THE MARCELLUS SHALE: EROSIONAL BOUNDARY AND PRODUCTION ANALYSIS, SOUTHERN WEST VIRGINIA, U.S.A.

by

Mallory Stevenson

November, 2015

Director of Thesis: Dr. Donald W. Neal

Major Department: Geological Sciences

The Middle Devonian Marcellus Shale is a natural gas producing formation that was deposited in the Appalachian foreland basin in what is now eastern North America. An unconformity truncates the Marcellus in southern West Virginia and progressively younger units onlap progressively older units. The zero isopach line that marks the edge of the Marcellus is mapped to reveal the southeastern boundary. A well production analysis is conducted to locate the region of maximum natural gas production. Four lithologic completions intervals in three different well fields are compared. This study shows that the most economically viable drilling is from the Marcellus Shale completion intervals that are less than 30 feet in Chapmanville gas field in western Logan County, West Virginia. Outside of the zero isopach are areas comprised of onlapping featheredges of younger formations that comprise a black shale unit mistakenly identified as "Marcellus Shale." These areas produce significantly less gas than the "true" Marcellus Shale.

THE MARCELLUS SHALE: EROSIONAL BOUNDARY AND PRODUCTION ANALYSIS, SOUTHERN WEST VIRGINIA, U.S.A.

A Thesis

Presented To the Faculty of the Department of Geological Sciences

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Geology

by

Mallory Stevenson

November, 2015

THE MARCELLUS SHALE: EROSIONAL BOUNDARY AND PRODUCTION ANALYSIS, SOUTHERN WEST VIRGINIA, U.S.A.

by

Mallory Stevenson

APPROVED BY:

DIRECTOR OF THESIS:

_______________________________________ Donald W. Neal, Ph.D.

COMMITTEE MEMBER:

_______________________________________ Katharine Lee Avary, M.S.

COMMITTEE MEMBER:

_______________________________________ J. P. Walsh, Ph.D.

COMMITTEE MEMBER:

_______________________________________ Richard K. Spruill, Ph.D.

CHAIR OF THE DEPARTMENT
OF GEOLOGICAL SCIENCES:

____ Stephen Culver, Ph.D.

DEAN OF THE
GRADUATE SCHOOL:

_______________________________________ Paul J. Gemperline, PhD

ACKNOWLEDGEMENTS

I greatly appreciate Dr. Donald Neal's advice and encouragement throughout the thesis process. East Carolina University's Department of Geological Sciences faculty and Katharine Lee Avary have also been incredibly helpful. I would like to thank my parents for providing me with the opportunity to gain this tremendous education and the necessary tools to succeed in life. I am also very thankful to Brian Klipp for his love and support along the way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

CHAPTER ONE: INTRODUCTION

The Marcellus Shale was deposited in the Appalachian Basin during the Middle Devonian about 390 million years ago. The Marcellus Shale can be found in outcrop and in the subsurface throughout the eastern United States. It extends over an area of 95,000 square miles from central New York to southern West Virginia and parts of western Virginia, with a small section in eastern Kentucky. The western margin of the Marcellus is in east-central Ohio east of the Cincinnati Arch and the northern margin is south of the Adirondack Mountains, whereas the eastern margin runs through eastern New York and Pennsylvania, western Maryland, West Virginia, and a thin slice of western Virginia along the eastern overthrust belt (Fig. 1). The margins are erosional in all geographic directions (Bruner and Smosna, 2011).

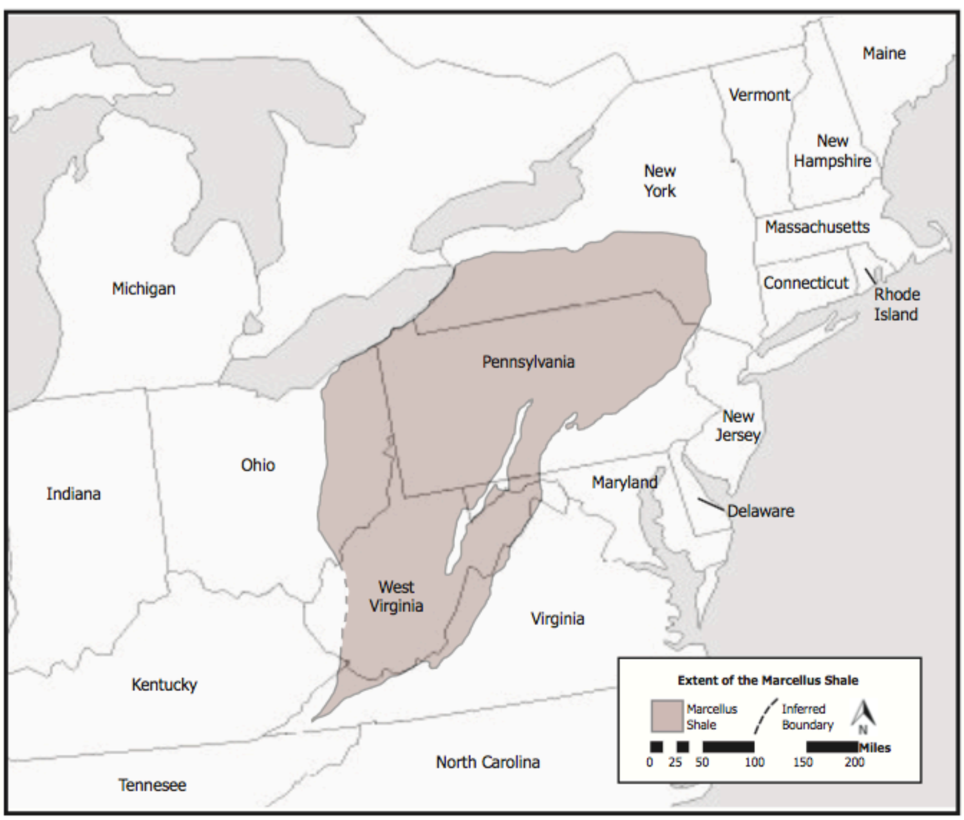


Figure 1: Extent of the Marcellus Shale in the northeastern United States. Note the inferred southern boundary (modified from Avary and Lewis, 2008).

Subsurface bodies of rock that have sufficient porosities and permeabilities to store and transmit oil and gas are called reservoirs. Conventional oil and gas reservoirs typically consist of a trap, seal, high porosity and permeability values, and a relatively easy and economic extraction process. The extremely low porosity and permeability of the Marcellus Shale categorize it as a shale gas unconventional reservoir. Unconventional reservoirs require different extraction techniques than the vertical drilling of conventional reservoirs; most commonly used is horizontal drilling combined with some type of stimulation process (Fig. 2). Hydraulic fracturing is a frequently used stimulation technique consisting of fracturing of rock by a hydraulically pressurized liquid (Hubbert and Willis, 1972; Phillips, 1972; Holahan and Arnold, 2013). Average reservoir porosities of sandstones can reach up to 30% (Ehrenberg and Nadeau, 2005), whereas porosity of the Marcellus Shale is in the range of 0.5%-5.0% and fracture porosity ranges from 2.0-7.0% (Lee et al., 2011). Permeability of oil and gas reservoirs can range from ten to several hundred millidarcys (Bear, 1972), however the Marcellus' permeability is in the micro- to nanodarcy range (Lee et al., 2011).

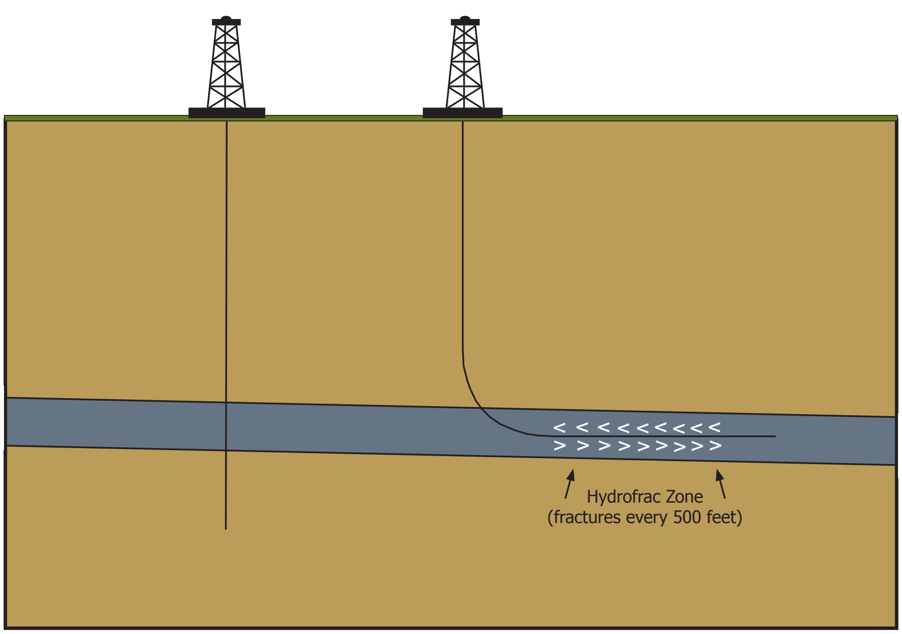


Figure 2: The left well shows conventional vertical drilling into sandstone or limestone. The right well shows the unconventional drilling method used for the Marcellus Shale: a combination of directional drilling and hydraulic fracturing technology. (modified from King, 2015)

Commercial production of oil and gas in West Virginia began in 1859 (Wickstrom et al., 2005). Shallow, organic-rich zones with high concentrations of natural fractures were popular targets for early drilling using conventional techniques (Perry and Wickstrom, 2010). Horizontal drilling and hydraulic fracturing have been utilized since the 1920s, but it was not economically viable for commercial use until the late 1980s. This technique was successfully used on the Marcellus Shale play in 2003 by Range Resources (Perry and Wickstrom, 2010). Since then, natural gas production from the Marcellus has significantly increased, occurring in Pennsylvania, West Virginia, Ohio, and New York (however, hydraulic fracturing has recently been banned in New York). Production from 2007-2010 did not exceed 2 Bcf/d, but by mid-2014, production reached over 15 Bcf/d (Lieskovsky et al., 2014). June 2015 values account for more than 36% shale gas production and more than 18% total dry natural gas production in the United States (EIA, 2015). As of 2011, an official estimate of gas-in-place, or total gas contained, regardless of the ability to produce it, is 500 Tcf (Bruner and Smosna, 2011).

An unconformity exists between the Middle and Upper Devonian rocks in southern West Virginia resulting in the removal of much Middle Devonian strata (Duffield and Warshauer, 1981). The Marcellus Shale was one of the units affected by the truncation of the units as a result of the unconformity, its thickness decreases to the south and to the west. The West Virginia Geological and Economic Survey (WVGES) published a map showing the edge of the Marcellus Shale (Fig. 3). However, recent drilling and new data indicate that the zero thickness line does not occur where originally believed. Production of natural gas from the Marcellus Shale is reported from beyond the edge of the Marcellus. Some of this production might actually be from the Marcellus, but it is likely that most is not. This suggest that the zero isopach line actually lies west of where it was initially plotted. The purpose of this study is to reevaluate the existing data to establish the nature and location of the edge of the Marcellus Shale in southern West Virginia and to assess the gas production from basal black shale along the boundary.

The study area is located in southern West Virginia where the Marcellus is 4,000-7,000 feet below the surface (Fig. 4). Geophysical logs can be used to understand the subsurface stratigraphy and visualize the thickness of the Marcellus Shale. Locating the zero isopach line shows the location of the edge of the Marcellus where the formation was completely removed due to the unconformity. Constructing cross sections by correlating well logs provides an additional view of the unconformity and its effect on the surrounding units. Maps and cross sections can be used to estimate amounts and locations of resources and to find the most economical locations for hydrocarbon extraction.

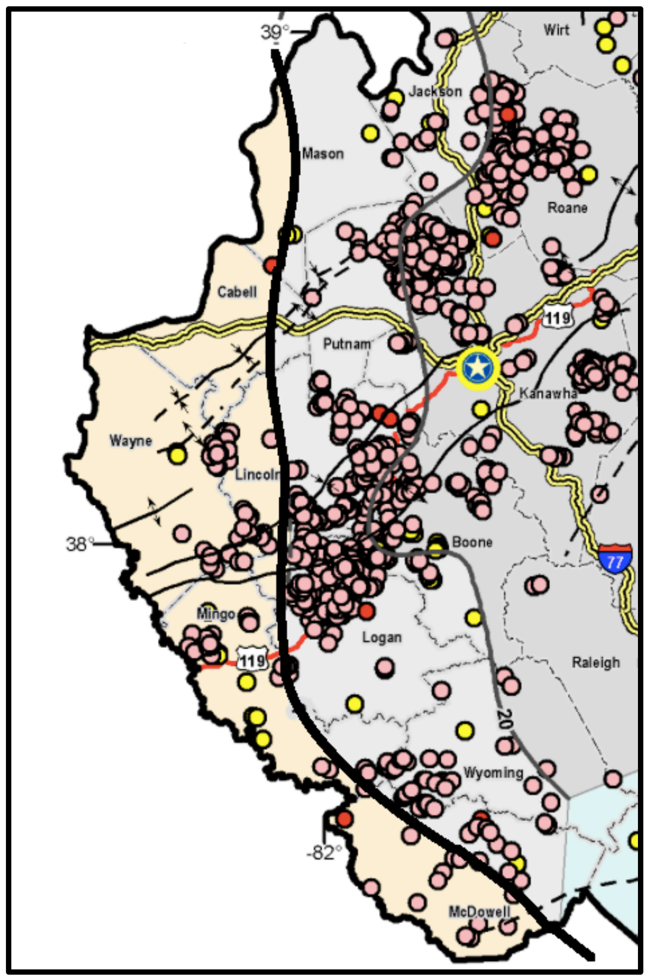


Figure 3: Close-up of the study area. The thick black line represents the zero isopach line drawn by the West Virginia Geological and Economic Survey (WVGES). Note the completed "Marcellus" wells (in pink) outside of the zero isopach line (WVGES, 2015).

A well field analysis is useful in understanding the production differences across the zero isopach line. Chapmanville gas field is located in northern Logan County, within the Marcellus boundary. Comparing values from Chapmanville with values from Magnolia and Crum-Kermit gas fields, primarily located in Mingo County outside the realm of the Marcellus, will show the economic importance of drilling the

Marcellus Shale and identifying the producing units.

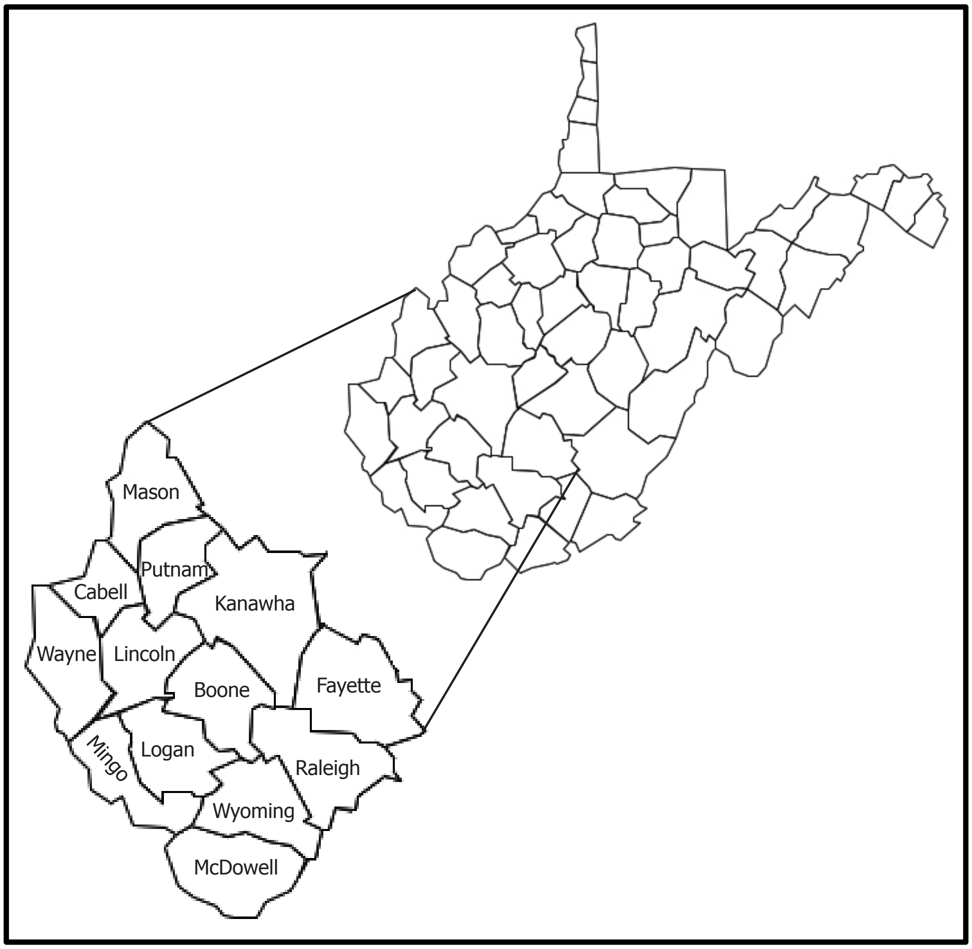


Figure 4: Confines of the study area in southern West Virginia. The area covers the following counties: Mason, Putnam, Cabell, Wayne, Lincoln, Logan, Kanawha, Boone, Mingo, McDowell, Wyoming, Nicholas, and Fayette. The decision to choose this area was based on Marcellus occurrence in the area. In some places the Marcellus Shale is fully present, making it easier to understand and study the contrasts of the areas where it is absent. The study area covers 6,642 mi^2 (17,202 km^2) (U.S. Gazeteer Files, 2014).

CHAPTER TWO: BACKGROUND

GEOLOGIC SETTING

The Marcellus Shale was deposited in the Appalachian foreland basin during the Middle Devonian. The asymmetric Appalachian Basin is a downwarped region that extends from the Canadian Shield in southern Quebec and Ontario Provinces to central Alabama (Fig. 5). South of the Adirondack Uplift, the Appalachian Basin covers an area of about 206,900 square miles (536,000 square kilometers). At 1,030 miles (1,657 kilometers) long and 330 miles (530 kilometers) wide, it can be found in the subsurface in a majority of eastern American states (Colton, 1970). Intermittent subsidence that started in the late Precambrian created the space for a series of Paleozoic seas to deposit the thick sedimentary rocks that occupy the basin (Colton, 1970). Sediments from the orogen accumulated in a prograding deltaic environment along the

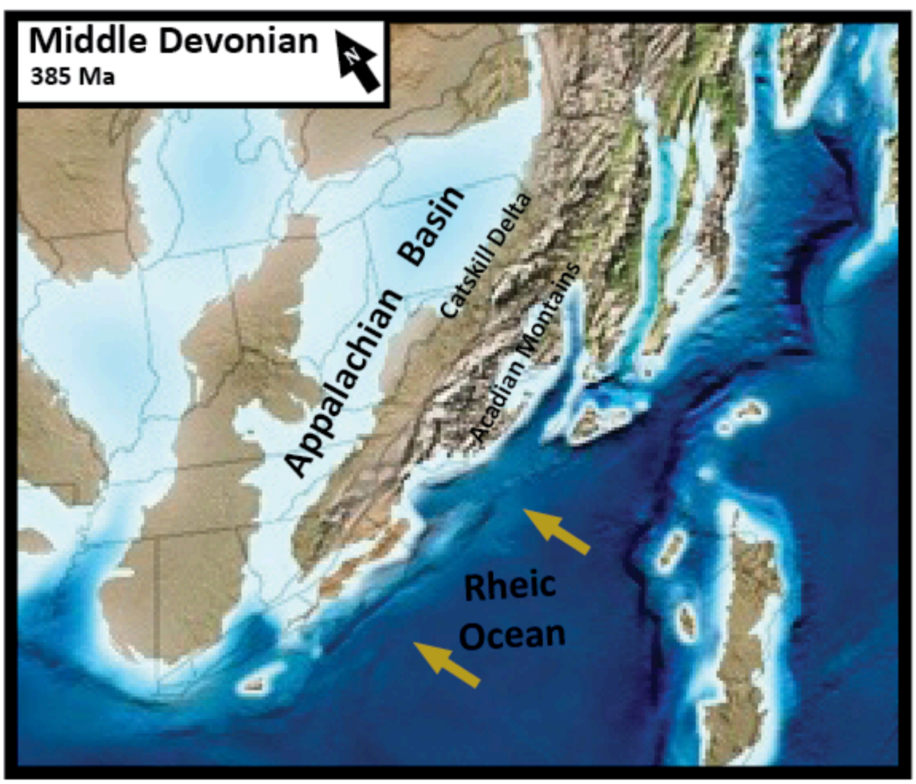


Figure 5: Eastern North America during the Middle Devonian. The yellow arrows represent trade wind direction. Note the change in north arrow direction, showing the paleogeographic orientation of what is now the eastern United States. (After Wrightstone, 2009 and Blakey, 2005).

eastern margin, whereas central basin sediments are associated with a marine trough that transitions to craton-drowned sediments on a shallow peripheral platform or shelf (Colton, 1970).

TECTONIC SETTING

Structure of the Appalachian Basin can be attributed to the original downwarping of the earth's crust and deformation of Precambrian crystalline basement with the load of younger sedimentary rock (Colton, 1970). The basin has experienced many episodes of deformation, the first of which started in the Proterozoic. Some of the more notable orogenies, for this depositional system, were the Late Ordovician Taconic orogeny and the Middle to Late Devonian Acadian orogeny. The complex series of orogenic episodes that make up the Taconic include the closure of the Iapetus Ocean by the collision of the Laurentian margin with a convergent plate boundary (Rodgers, 1971; Hanson and Bradley, 1989; Macdonald et al., 2014). Evidence of the Taconic can be seen in many places, particularly parts of Pennsylvania and New Jersey, and south of the Adirondack uplift (Colton, 1970; Bradley, 1989). A gentle, widespread epeirogenic uplift event occurred immediately before the Late Devonian and resulted in an unconformity across parts of the Appalachian Basin (Colton, 1970). The Acadian Orogeny saw the oblique collision of the eastern margin of Laurentia with the Avalon microcontinent (Williams and Hatcher, 1982; Ettensohn, 2004). Thick, clastic sequences resulted from convergence and uplift along the southeastern margin of Laurussia (Ettensohn, 2004). Ettensohn (1985a, 2004) breaks these Paleozoic orogenies up into tectophases; the Acadian Orogeny was broken up into four tectophases, with the Marcellus Shale being deposited during the second (Fig. 6). The term tectophase is used to refer to "all the events in a particular pulse or phase of orogeny, mostly concentrated at a certain time and place along an orogenic belt" (Ettensohn, 2004; Johnson 1971). The third-order stratigraphic successions that are associated with each Acadian tectophase have a base layer of limestone or sandstone, followed by a basal black shale, then shale with an unconformity on top (Ettensohn, 1985a). Each broad lithologic type within the tectophases resulted from a specific flexural response to different events of deformational loading or lithospheric relaxation during the orogeny (Ettensohn, 2004). Observed repetitions through time and space suggest that these patterns are typical of particular types of foreland basins (Ettensohn, 2004).

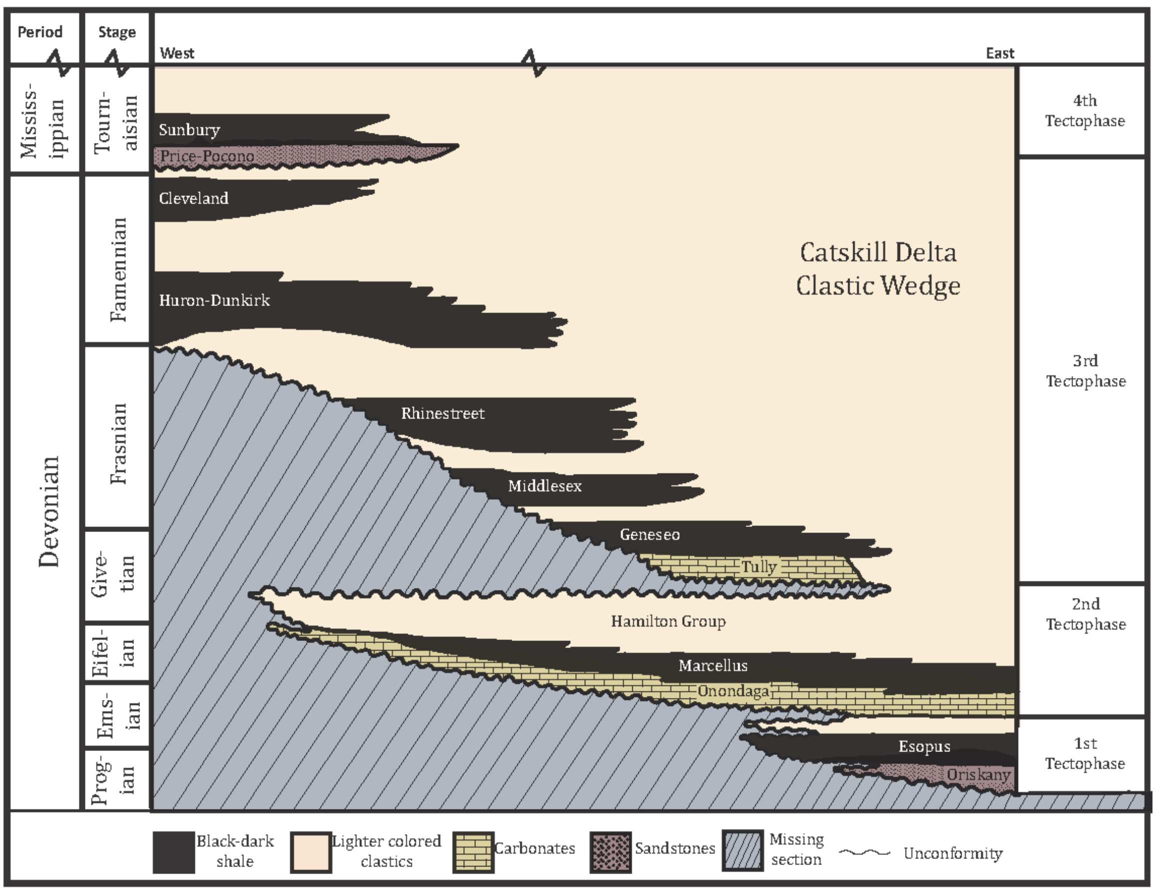


Figure 6: Diagram of the four tectophases of the Acadian Orogeny. In ascending order, each tectophase contains a limestone or sandstone, a basal black shale, shale, and an unconformity (Ettensohn, 2004).

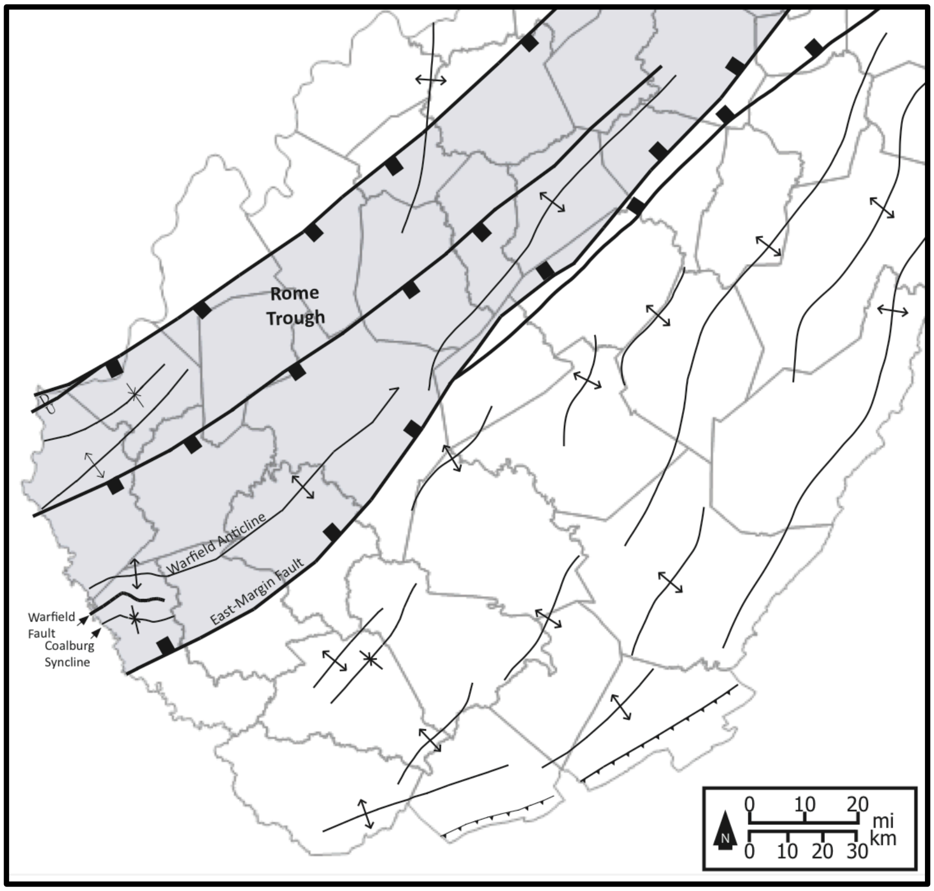
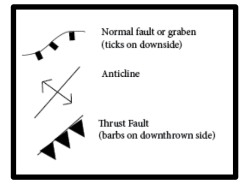
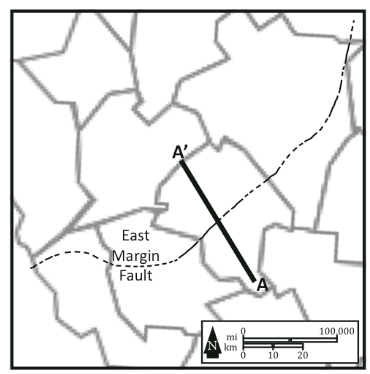


Figure 7: Selected structural features of the study area (Thomas, 1991; Shumaker, 1993; Gao et al., 2000; Coolen, 2003).



STRUCTURE

The opening and development of the Iapetus-Theic Ocean during the Early and Middle Cambrian played a major part in developing the basement structure beneath the Appalachian Basin (Thomas, 1991; Gao et al., 2000). One of the main features that resulted from this opening is the Rome Trough, located in eastern Kentucky through western West Virginia to Pennsylvania, and formed in association with late-stage opening of the ocean at the plate margin (Gao et al., 2000) (Fig. 7). Within the Rome Trough are several large basement faults that formed during the Proterozoic Grenville Orogeny (Gao et al., 2000). The East-Margin Fault is a master synthetic fault that represents the eastern boundary of the Rome Trough. Rift and post-rift deposition was affected by syndepositional motion along the fault (Gao et al., 2000). The East-Margin fault, among other lower interior faults, greatly impacted the Cambrian, Ordovician, Silurian, and Early Devonian sedimentary deposits that filled the trough. However, it did have a slight uplifting effect, and possibly some thickening of the units above the Onondaga Limestone through the Lower Mississippian from the later inversion of the East-Margin Fault (Gao et al., 2000) (Fig. 8). Additional evidence showed intermittent normal displacement of the fault throughout the Paleozoic (Gao et al., 2000). Qualities of reservoir facies, trapping geometry, and hydrocarbon accumulation throughout the segments of the Rome Trough make it a target for hydrocarbon exploration. For example, zones along the master synthetic fault could potentially



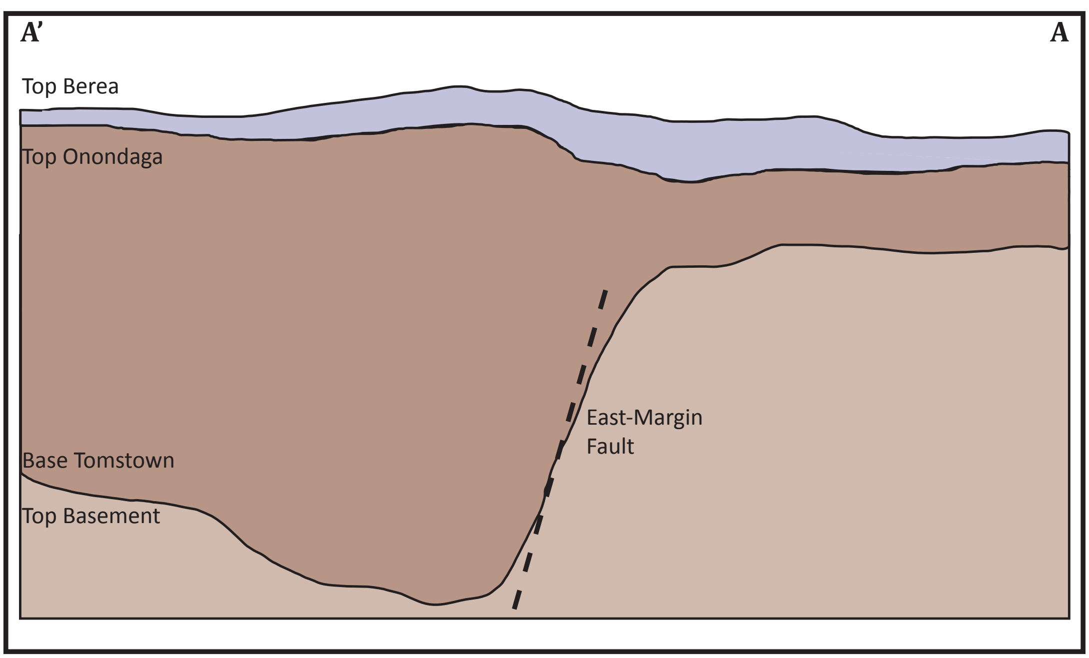


Figure 8: Cross section of the East-Margin Fault, which defines the eastern boundary of the Rome Trough in southern West Virginia. The middle segment includes the Onondaga Limestone through the Cambrian Tomstown Formation. The original diagram that this was modified from was drawn from seismic data, so no vertical axis values are assigned because of the vertical shift of the arrival times and time difference curves (modified from Gao et al., 2000)

contain significant hydrocarbon accumulation (Gao et al., 2000). Post-Marcellus structural features can be seen in a series of Alleghanian faults, arches, and folds called the Warfield structures, located in the southern region of the Rome Trough (Coolen, 2003). After deposition, Appalachian basin strata experienced regional compression that produced numerous anticline-syncline fold pairs such as the Warfield Anticline and the Coalburg Syncline. The Coalburg Syncline is interpreted as a post- to late Middle Pennsylvanian structure that is parallel to the Warfield structures (Greb et al., 2005). The Warfield Anticline extends a distance of over 80 miles (130 km) through Silurian to Pennsylvanian strata (Coolen, 2003). The Warfield Fault was created during a period of extension/relaxation (Coolen, 2003). Displacement of strata by the Warfield fault can be seen at land surface (Greb et al., 2005). However, the magnitude of influence that these structures had on the Marcellus Shale in the study area is unclear.

DEPOSITION

During the Middle Devonian, eastern North America, including the Appalachian Basin, was rotated clockwise 90° south from its present position and was located about 25-25° south of the equator (Ver Straeten, 2007). Due to these latitudes, among other factors, the climate ranged from tropical to subtropical (Ettensohn and Barron, 1981). At this time, the Appalachian basin was adjacent to the Acadian Orogen. The positioning of the seaway with respect to the mountain range and the Iapetus Ocean created an orographic effect, where easterly trade winds carried moisture into the basin. This made for a seasonally variable, arid to semi-arid climate and frequent near-shore and offshore storm events within the basin (Werne et al., 2002).

The erosion of preexisting muds, mudstones, and shales provides the clay minerals, fine quartz, feldspar, and detrital micas that make up the terrigenous mud that is eventually used to create new shales (Potter et al., 1980). Sources of these minerals include unstable silicates formed at high pressure and temperature, abrasion by continental ice sheets, volcanic dust, and dust from the deflation of continental deserts (Potter et al., 1980). Factors that control mud production are relief, rainfall, vegetation, and source rocks (Potter et al., 1980). These fine mud particles that compose shales are typically transported in water through hydraulic suspension before being deposited (Potter et al., 1980). A particle begins to sink out of suspension when it is too large to be carried by a particular flow. Fall velocity is determined by the shape and diameter of the particle. Epicontinental, marine, organic-rich black shale deposition is rather controversial (Ettensohn and Barron, 1981; Pederson and Calvert, 1990; Demaison, 1991; Ettensohn, 1997). However, the general consensus requires bottom-water anoxia, high organic productivity, and sediment starvation (Ettensohn, 1997). The Devonian black shales, including the Marcellus Shale, most likely accumulated in tranquil basinal waters (Roen, 1983).

Outcrops of the Marcellus Shale can be found throughout the Valley and Ridge of New York and Pennsylvania, to western Virginia and eastern West Virginia (de Witt et al., 1993). Overall, depth of the top of the Marcellus Shale increases to the east. Thickness is greatest in central Pennsylvania and thins to the west with greater distance from the sediment source. Additional thinning and truncation occurs to the south and southwest as a result of the Middle Devonian unconformity.

STRATIGRAPHY

Appalachian Basin stratigraphic nomenclature varies geographically due to early studies naming systems based on locally exposed outcrops (Roen, 1983). This section focuses on the general stratigraphy that is related to the study area (Fig. 9). Figure 10 shows the sea level curve associated with the stratigraphy.

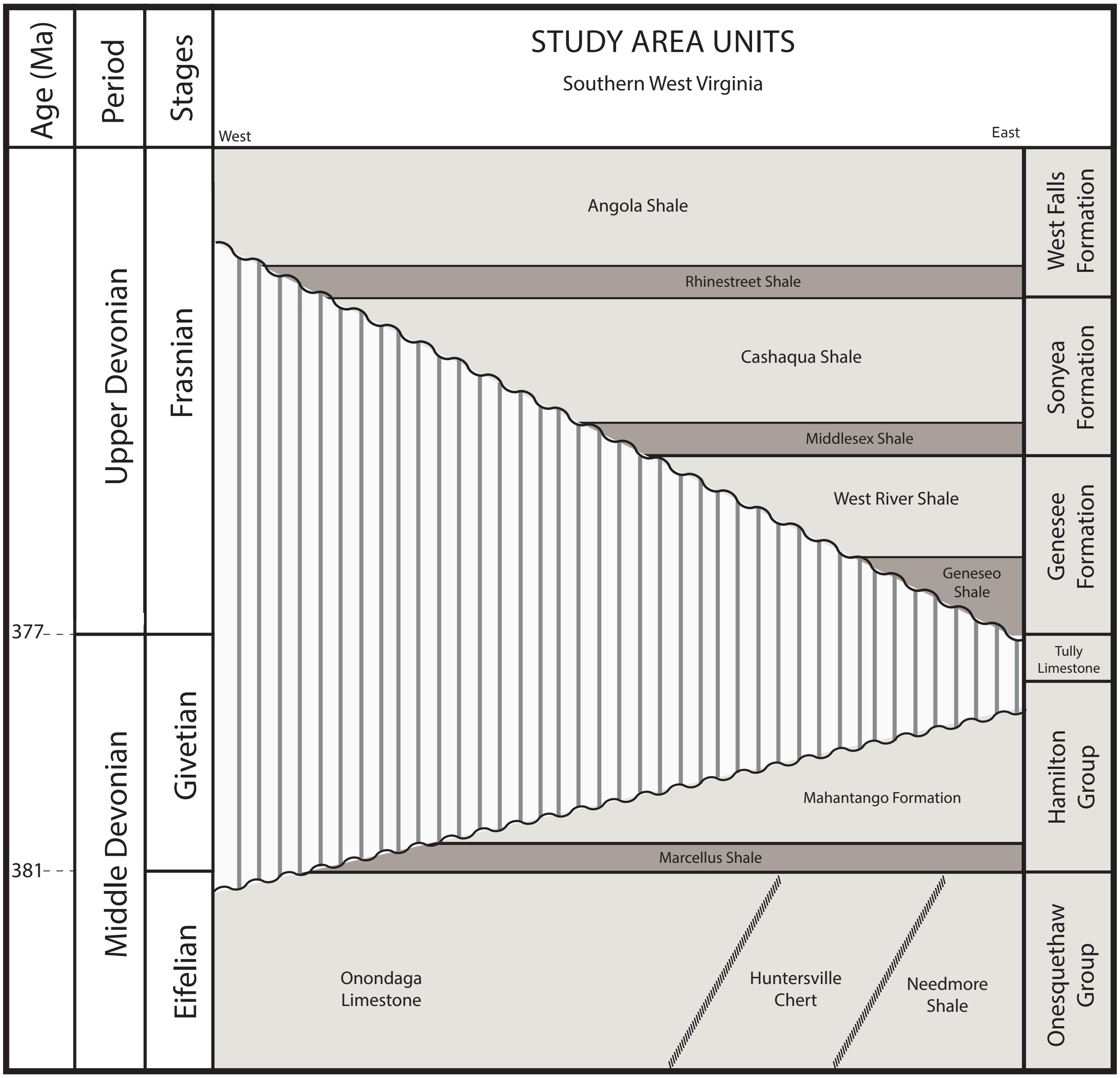


Figure 9: Stratigraphy of the Middle to Upper Devonian units of southern West Virginia. Not to scale. Depth varies greatly throughout the study area.

