Fractured Gas Shale Potential in New York

Prepared for:

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NOTICE

FOREWARD

This report was prepared for New York State Energy Research and Development authority by TICORA Geosciences, Inc. under subcontract to Gas Technology Institute.

The objective of the project was three fold:

Task 1 - Conduct a literature search of the black shale in New York State and construct an electronic bibliography. In addition, gather appropriate references to be used for the following task.

Task 2 - Aggregate, analyze and summarize the productivity potential for Devonian and Ordovician Shales in New York State. General areas include basin geology, regional geology, extent of the shales, shale geochemical characteristics, thickness and fracturing.

Task 3 – Make a presentation on the study results at the New York Independent Oil and Gas Association meeting in New York on November 2002, and prepare a final report for distribution.

ACKNOWLEDGEMENTS

It is important to note the contribution to this report from several people: John Martin of NYSERDA for his continued support of trying to unlock the potential of fractured gas shale in the Northern Appalachian; Richard Nyahay, Rose Schulze, Taury Smith, and Mike Pascucci of the New York Geologic Survey for their invaluable contribution of obtaining reports, well files and geophysical logs; Art Van Tyne for his insights and contribution to the understanding of the Devonian Shales of New York, Don Drazan of the Bureau of Resource Management and Development for his assistance with production data, and for the many researchers who have contributed to the rich geologic literature of New York.

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EXECUTIVE SUMMARY

In 1821, a shallow well drilled in the Devonian-age shale ushered in a new era for the United States when natural gas was produced, transported and sold to local establishments in the town of Fredonia, New York. Following this discovery, hundreds of shallow shale wells were drilled along the Lake Erie shoreline and eventually several shale gas fields were established southeastward from the lake in the late 1800's. Since the mid 1900's, approximately 100 wells have been drilled in New York to test the fractured shale potential of the Devonian and Silurian-age shales. In the 1980's, several shale gas research and development projects were conducted by the United State Department of Energy (DOE) and the New York State Energy Research and Development Authority (NYSERDA). From this work, several one-well shale gas fields were established, of which several are still producing today, however, the drilling activity for fractured shale did not proliferate in the state. Low production rates, low reserves from the shale gas wells and deeper more economically attractive targets contributed to the lack of activity.

While the resource for shale gas in New York is large, ranging from 163–313 trillion cubic feet (Tcf) and the history of production dates back over 180 years, it has not been a major contributor to natural gas production in New York. A review of the history and research conducted on the shales shows that the resource in New York is poorly understood and has not been adequately tested. New technologies in drilling, formation evaluation and stimulation coupled with multiple reservoir completion technology could make shale gas production more economically attractive to operators. Deeper shale-bearing formations such as the Silurian and Ordovician may also hold promise as new commercial shale gas reservoirs. With only a hundred wells drilled over the past century, the true potential of fractured shale reservoirs has not been thoroughly assessed, and there may be a substantial resource available to interested operators in New York.

Experience developing shale gas plays in the past 20 years, has demonstrated that every shale play is unique. A very large number of wells are required to economically and systematically develop a fractured gas shale play. Over 20,000 Devonian Shale wells are producing today in the Appalachian Basin. Over 7,000 Antrim Shale wells are producing in the Michigan Basin and over 1,200 Barnett Shale wells are producing in the Fort Worth Basin today. Each individual play has been defined, tested and expanded based on understanding the resource distribution, natural fracture patterns, and limitations of the reservoir, and each play has required solutions to problems and issues required for commercial production. Many of these problems and solutions are unique to the play. While hundreds of wells have likely been drilled into and produced from the Devonian Shale in New York, over the last 30 years, less than 100 wells have been drilled in the last 30 odd years that tested the gas shale potential. Very few wells have tested the Silurian shales, and no known wells directly have tested the Ordovician Utica Shale.

The data and information available on the Devonian, Silurian and Ordovician shales in New York is limited. A substantial amount of work has been performed concerning geology, including stratigraphy, structure, tectonics, glacial history, however little reservoir characterization work has been done, and only surface natural fracture characterization work has been done on the shales. Continued investigation of the shale potential in New York is warranted. Efforts to study the shale need to be focused in broader geographic areas and should include the evaluation of deeper formations. More data is needed that address the geologic and reservoir properties of the shale. Modern protocols should be used in drilling, testing, completing, stimulating and producing new wells.

1 FRACTURED SHALE HISTORY

The Appalachian Basin in the northeastern United States is an important hydrocarbon province that has been producing oil and gas since the early 1800's. More than 40 trillion cubic feet (Tcf) of natural gas and millions of barrels of oil have been produced from reservoir rocks of all ages. Devonian-age shales are a significant resource in the basin. The Devonian Shale of the basin has been estimated to contain up to 900 Tcf of natural gas, and an estimated 120,000 wells have produced roughly 3.0 Tcf of natural gas in the past 30 years. In addition to Devonian Shale, other stratigraphically older and deeper black shales are present in the basin, and the organic-rich Ordovician shales are believed to be a principle source rock for many of the productive reservoirs in the basin. These shales, though not frequently produced, are often noted in drillers' logs to have significant gas shows when drilling through them, and may be potential reservoirs.

The black shales of New York State have long been known to contain natural gas. In fact, the first known commercial shale gas well was drilled in Chatauqua County in 1821. Since then, many wells have been drilled into and produced from the shales, several fields were established, a large amount of geologic data has been gathered, potential fairways have been identified, and natural fracturing has been studied. Yet despite the early development start and continued interest and study, the potential of black shales has not been adequately tested or developed widely in the state.

Curiosity about the black shales of New York from a geologic perspective and as a fuel source dates back to the late 1700's. The black coal-like appearance and slightly combustible nature of the shales were of interest to the coal industry, and gas seeps in creek beds motivated early explorationists to study the rocks and find use for them. The first know commercial shale gas well was drilled in 1821 in the town of Fredonia, Chatauqua County, New York near a gas seep along Canadaway Creek.[1] The well, drilled by William Aaron Hart, was completed as a gas producer in the shallow Dunkirk Shale. The well was connected to pipeline and provided natural gas to Fredonia's main street businesses and street lamps in the 1820's. Following Hart's success, the development and use of shale gas proliferated along the south shore of Lake Erie, eventually spreading southward into Pennsylvania, Ohio, Indiana, and Kentucky. By the turn of the century hundreds if not thousands of wells had been drilled along the lakeshore and in the basin, and were producing shale gas for domestic and small commercial use. However as exploration advanced, the development of shale gas wells diminished in favor of more productive conventional oil and gas horizons. It was observed early on that shale gas was tight, and while successful wells produced steadily over long periods of time, production volumes were extremely variable and unpredictable, but usually low (<100 mcfd). The mechanisms controlling production from these wells were not understood, and the technology to optimize production was in its infancy.

In the late 1960's, as natural gas reserves in the United States began to diminish, the U.S. Energy Research and Development Administration (ERDA, later the U.S. DOE) initiated a program to evaluate the Nation's gas resource. Recognizing that the Devonian and Mississippian black shales were a major gas resource that required advanced production methods for recovery, the ERDA launched the *Eastern Gas Shales Project* (EGSP) in 1976. The project was a joint research project between the DOE and numerous State, Federal, and private industrial organizations, which were brought together to participate in the research. NYSERDA entered the project in 1979 by initiating a 4 well R&D program. The first well was drilled in northern Allegany County in the summer of 1979, and from 1979 to 1985 thirteen other wells were drilled as part of the program. Detailed analyses of the cores and wells were performed. Core analyses included petrographic and chemical analysis, which are discussed later. The wells were cased, fracture stimulated, and production tested. Several produced enough gas for small-scale commercial use.

2 REGIONAL GEOLOGY

The regional geologic history of the Appalachian Basin is quite complex and lengthy. Many excellent papers and reports provide detailed accounts of all or portions of the structural history and stratigraphy of the basin, many of which are referenced in this document and found in the attached bibliography (Appendix A). This section is a brief overview of the Appalachian Basin.

2.1 NORTHERN APPALACHIAN BASIN SETTING

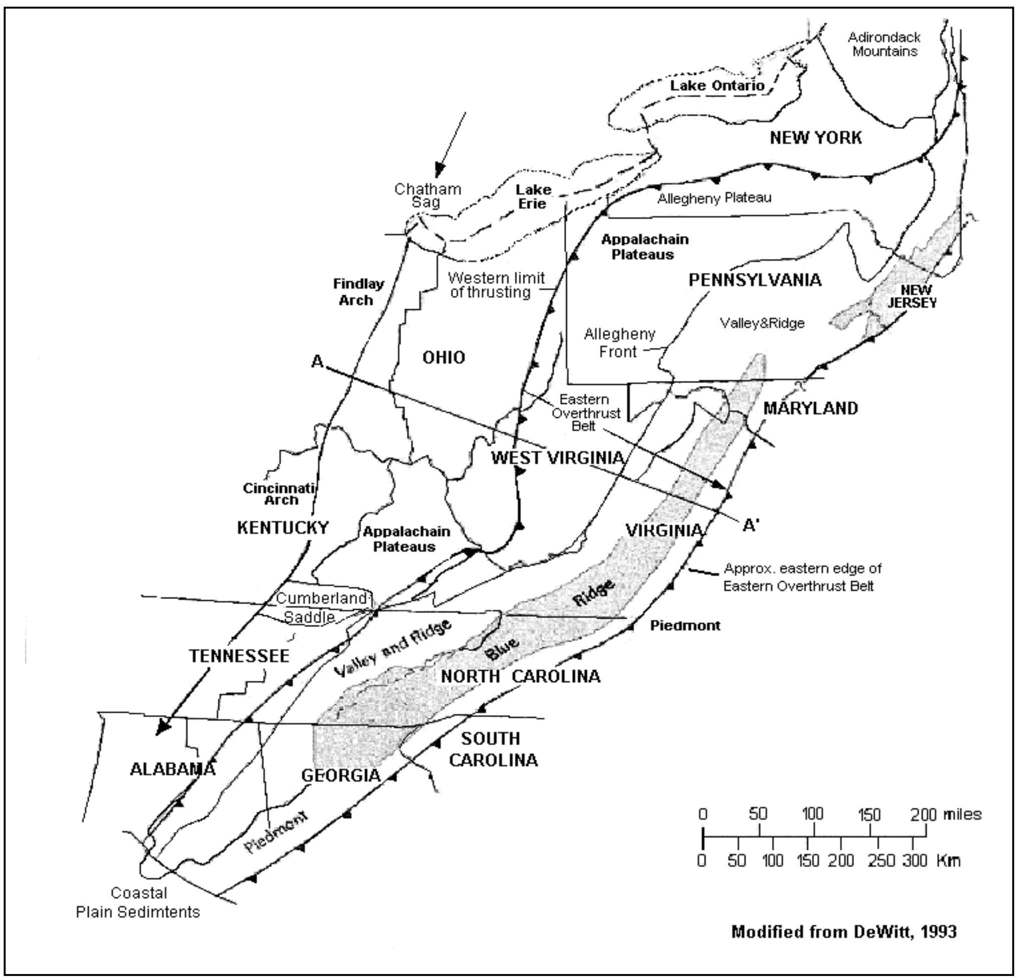
The Appalachian Basin is a northeast-trending, elongate, basin that extends southward from the shores of Lake Erie and Ontario for more than 1,000 miles through New York, Pennsylvania, Ohio, West Virginia, Maryland, Kentucky, Virginia, and Tennessee, into northern Alabama and Georgia (Figure 2.1). Covering an area of roughly 230,000 mi^2, the basin ranges from 75 to 350 miles wide and contains up to 45,000 feet of Paleozoic sedimentary fill. The basin is defined by numerous structural features that were tectonically active during the time that the Paleozoic sediments were being deposited in the basin. Four major structural events shaped the Appalachian Basin; the Grenville, Taconic, Acadian, and Alleghanian Orogenies. These were regional tectonic events that triggered basin subsidence and regional uplift, and associated folding, faulting and natural fracturing. Subsequent erosion of uplifted highland areas supplied the sediments that were ultimately deposited in the Appalachian Basin.

Within the Appalachian region, four broad provinces are recognized.[2] The ***Appalachian Plateaus*** covers about 135,000 mi^2 along the eastern flank of the Cincinnati Arch from Lakes Erie and Ontario to central Alabama where it melds with the Black Warrior Basin. The Plateaus terminate against the Allegheny Front, an east-facing escarpment that extends from New York to Alabama. The ***Valley and Ridge*** covers an area of about 45,000 mi^2 from eastern New York to central Alabama, abutting the Appalachian Plateau segment on the east. It is extensively folded and faulted with crystalline rocks of the Blue Ridge. The Valley and

Ridge and Appalachian Plateaus are composed primarily of Paleozoic sediments. The over-thrusted metamorphic and igneous rocks of the ***Blue Ridge*** and **the *Piedmont*** border the Valley and Ridge on the east.

The basin is asymmetric in cross section. Paleozoic rocks on the west flank of the basin dip gently eastward under the Blue Ridge (Figure 2.2).[2] Along the eastern margin of the basin, especially in the Valley and Ridge segment, the rocks have been greatly thrust faulted, folded, and telescoped by orogenic events of the Allegheny Orogeny. The Blue Ridge and Piedmont segment were thrust westward more than 150 miles over a wedge of the Paleozoic Valley and Ridge sedimentary rocks which were as much as 20,000 feet thick. As a result of the thrusting, the easternmost segment of the Appalachian Basin is hidden beneath the Blue Ridge and contiguous Piedmont province, and is not well defined.

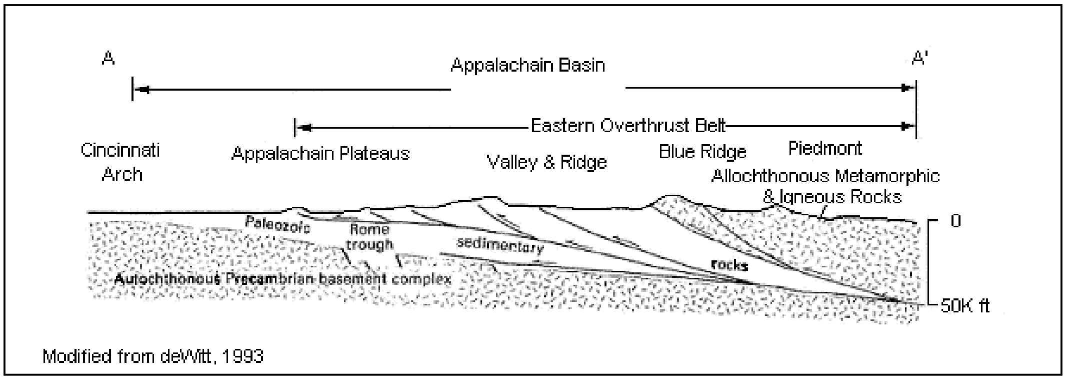
Figure 2.1. Regional Extent of the Appalachian Basin.



The Paleozoic sedimentary rock sequence forms a wedge that thickens from the north toward the southeast. The oldest rocks crop out along the basin margins in the north and east along the Appalachian Mountain belt, and the entire unit ranges from several hundred feet in thickness in the north to over 45,000 feet to the south. Deposition of the rocks was cyclic in nature and the sedimentary layers consist of alternating and interfingering marine and continental deposits lain down as ancient oceans inundated the region and then withdrew. The deposits reflect a myriad of environments of deposition, from deep marine to continental slope and shelf, shallow marine, beach-front, tidal pools, massive deltas, and clastic floodpains.

Both gas and oil have been produced from rocks of most ages in the Appalachian Basin. Conventional reservoirs include the Trenton-Black River Group, Queenston, Medina and Oriskany (Table 2.1). The source of the oil and gas is attributed to the thick, organic-rich black shales. Hydrocarbons generated by these organic-rich zones migrated to the more porous and permeable beds via natural fractures in the rocks, however many of the black shales remain gas charged and have been produced from several small fields in the state (for further discussion see Section 3). They are most productive in the south-central portion of the basin in southwestern Virginia, eastern Kentucky, and southwestern West Virginia, where they are thermally mature and abundantly fractured.[3]

Figure 2.2. Orientation of the Paleozoic Rocks, Central Appalachian Basin.



Through 1999, the Appalachian Basin contained over 21,000 gas shale wells producing approximately 120 Bcf of natural gas annually.[4] Gas resource estimates for this basin range from 206 Tcf to 2,000 Tcf, with technically recoverable resource estimates ranging from 14.5 Tcf to 27.5 Tcf.[5,6,7,8] Most notable are the Devonian-age shales of the basin, which are composed of a complex lithologic sequence of alternating black (organic-rich) and gray (organic-poor) shales. The majority of shale gas production in the Appalachian Basin has been from the Big Sandy and associated fields in Kentucky and southwestern West Virginia. Minor production has come from the Upper Devonian Rhinestreet Member of the West Falls Formation, Dunkirk Shale Member of the Perrysburg Formation and the Lower Devonian Marcellus Shale in New York State.[9]

Table 2.1. Stratigraphic Column of New York; Oil and Gas Producing Horizons

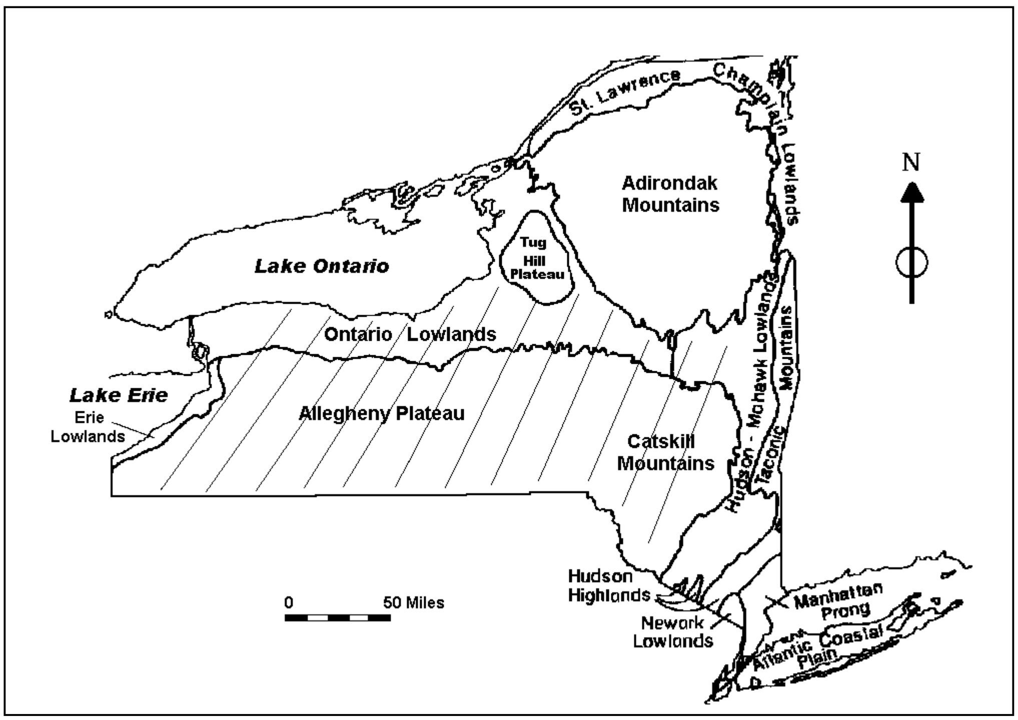
PERIOD		GROUP	UNIT	LITHOLOGY	THICKNESS (feet)	PRODUCTION
PENNSYLVANIAN		Pottsville	Olean	Ss, cgl	75 – 100	
MISSISSIPPIAN		Pocono	Knapp	Ss, cgl	5 – 100	
DEVONIAN	UPPER	Conewango	Riceville	Sh, ss, cgl	70	
		Conneuat	Chadakoin	Sh, ss	700	
		Canadaway	Undiff	Sh, ss	1100 – 1400	Oil, Gas
			Perrysburg-Dunkirk	Sh, ss		Oil, Gas
				Sh		
		West Falls	Java	Sh, ss	365 – 125	
			Nunda	Sh, ss		Oil, Gas
			Rhinestreet	Sh		
		Sonyea	Middlesex	Sh	0 – 400	Gas
		Genesee	Geneseo	Sh	0 – 450	Gas
	?		Tully	Ls	0 – 50	Gas
	MIDDLE	Hamilton	Moscow	Sh	200 – 600	
			Ludlowville	Sh		
			Skaneateles	Sh		
			Marcellus	Sh		Gas
			Onondaga	Ls	30 – 235	Gas, Oil
	LOWER	Tristates	Oriskany	Ss	0 – 40	Gas
		Heldergerg	Manlius	Ls	0 – 10	
			Rondout	Dol		
SILURIAN	UPPER		Akron	Dol	0 – 15	Gas
		Salina	Camillus	Sh, gyp	450 – 1850	
			Syracuse	Dol, sh, slt		
			Vernon	Sh		
		Lockport	Lockport	Dol	150 – 250	Gas
		Clinton	Rochester	Sh	125	Gas
			Irondequoit	Ls		
	LOWER		Sodus	Sh	75	Gas
			Reynales	Ls		
			Thorold	Ss		
		Medina	Grimsby	Sh, ss	75 – 150	Gas
			Whirlpool	Ss	0 – 25	Gas
ORDOVICIAN	UPPER		Queenston	Sh	1100 – 1500	Gas
			Oswego	Ss		
			Lorraine	Sh		
			Utica	Sh	900 – 1000	
	MIDDLE	Trenton-Black River	Trenton	Ls	425 – 625	Gas
			Black River	Ls	225 – 550	
	LOWER	Beekmantown	Tribes Hill-Chuctanunda	Ls	0 – 550	
CAMB.	UPPER		Little Falls	Dol	0 – 350	
			Galway	Dol, ss	575 – 1350	Gas
			Potsdam	Ss, dol	75 – 500	Gas
PRECAMBRIAN				Gneiss, marble, quartzite		

(Modified from NYSERDA 1985).

2.2 NEW YORK STATE

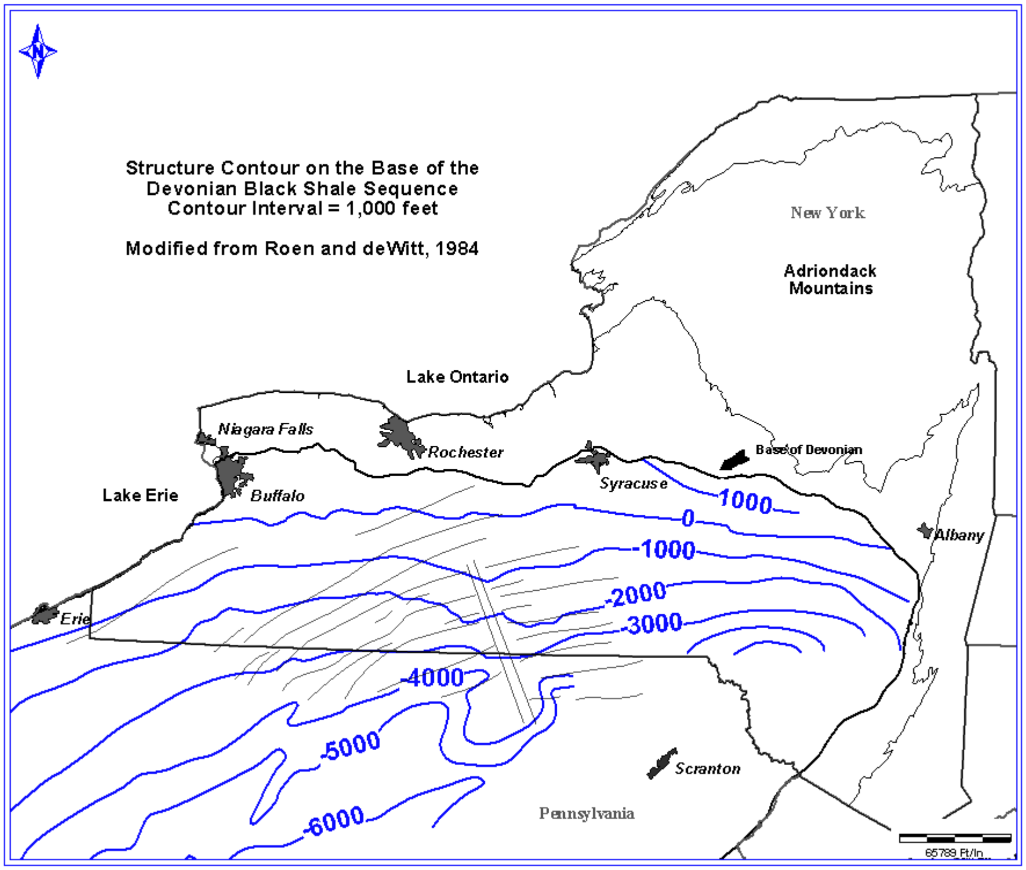
The Appalachian Basin's northern extremity lies in New York State and is defined by the outcrop of Ordovician and younger rocks in the central and western portions of the state which encompass the Ontario Lowlands and Allegany Plateau (Figure 2.3). Lake Ontario and the Adirondack Mountains form the northern boundary, the eastern margin is formed by the Hudson Lowlands and Taconic Mountains, and to the west terminates at the shore of Lake Erie. The structure of this region is fairly simple. Paleozoic rocks overlying the Precambrian crystalline basement outcrop along the northern extent of the Allegany Plateau, and dip gently to the southwest. In the southern portion of New York, a series of small-scale folds are present, extending from Chatauqua to Tioga counties (Figure 2.4). The folds are small anticlines, dipping less than 2^{o}, which are associated with the Appalachian Fold Belt, an arcuate belt of anticlines and synclines that extend southward into West Virginia.[10]

Figure 2.3. Physiographic Regions of New York.



Both gas and oil have been produced from rocks of many ages in New York, and the primary targets for operators in the past have been the gas-bearing sands in the Oriskany, Medina, Queenston, Chemung and Fulmer Valley formations (Table 2.1). The organic-rich black shales are the principal source rock for much of the oil and gas in the basin.[3] In addition, gas shows have been noted frequently in drillers' logs and petroleum related hydrocarbons have been observed in cuttings from the Ordovician-age Utica Shale.[11]

Figure 2.4. Structural Setting, New York.



2.3 STRATIGRAPHY

Organic-rich black shale beds are found in many different age rock formations in New York. Some are massive and very widespread correlating well to the shales in other regions of the Appalachian Basin, while others are thin and limited in area. The following section provides an overview of the stratigraphy of the primary black shale intervals in the Paleozoic section of New York. A large volume of literature exists that thoroughly discuss the many stratigraphic units and variances in New York. Several key references are presented in Table 2.2 and are just a few of the excellent resources which provide a more detailed account of the stratigraphy (for additional references see Bibliography in Appendix A).

2.3.1 Ordovician

One of the oldest and most widespread black shales is the Ordovician-age Utica Shale. The Utica Shale lies conformably above the Trenton Limestone/Dolgeville Formation in New York (Table 2.1). It was deposited very broadly across the Appalachian Basin and into Ontario, and covers thousands of square miles. In New York the Utica is found in outcrop along the west and south-southeast sides of the

Adirondack Mountains, and is well exposed in several locals along the northern margin of the Allegany Plateau (Figure 2.5). It is deeply buried over most of the state of New York, and from outcrop it dips to depths over 9,000 feet in the southern portion of the state.[12]

Table 2.2. Selected References of New York Stratigraphy.

"Geology of New York, *A Simplified Account*, " New York State Museum Educational Leaflet 28, Y.W. Isachsen, E. Landing, J.M. Lauber, L.V. Rickard, W.B. Rodgers, Editors, 2000.
"Distal Sedimentation in a Peripheral Foreland Basin: Ordovician Black Shales and Associated Flysch of the Western Taconic Foreland, New York State and Ontario" D.L. Lehmann, C.E. Brett, R. Cole, G.Baird, GSA Bulletin, June 1995, Vol. 107, No. 6, pp 708-724.
"Silurian of Western and Central New York State", Carlton E. Brett, *in* Sedimentary Sequences in a Foreland Basin: The New York System, 28th International Geological Congress Field Trip Guidebook, July 2-8, 1989, pp. T156: 7-15f
"Stratigraphy of Devonian Black Shales and Associated Rocks in the Appalachian Basin," W. de Witt, Jr., J.B. Roen and L.G. Wallace, *in* Petroleum Geology of the Devonian and Mississippian Black Shale of Eastern North America, USGS Bulletin B 1909, Chapter B, 1993.
"Thickness, Extent of and Gas Occurrences in Upper and Middle Devonian Black Shales of New York," A.M. Van Tyne and J.C. Peterson, Second Eastern Gas Shales Symposium, Volume 1, 1978.
"Stratigraphy of the Subsurface Lower and Middle Devonian of New York, Pennsylvania, Ohio and Ontario," Lawrence V. Rickard, New York State Museum Map and Chart Series Number 39, 1989.

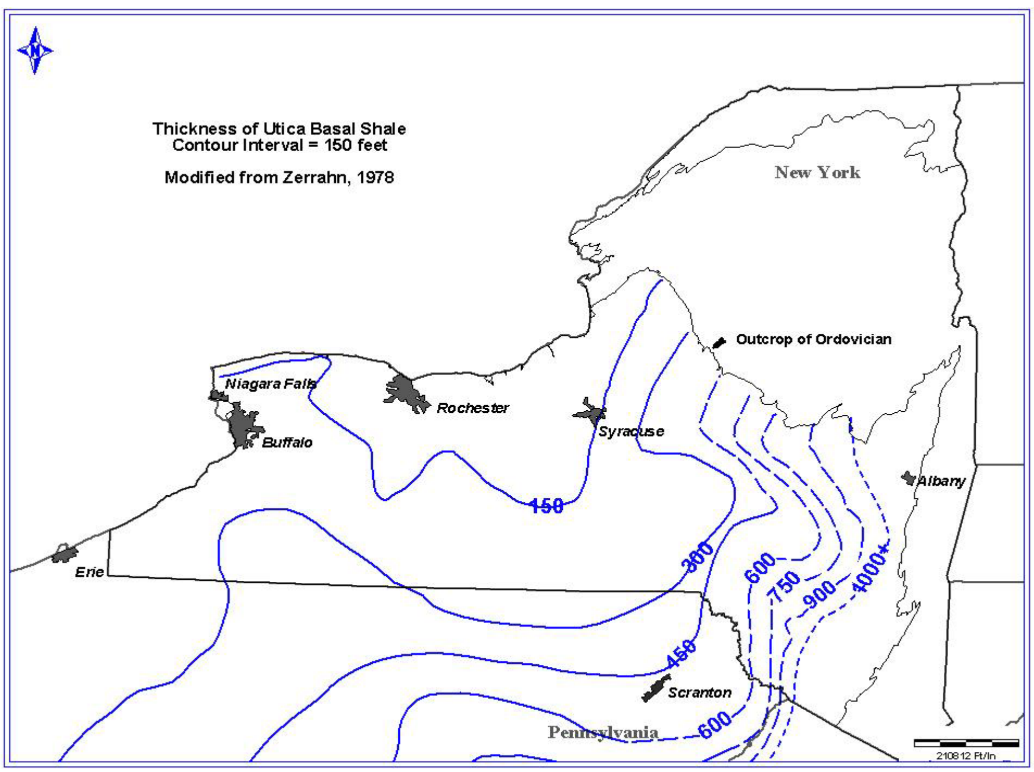
The Utica is a massive, fossiliferous, organic-rich, thermally mature black to gray-black shale, and is considered to be the source rock for Lower Devonian through Cambrian production and shows. The Utica was deposited in a deep marine basin with a subsiding trough that generally trended north-south. It interfingers with the basal Dolgeville formation, which is composed of alternating beds of limestone and shale. Source rock for the organic-rich black shale was supplied from the eroding highlands to the east. Slowly the deep marine trough was filled in, and deposition of the upper Utica spread westward. The westward migration was periodic which is reflected in the presence of at least five facies intervals, which are bounded by unconformities or condensed beds.[13] Each unit represents a pulse of subsidence and subsequent sedimentation in the basin, and all have several similarities. Each interval onlaps argillaceous limestone, and has shifted westward with respect to the underlying unit. The base of each unit is defined as a disconformity and/or stratigraphically condensed interval, and each appears to record a localized deepening event. The overlying black shale unit is thinner than the previous unit.

