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The Utica Shale Play in Pennsylvania

A Characterization of the Reedsville, Antes, Utica, and Point Pleasant Formations

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Senior Comprehensive Project
Allegheny College, Geology Department
May 2013

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A Senior Comprehensive Project in Geology
Allegheny College, Geology Department
May 2013

Submitted to the Department of Geology at Allegheny College
In Partial Fulfillment of the Requirements for a Bachelors of Science Degree in Geology

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I hereby acknowledge that I have fulfilled my responsibilities, as defined by the Honor Code, and maintained the integrity of both myself and the college community as a whole.

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ACRONYMS AND ABBREVIATIONS

ASTM – American Society for Testing and Materials
    D2797 – Standard Practice for Preparing Coal Samples for Microscopical Analysis by Reflected Light
Eq. - equivalent
KGS - Kentucky Geological Survey
MMBbl – Million barrels (of oil)
PaGS – Pennsylvania Geological Survey
Ro_{eq} – Vitrinite reflectance value equivalent
SHRo – Solid hydrocarbon reflectance value
Tcf – Trillion cubic feet (of natural gas)
TC – Total carbon
TIC – Total inorganic carbon
TOC – Total organic carbon
Tmax – Maximum temperature reached during burial
XRD – X-ray diffraction

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ABSTRACT

The Utica Shale is attracting considerable attention in Pennsylvania, Ohio, and New York. It was recently estimated by the U.S. Geological Survey to contain a mean undiscovered resource potential of 940 MMBbl oil, 38.2 Tcf gas, and 208 MMBbl natural gas liquids (Kirchbaum *et al*, 2012). Due to the potential importance of this undiscovered resources, the purpose of this study was to explore the Utica Shale play by comparing and contrasting individual stratigraphic formations of the play across Pennsylvania using a combination of publicly available rock cuttings, outcrop samples, well and geologic data. Deep wells from six counties in Pennsylvania were selected to represent a range of thermal maturities across the state: Crawford County (oil to wet gas area), Mercer County (wet gas area), Warren County (dry gas area), Armstrong County (dry gas to overmature area), and Centre and Sullivan counties (overmature area). Rock cutting samples from these wells were collected to represent the formations of the Utica play: the Reedsville Shale, the Antes Shale, the Utica Shale and the Point Pleasant Formation. Selected cuttings and outcrop samples were evaluated for mineralogical content using XRD methods. Cuttings were also evaluated for total organic carbon (TOC) content and bitumen reflectance to assess organic richness and thermal maturity.

The formations of the Utica play have unique mineralogical compositions. The Reedsville Shale is particularly deficient in quartz (20.41%-50.00%) with a mean of 36.63% weight. The Point Pleasant is the most quartz-rich formation (39.60%-53.00%) with a mean of 44.40% weight. In addition, the Point Pleasant Formation is also the most abundant in carbonate minerals with 16.69% calcite and 2.49% dolomite. The Antes Shale and Utica Shale have comparable mineralogy in almost all of the mineral families, particularly quartz with mean values of 41.18% and 42.27%, respectively. However, the Antes Shale and Utica Shale vary greatly in carbonate content with the Antes Shale being much more carbonate rich. Since the Antes Shale only exists in outcrop, the Antes was not assessed for maturity or total organic carbon content. Vitrinite reflectance ($R0_{eq}$) values, estimated from bitumen reflectance measurements (SHRo) using the methods of Jacob (1989) and Landis and Castaño (1995), indicate that the Utica Shale is the most mature with a range of 1.61-3.20 Ro_{eq} values. The highest thermal maturity data in the Utica Shale is associated with well locations in Sullivan County (Pennsylvania's overmature area). The Point Pleasant Formations has a wide range of Ro_{eq} values, 1.04 to 1.91, representing counties spanning a wide range of thermal maturities (from oil and wet gas to overmature areas) across the state. TOC results, intended to assess the organic richness of these samples, indicate the Point Pleasant as the most organic-rich of the formatoins with a mean TOC value of 2.03. The Reedsville shale is the least organic rich with a mean TOC value of 0.25. Metal oxides within the Utica Shale and Point Pleasant Formation, along with high maturity values, suggest influence from the migration of underlying Trenton Group hydrothermal fluids. However, more work needs to be performed on this topic to conclude the above hypothesis. Given mineralogy, thermal maturity, and organic content, the Utica Shale and Point Pleasant Formation are the most viable hydrocarbon reservoirs in Pennsylvania.

1.0 INTRODUCTION

1.1 History of Shale Gas

Pennsylvania has a rich history of oil and gas production from Devonian and Silurian-age siliciclastic reservoirs. In the early 2000's, the Devonian Marcellus Shale play became a focus of major production efforts across the state when organic-rich shale was recognized to contain a significant amount of natural gas, accessible by hydraulic fracturing and other stimulation techniques (Carter *et al*, 2011). Until this time, shale had been overlooked as a reservoir rock in petroleum systems due to a lack of permeability and porosity. In the conventional hydrocarbon reservoir model, organic material matures in shale, an organic-rich source rock, and migrates to a porous and permeable reservoir rock before being sealed by another impermeable rock layer (Fig. 1). Recently, it has been recognized that in marine shale source rocks, gas can be adsorbed to organic and clay molecules and remain within the source rock, which doubles as a low permeability and porosity reservoir (Jarvie, 2011). In this unconventional reservoir model, shale is able to act as a reservoir, source, and seal in a petroleum system (Aplin and Macquaker, 2011). Recently, the Appalachian Utica Shale play (Fig. 2), a deeper and much larger play than the Devonian and Silurian-age deposits, has been attracting considerable attention in the Appalachian Basin states. The Utica Shale play has been estimated by the U.S. Geological Survey to contain a mean undiscovered resource potential of 940 MMBbl oil, 38.2 Tcf natural gas, and 208 MMBbl natural gas liquids (Kirchbaum *et al*, 2012). Due to the considerable size of hydrocarbon production potential within this reservoir, the geochemical and geophysical features of the individual formations must be understood to properly assess and explore the Utica Shale play.

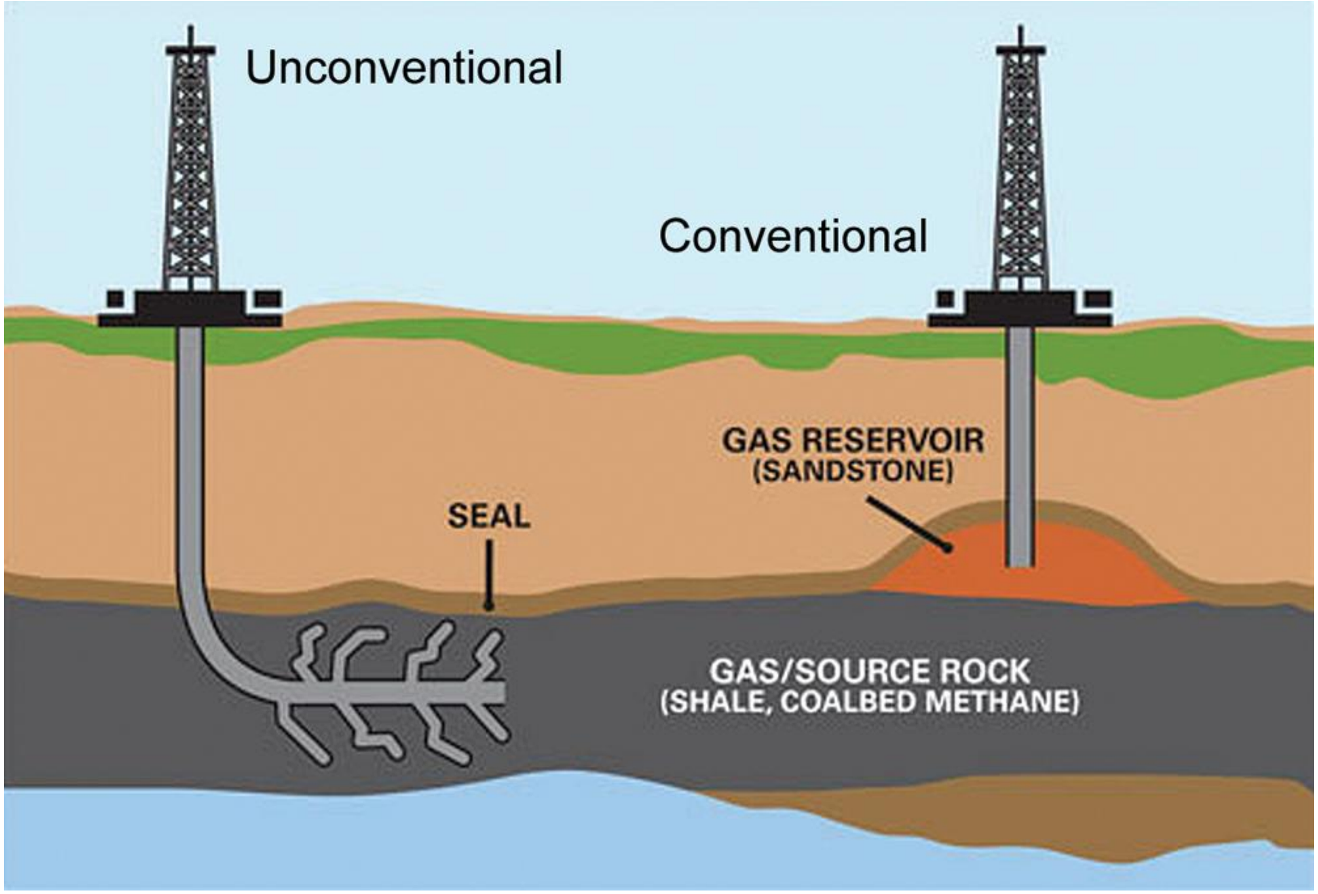

Figure 1. Schematic comparison of conventional and unconventional shale gas reservoirs.

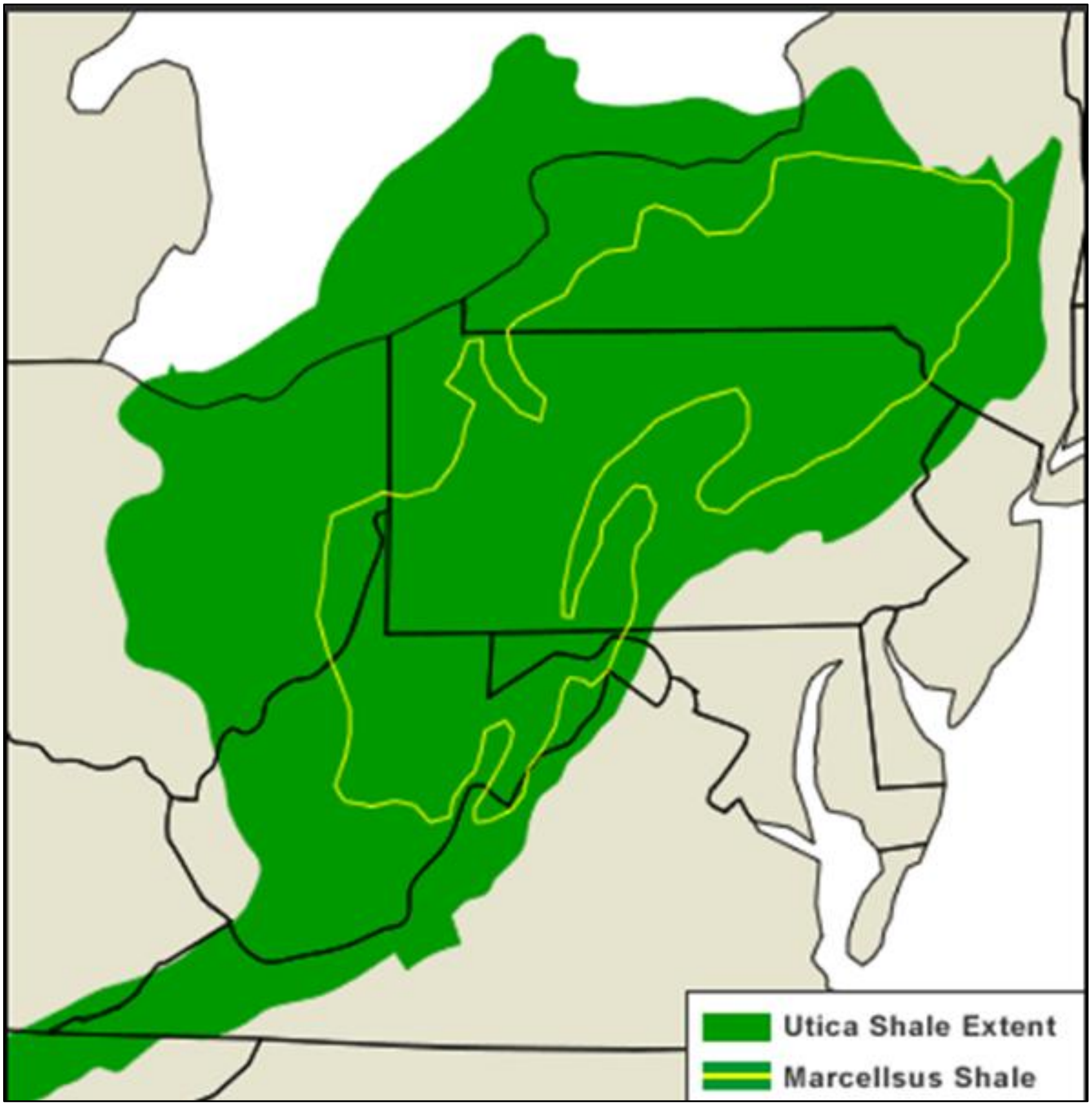

Figure 2. Extent of the Devonian Marcellus Shale and the Ordovician Utica Shale in the Appalachian Basin (Modified from EIA, 2012 and Geology.com, 2013).

1.2 Statement of the Problem

Unconventional shale gas reservoirs are characterized by complex textural and mineralogical heterogeneities (Aplin and Macquaker, 2011). These variations in hydrocarbon reserves within shale source rocks occur due to differences in environments of deposition (Jarvie, 2011) and can be used to assess hydrocarbon availability and production. Advances in horizontal drilling and hydraulic fracturing have increased interest in and development of these unconventional shale plays. In order to thoroughly understand the Utica Shale play and its hydrocarbon producing potential, physical and geochemical differences within individual formations within the play must be studied and understood. While the extent and production potential of the play has been estimated, changes in geochemical and geophysical properties of individual formations need to be further explored. One major complication in understanding the Utica Shale play is the implication of nomenclature. The nomenclature for the Utica Shale play changes from state to state, making the boundaries between formations across the basin difficult to distinguish. In Pennsylvania alone, multiple formations have been identified that change discretely with depth, lateral extent, and presence of outcropping (Fig. 3). The term “Utica” has been applied to the Ordovician shale in Pennsylvania throughout the 19th century (PaGS-USGS, 2012). Since that time, the Utica Shale play has been divided into the Reedsville Shale and equivalent Martinsburg Shale, the Utica Shale and equivalent Antes Shale, and the Point Pleasant Formation which may or may not include the underlying gradational contact with the underlying Trenton Limestone. Within each of the formations, discrete changes in mineralogy, organic content, and maturity take place both laterally and vertically. These changes affect the reservoir quality of the formations therefore creating differences in production potential within the Utica Shale play.

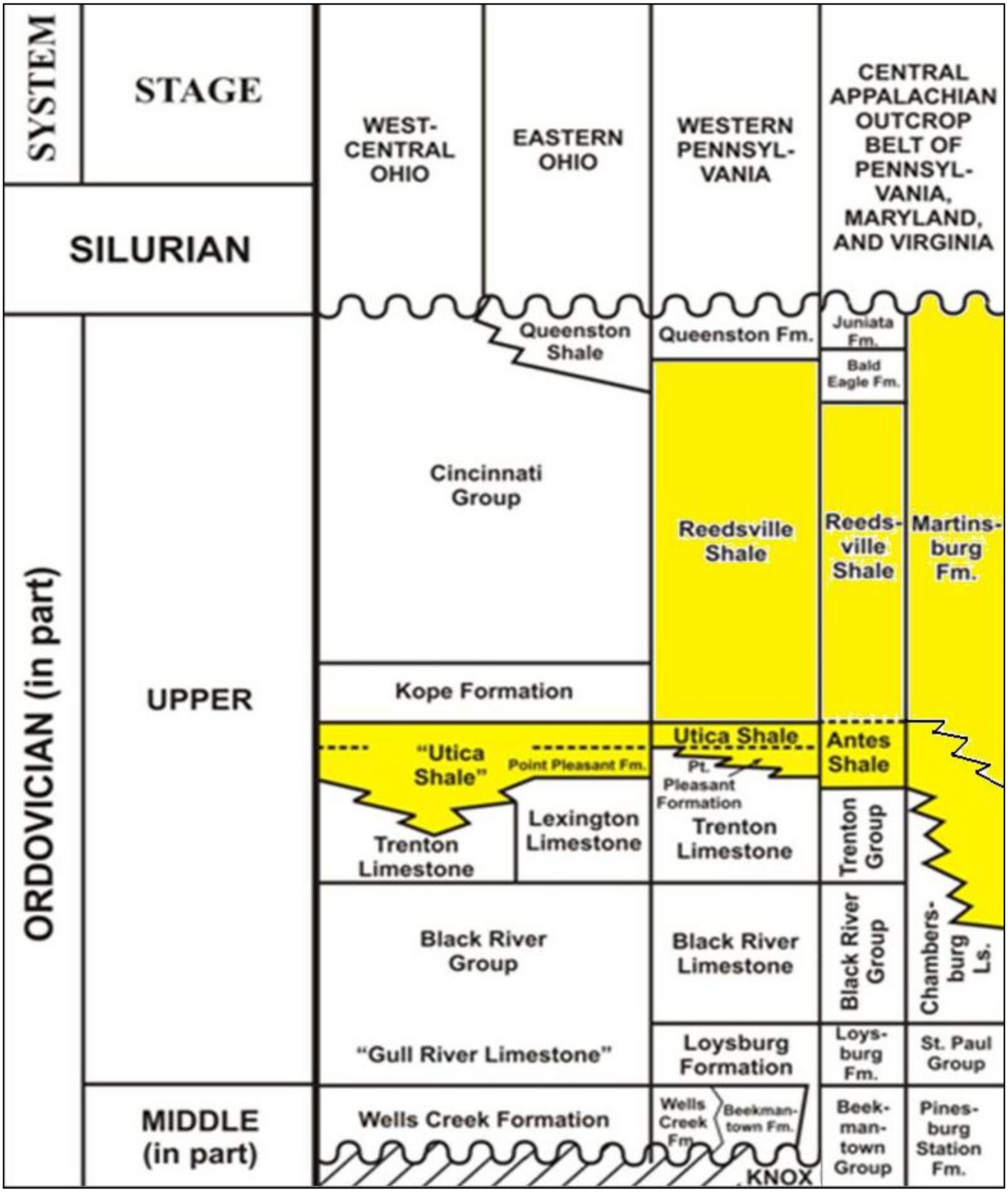

Figure 3. Regional stratigraphic correlation chart illustrating relationships for the Upper Ordovician black shale of the Appalachian Basin (PaGS, 2012). Notice the differences in stratigraphy and nomenclature across Pennsylvania.

Facies analysis has been used as a stratigraphic and sedimentological tool for decades to identify and characterize the lithologic aspects rock facies (Wang and Carr, 2012). However, because shale lacks the typical physical structures used to identify facies through facies analysis, other relationships among shale formation data must be employed such as mineralogy, organic content, and thermal maturity. These geochemical and geophysical analyses allow for the distinction between otherwise seemingly uniform shale formations. In this study, the term "formation" will be applied to describe four unique stratigraphic horizons representing laterally and vertically continuous zones of similar mineral composition, maturity, and organic content within the Utica Shale Play. By understanding the implication of mineralogy, maturity, and organic content within each formation, the important characteristics of the Utica Shale Play can be explored.

1.3 Research Objective

The purpose of this study is to identify and characterize the various formations within the Utica Shale play in Pennsylvania, the Reedsville Shale, the Utica and Antes Shale, and the Point Pleasant Formation for mineralogy, organic content, and thermal maturity to assess reservoir quality for each formation and determine which of these formations represents the most ideal hydrocarbon reservoir in Pennsylvania. Additionally, this study will address the geophysical and geochemical characteristics that change within the play and allow for characterization of the four distinct formations.

1.4 Regional Geology

The Utica Shale play is an Ordovician-age shale deposit (485 mya - 450 mya) spanning much of New York, Pennsylvania, Ohio, West Virginia, and Kentucky (Fig. 2). From Pre-Cambrian to Ordovician time, an eastward thickening, passive margin developed on the eastern edge of the Precambrian Laurentian Craton (Shultz, 1999). Throughout Cambrian time, multiple, spasmodic transgressions occurred on the low areas of the North American continent and quartz-rich sand was deposited in shallow shelf settings (Prothero and Dott, 2010). By Early Ordovician time, carbonate deposition replaced quartz-sand deposition with further submergence of the continent (Prothero and Dott, 2010). After several million years of carbonate deposition, the sea retreated and a widespread unconformity was produced over much of the craton (Prothero and Dott, 2010). During the middle Ordovician, the Taconian Orogeny began and central Pennsylvania transformed from a carbonate platform to a foreland basin, receiving terrigenous sediments in the subsiding foreland basin to the east as wise shallow seas developed to the west (Shultz, 1999 and (Arens and Cuffey, 1989). Renewed transgression of the sea resulted in further carbonate deposition to the west and development of the Trenton and Lexington platforms (Fig. 4) (Prothero and Dott, 2010). In the Appalachian Basin, as Late Ordovician carbonates were being deposited in the shallow sea to the west, dark brown and black organic-rich mud was delivered by the eroding Taconic orogeny to the deeper subsiding basin in the east (Riley *et al*, 2006). During Late Ordovician time, the increase in Taconic intensity caused a rapid rise in sea level with increased subsidence as the Utica Shale replaced carbonate deposition and formed the Utica/Point Pleasant sub-basin between the Trenton and Lexington platforms (Riley *et al*,

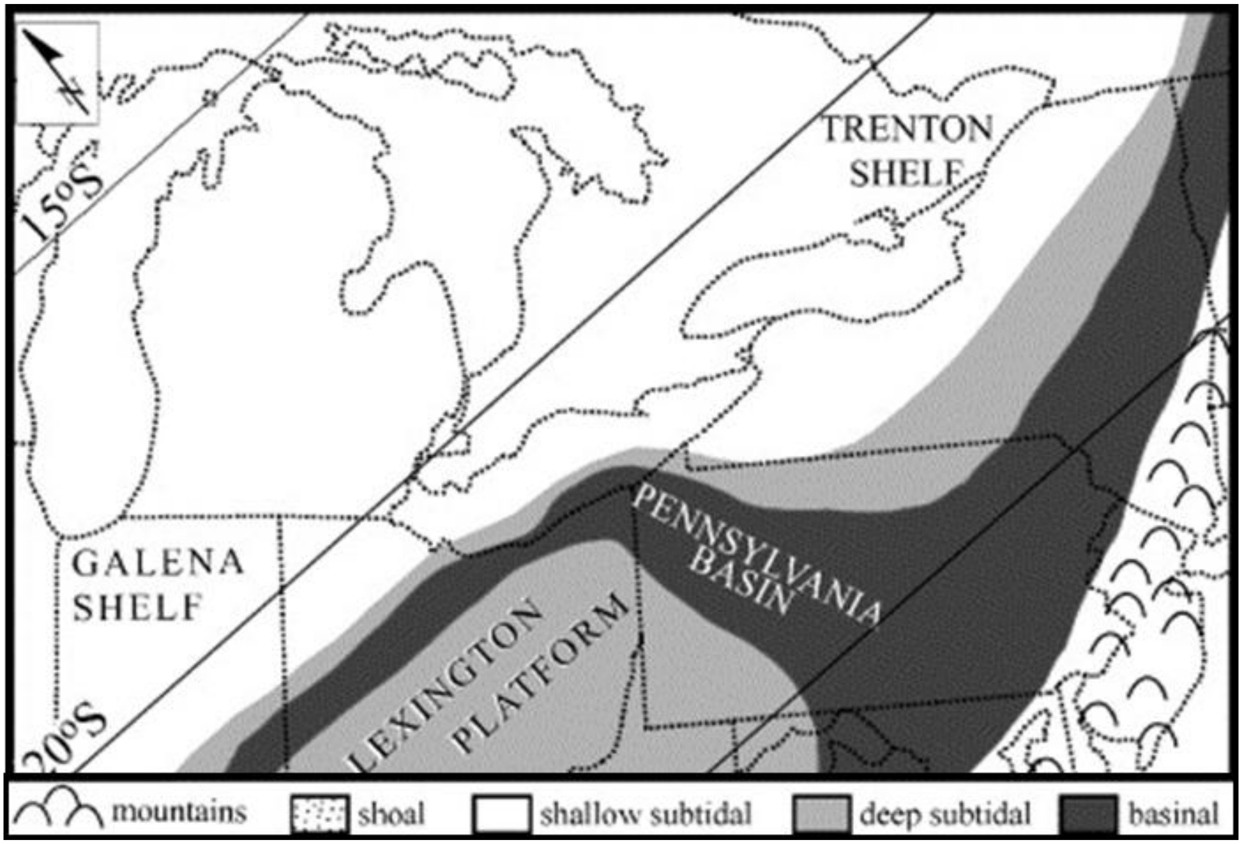

Figure 4. Paleogeographic map of Laurentia during the Late Ordovician (modified from McLaughlin and Brett, 2004). The Lexington Platform and Trenton Shelf (Platform) border the Utica/Point Pleasant sub-basin (Pennsylvania basin).

