INVESTIGATION OF THE 1000 ISLANDS REGION TO ASSESS NATURAL GAS RESERVOIR POTENTIAL: PHASE 1 REGIONAL RECONNAISSANCE

Agreement #8936

Final Report

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ABSTRACT

The investigation detailed in this report is the fourth and concluding study undertaken in northern New York State by the authors. Overall that part of the state is not favorably regarded as having economically feasible hydrocarbon resources. In the 1000 Islands Region, however, there are many previously unrecognized faults which, combined with the existence of strata dipping gently to the southwest, off the Frontenac Arch towards Lake Ontario, fueled optimism that natural gas exploration might be a worthwhile undertaking there. That is negated, though, by the shallow depths of good potential reservoir rocks at the edge of Lake Ontario. Offshore could be a different story, but the current moratorium on drilling and exploration in the Great Lakes prevents that as well. If that moratorium were to be lifted, marine seismic work would be a worthwhile venture that could lead to the discovery of additional hydrocarbon resources in New York State.

West of the Frontenac Arch the 1000 Islands region is underlain principally by the carbonates of the Trenton and Black River Groups, although subordinate amounts of Grenvillian basement, Potsdam and Beekmantown Group rocks also crop out. The arch, itself, is comprised of Grenvillian rocks, with few small Paleozoic outliers, but to the east formations within the Potsdam and Beekmantown Groups underlie the area. Faults appear primarily as nearly vertical lineaments that parallel, and belong to, the northeast-oriented St. Lawrence fault zone and separate older, topographically higher strata from younger, topographically lower units. Those faults are well expressed magnetically as well as topographically. Intense granulation and locally steeply dipping beds attributed to approximately horizontal overthrusting affecting the sandstones of the Potsdam Group, northwest-trending faults and broad, gentle folds are also present.

ACKNOWLEDGMENTS

The authors of this report gratefully acknowledge NYSERDA for having provided funding for this study and, in particular, wish to thank the project manager, John Martin, for his continued and on-going support. Again a special thank you is accorded Bruce Sanford for his forays in the field with the authors. Bruce has been studying the Potsdam Group and also has considerable experience with the Trenton and Black River Groups.

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Chapter 1 INTRODUCTION

1.1 GENERAL STATEMENT AND OBJECTIVE

Multidisciplined geoscientific work to assess the potential for natural gas exploration was undertaken in much of Jefferson County which largely completes this team's reconnaissance work in the Paleozoic rocks of northern New York State. The earlier works are presented in JL Wallach Geosciences Inc & MIR Télédétection inc (2002, 2004, 2005). In the area of Lake Champlain it may be worthwhile carrying out some subsurface work, but across the rest of the area, no such efforts are recommended. That even includes Jefferson County where, because of the generally inclined pattern of the Black River and Trenton Groups towards Lake Ontario and the suspicion of faults, there was hope that area might be a potential target for natural gas. Though the suspicions about faulting were borne out Jefferson County is not viewed as a viable exploration target, although if the moratorium on offshore drilling were lifted, it is recommended that seismic work be carried out across Lake Ontario.

As in previous investigations information in this report is derived from remotely sensed and digital elevation data, combined with ground-based geological and magnetic surveys. Structural emphasis has been on faults and fractures, principally expressed as some of form of linear topographic element, such as ridges and streams. Lithologically attempts have been made to map, carefully, the different carbonate units of the Black River and Trenton Groups, no mean feat as instances occur where it is difficult to identify precise contacts.

1.2 REMOTE SENSING AND GIS TECHNIQUES

A remote sensing and GIS study was implemented by producing a geoscientific database and integrating remotely sensed, topographical, gravity and magnetic data in order to identify and interpret topographically and geophysically expressed linear structures. The database was produced by using a combination of different programs operating in Windows XP which include: **Geomatica** software for remotely sensed data processing, **Microstation** products for vector data capture and structuring and **ArcGIS** for the final database generation and related analysis.

1.3 DATA ACQUISITION

1.3.1 Remotely Sensed Data

After a review of available satellite data and evaluation of the data quality Landsat 7 remotely sensed data (Table 1-1), acquired on August 25, 2001, were recovered from the internet, processed and used for the lineament analysis. Those data, consisting of one panchromatic channel and seven multispectral channels, are contained in a 185 km x 185 km scene which covers the total study area.

TABLE 1-1– Characteristics of the Landsat data

Category	Orbit	Date of Acquisition	Coverage	Characteristics
Landsat TM	Path 16 Row 29	2001-08-25	185km x 185km	• 15 m panchromatic channel: TM8: 0,52 – 0,90 • 30 m multispectral channels: TM1: 0,45 – 0,52 TM2: 0,52 – 0,60 TM3: 0,63 – 0,69 TM4: 0,76 – 0,90 TM5: 1,55 – 1,75 TM7: 2,08 – 2,35

1.3.2 Geoscientific Data

The geoscientific components integrated into the database include a digital base map along with geophysical and geological data (see Table 1-2). Planimetric data, obtained from the USGS web site and consisting of main and secondary roads, stream courses and lake boundaries, were used for image geocoding and for image map generation. High resolution topographical data were all downloaded from USGS FTP sites and correspond to regular grid files of elevation data generated from 1:24 000 scale maps. Regional geophysical data were recovered from the Geological Survey of Canada and from a previous project undertaken for NYSERDA along the St. Lawrence Lowlands, and include Bouguer gravity and total field magnetic data for Canada and New York State. Each file of geophysical data was produced from the gridding of magnetic profile and gravity points for the entire region. Magnetic measurements in Canada were made along lines spaced 1 km apart, whereas those from New York State were obtained from lines spaced 4 km apart. Additional magnetic data, collected in the field as part of the present study and consisting of measurements made at an average spacing of 2 km, were also integrated into the database. Geological information was received in the form of a digital regional geological map, produced by and acquired from the New York State Museum, which includes bedrock lithological polygons with proper attributes providing lithological descriptions and associated code (in ArcView format). Data processing began by utilizing a Universal Transverse Mercator map covering NAD 83, UTM Zone 18 as the reference projection for the database generation.

1.4 DATABASE GENERATION

1.4.1 Vector Data

The digital planimetric data (roads and hydrography) were recovered in ArcGIS format and were used both for geocoding the Landsat data and for base map information during image map production. Geological data were integrated as polygon layers associated with specific lithologies, with the original attributes attached to each polygon having been preserved. A sub-set was generated for the Paleozoic coverage. Field magnetic data were also integrated into the database and comprise both the locations of the measurements as specific UTM coordinates and the magnetic intensity measured in nanoteslas (nT).

TABLE 1-2 – Geoscientific data integrated into the project

Category	Type	Characteristic
Base Map Data	Road and Hydrography	• 1 :100 000 scale coverage • ArcGIS format
	Elevation	• 1 :24 000 scale coverage • 10 m elevation accuracy • 10 m grid spacing
Geophysical Data	Gravity	• Regional Gridded data • 500m grid spacing (NY coverage) and 2 km grid spacing (Canada) • Bouguer anomaly
	Magnetism	• Regional Gridded data • ***200m grid spacing (Canada) and 1 km grid spacing (NY coverage)*** • Total field
	Magnetism	• Field measurement point data • Average of 2 km point spacing (NY coverage only) • Total field
Geology Data	Geological map	• Digital geology data • ArcGIS format

1.4.2 Raster Data

Orthorectification of the Landsat image was undertaken with ground control points collected from digital planimetric data (roads) providing residual errors on the order of 15 m, which correspond to the final resampling grid cell. Orthoimages were generated for each channel. Edge enhancement and linear contrast stretch were finally applied to each channel followed by merging the panchromatic channel and the TM4, 5 and 3 channels, resulting in the Landsat color composite image shown in Figure 1-1.

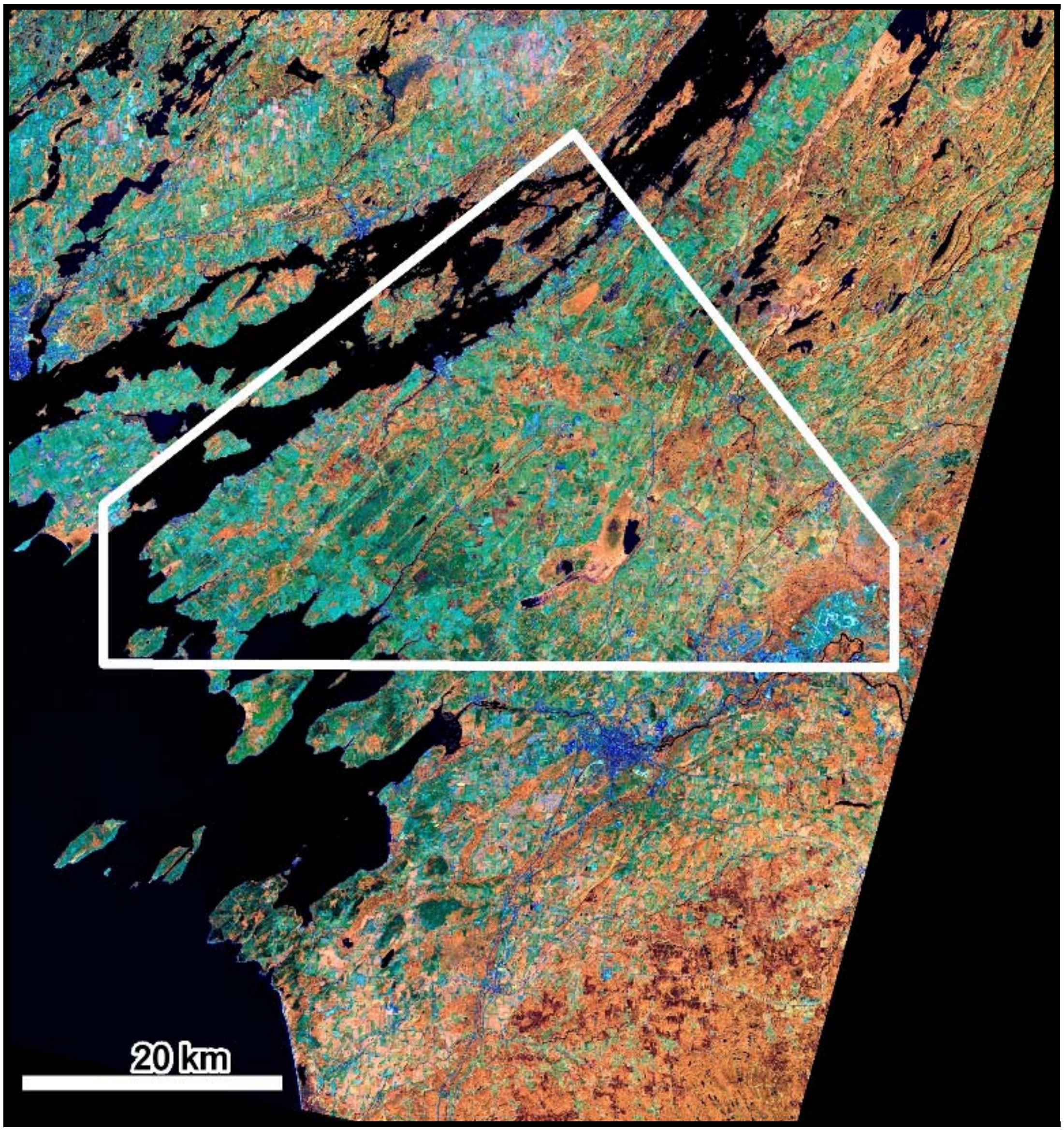


Figure 1-1 Landsat 7 Color Composite With Outline of the Study Area. Black Linear Band Parallel to the White Line Along the Upper Left Side of the Outline is the St. Lawrence River and the Black Area in the Lower Left Corner is Lake Ontario.

Regional geophysical data were converted from their original ASCII format to a gridded georeferenced raster image (PCIDISK Format). For the magnetics, the New York data were resampled and calibrated in accordance with the Canadian data which are more accurate. On the other hand the Canadian gravity data were resampled and coordinated with the more accurate gravity data from New York. An adaptive color palette was finally applied to each parameter and all enhanced files were then integrated into the ArcGIS database (Figure 1-2).

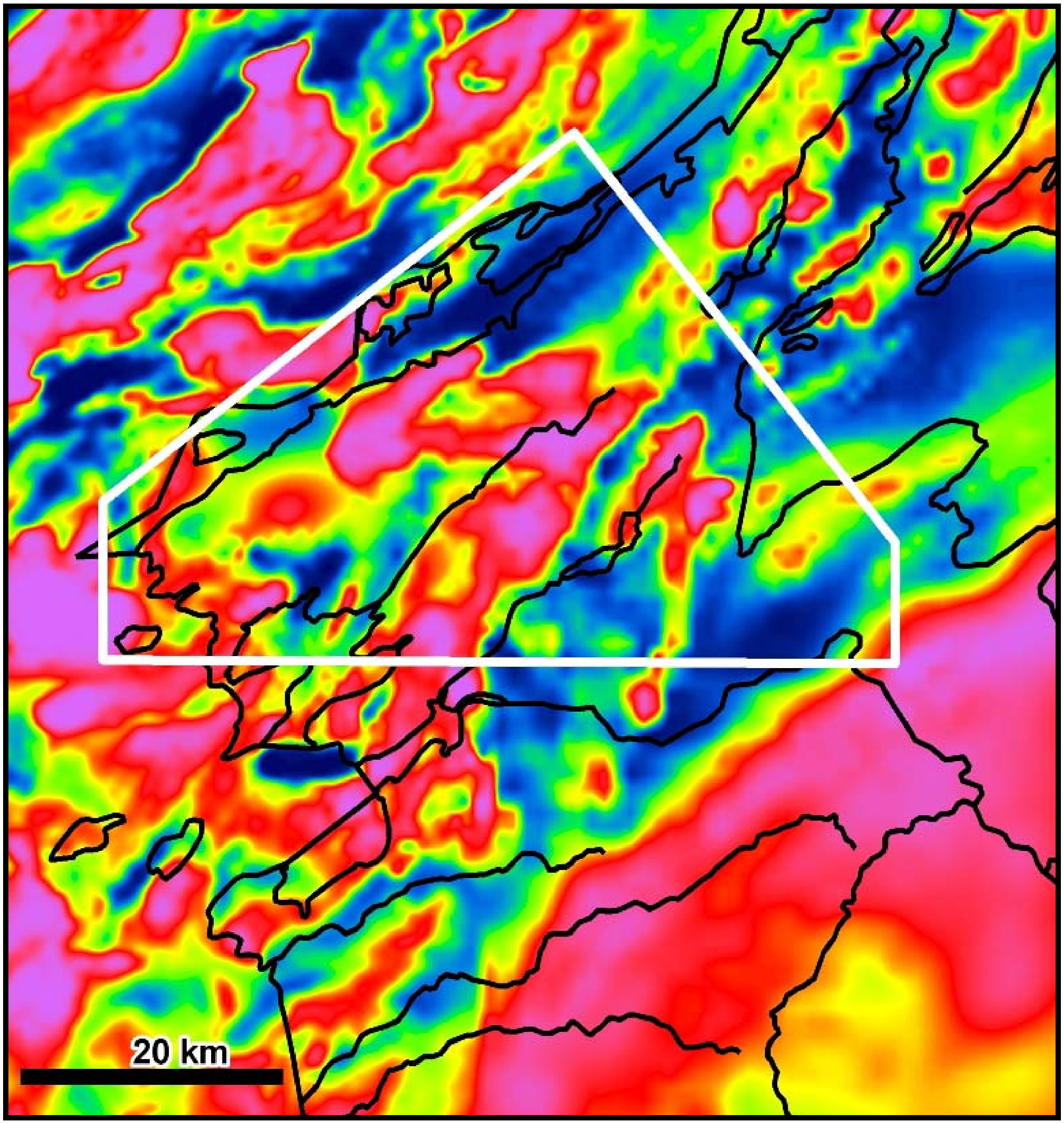


Figure 1-2 **Regional Total-Field Magnetic Map Showing the Outline of the Study Area (in White).**

Field magnetic data were gridded at a 500 m cell spacing, using the inverse distance weighted (IDW) value method, and were properly smoothed to show more effectively the spatial arrangement of the magnetic anomalies. An adaptive color palette was finally applied to the results enabling the integration of the map into the ArcGIS database (Figure 1-3).

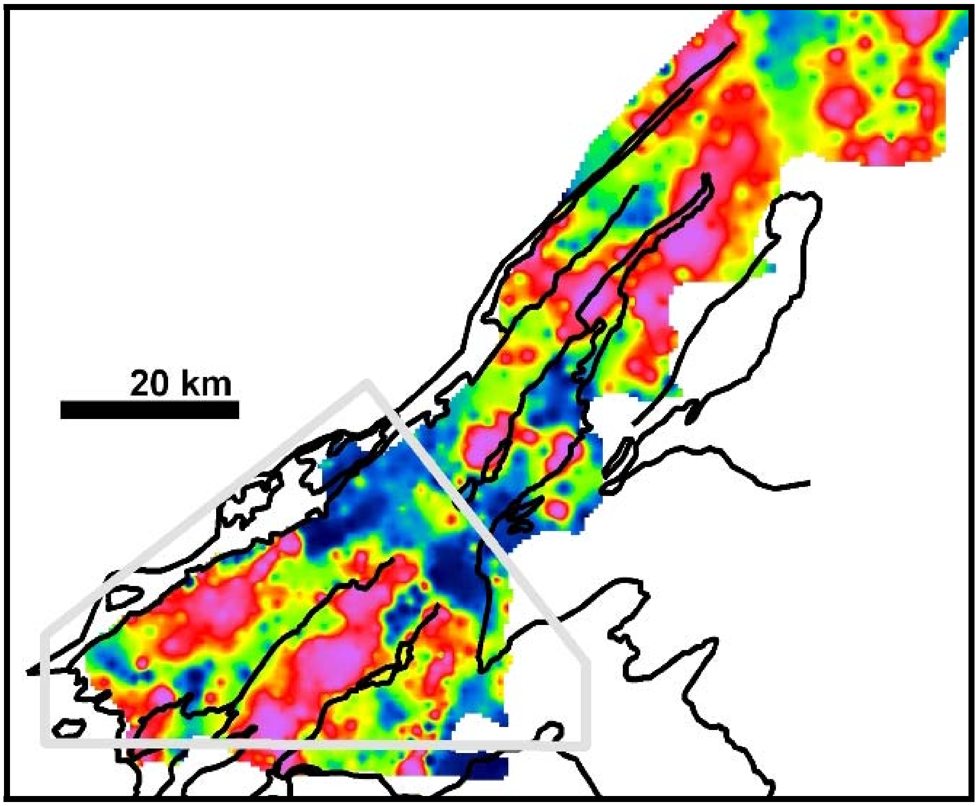


Figure 1-3 Total-Field Magnetic Color Map Generated From Ground Measurements.