The thickest section of the Utica is found along the Mohawk Valley and was deposited in the subsiding trough where it is well over 2,000 feet thick. It thins to the north and west to less than 100 feet along the Lake Erie shoreline where it becomes somewhat silty. Over much of New York State, the Utica is less than 300 feet thick (Figure 2.6).[14] The Utica is overlain by coarser clastics of the Lorraine Shale, which consists of shale, siltsone and fine-grained sandstones, which were deposited as the marine environment prograded westward and deltaic deposits pushed across New York from the east. Oil and gas shows have been reported in the black shale of the Utica and in its Dolgeville member, including a recent report of 1 MMscf/day.[15]

Figure 2.5. Utica Shale near Dolgeville, New York.

(from University of Rochester, www.earth.rochester.edu/ees201/Mohudtrip/dolge.html).

Figure 2.6. Isopach of the Utica Shale.



2.3.2 Silurian

The Silurian rocks of New York were deposited in the northern end of the Appalachian foreland basin during a relatively quiet tectonic time. They represent a short interval of geologic time, roughly 20 million years, however reflect a wide variety of depositional environments. Many of the Silurian rocks are extremely fossiliferous, indicating deposition in relatively shallow warm water. Silurian rocks in New York consist primarily of dolostone, limestone, evaporites, medium-gray and greenish-gray shales, and thin but persistent beds of phosphatic nodules and oolitic or fossil-rich hematite. No information regarding the organic content and thermal maturity of Silurian shale has been found. As they are primarily gray shales (there is one black shale member) they are not organically rich in general, however two shales in the Clinton Group are of interest because of their close proximity to the gas-charged productive horizons, and because two wells are reported to produce natural gas from Clinton Groups shales. However it may be that the gas in the producing rocks migrated there from other source rocks.[16]

At the base of the Silurian is the Medina Group (Table 2.1), a clastic wedge that prograded from the southeast to northwest.[17] It consists of a basal, fine-grained sandstone, deposited as beach and dune sands near the shore of a shallow transgressing sea. This is overlain by layers of mud, sandstone, siltstone, and shale, which record alternating marine/continental deposition. A quartz pebble conglomerate marks the base of the Clinton Group, a dominantly marine succession of rocks consisting of fossil-rich shale and shell-rich carbonates containing iron-ore deposits, but also fossil poor siltstones and shales, gray, green and black in color.

The Sodus Shale was deposited near shore in shallow warm water, and contains a readily identifiable "pearly shell" limestone layer, which formed as a result of a very dense population of small shellfish. The shale is greenish-gray to purplish and was probably deposited in shallow, stagnant, low energy water. One well is reported to produce from the Sodus Shale in Seneca County (see Section 4.3). Overlying the Sodus is the Williamson Shale, a black shale which was deposited in deep, almost lifeless, anoxic water which was created by the presence of a great deal of iron in the sediments. In a drastic change of environment, the Williamson is overlain by a fossil rich limestone bed, and the Rochester Shale. The Rochester Shale is brownish-gray, calcareous, and fossiliferous with interbedded argillaceous limestone layers, and is well exposed in numerous road cuts and creeks (Figure 2.7). One well is also reported to produce from the Rochester Shale in Seneca County (see Section 4.3).

Overlying the rocks of the Clinton Group is a continuing sequence of near-shore/marine rocks of the Lockport Group. The alternating layers of sand, shale, limestone are rich in fossils. The overlying Salina Group was deposited near-shore, and contains shales, dolostone, and numerous evaporite beds. The salt beds of the Salina had a great influence on the structural deformation of overlying rocks in the basin. The salt layer divides the rocks of the Allegheny Plateau horizontally, separating the youngest Silurian and Devonian rocks above from lower Paleozoic rocks below.[18] The salts, which are extremely malleable, provided a zone of weakness that allowed the younger rocks above to slide to the northwest during regional compression without significant folding and faulting. The resulting horizontal fault, or *décollement* separates the fixed rocks below form the transported rocks above. This is further discussed in section 2.6.

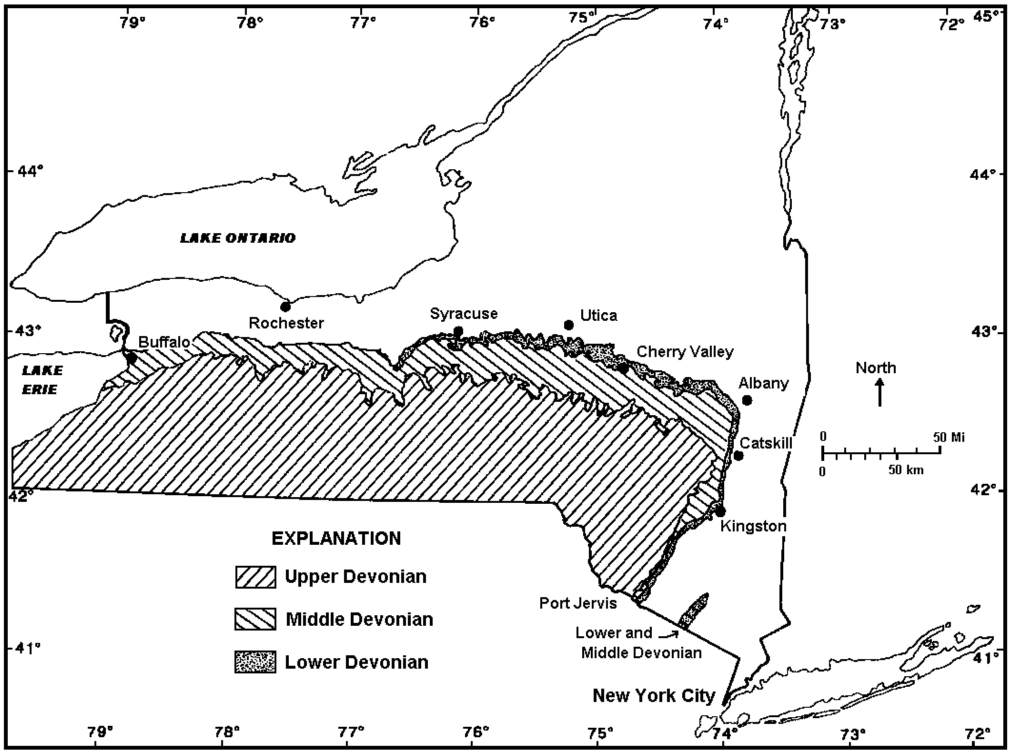
Figure 2.7. Rochester Shale Outcrop in New York.

(from http://www.earth.rochester.edu/ees201/ Rochester_FT/rochester.html).

2.3.3 Devonian

The Devonian section covers approximately 22,500 square miles in south-central New York (Figure 2.8), and represents some 50 million years of history. It crops out along the northern and eastern margin of the Allegheny Plateau and is roughly 3,000 feet thick near Lake Erie, where it is composed primarily of rocks with marine origins. To the southeast, it thickens to over 9,000 feet, and is composed primarily of rocks of continental origin.[18] Depth to the base of the group increases from outcrop to over 4,000 feet in southern New York (Figure 2.9). The black shales in the Devonian section generally are thickest in the western and central portion of the Allegheny Plateau. To the east, they thin and pinch out, grading into coarser gray shales and siltstone. Interbedded are several thin, but widespread limestone units, which serve as marker beds used to differentiate between the numerous formations.

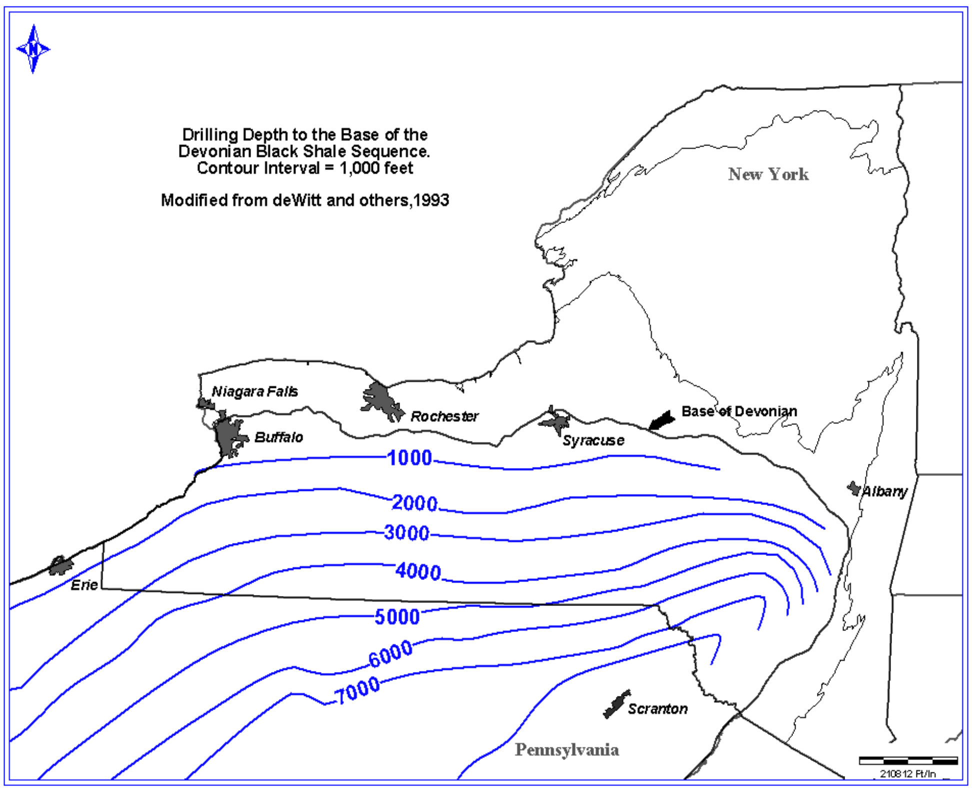
Figure 2.8. Devonian Outcrop in New York[18]



The gas-bearing shale portion of the Devonian in New York occurs in the Middle and Upper Devonian, and extends from the top of the Onondaga Limestone through the Perrysburg Formation (Figure 2.10) [19]. They are in ascending order: the Hamilton Group, Genesee Formation, Sonyea Group, West Falls Formation, and Canadaway Group. The rocks of the Hamilton Group are the oldest strata of the Devonian gas shale sequence. The group overlies the Onondaga Limestone, and consists of black and dark gray shales in the lower part, and limestone, light gray shale and mudstone in the upper part. The Hamilton Group outcrops along the northern margin of the Allegheny Plateau, and thickens eastward from 250 feet near Lake Erie to over 2,500 feet in Ulster and Green counties. The Hamilton has been subdivided into four units: the Marcellus, Skaneateles, Ludlowville, and Moscow, which are separated by thin limestone beds. The basal unit of the Hamilton is the Marcellus Shale. The Marcellus formation is highly radioactive and regionally extensive, covering most of the Allegheny Plateau and extending southward through the Appalachian Basin. It is a “sooty” black/brown to dark gray fissile shale with interbedded layers of medium-gray shale and limestone nodules or beds of dark gray to black limestone. It ranges from 25 feet to over 100 feet in thickness.

The Stafford Limestone overlies the Marcellus and marks the base of the Skaneateles Formation, which is a dark to medium gray fossiliferous shale and mudrock, containing a thin, black shale, the Levanna Shale. The Skaneateles is more clastic in nature than the Marcellus and contains some sandy layers. It is overlain by the Centerfield Limestone, which marks the base of the Ludlowville Shale. The Ludlowville is a dark gray basal shale, overlain by a lighter shale. Overlying the Ludlowville is another limestone, the Tichenor Limestone (Portland Point Limestone near Ithaca), and the Moscow Shale. The Moscow consists mainly of medium-gray calcareous mudrock and shale, overlain by the Tully Limestone in west-central New York. The Genesee Formation overlies the Tully Limestone in west-central New York where the Tully is present, and is the basal Upper Devonian Formation. The Genesee Formation thickens eastward from only several feet at Lake Erie to over 1,200 feet in central Tioga County, and is subdivided into the Geneseo Shale, Lodi Limestone, Penn Yan Shale, Genundewa Limestone, and West River Shale. Several of the shales grade eastward into each other to from coarse-grained shale and sandstones units including the Ithaca, Renwick and Sherburne members.

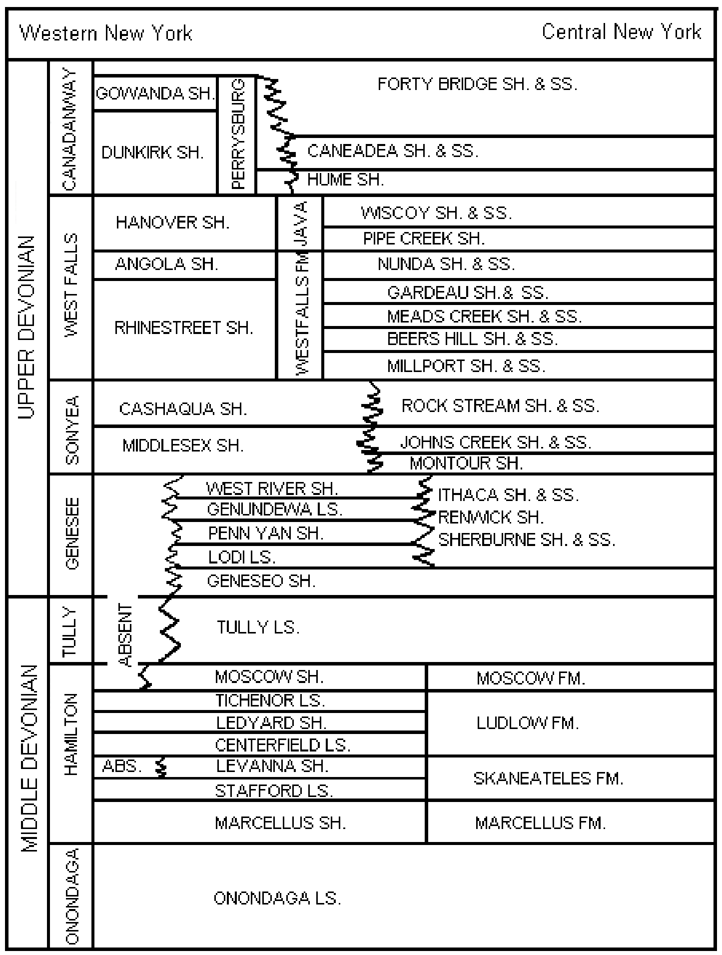
Figure 2.9. Drilling Depth to Base of the Devonian.



The Geneseo Shale is the basal unit, and is the primary black shale in the formation. It is a fissile, organic-rich shale which when broken emits a distinct petroleum odor.[2] The Geneseo attains a maximum thickness of 125 feet in central Steuben County. The Lodi Limestone overlies the Geneseo and consists of large discoidal limestone nodules in a bed of dark-gray fossiliferous siltstone. The overlying Penn Yan and West River shales are dark gray to medium gray organic-rich shale and mudstone, with some beds of black shale that extend into the Renwick. A thin limestone, the Genundewa, is found between the two shales in central New York, but pinches out southward and the shales grade into each other.

The Sonyea Group overlies the Genesee Formation and is subdivided into the Middlesex Shale and the Cashaqua Shale. Thickness of the Sonyea increases from approximately 10 feet at Lake Erie to over 800 feet in Tioga County. Like the Geneseo, the Middlesex is a black, organic-rich shale in western New York. Interbedded are layers of dark gray and brownish-black shales. It covers much of southern New York, and averages 65-75 feet thick in Yates and Steuben counties, and thins to the west to less than 10 feet. The Cashaqua is a gray shale with an abundance of flat ellipsoidal limestone nodules, and a few thin layers of black shale. The two shale members grade eastward into a thickening sequence of siltstone and silty shale, which is part of a common turbidite facies of the Catskill Delta.

Figure 2.10. Devonian Stratigraphic Column.[19]



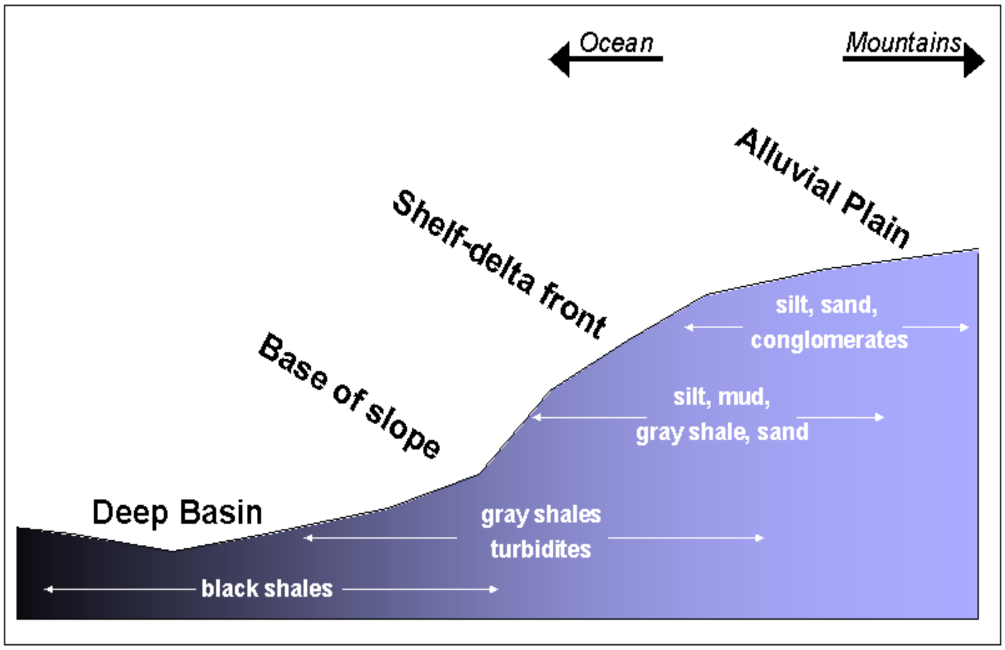
The West Falls Formation overlies the Sonyea Group, and consists of two shale-bearing formations, the West Falls Formation and the Java Formation. The Rhinestreet is the basal shale unit of the West Falls Formation. It is a thick, fissile, black shale out ropping in Chatauqua County where it is about 140 feet thick. To the east it thickens rapidly as it grades into and interfingers with the overlying gray Angola shale reaching a thickness of over 1,200 feet at the Allegany-Steuben County line, however the black shale component of the Rhinestreet thins eastward to less than 5 feet in Allegany County. The Overlying Java Formation ranges from 100 feet in thickness in western New York to over 600 feet in Steuben County. At the base of the Java is the thin, black Pipe Creek Shale. It is persistent, organic-rich black shale throughout its lateral extent. It is thin, not more than 25 feet at its maximum in south-central Cattaraugus County, and pinching out in northern Steuben County. The Hanover Shale is a gray shale, with some interbedded black shale beds. It thickens to the east grading into silty shale, siltstone, and sandstone.

The uppermost unit of the black shale sequence is the Perrysburg Formation of the Canadaway Group. It is approximately 300 feet thick near Lake Erie and increases in thickness to over 700 feet in Cattaraugus County, thinning again toward Steuben County. The Perrysburg consists of a basal black shale, the Dunkirk Shale, overlain by the gray Gowanda Shale Member. The Dunkirk is another extensively deposited, organic-rich, black shale in the basin with equivalent shales (the Huron and Ohio) extending south in to Alabama. In New York, the Dunkirk is a grayish-black to black shale containing some medium gray shales and siltstones in the upper part. It crops out and is well exposed in the vicinity of Dunkirk, Chatauqua County, ranging from 50 feet in thickness in the east to 110 feet in central Erie County. The black shale component of the Dunkirk varies from 50 feet in Chautauqua County to less than 25 feet in south Cattaraugus County.[20] The overlying Gowanda Shale is a gray shale with siltstone and very fine-grained sandstone, and an occasional black shale bed. In central and eastern New York the black shale content diminishes rapidly as the two formations grade into one another. From the Late Devonian into the Early Permian, the basin continued to fill with coarse clastics primarily of continental origin, which were deposited as the delta migrated to the west.

2.4 DEPOSITIONAL ENVIRONMENT AND THICKNESS OF BLACK SHALES

The environment of deposition for the marine shale sequences in the Appalachian Basin consisted of four broad regions; an alluvial plain, a shelf-delta front, the base of the slope, and the deep basin as depicted in Figure 2.11.[21] Deposition of the Paleozoic sediments occurred as mountains generally located to the east of the basin eroded. Sediments were then transported westward via a massive delta complex and deposited on the alluvial plain and into the adjacent marine environment. Rocks of the alluvial plain are coarse conglomerates, pebbly sandstones, and siltstones and mudstones that contain few animal fossils. Rocks of the shelf and delta front were deposited in the near shore marine environment, and consist of very fine grained sandstone, gray and green shale, siltstone and mudstone. Marine fossils are abundant as animal life thrived in the nutrient-rich, warm water, and limestone layers formed on the shelf in quiet water during times of low sediment input. The rock layers of the shelf commonly show ripple marks, cross-bedding, laminations, bioturbation, and roots traces. The rocks become more fine grained seaward and are layered in very thin beds. Rocks of the Slope consist of black and medium to dark gray shale, mudstone and siltstone. Occasional layers of thin very fine-grained sandstone are interbedded. Fossils are not abundant as marine life associated with the deeper water consisted mainly of swimmers and bottom dwellers. Rock layers are finely laminated, and contain casts of grooves, trails and tracks of the bottom dwellers, and ripple marks. Turbidite beds of siltstone are frequently present on the slope and at the base of the slope, and were deposited by density currents caused by churned up sediments that flow down-slope along the bottom of the sea floor. [22] At the base of the slope is the deep basin where only very fine-grained mud and organic matter were deposited. Commonly this water is so deep that is devoid of oxygen, thus the organic matter accumulates without breaking down and organic-rich black shale forms. The lack of oxygen in the water also contributes to the accumulation of iron, and is observed in the presence of iron sulfide minerals (pyrite).

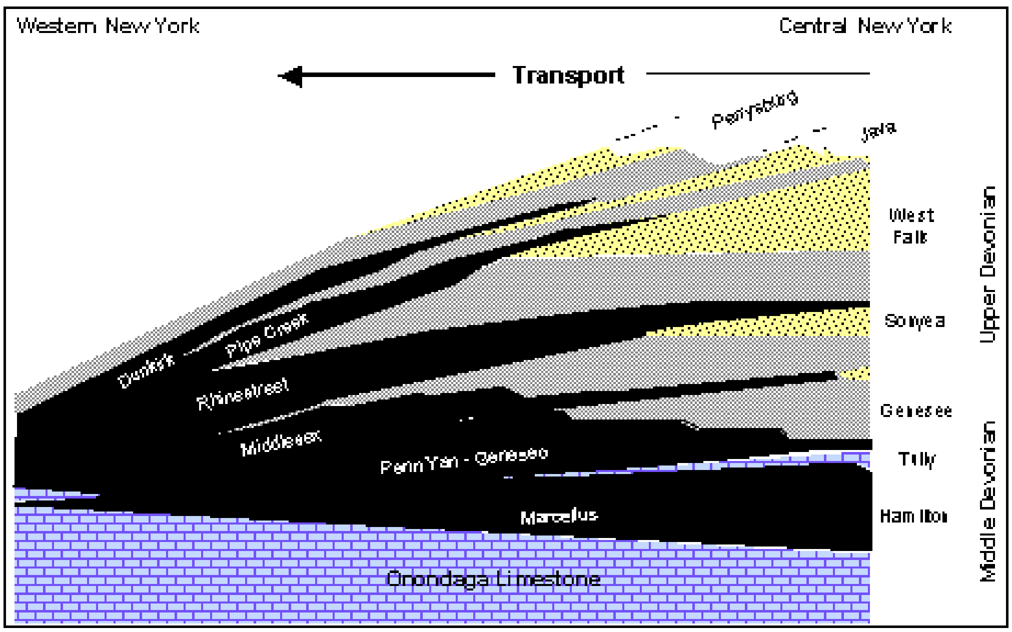
Figure 2.11. Deposition Model; Organic-rich Black Shales.[21]



The resulting clastic wedge that formed from the eroding highlands consists of very thick coarse conglomerates and sands in the east that grade westward (seaward) into finer-grained beach deposits, and open marine deposits (Figure 2.12).[22] The black shales coalesce in western New York where the deep marine basin existed quite constantly, and most extend south and west into Pennsylvania, Ohio, and West Virginia to varying extents. Changes in sea level and fluctuations in the rate of sediment supply caused the transgression and regression of the marine environment. During marine transgression, the deep marine basin environment would expand up the slope, onto the shelf and perhaps even across the shore zone, spreading east and south. This is reflected in the deposition of black shales over gray and green shales and sands of the near shore environment. When sediment supply increased, or sea level dropped, the marine environment regressed and the delta complex and associated clastic rocks pushed westward, depositing the interbedded gray shales, siltstones and sandstones. This type of cyclic deposition occurred repeatedly during Devonian time affecting the extent of deposition of each interval.

The thickness of the Devonian black shale has been evaluated by several authors, including Van Tyne, De Witt, and Roen.[19, 23, 24] The thickness of each black shale bed is not depicted in this report but is well depicted by these authors in numerous reports, however thickness of each unit varies somewhat by author depending upon their methodology. Most black shales are easily recognizable on gamma-ray logs by their strong positive deflections (Figure 2.13). Thickness is determined by picking shale where the gamma-ray log exceeds 20 API units in positive value above the gray-shale base line. However, Van Tyne noted that "in certain cases, much of the black shale present does not exceed the 20 API limit and thus constitutes a thicker section than that measured in this way from the log," which was particularly true in the Genesee and Hamilton groups, where differences in thickness in the sample studies exceeded the log response pick by a factor of 10 or greater.[19]

Figure 2.12. Facies of the Middle and Upper Devonian.



De Witt noted in his evaluation that throughout much of the western and central Appalachian Basin the 20 API criteria are applicable in picking black shale thickness; however that it cannot be applied with assurance in the eastern part of the basin where the black shales lose the positive gamma-ray deflection.[23]

As determined by de Wit using the 20 API gamma ray cut off, the net thickness of radioactive Devonian black shale in New York ranges from less than 100 feet to over 500 feet (Figure 2.14).[23] Generally the individual black shale units thicken from the western-central portion of the Allegheny Plateau toward the south/southeast. They are thickest in south-central New York, and thin to the east, grading into gray shales. The Hamilton Group black shales (primarily the Marcellus) range from less than 50 feet to about 100 feet over much of southern New York, but locally thicken to over 250 feet in northeast Tioga County. The Genesee Formation black shale is present in the western and central portion of the Allegheny Plateau, and ranges from less than 25 feet to over 125 feet in southern Steuben County. The Sonyea Formation (Middlesex black shale) is fairly thin, and not widespread, and ranges from less than 25 feet to just over 75 feet. The West Falls Formation, containing the massive and extensive Rhinestreet Shale, ranges from less than 150 feet to over 300 feet in southwestern New York. The Perrysburg Formation is present in southwestern New York, and thickens from less than 50 feet Chatauqua County to over 100 feet in central Erie County.

Figure 2.13. Gamma Ray Signature of Radioactive Black Shale.

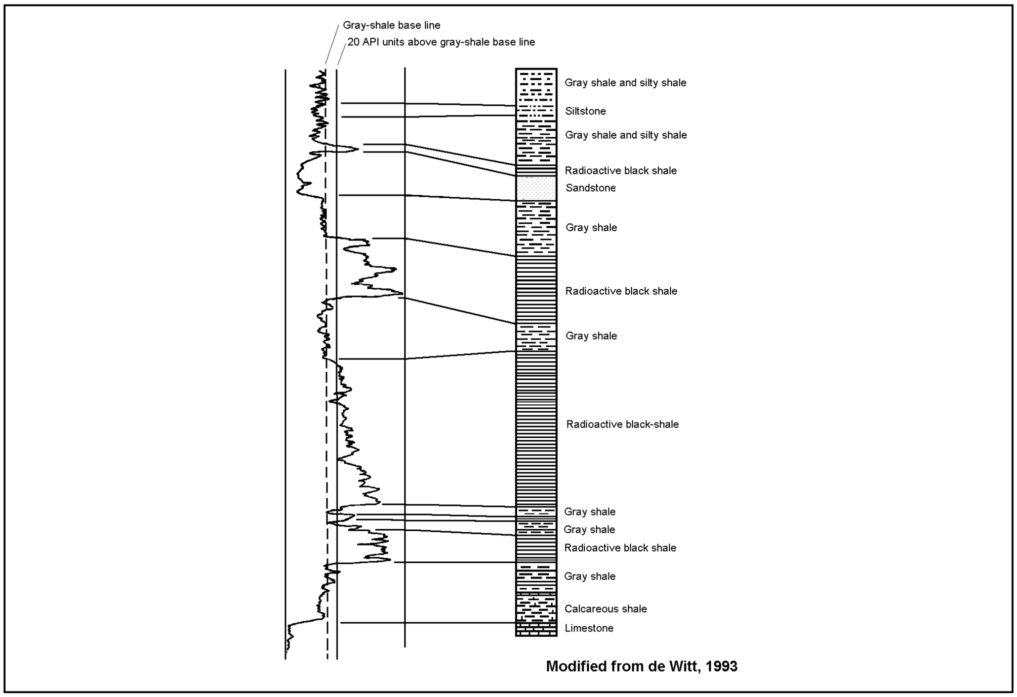
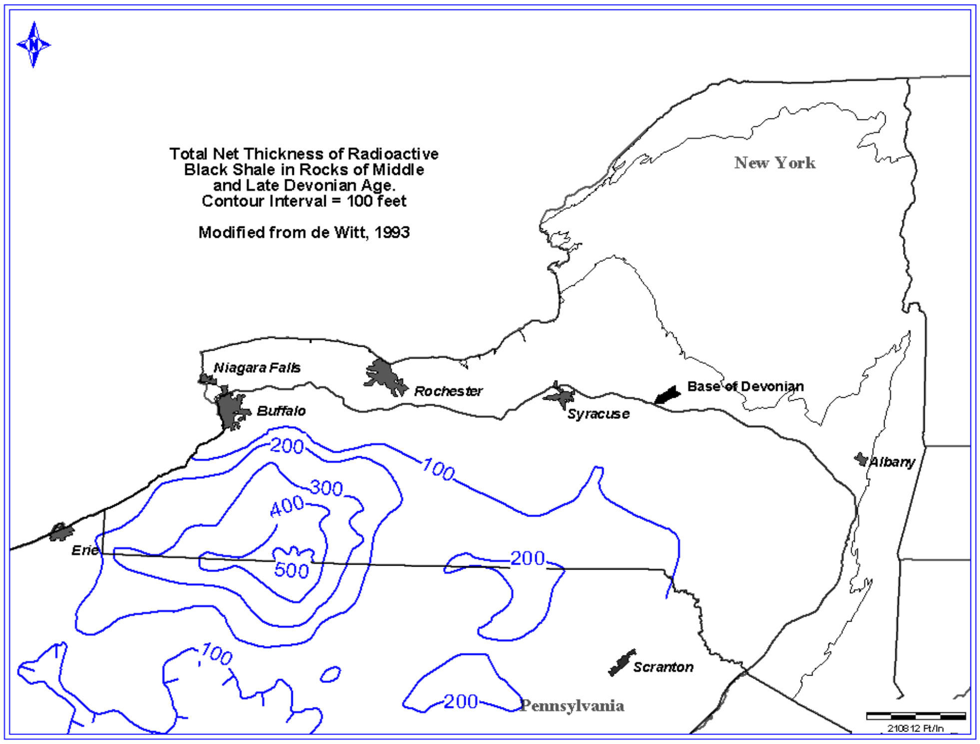


Figure 2.14. Radioactive Black Shale Thickness in New York.



