A PRIMER ON NEW YORK'S GAS SHALES

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ABSTRACT

Though New York's first shale well was drilled in 1821, shale has not been a major contributor to natural gas production in the state. Recent price increases and the development of more efficient drilling and completion technology now make these rocks attractive for exploration. The resource in New York is significant: Previous estimates of the state's shale gas resource range from 163 to 313 trillion cubic feet (Tcf) out of just the Devonian section.

The New York State Energy Research and Development Authority (NYSERDA) has been investigating New York's shale resource for more than two decades. Early work completed in the 1980s targeted the Devonian shales, including the Marcellus. Starting in the mid-1990s, the NYSERDA began to look at the possibility that all the state's shale formations may offer production potential. Recent NYSERDA sponsored projects are helping to characterize both the Devonian and Ordovician shales. Prospective shales include the Ordovician Utica, the Middle Devonian Hamilton (Marcellus), and suite of Late Devonian shales that are separated by silt/sandy layers.

Experience developing shale gas plays in the past 30 years has demonstrated that every shale play is unique. Each individual play has been defined, tested and expanded based on understanding the geology, resource distribution, natural fracture patterns, and limitations of the reservoir, and each play has required solutions to problems and issues required for commercial production.

ANATOMY OF PRODUCTIVE GAS SHALES

Though shale production dates all the way back to 1821, the conditions for wide-spread field development have only become apparent in the last decade. The key driver is the application of technology and reservoir management practices that increase production levels considerably over those seen in the Eastern Gas Shales program. Tightening North American supply also make "unconventional resources" more attractive by creating a bullish pricing environment. Finally, the Antrim and Barnett shales, which serve as endpoints in the shale spectrum between adsorbed gas production and fracture gas production, prove that multiple exploration and extraction models exist for shale (Drake 2007).

Gas shales are often the origin of hydrocarbon stored in conventional reservoirs. These hydrocarbons have been expelled, migrating upward into a trap of reservoir quality rock below a sealing unit (often shale). In gas shale systems, the shale is all three: hydrocarbons are generated, stored and held in place. The preserved organic matter is "consumed" through biogenic or thermogenic processes to generate smaller chain hydrocarbons (gas or liquid). The remaining carbon that cannot be converted (dead carbon) and clay minerals form a storage mechanism through adsorption, which increases tremendously the potential storage volume. The relationship between temperature, pressure, available volume and the general attractiveness of methane (partial pressure) will define ultimate adsorbed storage capacity. Even after a great amount of generated gas is expelled out of the shale (as source rock), there can remain an enormous quantity as adsorbed gas. Gas will also reside in rock matrix pore space and fractures if there is a "seal" to keep the gas in these spaces (Figure 1).
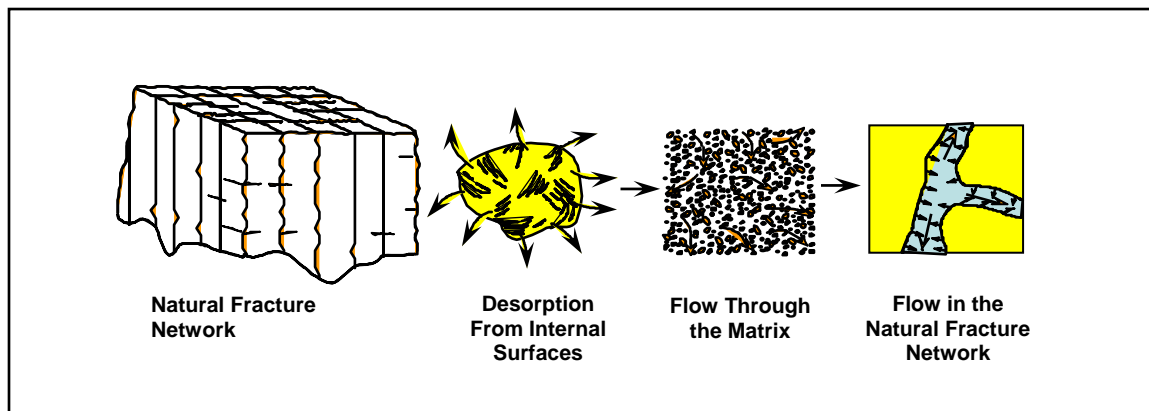

Figure 1. Gas Production Methods (after McDonald, 2002)

Productive oil and gas shale range in age from the Cambrian to the Jurrassic. Age is less relevant than the volume of rock available. Productive shales are usually vertically substantial (30 meters or more) and geographically prevalent (hundreds of square kilometers). Most are marine but there is at least one productive lacustrine (Green River Shale) formation (Chornoboy, 2007). Key to producibility is that the shale must be deposited in an anoxic environment to preserve enough organic material for gas generation.

Hydrocarbon generation in organic black shales take on varying physical and chemical characteristics. One constant is the presence of organic material that provides for a source of liquid and gaseous hydrocarbons and a potential storage site. 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. This also assumes that the natural gas has remained, to some extent, trapped in the source to become a "reservoir."

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. In the Appalachian Basin, darker zones within the Devonian Shale (higher organic content) are usually more productive that the organic-poor gray zones (Schmoker 1980).

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 (1961). A plot of the ratios, called the Van Krevelen diagram, was developed to diagrammatically determine kerogen types and thermal maturation. 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 (Espitaliè 1977). This modified diagram is used to determine kerogen types. Figure 2 is a further breakdown and description of the four common types of kerogen.

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

Figure 2. Kerogen Types (Waples 1985)

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 altercation index and conodont alteration index. Multiple techniques should be employed to help determine thermal maturity of a shale.

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 "reworked." Figure 3 is a breakdown of the different stages of maturation with vitrinite reflectance. Vitrinite reflectance and organic content can be used to develop an adsorption isotherm that displays the ability of the shale to chemically adsorb methane at different pressure and temperature conditions (TerraTek 2004).

Other optical measures of thermal maturity include conodont alteration index and the thermal alteration index (TAI). The TAI uses 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) (Staplin 1969). 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) (Epstein 1977). In general, the CAI of a conodont increases with depth and temperature as a result of metamorphisim.

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.	

Figure 3. Vitrinite Reflectance Categories for Thermal Maturity

The degree of kerogen conversion to liquid or gas hydrocarbons is measured by a series of indices, many created through RockEval. 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 (Peters 1986). The top of the oil window is generally assumed to occur between T_{max} values of 435ºC and 445ºC and the bottom of the oil window occurs at 470ºC. Plotting T_{max} and hydrogen index can proxy the thermal maturation and kerogen type of the samples. Estimates of hydrogen index, transformation ratio and production index are also be used to distinguish remaining hydrocarbon potential from generated hydrocarbons. These are particularly useful in situations of high maturity since Tmax becomes unreliable. Productive shales may be in the generating window (like the Antrim and Woodford) but can also be beyond generation (Fayettville and some Barnett fields).

The amount of gas in place in shale is dependent on the presence of organics and clays as well as the ability for methane to adsorb onto the solid lattice internal surface. Organic content and quality give an idea of the storage capacity while rock characteristics give an idea of the ability to deliver the gas from the rock to the borehole. Mineralogy and rock fabric help define the ability of the rock to move gas out of the storage and matrix and into the larger fracture network.

Open, orthogonal or multiple sets of natural fractures increase the productivity of gas shale reservoirs due to the extremely low matrix permeability of shales (Hill 2000). Fractures must be present, whether natural or induced through hydraulic fracturing. 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.

SHALE GAS IN NEW YORK

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. Their coal-like appearance, wide spread distribution, and stratigraphic nearness to the surface led to interest and use as an energy source dating back to the 1700's. 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 trillion cubic feet (Tcf) of natural gas in the past 30 years (Milici, 1996). 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 driller's logs to have significant gas shows when drilling through them. As of 2007, exploratory drilling was underway to begin producing the Utica Shale of eastern and central New York 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 (de Witt 1997). 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 lake shore 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. NYSERDA has continued research and testing to help define the gas shale potential in New York State.

