INVESTIGATION OF THE ST. LAWRENCE FAULT ZONE IN NEW YORK STATE & SW QUÉBEC TO ASSESS NATURAL GAS RESERVOIR POTENTIAL
PHASE 1-REGIONAL RECONNAISSANCE

Final Report Submitted to

THE NEW YORK STATE ENERGY
RESEARCH AND DEVELOPMENT AUTHORITY

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ABSTRACT

A multidisciplinary investigation involving remote sensing, GIS, geophysics and field geology was conducted across a large portion of northern New York State to assess the potential for natural gas reserves. There is little rock exposure in the area from about Ellenburg to Ogdensburg, thus in that area the interpretations of the New York State geological map were generally used. From near Ogdensburg southwest into the 1000 Islands region, there was much more rock exposed which permitted detailed geological mapping that focused on the post-Grenvillian sedimentary rock cover dominated by sandstones of the Potsdam Group. Many ridges and valleys seem to correlate well with geophysically expressed lineaments that pass upwards from the Precambrian basement into the overlying Paleozoic cover and, therefore, probably denote rejuvenated, basement-controlled fault and fractures. There are, however, other locations in which geophysical lineaments do not correlate well with faults despite unequivocal stratigraphic evidence which compels the interpretation of faulting. In the 1000 Islands region the larger faults were recognized by mismatched stratigraphy across major lineaments. To the northeast where rock exposure is poor reliance was placed upon lineament analyses to reinterpret tight folds, denoted on the New York State geological map, as faults because there are no tight folds in the sedimentary rocks anywhere within the study area.

Broad, gentle northeast and northwest trending folds attributed, respectively, to Paleozoic compression and possibly deformation in response to the current stress field occur throughout the area. Faults also trend predominantly northeast and northwest. Evidence exists for arguing in favor of repeated, but diverse brittle movements along strike-slip faults which initially formed under ductile conditions during the Grenvillian orogeny.

Natural gas may be present locally, but the shallow occurrences of sandstones of the Potsdam and Beekmantown Groups throughout much of the area preclude the existence of any commercial reservoirs. From about Ogdensburg northeastwardly to the limits of the study area, which are in Québec, the Oxford Formation crops out on the surface and the sedimentary section thickens to fill in the Ottawa Embayment. Consequently the sandstones within the Potsdam and Beekmantown Groups in Québec would be more deeply buried and, therefore, potentially better target areas than their New York counterparts. No exploration program is recommended in the New York State portion of the study area.

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 support. Frank Revetta of SUNY Potsdam supplied us with his gravity data, for which we are greatly appreciative. A special thank you is accorded Bruce Sanford, retired Geological Survey of Canada stratigrapher, who has been addressing the characteristics of the Potsdam group for several years on both sides of the international boundary. He kindly accompanied the writers in the field and willingly shared his data and interpretations on the siliciclastic sequence of the Covey Hill and Nepean sandstones that comprise the Potsdam Group. His efforts are to be the subject of both a doctoral dissertation at the University of Ottawa and a forthcoming bulletin to be published by the Geological Survey of Canada.

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Chapter 1 INTRODUCTION

1.1 GENERAL STATEMENT AND OBJECTIVE

As in previous investigations conducted by MIR Télédétection inc and JL Wallach Geosciences Inc., a multidisciplinary investigation involving remote sensing, geophysics and regional geology was undertaken as a first step in deciding whether or not there may be economical quantities of natural gas available. That approach proved to be very valuable in this investigation due to the bedrock being covered by glacial and glaciolacustrine sediments over much of the area, thereby hampering direct bedrock observations. Concealed bedrock prevails from the northeast corner of the study area southwest to just beyond Ogdensburg (Figure 1-1). From about Ogdensburg into the 1000 Islands region, bedrock exposure is far more abundant. As a result different ground-based studies were emphasized in the two areas. Along the Canadian border westward to Massena, a detailed magnetometer survey was conducted in order to try to determine the character and trends of the subsurface structural fabric. Between Ogdensburg and the 1000 Islands prominence was given to field geological work, albeit supplemented with magnetometer data as well. Patterns from the New York State geological map were largely retained for the geological map of the total area (Figure 1-2), however some elements that coincide with lineaments were re-interpreted as faults rather than as tight folds. Because of the greater outcrop coverage between Ogdensburg and the 1000 Islands the treatment of observed bedrock characteristics, including a more detailed geological map (Figure 1-3) and bedrock location maps (Figures 1-4a, b), is confined to that area. Data from the ground magnetometer survey are included in the magnetic maps of the entire study area.

Rectilinear and curvilinear features from across the entire area and in all terrains were identified through the use of 1:100,000 scale Landsat 7 ETM+ and shaded topographic images then were subsequently classified as first order (faults or lithological discontinuities), second order (bedding or foliation) or third order lineaments (fractures). Bedrock mapping, however, was much more restricted owing to the conditions noted in the previous paragraph. It was carried out principally in the Paleozoic cover rocks although a minor effort was also expended in the Precambrian basement. Besides mapping lithological types and characterizing them stratigraphically, structural and elevation measurements were recorded. Outcrop-scale structures were documented because rocks deform at all scales, consequently they can be very revealing in terms of the large-scale geological framework. Elevations are important in order to identify and establish vertical separations along major faults. Elevation data were also very useful in making the geological map for they generally permitted drawing the contacts along topographic contours due to the sedimentary rock units being largely gently dipping to flat lying.

The current work addresses platform sedimentary rocks in northern New York State in order to determine whether or not there may be viable natural gas reservoirs. As noted in JL Wallach Geosciences Inc. (2004), which focused on the northeastern corner of the state including the Champlain Valley, northern New York State has not been subjected to geological investigations directed at that undertaking. Presumably the overwhelming dominance of the Precambrian basement and the surficial exposures of potential reservoir rocks there, such as the Cambro-Ordovician sandstones, have been discouraging factors. Nonetheless it is important to try to understand the stratigraphic and structural relationships, along with rock properties, of the sedimentary sequence in order to help in assessing the reservoir potential in other areas of New York State in which the same stratigraphic units occur.

1.2 REGIONAL SETTING AND GAS POTENTIAL

Rocks ranging upward from the Precambrian Grenvillian basement to the Lower or possibly lower Middle Ordovician crop out in the study area and show a progressively time transgressive trend from oldest in the southwest to youngest in the center and northeast. Faults and gentle folds coexist in the area from Ogdensburg to the 1000 Islands, but very little information has been published on them. Buddington (1934) identified faulting along a structure subsequently named the Black Lake fault by Grier (1993). Guzowski (1978) described and named the Black Creek, Grass Creek and Noname faults, all of which appear to be part of the Black Lake fault described in this report (section 4.3.2), and Barber (1977) recognized a normal fault which Grier (1993) suggested might line up with the Black Lake fault. Dames and Moore (1974) identified several structures in the St. Lawrence Valley and adjacent areas, including northeasterly and northwesterly trending folds, and concluded that all folding was produced by slumping off Precambrian knobs. Barber and Bursnall (1978) described northeast trending folds north of Theresa and they, too, suggested that slumping caused the folding. Bursnall and Elberty (1993) noted the existence of gentle northeasterly trending folds in the Theresa Formation as well as evidence of slip along the Precambrian/Paleozoic unconformity at a classic exposure near Alexandria Bay.

Isachsen and McKendree (1977) recorded several features they referred to as brittle structures, which includes faults and fractures.

One of the most prominent structural elements cutting through the area is the St. Lawrence fault zone, which trends generally north-northeast to northeast. Linear magnetic patterns within the St. Lawrence fault zone in the area between Potsdam and Ogdensburg were interpreted by Billman and Fagan (1998) as indicating a series of horsts and grabens. That interpretation is reasonable because further to the southwest there is unequivocal evidence of normal faulting along that fault zone (Wallach, 2002).

In the Rochester Basin of eastern Lake Ontario, a long linear depression within the St. Lawrence fault zone, Richard Thomas (personal communication) observed gas signatures in the seismic profiles and side-scan sonar records of unconsolidated sediments. The occurrence of gaseous emanations at least in the Rochester Basin of the St. Lawrence fault zone has implications for examining that fault zone more closely as a natural gas conduit and for possible traps.

1.3 STUDY AREA

The study area is cut by the St. Lawrence River and includes portions of Ontario and Québec in Canada in addition to a sliver of northern New York State (Figure 1-1). It is bounded approximately by coordinates 45°31', 74°12’ (NE corner), 45°16’, 73°50’ (SE corner), 44°47’, 76°10’ (NW corner) and 44°20’, 75°50’ (SW corner). Remotely sensed data were evaluated throughout the study area, but field geological and geophysical work was conducted mostly in New York State. The area was selected because of a rather surprising announcement of a possibly significant natural gas play in the nearly surficial Beauharnois Formation (Oxford equivalent) in southern Québec. It turns out that no other natural gas zones have been found there, nonetheless this investigation yields information on the regional geological setting of an area that connects two others in northern New York State in which shallow natural gas reservoirs may be present.

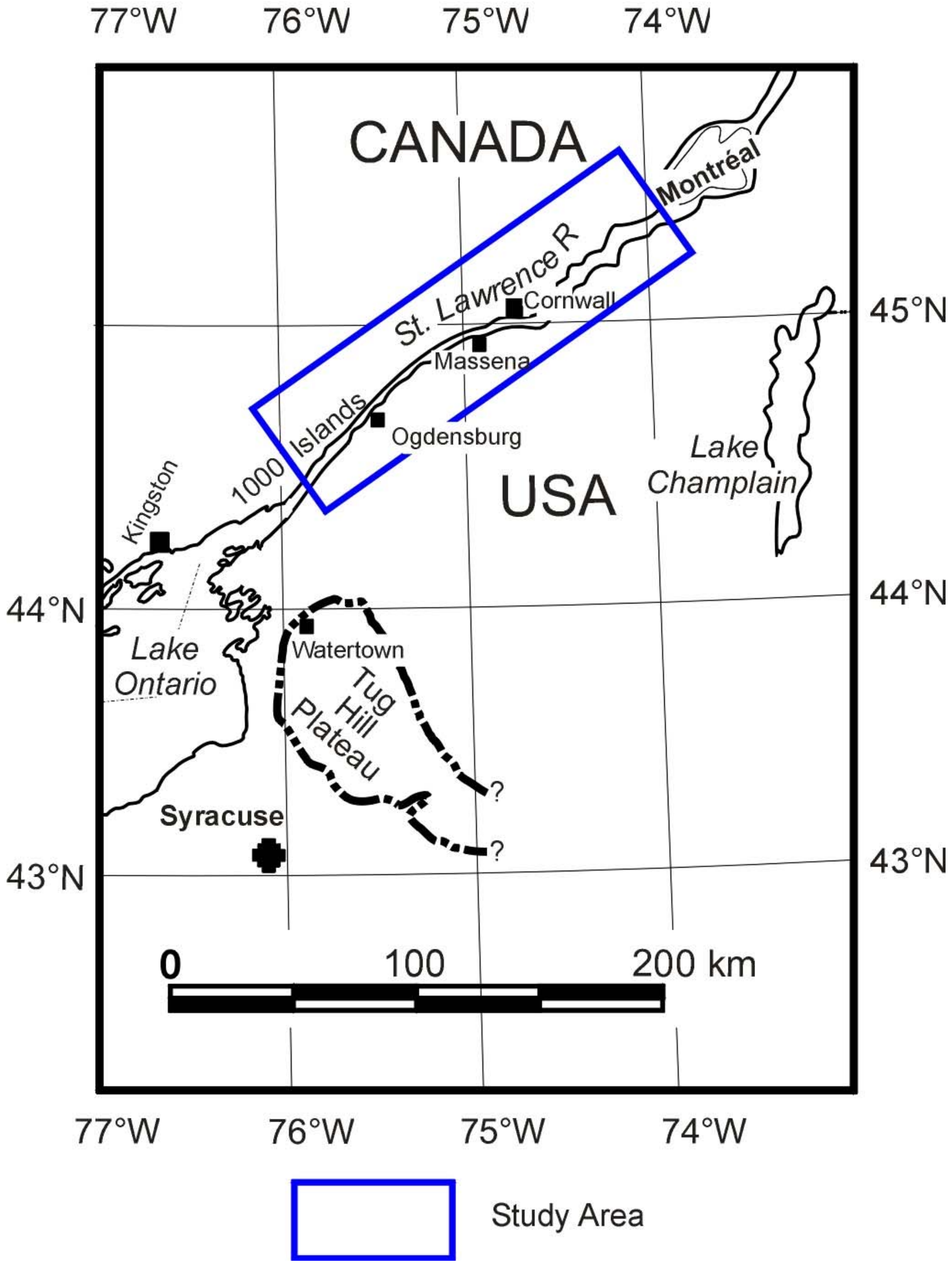


Figure 1-1 Location Map.

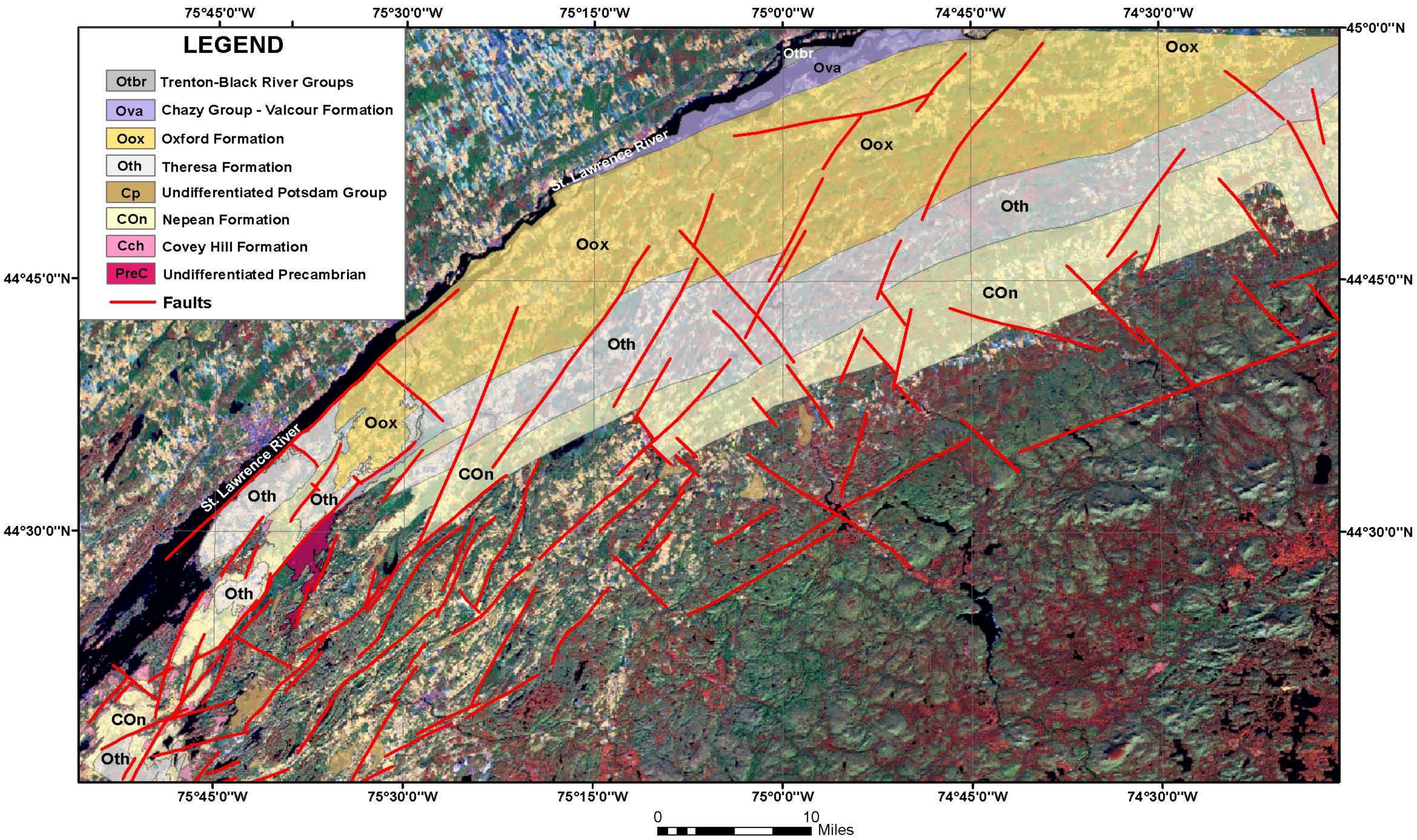


Figure 1-2 Regional Geology Superimposed on a Landsat Color Composite Image of the Study Area Within New York State.

Text

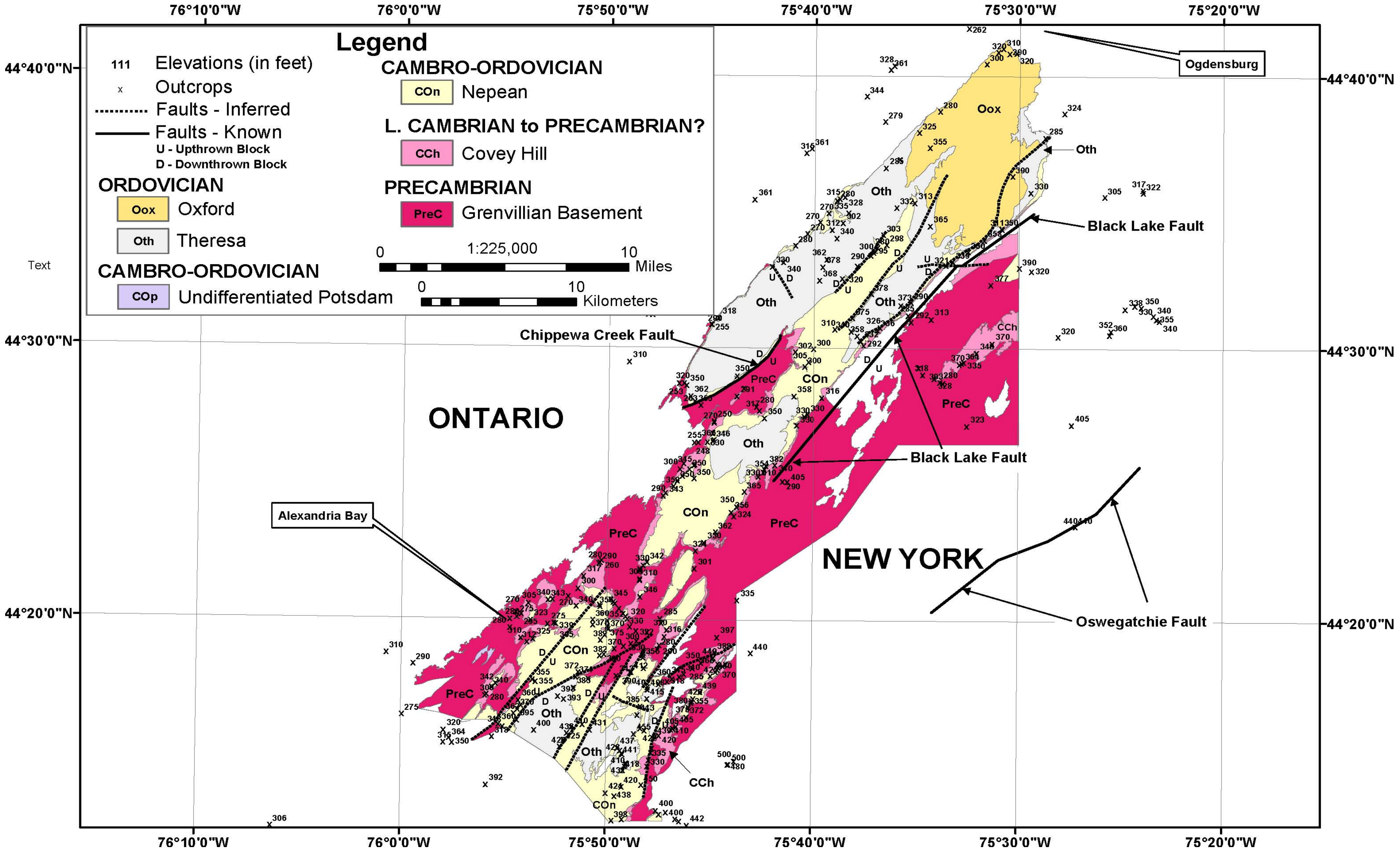


Figure 1-3 Geological Map of the Area Along the St. Lawrence River in New York State From Ogdensburg to the 1000 Islands Region.