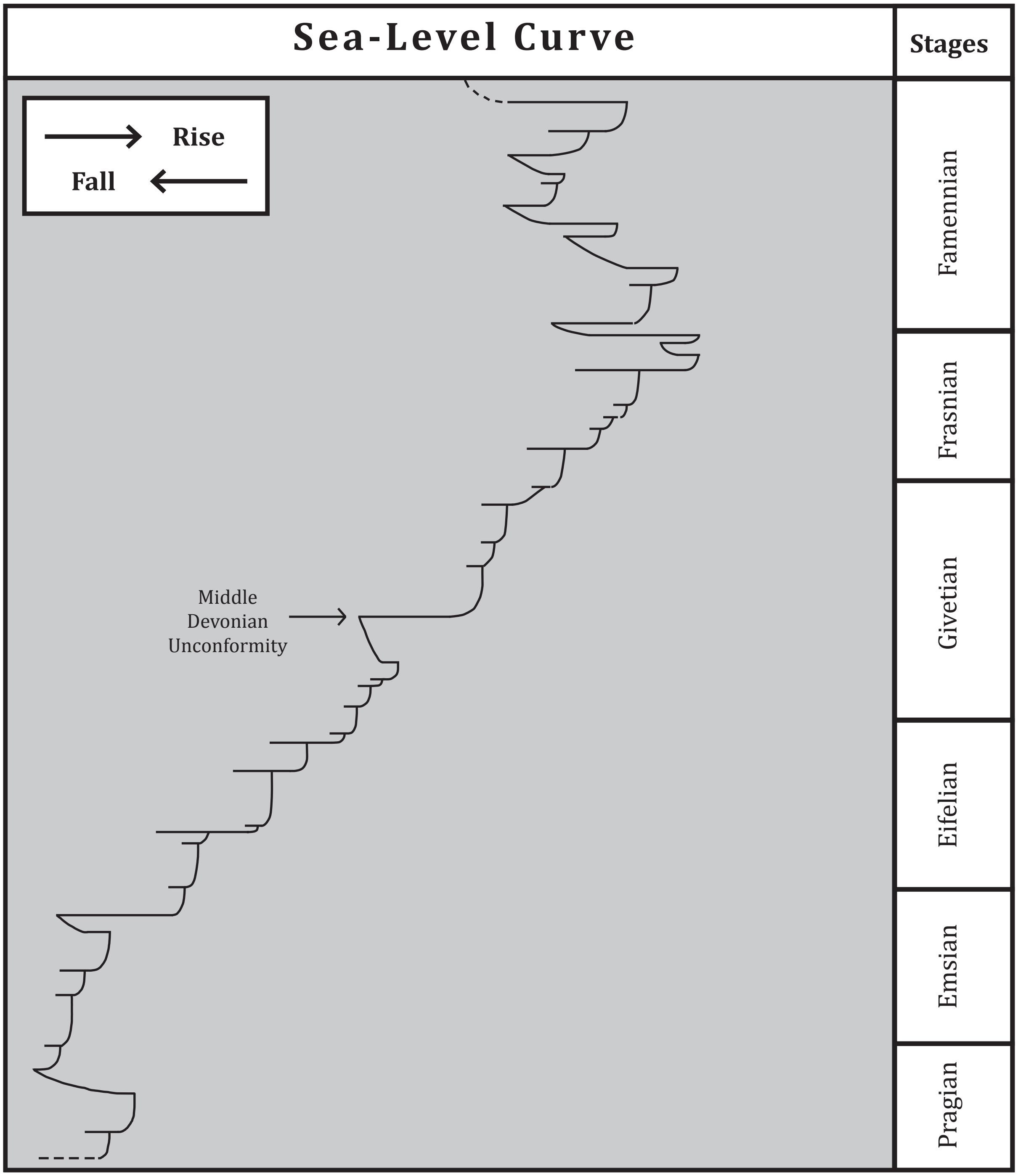


Figure 10: Devonian sea level curve. The Marcellus Shale was deposited during the early Givetian (Modified from Brett et al., 2011).

PRE-UNCONFORMITY STRATIGRAPHY

Onondaga Limestone – Huntersville Chert – Needmore Shale

Pre-Marcellus stratigraphy is composed of three facies equivalent formations: Onondaga Limestone, the Huntersville Chert, and the Needmore Shale. From the central Appalachians, the Huntersville Chert grades into the Onondaga Limestone to the west and the Needmore Shale to the east (Donaldson and Scoff, 1985; Wrightstone, 2009). Interfingering of the three units occurs throughout West Virginia (Dennison, 1960), but the Onondaga Limestone and the Huntersville Chert are present in southern West Virginia.

Previous to the Marcellus deposition, there was an episode of decreased subsidence and erosion and increased carbonate production (Swan, 2012). The depositional environment of the Onondaga Formation varied slightly throughout the Appalachian Basin, but it was primarily subtidal marine (Feldman, 1980). The massive, fine-to-medium grained, bioclastic Onondaga Limestone is composed of cherty limestones, light gray to black chert, non-cherty limestone, calcareous shale, argillaceous lime muds, and bentonite (Inners, 1975). In eastern New York, the Onondaga thickness measures up to about 160 feet (Feldman, 1978). Thickness in the southern West Virginia study area is about 70 feet (API: 4704302678). The upper contact of the Onondaga Limestone with the base of the Marcellus Shale is representative of the influx of terrigenous sediment into deeper, poorly oxygenated water (Feldman, 1978).

The Huntersville Chert is a gray-to-black, irregularly bedded, sandy chert with some streaks of green phosphatic sandstone (Inners, 1975). This chert was deposited in a restricted sea within a detrital sediment-starved basin. Silicisponges were very common within the sea (Donaldson and Skoff, 1985). A moderately dipping ramp near the western margin of the Rome

Trough might have been responsible for the chert to limestone transition (Donaldson and Skoff, 1985). The Huntersville Chert is found in the northeastern region of the study area.

The Needmore Shale is made of the three subfacies: black shale, calcitic shale, and calcitic shale with limestone (Dennison, 1960). The Needmore Shale thins to the north in Pennsylvania and to the west in West Virginia, and is thickest in northeastern West Virginia (Dennison, 1960).

Hamilton Group

In New York, the Hamilton Group contains the Marcellus, the Skaneateles, the Ludlowville, and the Moscow Shales (de Witt et al., 1993), all of which can be further divided into members. The Skaneateles and the Marcellus are the two basal black shales of the Hamilton Group (Roen, 1983). In Pennsylvania and south, formations above the Marcellus Shale cannot be distinguished and the equivalent interval is called the Mahantango Formation. Neal (1979) found that the Marcellus Shale is the only formation of the Hamilton Group in southern West Virginia.

James Hall first described the Marcellus Shale in 1839, based on exposures near Marcellus Village in Onondaga County, New York (Neal, 1979). First production of Devonian shale gas in the Appalachian Basin took place in 1821 in Fredonia, New York (Perry and Wickstrom, 2010). Outcrops of the Marcellus Shale can be found along the Valley and Ridge from New York to western Virginia and eastern West Virginia (de Witt et al., 1993, Avary, personal communication, November 11, 2015). It is typically described as a “sooty” or slaty black shale with some beds of medium-gray shale and limestone nodules or dark gray to black limestone beds (Fig. 11) (Neal 1979; de Witt et al., 1993). Figure 12 shows the typical mineral composition for the Marcellus Shale. Thicknesses of about 1000 feet have been found in central Pennsylvania (de Witt et al., 1993). The Marcellus contains members, which can be used to subdivide the Marcellus into Upper and Lower Marcellus intervals, with the lower Marcellus displaying a significantly higher organic matter concentration (Popova et al., 2015). The Cherry Valley and Purcell Limestone Members can be found within the Marcellus Shale. The Cherry Valley extends through New York, Pennsylvania, and northern West Virginia. The Purcell can be found in the subsurface and outcrops of Pennsylvania, Maryland, and West Virginia and is made up of gray silty shale and mudrock, with limestone nodules and some siltstone (de Witt et al., 1993). Neither limestone unit extends to southern West Virginia. The variations in internal Marcellus stratigraphy are associated with the variations in aerobic, dysaerobic and anaerobic conditions during deposition (Ettensohn, 1985a). The top of the Marcellus throughout the northeastern United States is located 1,000 to 8,000 feet below sea level (Popova et al., 2015).

Figure 11: Photo of Marcellus Shale outcrop in New York State. Hammer for scale (Sorkhabi, 2009).

Temperatures that a source rock is exposed to over time are represented as thermal maturity. The Marcellus in southwestern Pennsylvania, West Virginia, and southeastern Ohio is less thermally mature than in northeastern Pennsylvania; thus it produces more liquids-rich natural gas, meaning lower natural gas-to-oil ratios (Popova et al., 2015) (Fig. 13). Thermal maturity can

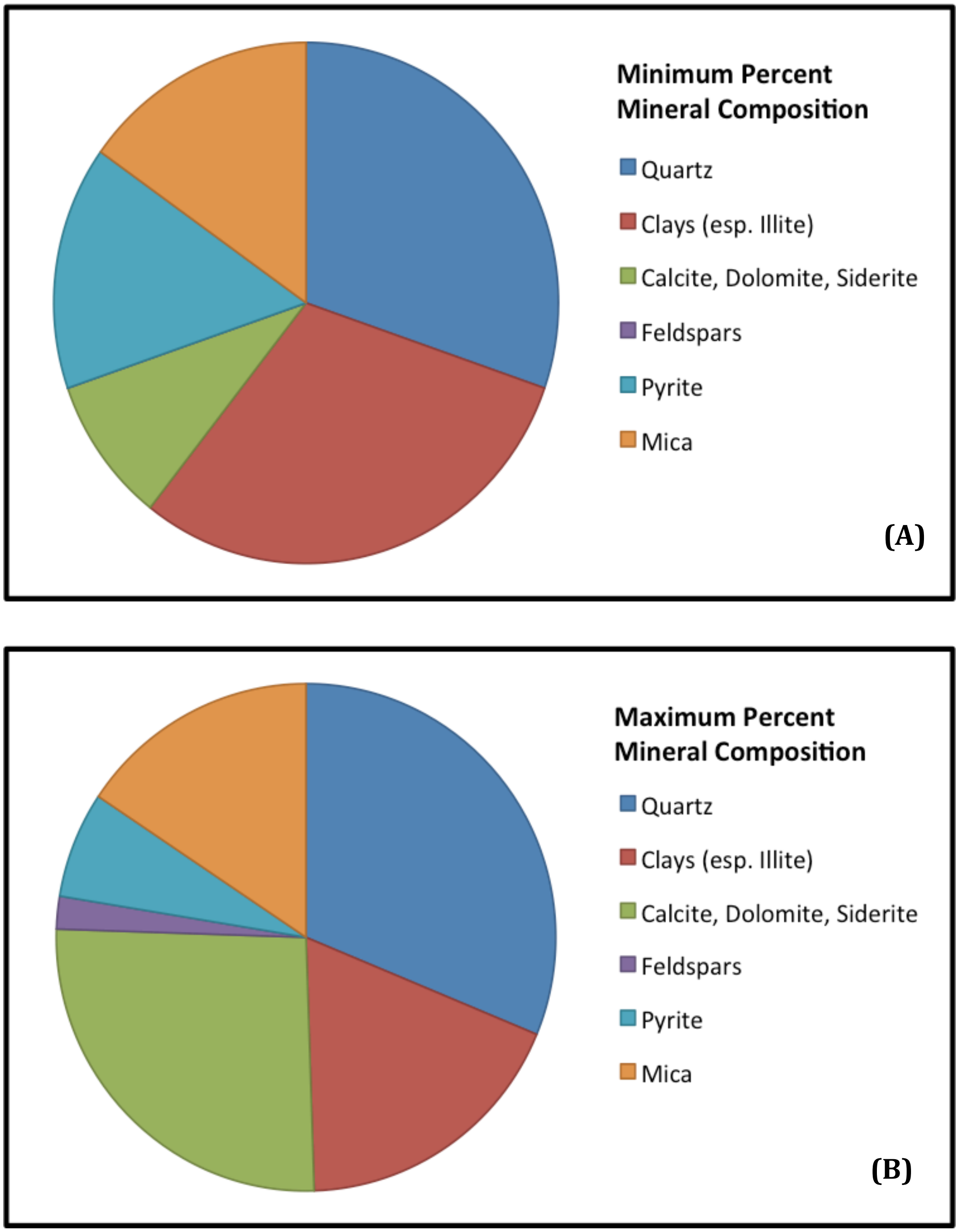
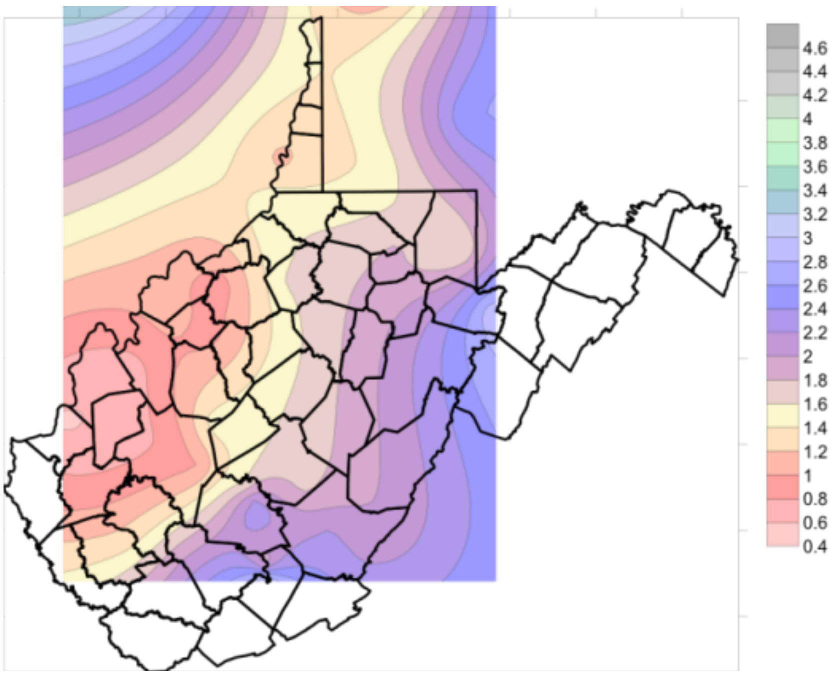


Figure 12: (A) Minimum percent of mineral composition in the Marcellus Shale (B) Maximum percent mineral composition of the Marcellus Shale. Phosphate and gypsum occur only in trace amounts in both. Modified from Bruner and Smosna, 2011.



Maturity		R_o (%) Oil Generation	R_o (%) Gas Generation
Immature		0.2-0.6	< 0.7%
Mature	Early	0.6-0.65	0.7%-3.0%
	Peak	0.65-0.9	
	Late	0.9-1.35	
Postmature		>1.35	> 3.0%

Figure 13: Thermal maturity as recognized by vitrinite reflectance across West Virginia (Kostelnik and Laughrey, 2008).

be measured from vitrinite reflectance (R_o%) or from the conodont color alteration index (CAI) (Repetski et al., 2014). The Marcellus Shale, as well as the overlying Upper Devonian Shales typically contain conodonts (Harris et al., 1994, Repetski et al., 2014).

Above the Marcellus Shale is the Mahantango Formation, which can reach thicknesses of over 1,300 feet in Pennsylvania and New York (Metz, 2009). The name comes from Mahantango Creek in Pennsylvania, where exposures can be found along the north branch of the creek (Metz, 2009). The Mahantango can be found in the far northeast section of the study area. Its depositional environment was shallow marine, represented by the fossiliferous interbedded medium- to dark-gray shale, siltstone, mudstone, sandstone, and some limestone (Schwietering, 1979; de Witt et al., 1993; Metz, 2009).

Tully Limestone

Above the Hamilton Group is the Tully Limestone, a dark-gray to black cobbly weathering, fossiliferous limestone (de Witt et al., 1993). The Tully can be found in central New York, central and eastern Pennsylvania, and parts of northern West Virginia. Maximum thickness is over 200 feet in north-central Pennsylvania (de Witt et al., 1993). Deposition occurred in the late Middle-Devonian during a brief pause in detrital input into the Appalachian Basin (Faill, 1985). In central and southern West Virginia, the Tully Limestone was removed by the Middle Devonian unconformity (de Witt et al., 1993).

THE MIDDLE DEVONIAN UNCONFORMITY

The development of unconformities is mainly controlled by two interrelated factors: changes in depositional base level and sediment supply or production (Christie-Blick, 1991). Depositional base level refers to "the hypothetical surface asymptotic approximately to sea level and above which significant sedimentation is not possible" (Christie-Blick, 1991). Anything at base level is subject to sediment bypassing, and anything above base level is subject to erosion (Christie-Blick, 1991). Deposition was suspended three times in the central Appalachian Basin: immediately after the Lower Devonian Oriskany Sandstone, during the Middle and early Late Devonian from New York to Ohio (including southern West Virginia), and at the Catskill-Spechty Kopf boundary in east-central Pennsylvania (Faill, 1985). The Middle Devonian unconformity is attributed to a drop in sea level during the mid-Givetian (Fig. 10). This drop is most likely in response to an increase in basin subsidence (Faill, 1985). This subsidence was a result of the collision between the Avalon terrace and the New York promontory, which is indicated by the regional uplift associated with the unconformity at the boundary between the Middle and Late Devonian (Ettensohn, 1985b). In West Virginia the unconformity is below the Genesee Formation and younger Upper Devonian units. In this area, progressively younger units can be found onlapping progressively older units. For example, Upper Devonian black shales can be found on top of Middle Silurian Rocks in central Kentucky, and Upper Devonian rocks can be found on Upper Ordovician shales and limestones in central Tennessee (de Witt et al., 1993).

Depositional sequences that are bound by unconformities usually show stratal onlap at the base and offlap at the top (Christie-Blick, 1991). Signs of offlapping by the Marcellus Shale have been discussed in previous work (Strecker et al., 2011; Ver Straeten et al., 2011; and Luker, 2012). Onlap and offlap refer to the progressive up-dip termination of strata against an underlying and overlying surface, respectfully (Christie-Blick, 1991). The mean accumulation rate for foreland basin deposits is 0.186 m/1,000 yrs, and, specifically, 0.070 m/1,000 yrs for clastics within the Appalachian basin (Schwab, 1976). Areas with low subsidence rates tend to feature an increase in the hiatus represented by the unconformity (Christie-Blick, 1991). The subsidence rate during the Middle Devonian in the region of the Appalachian Basin that is now southern West Virginia was greatest in the eastern part of the basin, where the largest volume and coarsest sediments were deposited (Ettensohn and Barron, 1981; Faill, 1985). Grain size and thickness decreased to the southwest, reflecting a decrease in subsidence (Faill, 1985). These subsidence patterns may correlate with the impact of the unconformity in the study area, specifically, the complete removal of the Marcellus Shale to the west, and only partial removal toward the east. Additionally, the zero-thickness line, or the edge of a formation, may reflect the presence of an ancient shoreline (Weijermars, 1997).

POST-UNCONFORMITY STRATIGRAPHY

Genesee Formation

The Upper Devonian Genesee Formation occurs above the unconformity and consists of two members in the study area: the Geneseo Shale Member and the West River Shale Member (Neal, 1979; de Witt et al., 1993; Avary, 2009b). In addition to the large amount of black and dark-gray shales and mudrock, the Genesee Formation also consists of some medium-gray shale, calcareous nodules, limestone, and some siltstone (de Witt et al., 1993). The Geneseo Shale Member is a basal black shale, mostly grayish-black, brownish-black, and olive-black fissile shale (de Witt and Colton, 1978). Glenwood Creek and Taughannock Creek, New York, feature the thickest portion of the Geneseo Shale, at 130 feet. In contrast, the Geneseo Shale across the study area maintains a thickness of less than 10 feet. The West River Shale is a dark- to medium-gray shale or mudrock with some black shale beds, limestone nodules, and sparse dark-gray siltstone beds (de Witt et al., 1993). Because it gradually onlaps the unconformity, it is very thin in the study area (typically less than 4 feet).

Sonyea Formation

The Upper Devonian Sonyea Formation lies on top of the Genesee Formation. The Sonyea Formation contains two members in the study area: the Middlesex Shale and the Cashaqua Shale. It has been suggested that both units were deposited on the marine slope and basin of the Appalachian Basin (Sutton et al., 1970). The Sonyea Formation reaches over 1000 feet, its maximum thickness, in eastern New York (Sutton et al., 1970). Its lithology includes mudstones, siltstones, sandstones and shales. It also contains abundant marine fauna, specifically brachiopods and bivalve mollusks (Sutton et al., 1970). The Middlesex Member represents the "typical" Middle- to Upper- Devonian basal, organic-rich black shale. Exposures of the Middlesex Shale Member can only be found in western and central New York (Roen, 1983). It reaches a maximum thickness of 75 feet in the subsurface along the New York-Pennsylvania border (Roen, 1983). In the study area the Middlesex varies in thickness because of its onlapping nature. When present, it is typically 10-20 feet. Above the Middlesex is the greenish-gray Cashaqua Shale (Sutton et al., 1970). Flat, ellipsoidal limestone nodules can be found in the Cashaqua (de Witt et al., 1993). To the northeast, the Cashaqua grades into a light-gray turbiditic sandstone and silty gray shale (de Witt et al., 1993). Thickness of the Cashaqua Member varies greatly in the study area.

A core taken from Lincoln County showed no sign of conodonts in the black shale immediately above the Onondaga Limestone (Duffield and Warshauer, 1981). The first encountered conodonts indicate a Frasnian age. This absence of conodonts may indicate this is a black shale erosional remnant comprised of reworked weathered Onondaga Limestone and onlapping younger shales. Where there is a stratigraphic convergence of weathered residue and the featheredge of onlapping shales, it is difficult to trace log signatures. Erosional remnants are commonly found along pre-existing anticlines and faults (Ryder, 1987). It is possible that this black shale remnant that is barren of conodonts has been mistaken for the Marcellus Shale and may be responsible for the reported drilling from the Marcellus outside of the zero isopach line.

West Falls Formation

The uppermost formation in this study is the Upper Devonian West Falls Formation. The two members contained in the West Falls are the Rhinestreet Shale Member and the Angola Shale Member. The Rhinestreet Shale is the basal, organic-rich brownish-black to black shale. It can also contain some medium-gray shale, light-gray siltstone, and limestone nodules (de Witt et al., 1993). It is one of the thickest and farthest-reaching black gas shales (de Witt et al., 1993). Thickness can reach over 150 feet in parts of West Virginia (de Witt et al., 1993) and over 200 feet in southwestern New York and northwestern Pennsylvania (Roen, 1983). The Angola Shale Member is a gray shale and mudrock with limestone nodules and some thin siltstone beds (de Witt et al., 1993). Due to the onlap, the Angola can be found slightly farther west than the Rhinestreet Shale.

CHAPTER THREE: METHODS

WELL LOGS

Wireline geophysical logging is used to measure properties of rocks surrounding a borehole (Luthi, 2001). The development of logging in 1927 was a turning point in oil exploration (Luthi, 2001). Examination of the subsurface became easier and more efficient. Correlating between well logs also proved to be more accurate and cheaper than correlating between drill cuttings (Luthi, 2001; Schlumberger, 1932). The advantage of wireline logs is in their sensitivity to measurements of minor contrasts in different lithologies; each log measures or responds to a different property (Potter et al., 1980). The West Virginia Geological and Economic Survey (WVGES) provides a database of well logs for over 30,000 wells. Each well is identified on the basis of a standard code set by the American Petroleum Institute (API). These API numbers can have up to 14 digits; the first two digits represent the state code, the next three are the county code, and the remaining digits represent the permit number of the well (Fig. 14). West Virginia's state code is "47" and the county codes are listed in Appendix A. The "Marcellus Interactive Mapping Application" and the Pipeline system of the

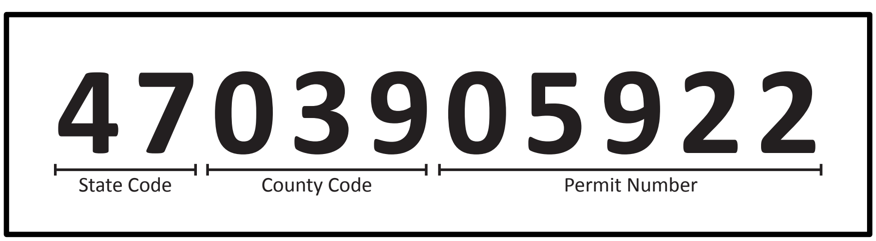


Figure 14: Example of code structure for API names. The numbers "039" are used for Kanawha County.

WVGES are valuable tools that are used to filter out properties and search for specific wells. The interactive map displays every completed and permitted Marcellus well currently up to June 2015. Completed wells feature one or more Marcellus Shale intervals that have been prepped for production, and permitted wells target the Marcellus (or Devonian Shale in general) or deeper units. The pipeline application allows the user to search for wells based on the West Virginia county name and permit number. Data types can be selected to narrow down the search: location, production, plugging, owner/completion, stratigraphy, sample, pay/show/water, logs, or bottom-hole location. Available log types include density logs, photoelectric adsorption, gamma ray, induction, neutron, and more. This project primarily focused on gamma ray and density logs.

Gamma ray logs reveal the lithology of the well by measuring the natural radioactivity of the rocks (Pirson, 1963). High-energy electromagnetic waves are emitted from the disintegration of radioactive elements. These radioactive elements include Uranium, Thorium, and Potassium (Pirson, 1963). Shales are primarily made up of minerals that contain these radioactive elements, thus their gamma-ray values are much higher than other lithologies (Fig. 15).

Sandstones have very low gamma-ray readings due to their lack of radioactive elements. Limestones usually only have a slightly higher gamma-ray signature than sandstones. However, the differences depend on many factors such as porosity and mineral content. For example, shaly sandstones can have much higher readings than quartz sandstones (Pirson, 1963). Among other factors, the large amounts of illite and chlorite (Wang and Carr, 2013) cause the Marcellus Shale to have diagnostically high radioactive values shown as strong positive deflections on gamma-ray logs (de Witt et al., 1993) (Fig. 16). The Onondaga Limestone is represented by very low gamma-ray values beneath the Marcellus Shale. The measurement for the top of the Marcellus varies throughout the 18 counties in the study area, usually between 110-220 and 200-350 API units, respectively. Overlying units that contain basal black shales, including the Geneseo Shale, Middlesex Shale, and the Rhinestreet Shale, are recognizable by their own unique signature. Radioactivity tools are used to emit gamma rays into a formation and then record the amount of gamma radiation that returns from the formation (Selley, 1998). After correcting for outside effects (borehole diameter and mudcake thickness) the reading is related to the bulk density of the formation. Bulk density can be used to understand the lithology and porosity, bed boundaries, and the presence of gas (Selley, 1998; Stark, 2008). Sandstone density values are typically 2.65

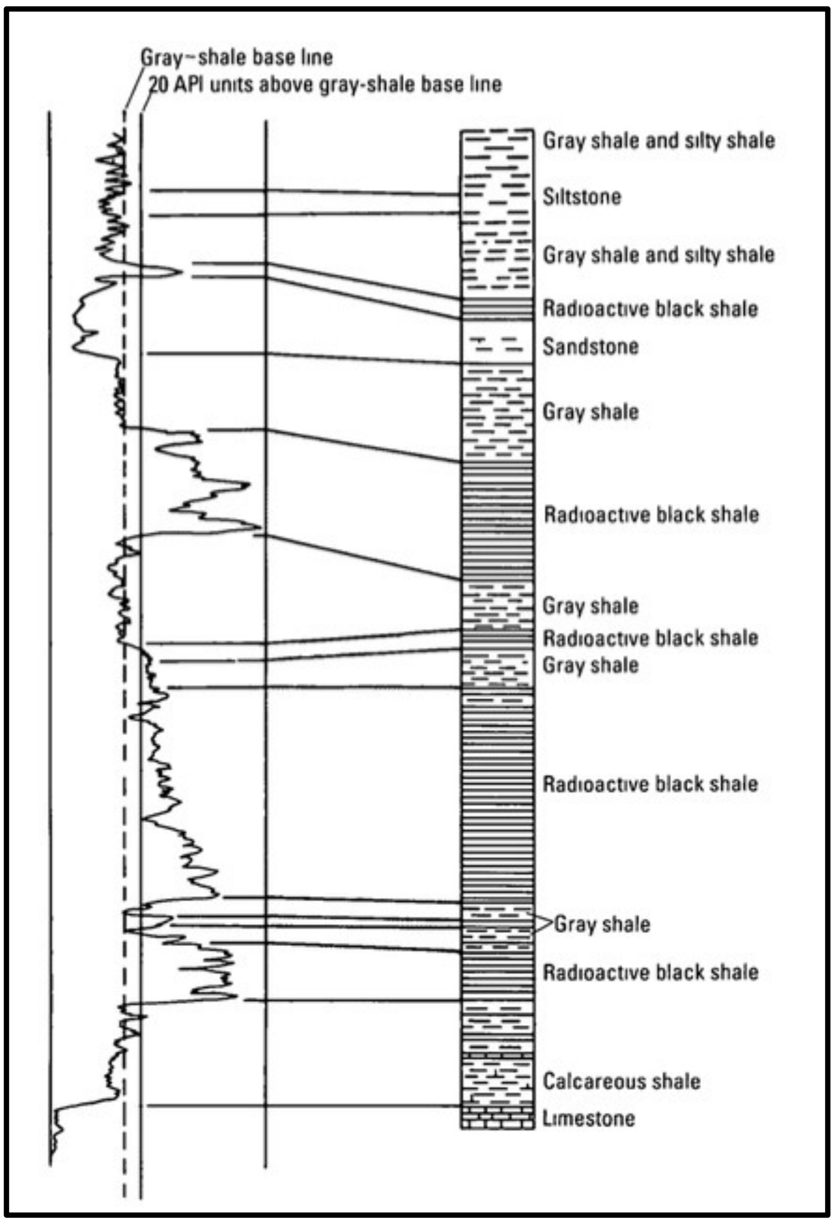
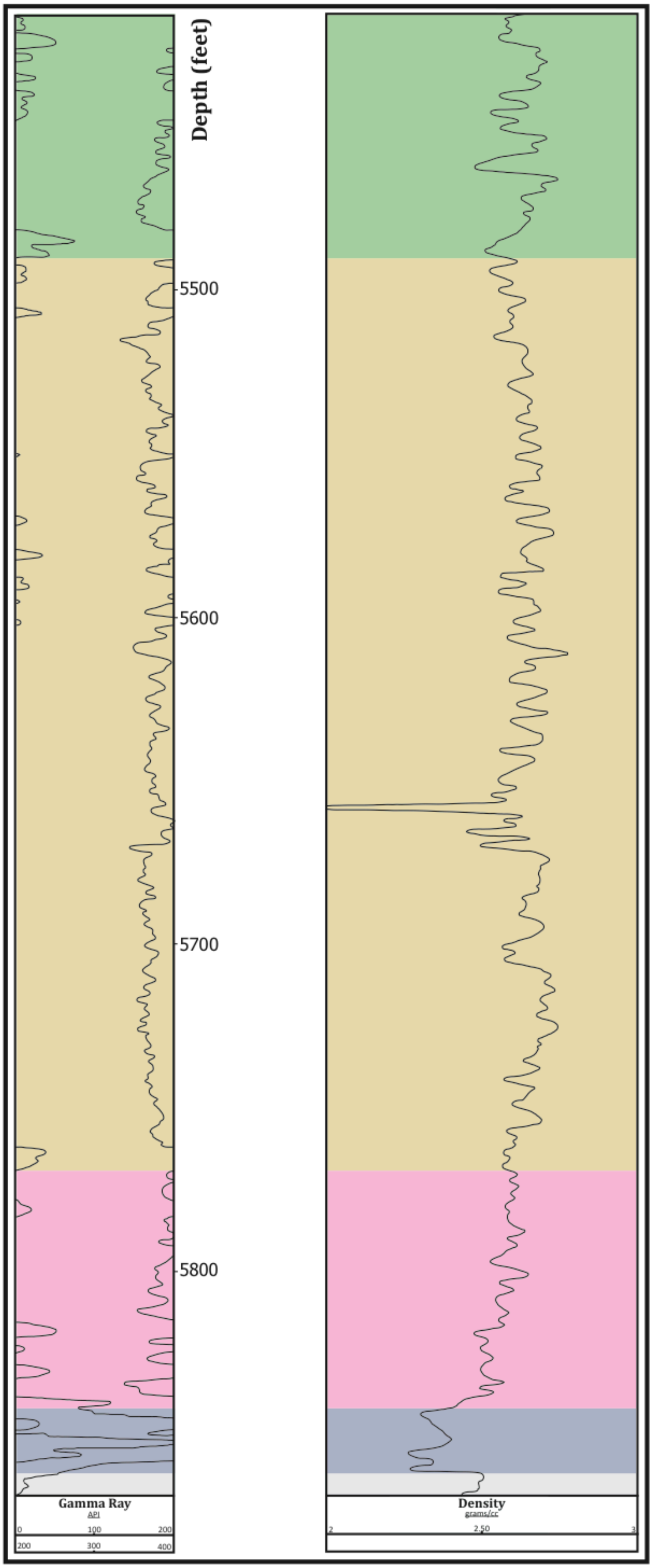


Figure 15: Comparison of gamma ray logs to lithologic logs. These are general values intended to display the variations in each log (modified from de Witt et al., 1993).



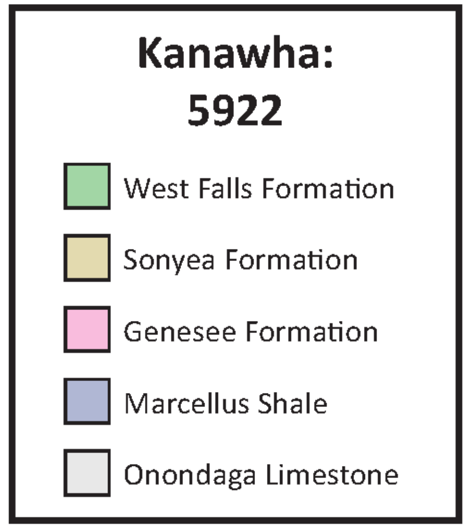
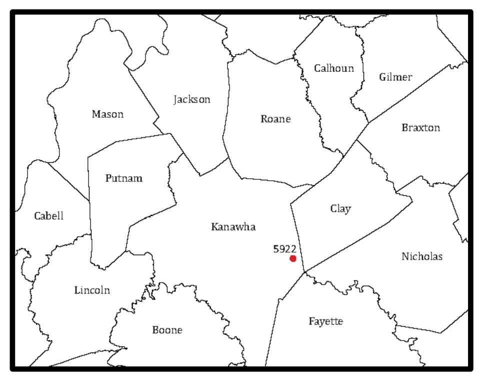


Figure 16: Type log from Kanawha County (permit number: 5922) showing the typical gamma log readings of the Middle to Upper Devonian stratigraphy of the study area.



g/cc and limestones are 2.71 g/cc (Selley, 1998). Marcellus Shale density values are closer to 2.27-2.42 g/cc. A sudden change of density within a shale interval is indicative of a change in depositional environment, thus the presence of a possible unconformity (Shanmugam, 1988).

CROSS-SECTIONS

Correlating well logs into cross sections is used to visualize the thickness and extent of the units in the subsurface. Well logs for cross sections were chosen based on quality and location. They were required to run through the Marcellus Shale and penetrate the top of the Onondaga, because the top of the Onondaga was the most continuous unit in the study area and was used as the datum to line up the logs. Five cross sections were constructed across southern West Virginia (Fig. 17). To allow for maximum interpretation of the study area, the cross

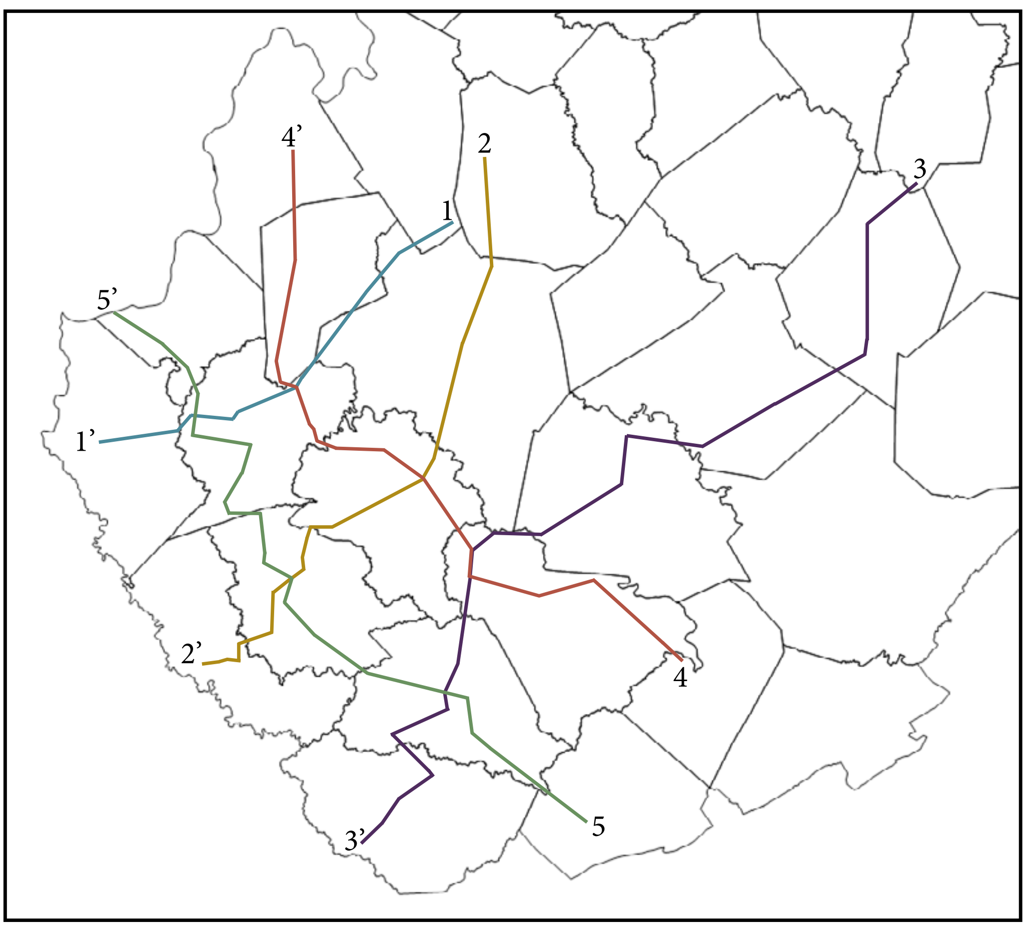


Figure 17: Location of the five cross-sections transects through the study area.

sections were oriented in both a northeast-southwest trend and a northwest-southeast trend. Adobe InDesign was used to create the cross-sections because of its user friendly and graphic design advantages.

MAPS

Isopach maps are used to show the thickness of a rock unit. In the case of this study, the isopach map was crucial because it showed the zero isopach line of the Marcellus Shale, or the edge of the Marcellus Shale where thickness was zero. Well logs from the WVGES were used to find the depth of the top of the Onondaga Limestone and the top of the Marcellus Shale. The difference between these two numbers was the thickness of the Marcellus. Another isopach map was created to show impact of the unconformity on thicknesses of the overlying units. For this map, the sum of the thicknesses of units between the unconformity and the base of the West Falls Formation was plotted on a map for each well. The structure contour map of the Onondaga Limestone was constructed using the subsea values of the top of the Onondaga Limestone from the well logs. Reading and interpreting this map was done in the same way as a topographic map (Allaby and Allaby, 1999). The UTM easting, UTM northing, and thickness values for 621 points were plotted in Surfer (Fig. 18). Surfer used kriging to create a grid and to produce these contour maps.