GEOLOGY

New York forms the northern edge of the Appalachian Basin that exists from southern Ontario to Tennessee. With few exceptions, the state's bedrock primarily consists of Devonian-age and older formations. The younger rocks lie to the south and all sedimentary formations outcrop to the north, at the edge of the Adirondack uplift. The Ordovician and Cambrian become visible again in the St. Lawrence Lowlands.

The rocks in New York have been impacted by at least one of the three major Paleozoic tectonic events. This has left the subsurface folded, fractured, and compressed. Also, numerous sea level changes created significant unconformities including the Knox Unconformity. Studies indicate that the Devonian age and older rocks underwent deep burial before being uplifted to their current elevation. This tectonic history created the environment for hydrocarbon development and the trapping mechanisms to accumulate economic quantities of oil and natural gas. 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. 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. The folds are small anticlines, dipping less than 2°, which are associated with the Appalachian Fold Belt, an arcuate belt of anticlines and synclines that extend southward into West Virginia (Frey 1973).

In the last 1 million years, New York has endured significant continental glaciation, with ice thicknesses approaching one mile. According to Robert Milici, "glacial loading and post-glacial isostatic rebound in the gas-producing regions to the south of the Great Lakes appears to have created the fractured pathways for gas to have migrated from black shale source rocks into intercalated brittle silty and sandy reservoirs, as well as to have fractured and enhanced the storage capacity of these reservoirs (Milici 1996). 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 (Isachsen 2000). 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 (Charpentier 1982). The presence of horizontal fractures in the Devonian is mentioned in well records, and has been attributed to glacial unloading (Imbrogno 2003). Gas-charge horizontal bedding plane fractures also existing in the shale sections of the Upper Trenton Formation and may owe their existence to glacial loading and unloading as well (Kerr 2006; Smith 2008).
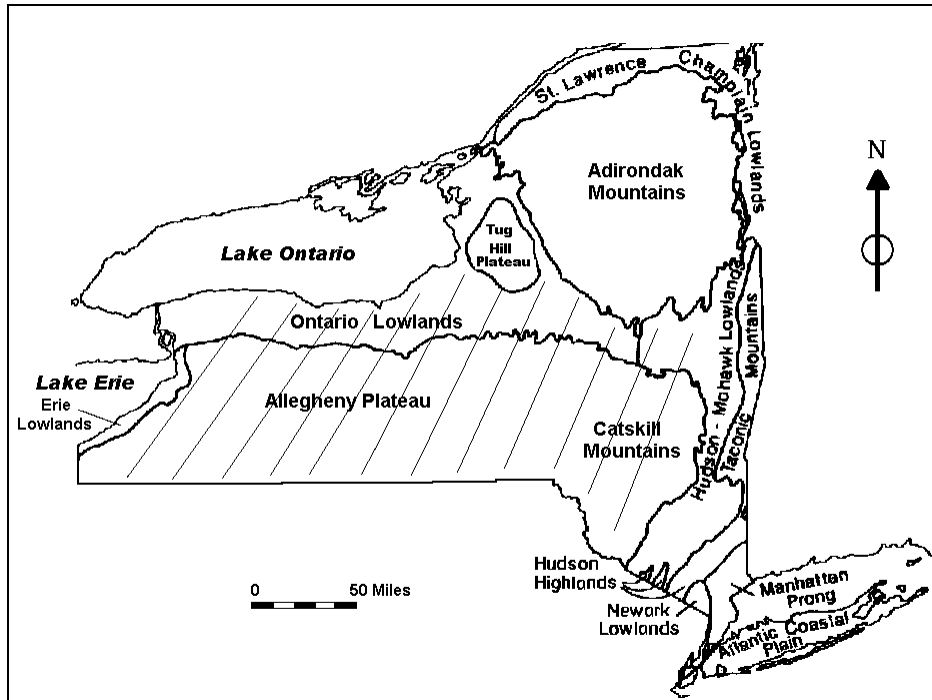

Figure 4. Physiographic Regions of New York

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. The organic rich black shales are the principal source rock for much of the oil and gas in the basin (Milici 1992). 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 (Robinson 1989).

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.

Ordovician. --- One of the oldest and most widespread black shales is the Ordovician-age Utica Shale. 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. 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 (Wallace 1988). 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 (Trevail 2003). In 2007, Two test wells were drilled in Otsego County but results remain inconclusive.

The Utica is a massive, fossiliferous, organic-rich, thermally-mature black to gray-black shale deposited in a subsiding trough that generally trended north-south. Source rock for the organic-rich black shale was supplied from the eroding Taconic highlands to the east. As the deep marine trough was filled in, the deposition of the lower members of the group onlapped westward over the carbonate platform. The westward migration was periodic which is reflected in the presence of multiple facies intervals, which are bounded by unconformities or condensed beds (Lehmann 1995). Each unit represents a pulse of subsidence and subsequent sedimentation in the basin, and all have several similarities. Each interval onlaps argillaceous limestone, condensed interval, and each appears to record a localized deepening event. The overlying and has shifted westward with respect to the underlying unit. The base of each unit is defined as a disconformity and/or stratigraphically black shale unit is thinner than the previous unit (Lehmann 1995).

The Flat Creek Member is the basal unit of the Utica and sits unconformably on units of the Trenton carbonates (Joy 2000). It is a transgressive deep basinal calcareous shale that represents the first mud flux from the erosion of the Taconian Island Arc to the east (current orientation). The Flat Creek is usually dark gray to black, variably calcareous shale with minor thin beds of argillaceous micrite and biomicrite (Lehmann, 1995) as shown in Figure 5). Vertical calcite filled veins cut the Flat Creek Member as shown in Chuctanunda Creek, Florida, NY (Fig. 5d).

Figure 5. Clockwise from left: a-c) Flat Creek Member along Route 5S, Florida, Montgomery County, d) Flat Creek Member along the Chuctanunda Creek, Florida, Montgomery County (Martin, 2008, Nyahay, 2008)

The depocenter for the Flat Creek may very well have been east of the Hudson River, New York State. The unit is extremely thick in the Hudson Valley but thins and subcrops to as one moves to central New York. Nyahay identifies the pinchout as the point where the Steuben Limestone appears and thickens to the west (Nyahay, 2008).

The middle member of the Utica is the Dolgeville, a "pulse" carbonate/shale with turbiditic attributes (Mehrtens 1988). Shale members resemble Flat Creek; limestone members resemble Denley Limestone (Trenton Group). The Dolgeville, interpreted as a slope facies peripheral to the Trenton platform, interfingers with the basal Flat Creek black shale member (Nyahay, 2008). Microfolding created significant fracturing for gas migration from the organic-rich shale interbeds (Figure 6).

Figure 6. Dolgeville Member from left to right: a) microfolds near Paradise Road, Herkimer County, b) top of the Dolgeville along the NYS Thruway near Little Falls (Martin 2008, Nyahay 2008).

The uppermost member of the Utica is the Indian Castle, a transgressive, fissile shale with some calcareous interbeds. The upper units are more monotonous and fissile while the lower units are more blocky with impure limestone beds (Figure 7).

Figure 7. Indian Castle Member from left to right: a) Upper Indian Castle at Little Falls exit of the NYS Thruway, b) Lower Indian Castle at Paradise Road. Herkimer County (Martin 2008, Nyahay 2008).

