INVESTIGATION OF PARTS OF THE ALLEGHENY PLATEAU, THE ONEIDA LAKE BASIN AND THE MOHAWK VALLEY: PHASE 1 REGIONAL RECONNAISSANCE

Agreement #10110

Final Report

Submitted to

NYS Energy Research and Development Authority
17 Columbia Circle
Albany, New York, 12203-6399

by

JL Wallach Geosciences Inc
2 Deguire Court
Russell, Ontario K4R 1C1
Canada

and

MIR Télédétection Inc.
110, rue de la Barre, Suite 212
Longueuil, Québec J4K 1A3
Canada

April, 2010

Notice

This report was prepared by JL Wallach Geosciences Inc. and MIR Télédétection Inc, in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter the "Sponsor"). The opinions expressed in this report do not necessarily reflect those of the Sponsor or the State of New York, and reference to any specific product, service, process or method does not constitute an implied or expressed recommendation or endorsement of it. Further, the Sponsor and the State of New York make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods or other information contained, described, disclosed, or referred to in this report. The Sponsor, the State of New York and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

ABSTRACT

The study area extends from approximately the southwest end of the Tug Hill Plateau southwestwardly to beyond Ithaca, on the Allegheny Plateau, and occupies about 5,625 square miles. To gain an understanding of that area germane to hydrocarbon potential a cursory examination of the Albion-Scipio area in Michigan was conducted. There are similarities between the two in that both are underlain by Silurian salt and have similar stratigraphy, and brittle structures are important in accounting for the oil and gas plays. Stratigraphically the picture in the study area is rather simple, with the units at the surface showing a decrease in age southward owing to the gentle southerly regional homocline of 40-55 feet/mile. Moreover the limestones of the northern part of the area give way southward to a mixture of shales, siltstones and sandstones, some of which are calcareous, but still with some accompanying limestones. At least three black shales, the Utica, Marcellus and Geneseo, occur within the sequence. Magnetic, gravimetric and topographic lineaments imply strongly that many major surface fractures, if not faults, propagated upward from the Precambrian basement. Magnetic data in particular also make a persuasive argument to account for structural control of Cayuga Lake. The same also applies to the other Finger Lakes, though the relationship is not as clear. Outcrop control is poor and there appears to be little deformation, but there are exposures of dipping strata, monoclines and reverse faults. Solution-induced folds occur along the Allegheny Front and gentle folds related to Appalachian deformation are present at least in the southern and western Finger Lakes region. A tectonic model, based upon fault-controlled fluid flow to explain the Trenton/Black River plays, was advanced by Smith (2006). That model is predicated on fluids following transtensional faults, which are strike-slip induced, tensional splays. Mechanisms other than those proposed by Smith (2006) may have also been operative but, as Smith (2006) noted and specifics aside, it appears that basement rooted fractures and faults served as fluid conduits thereby allowing both Trenton/Black River and non Trenton/Black River fields to develop. Three gas fields, in which the reservoirs are present in strata younger than the Trenton/Black River groups, occur within the study area. Existence of those fields, along with the favorable stratigraphy, leads to the recommendation that more attention ought to be focused on the study area in which natural gas exploration should prove to be fruitful.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 INTRODUCTION

1.1 General Statement

The study area occupies about 5,625 square miles in central New York and extends from south of Ithaca, at the southern tip of Cayuga Lake, northeasterly to the base of the Adirondack Mountains (Figure 1). It also incorporates a segment of the Mohawk Valley and what may be termed the Oneida Lake basin, just south of the Tug Hill Plateau (Figure 1). Most of the area is underlain by layered, predominantly clastic sedimentary rocks, with the oldest exposed rocks being the Upper Middle Ordovician carbonates of the Trenton Group and the youngest the Upper Devonian sandstones, siltstones and shales of the Sonyea Group. Generally the strata strike almost perfectly east-west and dip gently to the south at about 40-55 feet per mile. It is not an area noted for intense and extensive hydrocarbon exploration, but at the present time it contains three producing gas fields.

General geological conditions suggest that the area may have a higher potential than heretofore suspected. Regional work by EarthSat (1997) resulted in their having identified a series of fields to which they referred as exploration fairways and which they regarded as "*areas of high fractured reservoir potential*". Among those fairways are fields that have already been exploited, such as the currently active Fayette-Waterloo field between the northern portions of Seneca and Cayuga Lakes, and formerly active ones on and adjacent to the Tug Hill Plateau. Work was also conducted in the areas of Skaneateles Lake by Stroup et al (2006) and Seneca and Cayuga Lakes by Scholz (personal communication).

Published information suggests that, from a hydrocarbon exploration and exploitation perspective, relatively little is known about the geology of the area although staff of the Reservoir Characterization Group of the New York State Museum have conducted work in the Mohawk Valley germane to establishing analogues for subsurface hydrocarbon reservoirs (Agle et al, 2006). Agle, et al (2006) added that renewed interest in the Cambro-Ordovician section of the Mohawk Valley has emerged owing to significant natural gas discoveries within the suite of Trenton-Black River Group rocks.

Emphasis in this study has been placed on the regional structure and stratigraphy. Outcrop-scale structures were sought because rocks deform at all scales, and the small structures mimic the character of the much larger ones. Lineament intersections were also targeted because they are very important foci for hydrothermal fluid flow and stress accumulations.

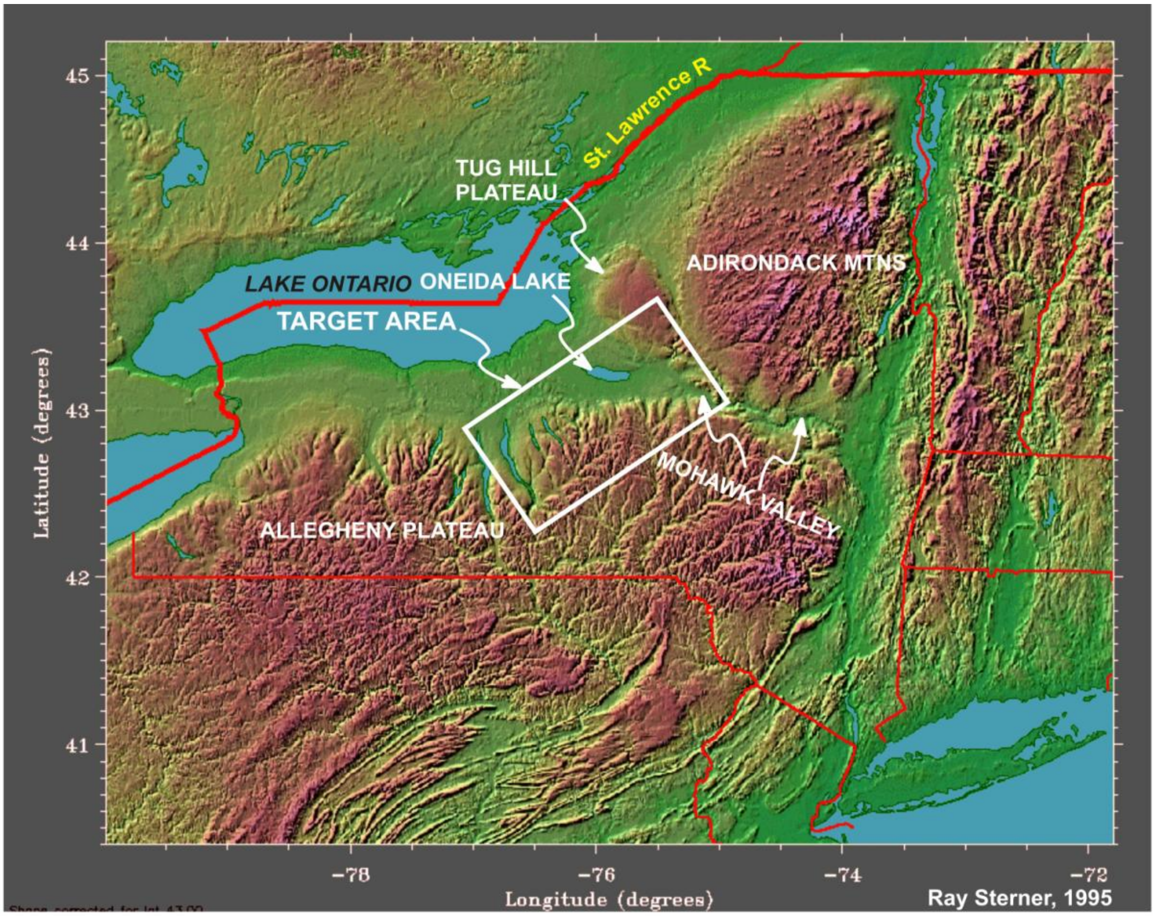


Figure 1 Shaded Relief Map of New York State Showing Study (Target) Area.

1.2 Database Generation

Geological and drill hole data were recovered from Michigan and New York State, and integrated into this study's database, along with Landsat 7, regional topographical and national geophysical data. Geological data include information on stratigraphy and all oil and gas wells drilled since the beginning of the last century and were used for a better understanding of the relationship among stratigraphic units, the spatial distribution of the wells and major lineaments. Shaded relief and color images of the magnetic and gravity fields were generated using Universal Transverse Mercator, WGS84 as the reference map projection. Specifically the following data sets were obtained (sources in parentheses):

- Landsat 7 data (USGS)
- Digital elevation data (USGS and New York State)
- Base map cartographic data (USGS and New York State hydrography, roads)
- Regional aeromagnetic data (USGS and Centennial Geoscience, Inc.)
- Regional gravity data (Centennial Geoscience, Inc.)
- Geological data (State of Michigan, the New York State Museum and NYSDEC; stratigraphy, oil and gas wells)

Regional digital elevation and the base map data were recovered from the US government. Shaded relief images were generated under different illumination conditions and enhanced, where necessary, and color-shaded products were generated by merging color relief images with shaded topographic images. Two consecutive Landsat 7 images, collected in November of 2000, were ordered from the USGS web site, each of which is characterized by data at 15 m and 30 m resolution for the panchromatic channel and the 6 multispectral channels, respectively. Each image was orthorectified and merged to cover the entire area. Enhancement was applied to generate color products and optimize the display of the structural geology, land use cover and integrated geophysical data which include the Bouguer anomaly, magnetic total field and first vertical derivatives.

Chapter 2 COMPARING ALBION-SCIPIO AND CENTRAL NEW YORK STATE

Selection of the study area resulted from an overview of the Michigan Basin and that portion of the Appalachian Basin in New York State where there have been, and still are, hydrocarbon yields. In southern Michigan the Albion-Scipio field is a well known hydrocarbon producer located within the Michigan Basin, which is characterized by Cambro-Ordovician clastics overlain by evaporites and carbonate rocks of Siluro-Devonian age (Wood et al, 2002). The Albion-Scipio oil and gas field reveals an alignment of principally oil-producing wells from an HTD type reservoir that parallel north-northwest oriented topographic and magnetic lineaments, which likely played a significant role in the development of the oil reservoir.

In New York State the geological setting is similar, albeit not identical, to that in the Michigan Basin. Silurian-aged salt occurs within a segment of the Appalachian Basin that extends across much of the central and western parts of the state. Portions of that basin underlie the uplifted Allegheny Plateau, whereas the northernmost edge of the basin occurs beneath the wide-east-west valley, which separates the Allegheny Plateau to the south from the uplifted Tug Hill Plateau and the Adirondack Mountains to the north. Faults are not abundant on the state map, but Stroup et al (2006) identified several in the Skaneateles Lake area. Scholz (personal communication) stated that there are faults that cross Seneca and Cayuga Lakes and EarthSat (1997) interpreted a plethora of rather small-scale faults in the region encompassing those two lakes.

Stratigraphically the same sequence that underlies Michigan also underlies the study area in New York. It features, among others, sandstones of the Potsdam group, the Theresa Formation (Rose Run in Ohio), carbonates of the Trenton/Black River Groups, the Utica Shale, the Silurian-aged Salina Group and a succession of shales which overlies the limestones of the TriStates Group, which includes the Onondaga Formation. For exploration the formations of interest are generally beneath the surface, particularly in the western part of the study area, but east of Utica, the Dolgeville Formation of the Trenton Group and the Utica Shale both crop out at the surface. Across the state is an east-west striking, gently southerly dipping regional homocline, illustrated by the structural contours on top of the Salina Salt Zone. Despite the southwardly increase in depth to the Trenton-Black River, owing to the gentle southerly dip, there was production from wells intersecting those rocks south and southeast of Seneca and Cayuga Lakes.

Chapter 3 ALBION-SCIPIO

3.1 Regional Geology

The Michigan Basin represents a typical intracratonic basin in Northern America, the morphology of which was directly controlled by the relief of the Precambrian basement (Wilson et al., 2001). The basin is nearly circular with the youngest lithological units at the center and the oldest units along the margins (Figure 2). Beds dip gently toward the center, where the total thickness of the sediments is estimated to be approximately 5000 m. The basin corresponds to a large depression developed over the Michigan Keweenawan Rift Zone and is bounded by relatively high relief: the Canadian Shield to the north, northwest and northeast, the Wisconsin Arch to the west, the Kankakee Arch to the southwest, the Findlay Arch to southeast and the Algonquin Arch to the east (Wilson et al., 2001). It's stratigraphy spans almost the entire Paleozoic era and comprises a series of sedimentary cycles, mostly characterized by marine sequences and delimited by erosional or non-depositional episodes. Sedimentation began in the Cambrian and, but for an apparent hiatus in the latest Paleozoic and earliest Mesozoic, concluded in the Jurassic. Unconsolidated sediments generated during the Wisconsinan glaciation cover the entire basin.

The largest single field in Michigan is the Albion-Scipio in Hillsdale, Jackson and Calhoun counties. Oil prospecting there appears to be focused on a series of wells which define, for the most part, a south-southeast trend (Figures 3 and 4) and intersect the Trenton and Black River groups. The Black River Group is Middle Ordovician and consists of micritic dense lime mudstone to wackestone with some brachiopods and locally brown chert nodules. Like the overlying Trenton, the Black River is thinner and more argillaceous in the northeast quadrant of the basin, otherwise it is a remarkably uniform unit, thickening gradually toward the southeast. Overlying the Black River Group and separating it from the younger Trenton Group is a series of widespread K-metabentonites. Rocks of the Trenton Group are quite similar to those of the Black River Group, both sets being characterized mainly by fossiliferous marine carbonates. However, the Black River, which is cherty, contains more brown lime peloidal mudstone and less packstone. In the northern part of the basin, the upper Trenton includes the Collingwood shale, a thin organic-rich shale, which, together with similar ones described in the east-southeastern part as Cynthiana or Pleasant Point Shale, is considered as the most probable source of hydrocarbons.

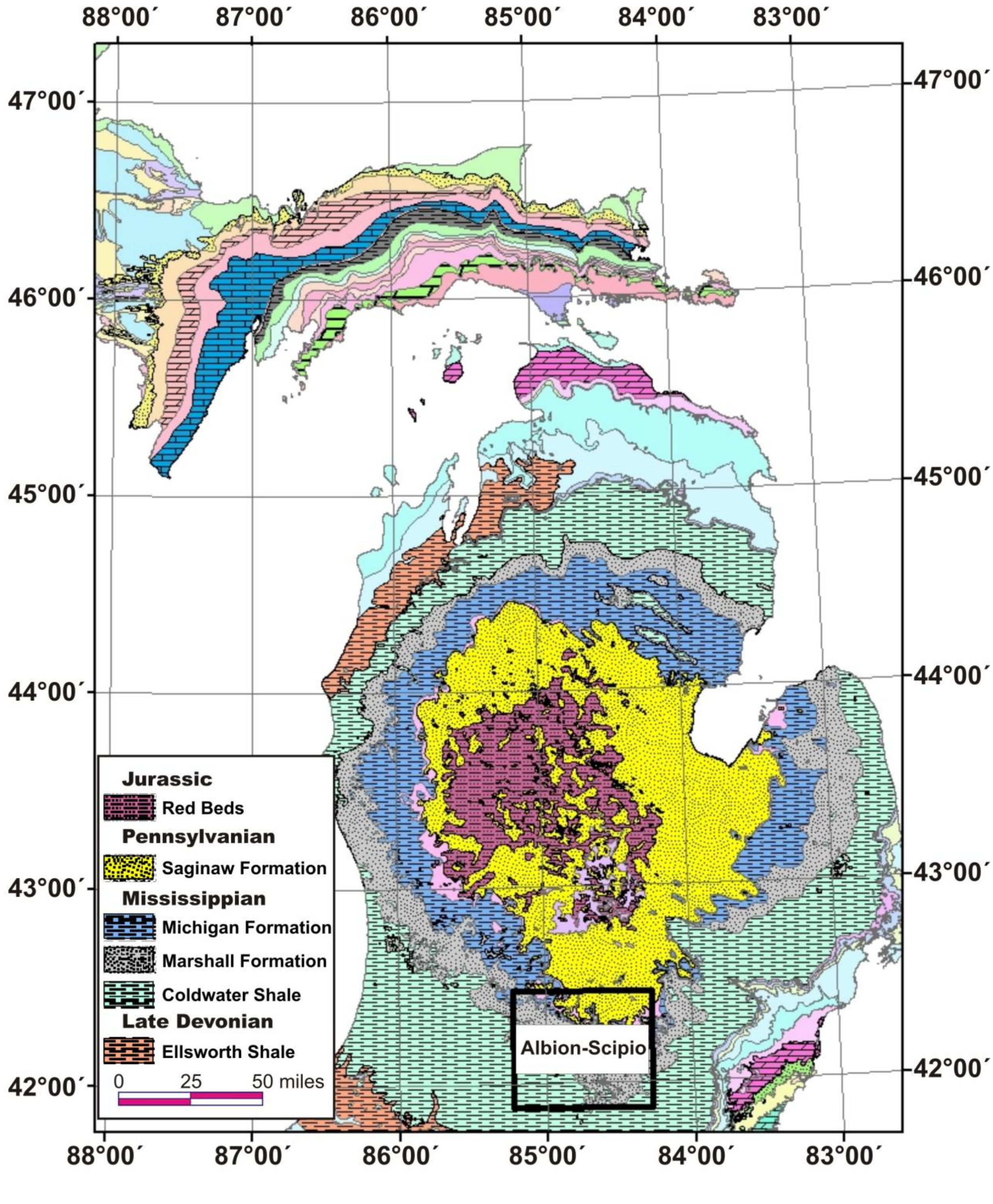


Figure 2 **Geological Map of the Michigan Basin and the Albion-Scipio Field. (From the Michigan Department of Environmental Quality (MDEQ) - Geologic Survey Division)**

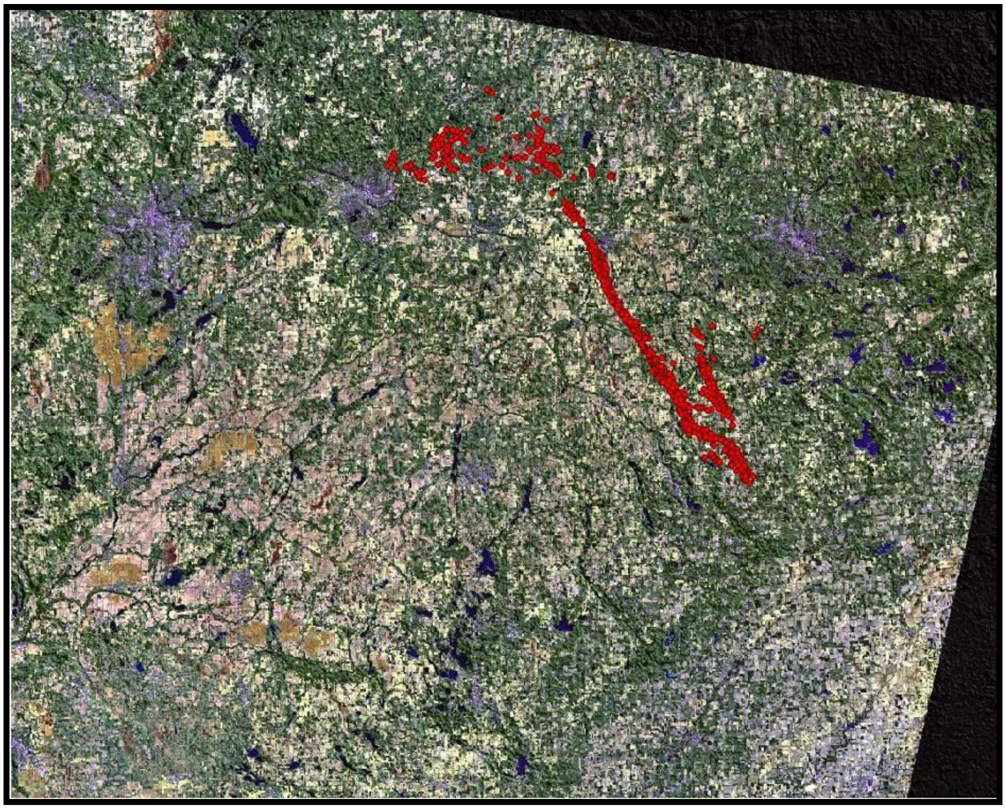


Figure 3 **Landsat Color Composite Showing the Oil Wells (Red Dots) of the Albion-Scipio Field. Line Defined by Wells trends 330° (150°)**

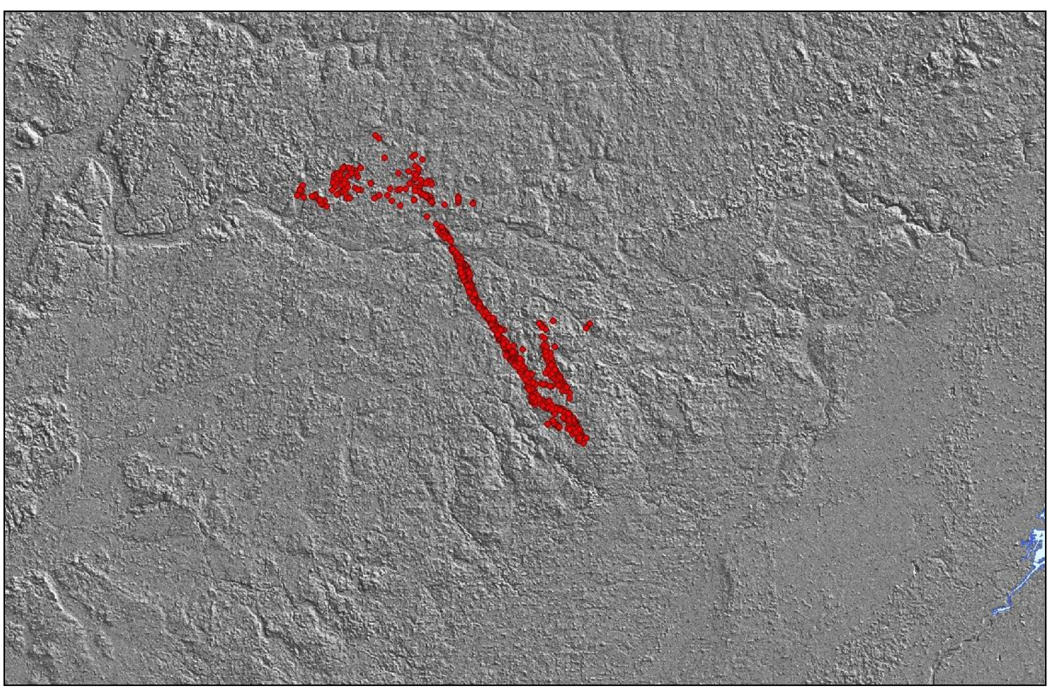


Figure 4 **Shaded Topography Showing the Oil Wells (Red Dots) of the Albion Scipio Field.**

3.2 Topographic lineaments

Both topographic and magnetic lineaments were assessed within the area encircling the Albion Scipio oil field and the results were compared to identify surface discontinuities that may have propagated upward from the basement. Topographic lineaments were identified using both shaded relief imagery, with illumination from the northwest, north, northeast and east, and Landsat 7 multispectral color imagery. Those lineaments correspond generally to different geomorphologic features (valleys, ridges, etc), but given the high degree of agricultural activity interpreting some was rather challenging. The challenge was particularly acute in addressing east-west lineaments owing to the important footprint of agricultural activity in that direction. Five lineament trends were recognized, 025°, 060°, 115°, 135° and 155° (Figure 5). Most are short and discontinuous, however those oriented 025°, 060° and 115° are also aligned thereby suggesting that they may be regionally extensive. Some of those are probably related to faults. The 135°-trending lineaments are the least numerous and also seem less likely to be extensive.

3.3 Magnetic lineaments

Large areas of positive magnetic anomalies probably correspond to the different arches which delimit the basin, whereas the center of the basin shows smoother magnetic anomalies, due to the thick sedimentary pile which acts as a filter over the Precambrian basement. Magnetic lineaments associated with basement magnetic contrasts were interpreted from color images of the total magnetic field covering a large portion of the State of Michigan (Figure 6). Some of the lineaments appear to be several km long and define four sets oriented north-northeast, east-northeast, east-southeast and south-southeast. They denote linear features in the basement, presumably faults/fractures or fault/fracture-controlled lithological changes, the orientations of which correlate very well with those of the topographic lineaments on the surface (Figure 7). That suggests that many topographic lineaments are related to deeply rooted basement discontinuities. Topographic counterparts of the south-southeast trending magnetic lineaments are not particularly abundant, though that has no bearing on their possible relationship to basement structures.