High resolution digital elevation data were integrated into a single file covering the whole study area at 10 m grid spacing. Shaded relief images were produced under two different mutually perpendicular illumination conditions, the first from the north (000°) and the second from the east (090°) (Figure 1-4).

A total-field magnetic color image was superimposed on the shaded relief topographical data (illumination from the east) through the use of mathematical transformations which enabled correlating surface topographical lineaments with subsurface magnetic or gravity lineaments (Figure 1-5). The original magnetic data, generated at 200 m grid spacing, were resampled at a 10 m grid spacing to be compatible with the topographical data.

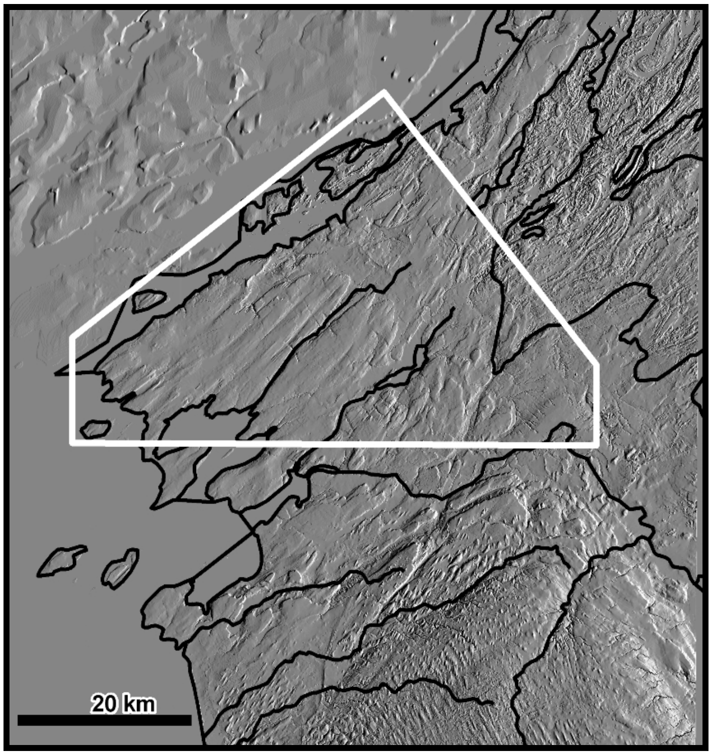


Figure 1-4 Shaded Topography; Illumination From the East.

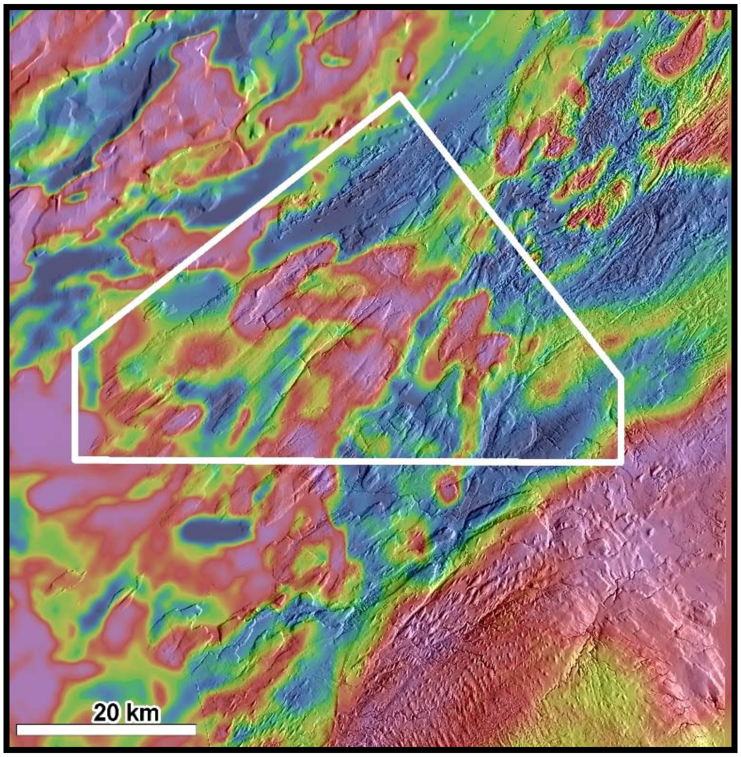


Figure 1-5 Shaded Topography Superimposed on the Total Magnetic Field Showing the Dominantly Northeast-Oriented Fabric Common to Both.

Chapter 2 GEOLOGY

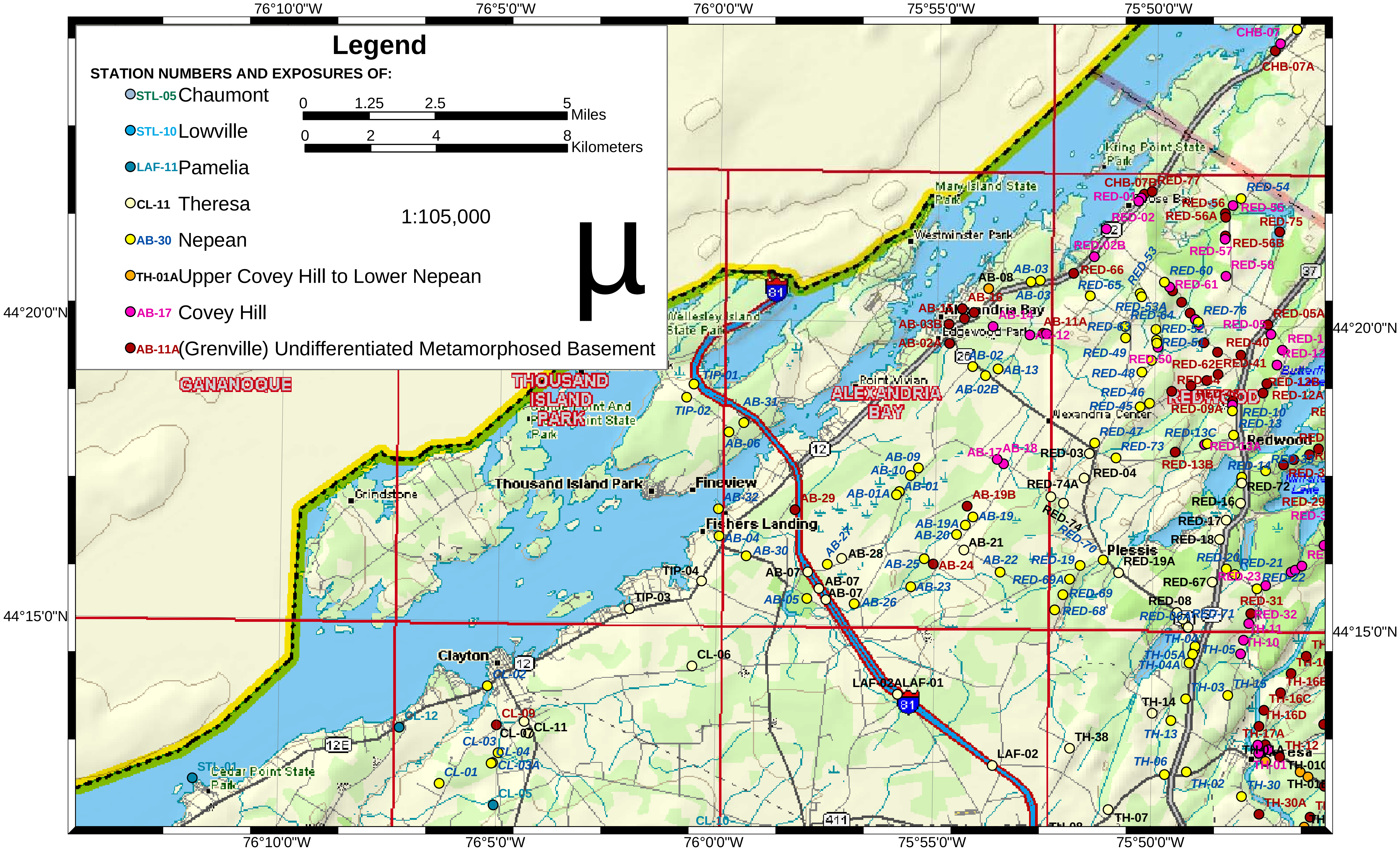
2.1 GENERAL STATEMENT

Outcrops occur throughout the study area, but are most abundant and concentrated in the northeastern portion, whereas elsewhere they are much more dispersed (Figures 2-1a and 2-1b). That notwithstanding, a clear generalized picture of the geology has emerged (Figure 2-2) although a lack of good cross-sectional exposures leaves a residue of unresolved questions concerning both detailed stratigraphic and structural features. For example, the relative abundance of outcrops along the shore of Lake Ontario affords only plan views or very thin cross sections which, in the absence of a feature typical of any particular formation, render the unequivocal identification of some stratigraphic units difficult, if not impossible.

Formational boundaries were interpreted from the outcrop distribution of differing lithologies, as usual, but were modified according to topographic contours (Figure 2-3). For example the locations and elevations of exposures of different formations were determined using a hand-held GIS unit and in combination with topographic maps. The 10-foot contour value that approximates the elevation midway between neighboring outcrops exposing different formations was traced to present a more refined interpretation of the boundary between the formations.

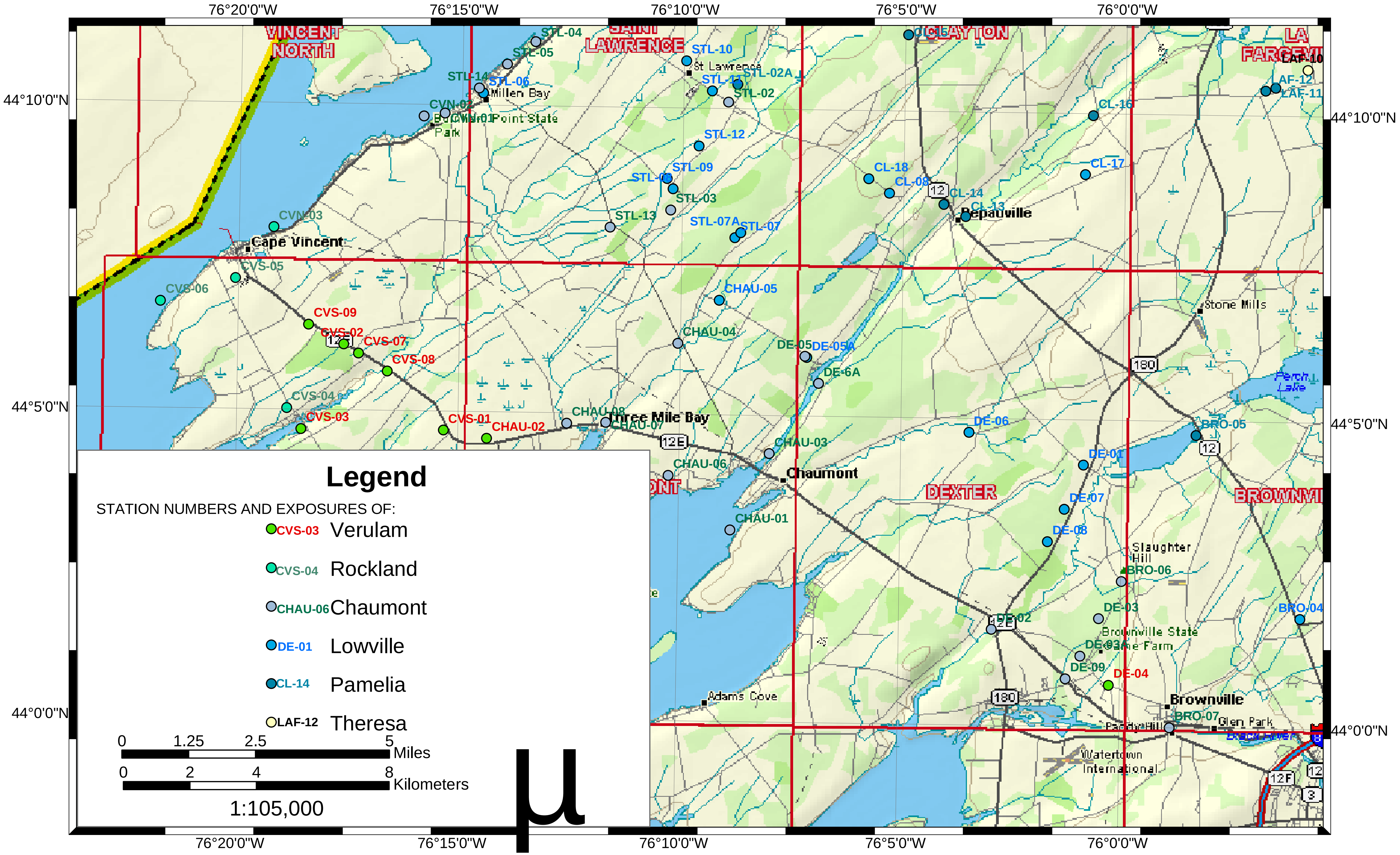
2.2 STRATIGRAPHY

The strata underlying the study area comprise the upper Cambrian to Lower Ordovician Nepean Sandstone (upper Potsdam), the lower Ordovician Theresa Formation (interlayered limestone and Nepean-like white quartz arenite), and the limestones of the middle Ordovician Black River and Trenton groups (Table 2-1). The Black River embraces the Pamelia, Lowville and Chaumont limestones, whereas the younger Trenton Group consists of the Rockland and Verulam limestone formations. For the most part New York stratigraphic nomenclature was used, with the exception of the Verulam Formation, which was taken from Ontario. Despite this rather simplistic categorization classification of formations within the Black River and Trenton Groups in northern New York and adjacent Ontario is unnecessarily complex. What is needed, but which goes beyond the scope of this study, is a careful revision of the stratigraphic nomenclature of both groups by a team of stratigraphers dedicated solely to that objective.



(a)

Figure 2-1a Station Locations, Northeastern Part of Map Area. Words Outlined in Red Are Quadrangle Names.



(b)

Figure 2-1b Station Locations, Southwestern Part of Map Area. Words Outlined in Red are Quadrangle Names.

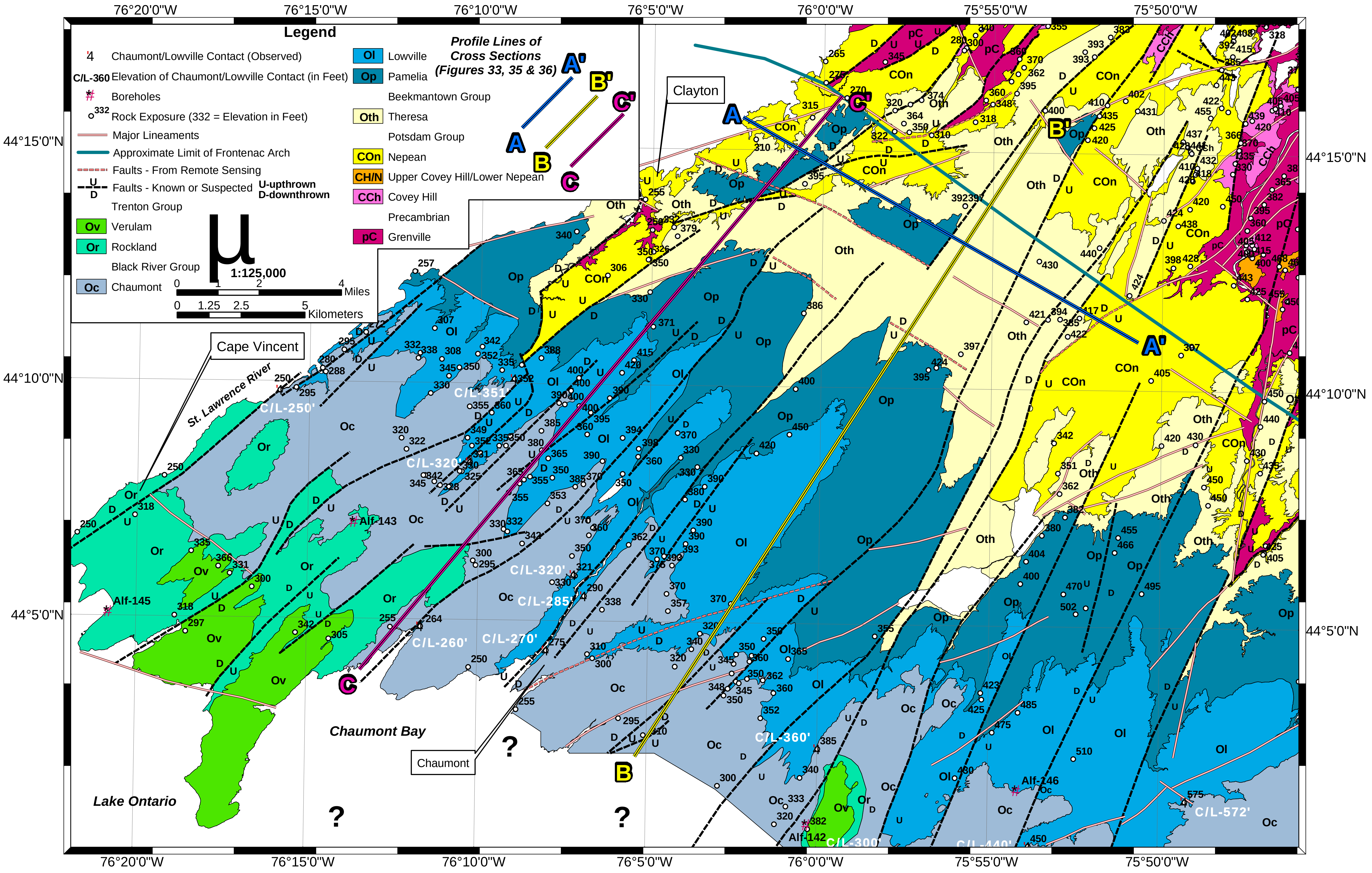


Figure 2-2 Geological Map of the Study Area. Numbers are Elevations of Outcrops in Feet.

