middle and Lower Woodford believed to be present in the cored interval. Microscopic analysis of thin-sections show areas of microporosity development associated with chert-filled burrows and surrounding authigenic pyrite grains. Increased microporosity is also present within chert-filled liptinite macerals observed in silica-rich layers, while the opposite is true in compacted liptinite macerals associated with argillaceous layers. Large-scale features such as layers rich in phosphahtic nodules and lenses are correlative over a distance of at least 600 ft. along the quarry walls. Characteristics identified in this project will be used for application in Woodford wells which may not have as extensive a dataset in hopes of assisting in decisions regarding lateral target zones and completion practices.
STRATIGRAPHY OF THE WOODFORD SHALE FROM BEHIND-OUTCROP DRILLING, LOGGING, AND CORING

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Determine most favorable stratigraphic zones for drilling and fracing based on sequence stratigraphy from wells and seismic

1. Identify key wells and 3D seismic volumes
2. Establish lithofacies/sequence stratigraphy from core
3. Biostratigraphic age/environment determination
4. Calibrate lithofacies/mineralogy to log response using GAMLS
5. Identify lithofacies (mineralogy) in uncored wells using GAMLS
6. Regional to local mapping of lithofacies in uncored wells
7. Determine log-based petrophysical parameters using GAMLS
8. 3D seismic stratigraphic interpretation of key areas
9. Calibrate seismic facies to lithofacies using synthetics and seismic inversion
10. Regional to local mapping of lithofacies from seismic
11. Geochemical/microporosity relations of lithofacies
12. Compare stacking of lithofacies with stratigraphic distribution of frac-induced micro-seismic events
13. Determine fracture potential/geomechanics of lithofacies
14. Establish lithofacies vs. petrophysics relations
15. Map significant petrophysical, geochemical and geomechanical properties using logs and seismic

Determine and map most favorable stratigraphic zones for drilling/fracing
Recent Behind-Outcrop Studies: to relate rock and well log properties at and laterally beyond the wellbore

- Behind-outcrop drilling, logging (*including borehole image logs*), coring, and shallow seismic:
  - *Mt. Messenger Fm.*, New Zealand, 1994 (Browne and Slatt, 2002)
  - *Jackfork Group*, Arkansas, 2006 (Rothfolk, 2006; Slatt and Davis, in press)
  - *Woodford Shale*, Oklahoma (Buckner, M.S. thesis, in prep.)
Note proximity to two Woodford exposures. Explosives shed seen in picture and aerial photo.
Drillsite location at east quarry wall

Horizontal beds
Phosphatic nodules seen as bright circular features on the image log.

Core in this photo is from same depth interval as log at right below.

Also note the high silica (yellow dotted in ELAN track) at this depth compared with that just above the Hunton contact.
Gamma ray dependence on U in Woodford → use GR as transgressive-regressive cycle indicator
Note slight increase in dip above the interpreted U. Woodford and M. Woodford members.
Pyrite is seen as dark circular features with bright colored halos on image log.
Basal Contact

FMI & ELAN shown above.

Directly above Hunton:
9° at 329° azi (315 is due NW)

Uphole:
3° at 316° az

Note erosional nature of contact between the Woodford Sh and underlying Hunton Ls.

Effects of localized post-Woodford depositional structure (Lawrence Uplift)

Note: Not a picture of the core under study. Photo courtesy of Bill Coffey.
Keep in mind that these color variations are based on variations in the scaled image. This image is affected by the total range of resistivity found within the footage of log being processed. Therefore, a wider variation in resistivity values will yield a more subtle change in color and its interpreted lithology.