Supercrop and subcrop maps were also constructed to better understand the unconformity. Supercrop maps show the distribution of the strata overlying a surface at a given time (Neuendorf et al., 2005). In this case, the surface was the unconformity, so the occurrences of the Genesee, Sonyea, and West Falls Formations were plotted on one map to show the post

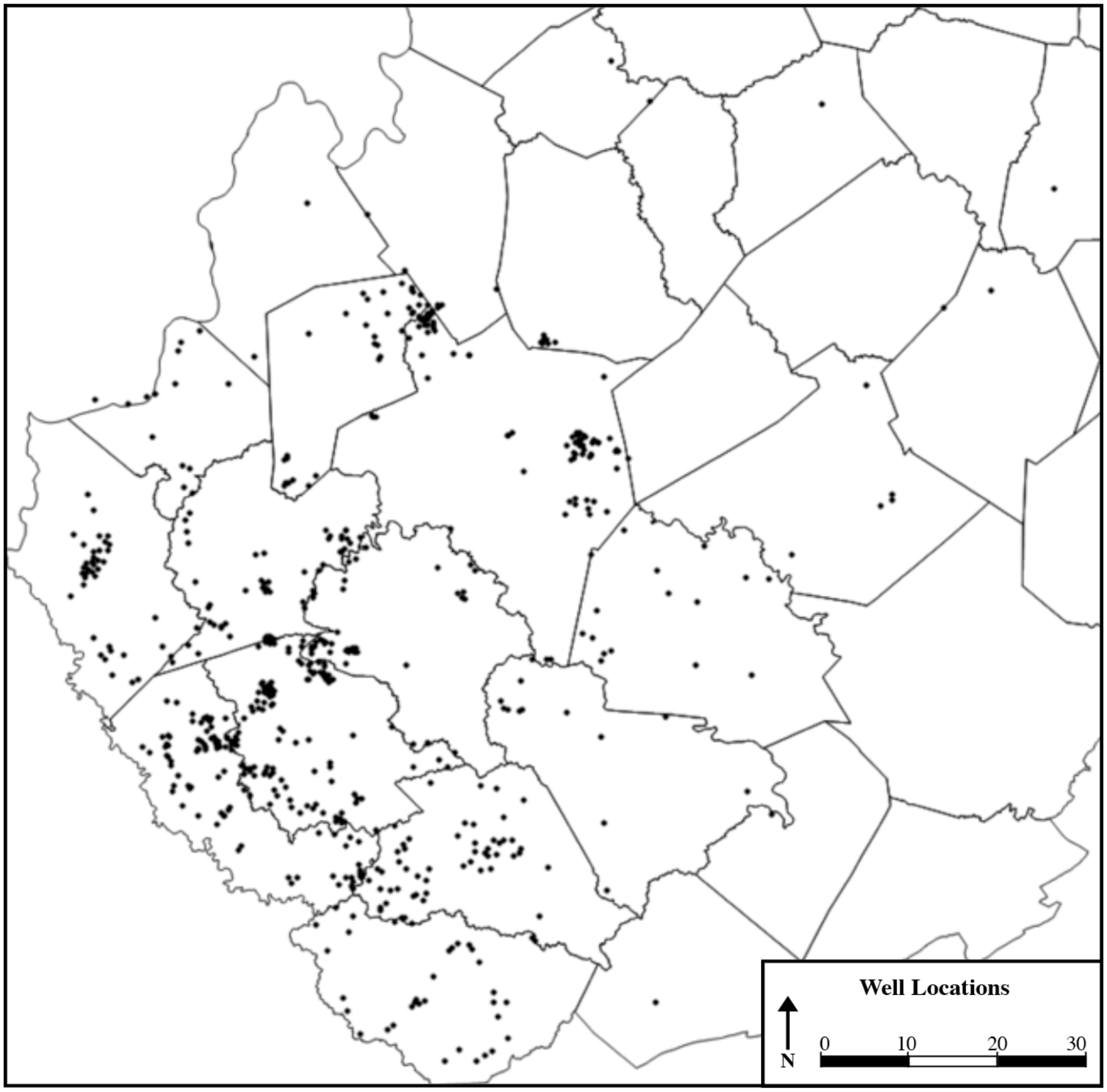


Figure 18: Location of plotted points used for the isopach map of the Marcellus Shale in southern West Virginia.

unconformity units and their onlapping nature. Subcrop maps show the distribution of the formations that have been preserved and covered beneath a stratigraphic unit (Neuendorf et al., 2005). The occurrences of the Onondaga Limestone, Marcellus Shale, the Mahantango Formation, and the Tully Limestone were plotted and mapped.

Surfer is commonly used to make grid-based maps from XYZ-data files, where X and Y are the spatial coordinate locations and Z is an attribute variable. Examples of grid-based maps are contour maps, image maps, shaded relief maps, and vector maps. Surfer allows the user to control gridding parameters. Many gridding options are available, including, but not limited to, kriging, natural neighbor, nearest neighbor, polynomial regression, and minimum curvature. The grid line geometry function is used to control the grid limits and spacing.

Parameter values must be assigned to each node within the grid in order to contour correctly. This is difficult when the field data are sparse or unevenly distributed. Interpolating the measured data points can assist in defining the spatial variability across the grid. Kriging is a statistical interpolation method that is used to understand and visualize the relationships between scattered data points by choosing the Best Linear Unbiased Estimator of the unknown variables (Journel and Huijbregts, 1978; Kitanidis, 1997; Anderson and Woessner, 1992). Each variable is determined by its own variogram, the measure of the change in the variable with changes in distance (Anderson and Woessner, 1992). A higher correlation, or weight, is assigned to smaller distances, and larger distances carry smaller weights.

The calculations to achieve just one output pixel of a node involve the dot product of a known input point value (Z_i) with a weight factor (w_i). The weight factor is based on the solution to a matrix equation (Dubrule, 1984). These output pixels are then interpolated to create a contour map. Contour maps are typically made to show depth, thickness, or elevation of an area. Surfer provided a search option to specify different sectors to distribute amount of data used. For the isopach map, an advanced Kriging option was selected: No Search (use all of the data). Kriging is the best method to use for this type of work because it balances the spatial structure of the variable and it preserves the value at measured points as opposed to other methods that use a least squares fitting of a polynomial (Anderson and Woessner, 1992). Kriging has also been used in mining and groundwater modeling (Anderson and Woessner, 1992).

WELL PRODUCTION ANALYSIS

The WVGES publishes an oil and gas report that includes gas production information for every month of every year for all producing wells. Wells surrounding the isopach line in the southern part of the study area were picked based on location with respect to the isopach line, completion interval formation, and availability of logs. A completion interval represents the region between the top of the productive or operational portion of a well to the bottom of the same operational interval. The completion interval values were obtained through the WVGES pipeline application. To fairly and accurately quantify efficiency of each well, only the sum of the first 12 months of actual production was analyzed. The wells were divided into completion interval categories: Marcellus Shale, Rhinestreet Shale, overall West Falls Formation, and Rhinestreet plus the black shale remnant. Each section was analyzed for amount of production from the wells, thickness of producing formation and its relationship to production, distance to zero isopach, well spacing, completion data, and more. Cross sections were made to verify where production was coming from and the nature of the units in the subsurface. These cross sections were constructed in the same manner as the previously described sections. The sections also included the completion interval for each log. Some wells had multiple completion intervals, but this analysis focused on those that were at the approximate Marcellus, or what was reported as Marcellus, depth.

West Virginia well fields before the 1930's were mainly located in the northwest and targeted shallower units. Oil and gas field development in southeastern West Virginia did not occur until the 1940's, and rapidly increased in the late 1990's and early 2000's (Avary, 2009a).

The wells that were chosen began producing in different years; some started producing as early as 1987, but most began in the late 2000s. All wells came from Magnolia, Chapmanville, or Crum-Kermit fields, which are located in Logan and Mingo counties.

Magnolia field is located in central to southern Mingo County and extends into southwestern Logan County (Fig. 19). It was discovered in 1951 (Atlas of Major Appalachian Gas Plays). Magnolia is considered a large gas field (Haught, 1963). In addition to the "Marcellus Shale", natural gas production was also reported from the Mississippian Greenbrier Limestone ("the Big Lime"), the Berea Sandstone, and the Lower Huron (Haught, 1963; Neal and Price, 1986, WVGES Pipeline). Some Lower Huron wells were drilled horizontally in the 2000's (Avary, personal communication, November 11, 2015).

The Chapmanville field spans parts of three counties: the northwest corner of Logan County, the southern part of Lincoln County, and the northeastern corner of Mingo County (Fig. 20). The field was discovered in 1910 (Neal and Price, 1986). In addition to the "Marcellus Shale", natural gas in Chapmanville was also produced from the Big Lime, Salt sands, Maxton sand, Big Injun sand, Berea Sandstone, Lower Huron, Onondaga Limestone, and the Rhinestreet Shale (Haught, 1963; Neal and Price, 1986). Some Lower Huron wells in Chapmanville Field were also drilled horizontally in the 2000's (Avary,

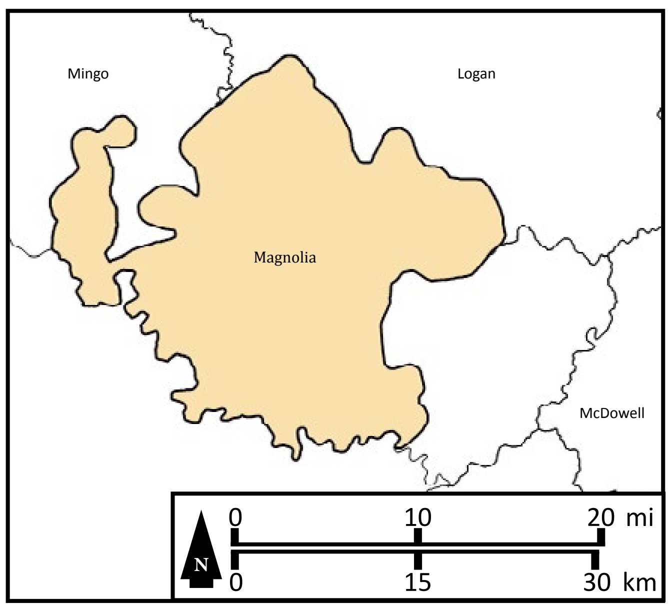


Figure 19: Location of Magnolia gas field in Mingo County and part of Logan County in southern West Virginia.

personal communication, November 11, 2015).

Crum-Kermit is mainly located in central to north Mingo County, with parts in southern Wayne County and the southwest corner of Lincoln County (Fig. 21). It was discovered in 1899, based on production from the Big Lime and the Big Injun (Atlas of Major Appalachian Gas Plays). Additional production comes from the Berea, which was discovered in 1913, and the Lower Huron, which was discovered in 1929 (Atlas of Major Appalachian Gas Plays). Big Lime and the Big Injun shale, but the Huron Shale is one of the main producers in Crum-Kermit (Haught, 1963; Neal and Price, 1986).

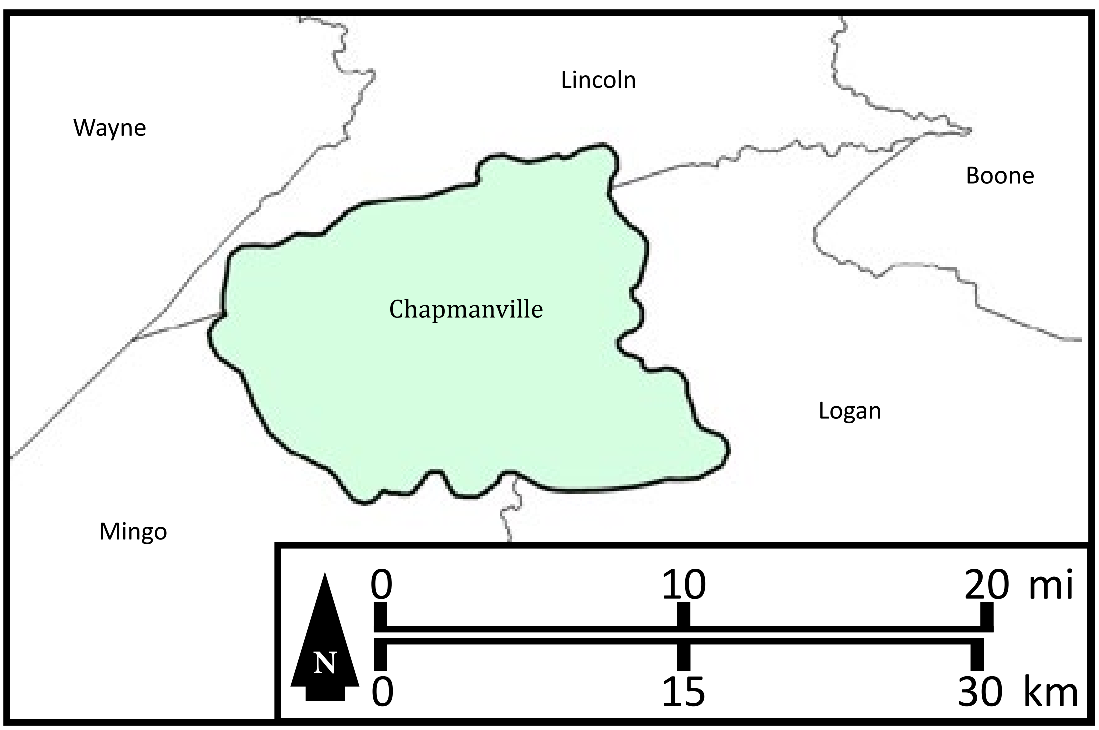


Figure 20: Location of Chapmanville gas field in Logan, Mingo, and Lincoln Counties in southern West Virginia.

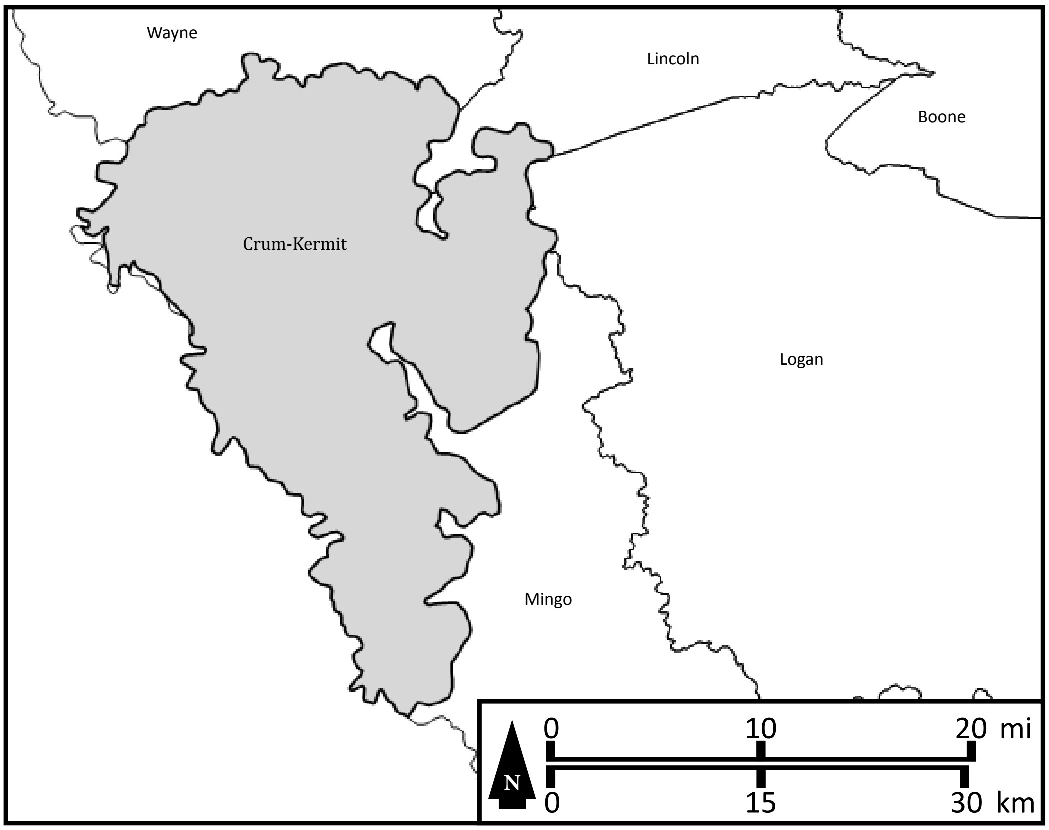


Figure 21: Location of Crum-Kermit gas field in Mingo and Wayne Counties in southern West Virginia.

CHAPTER FOUR: RESULTS

CROSS SECTIONS

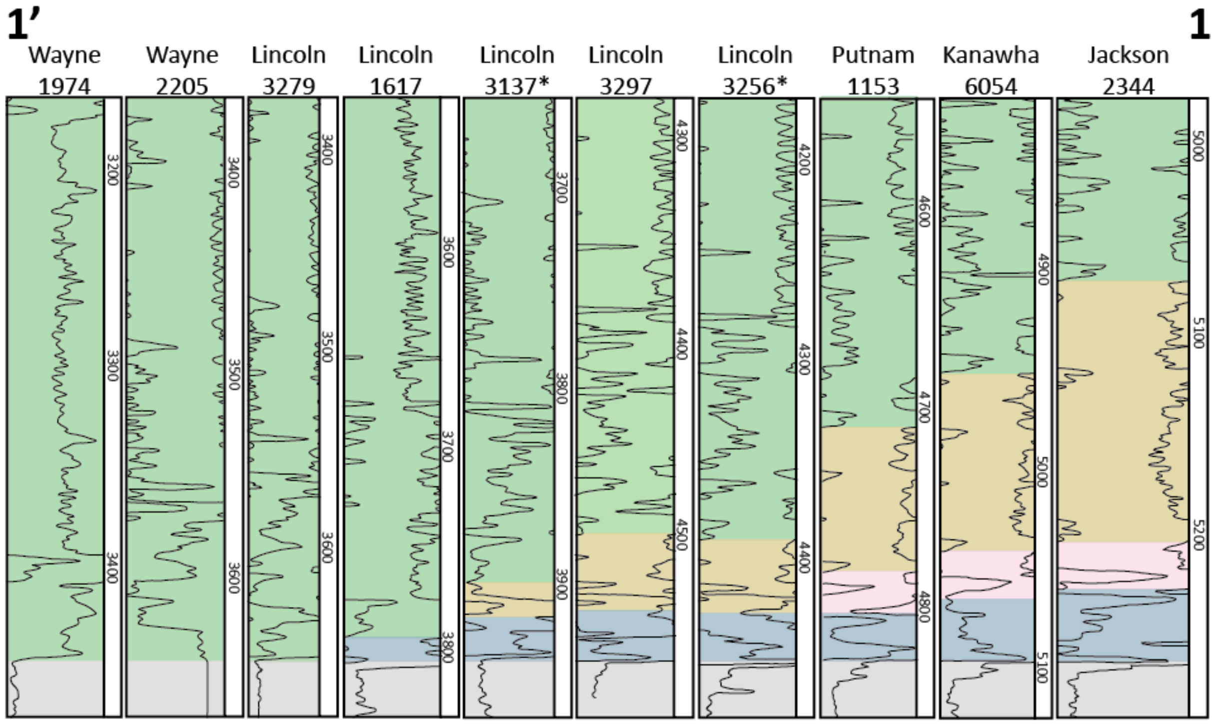
Five cross sections in southern West Virginia were created using well logs (Fig. 17). These cross sections were correlated based on signature patterns from gamma ray and bulk density curves as described above.

CROSS SECTION 1

The first cross section consists of 10 well logs and had a northeast-southwest trend through Jackson, Kanawha, Putnam, Lincoln, and Wayne counties (Fig. 22). Cross section 1 is the northernmost section with this orientation. The Marcellus is at its deepest, 5,229 feet, in the first log in this section, in Jackson County. Depth decreases towards the south. Like depth, thickness of the Marcellus also decreases. The Marcellus is also thickest in the Jackson County log, 38 feet. The southwestern-most Marcellus on this cross section is found in Lincoln 1617 (API: 4704301617) with a thickness of 14 feet at a depth of 3796 feet. The rest of the section, from Lincoln 3279 (API: 4704303279) into Wayne County, shows the Marcellus removed by the unconformity and the West Falls Formation on the Onondaga Limestone.

CROSS SECTION 2

Cross section 2 also runs in a northeast-southwest trend, but is positioned slightly east of cross section 1 (Fig. 23). It is made up of 19 well logs and crosses the following counties: Roane, Kanawha, Boone, Logan, and Mingo. It includes the Onondaga Limestone, the Marcellus Shale, the Genesee Formation, the Sonyea Formation, and the West Falls Formation. The northern part of the section has very clear boundaries between units. Clearly, these boundaries become vaguer



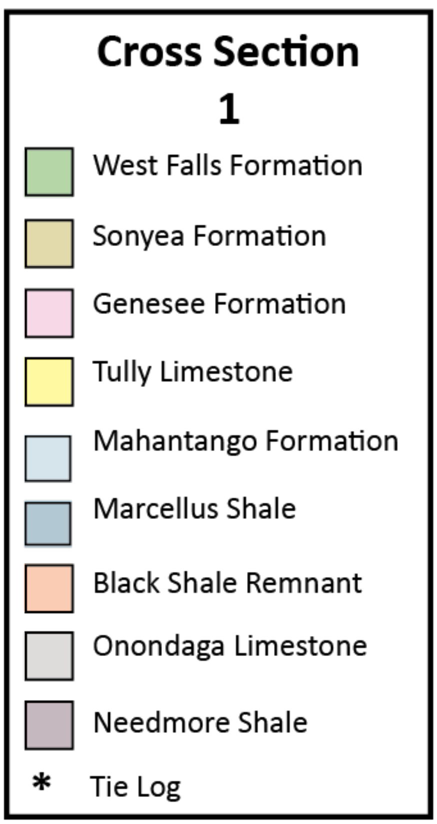
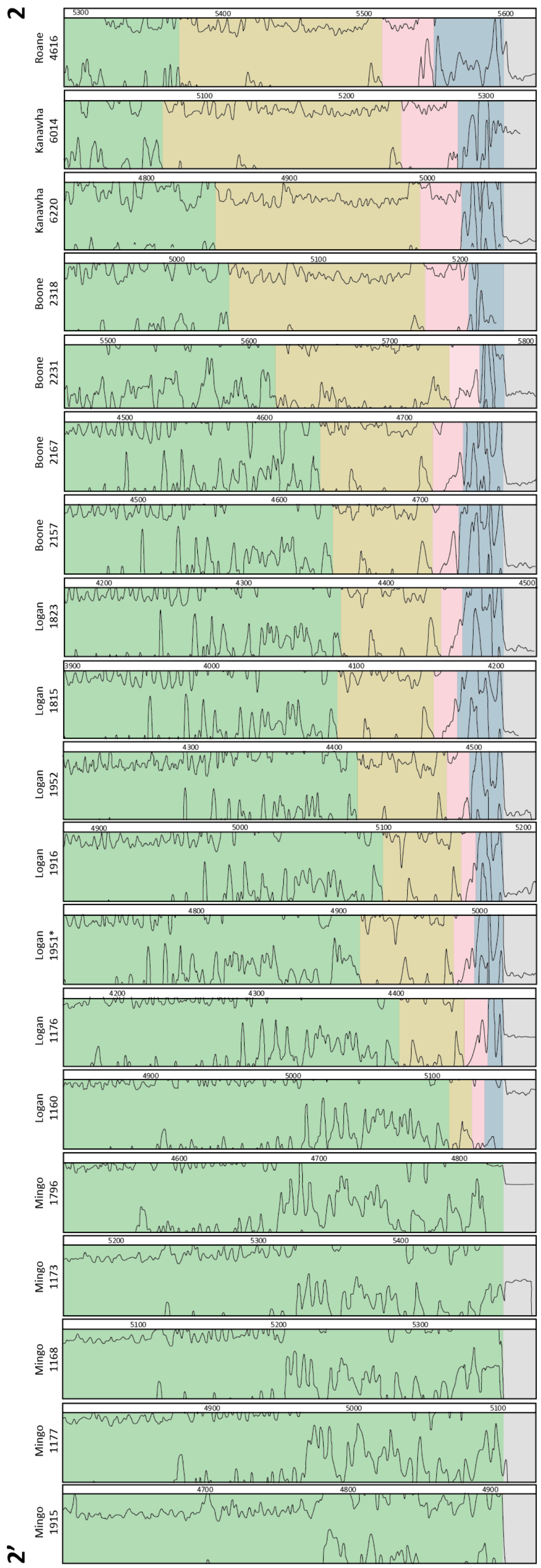


Figure 22: Gamma-ray logs of cross-section 1 in southern West Virginia. API value for each log is 0-200 API units. The top of the Onondaga Limestone was used as the datum. See Figure 17 for location of cross-section.



Cross Section 2

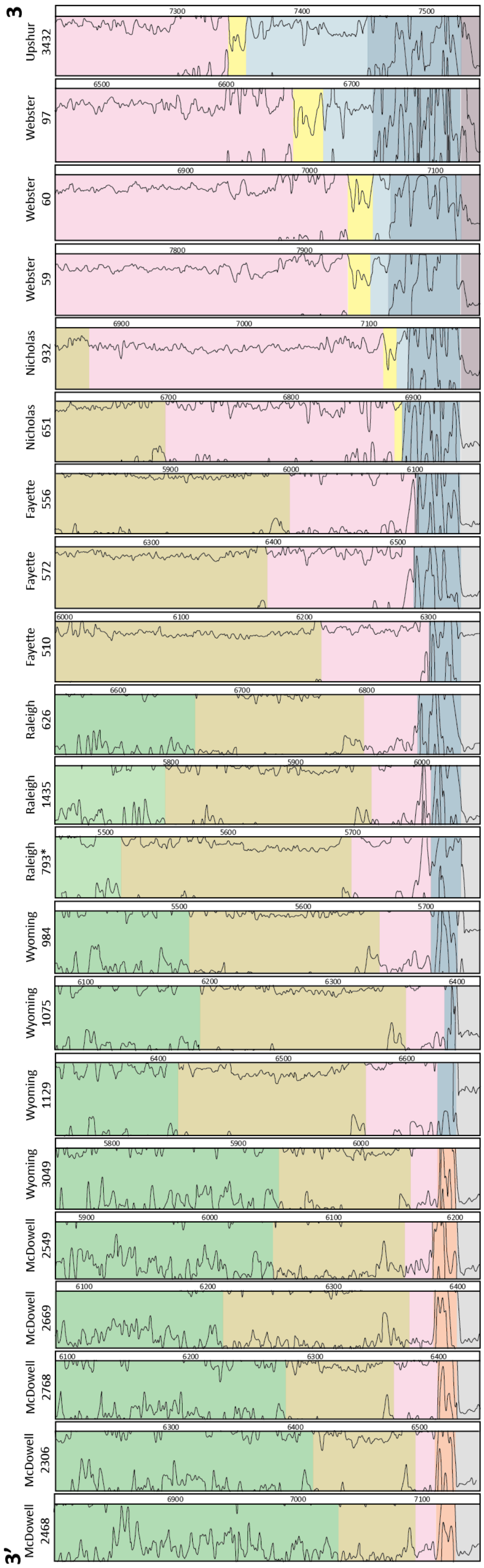
- West Falls Formation
- Sonyea Formation
- Genesee Formation
- Tully Limestone
- Mahantango Formation
- Marcellus Shale
- Black Shale Remnant
- Onondaga Limestone
- Needmore Shale
- * Tie Log

Figure 23: Gamma-ray logs of cross-section 2 in southern West Virginia. The datum is the top of the Onondaga Limestone. See Figure 17 for location of cross-section.

to the south. The gamma-ray log readings do not penetrate the top of the Onondaga Limestone in Boone 2318 (API: 4700502318), but the base of the Marcellus Shale can still be seen in the density log. Marcellus thickness is greatest in the northern counties, with a maximum thickness of 50 feet in Roane County. It thins to about 2-30 feet in the middle part of the section, and then to zero in the central to southern section of Logan County. Depth of the top of the Marcellus begins at around 5,550 feet in Roane County, shallows to about 4,200-5,000 feet in the middle of the section, and then becomes deeper right before it disappears in southern Logan County at 5,150 feet. The top of the Marcellus is deepest in Boone County (API: 4700502231) at 5,763 feet. Aside from the West Falls Formation, the other formations generally follow the same thinning pattern as the Marcellus Shale.

CROSS SECTION 3

The southernmost cross section with a northeast-southwest trend is cross section 3, which has 21 well logs and runs through Upshur, Webster, Nicholas, Fayette, Raleigh, Wyoming, and McDowell counties (Fig. 24). Because cross section 3 covers such a large distance, it is much easier to see the contrast of certain units at their fullest extent, and the subsequent truncation. The Genesee Formation is shown to be very substantial in the northeastern section of the study area, as are its subunits, the Geneseo Shale and the West River Shale. The Marcellus Shale eventually grades into the black shale remnant that can be seen in the other cross sections. The initiation of the truncation of Marcellus occurs during the transition from Wyoming 984 (API: 4710900984) to Wyoming 1075 (API: 4710901075). Maximum thickness of the Marcellus Shale is 72 feet in southern Upshur County. Thickness slowly but gradually decreases to 25 feet in mid-Wyoming County. Marcellus depth varies throughout the section. The deepest region was in the north,



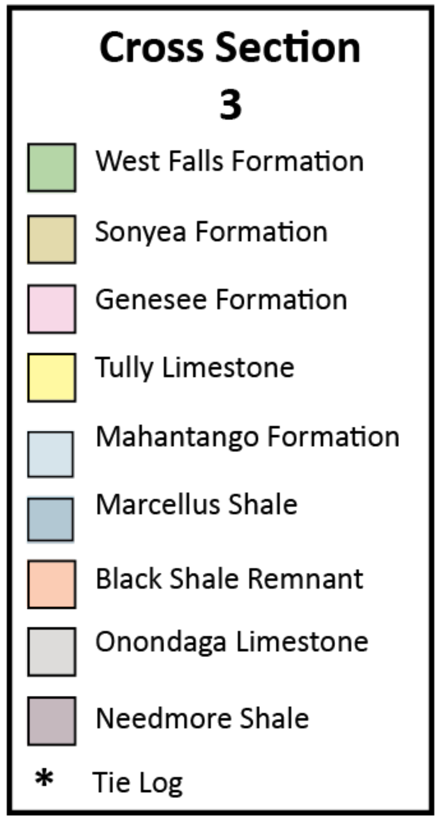


Figure 24: Cross section 3 was the eastern-most cross section with a northeast-southwest orientation. See Figure 17 for location of cross-section.

through southern Upshur to Webster, where depth ranges from 7,450 to 7,967 feet, respectively. Depth gradually decreases to about 5,700-6,600 feet in the middle part of the section, and then increases again to 7,126 feet into McDowell County.

CROSS SECTION 4

The fourth cross section runs in a northwest-southeast direction through Mason, Putnam, Lincoln, Boone, Raleigh, and Summers counties (Fig. 25). It contains 17 well logs. Thickness of the Marcellus Shale in Summers County is 20 feet and increases to 32 feet in Raleigh County (API: 4708100688). From there, thickness decreases, but stays relatively consistent until it completely disappears in mid-Putnam County. Depth of the Marcellus in Cross Section 4 maintains a similar pattern to thickness. Depth is greatest in Summers and Raleigh counties where it ranges from 6,890-7,904 feet. It decreases to 6,000 feet in the northwestern part of Raleigh County, then to 4,000-5,000 feet in Boone, Lincoln and Putnam. The contact between the Onondaga Limestone and the West Falls in Mason County is at a depth of 3,813 feet. The Genesee Formation is absent after the transition from Boone 2187 (API: 4700502187) to Lincoln 3314 (API: 4704303314), and the Sonyea Formation disappears with the truncation of the Marcellus during the transition from Putnam 1356 (API: 4707901356) to Putnam 1160 (API: 4707901160). Similar to Cross Section 3, Cross Section 4 also contains the Mahantango Formation. However, in this transect it is found in the Summers County log (API: 4708900005). A fault is identified in the Raleigh 296 log (API: 4708100296), at a depth of about 7,780 feet. This fault is represented by the repeating pattern of what appears to be the top of the Genesee Formation and the base of the Sonyea, or the Middlesex Member.

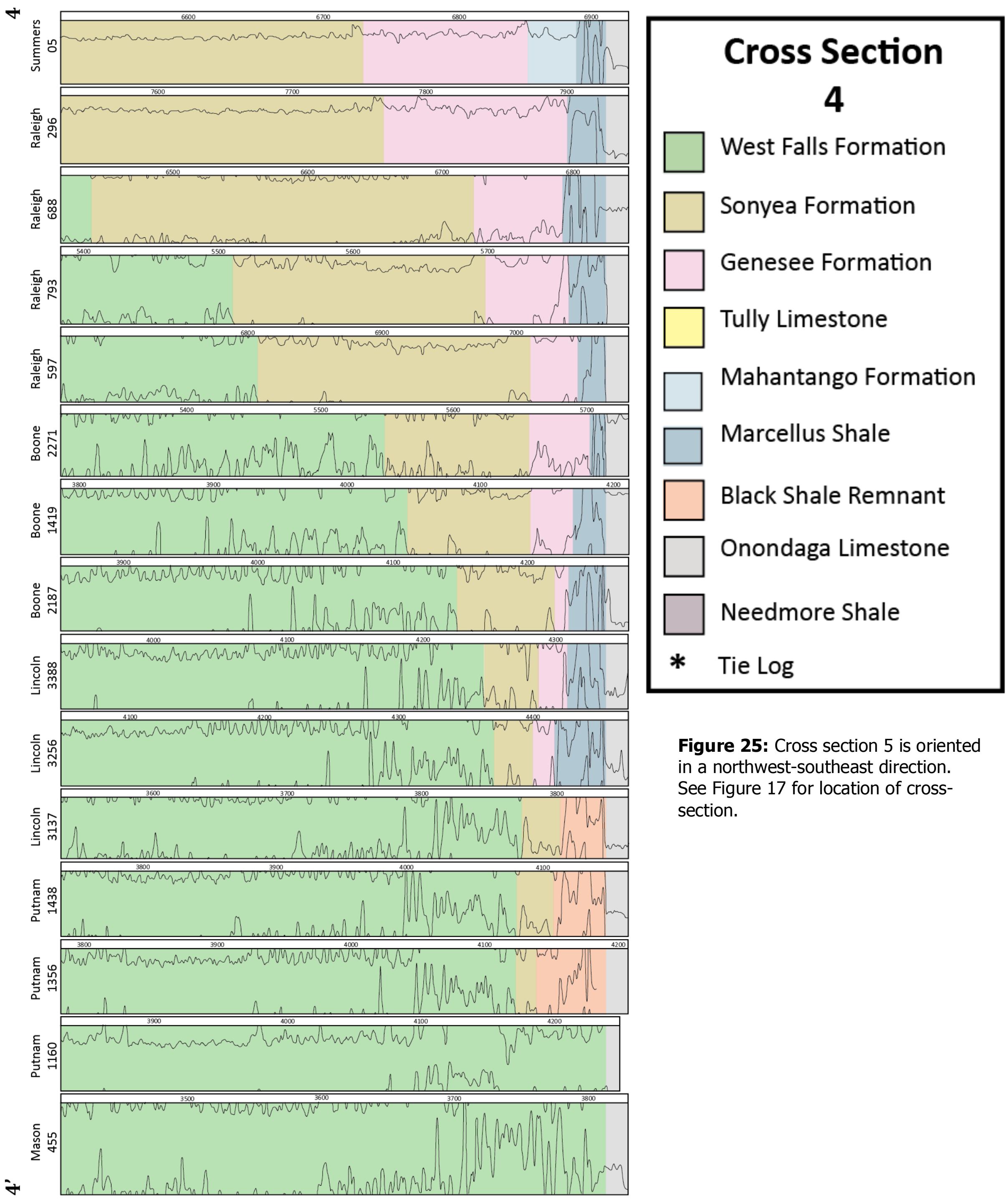


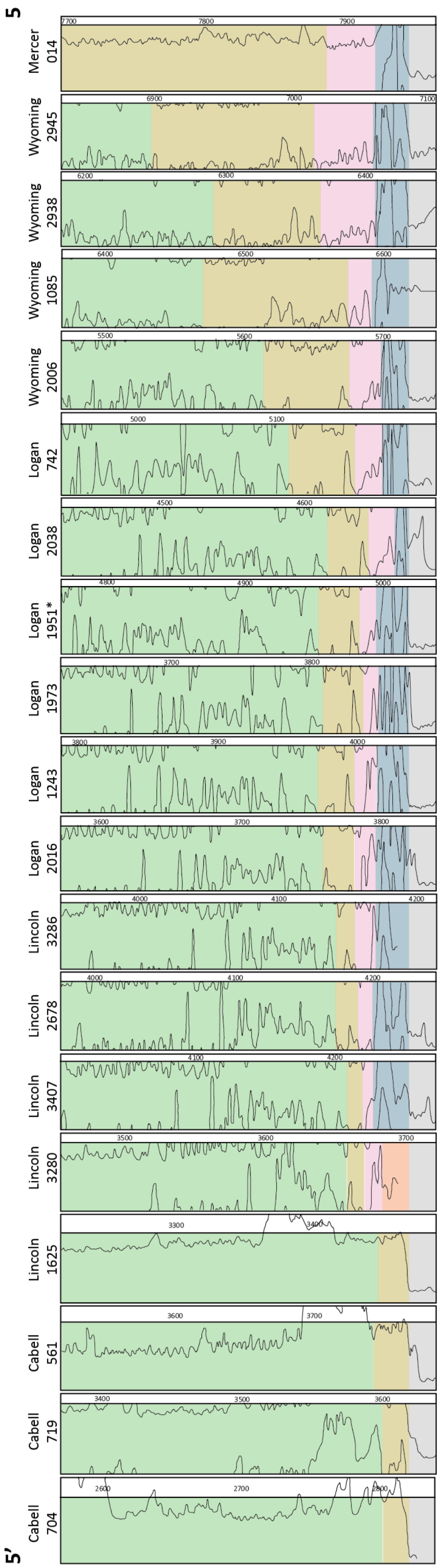
Figure 25: Cross section 5 is oriented in a northwest-southeast direction. See Figure 17 for location of cross-section.

CROSS SECTION 5

Cross section 5 also has a northwest-southeast trend, which begins in Cabell County, and continues into Lincoln, Logan, Wyoming, and Mercer counties (Fig. 26). Twenty well logs are used in this cross section. Thickness of the Marcellus Shale ranges from 0 to 28 feet throughout the section. Maximum thickness is found in southeastern Wyoming County (API: 4710902945) and thicknesses of zero begin in mid-Logan County (API: 4704502038). The Marcellus transitions into the black shale remnant across the Logan-Lincoln border. This remnant continues into mid-Lincoln, but disappears in northern Lincoln (API: 4704301625) and is absent in north Cabell County (API: 4701100704). The last appearance of the Genesee Formation is also at the boundary of Logan to Lincoln County. The Sonyea Formation is completely gone in mid Lincoln County (API: 4704303407). Maximum depth of the top of the Marcellus Shale is 7,721 feet in Mercer County. Depth decreases to 4,000-6,000 feet in Wyoming to Logan Counties, and to 3,796 feet where the Marcellus ends in north Logan County.

MAPS

The isopach map was created to show the thickness of the Marcellus Shale in the subsurface. Some points outside the study area were included to show continuity and reduce edge effect (Fig. 27). The most notable part of the map, for the purposes of this study, was the zero isopach line, or the edge of the Marcellus (Fig. 28). The Marcellus was thicker in the northeast region of the study area. The 70, 60, 50, and 40-foot thick intervals were relatively smooth in a gently curving orientation. The 30-foot isopach interval generally followed the pattern of the above contours, but it also had a section that extended into Fayette County, with a



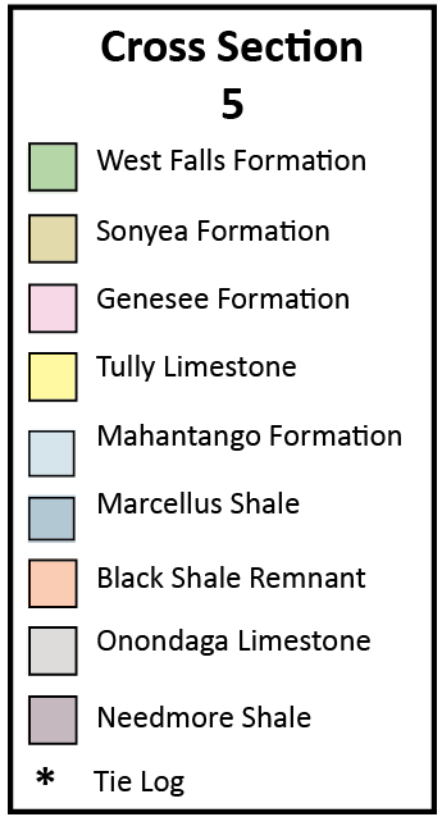


Figure 26: Gamma-ray logs of cross section 5 in southern West Virginia. See Figure 17 for location of cross-section.

40-foot region in the interior. The 20 and 10-foot contour lines were significantly more jagged than the others. The 20- to 30-foot interval was the widest in the region, encompassing a much larger area than the other intervals: Monroe, Mercer, Summers, parts of Greenbrier and Fayette, Raleigh, the northern half of Wyoming, parts of Boone, Logan, and Lincoln, most of Kanawha County, and small sections of Clay, Roane, Jackson, and Putnam counties were

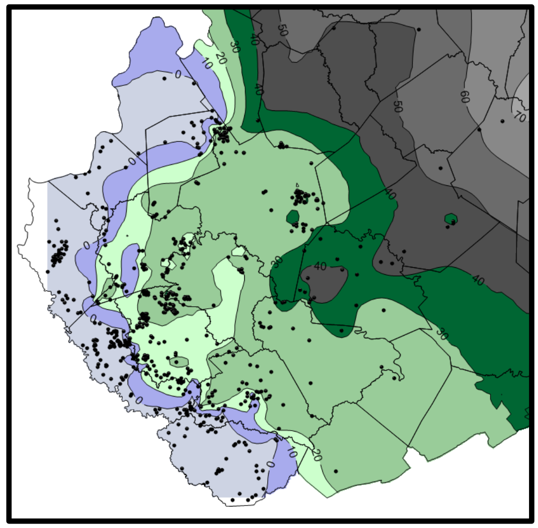


Figure 27: Locations of control points used for the isopach map.