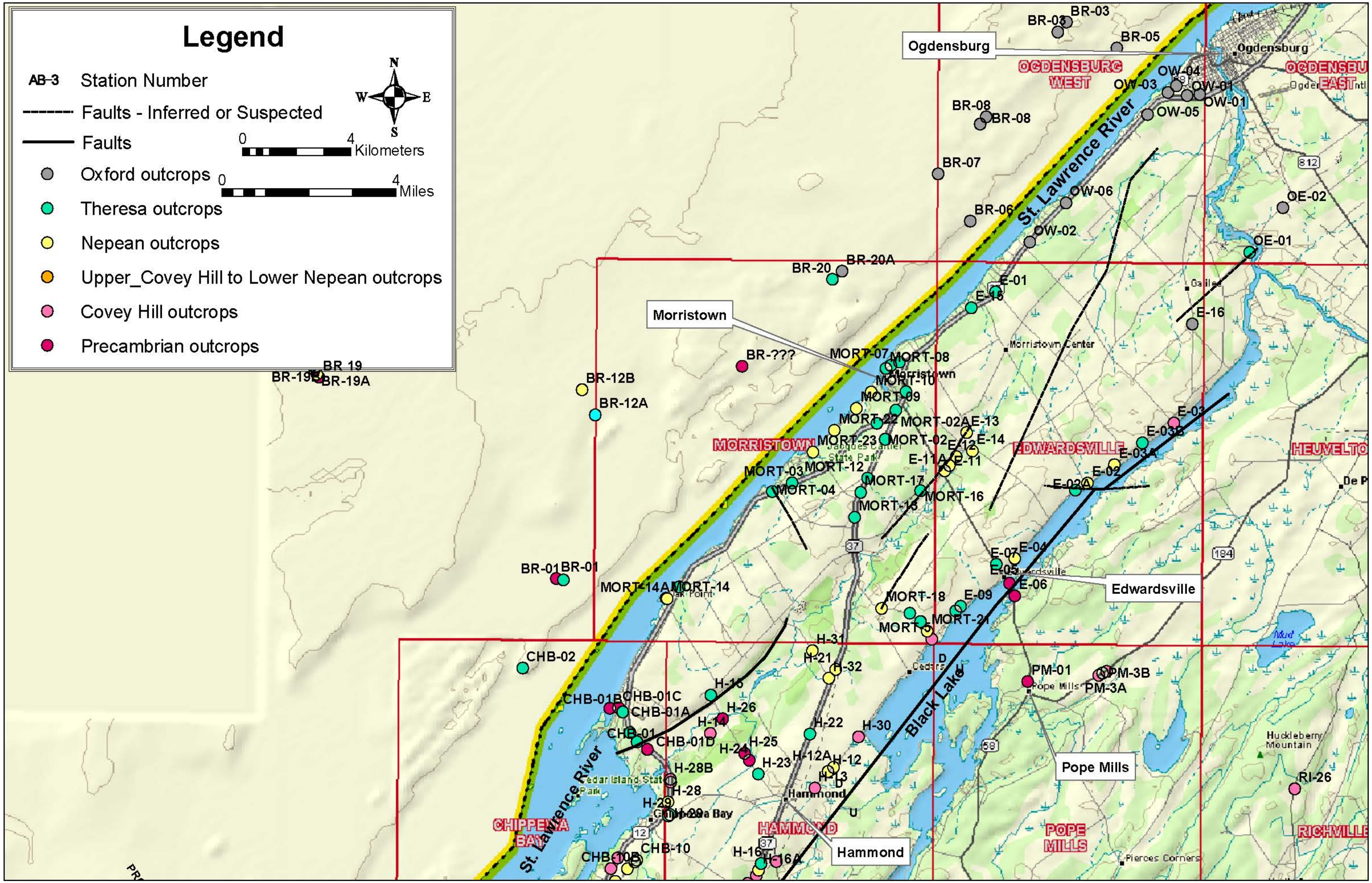


Figure 1-4a Outcrop Location Map - Northern Portion of the Ogdensburg-1000 Islands Area

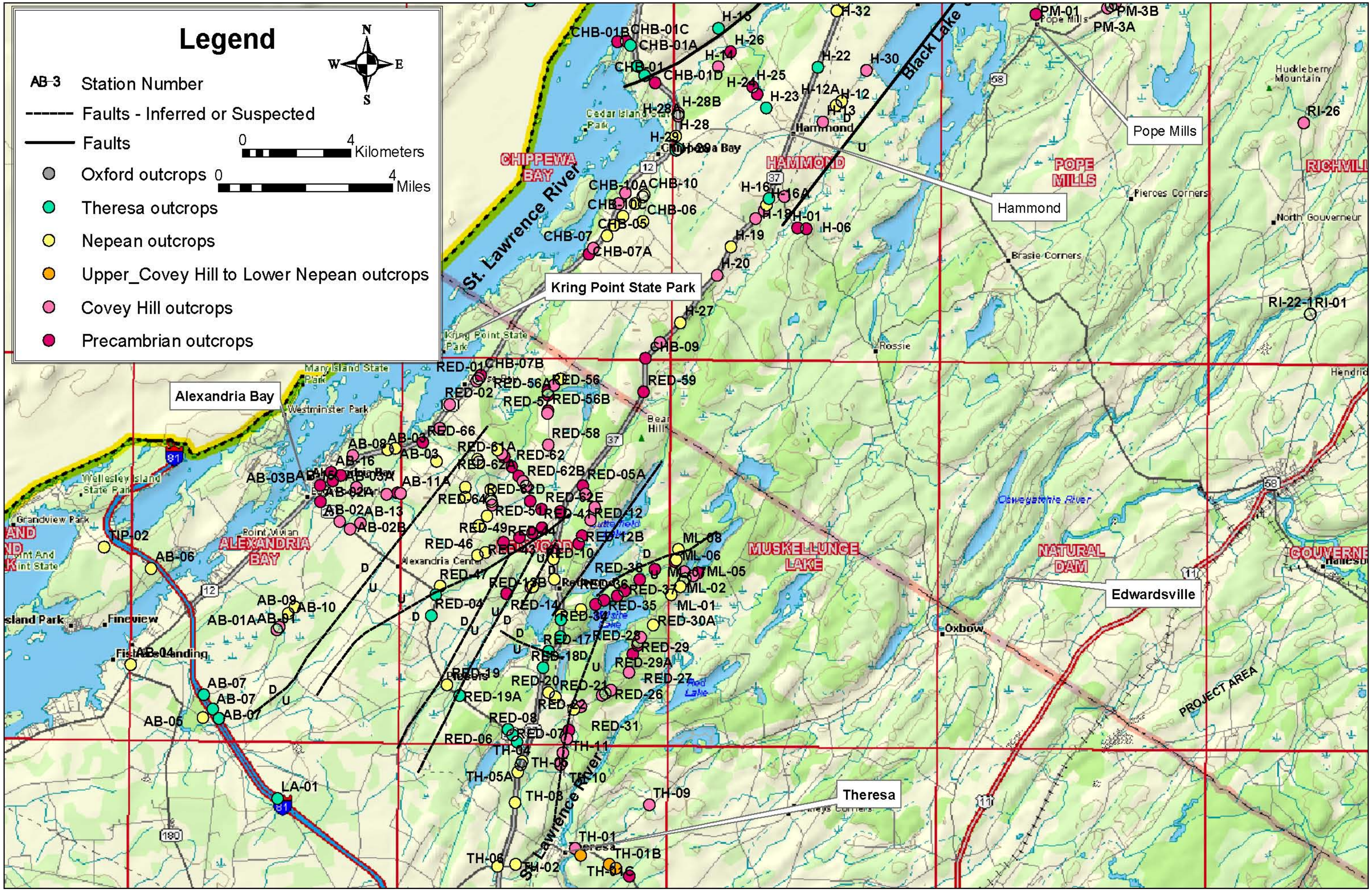


Figure 1-4b Outcrop Location Map - Southern Portion of the Ogdensburg-1000 Islands Area

Chapter 2 REMOTE SENSING AND GIS TECHNIQUES

2.1 DATA ACQUISITION

A remote sensing and GIS study was undertaken in order to support the field investigations and the preparation of the final geological interpretations. This work involved integrating remotely sensed, topographical and geophysical data (gravity and magnetic) into a geoscientific database followed by the identification and detailed interpretation of both topographically and geophysically expressed lineaments. The database was produced by using a combination of different application programs operating on a Windows XP platform. The software used includes Geomatica for remotely sensed data processing, Microstation products for vector data capture and structuring, and ArcGIS for the final database generation and related analysis.

2.1.1 Remotely Sensed Data

After reviewing available satellite data and evaluating the data quality, two consecutive Landsat 7 scenes covering 185 km x 185 km were obtained from the internet and used for the analysis. The two Landsat 7 scenes were acquired on November, 1999 and consist of one panchromatic channel and seven multispectral channels (Table 2-1). Acquisition of autumnal scenes was favored since the low sun angle at that time gives a sharper portrayal of the structural geology.

Table 2-1 Characteristics of the Landsat Data

Category	Orbit	Date of Acquisition	Coverage	Characteristics
Landsat TM	Path 15 Row 28 And Path 15 Row 29	1999-11-15	185 km x 185 km	• 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

2.1.2 Geoscientific Data

Information in the database comprises a digital base map, generated from a Universal Transverse Mercator map projection utilizing NAD 83, UTM Zone 18 data, along with geophysical, geological, planimetric and hydrographic data (see Table 2-2). Planimetric data, consisting of roads, streams and lakes, were recovered from the USGS web site, and were used for image geocoding and map generation. High resolution topographical data, comprising gridded files generated from 1:24 000 scale maps, were downloaded from a USGS FTP site and were complemented with SRTM (Shuttle Radar Topographical Mission) data for the regional coverage. Regional gridded magnetic and gravity data were recovered from the Geological Survey of Canada (GSC) web site and from a previous project undertaken for NYSERDA, and include both Bouguer gravity and total-field magnetic coverage. Each file was produced from the gridding of magnetic profile and gravity point data covering the whole region. The line spacing for the Canadian magnetic data is 1 km whereas for the New York State data it is 1-4 km. On the other hand the number of gravity points measured from the New York coverage is about twice that available from the Canadian coverage. The geology layer consists of a regional digital geological map produced by the New York State Museum and Science Service.

2.2 DATABASE GENERATION

2.2.1 Vector Data

The digital planimetric data (roads and hydrography) were recovered in ArcGIS format and were used for geocoding the Landsat data and for base map information during image map production. The geological data were also integrated as polygon layers associated with specific lithologies, with the original attributes of each polygon having been preserved. A subset was generated for the Paleozoic coverage.

Table 2-2 Geoscientific Data Used in the Project

Category	Type	Characteristics
	Roads and Hydrography	• 1 :100 000 scale coverage • ArcGIS format
Base Map Data	Elevation	• 1 :24 000 scale coverage • 10 m elevation accuracy • 10 m grid spacing
	Elevation	• SRTM data coverage • 30 m elevation accuracy • 3 arc-second 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
Geology Data	Geological map	• Digital geology data • ArcGIS format

2.2.2 Raster Data

Geocoding and mosaicking of the two Landsat images were undertaken. Ground control points were collected from digital planimetric data (roads) providing residual errors on the order of 15 m, which correspond to the final re-sampling grid cell. Orthoimages were generated for each scene and a final mosaic was created by integrating both scenes. Edge enhancement and linear contrast stretch were applied to each channel followed by the integration of the panchromatic channel and the TM 3, 4 and 5 channels. Figure 2-1 shows the Landsat color composite resulting from this integration.

The regional geophysical data were converted from their original ASCII format to a gridded georeferenced raster image analysis format (PCIDISK Format). Magnetic data from New York were re-sampled and calibrated to conform to the Canadian data which appear to be more accurate. For gravity data, however, the converse was true in that the Canadian data required re-sampling and calibrating in order to match those from New York. The vertical gradient was calculated for each geophysical parameter, to which an adaptive color palette was applied, to provide a better display of the anomalies located closer to the surface. All enhanced files were then integrated into the ArcGIS database.

Digital elevation data were placed into a single file covering the entire study area at 10 m grid spacing for the high resolution data and at 50 m grid spacing for the SRTM data. Those data were then enhanced by producing shaded relief images under two different illumination conditions, the first from the north (0° azimuth) and the second from the east (90° azimuth). The results, applied to the high resolution data from northern New York, are shown in Figure 2-2.

The magnetic vertical gradient and the Bouguer vertical gradient were superimposed on the SRTM shaded data (illumination from the east) through the use of mathematical transformations, thereby enabling comparisons between topographical and geophysical lineaments. The original gravity and magnetic vertical gradient data, generated respectively along grids of 500 m and 200 m, were re-sampled at a 50 m grid spacing to be compatible with the SRTM data pixel size.

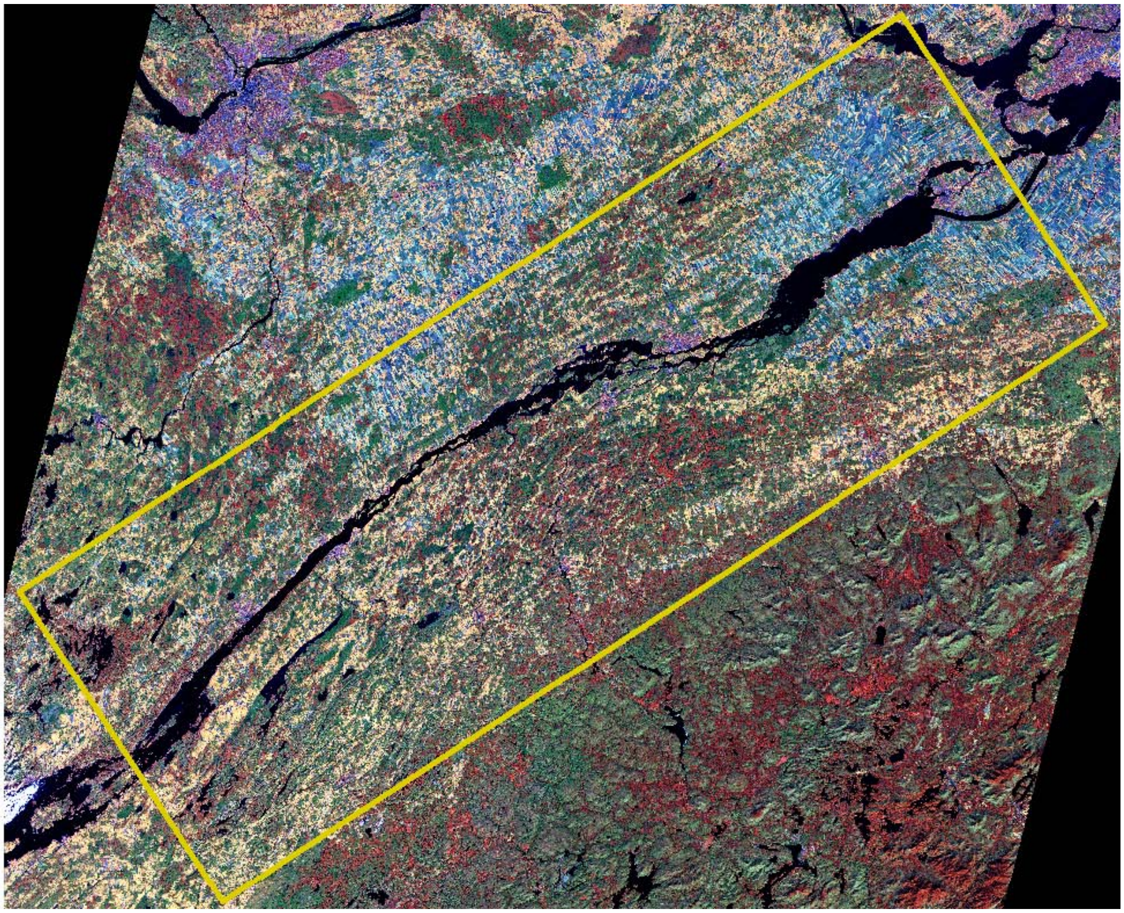


Figure 2-1 Landsat 7 Color Composite With Outline of the Study Area

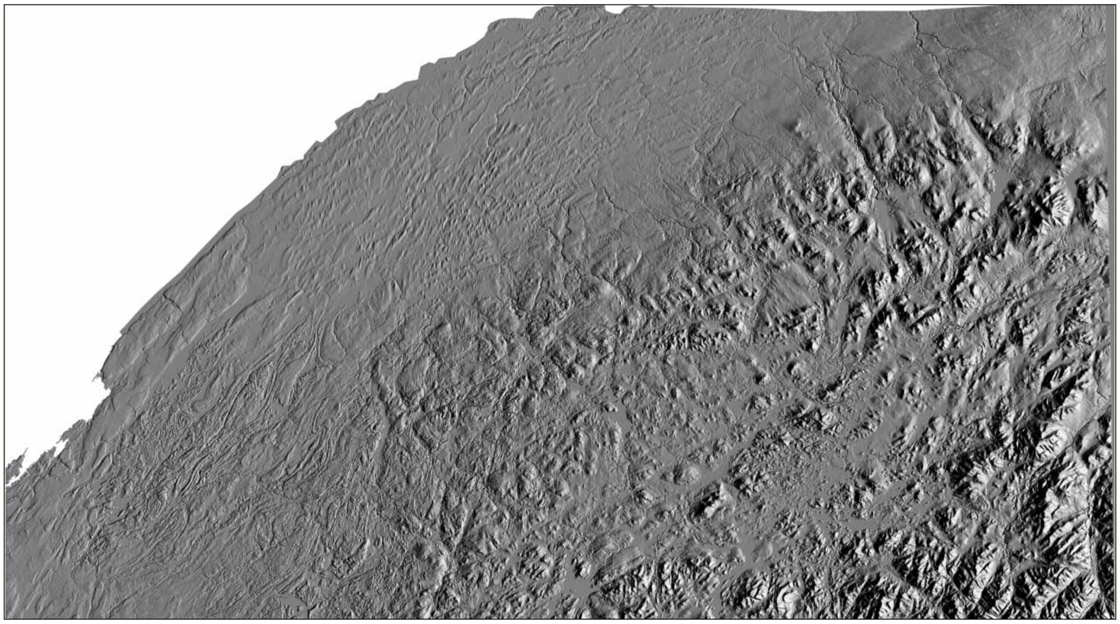


Figure 2-2 Shaded Relief Topography of Northern New York. Illumination From the East.

Chapter 3 STRATIGRAPHY

3.1 POTSDAM GROUP

3.1.1 Covey Hill Formation

The sandstone at the base of the section of unmetamorphosed sedimentary rocks that overlie the Precambrian basement, classically referred to as the Potsdam Formation, is comprised of at least two and possibly three different facies (Sanford, personal communication). East of the Adirondack Dome gray to pinkish gray feldspathic quartz sandstones of the Covey Hill Formation overlie rather small, isolated pockets of redbeds, informally named the Jericho formation (JL Wallach Geosciences, 2004) which, in turn, rest unconformably on the basement. North of the dome no Jericho was recognized, thus the feldspathic Covey Hill, which is generally whiter in color than its counterpart to the east, lies directly on the Precambrian. In both areas the Covey Hill is overlain by the very light gray to white Nepean Sandstone. In the area from just southwest of Ogdensburg to the eastern 1000 Islands (Figure 1-3) the Covey Hill is generally a pure, cross-bedded, quartz sandstone that may be predominantly pink at the base (Figure 3-1), but is commonly white with thin, pink bands. At and near the top of the unit the pink bands are absent, therefore the sandstone is white and lithologically indistinct from the overlying Nepean (Figure 3-2). At Station AB-3 (Figure 1-4b) the entire Covey Hill is exposed and reveals a thickness of approximately 35 feet (10.6 m).

