Marcellus Shale - Geologic Considerations for an Evolving North American Liquids-Rich Play*

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Editor’s note: Please refer to related articles by the author and colleagues:
“The Appalachian Marcellus Shale Play - Discovery Thinking, Timing and Technology,” Search and Discovery Article #110138 (2010).
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Abstract

It is my intent in this presentation to cover the history and evolution of the Marcellus liquids rich play in SW PA, provide some regional perspectives on its unique geologic characteristics and compare it to other portions of the Marcellus play and other US liquids rich plays. I also will cover the importance of landing target selection and provide examples of various reservoir evaluation techniques and technologies used in the characterization and development of this play including 3D seismic, microseismic, core data, and most recently FIB SEM analysis.

AAPG Playmakers Forum – January 24, 2013
William A. Zagorski – Vice President – Geology
Range Resources Corporation - SMSD
Liquids-rich portion of play in SW PA discovered in 2006 and 2007. Play in full development now.

Initial results and potential not immediately evident.

Proved/de-risked portion of play under development in SW PA, northern WV and WV Panhandle.

Northern PA still unexplored and problematic thus far.

NY political climate prohibited testing there.
NE Play – Ro 1.5% to 3.5%. Eastern Limit defined at approximately 3.3% - 3.5% Ro. Appears to have more mature (deeper) burial history. NGL production not yet well defined.

SW Play – Ro 0.95% to 2.5%
Western limit approximately 0.95% Ro
Coincident with Rome Trough
NGL play well defined at 0.95% Ro to 1.4% Ro
Regional Oriskany Structure * Major Fold Trends

**NE Play** – NE Play area situated with major fold belt with relatively high amplitude folding. Salt thickness significantly higher in NE play affecting density of fracturing and faulting in the Marcellus.

**Salt-Cored Thrusts**

**SW Play** – SW Play area located in lower fold amplitude areas further from Allegheny Structural Front. Salt thickness significantly lower resulting in more potential deformation, fracturing and faulting in the overlying Marcellus.

**Salt-Cored Thrusted with Shale Detachments.**

Modified from Cate (1961)
Closely related to burial history associated with Rome Trough.

Presence of underlying Salina interval is key to pressure gradients.

NE Play Area – Approximately 0.50 to 0.82 psi/ft.

SW Play Area – Approximately 0.455 psi/ft to 0.70 psi/ft.
SW Play – Marcellus gross thickness 50 feet to 200 feet. Sedimentation rates appear lower in SW and favor the preservation of organic matter.

Depositional patterns influenced both by position of the Rome Trough and by NW-by-SE trending cross strike faulting.

NE Play – Marcellus gross thickness over 150 feet to over 350 feet. Sedimentation rates appear significantly higher in NE play.

Depositional patterns influenced both by position of the Rome Trough and by NW-by-SE trending cross strike faulting.
**Regional Stratigraphic Cross-Section**

**SW PLAY**
Very thin, condensed section.  
High NTG Ratio.  
Higher TOC%.  
Tully to Marcellus interval condensed.  
SW PA sedimentation rate lower.  
Key pay intervals are MFS’s in Marcellus.

**NE PLAY**
Very thick, expanded section.  
Lower Avg. TOC.  
Low NTG Ratio.  
Tully to Marcellus interval expanded.  
NE PA sedimentation rate significantly higher.  
Key pay intervals are MFS’s in Marcellus.
SW PA Marcellus Core Area – 2004 to Present

SW Play Area
GIP - 40 BCF/mile to 150 BCF/mile.

IPS - 1.0 Mmcfe/d to over 20 Mmcfe/d per lateral completion.

EUR - 2 Bcfeq to over 20 Bcfeq per lateral.

NGL’s - Significant, up to 425,000 Bbls. per lateral in ngl-rich areas.

NGL-rich areas have superior economics over dry-gas areas at current economics.
First three lateral wells tested 0 MCFPD to 600 MCFPD. Fourth and afterwards tested 1,614 MCFPD to 14,100 MCFPD...What was the driver? All have similar azimuths and length. Initial laterals in liquids rich portion of play highlighted in green and were among the first laterals in the play.
Initial four wells on left landed lower in Marcellus section all low IP’s. Four laterals on the right landed higher in section with major changes in results. Landing point/target = Major driver! Note the sequence and IP’s of the liquids-rich laterals. IP test rate strong driver in focus of field development but not the entire story.
Cross section shows significant differences between western liquids-rich area and eastern dry-gas trends. Note the rapid thinning from east to west but see hints of increasing porosity and permeability.
Play area is significantly west of major Appalachian Fold Belt. Key structural features affecting area are basement-faults systems related to Rome Trough rift system and later-day recurrent strike-slip movement.
The number and width of vertical calcite-filled fractures increases significantly from the Western Washington County cores to the eastern Greene County cores.
GIP ranges from 50 BCF/mi² to over 140 BCF/mi² with lower values in liquids-rich portion of play. Note strong control by basement faults.
Net pay thickness ranges from 40 to 150 feet with rapid thinning associated with the western liquids-rich portion of the play.
Note the decrease in bulk density to the west suggesting increased porosity and permeability on a unit of pay basis. Note control of basement-fault blocks.
Note the increase in average TOC content to the west and strong influence of basement faults.
Estimated Ethane Distribution
SEISMIC EVIDENCE OF LIQUIDS IN MARCELLUS
SW PA Wet Area Marcellus Type Curve

