NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

Chapter 4

Geology

Final

Supplemental Generic Environmental Impact Statement

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Chapter 4 - Geology

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Chapter 4 - GEOLOGY

This Chapter supplements and expands upon Chapter 5 of the 1992 GEIS. Sections 4.1 through 4.5 and the accompanying figures and tables were provided in essentially the form presented here by Alpha Environmental, Inc., under contract to NYSERDA to assist the Department with research related to this SGEIS.[62] Alpha's citations are retained for informational purposes, and are listed in the "consultants' references" section of the Bibliography. Section 4.6 discusses how NORM in the 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 Section 5.8 (Hydraulic Fracturing Design), and Appendix 11 (Analysis of Subsurface Fracturing 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 terms "conventional" and "unconventional" are related more to prevailing technology and economics surrounding the development of a given play than to the reservoir rock type from which the oil or natural gas resources are derived. Gas shales (also called "gas-containing shales") are one of a number of reservoir types that are explored for unconventional natural gas, and this group includes such terms as: deep gas; tight gas; coal-bed methane; geopressurized zones; and Arctic and sub-sea hydrates.

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

62 Alpha, 2009.

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 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.[63]

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, such as the Marcellus Shale, 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 are 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

[63] Alpha, 2009, p. 121.

where there is evidence that a significant amount of gas has formed and been preserved from the TOC during thermal maturation.[64]

Oil and gas are stored in isolated pore spaces or fractures and adsorbed on the mineral grains.[65] 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.[66] Porosity values of 1 to 3 percent are reported for Devonian shales in the Appalachian Basin.[67] 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).[68] 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.[69] The presence of naturally occurring radioactive materials (NORM) induces 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 (i.e., fragments of rock) 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.[70]

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[64] Alpha, 2009, p. 122.

[65] Alpha, 2009, p. 122.

[66] Alpha, 2009, p.122.

[67] Alpha, 2009, p.122.

[68] Alpha, 2009, p.122.

[69] Alpha, 2009, p. 122.

[70] Alpha, 2009, p. 123.

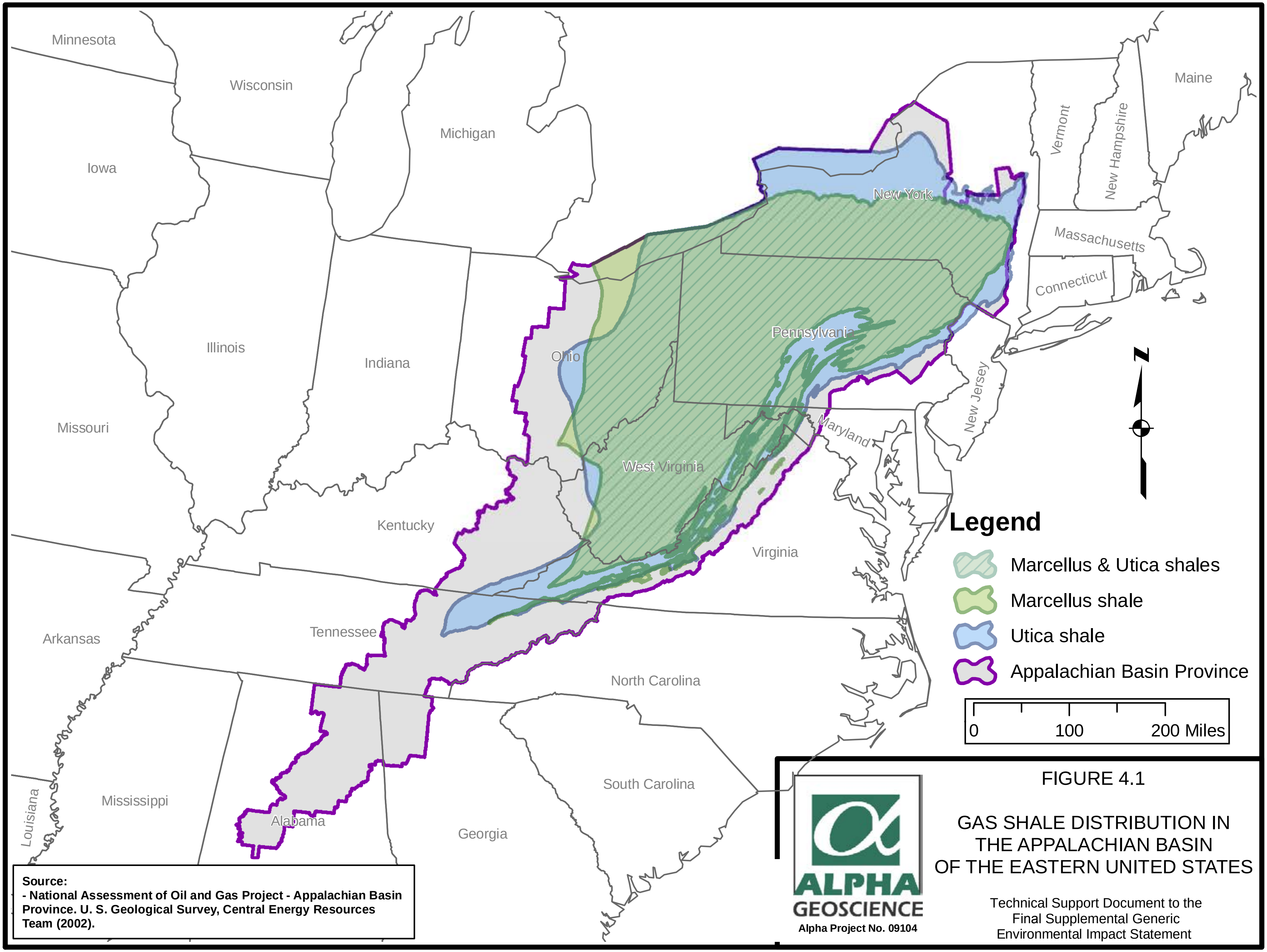
Minnesota
Wisconsin
Michigan
Iowa
Illinois
Indiana
Ohio
Missouri
Kentucky
Arkansas
Tennessee
Mississippi
Louisiana
Alabama
Georgia
South Carolina
North Carolina
Virginia
West Virginia
Maryland
Pennsylvania
New York
New Jersey
Connecticut
Massachusetts
Vermont
New Hampshire
Maine
N
Legend
Marcellus & Utica shales
Marcellus shale
Utica shale
Appalachian Basin Province
0
100
200 Miles
Source:
- National Assessment of Oil and Gas Project - Appalachian Basin Province. U. S. Geological Survey, Central Energy Resources Team (2002).
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FIGURE 4.1
GAS SHALE DISTRIBUTION IN THE APPALACHIAN BASIN OF THE EASTERN UNITED STATES
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The stratigraphic column for southwestern New York State is shown in Figure 4.2 and includes oil and gas producing horizons. This figure was initially developed by Van Tyne and Copley,[71] from the analysis of drilling data in southwestern New York State, and it has been modified several times since then as various authors have cited it in different studies. The version presented as Figure 4.2 can also be found on the Department's website at http://www.dec.ny.gov/energy/33893.html. Figure 4.3 is a generalized cross-section from west to east across the southern tier of New York State and shows the variation in thickness and depth of the different stratigraphic units. This figure was initially developed by the Reservoir Characterization Group of the New York State Museum. It is important to note that the geographic areas represented in Figure 4.2 and Figure 4.3 are not precisely the same, and the figures were originally developed by different authors. For example, the Marcellus Shale is shown in Figure 4.2 as the basal unit of the Hamilton Group, but it appears as a discrete unit below the Hamilton Group in Figure 4.3 to highlight its gas-bearing potential. Similarly, the "Devonian Sandstone and Shale" of Figure 4.3 correlates to the Conewango, Conneaut, Canadaway, West Falls, Sonyea, and Genesee Groups of Upper Devonian age shown in Figure 4.2.

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 other black shale formations (Figure 4.2 and Figure 4.3) in New York that may produce natural gas on a localized basis.[72] 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.

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[71] Van Tyne and Copley, 1983.

[72] Alpha, 2009, p. 123.

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).[73] 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.[74]

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 indicates 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.[75]

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 an argillaceous calcareous mudstone to the east. These two members are time-equivalent and grade laterally toward the west into Trenton limestones.[76] 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.[77] This depth corresponds approximately with the base of the organic-rich section of the Utica Shale.

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[73] Alpha, 2009, p. 124.

[74] Alpha, 2009, p. 124.

[75] Alpha, 2009, p. 124.

[76] Alpha, 2009, p. 124.

[77] Alpha, 2009, p. 124.