3.1.2 Nepean Formation

The Nepean is a locally cross-bedded, white to light gray, medium- to medium fine-grained, quartz-cemented quartz sandstone, although it may also contain some thin limestone layers. Ripple marks indicative of a near shore, shallow water environment may also be present. Besides their general difference in color the Nepean may also be distinguished from the underlying Covey Hill by the presence of fauna in the former and their absence from the latter (Sanford, personal communication). That point was emphasized by the profusion of stromatolites observed at the base of the Nepean Sandstone in the Muskellunge Lake quadrangle (Figure 3-3). At Station CHB-1A (Figure 1-4b) both the upper and lower contacts of the Nepean with the Theresa and Covey Hill, respectively, are exposed thereby indicating its thickness to be 30.5 feet (9.2 m).

In the Lake Champlain study (JL Wallach Geosciences Inc., 2004) it was suggested that the Covey Hill grades upwards into the Nepean, though no exposures of the contact between the two formations were ever seen. Sanford (personal communication), however, maintained that the Covey Hill and Nepean must be separated by an unconformity and supported that argument with reference to a striking angular unconformity that he had observed and photographed near Perth, Ontario, about 100 km southwest of Ottawa. During the present investigation the contact between the Nepean and Covey Hill formations was seen at several exposures and, overall, that contact is clearly unconformable (Figure 3-4), a point reinforced by fragments of fractured white Covey Hill in the basal Nepean. At two exposures (Stations AB-3 and H-12), however, it appears that the white, quartz-cemented quartz sandstone at the top of the Covey Hill passes conformably into the basal Nepean (Figure 3-2). That lithological continuity makes the unconformity suspect at only those two locations although at both the two formations are separated by a distinct bedding-plane fracture and the Nepean shows suggestions of trace fossils which are not present in the Covey Hill.

Figure 3-1 Cross-Section of the Banded, Pink Covey Hill Sandstone Resting Unconformably on the Underlying Grenvillian Basement at Station RED-2A.

Figure 3-2 Indistinguishable Nepean and Covey Hill sandstones at Station AB-3.

Figure 3-3 Stromatolites in Plan View of the Nepean Sandstone at Station ML-1.

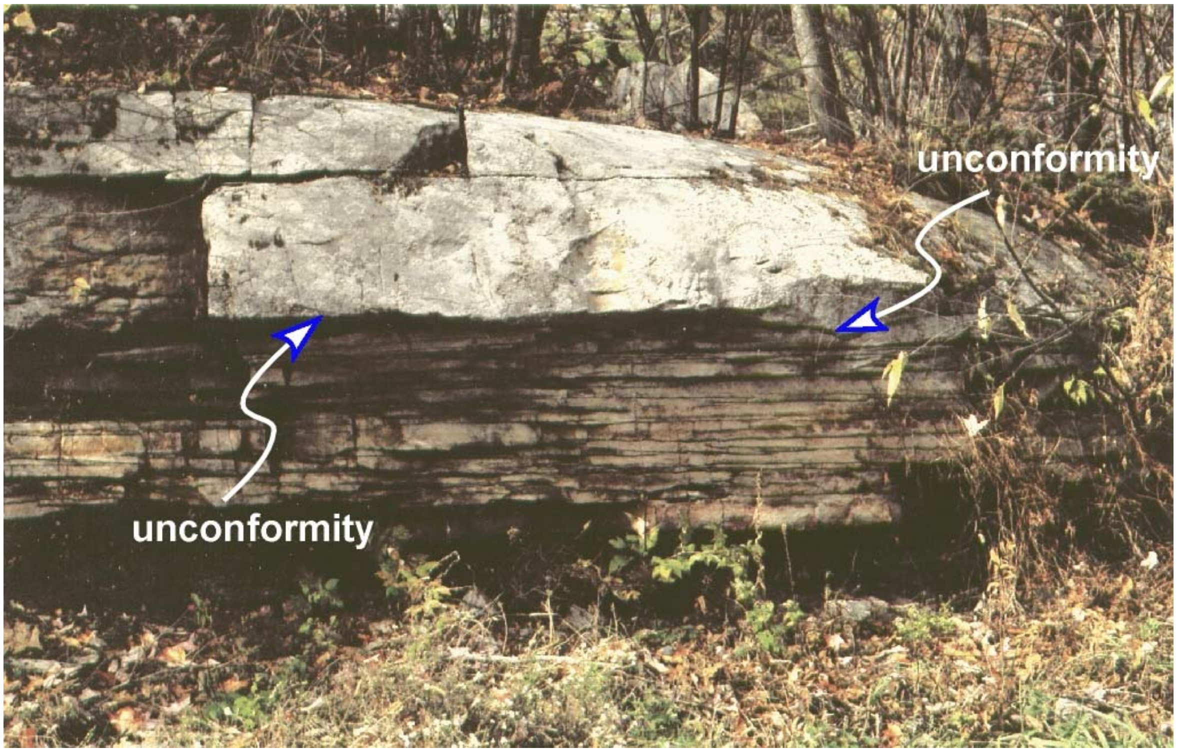


Figure 3-4 **Unconformity Between the Flaggy Beds of the Covey Hill and the Thicker Strata of the Overlying Nepean at Station CHB-10.**

3.2 BEEKMANTOWN GROUP

3.2.1 Theresa Formation

The Theresa Formation, estimated to be on the order of 50 feet (16 m) thick, is composed predominantly of interlayered gray sandy carbonate, most commonly limestone, and Nepean-like quartz sandstone which, in places, are more than 3 feet (1 m) thick (Figure 3-5). Rusty alteration along bedding and fractures may be seen due to the transport of presumably iron-bearing fluids along those pathways. Generally the Theresa rests conformably upon the Nepean, although near Ottawa the two are separated by an unconformity or, perhaps more likely, a diastem. In cross section the distinction between the Nepean and Theresa formations is generally rather clear, but it is difficult to distinguish between them where there is only rock pavement or a very thin vertical exposure of white to light gray quartz sandstone.

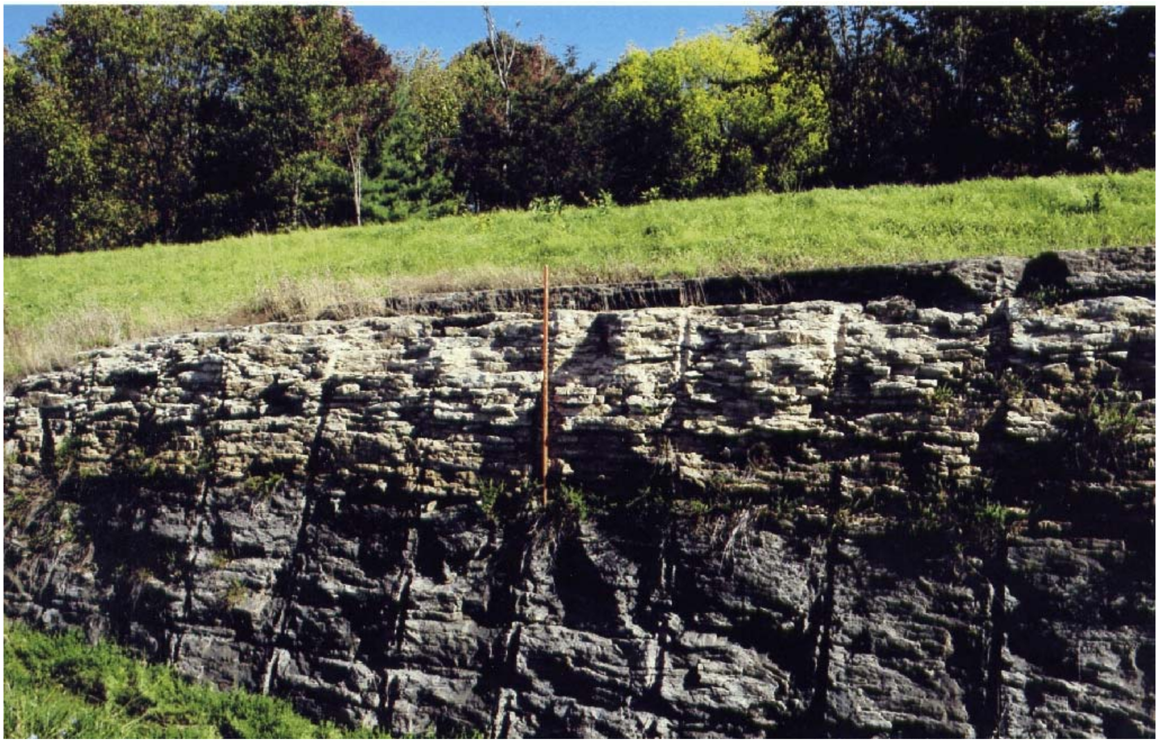


Figure 3-5 **Nepean-Like Sandstone Layer in the Theresa at Station CHB-1. Measuring Stick, 1.5 m High, Rests Upon the Contact Between the White Sandstone Layer and the Underlying Gray Carbonate. The Thin Unit at the Top of the Exposure is Also Carbonate.**

3.2.2 Oxford Dolostone

The Oxford is a brownish-gray to light gray weathering, medium- to medium-dark gray, fine-grained dolostone that is generally quite distinctive from the underlying Theresa (Figures 3-6 and 3-7). Besides being purely dolostone it may also embody layers of argillaceous and calcareous dolostone as well as limestone and may display laminations, cross beds and mudcracks. Overall it is quartz-free though, in places, there are some rather noticeable accumulations of well rounded quartz grains. The component dolomite may appear as perfectly formed rhombohedral crystals creating what appears to be a rather tight, low-porous matrix, whereas elsewhere the component grains may be far more irregularly shaped. Individual layers are commonly a few centimetres thick and normally display undulating surfaces. In the 1000 Islands area, there is no Oxford, but in the vicinity of Ogdensburg the formation attains a maximum thickness of up to about 90 feet (28 m) and further to the northeast, near Massena, it is at least 165 feet (50 m) thick.

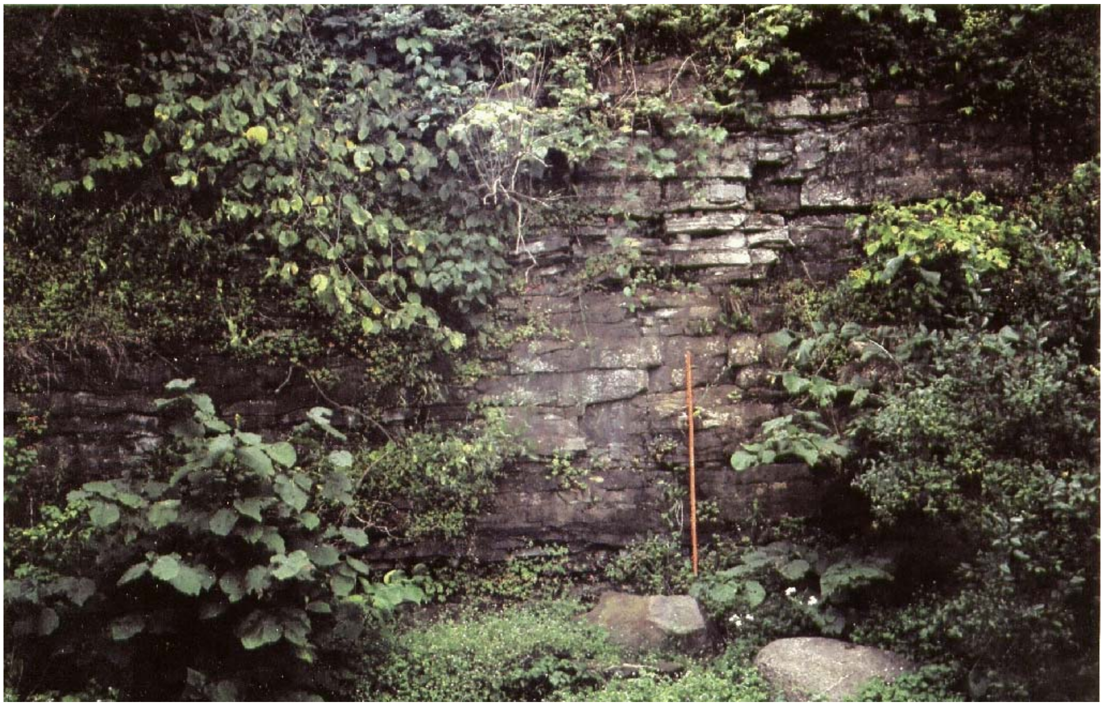


Figure 3-6 **Cross Section of the Oxford Dolostone at Station OW-5. Measuring Stick 1.5 m High.**

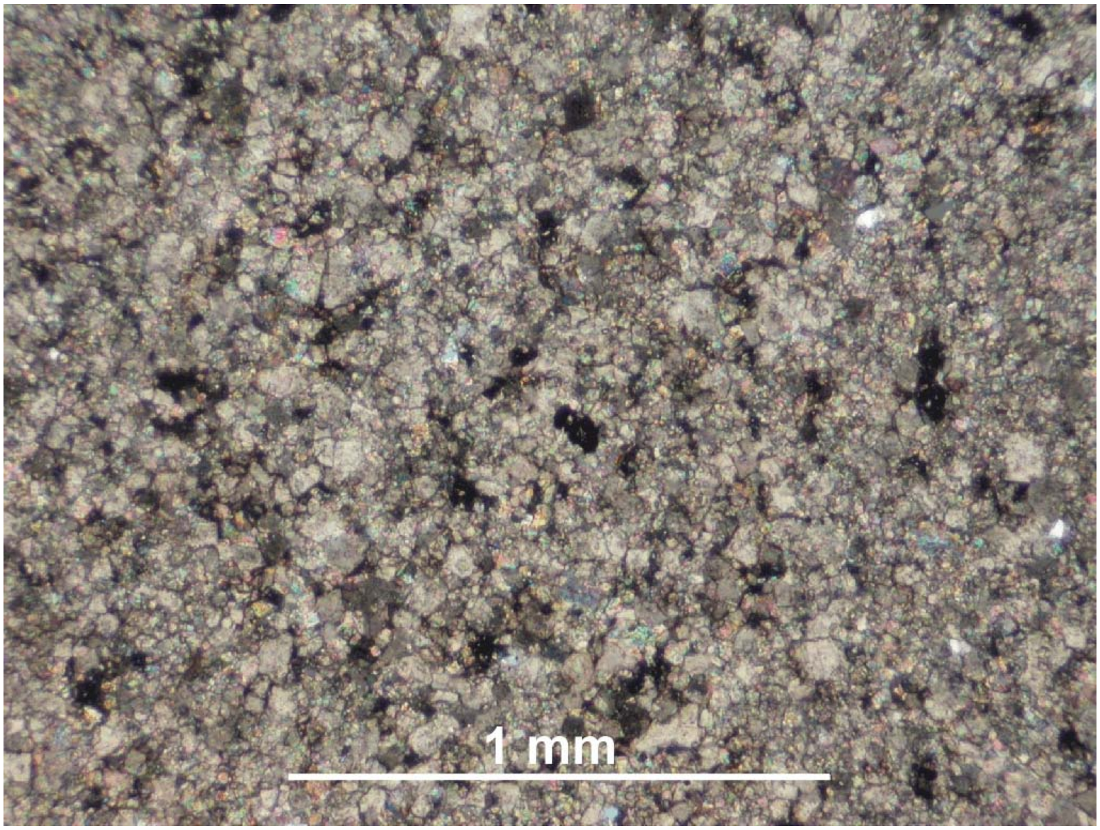


Figure 3-7 **Photomicrograph of Oxford Dolostone.**

Chapter 4 LINEAMENT AND STRUCTURAL ANALYSES

4.1 TOPOGRAPHICAL LINEAMENTS

4.1.1 First Order Lineaments

First order topographic lineaments correspond to regional discontinuities such as scarps and hydrographic patterns, and are inferred to represent lithologic contacts or fault zones. The principal orientations of the major sets are east-northeast, north-northeast and north-northwest (Figures 4-1 and 4-2). Those which trend east-northeast and north-northwest occur throughout the study area, but are most obvious in the southeastern part within the rugged Grenville basement (Figure 4-1). North-northeast trending lineaments are particularly evident in the center of the study area. Based on the good relationships among the topographical and geophysical lineaments (Section 4-2) the former are suspected as having resulted from the upward propagation of basement faults, but they also may be associated with folding of the Cambro-Ordovician sequence.

4.1.2 Second Order Lineaments

Second order lineaments are related to geomorphic features, most notably ridges. Within the Paleozoic they are interpreted as probable bedding whereas in the Grenvillian basement they are inferred to represent foliation. Paleozoic bedding trends are predominantly northeast to east-northeast, but in the Grenville basement the regional foliation fabric, though also principally northeast to east-northeast, may show other trends as well.

4.1.3 Third Order Lineaments

Third order lineaments are the expressions of ridges or streams and are interpreted as fractures or small faults with minor displacement. Five sets of fractures were recognized and they display orientations of north-south, north-northeast, northeast, southeast and south-southeast (Figure 4-2). They appear throughout the entire area, regardless of the geological setting, and are probably associated with different deformational episodes. The southeast set of fractures is the most abundant and occurs in both the Grenville and Paleozoic terrains.