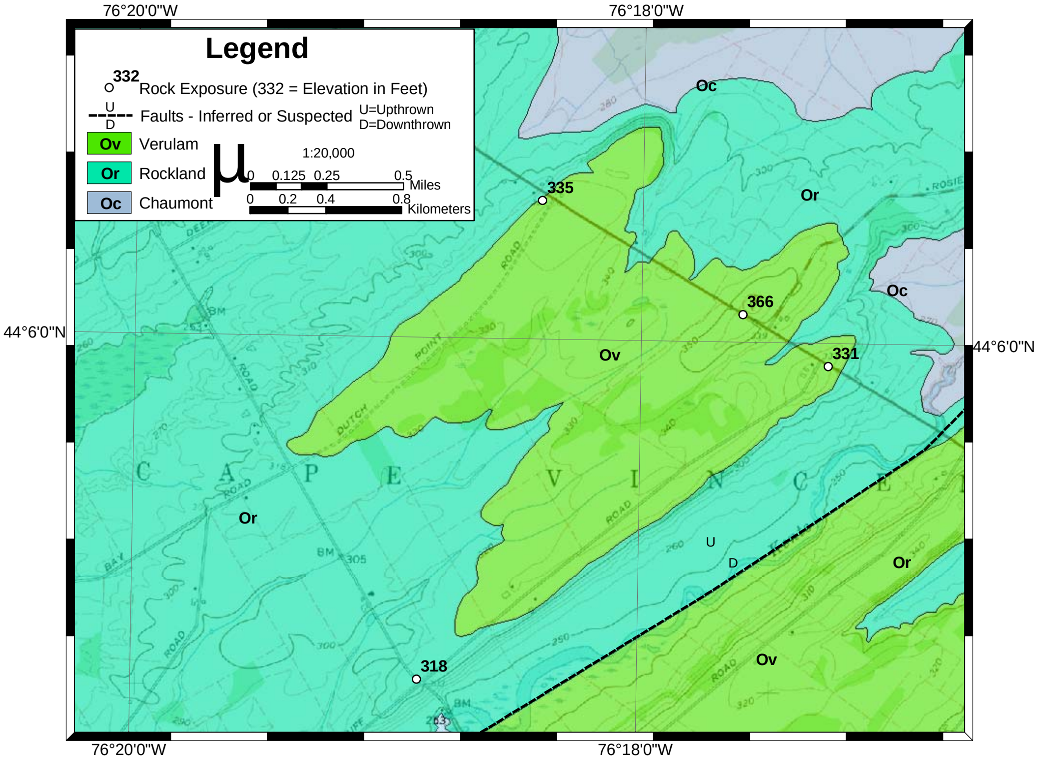


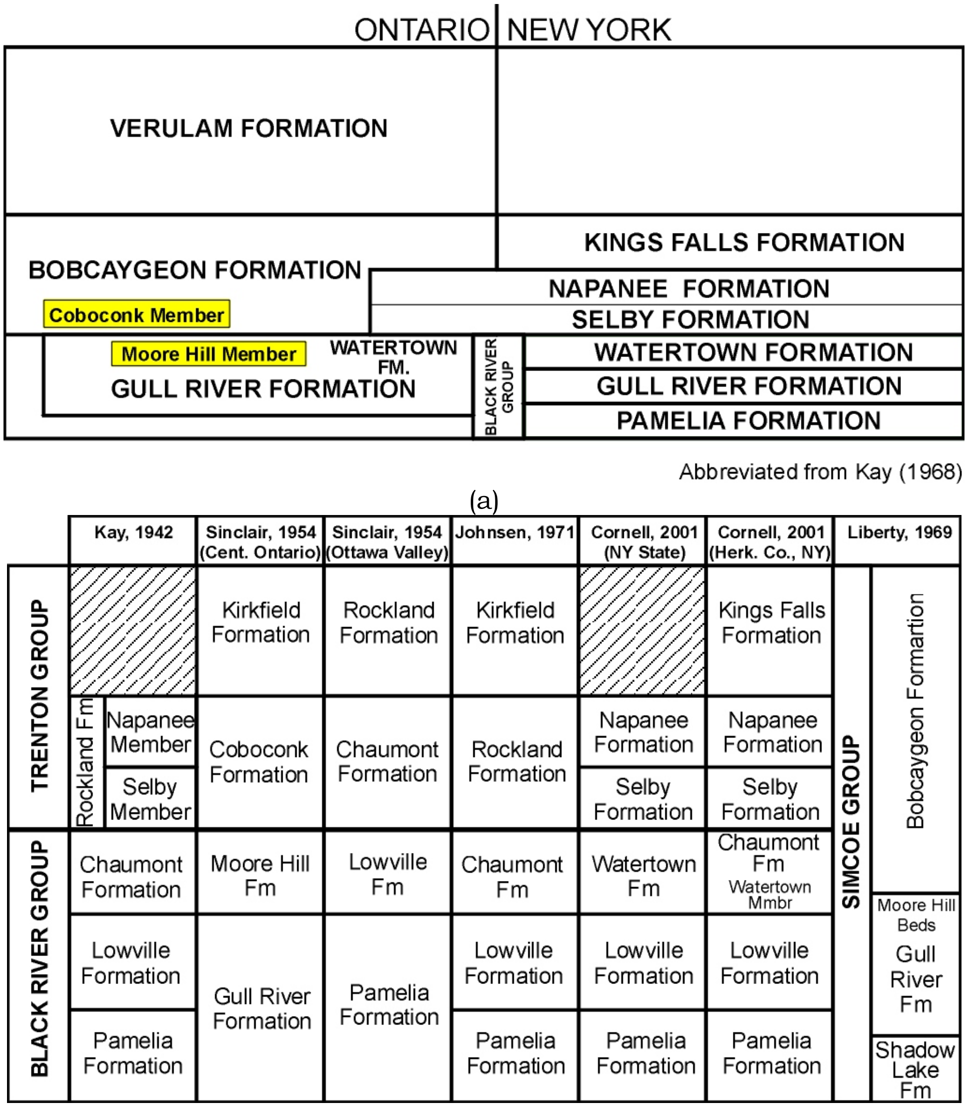
Figure 2-3 Interpretation of Formational Contacts by Using Topographic Contours.

TABLE 2-1 – Generalized stratigraphic column

Age	Generalized Lithology	Group	Formation
Middle Ordovician	Thinly bedded fossiliferous interlayered calcarenite and shaly limestone	Trenton	Verulam
	Thickly bedded fossiliferous calcarenite to calcilutite	Trenton	Rockland
	Thinly to thickly bedded micrite; chert & silicified fossils	Black River	Chaumont
	Micrite; locally fossiliferous	Black River	Lowville
	Interlayered micrite and buff-weathering dolostone	Black River	Pamelia
Lower Ordovician	Interlayered limestone & white quartz arenite	Beekmantown	Theresa
Upper Cambrian to Lower Ordovician	White quartz arenite	Potsdam	Nepean

A small accounting of the confusion is illustrated in the correlation charts of Figure 2-4, the first of which is derived and abbreviated from a chart produced by Kay (1968).

Among the confusing elements is that different names are used for parts of the same formations in that area, such as the Kings Falls and Kirkfield, Napanee and Bobcaygeon the partial equivalents of which may also be referred to as the Rockland and Coboconk formations. Furthermore the Coboconk is not granted formation status by all, but has been relegated to member status by some (Figure 2-4). The formational names Watertown and Chaumont, used by Kay (1968) and Johnsen (1971), respectively, refer to the same lithostratigraphic unit resting on the Lowville Limestone. Fisher (1977) elevated the Watertown to formation status, but in places Cornell (2001) retained the Watertown as a member of the Chaumont. Thus not only are multiple names employed for the same formation, but some units, such as the Watertown, appear as both formations and members.



Abbreviated from Kay (1968)

(a)

(b)

Figure 2-4 Correlation Charts Illustrating Part of the Confusion of Black River and Trenton Nomenclature.

Aside from problems of nomenclature the nature of boundary contacts may also, in part, bear on that cited above. For example, Cornell (2001), in describing the Chaumont (Chaumont) Formation stated: "*The medium textured, massive gray wackestones and packstones resemble the House Creek/Moore Hill beds – except that they contain well developed cephalopod faunas and are much more massive. For this reason, much confusion has resulted from trying to identify the Chaumont limestones in regions outside of northern New York State. Without the recognition of the sharp contact with the Glenburnie shale at its base, the Chaumont would appear to be part of a continuous succession."* Johnsen also reported the difficulty in drawing the boundary between the Trenton and underlying Black River Group rocks because the contact between the Chaumont (Black River) and the overlying Rockland (Trenton) is nowhere to be seen in Jefferson County. Moreover there are lithostratigraphic and biostratigraphic names generally designated for the same or approximately the same interval of rock as in the case of, for example, the Rockland Formation (biostratigraphic) and the Bobcaygeon Formation (lithostratigraphic) (Liberty, 1969). Adding to the confusion Liberty (1969) even abdicated the group terms Black River and Trenton by having replaced both with his, at the time, newly created Simcoe Group (Figure 2-4).

A major source of the problem may have been explained by Wilson (1964). She observed that in the Ottawa-St. Lawrence Lowland the distinction among the formations within the Black River and Trenton is largely established on the occurrence of certain fossils, albeit the paleontological limits are rather indefinite and there are "*minor and frequently repeated differences in lithology*". She added that the character of the Black River and Trenton, to which she referred as formations, is homogeneous based on chemical analyses indicating a carbonate percentage of 86-100% throughout.

The writers are not presumptuous enough to believe they are able to sort out the existing stratigraphic confusion. Rather they make use of some rather simple stratigraphic nomenclature, such as that generally employed by Johnsen (1971). To begin with the group terms Black River and Trenton are firmly established in the literature and are, therefore, used in this report. The component formations of the Black River Group are, from oldest to youngest, the Pamelia, Lowville and Chaumont, whereas those making up the Trenton, again from oldest to youngest, comprise the Rockland, Verulam and Cobourg[1] formations.

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[1] Does not occur in the study area

2.2.1 Black River Group

2.2.1.1 Pamelia Formation

The Pamelia is a light gray weathering, medium light bluish gray to medium or dark gray, moderately thickly bedded, locally laminated calcilutite in which fossils may be found, but are not particularly abundant. Buff-weathering dolomitic layers are characteristic of this unit and it is that characteristic, in particular, that enables distinguishing the Pamelia from the overlying Lowville, from which the dolomite layers are absent (Figure 2-5)**.** Johnsen (1971) described a transitional unit between the two, a necessary evil because there are localities where the precise formational contact cannot be ascertained. In Ontario the distinction between the two has been overcome by combining both the Pamelia and Lowville formations into the Gull River Formation.

Figure 2-5 Predominantly Buff-Weathering Dolomitic Limestone Beds Typical of the Pamelia Formation Sandwiching a Light Gray Weathering Micrite Layer. Location Station BRO-1

2.2.1.2 Lowville Formation

Light gray weathering, dove-gray, medium brown-gray and darker gray, thinly to rather thickly bedded micrites are commonplace within the Lowville (Figures 2-6 thru 2-9). Fossils are much more common than in the Pamelia, such as cephalopods and ostracodes, but are not ubiquitous. One that was almost used in a definitive sense by Johnsen (1971) to identify the Lowville is the calcite-filled worm tube *Phytopsis tubulosa* (Figure 2-9) which, in plan view, can be readily recognized by its bird's eye appearance. Flattened limy clasts and small cross beds appear locally.

Figure 2-6 Station CHAU-5, Cross Section of the Lowville Formation.

Figure 2-7 Station STL-7A, Cross Section of the Lowville Formation. Hammer in the Center of the Photograph is 1.3 feet (40 cm) high

Figure 2-8 **Station STL-7A, Close-up of Undulating Bedding Surfaces Seen Behind the Hammer in the Previous Photograph.**

Figure 2-9 **Calcite-Filled Worm Tubes (*Phytopsis tubulosa*) in the Lowville Formation.**

2.2.1.3 Chaumont Formation

One of the most distinctive formational boundaries is that between the Chaumont and Lowville limestones. Locally the contact is rather obvious (Figure 2-10), whereas elsewhere it is gradational. Both formations tend to be micritic, but the presence of chert or silicified fossils in the Chaumont (Figure 2-11), as recognized by Johnsen (1971), and the nodular texture, attributed to algae (Figure 2-12) (Sanford, personal communication), are the principal characteristics permitting differentiation of the two formations. The mottled appearance of weathered Chaumont versus the smooth weathered surfaces of the Lowville is also rather helpful. The Chaumont is at least 10 feet (3.5 m) thick and is comprised commonly of micrite thereby, in some cases, making it difficult to distinguish from the Lowville if the two cannot be seen together (Figure 2-13).

Figure 2-10 Contact Between the Chaumont and the Underlying Lowville, Marked by the Prominent Black Horizontal Zone Behind the Hammer. Hammer Head Rests on Uppermost Layer of Lowville.

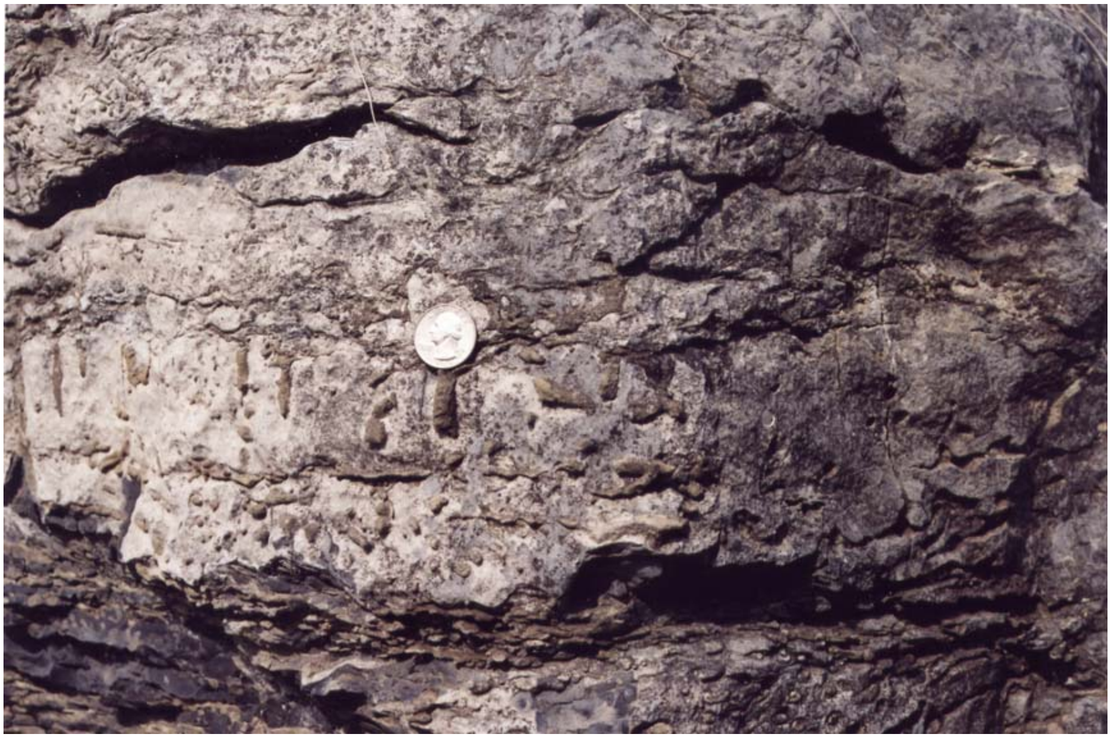


Figure 2-11 Silicified Fossils (Dark, Short, Predominantly Vertical Items in the Layer Underlying the Quarter) in the Chaumont Formation.

Figure 2-12 Nodular Texture, a Commonplace Feature of the Chaumont Formation.

Figure 2-13 Nodular-Looking Lowville Which May be Confused With the Chaumont

2.2.2 Trenton Group

2.2.2.1 Rockland and Kirkfield Formations

Very few exposures of Rockland, the oldest formation within the Trenton Group (Table 2-1), crop out in the study area (Figure 2-1b). Of those that do, none that was identified during the course of this study features characteristics similar to the Rockland in and near the type locality of Rockland, Ontario (Figures 2-14 and 2-15). No separate map pattern has been designated for the Kirkfield Formation (Figures 2-16 and 2-17), although it is distinguishable from the overlying Verulam. The Kirkfield appears to be an upwards gradation of the Rockland and more closely resembles the Rockland than it does the Verulam, which is why the Rockland and Kirkfield have been lumped together.

Because of the paucity of exposures of both the Rockland and Kirkfield in the study area, those formations were examined in eastern Ontario in order to try to characterize them and determine their lithological relationships. The Rockland formation, west of Rockland, Ontario, is denoted by thickly bedded, medium gray weathering, medium gray calcarenite and calcisiltite with beds ranging in thickness from 6-47 in (15-120 cm) (Figure 2-14). Near the top, however, it becomes more thinly bedded and is gradually succeeded by thinly interlayered limestone and shaly limestone layers typical of the Verulam (see below). In the village of Rockland thickly bedded interlayered calcarenite and calcisiltite, 6-23 in (15-60 cm) thick, along with laminated calcilutite and 1-2 in (2-5 cm) thick shaly partings compose the formation (Figure 2-15). To the south, at the type section, the unit is, again, a rather thickly bedded sequence of medium-dark gray calcilutite, calcisiltite and calcarenite along with thin, irregular, sandy colored weathering, darker gray argillaceous(?) partings. Fossils are present but, where the exposure was examined, are generally not abundant.

Thinly bedded, but massive to very thinly almost imperceptibly laminated medium gray coarse-grained calcisiltite or fine-grained calcarenite marks the Rockland at Station CVN-3 (Figure 2-1b). Station CVS-4 (Figures 2-1b and 2-17) exposes rather thin limestone layers with undulatory surfaces. Bedding thickness ranges from 3-5 in (7-14 cm) with the thickest bed made up mostly of medium gray calcarenite; although there is also some medium gray calcilutite.

