# [PS]Meso- and Macro-Scale Facies and Chemostratigraphic Analysis of Middle Devonian Marcellus Shale in Northern West Virginia, USA*

**Thomas Paronish[1], Timothy R. Carr[1], Dustin Crandall[2], and Johnathan Moore[3]**

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## Abstract

Marcellus Shale Energy and Environmental Laboratory (MSEEL) consists of four produced horizontal wells and two vertical pilot wells. In order to gain a detailed understanding of the Middle Devonian Marcellus Shale and surrounding Upper Devonian shale intervals, we focused on the two vertical pilot wells (MIP-3H and MIP-4H). Understanding the vertical and lateral distribution of the shale lithofacies and changes in chemostratigraphy are critical to understanding the impact of depositional and diagenetic environments on hydrocarbon generation and production. Integrated geological and petrophysical characterization of the Marcellus and adjacent Onondaga through Mahantango units was performed using core and well log data. Macro-scale lithofacies were determined through a combination of core and CT-scan descriptions. Meso-scale shale lithofacies based on mineralogy and total organic content were developed using a combination of triple combo and advanced logging tools and calibrated to core data (XRD and source-rock pyrolysis).

Chemostratigraphic analysis utilizes x-ray fluorescence to determine the major and trace-element trends associated within the Devonian Marcellus-Mahantango interval. Devonian Marcellus-Mahantango interval is composed of six shale lithofacies, both at the meso- and macro-scale. Petrophysical analysis shows three well developed organic mudstone facies are present in the Marcellus interval. Chemostratigraphic (trace element concentrations) and petrophysical data (spectral gamma derived uranium content) indicate the highly organic mudstone (TOC > 6.5 weight percent) facies in the lowest part of the Marcellus Shale were deposited in a highly anoxic environment compared to overlying units, and the decreased detrital influence indicated by silicon, aluminum, and titanium trends, allowed for better preservation of organic matter.

# Meso- and Macro-Scale Facies and Chemostratigraphic Analysis of Middle Devonian Marcellus Shale in Northern West Virginia, USA


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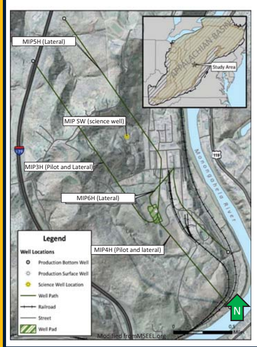
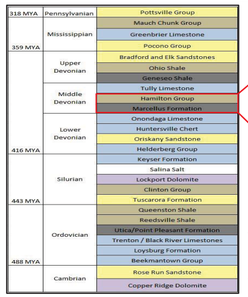
The Devonian Marcellus-Mahantango interval is composed of six shale lithofacies both at the meso- and macro-scale . Petrophysical analysis shows three well developed organic mudstone facies are present in the Marcellus interval. Chemostratigraphic (trace element concentrations) and petrophysical data (spectral gamma derived uranium content) indicate the highly organic rich mudstone (TOC > 6.5 weight percent) facies in the lowest part of the Marcellus Shale were deposited in a highly anoxic environment compared to overlying units, and the decreased detrital influence indicated by silicon, aluminum, and titanium trends, allowed for better preservation of organic matter.

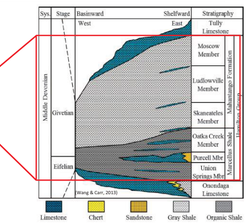

## Study Area: Marcellus Shale




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).