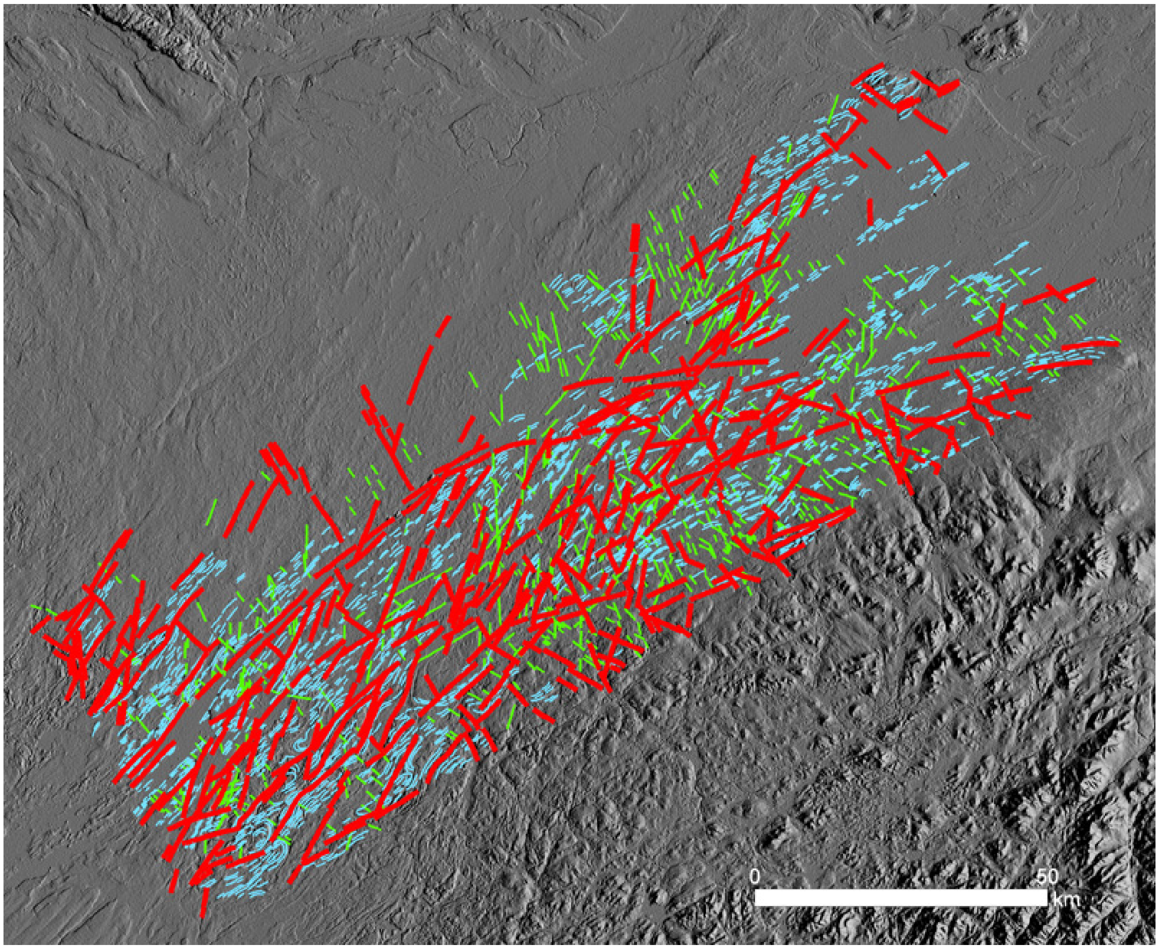
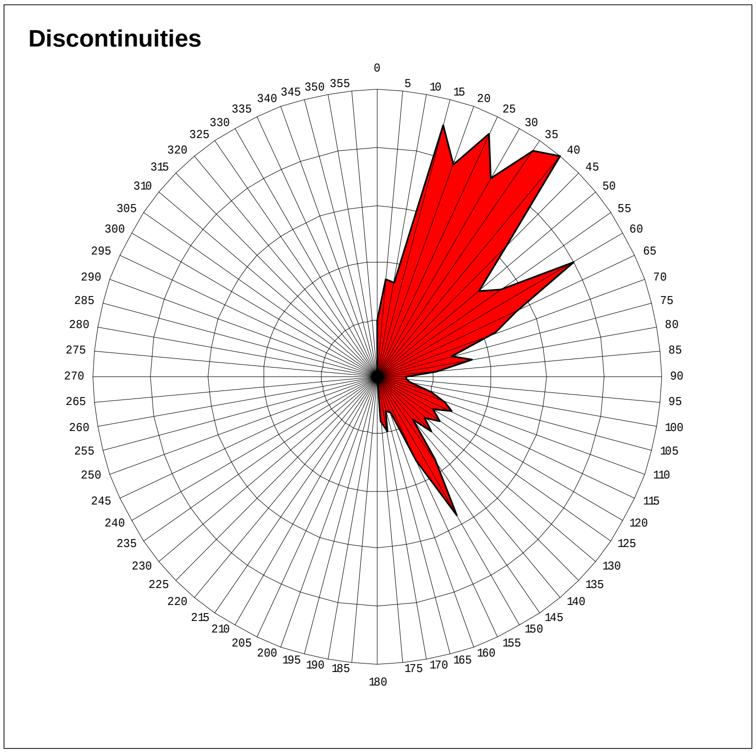


Figure 4-1 Shaded Relief Map Showing Topographic Lineaments: Regional Discontinuities (First Order) in Red, Bedding (Second Order) in Blue and Fractures (Third Order) in Green. The Rugged Topography in the Southeastern Portion Is Underlain by the Grenvillian Basement Whereas the More Subtle Relief Characterizes the Paleozoic Cover Rocks.



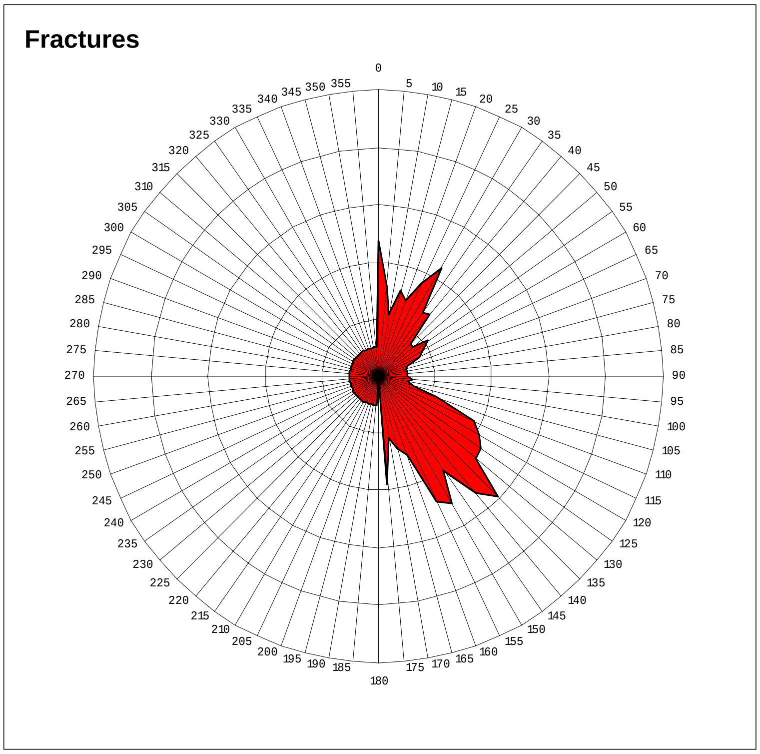


Figure 4-2 Rose Diagrams of Interpreted Discontinuities (1st Order Lineaments) and Fractures (3rd Order Lineaments)

4.2 GRAVITY AND MAGNETIC LINEAMENTS

Regional gravity lineaments trend east-northeast to north-northeast and west-northwest to north-northwest (Figure 4-3), and probably reflect Grenvillian tectonism. Among those which trend north-northeast, two define a zone about 10-20 km wide which extends from New York into southern Ontario, and others appear to be displaced in a right lateral sense by members of the set trending east-northeast (Figure 4-3). The latter is a macroscopic feature which is consistent with observed outcrop-scale faults that occur adjacent to the Black Lake fault (Section 4.3.2). North-northwest trending lineaments are particularly evident in New York State along the contact between the exposed Grenville basement and the Paleozoic cover rocks and are suspected of denoting normal faults, though similarly oriented strike-slip and high angle reverse faults also occur. All of the lineaments suggest a succession of faults, some of which probably formed early in the geological history of the area, but were reactivated during later tectonic events.

The pattern of regional linear magnetic anomalies appears to be more complex than the gravity pattern, but the orientations are identical (Figure 4-4) and suggest the presence of two orthogonal systems. North-northwest and east-northeast sets comprise one of the systems whereas west-northwest and north-northeast sets make up the second. It is, however, difficult to be definitive about lineament patterns without exhaustive ground-truthing because there are other possible pairings. For example, the west northwest and east northeast sets, seen among both the gravimetric and magnetic lineaments (Figures 4-3 and 4-4), could be inferred to represent a conjugate strike-slip fault system with the west-northwest faults showing sinistral slip and the east northeast faults displaying dextral displacement. In fact members of both component sets of that system have been recognized on the ground near Chicoutimi, Québec (unpublished data) and right-lateral northeast striking faults occur within the Black Lake fault zone located in the current study area (Section 4.3.2).

Topographic and geophysical lineaments display essentially identical orientations (Figures 4-5 and 4-6) and, in some locations, also correlate rather well. Both properties, particularly the correlations, suggest the presence of fault zones which formed initially as a consequence of Grenvillian tectonism then were propagated upward during subsequent Phanerozoic tectonism. Within the 1000 Islands area the lineament patterns are no different than throughout the entire region, as expected, but only faults oriented nominally northeast seem to correlate well with those lineaments (Figure 4-7).

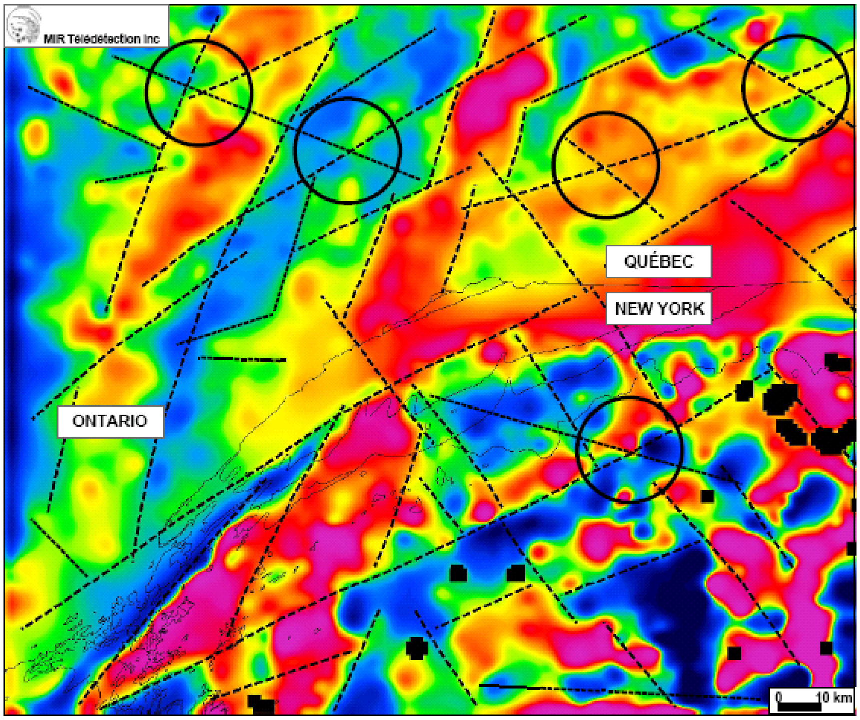


FIGURE 4-3 Bouguer Vertical Gradient Map With Interpreted Regional Gravity Lineaments. Encircled Areas Show Interpreted Intersecting Conjugate Pairs About An E-W Axis. Note Dextral Displacements of North-Northeast Lineaments At and Near North-Central Part of Map.

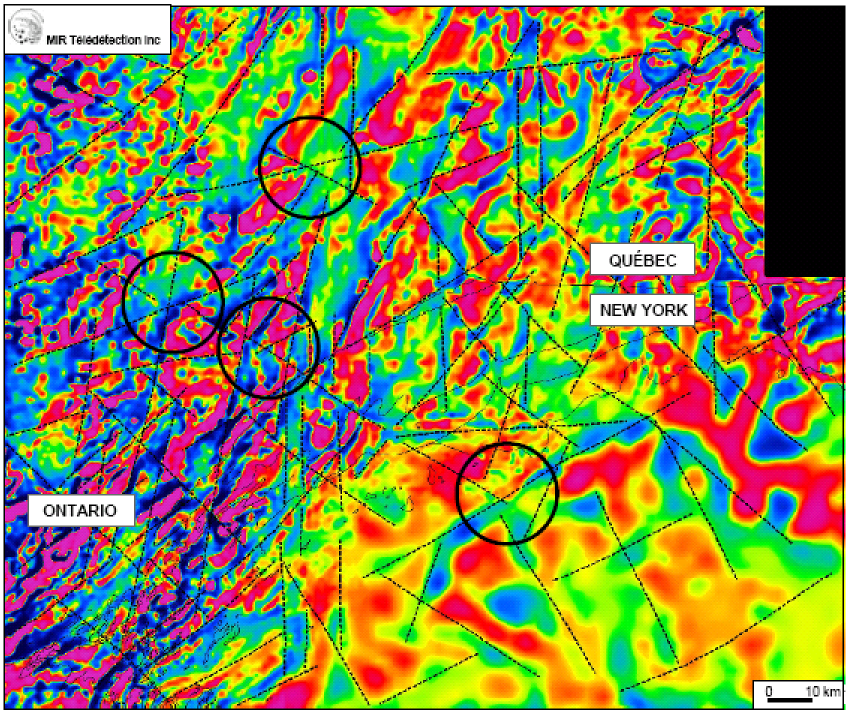


FIGURE 4-4 Magnetic Vertical Gradient Map With Regional Magnetic Lineaments. Encircled Areas Show Interpreted Intersecting Conjugate Pairs About An E-W Axis.

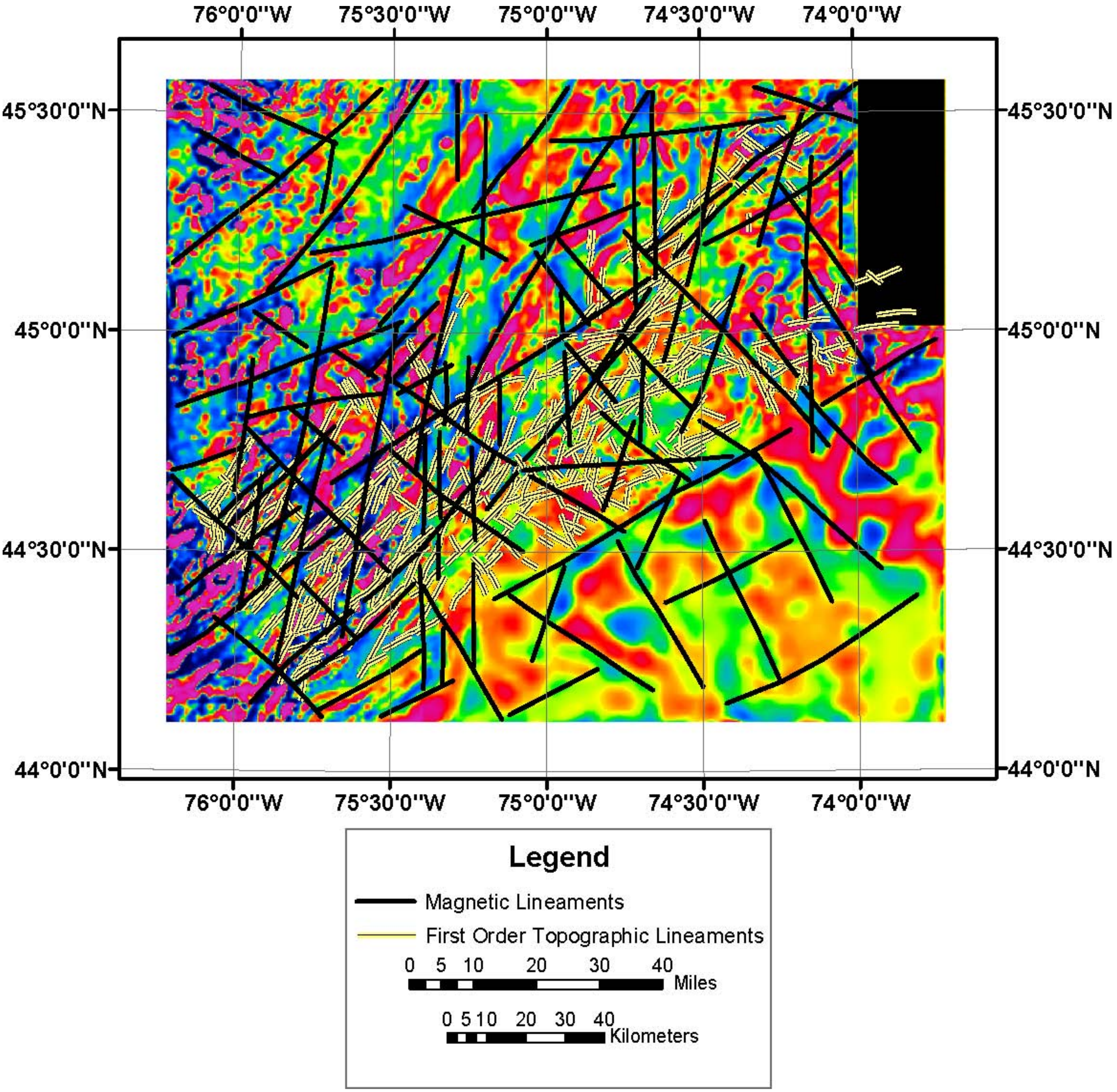


Figure 4-5 **Magnetic Vertical Gradient Map with Superimposed Magnetic and First Order Topographic Lineaments.**

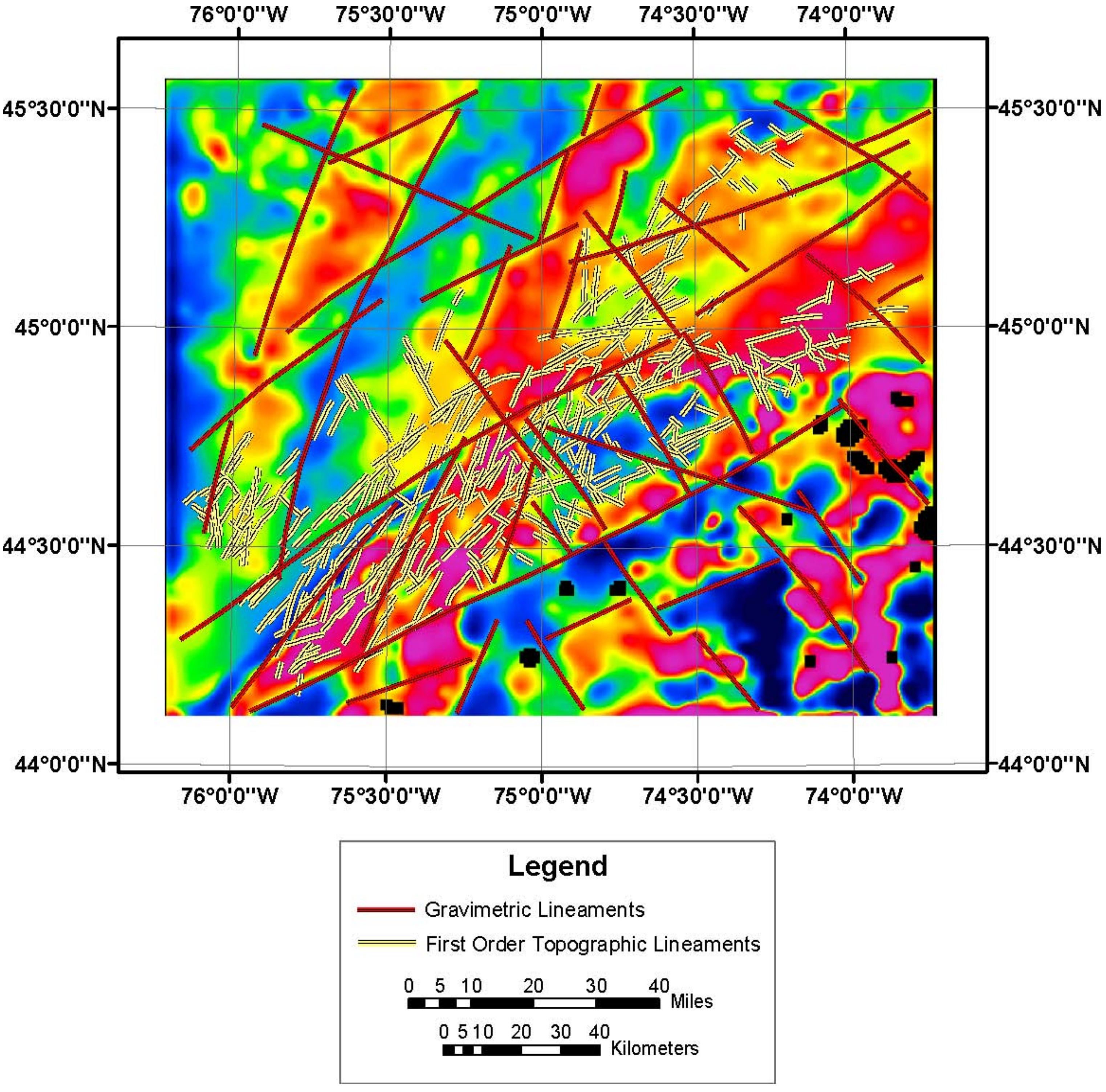


Figure 4-6 **Bouguer Vertical Gradient Map with Superimposed Gravimetric and First Order Topographic Lineaments.**

