Chapter 4 GEOLOGY

CHAPTER 4 GEOLOGY **4-1**

4.1 INTRODUCTION 4-2
4.2 BLACK SHALES 4-3
4.3 UTICA SHALE 4-6
4.3.2 Thermal Maturity and Fairways *4-14*
4.3.3 Potential for Gas Production *4-14*
4.4 MARCELLUS FORMATION 4-15
4.4.1 Total Organic Carbon *4-17*
4.4.2 Thermal Maturity and Fairways *4-17*
4.4.3 Potential for Gas Production *4-18*
4.5 SEISMICITY IN NEW YORK STATE 4-24
4.5.1 Background *4-24*
4.5.2 Seismic Risk Zones *4-25*
4.5.4 Seismic Events *4-29*
4.5.5 Monitoring Systems in New York *4-35*
4.6 NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) IN MARCELLUS SHALE 4-36

Figure 4.1 - Gas Shale Distribution 4-5
Figure 4.2 - Stratigraphic Column of New York 4-8
Figure 4.3 - East West Cross-Section of New York State 4-9
Figure 4.4 - Extent of Utica Shale in New York State 4-10
Figure 4.5 - Depth to Base of Utica Shale 4-12
Figure 4.6 - Thickness of High-Organic Utica Shale 4-13
Figure 4.7 - Utica Shale Fairway 4-16
Figure 4.8 - Depth and Extent of Marcellus Shale 4-19
Figure 4.9 - Marcellus Shale Thickness 4-20
Figure 4.10 - Total Organic Carbon of Marcellus Shale 4-21
Figure 4.11 - Marcellus Shale Thermal Maturity 4-22
Figure 4.12 - Marcellus Shale Fairway 4-23
Figure 4.13 - Mapped Geologic Faults 4-26
Figure 4.14 - New York State Seismic Hazard Map 4-27
Figure 4.15 - Seismic Events 4-34

Table 4.1 - Modified Mercalli Scale 4-30
Table 4.2 - Summary of Seismic Events 4-31

This Chapter supplements and expands upon Chapter 5 of the GEIS. Sections 4.1 through 4.5 and the accompanying figures and tables were provided in their entirety by Alpha Environmental, Inc., under contract to NYSERDA to assist the Department with research related to this SGEIS.[1] Alpha's citations are retained for informational purposes, and are listed in the "consultants' references" section of the Bibliography. Section 4.6 discusses how Naturally Occurring Radioactive Materials (NORM) in Marcellus Shale Marcellus Shale is addressed in the SGEIS.

The influence of natural geologic factors with respect to hydraulic fracture design and subsurface fluid mobility is discussed Chapter 5, specifically in Sections 5.8 (hydraulic fracture design) and 5.11.1.1 (subsurface fluid mobility).

4.1 Introduction

The natural gas industry in the US began in 1821 with a well completed by William Aaron Hart in the upper Devonian Dunkirk Shale in Chautauqua County. The "Hart" well supplied businesses and residents in Fredonia, New York with natural gas for 37 years. Hundreds of shallow wells were drilled in the following years into the shale along Lake Erie and then southeastward into western New York. Shale gas fields development spread into Pennsylvania, Ohio, Indiana, and Kentucky. Gas has been produced from the Marcellus since 1880 when the first well was completed in the Naples field in Ontario County. Eventually, as other formations were explored, the more productive conventional oil and natural gas fields were developed and shale gas (unconventional natural gas) exploration diminished.

The US Energy Research and Development Administration (ERDA) began to evaluate gas resources in the US in the late 1960s. The Eastern Gas Shales Project was initiated in 1976 by the ERDA (later the US Department of Energy) to assess Devonian and Mississippian black shales. The studies concluded that significant natural gas resources were present in these tight formations.

The interest in development of shale gas resources increased in the late 20th and early 21st century as the result of an increase in energy demand and technological advances in drilling and

[1] Alpha, 2009

well stimulation. The total unconventional natural gas production in the US increased by 65% and the proportion of unconventional gas production to total gas production increased from 28% in 1998 to 46% in 2007.[2]

A description of New York State geology and its relationship to oil, gas, and salt production is included in the 1992 GEIS. The geologic discussion provided herein supplements the information as it pertains to gas potential from unconventional gas resources. Emphasis is placed on the Utica and Marcellus shales because of the widespread distribution of these units in New York.

4.2 Black Shales

Black shales are fine-grained sedimentary rocks that contain high levels of organic carbon. The fine-grained material and organic matter accumulate in deep, warm, quiescent marine basins. The warm climate favors the proliferation of plant and animal life. The deep basins allow for an upper aerobic (oxygenated) zone that supports life and a deeper anaerobic (oxygen-depleted) zone that inhibits decay of accumulated organic matter. The organic matter is incorporated into the accumulating sediments and is buried. Pressure and temperature increase and the organic matter is transformed by slow chemical reactions into liquid and gaseous petroleum compounds as the sediments are buried deeper. The degree to which the organic matter is converted is dependent on the maximum temperature, pressure, and burial depth. The extent that these processes have transformed the carbon in the shale is represented by the thermal maturity and transformation ratio of the carbon. The more favorable gas producing shales occur where the total organic carbon (TOC) content is at least 2% and where there is evidence that a significant amount of gas has formed and been preserved from the TOC during thermal maturation.[3]

Oil and gas are stored in isolated pore spaces or fractures and adsorbed on the mineral grains.[4] Porosity (a measure of the void spaces in a material) is low in shales and is typically in the range of 0 to 10 percent.[5] Porosity values of 1 to 3 percent are reported for Devonian shales in the

[2] Alpha, 2009

[3] Alpha, 2009

[4] Alpha, 2009

[5] Alpha, 2009

Appalachian Basin.[6] Permeability (a measure of a material's ability to transmit fluids) is also low in shales and is typically between 0.1 to 0.00001 millidarcy (md).[7] Hill et al. (2002) summarized the findings of studies sponsored by NYSERDA that evaluated the properties of the Marcellus Shale. The porosity of core samples from the Marcellus in one well in New York ranged from 0 to 18%. The permeability of Marcellus Shale ranged from 0.0041 md to 0.216 md in three wells in New York State.

Black shale typically contains trace levels of uranium that is associated with organic matter in the shale.[8] The presence of naturally occurring radioactive materials (NORM) induce a response on gamma-ray geophysical logs and is used to identify, map, and determine thickness of gas shales.

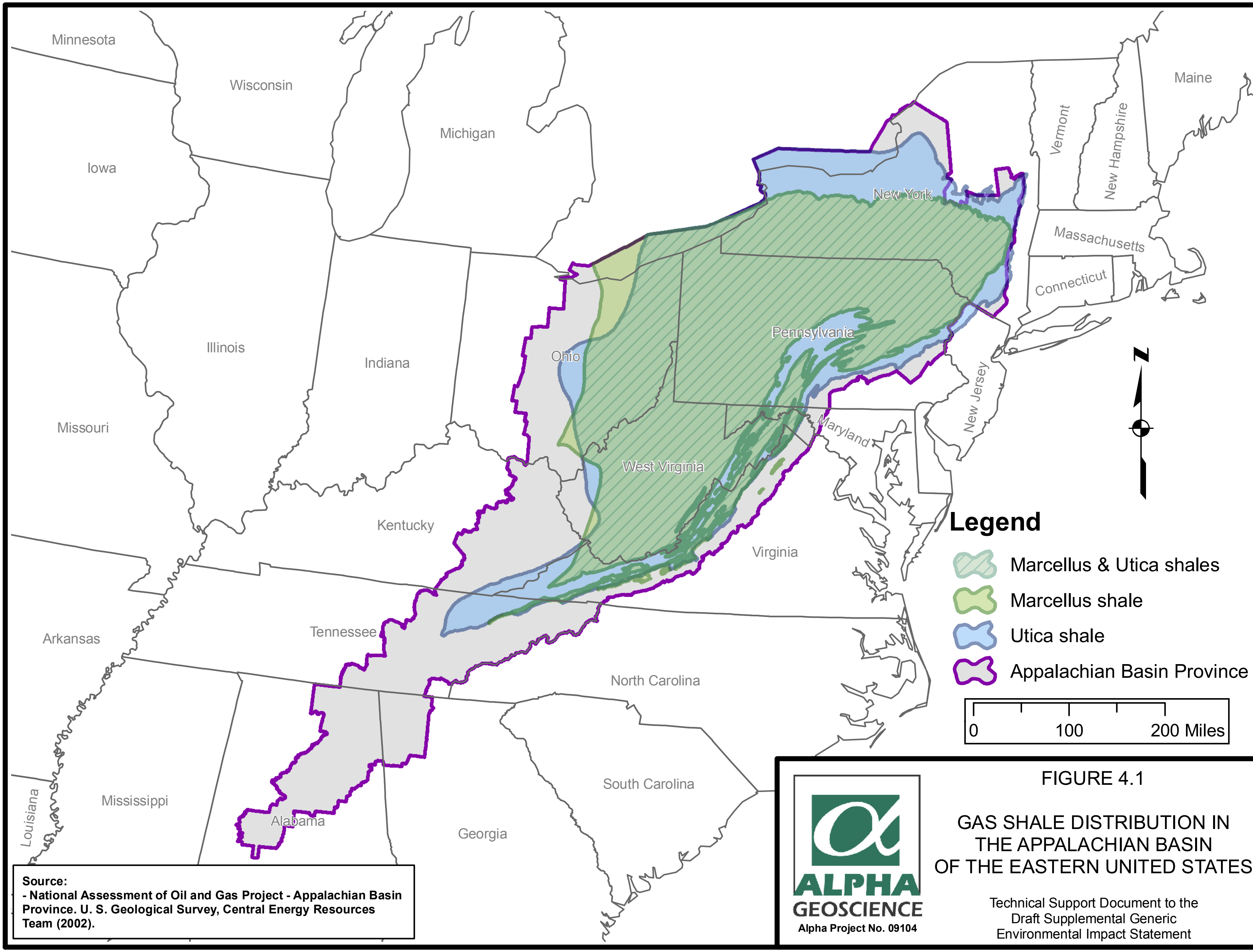
The Appalachian Basin was a tropical inland sea that extended from New York to Alabama (Figure 4.1). The tropical climate of the ancient Appalachian Basin provided favorable conditions for generating the organic matter, and the erosion of the mountains and highlands bordering the basin provided clastic material for deposition. The sedimentary rocks that fill the basin include shales, siltstones, sandstones, evaporites, and limestones that were deposited as distinct layers that represent several sequences of sea level rise and fall. Several black shale formations, which may produce natural gas, are included in these layers.[9]

[6] Alpha, 2009

[7] Alpha, 2009

[8] Alpha, 2009

[9] Alpha, 2009



Source:
- National Assessment of Oil and Gas Project - Appalachian Basin Province. U. S. Geological Survey, Central Energy Resources Team (2002).

FIGURE 4.1

GAS SHALE DISTRIBUTION IN THE APPALACHIAN BASIN OF THE EASTERN UNITED STATES

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

The stratigraphic column for New York State is shown in Figure 4.2 and includes oil and gas producing horizons. Figure 4.3 is a generalized cross-section from west to east across the southern tier of New York State and shows the variation of thickness and depth of the various stratigraphic units.

The Ordovician-aged Utica Shale and the Devonian-aged Marcellus Shale are of particular interest because of recent estimates of natural gas resources and because these units extend throughout the Appalachian Basin from New York to Tennessee. There are a number of other black shale formations (Figures 4.2 and 4.3) in New York that may produce natural gas on a localized basis.[10] The following sections describe the Utica and Marcellus shales in greater detail.

