An overview of Some Key Factors Controlling Well Productivity in Core Areas of the Appalachian Basin Marcellus Shale Play*

W. A. Zagorski¹, Douglas C. Bowman¹, Martin Emery¹, and Gregory R. Wrightstone¹

Search and Discovery Article #110147 (2011)
Posted June 13, 2011

*Adapted from oral presentation at Session, U.S. Active and Emerging Plays--Paleozoic Basins and Cretaceous of Rockies, AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

¹Range Resource Corporation, Canonsburg, PA (bzagorski@rangeresources.com).

Abstract

The Middle Devonian Marcellus Shale is one of the premier gas shale plays of North America in terms of total gas resource, extent, production rates, and economic potential. The organic-rich shale of the Marcellus was deposited in a foreland basin setting that was sediment starved and allowed for accumulation and preservation of the organic material. The Marcellus Shale Formation is positioned in the lower portion of the Hamilton Group, which is bounded above by the Middle Devonian Tully Limestone and below by the Lower Devonian Onondaga Limestone. The Upper and Lower Marcellus Shale are divided by the Cherry Valley/Purcell Limestone.

Two major cores areas have developed in the 500-mi long, southwest-northeast trending Marcellus Shale play fairway. The two core areas display unique combinations of controlling geologic factors. Thickness, organic content, intra-organic matter porosity, overpressure, and maturity are some of the key Marcellus gas productivity factors. The Marcellus thickens from approximately 100 ft average gross thickness in southwestern Pennsylvania to over 300 ft average gross thickness in north-central Pennsylvania.

High organic content and the associated porosity and greater overpressure are key gas productivity factors for the Marcellus Shale. Organic content of the Marcellus can be inferred from GR- and density-log data calibrated with core measurements. The high organic content facies of the Marcellus is the key reservoir rock in terms of hydrocarbon storage. The organic content varies from approximately 2 to 15 wt% average in southwestern Pennsylvania to approximately 4 to 10 wt% average in north-central Pennsylvania and can be related to greater organic maturity to the north. The overpressure mechanism is conversion of liquid hydrocarbons to gas with increased organic maturity.

The key pore type in the Marcellus Shale is intra-organic porosity identified by FIB/SEM technology. The intra-organic porosity displays a degree of connectivity and is probably responsible for a significant portion of the Marcellus Shale productivity and gas in-place. Intra-organic pores range from <10 to 200+ nm. Other pore types include inter-particulate, inter-crystalline, and microcracks.
The major core areas of the Marcellus Shale play are examined and compared in terms of the regional thickness, structure, thermal maturity, overpressure trends. Within each core producing region we illustrate the various pore types within key reservoir units using various core, log, thin-section, standard SEM, and Ion Milled SEM work.

**Reference**

“An Overview of Some Key Factors Controlling Well Productivity in Core Areas of the Appalachian Basin Marcellus Shale Play”

W. A. Zagorski, Douglas C. Bowman, Martin Emery, and Gregory R. Wrightstone

2011 AAPG National Conference – Houston, Texas
Marcellus Shale Play – Core Areas

Marcellus Shale Play Area
28,179,200 ac
44,030 mi²

Reserve Potential
485 TCFG

Current Production
2.3 BCFG/D

NE PA Core

SW PA Core

Line of X-Section

Marcellus Shale Play
Play Area
28,179,200 ac
44,030 mi²
Reserve Potential
485 TCFG
Current Production
2.3 BCFG/D
Regional Stratigraphic Cross-Section

SW CORE
- Very thin, condensed section.
- High TOC.
- High NTG Ratio.
- Tully to Marcellus interval condensed.
- SW PA sedimentation rate lower.
- Key pay intervals are MFS's in Marcellus.

NE CORE
- 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.
Key Structural Features Affecting Marcellus Shale

- Presence of Salina below Marcellus interval.
- Basement Faulting associated with Rome Trough
- Cross strike wrench faulting
Regional Pressure Trends – Marcellus Shale

Closely related to burial history associated with Rome Trough.

Presence of underlying Salina interval is key to pressure gradients.

