[PS]Integrated Geologic Analysis from Two Marcellus Shale Science Wells in Northeastern West Virginia*

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Search and Discovery Article #51359 (2017)**
Posted February 13, 2017

*Adapted from poster presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The Marcellus Shale Energy and Environment Laboratory (MSEEL) consists of four horizontal production wells, and two special purpose vertical science wells to better understand the detailed geology of the Lower Devonian organic-rich Marcellus Shale and other shallower shale units. All activities are in coordination with the Department of Energy and the operator Northeast Natural Energy. Understanding the vertical and lateral distribution of the shale lithofacies is critical to decipher the impact of depositional, diagenetic and geomechanical environments on hydrocarbon generation and production. Integrated geological and petrophysical characterization of the Marcellus and surrounding Onondaga through Mahantango units was performed using core, sidewall cores and well log data. Mineralogy and Total Organic Carbon (TOC) content were estimated using triple combo logs and advanced logging tools (e.g., spectral gamma, lithoscanner, and nuclear magnetic resonance) calibrated to core data (XRD and source-rock pyrolysis). A series of multi-mineralogical models were used to understand the petrophysical heterogeneities of the shale units. Based on the mineralogy and organic content the Devonian Marcellus-Mahantango interval is composed of six shale lithofacies. Integrated petrophysical analysis shows that three well-developed organic mudstone facies are present in the Marcellus interval. Correlation of spectral gamma derived uranium content and organic carbon proportion indicates the highly organic mudstone (TOC> 7 weight percent) facies in the lowest part of the Marcellus Shale was deposited in a highly anoxic environment compared to overlying units. Bin porosities from the nuclear magnetic resonance log indicate that organic-rich mudstone facies contains pore sizes greater than 10 nanometers.

References Cited

Bhattacharya, S., T.R. Carr, and M. Pal, 2016, Comparison of supervised and unsupervised approaches for mudstone lithofacies classification: Case studies from the Bakken and Mahantango-Marcellus Shale, USA: Journal of Natural Gas Science & Engineering, v. 33 p. 1-15.

Wang, G., and T.R. Carr, 2013, Organic-rich Marcellus Shale lithofacies modeling and distribution pattern analysis in the Appalachian Basin: AAPG Bulletin, v. 97/12, p. 2173-2205.

Integrated Geologic Analysis from Two Marcellus Shale Science Wells in Northeastern West Virginia

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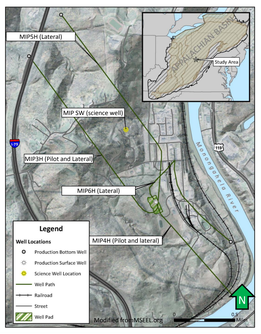
Abstract

Two science wells were drilled to better understand detailed geology of the Marcellus shale and other shallower shale units, in coordination with the Department of Energy and West Virginia University. Understanding the vertical and lateral distribution of the shale lithofacies is critical to decipher the depositional and diagenetic environments and their potential impact on hydrocarbon generation. Integrated geological and petrophysical characterization of the Devonian Mahantango/Marcellus interval were performed using core and well log data from the two wells.

Mineralogy and Total Organic Carbon (TOC) content were estimated using both triple combo logs and advanced logging tools (such as spectral gamma, lithoscanner, and nuclear magnetic resonance) calibrated to core data (XRD and rock-eval pyrolysis). A series of crossplots and multi-mineralogical models were used to understand the petrophysical heterogeneities of the shale units and calculate effective porosity.

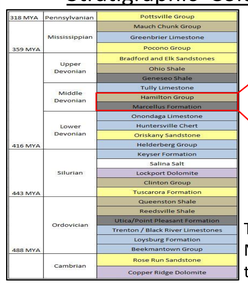
Preliminary results show that the Devonian Mahantango/Marcellus interval is composed of six shale lithofacies based on the mineralogy and organic content. Integrated petrophysical analysis shows that three well developed organic mudstone facies are present in the Marcellus interval. Correlation of spectral gamma derived uranium content and organic carbon proportion indicates the highly organic mudstone (TOC> 6.5 wt%) facies in the lowest most part of the Marcellus Shale was deposited in a highly anoxic environment compared to the shallower units.