2006). As Taconic intensity lessened at the end of the Ordovician and open marine environments were superimposed on the previous foreland basin setting, deposition continued with mixed shale and limestone. The transitions in sediment deposition are evident in the Taconian clastic wedge (Fig. 5) (Riley *et al*, 2006).

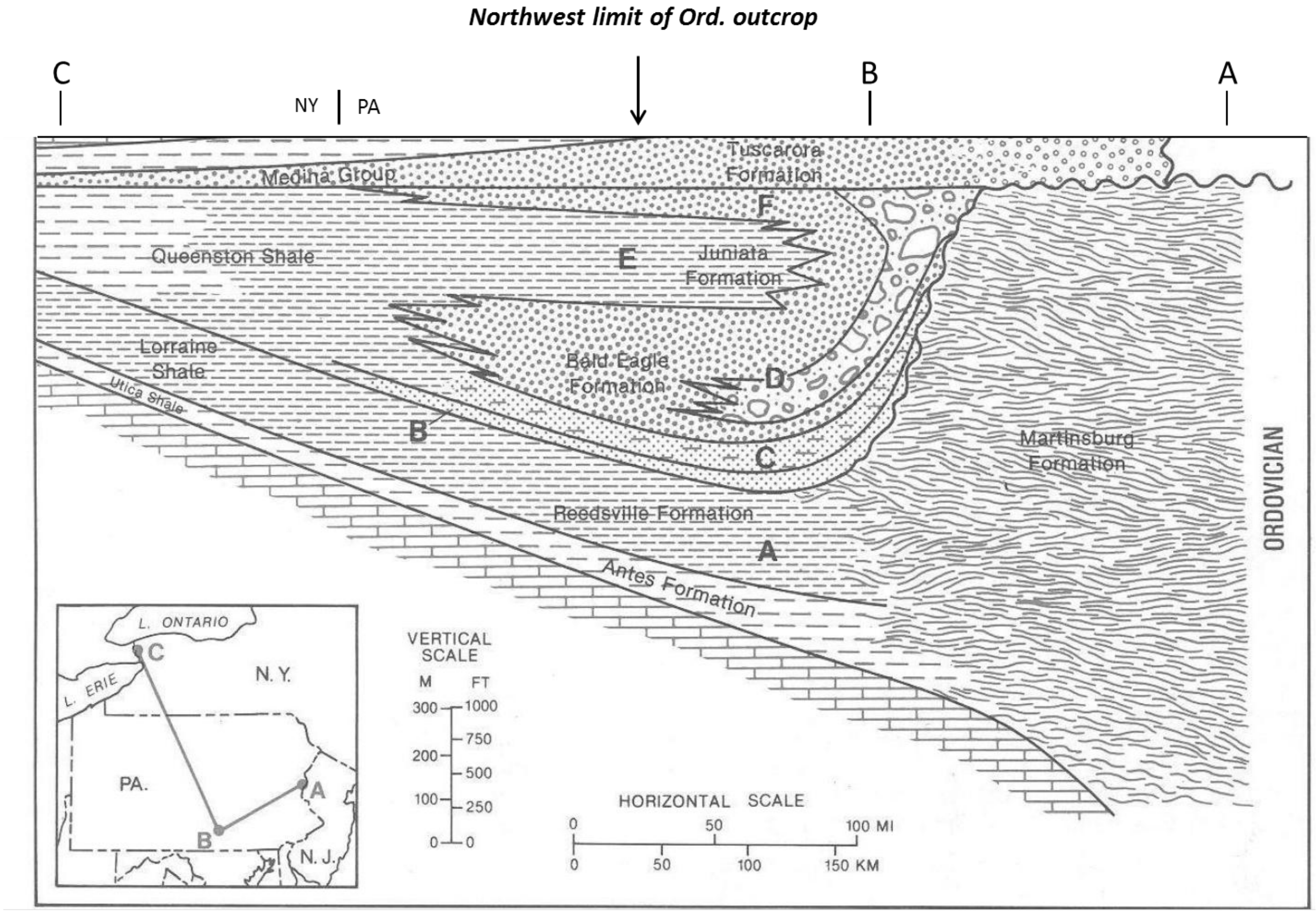

Figure 5. Schematic cross section through the Taconian clastic wedge showing transition of formations with proximity to the Taconian orogeny (adapted from Thompson, 1999).

The accumulation of Ordovician sediments can be summarized in three parts:

1. Stable carbonate platform deposition of the Trenton Limestone and Point Pleasant Formation in relatively anoxic, deep-water conditions.
2. Submergence of the carbonate platform with marine limestone and siliciclastic sedimentation resulting in gradation from the Trenton Limestone and Point Pleasant Formation to the Utica Shale.
3. Filling of the basin with both marine and continental sediment of the less organic Reedsville Shale in shallow water.

(Shultz , 1999)

This evolution of basin setting and associated depositional processes resulted in the Utica Shale play. The play consists of the Trenton Limestone overlain by inter-tonguing, interbedded limestone and shale of the Point Pleasant Formation and the black, organic Utica Shale (Patchen *et al*, 2006). The play is capped by less organic, brown shale with interbedded sand and silt called the Reedsville Shale. The play thickens and deepens to the south and east toward the Taconic foredeep as an asymmetrical basin (Shultz, 1999) (Fig.5).

1.5 Parameters Used to Determine Reservoir Quality

The geochemical and geophysical properties of shale are extremely important in petroleum exploration and production (Aplin and Macquaker, 2011) since shale productivity depends on a number of reservoir quality factors. Gas is stored within shale in three manners:

(1) as free compressed gas in open pore spaces and cracks

(2) as adsorbed gas on organic and clay surfaces

(3) as diffuse gas within solid organic matter

(Sondergeld *et al*, 2010)

Sondergeld *et al* (2010) propose a list of common reservoir attributes used in assessing gas-shale systems for reservoir quality (Table 1). These characteristics coincide with data from the Barnett Shale of the Fort Worth Basin in Texas (Pollastro *et al*, 2003) where the main producing shale facies is a black, organic-rich siliceous shale with roughly 45% quartz, 27% clay, and 10% carbonate along with 5% feldspar and 5% pyrite with a 5% TOC based on average weight percent. Pollastro *et al* (2003) also found that for the Mississippian-Pennsylvanian-age organic-rich shale, the greatest occurrence and explusion of hydrocarbons occurred in a "sweet spot" along the paleoaxis of the basin where thick siliceous shales are overlain and underlain by impermeable fractured limestone. Major hydrocarbon production is also found in the deepest parts of the asymmetrical shaped peripheral foreland basin (Pollastro *et al*, 2003). Like the Fort Worth basin, where major hydrocarbon production has occurred, the Ordovician black shale of the Appalachian basin overlies thick carbonate deposits. Using the characteristics porposed to Pollastro *et al,* (2003) and those summarized in Table 1 for an ideal hydrocarbon reservoir, can the individual formations of the Utica Shale play can be assessed.

Table 1. Desirable attributes for shale-gas producing reservoirs (adapted from Sondergeld et al, 2010, Riley et al, 2011, and Peters and Cassa, 1994).

Attribute	**High production variables**
Mineralogy	>40% quartz and carbonates <30% clays with biogenic silica
Reflectance (Ro)	Immature <.60 Oil generation 0.65-0.90 Capable of gas generation >1.1 Dry gas window of >1.4
Organic Content	>1%-2% total organic carbon

1.5.1 Mineralogy

According to Sondergeld *et al* (2010), mineralogy greatly controls shale properties and, therefore, reservoir production. Gas-shale is dominantly quartz, clay, and carbonate (Sondergeld *et al*, 2010). Although, intuitively, high quartz content would detract from the quality of a hydrocarbon reservoir, high quartz and carbonate content, rather than clay, produce a better hydrocarbon reservoir (for rocks of the same thermal maturity) (Wang and Carr, 2012). Quartz and carbonate produce a more brittle reservoir which is easier to stimulate via hydrofracturing techniques. The presence of these minerals, which lack the ability to adsorb gas, allow for extensive fracture networks free gas flow within the reservoir (Wang and Carr, 2012). Heterogeneities within shale can be used to characterize and compare shale formations.

1.5.2 Solid hydrocarbon reflectance

Solid hydrocarbons are solid phase accumulations of (mostly) hydrocarbons produced by petroleum generation from source rocks. Solid hydrocarbons can fill spaces in rock such as pores and vein, and migrate microns to tens of miles with significant variability in their soluble hydrocarbon content. In hand sample, solid hydrocarbons range from dark brown to black in color, have a vitreous luster, and exhibit conchoidal fractures. In the subsurface, accumulations of solid hydrocarbons from exhumed reservoirs are well understood, but hydrocarbons from shale are less-so. There are multiple optical forms of disseminated hydrocarbons, “degraded”, “homogeneous”, and “coked” (Fig. 6). Degraded bitumen represents organic material with very low reflectance values that has been degraded due to microbial activity in oxygenated environments. This type of bitumen indicates poor reservoir quality and little hydrocarbon generation. Homogenous solid hydrocarbons indicate suitable hydrocarbon reservoir quality and make for the most reliable correlation with other thermal indicators of reflectance (Landis and Castaño, 1995). Coked bitumen has matured past the point of viable hydrocarbon generation, producing very high reflectance values, and, like degraded bitumen, representing poor reservoir quality. Coked bitumen is often found in overmature areas that don’t produce gas or oil. Schoenherr *et al* (2007) concluded coking of bitumen to be a result of hydrothermal fluids derived from deeper strata which causes matures bitumen next to fractures. At increases distance from hydrothermal deposition, less mature bitumen is found. believe the presence of multiple bitumen types represents multiple hydrocarbon migration events Solid hydrocarbon reflectance (SHRo) provides a common parameter by which solid hydrocarbons, at all concentrations, can be characterized and compared

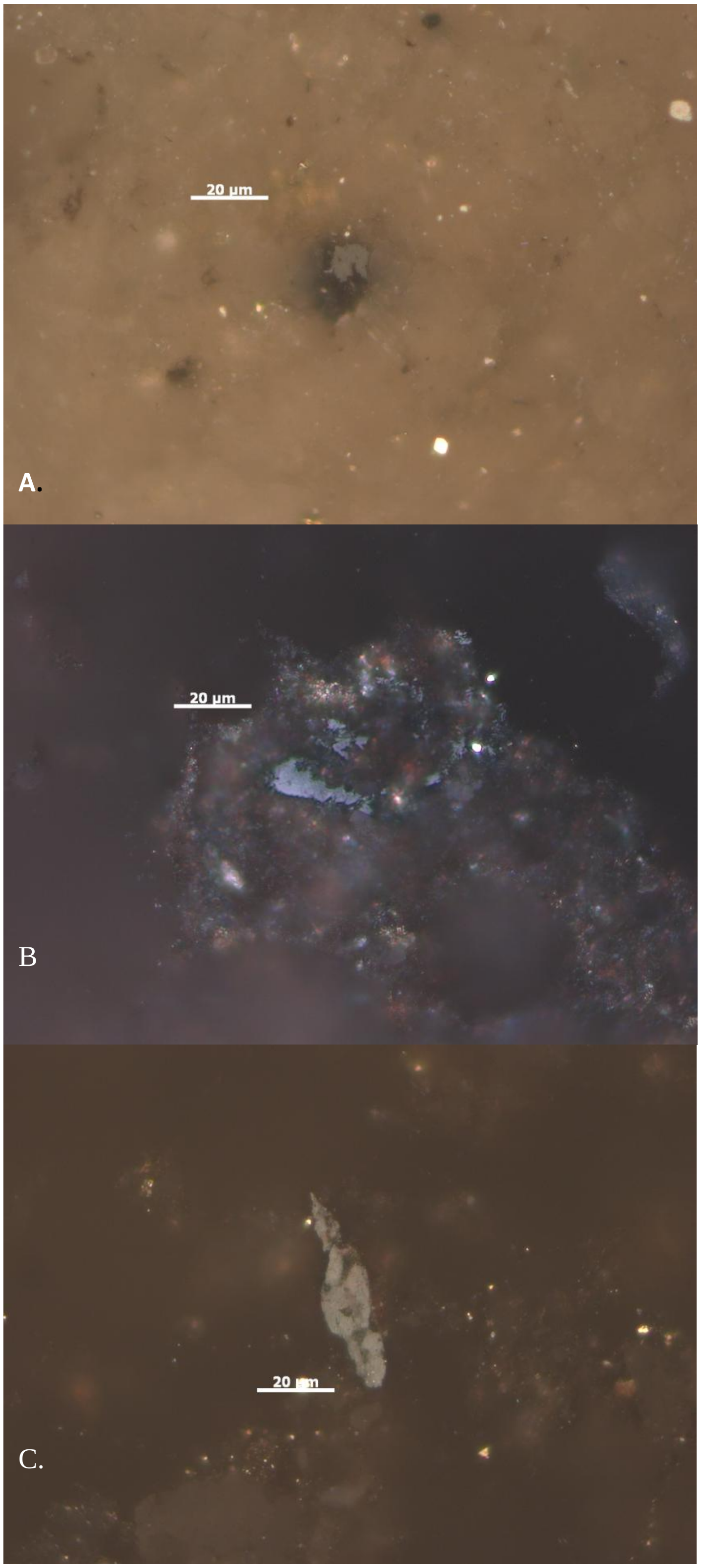

Figure 6. Solid (homogeneous) bitumen (A) and coked bitumen (B) from well 3903920007, Crawford County, Pennsylvania, depth 5500’-5550’ and 6150’-6200’, respectively. (C) degraded bitumen from Mercer County well 3708520116, depth 7050’-7100’

(Landis and Castaño, 1995). Reflectance can be performed on a number of hydrocarbon minerals. Vitrinite reflectance (Ro) is a tool for assessing thermal maturity of shale based on the reflectivity of vitrinite under a microscope equipped with an oil-immersion lens and photometer . Vitrinite is a maceral matter found in the cellulose and lignin of terrestrial plant walls (Riley *et al*, 2011). However, because terrestrial plants didn't evolve until Late Silurian time, organic matter in older shale must be analyzed by macerals from aquatic plants and life forms. Unlike vitrinite and other macerals, bitumen, a solid hydrocarbon, is not a framework matrix constituent, but fills available pore space as a result of thermal conversion of kerogen. Because bitumen is formed by the conversion of kerogen to solid hydrocarbon, it's presence within a hydrocarbon reservoir depends on the ability of a petroleum system to generate hydrocarbons rather than hydrocarbon generated by plants and organisms. Presence of bitumen therefore indicates a reservoir capable of producing hydrocarbons at multiple maturity levels (Landis and Castaño, 1995). Bitumen reflectance values (SHRo) can be obtained through a methodology for determining vitrinite reflectance equivalent (Ro_{eq}) values to assess hydrocarbon thermal maturity. Peters and Cassa (1994) suggest Ro values of 0.65-0.90 to represent petroleum source rocks of peak maturity for oil (Table 1). Sondergeld *et al* (2010) estimate a value of Ro >1.4 for peak maturity of dry gas (Table 1).

1.5.3 Organic content

Total organic carbon (TOC) is a common weight percent measurement of the quantity of organic carbon (both kerogen and bitumen) within a rock sample. Organic content is largely controlled by biologic production and oxygenation at the time of deposition. Generally, 0.5% is accepted as the minimum TOC value for defining a source rock, but any TOC of >1.0% is a good source rock for petroleum potential (Riley *et al*, 2011). TOC is commonly found through Rock Eval methods which pyrolysize organic matter to determine S1 (liquid hydrocarbons), S2 (convertible kerogen) and S3 (inorganic carbon dioxide) peaks produced from the rock. TOC can also be estimated from logs, indicated by increased porosity on porosity curves and increased gamma ray curve responses in marine source rocks (Sondergeld *et al*, 2010). Maximum temperature (Tmax), another Rock Eval measure, is related to thermal maturity and the temperature (°C) at which maximum hydrocarbons are released (Riley *et al*, 2011). TOC typically decreases with increasing thermal maturity.

2.0 METHODS

2.1 Sample Collection

2.1.1 Outcrop

Three trips to collect outcrop samples took place during the summer of 2012. Reedsville Shale and Antes Shale outcrops in Lycoming County, Centre County, and other nearby areas of central Pennsylvania were visited on June 27 and July 17, 2012 led by John Harper of the Pittsburgh Office of the Pennsylvania Geological Survey to collect samples for the potential use in this project and/or the Utica Shale Consortium. A third field trip, led by emeritus Professor at Penn State University, Duff Gold, focused on the collection of Reedsville Shale and Antes Shale samples from various quarries in central Pennsylvania. The samples were collected separately and labeled with location and description information which was then compiled into a spreadsheet (Appendix I).

2.1.2 Rock Cuttings

Using publically available data from the Pennsylvania Geological Survey (PaGS), a list of available Utica Shale play cuttings were compiled during the summer of 2012. Cuttings from 6 wells penetrating the Utica Shale were collected from the PGS warehouse in Hollywood, Pennsylvania. Where sample volumes allowed, 50 foot intervals were chosen for visual organic richness (dark color) from the top, middle, and bottom of each formation. Every 10 feet, within each 50 foot interval, 3-5 grams of shale were collected to make 1 representative sample. The samples were then measured and processed accordingly (Appendix II). A summary of lab analyses run on each cutting sample is presented in Appendix III.

2.2 Mineralogical Analysis

Samples were ground with a mortar and pestle and sieved through a #16 sieve. Roughly 5 grams of each sample was left with the Middletown office of the PaGS for XRD analysis. Bulk mineralogy was determined by powder XRD using a PANalytical Empyrean X-ray diffractometer and HighScore Plus software. Each sample was scanned a minimum of two times with the mean weight percent values recorded. The numbers were determined using the Reference Intensity Ratio (RIR) method, equivalent to a semi-quantitative estimate calculated based on the normal relative intensity of peaks that are generated by various minerals. Interpretations are taken from a standard database (International Centre for Diffraction Data Powder Diffraction File).

2.3 Bitumen Reflectance

Reedsville Shale, Utica Shale, and Point Pleasant samples were ground with a mortar and pestle and sieved through a #16 sieve. Approximately 1.5-2.0 grams of shale were added to roughly 3.0 grams of Beuhler TransOptic powder (20-3400-080) and mixed. The shale and power samples were placed into the Beuhler Simplimet 3000 Automatic Mounting Press which was treated with Buehler Release Agent (20-8185-002). The Simplimet was set to run for 15.50 minutes at 4000 psi. The resulting plugs were then labeled and placed into labeled bags with dehumidifying sponges for transport. During the first week of October, 2012, the samples were transported to the United States Geological Survey Headquarters in Reston, Virginia. There, the sample plugs were adjusted to be thicker by placing an additional 5.0 grams of TransOptic powder and the existing plugs into the Simplemet 2000. After setting overnight, the resulting plugs were then ground and polished using the Beuhler Ecomet 300.Plugs were analyzed for bitumen reflectance using a Leica DMRX microscope with MSP 200V4.3 and AxioVision software. Plugs were treated with 1 drop of Cargille Laboratories Inc. non-drying immersion oil for fluorescent microscopy (Type FF, cat. No. 16212). The microscope was calibrated using a yttrium-aluminum-garnet (YAG) .908 standard for samples for less thermally mature samples and a cubic-zirconium 3.13 standard for higher maturity samples. Using the American Society for Testing and Materials (ASTM) standard D2797, samples were visually assessed for bitumen macerals and 20 to 30 maceral measurements were made for each sample. Using the ASTM 7708 template, data were placed into a histogram and placed into three categories: coked bitumen, degraded bitumen, and homogeneous bitumen. The resulting data is summarized in Appendix IV. The bitumen reflectance values (SHRo) were then converted to vitrinite reflectance equivalent (Ro_{eq}) values using the methods of Jacob (1989) (eq. 1) and Landis and Castano (1995) (eq. 2) for comparison to vitrinite reflectance (Ro) data for other organic-rich shale:

$$Ro_{eq} = 0.618\ (SHRo) + 0.4 \qquad (1)$$

$$Ro_{eq} = 0.898\ (SHRo) + 0.43 \qquad (2)$$

The results from reflectance analysis have been compiled into Appendix IV.

2.4 Total Organic Content

Roughly 10 grams of ground and sieved (#16) Reedsville Shale, Utica Shale, and Point Pleasant Formation were sent to the Kentucky Geological Survey (KGS) for LECO TOC analysis. The shale samples were first pulverized to approximately 60-100 mesh Size. Then, two separate analyses were performed on the sample. A Total Carbon (TC) analysis was performed utilizing a LECO SC 144 Carbon and Sulfur Analyzer. A Total Inorganic Carbon (TIC) analysis was performed utilizing a UIC Carbon Dioxide Coulometer (CM5014). The Total Organic Carbon value was calculated by subtracting the Total Inorganic Carbon value from the Total Carbon value (eq. 3):

$$(TC-TIC=TOC). \tag{3}$$

TC on the LECO SC 144 analyzer consisted of weighing between 100 and 400 mg of the sample into a sample boat. The sample was combusted at a temperature of 1350 degrees Celsius. The instrument utilized an Infrared detector / cell that was calibrated against known reference standards. At that temperature, all forms of Carbon were released and detected in gas stream by the IR cell. TIC on the UIC coulometer consisted of weighing between 50 and 300 mg of the sample into a glass vial. Carbon dioxide gas evolved by dissolution in acid from carbonates in the sample was swept by a gas stream into a coulometer cell. The coulometer cell was filled with a partially aqueous medium containing ethanolamine and a colorimetric indicator. Carbon dioxide was quantitatively absorbed by the solution and reacts with the ethanolamine to form a strong, titratable acid which causes the indicator color to fade. The titration current automatically turned on and electrically generates base to return the solution to its original color (blue).

3.0 RESULTS

3.1 Reedsville Shale

3.1.1 Lithostratigraphy

The Reedsville Shale, the uppermost shale formation of the Utica Shale play, was originally referred to as the “Martinsburg” shale (eq. to the Utica in West Virginia) until Ulrich (1911) coined the term “Reedsville” for the Ordovician “Martinsburg” shale in central Pennsylvania in the early 20th century (PaGS-USGS, 2012). Today, the Reedsville Shale refers to the uppermost Ordovician shale in western and central Pennsylvania while the Martinsburg shale refers to the eastern Pennsylvania equivalent (Fig. 3). The type locality for the Reedsville shale occurs at an outcropping in Reedsville, Pennsylvania where it extends nearly 1,000 feet from the bottom of the Oswego sandstone to the top of the Trenton Limestone (Butts, 1945).

