EXPLORATION FOR NATURAL GAS NORTH AND EAST OF THE ADIRONDACK DOME IN NEW YORK STATE. PHASE 1-REGIONAL RECONNAISSANCE

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ABSTRACT

A multidisciplinary investigation involving remote sensing, GIS, geophysics and field geology was conducted in order to characterize the study area, with the ultimate objective being to assess the potential for natural gas reserves. Throughout the entire study area 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. On the northern rim of the Adirondacks, lineaments oriented north-northwest correlate very well with similarly oriented magnetic discontinuities. Along the western border of Lake Champlain and northward into southern Quebec the linear features trend predominantly north-south to north-northeast and are interpreted as east-dipping normal or thrust faults, any of which may represent potential pathways for the migration and trapping of natural gas.

Northwest- and northeast-trending fractures occur along the border of a major sub-circular magnetic anomaly, more than 70 km in diameter, which is located in the basement of southern Quebec. That regional geophysical anomaly is interpreted to be the signature of a major intrusion, the emplacement of which may have favored the development of normal fault zones on its border. Furthermore, that anomaly is bounded and cut by several northeast and northwest trending magnetic discontinuities along, or parallel to, which clusters of earthquakes have been recorded. Those earthquakes are clear indicators that those faults are presently active and may also represent conduits for hydrocarbon fluid flow.

Platform rocks rim the Grenvillian Adirondack Mountains in northern New York State. To the north and east of the Adirondacks they range progressively from the sandstones of the Potsdam Group (Late Precambrian to Early Ordovician) to the limestones of the Trenton Group (Upper middle Ordovician). Just north of the Quebec border, however, the black Utica Shale (Early late Ordovician) is also exposed.

Normal faults, seen in seismic profiles, are the earliest detectable structures in the study area and were succeeded by the emplacement of allochthonous thrust sheets, and accompanying reverse faults and folds during, and perhaps throughout most of, the Paleozoic. Later north-south to north-northeast oriented normal faults, likely to have occurred during Trio-Jurassic times, were followed by the emplacement of a suite of deuterically altered dikes and east-west trending, inferred normal faults, all of which

are suspected of having formed during the Cretaceous. A prominent sub-circular to slightly elongated geophysically expressed strongly positive anomaly in the Plattsburgh area, inferred to be a gabbroic pluton, is possibly also Cretaceous in age. Seismological data and terraces in the sedimentary rocks bordering the Adirondacks suggest present-day uplift.

Prospects for natural gas appear to be rather promising in Quebec immediately across the border from the study area. That, in combination with the geological setting, invites detailed, subsurface investigations in the northern Champlain Valley, which would focus on exploration for natural gas. Of particular interest in that context are the north-south, north-northeast and east-northeast to east-west-oriented fractures within, and adjacent to, the Champlain Valley.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

List of Tables

List of Figures

Chapter 1 INTRODUCTION

1.1 GENERAL STATEMENT AND OBJECTIVE

There has been considerable success in finding natural gas in central and western New York State, but the northern and northeastern portions of the state have not been subjected to focused investigations germane to that undertaking. A likely reason is that an overwhelmingly large percentage of that area exposes the crystalline basement of metamorphosed igneous and sedimentary rocks that form the Grenvillian basement of the Adirondacks. Nonetheless, there are large tracts of platform sedimentary rocks in the areas bounding the Adirondacks that should not be ignored. Along the northern flank the Potsdam sandstone predominates, but along the northeastern and eastern flanks carbonate rocks of the Beekmantown and Chazy Groups are present in sufficient amounts to warrant a closer look. Furthermore, according to the work of Fisher (1968), there is a multitude of faults in the area between the Adirondack Mountains and Lake Champlain, although the area north of the Adirondacks is not similarly marked (Isachsen and Fisher, 1970). To attempt to understand the geological framework of the area, as a first step in deciding whether or not there may be economical quantities of natural gas available, a multidisciplinary investigation involving remote sensing, geophysics and regional geology was undertaken.

Given the need to find new reservoirs of natural gas, sometimes in rather inaccessible areas, governmental agencies and private or public companies should have at their disposal different methods of rapidly acquiring the necessary geological information while reducing field survey costs. In that context remotely sensed data combined with the use of geographic information systems provide an invaluable and efficient means of fulfilling those two objectives. JL Wallach Geosciences Inc. and MIR Télédétection inc., under contract to the New York State Energy Research and Development Authority (NYSERDA) and the Canadian Space Agency, undertook a study utilizing RADARSAT-1 data and the latest developments in remote sensing, supported by existing and newly acquired, reconnaissance-scale geological and geophysical information to search for potential hydrocarbon plays in northern New York State.

1.2 REGIONAL SETTING AND GAS POTENTIAL

A structural suite of Cambro-Ordovician sedimentary rocks strikes southwest, parallel to the St. Lawrence River in Quebec, but curves southward and extends along and beneath Lake Champlain in both New York and Vermont. In Quebec that suite is marked by faults of unspecified character, whereas in New York most are labeled as normal faults, although there are places where thrust sheets are indicated. Within, and following the structural trend of that suite in Quebec, are several properties with permits for oil and gas exploration, suggesting that the southward continuation of those tectonostratigraphic units may have economical implications for New York State.

No comprehensive regional geoscientific investigations are known to have been undertaken throughout the entire study area, but mapping programs and a study of faults were carried out along Lake Champlain (e.g. Buddington and Whitcomb, 1941; Erwin, 1957; Fisher, 1968; Hudson, 1931 and Hudson and Cushing, 1931). Columbia Gas also conducted six seismic surveys in and east of Lake Champlain. One was a north-south profile along the east side of the lake, and the other five were east-west lines extending into the Green Mountains of Vermont (Dick Beardsley, personal communication). In Quebec, seismic data have been collected for the last 40 years along the northern projection of Lake Champlain. Most of those data were obtained along east-west lines, perpendicular to the structural grain, although there were also a few north-south lines as well.

Beardsley (personal communication) pointed out that thrust sheets representing the Taconic allochthonous sequence overlie, but are not cut by, normal faults. That being the case means there is a potential mechanism for trapping any upwardly migrating hydrocarbons depending, of course, on the permeability and porosity of the overlying allochthonous rocks. Though the case is oversimplified it is an attractive prospect. In the target area, such a relationship may exist in the extreme eastern portion where the leading edges of thrust sheets have been identified. Though nappes do not occur to the west of that thin area, the rest of the study area is poorly known and, therefore, merits a thorough examination.