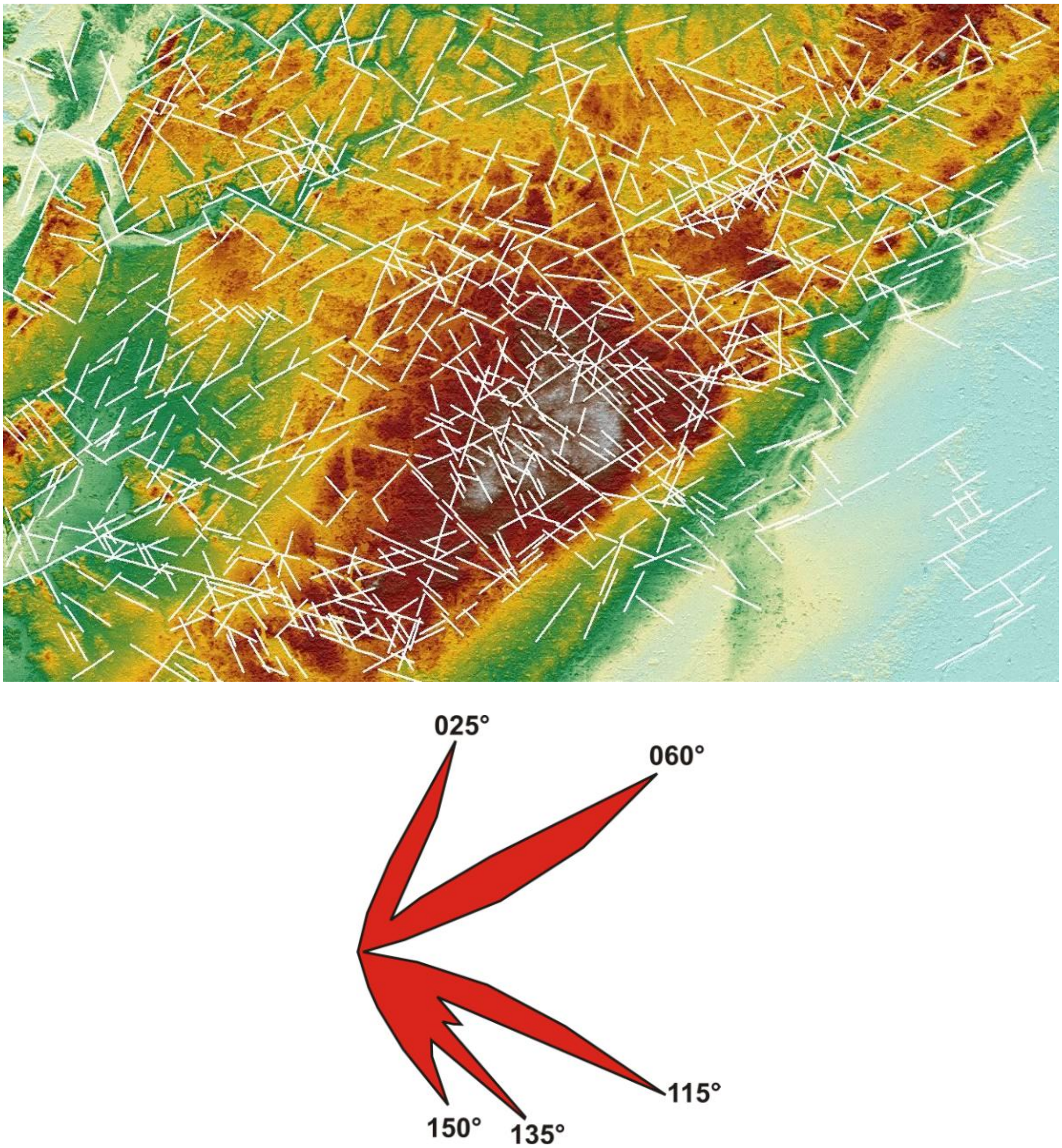


Figure 5 **Topographic Lineaments of the Albion Scipio Field Superimposed on a Colored Shaded Relief Image. Orientations Summarized in the Rose Diagram.**

3.4 The Proposed Role of Fractures in the Development of the Albion-Scipio Field

According to Wilson et al. (2001), the Albion-Scipio field corresponds to a sharply defined belt of collapse breccias and dolomite about 3/4 mi wide and more than 35 mi long and is actually portrayed as a depression on the Trenton platform. Its south-southeast trend is characterized by narrow tensional gashes a few hundred yards apart and accompanied by a second order east-southeast trend in the southern part. Collapse is interpreted to be Late Silurian-Early Devonian in age and is related to the reactivation of a Late Precambrian structure, followed by a later (Mid-Late Devonian?) partial collapse (Wilson et al., 2001).

A central depression in the middle of the belt is characterized by a series of irregular sinks with an average relief of 50 ft. The producing zones underlie that central depression and are, therefore, interpreted as being related to it. Vertical fault displacements are minimal to absent, and the system of fractures has been conjectured to result from transcurrent movement in the basement with very minor up throw to the northeast. No thinning of the Trenton-Black River groups over the field is inferred. The northern end of the field is about 1300 ft structurally lower than the southern extremity (Wilson et al., 2001).

In cross sections the porous zones are shown to be parallel to an overlying depression, hence porosity (cavernous and vuggy) would have been developed after the regional basin subsidence. Because the subsidence rate is inferred to have been greatest during Late Silurian-Early Devonian, the cavernous porosity zones probably did not form earlier than Late Devonian, and they may even be of Late Paleozoic age (Wilson et al., 2001).

Versical (1991 proposed a tectonic model to account for development of faults and fractures germane to the Albion-Scipio Field, in which the stress system responsible for the lineaments and fractures featured an east-southeast oriented maximum horizontal compressive stress (Figure 8). The resulting structures would be south-southeast striking sinistral faults, east-northeast trending dextral faults and east-southeast (115º) extension fractures, orientations that are identical to those of the lineaments interpreted in this study (Figures 5 and 8). Versical (1991) suggested that those structures either formed synchronously with the deposition of the Trenton-Black River groups or soon thereafter.

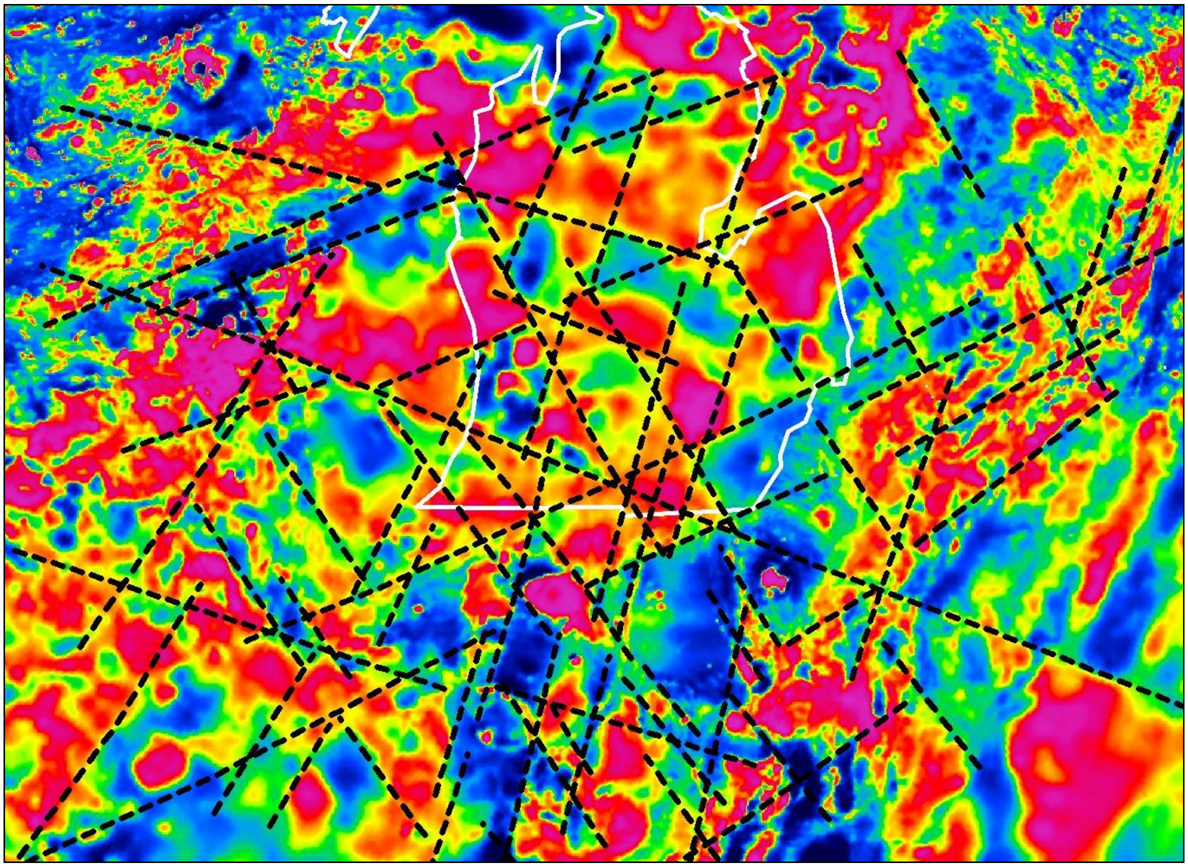


Figure 6 Total-Field Magnetic Map with Interpreted Magnetic Lineaments in Black. The Outline of the State of Michigan is Shown in White.

Given the "open space" character of the east-southeast striking (115°) extension fractures, it is presumed that they would be the most likely to have served as fluid pathways, yet the wells themselves show a south-southeast (150°) alignment (Figures 3 and 4). That suggests that the south-southeast striking sinistral shears, rather than the extension fractures, controlled the fluid flow. That could result if there were secondary extension fractures or shear fractures, which opened in response to the left-lateral translation (Figure 8). Alternatively the high permeability of the south-southeast corridor could have been accounted for by its intersection with the east-southeast extension fractures. In either case the circulation of hydrothermal fluids likely occurred along the south-southeast pathway resulting in dolomitization of the Trenton limestone and the development of a possible hydrothermal karst system (Wilson et al., 2001).

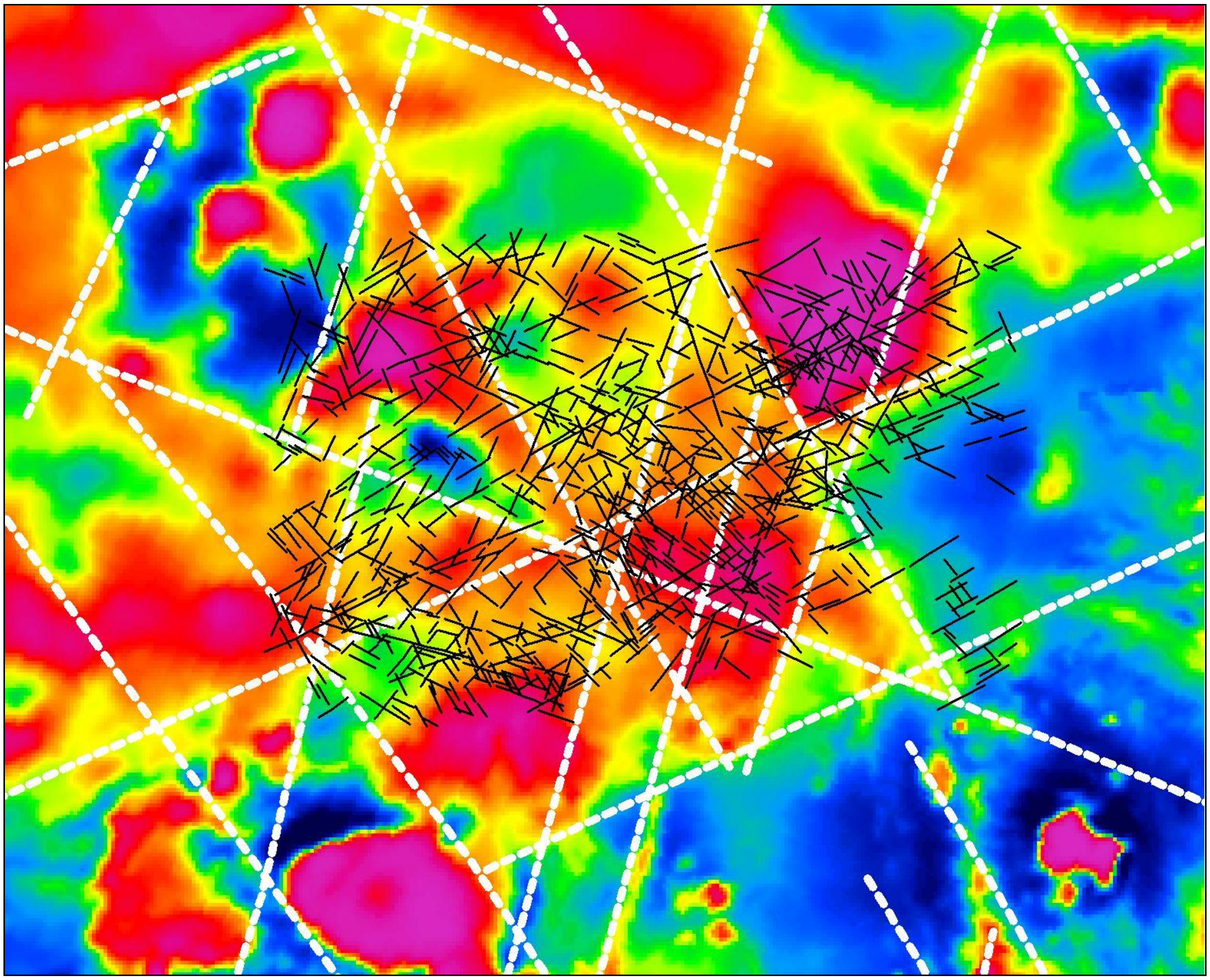


Figure 7 **Topographic (Black Lines) and Magnetic (White Lines) Lineaments Superimposed on the Magnetic Total Field.**

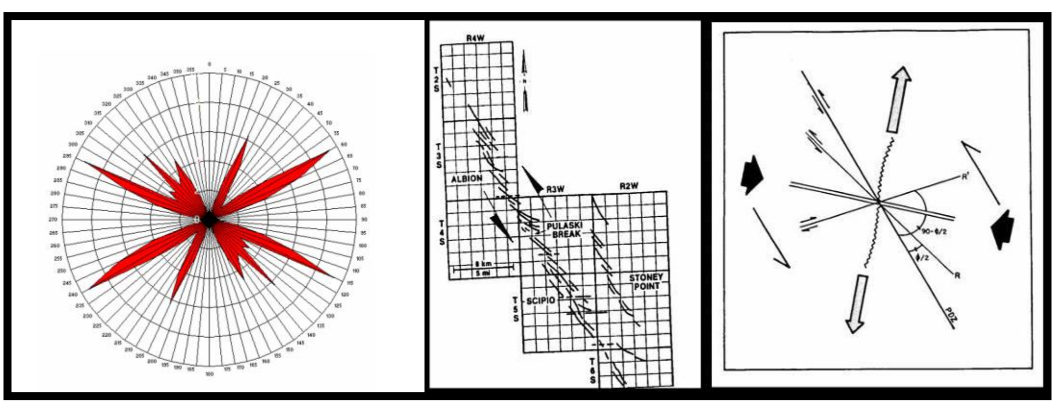


Figure 8 **Comparison of interpreted Lineaments in the Rose Diagram (left) to the Structural Model from Versical (1991).**

3.5 Summary

An analysis using topographic and Landsat data was undertaken at a regional scale in order to identify the dominant lineaments over the area of, and including, the Albion-Scipio Field. The interpreted topographic lineaments generally correspond to different geomorphologic features (valleys, depressions, cliffs, ridges, etc.), but the effects of human activity in the area limited the interpretation. For this reason, some lineaments, like those oriented generally east-west in the southeastern part, were not considered.

Results show that the southern part of the Michigan Basin is characterized by four specific sets of lineaments, north-northeast, east-northeast, east-southeast and south-southeast. The oil wells of the Albion Scipio oil field are aligned along the south-southeast trend, which locally seems to be offset along east-southeast splays. Furthermore the south-southeast alignment correlates with regional magnetic discontinuities near the intersection of east-southeast and east-northeast magnetic discontinuities (Figure 9).

Geological investigations of the area by Wilson et al., (2001, Wood et al., (2002) and Versical, 1991) in conjunction with the lineament analysis reveal:

1) The strikes of the interpreted topographic lineaments are just about identical to those of the wrench fault structural model (Versical, 1991), which suggests that the lineaments, too, formed in response to compression with the maximum principal stress oriented east-southeast-west-northwest. The south-southeast and east-northeast lineaments would represent, respectively, sinistral and dextral shear fractures with the east-southeast lineaments signifying open or extension fractures. Correlation among the surface lineaments (post-Devonian), mapped fractures at the top of the Trenton and magnetic discontinuities suggest that the fractures in the Precambrian basement propagated upwards into the younger sedimentary rocks.

2) The Albion Scipio oil field occurs at the intersections of south-southeast, east-southeast and east-northeast magnetic discontinuities. Intersecting fractures would have most likely facilitated hydrothermal fluid circulation and reservoir generation.

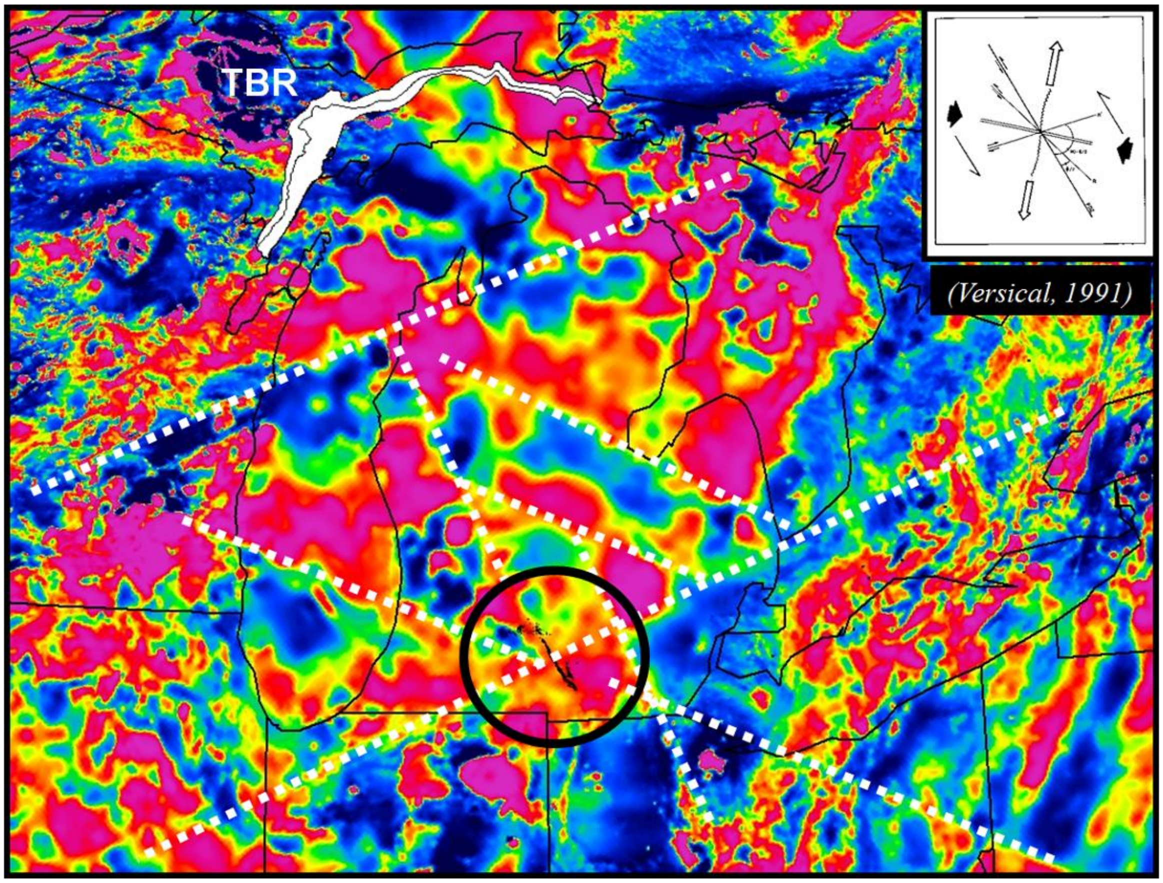


Figure 9 **Total-Field Magnetic Map With Major Interpreted Tectonic Elements (Shown by Dashed White Lines), Their Potential Contribution to the Albion-Scipio Oil Field Generation (Lineament Intersection Shown Within Black Circle) and the Relationship With a Wrench Fault Structural Model (inset Top Right). Surface Cropping of the Trenton/Black River (TBR) Groups is Shown to the North.**

Chapter 4 ALLEGHENY PLATEAU

4.1 Regional Geology

The Allegheny Plateau is located on the northeastern rim of the Appalachian Basin. In south-central New York State, its geological setting is similar, albeit not identical, to that in the Michigan Basin, although in the Michigan Basin the youngest unit is Jurassic in age (Figure 2). On the Allegheny Plateau a succession of Devonian-aged sedimentary units crop out on the surface ((Figure 10) and dip to the south at from about 40-55 feet/mile (Figure 11). It features, among others, sandstones of the Potsdam Group, the Theresa Formation (Rose Run in Ohio), carbonates of the Trenton-Black River Groups, the Utica Shale, the Silurian-aged Salina Group and a succession of shales which overlies the limestones of the Onondaga Group. The formations to be focused on are generally beneath the surface, particularly in the western part of the target (study) area, but east of Utica, the Dolgeville Formation of the Trenton Group and the Utica Shale both crop out at the surface. Stratigraphically much of the same sedimentary sequence that underlies Michigan also underlies the area of interest in New York.

Sedimentary strata across New York State strike nearly east-west and dip gently to the south, a property represented by the undifferentiated carbonates and the structural contours on top of the salt zone (Figure 11). Therefore gas-bearing units, such as the Utica and Marcellus shales, which crop out at the surface in the northern part of the study area, are rather deeply buried in the southern part, thereby making them attractive exploration targets. In addition further south and higher in the section are other units which look as if they, too, should be tested.

Silurian-aged salt occurs within a segment of the Appalachian Basin that extends across much of the central and western parts of the state. Portions of that basin underlie the uplifted Allegheny Plateau, whereas the northernmost edge of the basin occurs beneath the wide east-southeast valley that separates the Allegheny Plateau to the south from the uplifted Tug Hill Plateau and the Adirondack Dome to the north (Figure 10). Solution of the relatively near-surface salt by circulating groundwater and consequent loss of support of the overlying strata by the salt removal resulted in an east-west belt of slump folds (Phillips, 1955) which affected units as young as the Upper Onondaga Formation (Figure 12).