3.1.2 Description

The Reedsville Shale outcrops at various locations across central Pennsylvania where it varies is color and may be characterized by interbedded silt, sand, and limestone. About 60 feet of the Reedsville Shale is exposed at Antes Gap in Lycoming County. At Bellefonte (Fig. 7), the Reedsville Shale is grayish-brown to black, highly weathered, and slightly calcareous, exhibiting moderate effervescence when tested with hydrochloric acid. The grayish-brown Reedsville Shale at Antes gap is gradational with the lower and darker Antes Shale. In Centre County, the Reedsville varies from tan-gray to black and is weathered into thing, pencil-shaped lithons. At the Reedsville Exit outcrop, the Reedsville is characterized by tan-gray siltstone. In the walls of the Oak Hall Quarry (Appendix I), the Reedsville contains interbedded silt, sand, and limestone. The Reedsville appears to be very pyritic in places and contains large calcite crystals and vugs along with some thin ashy beds. At Sky Top Quarry, the Reedsville is extremely fossiliferous

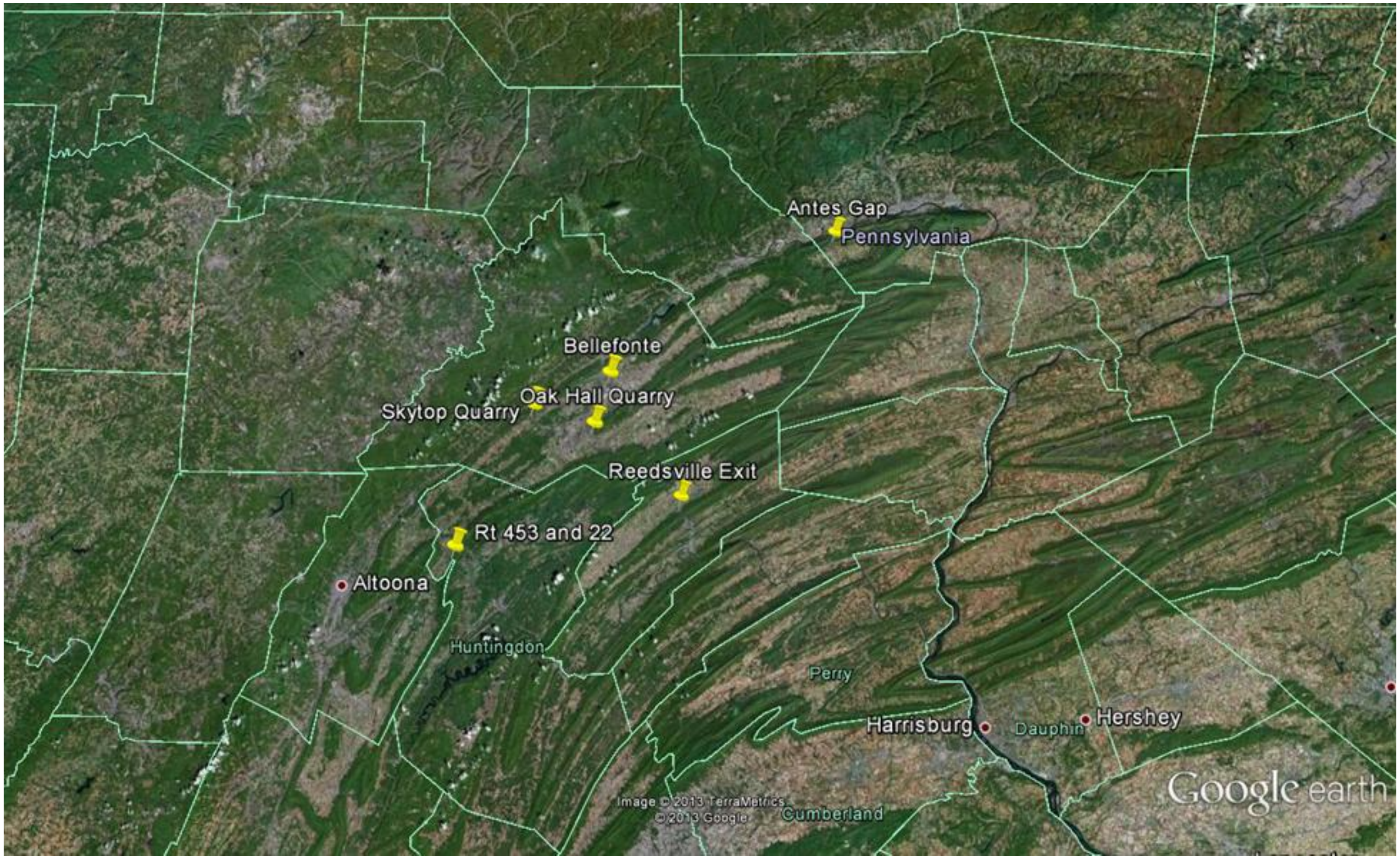

Figure 7. Reedsville Shale sample collection sites, central Pennsylvania (Google Earth, 2013).

with interbedded siltstone. At the intersection of Routes 453 and 22, the Reedsville is very black and slightly fossiliferous.

3.1.3 Mineralogy

Six cuttings samples and six outcrop samples from various depths within the Reedsville Shale were subjected to XRD analysis to assess mineralogy (Table 2). Sample 370272001 from 13800-13850 feet truly represents the Martinsburg Formation (equivalent to the Reedsville in eastern Pennsylvania) but has been included in the Reedsville Shale samples. The Reedsville Shale contains a mean weight percent of 36.63% quartz with a range of 20.41%-50.00%. For shale, this percentage of quartz is typically considered high, but the Reedsville has the lowest quartz content of the four formations within the Utica Shale Play. The low relative abundance of quartz in the Reedsville Shale is paired with high occurrence of clay minerals such as muscovite and chlorite with 32.30% and 6.42%, respectively. The Reedsville is relatively deficient in carbonate minerals, with calcite and dolomite only representing 8.82% and 1.09% weight, respectively. From these results, there does not appear to be any correlations with mineral weight percent and depth.

3.1.4 Reflectance Measurements

Due to lack or organic content relative to the other Utica Shale Play facies, only two cuttings samples of the Reedsville shale were submitted for bitumen reflectance. The samples, from Mercer (wet gas area) and Centre (overmature area) counties showed considerable differences in reflection values (Table 3). Average Ro_{eq} values in the wet gas area ranged from 1.3 (Jacob, 1989) to 1.73 (Landis and Castiño, 1995). In the overmature Reedsville Shale, Ro_{eq} values ranged from 1.66 (Jacob, 1989) to 2.26 (Landis and Castiño, 1995). Only degraded and homogenous bitumen was found in the Reedsville Shale samples (Fig. 8). The cuttings samples

Table 2. Mineralogical analysis of Reedsville Shale cuttings and outcrop samples

API	Depth (ft)	Quartz %	Muscovite %	Chlorite Group %	Plagioclase %	Orthoclase %	Calcite %	Dolomite %	Pyrite %	Gypsum %
3703920007	5500-5550	40.40	28.28	8.08	14.14	0.00	10.10	0.00	<1	0.00
3708520116	6400-6450	36.00	38.00	8.00	13.00	0.00	6.00	0.00	0.00	0.00
3712321050	7600-7650	32.32	41.41	8.08	13.13	0.00	7.07	0.00	<1	0.00
3700521201	10850-10900	50.00	10.00	9.00	27.00	5.00	0.00	0.00	0.00	0.00
3702720001	13800-13850*	33.66	47.52	7.92	7.92	0.00	1.98	0.99	0.99	0.00
3711320002	16050-16100	47.00	22.00	14.00	16.00	0.00	2.00	0.00	0.00	0.00
N/A	Rt. 99 Sky Top Quarry	27.72	42.57	7.92	18.81	0.00	1.98	0.00	0.99	0.00
N/A	Top of Bald Eagle Formation	31.00	40.00	9.00	18.00	3.00	0.00	0.00	0.00	0.00
N/A	Oak Hall Quarry; base of NW wall	43.00	16.00	5.00	12.00	0.00	19.00	2.00	4.00	0.00
N/A	Oak Hall Quarry; lower bench	42.00	34.00	0.00	0.00	0.00	8.00	4.00	6.00	7.00
N/A	Oak Hall Quarry; NW wall	20.41	38.78	0.00	5.10	0.00	33.67	2.04	0.00	0.00
N/A	Oak Hall Quarry; bottom of NW wall	36.00	29.00	0.00	11.00	0.00	16.00	4.00	0.00	5.00
	Average Mineralogy	**36.63**	**32.30**	**6.42**	**13.01**	**0.67**	**8.82**	**1.09**	**1.20**	**1.00**

* Martinsburg Formation

Table 3. Bitumen reflectance results for formations within the Utica Shale play.

API	County	Quad	Area	Formation	Depth (ft)	Min Bitumen SHRo	Max Bitumen SHRo	Average Solid SHRo	Estimated Vitrinite Ro_{eq} Jacob, 1989	Estimated Vitrinite Ro_{eq} Landis and Castino, 1995	Stand. Dev.	No. Measurements
08590010	Mercer	Sandy Lake	Wet Gas	Reedsville	7800-7850	0.68	2.27	1.45	1.30	1.73	0.47	21
02720001	Centre	Madisonburg	Overmature	Reedsville (Martinsburg)	13800-13850	0.98	3.20	2.04	1.66	2.26	0.56	22
				Reedsville Average		**0.83**	**2.74**	**1.75**	**1.48**	**2.00**		
12320150	Warren	Tidoute	Dry Gas	Utica	8100-8150	0.72	3.69	1.95	1.61	2.18	0.83	25
03920007	Crawford	Harmonsburg	Oil/Wet Gas	Utica	5950-5970	0.67	1.78	1.10	1.08	1.42	0.3	22
08520116	Mercer	Stoneboro	Wet Gas	Utica	6930-6950	1.14	3.18	2.30	1.82	2.50	0.62	20
00521201	Armstrong	Distant	Dry/Overmature	Utica	11780-11810	0.86	2.84	2.11	1.70	2.32	0.58	19
00521201	Armstrong	Distant	Dry/Overmature	Utica	11850-11900	1.28	3.39	2.28	1.81	2.48	0.75	18
11320002	Sullivan	Elk Grove	Overmature	Utica	16200-16250	1.91	3.41	2.96	2.23	3.09	0.43	20
11320002	Sullivan	Elk Grove	Overmature	Utica	16300-16350	1.90	3.65	3.09	2.31	3.20	0.51	20
				Utica Average		**1.21**	**3.13**	**2.26**	**1.79**	**2.46**		
12320150	Warren	Tidoute	Dry Gas	Point Pleasant	8250-8300	1.41	3.68	2.45	1.91	2.63	0.64	22
03920007	Crawford	Harmonsburg	Oil/Wet Gas	Point Pleasant	6150-6200	0.81	1.36	1.03	1.04	1.35	0.15	27
08520116	Mercer	Stoneboro	Wet Gas	Point Pleasant	7050-7100	0.95	3.21	2.36	1.86	2.55	0.56	23
02720001	Centre	Madisonburg	Overmature	Point Pleasant	14200-14250	1.02	3.25	2.11	1.70	2.32	0.64	17
				Point Pleasant Average		**1.05**	**2.87**	**1.99**	**1.63**	**2.21**		

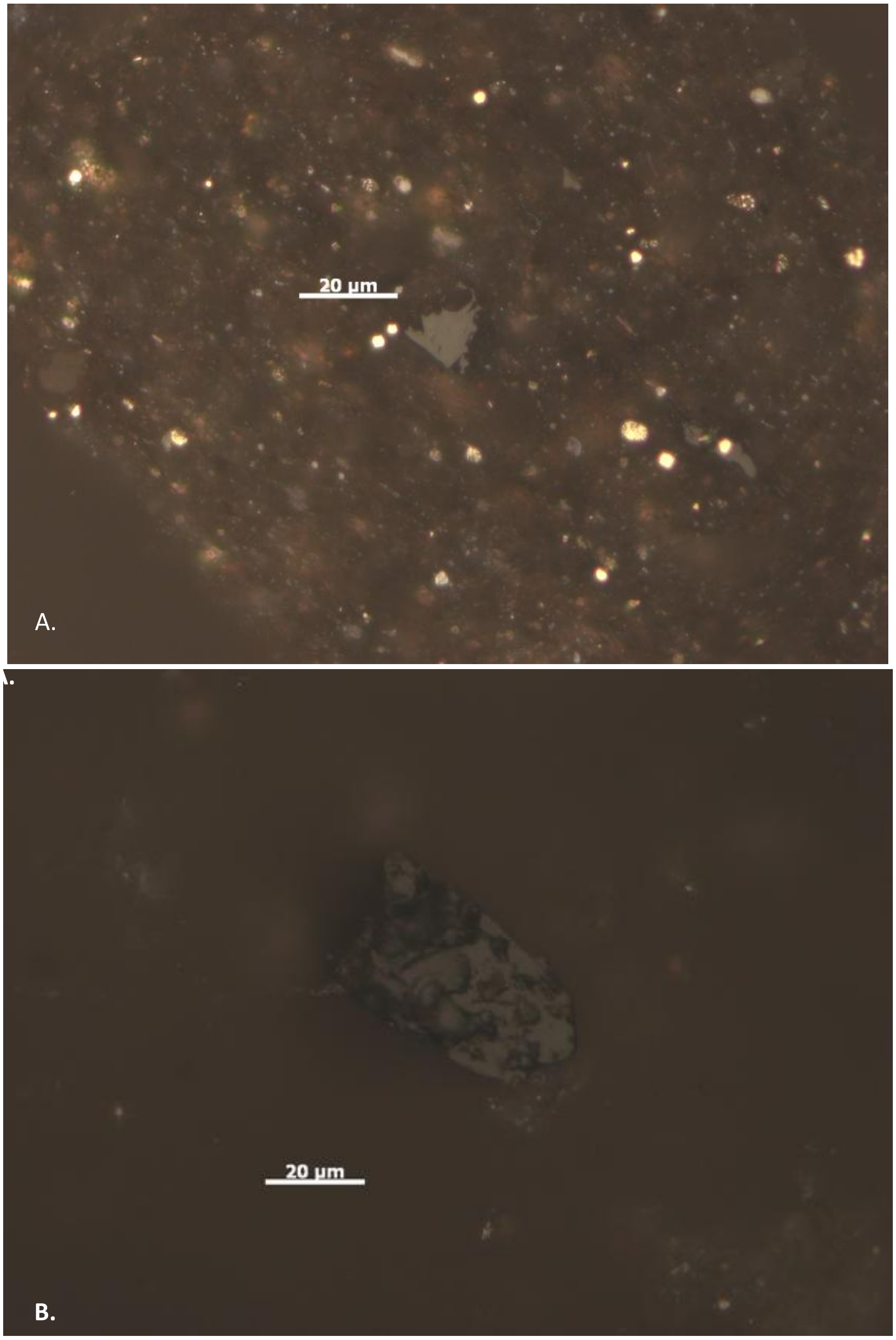

Figure 8. Bitumen macerals in Reedsville (and eq.) Shale. A Homogenous bitumen from Mercer County well 3908590010, depth 7800'-7850'. B. Degraded bitumen from Centre County well 390272001, depth 13800'-13850'.

from Crawford County detected only homogenous bitumen while the Mercer County cuttings had both degraded and homogenous bitumen.

3.1.3 TOC Analysis

Six cuttings samples of the Reedsville shale were assessed for total carbon content (Table 4). The Reedsville Shale produced the lowest values in TC, TIC, and TOC within the Utica Shale play. TOC values ranged from 0.14 to 0.42 with a mean of 0.25. Within the Reedsville Shale samples, TOC does not appear to change uniformly with depth. TC appears to increase with depth with the exception of on sample from Mercer County (high) and Armstrong County (low). With the exception of Mercer County, TOC appears to increase from east to west across the state (Fig. 9).

3.2 Antes Shale

3.2.1 Lithostratigraphy

The name “Antes” Shale refers to the Utica Shale in outcrop in central and west-central Pennsylvania. The Antes shale, named after Antes Gap in the Nippenose Valley of Lycoming County, outcrops as a black shale along Antes Creek and is conformable and gradational with the overlying Reedsville Shale. The lower Antes Shale is a dark-gray to black calcareous shale with interbedded limestone and makes contact with the underlying Coburn Formation of the Trenton Limestone in eastern and east-central Pennsylvania (Fig. 3) (Faill *et al*, 1989). A disconformity between the Coburn Formation and Antes exists in the center of the state (Lehmann *et al*, 2002).

Table 4. TOC results, in weight percent of Reedsville Shale cuttings samples.

API	Depth (ft)	TC	TIC	TOC
3703920007	5500-5550	2.84	2.65	0.19
3708520116	6400-6450	1.83	1.52	0.31
3712320150	7600-7650	1.58	1.38	0.20
3700521201	10850-10900	0.62	0.48	0.14
3702720001	13800-13850*	0.73	0.49	0.24
3711320002	16050-16100	0.88	0.46	0.42
	Average Reedsville	**1.41**	**1.16**	**0.25**

*Martinsburg Formation

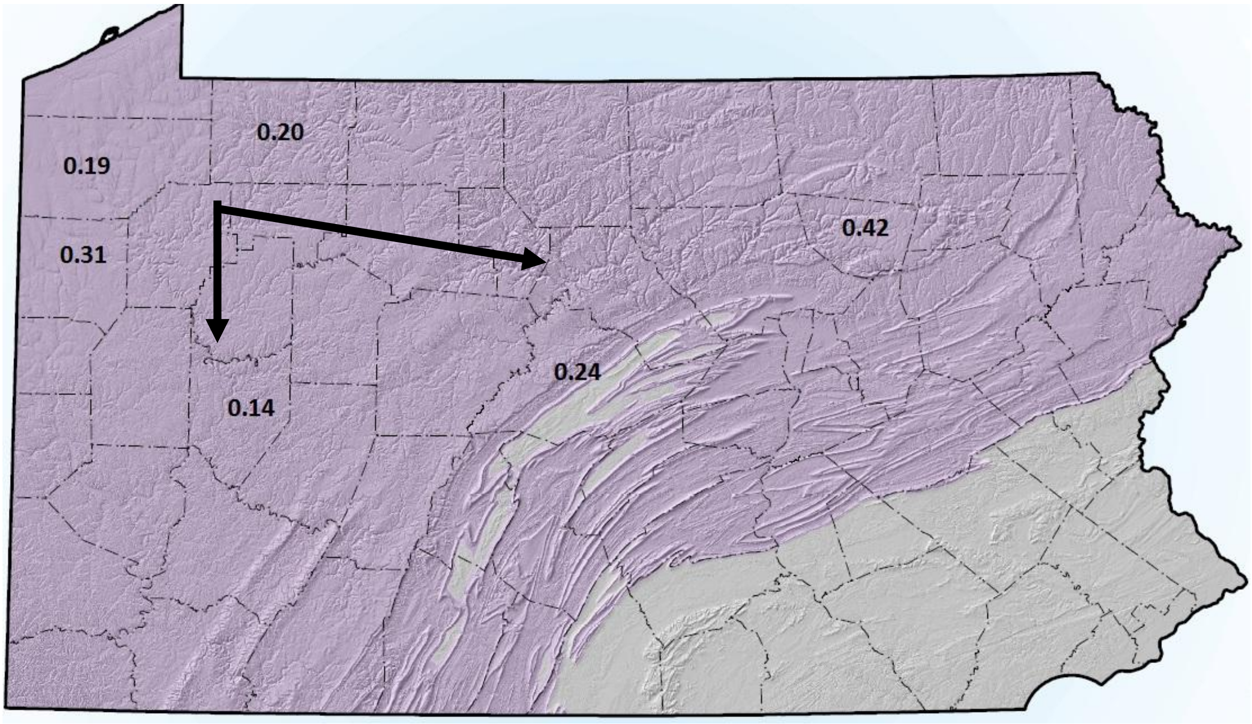

Figure 9. Reedsville TOC values for cuttings sample locations in Pennsylvania. Arrows indicate increasing TOC values. Map also shows the extent of the Utica Shale Play (modified from PaDCNR, 2011).

3.2.2 Description

The Antes Shale outcrops most notably at Antes Gap in Lycoming County, the type locality for the very dark black and highly weathered shale (Fig. 10). Here, the Antes grades into overlying Reedsville Shale. At the Reedsville Exit outcrop, the Antes is also in contact with the Reedsville Shale as well as the underlying Trenton Group carbonates. Here, the Antes is dark-grey to black, fissile, and thin-bedded shale with pyrite and sulfur deposits. At the Grier School in Birmingham, Centre County, PA (Appendix 1), the Antes shale has been highly deformed and is characterized by a glossy lustre where it lies near the Tyrone-Mt. Union lineament. Here, the Antes is very black and calcareous with numerous calcite nodules and veins and has been highly deformed. The Antes is also pyritic and has evidence of sulfur and iron dissolution. Again, the Antes directly overlies Ordovician carbonates. Both the Antes and the Ordovician carbonates have been overturned and foreshortened. At the Dutwiler house, near Nealmont, the Antes is dark black with obvious kerogen slicks and lies directly above the Coburn limestone of the Trenton Group.

3.2.3 Mineralogy

Nine outcrop samples of the Antes Shale were assessed for mineralogy by XRD analysis (Table 5). Quartz is the most abundant mineral in the Antes shale at 41.18% mean weight percent with a range of 22.00%-66.00%. Clay minerals such as muscovite and chlorite are present at 31.50% and 1.11%, respectively Chlorite is only present in three of the nine samples, but in all three it represents almost the same value, ~5%. The weight percent of calcite in the Grier School outcrop samples is significantly higher than the rest of the samples. The Antes Shale has a much higher occurrence of carbonate minerals than the Reedsville Shale with 13.22% calcite and 0.78% dolomite, respectively.

Figure 10. the Antes Shale sample collection sites, central Pennsylvania (Google Earth, 2013).

Table 5. Mineralogy of Antes Shale outcrop samples.

API	Depth (ft)	Quartz %	Muscovite %	Chlorite Group %	Plagioclase %	Orthoclase %	Clacite %	Dolomite %	Pyrite %	Gypsum %
N/A	Top of Reedsville Exit	39.00	28.00	0.00	17.00	0.00	15.00	0.00	1.00	0.00
N/A	Base of Reedsville Exit	51.00	22.00	0.00	15.00	12.00	0.00	0.00	2.00	0.00
N/A	Middle of Reedsville Exit	35.00	45.00	0.00	11.00	7.00	3.00	0.00	<1	0.00
N/A	Grier School, Rt. 435	22.00	44.00	0.00	6.00	0.00	27.00	2.00	1.00	0.00
N/A	Grier School, Birmingham	36.00	18.00	0.00	0.00	0.00	45.00	1.00	1.00	0.00
N/A	Antes Gap, upper shale unit	47.00	18.00	5.00	10.00	0.00	17.00	2.00	2.00	0.00
N/A	Skytop Quarry, Rt. 99	38.61	53.47	0.00	7.92	0.00	0.00	0.00	0.00	0.00
N/A	Raspberry Run Rd	66.00	18.00	0.00	17.00	0.00	0.00	0.00	0.00	0.00
N/A	US 322 and Tussey Mtn Rd	36.00	37.00	5.00	7.00	0.00	12.00	2.00	0.00	2.00
	Average Mineralogy	**41.18**	**31.50**	**1.11**	**10.10**	**2.11**	**13.22**	**0.78**	**0.88**	**0.22**

3.3 Utica Shale

3.3.1 Lithostratigraphy

The Utica Shale is a dark black, organic-rich shale ranging <100-300 feet thick in northwest-central and western Pennsylvania (Lytle, 1963). Baird and Brett (2012) divide the Utica Shale into an upper black, organic-rich, fissile shale and a lower calcareous black and dark gray shale. In western and west-central Pennsylvania, the Utica Shale is gradational with the underlying Trenton Formation (Baird and Brett, 2002). Today, the oil and gas industry uses the term "Utica Shale" to describe the black shale above the Trenton Limestone in the subsurface (PaGS-USGS, 2012).

3.3.2 Description

Since the Utica Shale only occurs in the subsurface of Pennsylvania, qualitative notes were taken during preparation of cuttings samples (Appendix II). The Utica Shale occurs at varying thicknesses and color across Pennsylvania. The Utica is only about 20 feet thick in the Kardosh well of Crawford County, and about 60 feet thick in the Fleck well of Mercer County. In the Fleck well, the top of the Utica is gray becoming dark brown to black at 50 feet deep. At this depth the bottom of the Utica is the same color as the Point Pleasant Formation. In the Shaw well of Warren County, the Utica is roughly 200 feet thick and darkens with depth where it is gradational with the Point Pleasant Formation. In the N. Martin #1 well from Armstrong County, the Utica Shale is also approximately 200 feet thick of dark gray to black shale. In the Dieffenbach Well of Sullivan County, the Utica Shale is roughly 350 feet thick and also darkens with depth. The Utica Shale appears to abruptly thicken from east to west across the state (Fig. 11).