Linear magnetic patterns within, and presumably parallel to, the St. Lawrence fault zone were recognized in the area between Potsdam and Ogdensburg, and were interpreted by Billman and Fagan (1998) as indicating a series of horsts and grabens. That is a reasonable interpretation, for further to the southwest there is unequivocal geological evidence of normal faulting along the St. Lawrence 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 possible association of the horst and graben series with the St. Lawrence fault zone, along with gaseous emanations in the Rochester Basin, has implications for examining that fault zone more closely as a natural gas conduit and for possible traps.

Besides the possible relationship of natural gas to the St. Lawrence fault zone, the autochthonous Cambro-Ordovician platform carbonates and quartz sandstone are also inviting exploration targets. In the proposed study area they comprise, from youngest to oldest, the Ogdensburg (Oxford, Beauharnois and Little Falls), Theresa (March or Rose Run) and Potsdam (Nepean or Chateauguay) formations which represent a respective sequence of dolostone, sandy limestone and quartz sandstone. All have been found to contain natural gas.

Along the St. Lawrence Valley in Quebec, the Beauharnois Formation has been targeted for gas exploration by Dykstra and Longman (1995) who emphasized that both the autochthonous and allochthonous dolomite of the Beekmantown have good reservoir potential. That potential does not appear to be ubiquitous, but is the result of either early formed pores escaping subsequent filling by later calcite deposition, or tectonic deformation (fractured and brecciated rock), as expressed in the anticlinal, thrust-faulted trap in the St. Flavien field (Dykstra and Longman, 1995). Natural gas also appears to emanate from the Theresa Formation in the St. Lawrence Valley of southeastern Ontario Furthermore, natural gas has been encountered in the Theresa Formation in Wyoming County in western New York State as well as in its equivalent in Ohio, the Rose Run Formation (Loewenstein, 1997). Sanford et al (1985) reported the presence of oil and gas-producing zones in Upper Cambrian rocks and determined that tilted fault blocks are responsible for trapping the hydrocarbons.

Chapter 2 STUDY AREA

The area of investigation, which includes a thin portion of southern Quebec, is bounded by latitudes 44°00' to 45°45'N and longitudes 73°00' to 75°00'W with the eastern and southern limits being Lake Champlain and the Grenvillian basement of the Adirondack Mountains, respectively (Fig. 2-1). The target zone, a subset of the study area, is located entirely within New York State with the bounding coordinates being 44°37.5' to 45° N latitude and 73°15' to 74° 22.5' W longitude. The area was selected because of the presence of known or suspected faults and presumed uplift associated with the Adirondacks, all of which suggest that it might enclose potential reserves of natural gas.

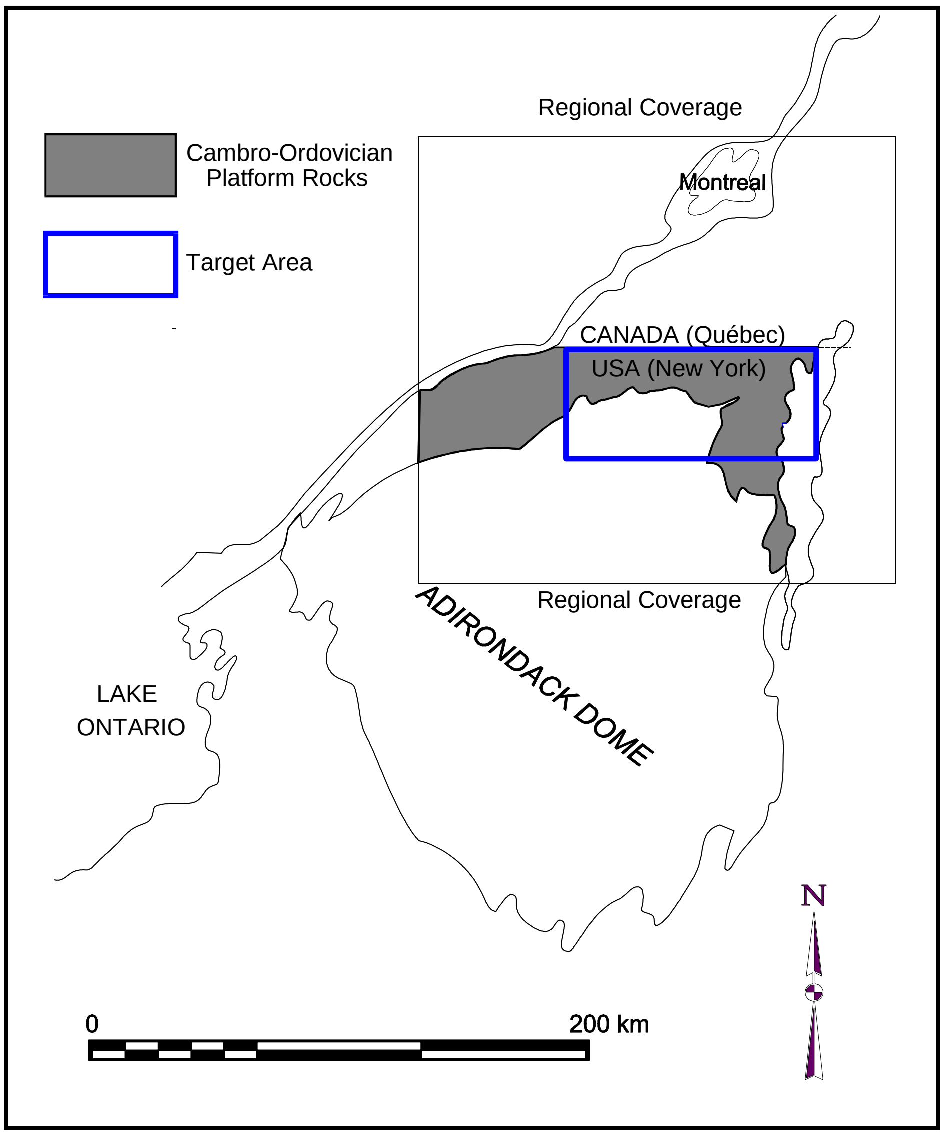


Figure 2-1 Location Map.