4.3 Utica Shale

The Utica Shale is an upper Ordovician-aged black shale that extends across the Appalachian Plateau from New York and Quebec, Canada, south to Tennessee. It covers approximately 28,500 square miles in New York and extends from the Adirondack Mountains to the southern tier and east to the Catskill front (Figure 4.4). The Utica shale is exposed in outcrops along the southern and western Adirondack Mountains, and it dips gently south to depths of more than 9,000 feet in the southern tier of New York.

The Utica shale is a massive, fossiliferous, organic-rich, thermally-mature, black to gray shale. The sediment comprising the Utica shale was derived from the erosion of the Taconic Mountains at the end of the Ordovician, approximately 440 to 460 million years ago. The shale is bounded below by Trenton Group strata and above by the Lorraine Formation and consists of three members in New York State that include: Flat Creek Member (oldest), Dolgeville Member, and the Indian Castle Member (youngest).[11] The Canajoharie shale and Snake Hill shale are found in the eastern part of the state and are lithologically equivalent, but older than the western portions of the Utica.[12]

---

[10] Alpha, 2009

[11] Alpha, 2009

[12] Alpha, 2009

There is some disagreement over the division of the Utica shale members. Smith & Leone (2009) divide the Indian Castle Member into an upper low-organic carbon regional shale and a high-organic carbon lower Indian Castle. Nyahay et al. (2007) combines the lower Indian Castle Member with the Dolgeville Member. Fisher (1977) includes the Dolgeville as a member of the Trenton Group. The stratigraphic convention of Smith and Leone is used in this document.

Units of the Utica shale have abundant pyrite, which indicate deposition under anoxic conditions. Geophysical logs and cutting analyses indicate that the Utica Shale has a low bulk density and high total organic carbon content.[13]

The Flat Creek and Dolgeville Members are found south and east of a line extending approximately from Steuben County to Oneida County (Figure 4.4). The Dolgeville is an interbedded limestone and shale. The Flat Creek is a dark, calcareous shale in its western extent and grades to a argillaceous calcareous mudstone to the east. These two members are time-equivalent and grade laterally toward the west into Trenton limestones.[14] The lower Indian Castle Member is a fissile, black shale and is exposed in road cuts, particularly at the New York State Thruway (I-90) exit 29A in Little Falls. Figure 4.5 shows the depth to the base of the Utica Shale.[15] This depth corresponds approximately with the base of the organic-rich section of the Utica Shale.

[13] Alpha, 2009

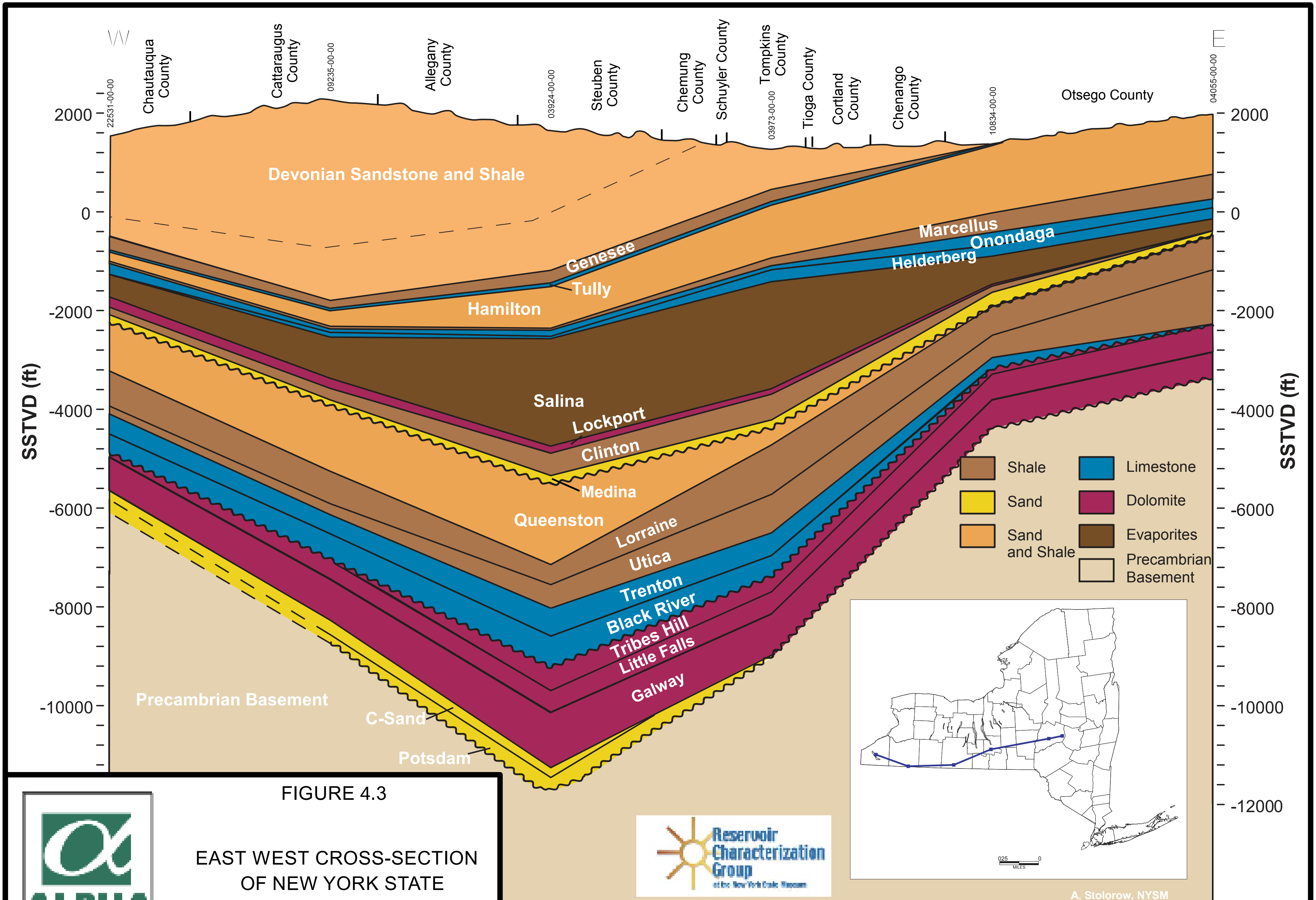
[14] Alpha, 2009

[15] Alpha, 2009

Figure 4.2

Stratigraphic Column of New York; Oil and Gas Producing Horizons
(from D.G. Hill, T.E. Lombardi and J. P. Martin, 2002)

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	1,100 - 1,400	Oil, Gas
			Perrysburg-Dunkirk	Sh, ss		Oil, Gas
				Sh, ss		
		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 - 1,850	
			Syracuse	Dol, sh, slt		
			Vernon	Sh		Gas
		Lockport	Lockport	Dol	150 - 250	Gas
		Clinton	Rochester	Sh	125	Gas
			Irondequoit	Ls		
	LOWER		Sodus/Oneida	Sh/cgl	75	Gas
			Reynales	Ls		
			Thorold	Ss		
		Medina	Grimsby	Sh, ss	75 - 150	Gas
			Whirlpool	Ss	0 - 25	Gas
ORDOVICIAN	UPPER		Queenston	Sh	1,100 - 1,500	Gas
			Oswego	Ss		Gas
			Lorraine	Sh		
			Utica	Sh	900 - 1000	Gas
	MIDDLE	Trenton-Black River	Trenton	Ls	425 - 625	Gas
			Black River	Ls	225 - 550	Gas
	LOWER	Beekmantown	Tribes Hill-Chuctanunda	Ls	0 - 550	
CAMB.	UPPER		Little Falls	Dol	0 - 350	
			Galway	Dol, ss	575 - 1,350	Gas
			Potsdam	Ss, dol	75 - 500	Gas
PRECAMBRIAN				Gneiss, marble, quartzite		

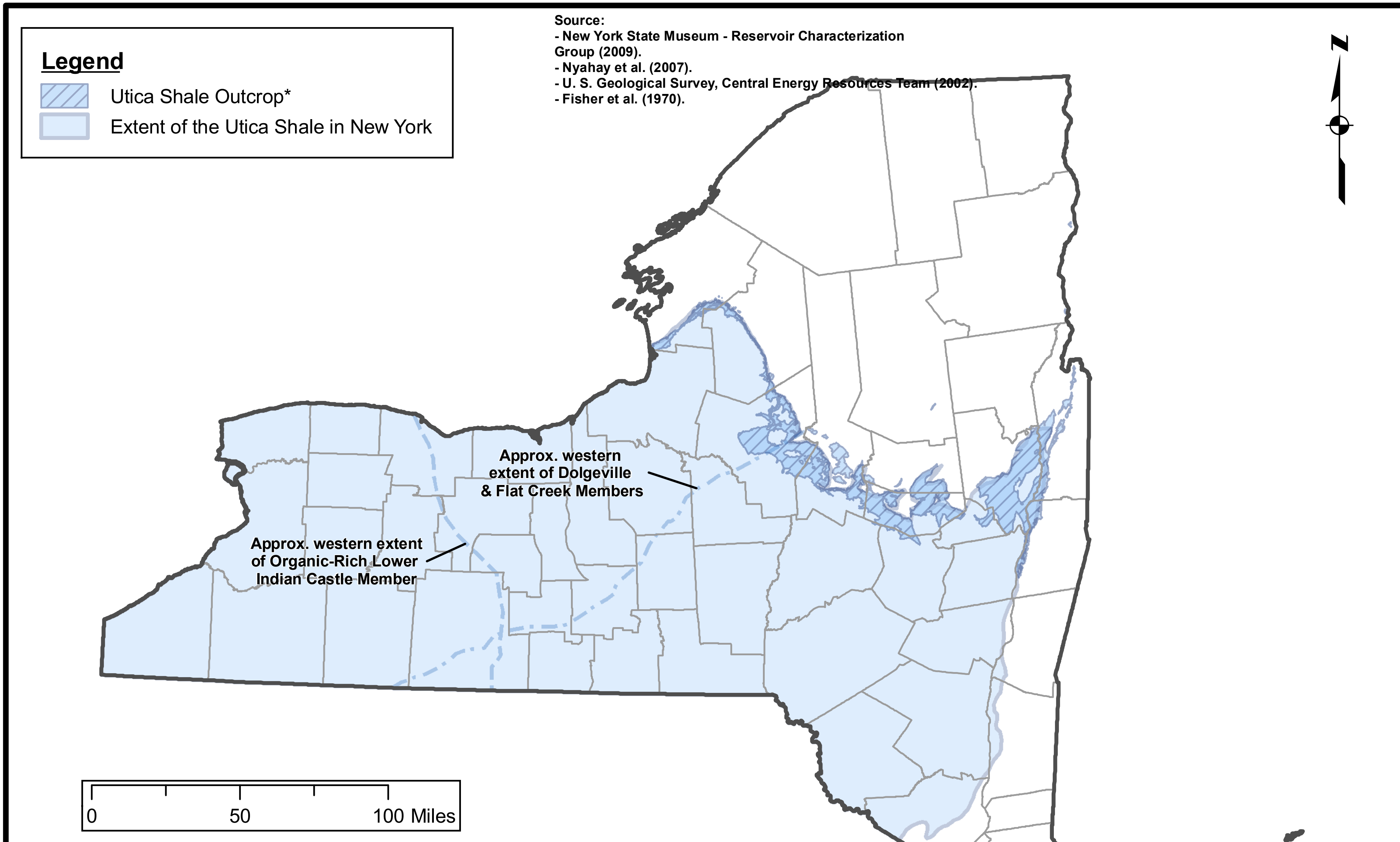


ALPHA GEOSCIENCE
Alpha Project No. 09104

FIGURE 4.3

EAST WEST CROSS-SECTION OF NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement



ALPHA GEOSCIENCE
Alpha Project No. 09104

FIGURE 4.4

EXTENT OF UTICA SHALE IN NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

4.3.1 Total Organic Carbon

Measurements of TOC in the Utica Shale are sparse. Where reported, TOC has been measured at over 3% by weight.[16] Nyahay et al. (2007) compiled measurements of TOC for core and outcrop samples. TOC in the lower Indian Castle, Flat Creek, and Dolgeville Members generally ranges from 0.5 to 3%. TOC in the upper Indian Castle Member is generally below 0.5%. TOC as high as 3.0% in eastern New York and 15% in Ontario and Quebec were also reported.[17]

The New York State Museum Reservoir Characterization Group evaluated cuttings from the Utica Shale wells in New York State and reported up to 3% TOC.[18] Jarvie et al. (2007) showed that analyses from cutting samples may underestimate TOC by approximately half; therefore, it may be as high as 6%. Figure 4.6 shows the combined total thickness of the organic-rich (greater than 1%, based on cuttings analysis) members of the Utica Shale. As shown on Figure 4.6, the organic-rich Utica Shale ranges from less than 50 feet thick in north-central New York and increases eastward to more than 700 feet thick.

