Marcellus Shale Asset Optimization through Increased Geological Understanding*

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Abstract

Large-scale, manufacturing-like shale gas development involves heavy capital investment. How to develop shale assets efficiently and effectively presents a big challenge to all of us, especially under current low-price market environment. Since 2007, the Marcellus Shale gas extraction has rapidly expanded. The industry has realized a cookie-cutter approach would not work well for this complex shale gas system. To increase efficiency and maximize asset value, different teams need to work together to identify key drivers to well performance and formulate a field development strategy.

As a vital part of this combined effort, many geological and geophysical investigations have increased our understanding of the Marcellus Shale. In addition to the identification of sweet spots, we appreciate the importance of placing the laterals in the high-quality target zone. Further studies reveal interdependence between various reservoir properties. Several parameters, such as thermal maturity, porosity, permeability, abnormal pore pressure, and rock mechanical properties, all play a key role in field development optimization. A solid geological understanding of reservoir quality, geomechanical properties, and geohazards helps to tailor our drilling and completion designs to honor variations in the shale gas reservoir, both vertically and horizontally across the field.

This presentation provides a few snapshots of our geological studies in the following areas:

- Marcellus stratigraphy
- Log analysis/Petrophysical modeling
- Key reservoir parameter mapping
- 3-D shared earth modeling
- FIB SEM investigation
- Role of seismic
- Landing point analysis
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Marcellus: One of the World-Class Supergiant Gas Fields

- Marcellus fairway is 40,000 – 50,000 square miles
- Largest producing field in North America
- SW PA acreages produce dry gas, wet gas, and super rich gas with condensate
Regional Study to Define Play Variability

- Marcellus not created equal
  - Gas in place
  - Reservoir quality
  - Completions quality
- Engineering practices
  - Drilling
  - Completions

Pressure Gradient Marcellus
Pressure Gradient (psia/ft) EUR BCFEQ/mi²

- Thickness
- Porosity
- GIP
- Vclay
- Structure
- Perm
- Vquart
- TOC
- Saturation
- BTU
- Young’s
- Density
- Net Pay
- Pressure
- Poisson’s

Pressure Gradient (psia/ft) EUR BCFEQ/mi²
0.9
0.1
0.0

State Boundary
County Boundary
Faults or Lineament
Stratigraphic Analysis

- Cyclic depositions (T/R sequences)
- 2 main pay packages in the Hamilton (S1-3, M2)
- Thickness and facies change from NW-SE
- Reservoir quality changes both horizontally and vertically

Organic Black shale log signature
- High GR
- Low bulk density
- High neutron porosity
- High resistivity
Log Analysis: Calibrated to Core Data

Color fill: original log   Black curve: new log   Dots: core measurement
Petrophysic Characterization of Horizontal Wells

Estimate petrophysical properties from MWD GR for horizontal wells
- TOC
- Bulk Density
- Porosity
- Young’s Modulus

Color Fill: Original log
Black Curve: Estimated log
Shared Earth Modeling: Keep it alive

• Build 3D shared earth models at very early stage of field development (1st static modeling and dynamic simulation in 2008)
  – Provide static models for reservoir simulation
  – Help visual understanding of reservoir heterogeneity
  – Aid drilling/completions look-back studies
• Keep the models updated with new data
Seismic Interpretation and Applications

- 3D Attributes: Sweet spots
  - TOC
  - Density
  - Rock mechanics
- Geohazards
  - Faults
  - Reefs
- Horizons/Structure
- Fractures
  - Variance
  - Curvatures
  - Ant Track

Wellsite selection
Geosteering
Reservoir modeling
Microseismic interpretation

3D Ant Track Volume
FIB-SEM Images Indicate Pore Development Variation across the Field

Ф = 1.7%  Kerogen = 27.7%  Pyrite = 4.4%

Ф = 3.3%  Kerogen = 32.7%  Pyrite = 1.7%

Ф = 0.3%  Kerogen = 17.1%  Pyrite = 5.04%

Ф = 4.1%  Kerogen = 21.6%  Pyrite = 0.4%
Majority of porosity and permeability is associated with kerogen. Three visible pore types; large mega pores, smaller pores, and a third textural indication any level of smaller pores below resolution and included in Kerogen in the right image.
Landing Target History and Variations
Landing in the Right Target Can Make a Huge Difference

- Pad 1 low-land wells have average 48% upside on mcfe per lb. of sand base
- Comparing Pad 2 and 3, low-land wells have 46% upside
Landing Point Analysis (Dry Gas)

Most of lateral in Sequence II – Initial IP Test 5.5 MMCFPD. Good Well!

Well A

Most of lateral in SQ I – Initial IP Test 12 MMCFPD. Better Well! The % of lateral in optimal target is a major driver!!!!!!

Well B

- If EUR is normalized by Total Sand, Well B has roughly 20% uplift over Well A, with 10-20’ difference in landing point.
Completions Case Study: EUR vs. Total Sand

Pie Chart: Size tied to Total Sand, proportional to Proppant Type
Background Contours: EUR (mcf)

Landing Point

Well | Fraced Stages | PLL (ft) | Total Sand (lb) | Avg Sand Per Stage (lb) | Cluster Spacing (ft) | Avg Treat Pressure (psi) | Avg Sand Per Ft PLL (lb) | Total Clean BBLs | Avg Rate (bbl/day)
--- | --- | --- | --- | --- | --- | --- | --- | --- | ---
A | 10 | 2726 | 5,009,977 | 503,998 | 94 | 6,945 | 1.849 | 82,512 | 67 |
B | 9 | 3418 | 4,546,514 | 505,168 | 93 | 7,027 | 1.880 | 83,564 | 64 |
C | 12 | 3395 | 6,054,205 | 505,350 | 97 | 6,763 | 1.786 | 112,734 | 65 |
D | 8 | 2208 | 3,985,313 | 495,664 | 96 | 6,483 | 1.796 | 61,961 | 66 |
E | 12 | 4018 | 5,768,750 | 480,733 | 98 | 6,772 | 1.436 | 111,819 | 59 |
F | 8 | 3548 | 6,556,734 | 504,364 | 93 | 7,194 | 1.848 | 122,688 | 60 |
G | 8 | 2639 | 4,037,201 | 504,650 | 91 | 6,840 | 1.530 | 68,436 | 66 |

Gr=0.899

Total Sand, [lbf]

4000000 5000000 6000000
• Compile a database-based Well Review Book integrating data from wellbores, geosteer, reservoir quality, completions, and IP/EUR for over 500 horizontal wells.
Lessons Learned

- A robust geological understanding is critical to our shale gas operations.
- A well-planned field development strategy and timely and on-going review is vital to our success of large-scale shale gas development.
- A small change in targeting and completions could make a big difference and creates huge impact considering number of wells to be drilled.
- As a geoscientist, you can define sweet spots at many different scales, from regional, through local, and down to microscopic level.