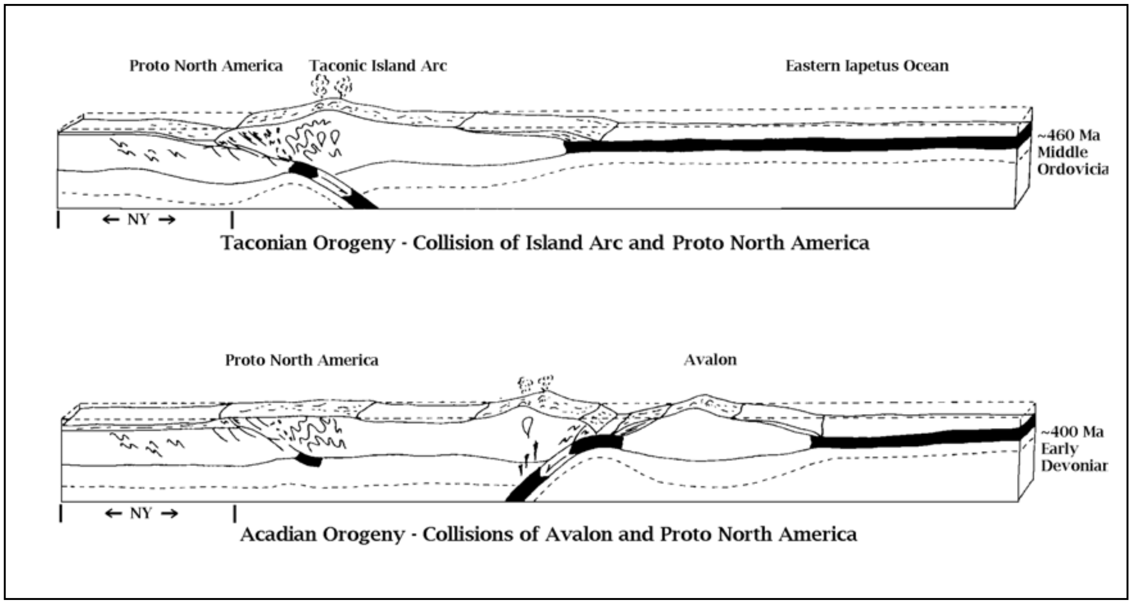
2.5 STRUCTURAL HISTORY

Several major events are very closely associated with the formation of the sedimentary rocks and structural features in New York and the Appalachian Basin. An excellent structural history of the state is presented in "**Geology of New York**, *A Simplified Account*, " New York State Museum Educational Leaflet 28, 2000.[18] Much of the following section comes from that report.

During the late Cambrian and Ordovician periods, about 500 million years ago (mya), the northeast region of North America was located near the edge of the proto-North American continent. At that time, the northeast consisted of a passive plate margin along continental shelf. It was a depositional center for the ancient Iapetus Ocean and sedimentary deposits collected on the shallow marine shelf. Much further to the east, on a separate plate, a volcanic island arc was forming. The proto-North American plate was slowly subducting under that plate, and eventually the North American Plate collided with the volcanic island arc resulting in the *Taconic Orogeny* (Figure 2.15).

During the Middle to Late Ordovician continued compression pushed the rocks in the east toward the west. Faulting and over-thrusting resulted in the formation of the Taconic Mountains along the eastern North American plate, and a foreland basin developed to the west of the mountains in a sea that covered the middle of proto-North America. As the mountains eroded, huge rivers flowed down the western flank and the deposits formed the enormous Queenston Delta of the Upper Ordovician. Sedimentation continued in the basin until the latest Ordovician/Early Silurian when the region rose above sea level and erosion dominated. The majority of the Silurian Era was relatively quite tectonically, as an inland sea spread across the region depositing shallow marine sediments and organic debris.

Figure 2.15. Acadian and Taconic Orogenies.[18]

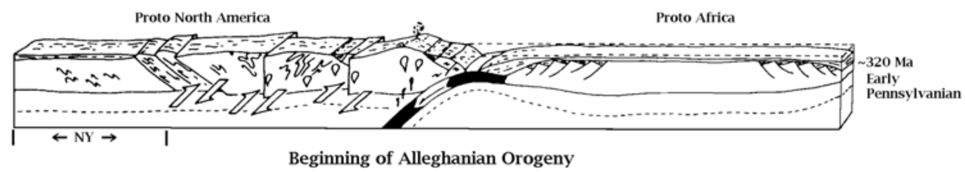


The next major event was the *Acadian Orogeny*, a continent-continent plate collision that began during Middle Devonian time and continued throughout Upper Devonian time (approximately 370-335 mya). The area of Acadian deformation was also located along the easternmost portion of North America. It caused uplift and faulting along the plate boundaries, and initiated subsidence of the foreland Appalachian Basin, which was submerged by an ocean. The Acadian Orogeny had several effects on New York structurally, but it was probably most intense to the north/northeast of New York. The highly metamorphosed rocks north and south of the Hudson Highlands and in the southeastern portion of the state reflect the intensity of the orogeny. A major facet of the orogeny was the elevation and subsequent erosion of the Acadian Mountain Range. As the mountains eroded, sediments were carried westward forming a thick clastic wedge termed the Catskill Delta that supplied the sediments comprising the Middle and Upper Devonian.

The last orogeny, the *Alleghanian Orogeny,* produced the modern structural configuration of the Appalachian Basin (Figure 2.16). It began during the late Mississippian to early Pennsylvanian time (from about 330-250 mya) and occurred as the proto-Africa slid southward past the proto-North American. As it slid, it rotated clockwise and pushed westward against North American. This created very strong compressional forces that caused faulting and uplift along the eastern margin of the Appalachian Basin.

The result was the creation of the Appalachian Mountains and the very complex Valley and Ridge, and Blue Ridge regions of the basin.

Figure 2.16. Beginning of the Alleghanian Orogeny.[18]



In New York, compression during the Alleghanian Orogeny was primarily from the southeast toward the northwest. The rocks in were slowly squeezed and eventually fractured. Major deformation did not occur however in the Devonian-age rocks because of the presence of the Salina salt beds (Upper Silurian) which created a *décollement*, (a horizontal fault plain) which allowed the layers above the salt to slide northwestward with relatively minor structural deformation. However, the Salina Salt pinches out just south of Buffalo, Rochester, and Syracuse, and this created a barrier for the sliding rocks. Rather than folding however, brittle limestones and sandstones broke into slabs and slid past each other stacking up like shingles on a roof. Weak shales and siltstones squeezed together like clay and shortened in response to the compression (layer-parallel shortening). The breaking of the stronger rocks resulted in the formation of a series of low-relief anticlines (less than 2^o dip) in southern New York (Figure 2.4).[25] They formed as the shales flowed and draped over brittle mounds of broken\stacked limestone units.

After the Alleghanian Orogeny, the continents had joined together to form one large continent, *Pangea*. This however was short-lived in geologic time, as the continent began pulling apart about 220 mya in a worldwide rifting event. A divergent plate margin developed between North America and Africa along the eastern seaboard, and as Africa pulled away, the continental crust broke and expanded, becoming a basin and range province.

2.6 NATURAL FRACTURING

The rocks of the New York were strongly affected by the various stress regimes operating during the orogenic events mentioned above, and several episodes of natural fracturing occurred in the region. Natural fracturing is visible at many locations in New York (Figure 2.17). The regional fracturing patterns in the Devonian rocks of New York have been studied in depth by numerous authors including Parker, Engelder, Evans, Gross, and Loewy.[25,26,27,28,29]

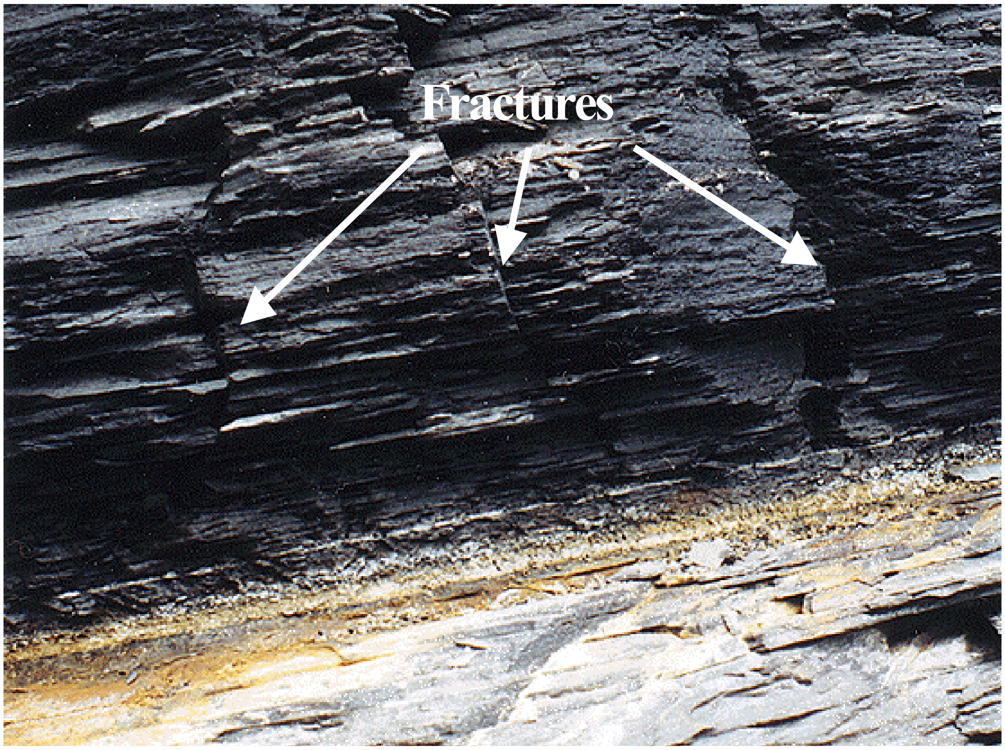
Geologic studies of natural fracturing in New York indicate that various different vertical joint sets are present within the rocks of Middle and Upper Devonian-age. Several different types of fractures (*joints*) are observed in the rocks, and each formed at different times and under varying circumstances.[18] *Alleghanian joints,* are planar cracks that formed during the Alleghanian Orogeny in response to the compression exerted upon the rocks. *Release joints* formed during the Mesozoic Era, and resulted from rock expansion as erosion removed many layers of overlying rock. *Unloading joints* formed later as the rock cooled and reflect the present stress field in the region.[18] The orientation of joints is related to the trajectory of the stress setting during the time of fracturing, and the orientation of maximum principal stress changed frequently during the regional geologic history. Generally, vertical joints propagate normal to the least principal stress, following the trajectories of the stress field at the time of propagation, thus the joint systems in the basin have varying orientations.

Organic content appears to have been a significant factor in joint development, and not all joint sets are present in all rocks. Black shales in particular have higher joint densities than adjacent gray shales, and joints often terminate at lithologic boundaries as seen in Figure 2.17.[25] Some beds contain several different joint sets, while adjacent beds may contain only one set, thus the total joint density in a rock layer depends on the organic content and propagation mechanisms of the jointing episode. Five joints sets have been categorized by Loewy, and were determined based on their "clustering of orientation and similarity of morphology" (Table 2.3). Timing of each jointing episode was determined by comparing abutting relationships between the different joints. Where a joint terminates against another joint, the terminating joint (abutting) is younger than the abutted joint. The various jointing episodes are discussed below from oldest to youngest as determined by Loewy.

The oldest and most dominant joint set consists of north-northwest to north-south (N-NW) cross-fold (CF) joints (Figure 2.18). These joints are deeply propagated fractures that are perpendicular to and cut across the low-relief anticlinal folds in southern New York.

Their orientation rotates slightly from northwest to north as the folds curve and flatten out. The cross-fold joints are present in black shales and are very well developed in gray shales and siltstones, and are rarely mineralized. Engelder has attributed the fold joints formation to natural hydraulic fracturing that occurs when fluid pressure increases in a rock layer by compaction or compression. The increase in pressure eventually causes jointing, and as the joint grows, the joint volume increases and internal fluids will decompress causing a decrease in the internal fluid pressure. Thus a natural hydraulic fracture propagates in increments and the fluid pressure must be recharged in order for a propagation to continue. Flow from matrix porosity can recharge the pore pressure within a joint.[29]

Figure 2.17. Natural Fractures in Utica Black Shale.

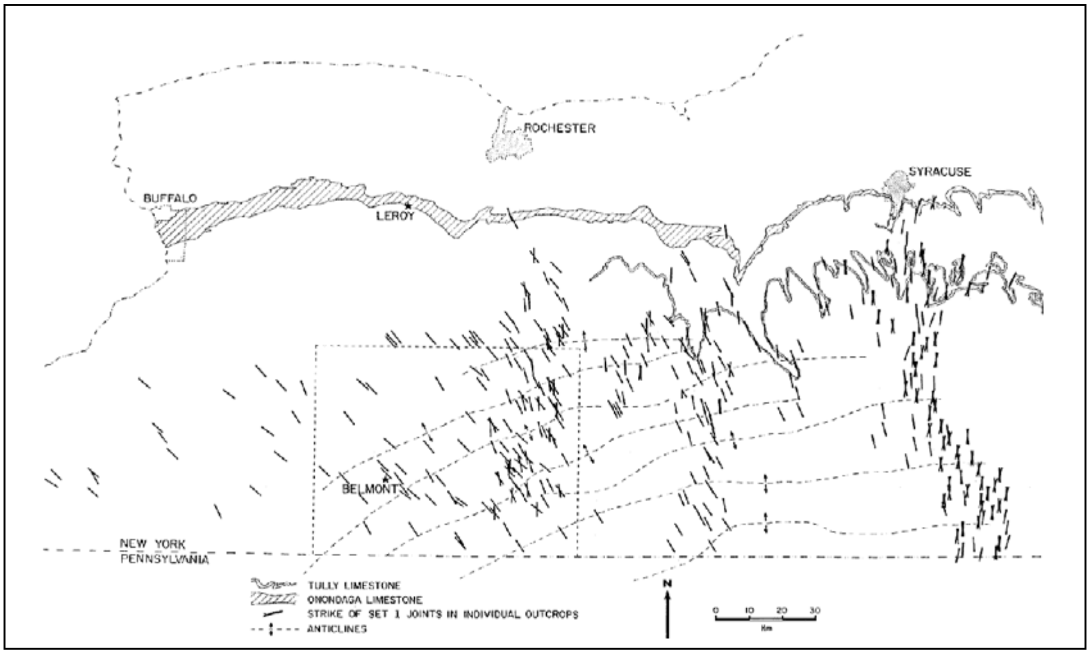


(from http://www.earth.rochester.edu/ees201/Mohudtrip/dolge.html).

Table 2.3. Primary Joint Sets in New York.

Order	Type	Orientation	Rock Type	Timing / Stress
1	Cross-fold (CF)* ***Set I*****	N-NW (320 º to 010 º)	Gray shale, siltstones, and Black Shale	Natural hydraulic fracturing during N-NNW compression during the Alleghanian Orogeny, formed at depth.
2	070º ***Set III*****	070º	Black/Gray Shale ***below*** Rhinestreet fm.	Release joints, propagating during basin uplift and regional rifting, formed at depth.
3	E-W	085 º	Rhinestreet & Ithaca Formation Black shales only	Relaxing of formation tension resulting in release joints, formed at depth.
4	Fold Parallel (FP) ***Set II*****	E-NE to E-W 070 º east to - 045 º west	Gray/Black shale Most dense in and above the West Falls Group	Unloading, Release joints propagated during uplift.
5	E-NE	E-NE	Gray shale, siltstones, and Black Shale	Unloading-type, Parallel present stress field (Neotectonic), shallow depth.
* Consists of several joint sets that are not differentiated ** Regional set nomenclature by Parker (1942)				

Figure 2.18. Strike of Cross-Fold Joints.[25]



A second set of long, planar joints strikes quite consistently at 070°, and are present in black and gray shales of the Middle Devonian rocks (below the Rhinestreet). They are long and planar, and commonly cross-cut local structure and cross-fold joints, however occasionally rotate perpendicular or parallel to a preexisting joint. Because the 070° joints cleanly cross cut significant structures, they may have formed at depth, however the inconsistency in abutting may indicate different depths of burial at the time of propagation or local variations in the stress field.[26] Loewy found that these joints are present in the Ithaca Formation, Geneseo Black Shale and the Moscow Gray Shale, but not in the overlying Rhinestreet Shale. The absence of the 070° joints in overlying formations has been attributed to the presence of a paleo-pressure seal (an impermeable layer) at the base of the Rhinestreet. This seal allowed overpressuring and related natural fracturing to occur below the seal, while overlying formations remained normally pressured. These joints propagated roughly 230 million years ago (mya) around the time major rifting associated with the break up of the super continent *Pangea*.

A third, much less common set of joints, is a fold parallel set present in black and gray shale. These joints are strike parallel to the anticlinal folds and orthogonal to the cross-fold joints, and are possibly release joints that propagated during uplift of the basin some 125 mya. Orientation of the joints changes from east to west. Strike ranges from 45° in the west to 070° in the east, and E-W father to the east, and follow the trends of the anticlinal folds. Loewy reported that the fold parallel sets appear densest in the West Falls Group and above. These joints commonly abut the cross-fold joints forming a checkerboard-like pattern.[26]

The forth joint set is consistently oriented E-W, and is present in the black shales of the Rhinestreet, and Ithaca formations, striking approximately 085 °, and abutting the cross-fold joints. Loewy reports that these joints are well developed in the black shales, but terminate or become poorly developed at lithologic boundaries. Additionally, E-W joints have been reported in the black shales of the Sonyea and West Falls Group, but not in the Geneseo.[29,30,31] These joints propagated at depth during regional uplift around 125 mya, and formed in response to tensile stress in thin black shales that were isolated between an upper and lower gray shale.

The fifth set of joints are the youngest, and formed in response to the contemporary stresses in the basin. They commonly abut cross-fold joints and E-W joints, and frequently curve to intersect pre-existing joints in a sigmodal shape, indicating that the joints had low stresses and propagated at fairly shallow depths.[26] They are most likely unloading joints associated with recent uplift beginning about 16 mya.

Figures 2.19 and 2.20 depict the locations and the rose diagrams for joint distribution in black shales and gray shales from Loewy's thesis. Rose diagram petals are drawn in 5° increments, and the area of each petal indicates the number of joints in each line (rose diagrams are not all the same scale). Note that the orientation of the joints varies from west to east, and that not all joints are dominant in all locations. The east-west joints are missing in Fillmore Glen and Moravia, however are the dominant joint sets in Stony Brook and Watkins Glen.[26]

Figure 2.19. Map of Fracture Measurement Locations.[29]

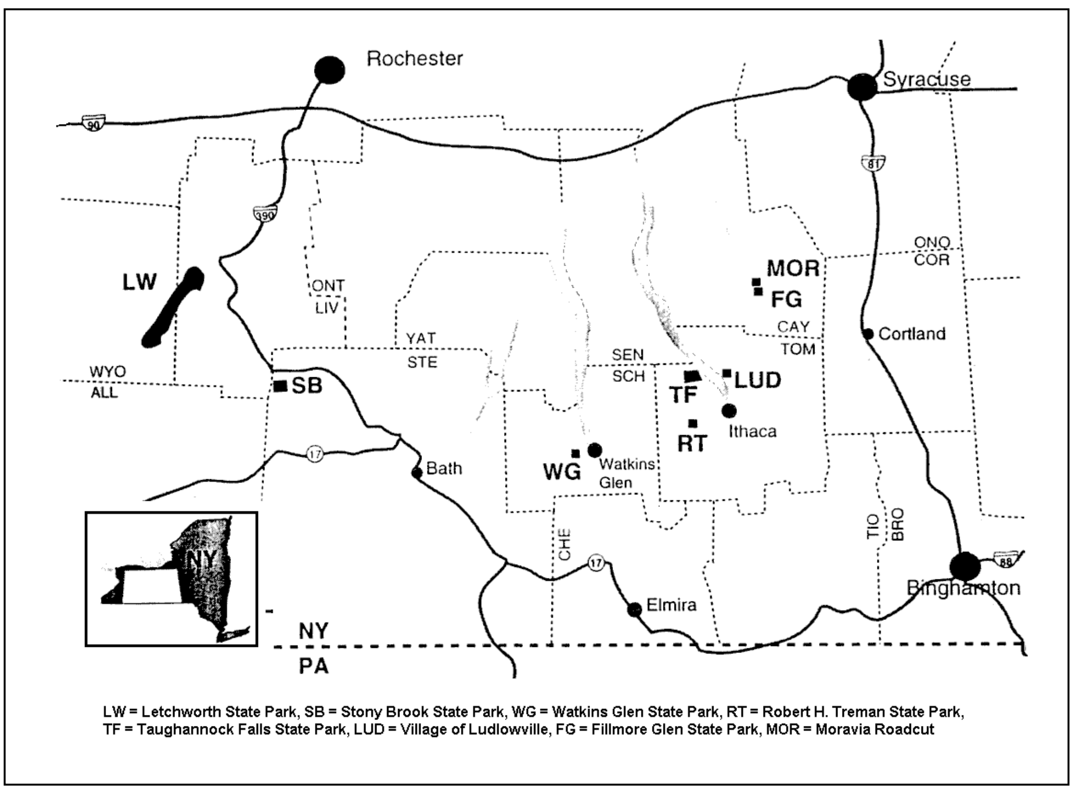
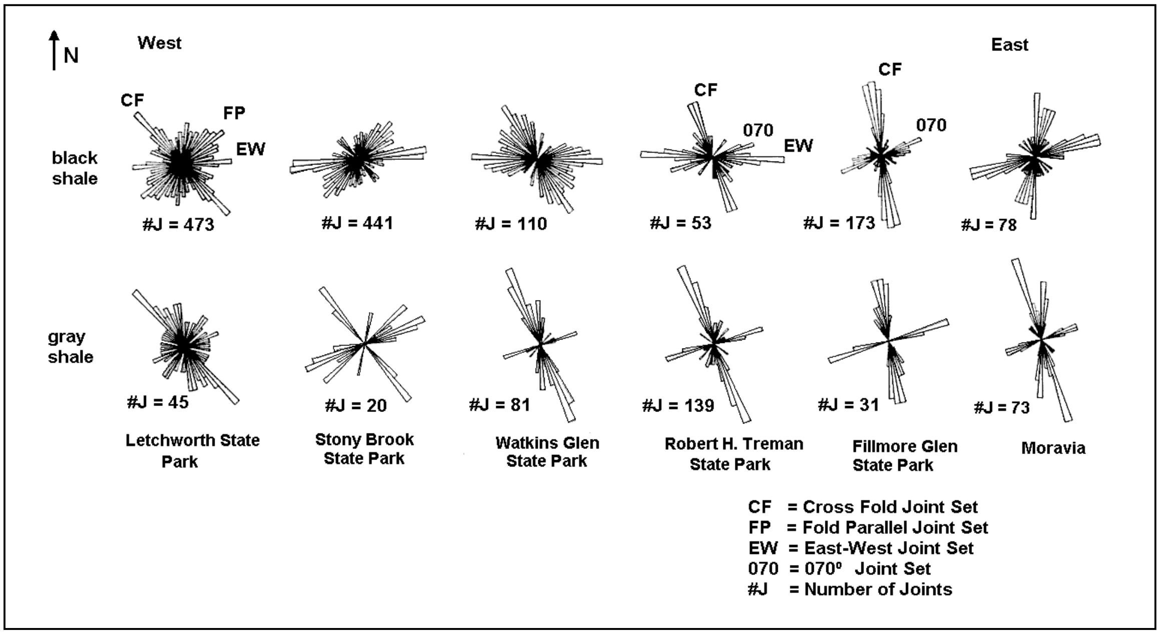


Figure 2.20. Rose Diagrams of Joint Orientations in Devonian Shales.[29]

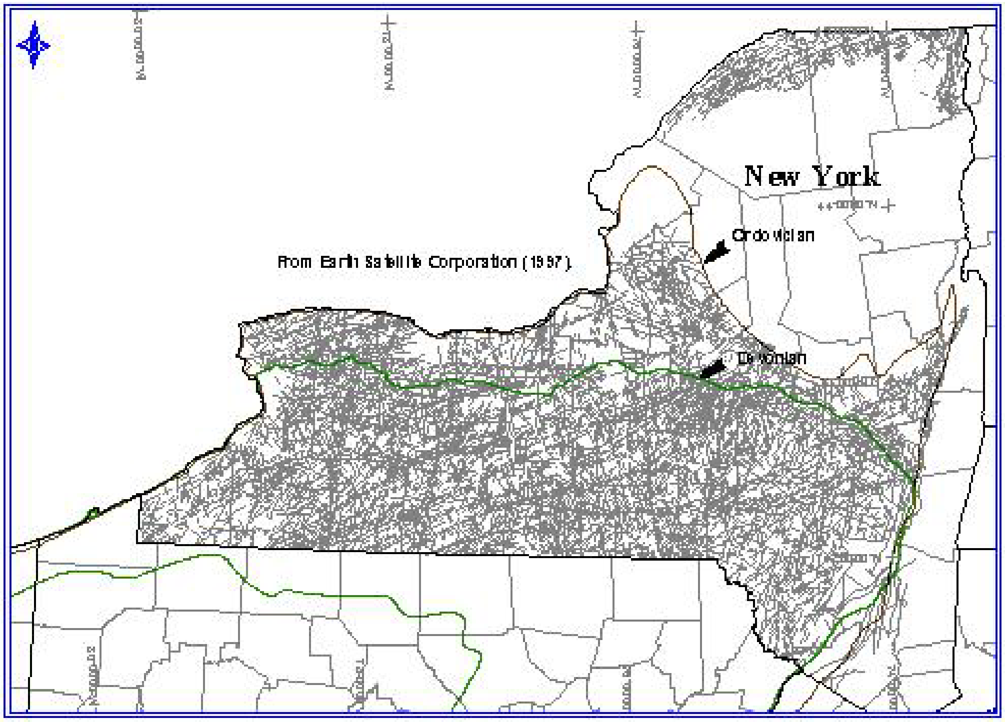


Joint spacing of the five joint systems varies from less than one meter to several meters. Density is greatest in black shales where it is usually less than one meter. In addition, joint densities are higher in thinner black shales than thicker black shales because of differences in total organic content (organic content is higher in thinner beds than thicker beds). Loewy also states that joint porosity decreases with increasing bed thickness, and that "overall joint porosities in the shales with the largest joint densities are less than 1%" [see Loewy thesis "Observations and Experimental Data" pages 13-45, for a thorough discussion].

Little literature exists that discusses the natural fracturing in the Silurian and Ordovician. Natural fractures are present however, as seen in road cuts through the Utica Shale (Figure 2.17). In 1997 the Earth Satellite Corporation performed a remote sensing and lineament analysis of the Appalachian Basin in New York.[32] The basis for their assessment was geologic interpretation of ten digitally-enhanced, Landsat Thematic Mapper ™ images within the outcrop of the Utica Shale in New York. Figure 2.21 depicts the fractures identified in the study.

The orientation of natural fractures was evaluated for four map sheets within the entire study area as depicted in Figure 2.22, and the rose diagrams generated by Earth Satellite Corporation show that the dominant fracture orientation varies from west to east. On sheets 1 and 2, where the upper Devonian sequence is very near the surface, northeast to eastern fractures dominate. On sheet 3, the wide variation in fracture orientation observed is "indicative of the fact that this sheet contains both the northeastern-most portion (mostly Ordovician section of the Appalachian Basin) and the St. Lawrence Lowlands portion of the study." Sheet 4 shows that "the effect of basement reactivation of trends associated with the Taconic orogeny (N5°-20°E and N5°-20°W trends) and the trends associated with the eastern-most portion of the Appalachian Basin (N45°-55°W, N25°-40°E and N45°-60°E) are evident."