As a result of basin development, 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 western New York State, the Utica is less than 300 feet thick (Figure 8) (Zerrahn 1978). The Utica is overlain by coarser clastics of the regressive Lorraine Shale that consists of shale, siltsone and fine-grained sandstones. The Lorraine was

deposited as the marine environment prograded westward and deltaic deposits pushed across New York from the east.
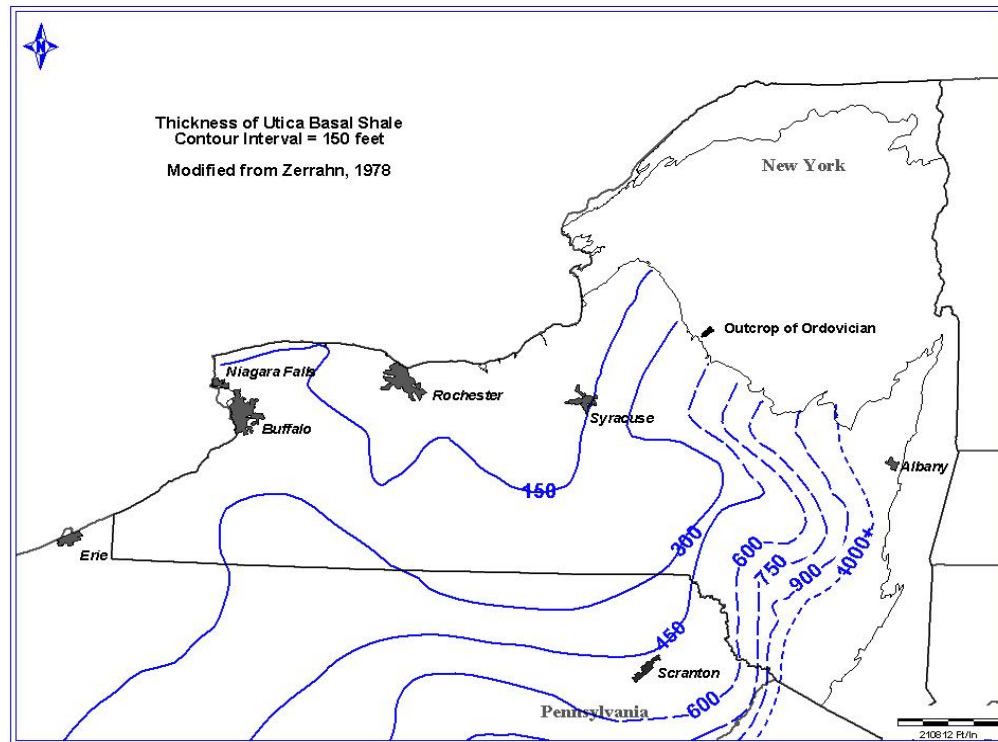

Figure 8. Isopach of the Utica Shale.

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 (Martin 2003).

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. 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 9). One well is also reported to produce from the Rochester Shale in Seneca County.

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 (Isachsen 2000). 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.

Figure 9. Rochester Shale Outcrop in New York (University of Rochester 2002)

Devonian. --- The Devonian section covers approximately 22,500 square miles in south-central New York (Figure 10), 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 (Isachsen 2000). Depth to the base of the group increases from outcrop to over 4,000 feet in southern New York (Figure 11). 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.

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 (Van Tyne 1978). 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.

The Geneseo Shale is the basal unit of the Genesee Formation, and is the primary black shale in the formation. It is a fissile, organic-rich shale which when broken emits a distinct petroleum odor (de Witt 1993). 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.
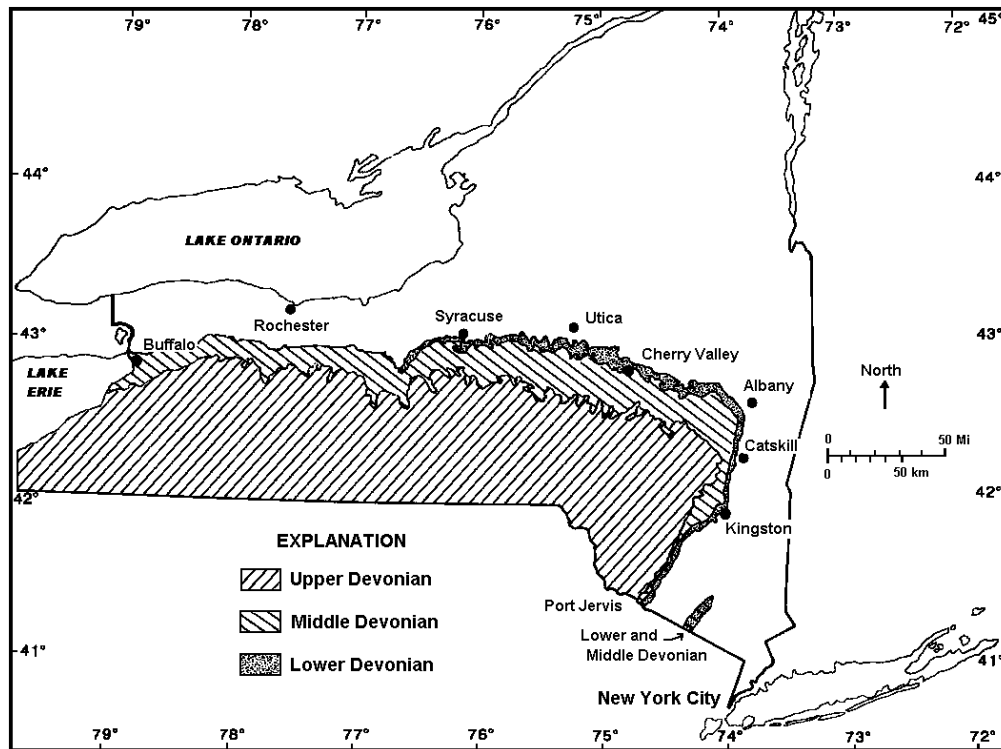

Figure 10. Devonian Outcrop in New York (modified from Isachsen et al 2000)

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.

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 outcropping 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.
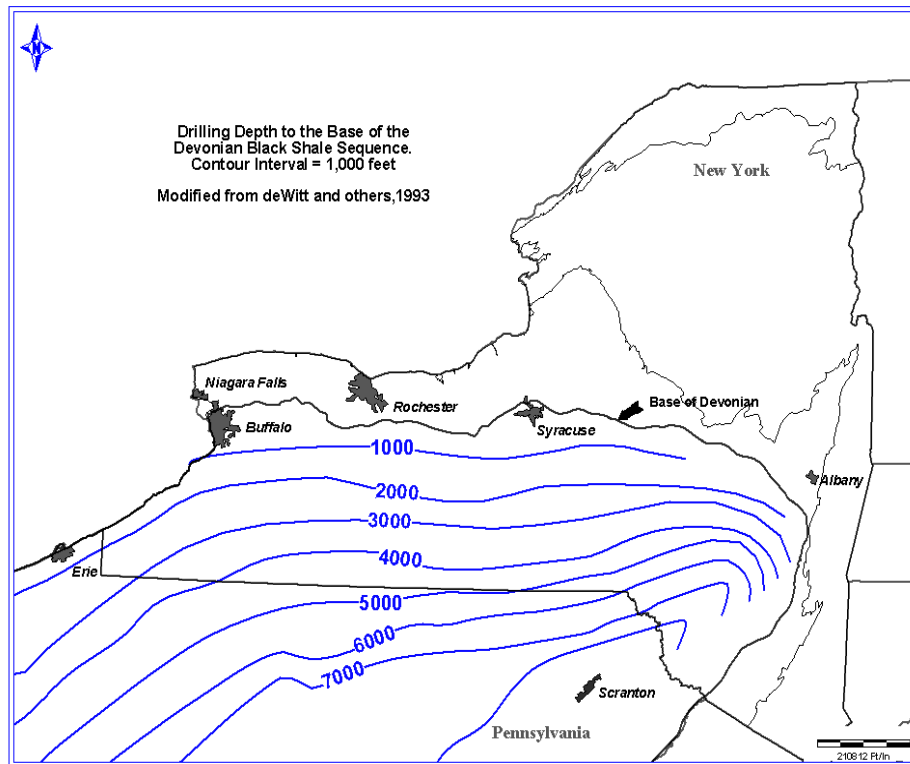

Figure 11. Drilling Depth to Base of the Devonian.