Chapter 3 REMOTELY SENSED AND REGIONAL GEOPHYSICAL DATA ACQUISITION

3.1 REMOTE SENSING AND GIS

3.1.1 Remotely Sensed Data

Remotely sensed (RADARSAT-1 and Landsat) and geoscientific (topography, geophysics, geology) data were integrated for both the region and the target zone, with the scale of the regional coverage at 1:250,000 (160 km EW x 200 km NS) and that for the target area at 1:100,000 (80 km EW x 45 km NS). Table 3-1 gives the characteristics of each data type. A preliminary geological interpretation was made from the integrated data for both the region and the target area, using both scales, with emphasis placed on identifying fault zones which may serve as potential gas conduits and traps.

RADARSAT-1 ScanSar Narrow (50 m resolution) and Landsat ETM data (15-30 m resolution) were chosen for the regional coverage of the surficial tectonic framework, and RADARSAT-1 Standard Mode data (25 m resolution) and Landsat ETM data were selected for the target zone because of their ability to enhance the detailed structural fabric (Table 3-1). A Landsat-7 scene, acquired on May 7, 2001, was used for both the regional coverage and the target zone. Scenes acquired in the spring or in the fall were favored because the lack of leaves in deciduous forests enables better penetration of the radar and a low sun angle provides an optimal shadow effect of the terrain. Moreover, spring data were expected to be more appropriate for agriculture areas where higher humidity in the soil may be associated with structural features.

3.1.2 Geophysical Data

Geophysical data available from the United States Geological Survey (USGS), the Geological Survey of Canada (GSC) and Géologie Quebec were compiled and integrated for both the region and the target zone (Table 3-1). For Quebec the data were recovered from the GSC database and were limited to two 1:250,000 map sheets, 31G and 31H. Gravity (Bouguer and second vertical derivative) and magnetic (total field and calculated vertical gradient) data, with respective pixel grid intervals of 2 km and 200 m, were selected (Table 3-1). For New York State, gravity (Bouguer and vertical gradient) and magnetic (total field and vertical gradient) data, all gridded at 1 km spacing, were integrated with the Canadian data.

3.1.3 Geological Data

Several geoscientific investigations were undertaken during the last 30 years within the Quebec portion of the study area and led to production of the following reports, all of which were ordered:

- Globensky, Y. *Géologie des Basses-Terres du St-Laurent*
- Lavoie, D; Bolduc, A; Castonguay, S; Malo, M; Ross, M; Salad Hersi, O; Séjourne, S; Tremblay, A; Lauzière, K; McIntosh, A. *The St. Lawrence Platform, Humber Zone, and Quaternary successions along Transect #1: Montréal-Appalachians*
- Rocher, M.;Tremblay, A.;Nadeau, L.;Lavoie, D. *Analyse structurale et tectonique de la plate-forme du Saint-Laurent (Quebec, Canada) : résultats préliminaires.*
- Castonguay, S; Dietrich, J R; Morin, C; Laliberté, J -Y. *Structural architecture of the St. Lawrence platform and Quebec Appalachians: insights from reprocessed (MNRQ) seismic reflection data;*
- Castonguay, S; Tremblay, D; Lavoie, D. *Geologic compilation map : Montréal-Mégantic, Appalachian section : Geological Bridges of eastern Canada transect 1.*
- Séjourné, S.; Dietrich,J. R. and M. Malo. *New interpretation of industry seismic lines, southern Quebec Appalachians foreland.*

A scanned file of the 1:250,000 scale geological map, produced by Globensky (1987), was ordered from Géologie Quebec for regional geological coverage of the Quebec portion of the study area. That was augmented by a search of the Internet for geotechnical data available for Quebec, which led to the recovery of 23,158 drill hole data points on the depth to rock, compiled by the "Association des Puisatiers du Quebec". Those data were integrated into the database and provided useful information for the geological analysis of the target area in Quebec where both outcrops and the surface expression of faults in bedrock are covered by Quaternary sediments and important agricultural activity. Earthquake data were extracted from the Canadian National Earthquake Data Base, on the Geological Survey of Canada website, and include epicenter locations, magnitudes and depths.

For New York State, the following were ordered:

- 1:250 000 scale geological map, Adirondack map sheet
- 1:250 000 scale Quaternary map, Adirondack map sheet
- Geological map of the Plattsburgh and Rouses Point, New York - Vt Quadrangles

- Stratigraphy and structure of Hoosick Falls
- Geological map of the Potsdam Quadrangle
- Geological map of the Santa Clara Quadrangle

3.1.4 Topographical Data

For Quebec, the following twelve 1:50,000 topographical raster map files were downloaded in GIF format from the Center for Topographic Information website: 31G01, 31G02, 31G07, 31G08, 31G09, 31G10, 31H03, 31H04, 31H05, 31H06, 31H11 and 31H12. Each sheet is delimited by 30 minutes of longitude and 15 minutes of latitude, and is characterized by 3200 pixels by 1600 lines, representing a grid cell of 0.00015625 degree.

Digital elevation contour data, at 10 m contour intervals, were ordered through the Banque de Données Topographiques du Quebec (BDTQ) to be used to generate a digital elevation model for the Quebec portion of the study area. Once created that digital elevation model was integrated with the elevation data for New York State, which were generated from 1:24,000 scale maps and were downloaded from the USGS website, to form a homogeneous digital elevation model, with a 10 m contour interval. Digital elevation data covering a small part of the study area within Vermont were also downloaded, although the contour interval for those data is 30 m. For both Quebec and New York State, a Digital Elevation Model (DEM) was also produced from 1:250,000 scale topographical maps. Those data are characterized by 3 arc-seconds grid spacing, in LAT/LONG coordinate system on a WGS 72 datum.

Different planimetric and hydrographic data for New York were recovered from the ESRI Data & Maps CD-ROMs, furnished with the ArcView 3.2 GIS software package, and include:

- Roads for New York State (NYRDS.shp): Shapefile provided by Geographic Data Technology Inc. The data are a modification of the Bureau of the Census TIGER/Line files. Largest scale 1:100,000.
- Rivers for New York State (NYRIVERS.shp): Shapefile provided by Geographic Data Technology Dynamap 2000 v.7.3 and are derived from the Bureau of the Census TIGER/Line files. Largest scale 1:35,000.
- Major Water bodies for the U.S.A. (MJWATER.shp): Shapefile provided by Geographic Data Technology Dynamap 2000 v.7.3. Largest scale 1:50,000.