Figure 2-14 **Cross Section of Calcarenite and Calcisiltite Layers in the Rockland Formation East of Rockland, Ontario.**

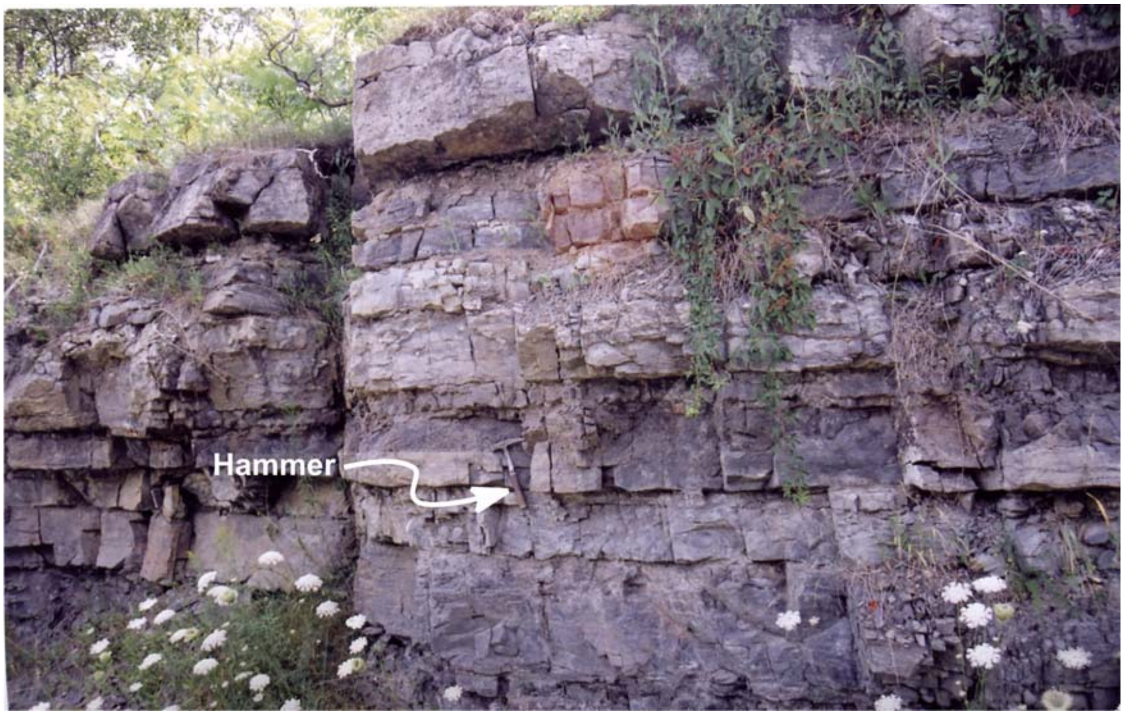


Figure 2-15 **Cross Section of Rather Thick Calcisiltite Layers and Thin Shaly Layers in the Rockland Formation at Rockland, Ontario. Hammer is 12 in (30 cm) Long.**

Figure 2-16 **Thin Limestone Beds in the Hull Formation (Kirkland Equivalent) in Gatineau, Québec. The Exposure Face is about 15 ft (4.6 m) High.**

Figure 2-17 **Thin Limestone Beds of the Kirkfield Formation, Herein Lumped in with the Rockland. Upper Photo from Napanee, Ontario, Where the Unit Was Identified as the Napanee Formation or Lower Kirkfield Formation by Cornell (2001); Lower Photo From Station CVS-4 in the Study Area.**

2.2.2.2 Verulam Formation

The Verulam Formation was named by Liberty (1955) as a rock unit to replace the previously used terms Sherman Fall and Cobourg, both of which he identified as biostratigraphic units. In Jefferson County, Johnsen (1971) correctly separated the Cobourg from the underlying Sherman Fall and utilized the names Denmark and Shoreham. Verulam is used in this report to embrace the Denmark and Shoreham Formations because the lithological distinctions between the two are very subtle, with the major differences being paleontological. In our report on the Tug Hill Plateau (JL Wallach Geosciences Inc and MIR Télédétection inc, 2002) the Kirkfield Formation was also lumped in with the Denmark and Shoreham, a classification now realized to have been erroneous.

Lithologically the strata within the Verulam are comprised of rather thin layers of bioclastic limestone, for the most part calcarenite, with intervening thin layers or partings of calcareous shale (Figure 2-18). For example, at Station DE-4 the Verulam is characterized by buff to light gray weathering, richly fossiliferous cross-bedded calcisiltite to bioclastic calcarenite and interlayered shaly limestone. The limestone layers are about 4-6 in (10-15 cm) thick; whereas the intervening shaly limestone layers are less than 0.1 in (1-2 mm) thick and the unit becomes progressively more shaly upwards. At another location (Station CHAU-2) the formation is comprised of a fossiliferous bioclastic calcarenite with thin limy shale partings. Limestone layers are 2.4, 2.4, 0.8, 0.8, 3.9, 7.1 in (6, 6, 2, 2, 10 and 18 cm) thick, respectively and bedding surfaces are undulatory; but show no cross beds. Within the study area there are some differences, but the overall lithology comprises interlayered limestone and argillaceous limestone or limy shale (Figure 2-18).

Figure 2-18 Flaggy Limestone and Argillaceous Limestone Beds in the Verulam Formation.

2.3 STRUCTURAL GEOLOGY

2.3.1 Topographic Lineaments

The lineament interpretation consisted of using both the Landsat color composite and panchromatic channel, along with shaded topographical relief images. Shaded topography, illuminated from the east, with elevation values overlain in color is shown in Figure 2-19. The interpretation was restricted to the defined study area (Figures 2-20 and 2-21), but was adjusted to the previous lineament interpretations produced along the St Lawrence River and across the Tug Hill Plateau. Linear and curvilinear features related to the structural fabric were extracted and classified into three main categories of probable geological significance: 1st order lineaments (faults or lithologic discontinuities which are shown in red in Figures 2-20 and 2-21), 2nd order lineaments (bedding or foliation shown in light gray in Figure 2-20) and 3rd order lineaments (fractures).

Sets of 1st and 3rd order lineaments were determined from rose diagrams with lineaments at both scales displaying obviously well defined sets which trend 065° and 120° (Figure 2-22). Parallelism of other orientations of 1st and 3rd order lineaments also exists, notably among those at 020°, 035° and 050°, however they are not as prominent among the 3rd order lineaments as they are among those of the 1st order.

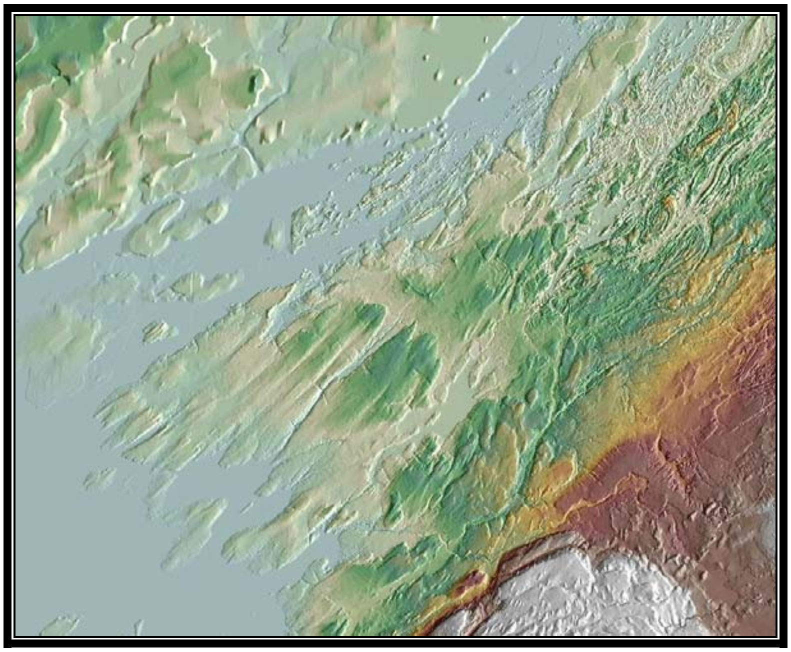


Figure 2-19 Shaded-Relief Topography, Illuminated from the East. Colors Represent Elevations.

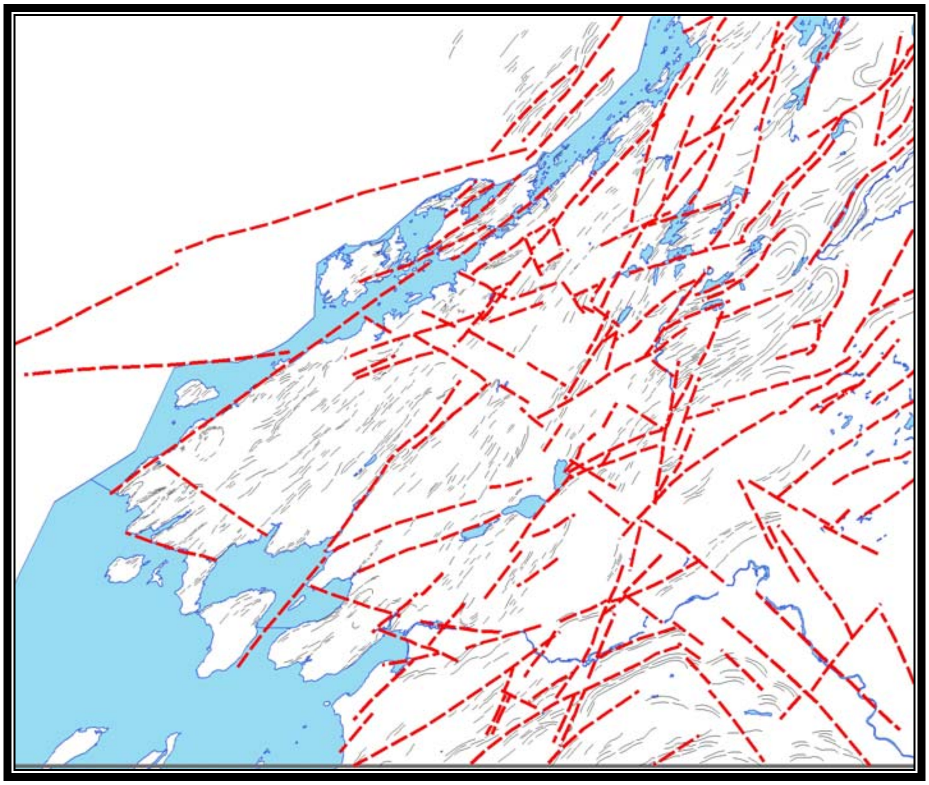


Figure 2-20 Lineaments: Regional Discontinuities (Red) and Bedding (Light Gray). NE-Trending Blue Band Across Upper NW Portion of Map is the St. Lawrence R.

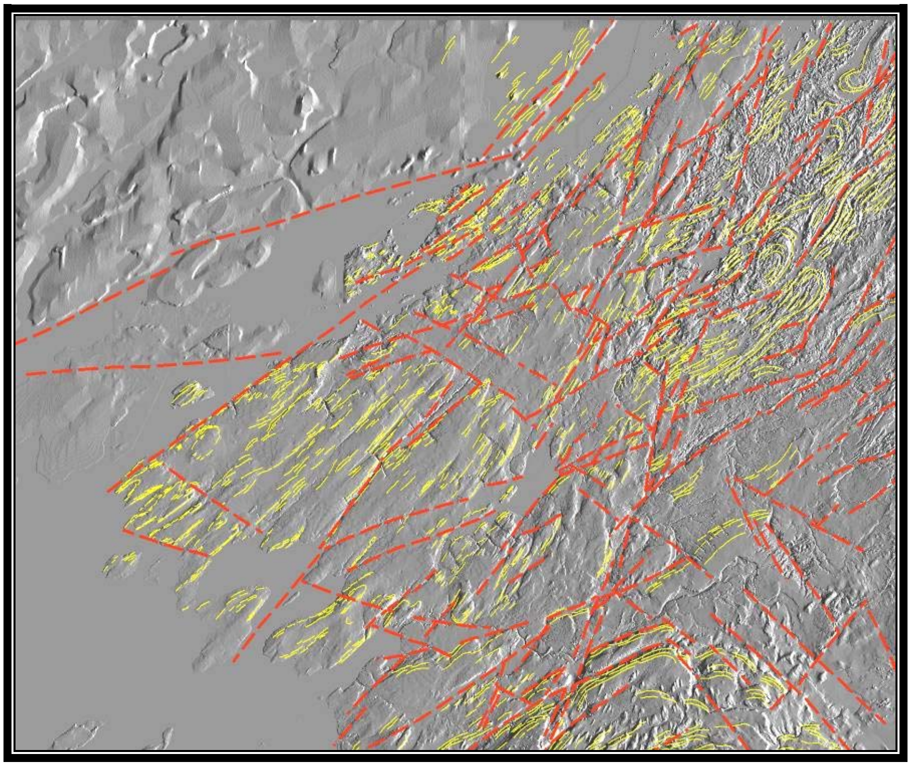


Figure 2-21 Lineaments Superimposed on a Shaded-Relief Image.

2.3.1.1 First order lineaments

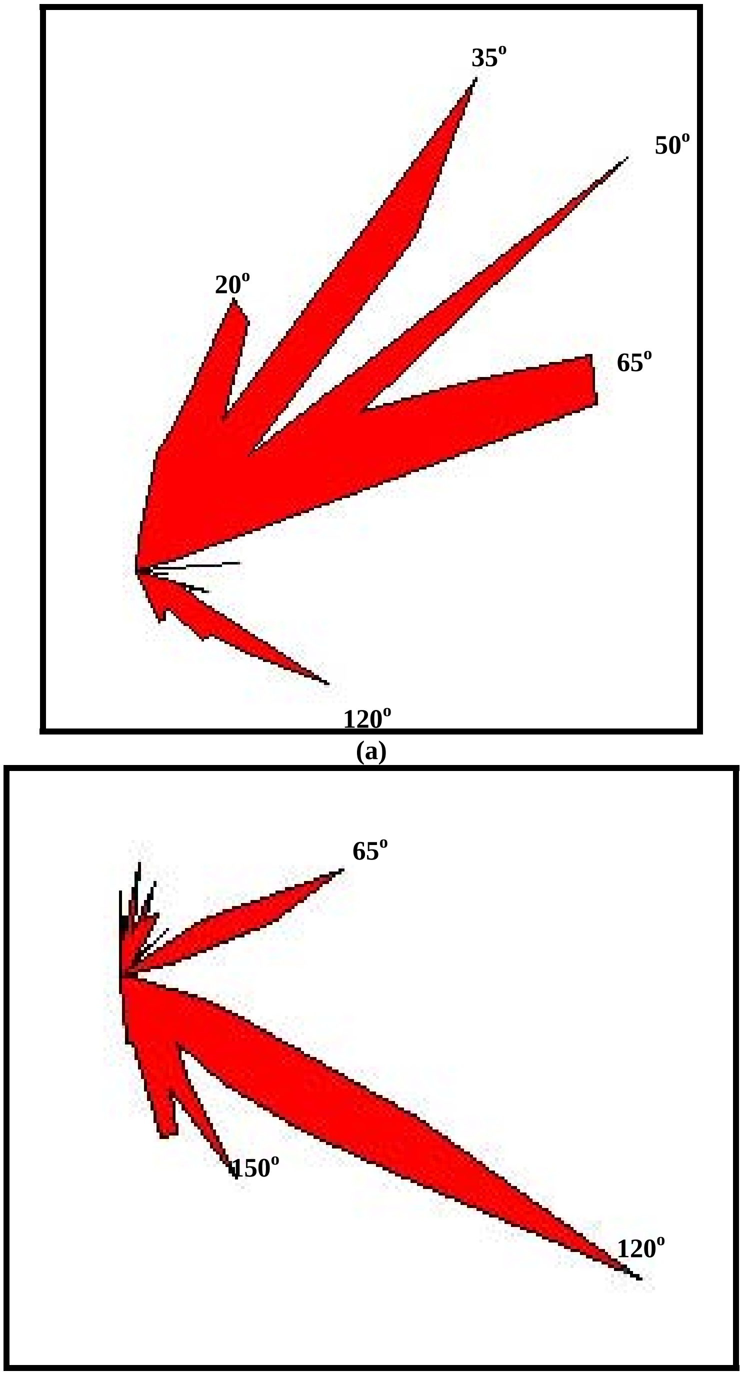
First order lineaments are regional topographic discontinuities reflecting scarps and hydrographic patterns which may, in turn, be controlled by lithostratigraphic contacts or fault zones. Among them are the major lineaments (Figure 2-2) and, though not shown explicitly, include all of the faults displayed in Figure 2-2. Four dominant sets of regional discontinuities are interpreted (Figure 2-22a) and trend north-northeast, northeast, east-northeast and southeast. Northward from the northern border of the Tug Hill Plateau, the east-northeast discontinuities define three specific corridors, each about 9.3 mi (15 km) wide, which are generally more subtly expressed over Paleozoic terrain than over the Grenvillian basement. The northeast set is more or less parallel to the northern limit of the Tug Hill Plateau and the St Lawrence River, both of which are parallel to, and probably controlled by, the dominant Grenvillian fabric. The north-northeast and east-northeast lineaments are similar in that they are greater than 25 mi (40 km) in length and cut through the entire stratigraphic sequence. Finally, a northwest-trending corridor of regional discontinuities in the central part of the area represents the extension of the eastern limit of the Tug Hill Plateau, interpreted by JL Wallach Geosciences and MIR Télédétection inc (2002) as a major northwest-oriented bounding fault, which they named the Black River fault.

2.3.1.2 Second order lineaments

Second order lineaments are inferred to represent probable bedding surfaces over Paleozoic terrain and foliations over the Grenville basement, and are expressions of short and repetitive curvilinear terrain features. Bedding shows a dominant northeast trend which is represented by geomorphically parallel ridges, the presence of which is likely due to accentuation resulting from northeast-controlled erosion of those gently dipping Paleozoic lithological units. In the Grenville basement, those features are more likely expressions of diversely oriented foliations which, locally, define sub-circular features associated with regional plutonic intrusions.