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 into 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 (Van Tyne 1978). 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.

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 12 (Kepferle 1993). Deposition of the Paleozoic sediments occurred as mountains, generally located to the east of the basin, were eroded. Sediments were then transported westward via a massive delta complex and deposited on the alluvial plain and into the marine environment.
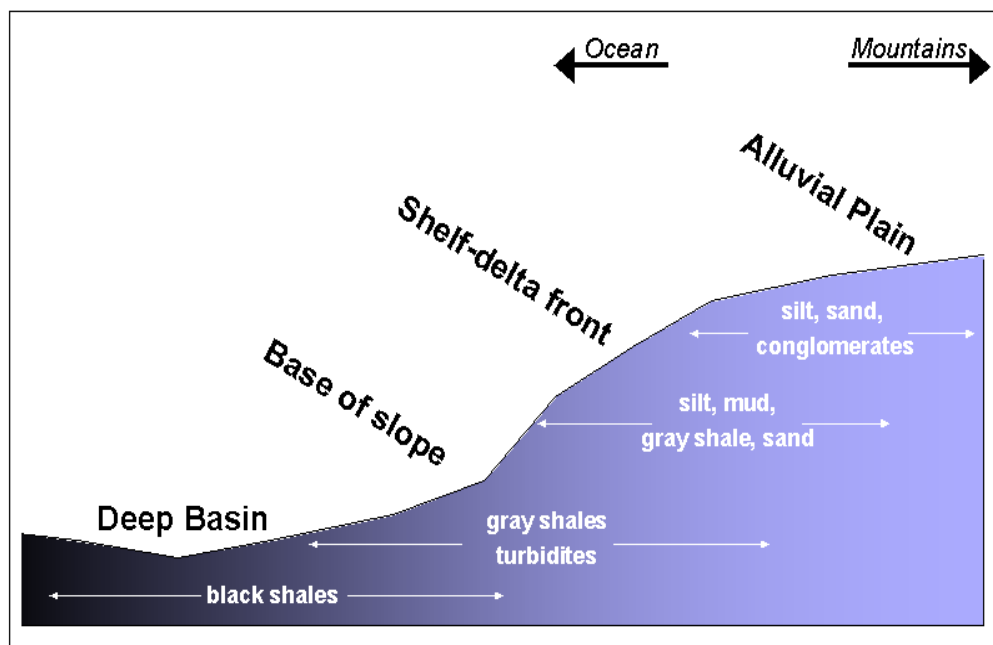

Figure 12. Deposition Model; Organic Rich Black Shales (modified from Kepferle 1993).

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 (de Witt 1993B). 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 (Van Tyne 1978 and 1997; de Witt et al. 1993; Roen 1984). 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 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 (Van Tyne 1978 1997).

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 (de Witt et al. 1993).
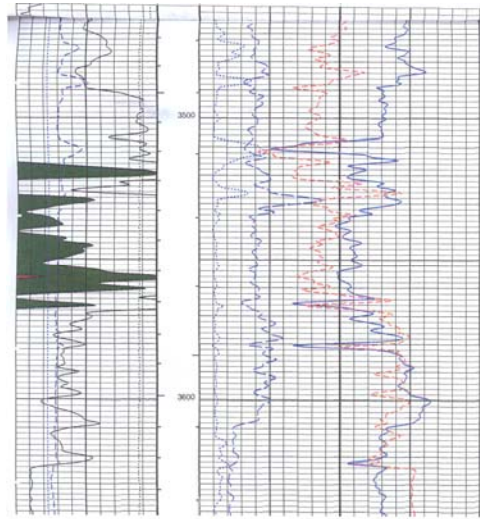

Figure 13. Sample Gamma Ray Signature of Radioactive Black Shale.

As determined by de Witt using the 20 API gamma ray cut off, the net thickness of radioactive Devonian black shale ranges from less than 100 feet to over 500 feet (Figure 14) (de Witt et al. 1993). 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.

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. The regional fracturing patterns in the Devonian rocks of New York have been studied in depth by numerous authors including Parker (1942), Engelder (1980), Evans (1994), Gross (1991), and Loewy (1995).

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 (Wallace 1988). *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 (Wallace 1988). 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.
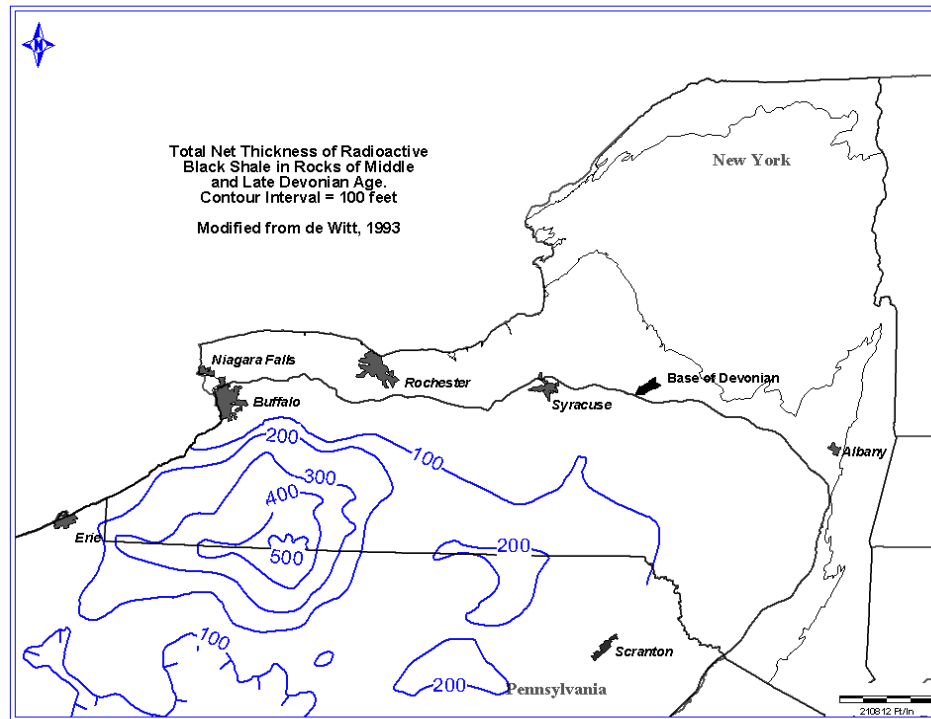
Figur14. Radioactive Black Shale Thickness in New York.

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. 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 (1995), and were determined based on their "clustering of orientation and similarity of morphology (Figure 15)." 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.

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 16). Earth Satellite Corporation performed a remote sensing and lineament analysis of the Appalachian Basin in New York (Earth Satellite Corporation 1997). 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.