Table 3-1 Characteristics of Input Data

DATA TYPE	PARAMETERS	CHARACTERISTICS
Remotely sensed data	• RADARSAT-1 ScanSAR Narrow (R)	• Regional coverage • 50m resolution • C-Band Frequency • HH Polarization • Ascending Orbit, looking ENE • Acquisition: September 4, 1999 • 20° - 40° Incidence angles
	• RADARSAT-1 Standard Mode S3 (R)	• Target zone • 25m resolution • Ascending Orbit, looking ENE • Acquisition : June 18, 2000 • 30° - 37° Incidence angles
	• RADARSAT-1 Standard Mode S3 (R)	• Target zone • 25m resolution • Descending Orbit, looking WNW • Acquisition : May 31, 2001 • 30° - 37° Incidence angles
	• RADARSAT-1 Standard Mode S6 (R)	• Target zone • 25m resolution • Ascending Orbit, looking ENE • Acquisition : October 8, 1999 • 41° - 46° Incidence angles
	• Landsat 7 ETM+ (R)	• Regional coverage and target zone • 30m resolution multispectral channels: • TM1: 0,45 – 52 • TM2: 0,52 – ,60 • TM3: 0,63 – 0,69 • TM4: 0,76 – 0,90 • TM5: 1,55 – 1,75 • TM7: 2,08 – 2,35 • 15m resolution panchromatic channel: • TM8: 0.52 – 0.90 • Path 14, Row 28 and 29 • Acquisition : May 7, 2001
Base map data	• Hydrography (V)	• Target zone • Line data • Source: 1:24,000 scale base maps • Streams course and water bodies • New York coverage
	• Planimetry (V)	• Target zone • Line data • Source: 1:24,000 scale base maps • Main roads and secondary roads • New York coverage

Table 3-1 Characteristics of Input Data (Continued)

DATA TYPE	PARAMETERS	CHARACTERISTICS
	• Elevation contours (V)	• Target zone • Source: 1:20,000 scale base maps • Total of 24 map sheets • Contour interval 10m • Quebec coverage
	• Digital Elevation Data (R)	• Target zone • 7.5 minutes base map coverage • Total of 56 maps • 10m grid spacing • New York coverage
	• Digital Elevation Data (R)	• Regional coverage • Source: 1:250,000 scale base maps • 3 arc seconds grid spacing
	• Topographical maps (R)	• Target zone • Total of 12 raster map sheets • Source: 1:50,000 base maps • 0.00015625 degree grid spacing • Quebec coverage
Geophysical data	• Bouguer anomaly (R)	• Regional coverage • 1000m grid spacing • New York coverage
	• Bouguer vertical gradient (R)	• Regional coverage • 1000m grid spacing • New York coverage
	• Bouguer anomaly (R)	• Regional coverage • 2000m grid spacing • Quebec coverage
	• Bouguer second derivative (R)	• Regional coverage • 2000m grid spacing • Quebec coverage
	• Total magnetic field (R)	• Regional coverage • 1000m grid spacing • New York coverage
	• Magnetic Vertical Gradient (R)	• Regional coverage • 1000m grid spacing • New York coverage
	• Total magnetic field (R)	• Regional coverage • 800m line spacing • 200m grid spacing • Quebec coverage
	• Magnetic Vertical Gradient (R)	• Regional coverage • 800m line spacing • 200m grid spacing • Quebec coverage

Table 3-1 Characteristics of Input Data (Continued)

DATA TYPE	PARAMETERS	CHARACTERISTICS
	• Geotechnical data (V)	• Regional coverage • Point data • Depth to the basement • Quebec coverage
Geological data	• Lithological contacts (V) • Faults (V) • Lithologic zones (V)	• Target zone • Line and polygon data • Dbase table of attributes linked to each type of data • New York coverage
	• Epicenters (V)	• Regional coverage • Point data • Seismic magnitude

(R) : *Raster data structure*

(V) : *Vector data structure*

3.2 DATABASE GENERATION

3.2.1 Raster Data

A raster database was first generated for both the region and the target zone. It involved geocoding and making a mosaic of the remotely sensed data, producing a Digital Elevation Model (DEM) file and converting the geophysical data into a format compatible with the remotely sensed data. Those geophysical data were then integrated with the remotely sensed data to improve the geological interpretation. The map projection used for the database is UTM, zone 18, NAD 83 (Table 3-2).

3.2.1.1 Topographical Data

DEM files at a scale of 1:250,000 were downloaded from the USGS in Lat-Long coordinates and converted into a UTM map projection, with a pixel size of 50 m. Those USGS digital elevation data (from 56 x 1:24,000 scale map sheets) were received in SDTS format for both New York (10 m) and Vermont data (30 m), and were converted to PCIDISK format. Following the conversion the data were integrated into a complete DEM mosaic, to which smoothing filters were applied to reduce the edge effect generated as a consequence of making the mosaic.

TABLE 3-2 ArcView Database

DATA	TYPE	STRUCTURE	ATTRIBUTES (IF APPLICABLE)
Frame	Territory	Vector : polyline	
RADARSAT-1 ScanSAR Narrow	Remotely Sensed	Raster	
RADARSAT-1 S3 Ascending	Remotely Sensed	Raster	
RADARSAT-1 S6 Ascending	Remotely Sensed	Raster	
RADARSAT-1 S3 Descending	Remotely Sensed	Raster	
Landsat 7 ETM+ colour comp.	Remotely Sensed	Raster	
Landsat 7 ETM+ panchromatic	Remotely Sensed	Raster	
Hydrography	Base Map	Vector : polyline	
Roads	Base Map	Vector : polyline	
Scanned topographical maps 50K	Base Map	Raster	
Shaded Relief of topography (regional coverage, 2 illum.)	Base Map	Raster	
Shaded Relief of topography (target zone, 4 illum.)	Base Map	Raster	
Bouguer anomaly	Geophysics	Raster	
Bouguer vertical gradient for NY	Geophysics	Raster	
Bouguer 2nd derivative for Que	Geophysics	Raster	
Total magnetic field	Geophysics	Raster	
Magnetic vertical gradient	Geophysics	Raster	
RADARSAT ScanSAR + magnetic vertical gradient	Geophysics	Raster	
DEM-250K + magnetic vertical gradient	Geophysics	Raster	
DEM-250K + magnetic total field	Geophysics	Raster	
Landsat panchromatic + magnetic vertical gradient	Geophysics	Raster	
DEM-20K +magnetic vertical gradient	Geophysics	Raster	
Scanned geology map (Globensky)	Geology	Raster	
Lithological polygons	Geology	Vector : polygon	Polygon Id Lithologic code Lithologic description
Lithological contacts	Geology	Vector : polyline	Line Id Contact description
Faults	Geology	Vector : polyline	Line Id Orientation Fault description
Lineaments	Geology	Vector : polyline	Line Id Orientation
Depth to basement in Quebec	Geology	Vector : point	Date Depth
Epicenters	Geology	Vector : point	Date Depth Magnitude