2.3.1.3 Third order lineaments

Third order lineaments are small expressions of linear topographic features, such as ridges or streams, and are interpreted as fractures or small faults with minor displacements. Three dominant sets, trending east-northeast, southeast and south-southeast (Figure 2-22b), occur throughout the entire study area, irrespective of the whether the terrain is underlain by metamorphosed Grenvillian basement or Paleozoic sedimentary rock. Those oriented east-northeast and southeast are parallel to first order lineaments, although the latter are more abundant. Fractures expressed as third order lineaments may be tied to a single tectonic event or, more likely, are the products of successive deformational episodes.



(a)

(b)

Figure 2-22 Rose Diagrams of Interpreted Discontinuities (a: 1st Order Lineaments) and Fractures (b: 3rd Order Lineaments).

2.3.2 Relationship of Topographic Lineaments to Magnetic Lineaments and Bedrock Geology

The dominant trend of the linear magnetic anomalies, most of which are related to lithological changes within the Grenvillian basement, is northeast to north-northeast. Magnetic lineaments in that orientation range, along with those oriented east-northeast, correlate quite well with their topographic counterparts, the latter particularly well in the western part of the area where some linear magnetic anomalies seem to change direction from east-northeast to northeast (Figure 2-23). No such obvious correlation could be established between topographic and magnetic lineaments trending northwest though, locally, the continuity of northeast-trending linear magnetic anomalies is disrupted where traversed by those striking northwest. That implies some sort of correlation between basement and surficial lineaments, though not as obvious as those cited above.

South of the study area, the north-northeast trend defines an 18.6 mi (30 km) wide corridor extending into Lake Ontario and at the border of which is located the Pulaski and Sandy Creek gas fields. The potential relationship of that corridor to the locations of those two gas fields at the southwest corner of the Tug Hill Plateau (JL Wallach Geosciences Inc and MIR Télédétection inc, 2002) may have implications for gas field development elsewhere, though that, by itself, is an overly simplistic notion.

In summary, the first order regional topographical lineaments, associated with fractures or faults, generally show a good spatial relationship to regional linear magnetic anomalies. This suggests that some of those regional topographical lineaments reveal fault zones that originate in the Grenville basement and were later reactivated to cut the Lower Paleozoic rocks. That impression is reinforced by the close correlation between mapped or interpreted faults cutting the Paleozoic rocks and the linear magnetic anomalies that are signatures from the basement(Figures 2-2 and 2-24).

The interpreted lineaments were superimposed on the generalized regional geological map recovered from the New York State database (Figure 2-25). The results show that the northeast oriented regional discontinuities generally border the contacts between Paleozoic units, but may also extend within those lithological units, suggesting that at least some of them are faults. That is the case for the three main sets, namely those oriented north-northeast, northeast and east-northeast, which cut units of the Potsdam, Beekmantown, Black River and Trenton groups.

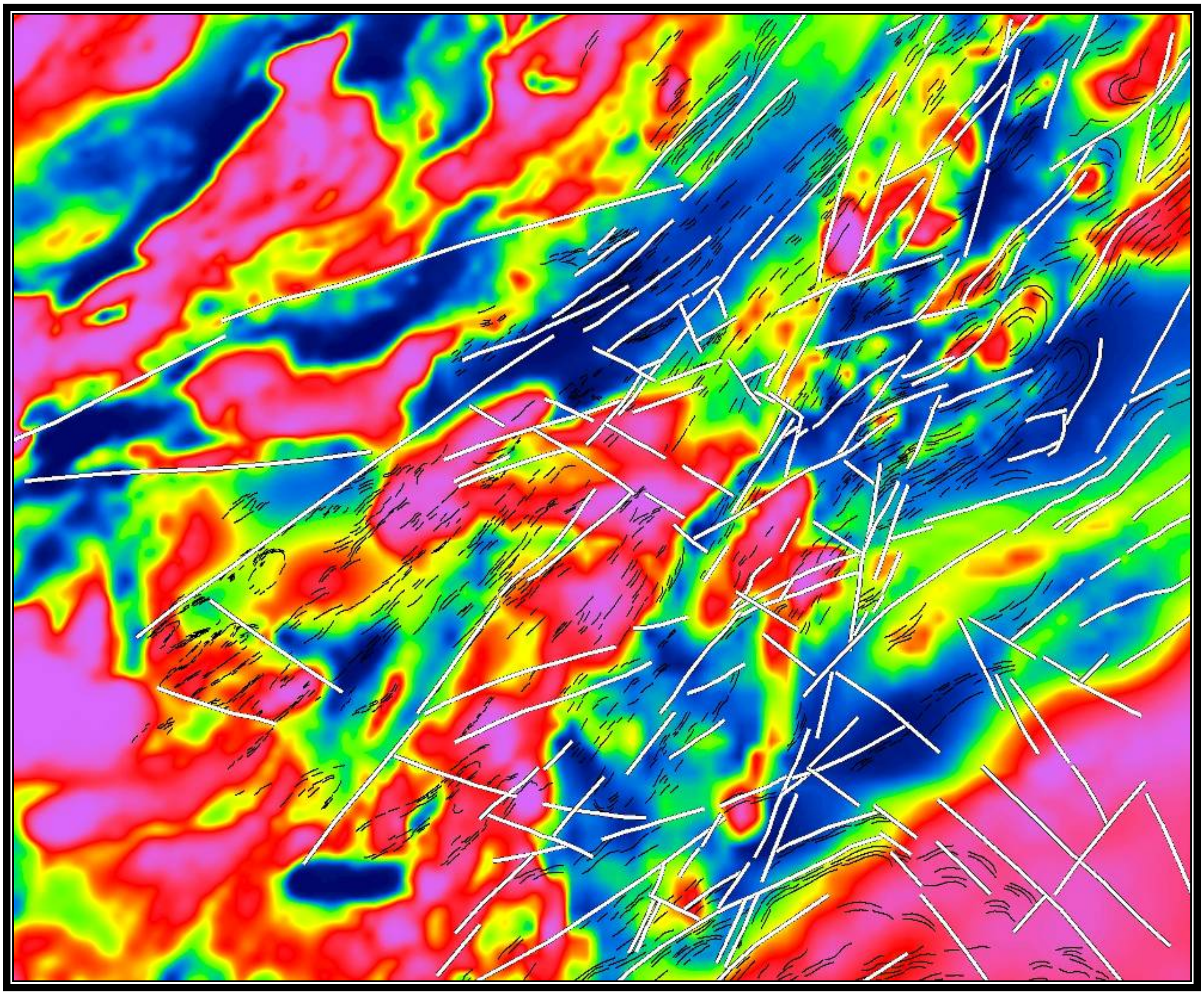


Figure 2-23 Total-Field Magnetic Map with Superimposed Topographic Lineaments.

Northwest trending lineaments define two specific corridors which border the northeastern and the southwestern limits of the Black River Group. This was thought to represent a physiographical limit, produced by erosion, without being necessarily related to faulting. From the geological work (Figure 2-2), however, it is seen to be bounded on the northeast by the west-northwest-oriented Frontenac Arch (Figures 2-2 and 2-24), which is proximal to the northeastern edge of the Pamelia Formation, the oldest formation within the Black River Group. On the southwest the bounding lineaments are parallel to the northwest-trending shoreline of Lake Ontario.

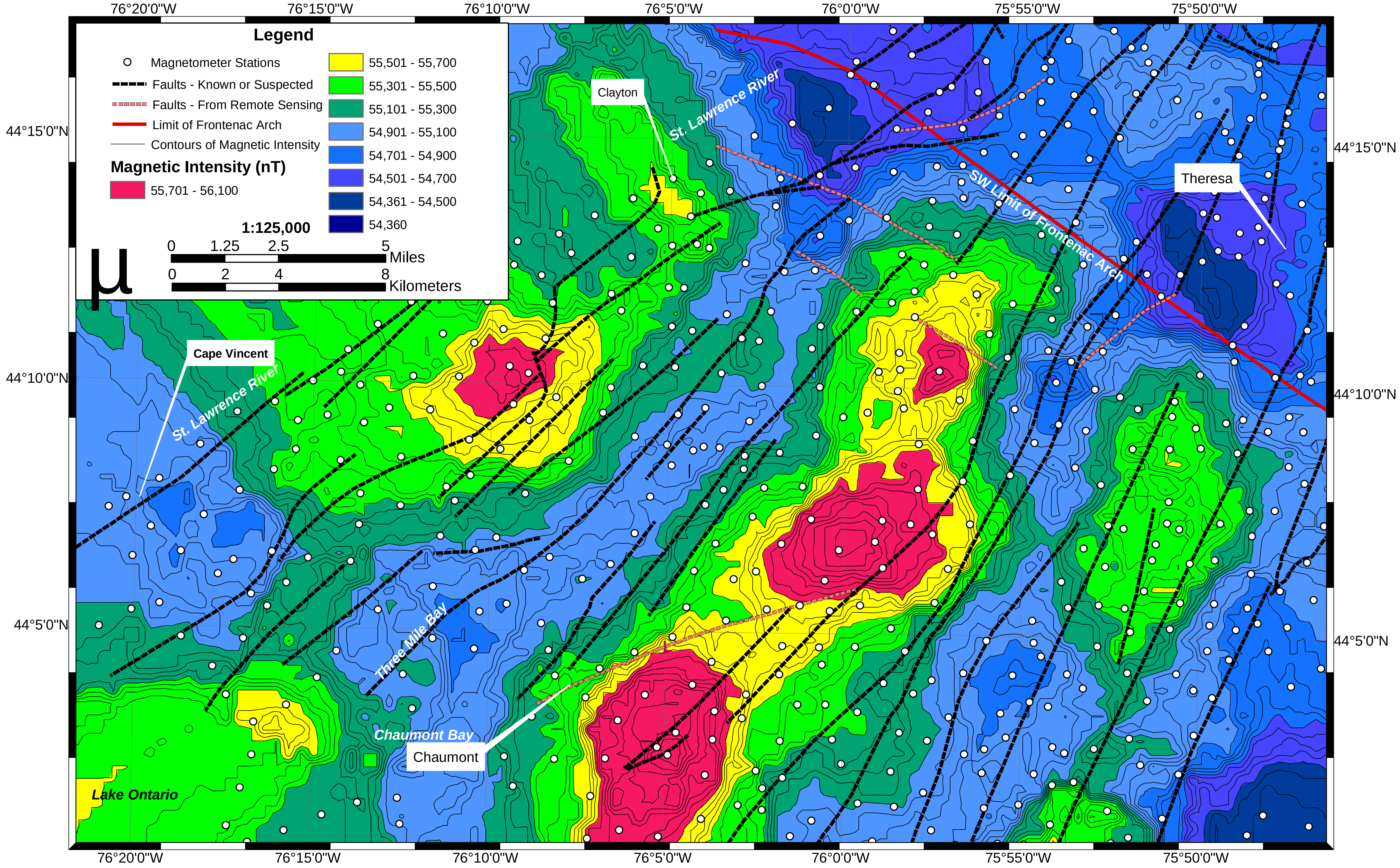


Figure 2-24 Geologically Mapped Faults Superimposed on Total-Field Magnetic Map.

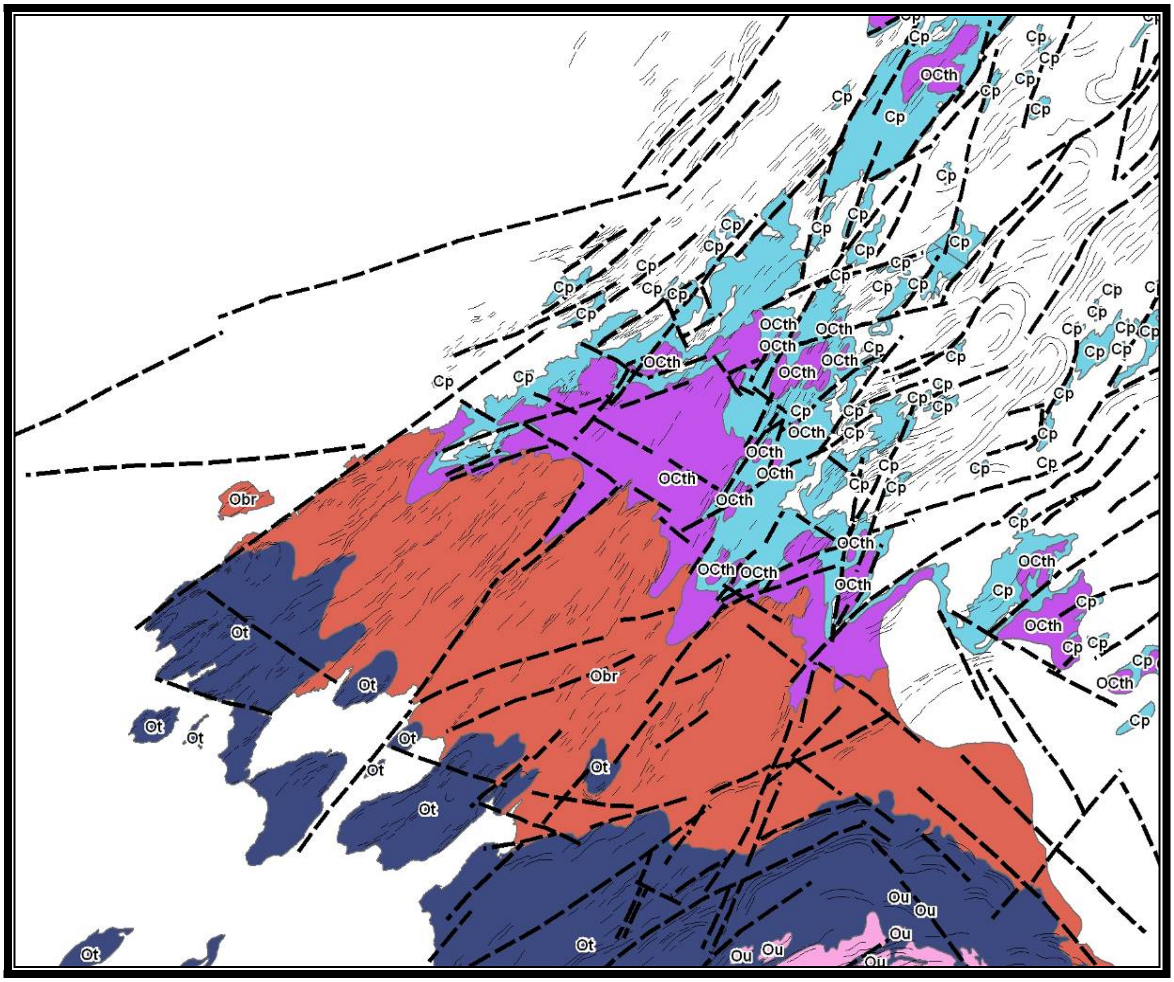


Figure 2-25 Topographic Lineaments Superimposed on the Generalized Bedrock Geology.

In the northeastern part of the study area members of the east-northeast and north-northeast lineament sets intersect. The same occurs east of the Tug Hill-bounding, northwest striking Black River fault, an area that is also underlain by undifferentiated Grenvillian basement (JL Wallach Geosciences Inc and MIR Télédétection inc, 2002). It appears as if that intersecting pattern may have locally altered the course of the St. Lawrence River because it is in that area that the flow direction of the river changes from east-northeast to northeast (Figure 2-20). In summary, many of the major topographical lineaments appear to be the surface expressions of previously unrecognized faults, the most significant of which are oriented east-northeast and north-northeast.

2.3.3 Regional Dip

Using the base of the Leray Formation (approximately equivalent to the Chaumont) Cushing et al (1910) recognized elevation changes in a west-northwesterly direction across the area yielding a dip of about 13 feet per mile (2.5 m/km). They acknowledged, however, that the dip direction is not west-northwest, but is approximately 210-225°, therefore they reasoned that the 13 feet/mile (2.5 m/km) dip was, at best, an apparent dip. No precise data could be utilized to make an accurate measurement or even a firmly rooted estimate, but Cushing et al (1910) projected the regional dip to be to the southwest at about 25-30 feet per mile (4-6 m/km). In the same general area Johnsen (1971) overestimated the southwesterly regional dip to be about 1°-2°, which translates to 92-184 feet/mile (17-35 m/km). In their study of the Tug Hill Plateau and the foreland to the north JL Wallach Geosciences and MIR Télédétection inc. (2002) wrote the following:

> "*Based on the elevations of stratigraphic contacts, it appears that the smoothed regional dip across the Tug Hill Plateau, as well as across the low-lying foreland to the north, is in the range of from about 4 to 8 m/km (20 to 40 ft/mi) in a southwesterly direction (about 220° to 240°).*"

The 20-40 feet/mile (4-8 m/km) estimate is much more in line with that of Cushing et al though it, too, may be slightly excessive. In the current study several outcrops exposed the Chaumont/Lowville contact, which was herein used to determine the regional dip. Because of the many faults that cut through the area (Figure 2-2) measurements were made between two different pairs of observed contacts, both pairs of which occur within a single fault-bounded interval (Figure 2-26). Between one of the pairs the distance is ≈1.6 miles (2.6 km) and the elevation change is approximately 15 feet (5 m), which translates to 9 feet/mile (1.7 m/km). Members of the second pair are separated by about 4 miles (6.3 km) with an elevation change of 60 feet (18 m) producing a gradient of 15 feet/mile. A third estimate, based on interpreted formational contacts between the Chaumont and Lowville formations (Figure 2-26) that are separated by 2.9 mi (4.6 km), also reveals a change of 60 feet, but the shorter distance yields a gradient of 21 feet/mile. Because the elevations were not precisely surveyed all of the foregoing must still be considered to be approximate values, thus an average value of the three aforementioned gradients of 15 feet/mile (2.8 m/km) is used in this report.