Order	Type	Orientation	Rock Type	Timing / Stress
1	Cross-fold (CF)* *Set I***	N-NW (320° to 010°)	Gray shale, siltstones, and Black Shale	Natural hydraulic fracturing during N-NNW compression during the Alleghanian Orogeny, formed at depth.
2	070° *Set III***	070°	Black/Gray Shale *below* Rhinestreet fm.	Release joints, propagating during basin uplift and regional rifting, formed at depth.
3	E-W	085°	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° east to -045° 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)				

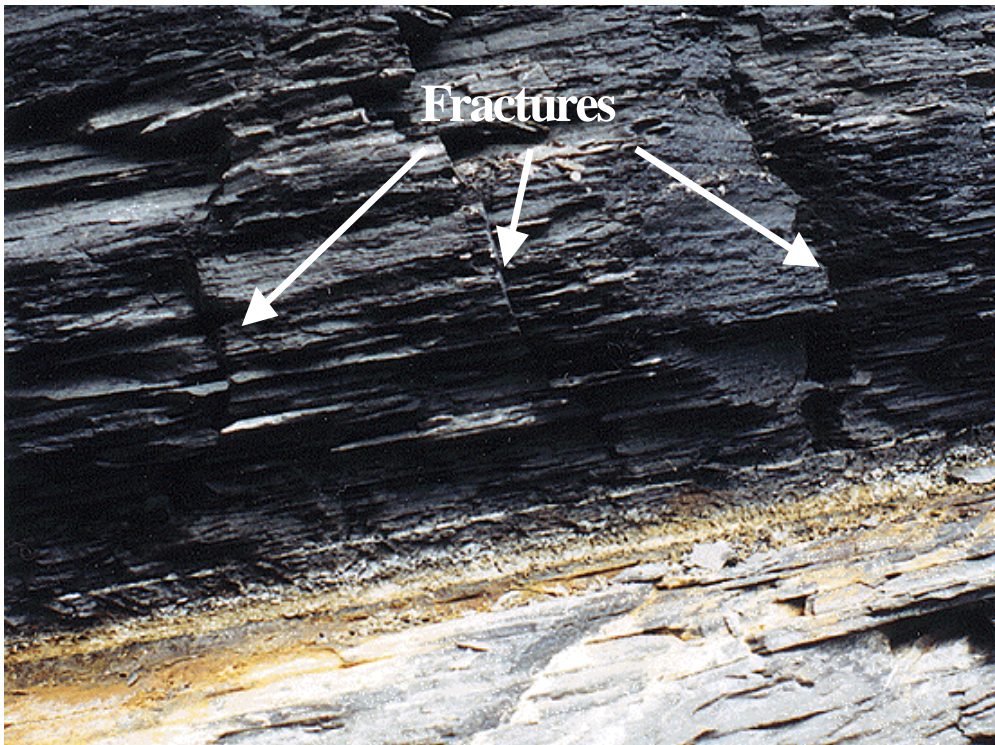Figure 15. Primary Joint Sets in New York

Figure 16. Natural Fracture in the Utica Black Shale (University of Rochester 2002)

The orientation of natural fractures was evaluated for four map sheets within the entire study area as depicted in Figure 17, and the rose diagrams generated by Earth Satellite Corporation (1997) 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."

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" (Earth Satellite Corporation 1997).
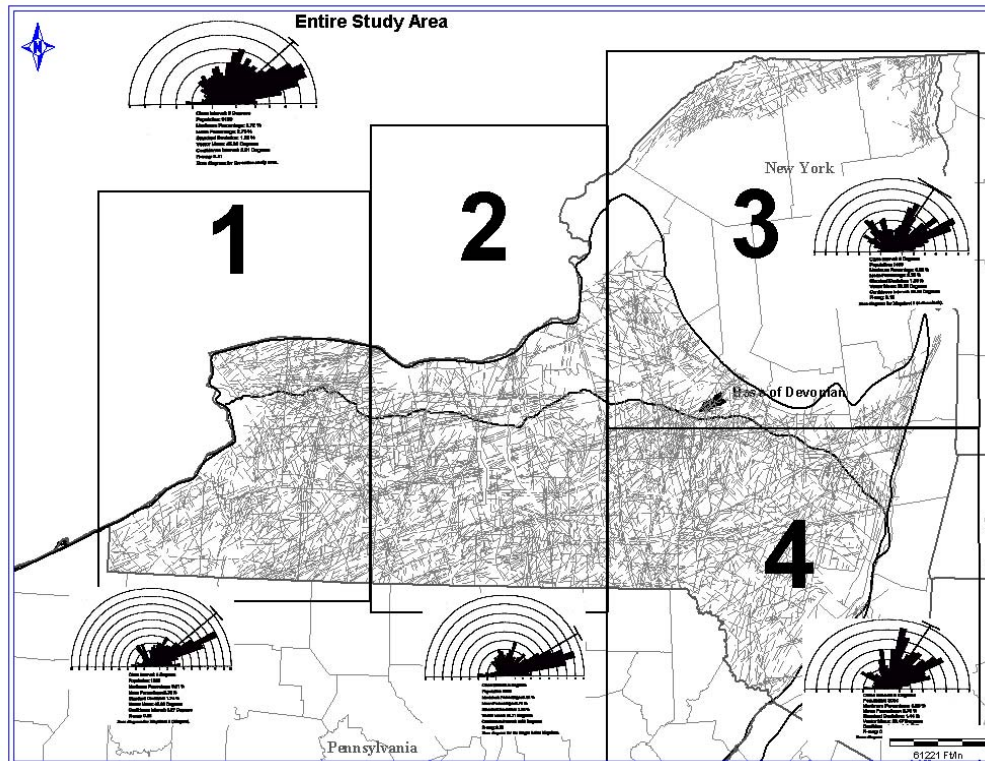

Figure 17. Rose Diagrams of Four Study Areas

GEOCHEMISTRY

Total Organic Carbon

Total organic carbon (TOC) measurements have been made on both core and drill cuttings in the Devonian Shale in New York. Figure 18 summarizes the measurements from core samples by formation (Streib 1981; Zielinski 1980) which 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 19). However, Weary, et. al. describe a Middle Devonian Marcellus cuttings sample taken from Livingston County with a measured TOC of 11.05% (Weary 2001). Finally, recent measurements taken from samples collected by the New York State Museum show total organic content in the Marcellus Shale to range from less than 1% to over 9% TOC (Martin 2006).

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

Figure 18. TOC from New York Devonian Shale Drill Cuttings

Figure 19. Average Organic Content (%) of the Marcellus Shale in New York and Pennsylvania (SOURCE Weary 2001; Repetski 2002, 2005, graphic by Frank Maio)

Measurements of total organic carbon in the Utica Shale have been reported in literature (Hay 1989; Hannigan 1994; Ryder 1998; Wallace 1988). The range is from approximately 0.16% to 4.0%. Recent measurements from samples collected by the New York State Museum range from less than 1% in western New York State to 5% in the east (Nyahay 2007).

<center>Kerogen Type</center>

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 20) (Weary 2000). 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.
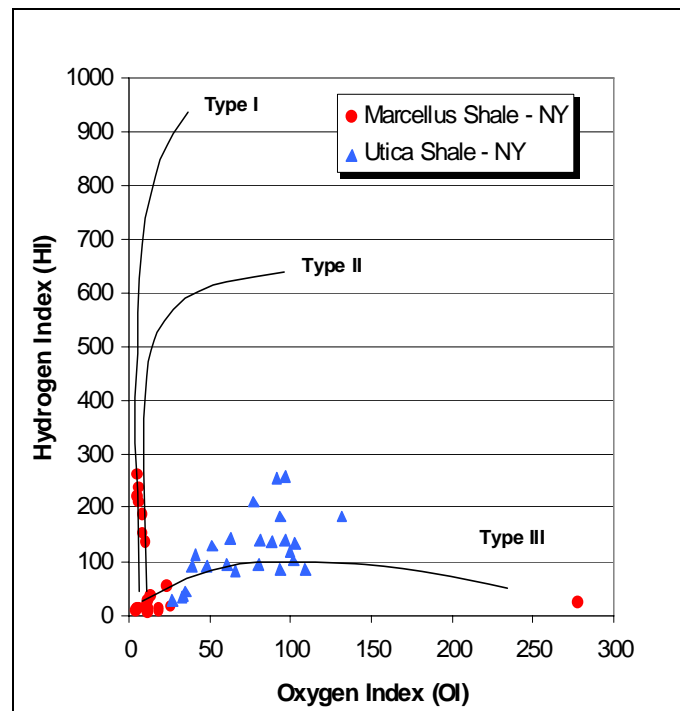

Figure 20. Published Rock-Eval Data for Marcellus and Utica Shales in New York Plotted on a Modified Van Krevelen Diagram.