---

[16] Alpha, 2009

[17] Alpha, 2009

[18] Alpha, 2009

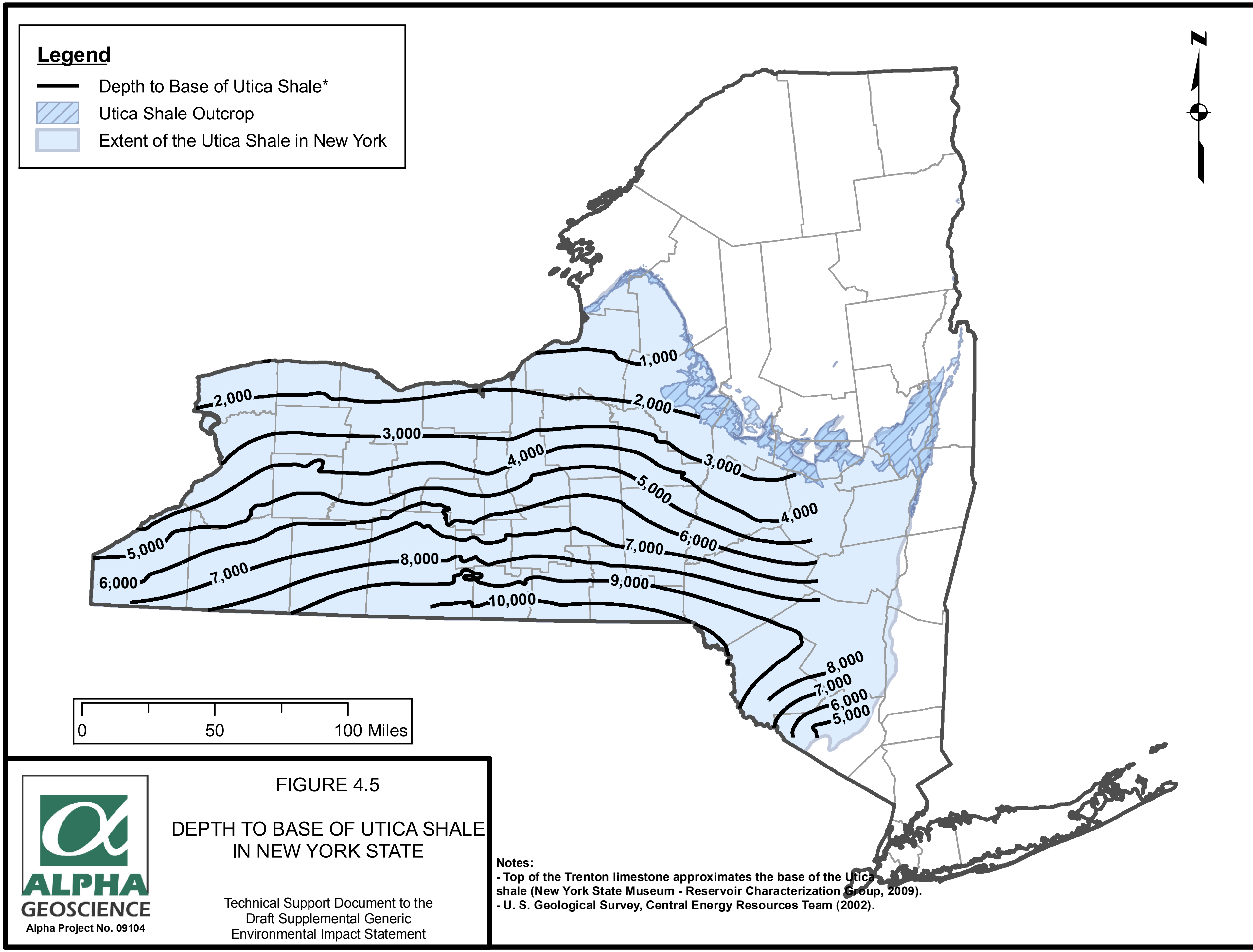


FIGURE 4.5

DEPTH TO BASE OF UTICA SHALE
IN NEW YORK STATE

Technical Support Document to the
Draft Supplemental Generic
Environmental Impact Statement

Notes:
- Top of the Trenton limestone approximates the base of the Utica shale (New York State Museum - Reservoir Characterization Group, 2009).
- U. S. Geological Survey, Central Energy Resources Team (2002).

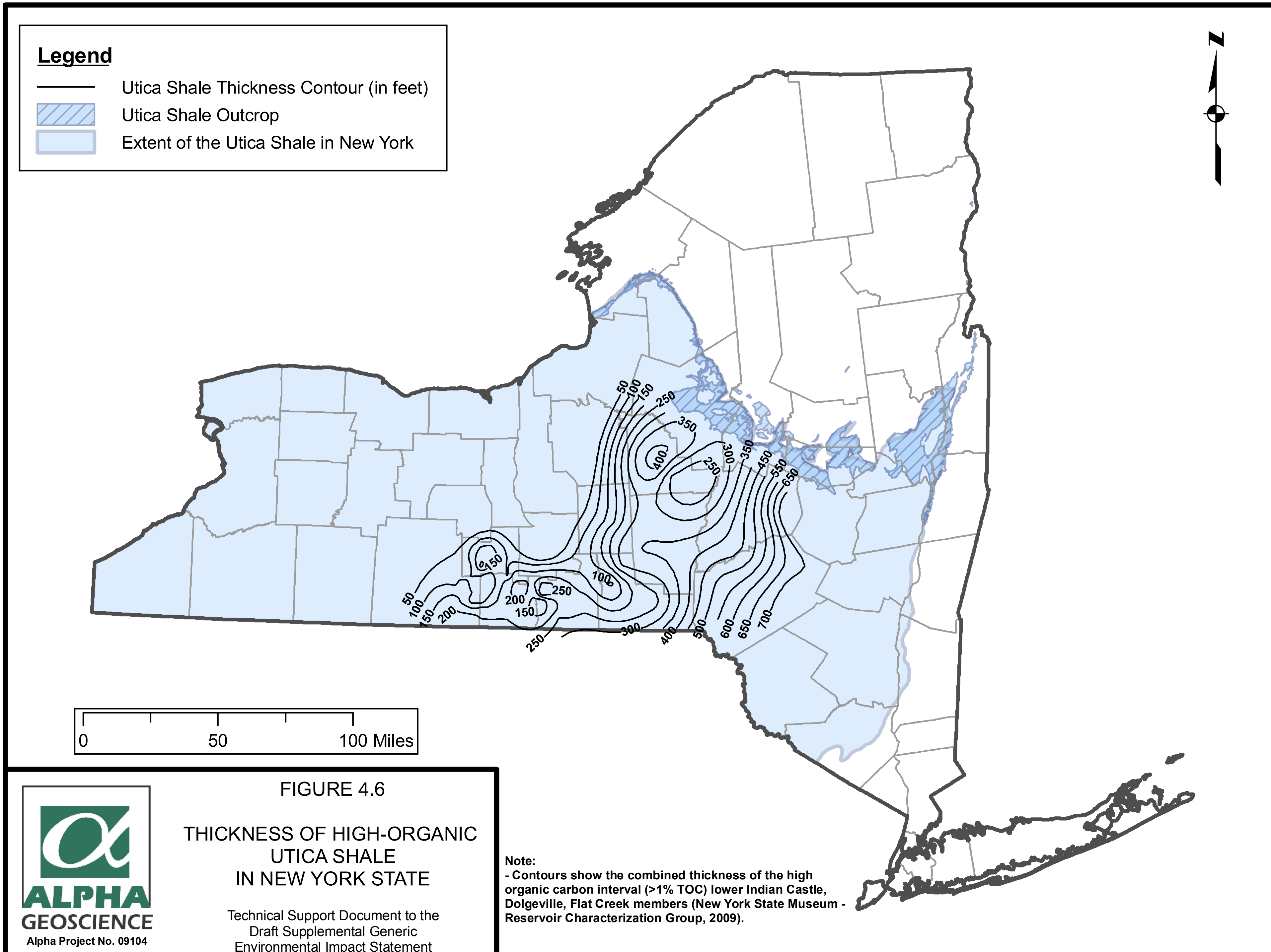


FIGURE 4.6

THICKNESS OF HIGH-ORGANIC UTICA SHALE IN NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

ALPHA GEOSCIENCE

Alpha Project No. 09104

Note:
- Contours show the combined thickness of the high organic carbon interval (>1% TOC) lower Indian Castle, Dolgeville, Flat Creek members (New York State Museum - Reservoir Characterization Group, 2009).

4.3.2 Thermal Maturity and Fairways

Nyahay, et al. (2007) presented an assessment of gas potential in the Marcellus and Utica shales. The assessment was based on an evaluation of geochemical data from core and outcrop samples using methods applied to other shale gas plays, such as the Barnett Shale in Texas. A gas production "fairway", which is a portion of the shale most likely to produce gas based on the evaluation, was presented. Based on the available, limited data, Nyahay et al. (2007) concluded that most of the Utica Shale is supermature and that the Utica Shale fairway is best outlined by the Flat Creek Member where the TOC and thickness are greatest. This area extends eastward from a northeast-southwest line connecting Montgomery to Steuben Counties (Figure 4.7). The fairway shown on Figure 4.7 correlates approximately with the area where the organic-rich portion of the Utica Shale is greater than 100 feet thick shown on Figure 4.6.[19] The fairway is that portion of the formation that has the potential to produce gas based on specific geologic and geochemical criteria; however, other factors, such as formation depth, make only portions of the fairway favorable for drilling. Operators consider a variety of these factors, besides the extent of the fairway, when making a decision on where to drill for natural gas.

The results of the 2007 evaluation are consistent with an earlier report by Weary et al. (2000) that presented an evaluation of thermal maturity based on patterns of thermal alteration of conodont microfossils across New York State. The data presented show that the thermal maturity of much of the Utica Shale in New York is within the dry natural gas generation and preservation range and generally increases from northwest to southeast.

4.3.3 Potential for Gas Production

The Utica Shale historically has been considered the source rock for the more permeable conventional gas resources. Fresh samples containing residual kerogen and other petroleum residuals reportedly have been ignited and can produce an oily sheen when placed in water.[20] Significant gas shows have been reported while drilling through the Utica Shale in eastern and central New York.[21]

---

[19] Alpha, 2009

[20] Alpha, 2009

[21] Alpha, 2009

No Utica Shale gas production was reported to DEC in 2009. Vertical test wells completed in the Utica in the St. Lawrence Lowlands of Quebec have produced up to one million cubic feet per day (MMcf/d) of natural gas, and horizontal test wells are planned for 2009 (June, 2009).