2009 - 2011 wells average 281 Mbbls (24 Mbbls condensate & 257 Mbbls NGLs) & 4.2 Bcf

Lateral Length 2,981 ft.
Stages 10

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<tr>
<th>Year</th>
<th>Condensate (MBBLS)</th>
<th>Residue (MMCF)</th>
<th>NGL (MBBLS)</th>
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<tr>
<td>1 Year</td>
<td>7.0</td>
<td>563.9</td>
<td>34.7</td>
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<td>2 Years</td>
<td>10.1</td>
<td>966.9</td>
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<td>3 Years</td>
<td>12.1</td>
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<td>5 Years</td>
<td>14.8</td>
<td>1,592.6</td>
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<td>10 Years</td>
<td>18.0</td>
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<td>141.5</td>
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<td>20 Years</td>
<td>20.7</td>
<td>3,152.4</td>
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2010 - 2011 wells average 400 Mbbls (95 Mbbls condensate & 305 Mbbls NGLs) & 3.9 Bcf

Lateral Length
3,742 ft.

Stages
14

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<th>Year</th>
<th>Condensate (MBL)</th>
<th>Residue (MMCF)</th>
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<td>1 Year</td>
<td>24.7</td>
<td>476.0</td>
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<td>2 Years</td>
<td>34.9</td>
<td>805.8</td>
<td>64.1</td>
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<td>3 Years</td>
<td>41.7</td>
<td>1068.2</td>
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<td>5 Years</td>
<td>50.8</td>
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<tr>
<td>10 Years</td>
<td>64.3</td>
<td>2179.4</td>
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<td>20 Years</td>
<td>78.8</td>
<td>3041.5</td>
<td>241.9</td>
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Actual Gas
Actual Liquids
Type Curve Gas
Type Curve Liquids
Marcellus Wet Gas Provides Significant Uplift

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<th>Component</th>
<th>Current - ethane rejection</th>
<th>Projected - ethane extraction</th>
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<tr>
<td>Gas (1040 Btu)</td>
<td>$3.33</td>
<td>$5.65</td>
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<tr>
<td>Condensate</td>
<td>$1.01</td>
<td>$1.52</td>
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<tr>
<td>NGLs (C3+)</td>
<td>$1.01</td>
<td>$2.52</td>
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<tr>
<td>NGLs (C2+)</td>
<td>$3.33</td>
<td>$3.62</td>
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Assumptions: $3.20 HH, $95.00 WTI, 30% WTI, 2.255 GPM (ethane rejection), 5.255 GPM (ethane extraction), all processing costs, shrink and fuel included. Based on SW PA wet gas quality (1266 processing plant inlet BTU). Wet Gas (Future) based on full utilization of current ethane / propane agreements.
Example standard SEM images are from NGL-rich portion of SW Core area. Note large degraded organics and suggestions of larger pore sizes and high concentration of organics. Large pore sizes and degree of interconnectivity not effectively imaged by standard SEM.
Use of Ar-Ion Beam milling techniques greatly aiding in showing role of organic porosity over standard 2D SEM
Example FIB/SEM images are from NGL-rich portion of SW Core area. Note large pore sizes and high concentration of organics. Large pore sizes and degree of interconnectivity only imaged by FIB-SEM.
Example 3D FIB/SEM images are from NGL-rich portion of SW Core area. Note large interconnected pore sizes and volume related to high concentration of organics combined with large pore sizes and surprising degree of interconnectivity.
Comparison of Landing Targets and FIB/SEM

Note SEM image shows moderate concentration of organics and the presence of much larger pores. Well results were excellent, opening a significant new development area.

Note SEM image shows high concentration of organics but no large pores. Well results disappointing.
Marcellus Shale Play – Giant Status!!!!! Future!!!!

Marcellus Play Potential – 84 TCF/3.5 Billion Bbls liquids (USGS 2011) to 489 TCF (Engelder PSU 2009)!!!