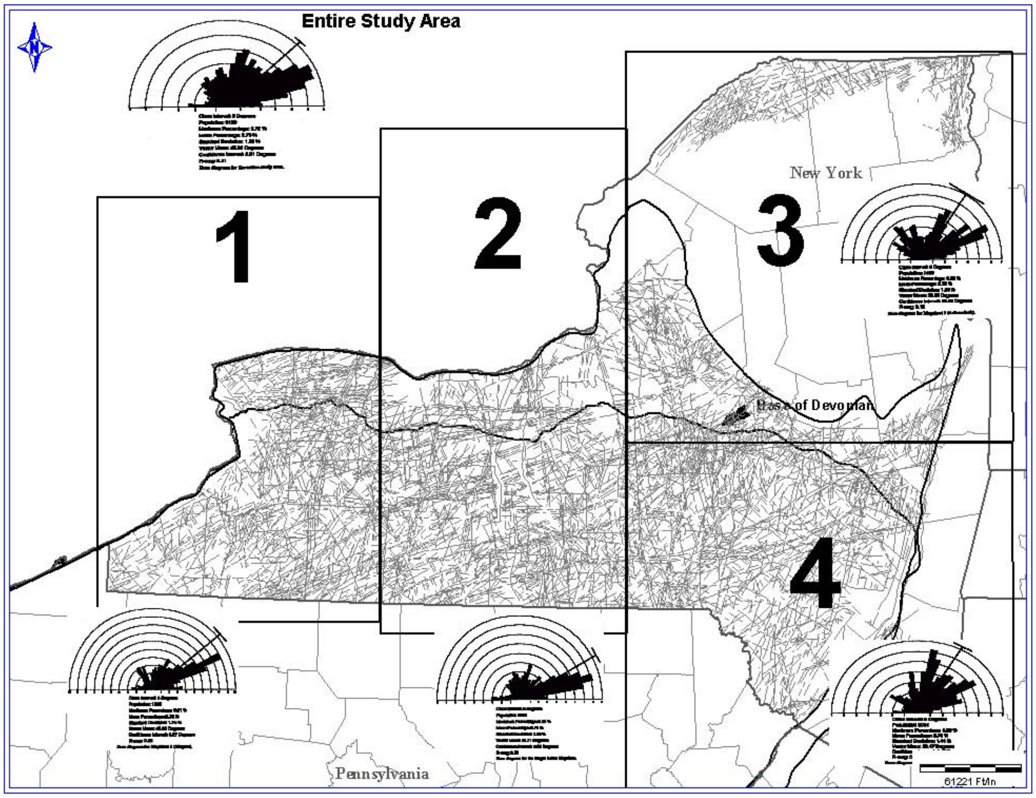
Figure 2.21. Fracture Orientation in New York State.[32]



Joints in Ordovician-age rocks are more profoundly influenced by preexisting basement structure, the Taconic Orogeny and related structural grain, and by the Salina Salts, which would have transferred "almost all the stress from subsequent tectonism to the overlying sequences and resulted in a muted effect in the underlying Ordovician Rocks".[32]

The potential for development of fractured shale reservoirs depends upon the presence of extensive natural fractures, and "current ambient stress in New York suggests that subsurface fracture orientations in a east-northeast direction will likely be most favorable as the major feeders for hydrocarbons into fractured reservoirs in either the source rocks or conduits to other reservoirs".[33]

Figure 2.22. Rose Diagrams of Four Study Areas.[32]



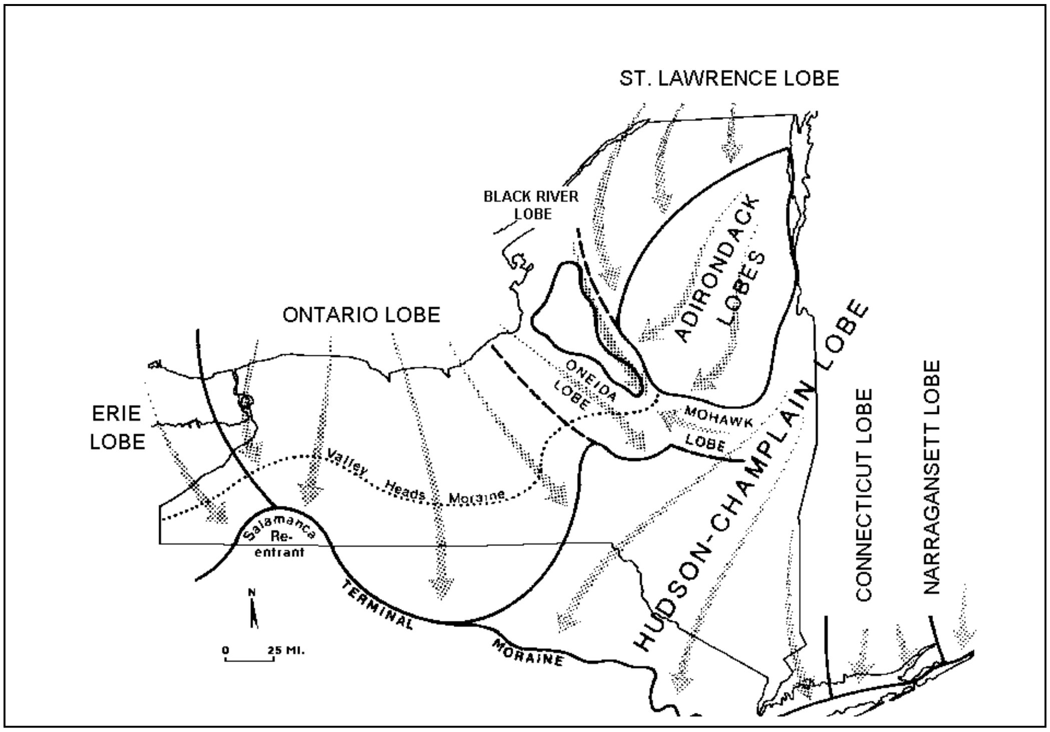
2.7 GLACIAL HISTORY

The glacial history of New York played an important role in shaping the topography in the state, but also may have affected the natural fracture geometry after the weight of the glaciers had been removed. It has been over 10,000 years since the last glacier withdrew from New York State but much of the state shows evidence of that event, in the loose glacial rocks deposits, landforms, and lakes left behind as last the glaciers retreated. The Great Lakes and the Finger Lakes were all carved out by glaciers. Scour marks and glacial striations are seen on exposed bedrock, and polished bedrock surfaces all reflect the glacial history of the area.

The onset of the glacial period began roughly 600 thousand years ago during the Pleistocene Epoch as global climates grew colder. Huge ice sheets formed in the artic regions and flowed southward in at least four major episodes. In New York, each ice advance affected roughly the same area, advancing approximately the same distance to the south and then retreating. Each glacial advance reworked prior glacial deposits and features, thus in areas where deposits have been superimposed it is difficult to recognize any individual event except the last stage – the *Wisconsin*.

The Wisconsin ice sheet reached its maximum expansion more than 21,000 years ago. It covered almost all of New York, reworking most all traces of earlier glacial advances, and left behind almost all glacial deposits found in the state. The glacier flowed across the state as several connected sheets or *lobes,* which glaciated the area in different directions (Figure 2.23).[34] The Erie Lobe flowed southeast from the Erie Basin. The Ontario Lobe flowed southwest across the St. Lawrence and Ontario Lowlands, then changed direction to flow south and southeast into the Appalachian and Tug Hill Uplands. The Salamanca Re-entrant is one of the only areas that escaped glaciation in the last advance. The Hudson–Champlain Lobe advanced southwestward through the lowlands to Long Island. The Connecticut Valley and Narragansett Lobes covered eastern Long Island.[18]

Figure 2.23. Direction of Wisconsin Glaciation.[34]



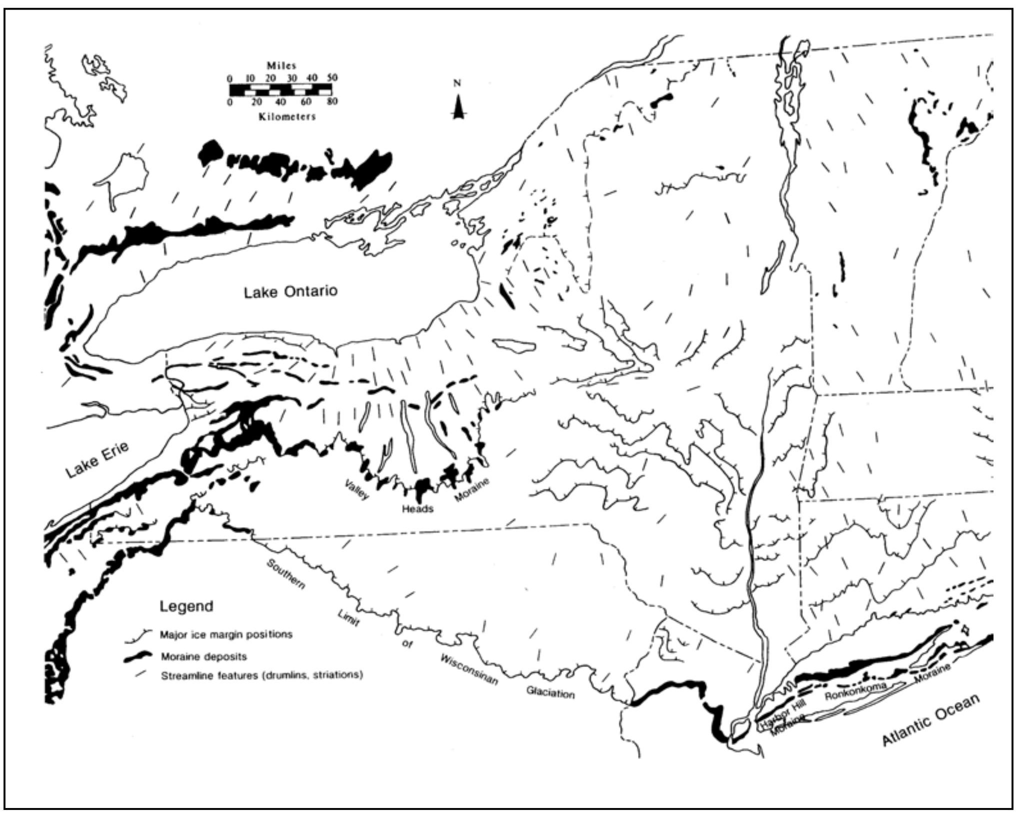
The effect of glaciation on the topography was tremendous (Figure 2.24). As the glacier moved along, erosion was the dominant process, removing and transporting incredible volumes of soil and bedrock. The ground was scraped, scored and scratched. River valleys were gouged into deep troughs, tributary rivers were cut off at right angles to rivers, while others were filled in with debris.

The retreat of the glacier occurred some 10,000 years ago and it occurred fairly rapidly. As the glacier melted, huge volumes of melt water and debris were liberated creating many distinctive landforms. Large amounts of mud, sand and gravel were deposited, filling in rivers, damming valleys, and creating temporary lakes. Several remnant lakes remain including the Great Lakes and Finger Lakes. Glacial till in New York ranges from less than 100 feet and is frequently absent from hills, to hundreds of feet in valleys.

The ice at its maximum extent is estimated to have been over 1 mile thick, and the shear weight of the ice sheet caused the region to compress and sag.[18] When the ice melted, ocean water temporarily flooded low-lying areas in the Champlain and St. Lawrence valleys that had been depressed forming the Champlain sea. Many marine deposits of this sea are now found at elevations exceeding 300 feet, indicating rebound of the region occurred. In the south where the glacial ice was thinner the rebound was less, however in the north where the ice was thicker, the rebound is over 400 feet. The uneven rebound is seen throughout northern New York. Glacial lake deposits that were once horizontal are now inclined to the north, and in the Lake Ontario region, the whole are has been tilted north to south.

Post-glacial rebound is now complete in New York, however the near-surface joint system has been enhanced and opened by the release of the glacial weight. The presence of horizontal fractures in the Devonian is mentioned in well records, and has been attributed to glacial unloading.[35] According to Milici, "glacial loading and post-glacial isostatic rebound in the gas-producing regions to the south of the Great Lakes appears to have created fractured pathways for gas to have migrated from black shale source rocks into intercalated brittle silty and sandy reservoirs, as will as to have fractured and enhanced the storage capacity of these reservoirs."[36]

Figure 2.24. Glacial Features in New York.[18]



3 Geochemistry

Geochemistry of shale consists mainly of understanding the amount, type, and thermal maturity of the organic material present in a formation. These make up the three main geochemical properties often associated with assessing the resource and productive potential of a shale.

The amount of gas present in organic-rich shales (at a given locality) is dependent on three factors: 1) the amount of organic matter originally deposited with the rock, 2) the relative origins of the different types of organic matter and the original capacity of each for gas generation, and 3) the degree of conversion of the organic matter to hydrocarbon natural gas. The first two factors are largely dependent on conditions present at the site of deposition, and the third is determined by intensity and duration of post-depositional heating, or load metamorphisim due to maximum depth of burial. The second factor is relatively constant for Devonian shale samples studied. This also assumes that the natural gas has remained, to some extent, trapped in the source to become a "reservoir".

3.1 TOTAL ORGANIC CARBON

With the exception of biogenic methane, hydrocarbons are predominately derived from the thermal transformation of organic matter preserved in fine-grained sediments, particularly shales.[37] Organic material or organic matter as defined by Tissot and Welte refers solely to material comprised of organic molecules in monomeric or polymeric form derived directly or indirectly from the organic part of organisms.[38] Mineral skeletal parts, such as shells, bones, and teeth are not included. Rock can contain both mineral matter and organic matter. Shales with organic matter greater than 0.5% by weight are considered potential source rocks.[38]

Kerogen is usually defined as the organic material in sedimentary rocks that is insoluble in ordinary organic solvents. The organic material extracted from the rock with a solvent is called bitumen. Kerogen and bitumen together constitute the total organic carbon in any rock.[37] Source rock quality is defined in terms of an amount and type of kerogen and bitumen and its stage of maturity.

The amount of organic carbon present in the rock is not only important as a source rock, but it also contributes to the natural gas storage by adsorption and or solution within the reservoir system. This is expanded upon in a following section. In the Appalachian Basin, darker zones within the Devonian Shale (higher organic content) are usually more productive that the organic-poor gray zones and are often the only interval considered prospective in the western part of the basin.[39]

Total organic carbon (TOC) measurements have been made on both core and drill cuttings in the Devonian Shale in New York. Table 3.1 summarizes the measurements from core samples by formation.[40,41] Table 3.2 summarizes TOC data from two published studies done on drill cuttings from wells drilled in New

York.[42,43]. Both tables are averages of multiple data points from individual wells and from multiple wells by Devonian Shale member. TOC values range from low values less than 0.5% in the Upper Devonian shales to over 6% in the Middle Devonian shales. The data also show a general trend of increasing TOC going from central New York to western New York as well as a general trend of increasing TOC with depth or age of Devonian Shale (Figure 3.1). However Weary, et al, describe a Middle Devonian Marcellus cuttings sample taken from Livingston County with a measured TOC of 11.05%.[44]

Table 3.1. New York TOC and Vitrinite Reflectance Data from Core Samples.

Formation / Unit	NY #1, NYSERA #3-6213 Alleghany County			NY #3, Scudder #1 Steuben County			NY #4, Valley Vista View #1 Steuben County		
	Depth (ft)	TOC (wt%)	R_o (%)	Depth (ft)	TOC (wt%)	R_o (%)	Depth (ft)	TOC (wt%)	R_o (%)
Canadaway									
Dunkirk	370 - 514	0.12	0.67						
Java									
Hanover Shale	514 - 983	0.14	0.75						
Pipe Creek	983 - 1,017	0.54	0.94						
West Falls									
Angola Shale	1,017 - 1,335	0.15	na						
Rhinestreet	1,335 - 2,346	0.34	1.32	1,203 - 1,263	0.20	1.36			
Sonyea									
Cashaqua Shale	2,346 - 2,493	0.15	1.43						
Genesee									
Middlesex Shale	2,493 - 2,628	1.33	1.42						
West River Shale	2,628 - 2,730	0.72	1.32						
Pen Yan Shale	2,740 - 2,865	1.16	1.48						
Lodi Shale	2,865 - 2,875	1.34	1.62						
Geneseo Shale	2,865 - 2,924	2.17	1.59				3,010 - 3,082	2.78	1.79
Hamilton									
Marcellus							3,790 - 3,848	1.72	1.82

No TOC data is available for Silurian shales in New York.

Measurements of total organic carbon in the Utica Shale have been reported in literature.[45,46,47,12] Table 3.3 is a summary of the data. The range is from approximately 0.16% to 4.0% with an average of 1.68%. Figure 3.2 depicts the regional variation of black shale in the Utica.

Figure 3.1. Average Organic Content (%) of the Devonian Shale in New York.

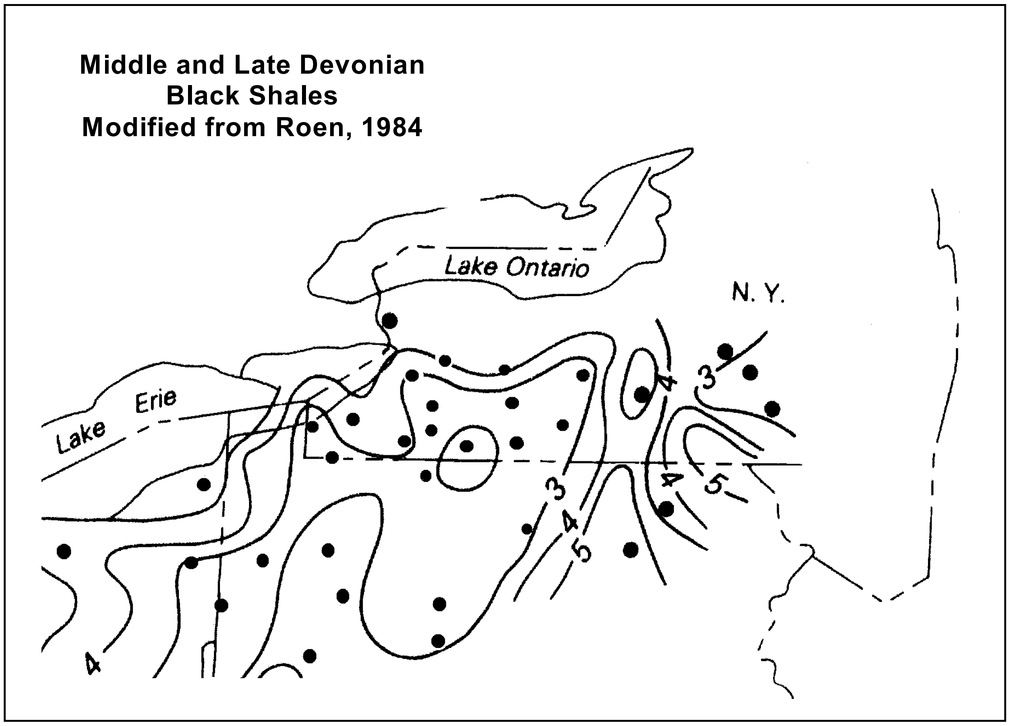


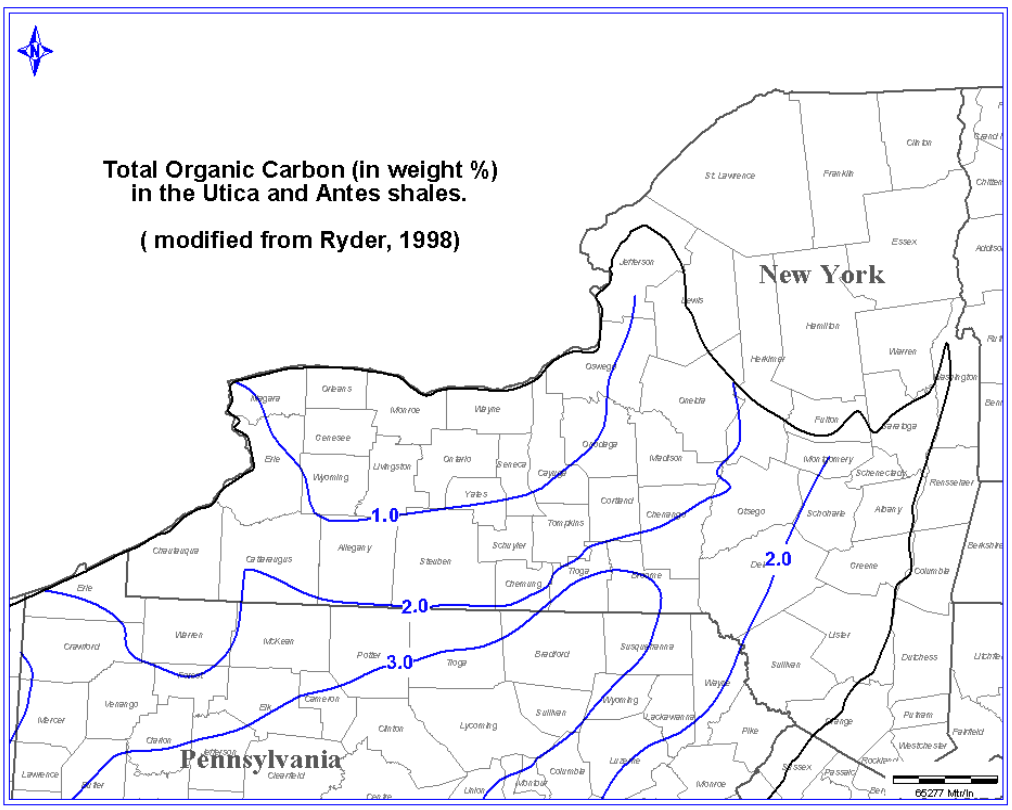
Table 3.2. TOC from New York Devonian Shale Drill Cuttings.

Group	Member	Van Tyne 9 Well Data Set Average All Wells / All Depths Total Organic Carbon (%)	USGS 20 Well Data Set Average All Wells / All Depths Total Organic Carbon (%)
	Dunkirk Shale		1.14
Canadaway			
	Hanover Shale		0.80
Java			
	Pipe Creek		
	Angola Shale		0.89
West Falls			
	Rhinestreet Shale	1.95	1.47
Sonyea	Cashaqua Shale		0.65
	Middlesex	2.83	1.50
	West River		1.34
Genesee	Pen Yan Shale	2.40	1.58
	Geneseo Shale	4.00	0.92
	Hamilton Shale		0.80
Hamilton			
	Marcellus Shale	6.05	3.87

Table 3.3. Published Organic Carbon Data for the Utica Shale in New York.[45, 46]

Source	Range of Weight Percent Organic Carbon
Hay and Cisne, 1989 / Outcrop in Central New York	1% – 3.5%, average 1.75%
Hannigan and Mitchell, 1994 / Outcrop, east-central New York	1% – 4%, average 2.22%
Wallace and Roen, 1989 / Subsurface and Outcrop	0.16% - 3.19%, average 1.09%

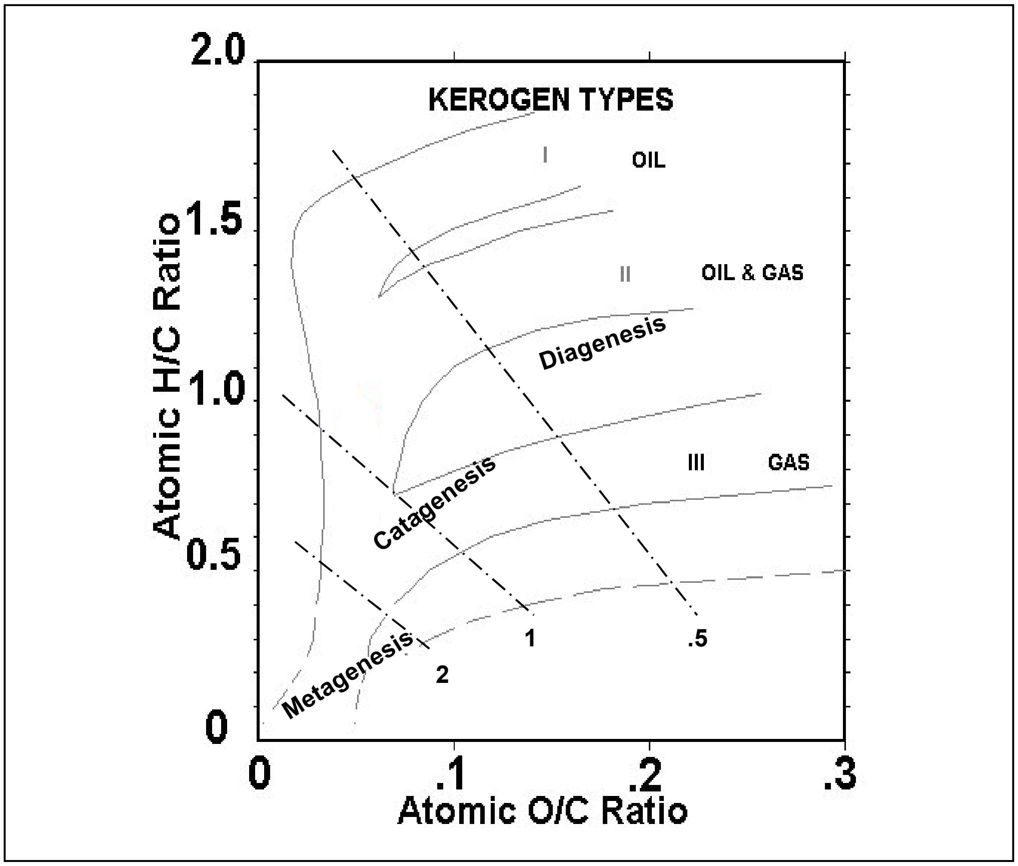
Figure 3.2. Total Organic Carbon (%) of Utica Shale.[47]



3.2 KEROGEN TYPE

Knowing the type of kerogen that is present in the rock provides information on hydrocarbon source potential and depositional environment. Kerogen type can also influence the amount of natural gases stored by adsorption as well as diffusion rate. The classification scheme for kerogen evolved initially from the optical maceral analysis of coal. Elemental analysis was later applied to kerogen analysis. The elemental analysis is based on the quantification of the hydrogen/carbon (H/C) and oxygen/carbon (O/C) ratios from Van Krevelen.[48] A plot of the ratios was developed by Van Krevelen to diagrammatically determine kerogen types and thermal maturation and is called the Van Krevelen diagram as depicted in Figure 3.3. From the plot, three distinct or main evolution paths are readily recognizable.

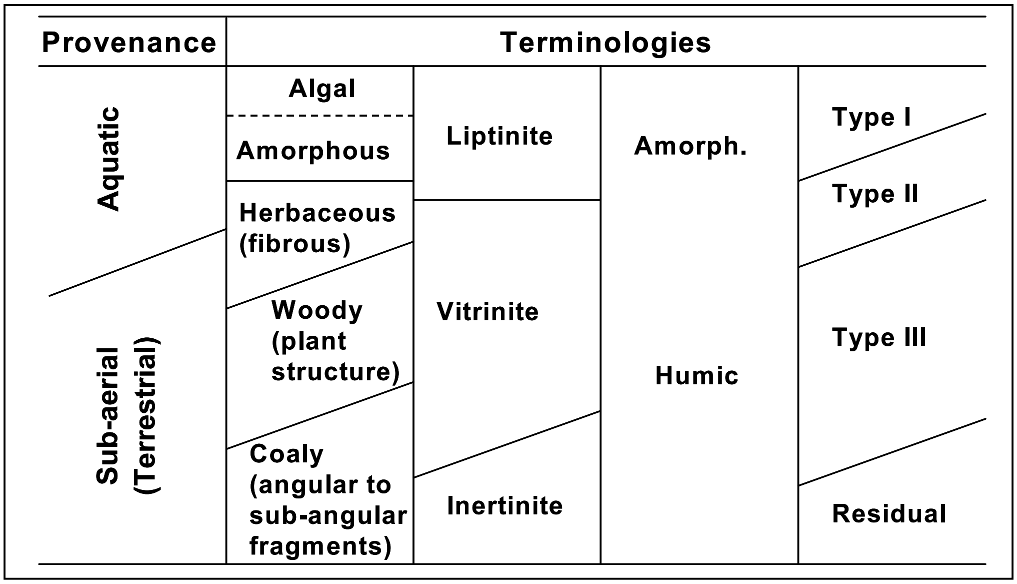
Figure 3.3. Van Krevelen Diagram.[48]



The ratios on the Van Krevelen diagram were replaced with the indices (HI and OI) from Rock-Eval data resulting in a modified Van Krevelen diagram.[49] This modified diagram, along with other plotting techniques is used to determine kerogen types. Figure 3.4 is a representation from Tissot and Welte that compares the various terms used in kerogen description.[38] In the gas shale literature, the “type” kerogen terminology is used to describe kerogen.

Figure 3.5 is a further breakdown and description of the four common types of kerogen. Type I kerogen (liptinite) has a high hydrogen-to-carbon ratio (1.5 or more), but low oxygen content (generally smaller than 0.1). These kerogens are derived mainly from algal material after partial bacterial degradation. Rocks with this kerogen type are typically fine grained organic-rich muds formed in quiet, oxygen poor shallow water environments such as lagoons, lakes and ponds.[50] The Green River Shale contains primarily Type I kerogen.

Figure 3.4. Comparison of Various Terms Used In Kerogen Description.[38]



Type II kerogen is usually a mixture of exinitic, liptinitic and vitrinitic particles. The hydrogen content is slightly less that Type I kerogen. This kerogen is usually related to marine sediments where an autochtohonous organic matter, derived from a mixture of phytoplankton, zooplankton and microorganisms (bacteria), has been deposited in a reducing environment. Nearly all marine black shales contain primarily Type II kerogen assemblages dominated by amorphous matter.

Type III refers to kerogen with a relatively low initial H/C ratio (usually <1.0) and high initial O/C ratio (as high as 0.2 or 0.3). This type of kerogen is less favorable for oil generation, but more favorable for gas generation if buried to sufficient depth. This type of kerogen is derived from continental (terrestrial) plants and often contains identifiable vegetal debris. Vitrinite rich kerogen corresponds closely with Type III kerogen defined by Tissot and Welte.[38] An example of Type III kerogen based shale is the lower Mannville shale in Alberta, Canada.

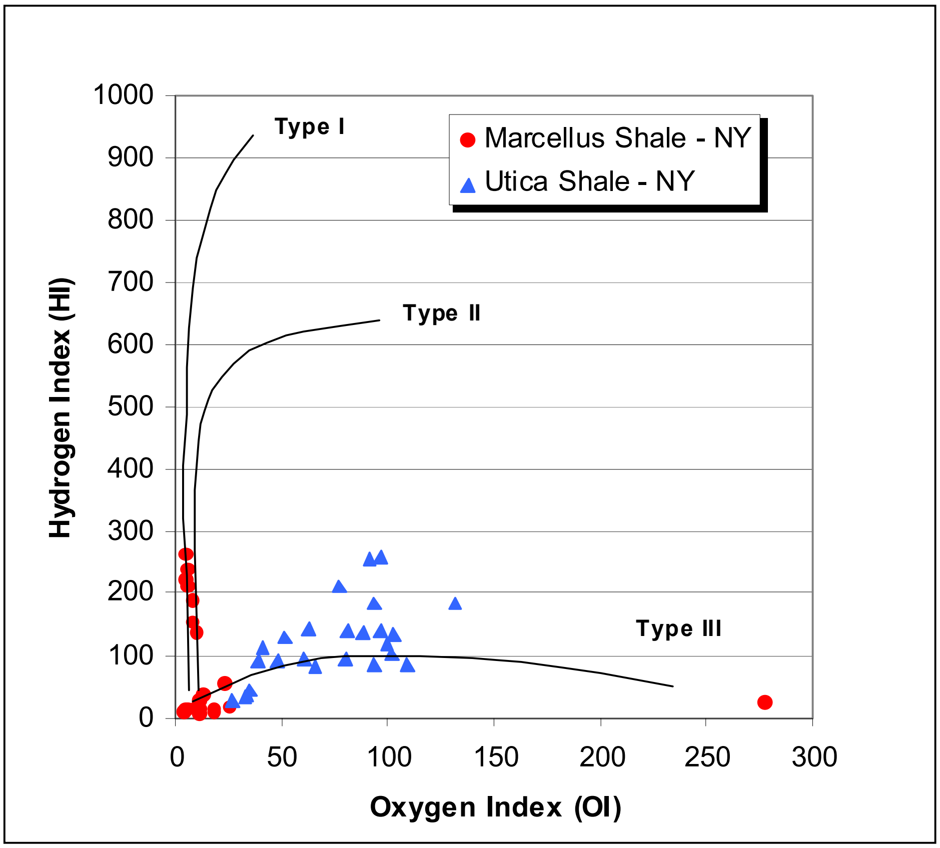
Figure 3.5. Kerogen Types.[37]

Kerogen Type	Depositional Environment	Organic Precursors	Hydrogen Product
I	Lacustrine	Algae	Liquids
II	Marine, Reducing Conditions	Marine Algae, Pollen, Spores, Leaf Waxes, Fossil Resins	Liquids
III	Marine, Oxidizing Conditions	Terrestrial-Derived Woody Materials	Gas
IV	Marine, Oxidizing Conditions	Reworked Organic Debris, Highly Oxidized Material	None

Type IV kerogen can be defined as a residual type of kerogen or dead carbon. It has abnormally low H/C ratios associated with high O/C ratios. This type of kerogen cannot generate any hydrocarbons and is considered dead carbon in the sense of petroleum generation.