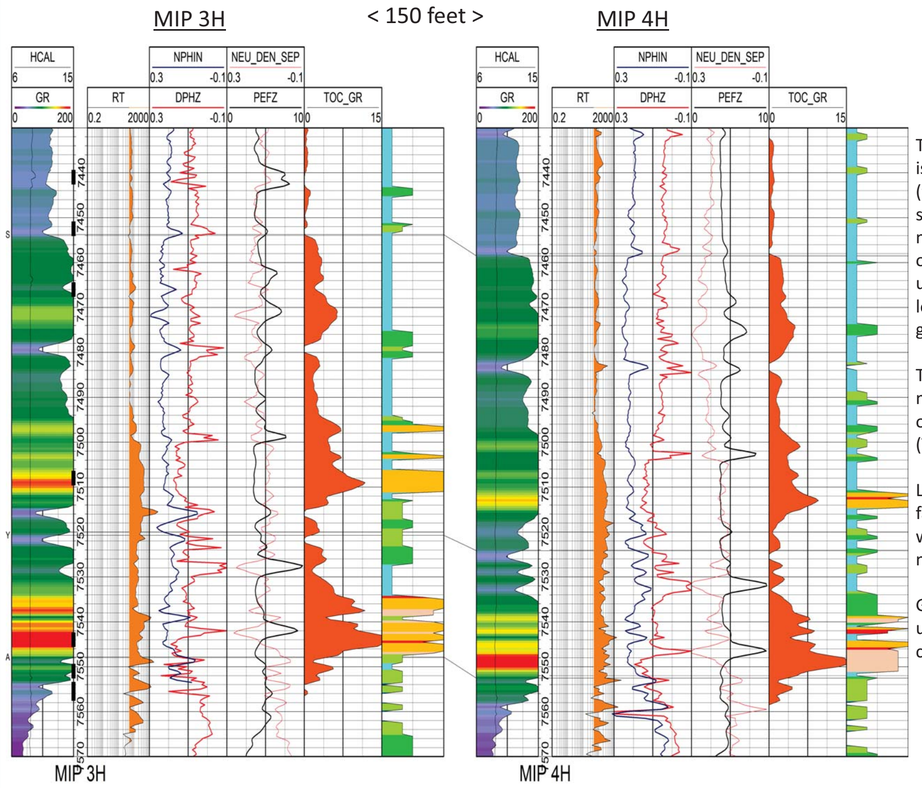
## Stratigraphic Column: Appalachian Basin




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

## Meso-Facies Analysis



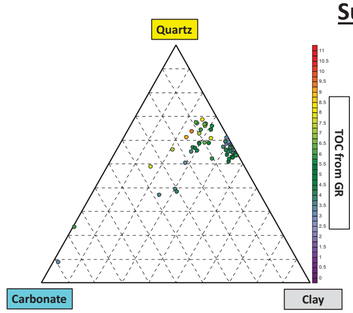

The Marcellus Shale is approximately 100ft (~30 m) thick in the study area and is made up of three organic-rich members upper, middle and lower, based on gamma ray peaks.

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.

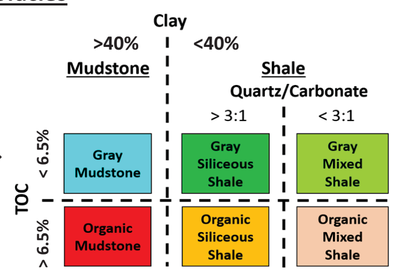
Gamma ray log was used for TOC calculation.

## Summary of Classified Shale Lithofacies



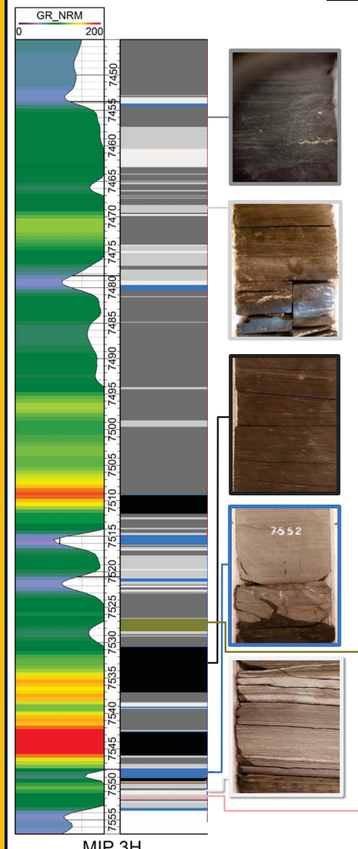

← XRD aids to constrain the cutoffs for the model. 6.5% TOC cutoff was used and a clay content of greater than 40% is considered a mudstone facies