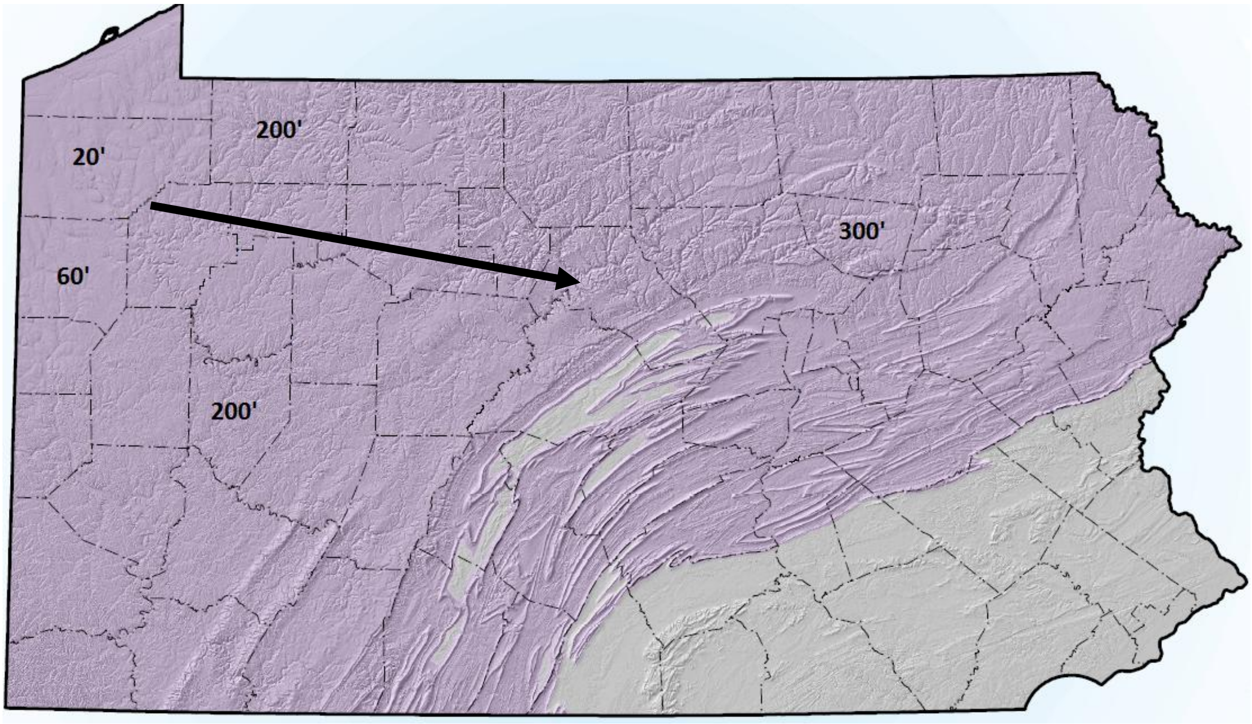

Figure 11. Thickness of Utica Shale in well cuttings across the state. Notice the E-W trend of thickening shale, indicated by arrow (modified from PaDCNR, 2011).

3.3.3 Mineralogy

Seven cuttings samples of the Utica Shale at various depths were subjected to XRD analysis and assessed for mineralogy (Table 6). Quartz is the most abundant mineral in the Utica Shale at 42.47% by weight percent and a range of 28.28%-54%. The relative occurrence of clay minerals in the Utica Shale is much higher than in the Antes Shale with 29.05% muscovite and 8.58% chlorite. Compared to both the Reedsville Shale and Antes Shale, the Utica Shale is relatively deficient in carbonate minerals with 6.86% calcite and 1.43% dolomite.

Table 6. Mineralogy of Utica Shale cuttings samples.

API	Depth (ft)	Quartz %	Muscovite %	Chlorite Group %	Plagioclase %	Orthoclase %	Clacite %	Dolomite %	Pyrite %	Gypsum %
3903920007	5940-6010	40	35	8	7	0	3	7	1	0
3908520116	6880-6950	42	29	7	12	0	9	0	1	0
3912320150	8100-8050	54	21	9	10	0	4	2	2	0
3900521201	11780-11810	47	26	11	13	0	3	0	1	0
3911320002	16200-16250	36	41	8	8	0	7	0	1	0
3911320002	16400-16450	28.28	34.34	9.09	13.13	0	15.15	0	1.01	0
3900521201	11850-11900	50	17	8	13	0	11	1	2	0
	Average Mineralogy	**42.47**	**29.05**	**8.58**	**10.88**	**0.00**	**6.86**	**1.43**	**1.29**	**0.00**

3.3.4 Reflectance Measurements

Seven Utica cuttings samples were analyzed via bitumen reflectance to assess maturity (Table 4). The Utica Shale samples represent the highest Ro_{eq} values in the Utica Shale Play ranging from 1.79 (Jacob, 1989) to 2.46 (Landis and Castiño, 1995). Values do not appear to directly increase with depth, though the highest Ro_{eq} values are represented by the deepest samples. The samples, both from Sullivan County, also represented the samples furthest west in the dataset (Fig. 12). The data suggests an east-west correlation. Degraded, homogenous, and coked bitumen were all present in samples of the Utica Shale (Fig. 13). In Armstrong County, the Utica Shale cuttings had anomalous SHRo values greater than 3.60. This was attributed to metal oxides present in the cuttings samples (Fig. 14). These oxide SHRo values range from 3.65- 5.11, much higher than any of the SHRo values for bitumen. Metal oxides were also found in Utica Shale samples from Warren County. The oxide SHRo value was recorded at 3.69, much higher than any of the SHRo values for bitumen.

3.3.5 Organic Content

Seven Utica cuttings samples were analyzed for total carbon content (Table 7). The Utica Shale produced a wide range of values for total carbon data. The deepest cutting sample represented the highest TC and TIC values, but did not produce the highest TOC value. The average TOC values for the Utica Shale ranged from 1.06-1.85 with a mean of 1.95, a value significantly higher than the Reedsville Shale. There does not appear to be any correlation of TOC values with depth. Although there appears to be an increase in TOC values from east to west across Pennsylvania, there is also high regional variability of values (Fig. 15). From two samples in

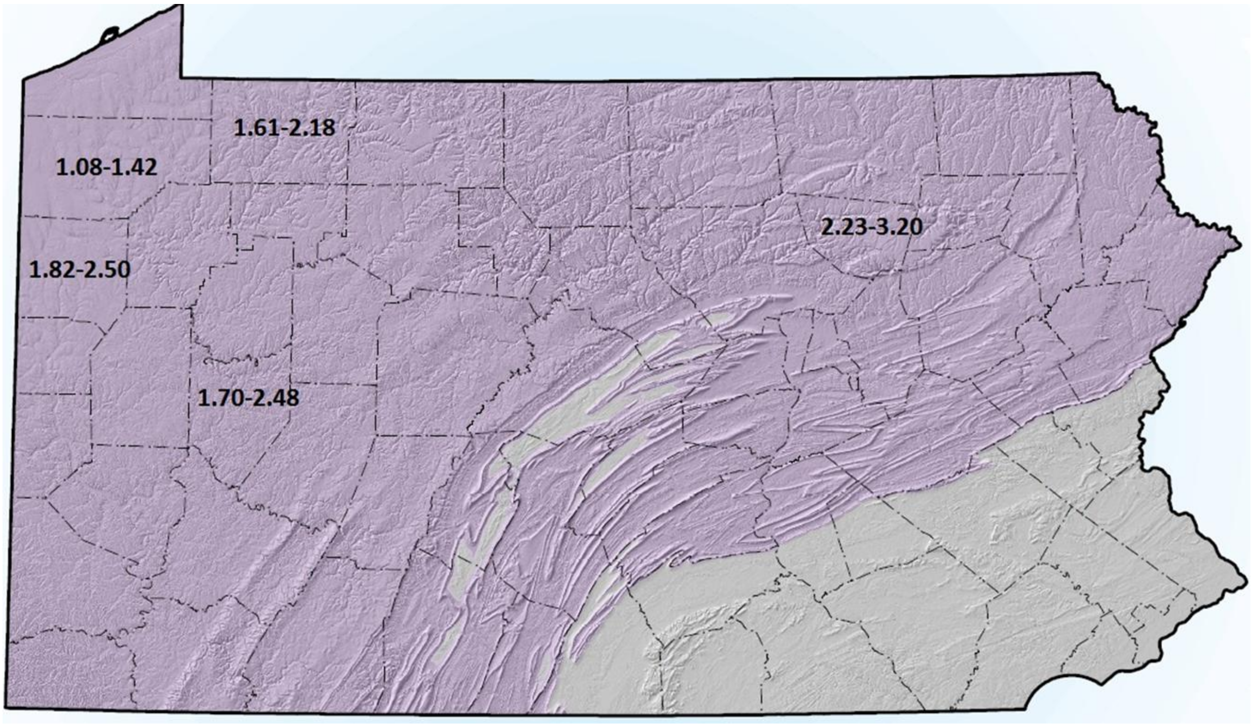

Figure 12. Range of Ro_{eq} values for Utica Shale cuttings samples, determined from Jacob (1989) and Landis and Castiño (1995), Pennsylvania. Map also shows the extent of the Utica Shale (modified from PaDCNR, 2011).

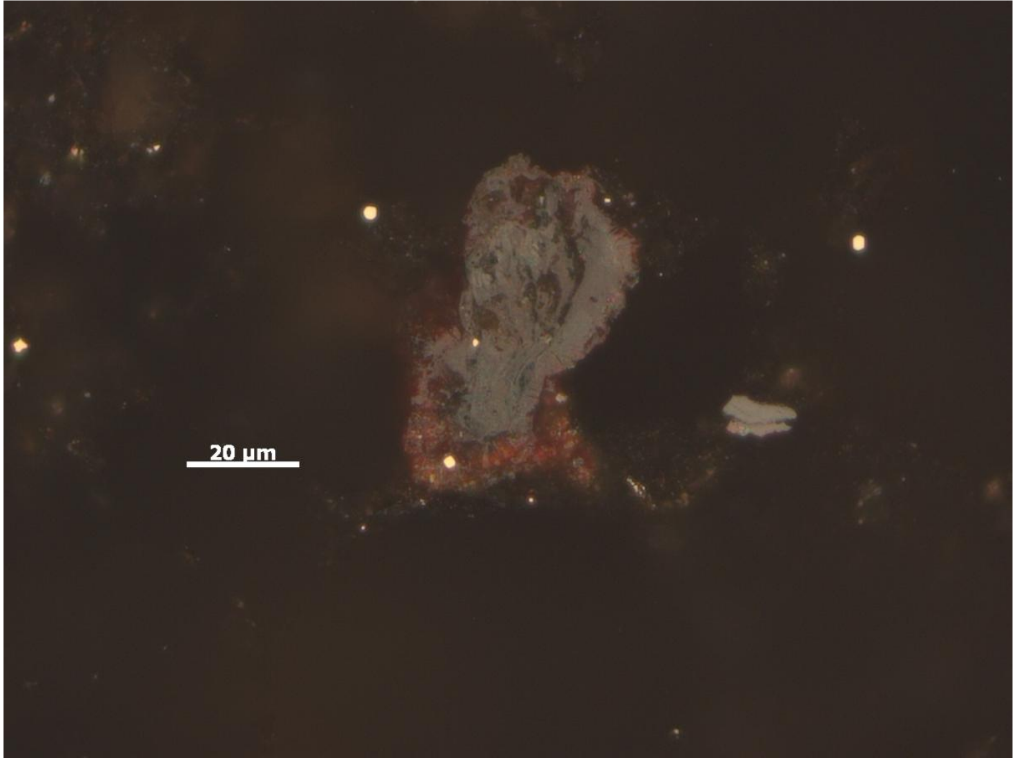

Figure 13. Degraded and homogenous bitumen macerals of the Utica Shale from Mercer County well 3908520116, depth 6930'-6950'.

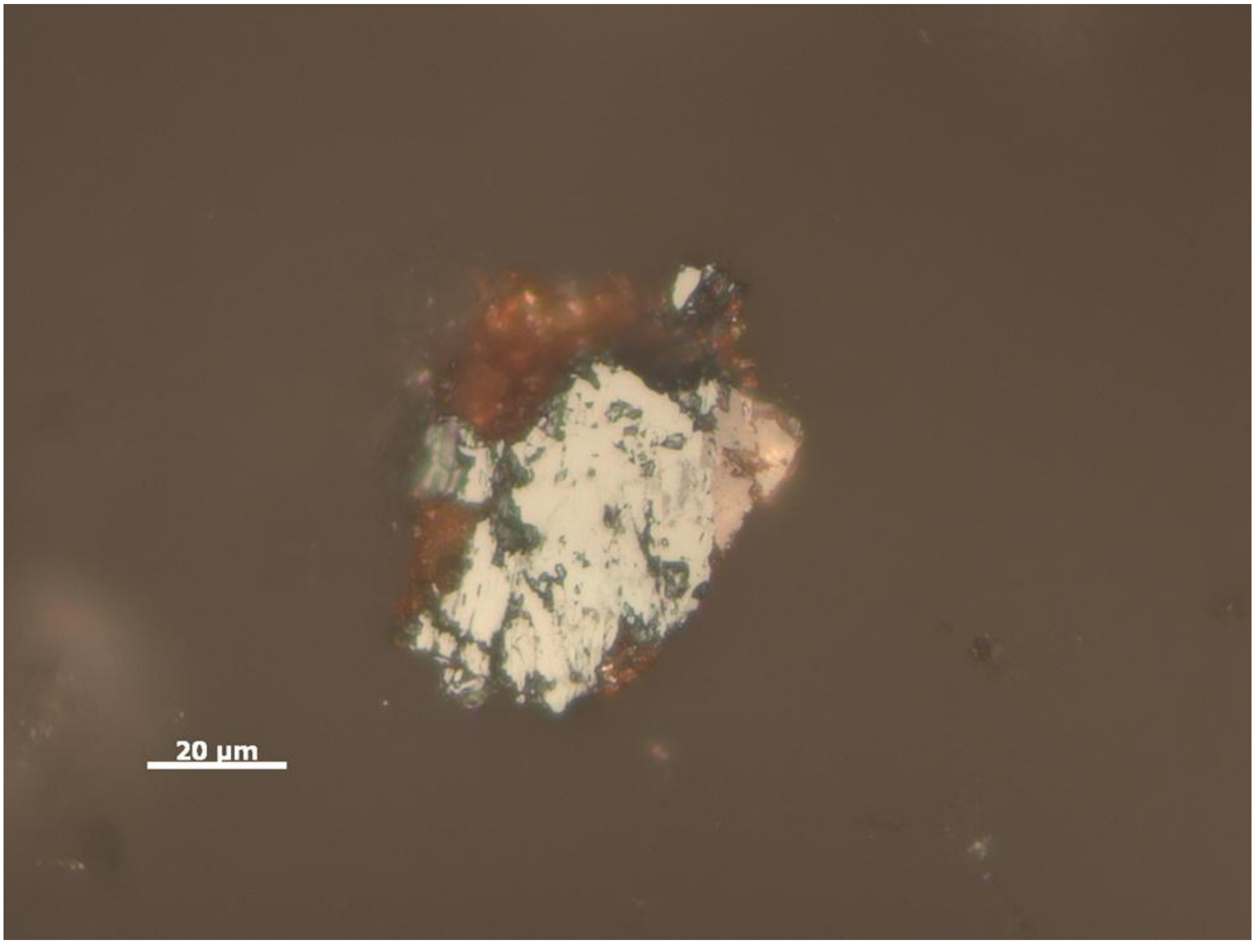

Figure 14. Metal oxide present in Utica Shale cuttings samples from Centre County, depth 13800'-13850'. Oxides reflect much brighter and generate much higher reflectance values than bitumen macerals

Table 7. TOC results, in weight percent, for cuttings samples of the Utica Shale.

API	Description	Depth (ft)	TC	TIC	TOC
3703920007	Utica	5950-5970	2.94	1.09	1.85
3708520116	Utica	6930-6950	5.16	2.89	2.27
3712320150	Utica	8100-8150	2.56	1.36	1.20
3700521201	Utica	11780-11810	2.26	1.20	1.06
3700521201	Utica	11850-11900	5.04	2.43	2.61
3711320002	Utica	16200-16250	4.21	1.87	2.34
3711320002	Utica	16300-16350	7.08	4.74	2.34
	Average Utica		**4.18**	**2.23**	**1.95**

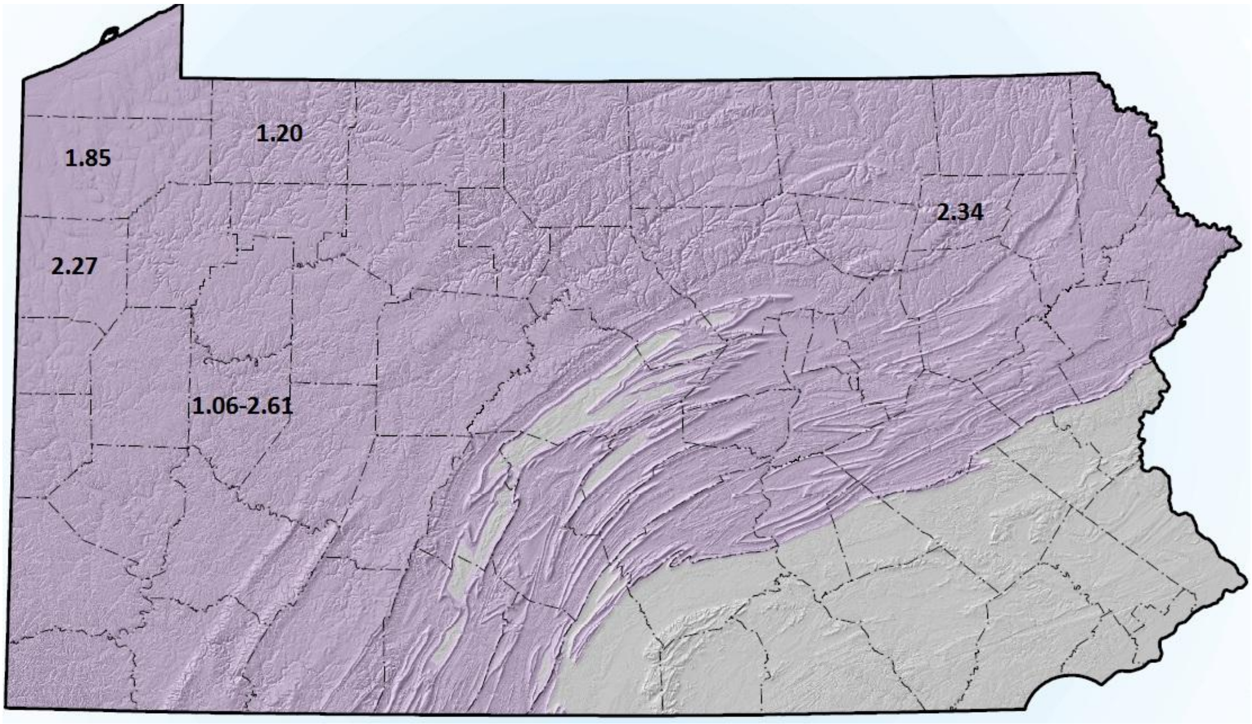

Figure 15. Utica TOC values for cuttings sample locations in Pennsylvania. Map also shows the extent of the Utica Shale Play (adapted from PaDCNR, 2011).

Armstrong County, TOC values range 1.06-2.61 but in two samples in Sullivan Country have identical mean TOC values at 2.34.

3.4 Point Pleasant Formation

3.4.1 Lithostratigraphy

In Ohio and western Pennsylvania, the upper Trenton Limestone is gradational with a very black, calcareous and interbedded limestone known as the Point Pleasant Formation (Fig. 3). The contact between the Utica Shale and the Point Pleasant Formation is discrete but typically marked by a transition from gray or black to very black, organic-rich shale. Often, the Utica Shale and Point Pleasant Formation are mapped together as one unit.

3.4.2 Description

The Point Pleasant Formation was not observed in outcrop, but qualitative notes were taken during preparation of cuttings samples (Appendix II). The Point Pleasant Formation occurs at various thicknesses across the state as, almost always, a dark black, organic-rich shale. In the Shaw Well of Warren County, the Point Pleasant Formation is about 130 feet thick and very dark black towards the bottom of the section. In the N. Martin #1 of Armstrong County, the Point Pleasant Formation is roughly 150 feet thick and very black, exhibiting increasingly darker color with depth. The Point Pleasant Formation is also 150 feet thick in the Fleck Well of Mercer County, though here, it is dark brown rather than black. In the Kardosh Well of Crawford County, the Point Pleasant is roughly 215 feet thick. Unlike the Utica Shale, which thickens to the west, the Point Pleasant becomes deeper to the west (Table 4) but thickens to the east (Fig. 16).

3.4.3 Mineralogy

Four cuttings samples of the Point Pleasant Formation were analyzed via XRD for mineralogy (Table 6). Quartz is the most abundant mineral in the Point Pleasant Shale, ranging 39.60% - 53% with a mean value of 44.40%.The Point Pleasant Formation represents the highest quartz percentage by weight of the four formations within the Utica Shale play. Quartz content also increases with depth within the Point Pleasant Formation (Fig.17) as well as west to east across the state (Fig.18). The Point Pleasant Formation has the lowest percentage of clay minerals with 21.96% muscovite and 5.99% chlorite. The Point Pleasant Formation has the highest carbonate content within the Utica Shale play with 16.69% calcite and 2.49% dolomite. There does not appear to be a lateral trend among the carbonate minerals (Fig. 18).

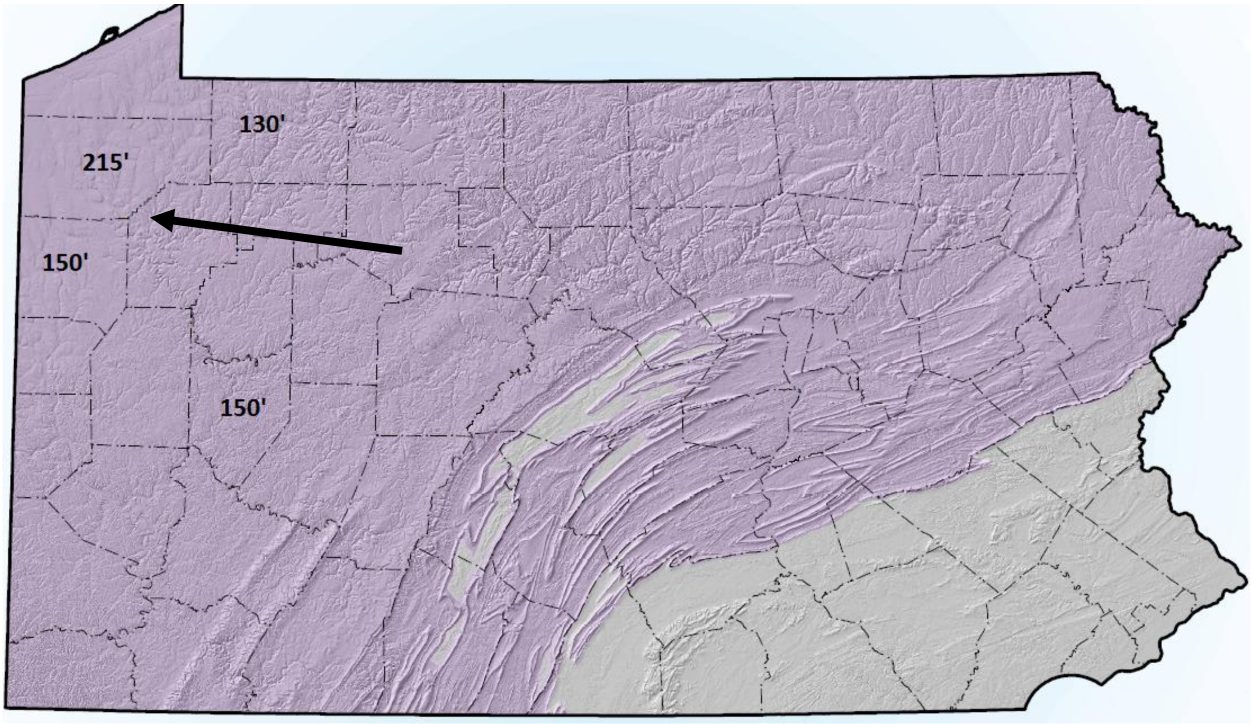

Figure 16. Thickness of the Point Pleasant Formation in well cuttings across the state. Notice how the shale thickens to the west rather than to the east. Map also shows the extent of the Utica Shale (modified from PaDCNR, 2011).

Table 8. Mineralogy, by XRD analysis, of Point Pleasant Formation cuttings samples, Pennsylvania.

