Importance of Natural Gas
• Currently supports 20% of U.S. energy requirements
• At present usage rate the Marcellus could supply domestic gas needs for up to 56 years
• Reduce dependence on foreign energy

Figure 1. Marine outcrop in Kistler, PA. Outcrop height is approximately 12 m.

Experiment Design
Unexposed hand samples were collected at 2 m intervals from an outcrop in Kistler, PA. Dip angles were measured along the outcrop to calculate a height of 112 m ± 22.5

Samples were crushed into bulk powders with a mortal and pestle and several were tested for the presence of carbonate with 25% HCl

The samples were then weighed and analyzed using a Eurovector elemental analyzer and GV Instruments gas source mass spectrometer

NIST standards Urea, NBS-19, and NBS-127 were used to measure elemental and isotopic abundances of C, S, N, δ¹³C, δ³⁴S, δ¹⁵N, and δ¹⁸O

Results

Figure 2. Sedimentary response to flexural downwarping of Laurentian Coast

Figure 5. Stratigraphic column of the Marcellus Fm, with plots of TOC, δ¹³C, δ³⁴S, δ¹⁵N, N, and S. Red data points represent samples that were analyzed with carbonate present. NBS = maximum flooding surface.

• TOC values in the upper half of the formation were consistently low, but after 50 m steadily increased down section to 8.9% ± 1.2
• δ¹³C data scattered above 65 m, more depleted down section
• Total N steadily increased down section to 0.43% ± 4.414 m above the base
• δ¹⁵N enriched down section, most enriched 14 m above the base
• Total S increases slightly toward base, but appears to drop just above the base
• δ³⁴S data scattered with large variation, most depleted 8 m above base
• Linear regression line through S/C graph intercepts S axis

Figure 6. Total sulfur vs. organic carbon. The solid linear regression line represents the Marcellus with anoxic bottom waters and the dashed line represents a normal saline environment (from Leventhal 1998).

Comparative Analysis
• Devonian aged shales from other Laurentian basins display similar trends in carbon and sulfur elemental and isotopic abundances
• δ¹³C values from the New Albany shale of the Illinois basin range from -19% to -30‰, and TOC values range from 1% to 12% (Hailer 1982)
• δ³⁴S values range from -3% to -30% and total S values range from 1% to 6% (Hailer 1982)
• Carbonate δ¹³C values range from -1% to -10%
• Similarities across multiple basins represent depositional conditions that were common throughout Laurentia

Maximum Flooding Surface
• The maximum flooding surface marks the farthest landward extent of deep water facies and terminates the transgressive depositional sequence
• 12 m above the base of the Marcellus likely represents the maximum flooding surface (Fig. 2)
• Highly depleted values of δ³⁴S and δ¹⁵C, a linear regression line intersecting the S axis on the S/C graph, and the highest concentration of organic matter are all consistent with an anoxic marine depositional environment associated with the maximum flooding surface
• This horizon is ideal for natural gas exploration because it is a source rock, and the impermeable shale provides a seal to trap any oil or gas generated

Conclusions
• Trends within the Marcellus reveal one strong peak in TOC that corresponds with peaks in S and N, enriched δ¹⁵N, depleted δ¹³C, and depleted δ³⁴S
• These data are not consistent with my hypothesis that TOC peaks will correlate with significant excursions in carbon isotope data, although there appears to be changes in δ³⁴S and δ¹⁵N abundances associated with the maximum flooding surface
• The horizon 12 m above the base of the Marcellus represented by the maximum flooding surface has the greatest potential for natural gas production

Sources of Uncertainty
• Dip angle of bedding ranged from 8° to 12°
• Differences between elemental composition of samples and standards
• Initial acid test revealed no carbonate, bulk powders used for analysis

Acknowledgments
I would first like to thank Dr. Jay Kaufman for his support and motivation throughout the duration of this project. I would also like to thank Craig Hebert for his help with the mass spectrometer. Thanks to Natalie Sievers for her help teaching me the unimaginably tedious task of sample preparation.

Figure 3. Standards used with elemental and isotopic abundances

Figure 4. Standards used with elemental and isotopic abundances

Hypothesis
Time series trends within the Marcellus will produce peaks in TOC that will correspond with excursions in δ¹³C, δ³⁴S, and δ¹⁵N

Geologic Setting
The Marcellus Formation is a sedimentary rock unit in the Appalachian basin of the eastern United States. It is composed primarily of black shale, the result of a high concentration of preserved organic matter. The Marcellus Fm. was deposited over 380 Ma in the Middle Devonian Period when eastern Laurentia was located 15-30° south of the equator (Werne 2002).

Sediments eroded from the Acadian orogenic belt accumulated in the continental deep-water basin as transgressive and regressive depositional sequences.

Sources of Uncertainty

Assessment of Natural Gas Production Potential in the Devonian Marcellus Shale of Pennsylvania

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REFERENCES

Figure 3. δ¹³C, δ¹⁵N, δ³⁴S, and δ¹⁸O values range from to values range from to 19‰ to 35‰, and δ¹³C values range from -19‰ to -30‰, and TOC values range from 1% to 12% (Hailer 1982)

Figure 4. Standards used with elemental and isotopic abundances

Figure 4. Standards used with elemental and isotopic abundances