Figure 4.2 - Stratigraphic Section of Southwestern New York State

Period		Group	Unit		Lithology
Penn.		Pottsville	Olean		Quartz pebble conglomerate & sandstone, quartz pebble, conglomerate, sandstone & minor shale
Miss.		Pocono	Knapp		
Dev.	Upper	Conewango			Shale & sandstone, scattered conglomerates
Dev.	Upper	Conneaut	Chadakoin		Shale & siltstone, scattered conglomerates
Dev.	Upper	Canadaway	Undifferentiated[1]	O G O G	Shale & siltstone Minor sandstone
Dev.	Upper	Canadaway	Perrysburg[2]	O G O G	Shale & siltstone Minor sandstone
Dev.	Upper	West Falls	Java Nunda Rhinestreet	 G	Shale & siltstone Argillaceous limestone
Dev.	Upper	Sonyea	Middlesex	G	Shale & siltstone
Dev.	Upper	Genesee			Shale with minor siltstone & limestone
Dev.	Middle		Tully	G	Limestone with minor siltstone & sandstone
Dev.	Middle	Hamilton	Moscow Ludlowville Skaneateles Marcellus	 G	Shale with minor sandstone & conglomerate
Dev.	Middle		Onondaga	O G	Limestone
Dev.	Lower	Tristates	Oriskany	G	Sandstone
Dev.	Lower	Helderberg	Manlius Rondout		Limestone & dolostone
Sil.	Upper		Akron	O G	Dolostone
Sil.	Upper	Salina	Camillus Syracuse Vernon	S S	Shale, siltstone, anhydrite & halite
Sil.	Upper	Lockport	Lockport	G	Limestone & dolostone
Sil.	Upper	Clinton	Rochester Irondequoit		Shale & sandstone
Sil.	Lower	Clinton	Sodus Reynales Thorold		Limestone & dolostone
Sil.	Lower	Medina	Grimsby Whirlpool	G G	Sandstone & shale Quartz sandstone
Ord.	Upper		Queenston Oswego Lorraine Utica	G G	Shale & siltstone with minor sandstone
Ord.	Middle	Trenton - Black River	Trenton Black River	G	Limestone and minor dolostone
Ord.	Lower	Beekmantown	Tribes Hill Chuctanunda		Limestone & dolostone
Camb.	Upper		Little Falls Galway (Theresa) Potsdam	G G	Quartz sandstone & dolostone; sandstone & sandy dolomite; conglomerate base
PreCamb.			Gneiss, Marble, Quartzite, etc...		Metamorphic & igneous rocks

1 - Includes: Glade, Bradford 1st, Chipmunk, Bradford 2nd, Harrisburg Run, Scio, Penny and Richburg.

2 - Includes: Bradford 3rd, Humphrey, Clarksville, Waugh & Porter, and Fulmer Valley.

O: Oil producing

G: Gas producing

S: Salt producing

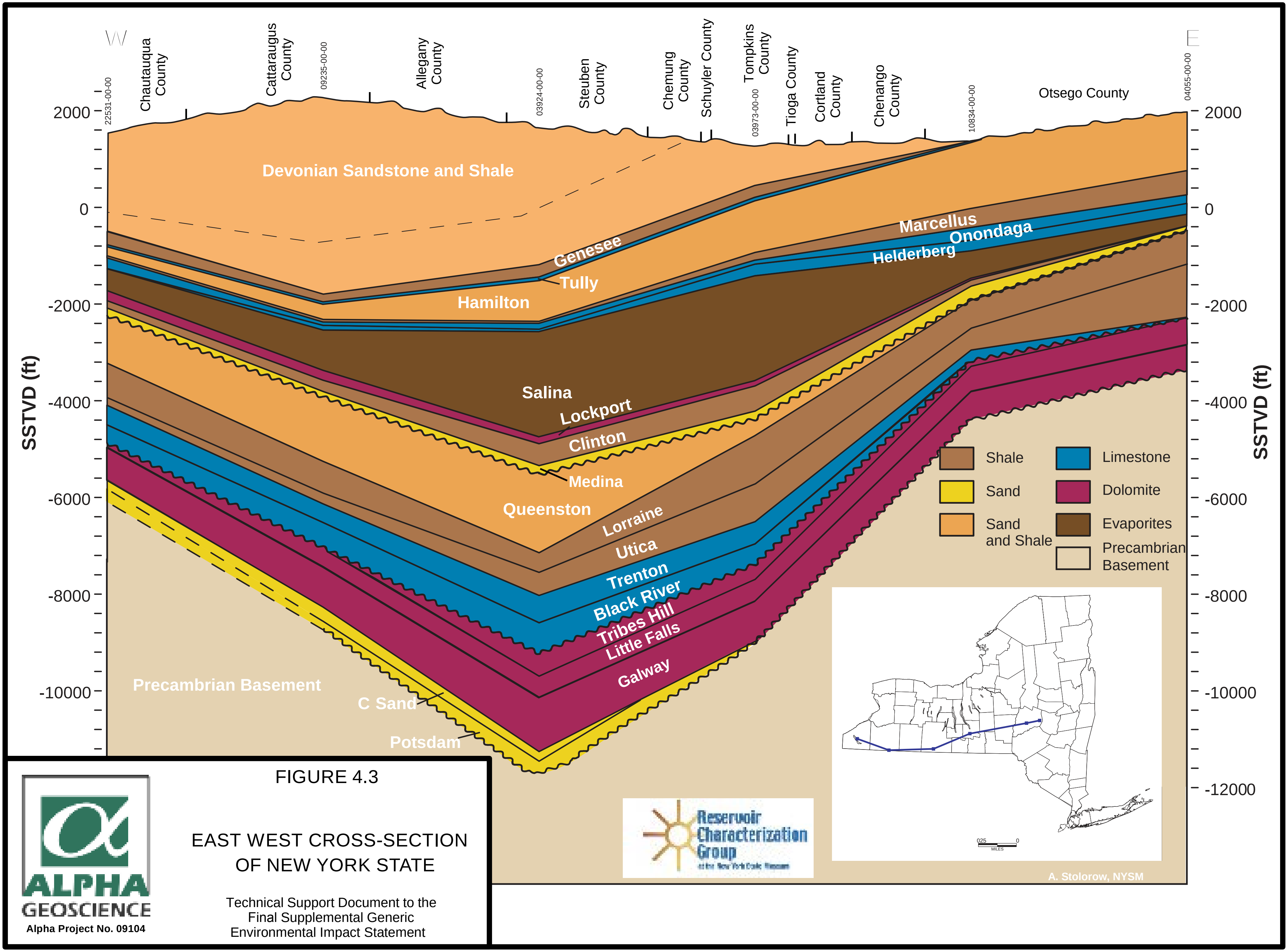

FIGURE 4.3

EAST WEST CROSS-SECTION OF NEW YORK STATE

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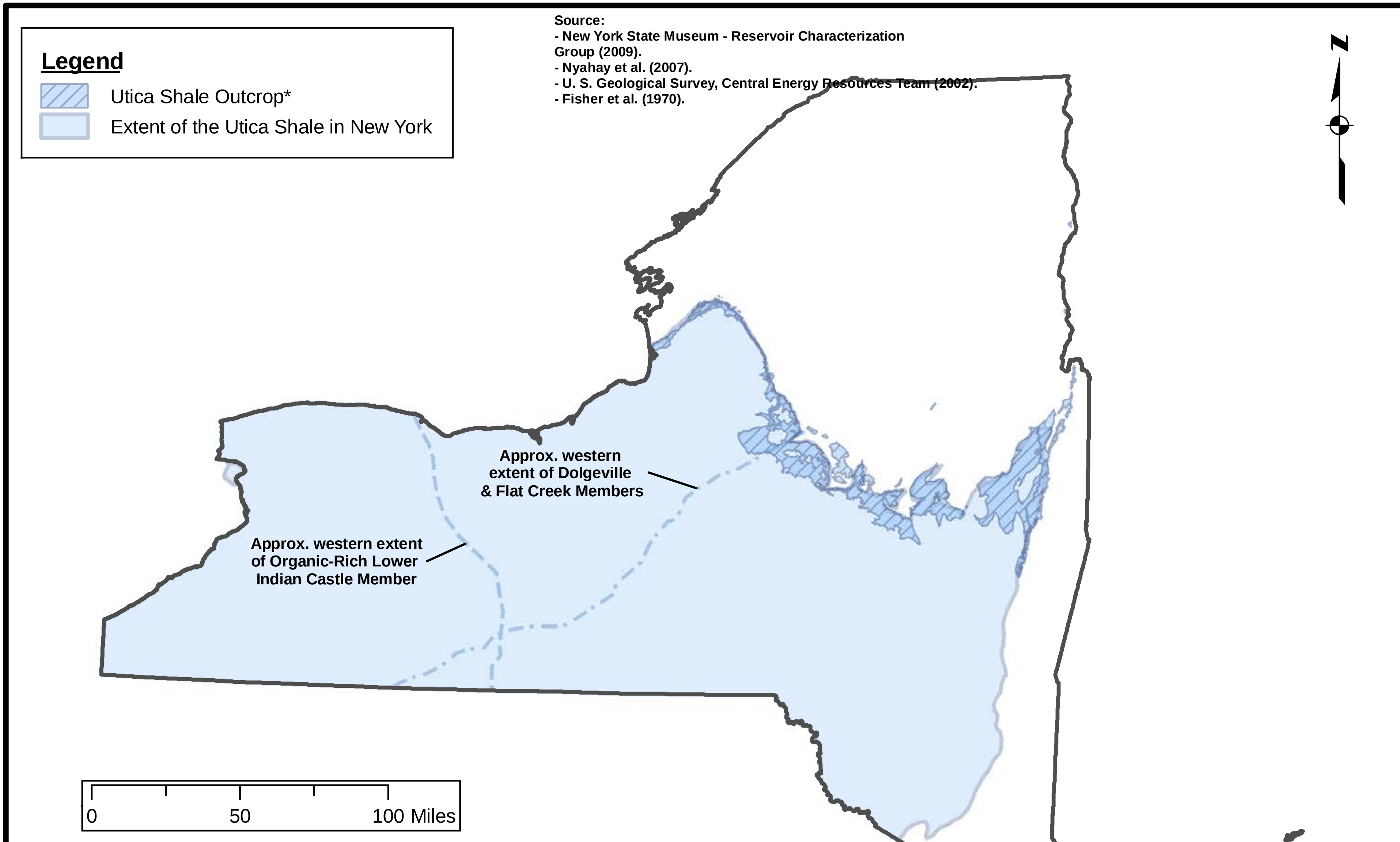

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FIGURE 4.4

EXTENT OF UTICA SHALE IN NEW YORK STATE

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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.[78] 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 values as high as 3.0% in eastern New York and 15% in Ontario and Quebec were also reported.[79]

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.[80] 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.