**Key for macro-facies** →
Warm colors are organic-rich facies (>6.5%) and cool colors are organic-lean (<6.5%) or 'gray'




modified after Bhattacharya and Carr, 2016

## Macro-Facies Analysis

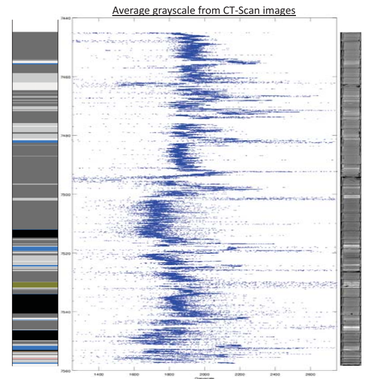



Macro-Facies (core-scale facies ) consist of a combination of core and CT scan description. We have found 6 facies (limestone/wackestone, light-gray shale, mixed dark-gray shale, dark-gray shale, black shale , k-bentonite) and one sub-facies (dark gray shale with nodules):

- **Limestone/Wackestone:** light gray color, heavy bioturbation, generally massive (some minor lamination),and an abundance of fossils
- **Light-Gray Shale:** light gray/gray shale highly laminated (strongly x-bedded) with floculate-like shell fragments, and are typically carbonate-rich
- **Mixed Dark-Gray Shale:** dark-gray shale , light gray/gray lamination (x-bedding)
- **Dark-Gray Shale:** dark-gray shale, minor laminations, minor pyrite
  - **Dark-Gray Shale w/Nodules:** high frequency of large calcite nodule
- **Black Shale:** black shale, very minor lamination, abundance of pyrite
- **K-Bentonite:** gray/grayish yellow, platty structure, mica-rich

- Limestone/Wackestone
- Light-Gray Shale
- Mixed Dark-Gray Shale
- Dark-Gray Shale
- Dark-Gray Shale w/Nodules
- Black Shale
- K-Bentonite

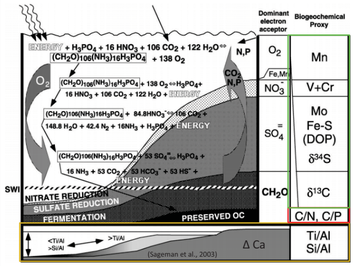
## CT-Scan and Core Facies Analysis

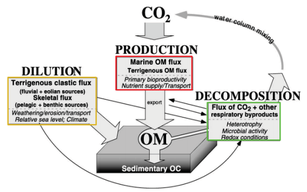



← Shown in the plot to the left is an example of how CT-scan imagery was used to aid the macro-facies description.
Average grayscales from each slice (.5mm) are plotted with depth.

- Grayscales generally range from about 1600 to 2200, high values relate to denser mineral and lower values have less dense mineral.
- Low gray scale values (<1600) are associated with missing material, either due to a fracture or missing core.
- High gray scale values (>2400) are associated with missing material, either due to a fracture or missing core.

# Chemostratigraphy:




**Chemical Proxies:**
**Paleo-Productivity:** Zn, Ni, V
**Phosphates:** P, Y
**Detrital deposition:** Si, Al, Ti, Zr, Rb (Ti/Al, Si/Al)
**Carbonate:** Ca, Mn (indirectly)
**Sulfur Enrichment (Chalcophiles):** Fe, S
**Paleoanoxia:** Mo, U

# X-ray Fluorescence (XRF):

XRF measures elemental proportions in a sample by measuring the energy return after the atom is disrupted by a source x-ray proton. We use 4 different XRF 'suites' to determine the elemental concentration of a larger number of elements and the reliability of each suite when compared to more precise methods of analysis.