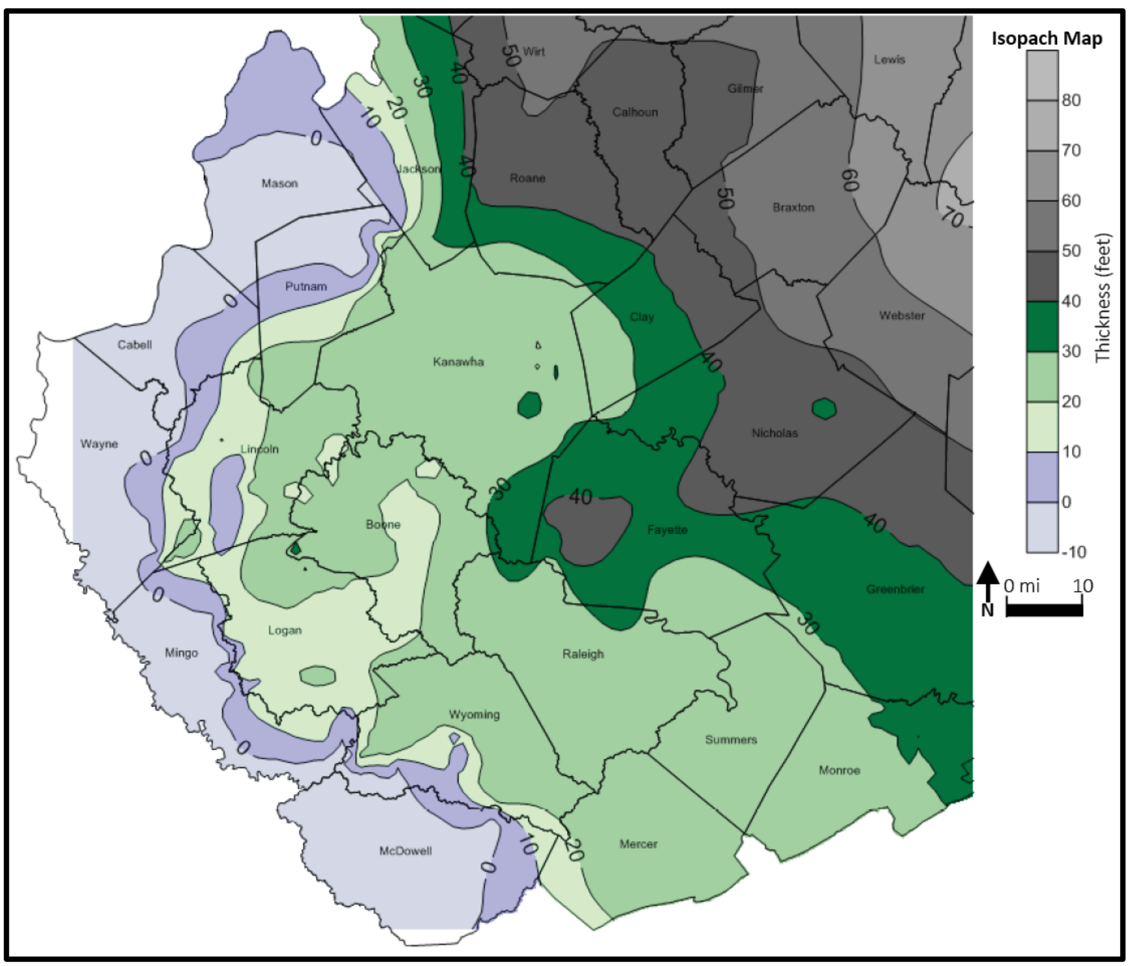
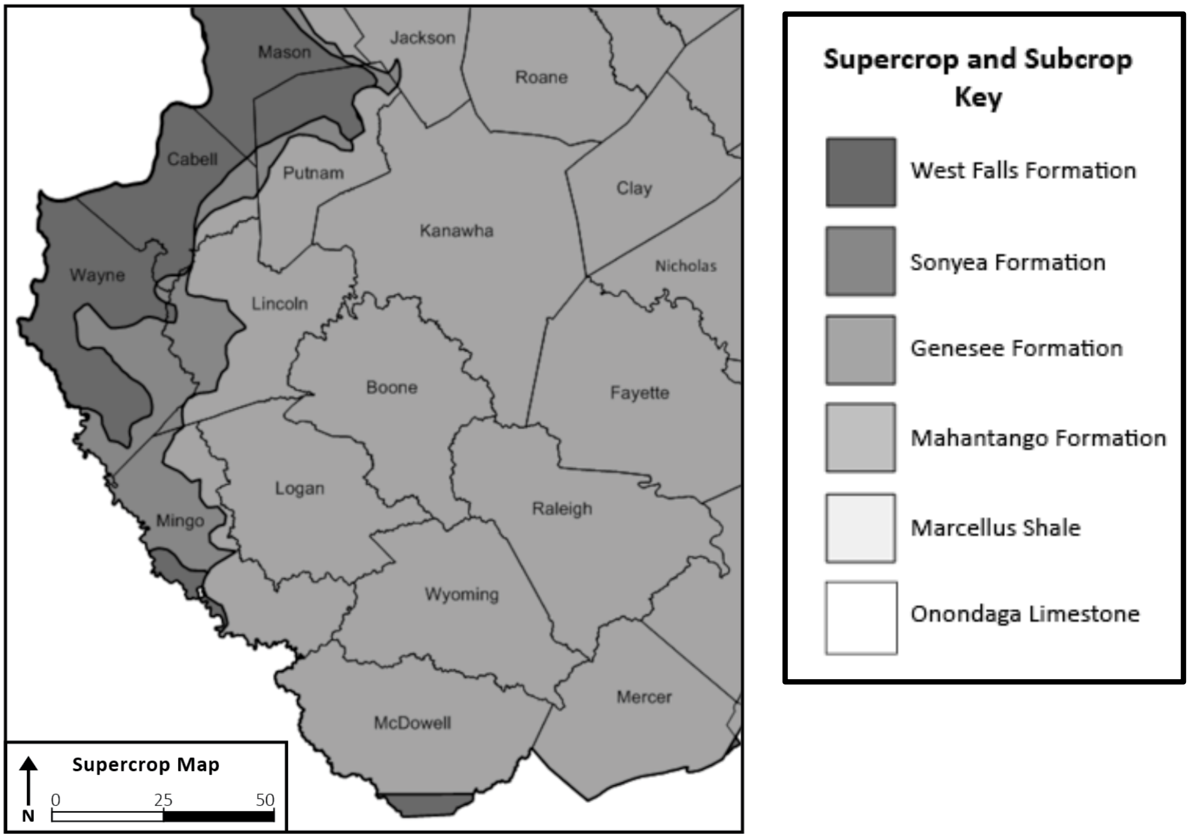


Figure 28: Isopach map of the Marcellus Shale in southern West Virginia. The light gray indicates the zero thickness zone.

included. Scattered artifacts in the form of “islands” of both high and low values were present within the 20- to 30-foot region. There is a round-shaped region of 30- to 39-foot thickness in southeastern Kanawha County. More asymmetric “islands” were present in Boone County, on the border with Lincoln County. These have a thickness of 10- to 19-feet. The 10- to 20-foot interval was much narrower than the 20- to 30-foot interval, but followed a similar pattern. It also had artifacts of varying elevation contained within. The 10-foot thickness interval also included a northward protruding region into the 20-foot interval. The zero isopach line maintained a trend similar to the other lines. The zero isopach line almost equally divided Mason and Cabell counties. Only a sliver of Lincoln County was devoid of the Marcellus. Most of Wayne, Mingo and McDowell counties also featured a relatively wide area where the Marcellus Shale was absent.

Additional maps were generated to aid in the characterization of the unconformity. The supercrop map displays the units above the unconformity (Fig. 29). These sediments were deposited by onlapping the unconformity. The formations shown in the map were the Genesee Formation, the Sonyea Formation, and the West Falls Formation. The West Falls Formation was the farthest west-reaching unit out of the two and it continues outside of the West Virginia border. The Sonyea Formation only occurs slightly west of the Genesee into Mason, Putnam, and Cabell counties, and much farther into Lincoln, Wayne, and Mingo counties.

Units below the unconformity are shown in the subcrop map (Fig. 30). The units affected by the unconformity, which are included in this map, were the Tully Limestone, the Mahantango Formation, and the Marcellus Shale. The Onondaga occurs below these units and extends



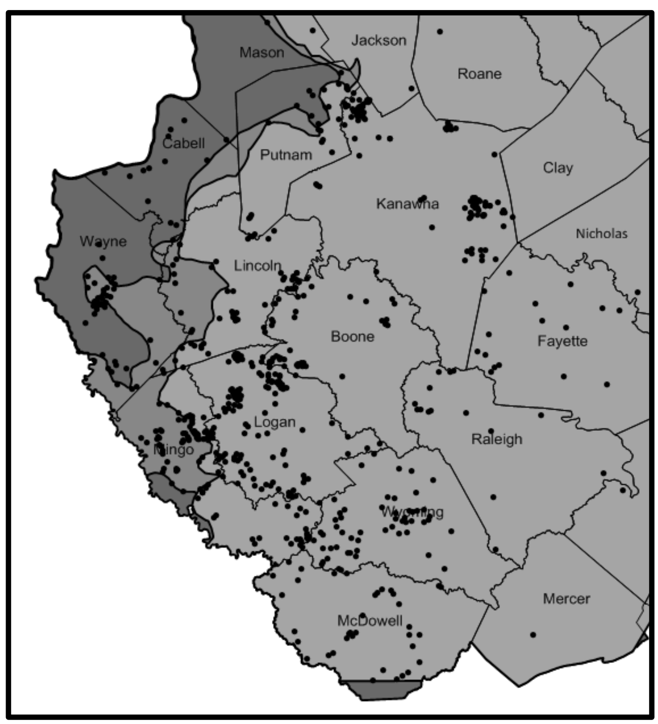


Figure 29: Supercrop map of the units above the unconformity. Corresponding map of control points is included.

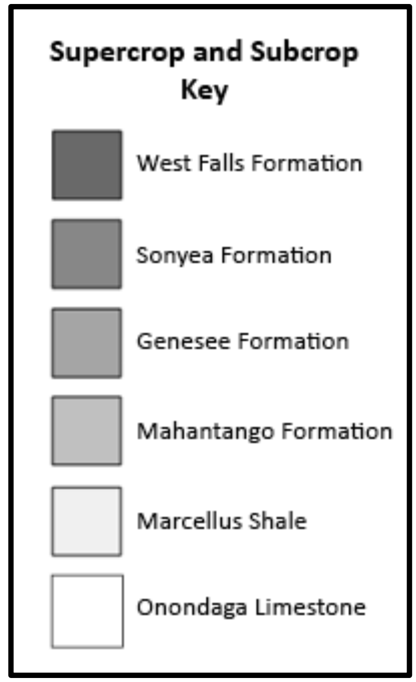
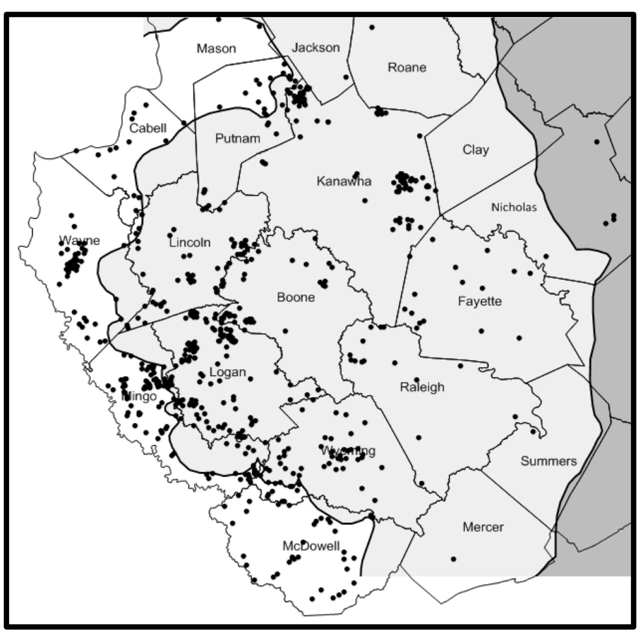


Figure 30: Subcrop map of units below the unconformity and corresponding map with control points.



westward past the West Virginia border. The Mahantango is the least areally extensive on this map. It was the thickest in northeastern Webster County and southern Upshur County, and thinned to the west through Clay, Nicholas, and Greenbrier counties. The Marcellus Shale's thickness was described in the previous sections, but this figure clearly demonstrates the magnitude of its exposure with respect to the other formations.

Another isopach map shows the thickness distribution of the units situated between the unconformity and the base of the West Falls and was constructed to further demonstrate the unconformity (Fig. 31). This map is the sum of the thicknesses of the Genesee Formation and the Sonyea Formation. An accompanying topographic profile was created from a transect through the center of the state (Fig. 32). These figures demonstrate the effect of the unconformity and the way these units were onlapped onto the unconformity surface. In similar fashion to the other

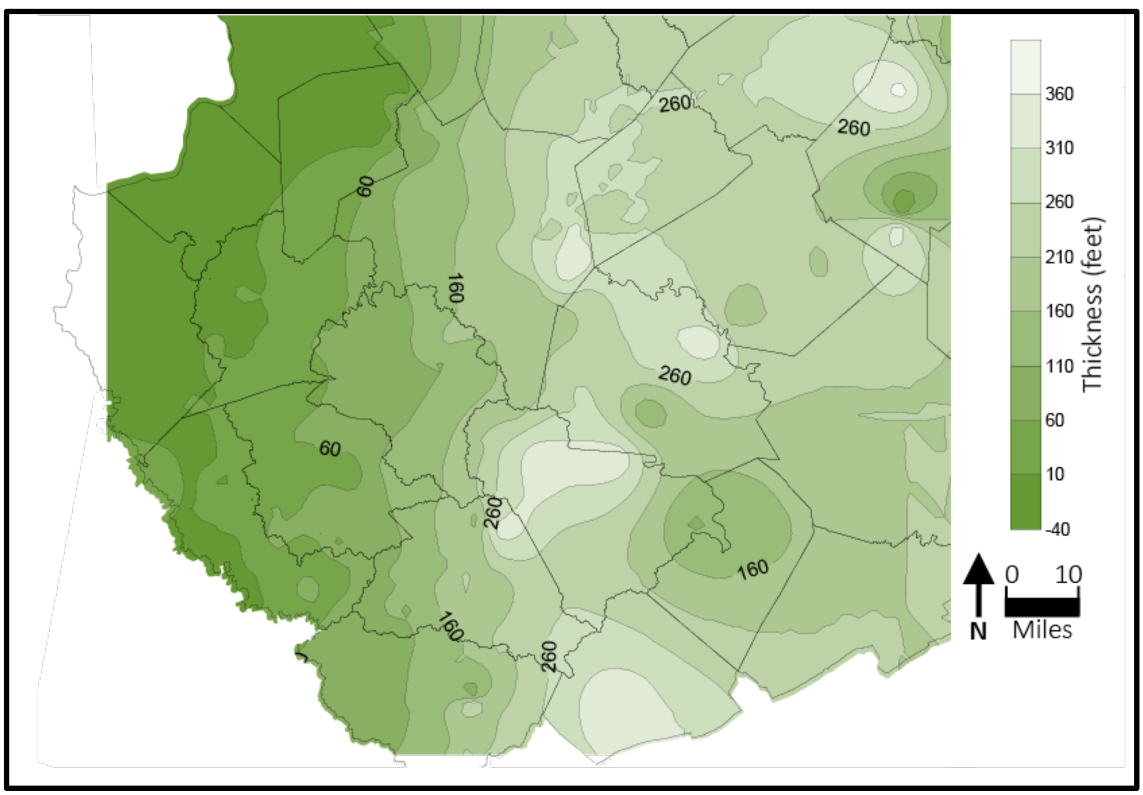
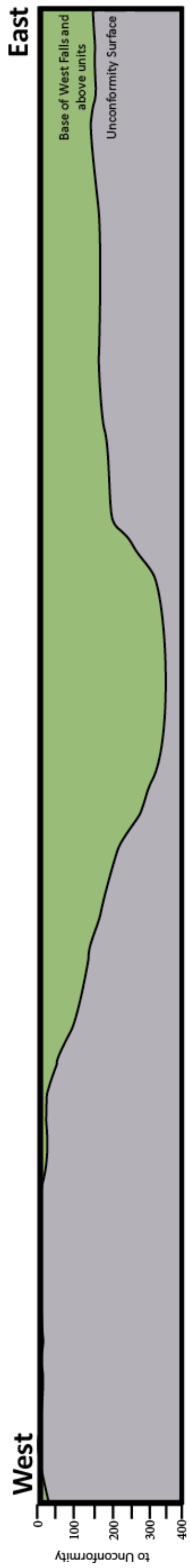


Figure 31: Isopach map of the thickness of units between the unconformity and the base of the West Falls Formation.



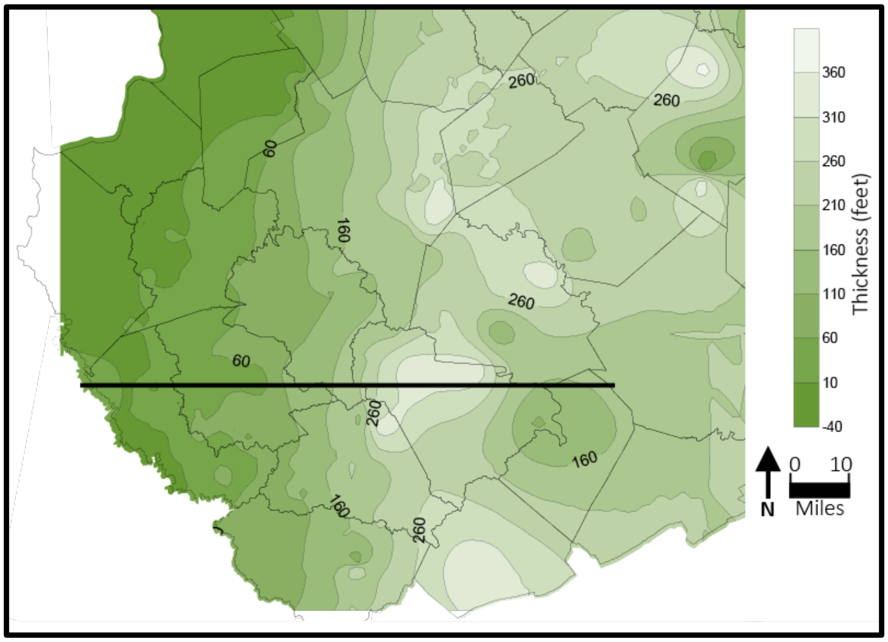
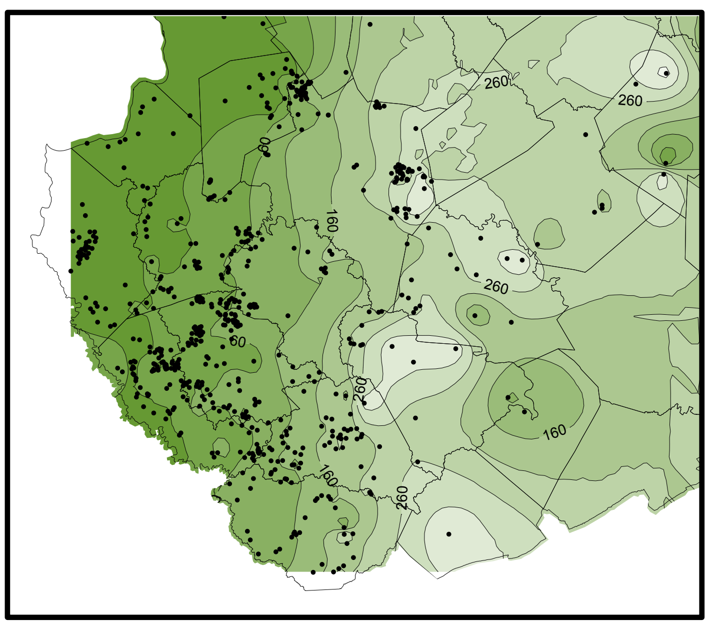


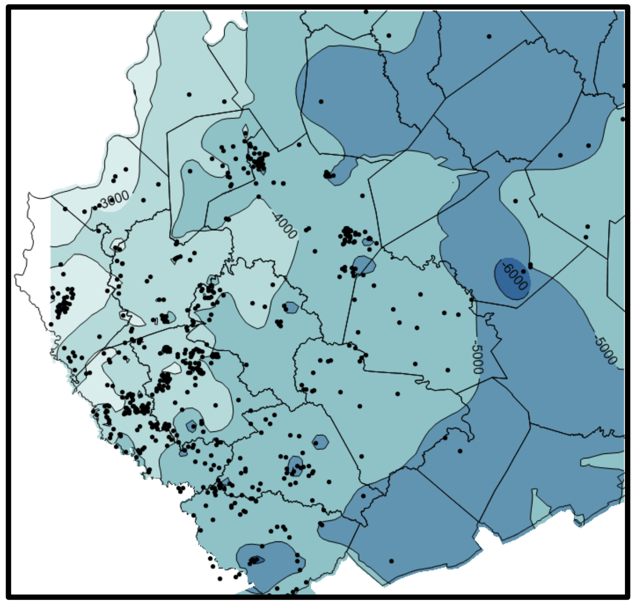
Figure 32: Topographic profile of a transect through the isopach map of the base of the West Falls to the unconformity. The green color represents the West Falls and above units and the gray color represents older units. The corresponding map of control points is shown below.

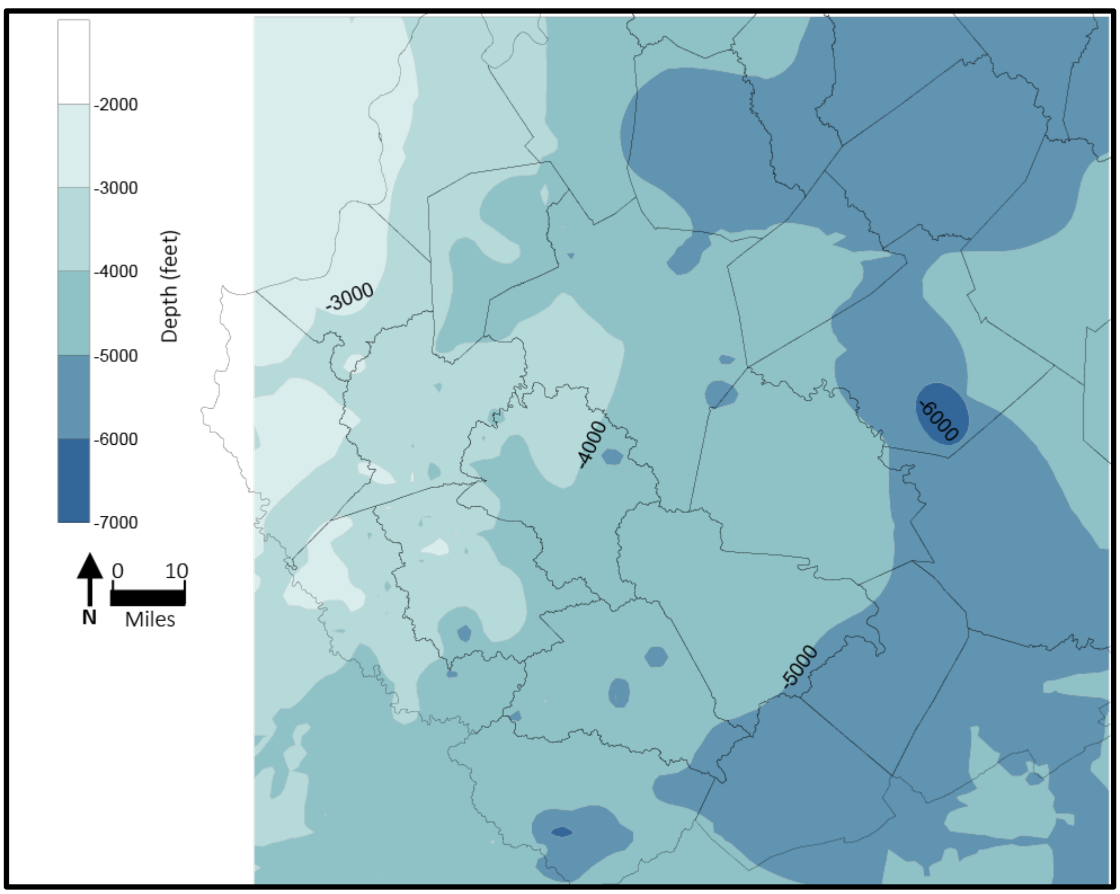


maps, this thickness was greatest to the east and decreased to the west. Its thickest point was in Webster County, where values reached 384 feet. An area of increased thickness extends from the highest point in Fayette County into western Kanawha and southern Roane Counties.

The Onondaga Limestone has a varying topography throughout the state, but it maintains a constant eastward-deepening trend and an increase in structural relief with depth (Fig. 33). Topographic highs exist in southeastern McDowell, Summers, Wyoming, throughout Lincoln, and northern Boone counties. A topographic low is present in southern Nicholas County. A pattern that may represent a plunging fold occurred in the northwest region of the figure, beginning in southern Jackson County, through Putnam, and Cabell Counties.

Figure 33: Structure contour map of the Onondaga Limestone in West Virgina. This figure shows the variations in topography of the Onondaga, as well as the eastward-deepening trend. A map of the control points is to the right.





WELL PRODUCTION ANALYSIS

Fifty-seven wells in the study area were analyzed on the basis of location, producing unit, first 12 months of production, and year of initial production. They were located in the south-central region of West Virginia in Mingo and Logan Counties (Fig. 34). The completion interval

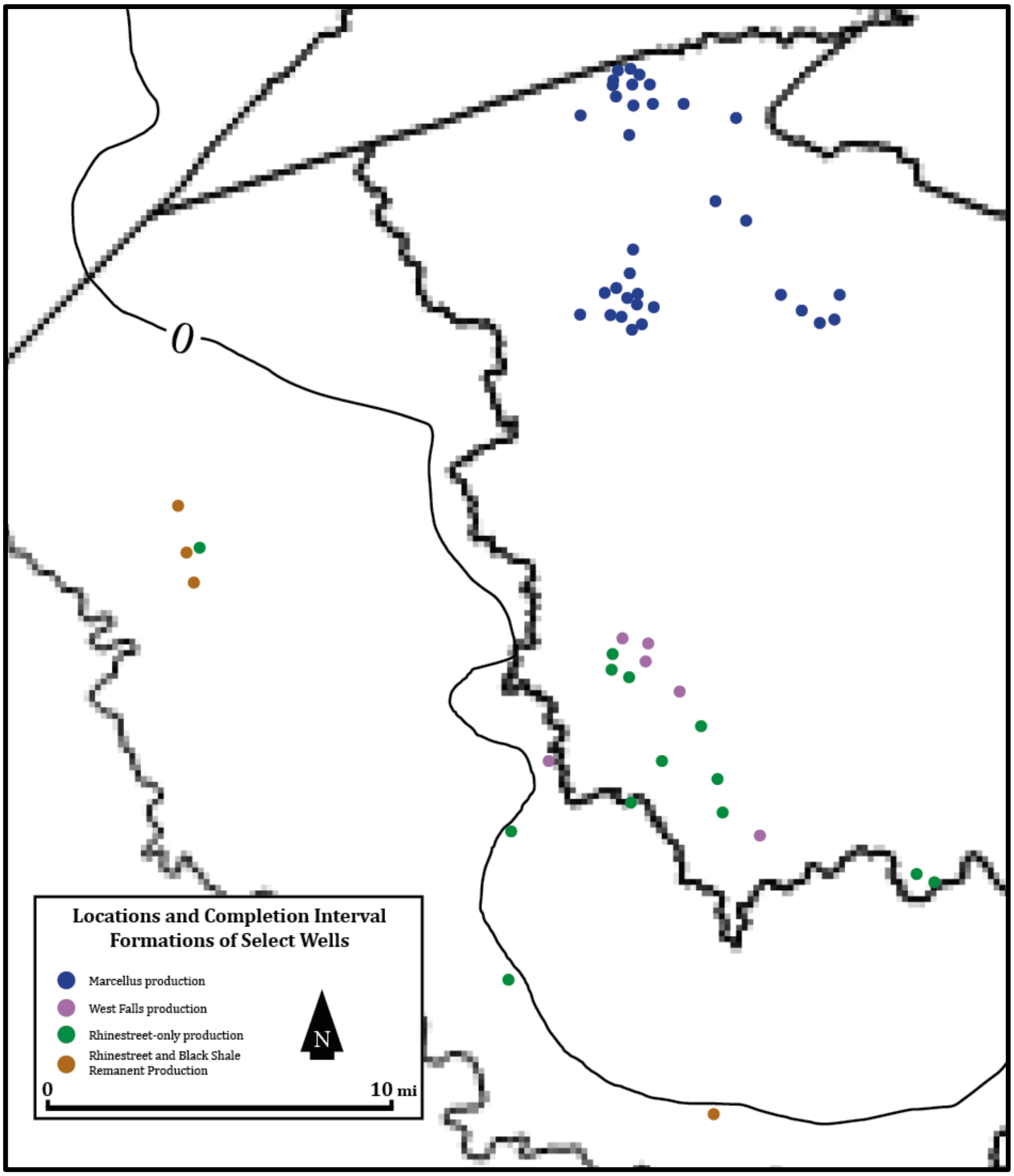


Figure 34: Locations of analyzed wells in Logan and Mingo County with corresponding classifications on the basis of producing formation. The line labeled "0" is the Marcellus zero isopach contour.

for each well was plotted on the log and then analyzed to determine the producing unit for each log. The natural gas from the analyzed logs came from the Marcellus Shale, the Rhinestreet Shale, the West Falls Formation, or the Rhinestreet Shale plus the black shale remnant. Each well was located in Chapmanville, Magnolia, or Crum-Kermit fields (Fig. 35). Data used for the well production analysis can be found in Appendices D and E.

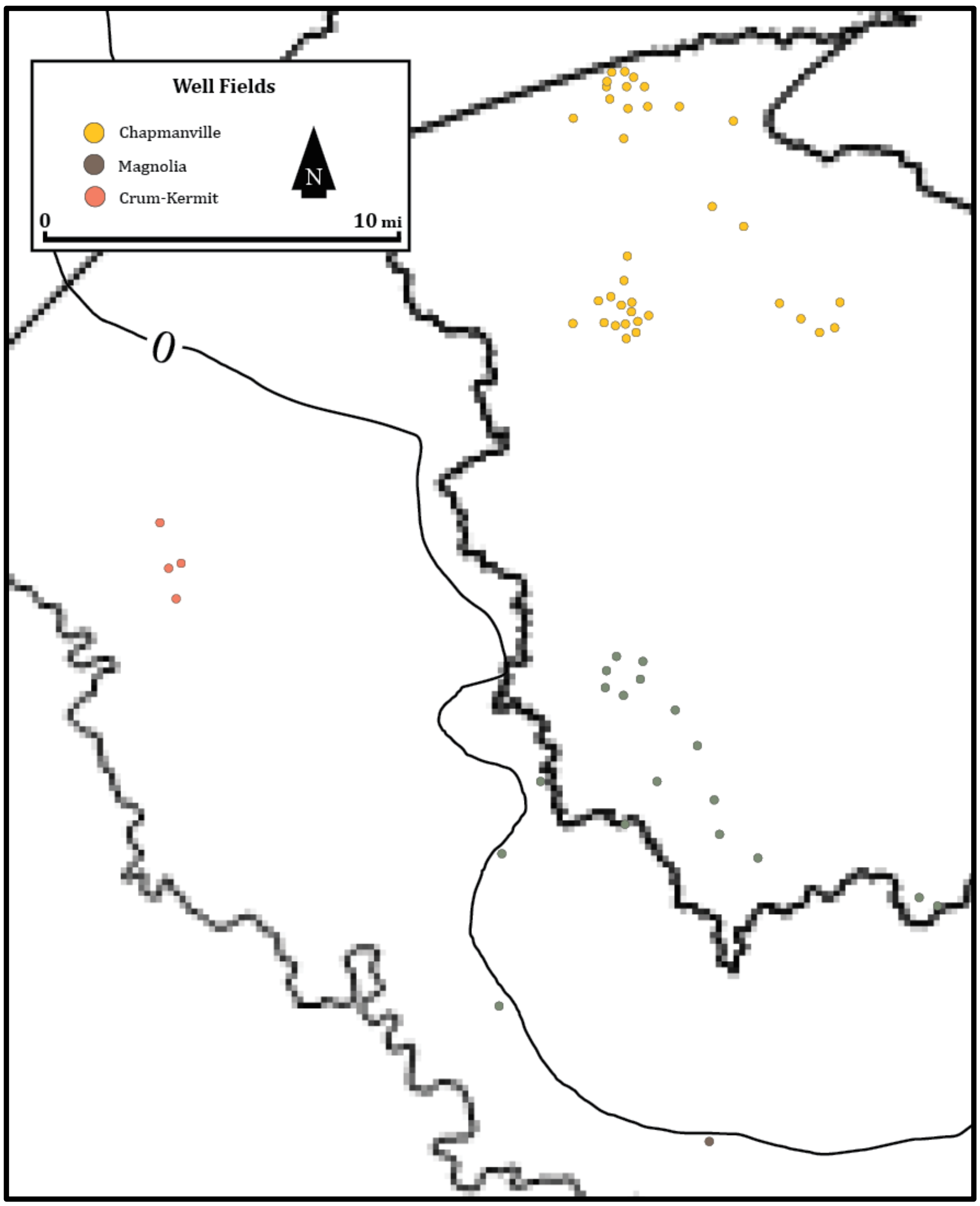


Figure 35: Well locations and their corresponding well fields. The line labeled "0" is the Marcellus zero isopach contour.

MARCELLUS SHALE PRODUCTION

Wells that produced only from the Marcellus were clustered within the boundary of the zero isopach line in northern Logan County. There were 34 wells in this category and all wells were found in the Chapmanville well field. Completion interval thickness among these wells ranged from 10-33 feet and the median thickness was 10 feet. Production from the Marcellus wells in Chapmanville Field ranged from 16,607 mcf to 110,739 mcf in the first year (Fig. 36). The average production was 36,852 mcf and median production was 34,731 mcf. The well with

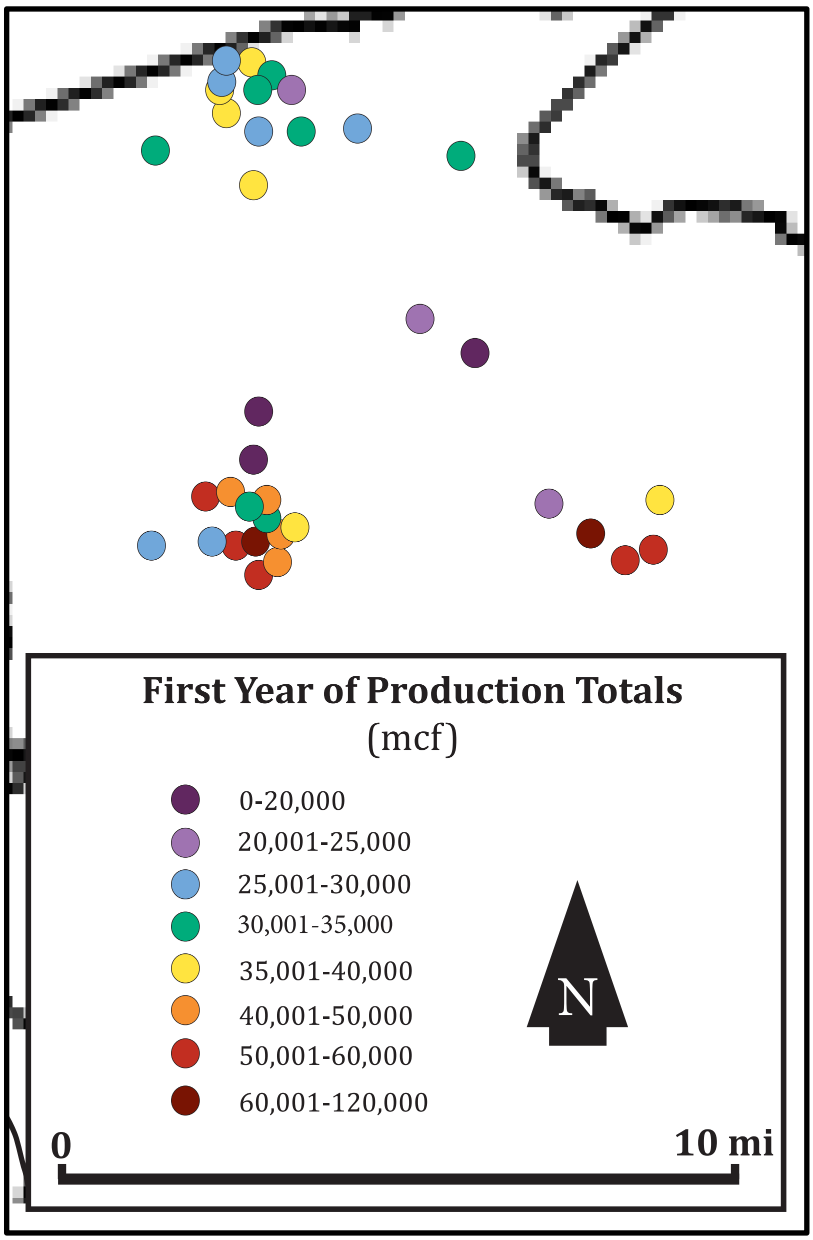


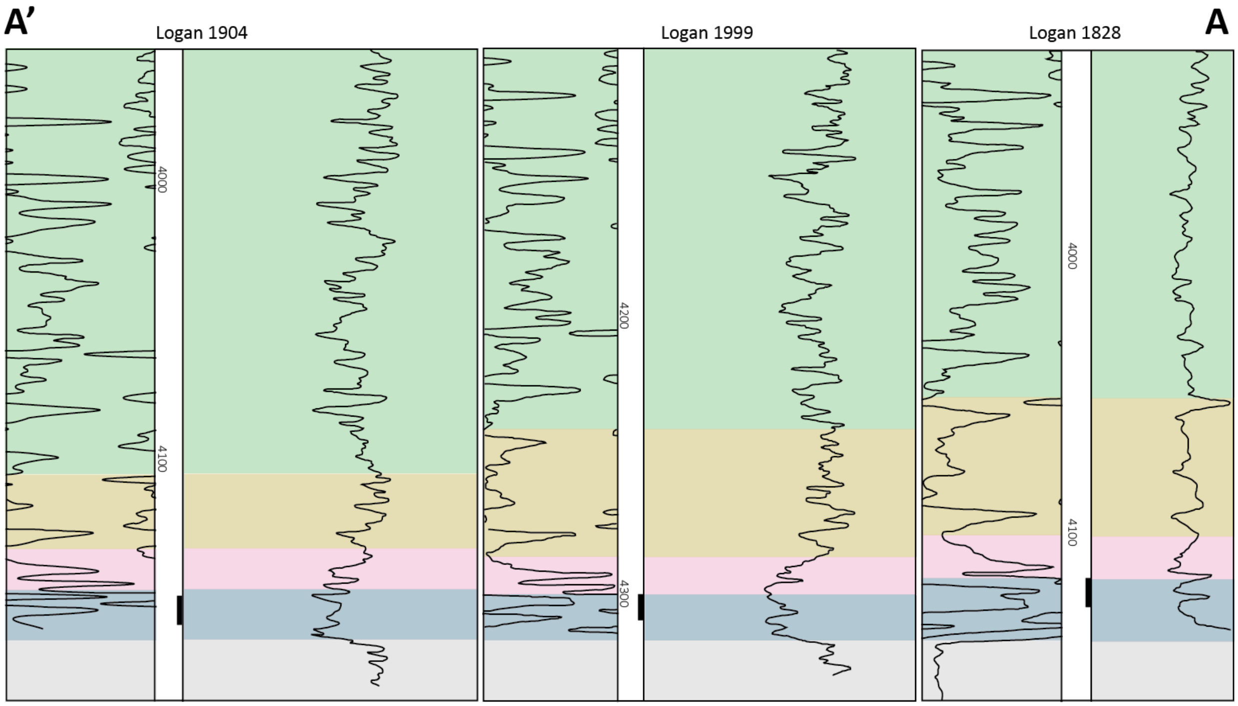
Figure 36: First year of production totals for Marcellus-only producing wells in Chapmanville Field.