Published Rock-Eval data for the Marcellus Shale and the Utica Shale in New York State was plotted on a modified Van Krevelen diagram (Figure 3.6).[44] The data show that the Marcellus is primarily Type II kerogen with a mixture of Type III and the Utica is primarily Type III kerogen with a mixture of Type II. Both shales with these kerogen assemblages are capable of generating liquids and gases. No Rock-Eval data is available for the Silurian Shales in New York.

Figure 3.6. Published Rock-Eval Data for Marcellus and Utica Shales in New York Plotted on a Modified Van Krevelen Diagram.



3.3 THERMAL MATURITY

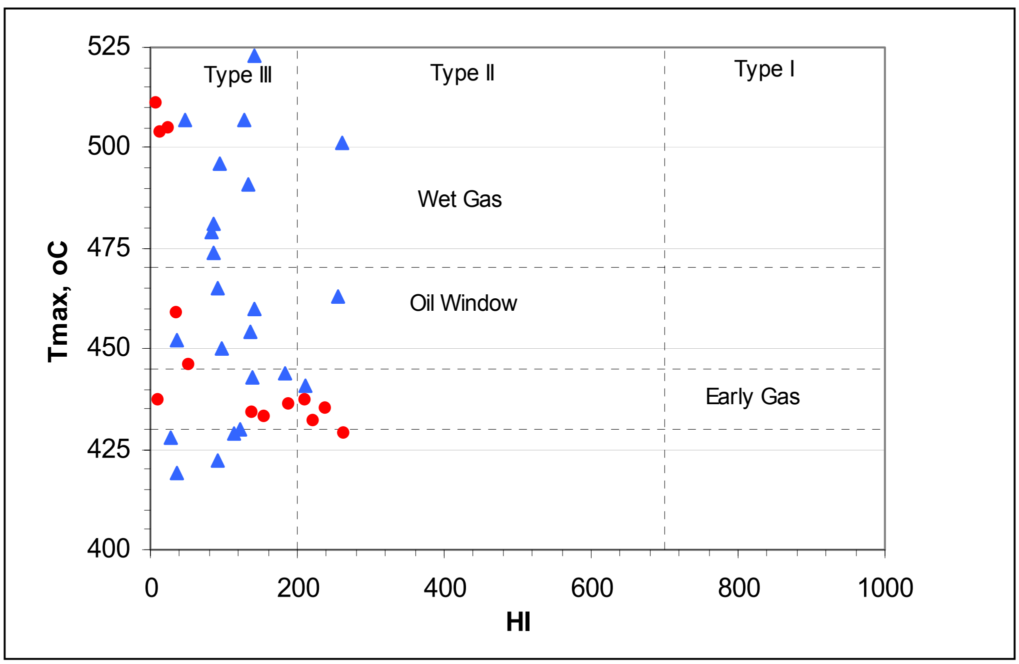
The maturation level of the kerogen is used as a predictor of the hydrocarbon potential of the source rock. It also is used to high-grade areas for fractured gas shale reservoir potential and as an indicator for investigation biogenic gas within a shale reservoir system. Thermal maturation of the kerogen has been found to also influence the amount of natural gas that can be adsorbed onto the organic matter in shale.

Thermal maturation can be determined by several techniques, including Rock-Eval, vitrinite reflectance, thermal alteration index and conodont alteration index. Multiple techniques should be employed to help determine thermal maturity of a shale.

3.3.1 Rock-Eval

Rock-Eval can be used to assist in determining the thermal maturation level of kerogen. Peters (1986) defined the thermal parameters in which T_{max} (maximum temperature) can be used to define the dimensions of the oil window.[51] The top of the oil window is generally assumed to occur between T_{max} values of 435°C and 445°C and the bottom of the oil window occurs at 470°C. Plotting T_{max} and hydrogen index can show the thermal maturation and kerogen type of the samples. Published Rock-Eval data for the Marcellus Shale and the Utica Shale in New York State was plotted using the technique after Peters.[51] Figure 3.7 shows the spread of maturity of the samples measured. The samples were from different depths and ranged from central New York to western New York. No Rock-Eval data is available for the Silurian shales in New York.

Figure 3.7. Published Rock-Eval Data for Marcellus and Utica Shale. Plotted After Peters.[51]



3.3.2 Vitrinite Reflectance

Reflectance of coal macerals in reflected light has long been used to evaluate coal ranks. Reflectance measurements have been extended to particles of disseminated organic matter occurring in shales and other rocks (kerogen) and have been the most widely used technique for determining maturity of source rock. Typical analysis normally shows a distribution of reflectance corresponding to the various constituents or macerals of the kerogen. Because humic or vitrinite particles are generally used for reference to the coalification scale, the mean random reflectance of vitrinite (Ro) is preferred to other particles. In some cases, there may be several groups of vitrinite particles with different reflectance present. In these situations, it is recommended that only the group with the lowest reflectance should be used. Other groups with higher reflectance are considered to be "reworked." Table 3.4 is a breakdown of the different stages of maturation with vitrinite reflectance.

Table 3.4. Vitrinite Reflectance Categories for Thermal Maturity.

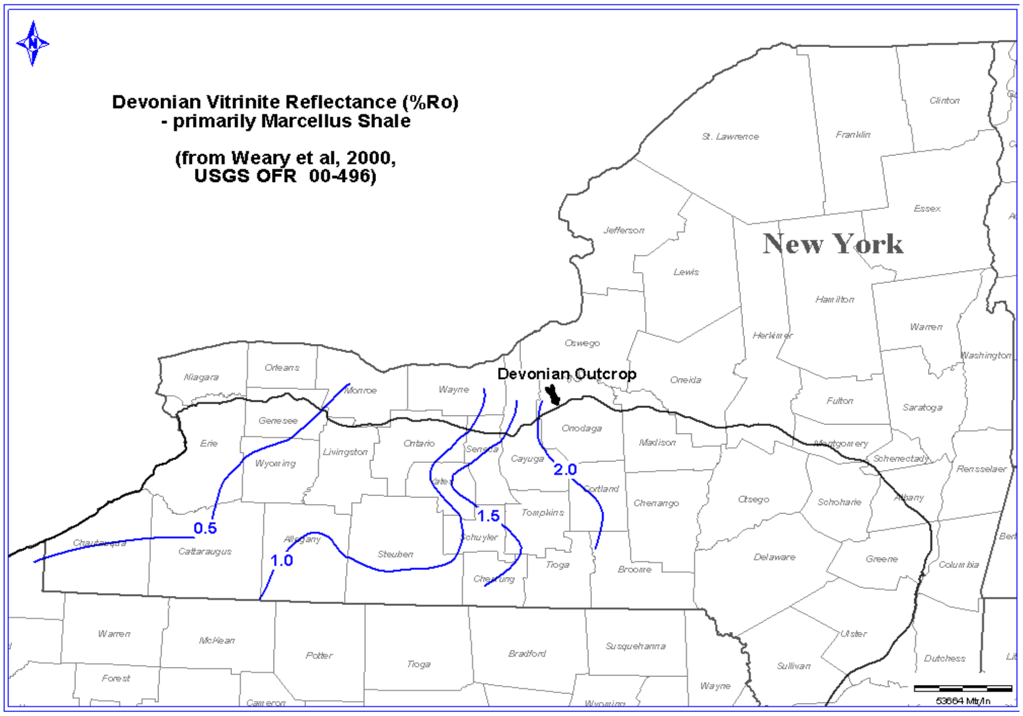
Vitrinite Reflectance	Comments
R_o <0.5 to 0.7%	Diagenesis stage, source rock is immature
0.5 to 0.7% >R_o<1.3 %	Catagenesis stage, main zone of oil generation
R_o >2.0%	Metagenesis stage, methane remains as the only hydrocarbon (dry gas zone)
R_o is the mean reflectance in oil.	

Table 3.5 summarizes vitrinite reflectance data from nine wells in the Marcellus Shale.[43] There is a general trend of increasing thermal maturity going from western New York toward central New York. This general trend in the Marcellus Shale is further supported by the vitrinite reflectance data reported from drill cuttings in the USGS report by Weary et al (Figure 3.8). No vitrinite reflectance data has been reported for the Silurian or Ordovician shales.

Table 3.5. Summary of Thermal Maturity Data; Marcellus , New York.[43]

Well / County	Depth (ft)	Ro (%)
St. Bonaventure , Cattaraugus County	3,600-3,640	1.23
Portville Central School, Cattaraugus County	4,140-4,180	1.2
Houghton College #1 Allegany County	2,270-2,290	na
Houghton College #2, Allegany County	2,380-2,410	1.18
BOCES Fee #1, Allegany County	3,240-3,290	1.27
Meter #1, Livingston County	1,570-1,600	1.31
Alfred University #1, Allegany County	3,950-3,960	1.65
Hammel #1,Allegany County	4,662-4,690	1.65
Valley Vista View #1, Steuben County	3,882-3,895	1.65
Average All Wells / All Depths		**1.39**

Figure 3.8. Devonian Vitrinite Reflectance (%Ro).



3.3.3 Thermal Alteration Index

The use of progressive changes of color and/or structure of pores, pollen or plant-cuticle fragments is also used as an indicator of thermal maturation of the kerogen. Kerogen coloration is reported on a scale of 1 to 5, and is referred to as Thermal Alteration Index (TAI), and is presented in Table 3.6.[52] Different types of spore or pollen grains can show different sorption values at low levels of maturation. TAI averaged 3.20 for the Rhinestreet Shale interval from NY#3 well in Steuben County New York that was cored from 1,203 to 1,263 feet.[40] Similar TAI values were measured from the NY#4 well in Steuben County, 3.2 for the Geneseo (2,970-3,080 feet) and 3.4 for the Marcellus (3,780-3,842 feet).[40] All samples indication maturation levels above 150°C. No TAI values were available for the Silurian or Ordovician shales.

3.3.4 Conodont Alteration Index

The thermal maturity of shales can also be inferred from published conodont alteration indices (CAI), a scale of color alteration in conodonts (a marine fossil).[53] In general, the CAI of a conodont increases with depth and temperature as a result of metamorphisim. Table 3.7 summarizes the indices. A recent study of thermal maturity in Ordovician and Devonian rocks has been completed by the USGS and New York Geological Survey.[44] In the Upper Devonian shales, CAI values range from less than 1.5 in to 2.5 west to east. In Middle Devonian shales, CAI increases from about 1.5 in western New York to 2.5–3 in the central area (Figure 3.9).[54] Silurian CAI values are similar to the Middle Devonian. Upper Ordovician rocks in western New York have CAI values of 2-3, which put them within the more advanced stage of wet gas generation. In southern New York, where CAI values are 3–5, the Ordovician rocks are prospective for dry gas (Figure 3.10). [44]

Table 3.6. Thermal Alteration Index.

TAI	Color	Comments
1	Light Yellow or Light Green	Fresh unaltered material, rock has not been exposed to temperatures greater 50 C, diagenesis
+1	Intense Yellow	Exposed to temperatures between 50 C and 100 C, diagenesis, onset of categenesis
2	Orange	Moderately altered, exposed to temperatures between 100 C and 150 C, categenesis
3	Brown	Strongly altered, temperatures above 150 C, metagenesis
4	Deep Brown or Blackish	Severely altered kerogen, metagenesis
5	Black	Rock has been exposed to temperatures in excess of 200 C, metamorphism

Table 3.7. Conodont Alteration Indices.[53]

CAI	Equivalent Ro (%)	Hydrocarbon Occurrence
1	< 0.8	Early-Mature Oil
1.5	0.7 –70.85	Early-Mature Oil
2	0.85 – 1.3	Late-Mature Oil
3	1.4 – 1.95	Wet Gas
4	1.95 – 3.6	Post-mature Dry Gas
5	> 3.6	Post-mature Dry Gas

Figure 3.9. Devonian Conodont Alteration Index (CAI) Isograds.

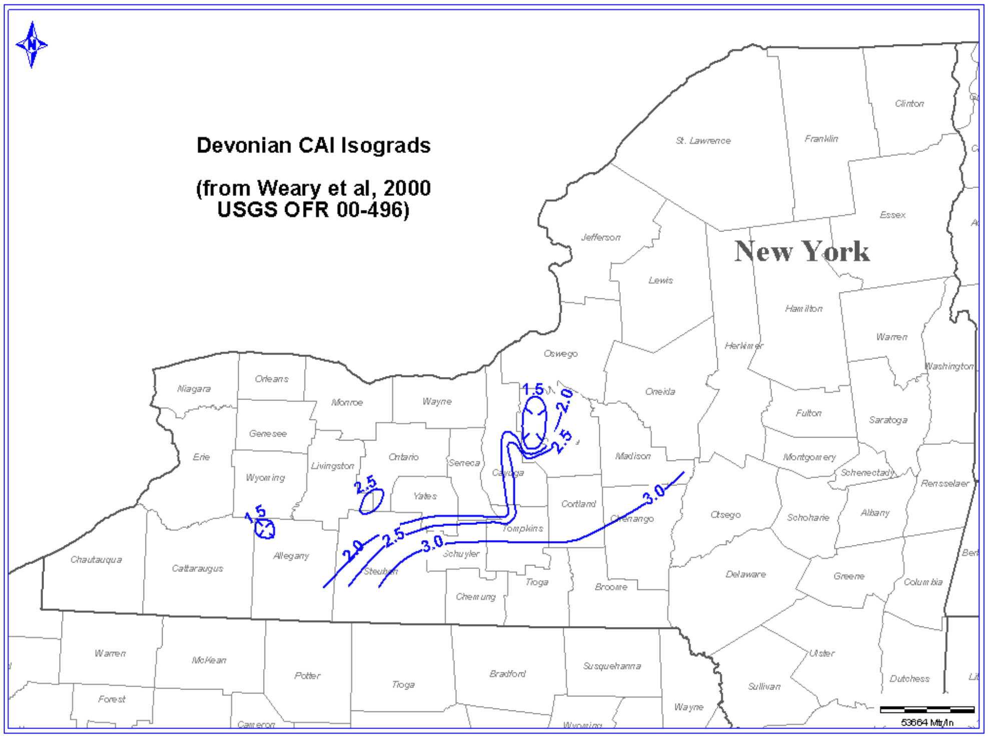
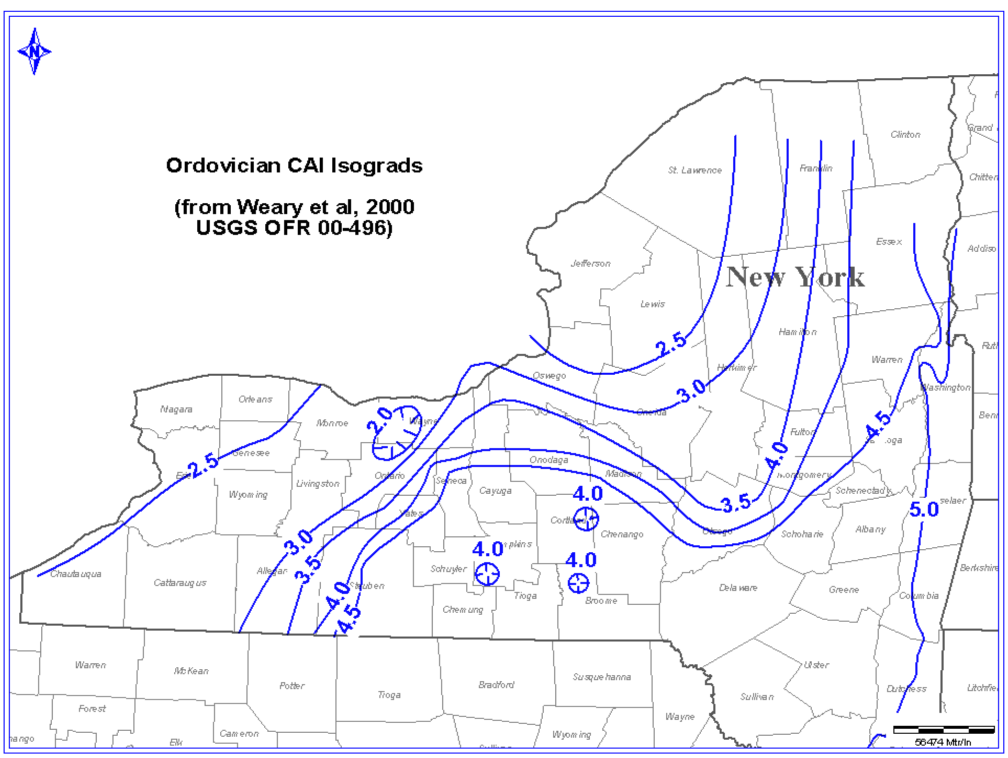


Figure 3.10. Middle and Upper Ordovician Conodont Alteration Index (CAI) Isograds.



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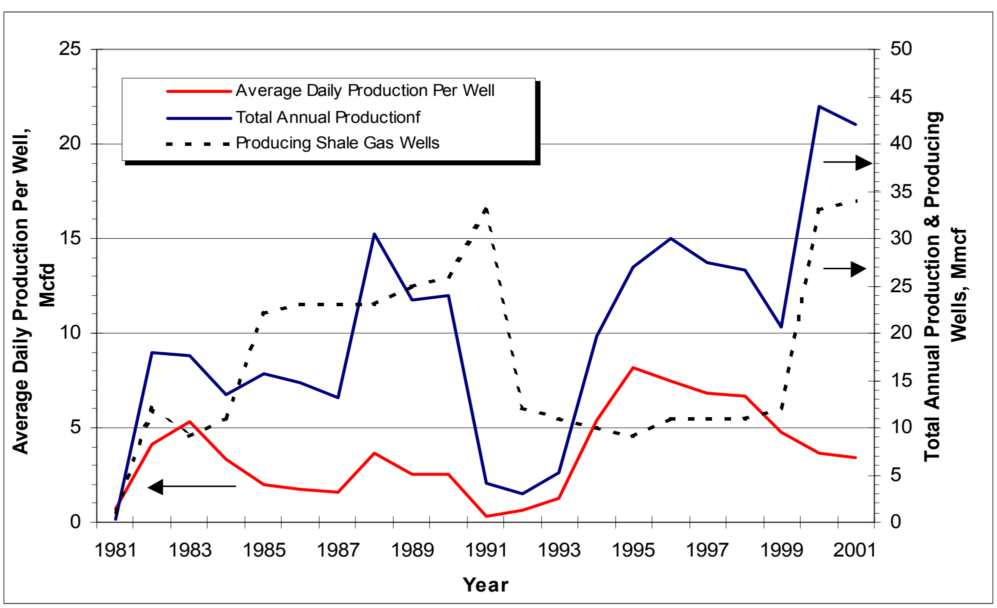
4 Natural Gas Resource and Production

The information and data available regarding the amount of natural gas resource contained in the organic-rich shales in New York is dated and only available for the Devonian-age shale. No information or studies have been done for the Silurian shales or Ordovician shales in New York or the Appalachian Basin. No estimates have been published for the technically recoverable reserves in the Devonian Shale in New York.

Natural gas production data was not reported to the State of New York prior to 1983. Data prior to this period is sketchy and is considered unreliable. Even though production data is now reported to the State, many of the shale wells producing today are for home or local use and may not be producing at fullest potential or from a reservoir management perspective. Some of these wells are not metered and estimates for annual production are provided. As of 2001, there are 8 wells producing from the Devonian-age shale in New York. Two wells are producing from Silurian-age shales and no wells are producing from the Utica Shale (Ordovician-age). Production data is shown in Figure 4.1, and highlights the annual natural gas production from shale wells in New York as well as the average daily production per well and the number of producing wells per year. This data is derived from the Annual New York State Oil, Gas, and Mineral Resources report published by the Division of Mineral Resources of New York State.[55] This figure shows that the average production rate is approximately 5 thousand cubic feet gas per day (Mcfd) from a typical shale gas well. This compares to average of 9.1 Mcfd for all gas wells producing in New York from 1991 to 1999.

Figure 4.1. New York Shale Gas Production Data from 1981-2001.



4.1 NATURAL GAS RESOURCE

The natural gas resource estimates for Devonian-age shales in the Appalachian Basin vary widely. Estimates range from a low of 225 Tcf to a high of 2,579 Tcf.[56,57] The estimates vary based on type of shale included in the analysis (black and or gray), reservoir thickness and gas content per cubic foot of reservoir. Estimates for the Devonian Shale resource in New York were calculated in the 1980 National Petroleum Council Study, Table 4.1.

Two estimates were made in the NPC study using either log-based data or sample-based data. The gas content for both approaches were the same: 0.6 scf/cf for black shale (>230 API units) and 0.1 scf/cf for gray shale (<230 API units). The net reservoir thickness varied for each approach as indicted in the table. For the log-based approach, black shale thickness was determined as shale with >230 API units from a gamma ray log. For the sample based approach, black and gray shales were identified by color. The area for assessment was 19,069 mi^2.[56]

Table 4.1. New York Devonian Shale Resource Assessment, 1980 NPC Study.

Study	Shale Thickness (Feet)	Resource Base (Tcf)	Resource Base (Bcf/Mi^2)
LOG DATA:			
Black Shale	59	19	0.99
Gray Shale	2,731	145	7.60
Total	2,790	164	8.60
SAMPLE DATA:			
Black Shale	619	198	10.38
Gray Shale	2,171	115	6.03
Total	2,790	313	16.41

For comparative purposes, Figure 4.2 presents the resource assessment on a state-by-state basis for the log data approach. New York ranks third in resource, behind Pennsylvania and West Virginia, accounting for 14.5% of the Devonian Shale natural gas resource in the Appalachian Basin. Unfortunately, no state-by-state estimates were made for technically recoverable natural gas in the 1980 NPC study.

In 1993, the U.S. Geologic Survey (USGS) published a resource assessment of the Devonian Shale in the Appalachian Basin[58] based on work done earlier by Charpentier.[59]. The assessment, described as qualitative, broke up the Appalachian Basin into 19 sub-areas (Figure 4.3). The approach used by the USGS for each of the 19 play areas was geologic based, and were based on structural and stratigraphic criteria. Parameters used to help define boundaries include: thickness of black shale, total organic carbon, thermal maturity of organic matter, and structural complexity (development of natural fractures). Table 4.2 summarizes the gas-in-place estimates from the study. The shale gas potential was rated using a **low**, **moderate** and **good** system. In areas where all of the parameters fall within ranges suitable for generation and accumulation of natural gas, a designation of **good** is used. In areas where *a* majority of the parameters fall within favorable ranges and the remaining are close to acceptable standards, a designation of **moderate** is used. In areas where a majority of the parameters do not fall within acceptable ranges, a designation of **low** is used. For detailed evaluation parameters within each individual play area and the basis for the potential designation, the reader is referred to the original USGS open file report. As with the 1980 NPC study, no estimates were made for recoverable natural gas for each play area.

Six of the play areas are in part within the New York State boundaries. Of these six plays, two are rated as good (Play 3 and 15), two are rated as moderate (Play 6 and 17) and two are rated as low (Play 16 and 19).[58]

Figure 4.2. Devonian Shale NPC Resource Assessment Comparison by State – Log Based Method.

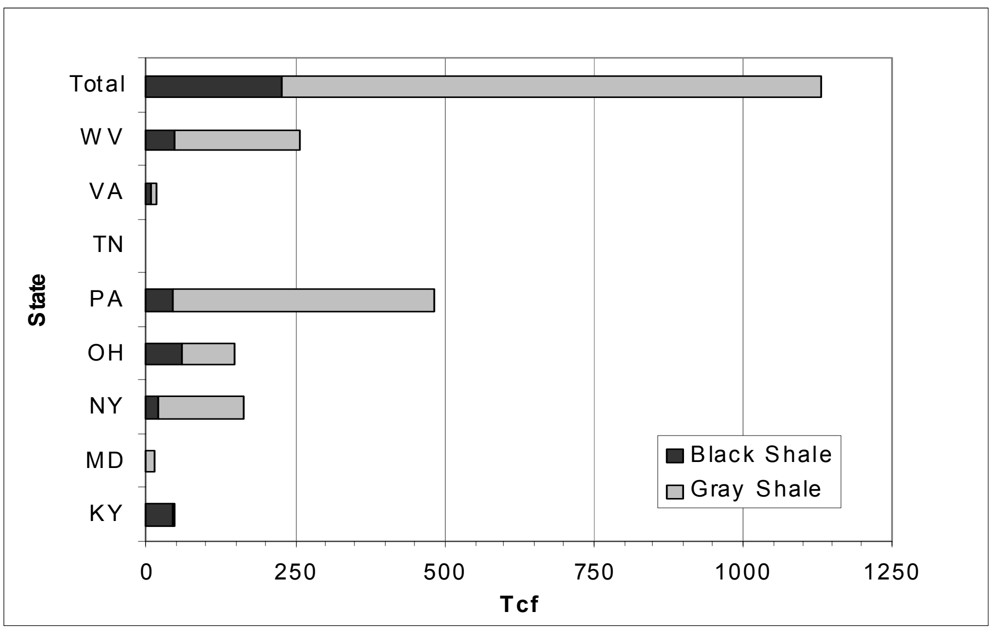


Figure 4.3. USGS Shale Gas Play Areas of the Appalachian Basin.

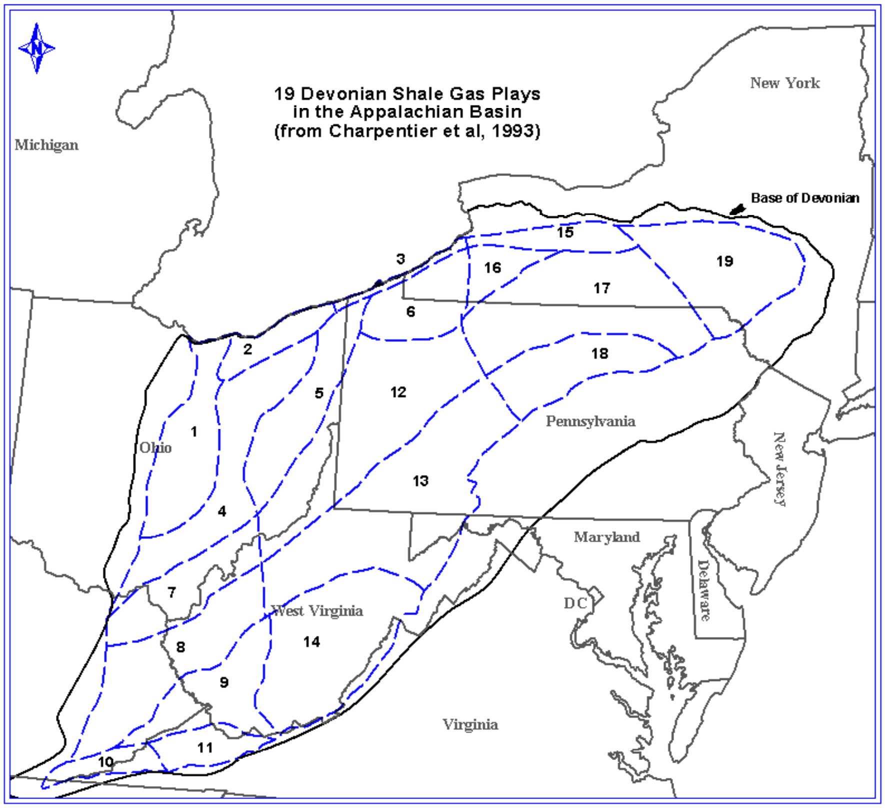


Table 4.2. Estimates of In-Place Natural Gas Resources in the Devonian Shale, by Play Area.

Play		Natural Gas Resource (Tcf)			
Number*	Name	Low F_{95}	High F_5	Mean	Shale Gas Potential
1	North-Central	17.9	34.2	25.9	Moderate
2	Western Lake Erie	21.7	31.3	26.5	Good
3	Eastern Lake Erie	2.1	3.3	2.7	Good
4	Plateau Ohio	44.4	76.2	59.9	Low
5	Eastern Ohio	35.2	55.1	44.7	Moderate
6	Western Penn-York	20.4	28.2	24.3	Moderate
7	Southern Ohio Valley	19.7	36.2	27.7	Moderate
8	Western Rome Trough	38.0	74.0	56.0	Good
9	Tug Fork	13.7	25.9	19.7	Good
10	Pine Mountain	10.7	18.7	14.6	Moderate
11	Plateau Virginia	3.9	10.2	7.1	Good
12	Pittsburgh Basin	76.8	129.9	102.1	Low
13	Eastern Rome Trough	70.7	132.5	100.3	Good
14	New River	38.5	91.7	63.1	Low
15	Portage Escarpment	8.5	21.3	14.6	Good
16	Cattaraugus Valley	10.4	23.2	16.6	Low
17	Penn-York Plateau	98.1	195.2	146.0	Moderate
18	Western Susquehanna	24.1	67.7	44.9	Low
19	Catskill	22.1	75.8	47.6	Low
	Basin Total	577.1	1130.8	844.2	

* *Basin,* Gray shading indicates play area, in part, resides within the state of New York

4.2 DEVONIAN SHALE GAS PRODUCTION IN NEW YORK

Natural gas production in black shales of the Dunkirk, Rhinestreet and Marcellus was established in numerous wells, and several small fields in New York during the 19th century, however few details are available for these early wells. A review of well records show approximately 100 wells that were drilled with designated API numbers for Devonian-age shale production (Figure 4.4). Most of these wells were drilled after 1970. At the end of 1999, 10 wells produced 6.3 Mmcf of natural gas from Devonian Shale. The average daily flow rate per well (assuming a full 12 months of production) was 1.73 Mcfd. Table 4.3 is a summary of the fields with Devonian Shale gas production. Figure 4.5 shows all of the gas shale fields in New York.

Figure 4.4. Location of Devonian Gas Wells.