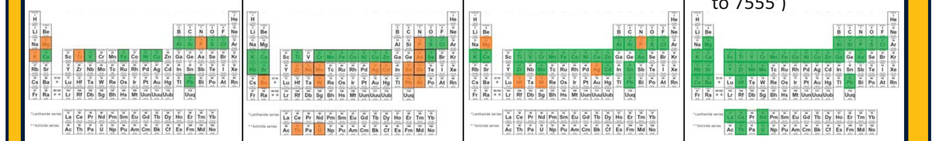
## XRF Suites

### Mining Suite
- 20 sec exposure time
- 2cm resolution (7444 to 7555')

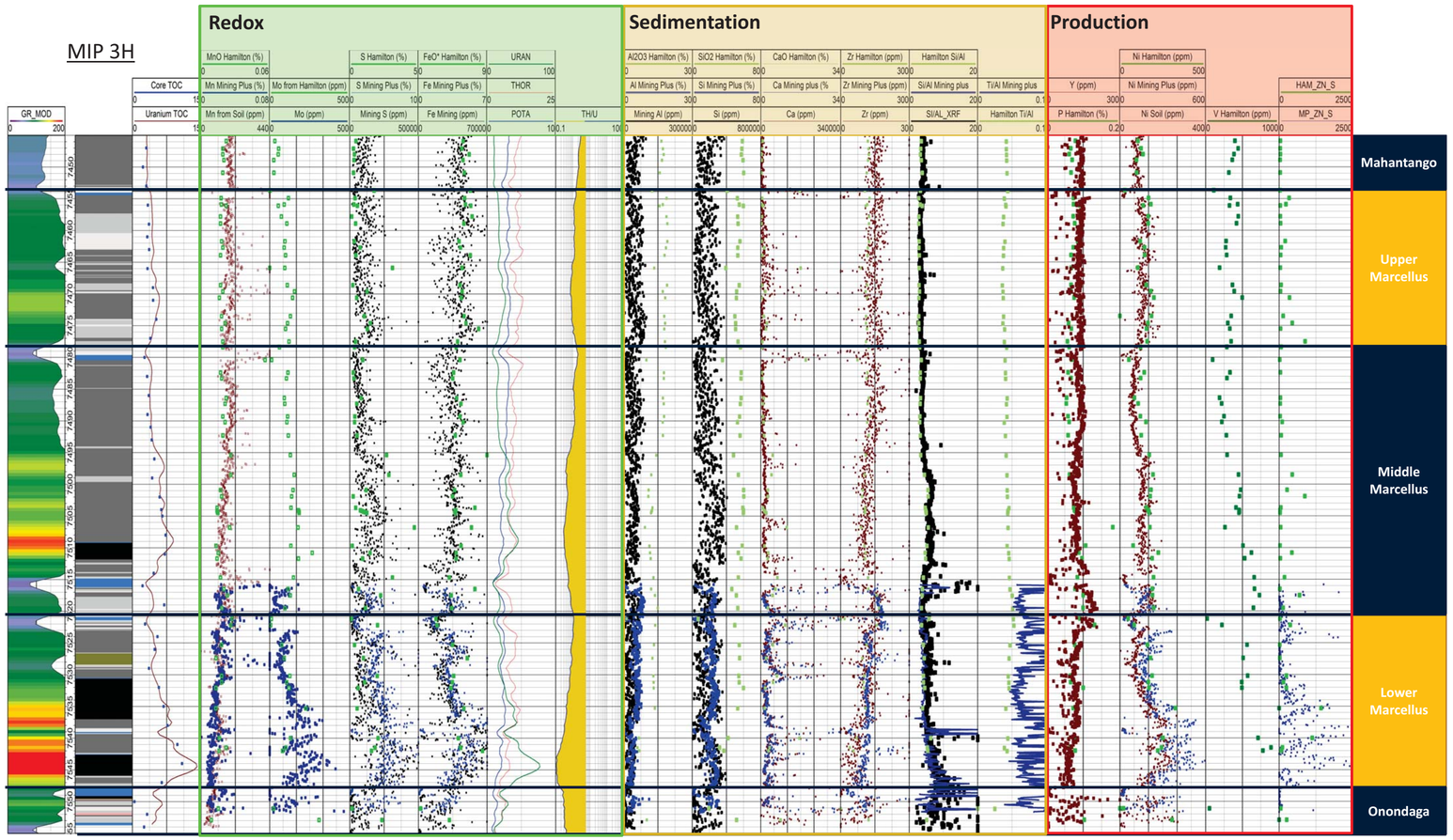
### Soil Suite
- 40 sec exposure time
- (Dual Beam 20 per beam)
- 2cm resolution (7444 to 7555')

### Mining Plus Suite
- 120 sec exposure time
- (Dual Beam 60 per beam)
- 2cm resolution (7515 to 7555')

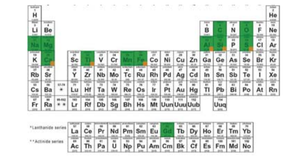
### Hamilton Suite
- Loss on Ignition at 900°C
- Provides higher precision
- 1-3 ft resolution (7444 to 7555')