<center>Thermal Maturity</center>

Rock-Eval. --- Published Rock-Eval data for the Marcellus Shale and the Utica Shale in New York State was plotted using the technique after Peters (Figure 21) (Weary 2000). This figure 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. The bimodal disctribution of Marcellus samples most like reflects the variability of shale maturity as shown by vitrinite reflectance and conodont alteration estimates (see below). The "scattershot" nature of the Utica data reflects the inability to pick a clear Tmax with extremely mature shales and may not be significant.

Vitrinite Reflectance. --- Figure 22 summarizes vitrinite reflectance data from nine wells in the Marcellus Shale (Van Tyne 1993). 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 (2000) (Figure 23).
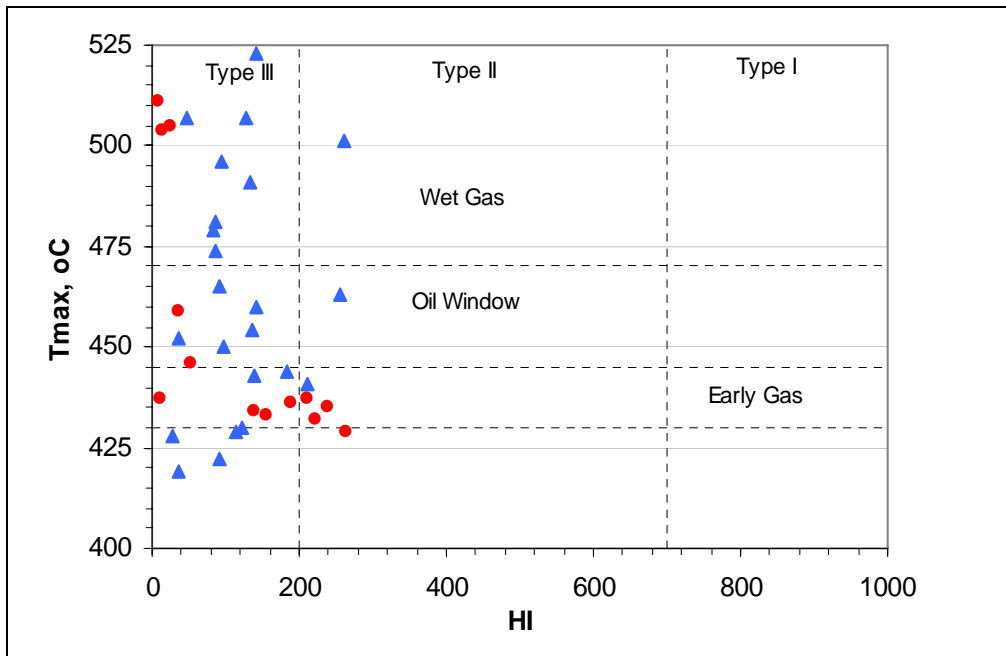
Figure 21. Published Rock-Eval Data for Marcellus and Utica Shale. Plotted After Peters (1986)

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 22. Summary of Thermal Maturity Data; Marcellus, New York

For the Ordovician rocks, Utica Shale vitrinite reflectance calculations were calculated by TerraTek, Inc. from samples collected by the New York State Museum from graptolites identified in core taken in the Mohawk Valley. Graptolytes were used because no vitrinite was present at the time the Utica was deposited in the Ordovician (TerraTek 2004). Average vitrinite reflectance values ranged from 2.28 to 4.32. The higher value,

which reflects a super-mature sample, was the farthest east sample taken in Saratoga County. This reflects the increasing maturity in the Utica as one moves closer to the Taconic front.

Thermal Alteration Index. --- The uses 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) (Staplin 1969). 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 (Streib 1981). 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) (Streib 1981). All samples indication maturation levels above 150°C. No TAI values were available for the Silurian or Ordovician shales.
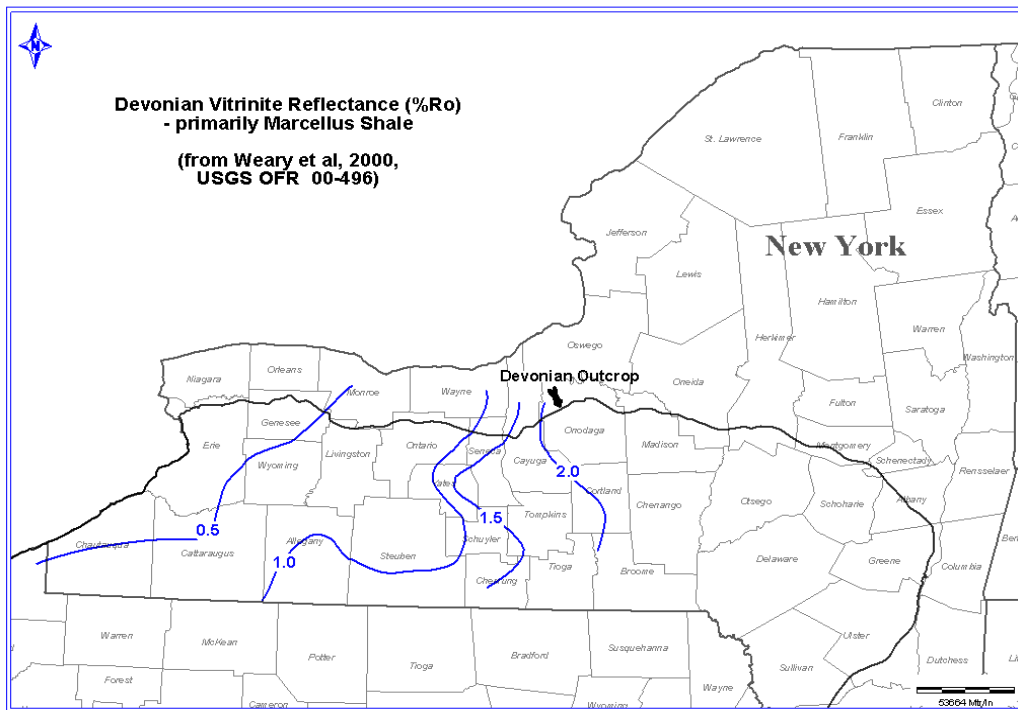

Figure 23: Devonian Vitrinite Reflectance (%Ro)