Elevation and contour data received from the Quebec government were converted from the ArcInfo Export format E00 to the ArcView shape file format, all in UTM map projection. Twelve 1:50,000 scale raster topographical files for Quebec were combined into a mosaic, which was then converted (GIF-8 bits to TIFF-24 bits) into a UTM map projection, with a pixel size of 15 m. The Quebec digital elevation data, from twenty-four 1:20,000 scale map sheets, were then integrated with the data for New York and Vermont. In order to generate a continuous model between the US and Canada, elevation values were extracted from the US elevation raster data within the overlapping border and combined with the elevation contours of the Canadian coverage. The DEM for Quebec was produced from vector files, and was combined with the elevation raster file for the US part in order to produce a final DEM mosaic of the total target area.

Shaded relief images of DEM data for both the regional area and the target zone were generated to enhance the topographical images of the structural fabric. North and east viewing directions were used for the regional coverage, and north, northeast, east, and southeast viewing directions were used for the target zone (Figures 3-1 and 3-2). The resultant shaded relief images were then superimposed onto the magnetic maps to show correlations between surface and subsurface lineaments.

3.2.1.2 Remotely Sensed Data

The four RADARSAT-1 images were read, which enabled recovering the ephemeris data required to produce orthoimages. A Lee filter was first applied on each scene with a convolution window of 3 x 3, then ground control points were collected on 1:24,000 scale hydrographic vectors for the US part and on 1:50,000 scanned topographic maps for Quebec. The 1:250,000 scale DEM coverage was used to attribute an elevation to each ground control point (GCP), for use in the generation of the orthoimages. Table 3-3 gives the residuals obtained for the geocoding of each RADARSAT image. Final re-sampling was applied at a pixel spacing of 20 m for the Standard Mode data and at 50 m spacing for the ScanSar data.

The Quebec digital elevation data were merged with the US data to produce a continuous DEM for both the regional coverage at 50 m grid spacing and the target area at 10 m grid spacing. Shaded relief images were then generated to enhance the structural fabric. Two perpendicular viewing angles (from the north and from the east) were used for the regional data, and four viewing angles were used for the target zone (north, northeast, east, southeast) (Figures 3-1 and 3-2). Shaded relief images were ultimately superimposed onto the magnetic data to show correlations between surface topographical discontinuities and deep geophysical discontinuities.

Geocoded images were generated for each RADARSAT-1 scene and the Landsat 7 data and ground control points were collected from available 1:24,000 and 1:50,000 scale base maps. DEM data were used for the orthorectification, with the final re-sampling applied at a pixel spacing of 15 m, whereas pixel spacings of 30, 20 and 50 m were applied to the Landsat, RADARSAT Standard Mode data and RADARSAT ScanSar data sets, respectively. An adaptive contrast stretch was applied to each RADARSAT orthoimage (Figure 3-3). A panchromatic enhanced image was generated through the application of a sharpening filter and contrast stretch, and a Landsat color composite of the multispectral channel was also produced. Contrast stretch was applied to channels TM 3, 4 and 5, and integration was achieved with the enhanced panchromatic channel, using the IHS-RGB color space transformation technique. Following the respective conversions from total field and Bouguer gravity anomalies into the common UTM map projections the magnetic and gravity data from New York were combined with those from Quebec, using standard image mosaicking techniques. Data were also re-sampled to accommodate the grid spacing of the Quebec data. The New York magnetic data were re-sampled from 100 m at 200 m grid spacing to fit the Canadian data, whereas the Canadian gravity data, produced at 2 km grid spacing, were re-sampled at 1 km spacing to accommodate the US data.

RADARSAT-1 ScanSar, Landsat panchromatic and shaded relief images were combined with the magnetic data, in order to see what correlations, if any, exist between surface and sub-surface lineaments. This operation consisted of overlaying the color of the geophysical parameter across the intensity of the surface parameter. The final product shows the arrangement of geophysical anomalies with a structural background provided by remotely sensed data or shaded topography.