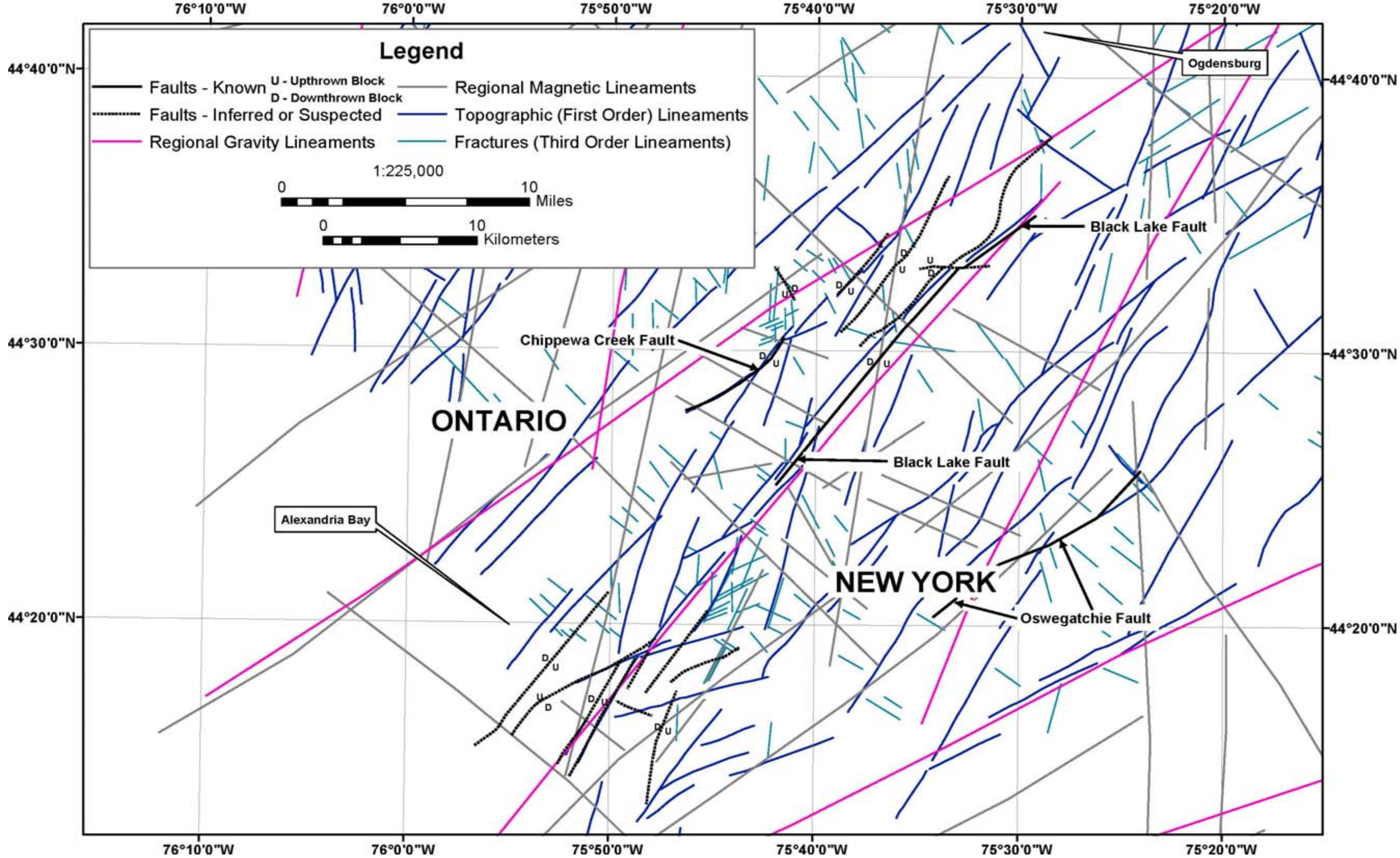


FIGURE 4-7 Faults, Fractures and Regional Topographic and Geophysical Lineaments in Precambrian and Lower Paleozoic Terrain in the 1000 Islands Region

4.3. STRUCTURAL GEOLOGY

4.3.1 Folds

Folds in the sedimentary strata are geometrically parallel flexural-slip structures that are not uncommon in the 1000 Islands area. They are, however, very gentle and usually not traceable beyond their cross sectional exposures, principally seen in road cuts (Figures 4-8 and 4-9). Where the structures can be seen in three dimensions their axes can be determined directly, otherwise it is necessary to measure bedding attitudes which permits determining their ß-axes. Because of the fold geometry, their ß-axes are equal to the fold axes. Despite the relative abundance of folds, data on the structures are rather sparse (Table 4-1) due to the difficulty of making reliable measurements on gently dipping uneven surfaces. Overall, the fold axes define four different sets which, read as angle of plunge/direction of plunge, are: a) 05°/065°, b) 03°/163°, b) 03°/206° and c) 00°/322° (Figure 4-10).

Figure 4-8 Gentle Anticline in the Theresa Formation At Station TH-8. Despite Appearances the Axis Plunges 0° and Trends 209°.

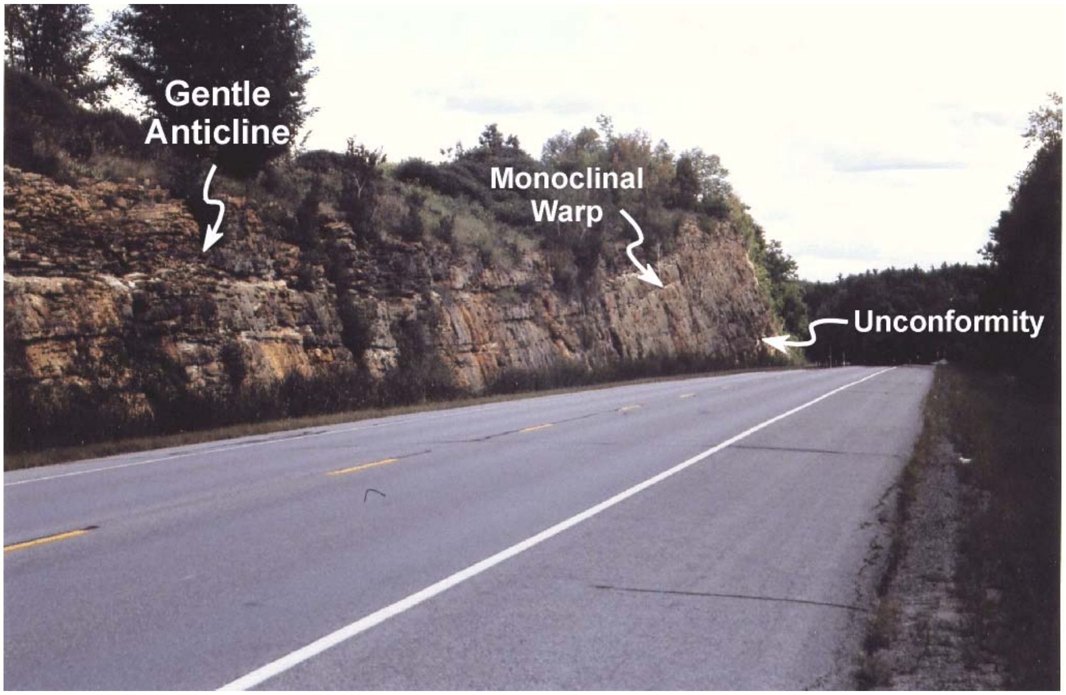


Figure 4-9 **Gentle Deformation of the Potsdam Group Rocks at Station AB-3. The Monocline Trends 030° and the Gentle Anticline is Oriented 012°. Grenvillian Basement Beneath Unconformity in the Distance.**

Table 4-1 Characteristics of Folds

Station	Axial Trend	Axial Plunge	Affected Formation(s)	Characteristics
AB-2	255°	00°	UCH/LNp	Open anticline
AB-3	191°	00°	CH & Nepean	Open syncline
AB-3	195°	00°	Qtz-fsp gneiss	Drag fold of PreC foliation beneath unconformity w/CH
BR-3	350°	01°	Oxford	Open anticline
CHB-1	230°	02°	Theresa & Nepean	Upward drag along Chippewa Creek fault; Fig. 4-15
CHB-1A	115°	05°	CH, Np and Theresa	Monocline
CHB-7	340°	00°	Covey Hill	Monocline
G-1	163°	02°	Lowville	Open anticline
JF-2A	055°	10°		Open anticline
JF-2A	066°	06°		Open anticline
ML-4	202°	01°	Covey Hill	Monocline
MORT-3	320°	00°	Theresa	Open anticline
MORT-4	254°	00°	Theresa	Open anticline
PM-1	164°	03°	Covey Hill	Open anticline
RED-2A	210°	00°	Gneissic granite	Drag fold of PreC foliation beneath unconformity w/CH
RED-12	320°	20°	Covey Hill	Syncline
RED-13C	320°	00°	Covey Hill	Monocline
RI-1	073°	11°	Nepean	Syncline

Table 4-1 Characteristics of Folds (Continued)

Station	Axial Trend	Axial Plunge	Affected Formation(s)	Characteristics
SFP-1	053°	09°	Covey Hill	Open anticline
SFP-4	022°	09°	Covey Hill	Open syncline; only in Covey Hill, not in Nepean
SFP-7	265°	00°	Nepean	Monocline
TH-1B	204°	03°	UCH/LNp	Open anticline
TH-1C	207°	01°	UCH/LNp	Open anticline
TH-3	285°	02°	UCH/LNp	Open anticline
TH-8	209°	00°	Theresa	Open anticline; Fig. 4-8
TH-11	240°	00°	Covey Hill	Monocline associated with high angle reverse fault
Hwy 15	330°	07°	Nepean	Open syncline; just north of Portland
Hwy 15	194°	00°	Nepean	Open anticline; just south of Elgin
Hwy 42	168°	01°	Nepean & Theresa	Open anticline; east of Philipsville
Almonte	321°	00°	Nepean	Open anticline

Key to Shorthand in Table 4-1:

CH	Covey Hill
UCH/LNp	Upper Covey Hill/Lower Nepean

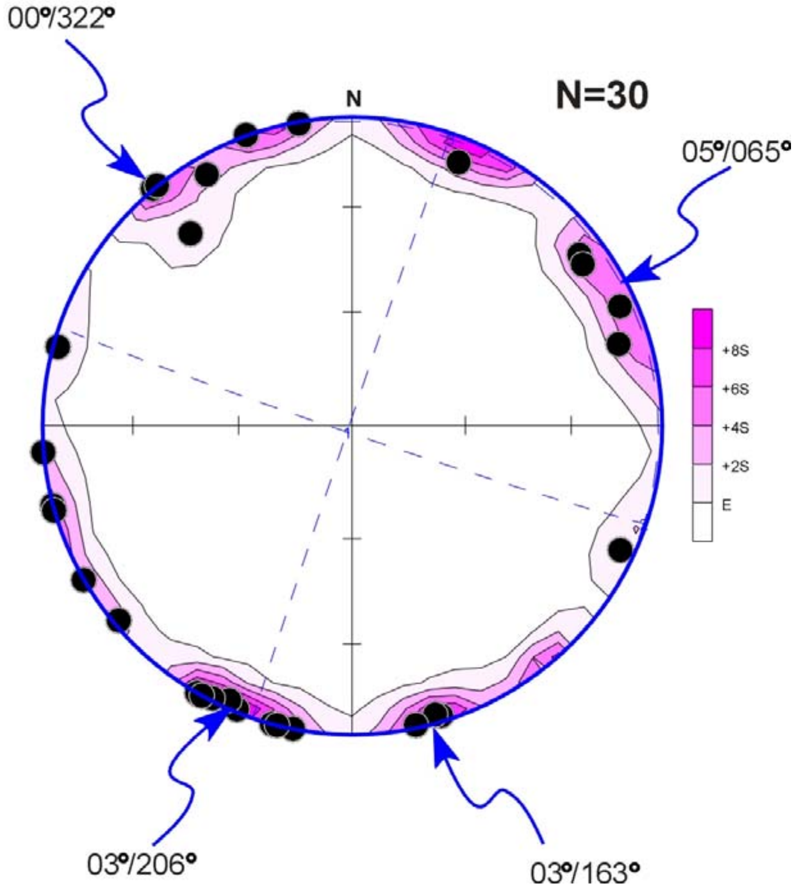


Figure 4-10 Equal Area, Lower Hemisphere Projection of Fold Axes.

4.3.2 Faults

The regional picture of macroscopic faults, detected through the use of remotely sensed imagery, shows a tendency to northeast and northwest orientations within the Paleozoic rocks (Figure 1-2). In the 1000 Islands area faults with similar trends were identified, largely as a consequence of mismatched stratigraphy across topographic lineaments. In the vicinity of some of those lineaments fault recognition was punctuated by drag folds or rigidly rotated blocks. Other faults were inferred because of the occurrence of outcrop-scale faults proximal to lineaments or recognition of older stratigraphic units being topographically higher than their adjacent, but younger counterparts. Though rather sparse and, irrespective of age or genesis, summary data on outcrop-scale faults in the 1000 Islands area (including Ontario) show the main orientations to be northeast to east-northeast, northwest and north-south (Table 4-2 and Figure 4-11).

Generally the 3-d kinematics on the major faults are unknown, but it is commonly possible to ascertain the 2-d vertical separation across them. The only good clue to characterizing the 3-d movements across the major faults comes from the outcrop-scale structures, where they, themselves, can be seen in 3-d or where well-stepped slickensided surfaces are present. Because structures form at all scales it is reasonable to assume that the properties of faults seen in rock exposures that are proximal to the major faults is a reflection of the properties of those larger faults which are expressed as topographic lineaments. Three such characterizations were made of major components of the St. Lawrence fault zone, the Black Lake, Chippewa Creek and Oswegatchie faults (Figures 1-3 and 4-7), discussed below. Movements along smaller faults were also inferred from outcrop-scale faults adjacent to notable lineaments. They include high-angle reverse faults cutting the Theresa and Covey Hill formations at Stations MORT-4 and TH-11, respectively, and a normal fault in the Theresa Formation at Station MORT-1 (Table 4-2; see Figures 1-4a and 1-4b for outcrop locations).

Table 4-2 Characteristics of Outcrop-Scale Faults

Station	Strike	Dip	Affected Formation(s)	Characteristics
AB-3	335°[1]	23°	Qtz/fsp gneiss	Brittle reverse fault w 30 cm of dip slip
AB-3	015°	75°	CH & Nepean	Normal separation
AB-3	060°	90°	CH & Nepean	Brittle dextral strike-slip; slicks plunge 23°-240°
CHB-1C	195°	75°	Precambrian	Brittle; kinematics unknown
CHB-1D	045°	60°	Granite	Brittle normal fault w/slicks & 2nd order shears; Fig 4-16

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[1] Right hand rule

Table 4-2 Characteristics of Outcrop-Scale Faults (Continued)

Station	Strike	Dip	Affected Formation(s)	Characteristics
CHB-1D	225°	63°	Granite	Brittle normal fault w/slicks & 2nd order shears; Fig 4-16
CHB-10B	335°	??°	Nepean	Healed breccia; angular fragments of sandstone
E-5	220°	80°	Gneissic granite	Ductile dextral strike-slip
E-6	060°	???	Gneissic granite	Ductile w/10 cm of dextral separation
E-6	040°	65°	Gneissic granite	Brittle normal fault w/stepped, slicked surface
G-2	028°	85°	Precambrian qtzte	Brittle; kinematics unknown
G-4	135°	80°	PreC & Lowville	Predominantly dextral with reverse component
G-6	220°	79°	Precambrian	Brittle oblique sinistral; slicks plunge 31°-220°
G-6	222°	82°	Precambrian	Brittle sinistral strike-slip; slicks plunge 15°-218°
G-6	185°	65°	Precambrian	Ductile; shows normal separation (healed)
G-6	073°	77°	Precambrian	Brittle; kinematics unknown
H-5	240°	80°	Gneiss & granite	Brittle dextral strike-slip; slicks plunge 06°towards 245°
H-9	280°	80°	Straight gneiss	Brittle normal fault with 2nd order shears & thin breccia
MORT-1	260°	80°	Theresa	Brittle normal fault
MORT-4	135°	75°	Theresa	High angle reverse fault; part of zone
RED-10	130°	85°	UCH/LNp	Brittle dextral strike-slip fault; slicks plunge 5°-310°
RED-13C	290°	87°	Covey Hill	High angle reverse fault; minor drag
RI-1	250°	65°	Precambrian	Brittle; kinematics unknown
RI-1	200°	60°	Precambrian	Brittle; kinematics unknown
RI-1	227°	80°	Precambrian	Brittle; kinematics unknown
RI-1	315°	80°	Precambrian	Brittle; dextral strike-slip; slicks pitch 18°towards 315°
RI-1	130°	55°	Precambrian	Brittle; normal; slicks pitch 90°
RI-1	305°	86°	Precambrian	Brittle; oblique strike-slip; slicks pitch 55°towards 125°
RI-1	040°	63°	Precambrian	Brittle; kinematics unknown
RI-1	296°	85°	Nepean/marble	Brittle; high angle reverse; slicks pitch 85°towards 295°
RI-1	240°	40°	Precambrian	Brittle; normal?
RI-1	248°	55°	Precambrian	Brittle; kinematics unknown
RI-1	240°	55°	Precambrian	Brittle; normal?
TH-1	185°	65°	Covey Hill	Ductile high-angle reverse fault with healed breccia
TH-1	215°	63°	Covey Hill	Ductile high-angle reverse fault with healed breccia
TH-1	035°	40°	PreC/CH contact	Brittle, dip-slip; inferred reverse fault
TH-11	062°	75°	Covey Hill	High-angle reverse fault

Key to Shorthand in Table 4-2:

bx	breccia
CH	Covey Hill
PreC	Precambrian

slicks plunge 23°-240°= slickenlines which plunge 23° in the direction 240°

UCH/LNp	Upper Covey Hill/Lower Nepean

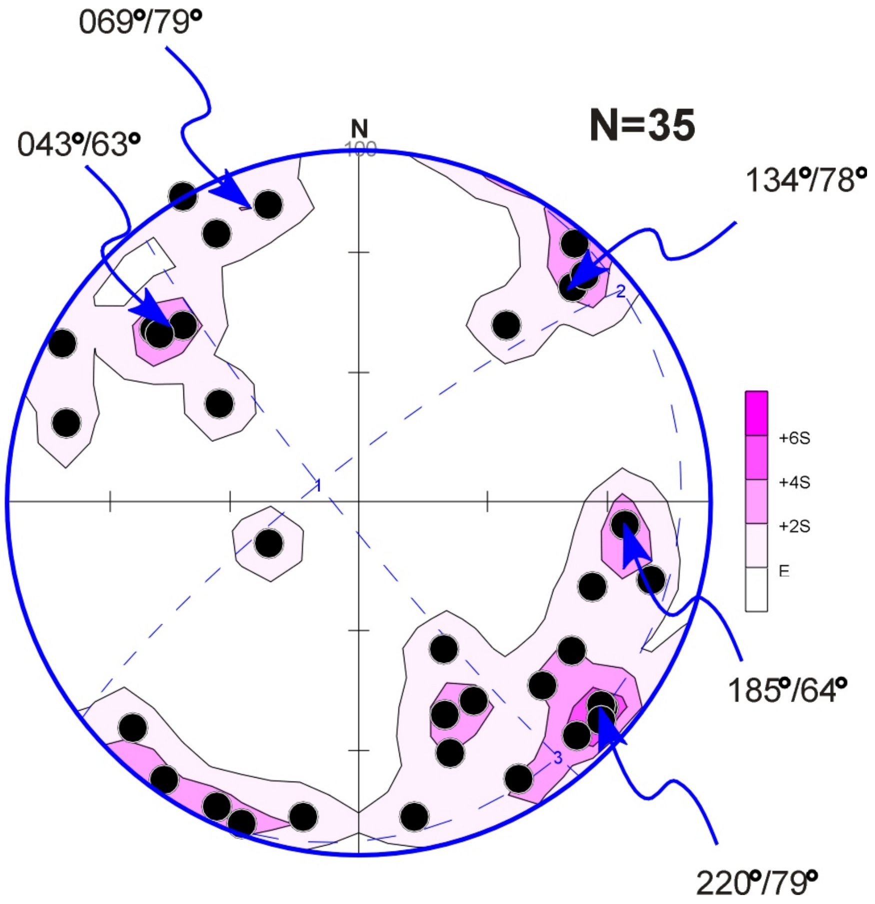


Figure 4-11 **Equal Area, Lower Hemisphere Projection of Poles to Fault Surfaces.**

<u>The St. Lawrence Fault Zone</u>

The St. Lawrence Valley lies within the northeast oriented St. Lawrence fault zone that extends more than 1,000 km (625 miles) from the Atlantic Ocean upstream at least as far west as the Dundas Valley in southwestern Ontario, just beyond the western tip of Lake Ontario. Comprised of many paleotectonic faults (Wallach, 2002) its existence within the St. Lawrence Valley, in the 1000 Islands region, is very obvious when looking northwestwardly from the flat surface of the Theresa Formation across the valley to the higher, but older Grenvillian basement in southern Ontario (Figure 4-12).