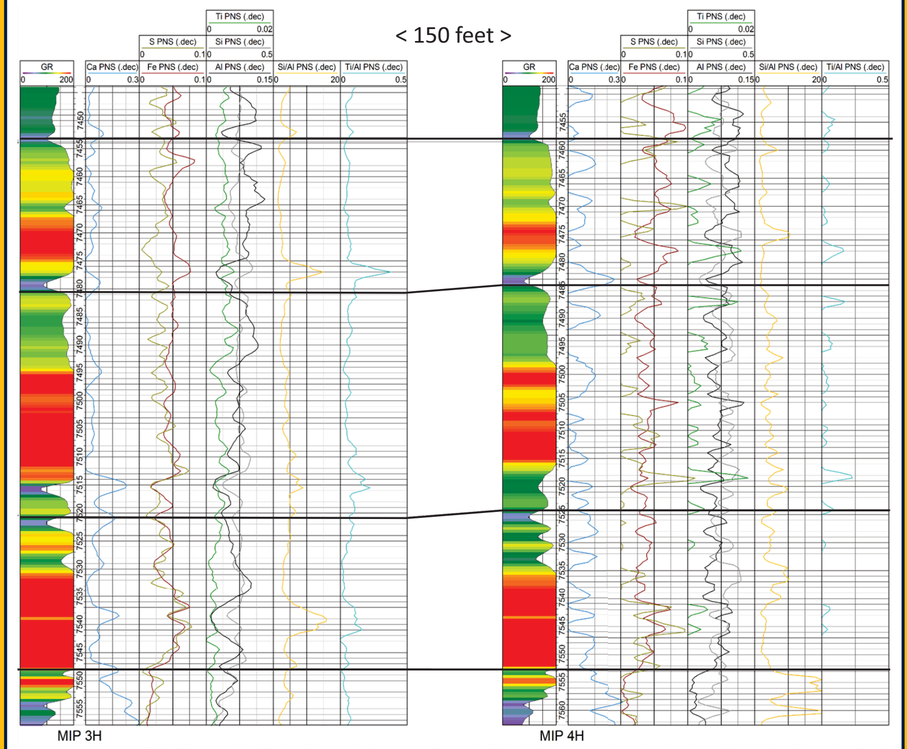
# Chemostratigraphy (Continued)




# Pulse Neutron Spectroscopy (PNS) logs



- Emits high energy Neutron into formation
- Scatter occurs
- Remaining energy is detected by 254 channel gamma-ray detector at base of sonde
- Produces a spectrum which includes inelastic (C, O, Ca, Al, Mg, Si, S, and Fe) and capture spectrum (H, Na, Cl, K, Ti, Cr, Ni, Ba, Gd, Ca, Al, Mg, Si, S, and Fe)




Cross-section of MIP3H and MIP4H: Tract 1: Gamma Ray (0-200 API with color display 0 – 300 API); Tract 2: PNS Calcium (0-.3); Tract 3: PNS Iron and Sulfur (0-.1), Tract 4: PNS Titanium (0-0.02),Aluminum (0-0.15), Silicon (0-0.5); Tract 4: Ratio of Silicon to Aluminum (Si/Al) (0-20); Tract 6: Ratio of Titanium to Aluminum (Ti/Al)(0-0.5)

# Conclusions

- Marcellus Shale has been divided into 6 different meso-facies and 5 different macro-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) in the meso-facies, and **Limestone/Wackestone, Light-Gray Shale, Mixed Dark-Gray Shale, Dark-Gray Shale,** and **Black Shale** (K-Bentonite found in Onondaga Limestone)
- **Organic Siliceous Shale** lithofacies has high silica and TOC content.
- Marcellus Shale in the MIP3H well ranges from anoxic to dysoxic throughout the well, Molybdenum and Uranium trends in the lower Marcellus suggest anoxic/euxinic conditions.
- Lower Marcellus has lower detrital influence relative to the Upper Marcellus, as seen through Zircon and Si/Al trends.
- Production increases with depth, with peak production in the Lower Marcellus, as seen through a decrease in Phosphorous and Yttrium and a increase in Nickel, Zinc, and Vanadium.

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**Sageman, B. B., Murphy, A. E., Werne, J. P., Ver Straeten, C. A., Hollander, D. J., & Lyons, T. W. (2003)**. A tale of shales: the relative roles of production, decomposition, and dilution in the accumulation of organic-rich strata, Middle–Upper Devonian, Appalachian basin. Chemical Geology, 195(1), 229-273.