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[78] Alpha, 2009, p. 124.

[79] Alpha, 2009, p. 125.

[80] Alpha, 2009, p. 125.

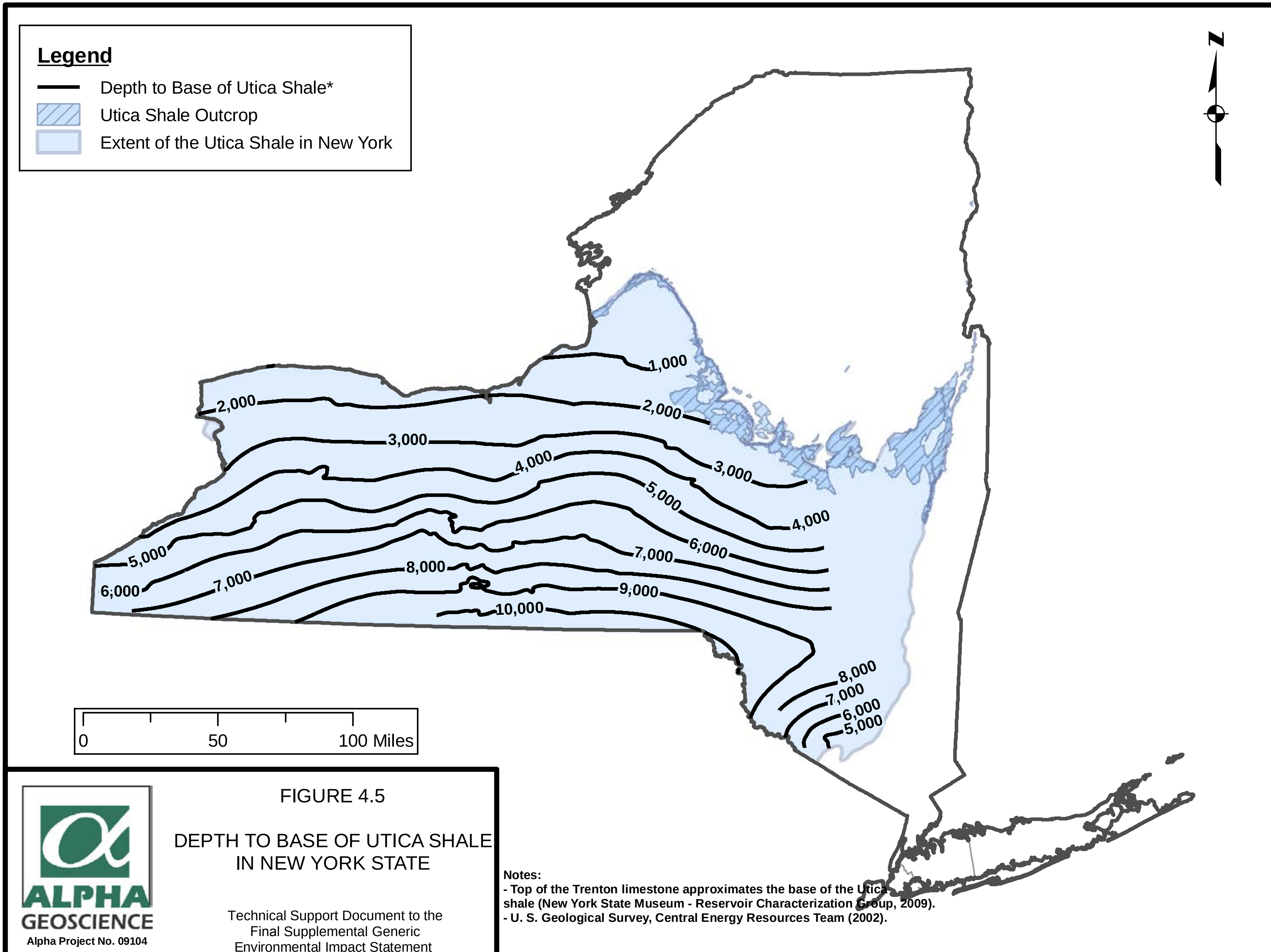

FIGURE 4.5

DEPTH TO BASE OF UTICA SHALE IN NEW YORK STATE

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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).

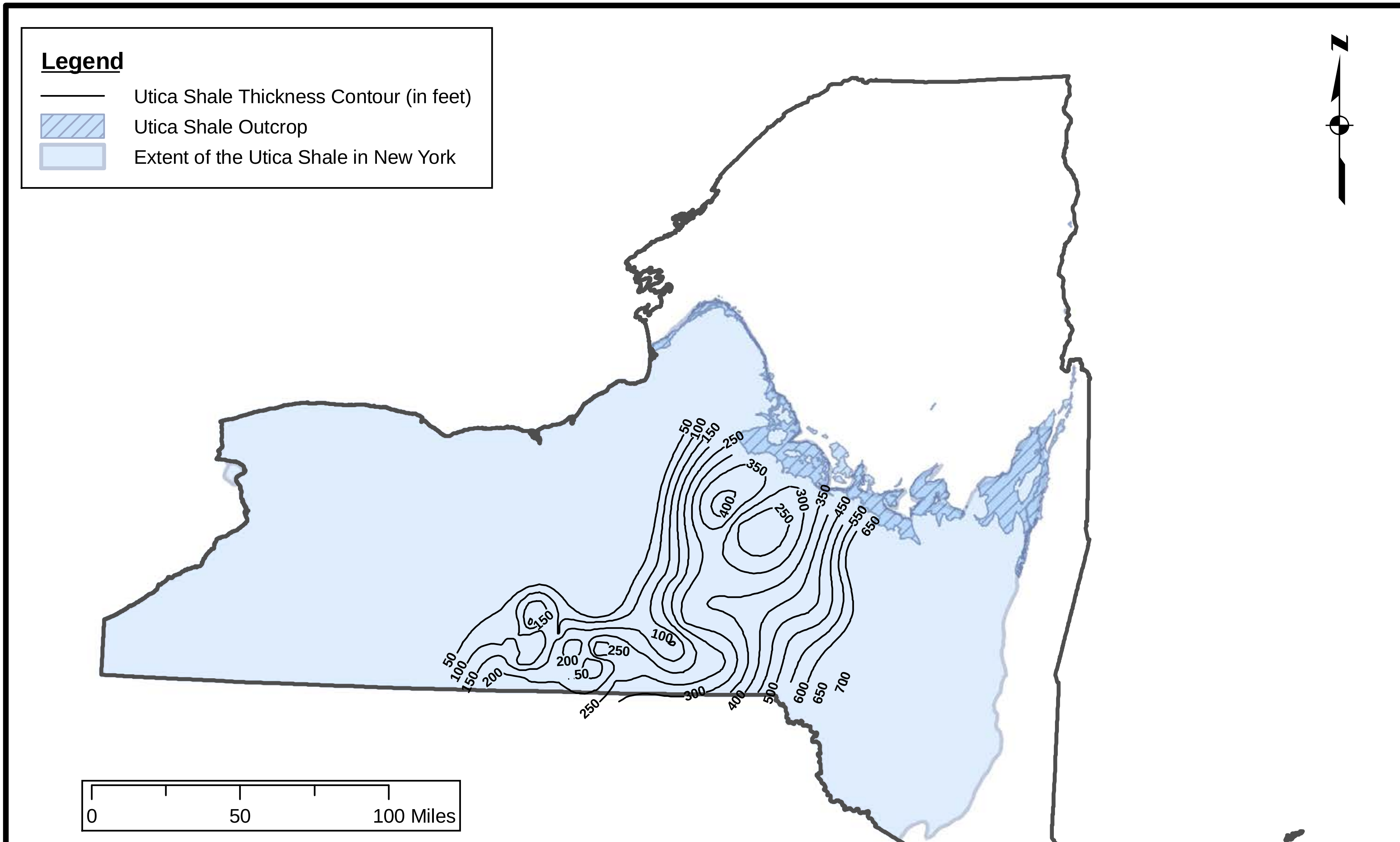

FIGURE 4.6

THICKNESS OF HIGH-ORGANIC UTICA SHALE IN NEW YORK STATE

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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.[81] 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.[82] Significant gas shows have been reported while drilling through the Utica Shale in eastern and central New York.[83]

[81] Alpha, 2009, p. 125.

[82] Alpha, 2009, p. 126.

[83] Alpha, 2009, p. 126.

No Utica Shale gas production was reported to the Department 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.