The Black Lake, Chippewa Creek and Oswegatchie faults are among the important components of the St. Lawrence fault zone. Details of the Black Lake and Chippewa Creek faults are presented in the indented and italicized passages on pp. 38-40 and are followed by a discussion of the Oswegatchie fault. From that information it can be seen that all three have clearly operated as normal faults during some points in their history.

Figure 4-12 View Across Flat Terrain Underlain by the Theresa Formation (Foreground) in New York State and the St. Lawrence Valley (Hidden in Mid-Ground) to the More Rugged Precambrian Terrain of Ontario (Background) Which Rises Above the Elevation of the Younger Theresa. The Mismatched Terrain Indicates a Major Fault Within the St. Lawrence Valley

Black Lake Fault

Ductile right-lateral strike separation along a well-developed 040° striking foliation, synchronous with or post-dating very tight folding, represents the earliest phase of faulting along the Black Lake fault (Figure 4-13). Because of slickenlines seen on fracture surfaces parallel to that foliation there were either two phases of right-lateral movements or a single protracted phase in which tectonism outlasted the ductile-brittle transition. Succeeding at least the earlier phase, if not all phases, of dextral oblique-slip faulting were normal faults, which utilized the same surfaces, but formed under entirely brittle conditions as evidenced by the brecciation, stepped slickensided surfaces and second order shear fractures (Figure 4-14). As stated in Wallach (2002):

> *In northern New York State the continuously exposed Precambrian basement…is truncated by the north-northeast oriented Black Lake fault which separates the topographically higher Precambrian rocks from the Cambro-Ordovician Potsdam Sandstone. Adjacent to, and on the southeast side of, the Black Lake fault a granite is cut by closely spaced and polished fractures trending about 040°, some of which still have preserved dip-slip and strike-slip slickenlines. One such surface, which strikes 225° and dips 85°NW, shows stepped slickenlines that pitch 30° in the direction 225° and indicate predominantly right-lateral*

> *slip with a high-angle reverse fault component. Second-order shears and steps on slickensided surfaces associated with another outcrop-scale fault signify normal fault movement. Prior to the brittle faulting, the granite had been subjected to intense ductile strain which produced both a penetrative recrystallized fabric throughout and localized ductile shear as exemplified by two outcrop-scale faults that strike 035° and 060°, and display right-lateral strike separation. Because right lateral displacements occurred under both ductile and brittle conditions, they may represent a single protracted event that transcended the ductile-brittle transition, or they may signify two distinct events that affected the granite. Thus, in combination with the normal faulting at least two, if not three, episodes of faulting have been documented along the Black Lake fault.*

Chippewa Creek Fault

Parallel to, and northwest of, the Black Lake fault is a prominent lineament within which lies Chippewa Creek. That lineament, named the Chippewa Creek fault by Wallach (2002), trends east-northeast to northeast and separates Precambrian granite and outliers of the overlying Covey Hill Sandstone on the southeast from the Upper Cambrian to Lower Ordovician Nepean and Theresa formations on the northwest. Recognition of the lineament as a fault was first suspected from the occurrence of inclined sandy limestone beds of the Theresa adjacent to the lineament at Station H-15 (Figure 1-4a). There the beds dip away from the exposed granitic basement at 8° in the direction 354°. To the southwest along the same lineament, at Station CHB-1 (Figure 1-4a), layers of the Theresa and Nepean are bent upward and dip towards the northwest with the axis of the warp plunging 02° in the direction 230° (Fig. 4-15). From the details in italicized text below, quoted from Wallach (2002), the Chippewa Creek fault is interpreted as a normal fault.

> *Within the granite* (at Station CHB-1D, which lies within the Chippewa Creek fault) *are well-developed northeast striking fractures that dip 75°-90° and generally traverse the entire thickness of the exposure face.* (Figure 4-16)*. They are commonly spaced at least 1 m (3 ft.) apart, but are much closer in the immediate vicinity of two parallel striking, but oppositely dipping fractures that also cut the entire thickness of the exposed granite. One of the long fractures, oriented 045°/60°SE, truncates closely spaced fractures which range in strike from 045° to 060° and dip from 80° to 90°, thereby suggesting a relationship between primary and second-order shear fractures* (Figure 4-16)*. The second long fracture, oriented 045°/63°NW, is also inferred to represent the principal slip surface of another primary-secondary pair of shear fractures* (Figure 4-16)*. Slickenlines are generally absent from the two principal fractures, but the southeast-dipping one is marked by small zones of finely comminuted rock and a dark green chloritic coating wherein there are faintly preserved dip-slip*

slickenlines. Those features, in combination with the second-order shears, suggest that the principal fractures are outcrop-scale, conjugate normal faults. The linearity of the valley and the characteristics at the two outcrop areas therein imply that the Chippewa Creek fault is a normal fault, with the southeast side having moved up relative to the northwest.

Figure 4-13 Tight Flexural Flow Fold and Ductile Right Lateral Strike-Slip Fault (Pen on Right) at Station E-5 on the Shore of Black Lake. Pens Point N. Axial Trace of the Fold and Strike of the Fault Parallel Black Lake and are Oriented 040°.

Figure 4-14 View, Looking SSW, of Normal Fault (Inclined to the Left) and Second Order Shears (Left of and Above the Pen, and Inclined to the Right) in Granite at Station E-6. Both the Fault and the Second Order Shears Parallel the Structures Seen in Figure 4-13.

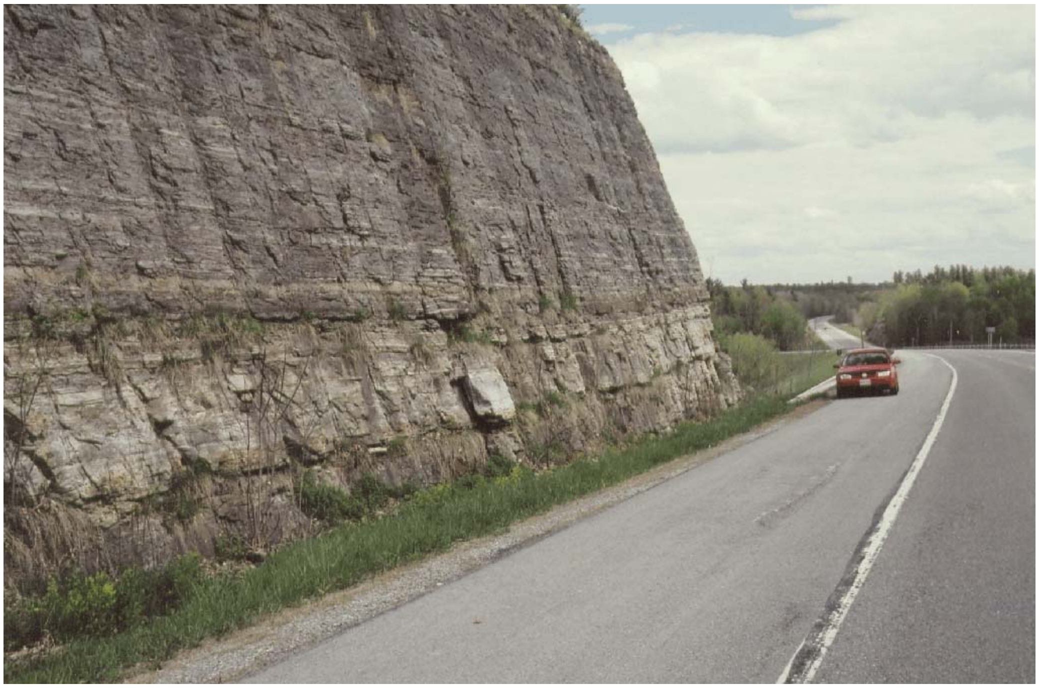


Figure 4-15 Upward Drag of the Theresa-Nepean Contact Along the Chippewa Creek Fault at Station CHB-1. Axis of Drag Fold Plunges 02° in the Direction 230°

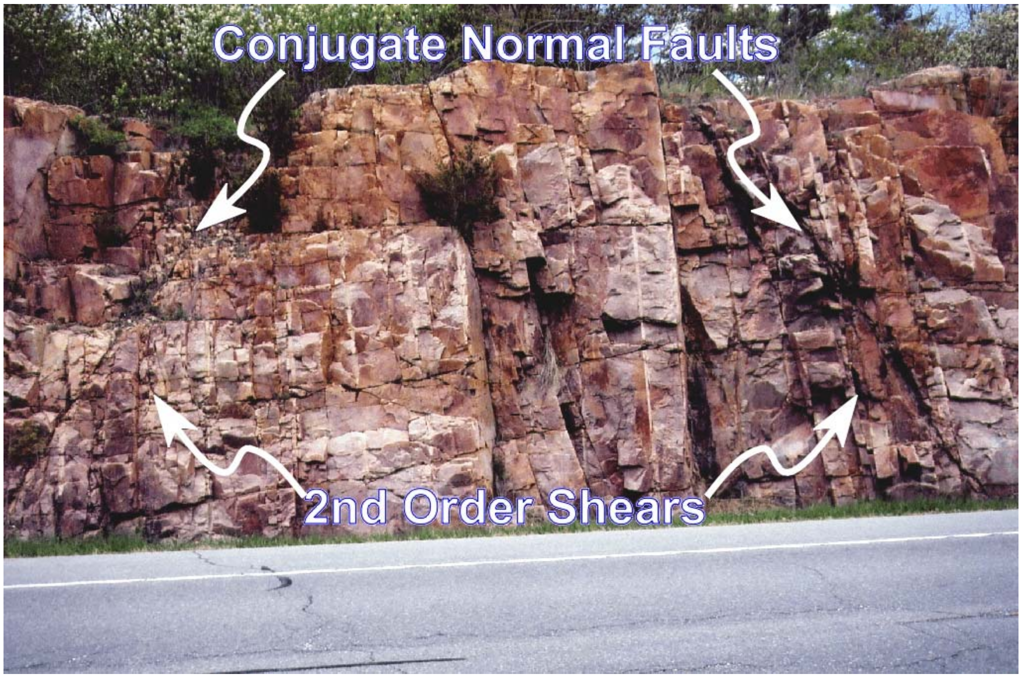


Figure 4-16 Pink Granite at Station CHB-1D Cut By Inclined Conjugate Normal Faults and Nearly Vertical Closely Spaced Second Order Shear Fractures.

Oswegatchie Fault

The Oswegatchie fault (Figures 1-3 and 4-7) was named by Wallach (2002) for a suite of well exposed and intensely brecciated rocks within the Grenville basement adjacent to the Oswegatchie River at Station RI-1 (Figure 1-4b). At the north end of the 400 m-long exposure there is a metamorphosed sequence of moderately to steeply dipping, fine-grained, well layered rocks with strata striking nominally 230° to 270° and dipping about 38°-60° to the northwest. Foliation, where present, is parallel to the layering. That sequence comprises, in ascending order, gray calcareous conglomerate (Figure 4-17), pale pink to brick red quartzofeldspathic rock (Figure 4-18) with angular fragments of very fine grained, dark gray to black microcline-quartz-biotite gneiss, and a gray-green microcline-biotite gneiss. Tourmaline, commonly idioblastic, occurs in various quantities in all, but the gray-green rock, and all, but the conglomerate, have been completely recrystallized so that no vestige of the original texture remains. The dominance of microcline and the fine-grained fabric of the pink and green rocks suggest their unmetamorphosed precursors to have been trachyte, with the green rock having been slightly more mafic due to the presence of biotite. Despite the preservation of primary conglomeratic textures and good layering throughout the sequence the presence of a tremolite-muscovite assemblage in some of the rocks and at least one altered, but clearly distinguishable pyroxene in another implies that metamorphism of the layered suite reached the lower amphibolite facies.

South of the aforementioned rocks is a coarse-grained massive to foliated white calcitic marble with minor muscovite; foliation in the marble parallels the layering in the stratified sequence. There are no minerals within the marble indicative of metamorphic grade, but the calcite crystals therein are significantly larger than in the stratiform rocks (Figure 4-19) suggesting the marble probably recrystallized under more severe metamorphic conditions. At its northern end the marble is abruptly truncated by a very large fracture surface that strikes 255° and dips 47° to the northwest. From the northern terminus of the marble to the layered stratiform sequence is a gap about 200 feet (60 m) long (Figure 4-20). The near juxtaposition of rocks apparently recording different metamorphic grades and the dip direction of the major fracture surface imply that the gap formed by erosion along a normal fault, the north side of which is down relative to the south side (Figure 4-20). A nearby fracture strikes 230°, dips 67° towards the northwest and, from the stepped slickensided surface, indicates predominantly normal displacement, but with a substantial component of sinistral slip as well. Slip along that surface has affected both the marble and clastic dikes of Nepean Sandstone implying that the northeast striking normal faults, though largely confined to Grenvillian rocks at that exposure, are Late Cambrian to Early Ordovician in age, if not younger. Low angle reverse faults, possibly even nappes, also cut the basement rocks of the area, but it appears that they have been rotated by movement on the normal faults suggesting that the normal faults are younger. Throughout the remainder of the exposure, but south of the river, there are other small faults, though none has produced deformation nearly as intense as that by the river. At the south end the Nepean Sandstone and Grenvillian marble are separated by a high angle reverse fault oriented 296°/85°. Though both movement on that fault and the normal faults post-date consolidation of the Nepean, the age relationship between them is not known.

Other Faults

The Theresa Formation at Station MORT-4 (Figure 1-4a) is cut by a zone of high angle reverse faults oriented 135°/75° (Figure 4-21), and across which there is a cumulative throw of 5.9 feet (1.8 m). That structure, which is about 45 feet (15 m) wide, coincides with a 3rd order lineament (Figure 4-7) and, according to Revetta (personal communication), is also expressed gravimetrically. At Station MORT-1 a nearly east-west striking normal fault cuts beds of the Theresa adjacent to a parallel lineament.

Figure 4-17 Metamorphosed Conglomeratic Limestone at Station RI-1.

Figure 4-18 **Pink Fine-Grained Metavolcanics Cut by Shear Zones at Station RI-1**

A very small high angle reverse fault zone, bounded by fracture surfaces oriented 063°/76° and 062°/75°, cuts across a massive pale pink sandstone which is the lower of two units within the Covey Hill Formation at Station TH-11 (Figures 3-3b and 4-22). That produced a monocline and accompanying fractures in the overlying, more thinly bedded banded pink and white quartz sandstone, also a member of the Covey Hill. The fractures strike 055° and 065° and dip 51° and 59° to the south-southeast, respectively. Bedding on the monocline is oriented 240°/55°, across which there is a displacement of about 50 cm (20 inches).

Healed angular breccia was recognized at different locations throughout the 1000 Islands area, but exclusively within the Nepean Sandstone. The sandstone fragments occur either in well defined fractures (Figure 4-23) or in rather large, irregularly shaped patterns across an outcrop implying a period of tectonism during the incipient stages of Upper Cambrian to Lower Ordovician sandstone lithification. Unfortunately fractures in which they occur show no preferred orientation, nor are there any clear kinematic indicators, therefore the nature of the faulting cannot be determined.

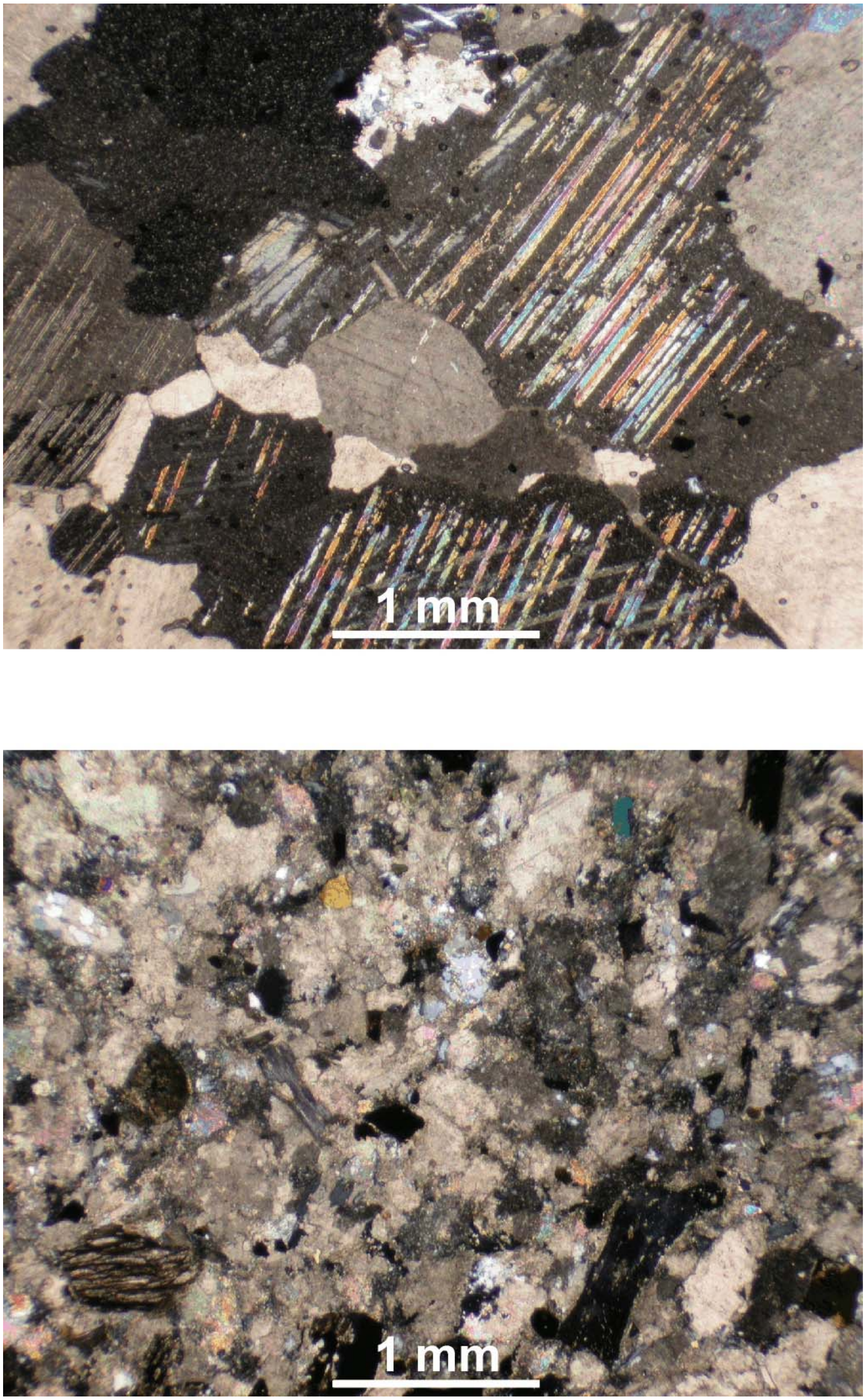


Figure 4-19 **Photomicrographs Showing Different Calcite Textures in Metamorphosed Carbonate Rocks South (Top) and North (Bottom) of the Gap at Station RI-1. Scales Are Equal in Both Photos.**