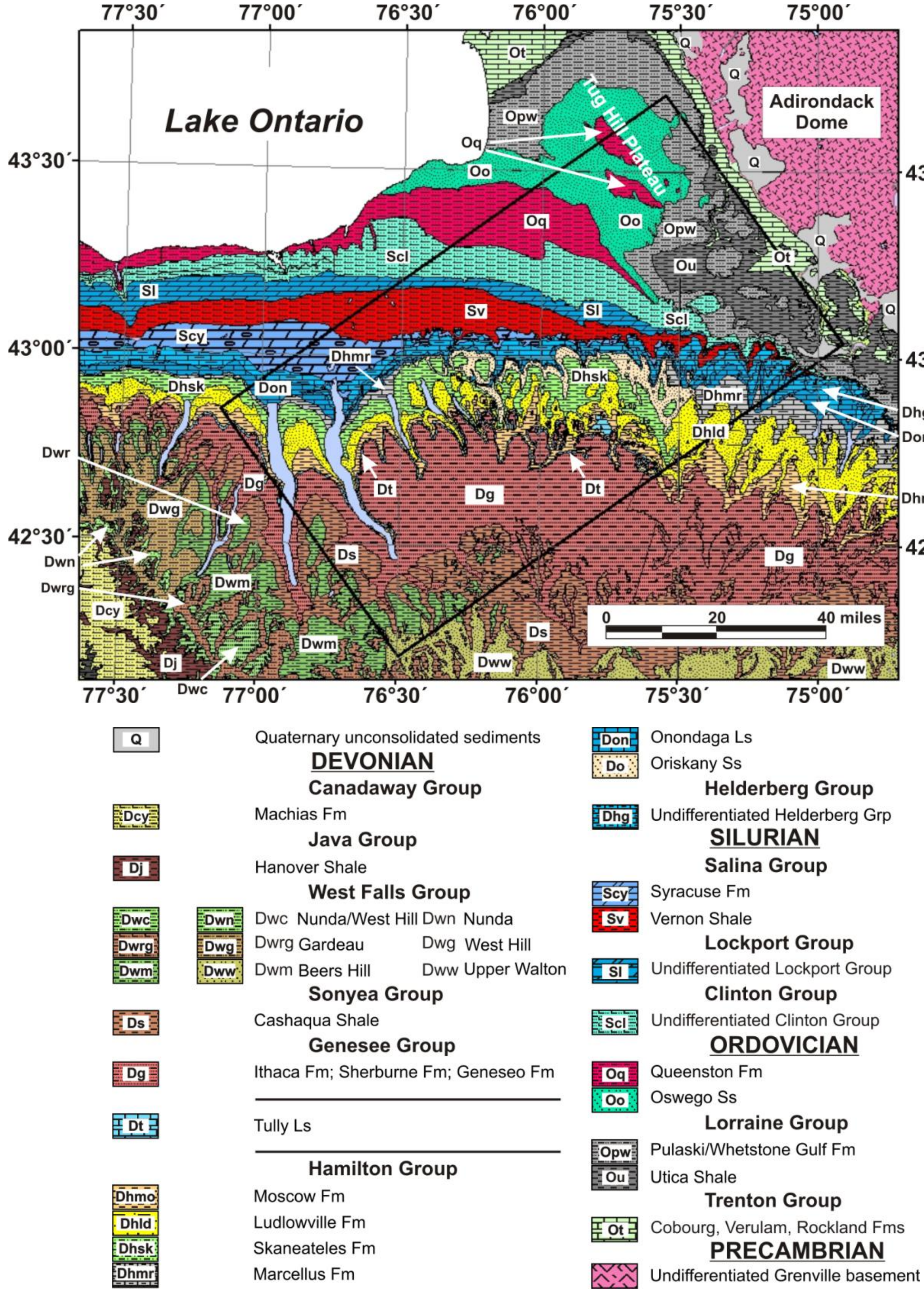


Figure 10 General Geological Map of Central New York State (From the New York State Geological Survey). Study Area Is Outlined by the Inclined, Black Rectangle.

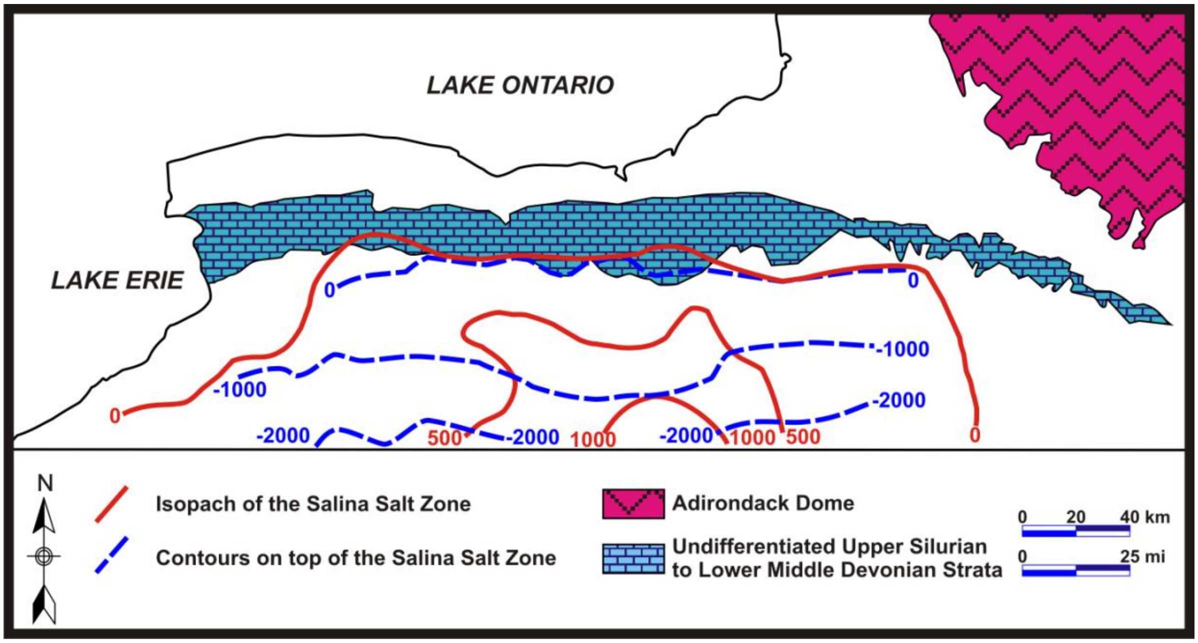


Figure 11 **Surface and Subsurface Distribution of the Salina Salt Zone. Structural Contours Illustrate the East-West Strike and Gentle, Southerly Dip Across Most of New York State (Data Summarized from Kreidler, 1957 Map reproduced from Kreidler, 1957)**

Figure 12 **Slump Folds in the Upper Onondaga Limestone at Station ROM-1 Caused By Salt Solution at Depth. See Figure 13 for Station Locations.**

Rocks on, and north of, the Allegheny Plateau in New York State appear to be undeformed, but that is an illusion. Wedel (1932) noted the existence of gentle east-northeast oriented folds in south-central New York State and attributed them to Appalachian folding. South-southwesterly dipping reverse faults oriented between 280° and 295° were described in the Syracuse area (Figure 13 for location) by Phillips (1955), Tolley (1957) and Chute (1964). Stroup et al (2006) identified several faults in the Skaneateles Lake area (Figure 13 for locations) based on remote sensing investigations. Scholz (personal communication) stated that there are faults which cross Seneca and Cayuga Lakes (Figure 13 for locations) and EarthSat (1997) interpreted a plethora of rather small-scale lineaments in the region encompassing those two lakes.

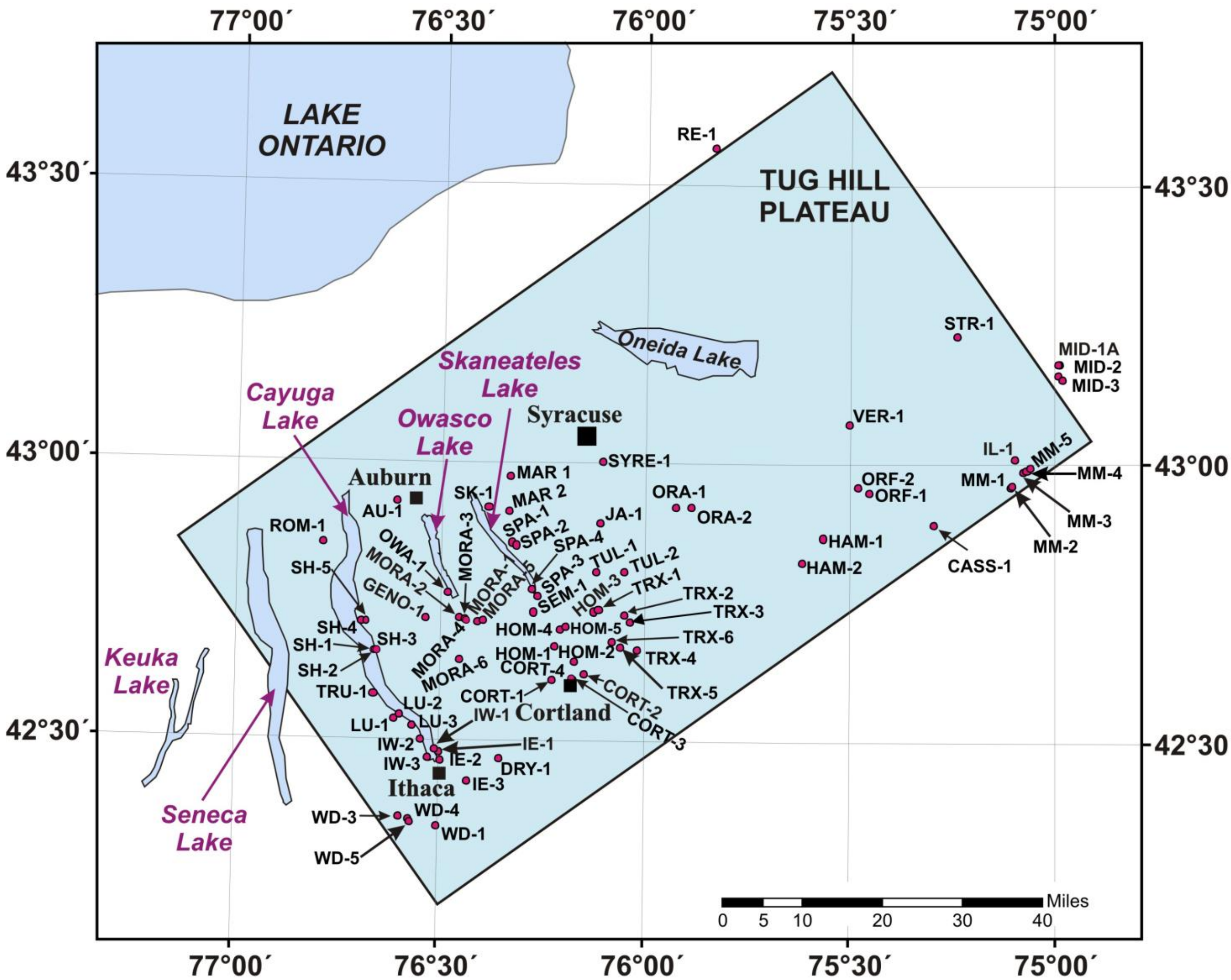


Figure 13 Station Location Map. Pale Blue-Green Rectangle is the Study Area.

4.2 Stratigraphy

The study area embodies rocks ranging from Middle Ordovician to Silurian carbonates and shales through to upper Devonian shales, siltstones and sandstones (Figure 10). Between them are Silurian-aged Clinton Group iron ore beds and Salina Group evaporites overlain by Lower to Middle Devonian carbonates. Three black shales, the Utica, Marcellus and Geneseo, are present within the sequence. In this study emphasis was placed on the sedimentary rocks exposed on the Allegheny Plateau, which is underlain by Lower to Upper Devonian strata (Table 1), therefore this section focuses on them.

Table 1. Devonian Units in Central New York State (Modified slightly from Allmon and Ross, 2005)

Upper Devonian	**Westfalls Group**	
	Sonyea Group	
	Genesee Group	Ithaca Formation
		Sherburne Formation
		Penn Yan Formation
		Geneseo Formation
Middle Devonian	Tully Formation (limestone)	
	Hamilton Group	Moscow Formation
		Ludlowville Formation
		Skaneateles Formation
		Marcellus Formation
	Onondaga Formation (limestone)	
Lower Devonian	Oriskany Formation	
	Manlius Formation	

Beginning at the base of the Devonian is the Manlius Formation of the Helderberg Group which, where observed, is comprised of medium light gray weathering, medium dark gray, thinly to thickly bedded micritic limestone with thin (1-2 inch) layers of argillaceous limestone and pinch and swell structures. Above that is the Oriskany Sandstone that was described by Rickard (1975) as embodying "*siliceous and calcareous quartz arenites, siliceous calcisiltites and calcarenites and quartz pebble conglomerates.*" Succeeding the Oriskany is the Onondaga Formation, which consists of four members, the Edgecliff, Nedrow, Moorehouse and Seneca. The Edgecliff is a light gray calcarenite that is readily distinguishable from the other three, which are medium to light gray, light gray weathering, fossiliferous calcilutites, plus or minus chert. Those three are difficult to separate from one another without the aid of fossils, which were used to divide the Onondaga into its component members (Oliver, 1954). Above the Onondaga fine to medium-grained clastic sedimentary rocks predominate except for the Tully

Formation (limestone) and limestones and calcareous facies in the Marcellus and Geneseo formations.

Immediately above the Onondaga is the shale-dominated Hamilton Group comprised of four formations (Table 1). The oldest, the Marcellus, rests directly on the Onondaga (Figure 14) and is made up of various combinations of shale and limestone, though only the black shale was seen across the study area. Limestone beds are not exposed everywhere yet even in their absence the carbonate affinity of the formation may be evident, at least locally, because of the presence of very darkly colored, elliptical and layer-parallel limestone concretions. Comprised of three shale members, the Union Springs, Chittenango and the Cardiff and one limestone member, the Cherry Valley, (Statkiewicz, 1956) the Marcellus is fundamentally a black to dark gray carbonaceous shale (Figures 14 and 15) making it an inviting natural gas exploration target at depth (Milici and Swezey, 2006; Milici, 2005; Wrightstone, 2009). Its map pattern shows an east-west strike across New York State (Figure 10), but when thickness information is provided the north-northeast grain of the rock and increased thickness to the east, indicating deposition into the Appalachian Basin, is unmistakable (Figure 16).

Figure 14 Contact Between the Gray Onondaga Limestone and the Overlying Black Marcellus Shale at Station ROM-1 (See Figure 13 for Location).

Figure 15 Black to Dark Gray Marcellus Shale at Station HAM-1.

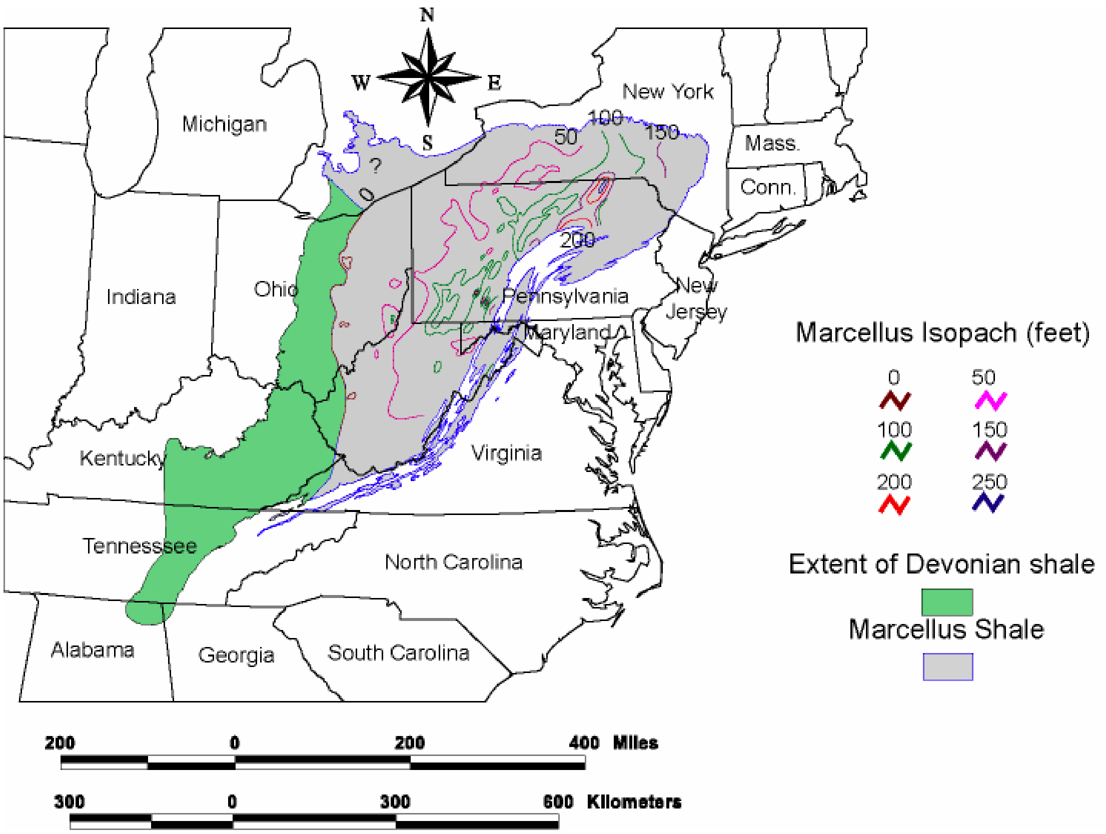


Figure 16 Regional Distribution and Thickness of the Marcellus Shale (From Milici, 2005).

Overlying the Marcellus are the Skaneateles and Ludlowville formations. The Skaneateles Formation is mostly a limy shale with a variable calcareous component (Statkiewicz, 1956). Muskatt (1965) described the upper member of the Skaneateles, the Centerfield, as being about 30 feet thick in the Syracuse area with the lower part a shaly to flaggy calcareous silty shale that grades upward into a flaggy to massive, partially cross-bedded calcareous siltstone. Concretions appear throughout the member.

Four members make up the Ludlowville. Smith (1935) noted that the basal member, the Otisco, is a 150-foot thick shale to silty shale unit. Overlying the Otisco is the 50-foot thick Ivy Point Member, which is mostly siltstone with an intervening silty shale. That is succeeded upward by the Spafford shale member, which also contains some siltstone, for a total thickness of approximately 25 feet, and finally the Owasco, which is a commonly cross bedded limy siltstone unit, 1 to 2 feet thick. According to Glenn (1957) the Ludlowville in the Otisco Valley is comprised of two members, the Spafford and the Owasco. There the older Spafford is about 20 feet thick, though it is 25 feet thick at its type locality. It is a moderately calcareous, medium to dark gray fissile shale, but "*approximately 13 feet from the top of the member is a highly calcareous lens*". The Owasco is less than 3 feet thick, thereby indicating the total thickness of the Ludlowville to be about 30 feet. That member is "*a cross-bedded, fine-grained, medium gray calcareous sandstone that weathers medium light gray*", therefore the contact between the two members is very distinctive.

At the top of the Hamilton Group is the Moscow Formation, commonly a brown-gray weathering, medium dark brown-gray to dark gray, weakly to non-calcareous fissile shale, though the formation also embodies similarly colored non-calcareous siltstone to fine-grained sandstone (Figure 17). Elongate concretions of medium- to medium-dark brownish gray calcilutite are one of the features in the shale (Figure 18), though they are neither omnipresent, nor existent in the siltstone. Thickness is about 175 feet.

Above the Hamilton Group is the Tully Limestone, which is, in turn, overlain by the Genesee and Sonyea groups. The Tully is a rather thickly bedded, fossiliferous, light gray weathering, medium to dark gray calcilutite to shaly calcilutite within which at least one disconformity was observed. Cubitt et al (1978) noted that the unit is generally less than 30 feet thick and rests unconformably on the Hamilton Group.

Figure 17 Siltstone Beds in the Moscow Formation at Station HAM-2.

Figure 18 Limestone Concretions in Shale of the Moscow Formation at Station TUL-1.

Overlying the Tully is the Genesee Group which comprises the Geneseo Shale, Sherburne and Ithaca formations (Figure 19). Starting at the base of the Genesee Group, the Genesee Shale is a non-calcareous black carbonaceous shale. There is no resemblance between the Geneseo and the other two formations within the Genesee Group, thereby making its inclusion in the group questionable. The Ithaca and Sherburne are lithologically similar in that they contain layers of impure sandstone, siltstone and shale and appear to have formed under identical environmental conditions. Cross beds (Figure 20) and paleochannels suggest that both were deposited under fluvial conditions.

Parkinson (1959) described the Sherburne as being at least 200 feet thick and comprised of thinly to thickly bedded siltstones and sandstones, and thinly bedded slightly sandy shales. The unit weathers medium gray to pale brown or brown-gray and is marked locally by small-scale cross beds and ripple marks. Glenn (1957) confirmed the minimum thickness to be 200 feet and described the sandstones and shales as being generally medium-to light gray although some are dark gray. He added that the shales are sandy and micaceous, the sandstones are commonly flaggy and become thicker and more abundant at the top, and that the upper part of the formation is lithologically indistinguishable from the overlying Ithaca.

Shales, siltstones and sandstones, about 440 feet thick, constitute the Ithaca Formation (Glenn, 1957). Because of its durability and relative resistance to erosion, the Ithaca was the most studied formation in this investigation. Characteristics of the formation observed during this study are largely in line with those of Glenn (1957), with both the sandstones and siltstones commonly argillaceous and at various locations also containing noticeable amounts of carbonate. The unit appears in various shades of gray or even pale greenish-gray as a result of minor amounts of chlorite. Commonly the formation is comprised of an interlayered sequence of at least two, if not all three, of the predominant rock types. At some locations fossils were identified and the sandstone or siltstone/shale ratio is approximately 60%/40%. Thin laminations and cross laminations (Figure 20) along with channels are features of the formation.

The Cashaqua Formation is in the Sonyea Group and comprises non-calcareous sandstones and shales. Shales are gray-brown weathering, black or very dark gray and locally rusty to gray-brown weathering with individual layers up to about 2 feet in thickness, whereas the sandstones occur as layers of thinly laminated and locally thinly cross-laminated gray brown weathering, medium gray rocks ranging from about 1 inch to 2 feet in thickness. At some exposures only the sandstone is present. Dugolinsky (1972) described the Enfield, which is in the same stratigraphic position as the Cashaqua, but lies to the east, as comprising "*interbedded siltstones, fine-grained sandstones and gray and dark-gray silty shales*". The Cashaqua is similar to the Ithaca except that the sandstone layers in the Ithaca are noticeably thicker (Figure 21).

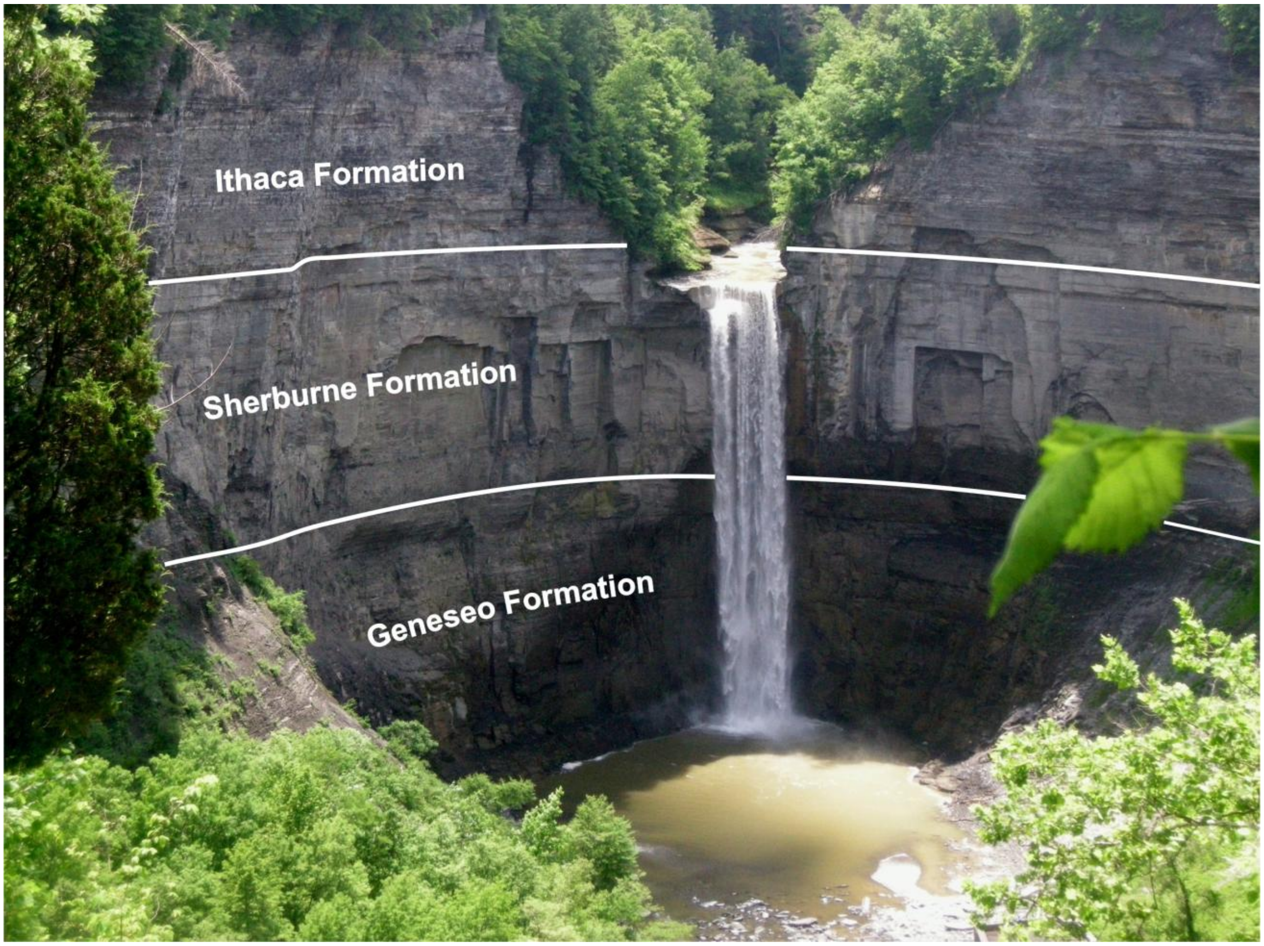


Figure 19 Cross Section of the Genesee Group at Taughannock Falls.

Figure 20 Cross Laminations (Top) and Channel (Bottom) in Sandstone of the Ithaca Formation.

Figure 21 Comparison Between the Ithaca (Top) and the Cashaqua Formations (Bottom). The Lithological Makeup of the Two Formations is Similar, but the Sandstone Layers in the Ithaca are Considerably Thicker Than Their Counterparts in the Cashaqua.