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[84] and ranges in thickness from less than 25 feet in Cattaraugus County to over 1,800 feet along the Catskill front.[85] 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 underlies an area of approximately 18,700 square miles in New York (Figure 4.8). 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.[86] 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 Shales 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

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[84] Alpha, 2009, p. 126.

[85] Alpha, 2009, p. 126.

[86] Alpha, 2009, p. 127.

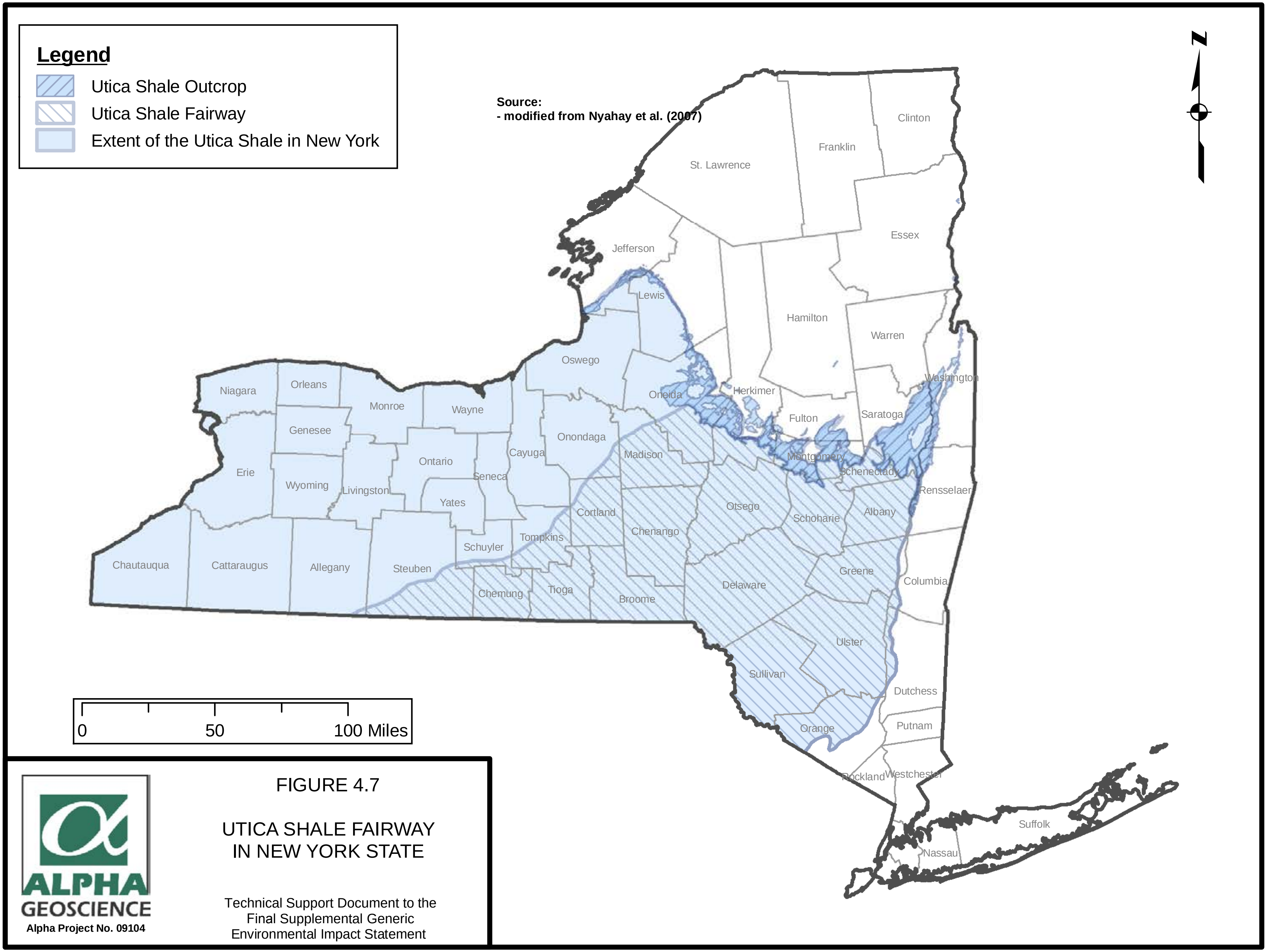

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FIGURE 4.7

UTICA SHALE FAIRWAY IN NEW YORK STATE

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lower-most portions of the Oatka Creek Shale.[87] 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.[88]

4.4.1 Total Organic Carbon

Figure 4.10 shows the aerial distribution of TOC in the Marcellus Shale based on the analysis of drill cuttings sample data.[89] 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 reported between 3 to 12%[90] and 1 to 10.1%.[91]

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.

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

[87] Alpha, 2009, p. 127.

[88] Alpha, 2009, p. 127.

[89] Alpha, 2009, p. 127.

[90] Alpha, 2009, p. 127.

[91] Alpha, 2009, p. 127.

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.[92] All gas wells completed in New York's Marcellus Shale as of the publication date of this document are vertical wells.[93]

The Department'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.[94] In 2010, the most recent reporting year available, a total of 34 MMcf of gas was produced from 15 Marcellus Shale wells in Livingston, Steuben, Schuyler, Chemung, Chautauqua, Wyoming 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 Tcf in all Devonian shales within the basin, including the Marcellus Shale. Approximately 164.1 Tcf, or 19%, of that estimated total, was attributed to the 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.

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[92] Alpha, 2009, p. 129.

[93] Alpha, 2009, p. 129.

[94] Alpha, 2009, p. 129.