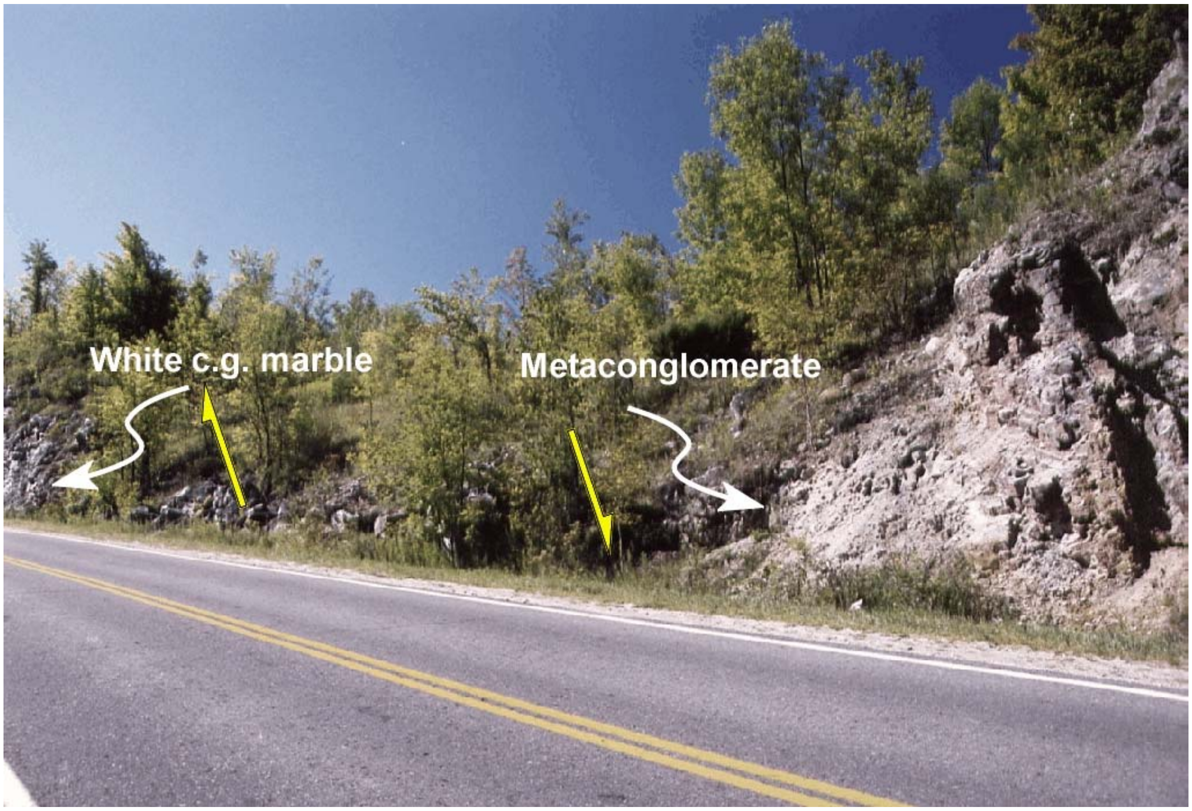
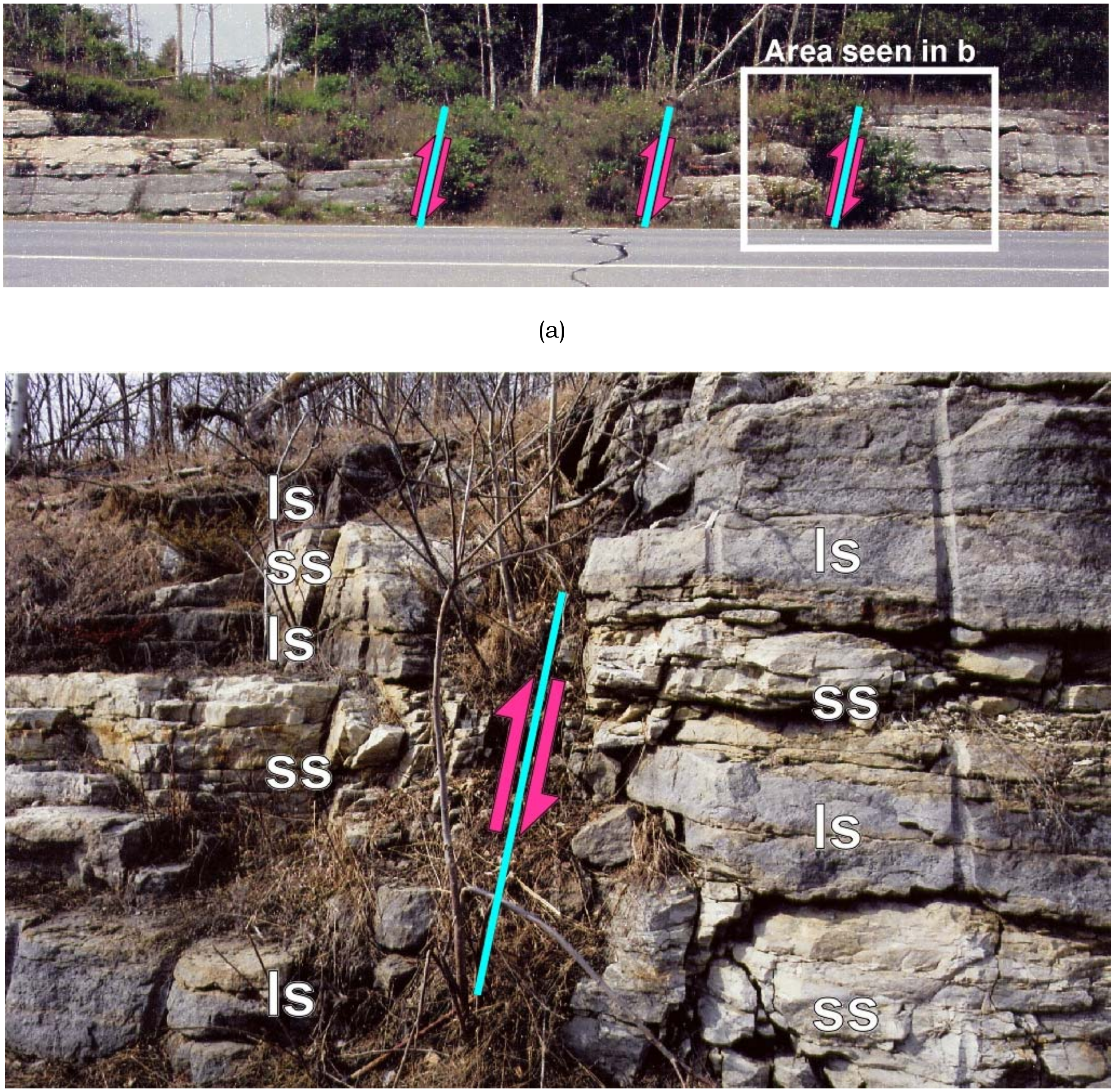


Figure 4-20 **Gap Inferred to be a Normal Fault Between Coarse-Grained Marble on the left and Metamorphosed Fine Grained Conglomeratic Limestone on the right at Station RI-1.**

Slip along the unconformity separating the Grenvillian basement from the basal Covey Hill has produced horizontally plunging, asymmetrical drag folds overturned to the west at two locations along Route 12 northeast of Alexandria Bay (Figures 4-24 and 4-25). At Station AB-3 the drag folds coexist with a gentle monocline, which formed as a consequence of the Grenvillian basement having been uplifted, and a broad open anticline (Figure 4-9). The drag folds trend 015°, whereas the monocline trends 012° and the open anticline is oriented 030°. The axis of the overturned drag fold at Station RED-2A (Figure 3-3A) trends 015° and, like the one at Station AB-3, displays a horizontal plunge (Figure 4-25).

Aside from dipping strata unmistakably associated with folding, there are locations where the beds show a uniform dip and dip direction with no obvious evidence of nearby folding. Many of those tilted strata are located next to prominent lineaments making it easy to infer that they signify blocks that were rigidly rotated as a consequence of faulting. They are diversely oriented and generally dip less than10°, but a few in excess of 20° were observed and there is even one, caught up within a small, outcrop-scale fault zone, that was rotated to a dip of 73° (Table 4-3 and Figure 4-26). The varied strikes replicate the diverse orientations of the faults themselves



(a)

(b)

Figure 4-21 **High Angle Reverse Faults Cutting the Theresa Formation. (a) Panoramic View. (b) Close-up of area outlined in (a). Note the dip of fractures to the left of the up arrow.**

Figure 4-22 Unconformity and Monoclinal Warp Produced by Reverse Faulting Within the Covey Hill Sandstone at Station TH-11. Inclined Bedding on the Monocline is Oriented 240°/55°.

Figure 4-23 Plan View of the Nepean Sandstone Showing a Linear Breccia Zone at Station CHB-10B. Pen Points North.

Figure 4-24 Lateral Drag of the Grenvillian Basement Beneath the Unconformably Overlying Covey Hill Sandstone at Station AB-3. Axis of the Drag Fold is Horizontal and Trends 015°. Covey Hill Translated to the West (Left) Relative to the Precambrian Basement. View Looking North.

Figure 4-25 Lateral Drag of the Grenvillian Basement Beneath the Unconformably Overlying Covey Hill Sandstone at Station RED-2A. Axis of the Drag Fold is Horizontal and Trends 030°. Covey Hill Translated to the West (Right) Relative to the Precambrian Basement. View Looking South-Southwest.

Table 4-3 Orientations of Inclined Strata

Station	Easting	Northing	Strike	Dip	Affected Formation(s)	Comments
BR-12	438431	4936197	242°	03°	Nepean	
BR-12A	437734	4935936	214°	03°	Nepean	
BR-13	439170	4934460	246°	03°	Theresa	
BR-19A	427414	4937426	212°	07°	Nepean	
BR-19B	427238	4937749	040°	05°	Theresa	
BR-29	441130	4937460	243°	09°	Nepean	
BRF-1	517997	4961631	178°	04°	Covey Hill & Nepean	
BRU-1	534907	4965277	178°	10°	Theresa	
CHA-1	571974	4972970	171°	08°	Covey Hill	In Chateaugay R. lin.
CHB-3	438570	4919804	305°	03°	Covey Hill	
CM-1	493724	4966017	300°	04°	Oxford	
E-3	459204	4935637	015°	04°	Covey Hill	
G-4	406690	4911030	114°	10°	Lowville	PreC/Lowville unconf.
H-2			253°	04°	Covey Hill	
H-2			236°	06°	Covey Hill	
H-12	446373	4922953	315°	07°	Covey Hill & Nepean	
H-15	442020	4925730	264°	08°	Theresa	Next to a lineament
H-16A	443794	4919368	283°	11°	Nepean	
H-18	443358	4918849	055°	03°	Covey Hill	
H-32	446401	4926357	035°	02°	Nepean	
HE-10	462818	4928321	095°	10°	Nepean	Next to a lineament
JF-4	406008	4936627	320°	17°	Covey Hill	Next to a lineament
JF-5	406196	4938043	355°	03°	Nepean	
JOV-2	390789	4912949	048°	25°	Covey Hill	
ML-3	440712	4905768	213°	15°	Covey Hill	
ML-7	440454	4906588	263°	10°	Nepean	
ML-9	440748	4906166	283°	06°	Covey Hill	
ML-11	440698	4907961	225°	10°	Covey Hill	
MORT-2	448181	4935630	283°	04°	Theresa	
MORT-11	448486	4935051	023°	06°	Theresa	
MORT-15	440849	4929677	142°	12°	Theresa	
PH-2	441418	4899332	130°	15°	Covey Hill	
PM-3	456703	4926599	000°	17°	Covey Hill	
PM-3B	456557	4926543	023°	11°	Covey Hill	
PM-7	455143	4925273	235°	25°	Covey Hill	Next to a lineament
RED-3	431553	4905326	065°	04°	Theresa	
RED-5	437087	4908957	020°	13°	Covey Hill	
RED-11	437437	4908477	250°	11°	Covey Hill	Next to a lineament
RED-13	435946	4905890	248°	10°	Nepean	
RED-13C	435146	4905627	295°	06°	Nepean	
RED-13C	435124	4905626	355°	18°	Nepean	Next to a lineament
RED-13C-3	435146	4905626	130°	73°	Covey Hill	In small rev. fault zone
RED-24	437705	4901711	220°	15°	Covey Hill	
RED-25	437829	4901779	258°	15°	Covey Hill	
RED-27	438709	4902532	255°	13°	U. Covey Hill/L. Nepean	
RED-29A	439018	4903513	270°	21°	Low grade PreC limestone	
RED-30	439147	4903800	279°	04°	Covey Hill	
RED-46	433118	4906744	189°	05°	Nepean	
RED-53A	433143	4910108	202°	06°	U. Covey Hill/L. Nepean	
RED-58	435716	4910730	355°	12°	Covey Hill	
RED-70	431265	4901918	225°	06°	Nepean	

Table 4-3 Orientations of Inclined Strata (Continued)

Station	Easting	Northing	Strike	Dip	Affected Formation(s)	Comments
RI-26	463682	4922324	265°	25°	Covey Hill	
TH-1A	436921	4895947	050°	25°	U. Covey Hill/L. Nepean	
TH-2	434505	4895625	225°	06°	U. Covey Hill/L. Nepean	
TH-10	436162	4899223	278°	09°	Covey Hill	
TH-17	436684	4896447	318°	19°	Covey Hill	
TH-18	437006	4896301	073°	24°	Covey Hill	
Hwy 401	445550	4940886	348°	04°	Theresa	Exit 698
Hwy 7	402823	4985611	290°	05°	Nepean	

Key to Shorthand in Table 4-3:

bx	breccia
CH	Covey Hill
PreC	Precambrian
UCH/LNp	Upper Covey Hill/Lower Nepean

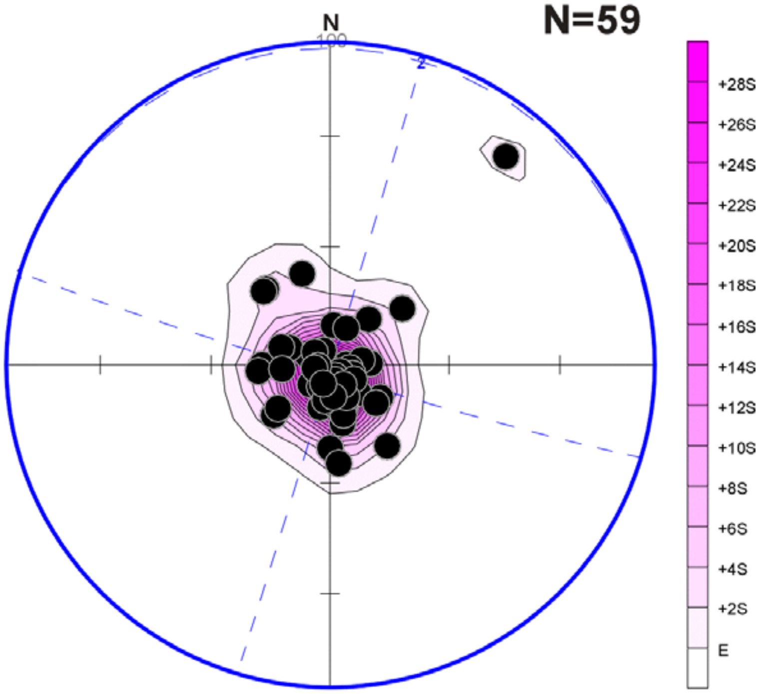


Figure 4-26 Equal Area, Lower Hemisphere Projection of Poles to Inclined Bedding From the Entire Study Area.

4.3.3 Neotectonic Structures

As noted in chapter 4.3.2 of this report the St. Lawrence fault zone is a major tectonic element in the study area and is composed of many paleotectonic faults, the details of which are presented in Wallach (2002), and summarized, in part, in the aforementioned chapter. Besides the ancient faults, neotectonic movements have occurred along the St. Lawrence fault zone beneath both eastern and western Lake Ontario, as documented by seismic profiles showing vertical displacements of unconsolidated sediments (Wallach, 2002). Seismic activity also marks this structure, with earthquakes of 5≤M≤7 having occurred in an area extending northeastward from Cornwall, Ontario-Massena, New York (M=5.9, in 1944) through the Charlevoix seismic zone northeast of Quebec City (M≈7 in 1925) and down river to the Lower St. Lawrence seismic zone (e.g. Lamontagne et. al, 2003).

Though geologically recent movements have been recorded and seismic activity has been documented along the St. Lawrence fault zone only five neotectonic structures were recognized along the zone within the study area, three of which occur in a quarry at Station OW-1 near Ogdensburg (Figure 1-4a and Table 4-4). Two are small quarry-floor pop-ups oriented 350° and 035°, respectively, and the third is bedding plane slip, marked by boreholes displaced in the direction 035°. Besides them two open field pop-ups were also recognized. At Station MORT-1 a pop-up in the Theresa Formation trends 260° and is cut by a normal fault which is oriented 260°/80°. The land surface conforms to the shape of the underlying pop-up, thus the very brittle character of the pop-up along with its influence on the local topography suggest that is younger than the fault. Pop-ups cored by faults have been observed elsewhere as well (unpublished data) and at each location it is they, not the faults, which influence the local topography. It is, therefore, inferred that the faults predated the pop-ups and provided a zone of weakness whereby the strain energy consequent upon the later stress application could accumulate and eventually be released producing the pop-up. A second pop-up was identified near Alexandria Bay (Station AB-1; Table 4-4). That structure trends north-northwest, protrudes at least a meter above the ground surface and disrupts a glacially striated surface (Figure 4-27), thereby demonstrating its post-glacial age.

Table 4-4 Neotectonic Structures

Station	Affected Formation(s)	Characteristics
AB-1	UCH/LNp	Pop-up oriented 340°; uppermost beds glacially striated
MORT-1	Theresa	Pop-up oriented 260°
OW-1	Oxford	Pop-up oriented 350°
OW-1	Oxford	Pop-up oriented 035°
OW-1	Oxford	Offset boreholes along bedding. Displaced 10 cm in direction 032°
Key to Shorthand in Table 4-3: UCH/LNp Upper Covey Hill/Lower Nepean		

Figure 4-27 **Pop-up in the Upper Covey Hill-Lower Nepean Unit at Station AB-1. The Upper Surface is Glacially Striated Indicating Pop-up Formation Within About the Last 11,000 Years.**

4.3.4 Tectonic Synthesis

Gravity and magnetic signatures in the study area are derived from the complexly deformed and lithologically variable Grenvillian basement and reveal linear trends, therein, which are also expressed in the Paleozoic cover rocks as faults and fractures (Figures 1-2, 1-3, 4-1 and 4-7). That implies that over time many of the structures which formed prior to deposition of the basal Paleozoic sequence were subsequently reactivated, examples of which are given in the succeeding paragraphs of this section.

Ductile, outcrop-scale, west-northwest-striking sinistral and east-northeast to northeast-oriented dextral strike-slip faults cut gneissic porphyritic monzonite near Chicoutimi, Québec. Ductile, right lateral northeast-striking faults also deform Grenvillian gneissic granite in the immediate vicinity of the Black Lake fault (Figures 4-13 and 4-14). Collectively the geometry and kinematics of those structures are strongly indicative of an early conjugate fault system that formed about an east-west axis of maximum horizontal compression. That conjugate system is also expressed as geophysical lineaments (Figures 4-3, 4-4 and 4-28).