4.3. Topographic Lineaments

A lineament-based structural analysis was undertaken utilizing: a) Landsat 7 multispectral color products (Figure 22) and b) shaded relief products, with illumination from the northwest, north, northeast and east (Figure 23). The analysis was conducted in two steps with the first focusing on topographic lineaments at a scale ranging from 1:150,000 to 1:250,000. Secondly linear magnetic and gravity anomalies were identified at scales ranging from 1:500,000 to 1:1,000,000 and their orientations and locations were compared to those of the topographic lineaments.

Five sets of topographic lineaments were recognized (Figure 24) and are interpreted as expressions of regional scarps and hydrographic patterns, some of which are probably associated with faults and fractures. They are not evenly distributed throughout, but are more numerous and concentrated in the southeastern part than in the northwestern part, most likely a reflection of the contrasting physiography between the low-relief Lake Ontario plain and the elevated and dissected Allegheny Plateau. The boundary between the different concentrations seems to follow a NE-SW trend, which is parallel to the predominant grain in the Precambrian basement (Figure 24).

Generally the strata on, and north of, the Allegheny Plateau appear to be undeformed except for fractures. In such situations orthogonal fractures are very common because the major axes of the causative stress field are orthogonal. The interpreted lineaments may be grouped into two systems of orthogonal sets, with the sets in one system oriented north-northeast and east-southeast, and in the other oriented east-northeast and south-southeast (Figure 25). Orientations of the two sets in the latter system suggest that they may be cogenetic with the Appalachian Basin, which trends approximately east-northeast south of the study area, but there is an implication that the two lineament systems may be unrelated. Fractures unaccompanied by distinct kinematic indicators, however, make it very easy to speculate, therefore it is perhaps likely that all four sets (two systems) are cogenetic and coeval. If the four sets are grouped differently than shown in Figure 25 then, based solely on geometry, two sets of interpreted conjugate shear fractures can be recognized. In the first instance those that trend east-northeast and east-southeast subtend an acute dihedral angle of 55° and in the second the north-northeast and south-southeast sets also intersect at 55° (Figure 24); the principal stress axes would be mutually perpendicular. Regardless no firm conclusions can be drawn about the genesis of the fractures and it is not unreasonable to postulate that members of all sets may have been reactivated by more recent events.

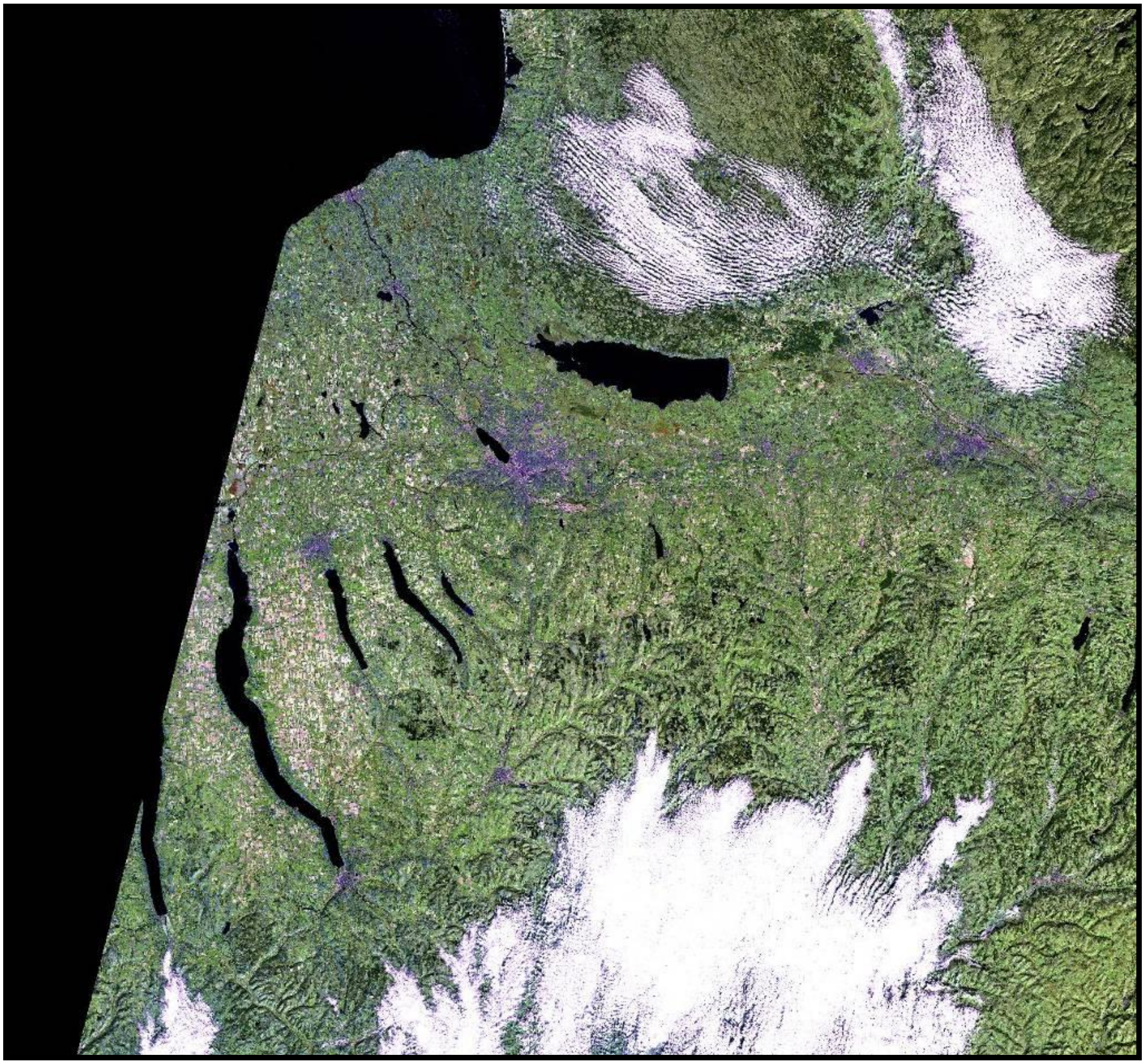


Figure 22 Landsat 7 Color Composite of Channels TM7, 5 and 2 in Red, Green and Blue.

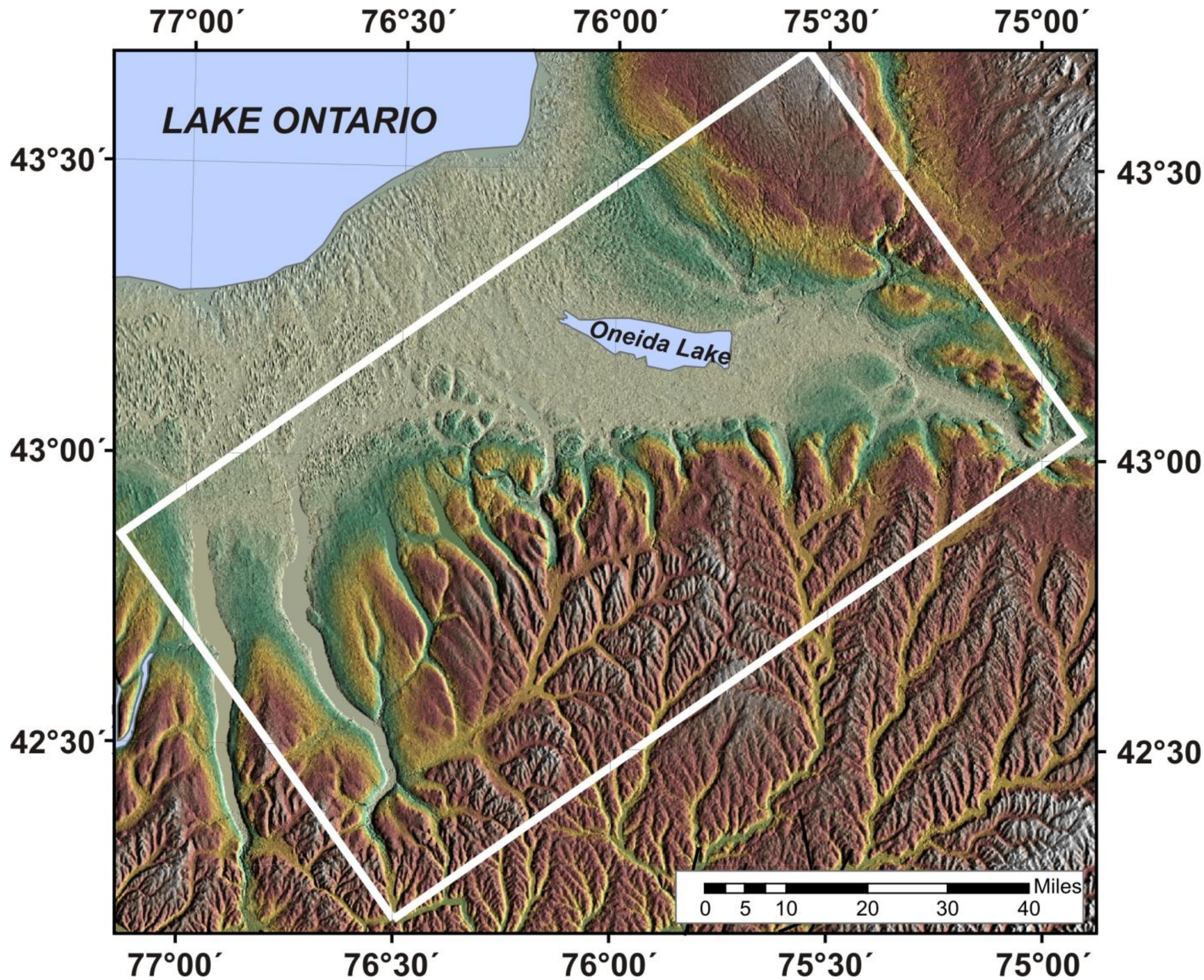


Figure 23 Color Shaded Relief Image of Central New York State. Inclined White Rectangle Denotes Study Area.

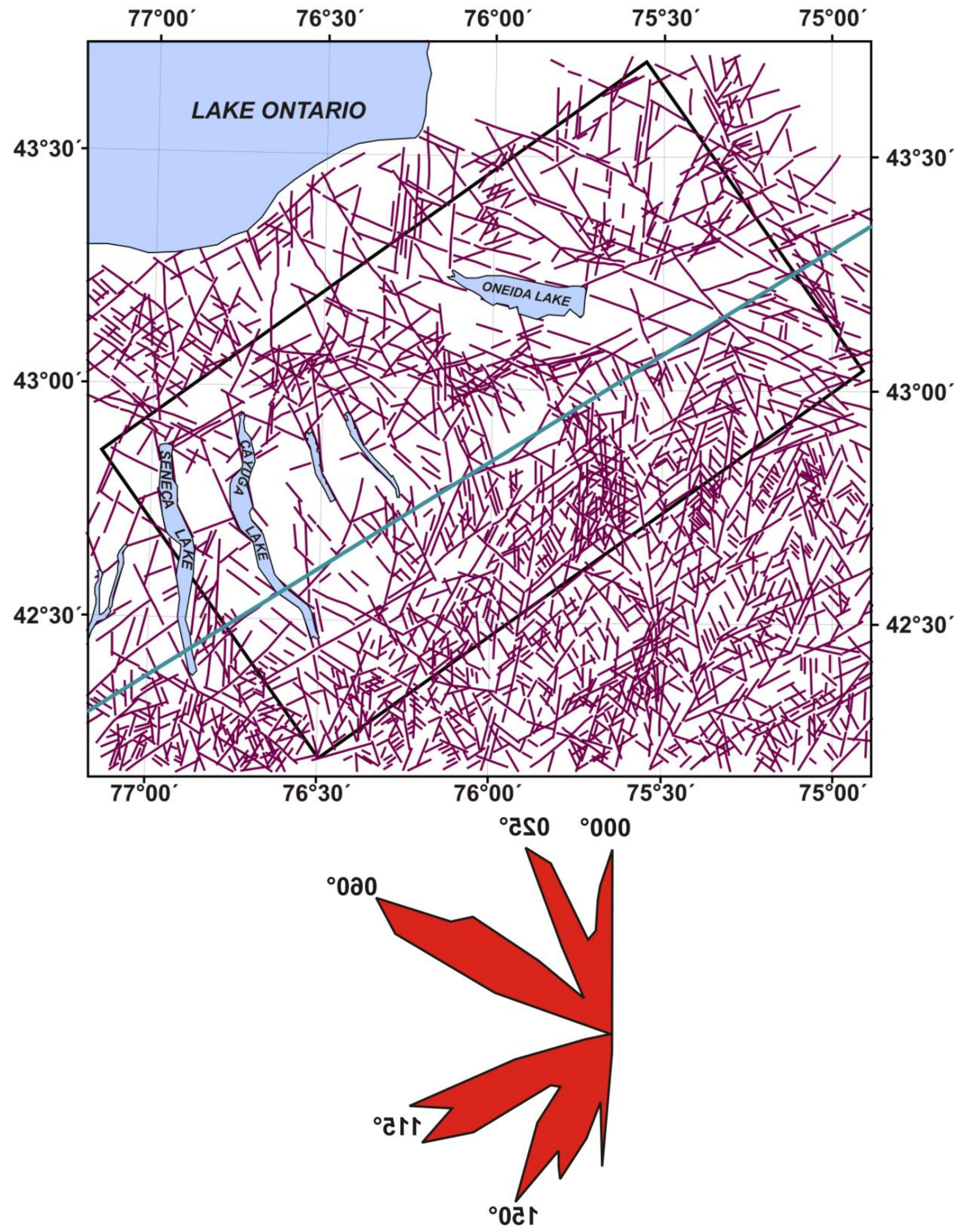


Figure 24 Interpreted Topographic Lineaments, Which Define Five Orientation Maxima, Shown in the Rose Diagram. The Blue-Green Line Separates a Generally Higher Concentration of Lineaments (to the SE) From a Lower Concentration (to the NW). Black Rectangle Encloses the Study Area.

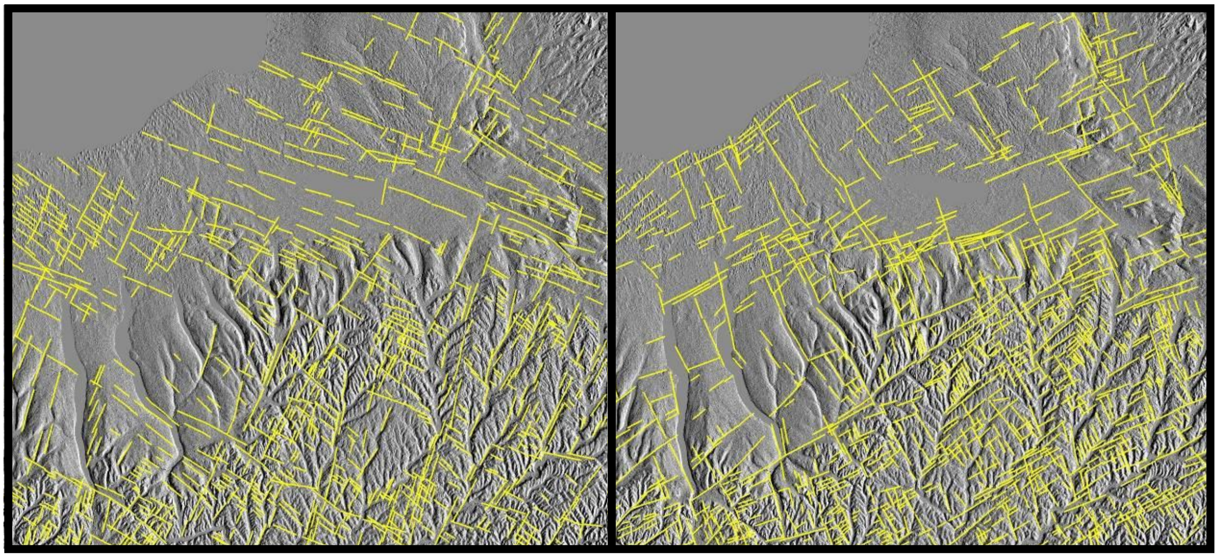


Figure 25 Two Systems of Orthogonal Sets of Interpreted Lineaments Shown in Separate Panels for Emphasis: NNE-ESE Network (Left) vs ENE-SSE Network (Right).

A second analysis was undertaken at scales ranging from 1:250,000 to 1:500,000 to identify lineaments which may be regional faults. The analysis consists of reviewing the lineament interpretation with the post-processing of the digital elevation data showing the relative topographical changes. This type of processing is based on the calculation of the elevation differences within a pre-defined convolution window. The color image resulting from the process is shown in Figure 26a, where elevation differences, directly related to the degree of erosion, range from blue denoting less erosion and minor elevation changes to red signifying greater erosion and high elevation changes. This technique allows for the identification of sharply defined major lineaments (Figure 26b).

4.4 Gravity Lineaments

Linear Bouguer anomalies (Figure 27) show a dominant trend parallel to the northeast to east-northeast fabric in the Grenville basement, though some trend southeast and still others are oriented nearly north-south. Good spatial correlations exist between many topographic lineaments and linear gravity anomalies suggesting that, in those cases, the regional topographic lineaments originated as fractures or faults in the Grenville basement and were later reactivated to cut the Paleozoic strata at the surface. That is poignantly illustrated by comparing the southeastern part of the large, positive northeast trending gravity anomaly (area in pinkish-red and a thin yellow border) that dominates the image in Figure 27, with a break in slope of the Utica Shale and nearly aligned topographic lineaments on the surface (Figure 28).

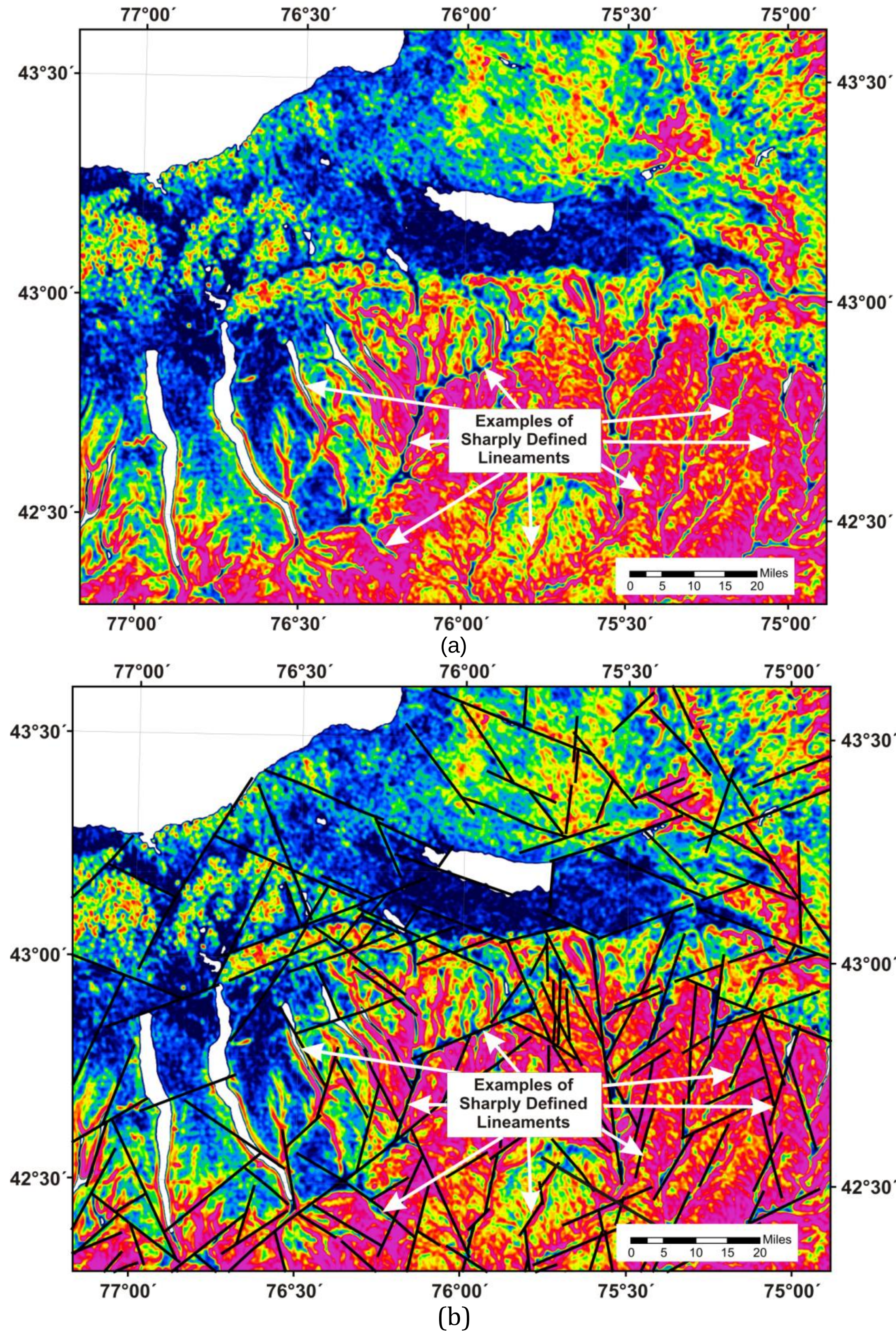


Figure 26 Topographic Texture Map Showing Sharply Defined Linear Features. Lakes Are in White. Bottom Figure Shows Interpreted Major Lineaments.