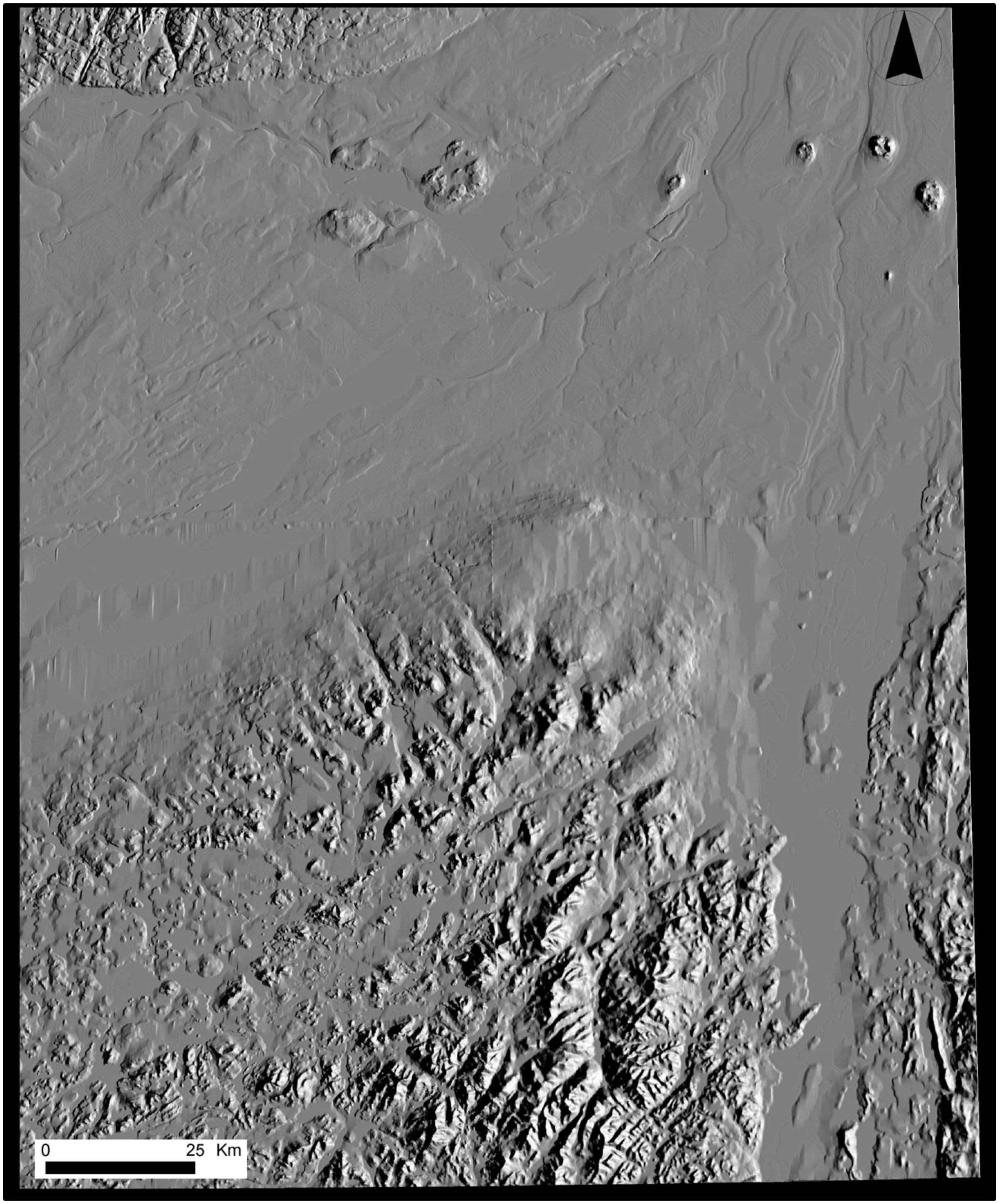


Figure 3-1 Shaded relief of the topography. Regional coverage. Illumination from East

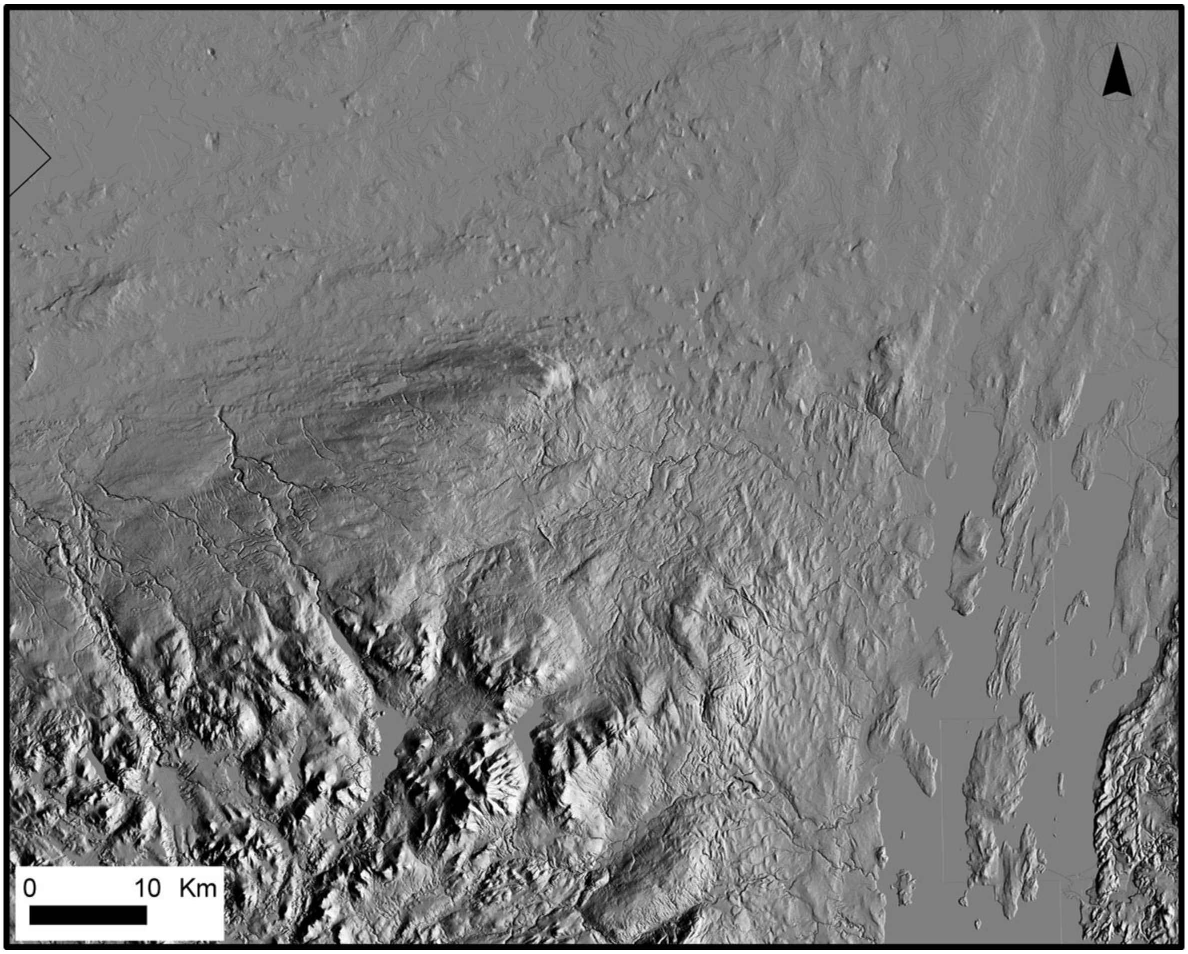


Figure 3-2 Shaded relief of Topography. Target zone. Illumination From the East.