Displaced patterns across the geophysical lineaments imply the existence of brittle failure (Figures 4-3, 4-6), a feature also indicated by slickenlines along the outcrop-scale fault surfaces. Identical movements under both ductile and brittle conditions along the same individual faults suggest that there were at least two periods of strike-slip faulting early in the history of the region, the first under ductile conditions, the second under brittle conditions. Alternatively there may have been only a single protracted episode that commenced during the Grenvillian orogeny and outlasted the transition from ductile to brittle conditions. The northwest striking Saguenay and Ottawa-Bonnechere grabens, along with the northeast trending St. Lawrence fault zone, imply that all three of those major structures originated as conjugate strike-slip faults early in the geological history of the study area. Those three major zones and a multitude of their parallel counterparts of structural weakness are well expressed by remotely sensed, geophysical and geological images (Figures 3-1, 3-2 and 4-1 thru 4-7). Furthermore they appear to have been rejuvenated, perhaps repeatedly, as eastern North America was subjected to different Phanerozoic tectonic episodes and have, therefore, controlled the orientation of many faults which deform not only the basement, but the overlying Paleozoic rocks.

Northeast-trending upright folds, high angle reverse faults (including the uplifted Grenvillian basement) and overturned asymmetric folds produced by drag along the Grenvillian-Covey Hill contact (Figures 4-8, 4-9, 4-21, 4-22, 4-24 and 4-25) are interpreted as the coeval results of regional horizontal compression attendant upon the Paleozoic collision between North America and Euro-Africa. Normal faults which strike northeast and are prominent within the St. Lawrence fault zone appear to have occurred along pre-existing, similarly oriented right lateral strike-slip faults. They may be lengthening by-products of Paleozoic compression and/or the results of re-opening of the Atlantic Ocean during the Mesozoic, however no unequivocal age relationship between those normal faults and the structures attributed to Lower to Middle Paleozoic collision could be established. All that can be stated with certainty is that both sets of structures are Ordovician or younger.

Northwest to west-northwest and east-northeast striking normal faults are prominently displayed within the area of the Ottawa-Bonnechere Graben and St. Lawrence Lowlands. The pattern they define in plan view is identical to the conjugate system that formed about an axis of east-west compression (compare patterns in Wilson, 1946 to those within the encircled areas of Figures 4-3 and 4-4), yet another example pointing to reactivation of earlier formed faults. According to Kumarapeli and Saull (1966) the normal faulting within the Ottawa-Bonnechere Graben is Cretaceous in age, based on its spatial relationship to the Cretaceous-age Monteregian Hills which are approximately aligned with, and located at the eastern end of, the graben.

Northwest oriented compressional structures, expressed in the study area by folds and high-angle reverse faults, are consistent with compression in response to the current stress field. For the folds that does not imply formation in recent times because of the rounded, rather than angular, fold hinges, which would form under elevated confining pressure, suggesting development at depth then uplift to the surface. The observed high-angle reverse faults may have formed at any time since the onset of the current stress field, including relatively recently, because there is topographic relief across them. In addition contemporary north-northwest oriented high angle reverse faults are forming, testimony for which is provided by earthquake focal mechanisms, such as for the 1983 Goodnow earthquake in the Adirondack Mountains (Dawers and Seeber, 1991).

Neotectonic activity is documented by the existence of the pop-ups and offset boreholes (Table 4-4; Figure 4-27). Very little data are available in the study area alone to permit drawing any sweeping conclusions, but the overall geometrical and kinematic pattern of those unquestionably neotectonic structures is consistent with the orientation of the present day stress field.

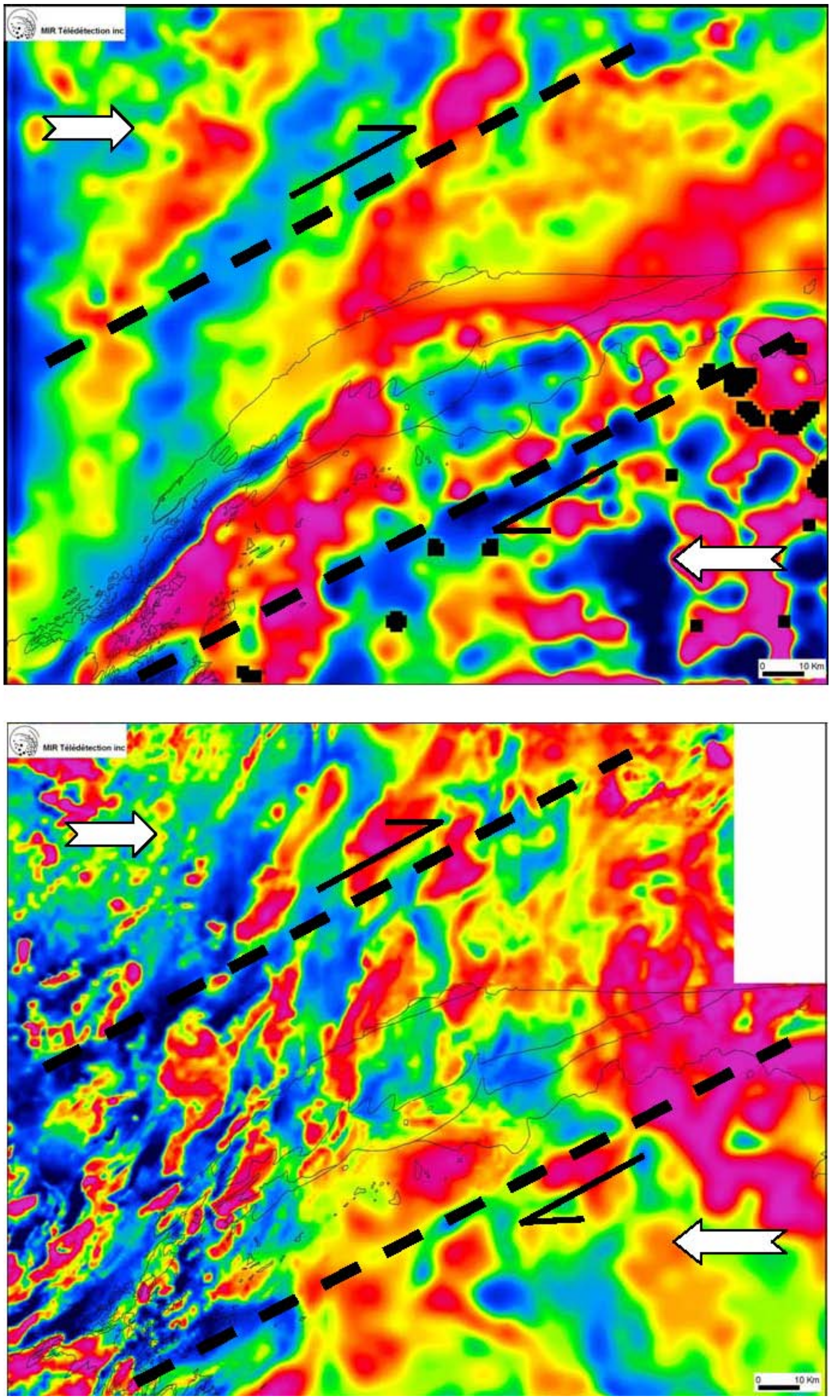


Figure 4-28 **Right Lateral Strike-Slip Faulting Interpreted on Both Gravity (Top) and Magnetic (Bottom) Maps. White Arrows Denote Inferred Maximum Horizontal Compressive Stress Operative at the Time and the Dashed Lines Outline the Inferred Right-Lateral Strike Slip Fault Zone.**

Chapter 5 NATURAL GAS POTENTIAL

The sedimentary rock units on the surface become progressively younger to the northeast (Figure 3-2). Near the 1000 Islands, and northeast of the Precambrian basement, the Potsdam Group of sandstones predominates, but is succeeded to the northeast by the overlying Theresa Formation which, in turn, gives way to the dolostones of the still younger Oxford Formation (Figure 3-2). The Oxford continues in a generally northeasterly direction to the end of the map sheet and, aside from a very narrow belt of Chazy and Black River Group rocks along the New York-Québec border (Figure 3-1), is the youngest stratigraphic unit in the area of investigation. All of that is attributed to the presence of the somewhat elongate Ottawa Embayment that underlies much of the area between the Ottawa and St. Lawrence Rivers (Sanford, 1993), the southeastern edge of which is expressed in northern New York.

Natural gas has been detected escaping from the Nepean sandstone at two locations north of the Adirondack Mountains, but in both cases, which were reported to the authors by the landowners, the Nepean is exposed at the surface. Consequently the Nepean should be considered to be a viable reservoir rock at depth, but throughout much of the study area it only occurs at, or near, the surface. No known gas has been detected in the underlying Covey Hill, but it may be an even better reservoir rock at depth than the Nepean because of its commonly being less well sorted and, accordingly, more porous. Added to the inherent porosity and permeability of the two sandstones would be fractures and faults.

The two Beekmantown Group formations, the Theresa and the overlying Oxford, are also potentially good reservoir rocks. Like the Potsdam Group formations, however, they are found at or near the surface over most of the area thus also making them seemingly unattractive for natural gas exploration. Nevertheless in New York State there is an overall gentle dip towards the northeast, a feature expressed on the regional geological map (Figure 5-1) by the presence of progressively younger stratigraphic units in that direction related to the presence of the Ottawa Embayment. As a consequence of the basin not only are the potentially good reservoir rocks buried more deeply, they are thicker as well which has the potential of inspiring exploration interest. In fact some optimism for exploration was generated at the Dundee site in Huntingdon, Québec, just north of the international boundary (Figure 5-2), which stimulated proposing this study.

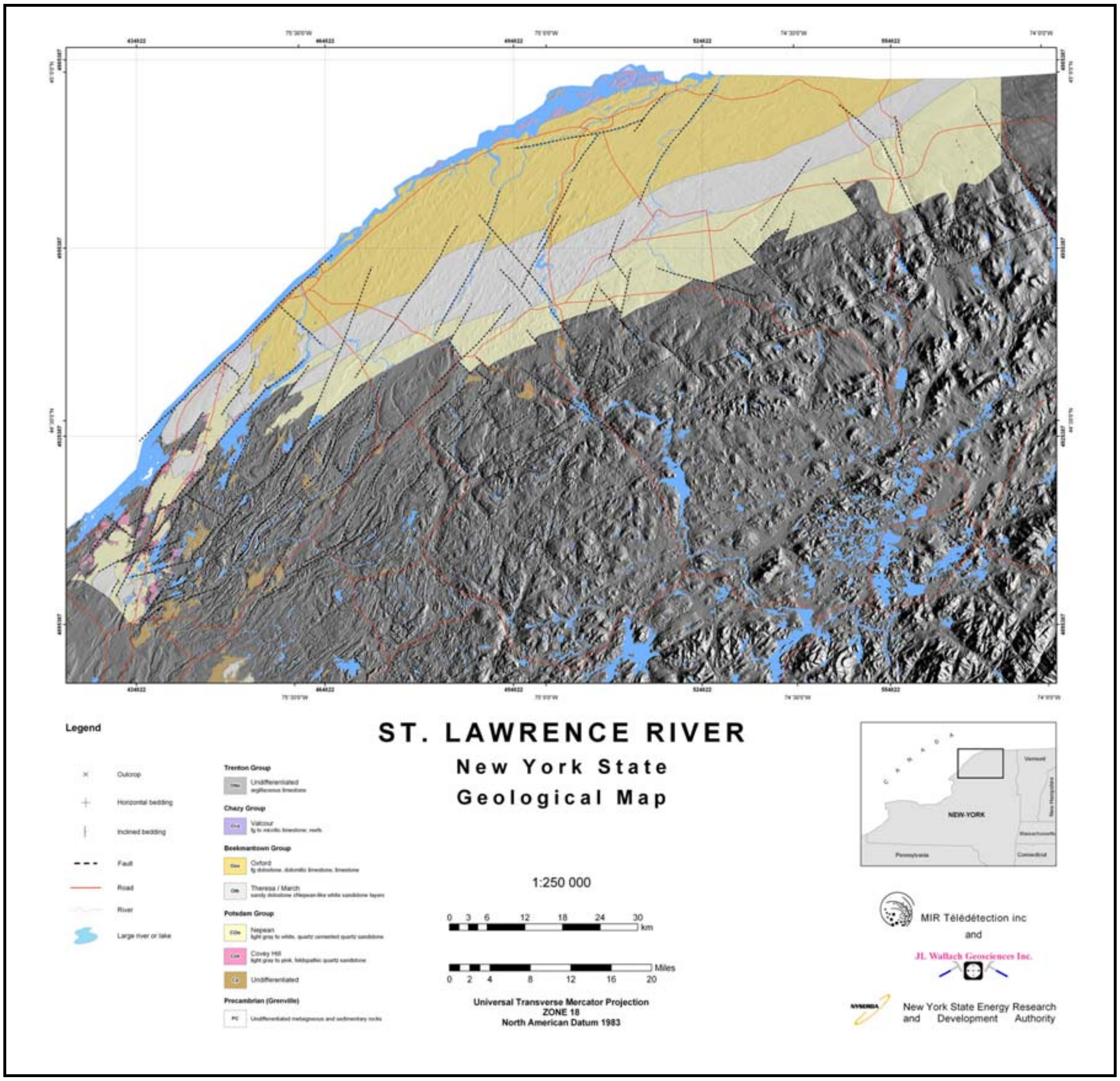


Figure 5-1 Regional Geological Map of the Study Area Superimposed on a Shaded Topographic Base.

Ditem Exploration, now Gastem, reported encouraging results from the Ditem Explorations Dundee No. 1 borehole drilled at the Dundee site in 2002 (Table 5-1). That hole, drilled to a depth of 422.8 m (1,387 feet), penetrated all of the formations underlying the site, but was stopped within the Covey Hill Formation and, therefore, did not reach the Precambrian basement. Twenty-nine porous zones were detected and gas pressures of 150 to 180 PSI were measured suggesting a potential production capacity of 300,000 cubic feet of gas per day, but no source rock for the gas was identified (Laroche, 2002). All of the gas, with one exception, was detected within the Beauharnois (Oxford) Formation (Table 5-1) with the most important occurrence recorded at a depth of 483 feet (Laroche, 2002). The sole exception came from a porous zone in the depth interval from 719 to 729 feet thereby placing it within the Theresa Formation.

Table 5-1 Stratigraphy and Gas Showings in Borehole Ditem Explorations Dundee No. 1

Material or Formation	Depth (m)	Formation Thickness (m)	Depth (ft)	Formation Thickness (ft)	Description
Surface Elevation - 48.9 m					
Soil Cover	0-15.2		0-50		Organic soil over gray clay.
Beauharnois (Oxford)	15.2-202.1		50-663		Beds of calcareous or light gray silty dolomite with some black shale. Silty sandstone near the base.
			449-459		Short period of gas bubbles, then nothing
			469-479		Gas bubbles
		186.9	478-488	613	Gas bubbles
			479-489		Small gas bubbles
			484-494		Strong gas showing; up to 150 psi
			486.5-496.5		Small gas bubbles which became large bubbles
			489-499		Gas bubbles
			499-509		Some gas bubbles
			509-519		Gas
			519-529		Gas
			529-539		Small gas bubbles
Theresa	202.1-257.0	54.9	663-843	180	Alternating silty-sandy dolomite and light to dark gray dolomitic sandstone progressing to quartz sandstone at the base
			719-729		Gas bubbles
Cairnside (Nepean)	257.0-339.6	82.6	843-1114	271	Sandy dolomite grading downward to gray-white quartz sandstone with some cross bedding
Covey Hill	339.6-422.8	>83.2	1114-1387 END	>273	Generally red, locally green, coarse grained sandstone with conglomeratic layers; abundant cross bedding

Modified From Laroche, 2002

Table 5-2 Stratigraphy in Borehole Gastem Dundee No. 1

Material or Formation	Depth (m)	Formation Thickness (m)	Depth (ft)	Formation Thickness (ft)	Description
Surface Elevation - 51.2 m					
Soil Cover	0-19.8		0-65		Soil cover.
Beauharnois (Oxford)	19.8-214.0	194.2	65-702	637.0	Dolomite; becomes a sandy silty dolomite towards the base.
Theresa	214.0-277.0	63.0	702-908.8	206.8	Sandy dolomite and dolomitic sandstone
Cairnside (Nepean)	277.0-352.5	75.5	908.8-1156.5	247.7	Dolomitic and quartz sandstone. Quartz arenite at the base
Covey Hill	352.5-374.3	>21.8	1156.5-1228 END	>71.5	Conglomeratic sandstone

Modified From Laroche, 2004

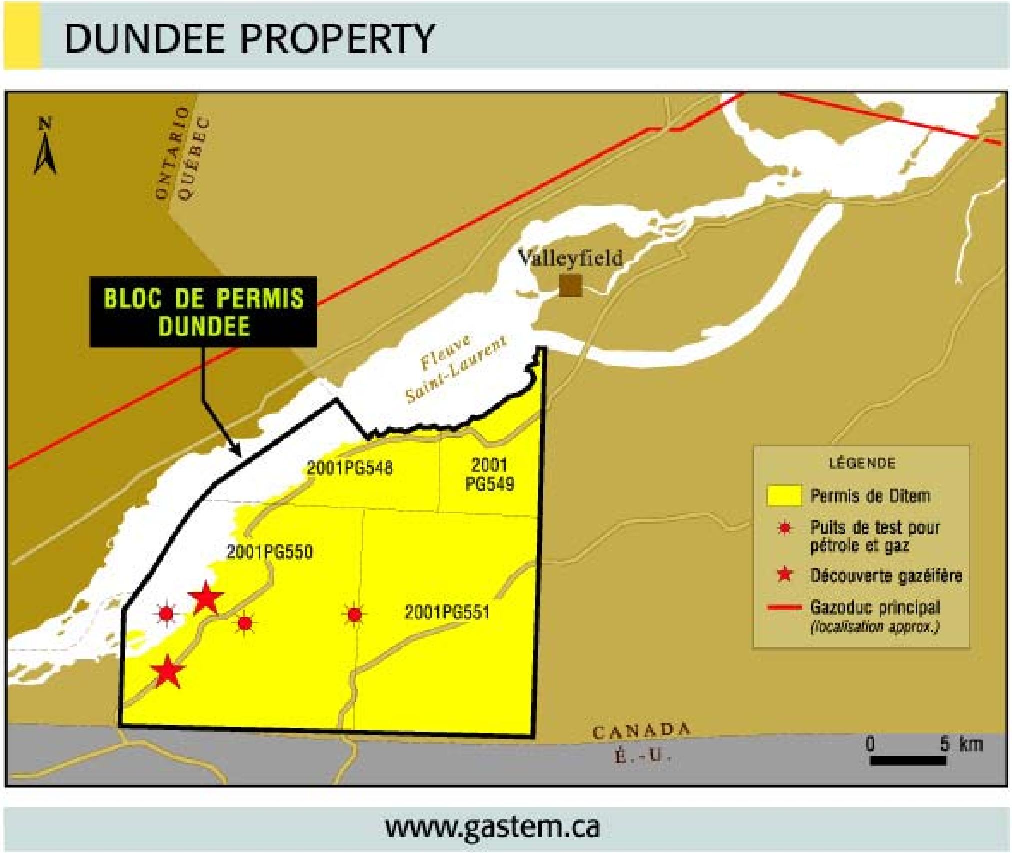


Figure 5-2 **Location of the Dundee Site Southwest of Valleyfield, Québec. The Red Stars Denote Locations of Gas Discoveries. The Smaller Red Circles Signify Test Wells.**

A second borehole was drilled in 2004, about 450 m north of the first one (Laroche, 2004). It was drilled to a depth of 374.3 m (1,228 feet) and traversed the same formations as the first borehole (Table 5-2), although the formational contacts were encountered at somewhat different depths (Compare Tables 5-1 and 5-2). Labelled Gastem Dundee No 1, that hole proved to be rather disappointing in that there were fewer porous and fracture zones than in the earlier drilled borehole. However at respective depths of 115.2 m (378 feet) and 121.3 m (398 feet), again in the Beauharnois Formation, gas flows of 16.1 and 17.5 mcf per day were measured. Subsequent tests failed to yield any significant gas flows, and only brine was sampled. Additional work has been recommended by consultants to Gastem, but at this time it is not clear whether or not that will be undertaken. If any more work should be conducted at the Dundee site and yield unfavorable results that would enhance the conclusion of this report that it would be inadvisable to pursue exploration activities within the area investigated during this study.

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