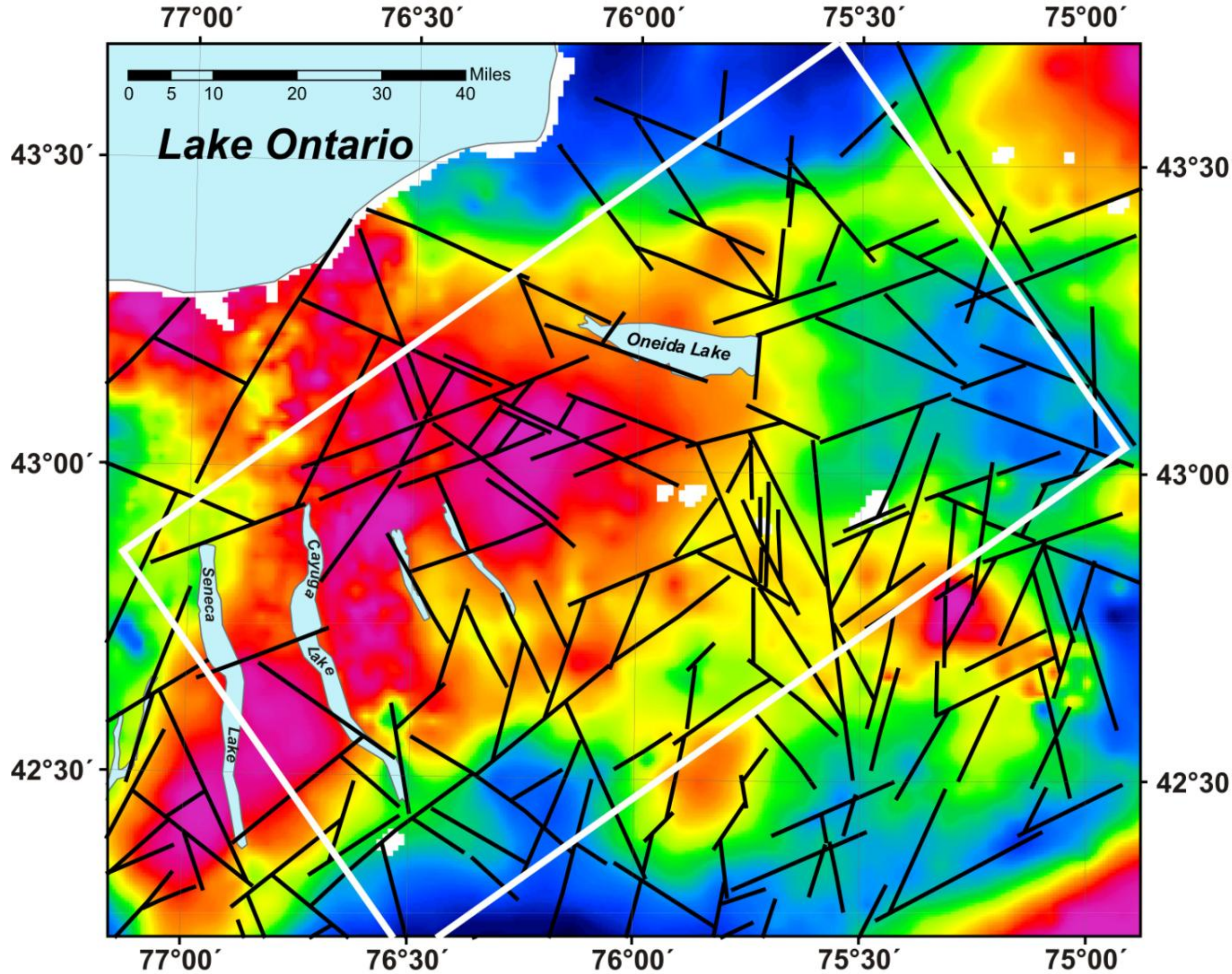
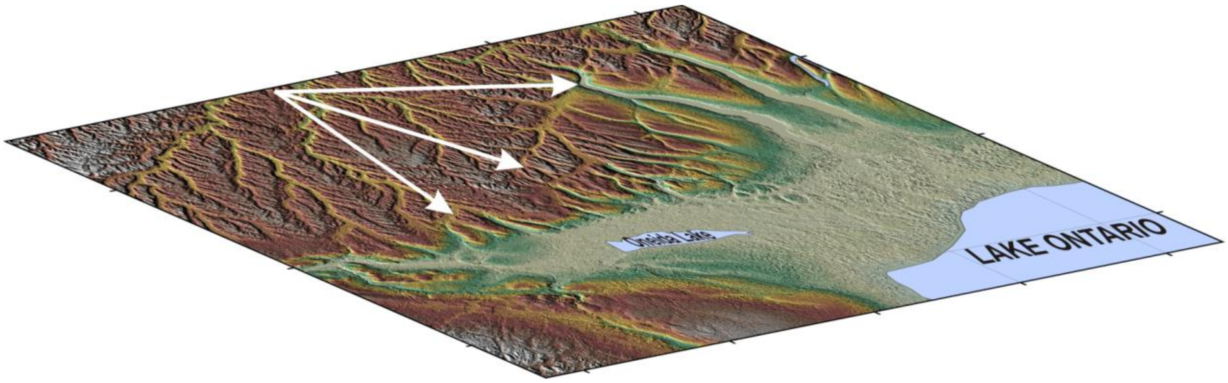
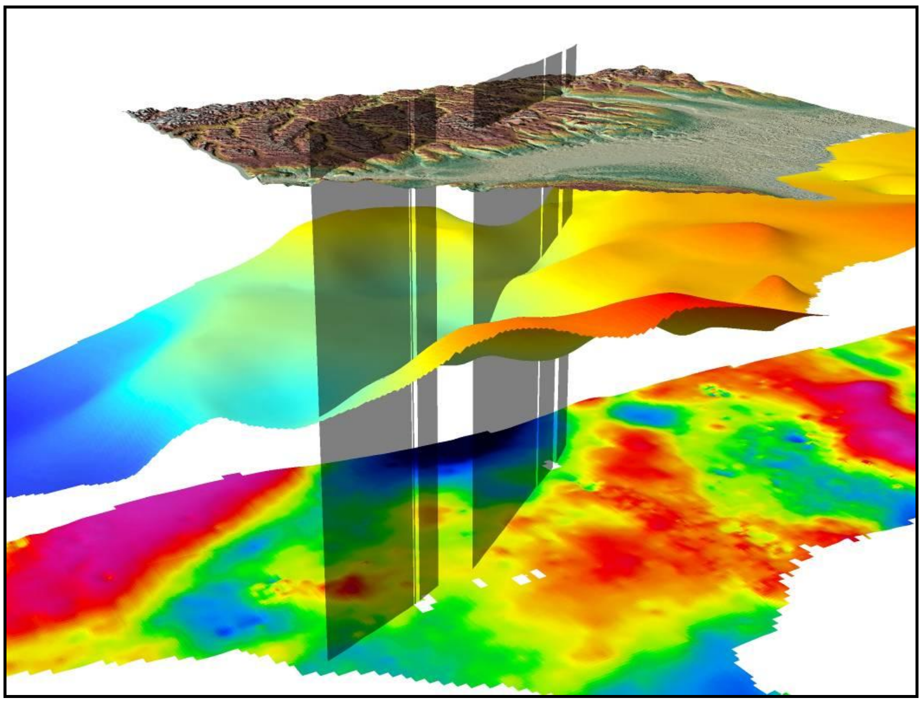


Figure 27 Interpreted Topographic Lineaments Superimposed on Bouguer Gravity Anomalies. Inclined White Rectangle Outlines the Study Area.



(a)



(b)

Figure 28 3D Perspective Looking Southwest Showing Nearly Aligned Topographic Lineaments, Indicated by the Arrows in (a), That Correlate With (b) the Southeastern Limit of the Dominant Gravimetric Anomaly, Also Seen in Figure 27, and With A Break in Slope in The Intermediate Layer That Represents an Approximation of the Top of the Utica Shale (Data Source - the New York State Museum).

4.5 Magnetic Lineaments

The magnetic data were acquired from an airborne survey (Figure 29), but because of locally inadequate resolution, a ground-based magnetometer survey was also conducted. The magnetic trends are predominantly northeast to north-northeast and correlate quite well with their topographic counterparts. That relationship also applies to those oriented east-northeast and west-northwest, though the correlation between a number of west-northwest trending magnetic and topographic lineaments appears to be more subtle than the others. As with the gravity lineaments the correlation between the magnetic and topographic lineaments reveals probable faults or fractures that likely originate in the Grenville basement, but were later reactivated allowing them to propagate to the surface.

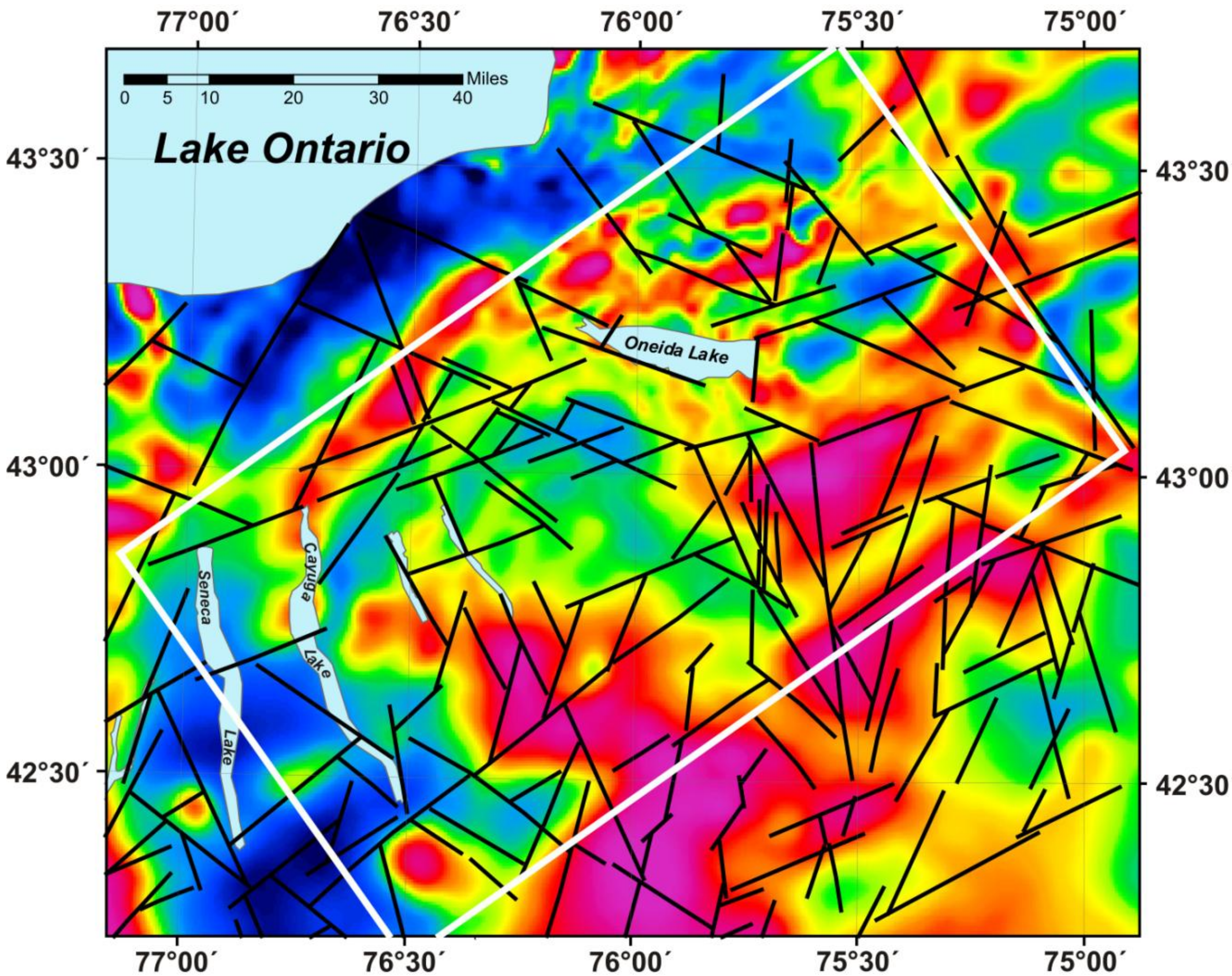


Figure 29 Interpreted Topographic Lineaments Superimposed on the Total Aeromagnetic Field. Inclined White Rectangle Outlines the Study Area.

4.6 Fractures

Gently and moderately dipping fractures are present (Figure 30), but most fractures are vertical to nearly vertical (Figures 31 - 33), oriented north-northwest to northwest and part of a regional fracture system. Though different fracture sets, defined by contour maxima and written as strike/dip, may dominate at different stations, the overall fracture pattern is rather consistent throughout. When all fractures from all stations are plotted and contoured on a single diagram they define two prominent mutually perpendicular sets, 067°/89° (right-hand rule) and 344°/85° (Figure 32), an expectation of fractures in virtually horizontal sedimentary rocks. A third set is also defined, 285°/88°, but is much less evident. Comparing the two main fracture sets with the principal lineament sets shows that, as anticipated for vertical to nearly vertical planes of weakness, they are just about parallel to each other (Figures 24 and 32).

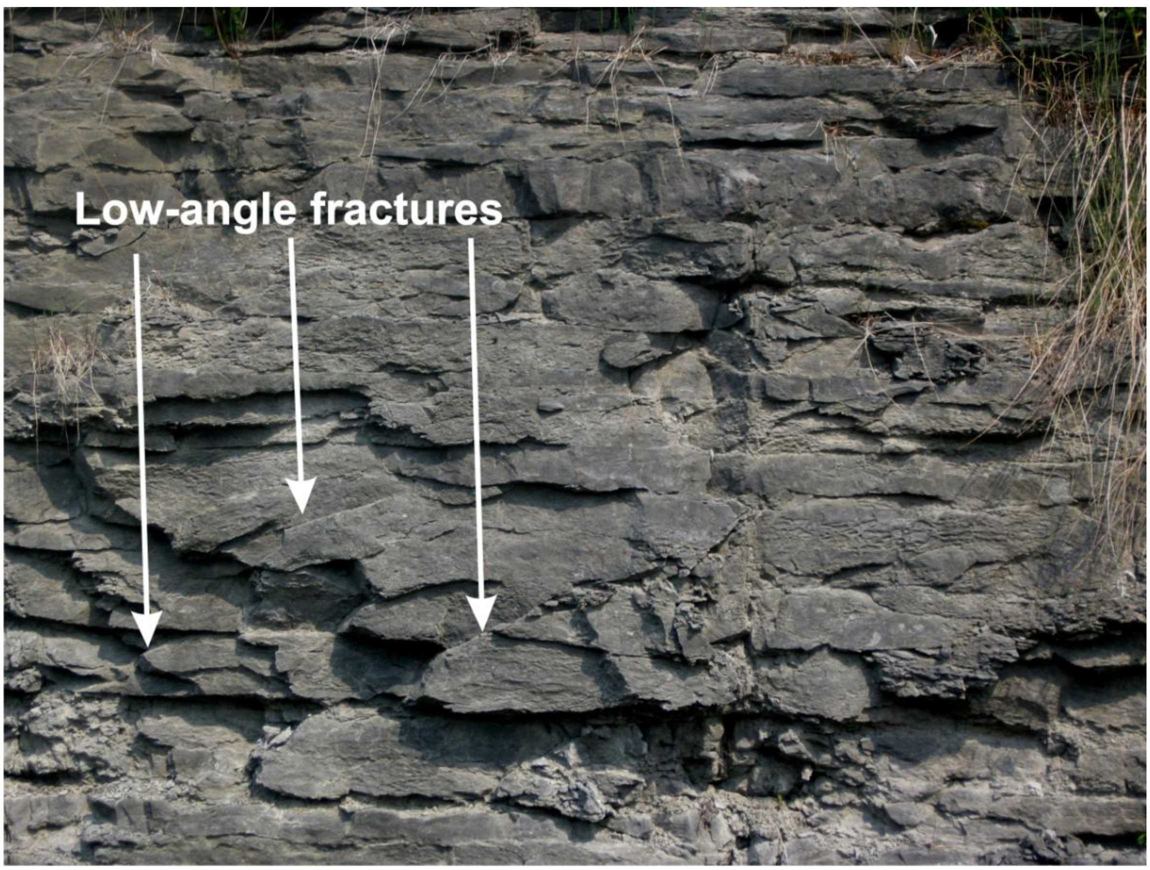


Figure 30 Gently Dipping Fractures in Sandstone of the Ithaca Formation at Station IE-1.

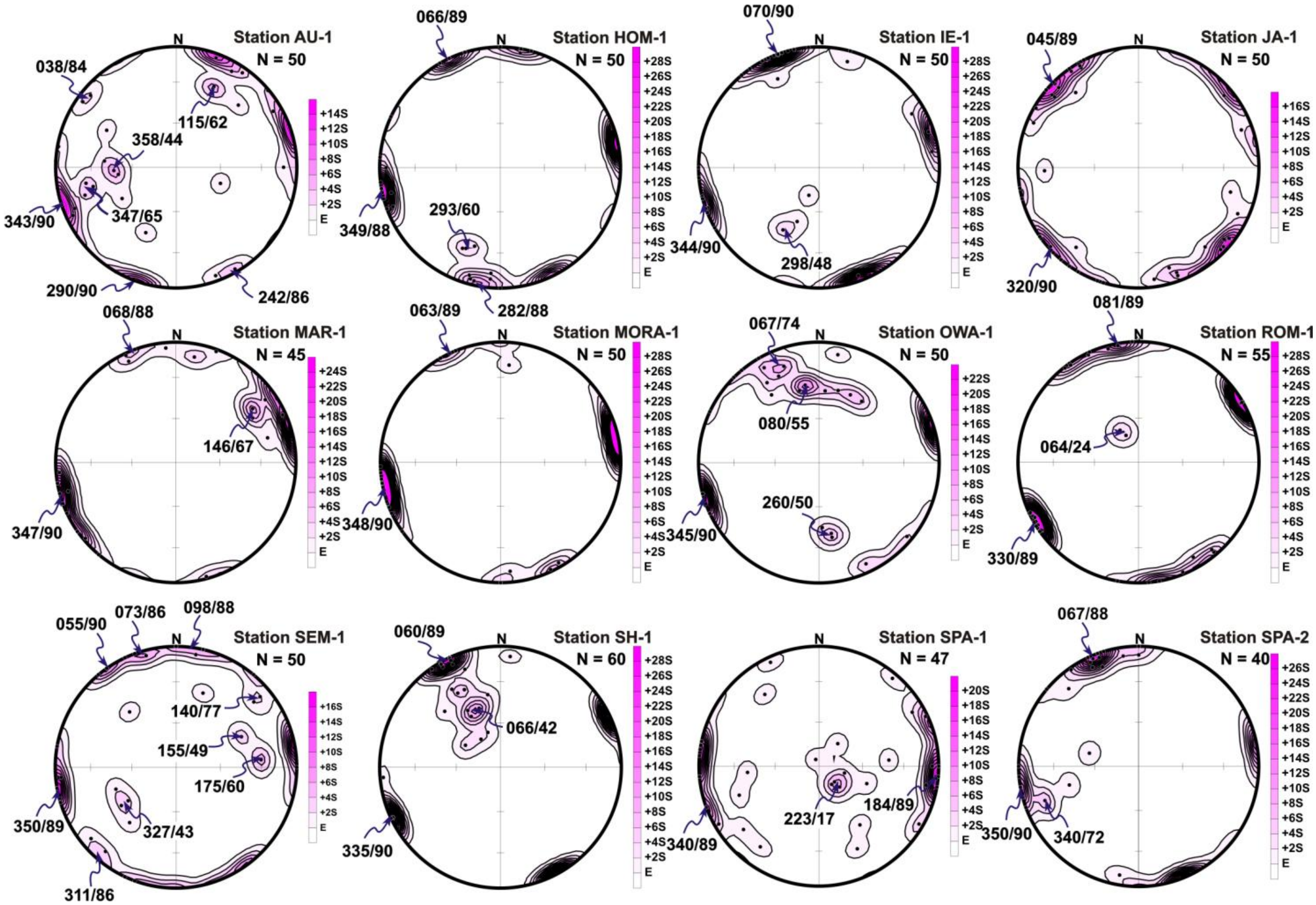


Figure 31 Equal Area, Lower Hemisphere Projections of Poles to Fractures.

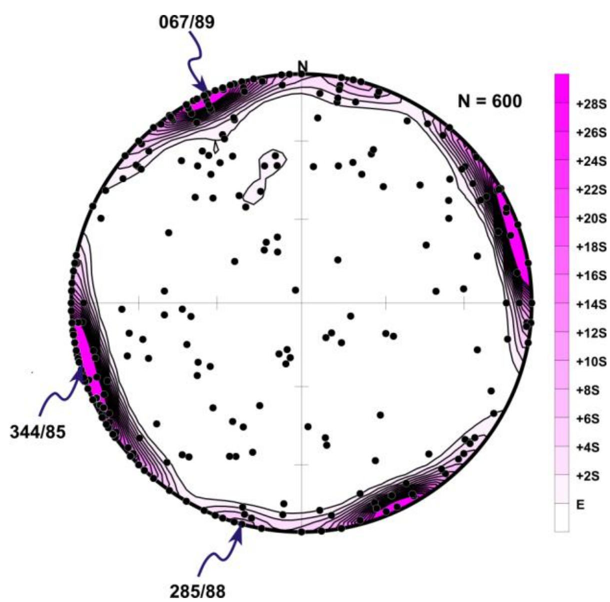


Figure 32 Composite Plot of Poles to Fractures Throughout the Entire Study Area.

Figure 33 Examples of Vertical Fractures Which Predominate in the Study Area: (Top) Cutting the Marcellus Shale at Station MAR-2; (Bottom) The Moscow Formation at Station SH-1.

4.7 Lineaments and Bedrock Geology

Most, if not all, topographic lineaments are probably mega-fractures and several may also be faults. North-northwest-trending lineaments abruptly truncate the Proterozoic-aged Grenville basement exposed in the Adirondack Dome and separate it from the Lower Paleozoic rocks of the Tug Hill Plateau to the west (Figure 34) along the Black River fault (JL Wallach Geosciences Inc., 2000). Other lineaments, oriented both northeast and southeast, cut across the strike of beds and mark formational boundaries, suggesting that they may also be faults, although care must be exercised in factoring in topographic effects on inclined beds, as are present in central New York State. Some show changes in the thickness of affected rock units, as seen in map-view, which might suggest syn-depositional faulting.

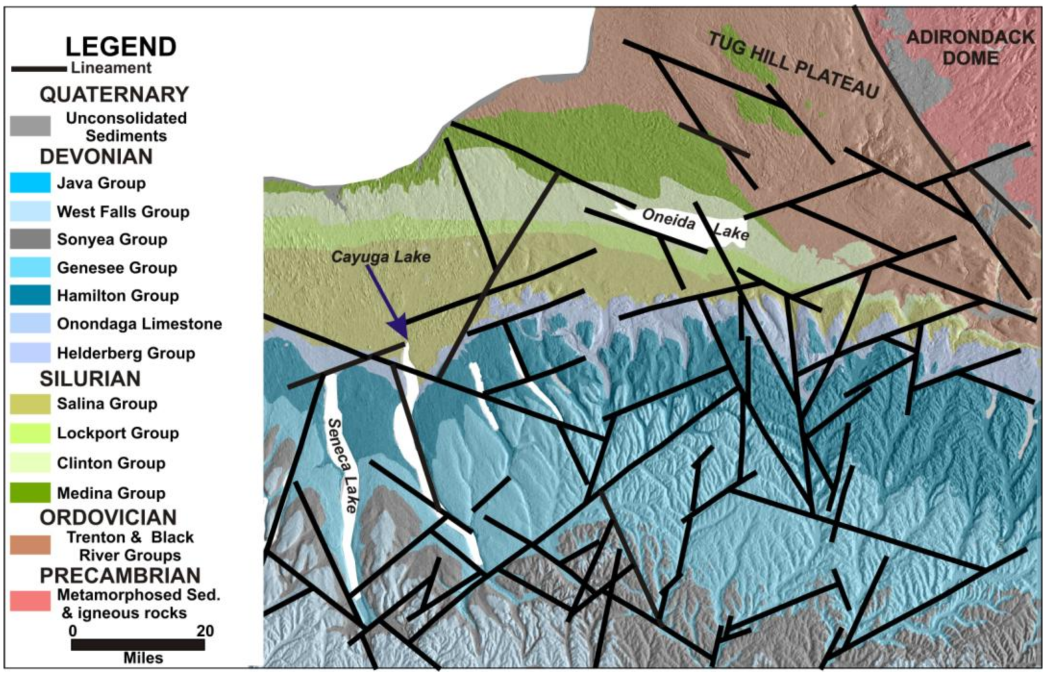


Figure 34 Major Topographic Lineaments, Which May be Faults, Superimposed on the Regional Geology.

4.8 Faults and Folds

Strata strike almost due east-west, and dip gently (less than 1°) to the south, however data from previous works commonly quote strikes as being northwest with a “regional” dip to the southwest. For example, Parkinson (1959) and Wolle (1956) reported that in the Tully area, south of Syracuse, the regional strike is N60°W with a southwesterly dip of 45-50 feet/mile. Glenn (1957) documented a nearly parallel strike and dip of N58°W, 42-50 feet/mile towards the southwest in the Otisco Valley. Sutton (1959) recorded a dip of 40 feet per mile in the direction S20°W (strike N70°W) in an area east and southeast of Cayuga Lake. The inconsistency of those orientations with the geological map pattern showing an overall east-west strike may be explained by the authors not having recognized faults, the existence of which might account for deviations from the true strike and dip. Suspicion of that possibility emanates from the observation of many remotely sensed lineaments marking formational boundaries (Figure 34) and, therefore, being interpreted as faults. Faults were, however, recognized by some previous workers, such as Lugert and others (2005), and Sutton (1959) noted the existence of a short east-northeast fault in which the south side moved up relative to the north side.

Deformed rocks were seen on outcrops widely dispersed throughout the area. Near Ithaca (Figure 13 for location) inclined strata strike approximately parallel to the magnetic fabric of the subsurface Precambrian basement at stations IE-2 and WD-1 (Figures 35 – 37 and Table 2), which is also where Wedel (1932) identified rather gentle folding associated with Appalachian crustal compression (Figure 38). Convoluted laminations, and rotated and internally deformed fragments of sandstone, indicative of seismicity prior to complete lithification of the Upper Devonian beds in which they occur, were also observed at station IW-1 and IE-2 (Figures 39 and 40), respectively. East of Skaneateles Lake, south of Syracuse, inclined strata (Figure 41) and a monoclinal warp (Figure 42) deform the Tully Limestone and, as in the Ithaca area, the trends of the beds parallel the magnetic fabric (Figure 43).

Two reverse faults at Station ROM-1 (Figure 13 for location), just west of the north end of Cayuga Lake, cut the Onondaga Limestone. One reveals a fold in the hanging wall and displaces the Onondaga – Marcellus contact (Figure 44) whereas the second is exposed as bedding plane slip that is succeeded by a monocline as the fault climbs section at an angle of 30° (Figure 45). Both are inferred to be cogenetic with the Appalachian folding to the south, but are not interpreted as being related to the west-northwest striking reverse faults in the Syracuse area (e.g. Chute, 1964). Undoubtedly there are other tectonic structures deforming the rocks of the plateau and the land to the north, but the only other folding seen was caused by subsidence attendant upon evaporite solution (Phillips, 1959) and recognized along a thin east-west belt north of and bordering the Allegheny Plateau (Figure 12).