API	Depth (ft)	Quartz %	Muscovite %	Chlorite Group %	Plagioclase %	Orthoclase %	Clacite %	Dolomite %	Pyrite %	Gypsum %
3703920007	6150-6200	41.00	28.00	8.00	7.00	0.00	14.00	0.00	2.00	0.00
3708520116	7050-7100	39.60	17.82	3.96	8.91	0.00	23.76	5.94	0.00	0.00
3712321050	8250-8300	44.00	26.00	6.00	6.00	0.00	16.00	3.00	1.00	0.00
3702720001	14200-14250	53.00	16.00	6.00	10.00	0.00	13.00	1.00	2.00	0.00
	Average Mineralogy	**44.40**	**21.96**	**5.99**	**7.98**	**0.00**	**16.69**	**2.49**	**1.25**	**0.00**

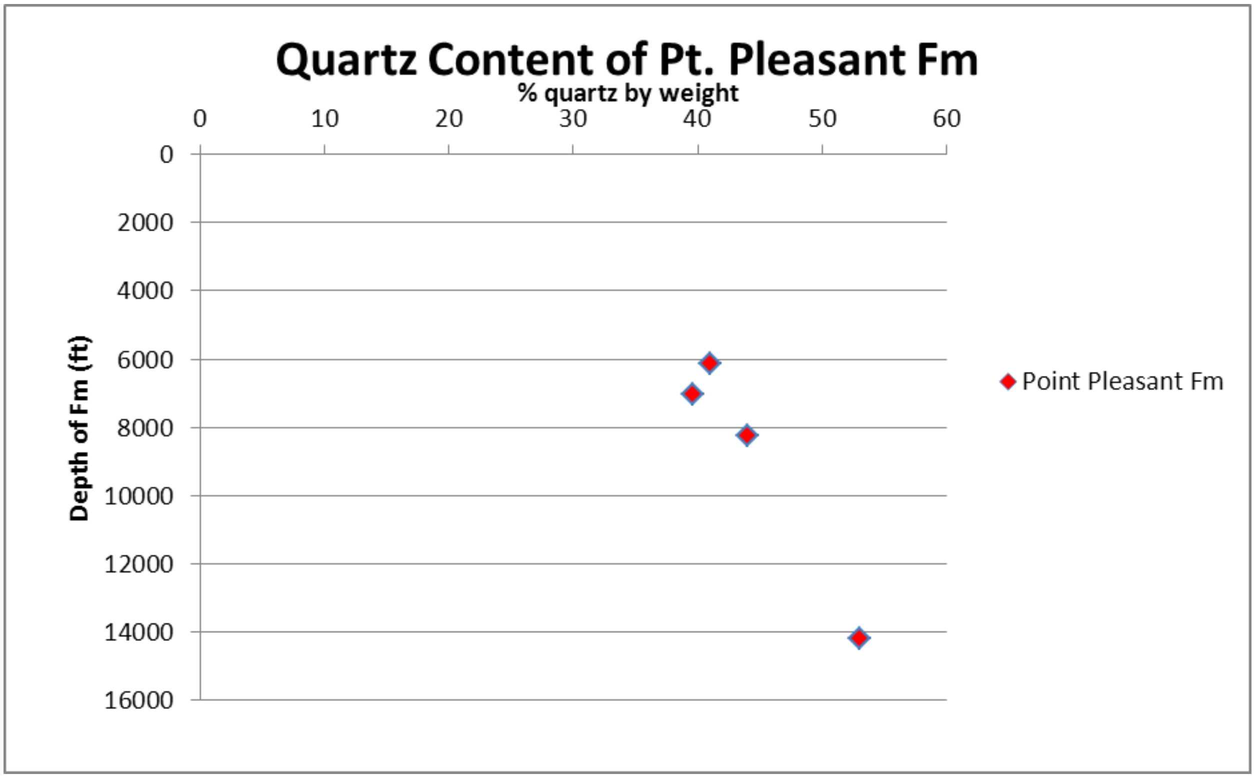

Figure 17. Quartz content of the Point Pleasant Formation as it increases with depth.

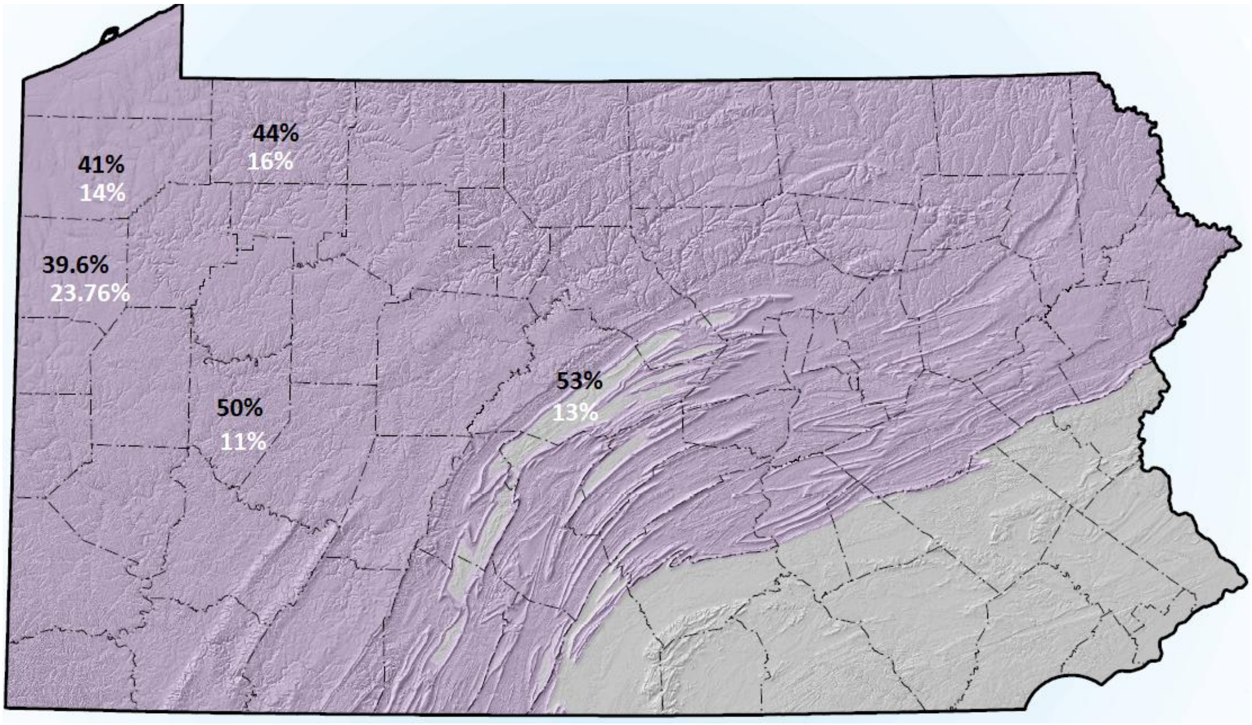

Figure 18. Mineralogy of the Point Pleasant Formation showing quartz (black) and calcite (white) by weight percent, Pennsylvania. Map also shows extent of the Utica Shale Play (modified from PaDCNR, 2011).

3.4.4 Reflectance Measurements

Four Point Pleasant Formation samples were submitted for bitumen reflectance via XRD analysis (Table 4). The mean Ro_{eq} values range from 1.63 (Jabob, 1989) to 2.21 (Landis and Castiño, 1995). The highest Ro_{eq} value is not represented by an overmature shale in the Point Plesant data set. Rather, the highest reflectance values are produced from shale in the dry gas and wet gas areas of Pennsylvania. These counties are also in the eastern part of the state, Warren and Mercer Counties (Fig. 19). Degraded, homogeneous, and coked bitumen were all found in Point Pleasant samples (Fig. 20). In Mercer County, bitumen macerals were observed with oxidation (Fig.21). Metal oxides were also observed in Crawford County and Warren County (Appendix IV), registering SHRo values greater than 3.50.

3.4.5 Organic Content

Four cutting samples of the Point Pleasant formation produced the largest TC, TIC, and TOC values within the Utica Shale Play (Table 9). TOC values range from 1.54 to 2.45 with a mean of 2.03. There are not enough samples to correlate TOC values with depth, and there does not to be a lateral trend across the state.

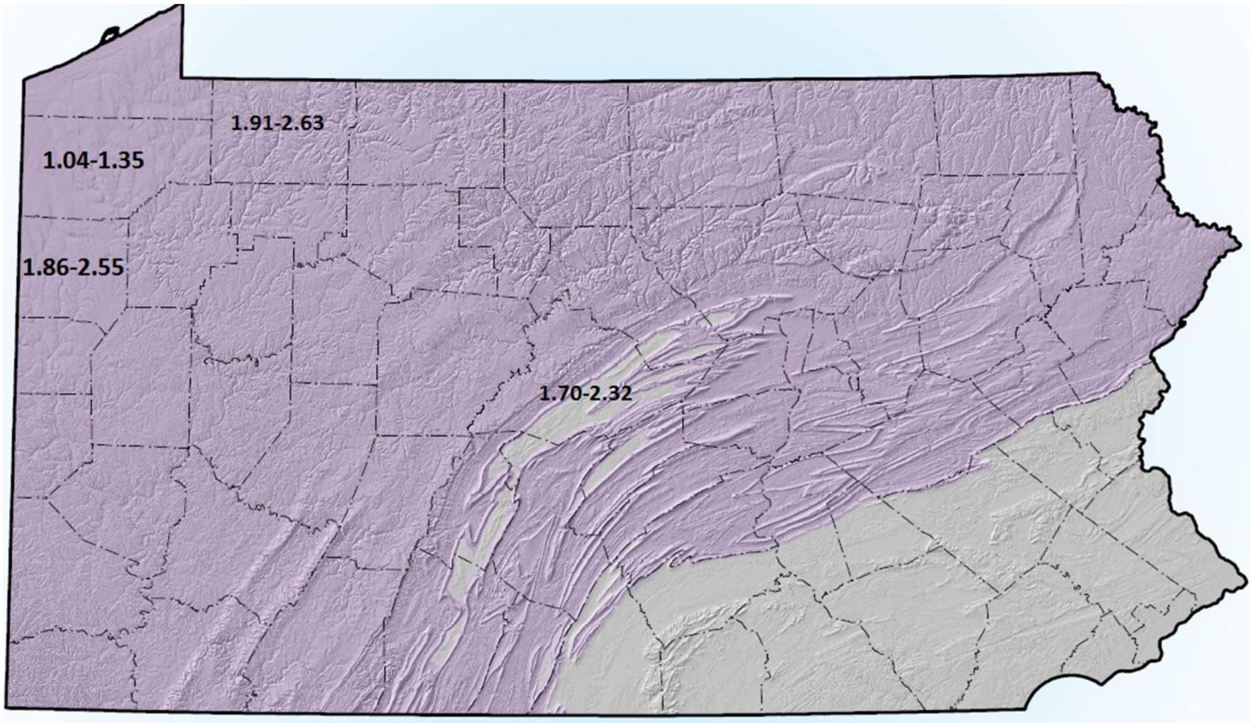

Figure 19. Range of Roeq values for the Point Pleasant Formation, Pennsylvania. Map also shows the extent of the Utica Shale Play (modified from PaDCNR, 2011).

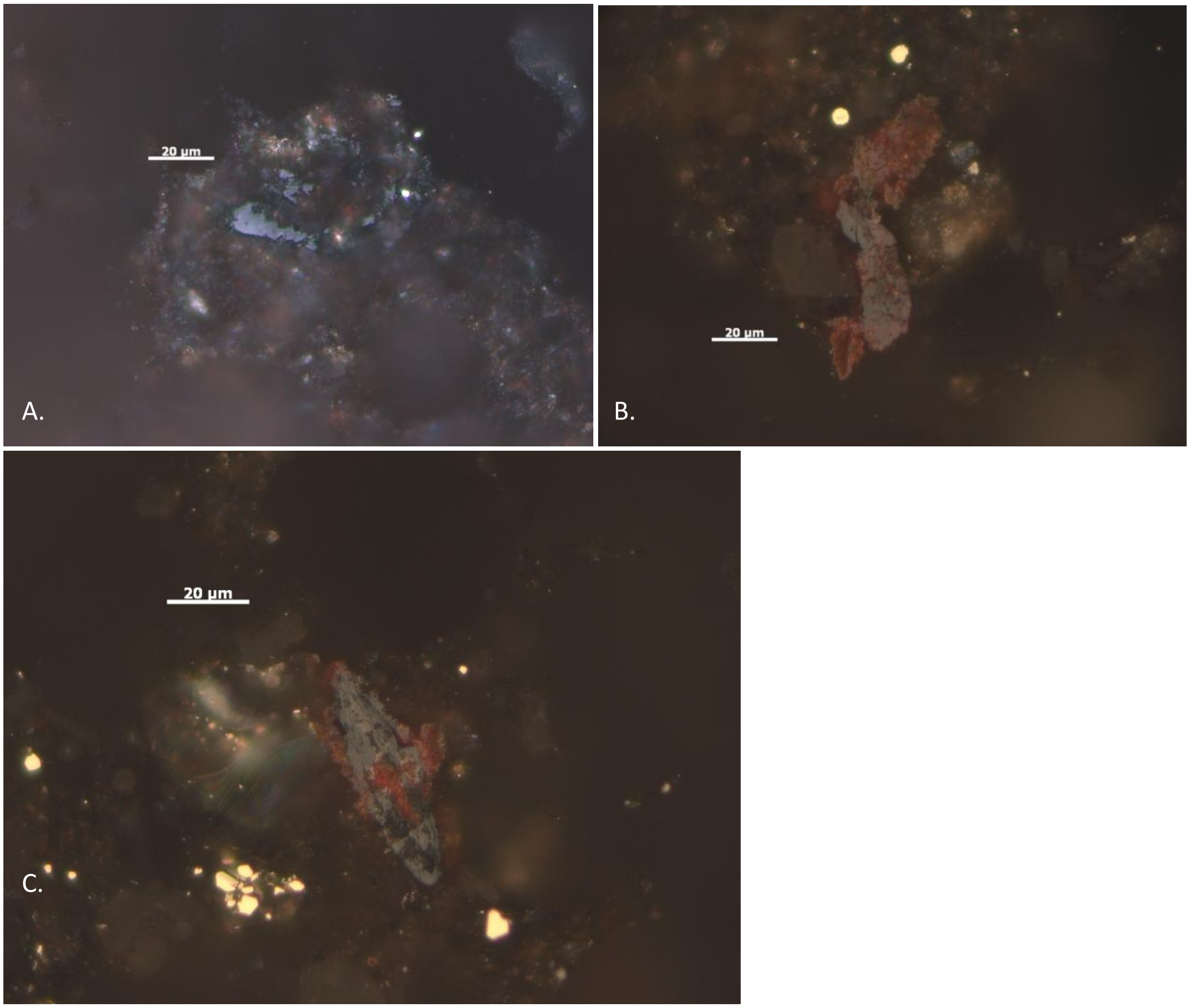

Figure 20. A. Coked bitumen from Crawford County well 3703920007, depth 6150’-6200’. B. Bitumen maceral with oxidation and C. coked bitumen maceral with oxidation from Mercer County well 3708520116, depth 7050’-7100’.

Table 9. Total carbon analysis, in weight percent, for cuttings samples of the Point Pleasant Formation, Pennsylvania.

API	Description	Depth (ft)	TC	TIC	TOC
3703920007	Point Pleasant	6150-6200	5.05	2.60	2.45
3708520116	Point Pleasant	7050-7100	6.12	4.03	2.09
3712320150	Point Pleasant	8250-8300	4.98	3.44	1.54
3702720001	Point Pleasant	14200-14250	4.02	1.99	2.03
	Average Point Pleasant		**5.04**	**3.02**	**2.03**

4.0 DISCUSSION

4.1 Mineralogy

According to Wang and Carr (2012), and Sondergeld *et al* (2010), the most important minerals to consider in petroleum reservoirs are quartz, carbonate, and clay minerals. All of the formations within the Utica Shale Play have significant quartz content, greater than 35%. However, the Reedsville Shale, the least quartz-rich formation in the Utica Shale Play falls below the 40% cut off for ideal quartz content in a petroleum reservoir. The Reedsville Shale also has a higher abundance of clay minerals, particularly muscovite, chlorite, and plagioclase, than the other formations, as well as relatively low carbonate content (Fig. 21). The Antes Shale and Utica Shale have very similar mineralogy (Fig. 22). The Antes Shale and Utica Shale have a narrow spread in quartz content, 41.18% and 42.47%, respectively. Both fall just above the 40% quartz cut off to be a viable petroleum reservoir. However, the Antes and Utica Shale vary greatly in clay mineral and carbonate content. The Utica Shale has significantly more chlorite than the Antes Shale and significantly less calcite than the latter formation. Although both have similar quartz content, the Antes Shale presents a better potential for a petroleum reservoir. The Point Pleasant Formation contains the highest quartz and carbonate content (both calcite and

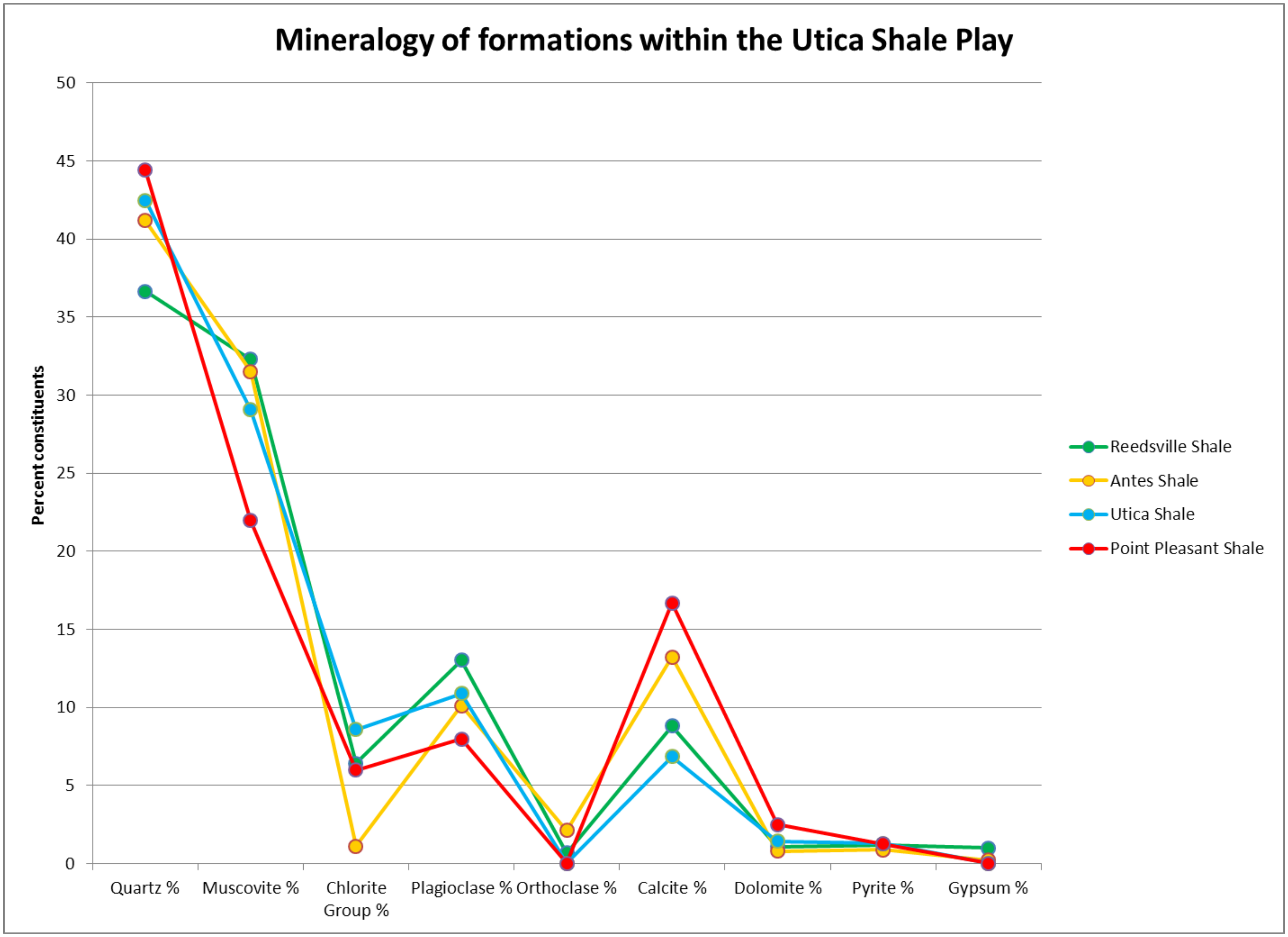

Figure 21. A Comparison of mineralogy of the formations within the Utica Shale play, Pennsylvania.

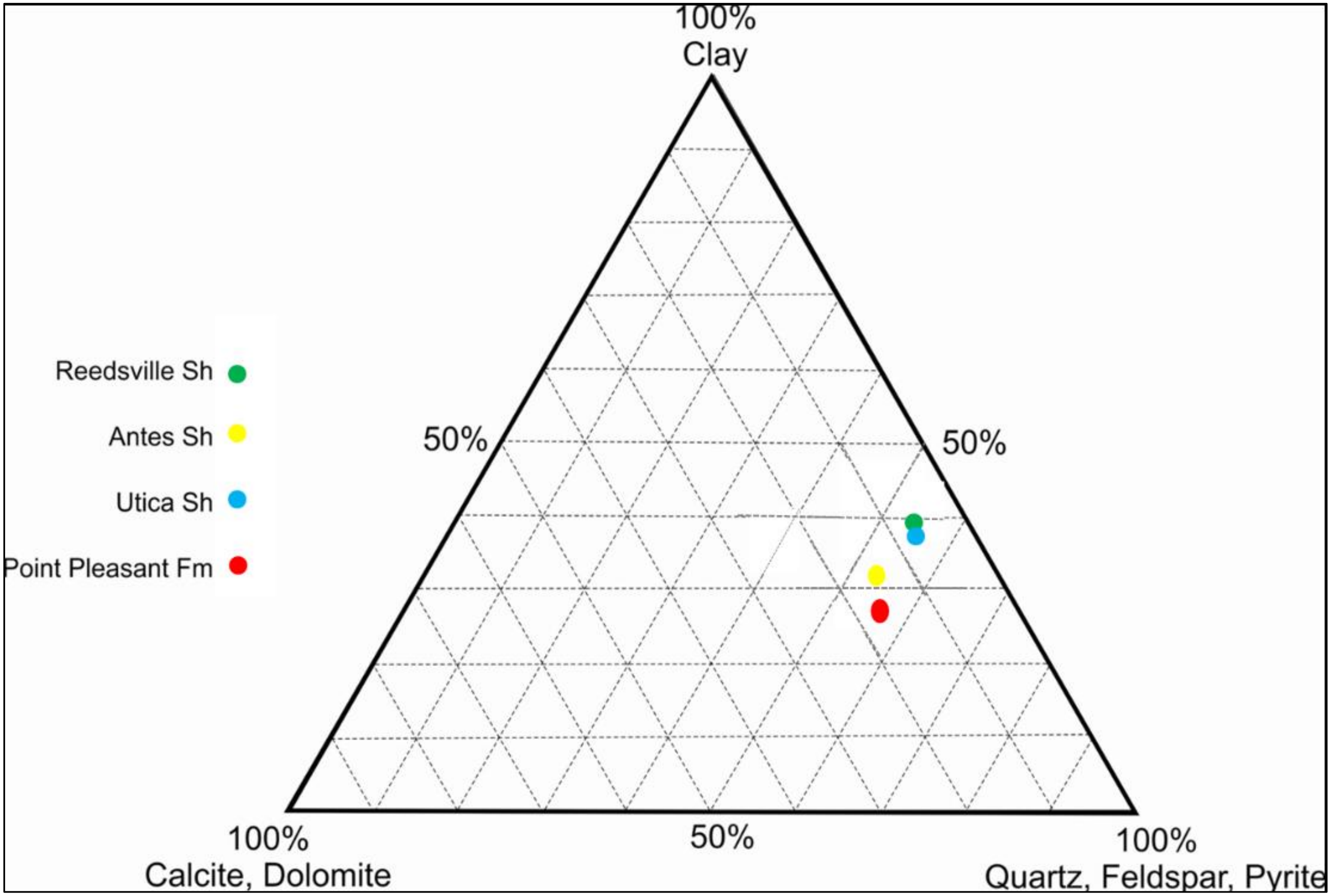

Figure 22. Ternary diagram showing average mineralogy for cuttings and outcrop samples of the Utica Shale play formations in Pennsylvania.

dolomite). The Point Pleasant Formation is also the only formation within the Utica Shale play with a clay mineral content below 30% at 27.35%, making it the only formation to fall within the clay mineral cutoff for a viable petroleum reservoir (Table 1). Based on mineralogy alone, the Point Pleasant Formation is the most promising petroleum reservoir with abundant quartz and carbonate minerals.