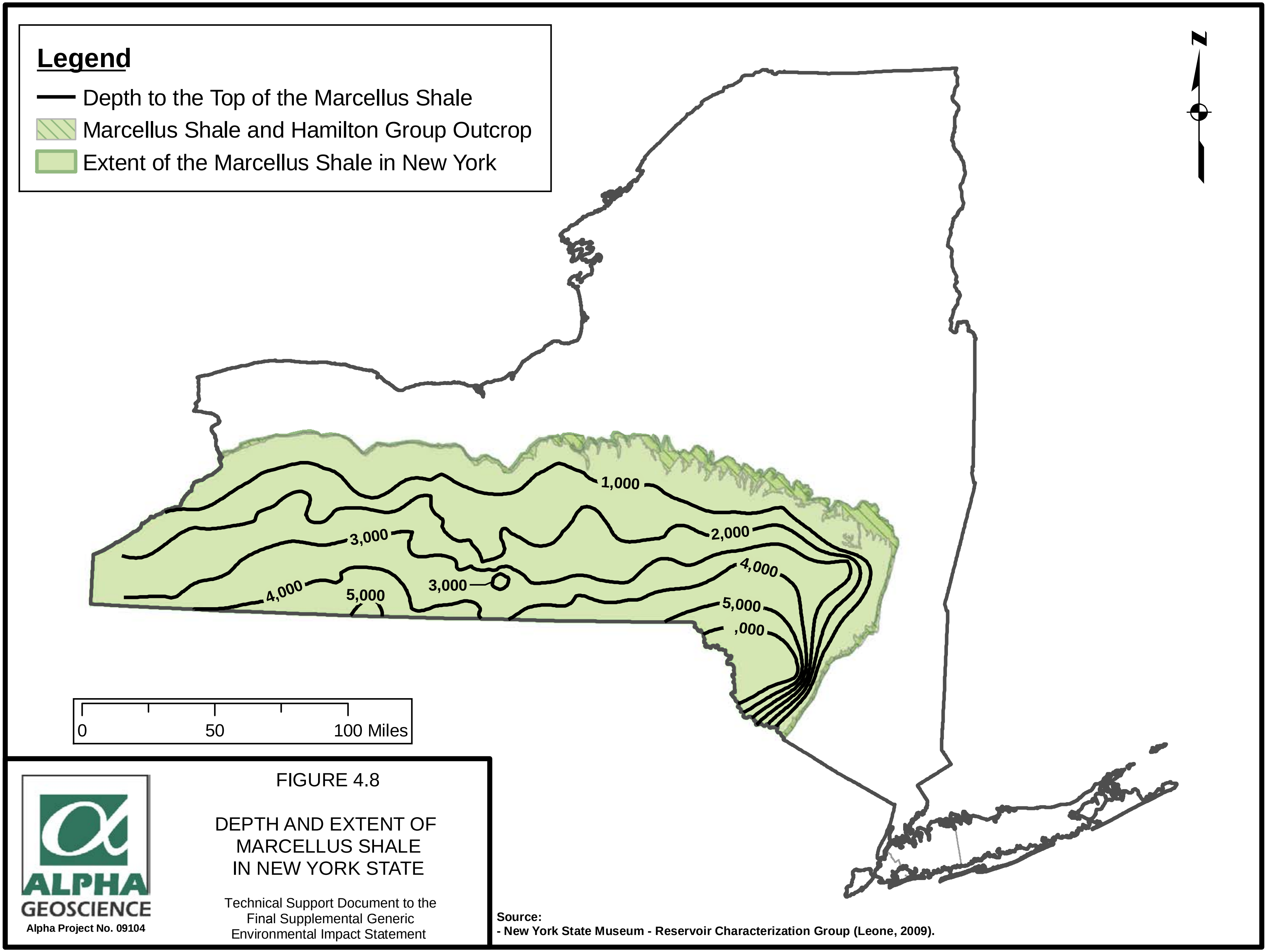

FIGURE 4.8

DEPTH AND EXTENT OF
MARCELLUS SHALE
IN NEW YORK STATE

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

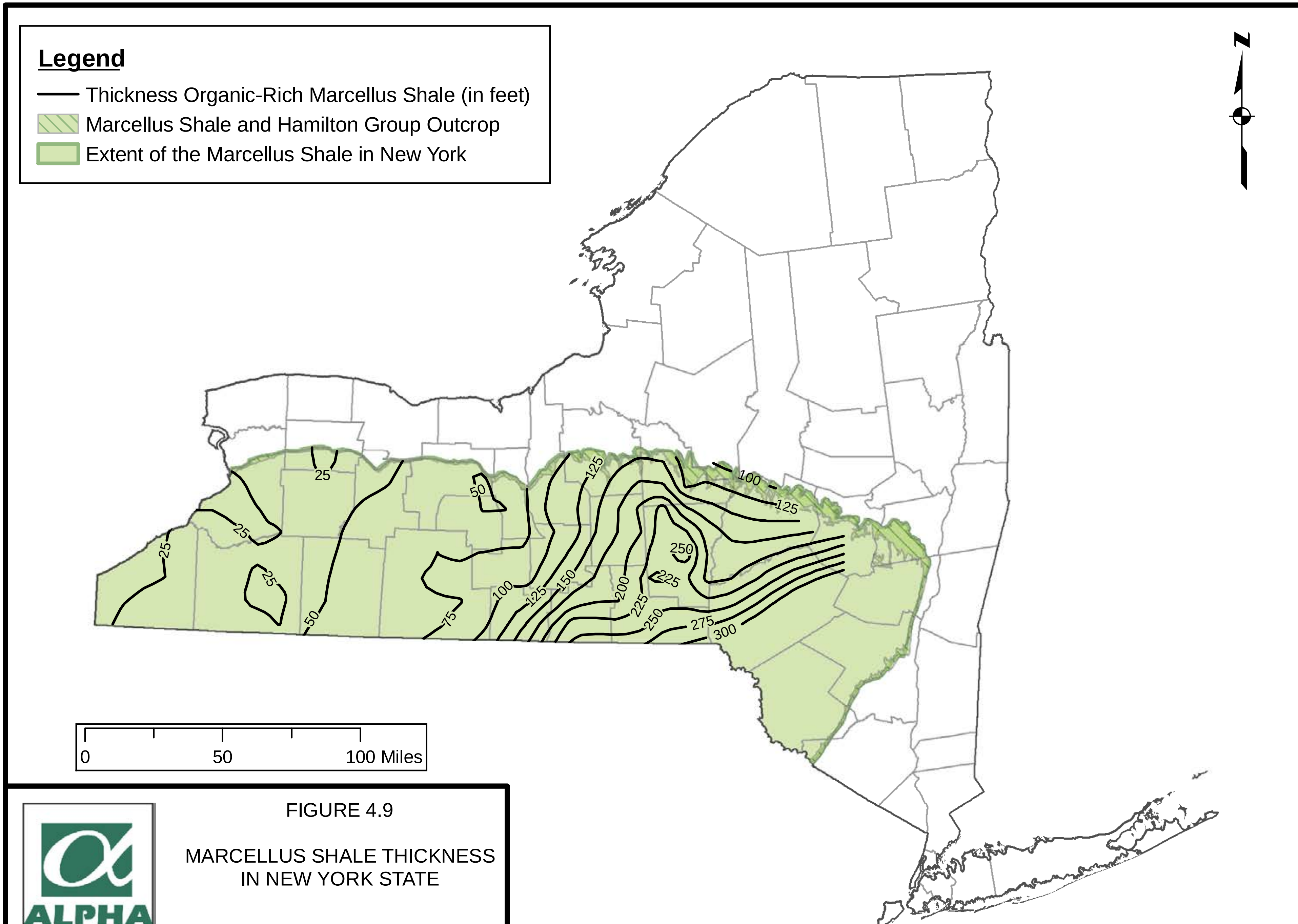

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FIGURE 4.9

MARCELLUS SHALE THICKNESS IN NEW YORK STATE

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

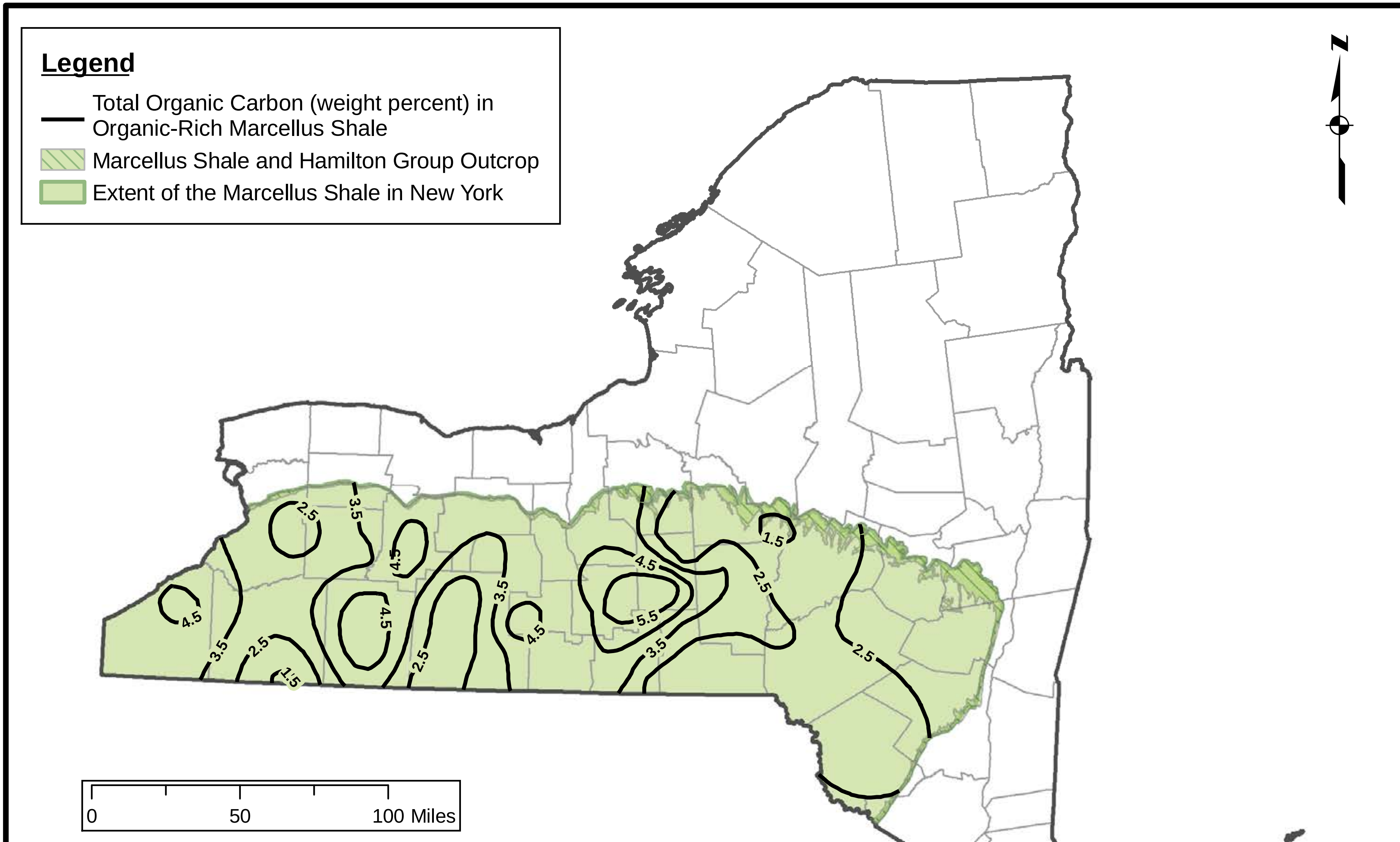

FIGURE 4.10

TOTAL ORGANIC CARBON OF MARCELLUS SHALE IN NEW YORK STATE

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

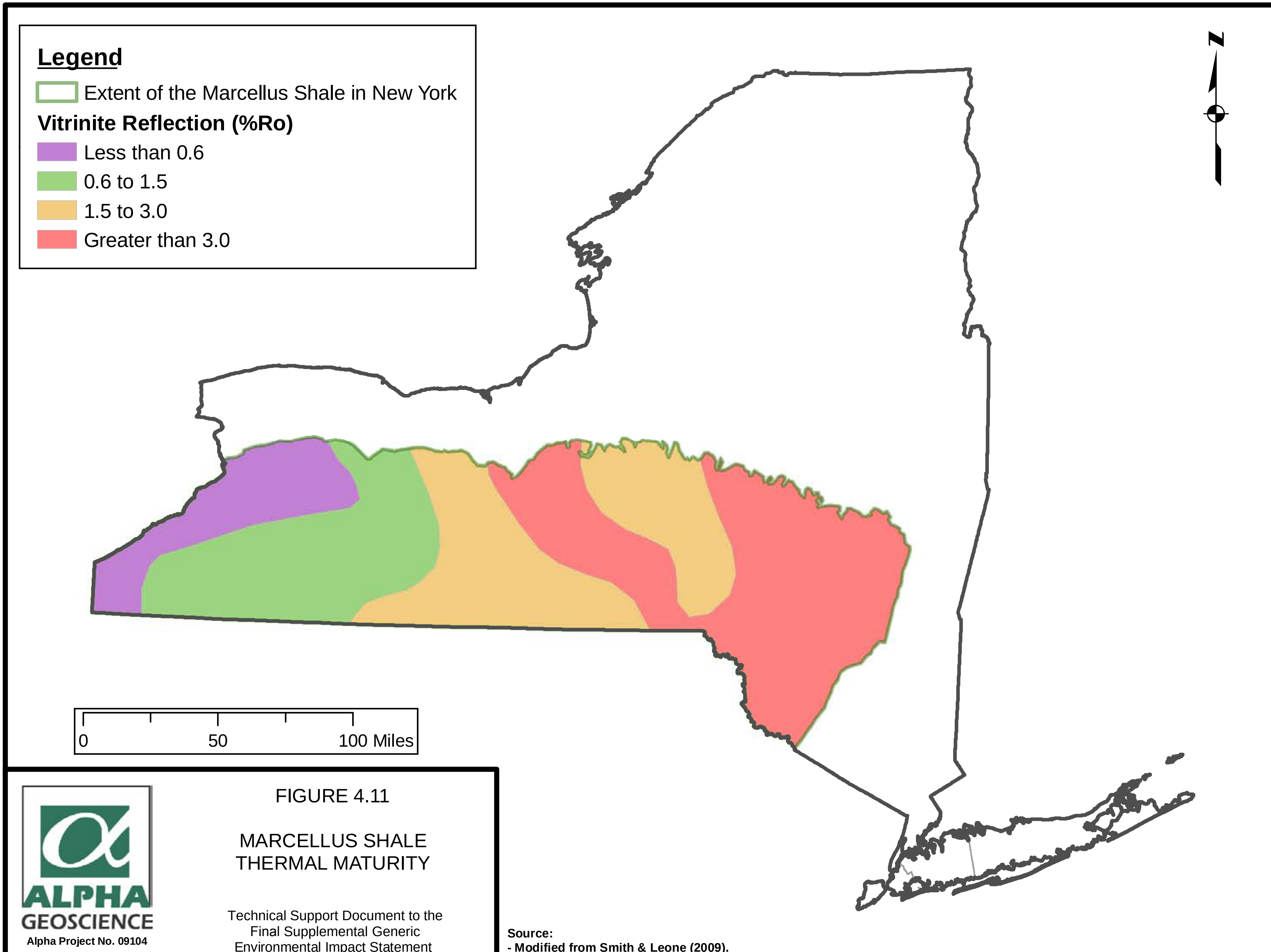

FIGURE 4.11

MARCELLUS SHALE THERMAL MATURITY

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

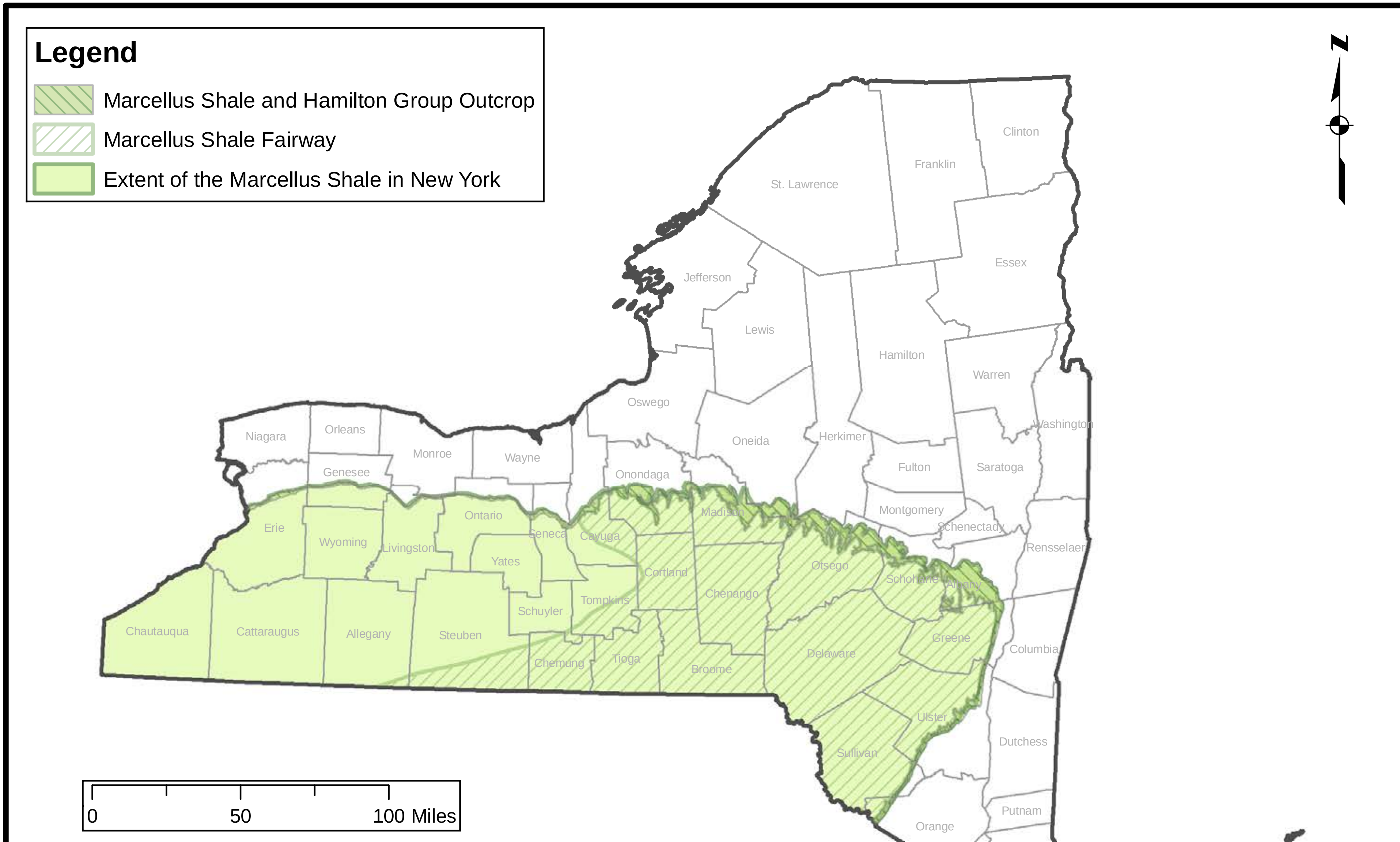

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FIGURE 4.12

MARCELLUS SHALE FAIRWAY IN NEW YORK STATE

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

In 2011, the USGS estimated a mean of 84.2 Tcf of technically recoverable undiscovered natural gas reserves in the Marcellus Shale in the Appalachian Basin, more than a 40-fold increase from its 2002 estimate of 1.9 Tcf. Engelder had previously estimated a 50% probability that 489 Tcf of gas would be produced basin-wide from the Marcellus after a 50-year decline, and assigned 71.9 Tcf of that total to 17 counties in New York.95 Engelder's basin-wide estimate appears to include both proven and undiscovered reserves. While Engelder's methodology is based on both geology and published information about initial production rates and production decline from actual wells in Pennsylvania, the USGS describes its approach as based on recognized geologic characteristics of the formation. There is insufficient information available to determine the validity of comparing these projections, but it is common for projections of these types to vary, as a function of the prevailing technologies and knowledge base associated with a given resource.

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. 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.

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 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.

[95] Engelder, 2009.

Figure 4.13 shows the locations of faults and other structures that may indicate the presence of buried faults in New York State.[96] 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 Allegheny orogenies that occurred 350 to 500 million years ago.[97] There is also 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.[98] 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.[99] 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 50-year period). The areas around New York City, Buffalo, and northern-most New York have a moderate to high seismic hazard class ratings (2% probability of exceeding 12 to 40 %g in a 50-year period).

[96] Alpha, 2009, p. 138.

[97] Alpha, 2009, p. 138.

[98] Alpha, 2009, p. 139.

[99] Alpha, 2009, p. 139.