4.4 Marcellus Formation

The Marcellus Formation is a Middle Devonian-aged member of the Hamilton Group that extends across most of the Appalachian Plateau from New York south to Tennessee. The Marcellus Formation consists of black and dark gray shales, siltstones, and limestones. The Marcellus Formation lies between the Onondaga limestone and the overlying Stafford-Mottville limestones of the Skaneateles Formation[22] and ranges in thickness from less than 25 feet in Cattaraugus County to over 1,800 feet along the Catskill front.[23] The informal name "Marcellus Shale" is used interchangeably with the formal name "Marcellus Formation." The discussion contained herein uses the name Marcellus Shale to refer to the black shale in the lower part of the Hamilton Group.

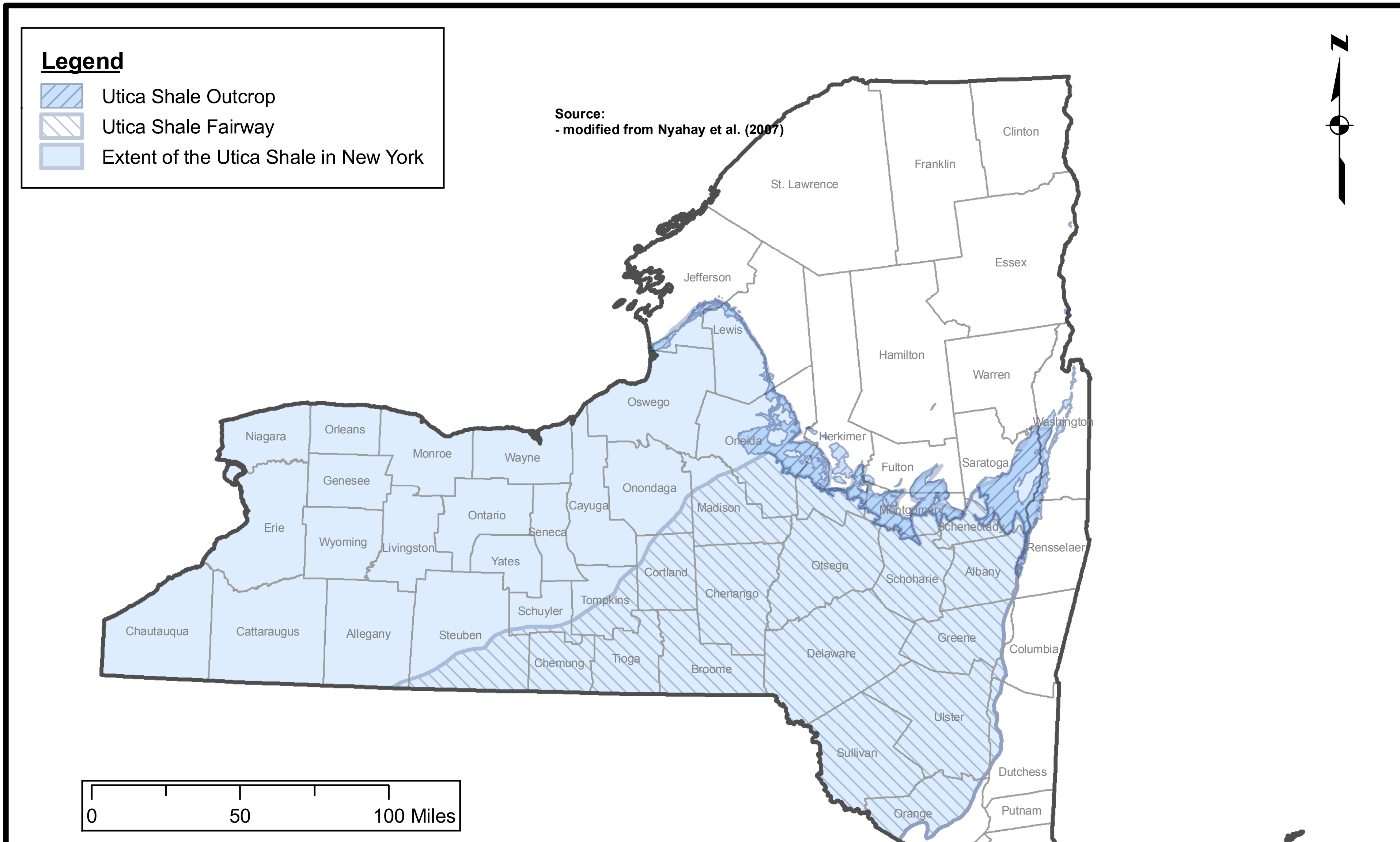
The Marcellus Shale covers an area of approximately 18,700 square miles in New York (Figure 4.8), is bounded approximately by US Route 20 to the north and interstate 87 and the Hudson River to the east, and extends to the Pennsylvania border. The Marcellus is exposed in outcrops to the north and east and reaches depths of more than 5,000 feet in the southern tier (Figure 4.8).

The Marcellus Shale in New York State consists of three primary members[24]. The oldest (lower-most) member of the Marcellus is the Union Springs Shale which is laterally continuous with the Bakoven Shale in the eastern part of the state. The Union Springs (and Bakoven Shale) are bounded below by the Onondaga and above by the Cherry Valley Limestone in the west and the correlative Stony Hollow Member in the East. The upper-most member of the Marcellus Shale is the Oatka Creek Shale (west) and the correlative Cardiff-Chittenango Shales (east). The members of primary interest with respect to gas production are the Union Springs and lower-most portions

[22] Alpha, 2009

[23] Alpha, 2009

[24] Alpha, 2009



ALPHA GEOSCIENCE
Alpha Project No. 09104

FIGURE 4.7

UTICA SHALE FAIRWAY
IN NEW YORK STATE

Technical Support Document to the
Draft Supplemental Generic
Environmental Impact Statement

of the Oatka Creek Shale.[25] The cumulative thickness of the organic-rich layers ranges from less than 25 feet in western New York to over 300 feet in the east (Figure 4.9).

Gamma ray logs indicate that the Marcellus Shale has a slightly radioactive signature on gamma ray geophysical logs, consistent with typical black shales. Concentrations of uranium ranging from 5 to 100 parts per million have been reported in Devonian gas shales.[26]

4.4.1 Total Organic Carbon

Figure 4.10 shows the aerial distribution of total organic carbon (TOC) in the Marcellus Shale based on the analysis of drill cuttings sample data.[27] TOC generally ranges between 2.5 and 5.5 percent and is greatest in the central portion of the state. Ranges of TOC values in the Marcellus were compiled and reported between 3 to 12%[28] and 1 to 10.1%.[29]

4.4.2 Thermal Maturity and Fairways

Vitrinite reflectance is a measure of the maturity of organic matter in rock with respect to whether it has produced hydrocarbons and is reported in percent reflection (%Ro). Values of 1.5 to 3.0% Ro are considered to correspond to the "gas window," though the upper value of the window can vary depending on formation and kerogen type characteristics.

VanTyne (1993) presented vitrinite reflection data from nine wells in the Marcellus Shale in Western New York. The values ranged from 1.18 % Ro to 1.65 % Ro, with an average of 1.39 %Ro. The vitrinite reflectance values generally increase eastward. Nyahay et al (2007) and Smith & Leone (2009) presented vitrinite reflectance data for the Marcellus Shale in New York (Figure 4.11) based on samples compiled by the New York State Museum Reservoir Characterization Group. The values ranged from less than 1.5 % Ro in western New York to over 3 % Ro in eastern New York.

---

[25] Alpha, 2009

[26] Alpha, 2009

[27] Alpha, 2009

[28] Alpha, 2009

[29] Alpha, 2009

Nyahay et al. (2007) presented an assessment of gas potential in the Marcellus Shale that was based on an evaluation of geochemical data from rock core and outcrop samples using methods applied to other shale gas plays, such as the Barnett Shale in Texas. The gas productive fairway was identified based on the evaluation and represents the portion of the Marcellus Shale most likely to produce gas. The Marcellus fairway is similar to the Utica Shale fairway and is shown on Figure 4.12. The fairway is that portion of the formation that has the potential to produce gas based on specific geologic and geochemical criteria; however, other factors, such as formation depth, make only portions of the fairway favorable for drilling. Operators consider a variety of these factors, besides the extent of the fairway, when making a decision on where to drill for natural gas. Variation in the actual production is evidenced by Marcellus Shale wells outside the fairway that have produced gas and wells within the fairway that have been reported dry.

4.4.3 Potential for Gas Production

Gas has been produced from the Marcellus since 1880 when the first well was completed in the Naples field in Ontario County. The Naples field produced 32 MMcf during its productive life and nearly all shale gas discoveries in New York since then have been in the Marcellus Shale.[30] All gas wells completed in the Marcellus Shale to date are vertical wells.[31]

The NYSDEC's summary production database includes reported natural gas production for the years 1967 through 1999. Approximately 544 MMcf of gas was produced from wells completed in the Marcellus Shale during this period.[32] In 2008, the most recent reporting year available, a total of 64.1 MMcf of gas was produced from 15 Marcellus Shale wells in Livingston, Steuben, Schuyler, Chemung, and Allegany Counties.

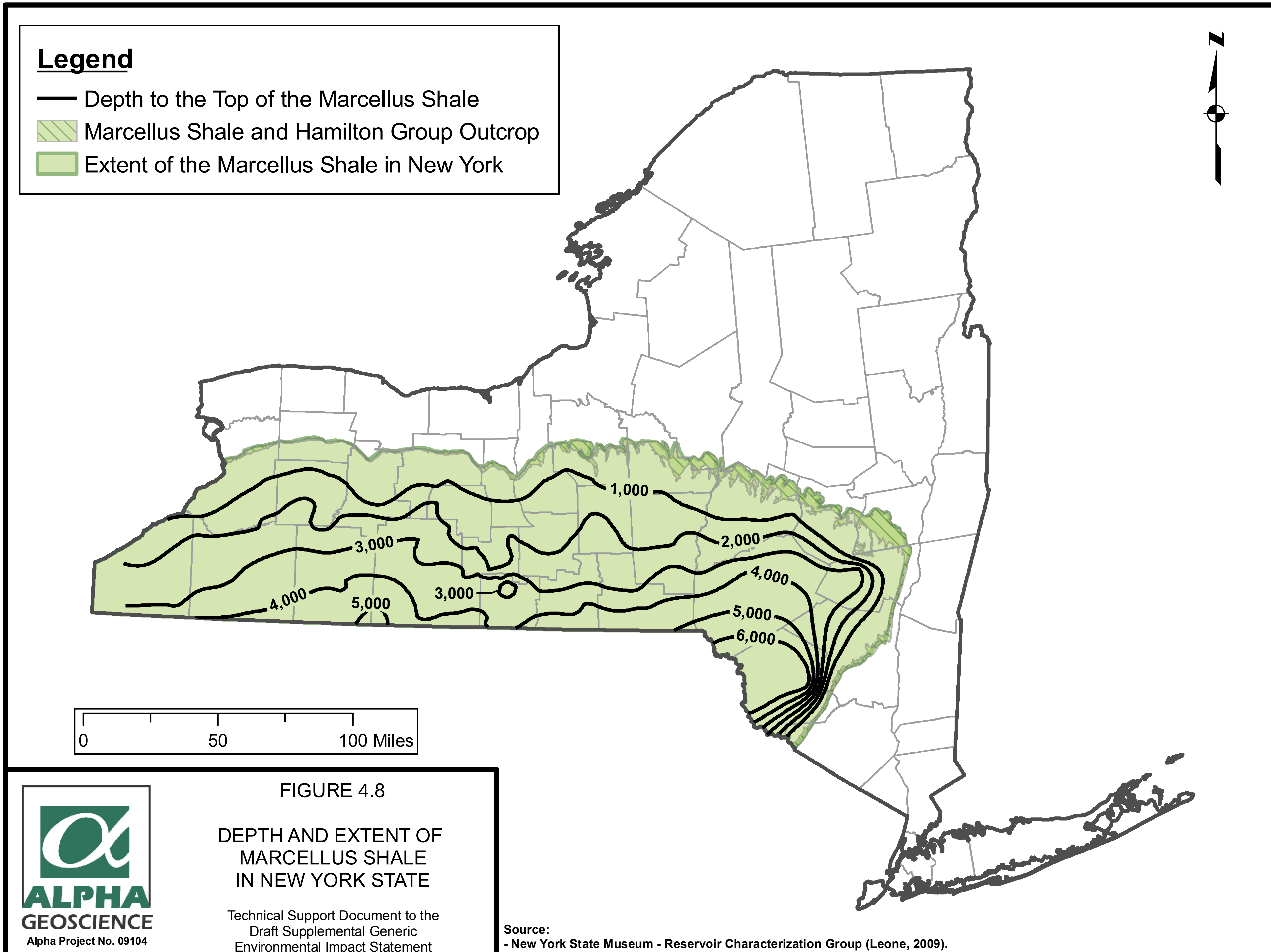
Volumes of in-place natural gas resources have been estimated for the entire Appalachian Basin. Charpentier et al. (1982) estimated a total in-place resource of 844.2 trillion cubic feet (tcf) in all Devonian shales, which includes the Marcellus Shale. Approximately 164.1 tcf, or 19%, of the total is from Devonian shales in New York State. NYSERDA estimates that approximately 15% of the total Devonian shale gas resource of the Appalachian Basin lies beneath New York State.