Figure 35 Inclined Strata in the Ithaca Formation at Station IE-2

Figure 36 Inclined Strata in Silty Sandstone of the Beer Hill Formation at Station WD-1

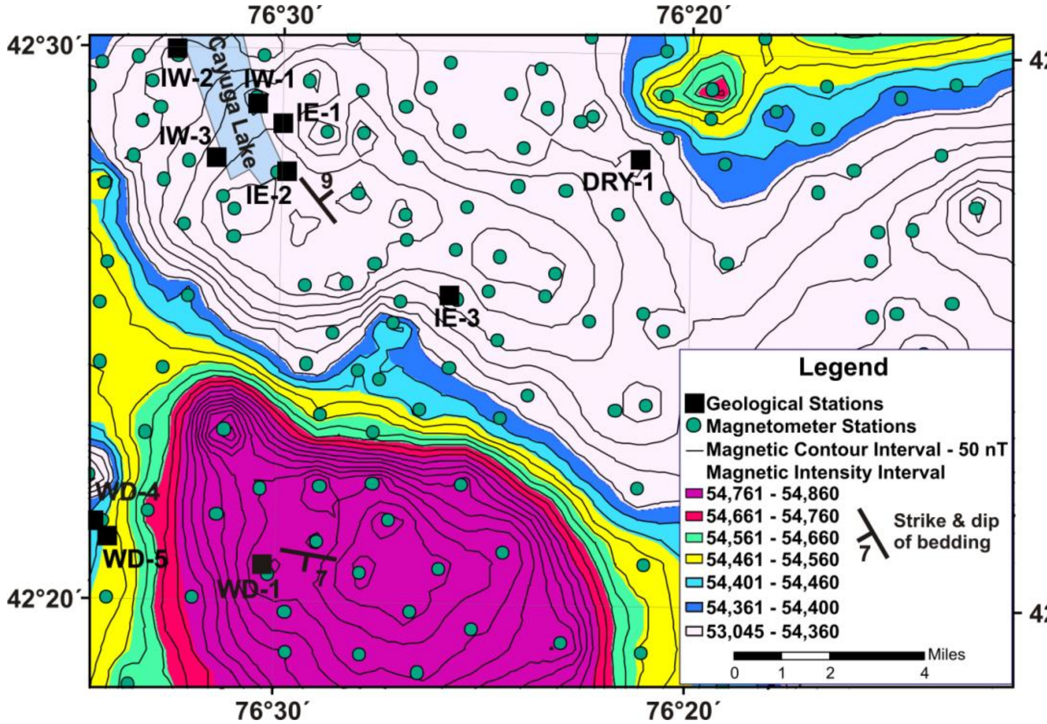


Figure 37 Total-Field Magnetic Map of the Area Enclosing Tilted Strata at Stations IE-2 & WD-1 (Figures 35 & 36), the Strikes of Which Parallel the Magnetic Grain.

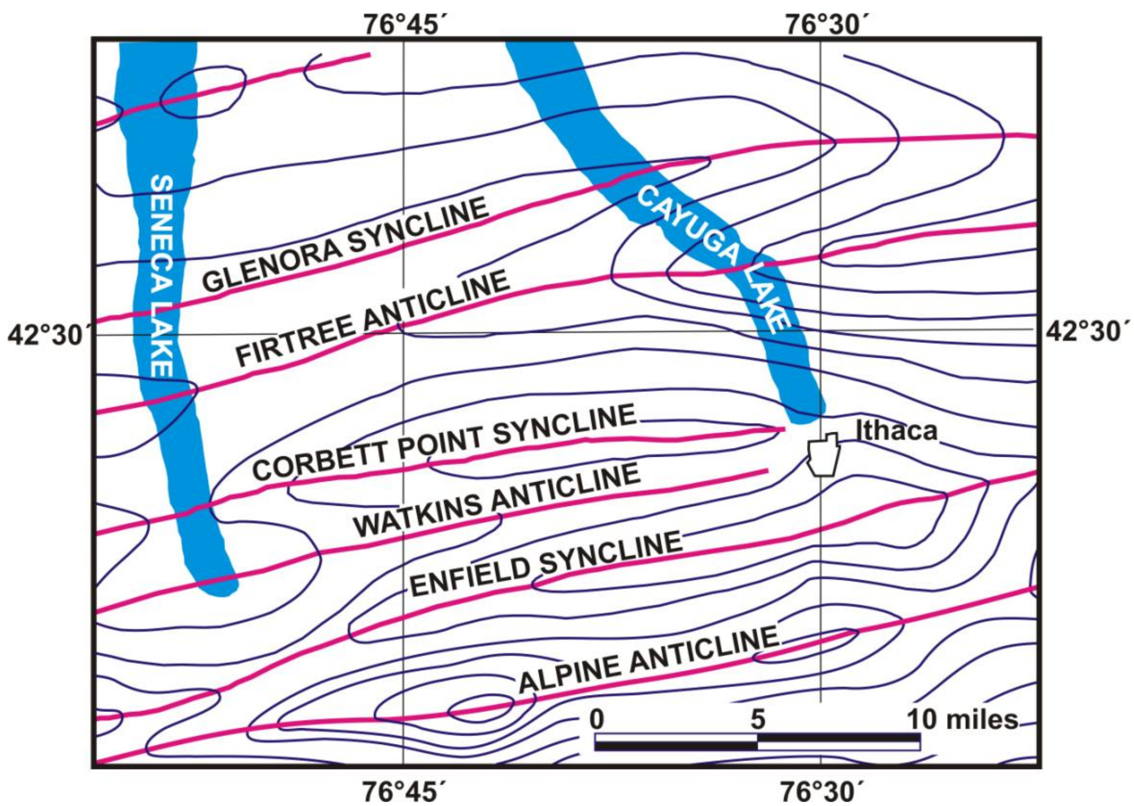


Figure 38 Folds in the Southern Cayuga-Seneca Lakes Area (Excerpted and Redrawn From Wedel, 1932).

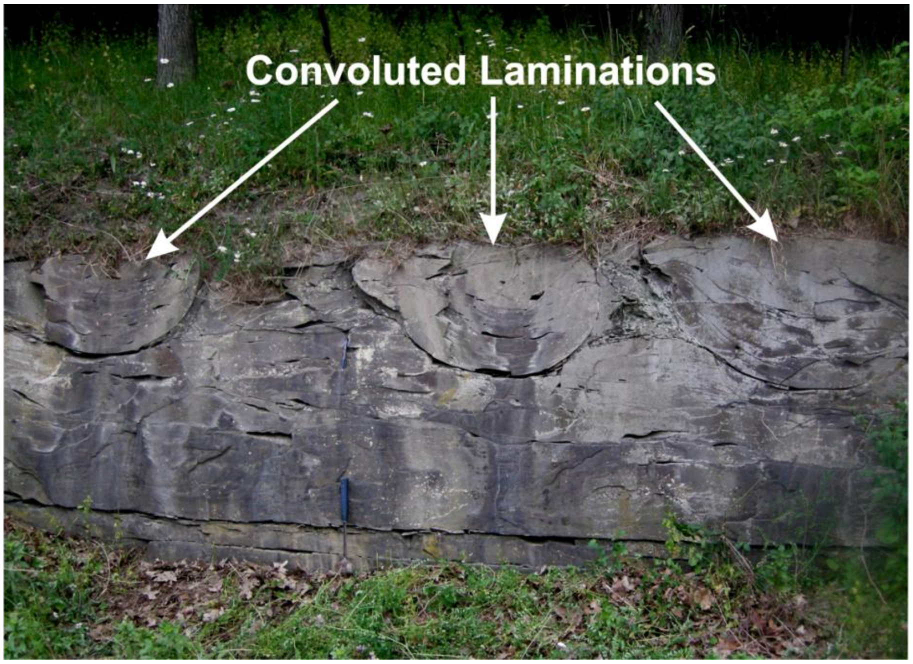


Figure 39 **Convoluted Laminations in Fine-Grained Sandstone of the Ithaca Formation at Station IW-1.**

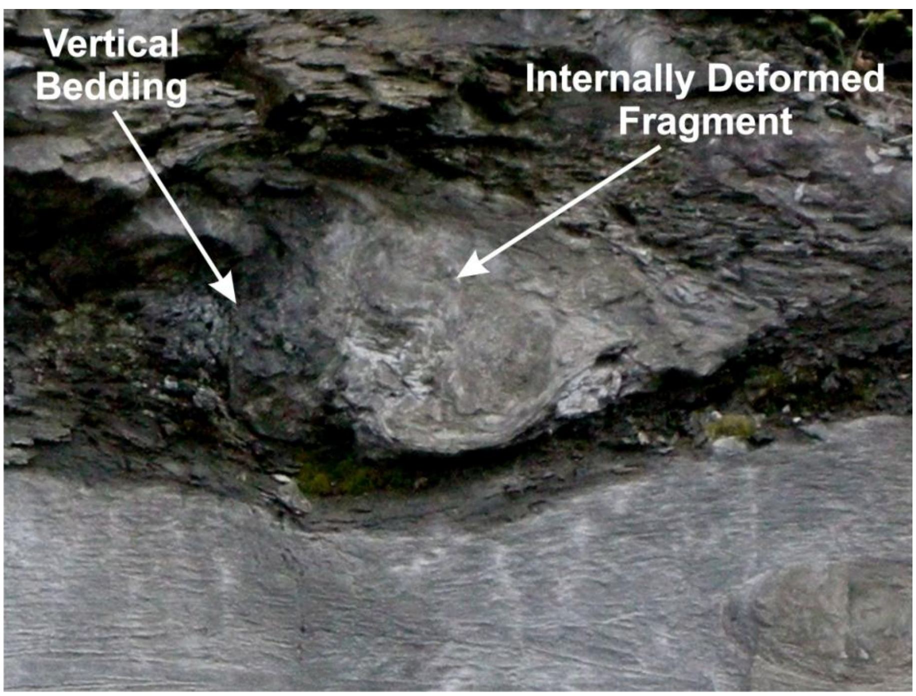


Figure 40 **Rotated and Internally Deformed Block of Sandstone in the Ithaca Formation at Station IE-2. Strata on the Left Side of That Block, Immediately Beneath the Small Arch are Nearly Vertical. Features in This and in Figure 39 are Inferred to be the Results of Paleoseismic Activity in the Ithaca Area Prior to the Complete Lithification of the Sediments.**

Figure 41 Inclined Strata Oriented 175°/30° in the Tully Limestone at Station SPA-2

Figure 42 Small Monocline at Station SPA-2

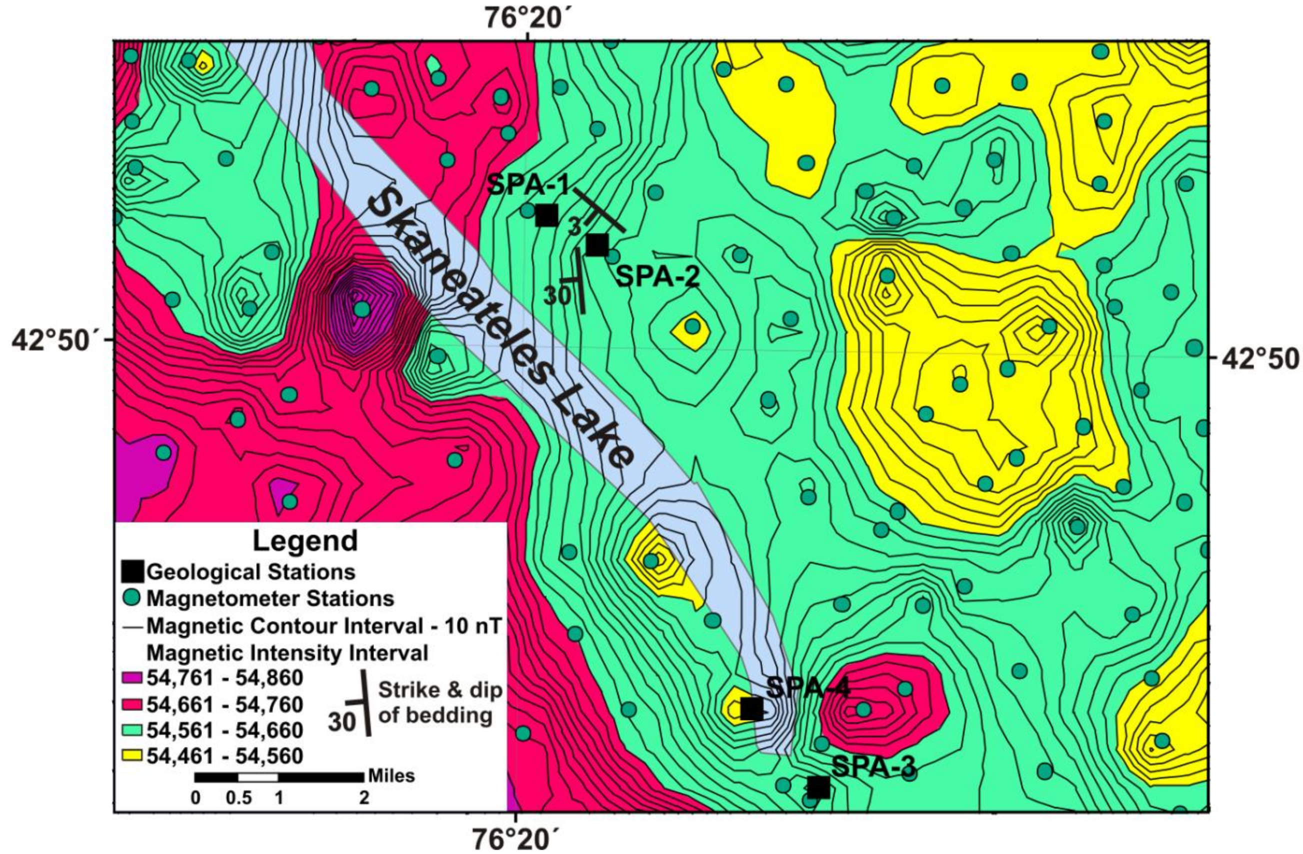


Figure 43 Total-Field Magnetic Map of the Area Enclosing Station SPA-2

Figure 44 Reverse Fault Oriented 040°/30° Displacing the Onondaga – Marcellus Contact at Station ROM-1.

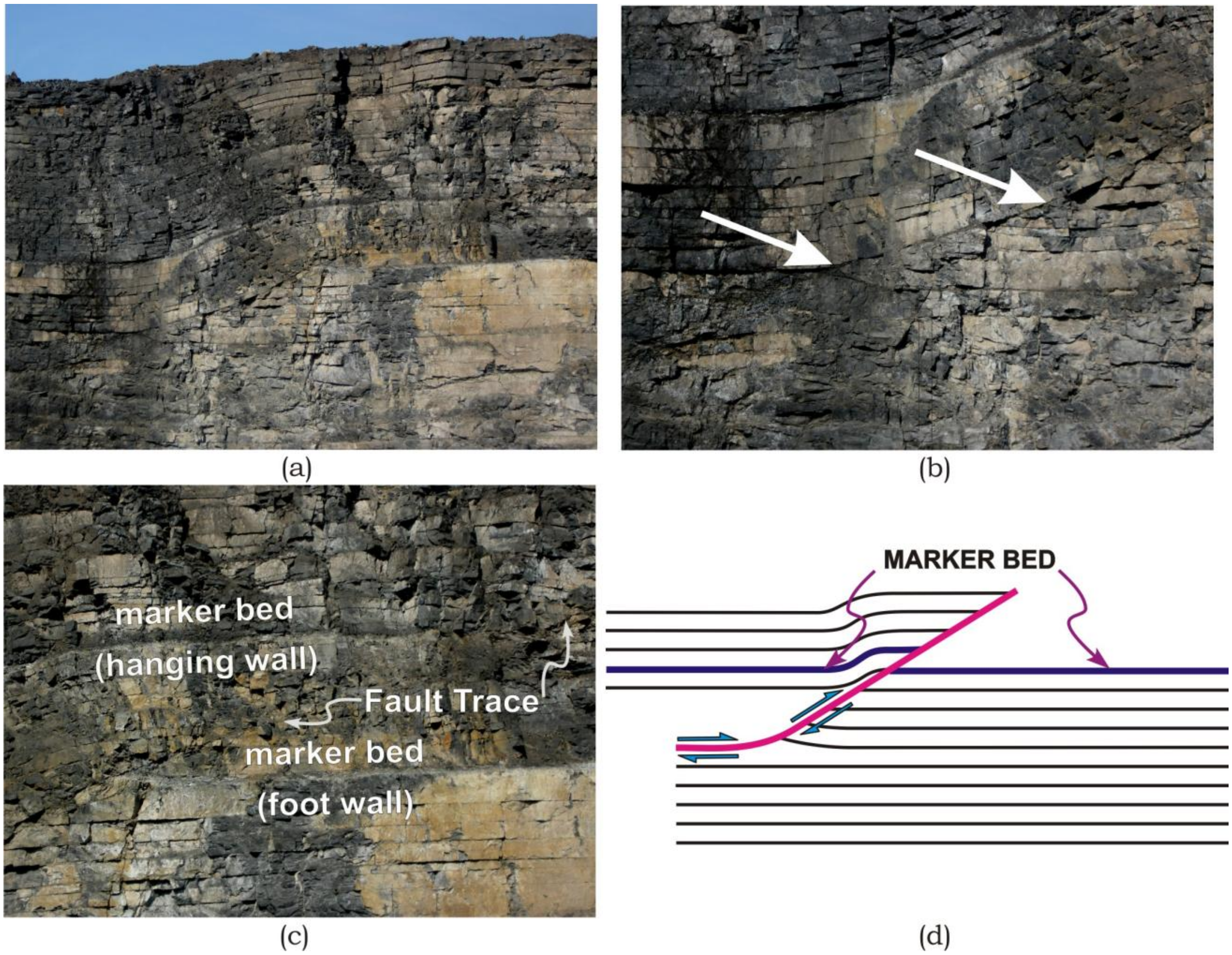


Figure 45 Reverse Fault Oriented 090°/30° in the Onondaga Limestone at Station ROM-1. (a) Shows Monoclinal Warp Beneath Which There is No Displacement Across Bedding; (b) Drag of Beds on the Footwall Between the Arrows; c) Displaced Marker Bed; d) Summary Drawing

Table 2. Mesoscopic-scale structures

LOCATION	STRUCTURE	STRIKE	DIP
Station IE-2	Inclined Strata	322°	09°
Station ROM-1	Reverse Fault	040°	30°
Station ROM-1	Reverse Fault	090°	30°
Station SPA-2	Inclined Strata	175°	30°
Station SPA-2	Monocline	130°	03°
Station WD-1	Inclined Strata	100°	07°

Besides lineaments, discussed above, the presence of mesoscopic-scale faults implies that there must also be macroscopic-scale faults. Stratigraphy furnishes a tenuous suggestion of vertical fault separation across the north-northwest lineament within which Owasco Lake lies (Figure 13 for location). In that case, based on the vertical positions of the Tully and underlying Moscow formations on opposite sides of the lake (Figure 46, stations MORA-1 on the east side and MORA-4 on the west side), it appears that the west side has moved down relative to the east side. If that is the case, as suspected, and because the 3-d kinematics is unknown the true nature of the displacement cannot be determined.

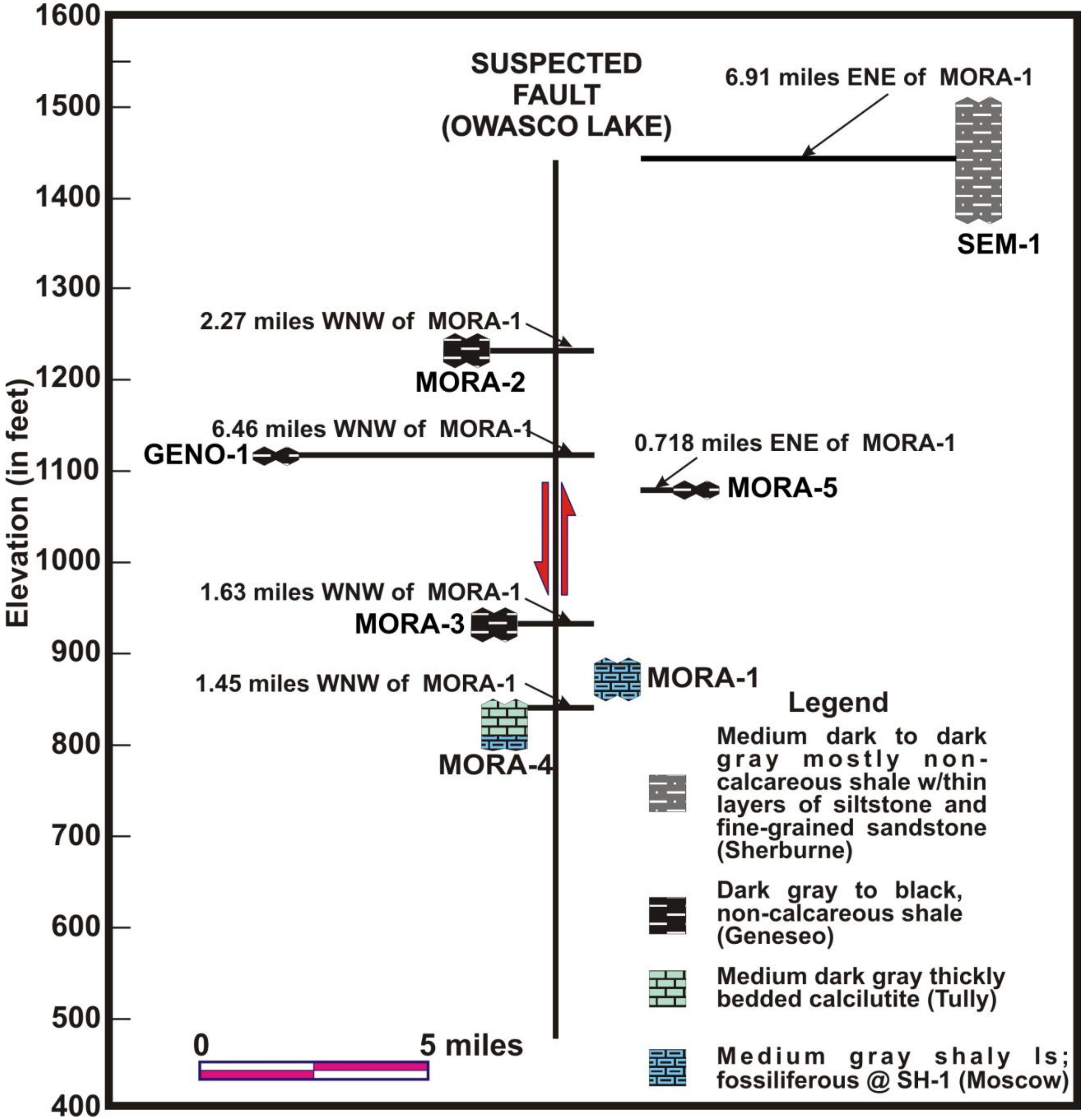


Figure 46 Cross Section Showing Owasco Lake as a Suspected Fault. View Looking North. Cited Stations Rim the Southern End of the Lake.

Tectonic control of the other Finger Lakes is also suspected, but the only convincing case points to Cayuga Lake. The trend of that lake conforms quite well to the orientation of the magnetic contours, which is clearly seen in the southern $^{2}/_{3}$ of the lake where both the contours and the lake are oriented north-northwest (Figure 47). Moreover a portion of the magnetic pattern shows a dextral separation there. Northward as the contours bend to a north-south orientation, particularly well expressed along the east side of the northern $^{1}/_{3}$ of the lake, the lake does likewise (Figure 47).

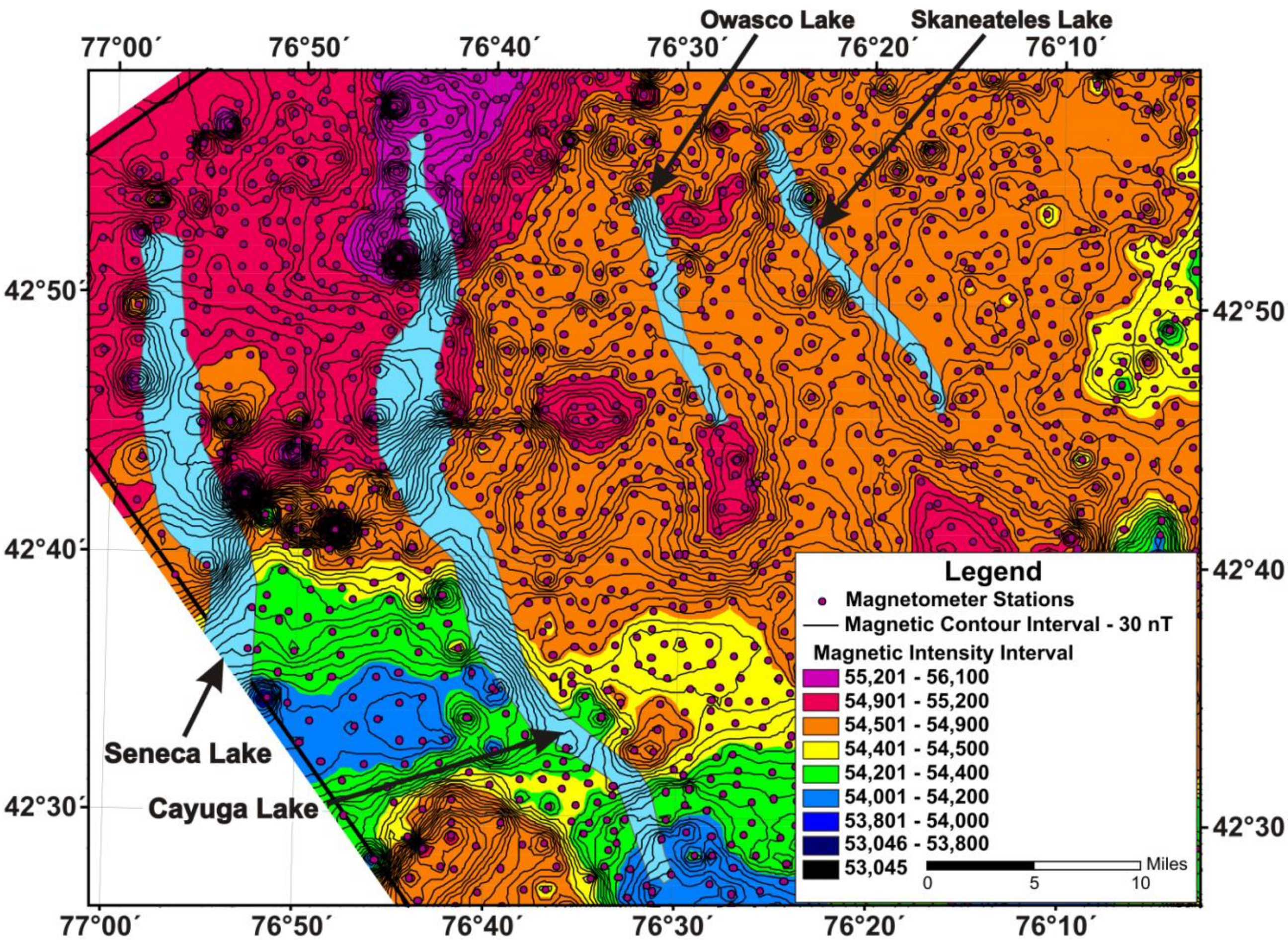


Figure 47 Ground-Based Total Field Magnetic Map of the Western Part of the Study Area.