<table>
<thead>
<tr>
<th>FMI Facies</th>
<th>To</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark brown (most conductive)</td>
<td>Organic rich black shale</td>
<td></td>
</tr>
<tr>
<td>Circular dark brown (conductive)</td>
<td>Nodular pyrite</td>
<td></td>
</tr>
<tr>
<td>Mottled light brown</td>
<td>Argillaceous</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-orange</td>
<td>Siliceous</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>Phosphatic nodules</td>
<td></td>
</tr>
<tr>
<td>Circular white (resistive)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White (most resistive)</td>
<td>Carbonate</td>
<td></td>
</tr>
</tbody>
</table>
Core Facies

Upper – Middle Wdfd Sh Contact

PMI Sampled
Sil Lam
Unrecovered
TRA

Calcareous Lam
Sil Lam FU or CU
Gray/Black Lam Sh
Lt Gray Lam Sh

Black Lam Sh
Unconsolidated Mud
Nodular Lam Sh
Blue/Gray Lam Sh
Core Facies

Upper – Middle Wdfd Sh Contact

Note this is same footage from rightmost image on previous slide

Hunton - Wdfd Sh Contact

PMI Sampled
Sil Lam
Unrecovered
TRA
Calcareous Lam
Sil Lam FU or CU
Gray/Black Lam Sh
Lt Gray Lam Sh
Black Lam Sh
Unconsolidated Mud
Nodular Lam Sh
Blue/Gray Lam Sh
Microflora-fauna

PS2 Core Depth 38.9’

PS3 Core depth 54.2’

All samples shown at same magnification

50 μm
Higher concentrations of eukaryotic biomarkers-C29 steranes indicating more oxic conditions

**U. Woodford**

Higher Concentrations of Chlorobiaceae indicating euxinic conditions (anoxic; H2S rich conditions)-probably stratified water column

**M. Woodford**
Sequence stratigraphy

- Steady decrease in γ-ray response with minor transgressive-regressive cycles superimposed
- 150 gAPI standard gamma ray track width
- Smaller transgressive-regressive cycles superimposed on sea-level fall

U. Woodford

M. Woodford
Note difference in character between fractures healed with predominantly quartz (two at left which appear to follow a much more jagged path) and predominantly calcite (right which has a much smoother edge). This calcite-filled fracture is also wider in aperture.

Quartz-filled microfractures

- Jagged (spider web) appearance
- Thin fracture width
- Associated microporosity
- May terminate or bend at lithologic boundaries
# FMI Fractures

<table>
<thead>
<tr>
<th>Bottom Depth (ft)</th>
<th>Vertical Extent (ft)</th>
<th>Type</th>
</tr>
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<tbody>
<tr>
<td>184.5</td>
<td>2.5</td>
<td>Healed</td>
</tr>
<tr>
<td>122.75</td>
<td>5</td>
<td>Healed</td>
</tr>
<tr>
<td>116.9</td>
<td>0.4</td>
<td>Healed</td>
</tr>
<tr>
<td>116.8</td>
<td>0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>115.1</td>
<td>0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>114.2/113.0</td>
<td>0.2/0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>113.5</td>
<td>0.6</td>
<td>Healed</td>
</tr>
<tr>
<td>112.6</td>
<td>0.3</td>
<td>Healed</td>
</tr>
<tr>
<td>110.1</td>
<td>0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>102.3</td>
<td>0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>101.0</td>
<td>0.6</td>
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<tr>
<td>98.3</td>
<td>0.2</td>
<td>Healed</td>
</tr>
<tr>
<td>93.9</td>
<td>0.1</td>
<td>Healed</td>
</tr>
<tr>
<td>82.0</td>
<td>0.1</td>
<td>Healed</td>
</tr>
</tbody>
</table>

The diagram shows the core fractures with a Frac Density per 2.5 ft on the vertical axis and depth on the horizontal axis. The fractures are color-coded and labeled as UW (Upper Well) and MW (Middle Well). The horizontal lines indicate healed fractures.
Microporosity:

Migration routes?
Planes of weakness?
Seismic and LiDAR shoots to relate fractures, lithology, and unconformity
Conclusions, Applications, & Future Work

- Highly variable lithology within Woodford Shale members; upper and middle Woodford differ;
- Log and rock properties are correlative;
- Middle Woodford TST; Upper Woodford HST;
- Strata are laterally continuous the length of the quarry (and undoubtedly farther away);
- Fracture variability as a result of quartz content;
- Fractures have microporosity;
- LiDAR Fracture Analysis & Shallow Seismic study underway to interrelate geological variables
- Biostrat and organic geochemical analyses are important.