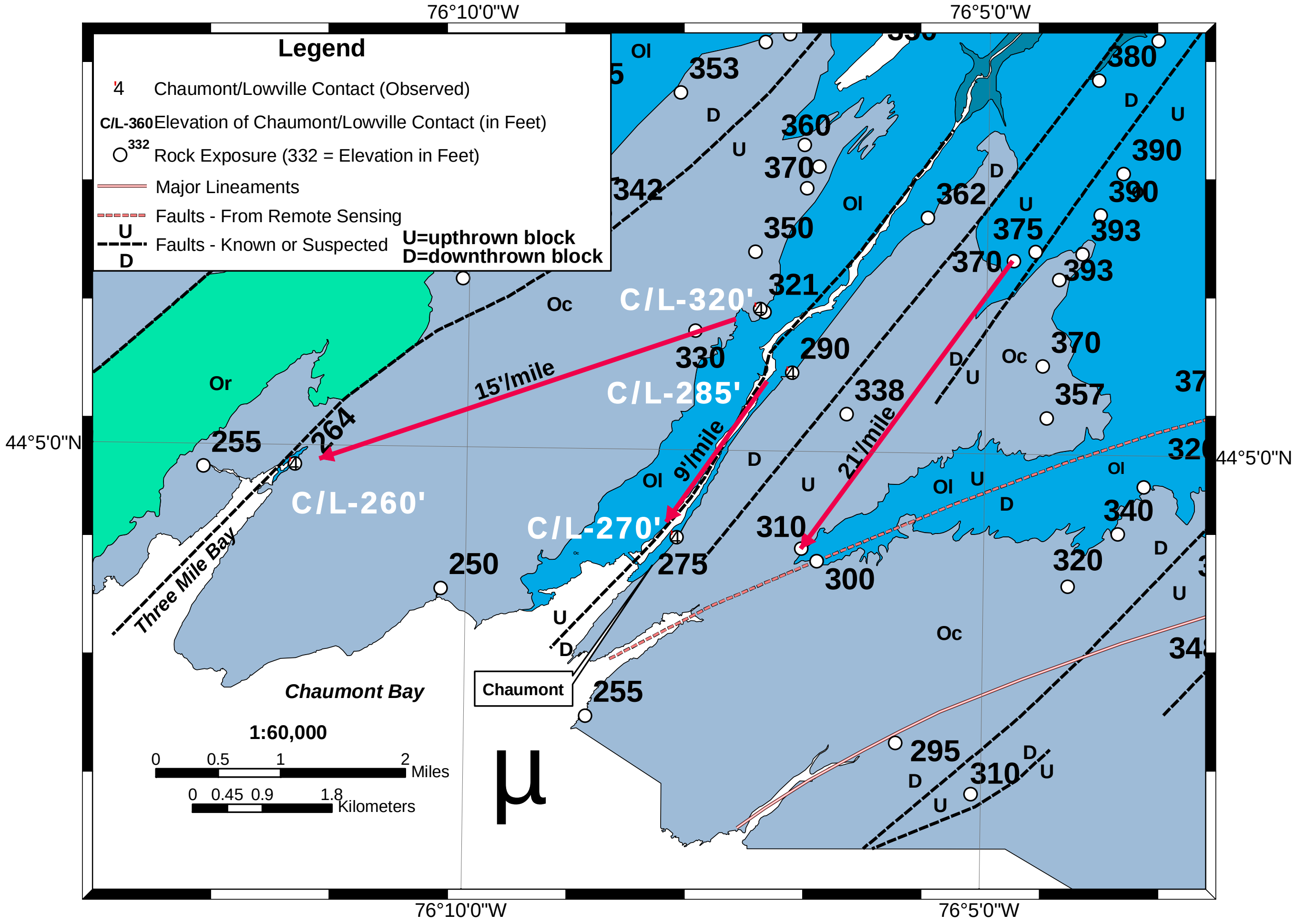


Figure 2-26 Portion of Geological Map (Figure 2-2) Showing Determination of Regional Dip Using Elevations of the Observed Chaumont-Lowville Contact. Gradients are Given Beneath and Along Straight Red Arrows, Which Point in the Down-Dip Direction, as 21´/Mile, 15´/Mile and 9´/Mile. Or, Oc, and Ol Represent the Rockland, Chaumont, and Lowville Formations, Respectively.

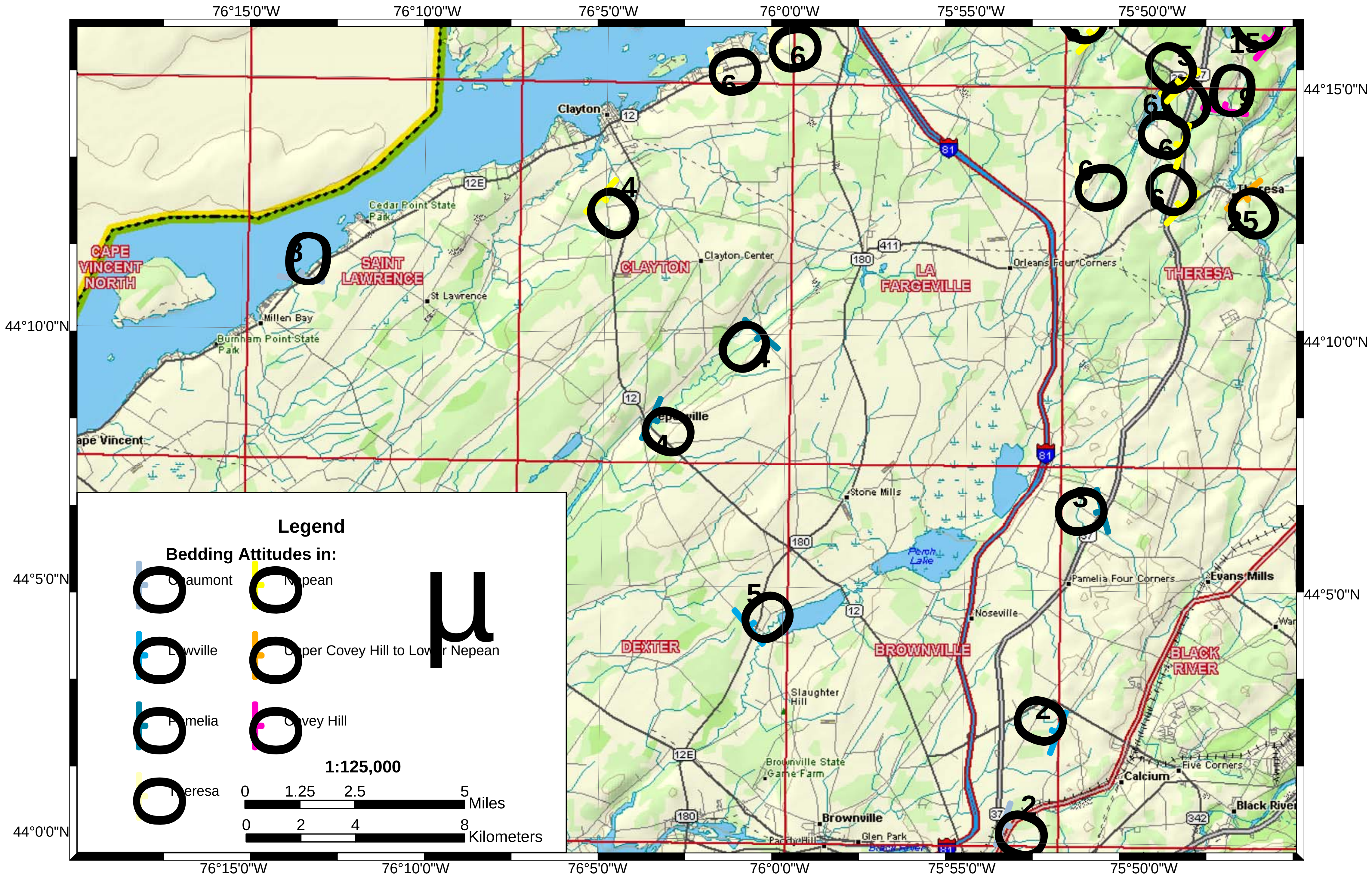


Figure 2-27 Measured Bedding Attitudes in Paleozoic Strata. Numbers Indicate Angles of Bedding Inclination. Where No Data are Given, the Bedding is Horizontal.

2.3.4 Faults

The map pattern outlined by the carbonates of the Black River and Trenton Groups would suggest intense north-northeast oriented folding having developed under metamorphosed conditions because of the tight "fold" pattern (Figure 2-2). That is merely a mirage, however, firstly because none of the rocks, except for those denoted as undifferentiated Precambrian, are even weakly metamorphosed. Secondly any discernible folding in the Paleozoic supracrustal rocks is very gentle, as evidenced by the low dip angles recorded in the Black River-Trenton strata (Figure 2-27).

Earlier mapping of the study area revealed the presence of only two faults, both of which trend northeast (Cushing, 1910). Johnsen (1971) reported none, yet there is a profusion of topographic lineaments (Figures 2-19 to 2-21) which could reasonably be suspected of being faults. In addition an examination of the observed Chaumont/Lowville contacts across the map area reveals progressive elevation decreases from east to west (Figure 2-2). For example in the southeastern corner of the map area, the contact is at 572 feet (174 m) above sea level, whereas at the next location to the west the elevation is at 440 feet (134 m), a drop of 132 feet (40 m). That can be neither an erosional feature, nor a consequence of drape on an irregular Grenvillian basement because the latter is several tens of feet beneath a sequence of originally flat-lying strata. Faulting, therefore, accounts for that difference.

Faulting along the St. Lawrence fault zone, which includes portions of New York State inland from the St. Lawrence River, has occurred throughout the history of the zone and has formed in response to both compressional and tensional stress fields. Resulting from those differences in the stress field have been strike-slip, reverse and normal faults (e.g. Saull and Williams, 1974; Rocher, et al., 2003; Wallach, 2002), though it appears that normal faults have had the greatest influence on the fault zone's present-day geometry (Wallach, 2002). Hence the major north-northeast to east-northeast oriented faults in the study area, which are members of the St. Lawrence fault zone, are represented as normal faults (Figure 2-28).

Many northeast striking faults, commonly marked by rather distinctive topographic lineaments, cut through the strata and have led to the lithological configuration of the area (Figure 2-2). Those faults were identified or interpreted independently of identifying the magnetic lineaments though, not surprisingly, they and the magnetic lineaments are commonly superimposed on one another (Figure 2-24). Besides the northeast faults, there are northwest-trending topographic (Figures 2-20 to 2-22) and magnetic lineaments (Figures 2-23 and 2-24) and some west to northwest-trending outcrop-scale normal faults (Figure 2-29). Several of the remotely detected northwest-striking topographic lineaments were ultimately inferred to be faults due to lithological relationships interpreted from both surface bedrock mapping (Figure 2-2) and the resulting cross sections (Figures 2-28, 2-30 and 2-31). One of the most imposing northwest-striking structures is the Frontenac Arch, a positive linear feature partially expressed by the 1000 Islands and underlain by the Precambrian basement that connects the Adirondack Dome of New York State to the main portion of the exposed Canadian Shield.

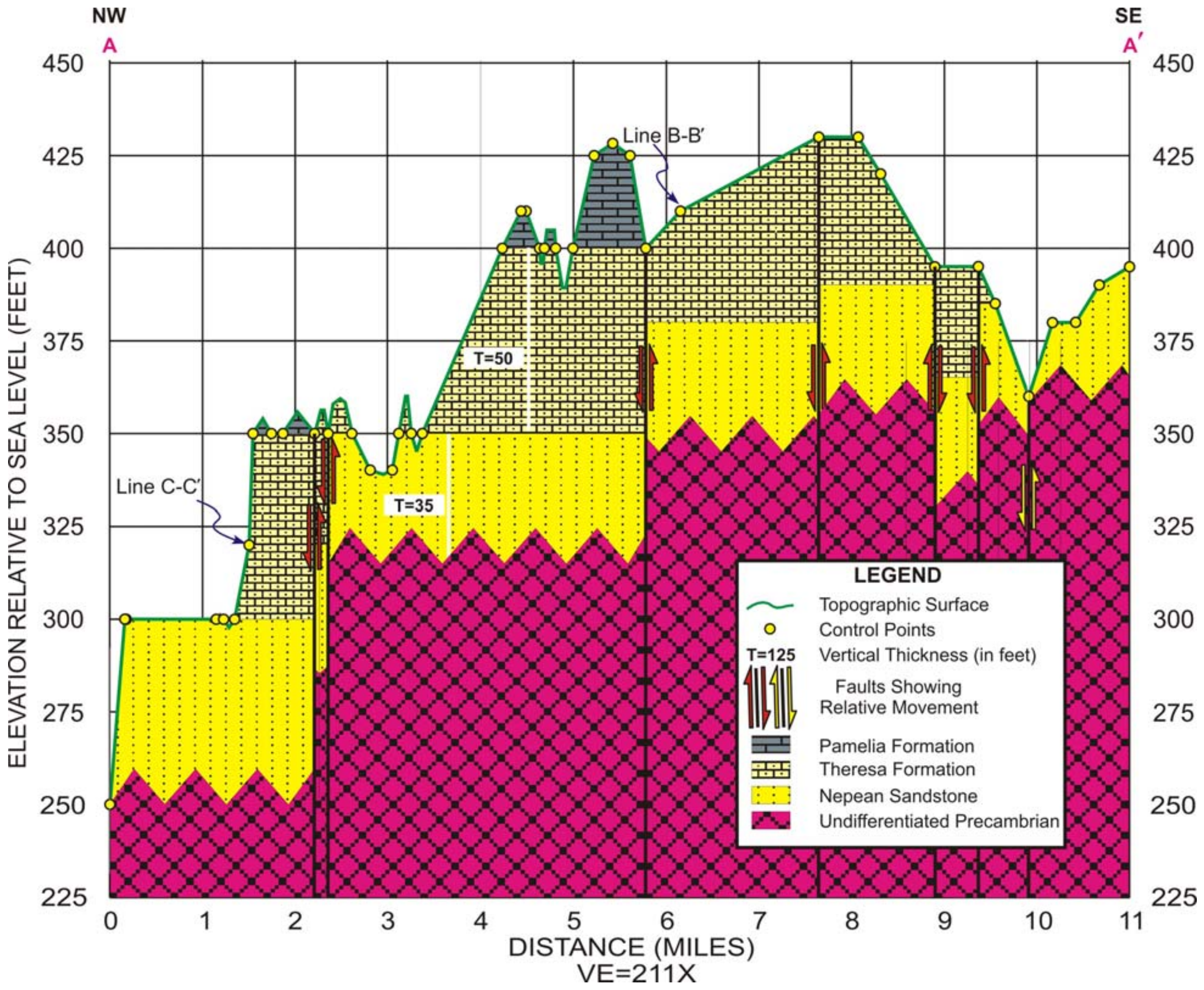


Figure 2-28 **Schematic Cross Section A-A´ Which Parallels the General Strike of the Carbonates (See Figure 2-2). The Jagged Contact Between the Nepean and Precambrian Signifies the Unconformity Between the Two Which is Also Seen in Figures 2-30 and 2-31.**

Vertical or steeply inclined outcrop scale faults (e.g. Figure 2-29), are easily recognizable. Those which parallel bedding, however, may be more difficult to identify. Two such faults were recognized, one in the village of Theresa (Station TH-01, Figure 2-1a, SE corner) and the second along Route 12, northeast of Alexandria Bay (Station CHB-07, Figure 2-1a, NE corner). At the exposure in Theresa there are two very prominent layer-parallel faults which traverse most, or all, of the exposure. The lower one, here designated as fault #1, appears at first glance to be an unconformity (Figures 2-32 and 2-33) because beneath it the beds are deformed into a broad syncline, whereas immediately above the structure the beds appear to be undeformed. The "unconformity", however, jumps section (Figures 2-32 to 2-34). Higher on the exposure face is a second prominent structure, labeled fault #2 (Figures 2-32 and 2-34). Though it looks like an ordinary, but well-defined, bedding plane the beds both above and below fault #2 are locally deformed, possibly into drag folds. At Station CHB-07 the Covey Hill Formation is about 70 feet (21 m) thick, which is twice its normal thickness. Sandwiched between the two approximately 35 foot (11 m)-thick sections of Covey Hill (Figure 2-35) is a light gray, nearly friable quartz arenite of the Nepean Formation with elliptical voids parallel to foreset beds (Figure 2-36) and what appear to be trace fossil tracks (Figure 2-37). Nearly the entire thickness of Nepean sandstone at that exposure has been brecciated and even nearly comminuted by the faulting, though there are remnants of more resistant rock which may give the impression that the fault is a non-angular unconformity, commonly referred to as a disconformity.