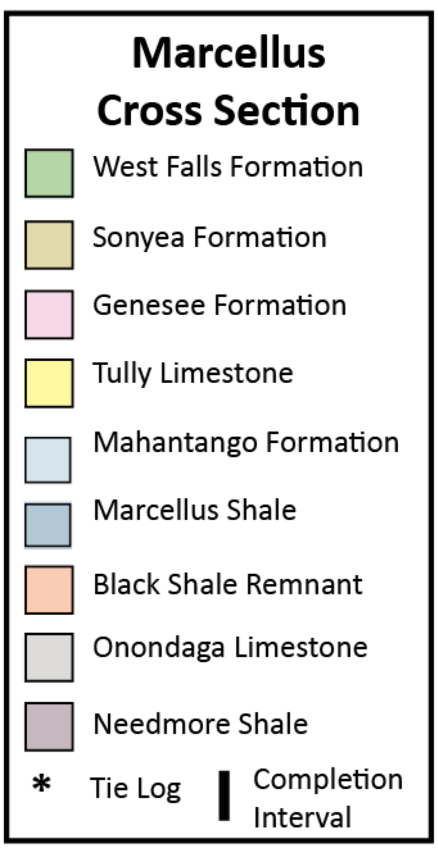
the most reported production (API: 4704501828) in Chapmanville Field began production in 2008, is located in the southern part of the cluster, and produces from only a 10-foot interval. The wells with the least reported production (API: 4704502089 and 4704502064) were spaced farther from the other wells in the clusters. Initial production year for all wells ranged from 2006-2009, and the median and average year of production was 2007.

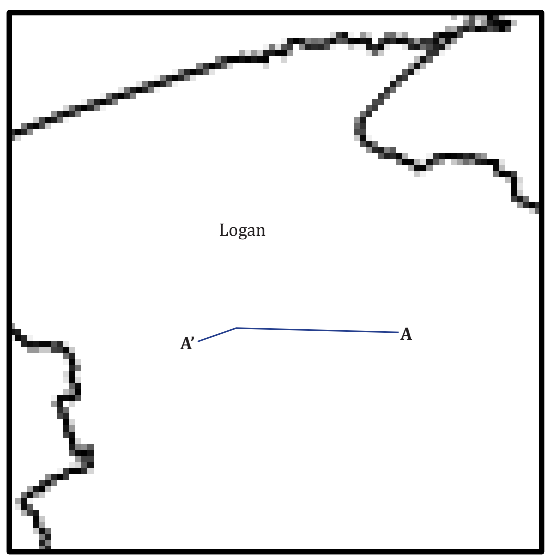
The Chapmanville cross-section runs through three of the more southern wells (Fig. 37). These logs show a complete range of the Marcellus, Genesee, Sonyea and West Falls. The base of the Marcellus Shale is used as the datum for this cross section. All formations thin to the west. The top of the Sonyea Formation/base of the Rhinestreet Shale ranges from 4,052 to 4,241 feet and averages 4,133 feet. The thickest Sonyea interval is 50 feet in the easternmost log and thins to 27 feet in the westernmost log. The top of the Genesee Formation ranged from 4,102 to 4,287 feet and has an average of 4,177 feet. The easternmost Genesee thickness is 15 feet and the westernmost thickness is five feet. The average depth to the top of the Marcellus Shale is 4,188 feet. The easternmost log has a Marcellus depth of 4,117 feet, the Marcellus in the middle log is 4,300 feet and the westernmost log has a Marcellus depth of 4,148 feet. The average thickness of the Marcellus Shale in this category is 19 feet. The thickness of the Marcellus in the easternmost log (API: 4704501828) is 22 feet and 18 feet for the other two logs.

RHINESTREET SHALE PRODUCTION

Thirteen wells produce from only the Rhinestreet Shale. These are located in southeastern Logan County and parts of Mingo County. All wells but one are within Magnolia field. The other is located in Crum-Kermit field. Two wells are located outside of the zero isopach line. The







Figures 37: Cross section for Marcellus producing wells in Chapmanville field. The top of the Onondaga Limestone and the base of the Marcellus Shale was used as the datum.

southernmost well located outside of the zero isopach line (API: 4705901144) produced only 11,701 mcf in 1992, its first year. The northernmost well that was located outside of the isopach line (API: 4705901814) produced more natural gas during its first year: 26,514 mcf in 2007. Completion thickness for Rhinestreet-producing wells is significantly greater than the Marcellus-producing wells, ranging from 71-231 feet with an average thickness of 156 feet. The median year of initial production is 1992 and the average year is 1993. The average production total for these wells is 37,241 mcf, and the median production total is 26,514 mcf (Fig. 38). The two wells with the most gas production (API: 4704501204 and 4704501211) are the two

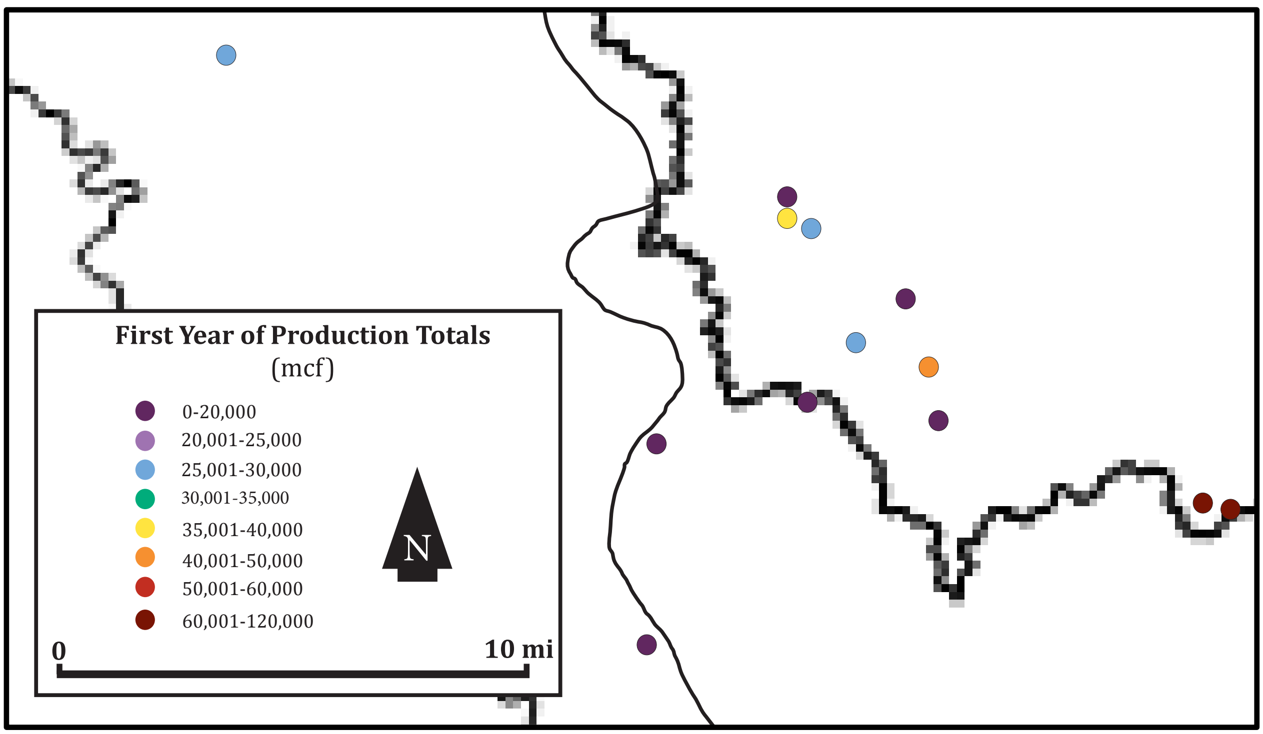


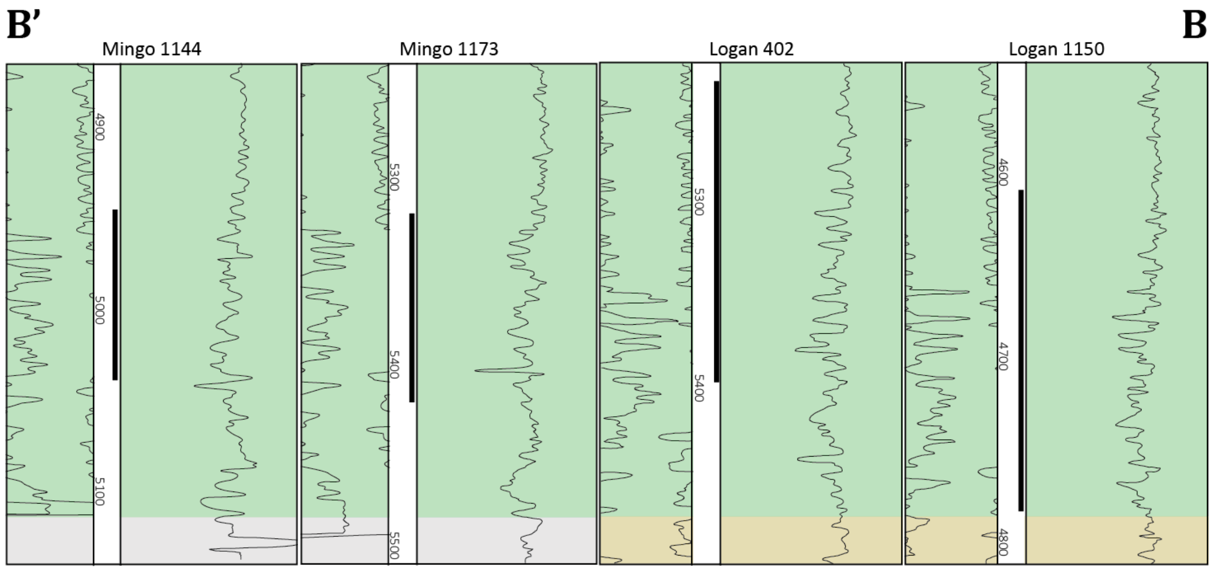
Figure 38: Map showing the first year of production totals for Rhinestreet producing wells. The thin black line running through the center is the Marcellus Shale zero isopach line.

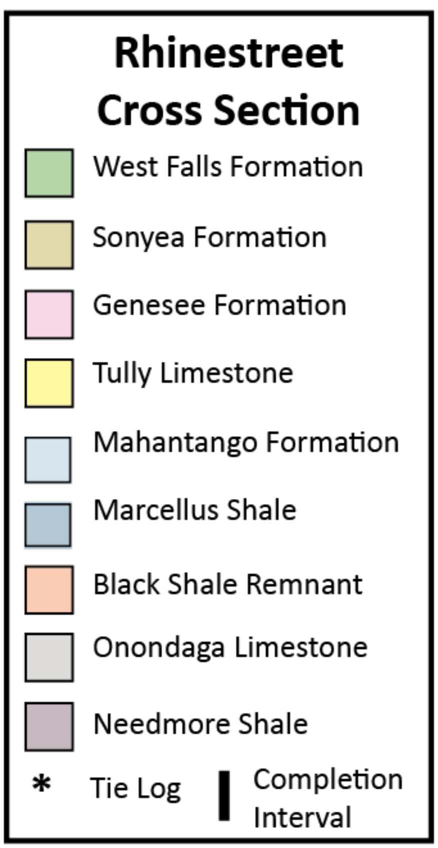
southeastern most wells in Logan County. They produced 119,934 and 118,728 mcf, respectively. The average production total for both of the wells located outside of the zero isopach line and the well closest to the isopach line within the boundary is 19,298 mcf, a very low value compared to the surrounding wells.

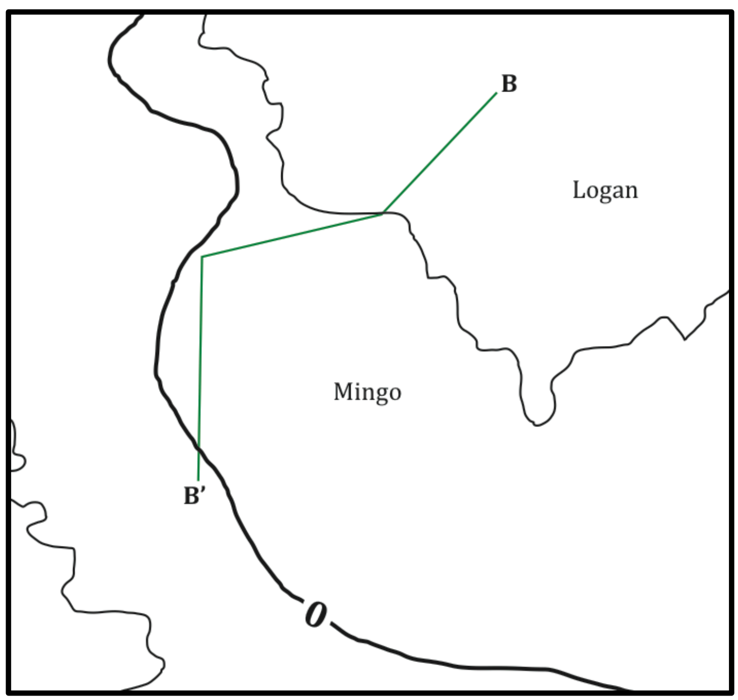
The Rhinestreet cross-section cross cuts the Logan-Mingo County border and the Marcellus Shale zero isopach line (Fig. 39). The base of the Rhinestreet is used as the datum for this cross section. The two easternmost logs show only the Sonyea Formation beneath the Rhinestreet Shale. The log that is just inside the zero isopach line (API: 4705901173) appears to be void of Marcellus. The log just outside the isopach line (API: 4705901144) also shows only the Rhinestreet Shale. The depth to the base of the Rhinestreet in this region remains relatively consistent throughout the cross section, ranging from 4,783 feet (API: 4704501150) to 5,470 feet (API: 4704500402) and averaging at 5,190 feet.

WEST FALLS FORMATION PRODUCTION

Only six wells that produce from the West Falls interval are found in the area. Well placement is relatively spread out, with a small cluster of wells to the north. Five of these wells are located in southwestern Logan County and one is in eastern Mingo County near the Mingo-Logan border. All wells are located in the Magnolia field. These wells are relatively older compared to the others. The earliest well in this area began production from the West Falls in 1987, the latest well began production in 1992, and the average year of initial production is 1990. Three out of the six wells have first year of production totals in the lowest range (0-20,000 mcf) (Fig. 40). Because this category spans all members of the West Falls Formation, the







Figures 39: Cross section for Rhinestreet producing wells. The datum for this cross section is the base of the West Falls Formation.

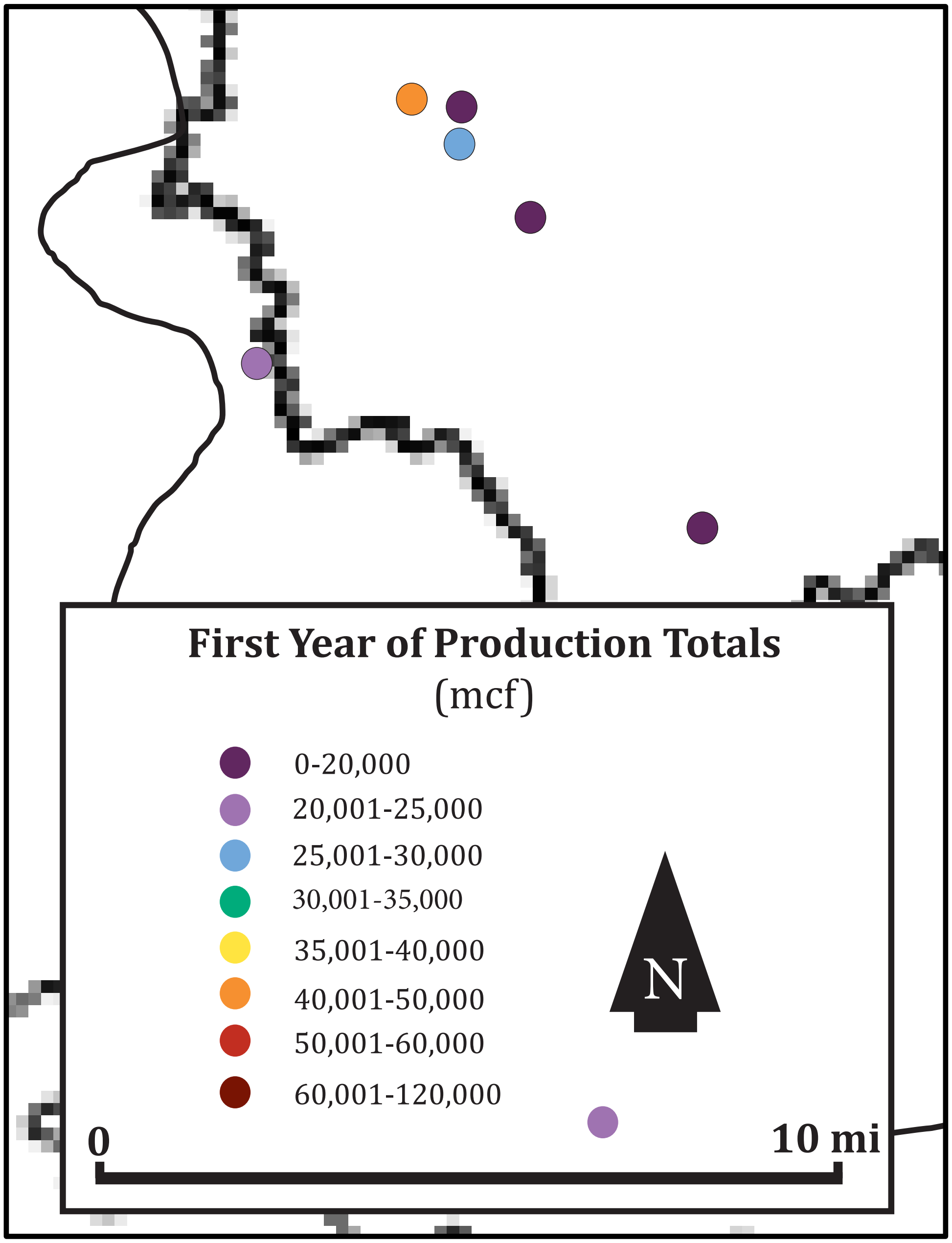


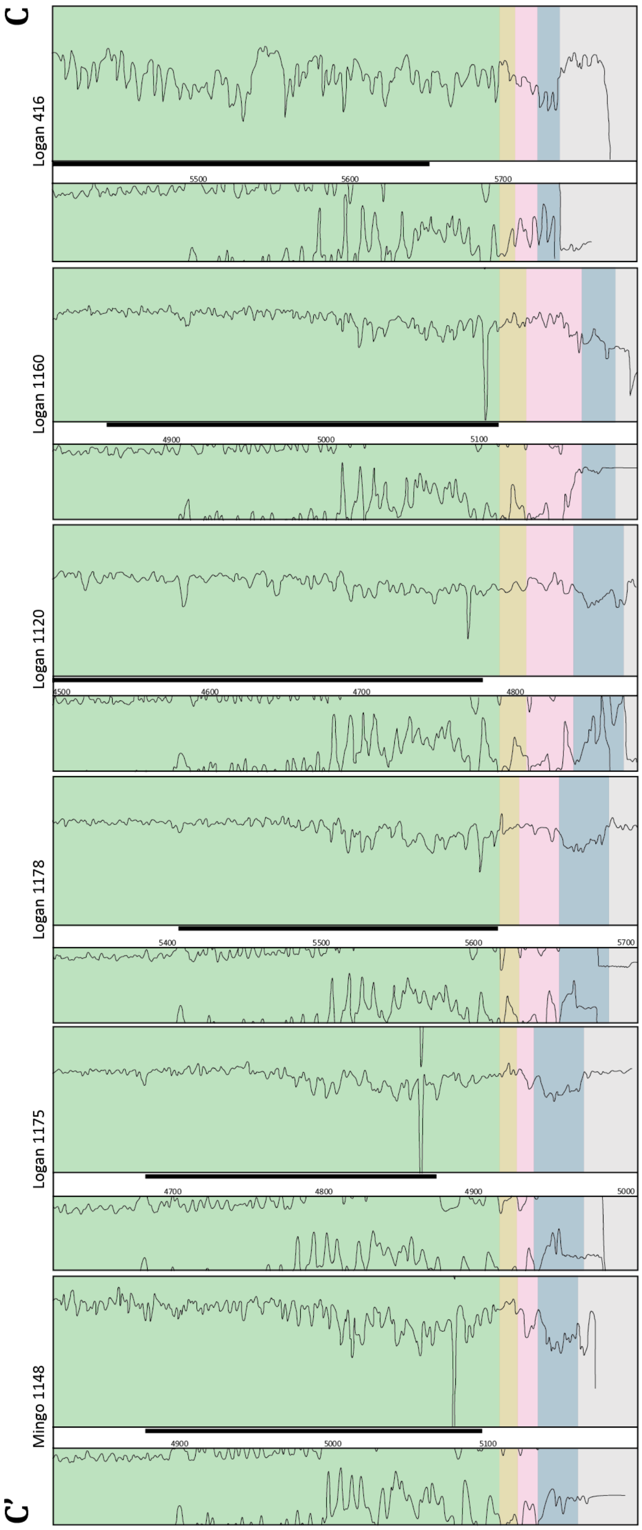
Figure 40: Map showing first year of production totals for West Falls producing wells. The thin black line running through the middle is the Marcellus Shale zero isopach line.

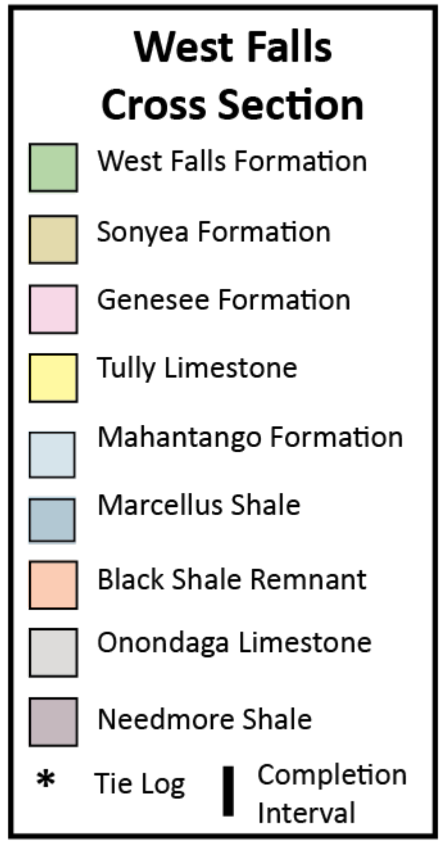
completion interval is significantly thicker compared to the other two categories; it ranges from 193-379 feet with an average of 260 feet. The well with the most production is in the northwest and has a production total of 45,285 mcf. The well with the lowest production totals produced only 2,182 mcf in the first year. Overall average first year of production is only 21,796 mcf and the median is 20,234 mcf.

The West Falls production interval cross-section runs through west-central Logan County to east-central Mingo County, but does not cross the Marcellus Shale zero isopach line (Fig. 41). The base of the West Falls Formation is used as the datum for the cross section. The transect passes through all six wells in this category. This section also includes the top of the Onondaga Limestone through the West Falls Formation. Depth to the base of the Rhinestreet ranges from 4,790-5,698 feet with an average depth of 5,270 feet. The deepest well is also the easternmost well in the southeast corner of the region (API: 4704500416) and the shallowest wells are farther to the west. Depth to the top of the Marcellus Shale has a range of 886 feet, from 4,838-5,724 feet. The average depth to the top of the Marcellus is 5,242 feet. Thickness of the Marcellus Shale varies from 16-26 feet with an average thickness of 25 feet. Thickness generally increases to the west.

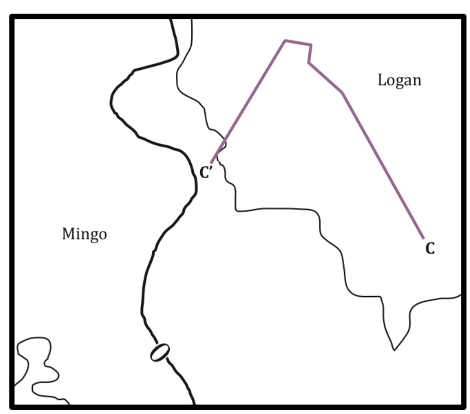
RHINESTREET SHALE PLUS BLACK SHALE REMNANT PRODUCTION

Four wells located in northeastern Mingo County in Crum-Kermit field produce from an interval that contains both the Rhinestreet Shale and the "Marcellus Shale," which actually turns out to be the black shale remnant (Fig. 42). This interpretation is based on the wells' location outside of the zero isopach line and on the readings from the gamma-ray logs. No wells produce





Figures 41: Cross section of West Falls producing wells in Magnolia Field. The base of the West Falls Formation is used as the datum in this cross section.



from only the black shale remnant. This category also involves multiple formations, so the average production interval thickness is 190 feet, a thicker value than expected. The average first year of production from all Rhinestreet and black shale remnant-producing wells is 21,870 mcf and the median value is 22,278 mcf. Overall, the range in production values is very low, at about 4,000 mcf. In fact, the lowest production is 19,431 mcf in 2008 from the central well (API: 4704501879). The highest producing well (API: 4705901792) is located just south of the lowest producing well and produced 23,493 mcf in 2006. This is the youngest category of wells, where the average initial year of production 2008.

The three northwestern-most logs are used for the cross section that shows production from the black shale remnant through the Rhinestreet Shale interval (Fig. 43). All wells are

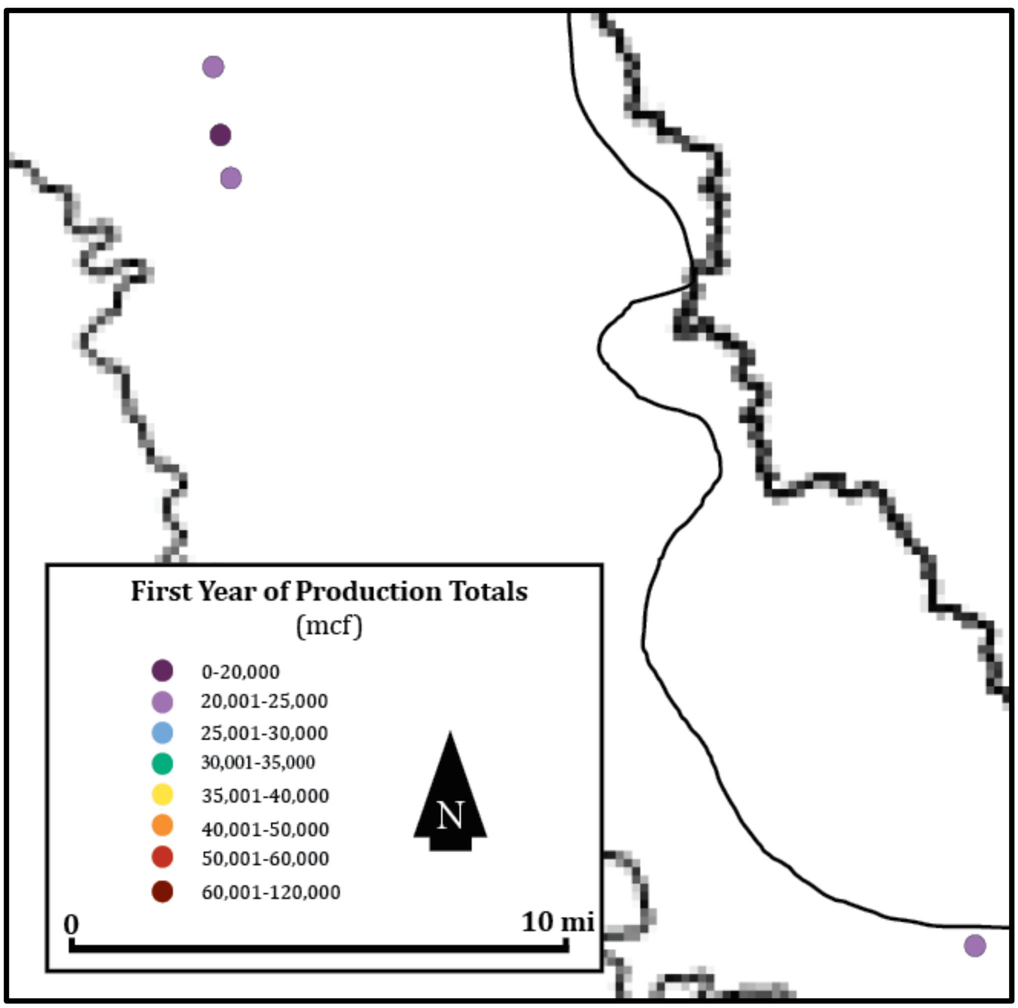
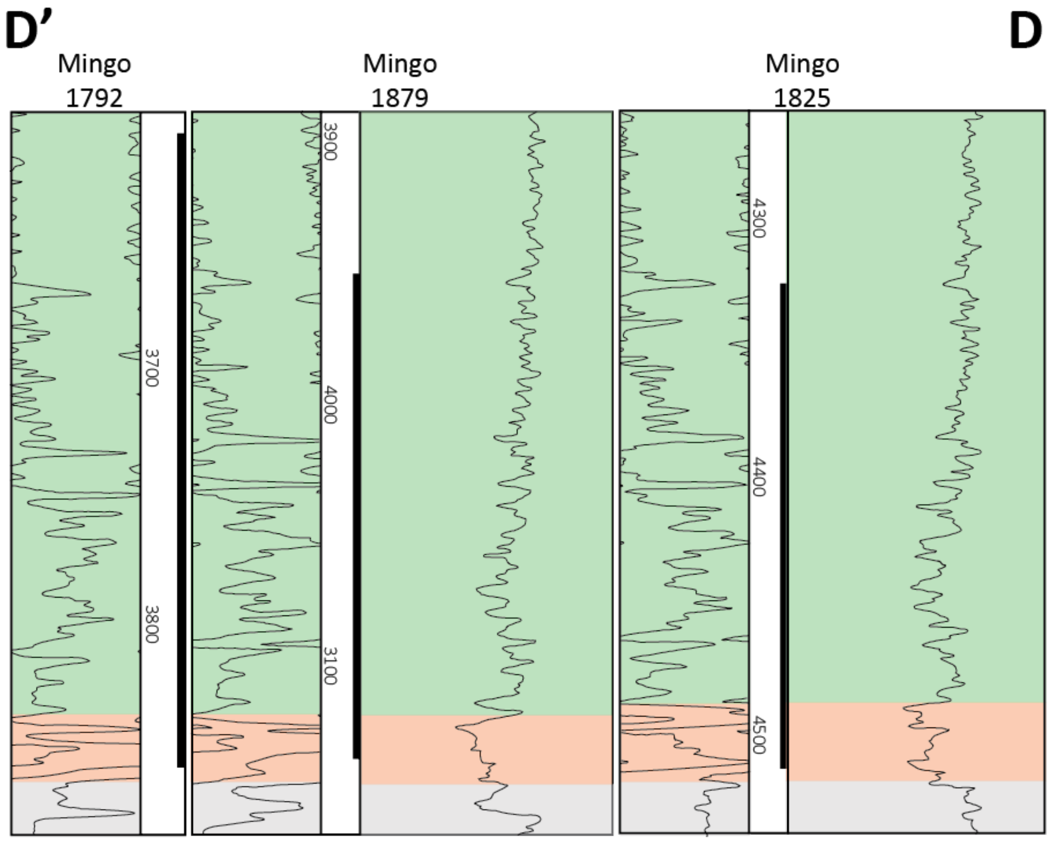
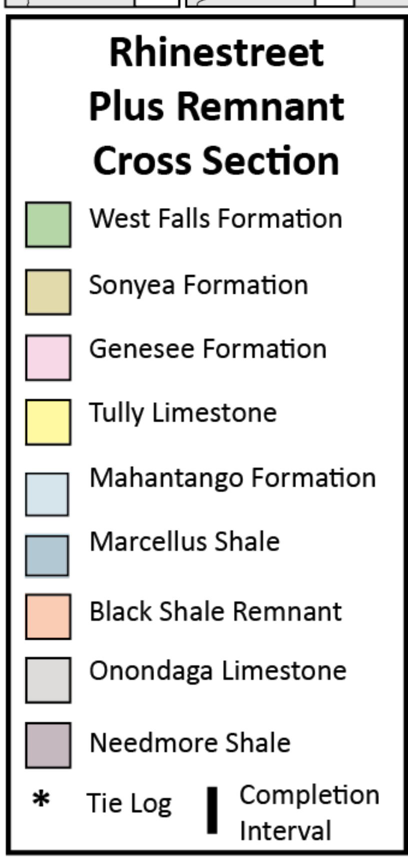
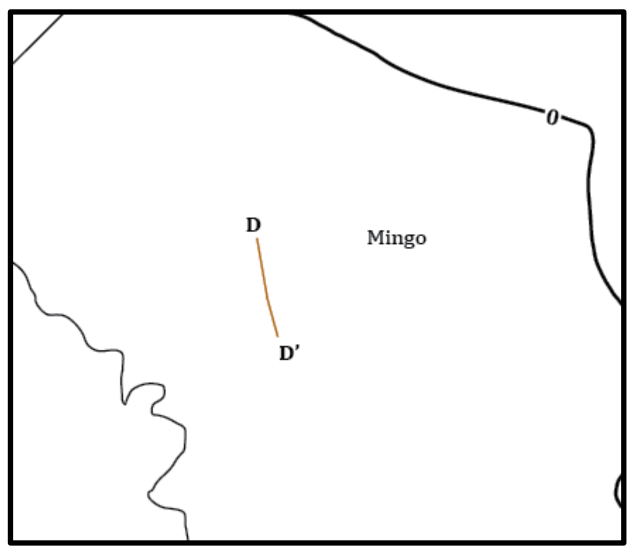


Figure 42: Map showing first year of production totals for wells that produce from both the







Figures 43: Cross section for the Rhinestreet Shale and the black shale remnant.

outside of the Marcellus boundary. The top of the black shale remnant is used for the cross section datum. The top of the Onondaga Limestone, the black shale remnant and the Rhinestreet Shale are the only formations present in this cross section. Depth to the top of the remnant ranges from 3,834-4,487 feet and averages 4,146 feet. The remnant is deepest (4,487 feet) in the northernmost well (API: 4705901825). Overall, depth decreases to the south. The difference in thickness of the remnant is 12 feet and the thickness range is from 18-30 feet. Average black shale remnant thickness is 24.6 feet. The one southeastern-most well that is excluded from the cross-section (API: 4705902137) contains a 10-foot trace of the black shale remnant. This is the thinnest evidence of the remnant in this category.

CHAPTER FIVE: DISCUSSION

MARCELLUS SHALE ZERO ISOPACH

The creation of cross-sections and maps enabled the characterization of the unconformity within the study area and clearly shows the location of the edge of the Marcellus Shale in the subsurface. In cross section 1 (Fig. 22), the overlying units truncated the Marcellus in southern Lincoln County. Cross section 2 (Fig. 23) showed that the Marcellus ended in Logan County, right before the border with Mingo County. Cross section 3 (Fig. 24) revealed the transition from Marcellus Shale in central Wyoming County to the black shale remnant in the southwest part of the cross section. Although cross section 4 (Fig. 25) had a different orientation than the previous sections, it still showed the edge of the Marcellus in mid-Putnam County. In cross section 5 (Fig. 26) we saw the edge of the Marcellus in western Logan County.

The Marcellus was less prevalent in the northwest. It was almost completely absent in Mason and Cabell Counties. Certain structural features (as seen in Fig. 7) may have influenced the deposition of the Marcellus Shale (Fig. 44). The anticline in southeastern McDowell County could have been responsible for the portion of 1-10 foot Marcellus thickness in that area, as thicker portions would accumulate on either side of the limb. The wide region of the 20-29 foot thickness interval in Kanawha County with thicker sediments and the adjacent topographic low in Fayette County are probably related to the reactivation via inversion of the East-Margin Fault. Similar signs of structural influence are seen in other locations, such as the thinning of sediments in the area between the East-Margin Fault and the slightly northern interior fault. There is little to no correlation between the structure of the Onondaga Limestone and the depositional pattern of the Marcellus Shale because the Onondaga structures are Alleghenian and came after deposition of the Marcellus Shale.

The Marcellus Shale and overlying units were removed by an unconformity during the Middle Devonian. This study hypothesized that the edge of the Marcellus Shale, where it was completely removed, is located somewhat west of the currently plotted zero isopach line from the WVGES. Combining the cross section results with the mapping results showed that the unconformity removed over 80 feet of the Marcellus Shale across the study area, and that the edge of the Marcellus occurs to the west of the previously mapped isopach line. The results supported the hypothesis.

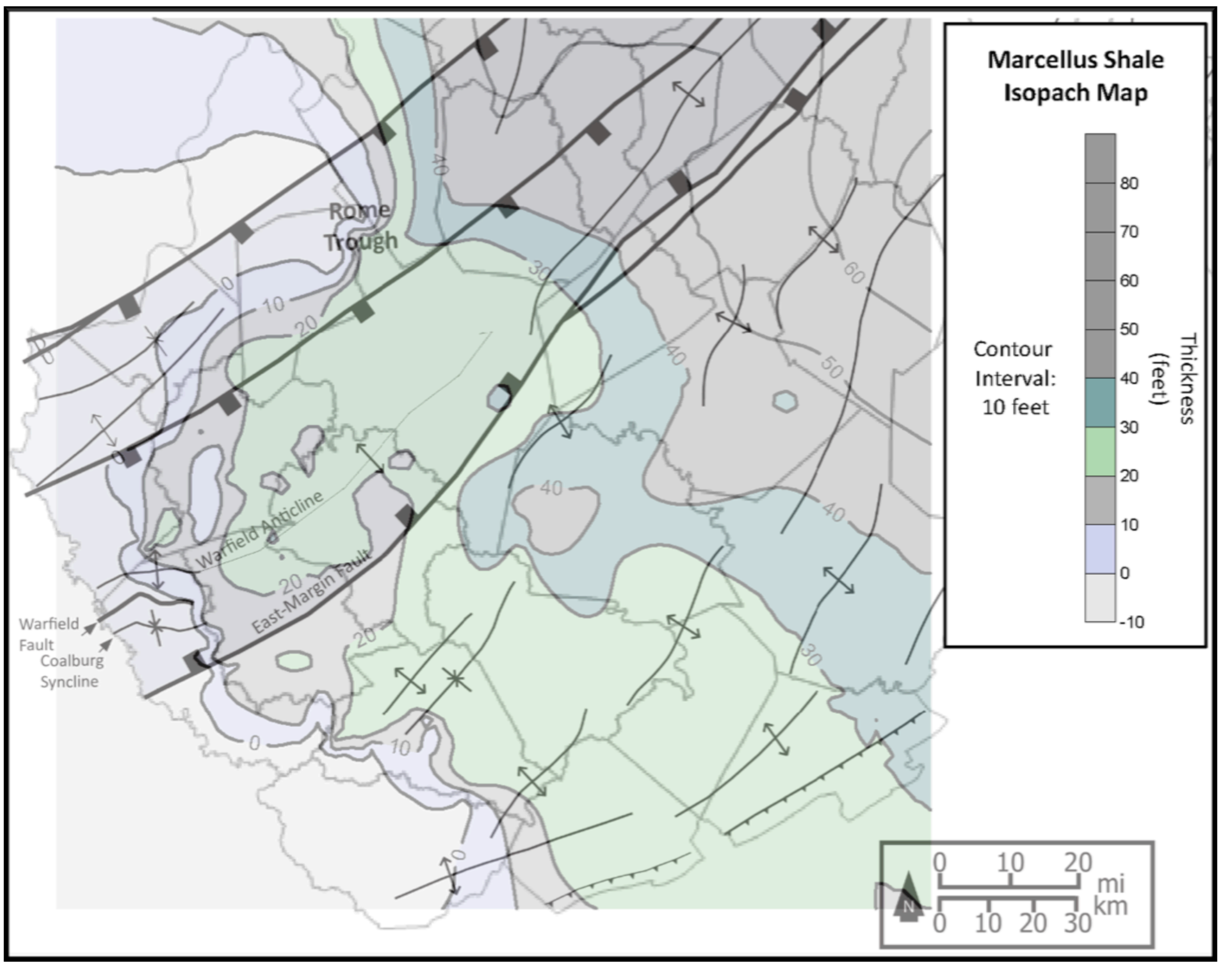


Figure 44: Marcellus Shale isopach map superimposed onto the structure map from Figure 7.

The isopach map featured an interesting pattern of V-shapes in the contour lines in northern Putnam County, continuing through Jackson and Roane counties to the northeast (Fig. 30). This could be representative of a large scale paleo-channel scouring out the Marcellus Shale. Following that logic, the channel would be flowing into the basin in a northeasterly direction. There appears to be some correlation between the thickness of the Marcellus Shale and the location of basement faults. Reactivation of movement along these faults may have influenced the areas of preservation and removal of the Marcellus Shale.