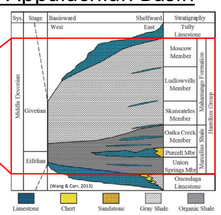
Study Area: Marcellus Shale



The MSEEL study area is located in the SW portion of the Marcellus Play in Northern West Virginia (USA). The site consists of 3 vertical pilot holes (MIPSW, MIP3H, MIP4H), and 4 lateral wells (MIP3H, MIP4H, MIP5H and MIP6H).

Stratigraphic Column: Appalachian Basin



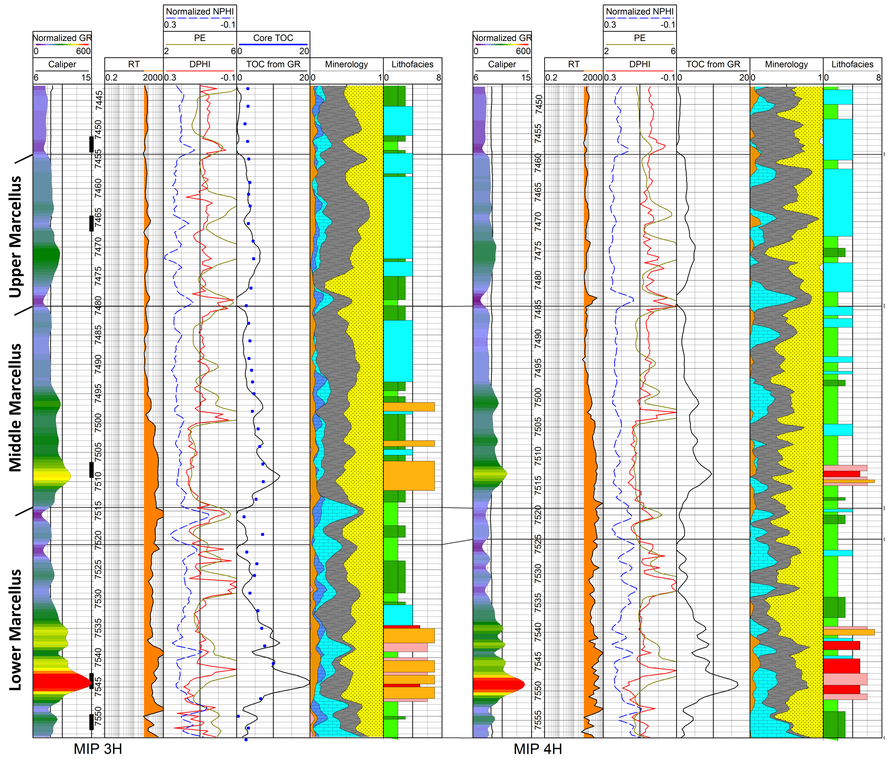


This study focuses on the Middle Devonian Mahantango/Marcellus formations within the Appalachian basin.

MIP 3H

< 150 feet >

MIP 4H



The Marcellus Shale is approximately 100ft (~30 m) thick in the study area and is made up of three organic-rich members upper, middle and lower, based on gamma ray peaks.

The middle and lower members contain high organic-rich facies (TOC ≥ 6.5%).

Lateral variation in facies is seen between wells based on lateral mineralogy changes.

Gamma ray log was used for TOC calculation.

Effective porosity was calculated correcting for kerogen content and clay volume.

Objectives

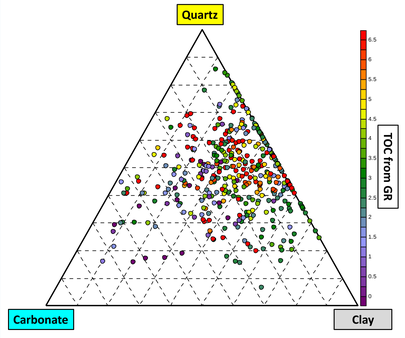
1. Identify different geological facies in the Marcellus Formation to better understand their depositional and diagenetic controls on mineral composition and TOC in the shale members
2. Investigate vertical and small scale lateral heterogeneity of the shale lithofacies, based on Total Organic Carbon (TOC), maturity and mineral composition
3. Interpret relation between shale lithofacies variation and their geomechanical and hydrocarbon production potential