Overall, there is a depth-mineralogy correlation within the Utica Shale play. Quartz content obviously increases with stratigraphic depth of formation, being least represented in the Reedsville Shale and most in the Point Pleasant Formation. Carbonate mineral content also roughly increases with depth, becoming most abundant in the Point Pleasant Formation. Inversely, clay mineral content decreases with stratigraphic depth of formation. An increase in quartz and carbonate content with depth, paired with a decrease in clay mineral content with depth, allows for more promising petroleum reservoir potential since increased quartz and carbonate content with depth allows for more brittle formations and free gas to be present. Additionally, while there is an overall depth-mineralogy trend for the Utica Shale play, there do not appear to be any trends within individual formations with the exception of the Point Pleasant Formation. There is an obvious increase in quartz content within the Point Pleasant Formation itself making the deepest part of the Point Pleasant Formation the most promising as a hydrocarbon reservoir.

4.2 Solid Hydrocarbon Reflectance

Two trends for solid hydrocarbon reflectance data were expected within the Utica Shale Play: a stratigraphic downward increase in reflectance values and a basinward increase in reflectance values toward the subsiding continental margin. Both of these models assume that burial depth affects temperature and therefore maturity of hydrocarbon generation within organic-rich shale. The stratigraphic increase in maturity values within the Utica Shale play was not observed.

While it would be expected that the Reedsville Shale would have the lowest maturity values and the Point Pleasant Formation the highest maturity values, it is the Utica Shale that represents the highest maturity values within the play (Fig. 23). The highest Ro_{eq} values occur in the Utica Shale of Sullivan County. The samples from Sullivan County, at 16200’-16350’, are deeper than any other samples in the Utica Shale play dataset, including samples from the Point Pleasant Formation. The Utica Shale samples depth, coupled with Sullivan County’s position farthest east and closest to the Appalachian structural front, account for the high RO_{eq} values observed. In Mercer and Warren Counties, where both Utica Shale and Point Pleasant Formation data exist, the Point Pleasant Formation has higher Ro_{eq} values. Drilling depth, rather than stratigraphic position, control bitumen reflectance values in the Utica Shale play.

Predictably, Ro_{eq} values increase basinward by hydrocarbon type producing area (Fig. 24). This is consistent with published maturity data (Fig. 25). The two Utica Shale samples which reflected the highest overall maturity data are from the overmature area of eastern Pennsylvania while the highest Point Pleasant reflectance data is from the dry gas area of Pennsylvania. In the Utica Shale play of Pennsylvania, Ro values transition basinward from 1.03-2.55 (Table 8) and with depth to formation.

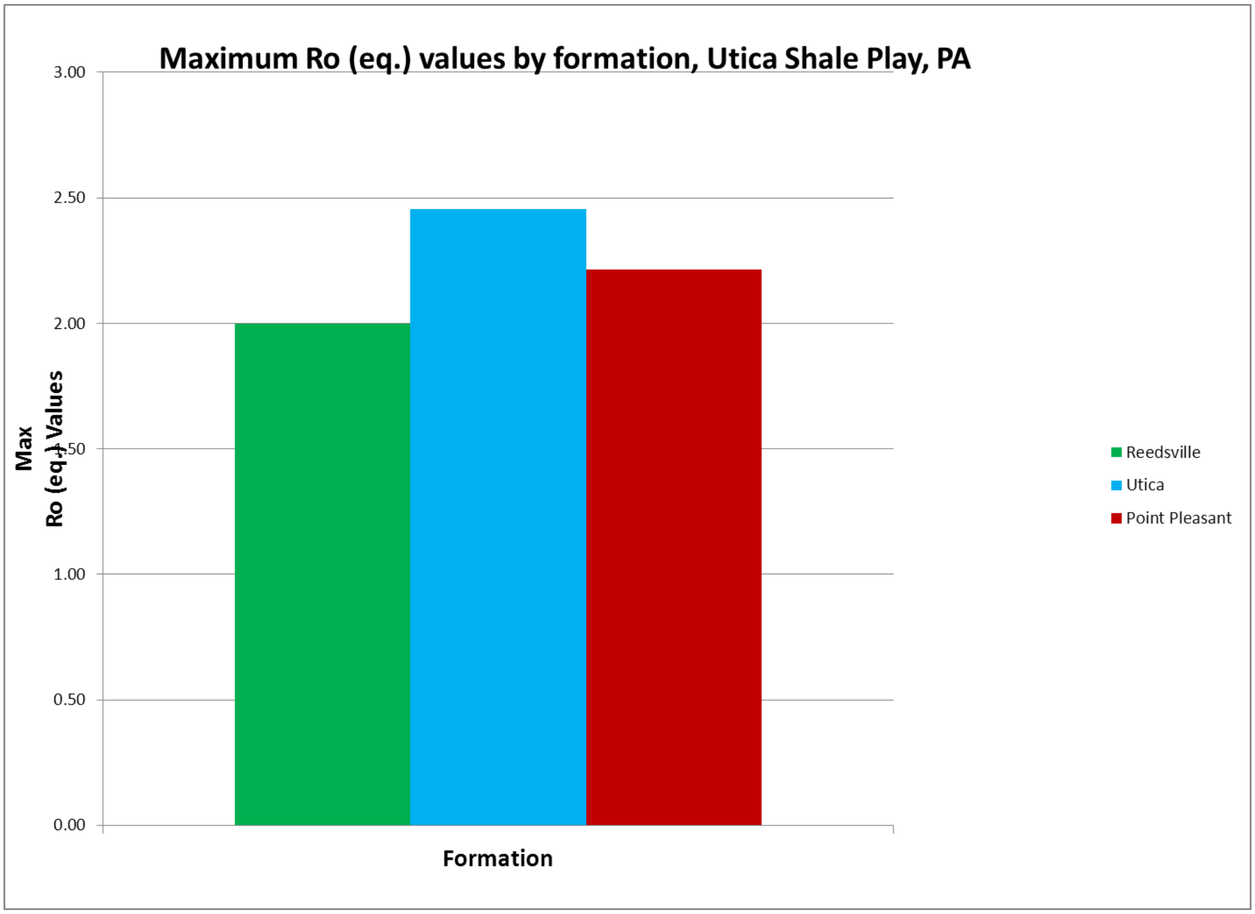

Figure 23. Maximum Ro_{eq} values by formation. Notice that Ro_{eq} values do not have a linear relationship with depth of formation.

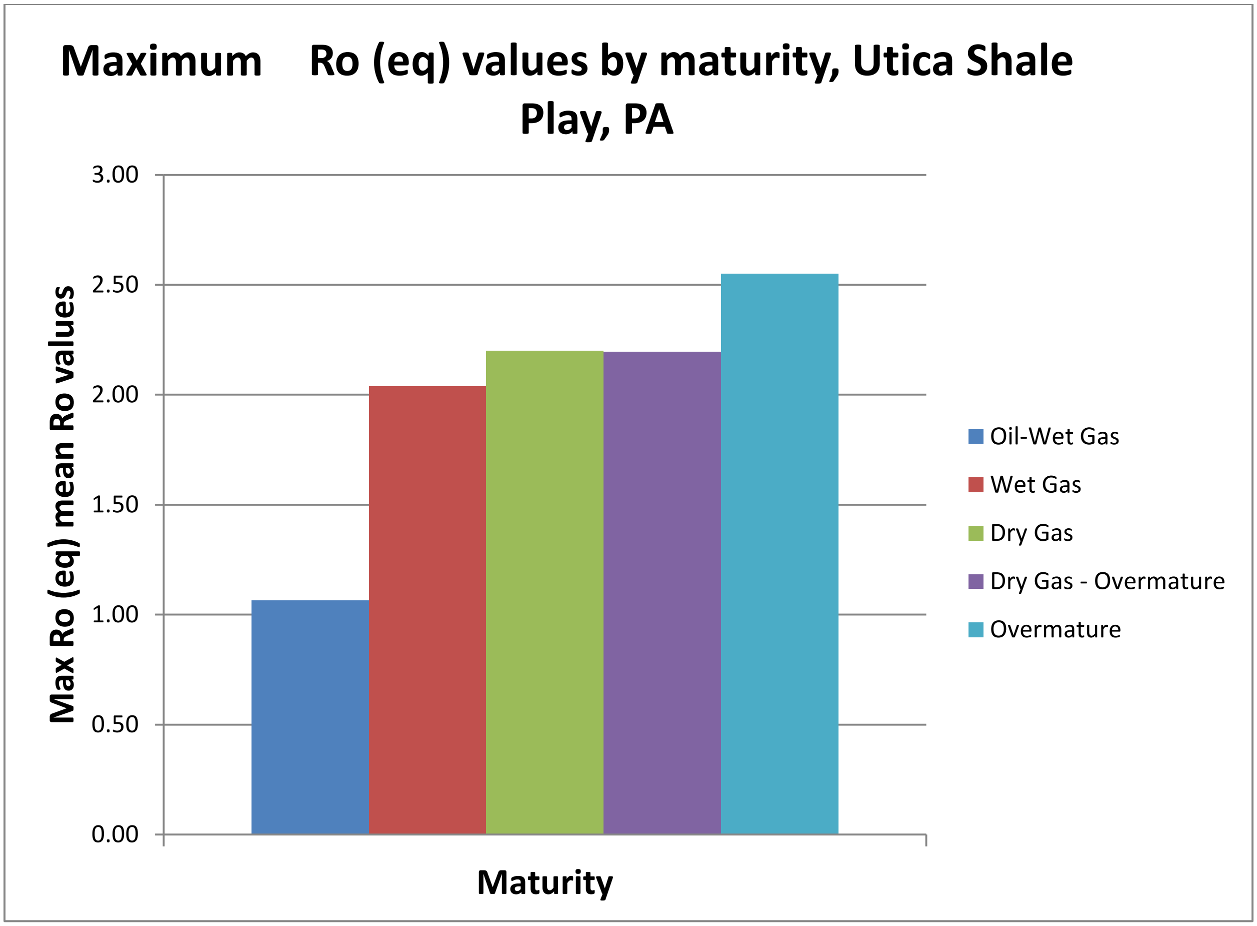

Figure 24. Maximum Ro_{eq} values arranged by area of maturity. Notice the clear increase in reflectance values with increased proximity to the submerging foreland basin.

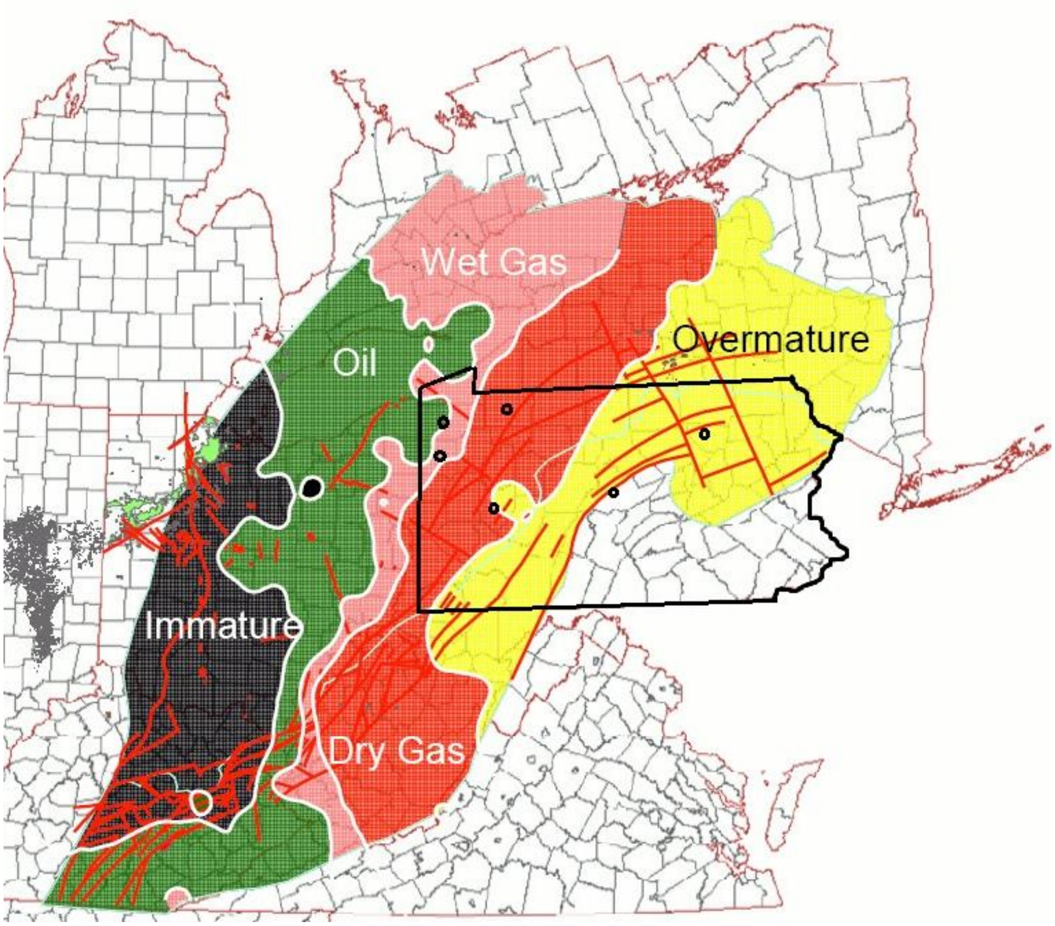

Figure 25. Source rock thermal maturity patterns for the Utica Shale play with Pennsylvania sample locations (Modified from Rowan, 2006).

4.3 Organic Content

For the four formations of the Utica Shale Play, TC, TIC, and TOC content increases with age of stratigraphic formation. The highest average TOC value was found in the Point Pleasant shale, the deepest of the formations (Fig. 26). This is consistent with the Point Pleasant Formation's deposition in the deep, anoxic, area between the Trenton and Lexington Platforms. However, when the TOC data is further examined, the highest individual TOC values are from the Utica Shale of Armstrong and Sullivan Counties and the Point Pleasant Formation of Crawford County. Although from different formations and opposite ends of the state, these

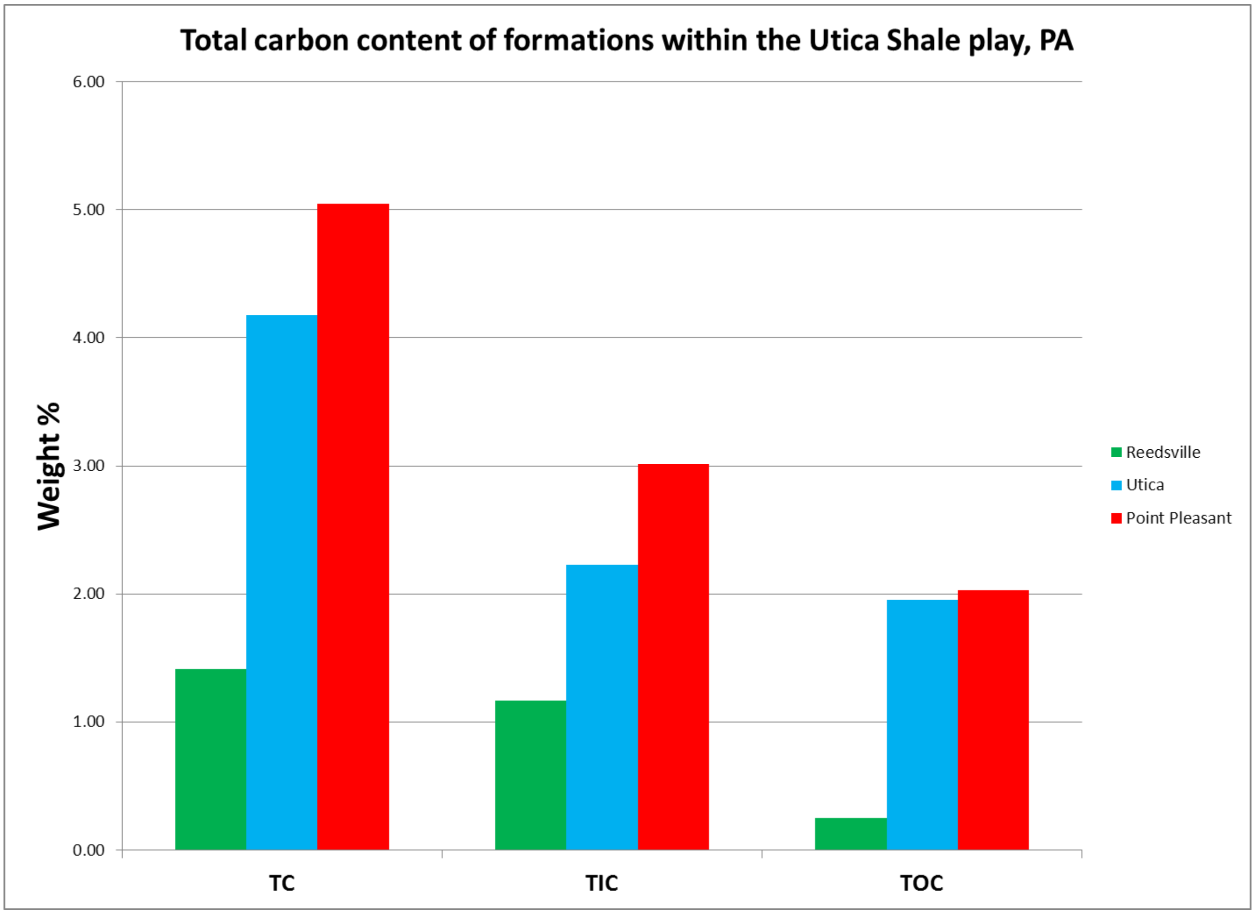

Figure 26. Total carbon data from formations of the Utica Shale play, Pennsylvania. Notice the trend of increasing carbon content with depth of stratigraphic horizon

areas mark the deepest areas of shale accumulation. Armstrong and Crawford County on the west side of the state fall within the Point Pleasant subbasin between carbonate platforms and Sullivan County falls in the deepest area of the Taconic foredeep. The areas of highest organic accumulation occur where water depth was deep enough, between the platforms and towards the foredeep, that anoxic conditions could prevail enabling preservation of organic material.

4.4 Implications for Reservoir Quality

Free natural gas is important for the production potential of an organic-rich shale, but gas can only be produced if enough organic material is present in the shale and subjected to certain temperature and maturity thresholds. Within the Utica Shale play, the Reedsville shale is the least viable petroleum reservoir. with a mineralogy that does not fall within the ideal mineralogy for reservoirs presented by Table 1, the lowest thermal maturity values, and the lowest average TOC. While the Reedsville Shale maturity values may indicate possible oil production with a range of 1.30-2.26 Ro_{eq}, the range of TOC values is well below 1% established by Riley *et al* (2011) as the minimum cut-off for organic-rich source rocks show that not enough organic material is present to generate such byproducts. This lack of organic content is exhibited by the tan-brown sandy shale observed in outcrop. Any hydrocarbons that would be produced in the Reedsville would be restricted from migration by the Reedsville Shale's lack of quartz and abundant clay content. Hydrocarbons would likely be adsorbed to clay minerals rather than free flowing. Under these conditions, the Reedsville shale can't be considered viable as a hydrocarbon reservoir.

The Antes Shale and Utica Shale present more promising qualities for oil and gas generation within the Utica Shale play but still fall short of the ideal reservoir qualities presented in Table 1. Both the Antes and Utica Shale have over 54% quartz by weight but both have over 30% clay minerals. The Antes Shale is much more calcareous at 14.00% than the Utica Shale at 8.29%. The abundance of calcite minerals within the Antes Shale is consistent with outcrop observations. Where the Antes overlies the Coburn Formation at Grier School, obvious signs of calcite precipitation were present in outcrop. Maximum and average Ro_{eq} values for the Utica Shale were much higher than the Reedsville Shale ranging from 1.08-3.20. The highest maturity values occurred in the deepest parts of the formation farthest east showing that both depth and proximity to the Allegheny structural front influenced burial temperatures and maturation of hydrocarbon macerals. The maturity values for the Utica Shale fall within natural gas generation cut offs presented in Table 1. TOC values for the Utica Shale are significantly higher than the Reedsville Shale ranging 1.06-2.61. The highest TOC value does not coincide with the highest SHRo values and does not occur in the deepest samples. Rather, the highest TOC value occurs in Armstrong County were the Point Pleasant subbasin occurs between the Trenton and Lexington platforms. The average TOC value for the Utica Shale, 1.95, falls well within the 1%-2% threshold for a viable petroleum reservoir presented in Table 1.

The Point Pleasant Formation presents the most ideal reservoir characteristics within the Utica Shale play. The Point Pleasant Formation has the highest quartz content at 55.9%, the lowest clay mineral content at 27.35%, and the highest carbonate content at 17.74% (Fig. 22). The entirety of the Point Pleasant Formation's mineralogy falls within the parameters presented in Table 1. While Ro_{eq} values for the Point Pleasant Formation are less mature than Ro_{eq} values for the Utica Shale, values fall within the high oil producing cut off and natural gas producing window, ranging 1.04-2.63. Additionally, results for bitumen reflectance for the Utica Shale reveal that much of the bitumen has been coked and, therefore, degrades reservoir quality. This coked bitumen accounts for the high Ro_{eq} values within the Utica Shale. The Point Pleasant Formation also has the highest TOC values, ranging 1.54-2.45. Both the highest reflectance values and the highest TOC values occur in the northwestern part of Pennsylvania, within the Point Pleasant subbasin. Recently, the USGS conducted an assessment of unconventional oil and gas resources of the Utica Shale, and equivalent Antes Shale and Point Pleasant Shale, in Maryland, New York, Ohio, Pennsylvania, Virginia, and West Virginia (USGS, 2012). The USGS (2012) Also determined that the Utica Shale Gas "sweet spot", an area with a TOC greater than 2% of the Utica and equivalent, was underlain by the shale facies of the Point Pleasant Formation (USGS, 2012). In this study, the Point Pleasant Formation itself represents the most viable hydrocarbon reservoir.

When compared to the findings of Pollastro *et al* (2003) in the Barnett Shale of Texas, the Point Pleasant Formation has the most similar mineralogy, with even higher quartz and carbonate content, and the most approximate TOC values. These results are consistent with the parameters in Table 1 for assessing ideal reservoir characteristics. Overall, the Point Pleasant Formation contains the most ideal characteristics to be a major hydrocarbon producing shale. The Point Pleasant Formation is extremely rich in the brittle minerals allowing for the existence of free gas within the formation and the release of gas with stimulation methods. Additionally, a lack of clay minerals eliminates the tendency for hydrocarbons to be adsorbed to clay mineral surfaces. Free gas can exist within this formation because of the high organic content. The Point Pleasant shale has the highest TOC values within the Utica Shale Play. Although the Utica Shale has higher Ro_{eq} values than the Point Pleasant Formation, the ideal mineralogy and high TOC values of the Point Pleasant Formation make it the most viable petroleum reservoir. These findings are consistent with the PaGS Source Rock Playbook (Laughrey *et al*, 2008).