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

SW Core Area – Approximately 0.455 psi/ft to 0.70 psi/ft.
Marcellus Thermal Maturity Patterns

NE Core – Ro 1.5% to 3.5%
Eastern Limit defined at approximately 3.5% Ro
Appears to have more mature (deeper) burial history.
NGL production not yet well defined.

SW Core – Ro 0.95% to 2.5%
Western limit approximately .95% Ro
Coincident with Rome Trough
NGL play well defined at 0.95% Ro to 1.4% Ro
Marcellus Shale Gross Thickness

NE Core – 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 Rome Trough and by NW-by-SE-trending cross strike faulting.

SW Core – Marcellus gross thickness 50 feet to 200 feet. Sedimentation rates appear lower in SW and favor the preservation of organic matter.

Deposition patterns influenced both by position of the Rome trough and by NW-by-SE-trending cross strike faulting.
NE Core – Established production in Marcellus between 3,500 feet to over 8,500 feet.

SW Core – Established Marcellus production between 5,000 feet to 8,000 feet.
Regional Oriskany Structure * Major Fold Trends

Modified from Cate (1961)

NE Core – NE Core 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.

SW Core – SW Core located in lower fold amplitude areas farther from Allegheny Structural Front. Salt thickness significantly lower resulting in more potential deformation, fracturing and faulting in the overlying Marcellus.
Vclay Comparison between SW & NE PA

From Chaoqing Yang, Range Resources

NE Play – Clay volume of Marcellus interval significant elevated and related to sedimentation rate and proximity to source. Patterns appear affected by NW/SE basement fault trends.

SW Play – Clay volume in SW play significantly lower than NE play. Sedimentation rate and proximity to sources potential links. Patterns appear related to NW/SE trending basement faults.
Vcalcite Comparison between SW & NE PA

From Chaoqing Yang, Range Resources

NE Play – NE Play shows overall lower calcite content and increased clay content suggesting closer proximity to source.

Susquehanna core area distinctly calcite-rich.

Distinct basement influence on mineralogy.

SW Play – SW Play area distinctly more calcite-rich suggesting distal position from source area.

Distinct basement influence on mineralogy.
**SW PA Marcellus Core 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 12 Bcfeq per lateral.
- **NGL's**: Significant, up to 250,000 Bbls. per lateral in wet areas.
- **NGL-rich areas** have superior economics over dry gas areas.
SW PA Marcellus Type Log

Upper Devonian

Burkett SH

Middle Devonian

Mahantango-Tully LS

Marcellus SH

Onon, LS

Very High GR

Triple-Combo Log

SW CORE

Very thin, condensed section.
High Net to Gross Ratio.
Higher TOC.
Higher Porosity and Permeability.
Tully to Marcellus interval condensed.
SW PA sedimentation rate lower.
Key pay intervals are MFS’s in Marcellus.

High \( \Phi_{\text{den}} \)

mfs

mfs

287 ft

153 ft

Very High Res Low Sw
Key Pore Types – SW PA Organic Rich Shales

Intra-organic
- Present in all successful gas shales
- HC don’t migrate far; organic C sorbent for HC
- Very low Sw
- Key pore type

Inter-crystalline/particulate
- Between pyrite crystals in framboidal pyrite
- Between platy clay crystals or detrital clay grains/plates
- Higher Sw

Marcellus Shale

High Vol% TOC

Very Low Sw
High Sg

Porosity: 7.3-12.3% BV
GF Porosity: 5.6-10.5% BV
Permeability: 373-1379 nD
TOC: 4.5-12.9 wt%
Ro: 0.85-1.86%
Traditional SEM Method

Ar-Ion Beam Milling Method

Pore Types – SW PA Organic Rich/Calcite-Rich Marcellus Shale

Intra-organic
- Present in all successful gas shales
- HC don’t migrate far; organic C sorbent for HC
- Very low Sw
- Key pore type

Inter-crystalline/particulate
- Between pyrite crystals in frambooidal pyrite
- Between platy clay crystals or detrital clay grains/plates
- Higher Sw

Present in all successful gas shales
HC don’t migrate far; organic C sorbent for HC
Very low Sw
Key pore type

Between pyrite crystals in frambooidal pyrite
Between platy clay crystals or detrital clay grains/plates
Higher Sw
Intra-organic porosity key storage component of shales.