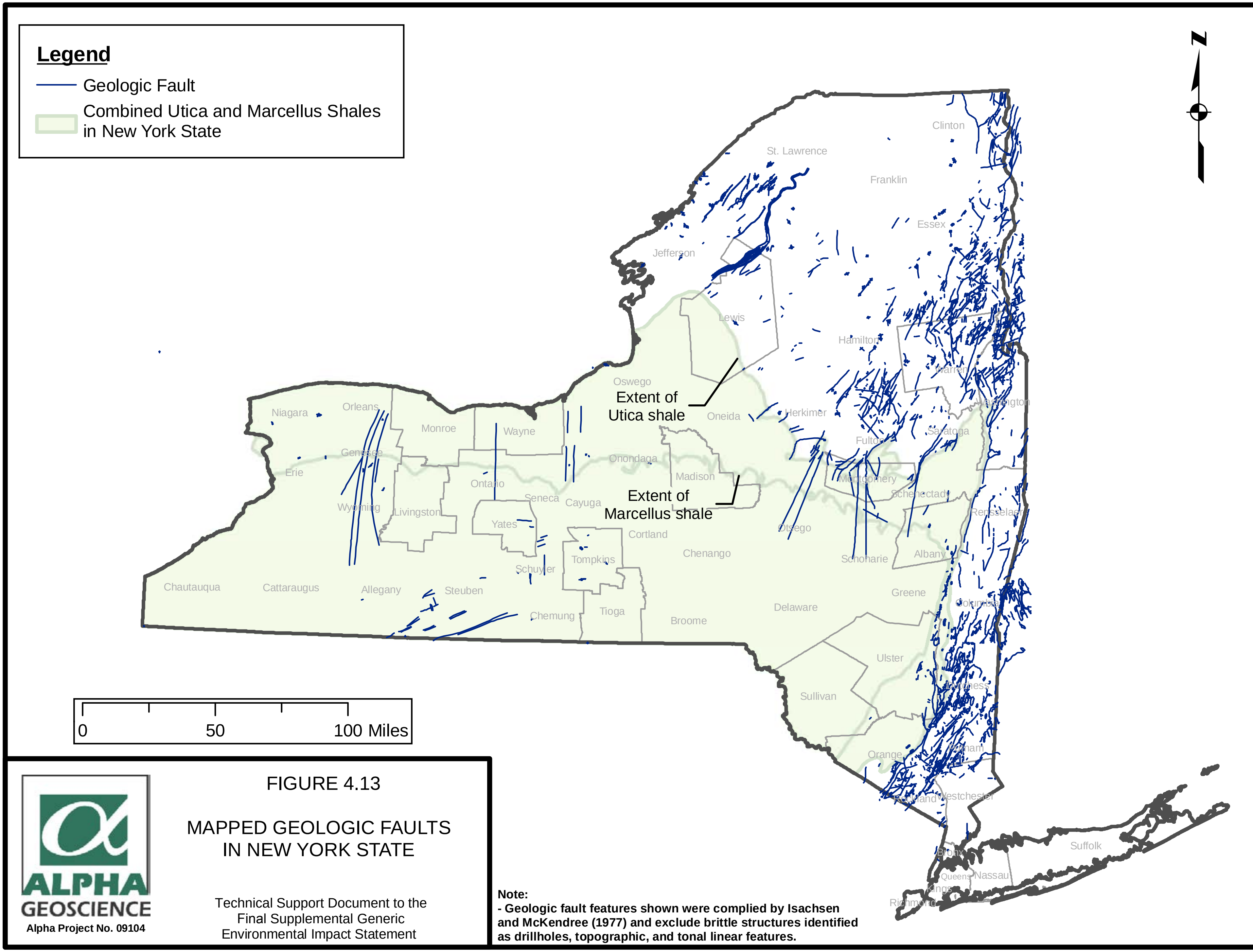

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FIGURE 4.13

MAPPED GEOLOGIC FAULTS IN NEW YORK STATE

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

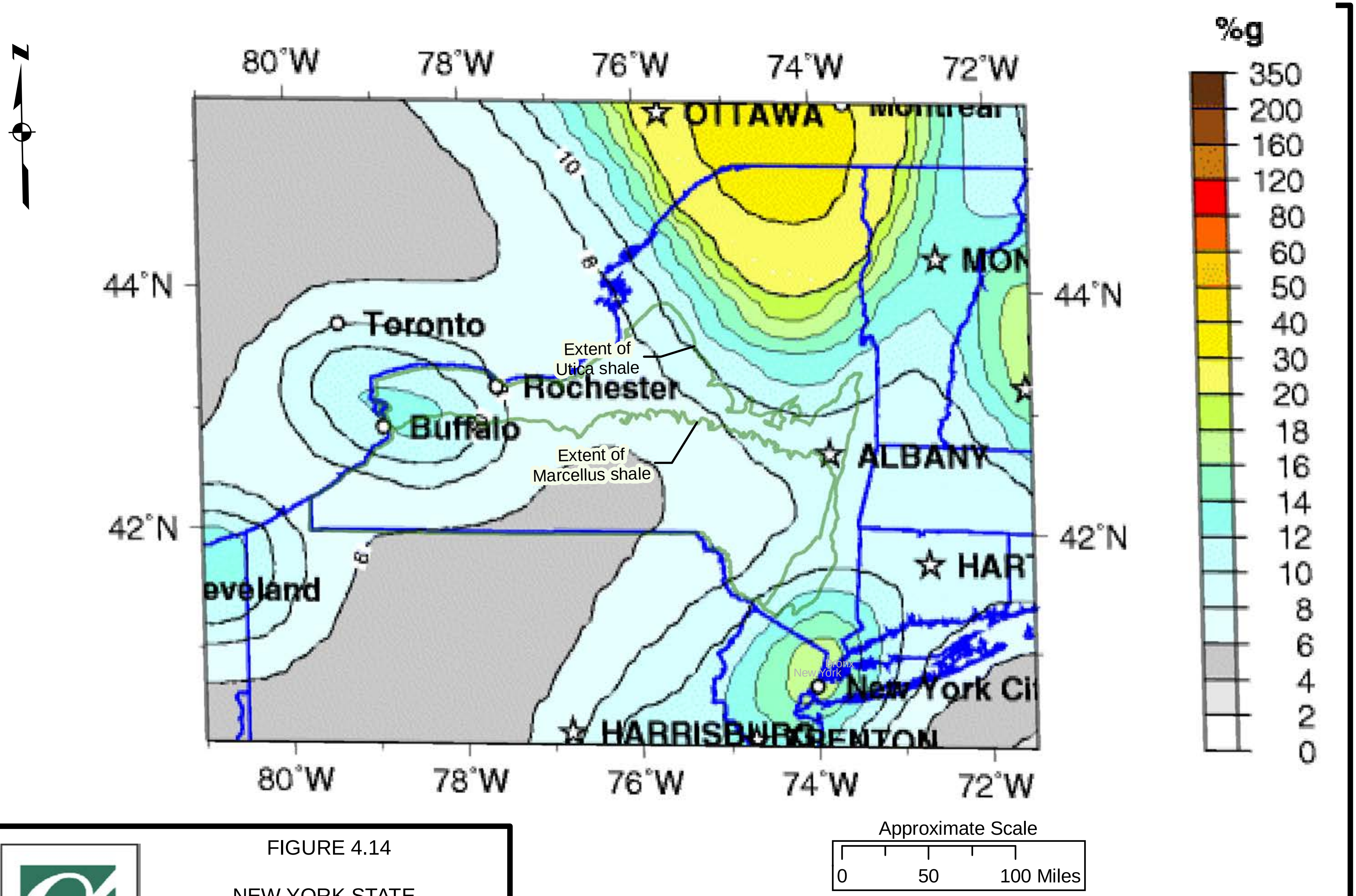

FIGURE 4.14

NEW YORK STATE
SEISMIC HAZARD MAP

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

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 with a magnitude less than 7 and both scales are logarithmic; an increase of two units of magnitude on the Richter scale 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 in 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.[100] 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

[100] Alpha, 2009, p. 140.

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 Plattsburgh, Clinton County.[101] 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.[102]

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).

Induced seismicity refers to seismic events triggered by human activity such as mine blasts, nuclear experiments, and fluid injection, including hydraulic fracturing.[103] 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.

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[101] Alpha, 2009, p. 140.

[102] Alpha, 2009, p. 140.

[103] Alpha, 2009, p. 138.

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 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

Hydraulic fracturing releases energy during the fracturing process at a level substantially below that of small, naturally occurring, earthquakes. However, some of the seismic events shown on Figure 4.15 are known or suspected to be triggered by other types of 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.[104] 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[105] 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 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

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[104] Alpha, 2009, p. 141.

[105] Alpha, 2009, p. 141.

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 ANSS, 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.[106] 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.[107]

[106] Alpha, 2009, p. 142.

[107] Alpha, 2009, p. 143.