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) (Epstein 1977). In general, the CAI of a conodont increases with depth and temperature as a result of metamorphisim. A recent study of thermal maturity in Ordovician and Devonian rocks has been completed by the USGS and New York Geological Survey (Weary 2000). In the Upper Devonian shales, CAI values range from less than 1.5 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 24) (Tetra Tech 1980). 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 25) (Weary 2000).
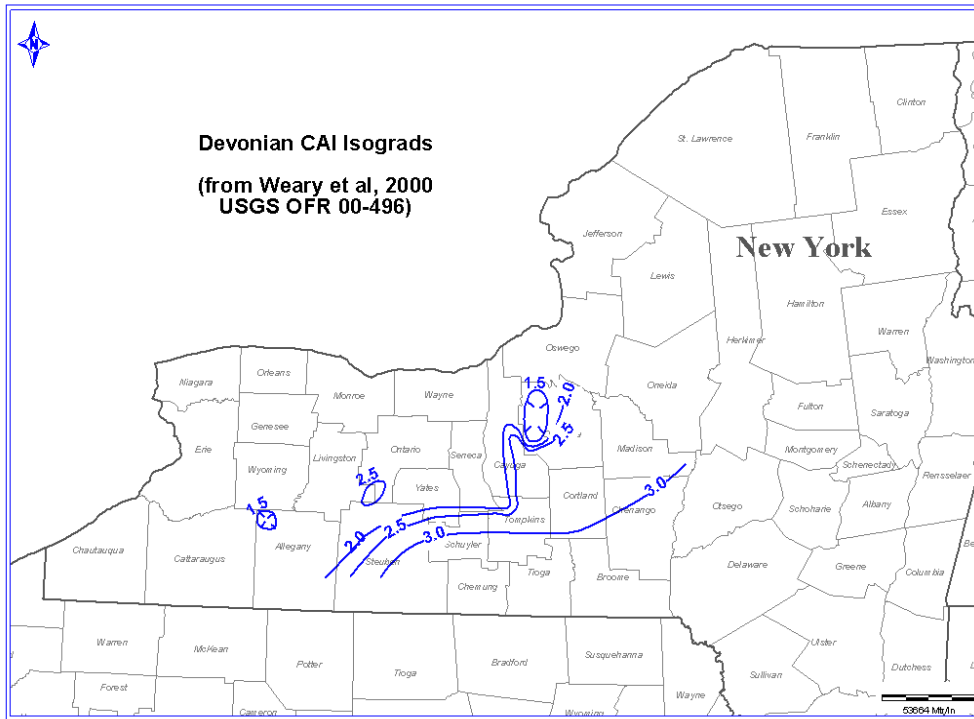
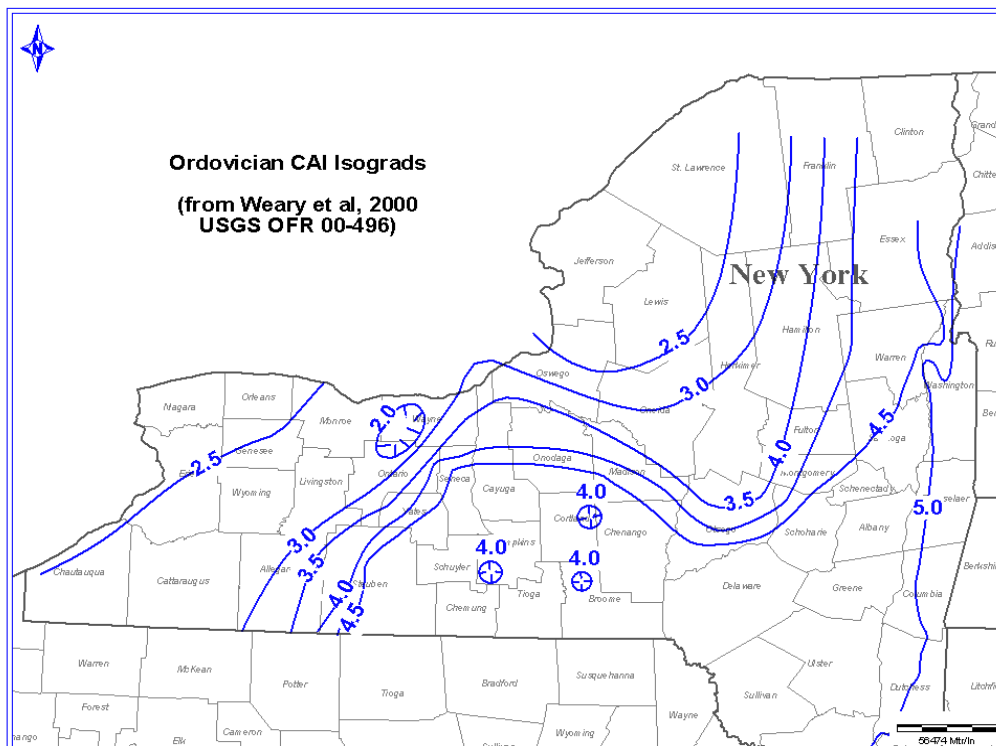Figure 24. Devonian Conodont Alteration Index (CA) Isograds.

Figure 25. Middle and Upper Ordovician Conodont Alteration Index (CAI) Isograds

Adsorption isotherms have been created for both the Devonian and Ordovician shales. According to Terratek, "the testing consisted of exposing, at constant temperature, the E.Q. moisture prepared coal sample to methane gas at a series of pressures, calculated to yield the desired equilibrium adsorption pressures (TerraTek, 2004; TerraTEk 200_)." As expected, the Marcellus sample, with TOC of 8.27%, can yield much higher adsorption figures compared to the Utica given the higher organic content, with TOC of 2.167%. (figures 26 and 27). Other factors such as clay content also affect adsorption.
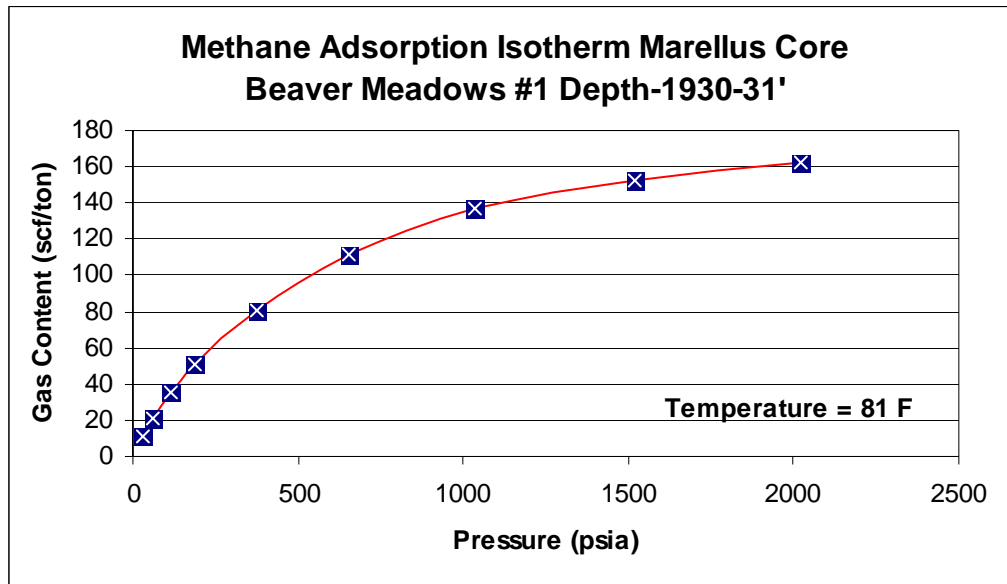
Methane Adsorption Isotherm Marellus Core
Beaver Meadows #1 Depth-1930-31'

Temperature = 81 F

Figure 26. Methane Adsorption Isotherm for a Marcellus Shale Sample, New York

Methane Adsorption Isotherm Utica Core
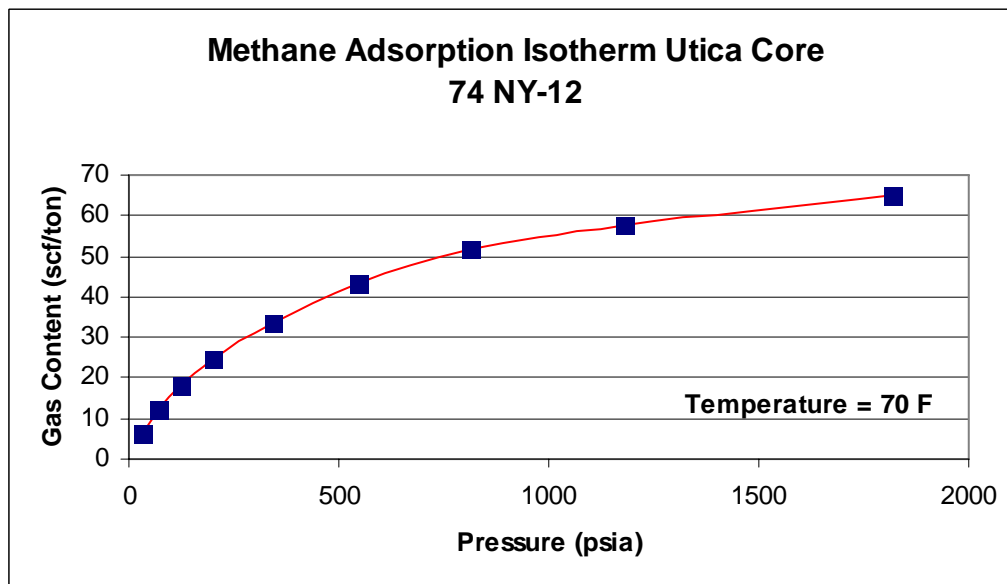**74 NY-12**

Temperature = 70 F

Figure 27. Methane Adsorption Isotherm for a Utica Shale Sample, New York (Terratek 2004)

RESERVOIR CHARACTERIZATION

Reservoir characterization in gas shale reservoir systems focuses primarily on natural fractures because most known productive gas shale reservoirs are gas saturated with 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 in 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.