---

[30] Alpha, 2009

[31] Alpha, 2009

[32] Alpha, 2009



ALPHA GEOSCIENCE

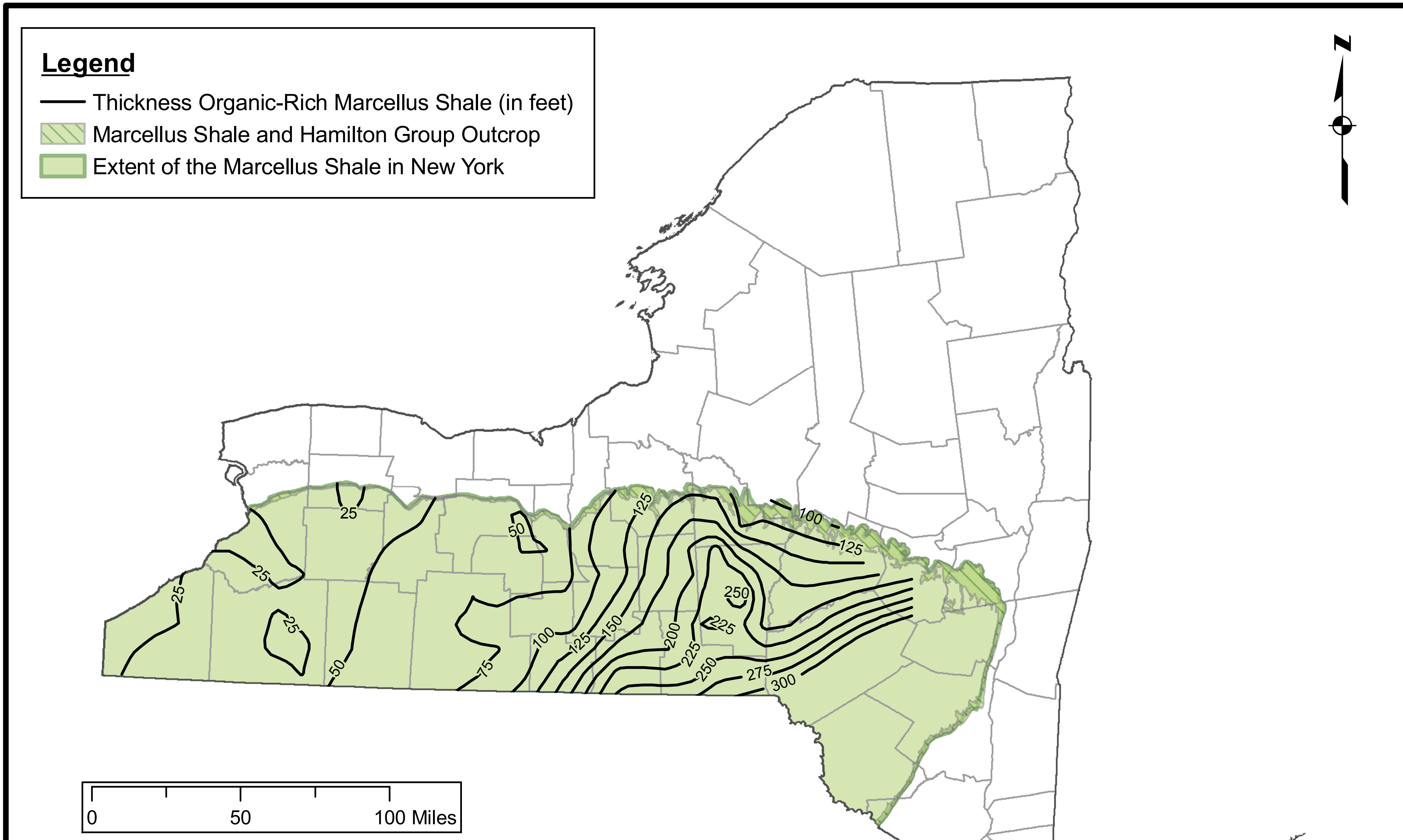
Alpha Project No. 09104

FIGURE 4.8

DEPTH AND EXTENT OF MARCELLUS SHALE IN NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

Source:
- New York State Museum - Reservoir Characterization Group (Leone, 2009).



ALPHA GEOSCIENCE

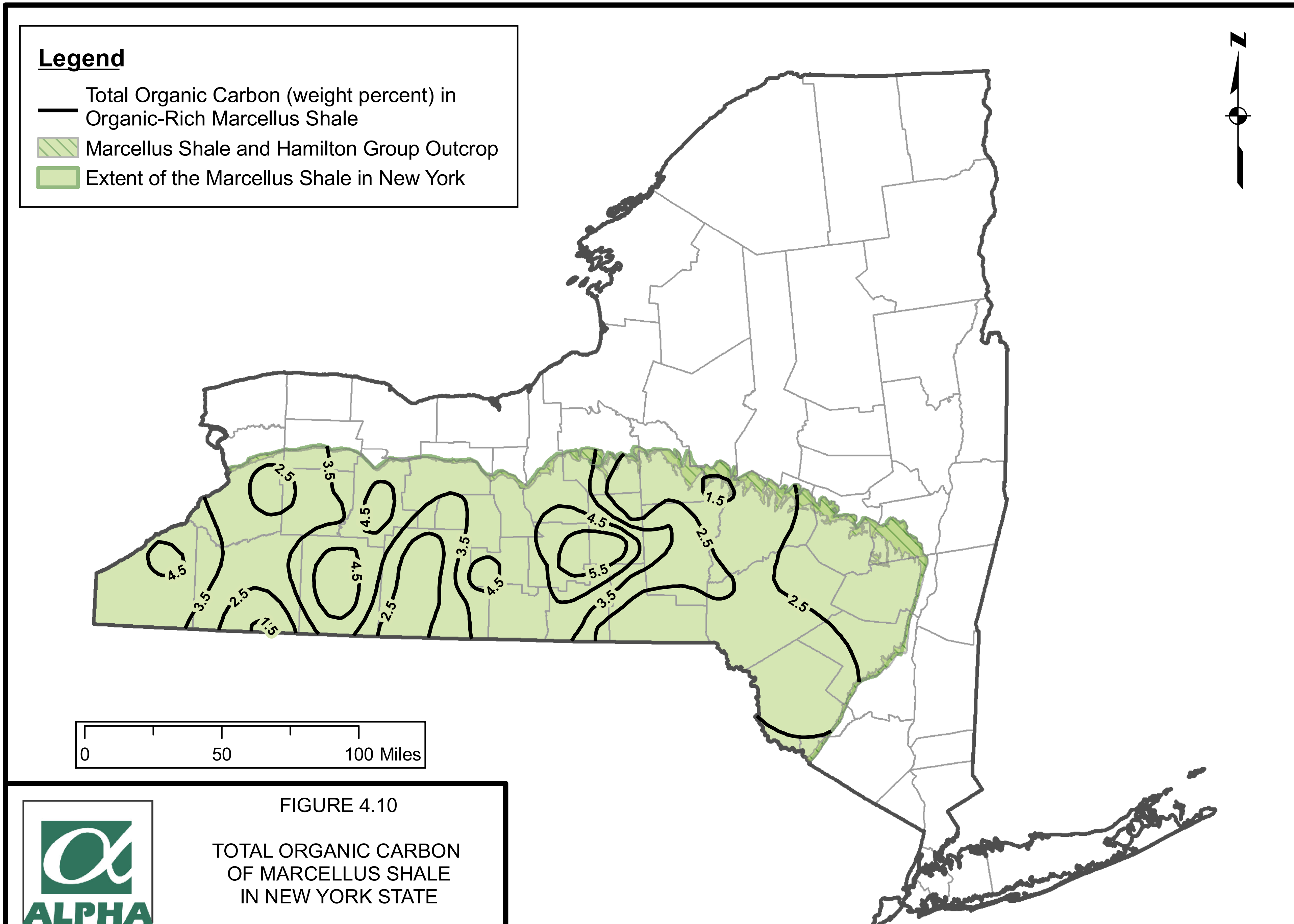
Alpha Project No. 09104

FIGURE 4.9

MARCELLUS SHALE THICKNESS
IN NEW YORK STATE

Technical Support Document to the
Draft Supplemental Generic
Environmental Impact Statement

Notes:
- Source: New York State Museum - Reservoir Characterization Group (Leone, 2009)
- Organic-rich Marcellus includes Union Springs and Oatka Creek Members and lateral equivalents.