The supercrop map (Fig. 29) shows progressive onlap. The subcrop map (Fig. 30) showed the removal patterns of the units beneath the unconformity. The Mahantango Formation was almost completely removed; its western-most current extent is in east-central Nicholas County and eastern Summers County. The Marcellus was the most prevalent sub-unconformity formation, because it remained in most of the southern region of the state. Complete removal of the Marcellus in the west and partial removal in the east are evidence of the previously discussed correlation between low subsidence rates and increase in hiatus (Christie-Blick, 1991).

The isopach map of the interval between the base of the West Falls Formation and the unconformity and the corresponding cross section (Figs. 31 and 32) serve as a proxy for the depositional surface on which post-Tully sediments were deposited. The surface was a broad platform that underwent extensive erosion. Any topographic irregularities associated with the reactivation of the bounding faults of the Rome Trough appear to have been beveled and subsequent deposition does not appear to be affected by these structures.

The zero isopach line represents the complete erosion of the Marcellus Shale. This line might represent the local shelf of the Appalachian Basin in what is now southern West Virginia (Weijermars, 1997). This erosion was subsequently followed by a transgressive period in which onlapping of the overlying units took place. The black shale remnant could easily be mistaken as the Marcellus Shale, but the gamma-ray signatures of the two are different. The Marcellus signature is typically "stronger," more condensed, thicker, and greater than the remnant signature (Fig. 45). The density signature of the Marcellus is also higher overall. This remnant is interpreted as a thin shelf, or nearshore, deposit that occurred just before the onlapping.

The formation process of the black shale remnant has two possible interpretations. The

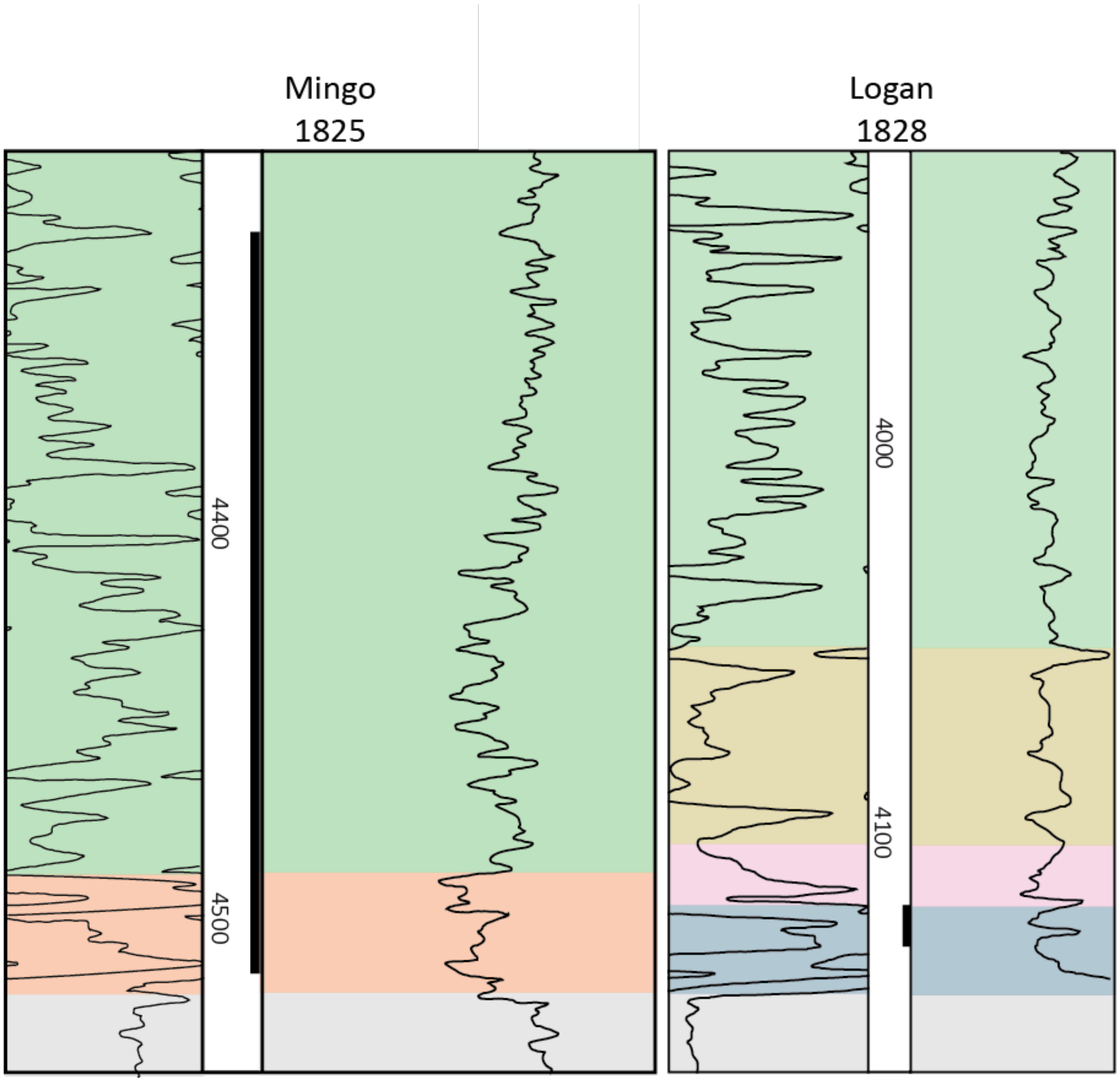


Figure 45: Comparison of gamma and density logs of the Marcellus Shale (right) and the black shale remnant (left).

first scenario occurred after deposition of the Marcellus Shale, when an unconformity removed a portion of the Hamilton Group (Fig. 46). This removal was followed by onlapping of the overlying units, resulting in progressively younger units on top of progressively older ones. The second scenario begins with deposition of the Marcellus shale within the basin (Fig 47a). Next, a relative sea level drop occurred, decreasing the depth to the Marcellus (Fig. 47b). Wave energy reworked the Marcellus and weathered the Onondaga (Fig. 47). These sediments were then deposited nearby in the form of the black shale remnant (Fig. 47d). Given the accessible data, it is not possible to unequivocally state how the remnant was formed.

Well-log data were not available in an evenly spaced pattern. This resulted in certain regions being poorly represented with a loose interpretation of the subsurface as the values of these regions had to be interpolated from surrounding points.

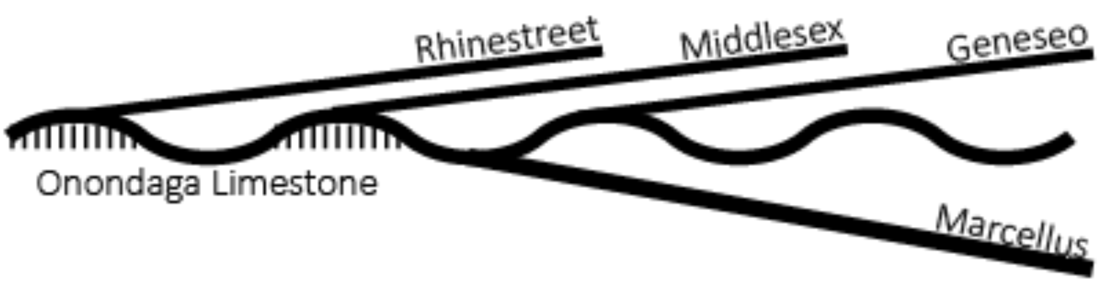


Figure 46: Sketch of the first scenario showing the origin of the Black Shale Remnant

WELL PRODUCTION ANALYSIS

The analyzed values for the well production analysis were plotted in charts to view a potential pattern. The first graph, completion interval thickness versus production total (Fig. 48), actually indicated that a thinner completion interval might lead to a higher production total. The cluster of values within the 0-50 foot range supports this idea. All wells that produced only

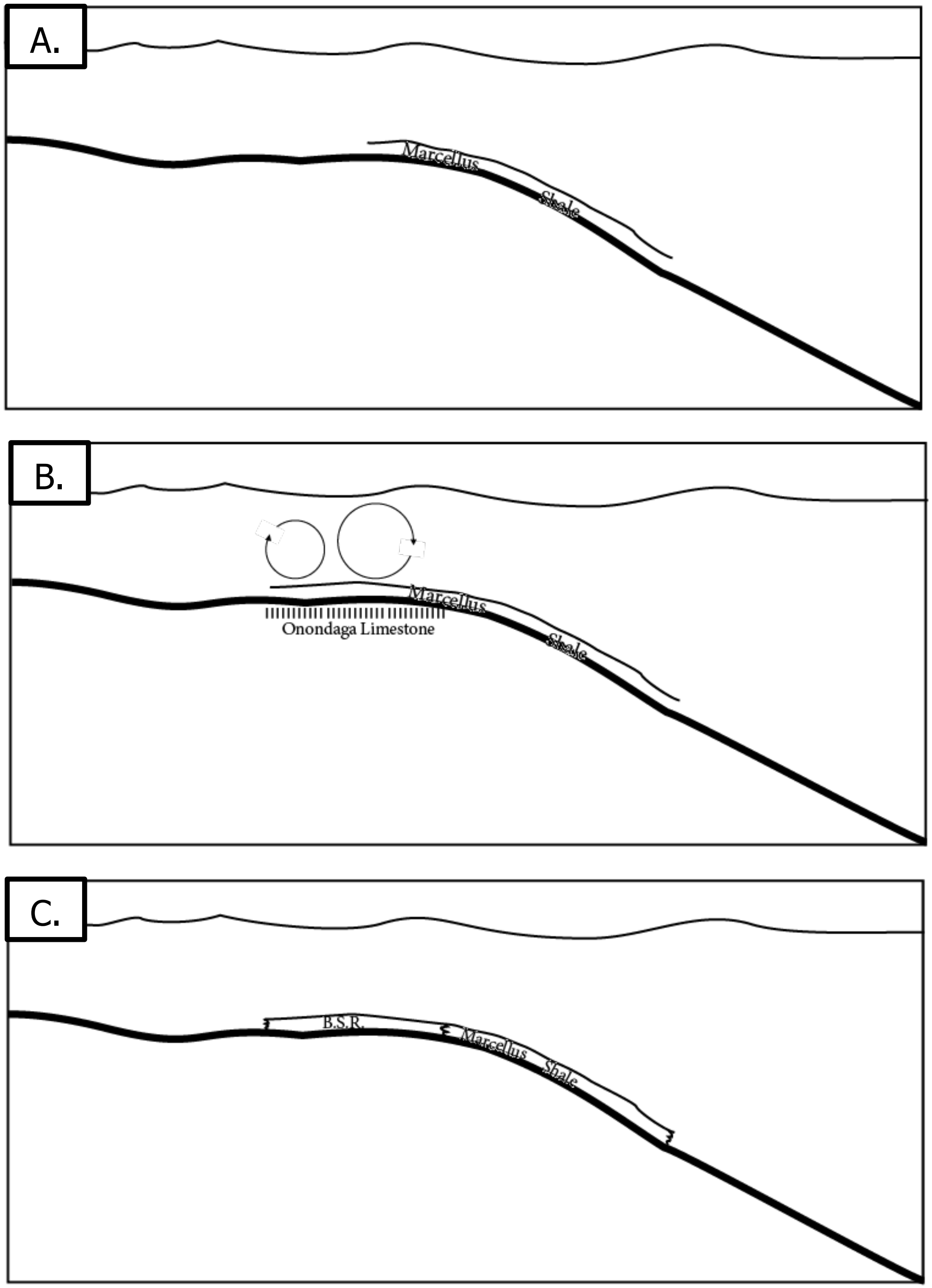
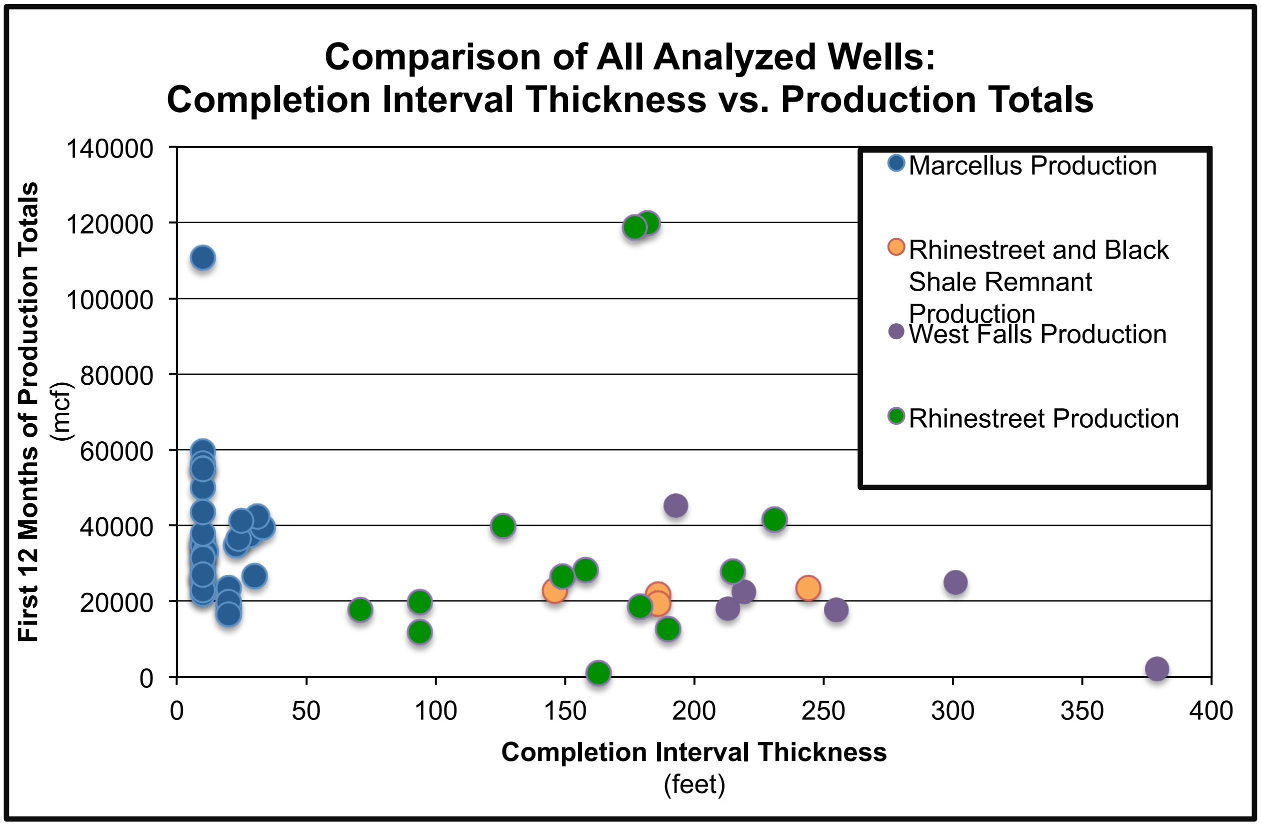


Figure 47: Scenario two showing the origin of the black shale remnant.



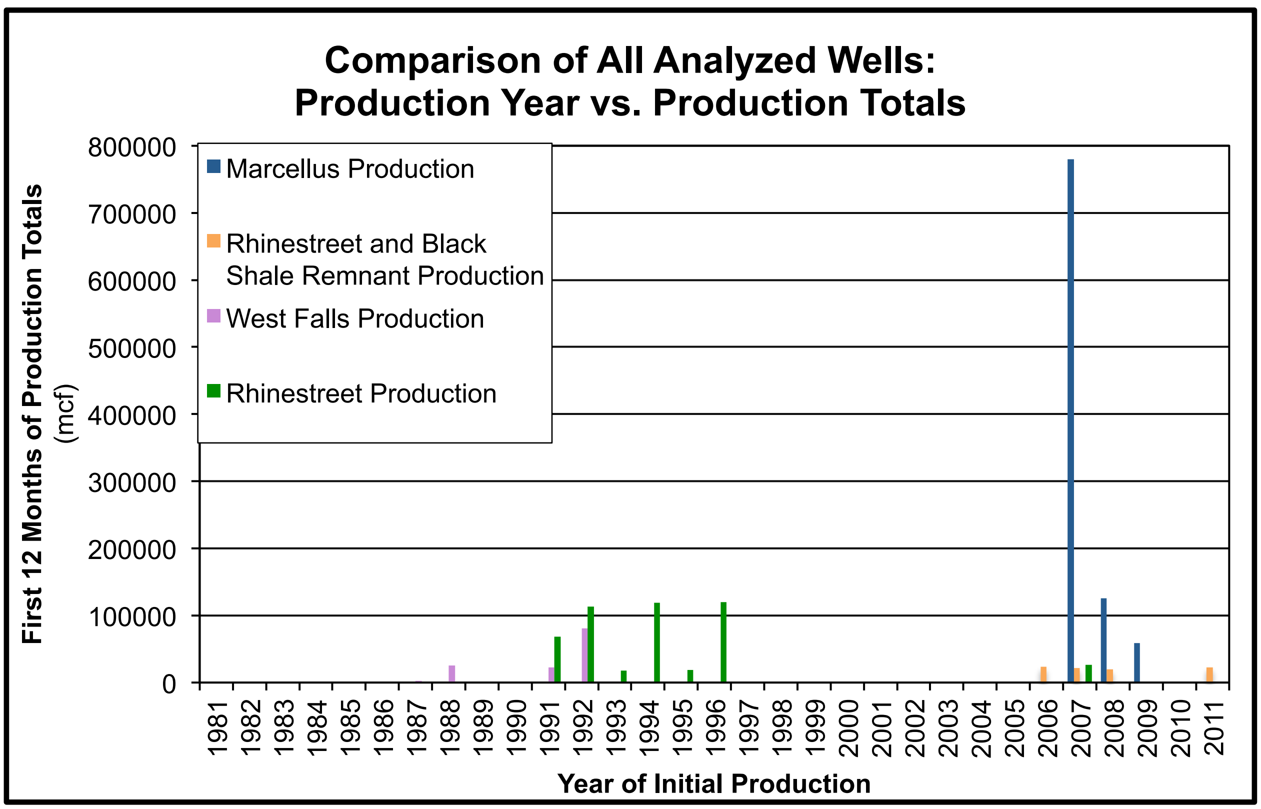


Figure 48: (top) Completion interval thickness versus first year of production totals for all analyzed wells.
Figure 49: (bottom) First year of production plotted against first year production totals.

from the Marcellus fell in this zone. The thickest completion interval was 379 feet (API: 4704500416) from the West Falls producing completion interval, and at 2,182 mcf, this well had the second lowest reported production of all the wells. Aside from some outliers, the chart that showed the initial production year versus the production total for that year indicated that, in general, the later the well began production meant the higher the production total during the first year (Fig. 49). This was clear from the large cluster that accumulated between the 2005-2010 year zone. The reason behind this is the wells from the West Falls Formation, including the Rhinestreet-producing wells, were targeted in a much shallower zone and clearly did not produce near as much as the Marcellus. The most common year for new drilling was 2007, which primarily targeted the Marcellus Shale. The 1990-1996 year range was also a popular time for non-Marcellus new drilling, but total production was noticeably lower than it was in between 2005-2010. Drilling from what turned out to be the black shale remnant was originally targeted as the Marcellus Shale. The low production totals further support the idea that the black shale remnant is different from the Marcellus Shale.

The comparisons made between the different interval categories make it clear that drilling from wells within the zero isopach line that target the Marcellus Shale are key to maximum production. The results show that that are in Chapmanville Field with completion interval thicknesses of less than 30 feet are the most economically viable from which to obtain gas from the Marcellus Shale in southern West Virginia. However, drillers should actually avoid this area because the average horizontal well in northern West Virginia often produces more than 100,000 mcf in a month alone (Avary, personal communication, November 11, 2015).

The Rhinestreet-only completion intervals had first year of production averages comparable to the Marcellus-only intervals (37,241 mcf versus 36,852 mcf, respectively).

However, after taking some weight off the outliers, the median of the Rhinestreet was only 26,514 mcf and the median of the Marcellus was 34,731 mcf. These “true” production values further validate the efficiency of the Marcellus Shale.

The first year of production averages showed that the completion interval that contained the Rhinestreet Shale and the black shale remnant was the least productive category. The explanation for this is understandable as the remnant is not Marcellus Shale but thin black shale deposited on the featheredge of onlapping Upper Devonian shales. The West Falls-only production average was also extremely low. Future drilling should actively avoid targeting these regions.

CHAPTER SIX: SUMMARY

1. Recent drilling and the addition of new data are used to map and better understand the Marcellus Shale zero isopach line. Both the isopach map and the cross sections that were constructed for this study show the nature of the Marcellus Shale and surrounding units in the subsurface of southern West Virginia. The overlying units truncated the Marcellus farther west than the previously mapped location.

2. The zero isopach line of the Middle Devonian Marcellus Shale might represent the shelf of the Appalachian Basin in what is now southern West Virginia. The erosion that took place was followed by the onlapping of the Upper Devonian Shales. Just before the onlapping, the black shale remnant was deposited on the featheredge of the shales. This remnant is not the Marcellus Shale, but is instead interpreted as a thin shelf, or nearshore, deposit.

3. The black shale remnant featheredge only slightly extends past the Marcellus in certain areas. This was apparent in the third cross section, which runs from the far northeast to the southwest, where the Marcellus ends and the remnant begins in southern Wyoming County. The northwest-southeast trending cross section 4 also features the remnant in mid-Putnam County. Cross section 5 runs through the eastern region of Lincoln County, which shows the remnant throughout. The well production analysis shows that the black shale remnant is also found farther past the isopach line in Mingo County.

4. In order to evaluate production, four different completion interval formations are compared in the well production analysis: the Marcellus Shale, the Rhinestreet Shale, the West Falls Formation as a whole, and the Rhinestreet Shale plus the black shale remnant. These are analyzed based on total production of natural gas during the first year of drilling, year of initial production, well spacing (particularly location with respect to the Marcellus Shale zero isopach line), and completion interval thickness. The greatest potential for successful and economic drilling in southern West Virginia is from the 30-foot or less Marcellus Shale completion interval in Chapmanville Field in Logan County.

CHAPTER SEVEN: REFERENCES

Abbott, K. C., and Boyd II, J. T., 1997, Money for nothing- Shut-in royalty clauses in oil and gas leases. Energy and Mineral Law Foundation. Eastern Mineral Law Institute: 16(15).

Allaby, A., and Allaby, M., 1999, Structural contour map, A Dictionary of Earth Sciences, Encyclopedia.com/; http://www.encyclopedia.com/doc/1O13-structuralcontourmap.html (accessed September 2015).

Anderson, M. P. and Woessner, W. W., 1992, Applied groundwater modeling: simulation of flow and advective transport: San Diego, Academic Press, Inc., 381 p.

Atlas of Major Appalachian Gas Plays, J. B. Roen and B. J. Walker, eds., W.V. Geological and Economic Survey Report: V-25, p. 93-99.

Avary, K. L., and Lewis, J. E., 2008, New interest in cores taken thirty years ago: the Devonian Marcellus Shale in northern West Virginia, AAPG: Eastern Section Meeting. Poster.

Avary, K. L., 2009a, Identifying constraints on increased natural gas production in southern West Virginia, West Virginia Department of Commerce. Report: http://www.wvcommerce.org/App_Media/assets/doc/energy/reports/Final-report-Constraints-on-NG-Prod-Pipelines.pdf (accessed June 2015).

Avary, K. L., 2009b, Overview of Gas and Oil Resources in West Virginia, West Virginia Geological and Economic Survey: http://www.wvgs.wvnet.edu/www/datastat/ WVOilGasResourcesGeology Marcellus_WVSAF02052009.pdf.

Bear, J., 1972, Dynamics of fluids in porous media: New York, American Elsevier Publishing Company, Inc., 800 p.

Blakey, R. C., 2005, Regional paleogeography – Paleogeography and geologic evolution of North America: Arizona, USA, Colorado Plateau Geosystems, http://jan.ucc.nau.edu/~rcb7/nam.html (accessed September 2014).

Bruner, K. R., and Smosna, R., 2011, A Comparative Study of the Mississippian Barnett Shale, Fort Worth Basin, and Devonian Marcellus Shale, Appalachian Basin, U. S. Department of Energy National Energy Technology Laboratory report 1478, 108 p.:

http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/publications/brochures/DOE-NETL-2011-1478-Marcellus-Barnett.pdf.

Christie-Blick, N., 1991, Onlap, offlap, and the origin of unconformity-bounded depositional sequences: Marine Geology, 97: 35-56.

Colton, G. W., 1970, The Appalachian Basin – Its Depositional Sequences and Their Geologic Relationships, *in* Fisher, G. W., Pettijohn, F. J., Reed Jr., J.C., and Weaver, K. N., eds., Studies on Appalachian Geology: Central and Southern, Interscience Publishers. 5-47.

Coolen, J. M., 2003, Coal mining along the Warfield Fault, Mingo County, West Virginia: a tale of ups and downs: International Journal of Coal Geology, 54: 193-207.

Dubrule, O., 1984, Comparing Splines and Kriging: Computers and Geosciences. 10(2-3): 327-338.

de Witt, W., Jr., and Colton, G. W., 1978, Physical Stratigraphy of the Genesee Formation (Devonian) in Western and Central New York: United States Geological Survey Professional Paper 1032-A, 28 p.

de Witt, W., Jr., Roen, J. B., and Wallace, L.G., 1993, Stratigraphy of Devonian black shales and associated rocks in the Appalachian Basin, *in* Roen, J. B. and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America, United States Geological Society of America Bulletin 1909, 417 p.

Demaison, G., 1991, Anoxia vs. productivity: what controls the formation of organic-carbon-rich sediments and sedimentary rocks?: Discussion: American Association of Petroleum Geologists Bulletin, 75(3): 499.

Dennison, J. M., 1960, Stratigraphy of Devonian Onesquethaw Stage in West Virginia, Virginia, and Maryland [Ph.D. dissertation]: Madison, University of Wisconsin, 593 p.

Donaldson, A. C., and Skoff, D., 1985, Lithostratigraphic Analysis of Huntersville Chert of Central Appalachians: American Association of Petroleum Geologitsts Bulletin, 69(9): 1435.

Duffield, S. L. and Warshauer, S. M., 1981, Upper Devonian (Frasnian) conodonts and ostracodes from the subsurface of western West Virginia: Journal of Petrology, 55(1): 72-83.

Ehrenberg, S.N., and Nadeau, P.H., 2005, Sandstone vs. carbonate petroleum reservoirs: A global perspective on porosity-depth and porosity-permeability relationships: American Association of Petroleum Geologists Bulletin. 89(4): 435-445.

EIA, 2015, Natural Gas Weekly Update: U. S. Energy Information Administration: http://www.eia.gov/naturalgas/weekly/ (accessed July 2015).

Ettensohn, F. R. and Barron, L. S., 1981, Depositional model for the Devonian-Mississippian black-shale sequence of North America: A tectono-climatic approach: U. S. Department of Energy Open-File Report 12040-2, 85 p.: http://www.netl.doe.gov/kmd/cds/disk7/disk1/EGS%5CDepositional%20Model%20for%20the%20Devonian-Mississippian%20Black-Shal.pdf.

Ettensohn, F. R., 1985a, The Catskill Delta complex and the Acadian Orogeny: A model, *in* Woodrow, D.W., Sevon, W.D., eds., The Catskill Delta: Geological Society of America, Special Paper 201, p. 39-49.

Ettensohn, F.R., 1985b, Controls on development of Catskill Delta basin facies, *in* Woodrow, D.W., Sevon, W.D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 65-77.

Ettensohn, F. R., 1997, Assembly and dispersal of Pangea: Large-scale tectonic effects on coeval deposition of North American, marine, epicontinental, black shales: Journal of Dynamics, 24(3/4): 287-309.

Ettensohn, F. R., 2004, Modeling the nature and development of major Paleozoic clastic wedges in the Appalachian Basin, USA: Journal of Geodynamics, 37: 657-681.

Faill, R. T., 1985, The Acadian Orogeny and the Catskill Delta, *in* Woodrow, D. L. and Sevon, W. D., eds., The Catskill Delta, p. 15-38.

Feldman, H. R., 1978, Brachiopods and Community Ecology of the Onondaga Limestone [Thesis]: New Brunswick, New Jersey, Rutgers University, 406 p.

Feldman, H. R., 1980, Level-bottom brachiopod communities in the Middle Devonian of New York: Lethaia, 13(1): 27-46.

Gao, D., Shumaker, R. C., and Wilson, T. H., 2000, Along-axis segmentation and growth history of the Rome Trough in the central Appalachian Basin: American Association of Petroleum Geologists Bulletin, 84(1): 75-99.

Greb, S. F., Eble, C. F., and Hower, J. C., 2005, Subtle structural influences on coal thickness and distribution: examples from the Lower Broas-Stockton coal (Middle Pennsylvanian), Eastern Kentucky Coal Field, USA, *in* Warwick, P. D., ed., Coal systems analysis: Geological Society of America Special Paper 387: 31-50.

Hanson, L. S., and Bradley, D. C., 1989, Sedimentary facies and tectonic interpretation of the Lower Devonian Carrabassett Formation, north-central Maine, *in* Tucker, R. D., and Marvinney, R. G., eds., Studies in Maine geology: structure and stratigraphy, Maine Geological Survey, 2: 101-126.

Harris, A. G., Stamm, N.R., Weary, D.J., Repetski, J.E., Stamm, R.G., and Parker, R.A., 1994, Conodont color alteration index (CAI) map and conodont-based age determinations for the Winchester 30'x60' quadrangle and adjacent area, Vierginia, West Virginia, and Maryland: U.S. Geological Survey Miscellaneous Field Studies Map MF-2239, 1 sheet. 40 p., scale 1:100,000.

Haught, O. L., 1963, Oil and Gas Fields in West Virginia: West Virginia Geological and Economic Survey Educational Series Bulletin, 30 p.

Holahan, R. and Arnold, G. 2013. An institutional theory of hydraulic fracturing policy. Ecological Economics 94: 127-134.

Hubbert, M.K., and Willis, D.G., 1972, Mechanics of hydraulic fracturing, *in* Cook, T.D., ed., Underground waste management and environmental implications: American Association of Petroleum Geologists, 18: 239-257.

Petroleum Database Management System (PDMS), "Completion Interval": Indiana Geological Survey: http://igs.indiana.edu/pdms/help/Completion_Interval.htm (accessed July 2015).

Inners, J. D., 1975, Stratigraphy and Paleontology of the Onesquethaw Stage in Pennsylvania and Adjacent States [Unpublished Ph.D. dissertation]: University of Massachusetts. 770 p.

Johnson, J. G., 1971, Timing and coordination of organic, epeirogenic, and eustatic events: Geological Society of America Bulletin 82: 3263-3298.

Journel, A. G., and Huijbregts, C.J., 1978, Mining Geostatistics: New York, Academic Press, 600 p.

King, H., Directional and horizontal drilling in oil and gas wells, Geology.com: http://geology.com/articles/horizontal-drilling/ (accessed May 2015).

King, H., 2015, Marcellus Shale: Appalachian Basin natural gas play, Geology.com: http://geology.com/articles/marcellus-shale.shtml (accessed May 2015).

Kitanidis, P. K., 1997, Introduction to Geostatistics: Applications in Hydrogeology, Cambridge University Press, 272 p.

Kostelnik, J., and Laughrey, C., 2008, An organic geochemistry database – evaluating the Marcellus Shale and other potential petroleum source rocks in Pennsylvania: Pennsylvania Geological Survey [Presentation]. American Association of Petroleum Geologists Eastern Section Meeting: Pittsburgh, Pennsylvania: http://www.papgrocks.org/kostelnik_p.pdf.

Lee, D.S., Hermann, J.D., Elsworth, D., Kim, H.T., and Lee, H.S., 2011, A critical evaluation of unconventional gas recovery from the Marcellus Shale, northeastern United States: Journal of Civil Engineering, Korean Society of Civil Engineers, 15(4): 697-687.

Lieskovsky, J., Yan, R., and Gorgen, S., 2014, Marcellus Region production continues growth: U. S. Energy Information Administration, Today in Energy: http://www.eia.gov/todayinenergy/detail.cfm?id=17411 (accessed June 2015).

Luker, A. T., 2012, A comparison of sequence stratigraphy and mineralogical variations associated with total organic carbon in the Marcellus Formation: Washington County, Pennsylvania [Master’s thesis]: University of Houston, 134 p.

Luthi, S. M., 2001, Geological Well Logs: Their Use in Reservoir Modeling: Berlin Heidelberg, Springer Verlag, 373 p.

Macdonald, F.A., Ryan-Davis, J., Coish, R.A., Crowley, J.L. and Karabinos, P., 2014, A newly identified Gondwanan terrane in the northern Appalachian Mountains: Implications for the Taconic Orogeny and closure of the Iapetus Ocean: Geology, 42(6): 539-542.

Metz, R., 2009, Trace Fossils from the Mahantango Formation (Upper Middle Devonian) Pike County, Pennsylvania: Bulletin of the New Jersey Academy of Science, 54(2): 9-17.

Neal, D. W., 1979, Subsurface stratigraphy of the Middle and Upper Devonian clastic sequence in southern West Virginia and its relation to gas production: West Virginia Geological and Economic Survey, United States Department of Energy Contract no. EY-76-C-05-5199, 152 p.

Neal, D. W., and Price, B. K., 1986, Oil and gas report and maps of Lincoln, Logan, and Mingo Counties, West Virginia: West Virginia Geological and Economic Survey Bulletin B-41. 10 leaves of plates, 68 p.

Neuendorf, K. K. E., Mehl Jr., J. P., and Jackson, J. A., 2005, Glossary of Geology: American Geological Institute. USA. 5th ed. 800 p.

Pederson, T. F. and Calvert, S. E., 1990, Anoxia vs. Productivity: What controls the formation of organic-carbon-rich sediments and sedimentary rocks?: AAPG Bulletin, 74(4): 454-466.

Perry, C. and Wickstrom, L., 2010, The Marcellus Shale play: geology, history, and oil and gas potential in Ohio [Presentation]: Ohio Division of Natural Resources and Ohio Geological Survey: http://geosurvey.ohiodnr.gov/portals/geosurvey/Energy/Marcellus/The_Marcellus_Shale_Play_Wickstrom_and_Perry.pdf.

Phillips, W. J., 1972, Hydraulic fracturing and mineralization: Journal of the Geological Society, London, 128: 337-359.

Pirson, Sylvain J., 1963, Handbook of Well Log Analysis: New Jersey, Prentice-Hall Inc., 326 p.

Popova, O., Frye, E., and Panarelli, E., 2015, Updated geologic maps provide greater detail for Marcellus Formation: U. S. Energy Information Administration, Today in Energy: http://www.eia.gov/todayinenergy/detail.cfm?id=20612.

Potter, P. E., Maynard, J. B., and Pryor, W. A., 1980, Sedimentology of shale: New York, Springer-Verlag, 303 p.

Repetski, R. E, Ryder, R. T., Weary, D. J., Harris, A. G., and Trippi, M. H., 2014, Thermal maturity patterns (conodont color alteration index and vitrinite reflectance) in Upper Ordovician and Devonian rocks of the Appalachian Basin: A major revision of USGS Map I-917-E using new subsurface collections, *in* Rullert, L.F. and Ryder, R. T., eds., Coal and petroleum resources in the Appalachian Basin; Distribution, geologic framework, and geochemical character, U.S. Geological Survey Professional Paper 1708, 72 p.

Rodgers, J., 1970, Tectonics of the Appalachians: New York, Interscience, 271 p.

Roen, J. B., 1983, Geology of the Devonian black shales of the Appalachian Basin: Organic Geochemistry, 5(4): 241-254.

Ryder, R. T., 1987, Oil and gas resources of the Cincinnati Arch, Ohio, Indiana, Kentucky, and Teneseee: United States Geological Survey Open-File Report 97-450Y, 30 p.

Schlumberger, C., Schlumberger, M., and Leonardo, E. G., 1932, Electrical Coring: A Method of Determining Bottom Hole Data by Electrical Engineering: *Trans. AIME*, 101 pp.

Schwab, F. L., 1976, Modern and ancient sedimentary basins: Comparative accumulation rates: Geology, 4(12): 723-727.

Schwietering, J. F., 1979, Devonian shales of Ohio and their eastern and southern equivalents: U.S. Department of Energy, Morgantown Energy Technology Center METC/CR-79/2, 68 p.

Selley, R. C., 1998, Elements of Petroleum Geology 2nd ed: London, U.K., Academic Press, 470 p.

Shanmugam, G., 1988, Origin, recognition, and importance of erosional unconformities in sedimentary basins, *in* Kleinspehn, K. L., and Paola, C., eds., Frontiers in Sedimentary Geology: New Perspectives in Basin Analysis: New York, Springer-Verlag, p. 83-108.

Shumaker, R. C., 1993, Geology of the Warfield anticline and its significance in regional structure: Program and Abstracts, 24th Annual Appalachian Petroleum Geology Symposium, I. C. White Memorial Fund, Publication no. 5: 85–106.

Sorkhabi, R., 2009, Rich petroleum source rocks, Thompson, V., photographer: GEOExPro. 6(6): http://www.geoexpro.com/articles/2009/06/rich-petroleum-source-rocks.

Stark, A., 2008, Seismic methods and applications: Boca Raton, Florida, U.S.A., BrownWalker Press, 592 p.

Strecker, U., Cheng, A., Azizov, I., Morris, M., Smith, M., and Singleton, S., 2011, Potemtoa; sequence stratigraphic controls on Frac Design: An integrated 3-D seismic reservoir characterization using P-wave impedence inversion data from Marcellus Shale, Pennsylvania: American Association of Petroleum Geologists, AAPG Hedberg Conference, Austin, TX. Search and Discovery Article 90122. 3 p.

Sutton, R. G., Bowen, Z. P., and McAlester, A. L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geological Society of America Bulletin, 81: 2975-2992.

Swan, E., 2012, Structural Framework of the Appalachian Plateau of Central West Virginia [Masters Thesis]: Morgantown, West Virginia, West Virginia University, 79 p.

Thomas, W. A., 1991, The Appalachian-Ouachita rifted margin of southeastern North America: Geological Society of America Bulletin, 103: 415-431.

U.S. Gazetteer Files, 2014, United States Census Bureau: http://www.census.gov/geo/maps-data/data/gazetteer2014.html.

Ver Straeten, C., 2007, Basinwide stratigraphic synthesis and sequence stratigraphy, Upper Pragian, Emsian and Eifelian stages (Lower to Middle Devonian), Appalachian Basin, *in* Becker, R. T. and Kirchgasser, W. T., eds., Devonian Events and Correlations: Geological Society of London Special Publications, 278: 39-81.

Ver Straeten, C., Baird, G., Brett, C., Lash, G., Over, J., Karaca, C., Jordan, T., and Blood, R., 2011, The Marcellus subgroup in its type area, Finger Lakes area of New York, and beyond, *in* New York State Geological Association Field Trip Guidebook Trip A-2, Central New York Association of Professional Geologists: http://www.nysm.nysed.gov/staffpubs/docs/20398.pdf.

Wang, G., and Carr, T. R., 2013, Organic-rich Marcellus Shale lithofacies modeling and distribution pattern analysis in the Appalachian Basin: American Association of Petroleum Geologists Bulletin, 97(12): 2173-2205.

Wickstrom, L. H., Venteris, E.R., Harper, J.A., and 26 others, 2005, Characterization of geologic sequestration opportunities in the MRCSP region: Final report under DOE cooperative agreement DE-PS26-05NT42255, Ohio Geological Survey Open File Report 2005-1: 152: http://www.dnr.state.oh.us/portals/10/pdf/OpenFileReports/OFR_2005-1.pdf.

Williams, H., and Hatcher, R. D., Jr., 1982, Suspect terranes and accretionary history of the Appalachian orogeny: Geology, 10: 530-536.

Weijermars, R., 1997, Structural Geology and Map Interpretation: Amsterdam, Netherlands, Alboran Science Publishing, 360 p.

Werne, J. P., Sageman, B. B., Lyons, T. W., and Hollander, D. J., 2002, An integrated assessment of a "type euxinic" deposit: evidence for multiple controls on black shale deposition in the Middle Devonian Oatka Creek Formation: American Journal of Science, 302(2): 110-145.

West Virginia Geological and Economic Survey (WVGES), 2015, Marcellus Shale in West Virginia. WVGES Map, 1 sheet, Scale 1:2,000,000: http://www.wvgs.wvnet.edu/www/datastat/Marcellus/Downloads/WVMarcellusPageSized_20150625.pdf.

Wrightstone, G., 2009, Marcellus Shale – Geologic Controls on Production: American Association of Petroleum Geologists Search and Discovery Article no. 10206.