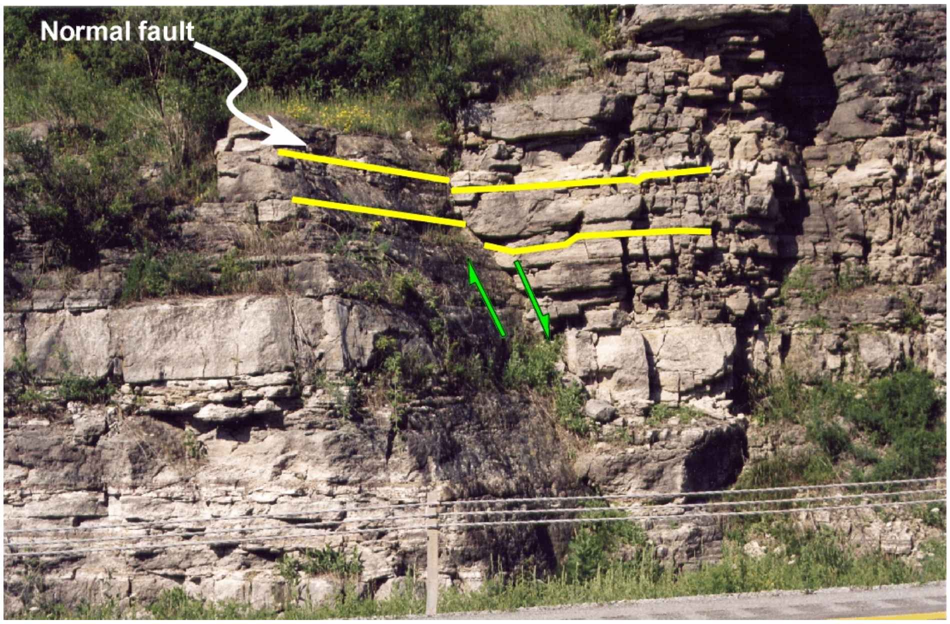


Figure 2-29 **West-Striking Normal Fault Cutting the Interlayered Limestone and Sandstone of the Theresa Formation.**

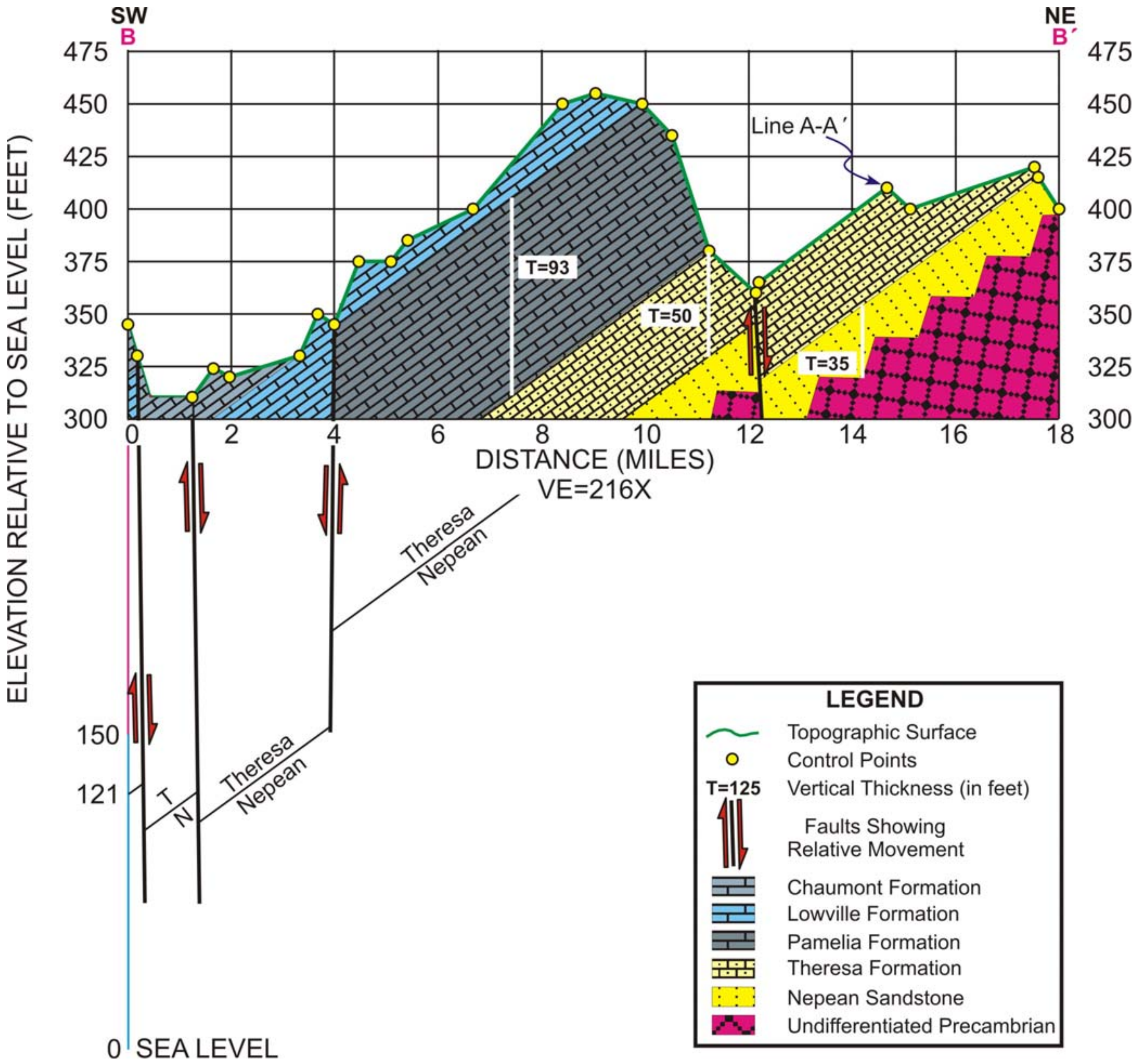


Figure 2-30 Schematic Cross Section B-B´ (See Figure 2-2). Regional Gradient Presumed to be Constant at 15 feet per mile (please see discussion on Regional Dip, pp. 31-32) and Strata Thicknesses are Also Inferred to be Constant (Table 2-2).

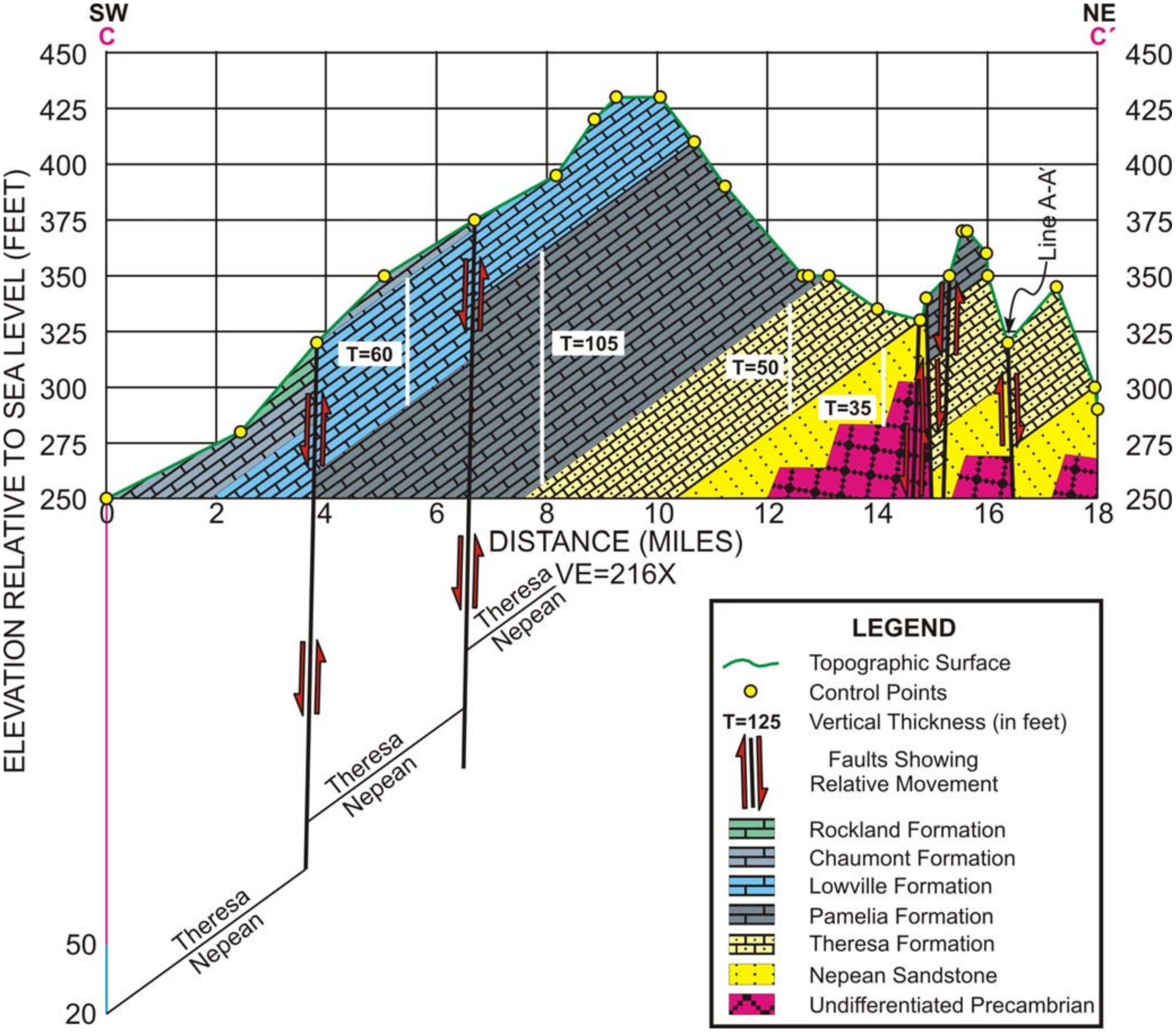


Figure 2-31 Schematic Cross-Section C-C´ (see Figure 2-2).

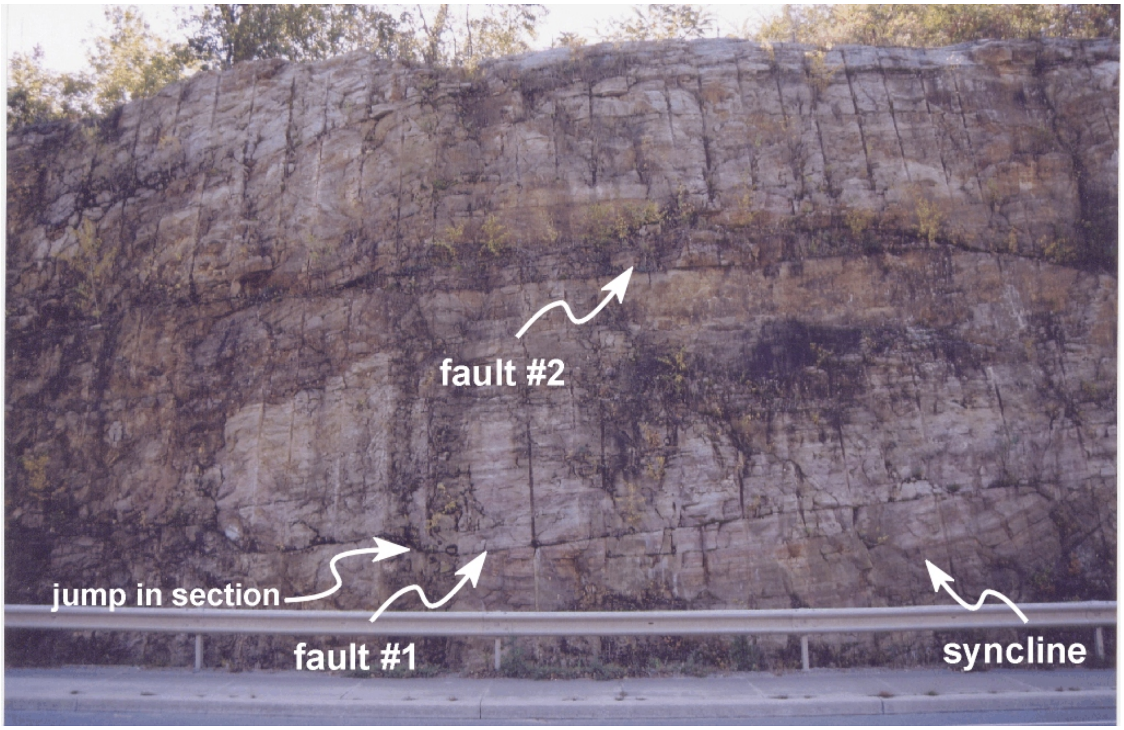


Figure 2-32 Cross-Section of Exposure at Station TH-1 in Theresa Deformed by Two Prominent Sub-horizontal Faults Crossing Most of the Exposure and a Broad, Open Syncline Beneath Fault #1.

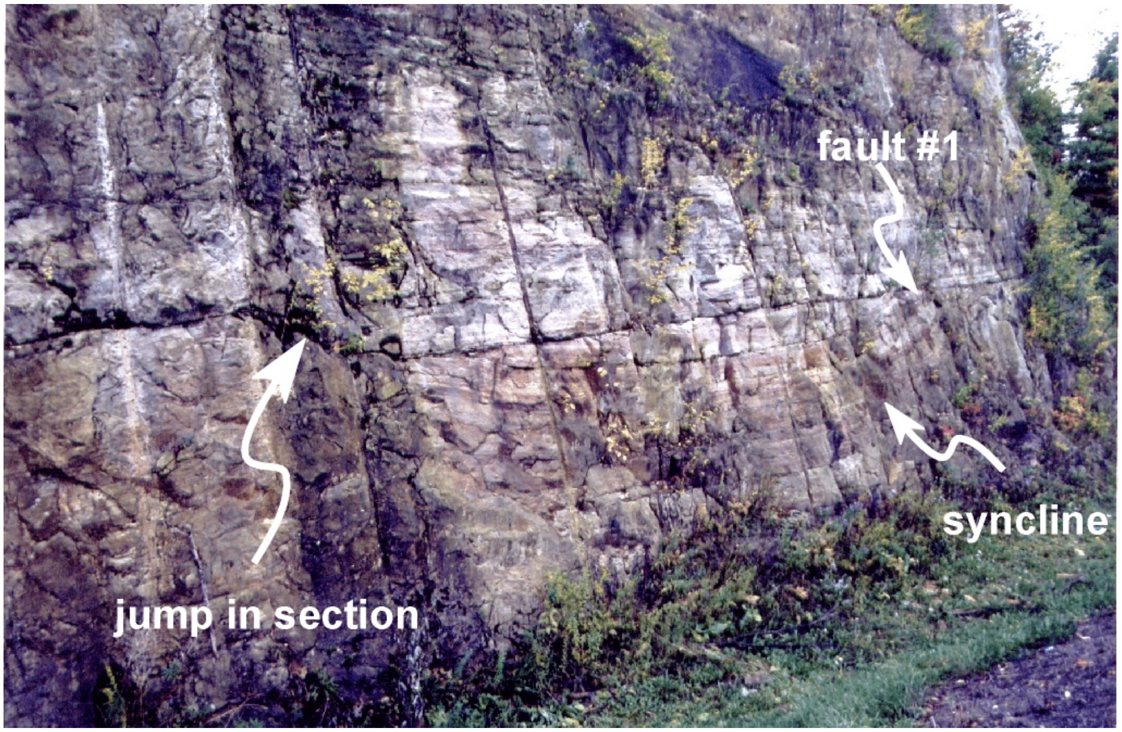


Figure 2-33 Oblique Section Showing a Closer View of Fault #1 and the Underlying Broad, Open Syncline Seen in Figure 2-32. Note, Again, the Jump in Section.

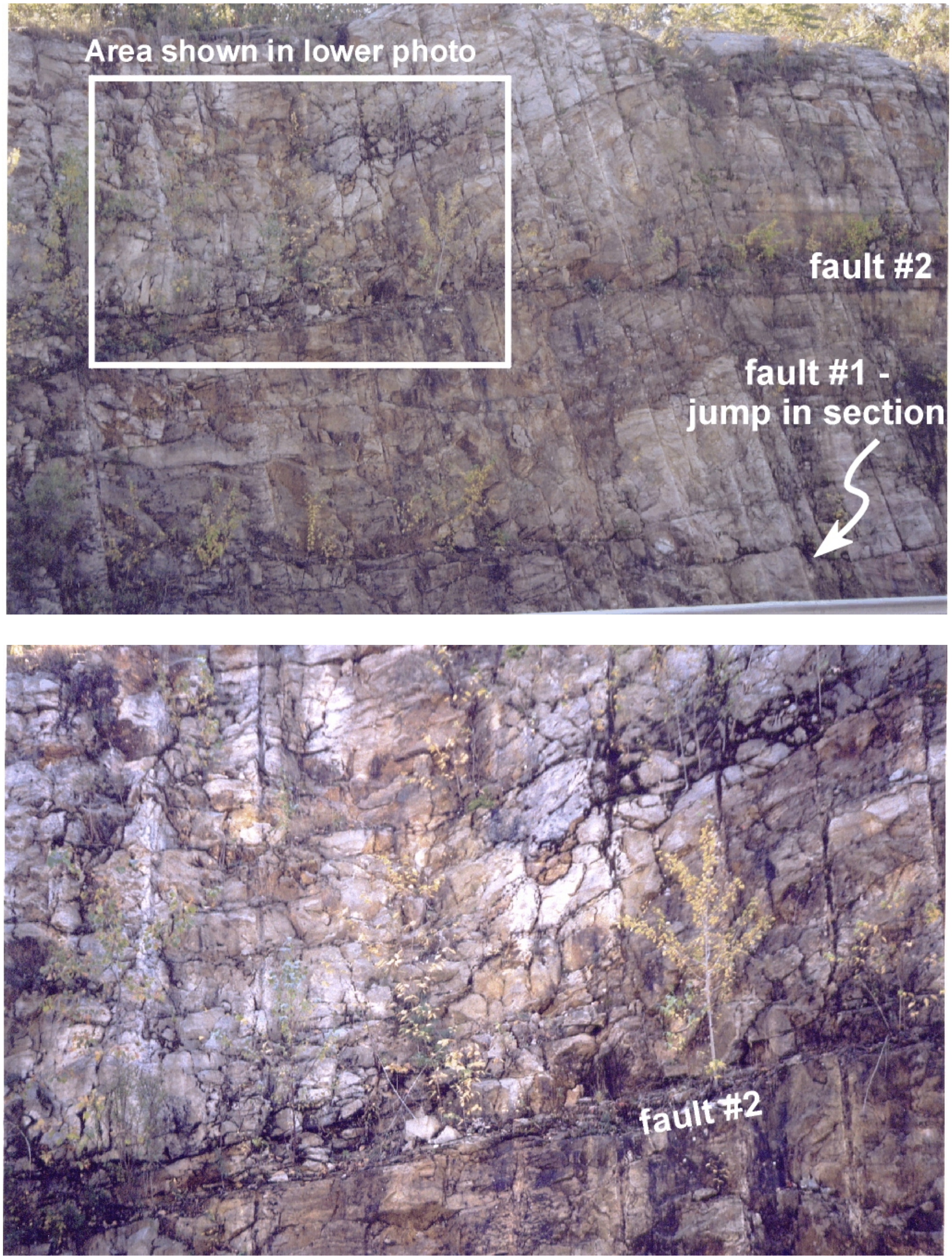


Figure 2-34 Deformation of Beds Above Fault #2 at Station TH-1. (Top) Panoramic View. (Bottom) Closeup. Note Brecciation Along the Fault in Lower Left Corner).