4.5 Metal Oxides and Implication of Hydrothermal Fluids

In the Utica Shale Play, with the exception of the samples from Sullivan County, the cuttings samples with the highest TOC and Ro_{eq} values occur in the Point Pleasant Formation or where the Utica Shale directly overlies the Point Pleasant Formation. The Point Pleasant Formation also happens to be gradational and intertonging with the Trenton Group and is often included as an upper facies of the Trenton Limestone. Hydrothermal mineralization plays an important role in the placement of hydrocarbons within the Trenton Group. Hydrothermal fluid deposits, such as metal oxides, have been found in the Ordovician carbonate deposits in the center of the state. Hydrothermal diagenesis can occur when fluids are introduced to a formation as a temperature that exceeds the temperature of that formation. Under these conditions, significant diagenesis can take place over short periods of time. The Utica Shale may act as a sealing shale for high-temperature fluids to flow up active faults from the highly fractured and permeable Trenton Group and Point Pleasant Formation. The high occurrence of coked bitumen, along with the appearance of metal oxides in Utica Shale and Point Pleasant samples, supports the activity of hydrothermal fluid migration from the underlying Trenton Group to the overlying Utica Shale. This diagensis, along with maturation that had already taken place within the formations, may have furthered improved the quality of the hydrocarbon reservoirs. The distribution of porous and permeable carbonate facies influences the subsurface conduits traveled by hydrothermal fluids. These samples also happen to be found in many of the western counties, far from the Taconic foredeep. While the location of the Sullivan County samples, along the structural front may explain the high reflectance values, another process caused the western county samples to overmature. Samples from Armstrong, Warren, and Centre County also produced metal oxides during SHRo analysis. In Armstrong, Warren, and Centre Counties, the Point Pleasant Formation is present and is gradational with the Trenton Limestone. Repetski *et al* (2008) also recognized the importance of the Ordovician Trenton Limestone because of its close approximation to thermal maturity patterns of the overlying Ordovician shale. With the exception of the Sullivan County Utica samples, which are in direct contact with the Trenton Group, the Point Pleasant shale has the most favorite results for reflectance data and TOC values. The position of the Point Pleasant directly above the Trenton Group (or it's inclusions as a possible facies within the group) supports the positive affect that the Trenton carbonates have on

Utica Shale Play production. Similar observations were also made in the Lima-Indiana basin, an eastward thickening carbonate and siliciclastic continental margin (Rider *et al*, 1998). As in the Barnett and Utica Shale basins, the most likely hydrocarbon producing facies in the Lima-Indiana basin are black shale and argillaceous limestone interbedded with black shale, including the Antes, Utica, and Point Pleasant shale (Ryder *et al*, 1998). While the presence of hydrothermal fluids appears to play a role in the maturation of the Utica Shale and Point Pleasant Formation, more work needs to be done to make further conclusions.

5.0 Conclusions

Based on mineralogy, hydrocarbon maturity, and organic content, the Point Pleasant Formation is the most viable hydrocarbon reservoir within the Utica Shale play. However, where the Utica Shale is deeper than the Point Pleasant Formation, or the Point Pleasant Formation does not exist, the Utica Shale is also a favorable hydrocarbon reservoir. Data from this study suggests two areas with major reservoir characteristics. In the east, where the Utica Shale directly overlies Trenton Group carbonates, and the Utica Shale is present at the deepest depths within the Taconian foredeep, the Utica Shale has favorable mineralogy and high TOC. In the west, in the Point Pleasant subbasin, the Point Pleasant Formation has favorable mineralogy, favorable maturity, and high TOC. These areas represent the most likely areas of hydrocarbon generation in viable reservoirs. However, because the Utica Shale near the Taconian foredeep has been overmatured, the Point Pleasant Formation makes for the best hydrocarbon reservoir. Additionally, hydrothermal fluids from the underlying Trenton Group carbonates may also influence the occurrence of high maturity values within the Utica Shale and Point Pleasant Formation, but more work needs to be performed to address the role that the fluids may play.

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Appendix I

Outcrop sample locations and descriptions

Location	Coordinates	Note	Location Number	Sample Number	Formation	Sample description	Fizz	Date Collected
Nippenose Valley (Antes Gap)	41.163916 -77.219722	Type Locality of Antes Shale	1	1	Antes/Reedsville	Roughly 60 ft exposed; Grayish brown-black, highly weathered	Moderate	6/27/2012
				2	Antes/Reedsville	Darker in color than sample 1; thin, planar, squared lithons	Moderate	
Salona	41.090694 -77.467972	Could not be found	2					
Bellefonte		Retrieved from debris on road side	3	1	Reedsville?	brown-gray; very thin bed, angular-square lithons	Strong	
				2	Reedsville?	brown-black, appears calcareous where weathered, pencil lithons	Moderate	
Reedsville Exit	40.665027 -77.601277	Top of section to bottom - 3, 1, 2	4	3	Reedsville	tan-gray silty pencil lithons; extremely cleaved in outcrop	Moderate	7/17/2012
				1	Reedsville/Antes	Antes-Reedsville contact; brown-black; massive, interbedded sand and silt at top of section; mostly interbedded gray and black shale, seperating 1 from 3	Slight - Strong	
				2	Antes	Dark gray-black, pencil shaped lithons; very cleaved; underlain by Trenton LS. SEE lab notes for illustration	Moderate	
Grier School, Birmingham	40.648305 -78.197805	Located alon Trenton-Union Furnace lineament and Union Furnace syncline; Also referred to in later trip	5	1	Antes	Very black, platy bedding; shale has been very deformed and squished; calcite nodules and veins especially on weather surfaces; punky, chalky, powdery; kerogens evident as sheen on fracture plane; possibly pyritic, evience of sulfur/iron dissolution; antes overlies Ord. carbonates; all overturned and foreshortened; pyritic, very calcareous, punky, soily, black	Slight to Moderate	
Intersection of Rt 322 and Tussy Mt Rd	N 40*46.737 W 77*45.574		6	1	Antes?	Gray-black carbonaceous shale; probably the more carbonaceous phase thanthe shaley phase; roughly 2 ft exposed with heavy vegetation cover; dark green weathered surface	Strong	7/30/2012
				2	Antes	Large chunks in drainage ditch; top of Coburn, dark brown, very thinly bedded and fissile (more typical of Antes); very calcaerous		
Oak Hall Quarry	N 40*47.948 W 77*48.803	814-466-5101 to reach curtain gap call Barry Davis 814-353-2352	7	3,2,1 (From top to bottom)	Reedsville	Northwest exposed wall, 2nd (higher) tier); pencil lithon cleavage; tan to olive gray interbedded silt and sand with black calcareous shale. Silty beds approx 4 - 5ft and shale beds approx 2 to 4 feet. Consistant bed thickness.	Slight - Moderate	
				3		interbedded silt and sandstone		These samples are not in numerical order, but that is the order that I labeled them in the outcrop, starting with 3
				2		contact of interbedded silt, sandstone, and shale		
				1		black, calcareous shale, silty in some places		
				4		About 30 ft downsection from sample 2; very beginning of 'true black shale'; very pyritic, interbedded shale and silt		
				5		About 10 - 15 ft downsection from sample 4; completely different cleavage (not pencil-like, large irregular chunks); approx 2 ft thick, very calcareous with large conspicuous calcite crystals but very dark gray - black otherwise	only slight fizz where there aren't large calcite cystals	
				6		light gray - tan, very silty. Pencil cleavage; appears to be pyritic, weathered iron staining	slight to moderate	
				7		Dark gray-black, pencil shaped lithons interbedded with more massively bedded silt and shale, large calcite veins and vugs	Slight - Moderate - Strong	
				8		Dark gray- black shale, pencil cleavage, ashy in places	slight	
				9	contact between limestone and shale	dark gray - black interbedded shale and limestone; some ash beds; fossiliferous	Strong	
				10		very fine, black shaly shale and limestone, weathers beige to brown; may pinch out to left of NW facing wall	Strong	
				11		very thinly bedded shale and ash; dark gray-black; calcareous and pyritic	slight	

Location	Coordinates	Note	Location Number	Sample Number	Formation	Sample description	Fizz	Date Collected
Sky Top Quarry	N 40*49.927 W77*57802	Contact Doug Tudy for clearence	8	1	Reedsville (float)	extremely fossiliferous	moderate where fossilised, otherwise no fizz	
				2	Reedsville (intact)	slightly fossiliferous, very silty; 1mm-3mm laminations of silt	none to very slight	
				3	Antes float	black shale interbedded with calcaerous, silty shale; punky, organic	moderate	
Sky Top Quarry Pond M	N 40*49.877 W 77*58.039	Was once an outcrop, landscape has since been changed. Not visited	9					
McCormick Pit	N 40*49.834 W 77*58.068	Get in touch with Reid McCormick, part of his property	10					
Dutwiler House (Near Nealmont)	N 40*40.209 W 78*12.877	3450 house number. Dutwiler Residence	11	1	Antes above Coburn	Dark black shale, conspicuous kerogen slicks	slight	
				2	Reedsville?	light tan to light gray thinkly bedded shale; silty; slightly calcareous	slight - moderate	
Tyrone Forge Quarry		Contact Jeff Lindsey; No samples, no shale	12					
House at St Route 1013 + 1010	N 47*30.117 W 78* 10.132	Part of the Canoe Mountain Syncline	13	1, 2	Reedsville	Axial planar cleavage; tan - brown interbedded shale and silt; slightly asymmetrical	moderate - strong	
Route 453 and 22 behind the transformer	N 40*34.296 W 78* 08.283		14		Reedsville	very black, slightly fossilif., silty in some places. 40 ft below overturned Bald Eagle contact, possible fault controlled?	none	
Foster house	N 40* 34.864 W 78*09.251	part of old quarry, speak to residence before visiting again	15	1,2 sepearted from 3 by float; appear to be two different shale formations	?	black and brown iron stained shale, rectangular cleavage, most of outcrop covered by vegetation or float	none	
Morris Rd Quarry	N 40*35.230 W 78*90.063	Not visited						

Appendix II.

Cuttings samples locations and descriptions

API Number	County	Quad	Farm Name	Coordinates		Elevation	Reedsville top depth	Reedsvile base depth	Reedsville Interval sampled	Antes top depth	Antes base depth	Antes Interval Sampled	Utica top depth	Utica base depth	Utica Interval Sampled	Point Pleasant top depth	Point Pleasant base depth	Point Pleasant Interval Sampled	Notes
3700521201	Armstrong	Distant	N. Martin #1	-79.3470755	40.88482721	1462	10762	11792	10760-11780 Reedsville composit 1 g every 10 feet; 3g ever 10 ft TOP 10850 - 10900; MID 11200-11250; BOTTOM 11500-11550	N/A	N/A	N/A	11792		11780-11810 Utica composit, 3 g every 10 feet to account for limited quantity of samples; 3g 11780-90 and 11790-1800. Not enough to sample 11800-10	11948	12106	11810-12030, I g every 10 ft; TOP 11850 - 11900 3 g/10 ft; BOTTOM 11950 - 12000 1 g/ 10 ft	Reedsville - Gray, Utica - dark gray to black, Point Pleasant - black; increasing color with depth
3702720001 <	Centre	Madisonburg	Long	4700' W 77*35	2150' S 41*00	N/A	12933	13875	13460-13875; Reedsville Top 13500 - 13550 2g/10 ft; Bottom 13800 - 13850 2g/10 ft 3g/10 ft	13875	14560	13874-14650 Utica; TOP 13900 - 13950 5 g / 10 ft; MID 14200-14250; BOTTOM 14450-14500	N/A	N/A	N/A	N/A	N/A	N/A	
3703920007	Crawford	Harmonsburg	Kardosh	4200' W 80*17'30"	12550' S 41*45'00"	N/A	5185	5942	TOP 5200-5250 MID 5500-5550 BOTTOM 5850-5900 3g/10 ft	N/A	N/A	N/A	5942	6006	TOP 5950-5970 BOTTOM 5980-6000 3g/ 10 ft and composit 5940-6010 2g/ 10 ft	6006	6220	Top 6010 -6060 3g/ 10 ft Bottom 6150-6200 3g/10 ft;	Top of Reedsville very red/gray.
3708520116	Mercer	Stoneboro	Fleck	8250' W 80*12'30	13900' S 41*30'	N/A	5962	6874	TOP 6000-6050 MID 6400-6450 BOTTOM 6800-6850	N/A	N/A	N/A	6874		TOP 6880-6900 BOTTOMG 6930-6950 3g/10 ft and composit 6880-6950 2g/10 ft	6952	7108	TOP 6960 - 7010 BOTTOM 7100 -7050 3g/10ft;	Top of Reedsvile very red and rocky; mid Reedsville very light gray; Top of Utica gray as Reedsville, bottom dark brown; changes color at 6940 - 50! Bottom of Utica same color as top of PP
3711320002	Sullivan	Elk Grove	Dieffenbach	2900' W of 76*27'30"	7400' S 41*22'30"	N/A	15384	16110	TOP 15400 -15450 BOTTOM 16100-16050	16257	16465	TOP 16300-16350 BOTTO	16110	16257	16100-16150 Bottom 16200-16250	N/A	N/A	N/A	Utica gets darker at 16120-16130
3712320150	Warren	Tiduote	Shaw	1.85 mi W 79*20'	91 mi S 41*40	N/A	7315	7985	TOP 7350 - 7400 BOTTOM 7850 - 7900 MID 7600 - 7650 3g/10 ft	N/A	N/A	N/A	7985	N/A	TOP 8000-8050 BOTTOM 8100-8050	8172	8298	TOP 8150-8200 BOTTOM 8250-8300	Reedsville starts to darken approx 7350; Utica starts to get dark 8120-8126; PP very dark at 8170-8185

Appendix III

Summary of lab analyses performed on cuttings samples

PERMIT	COUNTY	COMPANY	FARM	QUADRANGLE	longitude	latitude	Formation Sampled	Interval Sampled (ft)	XRD	Bitumen Refl.	TOC	Well Type	Area
3700521201	Armstrong	Dominion Exploration and Production	Nellie Martin #1	Distant	40.88482721	-79.3470755	Reedsville	10850-10900	X		X	Gas	Dry/Overmature
							Utica	11780-11810	X	X	X		
							Point Pleasant	11850-11900	X	X	X		
3702720001	Centre	Mobil Oil Co.	Long #1	Madisonburg	40.99409755	-77601445	Reedsville	13800-13850	X	X	X	Dry	Overmature
							Antes	14200-14250	X	X	X		
3703920007	Crawford	Benedum Interests	Kardosh #1	Harmonsburg	41.71555791	-80.3070494	Reedsville	5500-5550	X		X	Dry	Oil/ Wet Gas
							Utica	5950-5970		X	X		
							Utica Composite	5940-6010	X				
							Point Pleasant	6150-6200	X	X	X		
3708520116	Mercer	People's Natural Gas	James E Fleck #1	Hadley	41.46184849	-80.2384313	Reedsville	6400-6450	X		X	Gas	Wet Gas
							Utica	6930-6950		X	X		
							Utica Composite	6880-6950	X				
							Point Pleasant	7050-7100	X	X	X		
3708590010	Mercer	United Natural Gas	Maude Davidson #1	Sandy Lake	41.27246708	-80.0357871	Reedsville	7800-7850		X		Dry	Wet Gas
3711320002	Sullivan	Consol Gas Co	Dieffenbach	Elk Grove	41.35469297	-76.4685447	Utica	16050-16100	X		X	Dry	Dry Gas
							Utica	16200-16250	X	X	X		
							Utica	16300-16350		X	X		
							Utica	16400-16450	X				
3712320150	Warren	Biert & Johnson Co	Shaw #1	Cobham	41.65391267	-79.3689391	Reedsville	7600-7650	X		X	Dry	Dry Gas
							Utica	8100-8150	X	X	X		
							Point Pleasant	8250-8300	X	X	X		

Appendix IV

Results of bitumen reflectance

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

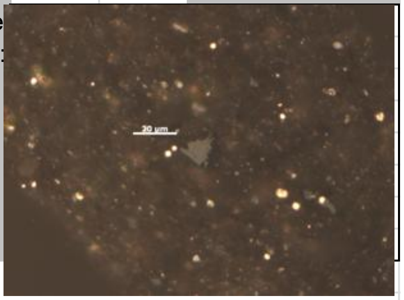
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

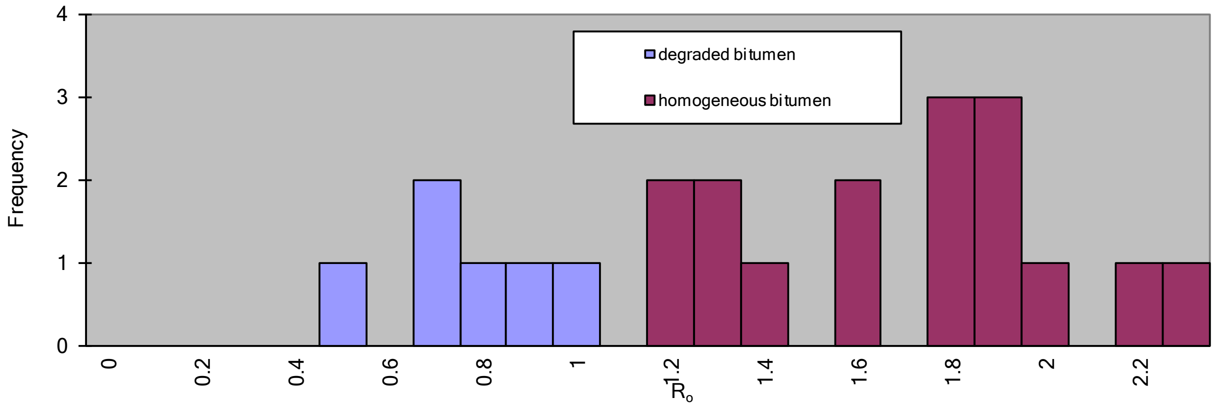
Sample ID: **3708590010 7800-7850**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 21
maceral type: bitumen
R_o: 1.45
s.d.: 0.47
Example Photograph:




08590010 7800-7850

DATA

0.450	1.358	2.134
0.680	1.570	2.274
0.696	1.584	
0.770	1.720	
0.828	1.744	
0.950	1.760	
1.178	1.833	
1.199	1.842	
1.228	1.865	
1.263	1.960	

All Data: **min:** 0.450 **max:** 2.274

Vitrinite Only: **min:** 0.680 **max:** 2.274 **V-types:** 17

COMMENT

Prepared by ASTM D2797; YAG [.908]
Mercer County - Reedsville

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

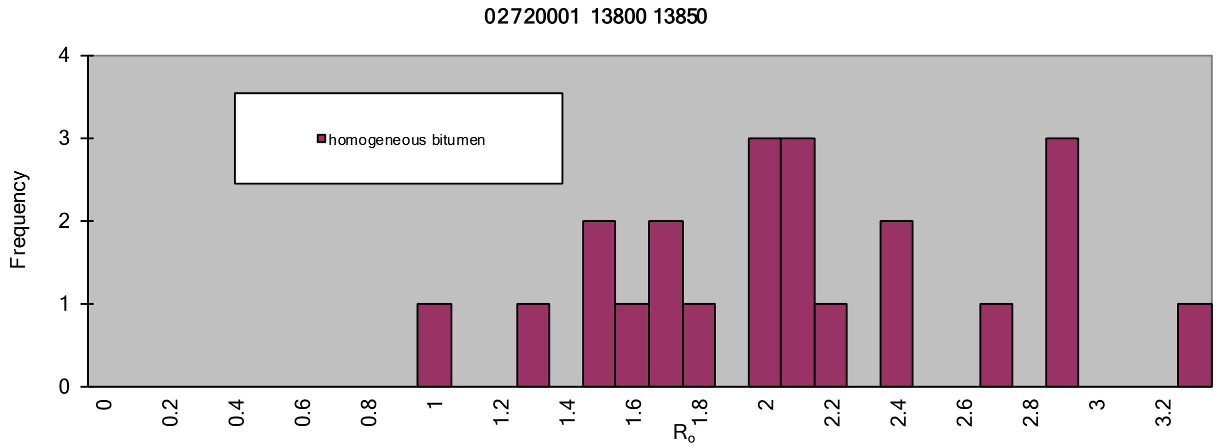
Submitted by: Michele Cooney
Date Submitted: 10.5.12
Project: Utica

Sample ID: **3702720001 13800-13850**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 22
maceral type: bitumen
R_o: 2.04
s.d.: 0.56
Example Photograph: N/A



DATA

0.984	1.983	2.842
1.209	2.034	3.201
1.425	2.035	
1.464	2.037	
1.540	2.184	
1.657	2.318	
1.693	2.343	
1.746	2.700	
1.918	2.820	
1.935	2.836	

All Data: **min:** 0.984 **max:** 3.201

Vitrinite Only: **min:** 0.984 **max:** 3.201 **V-types:** 24

COMMENT

Sample prepared by ASTM D2797; Standard Zirconia [3.13]
Centre County - Reedsville (Martinsburg)

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

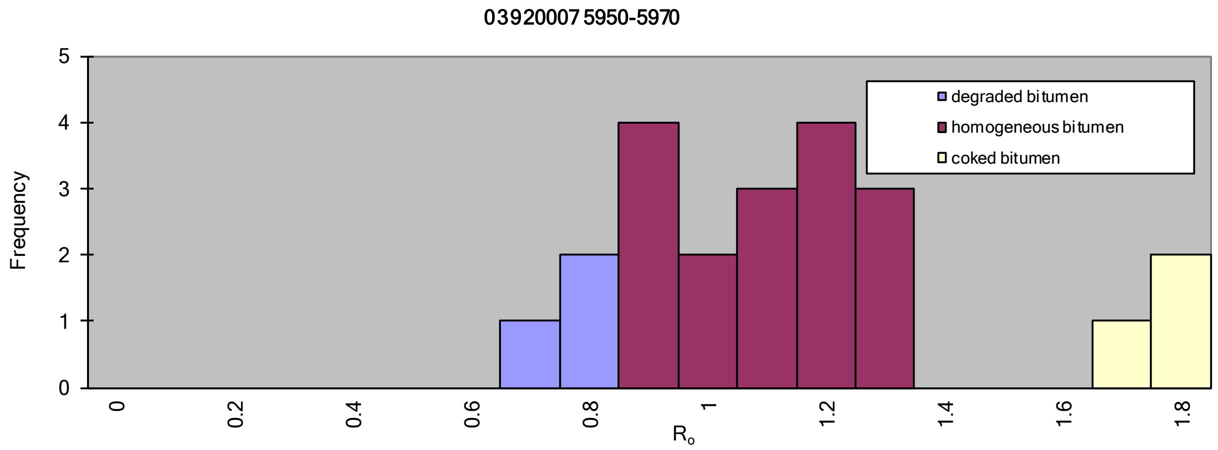
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

Sample ID: **3703920007 5950-5970**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 22
maceral type: bitumen
R_o: 1.10
s.d.: 0.30
Example Photograph: N/A



DATA

0.672	1.035	1.731
0.711	1.089	1.778
0.788	1.118	
0.844	1.158	
0.858	1.164	
0.866	1.168	
0.884	1.226	
0.910	1.282	
0.979	1.287	
1.017	1.626	

All Data: **min:** 0.672 **max:** 1.778

Vitrinite Only: **min:** 0.672 **max:** 1.778 **V-types:** 12

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Crawford County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

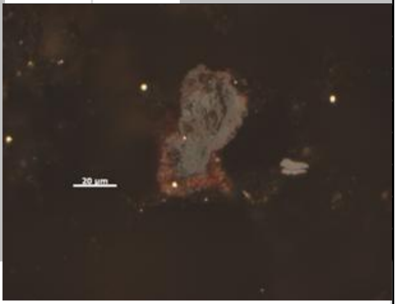
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

Sample ID: **3708520116 6930-6950**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

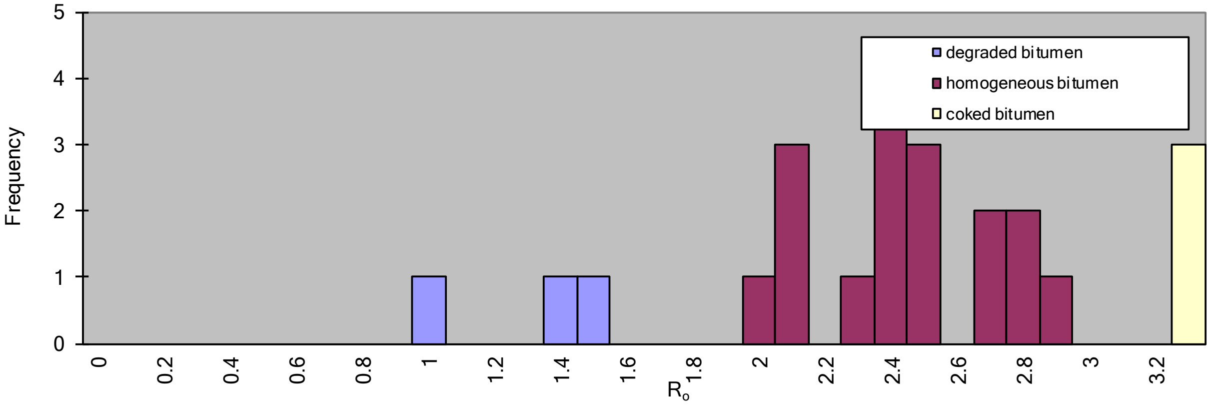
Standard: ASTM D2798 7708

RESULTS

No. measurements: 23
maceral type: bitumen
R_o: 2.36
s.d.: 0.56
Example Photograph:



08520116 6930-6950



DATA

0.948	2.355	3.209
1.370	2.392	3.209
1.451	2.417	3.209
1.971	2.483	
2.004	2.499	
2.058	2.633	
2.071	2.662	
2.222	2.768	
2.324	2.792	
2.330	2.826	

All Data: **min:** 0.948 **max:** 3.209

Vitrinite Only: **min:** 0.948 **max:** 3.209 **V-types:** 24

COMMENT

Prepared by ASTM D2797; YAG [.908]
Mercer County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

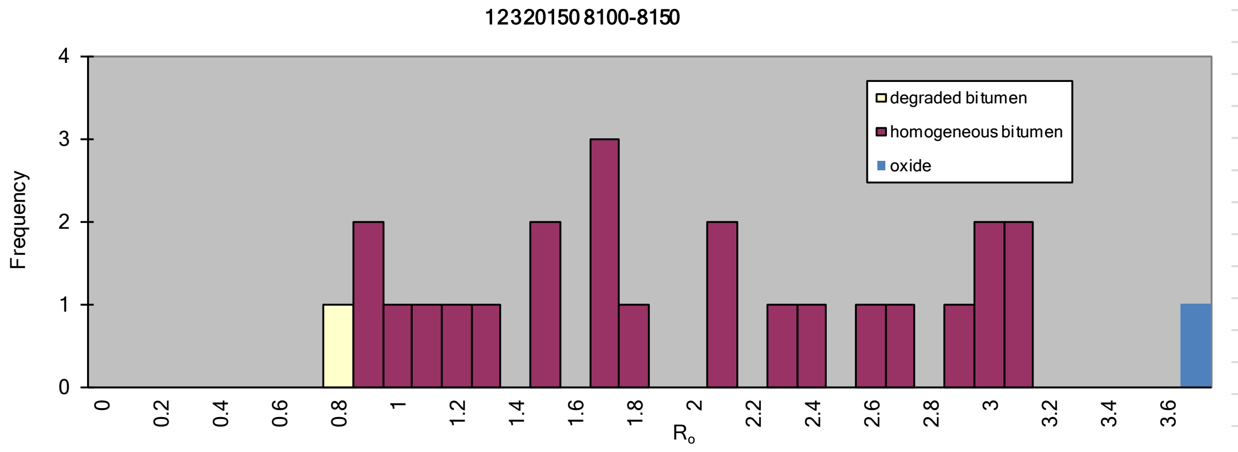
Run

SAMPLE INFORMATION

Submitted by:	Michele Cooney
Date Submitted:	10.4.12
Project:	Utica
Sample ID:	**3712320150 8100-8150**
Lab ID:	0
Sample Type:	cuttings
Date Analyzed:	10.5.12
Operator:	M.C.
Standard:	ASTM D2798 7708

RESULTS

No. measurements:	25
maceral type:	bitumen
R_o:	1.95
s.d.:	0.83
Example Photograph:	N/A



DATA

0.715	1.615	2.937
0.831	1.621	2.969
0.849	1.772	3.047
0.958	2.019	3.079
1.017	2.046	3.692
1.194	2.214	
1.223	2.379	
1.421	2.520	
1.491	2.629	
1.607	2.862	

All Data: **min:** 0.715 **max:** 3.692

Vitrinite Only: **min:** 0.715 **max:** 3.692 **V-types:** 30

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Warren County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

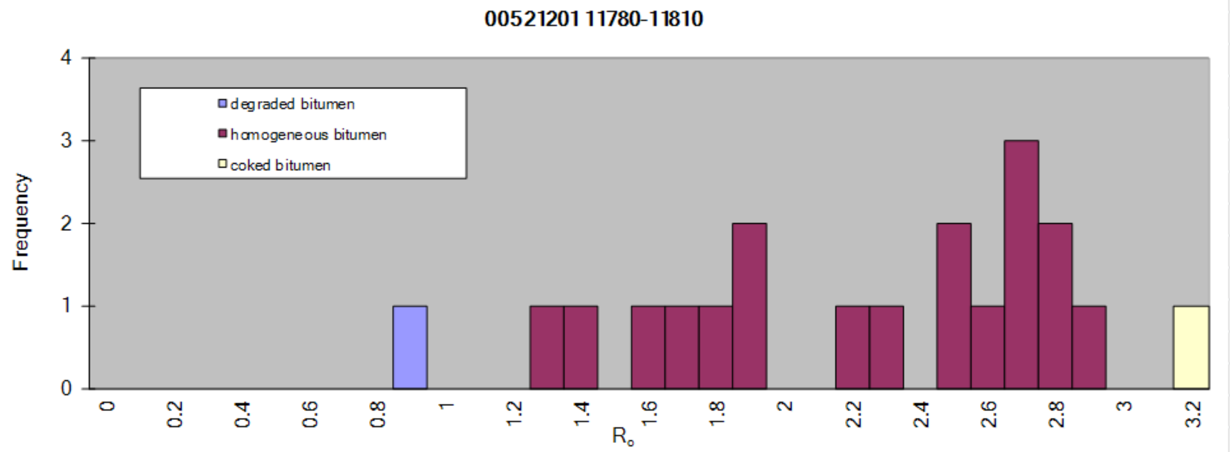
Submitted by: Michele Cooney
Date Submitted: 10.5.12
Project: Utica

Sample ID: **3700521201 11780-11810**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 19
maceral type: bitumen
R_o: 2.11
s.d.: 0.58
Example Photograph: N/A



DATA

0.863	2.421
1.236	2.448
1.308	2.584
1.563	2.620
1.632	2.627
1.788	2.693
1.828	2.740
1.831	2.745
2.130	2.839
2.270	3.192

All Data: **min:** 0.863 **max:** 3.192

Vitrinite Only: **min:** 0.863 **max:** 2.839 **V-types:** 21

COMMENT

Sample prepared by ASTM D2797; YAG [.908]
Armstrong County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

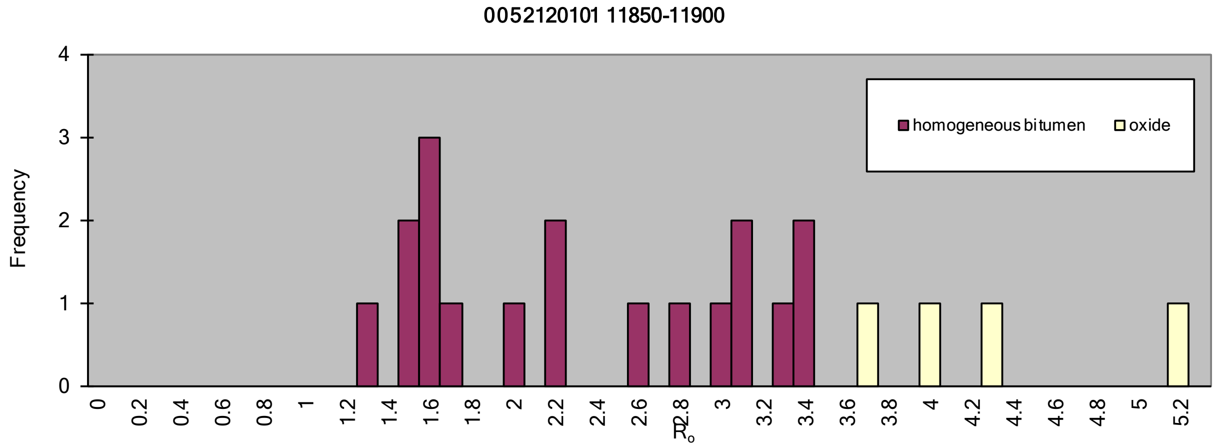
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

Sample ID: **3700521201 11850-11900**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 18
maceral type: bitumen
R_o: 2.28
s.d.: 0.75
Example Photograph: N/A



DATA

1.278	2.582	4.253
1.408	2.716	5.109
1.415	2.924	
1.506	3.073	
1.563	3.079	
1.575	3.288	
1.603	3.345	
1.935	3.390	
2.101	3.650	
2.174	3.915	

All Data: **min:** 1.278 **max:** 5.109

Vitrinite Only: **min:** 1.278 **max:** 3.390 **V-types:** 22

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Armstrong County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

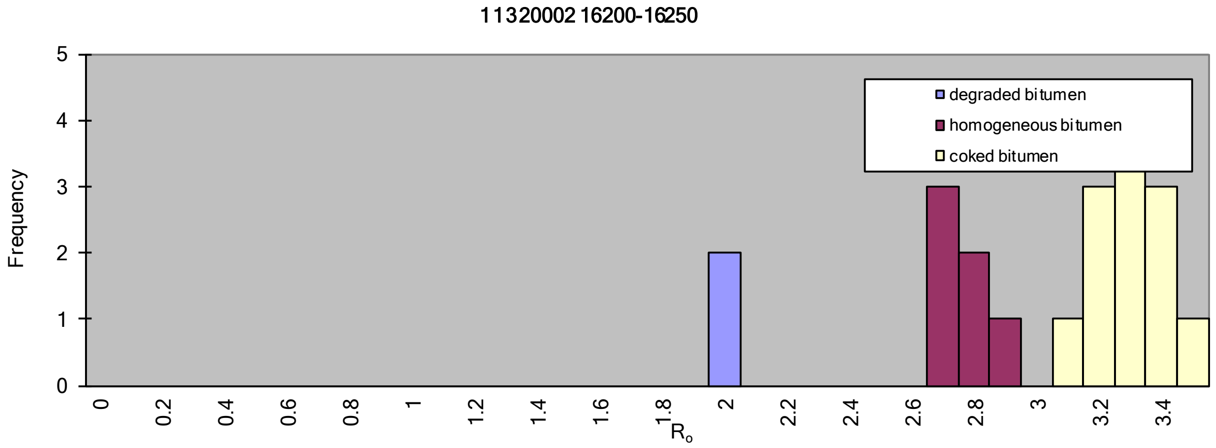
Run

SAMPLE INFORMATION

Submitted by:	Michele Cooney
Date Submitted:	10.4.12
Project:	Utica
Sample ID:	**3711320002 16200-16250**
Lab ID:	0
Sample Type:	cuttings
Date Analyzed:	10.5.12
Operator:	M.C.
Standard:	ASTM D2798 7708

RESULTS

No. measurements:	20
maceral type:	bitumen
R_o:	2.96
s.d.:	0.43
Example Photograph:	N/A



DATA

1.905	3.170
1.952	3.197
2.639	3.203
2.650	3.226
2.689	3.246
2.764	3.268
2.777	3.341
2.836	3.374
3.100	3.375
3.101	3.411

All Data:	**min:**	1.905	**max:**	3.411		
Vitrinite Only:	**min:**	1.905	**max:**	3.411	**V-types:**	16

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Sullivan County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

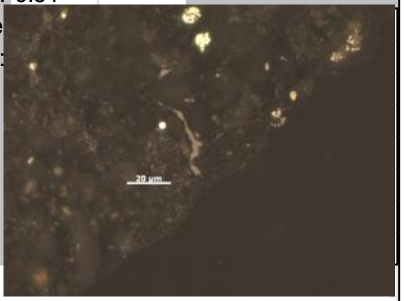
Sample ID: **3711320002 16300-16350**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

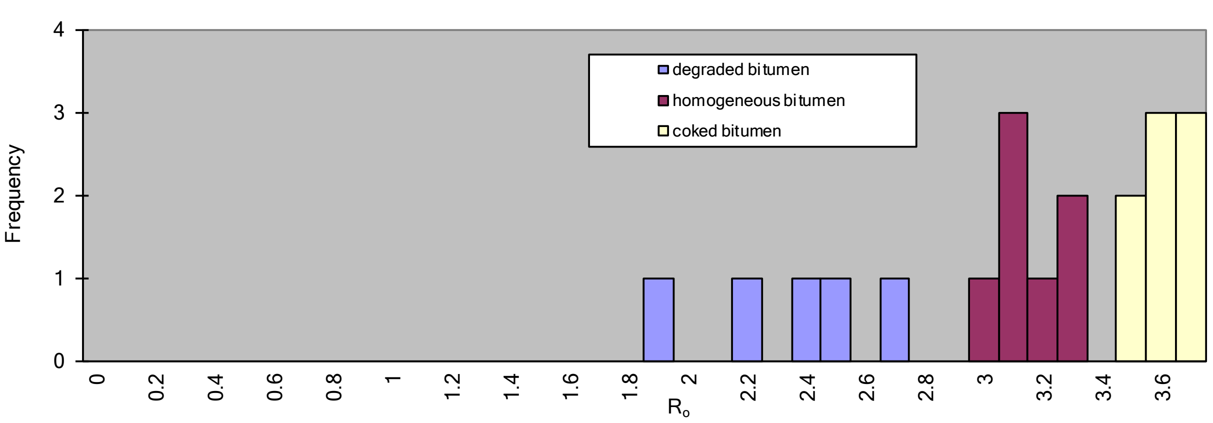
Standard: ASTM D2798 7708

RESULTS

No. measurements: 20
maceral type: bitumen
R_o: 3.09
s.d.: 0.51

Example Photograph:





DATA

1.899	3.207
2.137	3.300
2.362	3.403
2.496	3.441
2.696	3.535
2.997	3.541
3.014	3.567
3.064	3.615
3.078	3.637
3.130	3.653

All Data: **min:** 1.899 **max:** 3.653

Vitrinite Only: **min:** 1.899 **max:** 3.653 **V-types:** 19

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Sullivan County - Utica

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

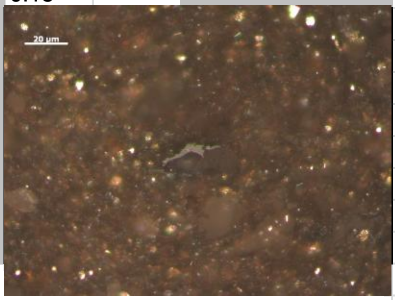
Submitted by: Michele Cooney
Date Submitted: 10.2.12
Project: Utica

Sample ID: **03920007 6150-6200'**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.3.12
Operator: P. Hackley

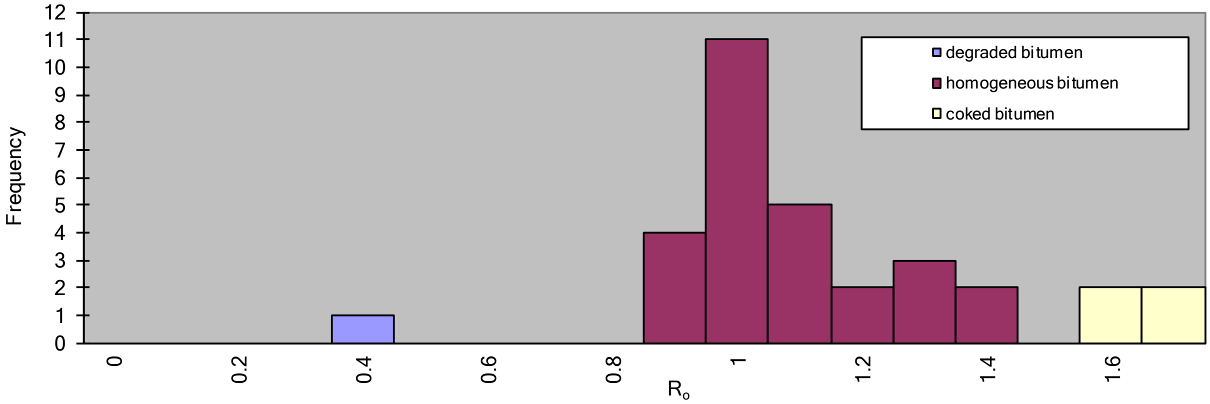
Standard: ASTM D2798 7708

RESULTS

No. measurements: 27
maceral type: solid bitumen
R_o: 1.03
s.d.: 0.15
Example Photograph:



0392007 6150-6200'



DATA

0.303	0.958	1.090	1.634
0.814	0.964	1.131	1.669
0.859	0.966	1.188	
0.866	0.970	1.220	
0.887	0.976	1.228	
0.903	0.988	1.272	
0.911	1.001	1.312	
0.916	1.015	1.355	
0.917	1.074	1.520	
0.923	1.075	1.567	

All Data: **min:** 0.303 **max:** 1.669

Vitrinite Only: **min:** 0.814 **max:** 1.355 **V-types:** 6

COMMENT

Sample prepared by ASTM D2797; YAG [.908]
Crawford County - Point Pleasant

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

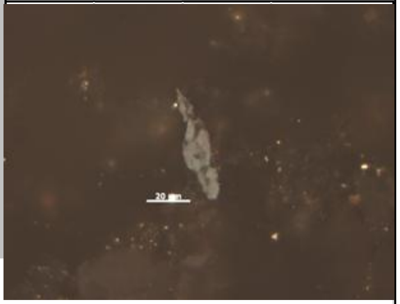
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

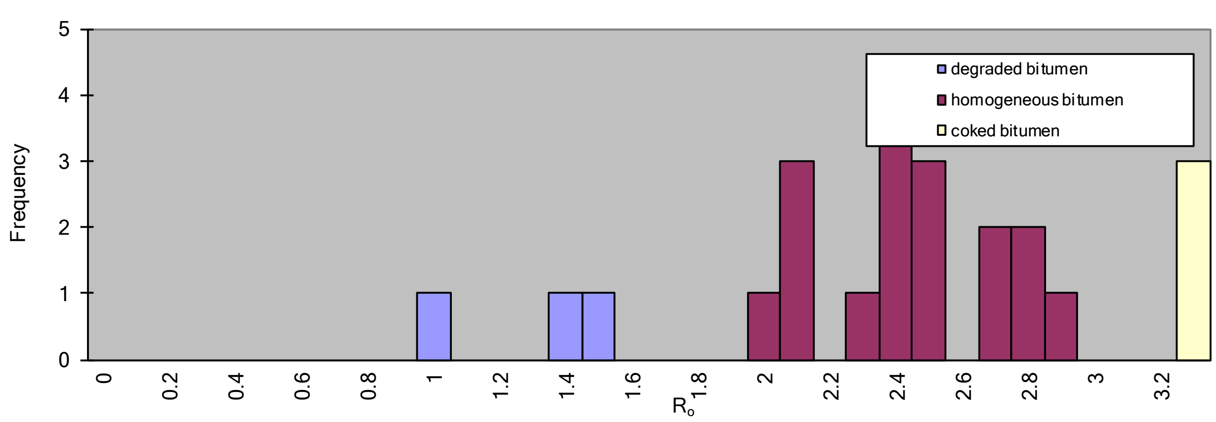
Sample ID: **3708520116 7050-7100**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 23
maceral type: bitumen
R_o: 2.36
s.d.: 0.56
Example Photograph:





DATA

0.948	2.355	3.209
1.370	2.392	3.209
1.451	2.417	3.209
1.971	2.483	
2.004	2.499	
2.058	2.633	
2.071	2.662	
2.222	2.768	
2.324	2.792	
2.330	2.826	

All Data: **min:** 0.948 **max:** 3.209

Vitrinite Only: **min:** 0.948 **max:** 3.209 **V-types:** 24

COMMENT

Sample prepared by ASTM D2797; YAG [.908]
Mercer County - Point Pleasant

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

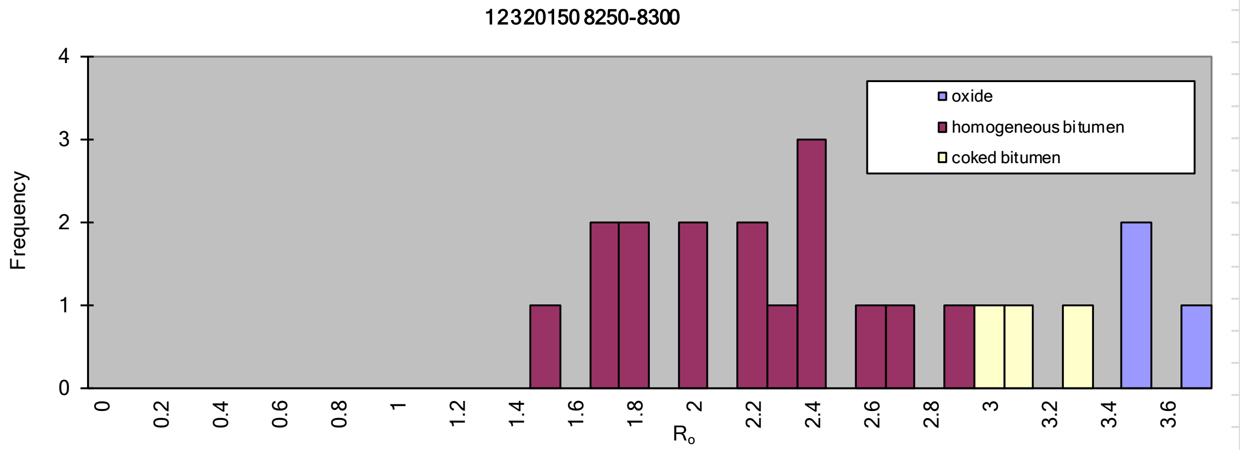
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

Sample ID: **3712320150 8250-8300**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 22
maceral type: bitumen
R_o: 2.45
s.d.: 0.64
Example Photograph: N/A



DATA

1.405	2.382	3.473
1.638	2.390	3.681
1.681	2.398	
1.703	2.584	
1.766	2.695	
1.959	2.882	
1.991	2.969	
2.146	3.052	
2.168	3.226	
2.285	3.471	

All Data: min: 1.405 **max:** 3.681

Vitrinite Only: min: 1.405 **max:** 3.681 **V-types:** 23

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Warren County - Point Pleasant

DISPERSED VITRINITE REFLECTANCE REPORT

Run

SAMPLE INFORMATION

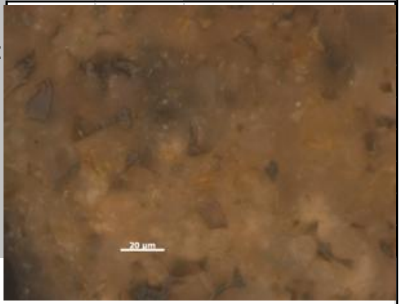
Submitted by: Michele Cooney
Date Submitted: 10.4.12
Project: Utica

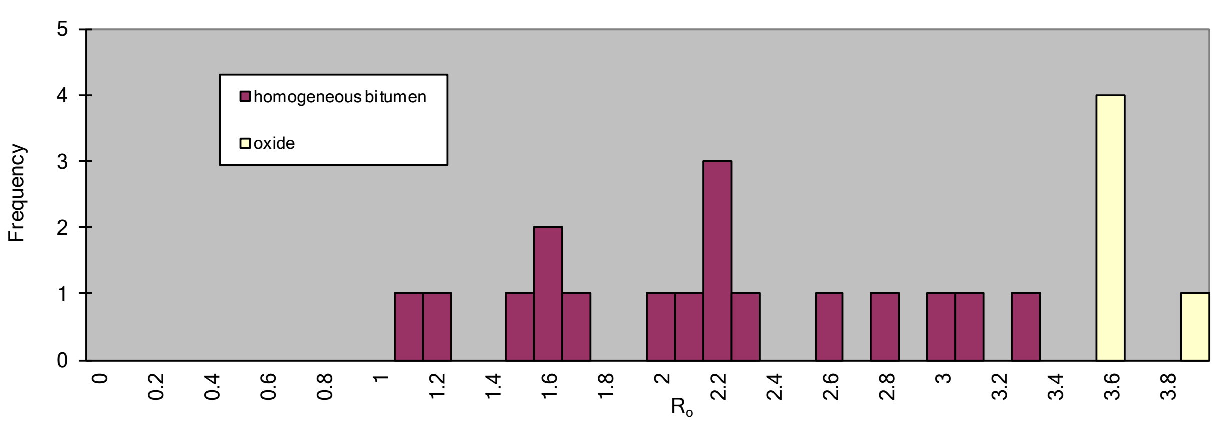
Sample ID: **3702720001 14200-14250**
Lab ID: 0
Sample Type: cuttings
Date Analyzed: 10.5.12
Operator: M.C.

Standard: ASTM D2798 7708

RESULTS

No. measurements: 17
maceral type: bitumen
R_o: 2.11
s.d.: 0.64
Example Photograph:





DATA

1.022	2.199	3.596
1.192	2.273	3.833
1.451	2.549	
1.543	2.784	
1.588	2.993	
1.653	3.095	
1.947	3.253	
2.054	3.506	
2.141	3.547	
2.151	3.593	

All Data: **min:** 1.022 **max:** 3.833

Vitrinite Only: **min:** 1.022 **max:** 3.253 **V-types:** 23

COMMENT

Prepared by ASTM D2797; Zirconia [3.13]
Centre County - Point Pleasant