APPENDIX A: API COUNTY CODES FOR WEST VIRGINIA

County

Code	Name
001	Barbour
003	Berkeley
005	Boone
007	Braxton
009	Brooke
011	Cabell
013	Calhoun
015	Clay
017	Doddridge
019	Fayette
021	Gilmer
023	Grant
025	Greenbrier
027	Hampshire
029	Hancock
031	Hardy
033	Harrison
035	Jackson
037	Jefferson
039	Kanawha
041	Lewis
043	Lincoln
045	Logan
047	McDowell
049	Marion
051	Marshall
053	Mason
055	Mercer

County (cont.)

Code	Name
057	Mineral
059	Mingo
061	Monongalia
063	Monroe
065	Morgan
067	Nicholas
069	Ohio
071	Pendleton
073	Pleasants
075	Pocahontas
077	Preston
079	Putnam
081	Raleigh
083	Randolph
085	Ritchie
087	Roane
089	Summers
091	Taylor
093	Tucker
095	Tyler
097	Upshur
099	Wayne
101	Webster
103	Wetzel
105	Wirt
107	Wood
109	Wyoming

APPENDIX B: ISOPACH DATA

Formation thicknesses for all logs for all analyzed lithological units. Blank cells indicate an absence of data. UTMs were displayed because they were used for plotting locations in Surfer.

API	UTME	UTMN	Sonyea Thickness (feet)	Genesee Thickness (feet)	Tully Thickness (feet)	Mahantango Thickness (feet)	Marcellus Shale Thickness (feet)	Black Shale Remnant Thickness (feet)
4700500885	434341.30	4201000.30	72	23	0	0	21	
4700502123	422292.30	4201395.30	50	17	0	0	21	
4700502120	424814.60	4203661.50	54	22	0	0	26	
4700502168	424354.60	4204422.20	54	22	0	0	26	
4700502165	423872.40	4204491.00	54	22	0	0	28	
4700502166	423900.40	4204024.00	55	24	0	0	27	
4700502167	424121.70	4203571.30	82	22	0	0	28	
4700502218	423241.30	4204110.60	63	12	0	0	26	
4700502148	422834.70	4204307.60	50	21	0	0	27	
4700502146	422876.30	4203599.00	51	23	0	0	25	
4700502147	422541.30	4203924.10	48	24	0	0	21	
4700502157	419344.60	4203552.60	71	17	0	0	34	
4700502102	419474.10	4205257.40	68	22	0	0	29	
4700502185	415675.20	4204201.10	39	8	0	0	30	
4700502244	415535.80	4204733.70	38	7	0	0	31	
4700502198	416073.40	4204792.60	37	8	0	0	38	
4700501984	416420.20	4205690.40	36	9	0	0	32	
4700502193	417182.70	4206298.50	40	12	0	0	32	
4700502195	417847.00	4205849.90	42	22	0	0	26	
4700502184	418058.00	4205287.50	41	24	0	0	21	
4700502183	418351.80	4205703.10	40	18	0	0	23	
4700502119	420773.30	4207614.90	50	21	0	0	25	
4700502265	416021.80	4214265.60	32	14	0	0	26	
4700502263	416271.60	4215116.00	54	28	0	0	13	
4700502266	416004.10	4215734.70	57	15	0	0	20	
4700502248	421866.30	4216138.10	66	19	0	0	21	
4700502253	422268.40	4217700.60	70	16	0	0	20	
4700500134	416993.70	4219796.70	52	17	0	0	18	
4700500075	417857.70	4220902.80	31	10	0	0	31	
4700502155	423001.10	4221398.90	69	17	0	0	19	

4700502187	424463.10	4221933.30	42	18	0	0	19	
4700502025	426463.50	4224248.70	76	24	0	0	23	
4700502197	443099.40	4227982.40	127	13	0	0	22	
4700502318	447795.90	4219737.80	139	31	0	0	26	
4700502250	447105.20	4220773.10	132	30	0	0	18	
4700502209	440426.80	4220465.10	116	26	0	0	20	
4700502219	445753.10	4215595.40	136	19	0	0	26	
4700502231	445408.10	4214483.00	80	21	0	0	17	
4700502271	445888.40	4214077.40	88	22	0	0	18	
4700502222	444543.3	4215313.9	121	26	0	0	20	
4700501419	436223.3	4221590.9	66	20	0	0	21	
4701100549	390500.6	4236143.3	0	0	0	0	0	46
4701100558	391459.6	4239933.8	0	0	0	0	0	44
4701100561	389996.5	4240507.8	0	0	0	0	0	47
4701100719	384246.5	4246127.7	0	0	0	0	0	60
4701100704	372963.9	4253578.3	0	0	0	0	0	51
4701100699	379404.4	4252573.1	0	0	0	0	0	52
4701100524	383015.1	4253973.4	0	0	0	0	0	47
4701100532	384603.5	4254739.2	0	0	0	0	0	60
4701100534	388602.6	4256469.6	0	0	0	0	0	62
4701100700	389335.2	4262978.5	0	0	0	0	0	55
4701100537	389905.5	4264702.6	0	0	0	0	0	62
4701100694	393459.3	4267050.2	0	0	0	0	0	58
4701100976	399320.3	4256537.7	0	0	0	0	0	54
4701100971	404421.5	4262005.7	0	0	0	0	0	56
4701900106	502599.1	4199016.4	140	60	0	0	25	
4701900176	491475.6	4201031.2	66	41	0	0	31	
4701900123	505937.4	4217960.6	174	186	0	0	45	
4701900241	501318.7	4218441.3	155	161	0	0	43	
4701900556	493259.6	4224632.2	197	108	0	0	31	
4701900572	491901.2	4213484.1	170	120	0	0	38	
4701900512	486011.6	4215282.5	129	114	0	0	42	
4701900490	484022.9	4219631.4	165	87	0	0	34	
4701900216	477314.3	4227767	156	77	0	0	35	
4701900504	470777.7	4222891	103	66	0	0	33	
4701900517	472092.8	4211934.3	162	83	0	0	43	
4701900511	469177.1	4207321.7	148	63	0	0	37	
4701900482	471152	4206410.4	176	63	0	0	30	
4701900507	474683.4	4204014.5	197	79	0	0	49	
4701900474	473418	4203213.4	122	77	0	0	41	
4701900510	472754.5	4202007.7	175	85	0	0	42	

4703905868	465811.20	4230738.40	138	51	0	0	23	
4703905987	473843.10	4231273.90	308	4	0	0	29	
4703905940	470468.30	4230899.20	228	70	0	0	21	
4703905941	470375.70	4231993.90	218	66	0	0	20	
4703905952	471307.00	4233422.90	256	78	0	0	25	
4703905953	470091.90	4233640.80	263	16	0	0	20	
4703905954	467658.80	4232757.10	224	74	0	0	22	
4703905931	469277.40	4244354.80	151	64	0	0	34	
4703905932	467662.30	4233795.00	231	61	0	0	36	
4703905936	466653.90	4233311.90	210	57	0	0	33	
4703905922	476016.10	4239773.20	279	70	0	0	23	
4703906152	478215.70	4241971.90	240	22	0	0	24	
4703905966	476138.30	4243317.80	189	68	0	0	23	
4703906161	475849.50	4243656.70	268	59	0	0	23	
4703906162	475671.60	4243319.20	312	58	0	0	21	
4703906035	474500.20	4245817.30	178	83	0	0	21	
4703905918	470981.30	4242477.30	180	44	0	0	34	
4703905998	470702.20	4242253.00	194	58	0	0	26	
4703905928	470751.90	4242655.20	70	81	0	0	26	
4703906032	469094.30	4242661.30	173	52	0	0	24	
4703905913	466993.40	4241671.80	226	49	0	0	27	
4703905926	467337.30	4241879.60	199	47	0	0	30	
4703905919	467677.80	4242602.50	195	51	0	0	21	
4703905825	467550.90	4243106.30	211	52	0	0	20	
4703905925	469516.40	4243678.00	212	52	0	0	20	
4703906151	469277.40	4244354.80	216	60	0	0	21	
4703906150	468617.90	4244453.90	208	62	0	0	19	
4703906148	468330.80	4245179.30	206	52	0	0	22	
4703906149	467879.60	4245020.10	220	66	0	0	18	
4703905899	468815.20	4245628.00	212	59	0	0	21	
4703906142	469384.20	4246491.10	224	61	0	0	25	
4703906143	469799.00	4246187.50	216	50	0	0	19	
4703905975	472336.20	4245036.10	220	67	0	0	27	
4703905970	471069.60	4244959.80	250	30	0	0	22	
4703905971	471329.40	4245683.10	217	51	0	0	24	
4703905842	465990.60	4244416.30	195	25	0	0	27	
4703905927	467272.50	4246245.60	224	41	0	0	30	
4703905896	468448.20	4246498.50	217	35	0	0	23	
4703905892	467982.30	4246709.50	211	61	0	0	27	
4703905893	468048.00	4247079.40	204	48	0	0	17	
4703905894	468449.80	4246949.10	216	59	0	0	21	

4703906220	454546.90	4246288.60	146	28	0	0	31	
4703906080	455338.40	4246946.50	145	24	0	0	22	
4703905993	473428.30	4258081.30	216	64	0	0	26	
4703906020	463740.10	4264915.10	189	50	0	0	26	
4703906011	462407.70	4264486.70	177	51	0	0	23	
4703903048	462057.70	4265373.50	179	54	0	0	20	
4703905884	457436.20	4239263.30	169	45	0	0	20	
4703906014	461281.50	4264556.40	171	55	0	0	21	
4703905886	461025.60	4264927.80	170	49	0	0	21	
4703905916	461478.60	4265440.60	170	54	0	0	20	
4703905890	461433.90	4266234.00	174	46	0	0	21	
4703906212	446673.80	4262193.70	119	35	0	0	20	
4703906095	440618.80	4272290.70	96	16	0	0	28	
4703906053	440458.10	4271710.00	90	26	0	0	29	
4703906051	439535.50	4270992.70	88	24	0	0	28	
4703906056	439498.80	4270376.70	90	30	0	0	28	
4703906137	438613.60	4272280.60	88	30	0	0	21	
4703906058	438695.20	4270527.70	86	26	0	0	28	
4703906155	438980.80	4269962.20	86	66	0	0	20	
4703906091	438498.60	4270024.60	103	14	0	0	20	
4703906086	438622.30	4269353.30	91	17	0	0	29	
4703906061	438052.00	4269583.00	83	24	0	0	28	
4703906068	437774.00	4269021.90	84	24	0	0	21	
4703906050	439777.90	4268910.00	91	30	0	0	25	
4703906054	439692.50	4268234.70	90	30	0	0	33	
4703906089	439832.70	4267589.90	92	31	0	0	23	
4703906070	440119.10	4267137.10	94	29	0	0	23	
4703906061	438052.00	4269583.00	83	22	0	0	30	
4703905988	438427.50	4266892.40	52	28	0	0	22	
4703906120	438661.60	4268113.80	50	27	0	0	26	
4703906062	438137.70	4268182.20	50	28	0	0	24	
4703906088	436751.20	4267871.10	81	23	0	0	27	
4703906132	437252.50	4269281.30	84	23	0	0	28	
4703906072	436991.50	4269816.60	79	26	0	0	29	
4703906127	435802.90	4270634.00	78	26	0	0	28	
4703906082	435307.70	4270602.60	75	30	0	0	22	
4703905979	434847.70	4271480.00	47	26	0	0	27	
4703906024	436914.10	4272300.40	48	32	0	0	21	
4703906049	434932.50	4265772.60	45	24	0	0	23	
4703906012	437439.90	4262345.70	52	19	0	0	29	
4703906212	446673.80	4262193.70	120	35	0	0	20	

4703906027	443574.20	4262552.80	67	30	0	0	24	
4703905768	438570.20	4257708.30	96	11	0	0	29	
4703906076	428306.50	4250042.50	70	22	0	0	20	
4703906185	427860.30	4250124.60	43	19	0	0	23	
4703906186	427475.40	4250439.90	46	18	0	0	21	
4703906014	461281.5	4264556.4	170	39	0	0	37	
4704303303	388235.10	4201756.70	7	0	0	0	12	
4704303302	387846.40	4202780.40	38	0	0	0	25	
4704303299	391132.90	4204941.30	0	0	0	0	23	
4704303300	393268.00	4203255.30	15	0	0	0	20	
4704303387	393070.20	4208312.10	15	0	0	0	26	
4704301234	399593.40	4206753.50	15	0	0	0	0	
4704303319	397881.90	4208319.30	22	9	0	0	19	
4704303318	397807.80	4208851.40	32	0	0	0	19	
4704303286	398651.10	4209372.10	15	0	0	0	0	
4704303395	396276.10	4208983.30	15	0	0	0	18	
4704303405	395428.80	4209444.80	26	0	0	0	18	
4704303288	395271.20	4212284.10	18	0	0	0	18	
4704303284	395585.30	4212940.00	8	0	0	0	19	
4704303350	414230.80	4212433.20	31	16	0	0	24	
4704303262	391553.00	4231054.30	13	0	0	0	0	
4704303279	390617.60	4229682.60	0	0	0	0	0	
4704303327	391015.10	4227283.00	0	0	0	0	0	
4704303280	391202.20	4225131.10	0	0	0	0	14	
4704303391	406732.40	4215948.10	28	0	0	0	20	
4704303380	405802.10	4217681.00	12	14	0	0	24	
4704300472	414300.00	4219380.50	18	26	0	0	20	
4704303407	404623.70	4222930.20	0	0	0	0	0	
4704303388	406187.30	4223041.10	27	0	0	0	21	
4704303308	421680.00	4223585.20	39	16	0	0	19	
4704303307	421163.60	4223445.30	40	17	0	0	20	
4704303322	422198.00	4223902.10	38	19	0	0	19	
4704303296	423224.40	4225216.50	42	21	0	0	16	
4704303294	422603.80	4225978.80	41	19	0	0	20	
4704303270	421492.60	4225909.00	39	19	0	0	17	
4704303326	419081.80	4225884.40	34	18	0	0	21	
4704303323	419250.00	4226623.10	52	0	0	0	25	
4704303321	418552.50	4227708.40	49	0	0	0	22	
4704303324	421548.30	4226697.10	38	18	0	0	21	
4704303295	422490.40	4227605.50	37	20	0	0	19	
4704303316	425290.40	4226243.40	48	22	0	0	17	

4704303420	413934.6	4213476.8	34	18	0	0	20	
4704303381	407420.4	4215581.8	14	17	0	0	19	
4704303382	406597.8	4215430.2	12	14	0	0	19	
4704303391	406732.4	4215948.1	14	15	0	0	19	
4704303390	406044.3	4216310.1	14	28	0	0	19	
4704303378	406246.4	4217112.6	12	14	0	0	20	
4704303377	407021.8	4217361.2	11	15	0	0	20	
4704302678	402723.3	4215930.5	12	0	0	0	0	
4704301637	392664.3	4217505.3	14	0	0	0	19	
4704303264	410533.1	4236976	12	19	0	0	21	
4704303265	410109.1	4236465.6	10	20	0	0	18	
4704303297	415105.9	4236411.7	36	0	0	0	26	
4704303256	416567.5	4238569.4	38	0	0	0	27	
4704303295	422490.4	4227605.5	40	18	0	0	20	
4704303137	400515.7	4229100.2	17	0	0	0	23	
4704303314	420198.8	4223535.2	48	0	0	0	21	
4704501099	422274.3	4170211.2	66	18	0	0	18	
4704501177	424274.8	4173781.8	59	14	0	0	12	
4704500579	424604.4	4174651.9	42	17	0	0	15	
4704501167	425538.5	4174723.9	37	22	0	0	13	
4704500496	424177.9	4175557.2	61	17	0	0	21	
4704501157	435766.8	4180951.2	105	26	0	0	24	
4704501085	440741.4	4182500.9	126	24	0	0	23	
4704501144	443897.5	4183744.6	131	23	0	0	21	
4704501172	435825	4185437	114	25	0	0	14	
4704501214	431579.8	4188998.3	100	24	0	0	14	
4704501130	423910.8	4187139.9	19	11	0	0	16	
4704501145	419195.5	4181788.9	66	15	0	0	13	
4704500563	419186.9	4180903.8	79	20	0	0	16	
4704500742	419580.4	4178192	45	20	0	0	25	
4704501330	416313.2	4180015	58	19	0	0	18	
4704500381	418019.6	4171813.5	85	8	0	0	10	
4704500379	416483.4	4173652.2	110	16	0	0	15	
4704500341	415969.5	4172848.1	32	16	0	0	16	
4704501101	414746	4173214.7	54	21	0	0	17	
4704500416	413380.6	4171909.1	22	0	0	0	16	
4704501183	411359.7	4174509.8	84	2	0	0	16	
4704500402	407401.3	4173470.7	63	16	0	0	18	
4704501151	408826.2	4175406.5	46	18	0	0	10	
4704501161	408174.8	4176443.8	42	28	0	0	8	
4704501150	410580.3	4176884.2	49	20	0	0	17	

4704501160	409647.8	4178487.8	16	9	0	0	13	
4704501149	407303.3	4179129.5	46	19	0	0	17	
4704501120	408019.7	4179861.9	50	18	0	0	17	
4704501178	408109.4	4180697.8	42	11	0	0	16	
4704501175	406920.6	4180904.3	37	1	0	0	17	
4704501190	406574.8	4180200	41	14	0	0	11	
4704501173	406389.7	4179477.8	42	19	0	0	13	
4704501876	404211.4	4179116.5	37	17	0	0	19	
4704501891	402317.8	4179621.5	37	16	0	0	11	
4704501843	403323.3	4180081.6	38	18	0	0	10	
4704501911	403471.3	4180541.5	38	17	0	0	13	
4704501878	404216.7	4180967.4	36	19	0	0	9	
4704502038	412524	4185724	30	18	0	0	10	
4704501176	409991.3	4188041	47	15	0	0	12	
4704501086	400309.7	4185395.9	22	14	0	0	16	
4704500121	400754.5	4186243.6	25	12	0	0	20	
4704500114	400600.3	4186808.8	32	10	0	0	23	
4704501165	401075.1	4187672.3	32	12	0	0	16	
4704501184	402301.3	4190703.9	30	16	0	0	14	
4704501154	403957.5	4191939.9	21	13	0	0	18	
4704501158	403805.5	4192718.5	38	14	0	0	19	
4704501192	405023.6	4192672.1	26	10	0	0	16	
4704501156	406080.2	4192156	40	14	0	0	16	
4704501180	404844.1	4193897.4	45	8	0	0	18	
4704501991	406321.3	4193574.7	27	22	0	0	18	
4704501155	407669.5	4193221.4	27	12	0	0	14	
4704501197	407831.3	4193300.1	30	26	0	0	20	
4704502002	407398.6	4194914.5	30	14	0	0	21	
4704501973	407868.8	4195215	30	12	0	0	21	
4704501999	408327.6	4195950.3	45	15	0	0	19	
4704501998	407906.5	4195713.5	32	15	0	0	18	
4704501972	407325.7	4195591.3	26	16	0	0	19	
4704501904	406858.1	4195516.1	8	8	0	0	8	
4704501885	406408	4195569.5	28	12	0	0	20	
4704501992	405007.8	4195585.6	24	12	0	0	18	
4704501980	407610.2	4196569.9	27	11	0	0	24	
4704501979	407173.4	4196365.6	27	15	0	0	20	
4704502009	406743.5	4196789	25	15	0	0	20	
4704501887	406146.1	4196618.7	25	12	0	0	22	
4704501243	407816	4197698.5	28	16	0	0	26	
4704502089	407314.6	4197478.8	13	0	0	0	29	

4704502028	405948.2	4197639.2	24	12	0	0	24	
4704502027	405671.2	4197336.6	23	13	0	0	20	
4704502137	405013.1	4204704.1	12	16	0	0	21	
4704502020	408366.9	4205229.3	25	9	0	0	23	
4704502017	407465.3	4205207.2	24	11	0	0	22	
4704502030	406632.5	4205586.9	12	20	0	0	20	
4704502023	408200.1	4206148.6	30	12	0	0	18	
4704502006	407378.8	4206109.6	13	23	0	0	20	
4704502018	406509.7	4206119.4	20	18	0	0	20	
4704502032	406464.4	4206381.8	21	16	0	0	21	
4704502008	407688.8	4206480.5	28	9	0	0	25	
4704502007	407354.6	4206822.3	14	20	0	0	26	
4704502016	406726.4	4206781.2	12	16	0	0	24	
4704502015	413777.6	4205927	20	16	0	0	20	
4704501975	413557.1	4204834.9	34	12	0	0	26	
4704501901	410956.3	4204508.6	28	12	0	0	24	
4704501196	428336.9	4168382.1	57	21	0	0	6	
4704501152	411092.4	4203686.3	17	16	0	0	23	
4704501987	415506.6	4203462.5	39	20	0	0	21	
4704501899	412948.5	4201992.4	30	18	0	0	20	
4704501906	413601.5	4201321.4	32	20	0	0	20	
4704501907	415192.4	4201079.4	51	7	0	0	28	
4704502104	415276.9	4201464.9	37	18	0	0	22	
4704502024	417088.1	4201591.2	39	19	0	0	21	
4704501823	418164	4201339	71	16	0	0	29	
4704501815	418304.8	4200919.1	68	17	0	0	33	
4704502049	417421	4199598	41	20	0	0	22	
4704502048	417890.1	4199667.8	65	16	0	0	30	
4704502047	418306.8	4199486.6	70	16	0	0	26	
4704502045	418898.1	4199062.3	64	20	0	0	22	
4704502046	417754.2	4198944.9	67	18	0	0	24	
4704502043	418187	4198763.5	67	18	0	0	22	
4704502042	418637	4198694.7	68	16	0	0	24	
4704502044	418454.1	4198101	70	18	0	0	24	
4704502067	419274.5	4197930.5	65	18	0	0	20	
4704501956	419799.5	4198168.2	68	16	0	0	23	
4704502041	418949.5	4197742	65	18	0	0	20	
4704501967	415196.6	4199920.5	59	17	0	0	21	
4704501977	416088.6	4199782.6	61	17	0	0	23	
4704501978	416020.1	4199364.8	59	16	0	0	20	
4704501828	414648	4198220.2	56	16	0	0	24	

4704501820	415119.4	4198150.1	59	17	0	0	20	
4704501952	416973.8	4196502.1	64	17	0	0	23	
4704501916	417125	4193877.1	55	11	0	0	20	
4704501951	414402.2	4191518.8	29	14	0	0	20	
4704701112	420521.6	4153103.1	39	29	0	0	0	24
4704701301	422906.6	4148361			0	0	0	25
4704700935	418866.9	4144822.4	81	24	0	0	0	8
4704702534	432109.6	4150292.7	58	37	0	0	0	16
4704702602	433485.8	4151315.5	66	38	0	0	0	16
4704700860	421949.7	4135305.4	40	18	0	0	0	16
4704701125	422832.2	4132657.6	46	34	0	0	0	18
4704700882	425305.2	4128366.3	66	32	0	0	0	20
4704702468	430669.2	4129028.4	62	16	0	0	0	14
4704702508	431834.6	4129855.8	63	40	0	0	0	24
4704702306	435501.3	4133501	82	16	0	0	0	15
4704702303	436856.9	4134245.7	78	34	0	0	0	26
4704702307	436124.2	4134580.8	76	34	0	0	0	17
4704702302	437932.1	4134887.2	79	35	0	0	0	16
4704702304	436368.4	4135051.8	73	39	0	0	0	17
4704702768	439598	4139444.6	87	36	0	0	0	18
4704702532	442736.4	4144672.7	107	39	0	0	0	19
4704702533	444629.4	4146176.5	108	46	0	0	0	20
4704702549	446767.8	4145901.4	106	22	0	0	0	24
4704702669	447356.7	4145080.7	150	19	0	0	0	22
4704702501	448823.8	4142444.3	91	57	0	0	0	17
4704702488	459310.2	4147154.2	166	79	0	0	0	20
4704702487	459789.9	4146608.4	123	80	0	0	0	79
4704702594	451493.1	4136434		70	0	0	0	17
4704701531	451545.5	4134357.5	215	85	0	0	0	15
4704702536	452388.5	4131564.8	118	72	0	0	0	20
4704702339	451345.7	4124775.4	118	70	0	0	0	16
4704700961	449892.4	4123914.8	157	69	0	0	0	20
4704700909	448277.1	4122894.6	134	66	0	0	0	17
4704702535	444772	4125205.1	98	35	0	0	0	14
4704702640	442060.5	4122786	87	51	0	0	0	25
4705901174	423963.6	4156857.1	71	22	0	0	0	12
4705901153	423502.9	4157537.3	44	15	0	0	0	15
4705901152	423815.8	4158339.2	44	20	0	0	0	14
4705901171	423500.1	4159034.2	47	20	0	0	0	16
4705901170	422540.3	4159027	40	22	0	0	0	14
4705901844	419791.8	4159439.3	21	17	0	0	0	13

4705901957	421115.4	4157757.2	44	20	0	0	0	14
4705902102	412861.7	4159245.7	90	0	0	0	0	12
4705902114	411774.4	4157888.6	18	0	0	0	0	13
4705902137	411187.6	4159121.4	0	0	0	0	0	10
4705901838	425447.8	4159064.7	52	20	0	0	0	18
4705901836	425241.9	4159436.8	0	69	0	0	0	16
4705901804	425735.2	4159588	48	20	0	0	0	16
4705901863	425167.3	4160101.2	48	18	0	0	0	11
4705901862	425316.4	4160582.7	51	18	0	0	0	18
4705901230	424860.5	4161810.1	49	17	0	0	0	15
4705900850	424973.4	4166112.3	46	16	0	0	0	17
4705901200	423361	4166945.9	44	20	0	0	14	
4705900641	422459.5	4165317.6	36	22	0	0	17	
4705900786	420276.6	4167573.2	42	16	0	0	16	
4705901281	417065.4	4168052.7	40	14	0	0	16	
4705901146	401162.2	4164585.5	0	0	0	0	0	16
4705901144	401636.9	4165276	18	15	0	0	0	18
4705901753	397028.8	4169553.1	0	0	0	0	0	13
4705901145	398239.7	4171196.1	0	0	0	0	0	17
4705901177	397684.9	4171911.1	0	0	0	0	0	11
4705901915	393328.4	4171355.1	0	0	0	0	0	24
4705901833	390224.4	4173278.3	0	0	0	0	0	11
4705901145	398239.7	4171196.1	51	0	0	0	0	21
4705901168	399219.4	4172359.1	38	0	0	0	0	16
4705901169	399597.1	4172982.2	35	0	0	0	0	17
4705901148	403555.2	4175273.1	50	0	0	0	0	12
4705901796	402311.6	4176301.8	0	0	0	0	0	21
4705900955	388035.1	4176205.2	0	0	0	0	0	36
4705900919	388340.1	4177234.2	0	0	0	0	0	20
4705901709	391523	4176613	0	0	0	0	0	25
4705901708	391752.5	4176932.3	34	0	0	0	0	18
4705901710	391385.6	4177194.6	39	0	0	0	0	25
4705900956	389219.7	4179110.9	37	0	0	0	0	16
4705901016	398250.8	4180012.7	46	0	0	0	0	20
4705901795	402522.1	4180584.9	0	0	0	0	0	12
4705900953	401740.4	4181189.7	0	0	0	0	0	19
4705900950	387846.9	4181173.7	0	0	0	0	0	15
4705900951	387937.7	4181945.1	0	0	0	0	0	16
4705901793	387308.1	4183016	0	0	0	0	0	8
4705901792	386974.2	4183326.4	0	0	0	0	0	23
4705901873	383747.2	4183906.7	33	0	0	0	0	29

4705901868	382299.1	4185038	50	0	0	0	0	9
4705901879	386655.7	4184783.7	0	0	0	0	0	24
4705901814	387238.9	4185065.4	0	0	0	0	0	16
4705901947	386951.8	4185467.3	0	0	0	0	0	26
4705901825	386298.7	4186832.9	0	0	0	0	0	27
4705901812	387283.4	4187189.6	0	0	0	0	0	23
4705901802	387682.3	4186926.6	0	0	0	0	0	12
4705900993	392847.6	4184076.8	75	0	0	0	0	74
4705900998	393381.5	4184325.6	0	0	0	0	0	16
4705900996	393262.1	4184660.5	0	0	0	0	0	20
4705901006	394682.7	4184410.4	0	0	0	0	0	18
4705901008	394585.6	4184936.4	0	0	0	0	0	19
4705901004	394460.7	4185522.9	0	0	0	0	0	26
4705901042	393753.4	4186169.9	0	0	0	0	0	20
4705901046	393339.6	4186400.6	46	0	0	0	0	26
4705901072	397042.7	4184737.7	48	0	0	0	0	16
4705901052	397460.3	4184931.3	33	0	0	0	0	19
4705901051	396838.4	4185182.6	42	0	0	0	0	16
4705901091	396706.3	4185691.4	0	0	0	0	0	25
4705901048	397211.9	4185624.1	45	0	0	0	0	17
4705901047	397123.4	4186095.3	0	0	0	0	0	21
4705901045	396715.7	4186349.8	47	0	0	0	0	22
4705901049	395821.2	4186757.8	0	0	0	0	0	26
4705901043	396247.3	4186958.1	0	0	0	0	0	22
4705901057	398673.1	4184964.8	0	0	0	0	0	16
4705901088	399815.5	4184452.2	30	0	0	0	0	14
4705901064	400903	4185211.7	51	0	0	0	0	13
4705901086	397285.3	4178845.6	50	0	0	0	0	15
4705901065	399810.8	4185402	39	0	0	0	0	5
4705901077	399736.9	4185950.1	38	0	0	0	0	14
4705901066	400189.1	4186073.4	53	0	0	0	0	20
4705901079	398937.1	4186501.7	22	12	0	0	0	15
4705901061	399025.4	4187021.1	19	10	0	0	0	22
4705900985	394883.5	4188128	46	0	0	0	0	21
4705900973	395704.4	4188882.6	40	0	0	0	0	25
4705900528	398567.6	4190528.6	44	0	0	0	0	10
4705901789	395571.4	4189965.7	0	0	0	0	0	22
4705901784	395725.5	4190704.2	0	0	0	0	0	24
4705901788	395189.7	4190340.7	0	0	0	0	0	28
4705901787	395068.4	4190937.9	41	0	0	0	0	20
4705901757	394404.8	4190640.5	0	0	0	0	0	30

4705900923	393680.6	4189780.1	48	0	0	0	0	28
4705901772	392161.6	4189913.1	0	0	0	0	0	26
4705900863	392190.9	4191494.6	0	0	0	0	0	20
4705900879	389011.9	4193661.4	0	0	0	0	0	28
4705900916	387079.8	4193963.5	0	0	0	0	0	40
4704501173	406389.7	4179477.8		0	0	0	0	
4706700932	528029.8	4232564.2		239	11	9	41	
4706700651	510613.7	4222765.5		185	8	0	45	
4706700895	525320.00	4256222.70		225	14	7	56	
4706700908	530372.90	4233774.10		193	14	12	40	
4706700910	530345.40	4234737.80		199	14	12	37	
4707901345	411144.60	4237107.80	22	0	0	0	32	
4707901438	411830.70	4237574.80	17	0	0	0	23	
4707901359	410342.60	4241634.70	25	0	0	0	31	
4707901357	410667.90	4241999.30	22	0	0	0	30	
4707901356	410718.9	4242459	20	0	0	0	31	
4707901506	422503.90	4270610.80	0	0	0	0	0	
4707901510	425847.80	4274427.70	0	0	0	0	0	
4707901509	426558.60	4273369.10	0	0	0	0	0	
4707901412	426293.00	4268124.10	0	0	0	0	0	
4707901321	428008.20	4265928.30	0	0	0	0	0	
4707901457	428000.70	4264666.10	0	0	0	0	0	
4707901459	428688.60	4264187.40	0	0	0	0	0	
4707901463	428945.10	4261396.00	17	0	0	0	7	
4707901462	429325.70	4262014.80	0	0	0	0	0	
4707901455	433340.40	4267217.00	0	0	0	0	0	
4707901503	430633.30	4270466.00	0	0	0	0	0	
4707901507	429741.50	4274858.30	0	0	0	0	0	
4707901429	437136.80	4274052.90	0	0	0	0	0	16
4707901466	435758.40	4274788.10	0	0	0	0	0	
4707901467	435486.50	4275015.60	0	0	0	0	0	
4707901469	435394.50	4275600.50	0	0	0	0	0	
4707901476	433527.80	4276372.20	0	0	0	0	0	
4707901040	433936.00	4279124.60	0	0	0	0	0	
4707901160	415144.5	4266493.2	0	0	0	0	0	
4707901153	431661.1	4258633.1	73	18	0	0	30	
4709901532	380103.8	4197777.6	0	0	0	0	0	9
4709901938	381376.7	4198231.4	0	0	0	0	0	14
4709901607	376177.7	4199056.8	0	0	0	0	0	25
4709902195	374785.1	4202096.1	0	0	0	0	0	7
4709902192	374012.8	4203123.1	0	0	0	0	0	23

4709902199	376058.2	4203867.9	0	0	0	0	0	12
4709902200	375535.8	4204890	0	0	0	0	0	10
4709902193	378622.9	4203137.3	0	0	0	0	0	22
4709902226	386094.2	4204623.5	0	0	0	0	0	28
4709901742	384624.8	4210380.4	0	0	0	0	0	43
4709901691	368001.5	4214612	0	0	0	0	0	43
4709902044	370470.9	4216958.6	0	0	0	0	0	45
4709902040	370845	4218224.3	0	0	0	0	0	42
4709902041	370182.2	4219071.9	0	0	0	0	0	40
4709902035	371084.4	4219122	0	0	0	0	0	41
4709902002	372929.4	4218722.8	0	0	0	0	0	48
4709901991	372184.8	4219507.1	0	0	0	0	0	44
4709902010	371322.4	4219923.1	0	0	0	0	0	40
4709902043	370492.6	4220387	0	0	0	0	0	40
4709901546	371246.1	4221216.7	0	0	0	0	0	40
4709902003	372460.2	4220941.7	0	0	0	0	0	68
4709901982	373416.3	4220035.2	0	0	0	0	0	42
4709901953	374485.3	4221520.2	0	0	0	0	0	48
4709901912	373476	4221841.7	0	0	0	0	0	46
4709901894	372249	4221603.3	0	0	0	0	0	16
4709901913	372648.3	4222450.2	0	0	0	0	0	46
4709901893	372694.2	4223350.9	0	0	0	0	0	44
4709901872	373629.7	4223720.2	0	0	0	0	0	46
4709901974	375435.1	4223630.4	0	0	0	0	0	36
4709901975	375693.7	4224753.3	0	0	0	0	0	52
4709901969	374897.2	4225301.3	0	0	0	0	0	48
4709901899	373822	4226573.5	0	0	0	0	0	44
4709902006	375280.3	4226573	0	0	0	0	0	52
4709901931	370531.3	4224898.2	0	0	0	0	0	42
4709901057	368588.2	4226728.1	0	0	0	0	0	41
4709902048	372449.1	4231541.4	0	0	0	0	0	52
4709901098	371526.1	4234925	0	0	0	0	0	48
4709902205	387160.6	4226007.1	0	0	0	0	0	
4710903039	435421.7	4150121.5	80		0	0	0	0
4710903036	433933	4151199.3	63	22	0	0	0	14
4710903005	429122.4	4152719.6	49	16	0	0	0	12
4710903006	429287.8	4153249.3	60	19	0	0	0	11
4710903007	430401.6	4154092.9	63	13	0	0	0	23
4710903049	437670	4154537.8	105	23	0	0	0	17
4710903004	436219.3	4155595.2	70	19	0	0	0	17
4710903027	435623.1	4155503.2	79	37	0	0	0	18

4710901131	432725.2	4156860.4	117	27	0	0	0	14
4710901217	431258.4	4156584.3	94		0	0	0	
4710901273	429188.8	4156778.7	80	20	0	0	0	16
4710902787	426924.7	4158707.6	82	18	0	0	0	11
4710903065	428735.1	4160721.7	85	22	0	0	0	16
4710902925	429442.3	4160128.2	45	18	0	0	29	
4710901205	438280.7	4158702	79	31	0	0	0	16
4710901132	436488.9	4159310.6	106	24	0	0	17	
4710901146	438907.4	4160711	124	14	0	0	20	
4710901816	432848.2	4162192.2	96					
4710901307	432509.8	4164158.5	92	24	0	0	24	
4710901108	433967.2	4164679.4	89	26	0	0	20	
4710901111	433810.2	4165761.4	88	26	0	0	22	
4710902006	432148.1	4169239.2	60	25	0	0	18	
4710902945	460584.1	4151561.6	208	39	0	0	28	
4710901780	462348.3	4161104.8	156	64	0	0	20	
4710901091	456964.1	4164834.1	175	25	0	0	22	
4710901086	456707.3	4164077.4	143	49	0	0	24	
4710901085	455454.8	4163423.8	95	50	0	0	27	
4710901129	451054.3	4160807.7	150	59	0	0	0	
4710901070	449008.9	4160433.4	159	58	0	0	15	
4710901157	447079	4162346.8	127	34	0	0	16	
4710901158	445560.6	4161455.4	138	43	0	0		
4710901210	449799.9	4163842.8	192	40	0	0	16	
4710901075	450382.7	4164677.6	164	32	0	0	0	
4710901083	447960.6	4164288.6	160	23	0	0	19	
4710901162	447953.5	4165821.5	135	29	0	0	16	
4710900929	455358.4	4166597.9	190	54	0	0	22	
4710901087	453586.1	4166414.4	108	30	0	0	21	
4710901161	452603.5	4166002.9	162	46	0	0	21	
4710901130	451536.8	4166474.4	162	51	0	0	28	
4710901237	446015.4	4169909.7	131	40	0	0	24	
4710900908	447766.9	4169493.7	141	21	0	0	27	
4710900984	453450.9	4171005.9	156	39	0	0	25	
4710901094	457673.1	4174350.1	258	86	0	0	22	
4710903009	452030.1	4176587.9	110	18	0	0	22	
4710900688	449042.2	4177152.4	178	26	0	0	27	
4710900902	442429.3	4180936.7	129	23	0	0	23	
4710900891	439207.8	4177959.6	112	30	0	0	24	
4710902938	456692.9	4154992.9	141	34	0	0	24	
4710501348	474736.7	4320242.8					60	

4701301511	482483.9	4312303.2						48	
4702105451	516489.1	4311954.8						50	
4710100097	549976.4	4274897.1		384	27	38		69	
4710100102	540663.2	4271625.4						59	
4710100060	549796.2	4247497.4			22	13		54	
4710100059	549189.8	4244130.1		339	19	13		56	
4709703432	561588	4283901	78	42	15	97		72	
4709703398	562340.4	4295206.4						70	
4705500014	483518.2	4134410.7	307	46	0	0		25	
4708900005	506623.2	4171700.3	70	50	40	0		20	
4703502344	452089.7	4275204.9	132	14	0	0		38	
4708704616	459433.4	4289844.5	144	36	0	0		50	
4708101497	473985.20	4156460.10	194	68	0	0		26	
4708101435	456919.30	4198066.50	165	47	0	0		24	
4708100255	473313.6	4169823	150	70	0	0		30	
4708100296	501604	4176103.5	56	46	0	0		28	
4708100688	485627.8	4190956.8	279	71	0	0		32	
4708100289	472707.2	4186865.8	235	81	0	0		25	
4708100336	466165.4	4191641.7	258	83	0	0		22	
4708100766	457162.2	4192232.5	195	57	0	0		30	
4708100793	456570.4	4191992.8	186	63	0	0		23	
4708100763	454529.4	4192391.5	169	49	0	0		25	
4708100756	453548.1	4192606.3	155	35	0	0		33	
4708100755	453088.7	4193961.7	163	48	0	0		22	
4708100627	462982.2	4202319.8	140	54	0	0		38	
4708100626	462048	4202066.4	136	41	0	0		36	
4708100597	459160.7	4202209.1	144	41	0	0		30	

APPENDIX C: ADDITIONAL MAP DATA

Data for additional maps, which includes: depth to the top of the Onondaga Limestone and the West Falls to Unconformity Total Thickness. Blank cells indicate an absence of data. UTMs were displayed because they were used for plotting locations in Surfer.