Disruption of the perfect fit between the contours and the lake might conceivably be related to the existence of other structures that cross the lake, such as the gentle east-northeast oriented folds recognized by Wedel (1932) (Figure 38). At the southern end of Cayuga Lake there is an unmistakable east-northeast magnetic fabric expressed by the contours and highlighted by the bright green color representing the magnetic intensity interval of 54,201-54,400 nanoteslas (nT). It is at that location that the Firtree anticline, also referred to by Wedel (1932) as the Firtree Point anticline, crosses Cayuga Lake (compare Figures 38 and 47). Just to the north is the Glenora syncline (Wedel, 1932), the effects of which also appear to impact on the magnetic fabric, which is, itself, interrupted by a particularly strong north-northwest magnetic trend. If the explanation is as offered, i.e., the superposition of one set of structures on another, it is still not possible to ascertain, unambiguously, the age relationship between the two.

Though the best example of basement-exerted structural control on the Finger Lakes is expressed by Cayuga Lake the magnetic patterns in the vicinity of other lakes suggest that their orientations have also been influenced by pre-existing structure. Immediately south of both Owasco and Skaneateles Lakes the magnetic contours correspond to the orientation of the respective lakes and even persist for some distance northwards, which for Owasco Lake adds support to the interpreted fault along the lake (Figure 45).

Chapter 5 OIL AND GAS CONDIDERATIONS

5.1 Regional Setting

The Appalachian Mountains extend northeastwardly in a sinuous pattern from Alabama to Newfoundland and are characterized by intensely folded, faulted and, in the interior, metamorphosed Paleozoic units. To the west are mildly deformed to undeformed Paleozoic platform rocks and the metamorphosed and deformed rocks of the Canadian Shield. Cutting and displacing the platform rocks in the north are two grabens with east-southeast orientations, the Saguenay and the Ottawa-Bonnechère, which are approximately perpendicular to the Appalachian fabric (Figure 48). Parallel to them is the linear Mohawk Valley that extends to the east-southeast from Oneida Lake and is likely also tectonically controlled, as suggested by the magnetic pattern in the vicinity, and to the east, of Oneida Lake (Figure 29). The locations of all three of those features and their parallelism suggest that they line up with some of the offshore transform faults and, as such, may be genetically related to them (Figure 48, inset).

Evaporite-bearing basins and similar stratigraphy are elements common to both the Albion-Scipio Field in Michigan (Michigan Basin) and the area of investigation in New York State (Salina Basin), although the youngest strata in the former are Pennsylvanian in age (Figure 2), whereas in the latter they are Upper Devonian (Figure 10). Geometrically the Michigan Basin is roughly circular, but the Allegheny Plateau in New York is oriented approximately east-west and parallels the Salina Basin. It is located on the edge of the Appalachian sedimentary basin, which is exemplified by the thickness of the Marcellus Shale and parallel to the Appalachian orogen (Figure 49).

Locations of the hydrocarbon-producing Michigan, Appalachian and Illinois basins are superimposed on the total-field magnetic map covering the eastern part of North America (Figure 50) which shows the dominant regional northeast trend produced by the tectonic fabric of the Grenville Province of the Canadian Shield. Besides the three basins and the regional Grenville grain, the map displays contrasting magnetic patterns separated from neighboring patterns by linear discontinuities (lineaments), which probably mark major fault zones.

Figure 48 **Regional Topography of Eastern North America Including the Albion-Scipio Oil Field (AS) and the Fortuna Gas Field (NY). O-B Graben – Ottawa-Bonnechere Graben. Arrows Represent the Regional Stress Regime Operative During the Taconic orogeny. Inset Shows the Mid-Atlantic Ridge Cut by Transform Faults.**

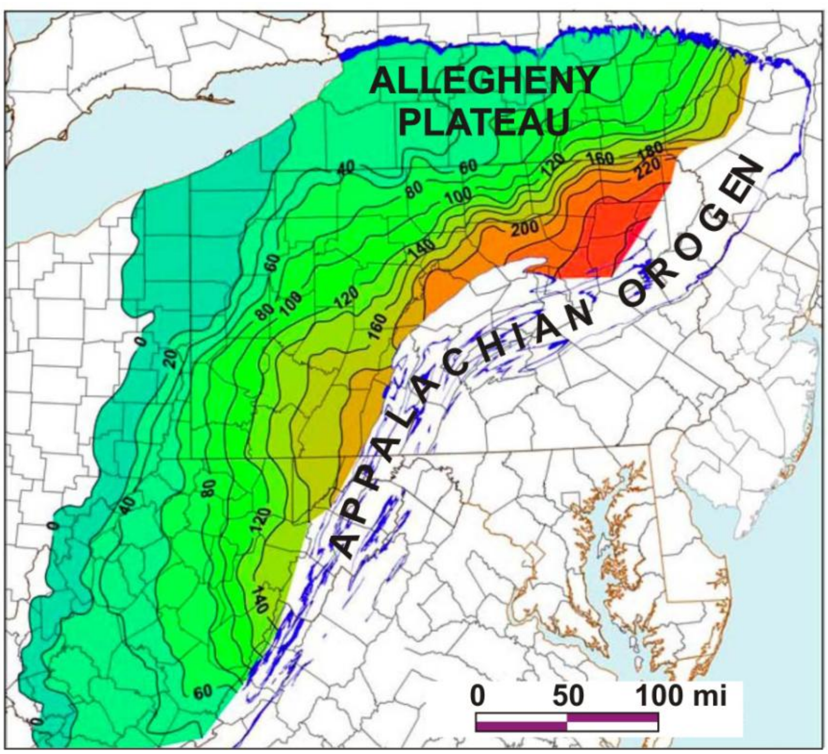


Figure 49 **Regional Isopach Map of the Marcellus Shale Showing the Influence of the Appalachian Basin on Its Orientation and Increase in Thickness (Modified Slightly From Wrightstone, 2009).**

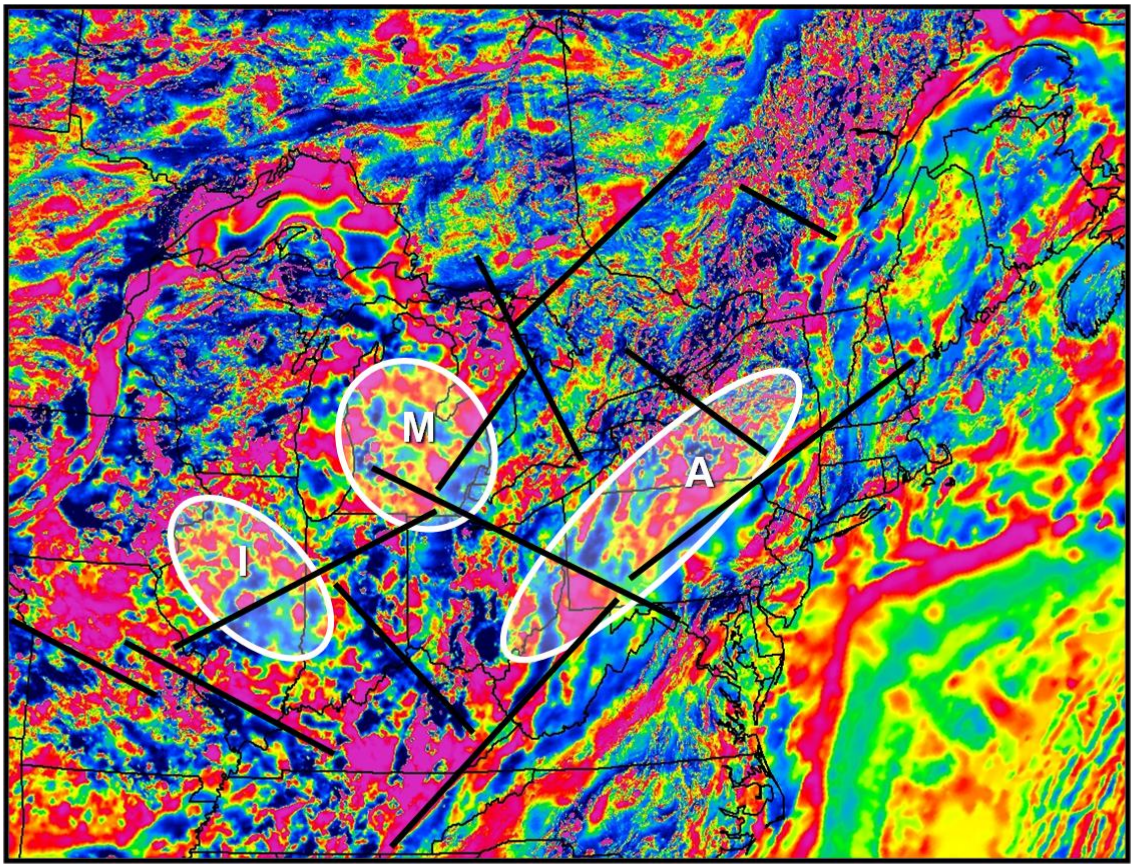


Figure 50 Major Regional Magnetic Lineaments (Black Lines) on the Total Magnetic Field of Eastern North America. I: Illinois basin; M: Michigan basin; A: Appalachian Basin

5.2 Hydrocarbon Exploration

Sedimentary strata across New York State strike nearly east-west and dip gently to the south, a property illustrated by the structural contours on the top of the Salina Salt Zone (Figure 11). Therefore sedimentary rocks, including the gas-bearing Utica and Marcellus shales, which crop out at the surface in central New York State, are rather deeply buried further south, thereby making them attractive exploration targets. An example is provided by the undifferentiated Trenton-Black River group which, despite its southwardly deepening owing to the gentle southerly dip, has been a successful exploration target in Steuben, Schuyler and Chemung Counties (Figure 51), south and west of the study (target) area. In 2004 significant quantities of natural gas were being produced from wells just outside the southwestern limit of the area (Figure 52).

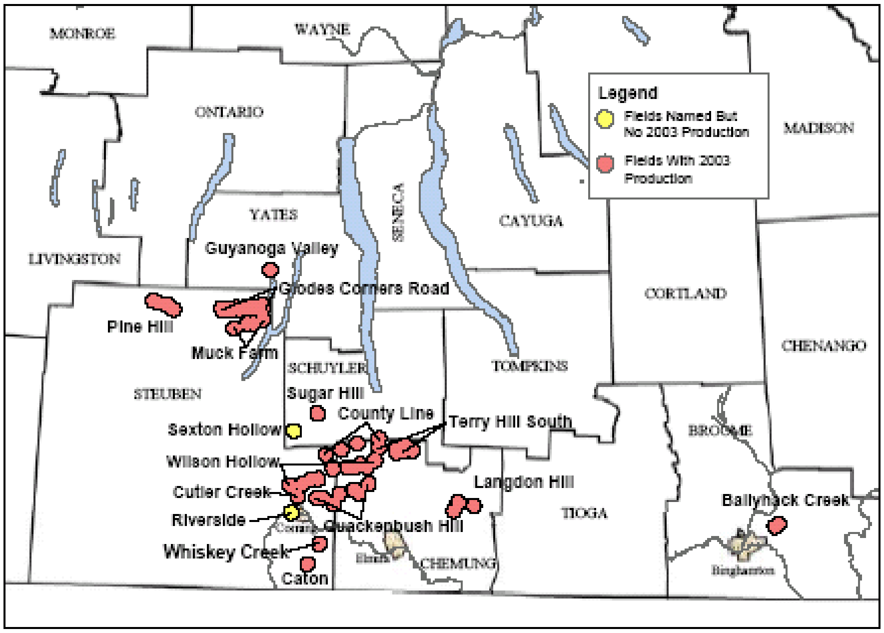


Figure 51 **Trenton-Black River Gas Fields in Central New York in 2003 (NYSDEC Annual Report).**

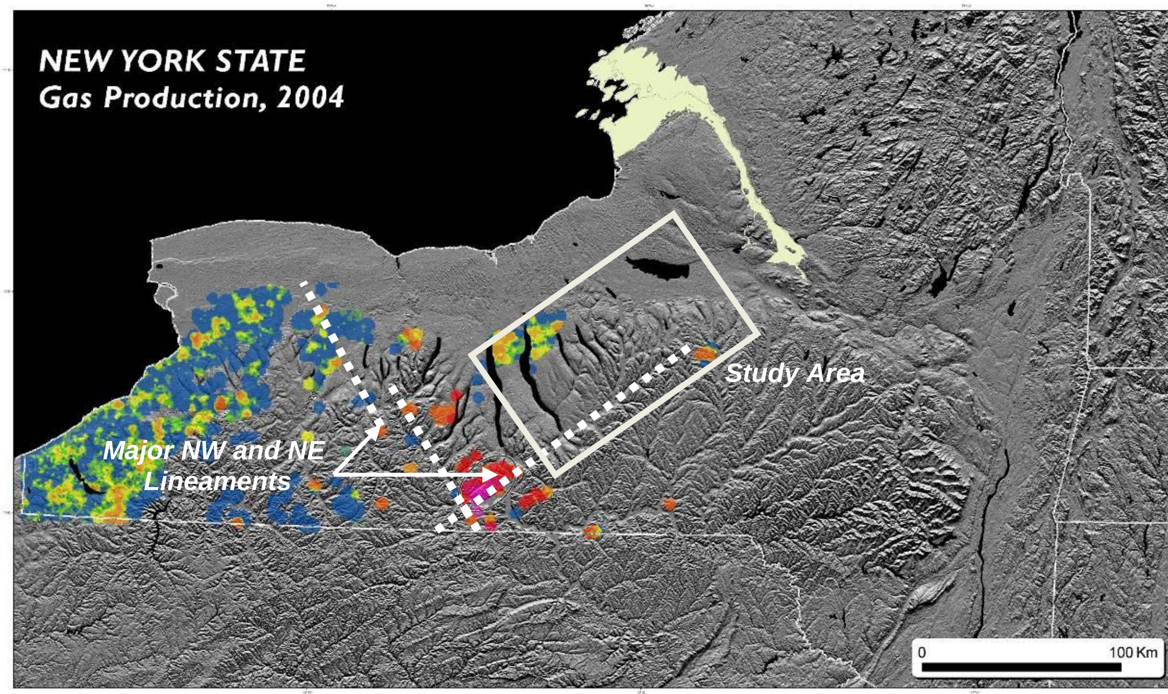


Figure 52 **Shaded Relief Image of New York State With Areas of Significant Gas Production in 2004 (Red Areas). The Intersecting Lineaments are Approximately in the Center of Fortuna's Producing Wells.**

Besides the actual wells, there are the exploration fairways described by EarthSat (1997) as "*very large, angular, and in some instances contain existing production or abandoned wells and fields*." Those features were defined from characteristics of satellite-recorded fracture zones combined with vegetation anomalies and oil and gas field information. They added that exploration pathways refer to "*areas of high fractured-reservoir potential and are not meant to delineate specific drill sites*…." The presence of a major lineament, about 60 miles long that extends to the northeast from approximately the center of a group of producing wells in the southern tier (Figure 53), should be noted. Along its trajectory it intersects a second important lineament that trends northwest as well as other lineaments, including the one in which Cayuga Lake is located. That 60-mile long lineament and its intersections, particularly in the area of the Fortuna field, seem to have been important elements in the discovery of the Fortuna gas field.

Targeting the Trenton/Black River for gas in south-central New York State has been, and continues to be, profitable and is certainly warranted, but other units are also proving to be productive, such as the interval from the Oswego (Upper Ordovician) to the Oriskany (Lower Devonian), the Onondaga Formation and undifferentiated Upper Devonian shales (NYSDEC, 2010). Some of those units have been found in parts of the current study area, which have been subjected to exploration and where there are still active fields (Figure 54). Loewenstein (2004), in a contracted report to Nornew, wrote that 11 of 14 wells within the confines of the Bradley Brook Field, located entirely within the study area (Figure 54) in southern Madison County, were producing wells. They were drilled into the Oswego and Oneida formations, which are both sandstone units that occur higher in the section than the typically targeted, undifferentiated Trenton/Black River Group of limestones. At that time, according to Lowenstein (2004), production was better where the two units are slightly structurally higher than in the adjacent areas, which also yielded gas, but were less prolific. Today that field is still active with an even greater number of producing wells.

Active wells located elsewhere in the study area are also producing from non-Trenton and Black River formations. They occur in the northwestern corner of the area just east of the northern limits of Seneca and Cayuga Lakes (Figure 54). Dense clusters of wells mark the Fayette-Waterloo Field just east of Seneca Lake where the Upper Ordovician Queenston is the producing stratigraphic unit. Just east of the northernmost extent of Cayuga Lake, lies the West Auburn Field, also marked by a rather dense concentration of active wells. There, too, the producing formation is the Queenston.

A concentration of wells east of Skaneateles Lake was the site of the Tully Brine Field (Figure 54), in which almost all of the wells, now plugged and abandoned, were brine wells (NYSEDEC, 2010). None penetrated below the Silurian-aged Salina Group (Syracuse and Camillus formations), but during the current investigation seismic crews from Alberta and Texas were seen in the area, among which was Dawson Geophysical, working under contract to Chesapeake Energy Corporation in the Spafford Quadrangle, immediately east of Skaneateles Lake (Figure 13 for location). Seismic lines were also strewn across fields and New York State Route 34 north of Ithaca. It is not known what formations were being considered, but the apparent viability of the Oswego Sandstone - Oneida Conglomerate interval in the Bradley Brook Field and the Queenston in the Fayette-Waterloo and West Auburn Fields, all stratigraphically beneath the Salina Group, are possibilities, as would be the limestones of the upper Middle Ordovician Trenton/Black River groups and the overlying Utica Shale.

Martin (2005) stated that the Utica Shale "*is considered to be the source rock for Lower Devonian through Cambrian hydrocarbon production.*". The Utica is clearly an important constituent of the stratigraphic framework of the study area and would probably be a very viable hydrocarbon contributor therein because of its burial southward as a consequence of the regional dip. Moreover, in addition to its source-rock potential as noted above, the Utica is considered to be a very promising shale gas reservoir target and drilling is actually underway within this unit to test artificially fractured reservoirs.

Going beyond rock types, models incorporating different geological properties have been proposed as an aid in hydrocarbon exploration in New York State, one of the most persuasive of which was that put forth by Smith (2006). He observed that hydrothermal dolomites are important factors in finding reservoirs and that the strong correlations between specific geochemical signatures and the position of basement-rooted faults suggest a fault-related hydrothermal origin for the dolomite precipitation. He added that hydrothermal dolomite plays are often related to basement-rooted faults which favored fluid circulation and limestone alteration, thus increasing the porosity of the host rock. Smith also stated that most fields occur in structural lows, rather than on highs as might be expected, and attributed the lows to small faults branching off from larger transtensional strike-slip faults that propagate upwards from the Precambrian basement.

In the area of south-central New York State where Smith (2006) concentrated his efforts, which is just beyond the study area, the Trenton/Black River wells are distributed largely along the axes of the gentle folds mapped by Wedel (1932) (Figure 55). No generalizations can be made, however, as to the association of those wells with either structural lows or highs. For example the wells of the Wilson Hollow and Terry Hill South Fields follow a synclinal trough, but those of the Quackenbush Hill and Glodes Corners Fields are lined up along anticlinal crests (Figure 55). Therefore it is only natural to assess the role, if any, that Appalachian folding may have played in the evolution of the gas fields in the southern tier. In other words were the folds genetically related to, or did they predate and control the orientations of, the faults along which dolomitizing fluids migrated creating pore spaces for natural gas?

The model of crustal flexure producing extension and normal faulting (Bradley and Kidd, 1991) in compression would account nicely for much of the fault-fold-wells relationship in the southern tier and would augment the model put forth by Smith (2006). Briefly it is based on the notion that in compression there is extension at the crests of anticlines, a phenomenon produced when an obducting plate is flexed by underthrusting of the subducting plate. Bradley and Kidd (1991) explained north-northeast normal faults that cross the Mohawk Valley in that way, and it is herein considered to be equally applicable to the situation in the southern tier.

Gravity anomalies supplemented by interpreted topographic lineaments (Figure 56) suggest the possibility that fields aside from the Trenton/Black River Fields addressed in Smith's (2006) model are controlled by fractures, if not faults, extending upward from the basement. The West Auburn Field occurs within the interval of three intersecting topographic lineaments that overlie the dominant gravity high (Figure 56). Wells of the Fayette-Waterloo Field overlie the same gravity high and are largely limited to the north by the same west-northwest lineament that crosses the West Auburn Field to the east. An even more convincing picture emerges by looking at the fields on a map of magnetic anomalies (Figure 57). The Fayette-Waterloo and West Auburn Fields show a definite two-dimensional spatial relationship to linear magnetic boundaries of the same anomaly. That anomaly is predominantly north-northeast oriented, but in the immediate vicinity of the northern Finger Lakes it swings to north-south, a relationship discussed on page 50 and illustrated in Figure 47 as a factor affecting the location of Cayuga Lake. The only other field of note in the study area is the Bradley Brook, which is located at the intersection of one relatively narrow magnetic anomaly which trends northeast, and a second, but wider anomaly oriented northwest.