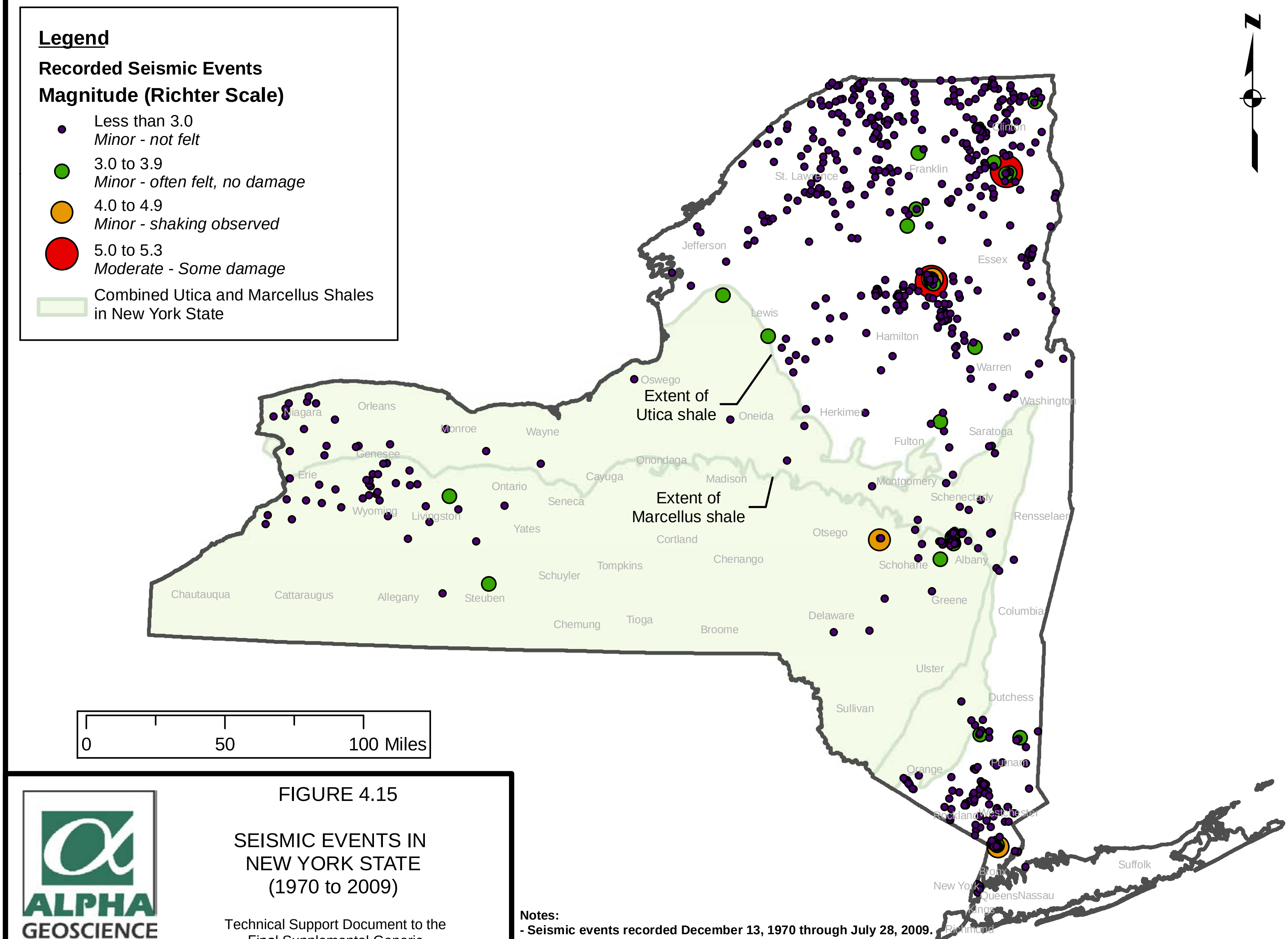

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FIGURE 4.15

SEISMIC EVENTS IN
NEW YORK STATE
(1970 to 2009)

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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)

4.6 Naturally Occurring Radioactive Materials (NORM) in Marcellus Shale

NORM is present to varying degrees in virtually all environmental media, including rocks and soils. 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 is known to contain concentrations of 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 having the potential to concentrate NORM need to come under regulatory oversight to ensure adequate protection of workers, the general public and the environment.

Chapter 5 includes radiological information (sampling results) from environmental media at various locations in the Appalachian Basin. Radiological data for the Marcellus in New York were derived from: a) drill cuttings and core samples from wells drilled through or completed in the Marcellus; and b) production brine from vertical wells completed in the Marcellus. Radiological data for the Marcellus in Pennsylvania and West Virginia were derived from: a) drill cuttings from wells completed in the Marcellus in Pennsylvania; and b) flowback water analyses provided by operators of 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.

4.7 Naturally Occurring Methane in New York State

The presence of naturally occurring methane in ground seeps and water wells is well documented throughout New York State. Naturally-occurring methane can be attributed to swampy areas or where bedrock and unconsolidated aquifers overlie Devonian-age shales or other gas-bearing formations. The highly fractured Devonian shale formations found throughout western New York are particularly well known for shallow methane accumulations. In his 1966 report on the Jamestown Aquifer, Crain explained that natural gas could occur in any water well in the area "which ends in bedrock or in unconsolidated deposits overlain by fine-grained confining material. Depth is not of primary importance because pockets of gas may occur in the bedrock at nearly any depth."[108] Upper Devonian gas bearing rocks at or near the surface extend across the southern tier of New York from Chautauqua and Erie Counties, east to Delaware and Sullivan counties (Figure 4.3).

As noted below, early explorers and water well drillers in New York reported naturally occurring methane in regions not then associated with natural gas well drilling activity. "Methane can occur naturally in water wells and when it does, it presents unique problems for water well drilling contractors. The major concern relates to flammable and explosive hazards associated with methane."[109] Gas that occurs naturally in shallow bedrock and unconsolidated sediments has been known to seep to the surface and/or contaminate water supplies including water wells. Often landowners are not aware of the presence of methane in their well. Methane is a colorless, odorless gas, and is generally considered non-toxic but there could be an explosive hazard if gas is present in significant volumes and the water well is not properly vented.

The existence of naturally occurring methane seeps in New York has been known since the mid 1600s. In August 1669 Rene Robert Cavelier de la Salle and Rene de Brehant de Galinee, while on their way to explore the Mississippi Valley, arrived in the Bristol Hills area of Ontario County, New York. It was here where the explorers observed natural gas flowing from joint planes in the Penn Yan Shale (Upper Devonian) at the foot of a falls over the Genundewa Limestone.[110] More recent studies and investigations have provided other evidence of naturally occurring methane in eastern New York. A private well in Schenectady County was gaged at 158 MMcf/d of natural gas by the Department in 1965. The well provided natural gas for the owner's domestic use for 30 years.[111] In 1987 the Times Union reported that contaminants, including methane, were found in well water in the Orchard Park subdivision near New Scotland, Albany County. Engineers from the Department reported the methane as "natural occurrences found in shale bedrock deposits beneath the development."[112] Ten years later, in 1997, a Saratoga Lake couple disclosed to a news reporter the presence of methane gas in their water

108 NYSDEC, 1992, GEIS, p. 10-6.

109 Keech, D. et al, 1982, pp. 33-36.

110 Wells, J. 1963.

111 Kucewicz, J. 1997.

112 Thurman, K. 1987.

well. The concentration of gas in the well water was concentrated enough for the owners to ignite the gas from the bathtub faucet.[113] According to a September 22, 2010 article in the Daily Gazette, water wells in the Brown Road subdivision, Saratoga County became contaminated with methane gas when water wells were “blasted” (fractured) to reach a greater supply of water.[114]

Methane contamination of groundwater is often mistakenly attributed to or blamed on natural gas well drilling and hydraulic fracturing. There are a number of other, more common, reasons that well water can display sudden changes in quality and quantity. Seasonal variations in recharge, stress on the aquifer from usage demand, and mechanical failures are some factors that could lead to degradation of well water.

Recently, as part of two separate complaint investigations in the towns of Elmira and Collins, New York, the Department documented that methane gas existed in the shallow aquifers at the two sites long before and prior to the exploration and development for natural gas[115, 116]. The comprehensive investigations included the following:

- Analysis of drilling and completion records of natural gas wells drilled near the water wells;
- Evaluation of well logs to ascertain cement integrity;
- Collection of gas samples for compositional analysis;
- Inspections of the water and natural gas wells; and
- Interviews with landowners and water well drillers.

Both investigations provided clear evidence that methane contamination was present in the area’s water wells prior to the commencement of natural gas drilling operations.

Drilling and construction activities may have an adverse impact on groundwater resources. The migration of methane can contaminate well water supplies if well construction practices designed

[113] Kruse, M. 1997.

[114] Bowen, K. 2010.

[115] NYSDEC, 2011.

[116] NYSDEC, 2011.

to prevent gas migration are not adhered to. Chapter 6 discusses these potential impacts with mitigation measures addressed in Chapter 7.

In April 2011 researchers from Duke University (Duke) released a report on the occurrence of methane contamination of drinking water associated with Marcellus and Utica Shale gas development. [117] As part of their study, the authors analyzed groundwater from nine drinking water wells completed in the Genesee Group in Otsego County, New York for the presence of methane. Of the nine wells, Duke classified one well as being in an active gas extraction area (i.e., a gas well within 1 kilometer (km) of the water well), and the remaining eight in a non-active gas extraction area. The analysis showed minimal amounts of methane in this sample group, with concentrations significantly below the minimum methane action level (10 mg/L) to maintain the safety of structures and the public, as recommended by the U.S. Department of the Interior, Office of Surface Mining.[118] The water well located in the active gas extraction area had 5 to 10 times less methane than the wells located in the inactive areas.

The Department monitors groundwater conditions in New York as part of an ongoing cooperative project between the USGS and the Department's Division of Water (DOW).[119] The objectives of this program are to assess and report on the ambient ground-water quality of bedrock and glacial-drift aquifers throughout New York State. In 2010 water samples were collected from 46 drinking water wells in the Delaware, Genesee, and St. Lawrence River Basins. All samples were analyzed for dissolved methane gas using standard USGS protocols. The highest methane concentration from all samples analyzed was 22.4 mg/L from a well in Schoharie County; the average detected value was 0.79 mg/L.[120] These groundwater results confirm that methane migration to shallow aquifers is a natural phenomenon and can be expected to occur in active and non-active natural gas drilling areas.

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[117] Osborne, S. et al, 2011.

[118] Eltschlager, K. et al, 2001.

[119] http://www.dec.ny.gov/lands/36117.html.

[120] NYSDEC, 2011.