API	UTME	UTMN	Onondaga Formation Subsea Elevation (feet)	West Falls to Unconformity Total Thickness (feet)
4700500885	434341.30	4201000.30	-4273	95
4700502123	422292.30	4201395.30	-4510	67
4700502120	424814.60	4203661.50	-5005	76
4700502168	424354.60	4204422.20	-4566	76
4700502165	423872.40	4204491.00	-4500	76
4700502166	423900.40	4204024.00	-4625	79
4700502167	424121.70	4203571.30	-4768	104
4700502218	423241.30	4204110.60	-4842	75
4700502148	422834.70	4204307.60	-4812	71
4700502146	422876.30	4203599.00	-4612	74
4700502147	422541.30	4203924.10	-3257	72
4700502157	419344.60	4203552.60	-4762	88
4700502102	419474.10	4205257.40	-3122	90
4700502185	415675.20	4204201.10	-3093	47
4700502244	415535.80	4204733.70	-3099	45
4700502198	416073.40	4204792.60	-3097	45
4700501984	416420.20	4205690.40	-3128	45
4700502193	417182.70	4206298.50	-3135	52
4700502195	417847.00	4205849.90	-3131	64
4700502184	418058.00	4205287.50	-3112	65
4700502183	418351.80	4205703.10	-3116	58
4700502119	420773.30	4207614.90	-3165	71
4700502265	416021.80	4214265.60	-3328	46
4700502263	416271.60	4215116.00	-3344	82
4700502266	416004.10	4215734.70	-3348	72
4700502248	421866.30	4216138.10	-4614	85
4700502253	422268.40	4217700.60	-4647	86
4700500134	416993.70	4219796.70	-4532	69
4700500075	417857.70	4220902.80	-3408	41

4700502155	423001.10	4221398.90	-3427	86
4700502187	424463.10	4221933.30	-4257	60
4700502025	426463.50	4224248.70	-4242	100
4700502197	443099.40	4227982.40	-3499	140
4700502318	447795.90	4219737.80	-5232	170
4700502250	447105.20	4220773.10	-5180	162
4700502209	440426.80	4220465.10	-3603	142
4700502219	445753.10	4215595.40	-4236	155
4700502231	445408.10	4214483.00	-4214	101
4700502271	445888.40	4214077.40	-4212	110
4700502222	444543.3	4215313.9	-4231	147
4700501419	436223.3	4221590.9	-3398	86
4701100549	390500.6	4236143.3	-3516	0
4701100558	391459.6	4239933.8	-2797	0
4701100561	389996.5	4240507.8	-2795	0
4701100719	384246.5	4246127.7	-3615	0
4701100704	372963.9	4253578.3	-2268	0
4701100699	379404.4	4252573.1	-2465	0
4701100524	383015.1	4253973.4	-3247	0
4701100532	384603.5	4254739.2	-2693	0
4701100534	388602.6	4256469.6	-2775	0
4701100700	389335.2	4262978.5	-2783	0
4701100537	389905.5	4264702.6	-2665	0
4701100694	393459.3	4267050.2	-2793	0
4701100976	399320.3	4256537.7	-3185	0
4701100971	404421.5	4262005.7	-3267	0
4701900106	502599.1	4199016.4	-4799	200
4701900176	491475.6	4201031.2	-4687	107
4701900123	505937.4	4217960.6	-4773	360
4701900241	501318.7	4218441.3	-4730	316
4701900556	493259.6	4224632.2	-4758	305
4701900572	491901.2	4213484.1	-4831	290
4701900512	486011.6	4215282.5	-4761	243
4701900490	484022.9	4219631.4	-4794	252
4701900216	477314.3	4227767	-4907	233
4701900504	470777.7	4222891	-4845	169
4701900517	472092.8	4211934.3	-4785	245
4701900511	469177.1	4207321.7	-4725	211
4701900482	471152	4206410.4	-4707	239
4701900507	474683.4	4204014.5	-4670	276
4701900474	473418	4203213.4	-4684	199

4701900510	472754.5	4202007.7	-4688	260
4703905868	465811.20	4230738.40	-4528	189
4703905987	473843.10	4231273.90	-4842	312
4703905940	470468.30	4230899.20	-4761	298
4703905941	470375.70	4231993.90	-4664	284
4703905952	471307.00	4233422.90	-6239	334
4703905953	470091.90	4233640.80	-4615	279
4703905954	467658.80	4232757.10	-4771	298
4703905931	469277.40	4244354.80	-4544	215
4703905932	467662.30	4233795.00	-4636	292
4703905936	466653.90	4233311.90	-4496	267
4703905922	476016.10	4239773.20	-4725	349
4703906152	478215.70	4241971.90	-4965	262
4703905966	476138.30	4243317.80	-4865	257
4703906161	475849.50	4243656.70	-4620	327
4703906162	475671.60	4243319.20	-5861	370
4703906035	474500.20	4245817.30	-4585	261
4703905918	470981.30	4242477.30	-4398	224
4703905998	470702.20	4242253.00	-4404	252
4703905928	470751.90	4242655.20	-5599	151
4703906032	469094.30	4242661.30	-4319	225
4703905913	466993.40	4241671.80	-4281	275
4703905926	467337.30	4241879.60	-4277	246
4703905919	467677.80	4242602.50	-4299	246
4703905825	467550.90	4243106.30	-4344	263
4703905925	469516.40	4243678.00	-4344	264
4703906151	469277.40	4244354.80	-4373	276
4703906150	468617.90	4244453.90	-4346	270
4703906148	468330.80	4245179.30	-4329	258
4703906149	467879.60	4245020.10	-4323	286
4703905899	468815.20	4245628.00	-5096	271
4703906142	469384.20	4246491.10	-4336	285
4703906143	469799.00	4246187.50	-4340	266
4703905975	472336.20	4245036.10	-4409	287
4703905970	471069.60	4244959.80	-4379	280
4703905971	471329.40	4245683.10	-4358	268
4703905842	465990.60	4244416.30	-4237	220
4703905927	467272.50	4246245.60	-4334	265
4703905896	468448.20	4246498.50	-4342	252
4703905892	467982.30	4246709.50	-4355	272
4703905893	468048.00	4247079.40	-4337	252

4703905894	468449.80	4246949.10	-4368	275
4703906220	454546.90	4246288.60	-4013	174
4703906080	455338.40	4246946.50	-4069	169
4703905993	473428.30	4258081.30	-4408	280
4703906020	463740.10	4264915.10	-5400	239
4703906011	462407.70	4264486.70	-5353	228
4703903048	462057.70	4265373.50	-5315	233
4703905884	457436.20	4239263.30	-4294	214
4703906014	461281.50	4264556.40	-4309	226
4703905886	461025.60	4264927.80	-5092	219
4703905916	461478.60	4265440.60	-4317	224
4703905890	461433.90	4266234.00	-4279	220
4703906212	446673.80	4262193.70	-4869	154
4703906095	440618.80	4272290.70	-4092	112
4703906053	440458.10	4271710.00	-4138	116
4703906051	439535.50	4270992.70	-4206	112
4703906056	439498.80	4270376.70	-4259	120
4703906137	438613.60	4272280.60	-3737	118
4703906058	438695.20	4270527.70	-5032	112
4703906155	438980.80	4269962.20	-4123	152
4703906091	438498.60	4270024.60	-5010	117
4703906086	438622.30	4269353.30	-5029	108
4703906061	438052.00	4269583.00	-5002	107
4703906068	437774.00	4269021.90	-4980	108
4703906050	439777.90	4268910.00	-4104	121
4703906054	439692.50	4268234.70	-4132	120
4703906089	439832.70	4267589.90	-4117	123
4703906070	440119.10	4267137.10	-5156	123
4703906061	438052.00	4269583.00	-5002	105
4703905988	438427.50	4266892.40	-5066	80
4703906120	438661.60	4268113.80	-4976	77
4703906062	438137.70	4268182.20	-4978	78
4703906088	436751.20	4267871.10	-4045	104
4703906132	437252.50	4269281.30	-4048	107
4703906072	436991.50	4269816.60	-4049	105
4703906127	435802.90	4270634.00	-4008	104
4703906082	435307.70	4270602.60	-4954	105
4703905979	434847.70	4271480.00	-4002	73
4703906024	436914.10	4272300.40	-4062	80
4703906049	434932.50	4265772.60	-3988	69
4703906012	437439.90	4262345.70	-4633	71

4703906212	446673.80	4262193.70	-4869	155
4703906027	443574.20	4262552.80	-4664	97
4703905768	438570.20	4257708.30	-3917	107
4703906076	428306.50	4250042.50	-3739	92
4703906185	427860.30	4250124.60	-3703	62
4703906186	427475.40	4250439.90	-4575	64
4703906014	461281.5	4264556.4	-4310	209
4704303303	388235.10	4201756.70	-3817	7
4704303302	387846.40	4202780.40	-2703	38
4704303299	391132.90	4204941.30	-2829	0
4704303300	393268.00	4203255.30	-4104	15
4704303387	393070.20	4208312.10	-3758	15
4704301234	399593.40	4206753.50	-3021	15
4704303319	397881.90	4208319.30	-2984	31
4704303318	397807.80	4208851.40	-2999	32
4704303286	398651.10	4209372.10	-3037	15
4704303395	396276.10	4208983.30	-4160	15
4704303405	395428.80	4209444.80	-2933	26
4704303288	395271.20	4212284.10	-4240	18
4704303284	395585.30	4212940.00	-2943	8
4704303350	414230.80	4212433.20	-3319	47
4704303262	391553.00	4231054.30	-3545	13
4704303279	390617.60	4229682.60	-2681	0
4704303327	391015.10	4227283.00	-2755	0
4704303280	391202.20	4225131.10	-3702	0
4704303391	406732.40	4215948.10	-4410	28
4704303380	405802.10	4217681.00	-3140	26
4704300472	414300.00	4219380.50	-3377	44
4704303407	404623.70	4222930.20	-4253	0
4704303388	406187.30	4223041.10	-3205	27
4704303308	421680.00	4223585.20	-4608	55
4704303307	421163.60	4223445.30	-3485	57
4704303322	422198.00	4223902.10	-3507	57
4704303296	423224.40	4225216.50	-3535	63
4704303294	422603.80	4225978.80	-3536	60
4704303270	421492.60	4225909.00	-4531	58
4704303326	419081.80	4225884.40	-3541	52
4704303323	419250.00	4226623.10	-3537	52
4704303321	418552.50	4227708.40	-3550	49
4704303324	421548.30	4226697.10	-3555	56
4704303295	422490.40	4227605.50	-4590	57

4704303316	425290.40	4226243.40	-3561	70
4704303420	413934.6	4213476.8	-3316	52
4704303381	407420.4	4215581.8	-4412	31
4704303382	406597.8	4215430.2	-3256	26
4704303391	406732.4	4215948.1	-4410	29
4704303390	406044.3	4216310.1	-3191	42
4704303378	406246.4	4217112.6	-3144	26
4704303377	407021.8	4217361.2	-4338	26
4704302678	402723.3	4215930.5	-3086	12
4704301637	392664.3	4217505.3	-2837	14
4704303264	410533.1	4236976	-4210	31
4704303265	410109.1	4236465.6	-4100	30
4704303297	415105.9	4236411.7	-3477	36
4704303256	416567.5	4238569.4	-3396	38
4704303295	422490.4	4227605.5	-4590	58
4704301625	392244.2	4235074.4	-3467	0
4704303137	400515.7	4229100.2	-2929	17
4704301617	401669.9	4230647.3	-3810	0
4704303314	420198.8	4223535.2	-4280	48
4704301625	392244.2	4235074.4	-3467	0
4704501099	422274.3	4170211.2	-4232	84
4704501204	420551.7	4170163.2		88
4704501199	421232	4170623.4		76
4704501216	420478.3	4170920.4		49
4704501232	421580.9	4171795.1		45
4704501177	424274.8	4173781.8	-4228	73
4704500579	424604.4	4174651.9	-4331	59
4704501167	425538.5	4174723.9	-4234	59
4704500496	424177.9	4175557.2	-4200	78
4704501157	435766.8	4180951.2	-4354	131
4704501085	440741.4	4182500.9	-4417	150
4704501144	443897.5	4183744.6	-4424	154
4704501172	435825	4185437	-4336	139
4704501214	431579.8	4188998.3	-4258	124
4704501130	423910.8	4187139.9	-3295	30
4704501145	419195.5	4181788.9	-4079	81
4704500563	419186.9	4180903.8	-4116	99
4704500742	419580.4	4178192	-4124	65
4704501330	416313.2	4180015	-5904	77
4704500381	418019.6	4171813.5	-4093	93
4704500379	416483.4	4173652.2	-4036	126

4704500341	415969.5	4172848.1	-4014	48
4704501101	414746	4173214.7	-4018	75
4704500416	413380.6	4171909.1	-5740	22
4704501183	411359.7	4174509.8	-3919	86
4704500402	407401.3	4173470.7	-3882	79
4704501151	408826.2	4175406.5	-3875	64
4704501161	408174.8	4176443.8	-3873	70
4704501150	410580.3	4176884.2	-3905	69
4704501160	409647.8	4178487.8	-3836	25
4704501149	407303.3	4179129.5	-3851	65
4704501120	408019.7	4179861.9	-3861	68
4704501178	408109.4	4180697.8	-3850	53
4704501175	406920.6	4180904.3	-3833	38
4704501190	406574.8	4180200	-3808	55
4704501173	406389.7	4179477.8	-3836	61
4704501876	404211.4	4179116.5	-3757	54
4704501891	402317.8	4179621.5	-3630	53
4704501843	403323.3	4180081.6	-3693	56
4704501911	403471.3	4180541.5	-3692	55
4704501878	404216.7	4180967.4	-3716	55
4704502038	412524	4185724	-3885	48
4704501176	409991.3	4188041	-3652	62
4704501086	400309.7	4185395.9	-3388	36
4704500121	400754.5	4186243.6	-3404	37
4704500114	400600.3	4186808.8	-3366	42
4704501165	401075.1	4187672.3	-3411	44
4704501184	402301.3	4190703.9	-3090	46
4704501154	403957.5	4191939.9	-3153	34
4704501158	403805.5	4192718.5	-3077	52
4704501192	405023.6	4192672.1	-3115	36
4704501156	406080.2	4192156	-3139	54
4704501180	404844.1	4193897.4	-3033	53
4704501991	406321.3	4193574.7	-2933	49
4704501155	407669.5	4193221.4	-3147	39
4704501197	407831.3	4193300.1	-3157	56
4704502002	407398.6	4194914.5	-3042	44
4704501973	407868.8	4195215	-3870	42
4704501999	408327.6	4195950.3	-2997	60
4704501998	407906.5	4195713.5	-2983	47
4704501972	407325.7	4195591.3	-3769	42
4704501904	406858.1	4195516.1	-3660	16

4704501885	406408	4195569.5	-4130	40
4704501992	405007.8	4195585.6	-4208	36
4704501980	407610.2	4196569.9	-4278	38
4704501979	407173.4	4196365.6	-3944	42
4704502009	406743.5	4196789	-2950	40
4704501887	406146.1	4196618.7	-4194	37
4704501243	407816	4197698.5	-2983	44
4704502089	407314.6	4197478.8	-2970	13
4704502028	405948.2	4197639.2	-2946	36
4704502027	405671.2	4197336.6	-2942	36
4704502137	405013.1	4204704.1	-4121	28
4704502020	408366.9	4205229.3	-3041	34
4704502017	407465.3	4205207.2	-4096	35
4704502030	406632.5	4205586.9	-4188	32
4704502023	408200.1	4206148.6	-4078	42
4704502006	407378.8	4206109.6	-4264	36
4704502018	406509.7	4206119.4	-3854	38
4704502032	406464.4	4206381.8	-4149	37
4704502008	407688.8	4206480.5	-4340	37
4704502007	407354.6	4206822.3	-3145	34
4704502016	406726.4	4206781.2	-3820	28
4704502015	413777.6	4205927	-3140	36
4704501975	413557.1	4204834.9	-3111	46
4704501901	410956.3	4204508.6	-3081	40
4704501196	428336.9	4168382.1	-4322	78
4704501152	411092.4	4203686.3	-3073	33
4704501987	415506.6	4203462.5	-3052	59
4704501899	412948.5	4201992.4	-3031	48
4704501906	413601.5	4201321.4	-3024	52
4704501907	415192.4	4201079.4	-3018	58
4704502104	415276.9	4201464.9	-3061	55
4704502024	417088.1	4201591.2	-4451	58
4704501823	418164	4201339	-3128	87
4704501815	418304.8	4200919.1	-3158	85
4704502049	417421	4199598	-3146	61
4704502048	417890.1	4199667.8	-3169	81
4704502047	418306.8	4199486.6	-3184	86
4704502045	418898.1	4199062.3	-3240	84
4704502046	417754.2	4198944.9	-4860	85
4704502043	418187	4198763.5	-3228	85
4704502042	418637	4198694.7	-3259	84

4704502044	418454.1	4198101	-3295	88
4704502067	419274.5	4197930.5	-3354	83
4704501956	419799.5	4198168.2	-3383	84
4704502041	418949.5	4197742	-4013	83
4704501967	415196.6	4199920.5	-4274	76
4704501977	416088.6	4199782.6	-4151	78
4704501978	416020.1	4199364.8	-4014	75
4704501828	414648	4198220.2	-3079	72
4704501820	415119.4	4198150.1	-4353	76
4704501952	416973.8	4196502.1	-3301	81
4704501916	417125	4193877.1	-3407	66
4704501951	414402.2	4191518.8	-3540	43
4704700618	416514.5	4149774	-4296	
4704701112	420521.6	4153103.1	-4362	68
4704701301	422906.6	4148361	-4572	
4704700935	418866.9	4144822.4	-4449	105
4704702534	432109.6	4150292.7	-4621	95
4704702602	433485.8	4151315.5	-4658	104
4704700860	421949.7	4135305.4	-4717	58
4704701125	422832.2	4132657.6	-3773	80
4704700882	425305.2	4128366.3	-4966	98
4704702468	430669.2	4129028.4	-4980	78
4704702508	431834.6	4129855.8	-4992	103
4704702306	435501.3	4133501	-4982	98
4704702303	436856.9	4134245.7	-4977	112
4704702307	436124.2	4134580.8	-7184	110
4704702302	437932.1	4134887.2	-6764	114
4704702304	436368.4	4135051.8	-4927	112
4704702768	439598	4139444.6	-4895	123
4704702532	442736.4	4144672.7	-4813	146
4704702533	444629.4	4146176.5	-4808	154
4704702549	446767.8	4145901.4	-4873	128
4704702669	447356.7	4145080.7	-4878	169
4704702501	448823.8	4142444.3	-4914	148
4704702488	459310.2	4147154.2	-4984	245
4704702487	459789.9	4146608.4	-5049	203
4704702594	451493.1	4136434	-4964	70
4704701531	451545.5	4134357.5	-5134	300
4704702536	452388.5	4131564.8	-5115	190
4704700932	454361.5	4127285.2	-4427	
4704702339	451345.7	4124775.4	-4456	188

4704700961	449892.4	4123914.8	-4461	226
4704700909	448277.1	4122894.6	-4411	200
4704702535	444772	4125205.1	-4872	133
4704702640	442060.5	4122786	-4956	138
4705901174	423963.6	4156857.1	-4443	93
4705901153	423502.9	4157537.3	-4385	59
4705901152	423815.8	4158339.2	-4376	64
4705901171	423500.1	4159034.2	-4367	67
4705901170	422540.3	4159027	-4320	62
4705901844	419791.8	4159439.3	-4269	38
4705901957	421115.4	4157757.2	-4320	64
4705902102	412861.7	4159245.7	-4091	90
4705902114	411774.4	4157888.6	-4084	18
4705902137	411187.6	4159121.4	-4081	
4705901838	425447.8	4159064.7	-4410	72
4705901836	425241.9	4159436.8	-5419	69
4705901804	425735.2	4159588	-4387	68
4705901863	425167.3	4160101.2	-4372	66
4705901862	425316.4	4160582.7	-5658	69
4705901230	424860.5	4161810.1	-4340	66
4705900850	424973.4	4166112.3	-4276	62
4705901200	423361	4166945.9	-4247	64
4705900641	422459.5	4165317.6	-4243	58
4705900786	420276.6	4167573.2	-4174	58
4705901281	417065.4	4168052.7	-4056	54
4705901146	401162.2	4164585.5	-3792	0
4705901144	401636.9	4165276	-3821	33
4705901753	397028.8	4169553.1	-4550	0
4705901145	398239.7	4171196.1	-3671	0
4705901177	397684.9	4171911.1	-3646	0
4705901915	393328.4	4171355.1	-4909	0
4705901833	390224.4	4173278.3	-4220	0
4705901145	398239.7	4171196.1	-3675	51
4705901168	399219.4	4172359.1	-3695	38
4705901169	399597.1	4172982.2	-3730	35
4705901148	403555.2	4175273.1	-3801	50
4705901796	402311.6	4176301.8	-3741	0
4705900955	388035.1	4176205.2	-3192	0
4705900919	388340.1	4177234.2	-3070	0
4705901709	391523	4176613	-4265	0
4705901708	391752.5	4176932.3	-4168	34

4705901710	391385.6	4177194.6	-4325	39
4705900956	389219.7	4179110.9	-3213	37
4705901016	398250.8	4180012.7	-3476	46
4705901795	402522.1	4180584.9	-3603	0
4705900953	401740.4	4181189.7	-3519	0
4705900950	387846.9	4181173.7	-4605	0
4705900951	387937.7	4181945.1	-3091	0
4705901793	387308.1	4183016	-3126	0
4705901792	386974.2	4183326.4	-3116	0
4705901873	383747.2	4183906.7	-4265	33
4705901868	382299.1	4185038	-2893	50
4705901879	386655.7	4184783.7	-3094	0
4705901814	387238.9	4185065.4	-3105	0
4705901947	386951.8	4185467.3	-3093	0
4705901825	386298.7	4186832.9	-3079	0
4705901812	387283.4	4187189.6	-3112	0
4705901802	387682.3	4186926.6	-3115	0
4705900993	392847.6	4184076.8	-3284	75
4705900998	393381.5	4184325.6	-3310	0
4705900996	393262.1	4184660.5	-3284	0
4705901006	394682.7	4184410.4	-3306	0
4705901008	394585.6	4184936.4	-3342	0
4705901004	394460.7	4185522.9	-3312	0
4705901042	393753.4	4186169.9	-3241	0
4705901046	393339.6	4186400.6	-2970	46
4705901072	397042.7	4184737.7	-3350	48
4705901052	397460.3	4184931.3	-4851	33
4705901051	396838.4	4185182.6	-3303	42
4705901091	396706.3	4185691.4	-3323	0
4705901048	397211.9	4185624.1	-3333	45
4705901047	397123.4	4186095.3	-3286	0
4705901045	396715.7	4186349.8	-3262	47
4705901049	395821.2	4186757.8	-3308	0
4705901043	396247.3	4186958.1	-3282	0
4705901057	398673.1	4184964.8	-3441	0
4705901088	399815.5	4184452.2	-3482	30
4705901064	400903	4185211.7	-3435	51
4705901086	397285.3	4178845.6	-3498	50
4705901065	399810.8	4185402	-3462	39
4705901077	399736.9	4185950.1	-3408	38
4705901066	400189.1	4186073.4	-3437	53

4705901079	398937.1	4186501.7	-3428	34
4705901061	399025.4	4187021.1	-3420	29
4705900985	394883.5	4188128	-3304	46
4705900973	395704.4	4188882.6	-4237	40
4705900528	398567.6	4190528.6	-4380	44
4705901789	395571.4	4189965.7	-3261	0
4705901784	395725.5	4190704.2	-3248	0
4705901788	395189.7	4190340.7	-3222	0
4705901787	395068.4	4190937.9	-3232	41
4705901757	394404.8	4190640.5	-3197	0
4705900923	393680.6	4189780.1	-3274	48
4705901772	392161.6	4189913.1	-2423	0
4705900863	392190.9	4191494.6	-4044	0
4705900879	389011.9	4193661.4	-2743	0
4705900916	387079.8	4193963.5	-2551	0
4704501173	406389.7	4179477.8	-3736	
4706700932	528029.8	4232564.2	-7172	239
4706700651	510613.7	4222765.5	-4842	185
4706700895	525320.00	4256222.70	-4900	225
4706700908	530372.90	4233774.10	-4867	193
4706700910	530345.40	4234737.80	-4845	199
4707901345	411144.60	4237107.80	-4398	22
4707901438	411830.70	4237574.80	-3291	17
4707901359	410342.60	4241634.70	-3281	25
4707901357	410667.90	4241999.30	-3282	22
4707901356	410718.9	4242459	-4191	20
4707901506	422503.90	4270610.80	-3776	0
4707901510	425847.80	4274427.70	-4714	0
4707901509	426558.60	4273369.10	-4678	0
4707901412	426293.00	4268124.10	-3902	0
4707901321	428008.20	4265928.30	-3849	0
4707901457	428000.70	4264666.10	-3853	0
4707901459	428688.60	4264187.40	-4797	0
4707901463	428945.10	4261396.00	-4720	17
4707901462	429325.70	4262014.80	-4705	0
4707901455	433340.40	4267217.00	-4947	0
4707901503	430633.30	4270466.00	-3985	0
4707901507	429741.50	4274858.30	-4654	0
4707901429	437136.80	4274052.90	-5056	0
4707901466	435758.40	4274788.10	-4063	0
4707901467	435486.50	4275015.60	-4044	0

4707901469	435394.50	4275600.50	-4063	0
4707901476	433527.80	4276372.20	-4058	0
4707901040	433936.00	4279124.60	-3910	0
4707901160	415144.5	4266493.2	-4240	0
4707901153	431661.1	4258633.1	970	91
4709901532	380103.8	4197777.6	-3182	0
4709901938	381376.7	4198231.4	-2481	0
4709901607	376177.7	4199056.8	-3195	0
4709902195	374785.1	4202096.1	-3115	0
4709902192	374012.8	4203123.1	-3147	0
4709902199	376058.2	4203867.9	-3493	0
4709902200	375535.8	4204890	-3508	0
4709902193	378622.9	4203137.3	-3202	0
4709902194	372565.9	4206481	-3186	0
4709902226	386094.2	4204623.5	-2724	0
4709901742	384624.8	4210380.4	-3706	0
4709901691	368001.5	4214612	-2176	0
4709902044	370470.9	4216958.6	-2320	0
4709902040	370845	4218224.3	-2299	0
4709902041	370182.2	4219071.9	-2320	0
4709902035	371084.4	4219122	-3026	0
4709902002	372929.4	4218722.8	-2384	0
4709901991	372184.8	4219507.1	-2340	0
4709902010	371322.4	4219923.1	-2340	0
4709902043	370492.6	4220387	-2333	0
4709901546	371246.1	4221216.7	-2990	0
4709902003	372460.2	4220941.7	-2451	0
4709901982	373416.3	4220035.2	-2358	0
4709901953	374485.3	4221520.2	-2383	0
4709901912	373476	4221841.7	-2388	0
4709901894	372249	4221603.3	-2297	0
4709901913	372648.3	4222450.2	-2388	0
4709901893	372694.2	4223350.9	-2386	0
4709901872	373629.7	4223720.2	-2300	0
4709901974	375435.1	4223630.4	-2384	0
4709901975	375693.7	4224753.3	-2452	0
4709901969	374897.2	4225301.3	-2383	0
4709901899	373822	4226573.5	-2369	0
4709902006	375280.3	4226573	-2385	0
4709901931	370531.3	4224898.2	-2348	0
4709901057	368588.2	4226728.1	-2947	0

4709902048	372449.1	4231541.4	-2399	0
4709901098	371526.1	4234925	-3164	0
4709902205	387160.6	4226007.1	-2661	0
4709901794	368716.3	4223780.7	-3447	0
4710903039	435421.7	4150121.5	2302	80
4710903036	433933	4151199.3	-4620	85
4710903005	429122.4	4152719.6	-4529	65
4710903006	429287.8	4153249.3	-4514	79
4710903007	430401.6	4154092.9	-4501	76
4710903049	437670	4154537.8	-4626	128
4710903004	436219.3	4155595.2	-4614	89
4710903027	435623.1	4155503.2	-4601	116
4710901131	432725.2	4156860.4	-4522	144
4710901217	431258.4	4156584.3		94
4710901273	429188.8	4156778.7	-4479	100
4710902787	426924.7	4158707.6	-4442	100
4710903065	428735.1	4160721.7	-5423	107
4710902925	429442.3	4160128.2	-4395	63
4710901205	438280.7	4158702	-4581	110
4710901132	436488.9	4159310.6	-4567	130
4710901146	438907.4	4160711	-4595	138
4710901816	432848.2	4162192.2		96
4710901307	432509.8	4164158.5	-4462	116
4710901108	433967.2	4164679.4	-3935	115
4710901111	433810.2	4165761.4	-4350	114
4710902006	432148.1	4169239.2	-4388	85
4710902945	460584.1	4151561.6	-4887	247
4710901780	462348.3	4161104.8	-4730	220
4710901091	456964.1	4164834.1	-4645	200
4710901086	456707.3	4164077.4	-4706	192
4710901085	455454.8	4163423.8	-4649	145
4710901129	451054.3	4160807.7	-4636	209
4710901070	449008.9	4160433.4	-4702	217
4710901157	447079	4162346.8	-4625	161
4710901158	445560.6	4161455.4		181
4710901210	449799.9	4163842.8	-4615	232
4710901075	450382.7	4164677.6	-6402	196
4710901083	447960.6	4164288.6	-4613	183
4710901162	447953.5	4165821.5	-4564	164
4710900929	455358.4	4166597.9	-4641	244
4710901087	453586.1	4166414.4	-4606	138

4710901161	452603.5	4166002.9	-4696	208
4710901130	451536.8	4166474.4	-6549	213
4710901237	446015.4	4169909.7	-4534	171
4710900908	447766.9	4169493.7	-4568	162
4710900984	453450.9	4171005.9	-4591	195
4710901094	457673.1	4174350.1	-5190	344
4710903009	452030.1	4176587.9	-4486	128
4710900688	449042.2	4177152.4	-4476	204
4710900902	442429.3	4180936.7	-4475	152
4710900891	439207.8	4177959.6	-4392	142
4710902938	456692.9	4154992.9	-4761	175
4710501348	474736.7	4320242.8	-4738	
4701301511	482483.9	4312303.2	-4870	
4702105451	516489.1	4311954.8	-5379	
4710100097	549976.4	4274897.1	-5101	384
4710100102	540663.2	4271625.4	-5128	
4710100060	549796.2	4247497.4	-4389	0
4710100059	549189.8	4244130.1	-4416	339
4709703432	561588	4283901	-4884	120
4709703398	562340.4	4295206.4	-5116	
4705300437	426704	4290062.3	-3744	
4705300455	414800.9	4292160.6	-3206	0
4705500014	483518.2	4134410.7	-5130	353
4708900005	506623.2	4171700.3	-5088	120
4703502344	452089.7	4275204.9	-4266	146
4708704616	459433.4	4289844.5	-5600	180
4708101497	473985.20	4156460.10	-5088	262
4708101435	456919.30	4198066.50	-4527	212
4708100255	473313.6	4169823	-4787	220
4708100296	501604	4176103.5	-5104	102
4708100688	485627.8	4190956.8	-4765	350
4708100289	472707.2	4186865.8	-4667	316
4708100336	466165.4	4191641.7	-4580	341
4708100766	457162.2	4192232.5	-4573	252
4708100793	456570.4	4191992.8	-4506	249
4708100763	454529.4	4192391.5	-4581	218
4708100756	453548.1	4192606.3	-4551	190
4708100755	453088.7	4193961.7	-4536	211
4708100627	462982.2	4202319.8	-4720	194
4708100626	462048	4202066.4	-4651	177
4708100597	459160.7	4202209.1	-4680	185

APPENDIX D: WELL PRODUCTION ANALYSIS COMPLETION INTERVAL INFORMATION

API	Completion Formation	Field	Top Completion Interval Depth (feet)	Completion Interval Thickness (feet)	UTME	UTMN
4704502137	Marcellus	Chapmanville	4100	23	405013.1	4204704.1
4704502123	Marcellus	Chapmanville	4294	28	406323.6	4204099.2
4704502030	Marcellus	Chapmanville	4156	24	406632.5	4205586.9
4704502018	Marcellus	Chapmanville	3836	10	406509.7	4206119.4
4704502032	Marcellus	Chapmanville	4132	10	406464.4	4206381.8
4704502016	Marcellus	Chapmanville	3800	10	406726.4	4206781.2
4704502007	Marcellus	Chapmanville	4180	10	407354.6	4206822.3
4704502008	Marcellus	Chapmanville	4320	10	407688.8	4206480.5
4704502006	Marcellus	Chapmanville	4246	10	407378.8	4206109.6
4704502023	Marcellus	Chapmanville	4061	10	408200.1	4206148.6
4704502017	Marcellus	Chapmanville	4078	10	407465.3	4205207.2
4704502020	Marcellus	Chapmanville	3784	10	408366.9	4205229.3
4704501884	Marcellus	Chapmanville	4228	10	409741.1	4205262.3
4704501901	Marcellus	Chapmanville	3939	11	410956.3	4204508.6
4704502063	Marcellus	Chapmanville	3765	20	410767.3	4201887.1
4704502064	Marcellus	Chapmanville	4320	20	412685.2	4199866.4
4704501830	Marcellus	Chapmanville	3834	10	414152.4	4198547.2
4704501828	Marcellus	Chapmanville	4117	10	414648	4198220.2
4704501820	Marcellus	Chapmanville	4333	10	415119.4	4198150.1
4704501819	Marcellus	Chapmanville	4318	10	415696.6	4198450.7
4704501829	Marcellus	Chapmanville	3897	33	415701.4	4198917.4
4704502122	Marcellus	Chapmanville	4130	20	407460.9	4198604.8
4704502089	Marcellus	Chapmanville	4155	20	407314.6	4197478.8
4704501887	Marcellus	Chapmanville	4175	10	406146.1	4196618.7
4704502009	Marcellus	Chapmanville	3663	31	406743.5	4196789
4704501979	Marcellus	Chapmanville	3926	10	407173.4	4196365.6
4704501980	Marcellus	Chapmanville	4239	25	407610.2	4196569.9
4704501981	Marcellus	Chapmanville	4272	10	407604.9	4196087.1
4704501999	Marcellus	Chapmanville	4300	10	408327.6	4195950.3
4704501904	Marcellus	Chapmanville	4150	10	406858.1	4195516.1
4704501885	Marcellus	Chapmanville	4112	10	406408	4195569.5
4704501992	Marcellus	Chapmanville	4173	30	405007.8	4195585.6
4704501973	Marcellus	Chapmanville	3858	10	407868.8	4195215
4704502002	Marcellus	Chapmanville	4069	10	407398.6	4194914.5
4705901825	Rhinestreet+Remanent	Crum-Kermit	4326	186	386298.7	4186832.9
4705901879	Rhinestreet+Remanent	Crum-Kermit	3950	186	386655.7	4184783.7
4705901792	Rhinestreet+Remanent	Crum-Kermit	3610	244	386974.2	4183326.4
4705902137	Rhinestreet+Remanent	Magnolia	5510	146	411187.6	4159121.4
4704500416	WF	Magnolia	5273	379	413380.6	4171909.1
4704501160	WF	Magnolia	4857	255	409647.8	4178487.8
4704501120	WF	Magnolia	4478	301	408019.7	4179861.9
4704501178	WF	Magnolia	5407	213	408109.4	4180697.8
4704501175	WF	Magnolia	4682	193	406920.6	4180904.3

4705901148	WF	Magnolia	4877	219	403555.2	4175273.1
4704501204	Rhinestreet	Magnolia	5221	182	420551.7	4170163.2
4704501211	Rhinestreet	Magnolia	4964	177	421530.2	4169815.9
4704501215	Rhinestreet	Magnolia	4991	179	411664.4	4172892.9
4704501183	Rhinestreet	Magnolia	4744	231	411359.7	4174509.8
4704501151	Rhinestreet	Magnolia	4769	158	408826.2	4175406.5
4704501150	Rhinestreet	Magnolia	4606	190	410580.3	4176884.2
4704501149	Rhinestreet	Magnolia	4553	215	4407303.3	4179129.5
4704501190	Rhinestreet	Magnolia	5401	71	406574.8	41802
4704501173	Rhinestreet	Magnolia	4700	126	406389.7	4179477.8
4704500402	Rhinestreet	Magnolia	5282	163	407401.3	4173470.7
4705901144	Rhinestreet	Magnolia	4945	94	401636.9	4165276
4705901173	Rhinestreet	Magnolia	5318	94	401795.3	4172022.3
4705901814	Rhinestreet	Crum-Kermit	3952	149	387238.9	4185065.4

APPENDIX E: WELL PRODUCTION ANALYSIS COMPLETION INFORMATION

API	Completion Formation	Field	Initial Production Year	First 12 Months of Production (mcf)	UTME	UTMN
4704502137	Marcellus	Chapmanville	2008	34783	405013.1	4204704.1
4704502123	Marcellus	Chapmanville	2008	37443	406323.6	4204099.2
4704502030	Marcellus	Chapmanville	2007	36484	406632.5	4205586.9
4704502018	Marcellus	Chapmanville	2007	36561	406509.7	4206119.4
4704502032	Marcellus	Chapmanville	2007	26492	406464.4	4206381.8
4704502016	Marcellus	Chapmanville	2007	25536	406726.4	4206781.2
4704502007	Marcellus	Chapmanville	2007	35353	407354.6	4206822.3
4704502008	Marcellus	Chapmanville	2007	34921	407688.8	4206480.5
4704502006	Marcellus	Chapmanville	2007	34699	407378.8	4206109.6
4704502023	Marcellus	Chapmanville	2007	21889	408200.1	4206148.6
4704502017	Marcellus	Chapmanville	2007	28138	407465.3	4205207.2
4704502020	Marcellus	Chapmanville	2007	31179	408366.9	4205229.3
4704501884	Marcellus	Chapmanville	2007	26480	409741.1	4205262.3
4704501901	Marcellus	Chapmanville	2008	33154	410956.3	4204508.6
4704502063	Marcellus	Chapmanville	2009	23452	410767.3	4201887.1
4704502064	Marcellus	Chapmanville	2009	18481	412685.2	4199866.4
4704501830	Marcellus	Chapmanville	2006	22988	414152.4	4198547.2
4704501828	Marcellus	Chapmanville	2006	110739	414648	4198220.2
4704501820	Marcellus	Chapmanville	2006	59486	415119.4	4198150.1
4704501819	Marcellus	Chapmanville	2006	56470	415696.6	4198450.7
4704501829	Marcellus	Chapmanville	2006	39479	415701.4	4198917.4
4704502122	Marcellus	Chapmanville	2008	19819	407460.9	4198604.8
4704502089	Marcellus	Chapmanville	2009	16607	407314.6	4197478.8
4704501887	Marcellus	Chapmanville	2007	50106	406146.1	4196618.7
4704502009	Marcellus	Chapmanville	2007	42492	406743.5	4196789
4704501979	Marcellus	Chapmanville	2007	31819	407173.4	4196365.6
4704501980	Marcellus	Chapmanville	2007	41198	407610.2	4196569.9
4704501981	Marcellus	Chapmanville	2007	31456	407604.9	4196087.1
4704501999	Marcellus	Chapmanville	2007	37829	408327.6	4195950.3
4704501904	Marcellus	Chapmanville	2007	55169	406858.1	4195516.1
4704501885	Marcellus	Chapmanville	2007	26947	406408	4195569.5
4704501992	Marcellus	Chapmanville	2007	26697	405007.8	4195585.6
4704501973	Marcellus	Chapmanville	2007	43639	407868.8	4195215
4704502002	Marcellus	Chapmanville	2007	55006	407398.6	4194914.5
4705901825	Rhinestreet+Remanent	Crum-Kermit	2007	21801	386298.7	4186832.9
4705901879	Rhinestreet+Remanent	Crum-Kermit	2008	19431	386655.7	4184783.7
4705901792	Rhinestreet+Remanent	Crum-Kermit	2006	23493	386974.2	4183326.4
4705902137	Rhinestreet+Remanent	Magnolia	2011	22755	411187.6	4159121.4

4704500416	West Falls	Magnolia	1981	2182	413380.6	4171909.1
4704501160	West Falls	Magnolia	1992	17790	409647.8	4178487.8
4704501120	West Falls	Magnolia	1988	25055	408019.7	4179861.9
4704501178	West Falls	Magnolia	1992	18099	408109.4	4180697.8
4704501175	West Falls	Magnolia	1992	45285	406920.6	4180904.3
4705901148	West Falls	Magnolia	1991	22370	403555.2	4175273.1
4704501204	Rhinestreet	Magnolia	1996	119934	420551.7	4170163.2
4704501211	Rhinestreet	Magnolia	1994	118728	421530.2	4169815.9
4704501215	Rhinestreet	Magnolia	1995	18541	411664.4	4172892.9
4704501183	Rhinestreet	Magnolia	1992	41638	411359.7	4174509.8
4704501151	Rhinestreet	Magnolia	1991	28270	408826.2	4175406.5
4704501150	Rhinestreet	Magnolia	1991	12703	410580.3	4176884.2
4704501149	Rhinestreet	Magnolia	1991	27803	4407303.3	4179129.5
4704501190	Rhinestreet	Magnolia	1993	17735	406574.8	41802
4704501173	Rhinestreet	Magnolia	1992	39889	406389.7	4179477.8
4704500402	Rhinestreet	Magnolia	1981	1009	407401.3	4173470.7
4705901144	Rhinestreet	Magnolia	1992	11701	401636.9	4165276
4705901173	Rhinestreet	Magnolia	1992	19679	401795.3	4172022.3
4705901814	Rhinestreet	Crum-Kermit	2007	26514	387238.9	4185065.4