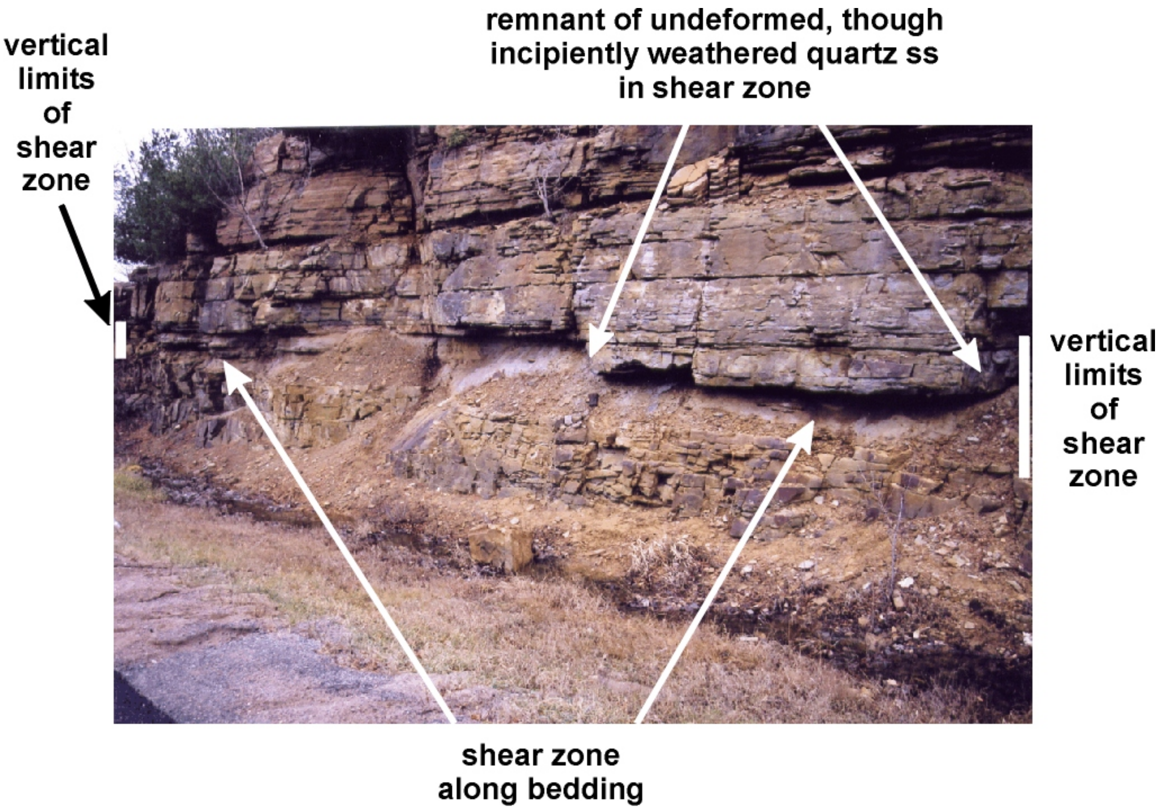


Figure 2-35 Layer-Parallel Shearing in the Nepean Sandstone Sandwiched Between Layers of Older Covey Hill at Station CHB-7.

Figure 2-36 Elongate Voids Parallel to Foreset Beds in the Nepean Sandstone at Station CHB-7.

Figure 2-37 Paired Linear Tracks on Bedding Surface of Nepean Sandstone at Station CHB-7. Tracks are Inferred to Have Been Caused by Tiny Fossils.

2.3.5 Folds

Besides the large-scale faults, a few outcrop-scale faults and folds were also identified. Broad, open folds trend northwesterly (Figure 2-38), part of a pattern of compressional structures, excluding pop-ups, recognized from Quebec City to Syracuse which are kinematically compatible with the current stress field. Whether or not they formed since the onset of the current stress field, estimated to be on the order of 10^7 years old, is unknown, but the rounded fold hinges suggest formation under somewhat elevated confining pressures. Pop-ups, oriented west-northwest to northwest, were also identified and are clear indications of a currently active stress field operative in the study area, as confirmed by the quarry superintendent, who noted that quarry floor pop-ups in the Lowville Formation formed in about 2002 (Figure 2-39).

Figure 2-38 Northwest-Trending, Broad, Open Anticline Deforming the Pamelia Formation.

Figure 2-39 Northwest-Trending (295-310°), Quarry-Floor Pop-Up Deforming the Lowville Formation. Structure Formed in 2002.

2.4 UPLIFT OF THE FRONTENAC ARCH AND RESULTANT MAP PATTERN

Southwest of the Frontenac Arch strata dip southwestwardly towards Lake Ontario, but northeast of the Arch they dip gently towards the northeast. Borehole data garnered from Johnsen (1971) suggest that the Black River and Trenton group carbonates, exposed in the study area only on the southwest side of the Arch, do not thicken towards Lake Ontario. Instead, as shown by complete sections of: a) the Pamelia in boreholes 142 and 146, b) Lowville in boreholes 142, 143 and 146, c) Chaumont in boreholes 142, 143 and 145, and d) Rockland in boreholes 142 and 145 (Table 2-2), each maintains a uniform thickness from east to west. Constant thickness of the individual formations across the area implies deposition on a uniform topographic surface, rather than in a localized basin or across a pronounced ridge. Furthermore the strata strike approximately parallel to the Frontenac Arch (Figure 2-2). Consequently, the constant thicknesses of the units and their parallelism to the Frontenac Arch suggests rigid body rotation of those rocks, attendant upon uplift of the Arch, as the likely cause of the orientation of Black River and Trenton group strata.

TABLE 2-2 –Formational Thicknesses Determined From Rock Core

Borehole 145	**Borehole 143**	**Borehole 142**	**Borehole 146**
Surface elev. - ≈255 ft	Surface elev. - ≈326 ft	Surface elev. - ≈350 ft	Surface elev. - ≈455 ft
Kirkfield 62.9 ft 19.2 m		Kirkfield >6.0 ft >2.0 m	
Rockland 57.2 ft 17.4 m	Rockland Fm >39.0 ft 11.9 m	Rockland 63.1 ft 19.2 m	
Chaumont 20.8 ft 6.3 m	Chaumont 20.0 ft 6.1 m	Chaumont 25.5 ft 7.8 m	
Lowville 14.6 ft 4.5 m	Lowville 121.2 ft 37.0 m	Lowville 123.3 ft 37.6 m	Lowville 131.8 ft 40.2 m
BOTTOM OF HOLE **ELEV. - ≈99.50 ft**	Pamelia 53.17 ft 16.2 m	Pamelia 108+ ft. 33+ m	Pamelia 107.1 ft 32.7 m
	BOTTOM OF HOLE **ELEV.- ≈92.6 ft**	BOTTOM OF HOLE **ELEV.- ≈24.1 ft**	Theresa 3.3 ft 1.0 m
			BOTTOM OF HOLE **ELEV. - ≈212.80 ft**

Boreholes arranged from west to east as per locations shown in Figure 2-2. (All data tabulated from Johnsen, 1971.)

Uplift of the Frontenac Arch and the rotation of the overlying limestones of the Black River and Trenton groups probably preceded the displacement along pre-existing north-northeast trending faults as suggested in Figures 2-40 and 2-41. The map pattern shown in Figure 2-40 is interpreted to have resulted from normal fault movements having displaced previously inclined strata and producing the right-lateral strike separation of lithological units, a kinematic inference that is illustrated in Figure 2-41. Furthermore, uplift of the Frontenac Arch modified the generally southerly dipping regional homocline seen across much of southern Ontario and central and western New York State resulting in the gentle southwesterly dip and the progressive appearance of stratigraphically younger units to the southwest (Figures 2-30 and 2-31). Consequently porous and gas-bearing reservoir rocks, such as both the Theresa Formation and the Nepean Sandstone, deepen in the direction of Lake Ontario.

Based on the cross sections shown in Figures 2-30 and 2-31, in which a uniform dip and constant bedding thicknesses are assumed, the tops of the Theresa and Nepean at the edge of the lake only project to respective depths of about 180 feet (55 m) and 230 feet (70 m) below the surface. According to the thickness and elevation data garnered from boreholes (Table 2-2), and taking the thicknesses of the Lowville, Pamelia and Theresa to be about 125, 108 and 50 feet, in that order, the tops of the Theresa and Nepean in borehole 145 would be expected to be encountered at depths of 233 feet (71 m) and 283 feet (86 m), respectively. Moreover, at least at the present time, hydrocarbon exploration is not permitted in the American waters of the Great Lakes, though it is allowed in Canadian waters. Therefore, unless seismic profiling is undertaken or additional boreholes are drilled to greater depths to show that the strata are deeper than predicted, natural gas exploration at the present time in western Jefferson County is not considered to be economically viable.

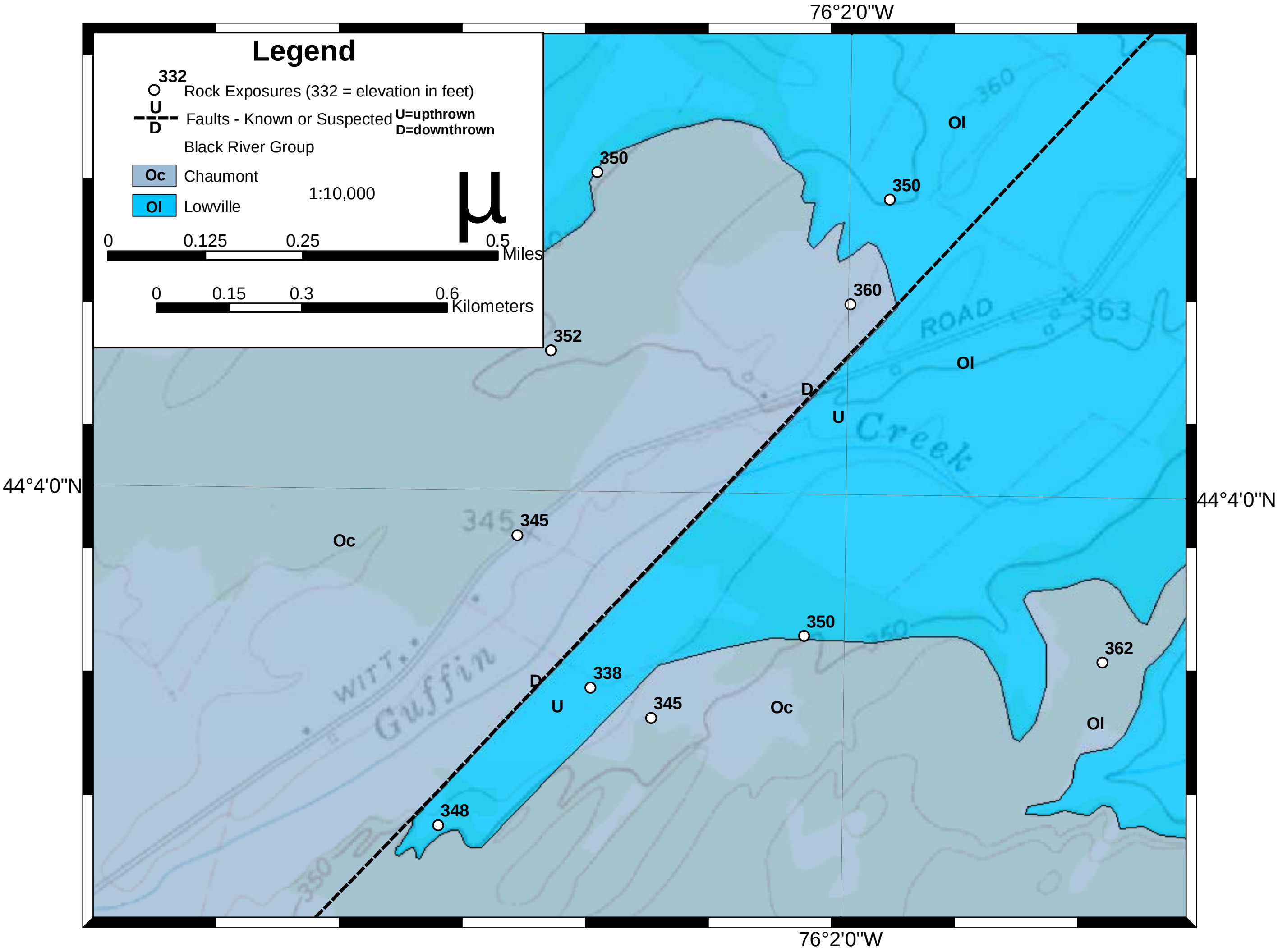


Figure 2-40 Locations of Outcrops and Dextral Separation Across a Fault.

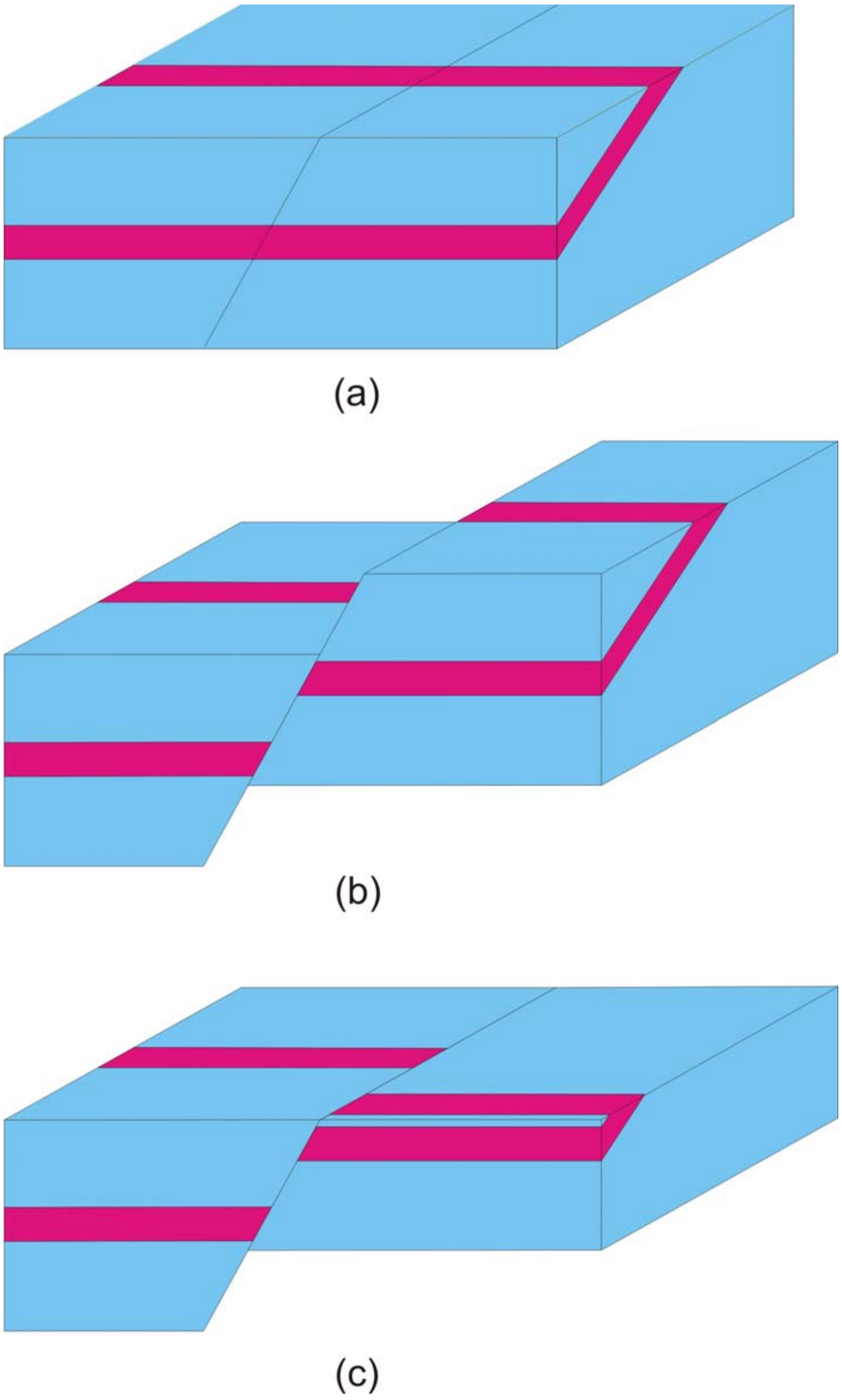


Figure 2-41 **Block Diagrams Illustrating Right Lateral Separation as a Consequence of Normal Faulting of Previously Inclined Strata (Shown in Red). (a) Before Faulting, (b) Pure Dip-Slip Normal Faulting (no Strike-Slip component), (c) Erosion of Upthrown Block Resulting in Right Lateral Separation. (Compare Surface view in (c) with Map Pattern in Figure 2-40.)**

Chapter 3 SUMMARY AND RECOMMENDATIONS

Geophysically and topographically expressed lineaments were identified from a careful study of remotely sensed satellite information combined with the results of a regional ground magnetometer survey. Not surprisingly lineaments from both are, in large measure, superimposed on one another. The most obvious correlations are between lineaments oriented north-northeast to east northeast. There also appears to be some sort of correspondence between those oriented northwesterly, but that relationship is more subtle.

Many of the lineaments are, surprisingly, newly discovered faults which parallel, and are members of, the St. Lawrence fault zone. For the most part the kinematics of the fault zone can only be inferred as there are few indicators of displacements at any scale in the study area. Nonetheless earlier studies have shown that reverse, strike-slip and normal offsets were documented, but that the overall configuration of the zone seems to be dominated by the normal faulting. In addition to the faults of the St. Lawrence fault zone, there are also west to northwest-trending normal faults, overthrusts and broad, gentle folds.

Uplift of the Frontenac Arch resulted in the gentle southwesterly dip and the progressive appearance of stratigraphically younger units at the surface towards Lake Ontario to the southwest (Figures 2-30 and 2-31). Consequently potentially good reservoir rocks, such as both the Theresa Formation and the Nepean Sandstone, deepen in the direction of Lake Ontario. Though that is of potential interest, the cross sections show that the tops of the Theresa and Nepean at the edge of the lake are too shallow to warrant any further work in Jefferson County (Figures 2-30 and 2-31). Moreover, at least at the present time, hydrocarbon exploration is not permitted in the American waters of the Great Lakes, though it is allowed in Canadian waters. Therefore, unless seismic profiling is undertaken or additional boreholes are drilled to greater depths to show that the strata on land within Jefferson County are deeper than predicted, natural gas exploration there is not considered to be economically viable at the present time.

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