TABLE 3-3 Residuals for RADARSAT Data Geocoding

RADARSAT BEAM	ORBIT	ACQUISITION DATE	GCPS COLLECTED	RESAMPLING	PIXEL SIZE	RMS X	RMS Y	RMS MEAN
Narrow ScanSAR A	Ascending	Sept. 4, 1999	22	Cubic, ortho	50m	26.05m	19.26m	32.40m
Standard Beam S3	Ascending	June 18, 2000	20	Cubic, ortho	20m	15.17m	19.20m	24.47m
Standard Beam S6	Ascending	Oct. 8, 1999	26	Cubic, ortho	20m	17.81m	17.42m	24.91m
Standard Beam S3	Descending	May 31, 2001	19	Cubic, ortho	20m	10.80m	16.37m	19.61m

An adaptive contrast stretch was applied to each RADARSAT orthoimage. Figure 3-3 shows an example of the enhanced ScanSar image. In order to create a stereo image of both S3 and S6 ascending images, a flat DEM was generated covering the target area at an elevation of 150 m, which is the mean elevation in meters. This type of model is required to preserve the parallax while producing the pseudo-orthoimages. GCP's elevation for both images was also set to the same elevation value and new orthorectifications were made using this DEM. Contrast stretch was then applied and an anaglyph was generated for the S3-S6 stereo pair.

The Landsat ETM data were geocoded using ground control points collected from 1:50,000 scale raster topographical data for the Canadian part, and from the hydrographic and planimetric vector data for the US part of the study area. The GCP were collected in UTM-18, NAD 83 map projection. The residuals obtained are shown on Table 3-4 below. Unfortunately, Landsat orthoimages could not be generated, given that ephemeris data were corrupted within the original files. Final registration was achieved through the use of an affine transformation and cubic convolution interpolation. The resampling was performed at 15 m for the panchromatic channel and at 30 m for the multispectral channels.

TABLE 3-4 Residuals for Landsat 7 Data Geocoding

IMAGE	ACQUISITION DATE	GCP COLLECTED	RESAMPLING	RMS X	RMS Y	RMS MEAN
Landsat 7 1428	2001/05/07	20	Cubic, first order	8.1 m	14.4 m	16.8 m
Landsat 7 1429	2001/05/07	49	Cubic, first order	16.2 m	15.6 m	22.5 m

Two Landsat enhanced products were generated. First, a panchromatic enhanced image was produced through the application of a sharpening filter and contrast stretch, followed by creation of a Landsat color composite of the multispectral channel. Contrast stretch was applied to the channels TM 3, 4 and 5, and was merged with the enhanced panchromatic channel, using the IHS-RGB color space transformation technique. Figure 3-4 shows the results of the enhanced Landsat color product.

3.2.1.3 Geophysical Data

The magnetic data for Quebec (from map sheets 31G and 31H; scale 1:250,000) were converted from the GXF ASCII Geosoft format to the PCIDISK format, at 200 m grid spacing in UTM map projection. Two separate files were generated, one for the total magnetic field and the other for the calculated vertical gradient.

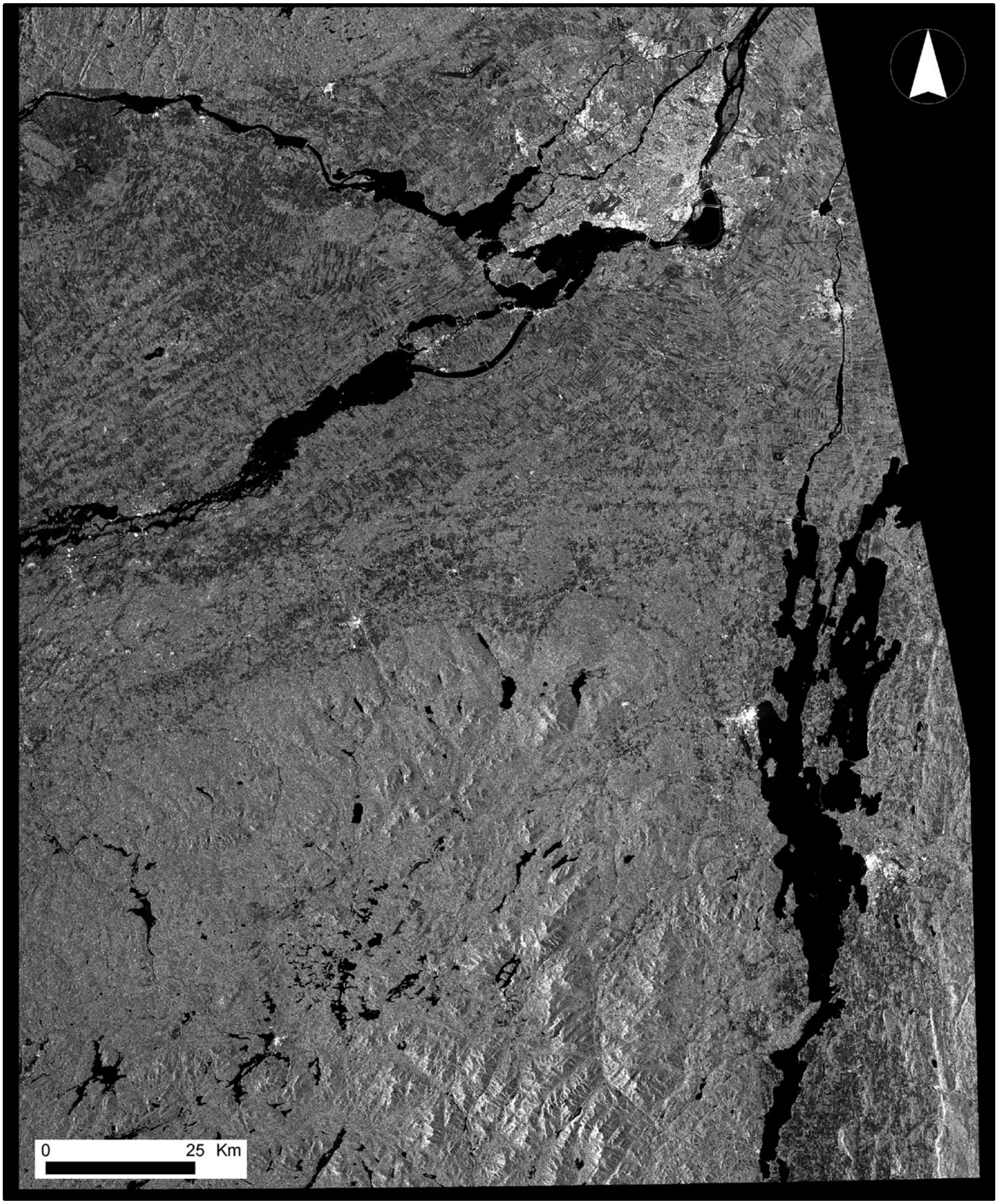


Figure 3-3 RADARSAT ScanSar Enhanced Image. Regional Coverage.