ALPHA GEOSCIENCE

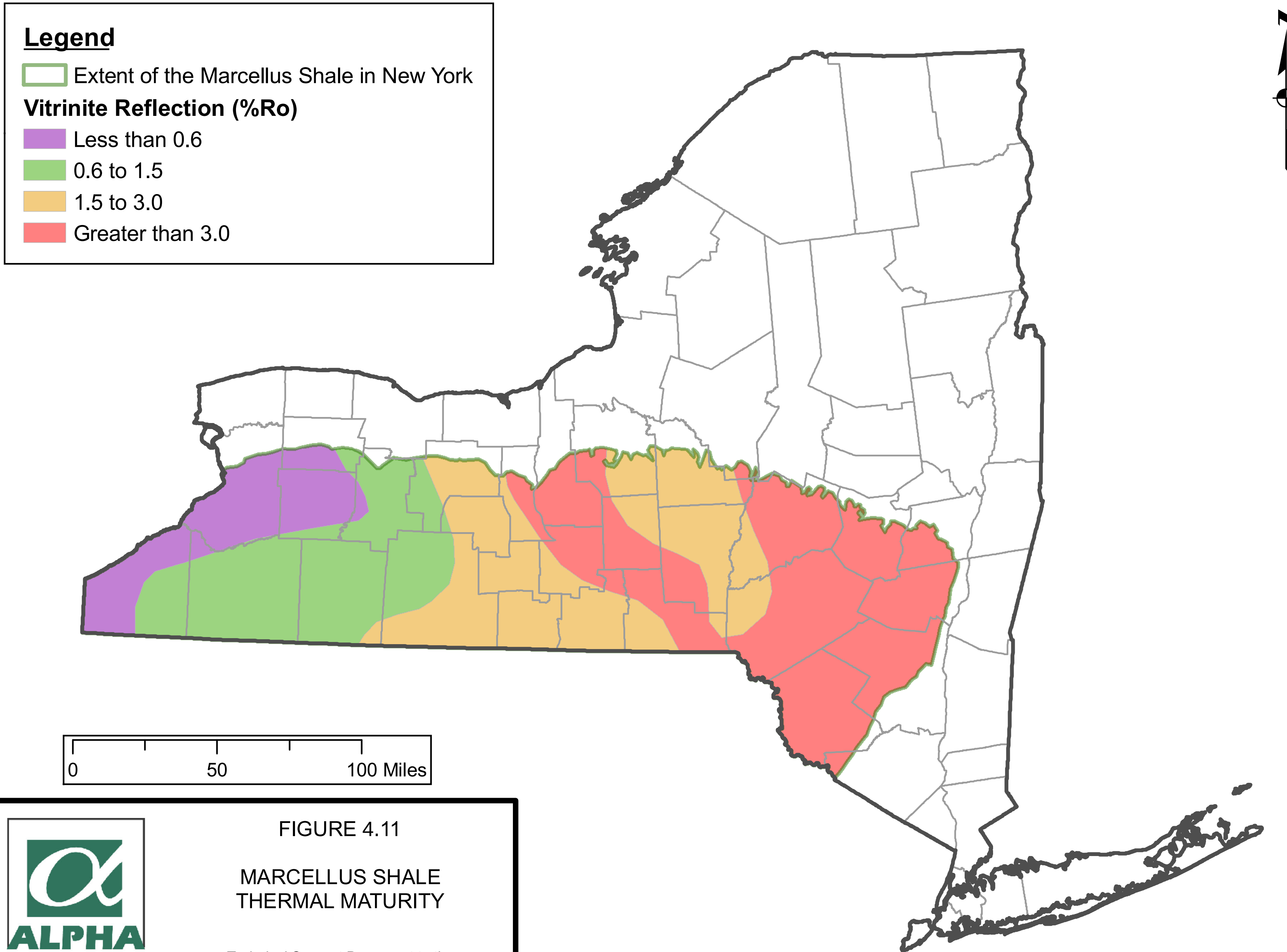
Alpha Project No. 09104

FIGURE 4.10

TOTAL ORGANIC CARBON OF MARCELLUS SHALE IN NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

Source:
- Modified from New York State Museum - Reservoir Characterization Group (Leone, 2009).



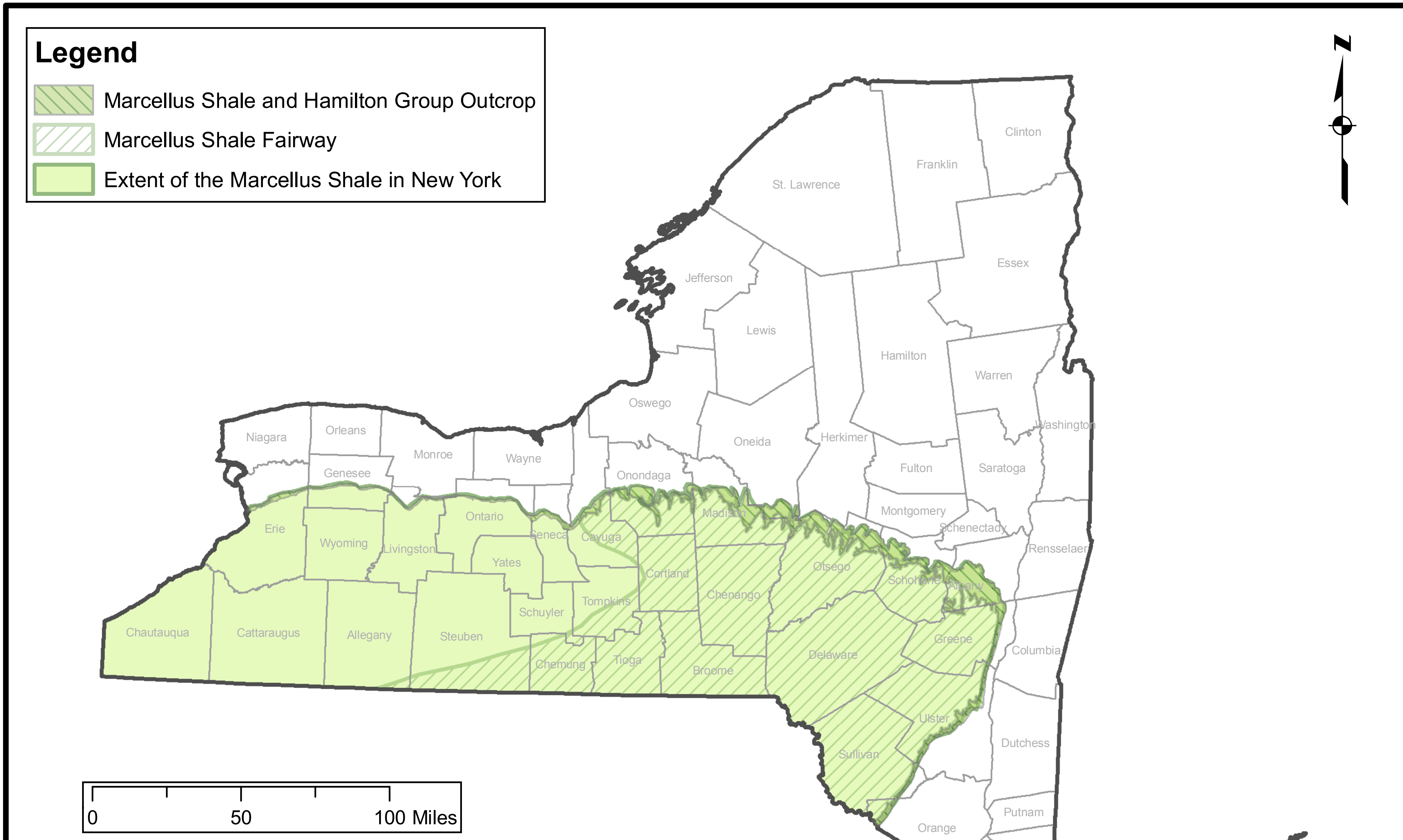
ALPHA GEOSCIENCE
Alpha Project No. 09104

FIGURE 4.11

MARCELLUS SHALE
THERMAL MATURITY

Technical Support Document to the
Draft Supplemental Generic
Environmental Impact Statement

Source:
- Modified from Smith & Leone (2009).



ALPHA GEOSCIENCE
Alpha Project No. 09104

FIGURE 4.12

MARCELLUS SHALE FAIRWAY
IN NEW YORK STATE

Technical Support Document to the
Draft Supplemental Generic
Environmental Impact Statement

Source:
- US Geological Survey, Central Energy Resources Team (2002)
- New York State Museum - Reservoir Characterization Group
- Nyahay et al. (2007)

Engelder and Lash (2008) recently estimated an in-place resource of 500 tcf in the Marcellus shale beneath New York, Pennsylvania, West Virginia, and Maryland. Other natural gas plays, such as the Barnett Shale, typically produce more than 10% of the in-place resource; therefore, the potential resource over time from Marcellus Shale in the four state region including New York is approximately 50 tcf. A 15% to 19% portion of 50 tcf translates to a potential resource of approximately 7.5 to 9.5 tcf of gas over time in the Marcellus Shale in New York State.

4.5 Seismicity in New York State

4.5.1 Background

The term "earthquake" is used to describe any event that is the result of a sudden release of energy in the earth's crust that generates seismic waves. Many earthquakes are too minor to be detected without sensitive equipment. Hydraulic fracturing releases energy during the fracturing process at a level substantially below that of small, naturally occurring, earthquakes. Large earthquakes result in ground shaking and sometimes displacing the ground surface. Earthquakes are caused mainly by movement along geological faults, but also may result from volcanic activity and landslides. An earthquake's point of origin is called its focus or hypocenter. The term epicenter refers to the point at the ground surface directly above the hypocenter.

Induced seismicity refers to seismic events triggered by human activity such as mine blasts, nuclear experiments, and fluid injection, including hydraulic fracturing.[33] Induced seismic waves (seismic refraction and seismic reflection) also are a common tool used in geophysical surveys for geologic exploration. The surveys are used to investigate the subsurface for a wide range of purposes including landfill siting; foundations for roads, bridges, dams and buildings; oil and gas exploration; mineral prospecting; and building foundations. Methods of inducing seismic waves range from manually striking the ground with weight to setting off controlled blasts.

Geologic faults are fractures along which rocks on opposing sides have been displaced relative to each other. The amount of displacement may be small (centimeters) or large (kilometers). Geologic faults are prevalent and typically are active along tectonic plate boundaries. One of the most well known plate boundary faults is the San Andreas fault zone in California. Faults also

[33] Alpha, 2009

occur across the rest of the U.S., including mid-continent and non-plate boundary areas, such as the New Madrid fault zone in the Mississippi Valley, or the Ramapo fault system in southeastern New York and eastern Pennsylvania.

Figure 4.13 shows the locations of faults and other structures that may indicate the presence of buried faults in New York State.[34] There is a high concentration of structures in eastern New York along the Taconic Mountains and the Champlain Valley that resulted from the intense thrusting and continental collisions during the Taconic and Alleghenian orogenies that occurred 350 to 500 million years ago.[35] There also is a high concentration of faults along the Hudson River Valley. More recent faults in northern New York were formed as a result of the uplift of the Adirondack Mountains approximately 5 to 50 million years ago.

4.5.2 Seismic Risk Zones

The USGS Earthquake Hazard Program has produced the National Hazard Maps showing the distribution of earthquake shaking levels that have a certain probability of occurring in the United States. The maps were created by incorporating geologic, geodetic and historic seismic data, and information on earthquake rates and associated ground shaking. These maps are used by others to develop and update building codes and to establish construction requirements for public safety.