Contains both free and adsorbed gas.

Low or no Sw
NE PA Marcellus Core Area

NE Core Area
- GIP: 40 BCF/mile to 180 BCF/mile
- IPS: 1.0 Mmcfe/d to over 21 Mmcfpd.
- EUR's: 2 Bcf to 20 Bcf per lateral.
- NGL: Not as significant to date as SW PA core area.

- Cabot Oil & Gas Corporation
  - Vertical IP rates range from 2 Mmcfd to 7 Mmcfd.
  - Horizontal IP rates range from 4 Mmcfd to 18.1 Mmcfd.

- Ultra Petroleum Corp/East Resources
  - Initial vertical IP rates up to 6 Mmcfd.
  - Horizontal IP rates from two wells average 14 Mmcfd.

- Fortuna Energy Inc.
  - Horizontal drilling, IP rates on recent horizontals reported at 6 Mmcfd.

- Range Resources Corporation
  - Initial vertical IP rates up to 6 Mmcfd.
  - Horizontal IP rates from two wells average 14 Mmcfd.

- Chesapeake Energy Corporation
  - Horizontal drilling, reported recent 18 Mmcfd discovery.
**NE PA Marcellus Type Log**

**NE Core**
- Very thick, expanded section.
- Lower Avg. TOC.
- Low Net to Gross Ratio.
- Lower porosity and Permeability.
- Tully to Marcellus interval expanded.
- NE PA sedimentation rate significantly higher.
- Key pay intervals are MFS’s in Marcellus.

**Triple-Combo Log**

- **Lower GR**
- **Higher Sw**
- **Lower $\Phi_{den}$**

**Middle Devonian**
- **U Dev**
  - Burkett SH
  - Tully LS
  - Mahantango

**Marcellus SH**
- Cherry Valley LS
- Onondaga LS
- Needmore SH

**NE PA Marcellus Type Log**

**Middle Devonian**

- **U Dev**
  - Burkett SH
  - Tully LS
  - Mahantango

**Marcellus SH**

- Cherry Valley LS
- Onondaga LS
- Needmore SH
NE PA Marcellus Shale Analysis Log

Marcellus Shale

240 ft

Higher Sw

Higher Vclay

Lower Vol% TOC

Interparticulate & Interxlln Φ

Intra-Organic Φ

Marcellus Shale

240 ft

Low Φ

Porosity: 4.6-11.1% BV
GF Porosity: 3.9-10.0% BV
Permeability: 50-200 nD
TOC: 4.4-9.7 wt%
Ro: 1.23-2.56
Pore Types – NE PA Clay – Rich Marcellus Shale

Intra-organic
- Present in all successful gas shales
- HC don’t migrate far; organic C sorbent for HC
- Very low Sw
- Key pore type

Inter-crystalline/particulate
- Between pyrite crystals in framboidal pyrite
- Between platy clay crystals or detrital clay grains/plates
- Higher Sw

Traditional SEM Method

Ar-Ion Beam Milling Method
NE PA Marcellus Intra-Organic Porosity

Intra-organic porosity key storage component of shales.

Contains both free and adsorbed gas. Low or no Sw.

3D Intra-Organic Φ

Photo Courtesy of Chris Laughrey

Marcellus

HFW 1.50 μm

Helios NanoLab 450S

Ion-Milled Sample

Ion-Milled Sample
Comments & Summary

- Organic content/concentration and associated intra-organic porosity at higher LOM are key factors for Marcellus Shale GIP and productivity
  - Less organic content and increased Vclay towards the NE Core area

- Higher intra-organic porosity and overpressure are related to maturity
  - Increased conversion of kerogen to HC and reduction of liquid HC to gas result in greater intra-organic porosity
  - Liquid HC converted to gas, in a relatively fixed pore space, is the overpressure mechanism

- SW Core and NE Core areas have similar Marcellus productivity (especially when liquids are included) despite the NE Core area having thicker gross Marcellus