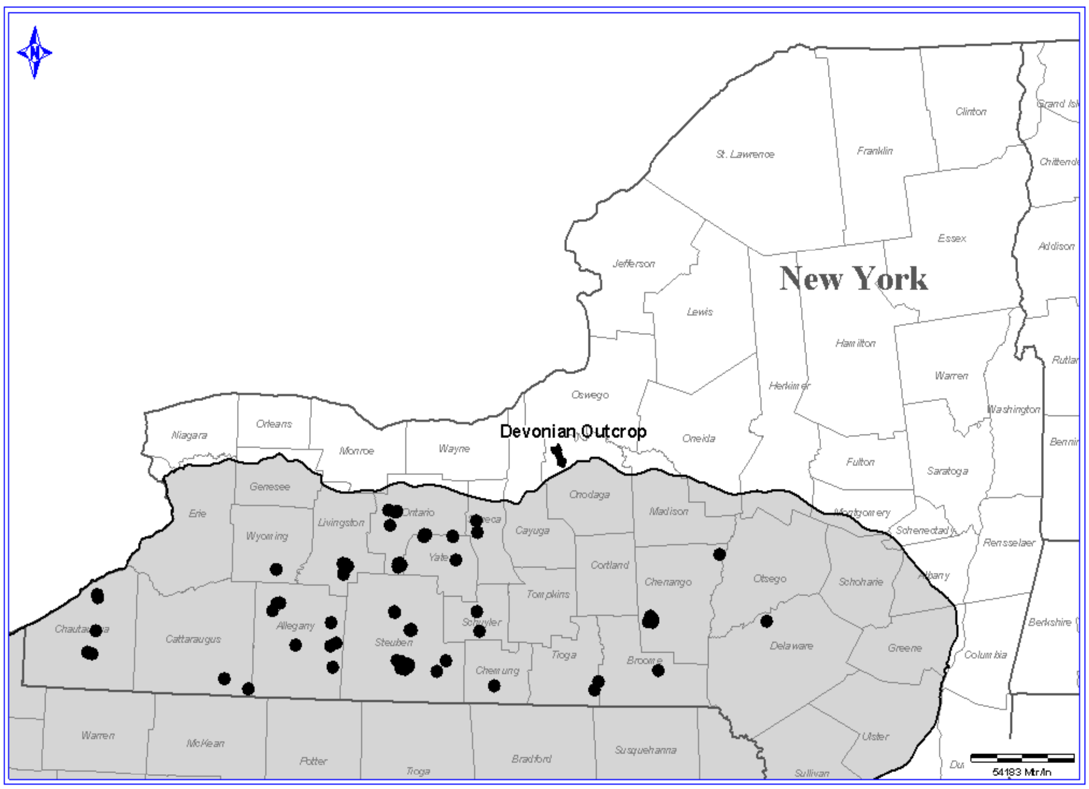
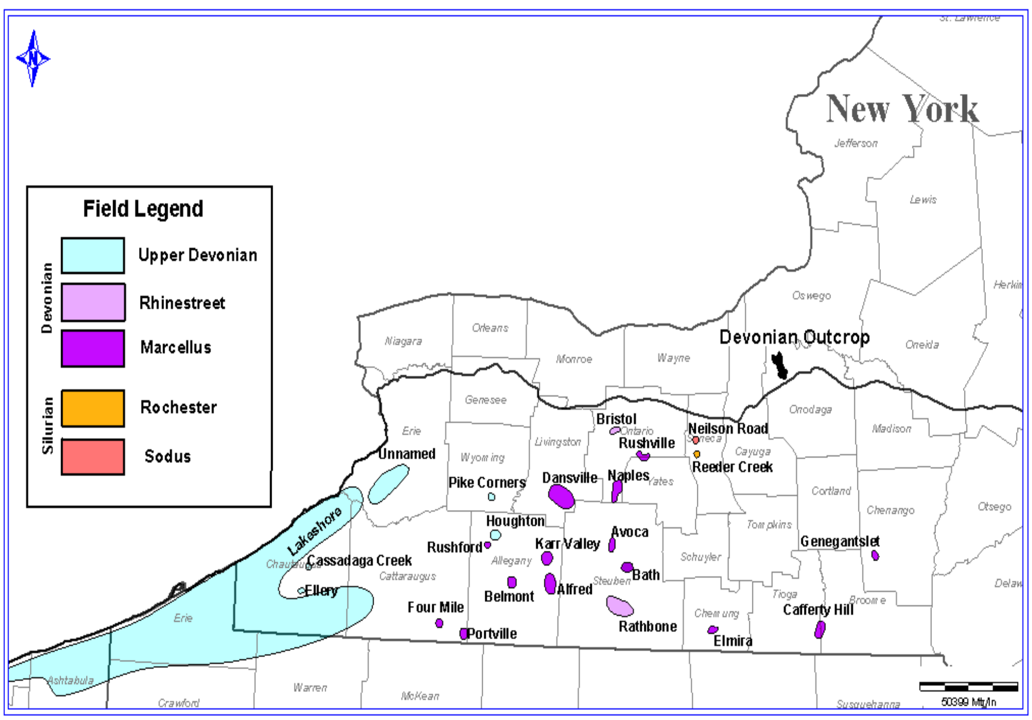


Table 4.3. Devonian Gas Shale Fields in New York in Order of Year of Discovery.

Gas Field	Year	Producing Zone	Avg. Depth (feet)	IP (mcfd)	Wellhead Pressure (psia)	No. of Prod. Wells	Status As of 1999	Cum. Prod. Thru 2001* (mmcf)
Lakeshore Belt	1821	Dunkirk	200	10-100?	?	300 (?)	?	52.89
Naples	1880	Marcellus	1,300	1.5-20	150 (?)	12	Abnd.	32.18
Dansville	1881	Lower Hamilton	1,000	10-100	50 (?)	7	Prod.	5.57
Rushville	1902	Lower Hamilton	650	60	35	10 (?)	Abnd.	Na
Bristol	1914	Marcellus	650	3-850	50	10	Abnd.	Na
Southern Erie County	1920's	Rhinestreet-Hamilton	800	40-150	225	?	na	Na
Rathbone	1931	Nunda, Rhinestreet	1,000	100-2,000	225	28 (?)		2.20
Genegantslet	1964	Upper Hamilton	1,200	2,166	565	3		Na
Pikes Corners	1978	Devonian Shale				1	Prod.	18.53
Alfred	1981	Marcellus	3,950	40	1720	1	Abnd.	1.28
Four Mile	1981	Marcellus	3,600	14	1520	1	Abnd.	
Elmira	1982	Marcellus	2950	86		1	Prod.	9.29
Cafferty Hill	1982	Marcellus		17		1	Prod.	3.1
Avoca	1982	Marcellus				2	Prod.	46.89
Karr Valley	1982	Marcellus	3,480	330	1,720	1	Prod.	15.69

Modified from Van Tyne, 1983. Discovery year is determined as date of first shale gas production for fields with gas production from other horizons.*Cumulative production data are obtained from New York State Oil and Gas Drilling and Production and Mineral Resources Annual reports and others sources as available and begins as of 1981.

Figure 4.5. Designated Fields Producing from Shales in New York.



Sometime during 1821, Edward Howard, a proud owner of a woolen mill in the town of Fredonia, New York, was dissatisfied with his water well (shallow and ran dry seasonally) and decided to drill a new well in the shale just below his mill. He began simply by "drilling" with an iron bar a few feet long. After drilling a few feet into the shale, he observed water and bubbles of gas escaping from the shale. A friend by the name of William Aron Hart, a gunsmith of the village, visited the mill from time to time and became interested in his friends experiment and its outcome.[60]

William Hart continued working on the hole that Edward had started under the mill until the "drill" broke, leaving a portion of the bar "steadfast in the shale" and shutting off the gas flow in the well. Mr. Hart abandoned the well and set about drilling another well nearby for gas. He went down successfully about 40 feet, but found no volume of gas. Still not discourage, he set about looking for the gas veins (fractures) that were well known in the area, which had been seeping gas at the surface for centuries. He located his third attempt near one of the largest natural gas seeps on the banks of Canadaway creek. He drilled down at least 26 feet and possibly 70 feet and found what he had been looking for – good gas flow.[60]

William Hart quickly realized the potential of the natural gas and built a crude gasometer to collect the gas. He laid a gas line using light-weight lead pipe, ¾ inch in diameter, to the Abell House (a hotel) and several stores opposite the hotel, and began to transport and sell the gas. Around 1830, the flow rate from the well was gauged at 880 cubic feet in 12 hours (1.76 Mcfd). The well continued to produce and supply the town through 1858 (37 years). A second well was drilled nearby by a newly formed gas company called Fredonia Gas Light Company. The well produced about 2 Mcf per day and continued to supply the town with natural gas for illumination. Drilling continued into the 20th century. Records indicate reports were made of salt water in the wells as early as 1887 and the need to pump the wells up to 4 times a year and to "never shut them in." A typical 300-foot shale well cost approximately $300 and the gas was sold for $1 per thousand cubic feet around the turn of the century.[60]

During the 1800's hundreds of shallow gas shale wells were drilled in the area and along the shores of Lake Erie, giving rise to the establishment of Lakeshore Field. During these early years, drilling for natural gas expanded geographically as well as geologically in New York and elsewhere across the nation. The oldest established gas shale field in New York is Naples located in southern Ontario County. The field was discovered in 1880 and 19 wells ranging in depth from 1,220 feet to 1,400 feet were drilled. Twelve were completed in the Marcellus, of which 11 were reported to be producing 1-2 Mcfd as of the early 1980's for a local utility.[61] Other fields discovered in the 19th century include the Lakeshore Field and the Dansville field. The Lakeshore field includes many of the early wells drilled along the shores of Lake Erie following the discovery made by William A. Hart in 1821.

During the first half of the 20th century several shale gas fields were discovered. These included Rushville, Bristol, Southern Erie County, and Rathbone fields. The Rathbone field was discovered in 1931 in Steuben

County, New York. Thirty-one wells were drilled in the field. Twenty-four wells were producers, four were dry holes, two were plugged and abandoned due to poor performance and one well produced oil. The wells were typically 900-1,500 feet in depth and targeted the Nunda and Rhinestreet shales of the West Falls Formation. Reservoir pressure was reported as 225 psig and flow rates (IP's) ranged from 100–2,000 Mcfd.[62]

Prior to the exploration funded by NYSERDA, the last shale gas field formally designated was Genegantslet, in Chenango County. In 1964 the Decker #2 well was drilled in the southern part of the town of Smithfield and encountered gas in the upper Hamilton. The well tested at 2,166 Mcfd, and was completed in the Marcellus Shale. Nine other wells were drilled, but only 3 wells produced gas (Table 4.4).[61]

Table 4.4. Genegantslet Field (Chenango County) Marcellus Shale Well Data.

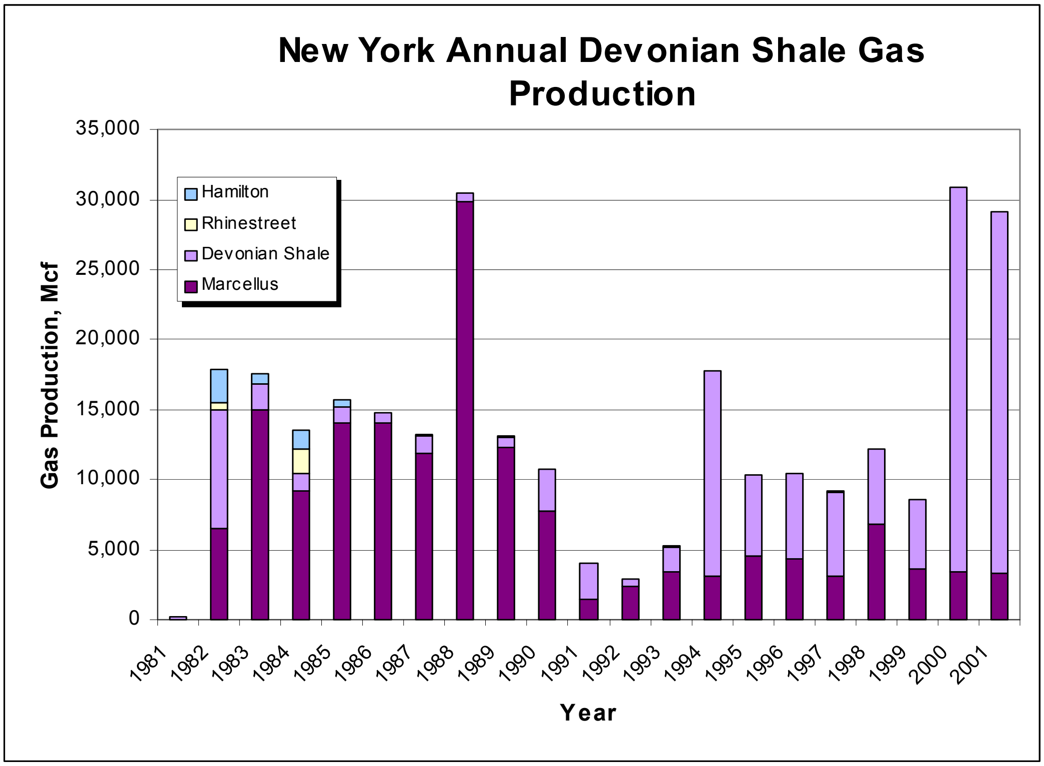
Well Name	Date	TD	Formation	IP, MCFD/Pressure
Decker #1	1963	3,265	Sand (Silt?)	Dry Hole
Decker #2	1964	2,050	Marcellus Sh	I0F 1650 Mcf/day down to 1000 Mcf blow after 54 hrs. IRP - 600# down to 540# after 2 wks; 1 yr later 1/7/65, NYSNGC gauged 2166 Mcf A/5 hrs. blow: RP - 565#
Decker #3	1964	3,685	Helderburg Lm	No show in Marcellus, Dry Hole
Decker #4	1964	2,002	Marcellus Sh	IOF 250 Mcf and FOF 332 Mcf, IRP at 565#
Flannigan #1	1965	2,462	Unknown	"scum" show @ 1110-1130 & gas show 25-50 mcfd @ 1502-1515 in Hamilton – Dry Hole
J. Bottle #1	1965	2,015	Marcellus Sh	25 Mcfd @ 1958' & 2-3 Mmcfd @1975' / 575# in 5 hours
J. Bottle #2	1965	2,100	Unknown	Dry Hole
Collyer 1	1966	2,201	Unknown	IOF-6.8 Mcfd in Hamilton, estimated RP-200 # -Dry Hole
Decker #5	1967	6,292	Hamilton	

Gas shows in many wells were reported during drilling and testing elsewhere in southern New York in subsequent years, yet only a handful of wells were drilled and completed as shale producers. Little information is available for these wells but IP's reported ranged from small to over 1 Mmcfd. Most of the wells were completed in the Lower Hamilton Group, including the Marcellus Shale. The wells were usually fracture-stimulated which sometimes improved production, but other times killed the well. It is estimated that 27 wells were completed as Marcellus producers since the 1960's. Cumulative production from these is unknown.

Following the NYSERDA funded exploration and testing program, several fields were established. Although many of the fields were established with only one well, several continued to produce through

2001. Many of the fields are designated for home use or private use. Production data is often not measured and produced volumes vary based on the needs of the user. Figure 4.6 shows the annual (1981-2001) natural gas production from Devonian-age shale. This data is taken from the Annual New York State Oil, Gas, and Mineral Resources report published by the Division of Mineral Resources of New York State. Over this 20 year time period, cumulative production from Devonian Shale wells was 288.3 Mmcf.

Figure 4.6. Annual Devonian Shale Gas Production from 1981-2001.



Several of the wells drilled as part of the NYSERDA research program had a primary objective to test the viability of drilling and completing wells in old fields and using modern technology. These four wells and fields are summarized in Table 4.5. Additional information about the wells is covered in a later section.

Table 4.5. NYSERDA Wells Drilled to Test Viability of Older Fields.

Well Name / API #	County/ Field	Field Discovery Date	Date	Tested/ Completed Formation	IP (Mcfd)	Cum. Prod. (Mmcf) Through 2001 / Status
Valley Vista View #1 31-101-15268	Steuben Rathbone	1931	July 1980	Rhinestreet Marcellus	Dry 200	3.453 P&A
Meter Farm #1 31-051-15480	Livingston Dansville	1881	Sept. 1980	Hamilton (Marcellus)	411	5.526 Active
Elliot #1 31-123-17347	Yates Rushville	1902	Aug. 1982	Marcellus	Dry (water)	Dry Hole
Widmer #1 31-069-17366	Ontario Naples	1880	Sept. 1983	Hamilton (Marcellus)	40	1.027 P&A
Data from NYSERDA 81-18, VOL IV, and USGS Bulletin 1909, pg M15, and New York Production Database.						

4.3 SILURIAN SHALE GAS PRODUCTION IN NEW YORK

Two gas fields have been discovered in Silurian shales (Table 4.6). Meridian Exploration discovered the Reeder field in Seneca County. The Ritter #1019-1 well was drilled in June 1989 and was completed open-hole in the Rochester Shale. Casing was set (4 ½ inch diameter) at 1,549 feet and the well reached a total depth of 1,782 feet (driller). The well was completed as an open-hole natural flow with a reported IP of 2,258 Mcfd. The well has produced 48.32 Mmcf through 2001.

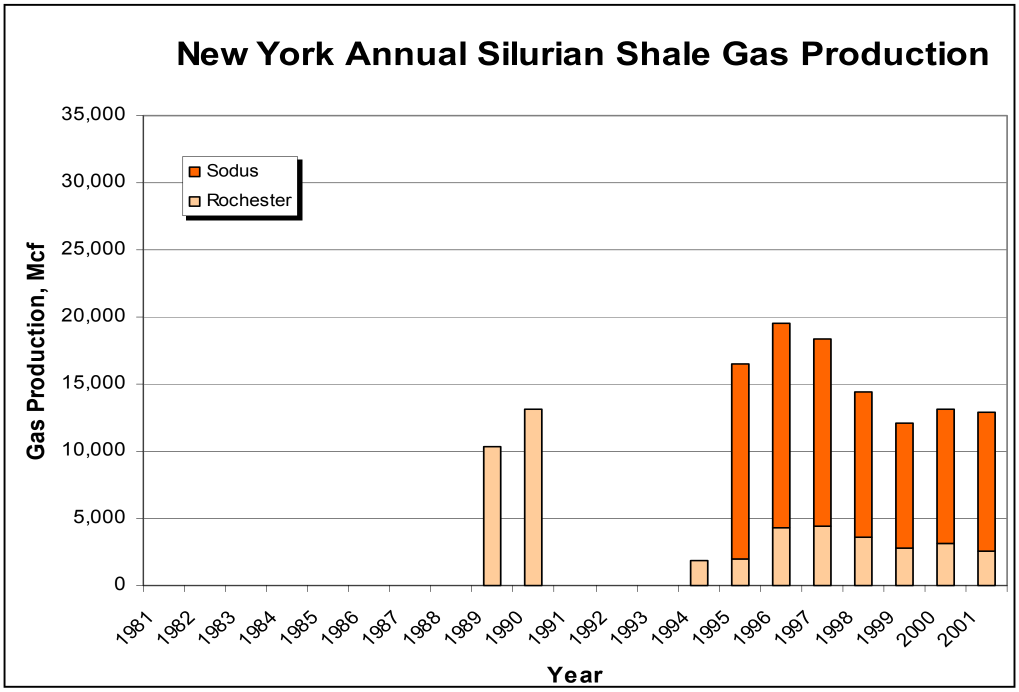
Table 4.6. Silurian Gas Shale Fields in New York in Order of Year of Discovery.

Gas Field	Disc. Year	Producing Zone	Avg. Depth (feet)	IP (mcfd)	Wellhead Pressure (psia)	No. of Prod. Wells	Status As of 1983	Status As of 2001
Reeder Creek	1989	Rochester Shale	1,782	2,258	568	1	Abnd.	Prod.
Neilson Road Pool	1990	Sodus Shale	1,865	6,038		1	Prod.	Prod.
Source: Public Records								

Meridian Exploration discovered the Neilson Road Pool in Seneca County. The Neilson #1146-1 well was drilled in January 1990 and was completed open-hole in the Sodus Shale. Casing was set (7” diameter) at 1,161 feet and the well reached a total depth of 1,865 feet. The well was completed as an open- hole natural flow with a reported IP of 6,038 Mcfd. The well has produced 83.94 Mmcf through 2001. An additional test was drilled by Belden and Blake Corporation. They unsuccessfully tested the Marcellus and Rochester shales in their Wonderview Farms 1-A well drilled in Schuyler County in early 2002 and the well was plugged and abandoned.

Figure 4.7 shows the annual (1981-2001) natural gas production from Silurian-age shale. This data is taken from the Annual New York State Oil, Gas, and Mineral Resources report published by the Division of Mineral Resources of New York State. Through 2001, cumulative production from the two Silurian gas shale wells was 132.3 Mmcf.

Figure 4.7. Annual Silurian Shale Gas Production from 1981-2001.



5 Research and Development Devonian Shale Wells

The most complete data packages available in the public domain for shale gas wells in New York come from the research & development (R&D) wells drilled by U.S. Department of Energy (DOE). NYSERDA sponsored three formal Devonian Shale exploration programs from 1980 to 1983.[63] DOE drilled two wells in the late 1970's prior to the NYSERDA programs to characterize the shale as part of their Eastern Gas Shale Project (EGSP).[22] In total there were 15 research wells drilled with different objectives and testing protocols used. Additional support for many of the NYSERDA wells came from the U.S. DOE. Several of the wells were cored and thoroughly analyzed, completed, treated and production tested. Tables 5.1 and 5.2 summarize the research wells. Figure 5.1 shows the location of the R&D wells relative to the shale gas fields in New York. Several of the wells produced gas for commercial use and four wells are still producing as of 2001. Both the U.S. DOE and NYSERDA research wells are summarized in the following sections.

Figure 5.1 Location of R&D Wells in New York and Associated Fields.

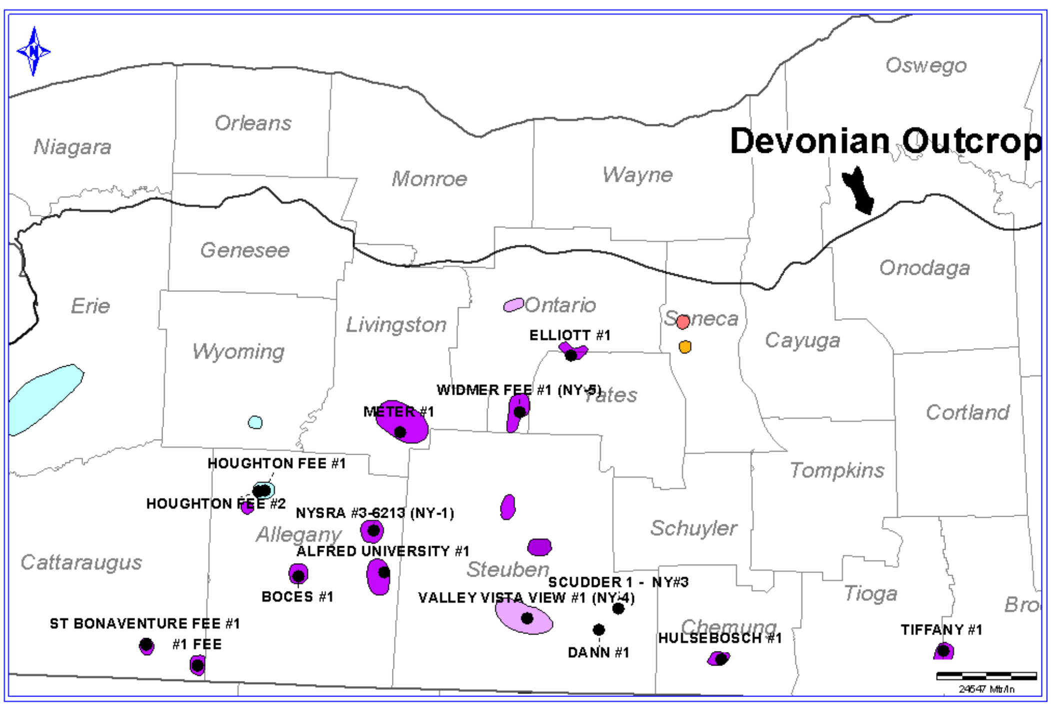


Table 5.1. Research and Development Devonian Shale Test Wells Drilled in New York.

Well Name API #	County	Date	TD (feet)	TD Fm.	Protocol
Alfred Univ. #1 31-003-16203	Allegany	1981	3987	Onondaga	Drill cuttings - chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
NYSERA #3-6213 (EGSP NY-#1) 31-003-13549	Allegany	1978	5325	Queenston	Core
BOCES #1 31-003-16227	Allegany	1981	3350	Onondaga	Drill cuttings - chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
Dann #1 31-101-15404	Steuben	1980	1400	Rhinestreet?	NA
Elliot #1 31-123-17347	Yates	1982	900	Onondaga	NA
Houghton College #1 Fee 31-003-14253	Allegany	1979	2333	NA	Drill cuttings - chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
Houghton College #2 Fee 31-003-16202	Allegany	1981	2471	Onondaga	Chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
Hulsebosch #1 31-015-17318	Chemung	1982	3030	Onondaga	NA
Meter #1 31-051-15480	Livingston	1980	1642	NA	Drill cuttings - chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
Portville Central School #1 Fee 31-009-16232	Cattaraugus	1981	4227	Onondaga	Drill cuttings - chemical analysis, mineralology, organic content, x-ray diffraction, pressure transient testing.
Scudder #1 (EGSP NY-#3) 31-101-15382	Steuben	1980	1300	Rhinestreet	Core
St. Bonaventure Univ. #1 Fee 31-009-16214	Cattaraugus	1981	3996	Onondaga	Drill cuttings - chemical analysis, mineralology, Organic content, x-ray diffraction, pressure transient testing.
Tiffany #1 31-107-17788	Tioga	1982	4457	Onondaga	NA
Valley Vista View #1 (EGSP NY-#4) 31-101-15268	Steuben	1980	3850	Onondaga	pressure transient testing and Core.
Widmer #1 31-069-17366	Ontario	1983	1220	Onondaga	NA

NA; Not Available/Not Reported

5.1 U.S. DEPARTMENT OF ENERGY FUNDED RESEARCH WELLS

The initial research done on the organic-rich Devonian Shale in New York was funded by the U.S. Department of Energy (DOE). Two wells were drilled in 1978 and 1979 by DOE.

5.1.1 NYSRA#3-6213 Well

Natural Fuel Gas Corporation well drilled the NYSRA #3-6213 in the September of 1978 in Allegany County New York. The well was targeted for the Medina formation and reached a total depth of 5,325 feet. Coring operations were conducted on this well as part of the U.S DOE Eastern Gas Shale Project (EGSP). The well was designated the EGSP NY #1 well. Core was taken from the Dunkirk (370-530 feet), Pipe Creek (965-995 feet), Rhinestreet (1,330-2,352 feet), Middlesex and West River (2,488-,657 feet), and the Pen Yan and Geneseo (2,725-2,894 feet). Extensive open-hole logs were run and the well was plugged in October 1978.[64]

In October 1981 the well was re-entered and the plugs were drilled out to a total depth of 3,670 feet. Casing was run (4 ½ inch diameter) to TD and cemented. The Marcellus Shale was perforated from 3,476-3,509 feet with 20 shots. A nitrogen foam fracture treatment was performed on the Marcellus on January 1982 placing approximately 30,000 pounds of proppant with 12,300 gallons of frac water and 529,000 scf of nitrogen. Reported IP was 333 Mcfd at flowing tubing pressure of 1,720 psi through a 2 inch choke. The well has produced intermittently since 1982 for a cumulative production of 15.69 Mmcf as of December 2001.

5.1.2 Houghton College #1 Well

The Houghton College #1 well was drilled in the summer of 1979. This was the first well jointly funded by DOE and NYSERDA to stimulate drilling for Devonian Shale gas production in New York. The well was drilled on the campus of Houghton College in Allegany County. The well was drilled to a total depth of 2,334 feet, penetrating the Tully Limestone and was logged and cased. The well was perforated in the Marcellus shale from 2,254-2,292 feet. A stimulation treatment was performed on the well October 1979, which consisted of a nitrogen foam hydraulic fracture treatment placing 50,000 pounds of proppant in 333 barrels of fluid.[65]

Table 5.2. Research & Development Devonian Shale Wells Completion Summary.

Well Name API #	County/ Field	Phase	Date	Tested/ Completed Formation	IP (Mcfd)	Calculated Open Flow (Mcfd)	Cum. Prod. (Mmcf) Through 2001 / Status
Alfred Univ. #1 31-003-16203	Allegany Alfred	1	June 1981	Marcellus	40	35	1.284 P&A
BOCES #1 31-003-16227	Allegany Belmont	2	June 1981	Marcellus	73	105	4.135 P&A
Dann Farm #1 31-101-15404	Steuben Rathbone	1	Aug. 1980	Rhinestreet	270	10	0.074 P&A
Elliot #1 31-123-17347	Yates Rushville	3	Aug. 1982	Marcellus	Dry (water)	0	Dry Hole
Houghton College #1 Fee 31-003-14253	Allegany Houghton	0	Nov. 1978	Marcellus	1,300	130	24.750 P&A
Houghton College #2 Fee 31-003-16202	Allegany Houghton	2	July 1981	Marcellus	77	23	0.788 P&A
Hulsebosch #1 31-015-17318	Chemung Elmira	3	Aug. 1982	Marcellus	86 (89)	545 (23)	7.086 Active
Meter Farm #1 31-051-15480	Livingston Dansville	1	Sept. 1980	Hamilton (Marcellus)	411	95	5.526 Active
NYSERA #3-6213 31-003-13549	Allegany Karr Valley	0	Jan. 1981	Marcellus	333		15.69 Active
Portville Central School #1 Fee 31-009-16232	Cattaraugus Portville	2	June 1981	Marcellus	22	18	1,130 P&A
Scudder Farm #1 31-101-15382	Steuben Rathbone	1	Aug. 1980	Rhinestreet	dry	0	0 Unknown
St. Bonaventure Univ. #1 Fee 31-009-16214	Allegany Four Mile	2	June 1981	Marcellus	14	19	2.592 P&A
Tiffany #1 31-107-17788	Tioga Cafferty Hill	3	Aug. 1982	Marcellus	17	9 (23)	1.658 Active
Valley Vista View #1 31-101-15268	Steuben Rathbone	1	July 1980	Rhinestreet Marcellus	dry 200	0 110, 142	3.453 P&A
Widmer #1 31-069-17366	Ontario Naples	1	Sept. 1983	Hamilton (Marcellus)	40	12	1.027 P&A

Data from NYSERDA 81-18, VOL IV, and USGS Bulletin 1909, pg M15, and New York Production Database.

An initial bottom hole pressure of 1,361 psig (0.59 psi/ft) was recorded in October 1979. A transient pressure test was run during March 1980 and the well was completed with 1 ½ inch tubing. Production began in November 1980 and the well produced 21.173 Mmcf through March 1983. In April 1983, additional pressure transient began. The well was shut in for 49 days and a stabilized surface pressure of 363 psig was recorded compared to the initial pressure of 1,361 psig. A drawdown test was then performed and the well was shut in again for a buildup. Analysis of the data yielded a permeability thickness product of 7.5 md-ft. Using the perforated height (38 feet), a permeability of 203 μd and a skin factor of –2.3 was calculated. Gas-in-place (GIP) estimates from P/Z (pressure/gas deviation factor) analysis ranged from 27.5 Mmcf to 31.4 Mmcf.[65] The well produced approximately 24.750 Mmcf prior to plugging and abandoning the well in 1984.