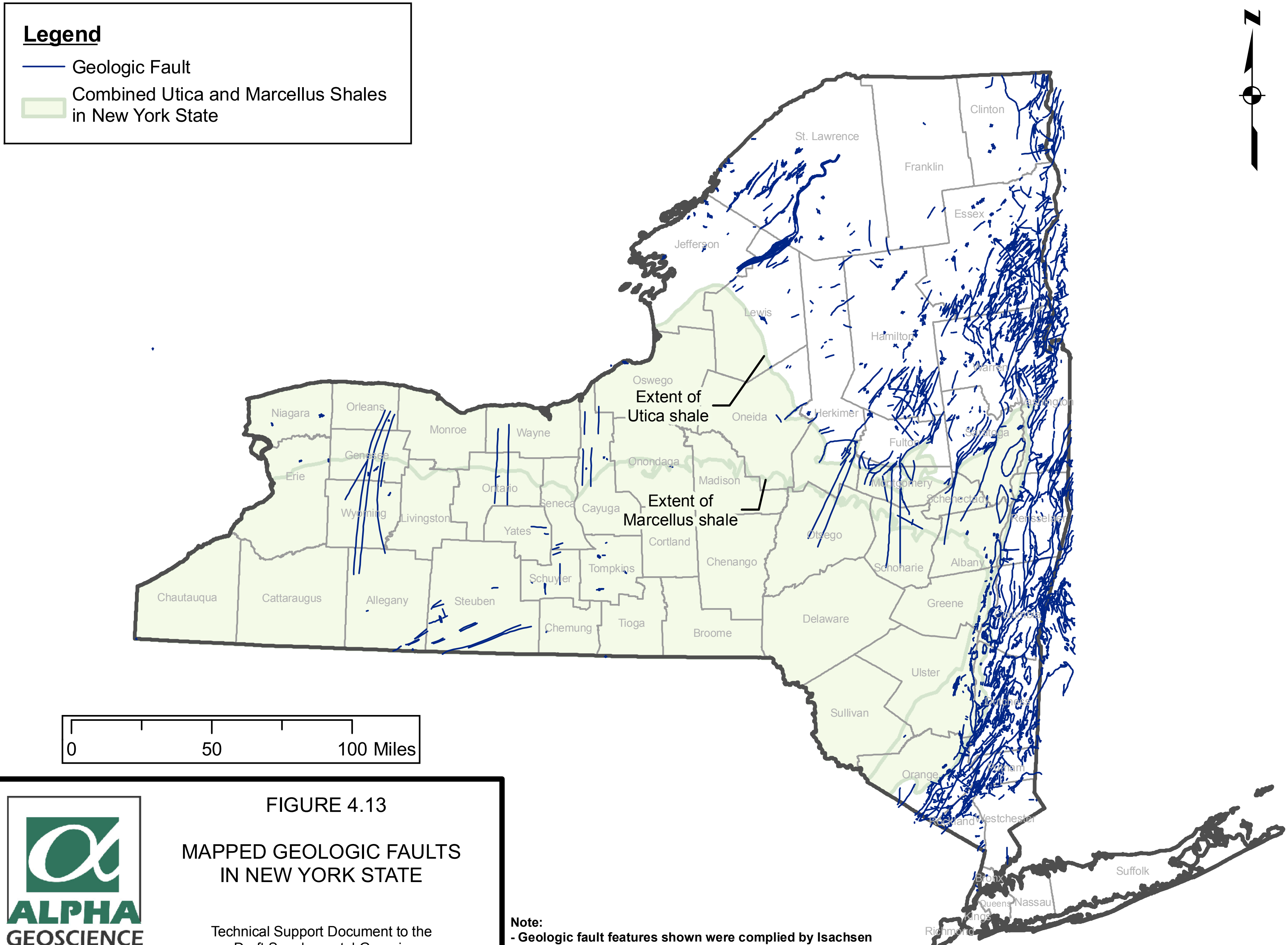
New York State is not associated with a major fault along a tectonic boundary like the San Andreas, but seismic events are common in New York. Figure 4.14 shows the seismic hazard map for New York State.[36] The map shows levels of horizontal shaking, in terms of percent of the gravitational acceleration constant (%g) that is associated with a 2 in 100 (2%) probability of occurring during a 50 year period[37]. Much of the Marcellus and Utica Shales underlie portions of the state with the lowest seismic hazard class rating in New York (2 % probability of exceeding 4 to 8 %g in a fifty year period). The areas around New York City, Buffalo, and northern-most

[34] Alpha, 2009

[35] Alpha, 2009

[36] Alpha, 2009

[37] Alpha, 2009



ALPHA GEOSCIENCE

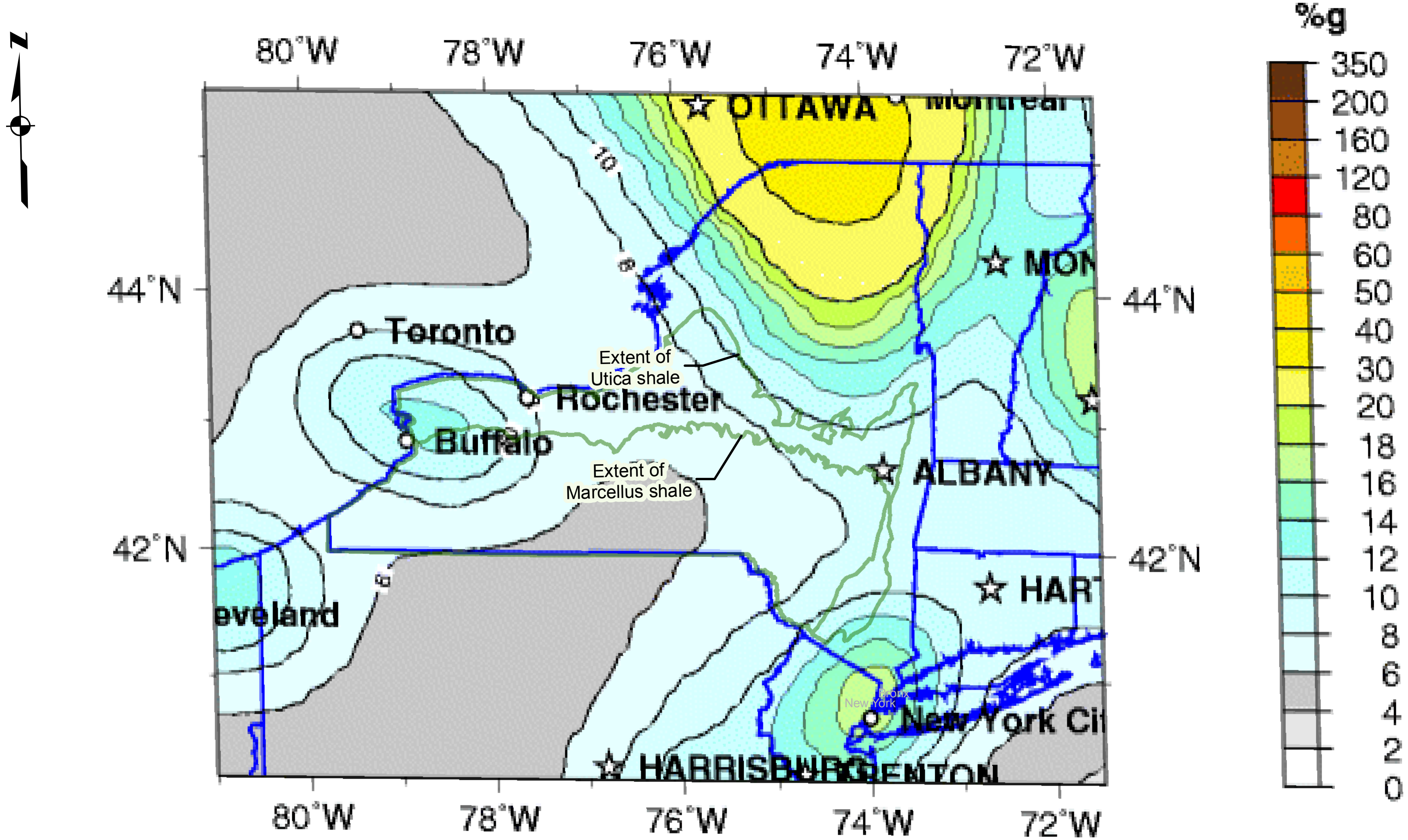
Alpha Project No. 09104

FIGURE 4.13

MAPPED GEOLOGIC FAULTS IN NEW YORK STATE

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

Note:
- Geologic fault features shown were complied by Isachsen and McKendree (1977) and exclude brittle structures identified as drillholes, topographic, and tonal linear features.



ALPHA GEOSCIENCE

Alpha Project No. 09104

FIGURE 4.14

NEW YORK STATE
SEISMIC HAZARD MAP

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

Notes:
- Map shows peak acceleration (%g) with 2% probability of exceedence in 50 years.
- Source - USGS National Seismic Hazard Maps (2008).

New York have a moderate to high seismic hazard class ratings (2% probability of exceeding 12 to 40 %g in a fifty year period).

4.5.3 Seismic Damage – Modified Mercalli Intensity Scale

There are several scales by which the magnitude and the intensity of a seismic event are reported. The Richter magnitude scale was developed in 1935 to measure of the amount of energy released during an earthquake. The moment magnitude scale (MMS) was developed in the 1970s to address shortcomings of the Richter scale, which does not accurately calculate the magnitude of earthquakes that are large (greater than 7) or distant (measured at a distance greater than 250 miles away). Both scales report approximately the same magnitude for earthquakes

less than a magnitude of 7 and both scales are logarithmic-based; therefore, an increase of one magnitude unit corresponds to a 1,000-fold increase in the amount of energy released.

The MMS measures the size of a seismic event based on the amount of energy released. Moment is a representative measure of seismic strength for all sizes of events and is independent of recording instrumentation or location. Unlike the Richter scale, the MMS has no limits to the possible measurable magnitudes, and the MMS relates the moments to the Richter scale for continuity. The MMS also can represent microseisms (very small seismicity) with negative numbers.

The Modified Mercalli (MM) Intensity Scale was developed in 1931 to report the intensity of an earthquake. The Mercalli scale is an arbitrary ranking based on observed effects and not on a mathematical formula. This scale uses a series of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, as summarized on Table 4.1. Table 4.1 compares the MM intensity scale to magnitudes of the MMS, based on typical events as measured near the epicenter of a seismic event. There is no direct conversion between the intensity and magnitude scales because earthquakes of similar magnitudes can cause varying levels of observed intensities depending on factors such location, rock type, and depth.

4.5.4 Seismic Events

Table 4.2 summarizes the recorded seismic events in New York State by county between December 1970 and July 2009.[38] There were a total of 813 seismic events recorded in New York State during that period. The magnitudes of 24 of the 813 events were equal to or greater than 3.0. Magnitude 3 or lower earthquakes are mostly imperceptible and are usually detectable only with sensitive equipment. The largest seismic event during the period 1970 through 2009 is a 5.3 magnitude earthquake that occurred on April 20, 2002, near Plattsburg, Clinton County.[39] Damaging earthquakes have been recorded since Europeans settled New York in the 1600s. The largest earthquake ever measured and recorded in New York State was a magnitude 5.8 event that occurred on September 5, 1944, near Massena, New York.[40]

---

[38] Alpha, 2009

[39] Alpha, 2009

[40] Alpha, 2009

Table 4.1
Modified Mercalli Intensity Scale

Modified Mercalli Intensity	Description	Effects	Typical Maximum Moment Magnitude
I	Instrumental	Not felt except by a very few under especially favorable conditions.	1.0 to 3.0
II	Feeble	Felt only by a few persons at rest, especially on upper floors of buildings.	3.0 to 3.9
III	Slight	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.	
IV	Moderate	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.	4.0 to 4.9
V	Rather Strong	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.	5.0 to 5.9
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.	
VIII	Destructive	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.	6.0 to 6.9
IX	Ruinous	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.	
X	Disastrous	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.	7.0 and higher
XI	Very Disastrous	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.	
XII	Catastrophic	Damage total. Lines of sight and level are distorted. Objects thrown into the air.	

The above table compares the Modified Mercalli intensity scale and moment magnitude scales that typically observed near the epicenter of a seismic event.