Mineralogy

Both the Ordovician Utica and Devonian Marcellus shales are calcareous shales. Xray diffraction was completed on a number of outcrop samples. Figures 28 and 29 show ternary diagrams of the relationship between three major constituent categories as derived from XRD data (Nyahay 2008B). The relationship shown here is quite similar to the productive units of the Barnett shale (Nyahay 2008B). To full assess the mineralogical composition, far more data is needed.
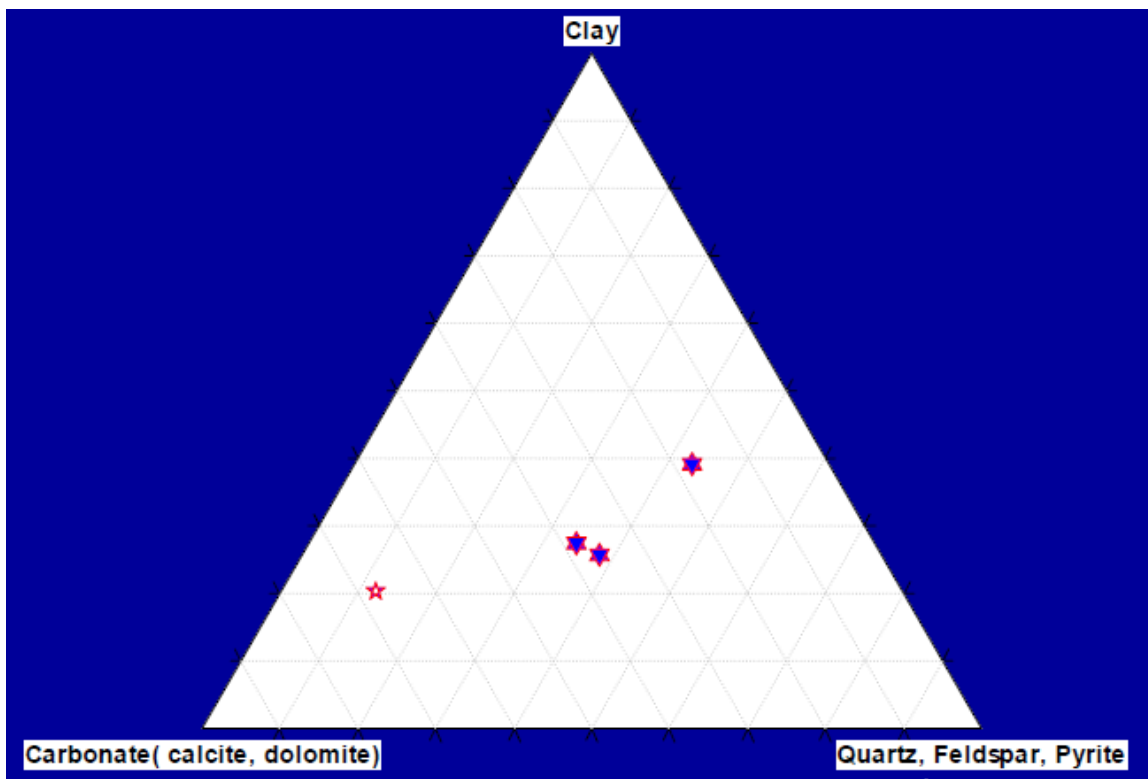

Figure 28. Utica Shale Ternary Diagram from Outcrop Samples (Nyahay 2008B)
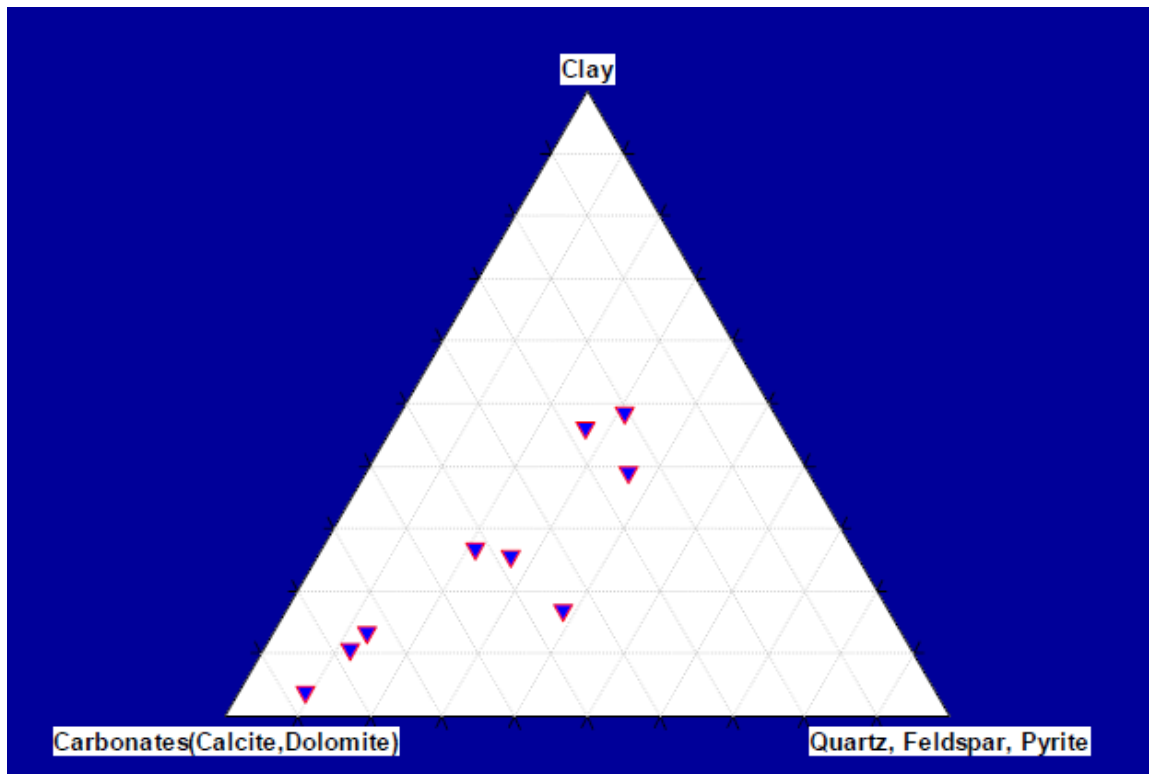
Figure 29. Marcellus Shale Ternary Diagram from Outcrop Samples (Nyahay 2008B)

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 (Walter 1997 2001). 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 (Moore 1987). In this report, six wells with natural gas production from Devonian Shale were analyzed along with one water well and one natural seep. The data shows methane concentrations of 80-95% and concentrations of ethane and propane from 3% to 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. However, analysis of the Utica Shale in Quebec indicate methane concentrations ranging from 88% to 96% (Beiers 1976).

Natural Fractures

Natural fracture formation was addressed previously. 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 (Cliff Minerals, Inc. 1980B 1980 1981).

Figure 30 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 (NYSERDA #3-6213) well was completed in the Marcellus Shale (which was not cored) and was producing intermittently at the end of 2001.

Group	Unit	NY #1 Depth (ft)	Fracture Orientation	NY #3 Depth (ft)	Fracture Orientation	NY #4 Depth (ft)	Fracture Orientation[1]
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. (Cliff Minerals, Inc. 1980B 1980C, and 1981)

Figure 30. Devonian Shale Natural Fracture Orientation from Oriented Core.

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 shale, 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.

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