Available Data

MIP 3H

- 111 ft. of whole core through the Marcellus (7445' to 7557')
- 50 Sidewall Cores for TOC and Microbial Research
- 111 Core Plugs taken at 1 ft. intervals :
  - Geomechanical testing
  - X-ray powder diffraction (XRD)
  - X-ray fluorescence (XRF)
  - Rock-eval Analysis
  - Inductively coupled plasma mass spectrometry (ICPMS)
- Well Logs Available:
  - Mineralogy logs (ELAN and Lithoscanner)
  - Sonic Scanner (Dipole sonic, Elastic moduli, Anisotropic stress)
  - Spectral Gamma Ray
  - Nuclear Magnetic Resonance (NMR)
  - Formation Micro-imager (FMI)

Summary of Classified Shale Lithofacies

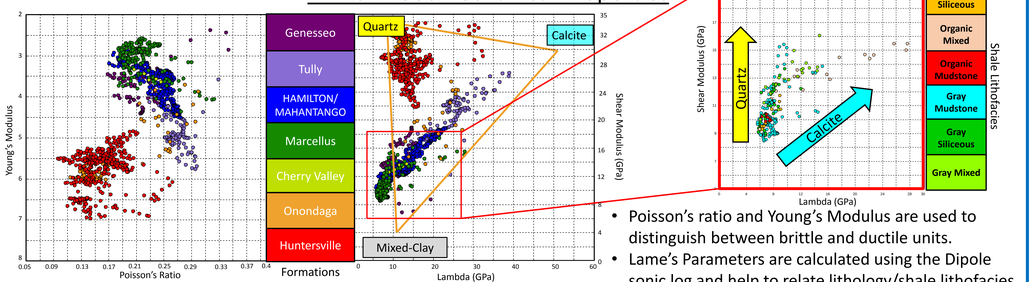


Shale Facies Classification

TOC	Clay > 30% Mudstone	Shale: Quartz/Carbonate > 3:1	Shale: Quartz/Carbonate < 3:1
< 6.5%	Gray Mudstone	Gray Siliceous Shale	Gray Mixed Shale
> 6.5%	Organic Mudstone	Organic Siliceous Shale	Organic Mixed Shale

modified after Bhattacharya and Carr, 2016

MIP 3H: Geomechanical Properties



- Poisson's ratio and Young's Modulus are used to distinguish between brittle and ductile units.
- Lame's Parameters are calculated using the Dipole sonic log and help to relate lithology/shale lithofacies.

Conclusions and Future Work

- Marcellus Shale has been divided into 6 different facies units such as **Organic Siliceous Shale**, **Organic Mudstone**, **Organic Mixed Shale**, **Gray Siliceous Shale**, **Gray Mixed Shale** and **Gray Mudstone**. Carbonate interlayers are present sometimes (in Mahantango).
- Mineralogy controls the brittleness in Shale lithofacies. **Gray Siliceous** and **Organic siliceous shale** are more brittle due to an increase in quartz content and **Gray Mudstone** and **Organic Mudstone facies** are more ductile due to an increase in clay content.
- **Organic Siliceous Shale** lithofacies has high silica and TOC content.
- This analysis is executed using petrophysical data alone, with the addition of XRD, XRF, and core derived TOC will allow us to refine the our shale lithofacies model and refine the depositional environment related to each of the shale lithofacies.

Acknowledgements:
US Department of Energy, National Energy Technology Laboratory for providing financial support through (DE-FE0014297) Marcellus Shale Energy and Environment Laboratory – MSEEL.

References (selected)

Wang, G., and Carr, T. R., 2013, Organic-rich Marcellus Shale lithofacies modeling and distribution pattern analysis in the Appalachian Basin. AAPG bulletin, 97(12), 2173-2205.

Bhattacharya, S. , and Carr, T.R., 2016, Comparison of supervised and unsupervised approaches for mudstone lithofacies classification: Case studies from the Bakken and Mahantango-Marcellus Shale, USA, Journal of Natural Gas Science & Engineering, 1-15.