Source: USGS Earthquake Hazard Program (http://earthquake.usgs.gov/learning/topics/mag_vs_int.php)

Table 4.2
Summary of Seismic Events in New York State
December 1970 through July 2009

County	Magnitude					Total
	< 2.0	2.0 to 2.9	3.0 to 3.9	4.0 to 4.9	5.0 to 5.3	
Counties Overlying Utica and Marcellus Shales						
Albany	27	20	3	0	0	50
Allegany	0	0	0	0	0	0
Broome	0	0	0	0	0	0
Cattaraugus	0	0	0	0	0	0
Cayuga	0	0	0	0	0	0
Chautauqua	0	0	0	0	0	0
Chemung	0	0	0	0	0	0
Chenango	0	0	0	0	0	0
Cortland	0	0	0	0	0	0
Delaware	1	2	0	0	0	3
Erie	7	5	0	0	0	12
Genesee	3	5	0	0	0	8
Greene	2	1	0	0	0	3
Livingston	1	5	1	0	0	7
Madison	0	0	0	0	0	0
Montgomery	1	2	0	0	0	3
Niagara	7	3	0	0	0	10
Onondaga	0	0	0	0	0	0
Ontario	1	1	0	0	0	2
Otsego	0	0	0	0	0	0
Schoharie	2	4	0	1	0	7
Schuyler	0	0	0	0	0	0
Seneca	0	0	0	0	0	0
Steuben	2	0	1	0	0	3
Sullivan	0	0	0	0	0	0
Tioga	0	0	0	0	0	0
Tompkins	0	0	0	0	0	0
Wyoming	8	5	0	0	0	13
Yates	1	0	0	0	0	1
Subtotal	*63*	*53*	*5*	*1*	*0*	*122*
Counties Overlying Utica Shale						
Fulton	1	2	1	0	0	4
Herkimer	4	3	0	0	0	7
Jefferson	5	3	0	0	0	8
Lewis	3	0	2	0	0	5
Monroe	1	0	0	0	0	1
Oneida	3	4	0	0	0	7
Orange	14	5	0	0	0	19
Orleans	0	0	0	0	0	0
Oswego	2	0	0	0	0	2
Saratoga	1	2	0	0	0	3
Schenectady	1	1	0	0	0	2
Wayne	0	0	0	0	0	0
Subtotal	*35*	*20*	*3*	*0*	*0*	*58*

Table Continuation

Table 4.2
Summary of Seismic Events in New York State
December 1970 through July 2009

County	Magnitude					Total
	< 2.0	2.0 to 2.9	3.0 to 3.9	4.0 to 4.9	5.0 to 5.3	
Counties Not Overlying Utica or Marcellus Shales						
Bronx	0	0	0	0	0	0
Clinton	60	30	5	0	1	96
Columbia	0	0	0	0	0	0
Dutchess	6	4	2	0	0	12
Essex	88	64	4	1	1	158
Franklin	40	19	3	0	0	62
Hamilton	53	10	0	0	0	63
Kings	0	0	0	0	0	0
Nassau	1	0	0	0	0	1
New York	3	2	0	0	0	5
Putnam	4	2	0	0	0	6
Queens	0	0	0	0	0	0
Rensselaer	1	0	0	0	0	1
Richmond	0	0	0	0	0	0
Rockland	15	3	0	0	0	18
St. Lawrence	84	29	0	0	0	113
Suffolk	0	0	0	0	0	0
Ulster	3	0	0	0	0	3
Warren	11	5	1	0	0	17
Washington	1	3	0	0	0	4
Westchester	61	11	1	1	0	74
Subtotal	*431*	*182*	*16*	*2*	*2*	*633*
New York State Total	***529***	***255***	***24***	***3***	***2***	***813***

Notes:
- Seismic events recorded December 13, 1970 through July 28, 2009.
- Lamont-Doherty Cooperative Seismographic Network, 2009

Figure 4.15 shows the distribution of recorded seismic events in New York State. The majority of the events occur in the Adirondack Mountains and along the New York-Quebec border. A total of 180 of the 813 seismic events shown on Table 4.2 and Figure 4.15 during a period of 39 years (1970–2009) occurred in the area of New York that is underlain by the Marcellus and/or the Utica shales. The magnitude of 171 of the 180 events was less than 3.0. The distribution of seismic events on Figure 4.15 is consistent with the distribution of fault structures (Figure 4.13) and the seismic hazard risk map (Figure 4.14).

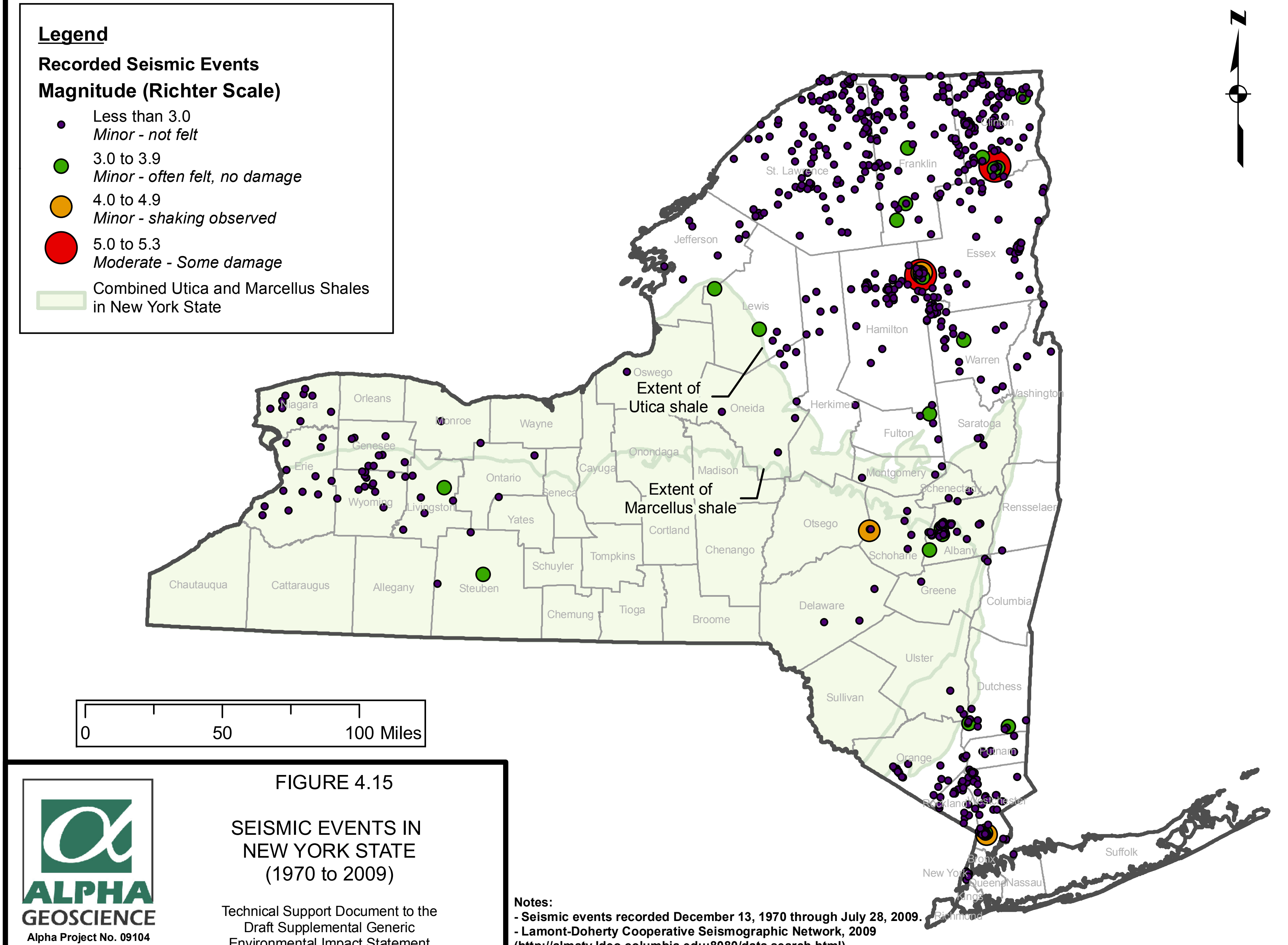
Some of the seismic events shown on Figure 4.15 are known or suspected to be triggered by human activity. The 3.5 magnitude event recorded on March 12, 1994, in Livingston County is suspected to be the result of the collapse associated with the Retsof salt mine failure in Cuylerville, New York.[41] The 3.2 magnitude event recorded on February 3, 2001, was coincident with, and is suspected to have been triggered by, test injections for brine disposal at the New Avoca Natural Gas Storage (NANGS) facility in Steuben County. The cause of the event likely was the result of an extended period of fluid injection near an existing fault[42] for the purposes of siting a deep injection well. The injection for the NANGS project occurred numerous times with injection periods lasting 6 to 28 days and is substantially different than the short-duration, controlled injection used for hydraulic fracturing.

One additional incident suspected to be related to human activity occurred in late 1971 at Texas Brine Corporation's system of wells used for solution mining of brine near Dale, Wyoming County, New York (i.e., the Dale Brine Field). The well system consisted of a central, high pressure injection well (No. 11) and four peripheral brine recovery wells. The central injection well was hydraulically fractured in July 1971 without incident.

The well system was located in the immediate vicinity of the known, mapped, Clarendon-Linden fault zone which is oriented north-south, and extends south of Lake Ontario in Orleans, Genesee, Wyoming, and the northern end of Allegany Counties, New York. The Clarendon-Linden fault zone is not of the same magnitude, scale, or character as the plate boundary fault systems, but

[41] Alpha, 2009

[42] Alpha, 2009



ALPHA GEOSCIENCE

Alpha Project No. 09104

FIGURE 4.15

SEISMIC EVENTS IN NEW YORK STATE (1970 to 2009)

Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement

Notes:
- Seismic events recorded December 13, 1970 through July 28, 2009.
- Lamont-Doherty Cooperative Seismographic Network, 2009 (http://almaty.ldeo.columbia.edu:8080/data.search.html)

nonetheless has been the source of relatively small to moderate quakes in western New York (MCEER, 2009; and Fletcher and Sykes, 1977).

Fluids were injected at well No. 11 from August 3 through October 8, and from October 16 through November 9, 1971. Injections were ceased on November 9, 1971 due to an increase in seismic activity in the area of the injection wells. A decrease in seismic activity occurred when the injections ceased. The tremors attributed to the injections reportedly were felt by residents in the immediate area.

Evaluation of the seismic activity associated with the Dale Brine Field was performed and published by researchers from the Lamont-Doherty Geological Observatory (Fletcher and Sykes, 1977). The evaluation concluded that fluids injected during solution mining activity were able to reach the Clarendon-Linden fault and that the increase of pore fluid pressure along the fault caused an increase in seismic activity. The research states that “the largest earthquake … that appears to be associated with the brine field…” was 1.4 in magnitude. In comparison, the magnitude of the largest natural quake along the Clarendon-Linden fault system through 1977 was magnitude 2.7, measured in 1973. Similar solution mining well operations in later years located further from the fault system than the Dale Brine Field wells did not create an increase in seismic activity.

4.5.5 Monitoring Systems in New York

Seismicity in New York is monitored by both the US Geological Survey (USGS) and the Lamont-Doherty Cooperative Seismographic Network (LCSN). The LCSN is part of the USGS’s Advanced National Seismic System (ANSS) which provides current information on seismic events across the country. Other ANSS stations are located in Binghamton and Lake Ozonia, New York. The New York State Museum also operates a seismic monitoring station in the Cultural Education Center in Albany, New York.

As part of the AANS, the LCSN monitors earthquakes that occur primarily in the northeastern United States and coordinates and manages data from 40 seismographic stations in seven states, including Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania, and

Vermont.[43] Member organizations that operate LCSN stations include two secondary schools, two environmental research and education centers, three state geological surveys, a museum dedicated to Earth system history, two public places (Central Park, NYC, and Howe Caverns, Cobleskill), three two-year colleges, and 15 four-year universities.[44]

4.6 Naturally Occurring Radioactive Materials (NORM) in Marcellus Shale

As mentioned above, black shale typically contains trace levels of uranium and gamma ray logs indicate that this is true of the Marcellus Shale. The Marcellus Shale formation is known to contain concentrations of naturally occurring radioactive materials (NORM) such as uranium-238 and radium-226 at higher levels than surrounding rock formations. Normal disturbance of NORM-bearing rock formations by activities such as mining or drilling do not generally pose a threat to workers, the general public or the environment. However, activities that have the potential to concentrate NORM need to come under government scrutiny to ensure adequate protection.

Chapter 5 includes radiological information (sampling results) from Marcellus drill cuttings and production brine samples collected in New York and from Marcellus flowback water analyses provided by operators for wells in Pennsylvania and West Virginia. Chapter 6 includes a discussion of potential impacts associated with radioactivity in the Marcellus Shale. Chapter 7 details mitigation measures, including existing regulatory programs, proposed well permit conditions and proposed future data collection and analysis.

[43] Alpha, 2009

[44] Alpha, 2009