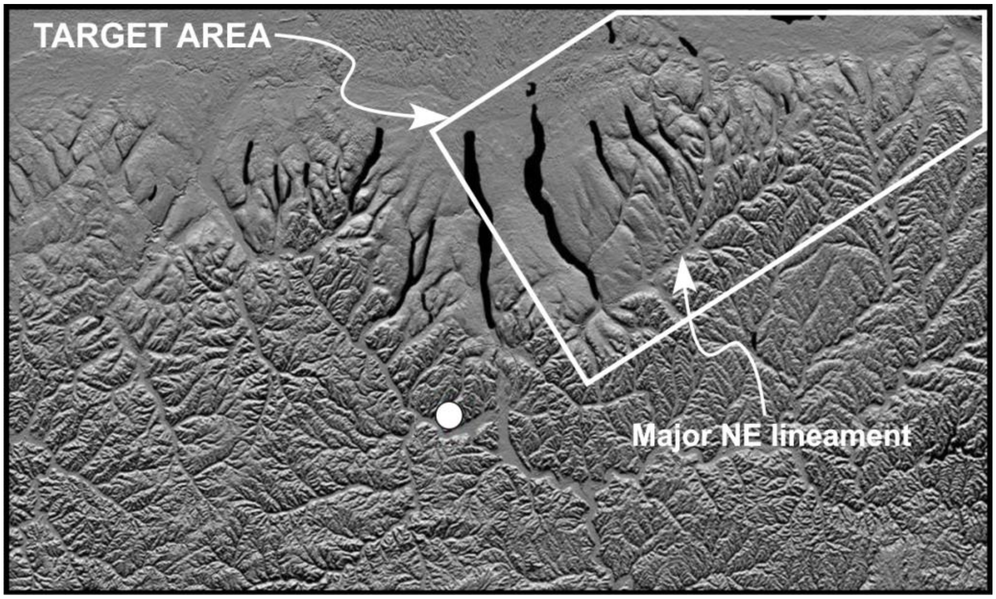


Figure 53 **Shaded Relief Image of the Southwestern Part of the Study Area. The White Circle, at the Intersection of Two Prominent Lineaments, is Approximately in the Center of a Producing Field.**

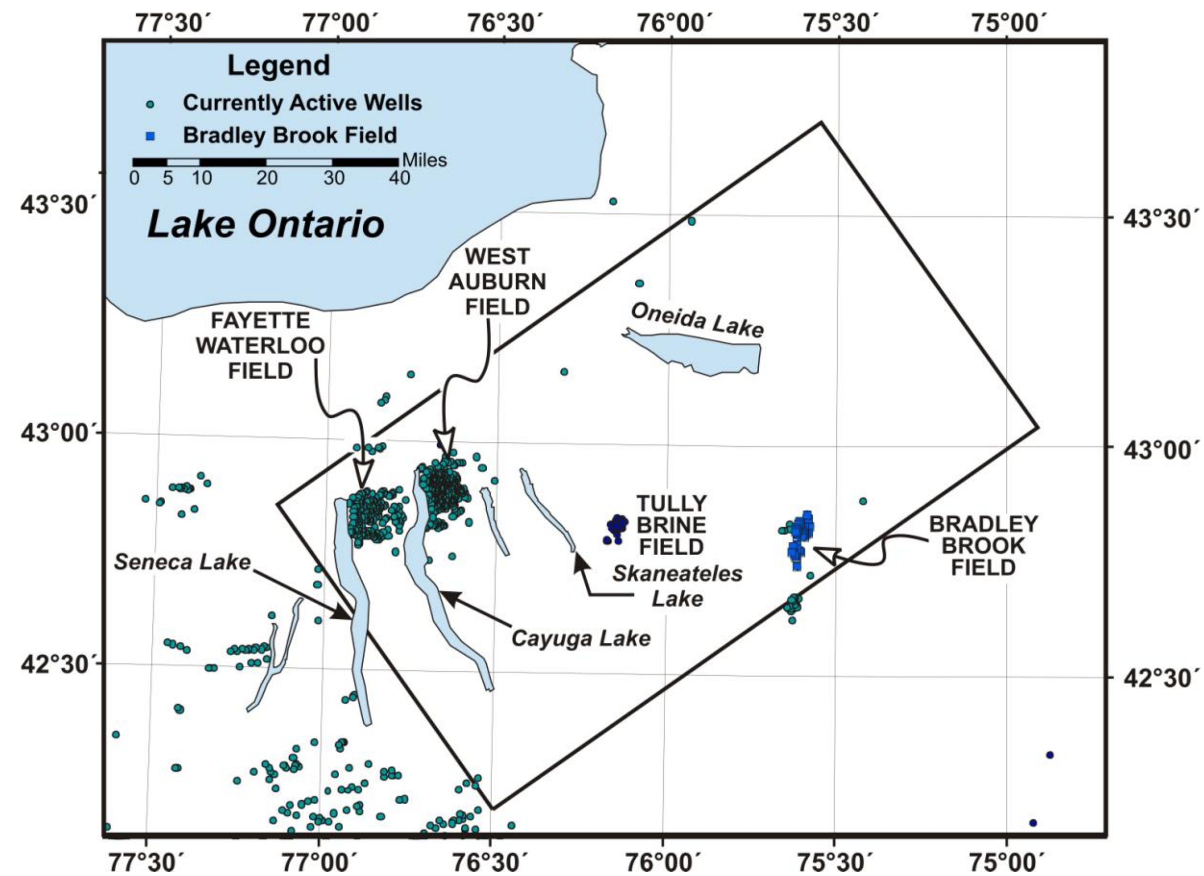


Figure 54 **Currently Active Gas Wells in and Near the Study Area (Inclined Rectangle). (Well Information From NYSDEC, 2010)**

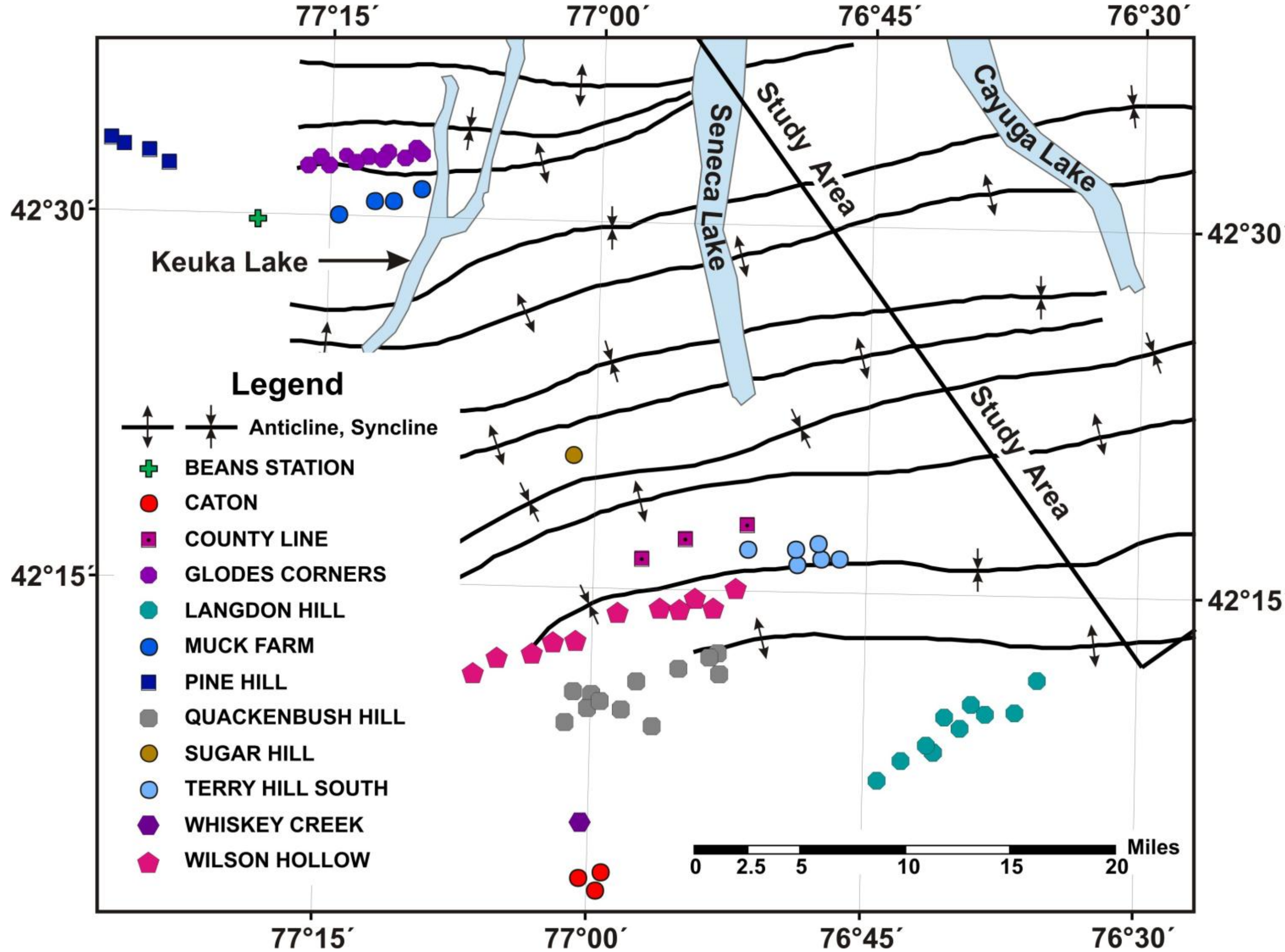


Figure 55 Trenton/Black River Fields Showing Currently Active Gas Wells Superimposed on Folds Near the Southwestern Portion of the Study Area. Folds Redrawn From Wedel (1932); Data on Wells from NYSDEC Data Base, 2010).

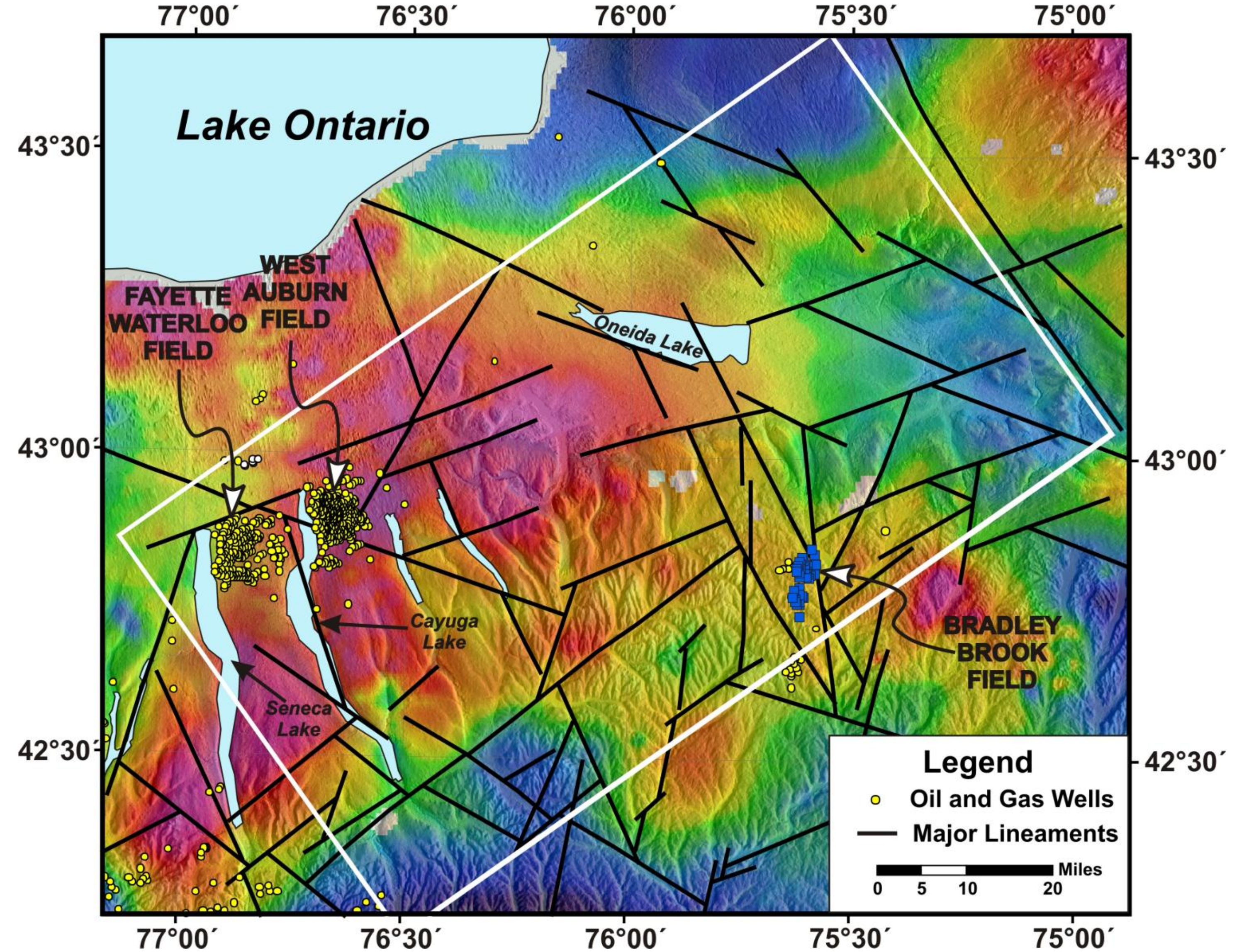


Figure 56 **Interpreted Major Topographic Lineaments and Currently Active Gas Wells on a Combined Bouguer Gravity/Physical Relief Map. (Well Information from NYSDEC, 2010)**

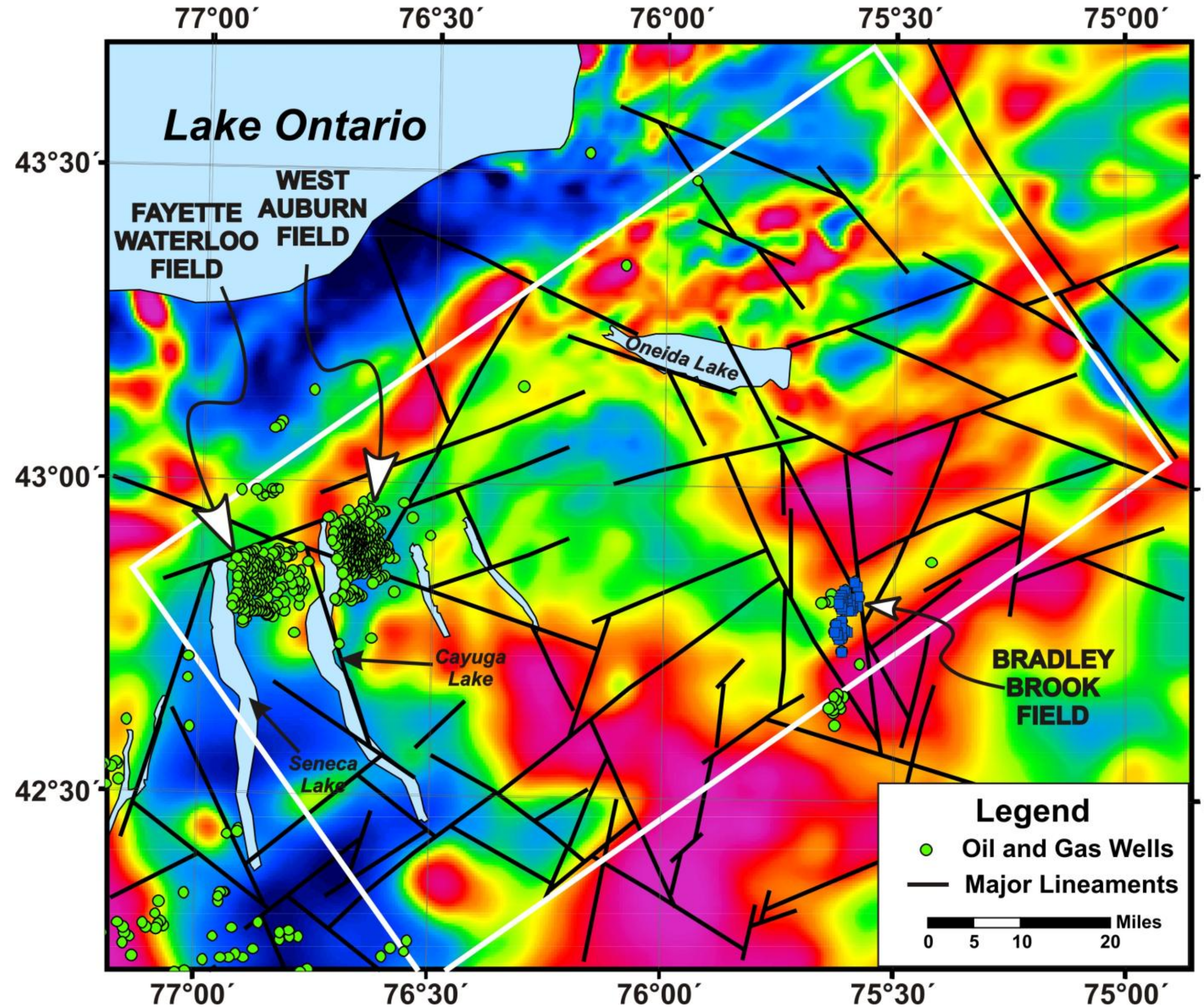


Figure 57 Total-Field Aeromagnetic Map with Currently Active Gas Wells and Interpreted Major Topographic Lineaments. (Well Information from NYSDEC, 2010)

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

Similarities exist between the area of the Albion-Scipio Field in Michigan and the study area in New York State. Both areas are underlain by similar sedimentary rocks, except that in the area of the Albion-Scipio field the youngest strata are Pennsylvanian whereas in the study area they are Upper Devonian. In addition evaporite basins are present in both areas. Visible examples of spectacular large-scale faults and folds are not apparent in either area, yet both areas have been subjected to tectonism. Two-dimensional spatial relationships between geophysical linear anomalies at depth and topographic lineaments on the surface in both areas suggest that, in those cases, basement-rooted structures have propagated upwards into the sedimentary rocks, presumably due to at least one post-Precambrian tectonic event. The existence of the Albion-Scipio Field appears to be a consequence of wrench fault tectonics, and faulted, folded and tilted rocks have been documented in the study area. Furthermore, like Albion-Scipio, a wrench fault tectonic model was invoked to explain the existence of Trenton-Black River plays in New York State, though Paleozoic folding may have also played an indirect role in the evolution of those plays. That suggestion derives from the spatial association of a large number of Trenton/Black River wells with the broad, gentle folds of the southern tier. It is not being argued, however, that the folding was directly responsible for the gas production or storage. Instead it is proposed that tectonism responsible for the fold axes, synclinal and anticlinal, was either cogenetic with the faults, or established the geometry which was ultimately used by fractures or faults, as suggested by Smith (2006), to provide pathways for upwelling hydrothermal fluids.

Tectonics is of regional extent, thus the development of the south-southeast and east-southeast fracture systems and their influence on the Albion-Scipio Field in southern Michigan is consistent with the crustal compression that affected the entire east coast and continental interior of North America. It is, therefore, recommended that east-southeast and south-southeast-trending lineaments and faults, oriented to have been active as extension fractures and strike slip faults, respectively, during Paleozoic crustal compression (Taconian through Alleghenian), be examined carefully. Hydrothermal fluid circulation along those fault patterns may have favored the dolomitization of limestone units and the development of HTD reservoirs. Lineament intersections are also areas that deserve scrutiny.

Gravity surveys in the study area give a general idea of where linear trends might be found in the basement and, indeed, showed some good correlations between those in the basement and those on the surface (Figure 28). Ground-based and airborne total-field magnetic surveys, however, seem to give sharper definition to linear basement anomalies, many of which underlie identically oriented topographic lineaments recognized on the surface. Two of the three non-Trenton/Black River Fields in the study area overlie the same linear magnetic anomaly, albeit along magnetic lineaments on opposite sides of the anomaly, and the third is located above a prominent intersection of basement lineaments (Figure 57). Consequently it is recommended that good magnetic data be used in reconnaissance mode to seek out other potential exploration targets for further investigation. That, along with favorable stratigraphy, makes the study area, particularly the southwestern part, very attractive for further natural gas exploration.

The area investigated in central and south-central New York State is part of the Allegheny Plateau, represents the northeastern extremity of the Appalachian basin and is marked by east-northeast- to north-northeast-trending lineaments which may be related to important syn-sedimentary fault zones. Whether or not the faults are growth faults they appear to be rooted in the Precambrian basement, given the correlation of their linear surface expression with geophysical discontinuities. Combined with the northwest thrusting and piling of the Appalachian belt during the Taconic orogeny, this has probably favored the thickening of sedimentary units toward the southeast.

In summary potential shale gas plays were documented within the Utica and the Marcellus formations, deposition of which may have been controlled by pre- to syn-Taconian structures. Consistent with the strong north-northeast to northeast tectonic grain inherited from the Grenville basement, the Appalachian Basin is oriented north-northeast to northeast and deepens to the southeast, thus it is possible that growth faults may have accompanied at least some of the deposition. The overall basin configuration, however, suggests that subduction at the onset of the prolonged Lower Paleozoic orogenesis produced the deep trough which is, today, represented by that basin (Sanford, personal communication).

Chapter 7 SELECTED REFERENCES

Agle, P. and others, 2006. Faulting and mineralization in the Cambro-Ordovician section of the Mohawk Valley. 78th Annual NYSGA Mtg., Field Trip A1, 53 p.

Allmon, W.D. and Ross, R.M., 2005. Ithaca is Gorges - A Guide to the Geology of the Ithaca Area. The Paleontological Research Institution, Special Publication No. 23, 24 p.

Bradley, D.C. and Kidd, W.S.F., 1991. Flexural extension of the upper continental crust in collisional foredeeps. Geological Society of America Bulletin, 103, pp. 1416-1438.

Chute, N.E., 1964. Structural features in the Syracuse area. *In* New York State Geological Association 36th Annual Meeting Guidebook. *Edited by* J.J. Prucha Syracuse University, pp 74-79.

Cubitt, J.M., Heckel, P.H., DelSignore, A.G. and Wooldridge, M., 1978. The Tully Limestone of central New York – stratigraphy and facies variation. New York State Geological Association 50th Annual Meeting Guidebook, pp. 273-281.

Dugolinsky, B.K., 1972. Sedimentation of the Upper Devonian Sonyea Group of south-central New York. Unpublished MS Thesis, Syracuse University, 119 p.

EarthSat, 1997. Remote sensing and fracture analysis for petroleum exploration of Ordovician to Devonian fractured reservoirs in New York State. NYSERDA Agreement No. 4538-ERTER-ER-97, 35 p.

Hill, D.G. and Lombardi, T.E., 2002. Fractured gas shale potential in New York. Report Prepared for the New York State Energy Research and Development Authority, 92 pp. plus Appendix.

Glenn, S.E., 1957. Geology of the southern half of the Otisco Valley 7½ Minute Quadrangle. Unpublished MS Thesis, Syracuse University, 40 p.

JL Wallach Geosciences Inc. & MIR Télédétection inc., 2000. A geological and remote sensing investigation of the Tug Hill Plateau in search of natural gas. NYSERDA Report 4883-ERTER-99

Kreidler, W.L., 1957. Occurrence of Silurian salt in New York State. New York State Museum and Science Service Bulletin 361, 56 p plus maps.

Lowenstein, S., 2004. Bradley Brook field report to Nornew, Appendix C, 13 p.

Lugert, C.M. and Jacobi, R.D., 2005. Tracing deep structure: fracture analysis in the Finger Lakes region of the Appalachian Plateau, New York State. Geological Society of America, Northeast Section, 40th Annual Meeting, Abstracts with Programs, v. 37.

Martin, J.P., 2005. Utica Shale deposition in the Taconic foreland basin: evolution and the potential for natural gas production. Abstracts with Programs, Northeast Section Geological Society of America 40th Annual Meeting, Paper 1-10.

Milici, R.C. and Swezey, C.S., 2006. Assessment of Appalachian Basin oil and gas resources: Devonian shale-middle and upper Paleozoic total petroleum system. US Geological Survey Open-File Report Series 2006-1237, 70 p.

Milici, R.C., 2005. Assessment of undiscovered natural gas resources in Devonian black shales, Appalachian Basin, Eastern U.S.A. USGS Open File Report 2005-1268 Online Only, Version 1.0.

National Energy Technology Laboratory, 2003. Geologic playbook for Trenton Black River Appalachian Basin exploration. DE-FC26-03NT41856. http://www.netl.doe.gov/technologies/oil-gas/NaturalGas/Projects.

NYSDEC, 2010. New York State Department of Environmental Conservation. www.dec.ny.gov/energy/1603.html

Oliver, W.A., 1954. Stratigraphy of the Onondaga Limestone (Devonian) in central New York. Geological Society of America Bulletin, 65, pp. 621-652.

Parkinson, R.W., 1959. The stratigraphy and structure of the northern half of the Tully, New York 7½ Minute Quadrangle. Unpublished MS Thesis, Syracuse University, 67 p.

Phillips, J.S., 1955. Origin and significance of subsidence structures in carbonate rocks overlying evaporites in Onondaga County, central New York. Unpublished MS Thesis, Syracuse University, 146 p.

Smith, B., 1935. Geology and mineral resources of the Skaneateles Quadrangle. New York State Museum Bulletin 300, 120 p.

Smith, L.B., 2006. Origin and reservoir characteristics of Upper Ordovician Trenton-Black River hydrothermal dolomite reservoirs. AAPG Bulletin, 90, pp. 1691-1718.

Statkiewicz, E.G., 1956. Geology of the northern half of the Otisco Valley 7½ Minute Quadrangle. Unpublished MS Thesis, Syracuse University, 50 p.

Stroup, J.T., Jacobi., R.D. and Nelson, T., 2006. Fracture intensification domains, lineaments and faults in the Skaneateles Lake region of the Alleghanian Plateau of New York State. Abstracts with Programs, Northeast Section Geological Society of America, 41st Annual Meeting, Paper 26-2.

Sutton, R.G., 1959. Structural geology of the Dryden and Harford Quadrangles New York. The State Education Department, The State University of New York, 15 p.

Tolley, W.P., 1957. The stratigraphy and structure of the southwestern part of the Canastota Quadrangle. Unpublished MS Thesis, Syracuse University, 161 p.

Versical, R. T., 1991, Basement control on the development of selected Michigan Basin oil and gas fields as constrained by fabric elements in Paleozoic limestones: M. S. Thesis, Western Michigan University, Kalamazoo, Michigan, 200 p.

Wedel, A.A., 1932. Geologic structure of the Devonian strata of south-central New York. New York State Museum Bulletin 294, 74 p.

Wilson, J. L., Budai, J. M., Sengupta, A. – 2001 – *Trenton – Black River formations of Michigan Basin.* Masera Corporation – Search and Discovery Article # 10020, http://www.searchanddiscovery.net/documents/trenton/index.htm

Wolle, P.C., 1956. The geology of the southern half of the Tully, New York 7½ Minute Quadrangle. Unpublished MS Thesis, Syracuse University

Wood, J.R. and Harrison, W.B., 2002. Advanced characterization of fractured reservoirs in carbonate rocks: The Michigan Basin. USDOE final report DE-AC26-98BC15100, 63 p.

Wrightstone, G., 2009. Marcellus Shale – geologic controls on production. Search and Discovery Article #10206. Adapted from extended abstract prepared fpr AAPG Annual Convention, Denver, Colorado, June 7-10, 2009.