5.2 NYSERDA RESEARCH AND DEVELOPMENT PROGRAM

As mentioned above, NYSERDA sponsored three programs that focused on improving the understanding of producing natural gas from Devonian-age shale in New York. During the program, thirteen wells were drilled from 1980-1983. Each of the three programs is summarized in the following sections.

5.2.1 Phase I - 1979-1980

The first phase of the NYSERDA program was primarily focused on exploration. Four shale wells were sited, drilled and completed during 1980 as part of this program.[66] Arlington Exploration was the operator and the NYSERDA contractor was Donohue, Anstey & Morril. Two of the wells were cored as part of the DOE Eastern Gas Shale Project.

5.2.1.1 Valley Vista View #1 Well (Rathbone Prospect)

The rationale for drilling this well was to test the use of modern stimulation techniques to revitalize old shale gas fields. The Rathbone shale gas field was discovered in 1931 and produced gas from the Rhinestreet Shale in the West Falls Formation of the Upper Devonian. Coring operations were also conducted on this well in the Geneseo and the Marcellus. The coring was part of the U.S DOE Eastern Gas Shale Project (EGSP). The well was designated the EGSP NY #4 well. The objective of the coring operations and analysis was to provide detailed characterization of the core recovered for the EGSP.[66]

The Valley Vista View #1 well was drilled in July 1980 by Donohue, Anstey & Morril within the old Rathbone shale gas field located in Steuben County, New York as a farm-out from Columbia Gas Transmission Corp. A substantial gas show of 1,300 Mcfd was encountered at a depth of 680 feet. A small show was also encountered in the Rhinestreet interval at approximately 1,838 feet. Drilling continued to the first core point at 3,010 feet and the gas was gauged at 200 Mcfd. Core was taken from 3,010-3,083 feet, which included collectively 69 feet of the Geneseo Shale member of the Genesee Formation. Drilling continued to the second core point at 3,790 feet. The coring operation was conducted from 3,790-3,848 feet and included collectively 54 feet of the Marcellus interval. A dry hole suite of logs was run. Forty feet of fill was encountered as well as water at 3,070 feet. The well was filled with KCL to run additional logs.[66]

Following the logging operations, 4½ inch diameter casing was run and cemented in place at 3,848 feet. A two-stage cement job was conducted on the well using a DV packer collar set at 2,927 feet. Review of the logs and core indicated that the Onondaga Limestone had not yet been encountered as originally believed. It was decided to deepen the well and carefully evaluate when the Onondaga was first penetrated. The well was deepened to 3,910 feet and encountered additional shale after reaching the Onondaga at 3,904 feet.[66]

Following the deepening operations, a stimulation treatment was conducted on the Marcellus interval on October 31, 1980 through 45 perforations from 3,820-3,835 feet. The stimulation treatment was a 75% quality nitrogen foam frac placing 80,000 pounds of proppant at increasing concentrations from 1 to 3 pounds/gallon during five stages. After cleanup, the well sustained an open flow of approximately 200 Mcfd and when shut in the well pressured up to approximately 2,156 pound per square inch gauge (psig) within 232 hours (0.56 psi/ft). This was followed by a modified isochronal test, which resulted in an absolute open flow calculated of 110 Mcfd.[66]

Following the Marcellus completion, a bridge plug was set at 1,300 feet to isolate the Marcellus and test the Rhinestreet Shale interval. The Rhinestreet interval was perforated and stimulated in early December 1980 through 19 perforations from 940-1,225 feet. The stimulation treatment was a 75% quality nitrogen foam frac placing 80,000 pounds of proppant at an average injection rate of 6.3 barrels per minute (bpm) with an average surface pressure of 1,721 pound per square inch absolute (psia). The well was production tested and was making 1.5 barrels of salty water per hour with approximately a trace of natural gas. Pressure buildup performance on this interval was poor. Following these operations, the Rhinestreet interval was squeeze cemented and the well was completed in the Marcellus Shale.[66]

The well produced from December 1982 through April 1983 resulting in 1.451 Mmcf of gas produced. Additional pressure transient pressure testing was conducted on the Marcellus interval from April through September 1983. Analysis showed a permeability range of 0.216 md to 1.47 md and a reservoir pressure of 1,340 psig at the end of the testing in September (0.35 psi/ft). Gas-in-place (GIP) estimates from P/Z analysis ranged from 5.32 Mmcf to 3.32 Mmcf.[65]

The well produced for a short period of time and total production was 3.453 Mmcf prior to plugging and abandonment.

5.2.1.2 Meter, Kennedy & Howe #1 Well (Dansville Prospect)

Similar to the Rathbone prospect, the Dansville prospect objective was to test the use of modern stimulation techniques to revitalize old shale gas fields. The Dansville shale gas field was discovered in 1881 and produced gas from the lower Hamilton Group of the Middle Devonian.

The Meter, Kennedy & Howe #1 well was drilled in September 1980 by Donohue, Anstey & Morril near the old Dansville shale gas field in Livingston County, New York. A slight show of gas and water was recorded at a depth of 1,017 feet. A small show was also encountered at approximately 1,560 feet. Casing (4 ½ inch diameter) was run to a total depth of 1,642 feet and cemented. The Marcellus Shale was perforated from 1,332-1,617 feet with 20 shots and stimulated on November 10, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The stimulation treatment was a 75% quality nitrogen foam frac placing 76,000 pounds of proppant at an average injection rate of 6.25 bpm with an average surface pressure of 2,394 psia.[65]

After cleanup, the well had an estimated flow rate of approximately 67 Mcfd. A modified isochronal test was attempted on the well during November. Results were speculative due to tampering with the well during the test. A second test was run on the well in January 1981. Results yielded a stabilized open flow of 411 Mcfd. A third test was run in February and a stabilized shut-in pressure of 703 psig was recorded, (0.478 psi/ft) and an absolute open flow of 95 Mcfd was calculated.[66]

From January 1982 to February 1983, the well produced 2.899 Mmcf of natural gas. The well was shut-in from April to September for pressure transient testing. After 131 days, the casing pressure had built up to 440 psig and was still building at a rate of approximately 1 psi/day. Due to time constraints, a modified isochronal test was initiated on the well. Unusual pressure behavior was observed and analysis was inclusive. Fluid build up in the wellbore was speculated as the cause of the behavior. Gas-in-place (GIP) estimates from P/Z analysis ranged from 7.25 Mmcf to 10 Mmcf.[65]

The well was converted to home use and is still active today. Cumulative production through 2001 is approximately 5.526 Mmcf.

5.2.1.3 Scudder #1 Well (North Corning Prospect)

The objective of the Scudder #1 well was to test an area that exhibited a highly fractured layer that could be communicating with the Rhinestreet interval as a conduit. The concept was based on gas shows reported in shales (not silts or siltstones) from wells within a given area. The area in Steuben County was selected based on reports from the Leach #1 well which encountered shale gas in what appeared to be a rubblized zone that was believed to be stratigraphically continuous over a large area. Unfortunately, no leases were available offsetting the Leach #1 well. An alternative location was selected nearby on the Scudder lease. Coring operations were also conducted on this well in the Rhinestreet. The coring was part of the U.S DOE Eastern Gas Shale Project (EGSP). The well was designated the EGSP NY #3 well. The objective of the coring operation and analysis was to provide detailed characterization of the core recovered for the EGSP.[66]

The Scudder #1 well was drilled in July-August 1980 by Donohue, Anstey & Morril near the town of Corning in Steuben County, New York. No gas shows were encounter while drilling to the first core point at 1,203 feet. Core was taken from 1,203-1,233 feet in the Rhinestreet interval. A second core run was made in the Rhinestreet from 1,233-1,263. No natural fractures were observed in either core. Drilling continued until 1,342 feet with no shows of natural gas. Open-hole logs were run and no production casing was run. After examination of the logs and core, a decision was made not to complete the well. The well was later plugged and abandoned.[66]

5.2.1.4 Dann #1 Well (Erwin Prospect)

The objective of the Dann #1 well was also similar to the Scudder #1 well, testing of an area that exhibited a highly fractured layer that could be communicating with the Rhinestreet interval as a conduit. Wells drilled to the Oriskany had recorded gas shows in the shale interval.

The Dann #1 well was drilled in August 1980 by Donohue, Anstey & Morril near the town of Corning in Steuben County, New York. While drilling to a total depth of 1,400 feet, a good gas show was encountered at 1,074 feet. An open flow test after 16 hours gauged the flow at 270 Mcfd. The well was completed open hole. Casing was run to 1,055 feet and cemented in place using a packer shoe. The well was plugged back to 1,088 feet with gravel, a bridge plug and Cal seal. An attempt was made to produce the well unstimulated, but the flow rates were very low against the line pressure.[66]

The well was broken down on October 20, 1980, but gas production did not improve. A stimulation treatment was performed on November 3, 1980 in the open-hole interval from 1,055-1,088 feet. The treatment was a nitrogen foam frac placing 15,000 pounds of proppant using 290,000 scf of nitrogen and 5,000 gallons of water at an average rate of 2.6 bpm and average surface treating pressure of 1,800 psi.[66]

After the well was cleaned up, it was shut-in for a build up test in early January 1981. Casing pressure reached 395 psig after 15 days. This was followed by a modified isochronal test. The calculated absolute open flow rate was 10 Mcfd. The stabilized shut-in reservoir pressure was 425 psia (0.397 psi/ft). The well produced only a minimal amount of gas and was later plugged and abandoned.[66]

5.2.2 Phase II – 1981-1982

The second phase of the NYSERDA program was directed at determining the economics of shale gas recovery for institutional users. Five wells were drilled in 1981 targeting the Marcellus Shale in the south-central portion of New York. Arlington Exploration Company drilled each of the wells on the property of education institutions in order to demonstrate the economic prospect of natural gas production for local end users.[67]

The gas-in-place estimates given are based on material balance using P/Z and do not include any contribution of gas by sorption. They are likely very conservative estimates. The pressure transient testing done on the wells was a modified isochronal test. All of the wells exhibited fluid build up during production and pressure transient testing, limiting the accuracy (uniqueness) of the test results. Each of the wells have been produced on an as needed basis by the end user, further limiting the value of the production data for interpretation of producibility and ultimate recovery estimates.[67]

5.2.2.1 Alfred University #1 Well

The Alfred University #1 well was drilled with air in June 1981 on the lands of Alfred University in Allegany County, New York. Total depth of the well was 3,987 feet. The well encountered a 35-foot section of Marcellus Shale with no associated gas shows the interval. Casing (4 ½ inch diameter) was run to a total depth of 3,985 feet and cemented. The Marcellus Shale was perforated from 3,932-3,970 feet with 17 shots and stimulated on August 4, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The well was stimulated with a 75% quality nitrogen foam hydraulic fracturing treatment consisting of 60,000 pounds of proppant in 50,000 gallons of foam at an average rate of 20 bpm. Treating surface pressure averaged 4,400 psi and the ISIP was recorded as 3,800 psi and the frac gradient of 0.94 psi/ft was reported. Of the 333 barrels of fluid pumped into the well, approximately 146 barrels was recovered for a recovery efficiency of 43.8%.[67]

After the well was cleaned up, the flow rate was estimated to be 40 Mcfd. Initial bottom hole pressure was calculated to be 1,971 psia (0.499 psi/ft). The well was placed on production on March 1982 and produced approximately 1.151 Mmcf of gas through March 1983, supplying gas to heat boilers for the dining hall at the University. Pressure transient testing was conducted on the well from March through October 1983. Pore pressure was calculated to range from 1,744 to 1,400 psia (0.44-0.35 psia/ft). Gas-in-place (GIP) estimates from P/Z analysis ranged from 10.5 Mmcf to 4.6 Mmcf.[65]

The well was later deepened and completed open hole in the Oriskany formation in 1986. In January of 1993 the well was plugged and abandoned.

5.2.2.2 St. Bonaventure #1 Well

The St. Bonaventure #1 well was drilled with air in June 1981 on the lands of St. Bonaventure University in Cattaraugus County, New York. Total depth of the well was 3,996 feet. The well encountered a 25-foot section of Marcellus Shale with no associated gas shows the interval. Casing (4 ½ inch diameter) was run to a total depth of 3,996 feet and cemented. The Marcellus was perforated from 3,568-3,630 feet with 32 shots and stimulated on July 28, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The well was stimulated with a 75% quality nitrogen foam hydraulic fracturing treatment consisting of 60,000 pounds of proppant in 50,000 gallons of foam at an average rate of 12 bpm. Treating surface pressure averaged 4,200 psi and the ISIP was recorded as 4,050 psi and the frac gradient of 1.29 psi/ft was reported. Of the 333 barrels of fluid pumped into the well, approximately 164 barrels was recovered for a recovery efficiency of 49.2%.[67]

After the well was cleaned up, the flow rate was estimated to be 14 Mcfd. Initial bottom hole pressure was calculated to be 1,520 psig (0.422 psi/ft). The well was placed on production on January 1982 and produced periodically supplying gas to heat boilers for the Administrative Building at the University. Cumulative production through December 1982 was 550 Mcf. Pressure transient testing was conducted on the well from May through October 1983. Pore pressure was calculated to be 1,325 psig (0.37 psig/ft). Gas-in-place (GIP) estimates from P/Z analysis ranged from 4.2 Mmcf to 6.2 Mmcf.[65]

The well was later deepened and completed open hole in the Oriskany formation in January 1986. In August of 1986 the well was plugged and abandoned.

5.2.2.3 Allegany County BOCES #1 Well

The Allegany County BOCES #1 well was drilled with air in June 1981 on the lands of Allegany County Board of Cooperative Educational Services in Allegany County, New York. Total depth of the well was 3,350 feet. The well encountered a 35-foot section of Marcellus Shale with no associated gas shows the interval. Casing (4 ½ inch diameter) was run to a total depth of 3,332 feet and cemented. The Marcellus shale was perforated from 3,242-3,282 feet with 21 shots and stimulated on August 15, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The well was stimulated with a 75% quality nitrogen foam hydraulic fracturing treatment consisting of 60,000 pounds of proppant in 50,000 gallons of foam at an average rate of 20 bpm. Treating surface pressure averaged 3,800 psi and the ISIP was recorded as 3,400 psi and the frac gradient of 1.12 psi/ft was reported. Of the 333 barrels of fluid pumped into the well, approximately 159 barrels was recovered for a recovery efficiency of 47.7%.[67]

After the well was cleaned up, the flow rate was estimated to be 72.5 Mcfd. Initial bottom hole pressure was calculated to be 1,600 psig (0.49 psi/ft). The well was placed on production on December 1981 and produced approximately 2.3 Mmcf of gas through April 1983, supplying gas to heat boilers for the Occupational Center. Pressure transient testing was conducted on the well from April through October 1983. The highest surface pressure recorded was 1,390 psig (0.426 psig/ft). Gas-in-place (GIP) estimates from P/Z analysis ranged from 14.8 Mmcf to 78.8 Mmcf.[65]

5.2.2.4 Portville Central School #1 Well

The Portville Central School #1 well was drilled with air in June 1981 on the lands of Portville High School in Cattaraugus County, New York. Total depth of the well was 4,227 feet. The well encountered a 30-foot section of Marcellus Shale with no associated gas shows the interval. Casing (4 ½ inch) was run to a total depth of 4,222 feet and cemented. The Marcellus was perforated from 4,142- 4,176 feet with 18 shots and stimulated on July 21, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The well was stimulated with a 75% quality nitrogen foam hydraulic fracturing treatment consisting of 60,000 pounds of proppant in 50,000 gallons of foam at an average rate of 16 bpm. Treating surface pressure averaged 4,500 psi and the ISIP was recorded as 4,000 psi and the frac gradient of 1.11 psi/ft was reported. Of the 333 barrels of fluid pumped into the well, approximately 164 barrels was recovered for a recovery efficiency of 49.2%.[67]

After the well was cleaned up, the flow rate was estimated to be 18 Mcfd. Initial bottom hole pressure was calculated to be 1,820 psig (0.438 psi/ft). The well was placed on production on January 1982 and produced approximately 853 Mcf of gas through February 1983. Pressure transient testing was conducted on the well from April through October 1983. The highest surface pressure recorded was 1,132 psig with fluid in the wellbore (0.272 psig/ft). Gas-in-place (GIP) estimate from P/Z analysis was 2.5 Mmcf.[65]

5.2.2.5 Houghton College #2 Well

The Houghton College #2 well was drilled with air in June and July of 1981 on the lands of Houghton College in Allegany County, New York. Total depth of the well was 2,471 feet. The well encountered a 45-foot section of Marcellus Shale with no associated gas shows through the interval. Casing (4 ½ inch diameter) was run to a total depth of 2,470 feet and cemented. The Marcellus shale was perforated from 2,382-2,416 feet with 17 shots and stimulated on August 8, 1981. Prior to the stimulation treatment, the interval was broken down with acid and a ball-out treatment was performed. The well was stimulated with a 75% quality nitrogen foam hydraulic fracturing treatment consisting of 60,000 pounds of proppant in 50,000 gallons of foam at an average rate of 20 bpm. Treating surface pressure averaged 3,200 psi and the ISIP was recorded as 2,800 psi and the frac gradient of 1.03 psi/ft was reported. Of the 333 barrels of fluid pumped into the well, approximately 168 barrels was recovered for a recovery efficiency of 50.5%.[67]

After the well was cleaned up, the flow rate was estimated to be 18 Mcfd. Initial bottom hole pressure was calculated to be 1,220 psig (0.51 psi/ft). The well was placed on production on January 1982 and produced periodically through April 1983 for a total of 595 Mcf of gas. The well provided gas for the boilers at the Portville High School. Pressure transient testing was conducted on the well from April through October 1983. The highest surface pressure recorded was 525 psig (0.219 psig/ft). Gas-in-place (GIP) estimate from P/Z analysis was 1 Mmcf. A straight portion of the Horner build-up plot was apparent for this well. Analysis indicated a permeability thickness product of 0.14 md-ft. Using a thickness of 34 feet, permeability was calculated at .0041 md and skin of –2.6.[65]

5.2.3 Phase III – 1982-1983

The NYSERDA program from 1982 to 1983, Phase III, was designed to address the exploration rationale and the economics of gas recovery from the shale. Four wells were sited and drilled. Two of the wells explored deep, thick shales in locations considered to be naturally fractured and two wells assessed the economic potential remaining in known shale gas fields at shallow depths.[63]

5.2.3.1 Tiffany #1 Well (Endicott Prospect)

One of the primary reasons for drilling the Tiffany #1 well was to test the thicker Marcellus Shale. The well was located southwest of the Genegantslet shale gas field (Chenango County, NY). The well was drilled with air in August of 1982 to a depth of 4,457 feet. The well encounter a 124-foot section of Marcellus Shale and a small gas show at 4,284 feet. A show was also noted in the Geneseo Shale at 1,073 feet of 50 Mcfd. Casing (4 ½ inch diameter) was run to a total depth of 4,448 feet and cemented. The Marcellus was perforated from 4,280-4390 feet with 13 shots and stimulated on September 20, 1982 using a nitrogen foam fracturing treatment carrying 60,000 pounds of proppant in 50,000 gallons of fluid at an average rate of 12 bpm. The well was cleaned up and a four-point production test was run. The initial IP was 17 Mcfd calculated open flow rate was 9 Mcfd. Pore pressure was estimated to be approximately 1900 psi (0.4388 psi/ft). The poor well response was attributed to the lack of natural fracturing encountered by the well.[63]

5.2.3.2 Hulsebosch #1 Well (Elmira Prospect)

The Hulsebosch #1 well was sited over the Elmira salt dome testing the concept that the uplift of the shale by the salt is likely to have generated extensive local natural fracturing. The well was drilled with air in August 1982 to a depth of 3,030 feet. The well encountered a 74-foot section of Marcellus Shale with no associated gas shows the interval. Minor shows were noted in the Geneseo Shale from 1,180 to 1, 612 feet. Casing (4 ½ inch diameter) was run to a total depth of 3,005 feet and cemented. The Marcellus interval was perforated from 2,900-2,960 feet with 10 shots and stimulated on August 19, 1982 using a nitrogen foam fracturing treatment carrying 60,000 pounds of proppant in 58,000 gallons of fluid at an average rate of 4.2 bpm. The well was cleaned up and a four-point production test was run. The initial IP was 86 Mcfd calculated open flow rate was 545 Mcfd. Pore pressure was estimated to be approximately 1900 psi (0.4388 psi/ft).[63]

5.2.3.3 Elliot #1 Well (Rushville Prospect)

The Elliot #1 well was sited in the Rushville field, discovered in 1902. The well was drilled in July-August 1983 to a total depth of 900 feet with a cable tool rig. Significant fresh water shows were encountered in the well that caused casing (4 ½ inch diameter) to be run earlier than planned. The casing was set at approximately 802 feet and cemented in. Below the casing salt water was encountered. Attempts were made to seal of the water flows with no success. Depletion was suspected to have caused the influx of salt water into the reservoir. No attempt was made to complete the well and it was plugged as a dry hole.[63]

5.2.3.4 Widmer #1 Well (Naples Prospect)

The Widmer #1 well was sited in the Naples field, the oldest gas shale field in New York. The well was drilled with air in September 1983. Seven inch diameter casing was set at 715 feet and the well reached TD at 1,220 feet in the Onondaga Limestone. No gas shows were encountered in the Marcellus Shale and a 50 Mcfd show was recorded in the Geneseo Shale at 500-505 feet. The well was completed open hole using explosive stimulation. Approximately 3,200 pounds of Judamite was used from 783 to 1,183 feet to create extensive fracturing in the well. After stimulation, estimated flow rate was approximately 40 Mcfd. Pressure transient testing resulted in a calculated open flow of 12 Mcfd. The well was then hooked up to the local winery for use.[63]

6 RESERVOIR CHARACTERIZATION

Reservoir characterization in gas shale reservoir systems focuses primarily on natural fractures because most known productive gas shale reservoirs have extremely low permeability and required multiple sets of open natural fractures for commercial production of natural gas. There are other properties that are also important with regard to characterizing the reservoir potential of shale. These properties are covered below and information is provided for the shales in New York where available. Unfortunately, there is very little published data on the reservoir properties of the shales in New York. The majority of the data comes from the three wells cored and studied as part of the US DOE Eastern Gas Shale Project. Additional data has been published on drill cuttings.

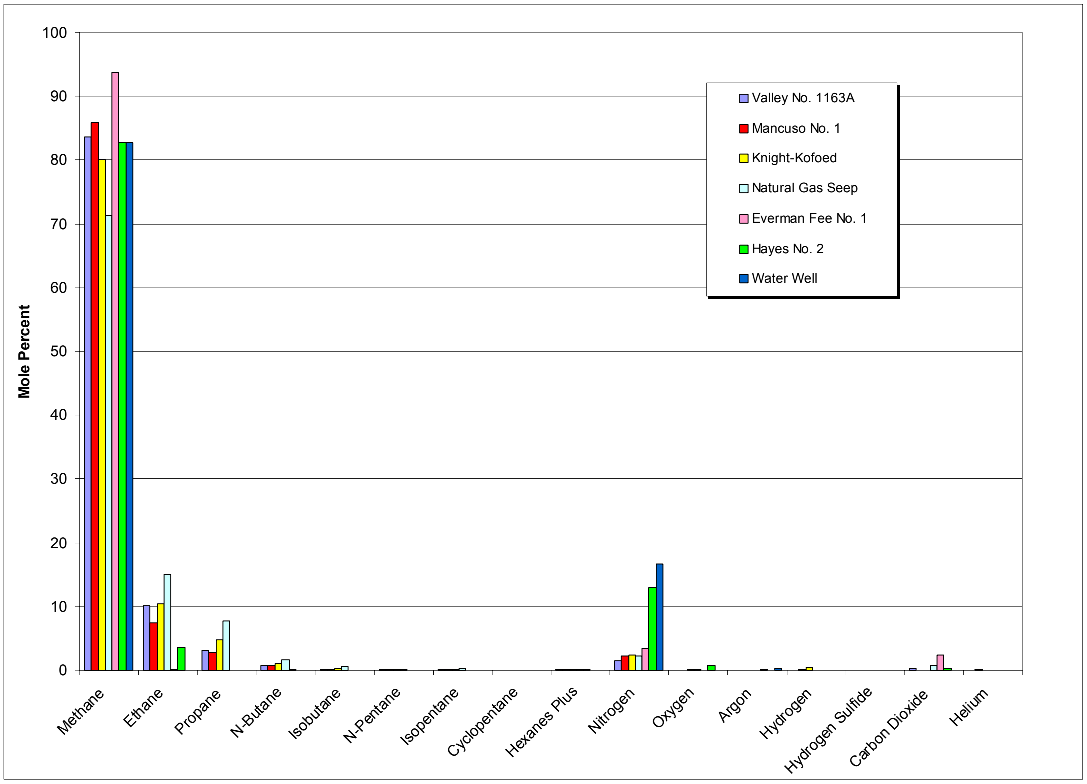
6.1 NATURAL GAS COMPOSITION

The composition of produced natural gas can have an impact on the overall economics of a gas shale play as well as provide information related to its source. In several fractured shale gas plays, the composition of the produced natural gas impacts economics and provides evidence of microbiologic and thermogenic processes.[68,69] Unfortunately, very little gas chemistry and gas and water geochemistry is available from shales in New York. Thus it is difficult to attempt to draw comparisons to other gas shale plays, such as the shallow biogenic Antrim Shale play in northern Michigan Basin.

The best source of natural gas composition from gas shales in New York was from the USBM project that looked at produced natural gas composition across the United States.[70] In this report, six wells with natural gas production from Devonian Shale were analyzed along with one water well and one natural seep. Figure 6.1 summarizes the gas composition from these eight data points.

The data shows methane concentrations of 80-95% and ethane and propane concentrations from 3-15%. The heating value of the gas measured (BTU) ranges from 901 to nearly 1300 BTU's. The majority of the data points were sampled in 1979. No detailed geochemistry is available to investigate the biogenic or thermogenic processes. No gas composition data is available for either the Silurian or Ordovician shales of New York.

Figure 6.1. Natural Gas Composition from Devonian-age Shales in New York.[70]



6.2 NATURAL FRACTURES

Open, orthogonal or multiple sets of natural fractures increase the productivity of gas shale reservoirs due to the extremely low matrix permeability of shales.[4] Natural fracture formation was addressed in Section 2.6. Finding these natural fracture systems are critical to commercial production of natural gas and is considered one of the primary exploration strategies. Identification and characterization of natural fractures is typically done either at the surface through outcrop studies or in-situ through the use of geophysical logs or core. In addition, indications of natural fractures are often associated with natural gas shows while drilling a well, especially on air or under-balanced.

In New York, only a minimum amount of oriented core has been taken in the shale reservoir systems for natural fracture characterization and no formation imaging logs or down-hole cameras results have been published for natural fracture characterization. Three wells were cored in New York during the DOE Eastern Gas Shale Program and natural fracture characterization was published for them.[71,72,73]

Table 6.1 summarizes the natural fractures identified in the oriented core from the Devonian Shale for the three research wells. No significant shows were associated with the cored intervals. The NY #1 (NYSERA

#3-6213) well was completed in the Marcellus Shale (which was not cored) and was still producing intermittently at the end of 2001.

Table 6.1. Devonian Shale Natural Fracture Orientation from Oriented Core.[71, 72, 73]

Group	Unit	NY #1	Fracture Orientation	NY #3	Fracture Orientation	NY #4	Fracture Orientation[1]
		Depth (ft)		Depth (ft)		Depth (ft)	
Canadaway	Dunkirk Shale	370-515	N85°W (1) N85°E (2)				
Java	Hanover Shale	515-546					
		963-984					
	Pipe Creek	984-1018	N85°E(2)				
West Falls	Angola Shale	1018-1021					
		1328-1355					
	Rhinestreet Shale	1335-2345	N35-45°W (4) N70-90°W (7) N70-90°E (14)	1203-1263	N2°E (2) N48°E (1)		
Sonyea	Cashaqua Shale	2345-2359	0				
		2486-2495					
	Middlesex	2495-2629	N45-65°E (4) N25°W (1)				
Genessee	West River	2629-2664	N40-70°E (1) (4)				
		2723-2730					
	Genundewa	2730-2737	N20°W (1)				
	Pen Yan Shale	2737-2866	N70-80°W (3) N35°E (1)				
	Lodi Limestone	2866-2876	0				
	Geneseo Shale	2876-2924	N35°E (1) N80°W (1)			3010-3080	N50°W (1)
Hamilton	Tully Limestone	2924-2929	0			3080-3084	N50°E - N60°E (major)
	Marcellus Shale					3790-3842	N50°W - N60°W (minor)

[1] Six feet of the Onondaga formation was cored and included 2 joints, 3 microcracks and 10 faults - major trend is N20°W-N30°W

Based on available information, cumulative production from the Devonian Shales is 15.89 Mmcf. The greatest number of fractures from the core analysis was in the Rhinestreet, which was not completed in this well. The NY #3 (Scudder #1) well was not completed and was plugged and abandoned. The NY #4 (Valley Vista View #1) well tested the Rhinestreet which proved to be poor and was eventually completed in the Marcellus Shale and produced for a short period of time before it was plugged and abandoned. Unfortunately, due to completion circumstances and poor well performance, no observations can be made for improved well performance related to the presence of orthogonal natural fractures.

No core or subsurface natural fracture descriptions are available for the Silurian or Ordovician shales.

6.3 NATURAL GAS STORAGE CAPACITY

In shale reservoirs, natural gas is stored three ways: as adsorbed gas on organic material, as free gas within the rock pores, and as free gas within the system of natural fractures. These different storage mechanisms affect the amount of gas stored as well as the speed and efficiency of gas production.

6.3.1 Adsorption

Natural gas can be adsorbed onto the surface area of organic material in shale and to some degree onto the surface area of clays (if dry). The process of adsorption is controlled by properties such as the amount of organic carbon present, the thermal maturity of the kerogen, reservoir temperature, pressure, in-situ moisture of the shale and gas composition.[74]

In many fractured gas shale reservoir plays, TOC has been correlated to total gas content. Figure 6.2 shows two correlations of gas content with TOC from the Antrim Shale in the Michigan Basin and the New Albany Shale from the Illinois Basin.[74] It should be noted that these correlations are specific to a given play and should be calibrated with measured data for different depths and reservoir pressure gradients. TOC can be derived from geophysical logs such as density.[39] Correlations have been developed in several gas shale plays using the density log to calculate the gas in place in shale with calibrated data.[75,76]

Based on the linear relationship of gas content to TOC, one would expect a similar relationship for adsorption isotherms. This was first established in the Antrim Shale by the Gas Research Institute, and has been further developed in other fractured shale plays [77,76] A large number of methane adsorption isotherms were run and the relationship of increasing storage capacity to TOC was apparent.

Figure 6.3 shows an example of multiple isotherms from an Antrim Shale well in the Michigan Basin. As the TOC value increases, the methane storage capacity is also increasing. As with the relationship to gas content, this relationship is play-specific and should be calibrated with measured data as the organic material changes with origin and maturity.

However, no gas content data or sorption isotherms have been measured in the Devonian shales of New York or for the Silurian and Ordovician shales. These are the type of data that should be collected to fully understand the storage and transport properties of natural gas in shale.

Figure 6.2. Comparison of Gas Content vs. Total Organic Carbon in Two Gas Shale Plays.

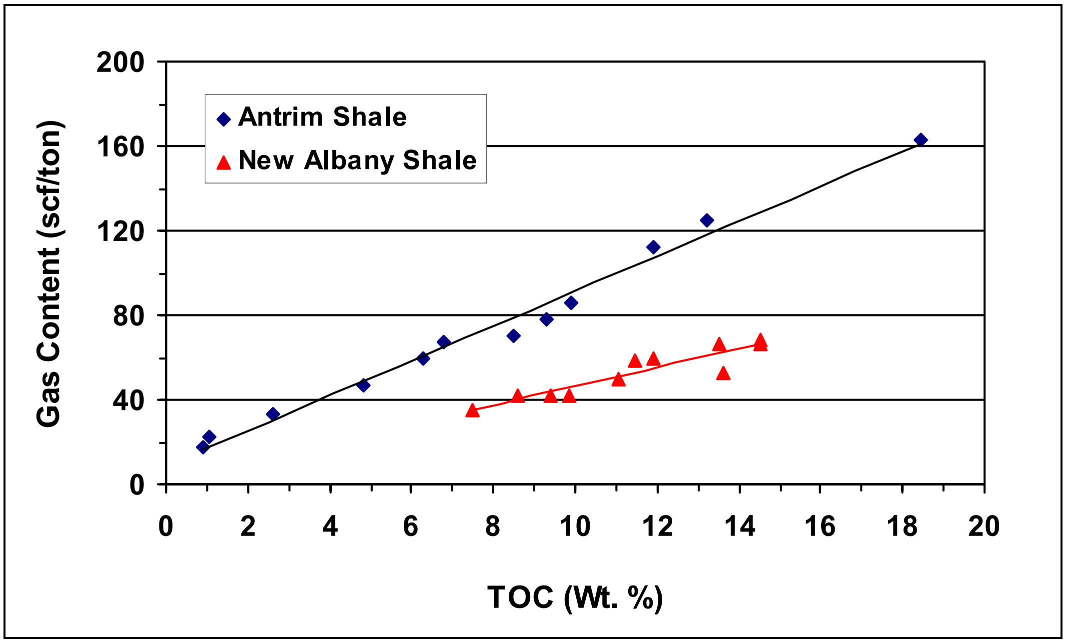
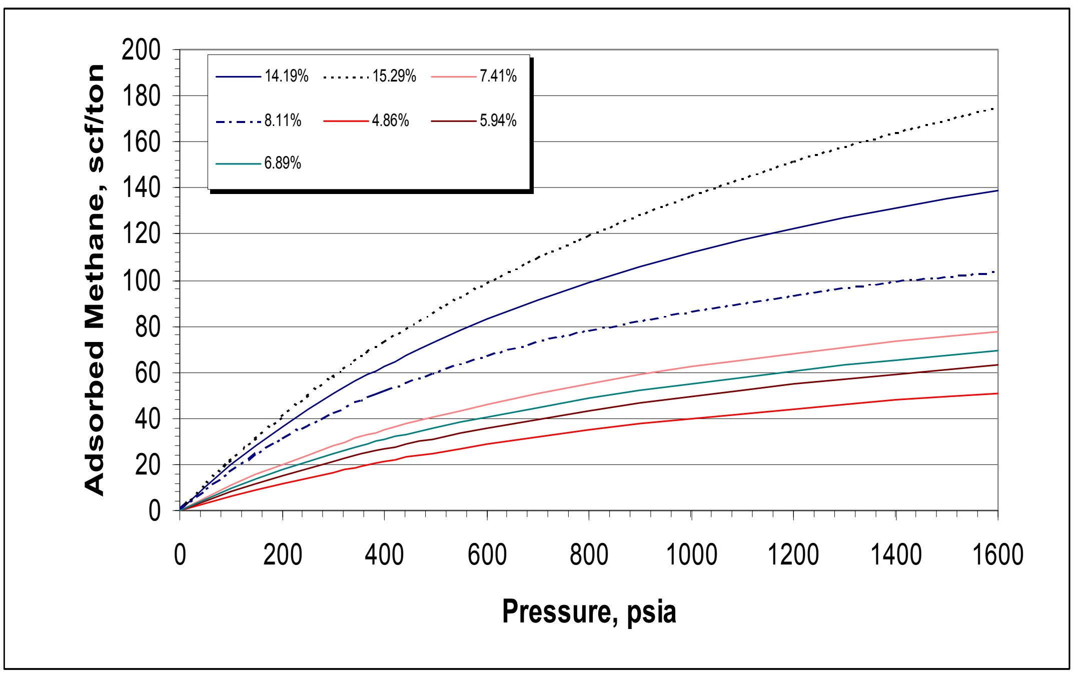


Figure 6.3. Multiple Methane Adsorption Isotherms, Antrim Shale Well, Michigan Basin.



6.4 POROSITY

In conventional reservoirs, porosity and fluid saturations are among the most important reservoir properties to determine. This is also true for gas shale reservoirs. Shale can have significant amounts of porosity and significant amounts of oil and free gas in that porosity. Even in older shales, such as the Ohio Shale in the Appalachian Basin or the Antrim Shale in the Michigan Basin, porosity can range up to 15 percent, and free gas can occupy up 50% of the porosity. It is important to be able to assess this potential, primarily from well logs, which should first be validated and calibrated from core analyses.

6.4.1 Historical Data

Although core data was collected and porosity was measured in three wells in New York, little effort was made to understand fluid saturations and develop well log interpretations during the US DOE EGSP. The most comprehensive porosity data was measured on NY #1 well in Allegany County, New York. Porosities were measured using the mercury intrusion method as well as determined from density data.[78] A wide range of porosity was reported, from a low of 0% to a high of 18.3% on a 10-foot basis from the core. No data was reported on fluid saturations.

6.4.2 New Methodology

The key data needed from core analyses to calibrate the log analyses are porosity and the saturations of gas, oil, and water. Prior to 1987, shale core analysis data in the Appalachian Basin was sparse and believed not to be very reliable. As a result of the several Gas Research Institute funded programs from 1987 to 1993, new core analysis methods were developed for measuring porosity and fluid contents.[79,80,81] These new methods, which rely primarily on crushing of the core, show much higher porosity and free gas contents than previously reported.

Procedures for these new methods, and some of the results, are summarized in the following.[80]

1. The cores (conventional full diameter, or rotary sidewall) should be kept preserved (sealed) until the time of analyses to avoid fluid alteration or kerogen oxidation.
2. Bulk density of each shale sample is first measured by weighing and by mercury immersion.
3. Each shale sample is crushed.
4. Oil and water is extracted from each weighed sample using boiling toluene (Dean-Stark method) for one/two weeks. The water is condensed into a sidearm collector. Sample size should be > 50 grams. The shale sample is then dried in an oven at roughly 230ºF for one/two weeks, and weighed. Extracted oil volume is calculated from the weight loss, less water collected. In some shales (such as Antrim) the kerogen can oxidize during the extraction and drying process that

may cause a weight gain and interfere with the material balance. For these shales, this is prevented by using a nitrogen blanket during extraction and by using a vacuum oven for drying.

5. Grain volume of the dried shale sample is then measured with helium in a standard Boyle's Law device.
6. Pore volume and porosity (Ø) are derived from the bulk volume and the grain volume. Water and oil volumes are subtracted from the pore volume to find the gas volume, and fractional saturation of each fluid (S_G, S_O, and S_W).

Table 6.2 shows typical shale properties using this new core analysis for three basins. Note all the measurements are at ambient conditions, assuming no stress loading.[80] Detailed analysis has shown a reduction of 0.5 p.u. to adjust the measurements to reservoir stress for comparison to geophysical log results.[81]

Table 6.2. Typical Shale Properties from Core Analysis, Three Basins.[80]

Basin, Shale	Ø, %	Sg, %	So, %	Sw, %	No. of Wells, No. Core Samples Analyzed
Appalachian, Ohio	4-9	15-50	0-20	35-70	4/519
Michigan, Antrim	8-12	10-50	10-45	20-70	2/249
Ft. Worth, Barnett	5	N/A	N/A	N/A	1/9

6.5 PERMEABILITY

Permeability is a primary reservoir property required for economical natural gas production from gas shale plays. Matrix permeability of shales is extremely low. However, wells produce natural gas at rates that require permeability to be much greater than measured in core. This "bulk" permeability of the reservoir incorporates the natural fracture system and is normally determined through well testing and production data analysis.

Older Devonian Shale literature reports matrix permeabilities in shale from less than 0.01 md to 1 md [82]. Absolute permeability measurements on NY #3 and NY #4 showed permeability in the < 10 to 191 microdarcy range.[83] These values were believed to be high due to the presence of microfractures due to stress release, core handling, and/or coring induced. More recent measurements using a novel testing protocol found matrix permeabilities in unfractured shale to be 0.2 $\times 10^{-8}$ md to 5.5 $\times 10^{-8}$ md.[81] The importance of matrix permeability was further defined through simulation. For matrix permeability (K_m) values within the range of 10^{-9} md $K_m < \times 10^{-6}$ md, K_m is one of the important controls on permeability. For matrix permeabilities less than 10^{-9} md, recovery is too low to be of economic interest. For matrix permeabilities > 10^{-6} md, recovery is essentially independent of K_m and is productivity is more controlled by natural fracture properties and spacing.[81]

As stated above, pressure-transient testing is typically done to characterize bulk permeability. In 1983, NYSERDA commissioned additional testing of eight research wells completed in the Marcellus Shale in New York. The primary objective was to estimate recoverable reserves and deliverability of the wells and to evaluate stimulation procedures used on the wells.[65]

The testing rationale for the wells incorporated modified isochronal testing. The general procedure consisted of flowing the wells at two increasing rates by use of a critical flow prover. The flow periods were designed to test ensure that the formation was tested. Where possible, the two rates would be used to examine skin factors. The test was followed by an extended shut-in period.[65]

The testing program was only partially successful. There were difficulties with obtaining reliable data which was attributed to fracture fluid buildup in the wellbore and that gas production at low pressures is likely from desorption and the associated analysis problems. No bottom hole pressure gauges were used, which would of assisted data analysis. Table 6.3 is a summary of the well performance characteristics from three of the eight wells.[65] The permeability-thickness product is generally similar to other pressure testing analysis from Devonian Shale wells (0.1-10 md-ft).[84]

Table 6.3. Well Performance Characteristics from Three Marcellus Shale Completions in New York.

Well	Slope ((M)$psia^2/cpx10^6$)	Perm-Thickness (md-ft)	Thickness (ft)	Permeability (µd)	Skin
Valley Vista View #1	8.5	3.25	15	216	-2.0
Houghton College #1	1.6	7.28	26	203	-2.3
Houghton College #2	16.1	0.14	34	4.1	-2.6

No matrix or bulk permeability measurements were available for the Silurian or Ordovician shales in New York.

6.6 RESERVOIR PRESSURE

Knowledge of reservoir pressure is critical in determining the amount of resource in place and reserves, and is an important input parameter for reservoir simulation. Reservoir pressure can be determined from pressure transient testing.

Pressure surveys were conducted on all eight research wells described in the previous section. The surveys were run following stimulation, subsequent to clean-up and shut-in operations. The pressure data shows a reservoir pressure gradient between 0.46 to 0.51 psia/ft.[65] This is higher that the reservoir pressure gradient found in other producing Devonian Shale gas fields in West Virginia and Kentucky (0.4 to 0.12 psia/ft).

6.7 ROCK MECHANICS

Because of the nature of the permeability and distribution in the reservoir system, most gas shale wells are either completed as a natural producer or stimulated in order to achieve commercial production. During the U.S. DOE EGSP and GRI Gas Shale programs, studies were conducted on measuring the mechanical properties of Devonian Shale to assist in the evaluation, optimization and understanding of hydraulic fracturing. Historically, the early Devonian Shale wells in New York were either completed openhole as natural producers or "shot" with nitroglycerin. In the 1980's, the wells were typically hydraulically fractured using a nitrogen foam and proppant to stimulate the well through casing/perforations. This section will focus on the work conducted in New York.

Extensive mechanical properties testing were done on oriented core samples from 30 wells taken during the U.S. DOE EGSP. This testing included directional ultrasonic velocity, point load, directional tensile strength and characterization of pre-testing fractures.[85] The overall analysis concluded that tests conducted under zero confining pressure are not useful for determining the orientation of maximum horizontal stress (σ_{Hmax}). This work was conducted on NY #1, NY #3 and NY #4 wells. Overall fracture orientation from NY #1 well was N60°E±15°. A secondary fracture orientation was reported N90°E±15°. Overall fracture orientation from NY #3 well in the Rhinestreet Shale interval was N90°E±15°. A secondary fracture orientation was reported N60°W±15°. For the NY #4 well, overall fracture orientation in the Geneseo Shale was N60°W±15°. The Marcellus Shale interval has a preferred fracture orientation N30°W±15° for this well. The present day stress direction (maximum horizontal stress) in the New York region is reported as N60°E.[27]

Fracture toughness was measured on five wells from the EGSP.[83] Two of the five wells were NY #3 and NY #4. The average fracture toughness value (K_{Ic}) for all five wells was 860 psi √in. The highest fracture toughness was measured on NY #3, 1202 psi √in. The average fracture toughness values for NY #3 was 1085 psi √in and for NY #4 was 848 psi √in.[83]

The most extensive study on in-situ stress in the Devonian section was conducted in three boreholes drilled in Steuben County, New York near the town of South Canisteo.[86] The wells were located approximately 12 miles southeast of NY #1 well. During this study, 75 open-hole stress measurements were made in the three wells from the Dunkirk Shale through the Tully Limestone. Readers are referred to the paper for more detail and information on the testing and analysis. The results of the study are summarized as follows:[86]

1. Horizontal stresses in the shales undergo a major transition in magnitude at a stratigraphic level that is coincident with a group of sand beds near the base of the Rhinestreet shale.
2. The principal *drop* in stress corresponds to an offset in S_h and S_H of 508 psi (3.5Mpa) and 1,305 psi (9 Mpa) respectively.
3. Above the group of sands, a "trust" regime conditions prevail, and the least horizontal stress in the shales is at least as great as the vertical stress.
4. Below the sands the regime is strike slip with both horizontal stresses showing lateral uniformity.
5. Stresses in the quartz-rich and limestone beds are substantially higher that the surrounding mudstones.
6. The orientation of maximum principal stress as determined by induced fracture direction is ENE throughout the section.
7. Significantly different orientations of fractures were obtained for adjacent tests in which almost identical ISIPS were observed, suggesting that the fractures quickly reorient themselves to propagate normal to the least principal stress direction.
8. Vertical traces were observed in those tests where ISIPs apparently reflect S_v, suggesting that rotation to a horizontal fracture was also rapid.

Further analysis by the authors found that the major systematic drop in stress level that occurs near the base of the Rhinestreet Shale (on the basis of local and regional strain data) corresponds to the top of the section that held abnormal high pore pressures.[87] The implications of this study suggest that hydraulic fracturing of the Rhinestreet Shale and intervals above could result in abnormally high treating pressures with the potential for the creation of horizontal fractures, at least in the region studied by the authors.

7 EXPLORATION AND DEVELOPMENT STRATEGIES

The following two sections outline strategies for exploration and development associated with fractured gas shale reservoirs in New York. The strategies are not intended to be all-inclusive, but rather provide operators and interested parties with methodologies, approaches and ideas to assist them in evaluating and developing the large natural gas resource that resides in fractured gas shale reservoir systems.

7.1 EXPLORATION STRATEGIES

Exploration strategies for gas shale plays should focus on locating areas with significant natural gas resource present that have sufficient permeability (both matrix and bulk) for economic production.

7.1.1 Geologic Mapping

The evaluation of a shale gas play should consider the geological circumstances that may have created a favorable environment for the deposition and accumulation of shales and the generation of hydrocarbons. Geologic mapping pertaining to formation thickness, depth and structure are basic requirements, as well as cross-section generation to view lateral changes in lithology and in geophysical well log response in the gamma-ray curve, and to identify zones that may indicate the presence of gas.

7.1.2 Formation Evaluation

Significant progress has been made in the area of formation evaluation for Devonian Shales using geophysical logs. GRI research has developed a log model based on core and log analysis from a large data set in the Appalachian Basin. This model has been extended to other shale plays such as the Antrim Shale and Barnett Shale.[81] When combined with other diagnostic tools such as the mud log, borehole television and temperature log, geophysical log analysis can be used to evaluate completion intervals in gas shales.

Like most of the Appalachian Basin, wells in New York are typically drilled on air. This limits the type of geophysical logs that can be run in an air-filled borehole. A typical logging suite in the Appalachian Basin for the GRI log analysis includes the following:[81]

1. Dual Induction
2. Temperature
3. Litho-Density with Photoelectric Adsorption Index (Pe)
4. Sidewall Neutron
5. Spectral Gamma Ray, and
6. Borehole Television

Log analysis in shales involves both standard techniques and special techniques. Depth shifting, environmental corrections and standardization are part of the pre-processing steps.[81] Because of the complex mineralogy of shales, log responses to various minerals present is taken into account before porosity and fluid saturations are determined. The GRI log model groups the minerals into five categories:[81]

1. Quartz (quartz, calcite, dolomite, k-feldspar and plagioclase)
2. Clay (illite, kaolinite and chlorite)
3. Pyrite (pyrite, ankerite and siderite)
4. Kerogen, and
5. Porosity

Readers are referred to the GRI reference for additional detail regarding the log model, its application and additional references. Once porosity is determined as part of the analysis, water saturation and bulk volume hydrocarbon are calculated.

If a wellbore can be filled with fluid as part of the logging process, natural fracture identification logs can be incorporated into the geophysical logging program.

Because the GRI log model was developed in the Appalachian Basin, it should be directly applicable for the Devonian shales in New York and also applicable to other shales with modifications as required by the various minerals present in the shale. Generally speaking, the most favorable completion intervals are those with the highest porosity (> 4.0%), most fractures and best sustained mud log shows. Kerogen-rich shales will typically have the best gas-in-place (free and adsorbed), the highest natural fracture density, and lowest stress.[81] However, it should be noted that in some parts of the Appalachian Basin, gray shales (organic-poor) are commercially productive.

7.1.3 Natural Fracture Identification

Operators have historically used multiple techniques to locate areas of increased natural fracture density. While seismic technology continues to advance, locating fracture systems in organic-rich shales remains elusive. Thus operators have attempted to correlate other techniques such as surface lineament analysis, outcrop studies, magnetics, and various geologic mapping approaches to look for areas where fracturing may be present due to basement structure, regional and local structure, or other tectonic influences.

With most naturally fractured gas shale reservoirs, finding indicators of productivity can be helpful with regard to evaluating a completion and identifying pay. This is often done during the drilling and logging phase of a well.

When drilling a well, natural gas shows are considered indicators of potential in many reservoir systems. This is especially true when drilling with air or in underbalanced conditions. In tight, naturally fractured reservoirs such as shales, strong shows of natural gas can also be considered indicators of potential. Good shows are characterized by high natural flow rates that do not degrade (blow down) quickly, but are carried to total depth of the well. In New York, many of the wells drilled on air often have shows of natural gas associated with shale sections in the well. In some circumstances the shows are so strong that the drilling is terminated at the show and the well is completed naturally open-hole.

However, if a well does not have a show of natural gas while drilling on air it does not mean that the well has poor reservoir potential. Gas shows are normally associated with natural fractures penetrated by the drill bit. In the Appalachian Basin, the majority of the natural fractures present at depth are vertical or nearly vertical. Unless the fracture spacing is very close, the likelihood of hitting a vertical natural fracture with a vertical wellbore is extremely small.

As mentioned earlier, geophysical logs can be used to help identify and characterize intervals with natural fractures present. A temperature log and noise log can identify intervals that are producing natural gas. In shale reservoirs, these indicators are often directly associated with natural fractures in the borehole. For natural fracture characterization, other logs are required.

Three log types are most often used for fracture characterization. They include microresistivity, acoustic reflectance, and borehole television logs. The first two devices required a liquid filled borehole for utilization. The borehole television device is ideal for an air-drilled hole. Each of the tools can determine natural fracture strike. The microresistivity and acoustic reflectance tools can determine dip magnitude and the borehole camera can only infer magnitude.[81] Research has shown that it is not the number of natural fractures encountered that make a good well, rather the presence of intersecting natural fractures. Table 7.1 summarizes the advantages and disadvantages of the tools.[81]

Table 7.1. Comparison of Fracture Identification Devices Used in Appalachian Basin.[81]

Tool	Advantages	Disadvantages
Microresistivity	High resolution Good strike/dip quantification of both natural and induced fractures Data routinely corrected for borehole deviation and magnetic declination Low operational sensitivity	Expensive Requires liquid in the borehole Limited coverage with a single pass (pad device) Joint identification dependent largely upon degree of spalling Large spalls difficult to quantify
Acoustic Reflectance	Essentially full borehole coverage usually results in superior fracture identification Good strike/dip quantification of natural; fair for induced fractures	Expensive Requires liquid in the borehole Joint identification dependent largely upon degree of spalling Large spalls difficult to quantify Tools not routinely corrected for borehole deviation and magnetic declination
Borehole Television	Quick and inexpensive Can be run in air filled borehole High resolution visual image easily reviewed and interpreted with TV and VCR Full borehole coverage Gas/fluid entry detection Can properly identify/quantify many large spalls as joints Good strike quantification, qualification of dips	Light intensity varies around borehole, slight view obstructions by arms No or poor dip quantification Poor identification of induced fractures Joint identification dependent largely upon spalling Limited identification of bedding

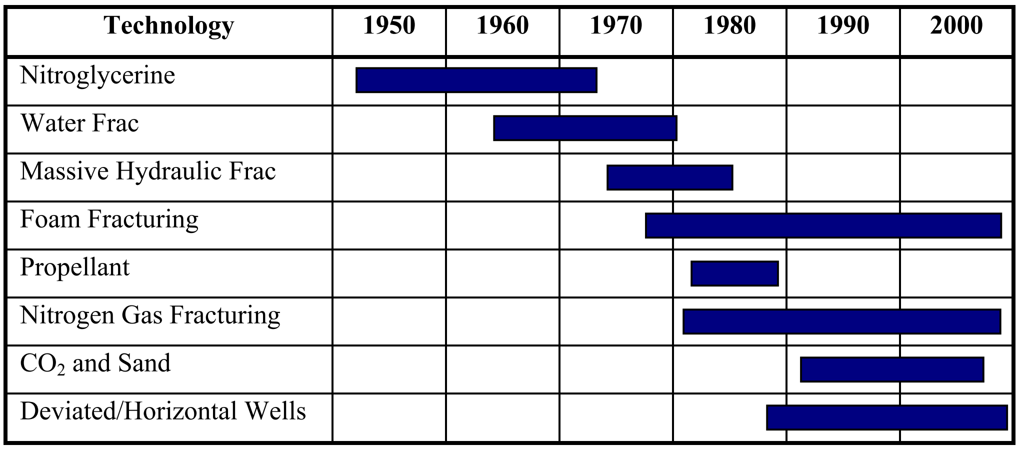
7.2 DEVELOPMENT STRATEGIES

Development strategies can be either focused on drilling and completing new wells or adding shale intervals in existing wells prior to abandonment often called pay additions. Historically, most shale wells in New York have been associated with the drilling of a new well. Because of the extremely low permeability of shale, development strategies will typically include stimulating the reservoir to maximize productivity.

7.2.1 Stimulation

Historically, shale wells in the Appalachian Basin were completed open-hole either naturally (no-stimulation) or shot with some form of propellant such as nitroglycerin. This is true for Devonian Shale wells in New York as well. As new forms of reservoir stimulation technology were developed, they were applied to the shale plays in the Appalachian Basin. Figure 7.1 shows a generalized timeline of the different technologies used over the past several decades.

Figure 7.1. Gas Development Strategies for Stimulation in the Appalachian Basin.



With the advent of hydraulic fracturing around the middle of the 20th century, shale wells have experienced a wide range of fracturing techniques in an attempt to provide the optimal stimulation with respect to fracture length and productivity. Today, nitrogen-based foam fracturing is the primary technique used in vertical shale wells in the Appalachian Basin. Foam-based systems are preferred because of the low fluid loss, lower amount of liquid pumped into the reservoir, and energy assist in flowing the wells back. Other techniques are also used today, but they are area-specific.

In New York, most of the early wells were completed naturally open-hole or shot with explosives such as nitroglycerin or judamite. During the early 1980's all of the research wells were stimulated with nitrogen foam system. All of these treatments were single-stage jobs pumped down casing and used from 25,000 to 80,000 pounds of proppant. Table 7.2 is a summary of eight foam fracture treatments[65]. Five of the wells have fluid volumes recovered during initial clean-up operations. The average fluid recovery is approximately 50%. This leaves 50% of the treatment fluid in the reservoir, which caused fluid loading problems short-term during testing and long-term during production operations. None of the wells used tubing and downhole pumps to assist in unloading the wells early in their life.

Table 7.2. Fracture Treatment Summary of New York Devonian Shale Wells.[65]

Well	Treatment Date	Total Sand (lbs)	Total Fluid Pumped (bbls)	Total Fluid Recovered (bbls)*	Fluid Remaining (bbls)
Valley Vista View #1	12/81	80,000	312	na	
Houghton #1	10/79	50,000	333	na	
Meter #1	11/80	76,000	289	na	
Houghton #2	9/81	60,000	333	168	165
St. Bonaventure	8/81	60,000	333	164	169
Portville	7/81	60,000	333	164	169
Alfred	7/81	60,000	333	146	187
BOCES	7/81	60,000	333	159	174
* Recovered during initial clean up of wells					

New fluid additives have been developed over the past decade as well as new design considerations, such as flowback and quality control, that have improved hydraulic fracture performance.[88] These new advances should improve well performance in New York as well. Other stimulation techniques, such as straight nitrogen gas fracturing and liquid CO_2 /sand, should be experimented with in the different shale reservoir systems in New York.[89,90] Coiled tubing fracturing technology has recently been applied to the Devonian Shale in the Appalachian Basin with good results.[91] This technology is effective in both new wells and in old wells for restimulation or recompletion operations.

7.2.2 Horizontal/High-Angle Wells

Since the early 1980’s high-angle and horizontal wells have been contemplated, studied and drilled in the Devonian shales of the Appalachian Basin. Much of the work in this area has been sponsored by the U.S. DOE. Horizontal well drilling technology continues to advance and numerous improvements have been made in drilling systems, wellbore orientation and drilling motors. The majority of the high-angle and horizontal wells drilled in the Devonian Shale have been technical successes, but marginal to poor economical successes. Most of the wells required some form of stimulation, which increased well costs dramatically.

With improved technology and reduced drilling costs, operators are beginning to reconsider horizontal and high-angle wells in tight naturally fractured reservoirs. This technology might be applicable in New York shales. Fracture spacing in New York may be larger than in other shale plays where vertical wells and hydraulic fracturing is applicable. For certain formations, geographic areas, and depth ranges in New York, hydraulic fracturing may create horizontal fractures (or very complex fractures) that might reduce the effectiveness of this fracturing. High-angle well bores may also provide a mechanism to contact more shale and increase the chances of intersecting multiple natural fracture sets. This may also be a viable technology to drill in or near older gas shale fields. These are a few of the reasons to investigate this technology as a development strategy in New York.

7.2.3 Recompletions

With several thousand existing well bores in New York, the potential to add additional pay zones that are behind pipe at low incremental costs can be very attractive, especially when the estimated reserves cannot support the drilling and completion of a new well. This is how the Lewis Shale in the San Juan Basin is being developed today.[92] In New York, there are multiple pay zones that can be tested and added to a well. From the Ordovician Utica Shale to the Upper Devonian Rhinestreet Shale, the potential for economical pay additions is increased due to large number of reservoirs to evaluate.

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Geologic Investigations of the Gas Potential in the Otsego County Region, Eastern New York State	Jacobi, R., Smith, G. , Cruz, K., and Billman, D.A.		Millennium Natural Resources Development, in conjunction with NYSERDA, September 2000		Natural gas, black shale, Ordovician, Utica, TOC, gas-in-place, Genegantslet field
Geology of New York - A Simplified Account	Isachsen, Y.W., Landing, E., Lauber, J.M., Rickard, L.V., and Rogers, W.B.		New York State Museum/Geological Survey Educational Leaflet No. 28, 1991		General geology
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Glossary of Oil and Gas field Names	New York State Department of Environmental Conservation, Division of Mineral Resources		New York State Department of Environmental Conservation, Division of Mineral Resources, 1986		Devonian, Silurian, Ordovician, gas fields, oil fields, field boundaries, status, producing formation, field name

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Isopach Map of Black Shale in the Genesee Group	Kamakaris D.G., and Van Tyne, A.M.		New York State Museum and Science Service Geological Survey, METC/EGSP Series 109, 198(		map
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Isopach Map of Black Shale in the Perrysburg Formation (& equivalent section)	Kamakaris D.G., and Van Tyne, A.M.		New York State Museum and Science Service Geological Survey, METC/EGSP Series 105, 198(		map
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Isopach Map of Genesee Group	Van Tyne, A.M., Kamakaris D.G., and Corbo, S.		New York State Museum and Science Service Geological Survey, METC/EGSP Series 120, 198(		map
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Isopach Map of West Falls Formation	Van Tyne, A.M., Kamakaris D.G., and Corbo, S.		New York State Museum and Science Service Geological Survey, METC/EGSP Series 118, 198(		map
Isopach of Radioactive Shale in the Genesee Group	Van Tyne, A.M., Kamakaris D.G., and Corbo, S.		New York State Museum and Science Service Geological Survey, METC/EGSP Series 129, 198(		map
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Log Analysis of Gas-Bearing Fracture Shales in the Saint Lawrence Lowlands of Quebec, SPE #7445	Aguilera, Roberto		53rd Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston TX, Oct. 1-3, 1978,		Black Shale, Utica Group, log analysis, reservoir properties, gas reservoirs, formation strength, gas-in-place,
Lower Paleozoic Carbonate, Clast Diamictites: Relationship to Thrust Sheets That Advanced Across the Floor of the Northern Appalachian Ordovician Foreland Basin.	Sanders, J.E.		Papers of the Northeast Geolgical and Environmental Science, Vol. 17, No. 1, Pages 23-45, 1995.		Champlain thrust sheet, diamicite, Ordovician, structural geology, thrust faulting
Mechanisims for Strain within the Upper Devonian Clastic Sequence of the Appalachian Plateau, Western New York	Engelder, T.		American Journal of Science. Vol. 279, Pages 527-542, 1979		clastic rocks, compression, deformation, Devonian, strain
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