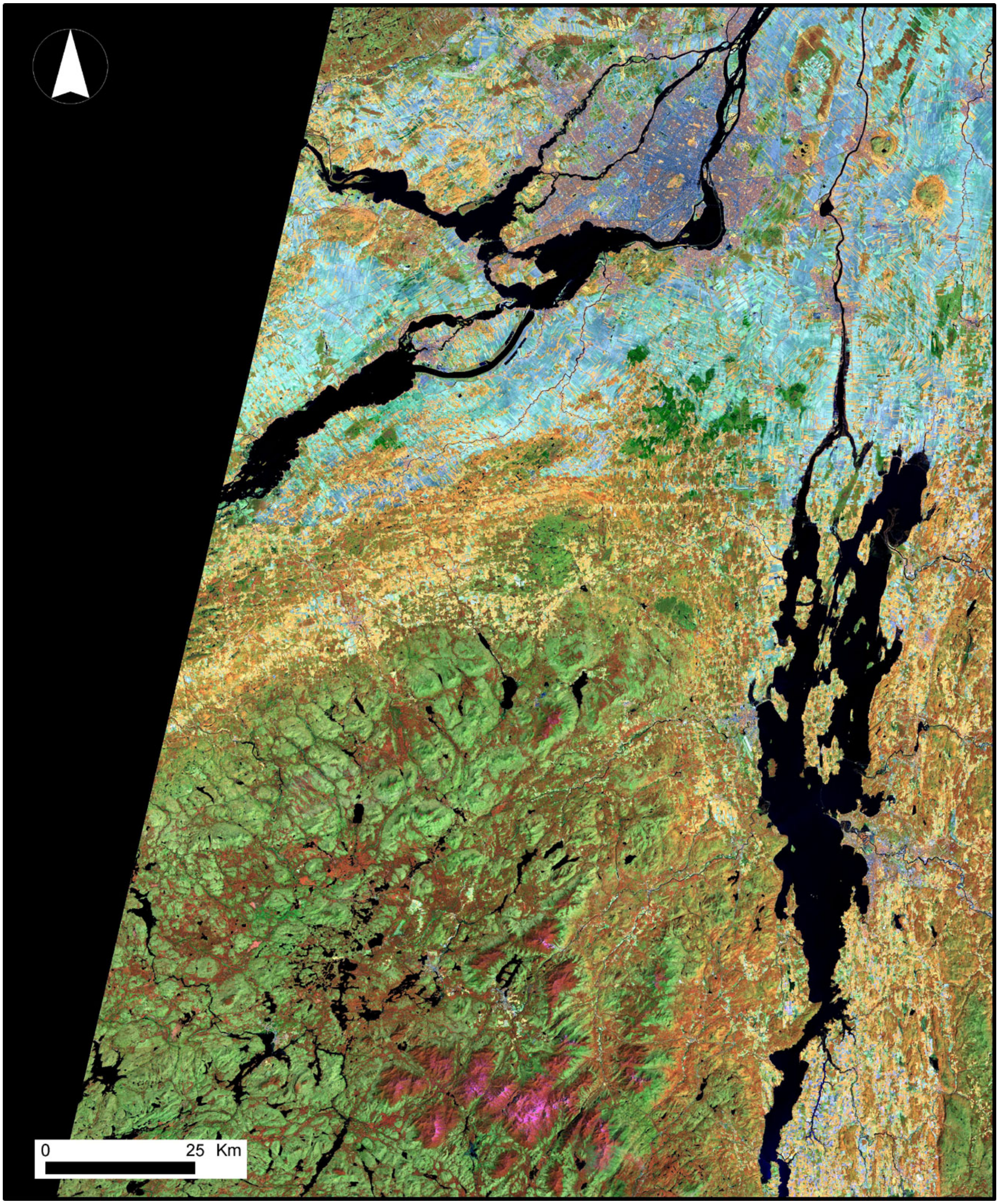


Figure 3-4 Color Composite of Landsat Channels TM3, 4 and 5 and the Panchromatic Channel. Regional coverage.

The geophysical data for New York State were integrated into the ArcView database. Two basic parameters, the total magnetic field and the Bouguer anomaly, were first converted into the common UTM map projection. Data were also re-sampled to accommodate the grid spacing of the Quebec data. The US magnetic data were re-sampled at 200 m grid spacing to fit the Canadian data and the Canadian gravity data, produced at 2 km grid spacing, were re-sampled to 1 km spacing to accommodate the US data. All were then combined, using standard image mosaicking techniques. Values within the overlapping regions of the two surveys were analyzed in order to calibrate the Canadian survey with the US survey. The magnetic vertical gradient was finally calculated from the total magnetic field.

Magnetic data were superimposed onto the remotely sensed and topographical data. RADARSAT-1 ScanSar, Landsat panchromatic and shaded relief images were then combined with the magnetic data in order to correlate topographical lineaments with sub-surface, magnetic lineaments. This operation consisted of overlaying the color of the geophysical parameter across the intensity of the surface parameter. The final product shows the arrangement of geophysical anomalies with a structural background provided by remotely sensed data or shaded topography (Figures 3-5 and 3-6).

3.2.1.4 Geological Data

For Quebec, the scanned geologic map of Globensky (1987) was geocoded, and reprojected onto the common map projection and datum used for the project, UTM 18 NAD 83. It was integrated into the ArcView database as a raster geologic information layer.

3.2.2 Vector Data

3.2.2.1 Cartographic Data

For New York State, the hydrographic (water course and water bodies) and planimetric data (main and secondary roads) of all the 1:24,000 scale map sheets were converted into the ArcView shapefile format. Following that conversion the data were merged into a single vector file for the entire target area.

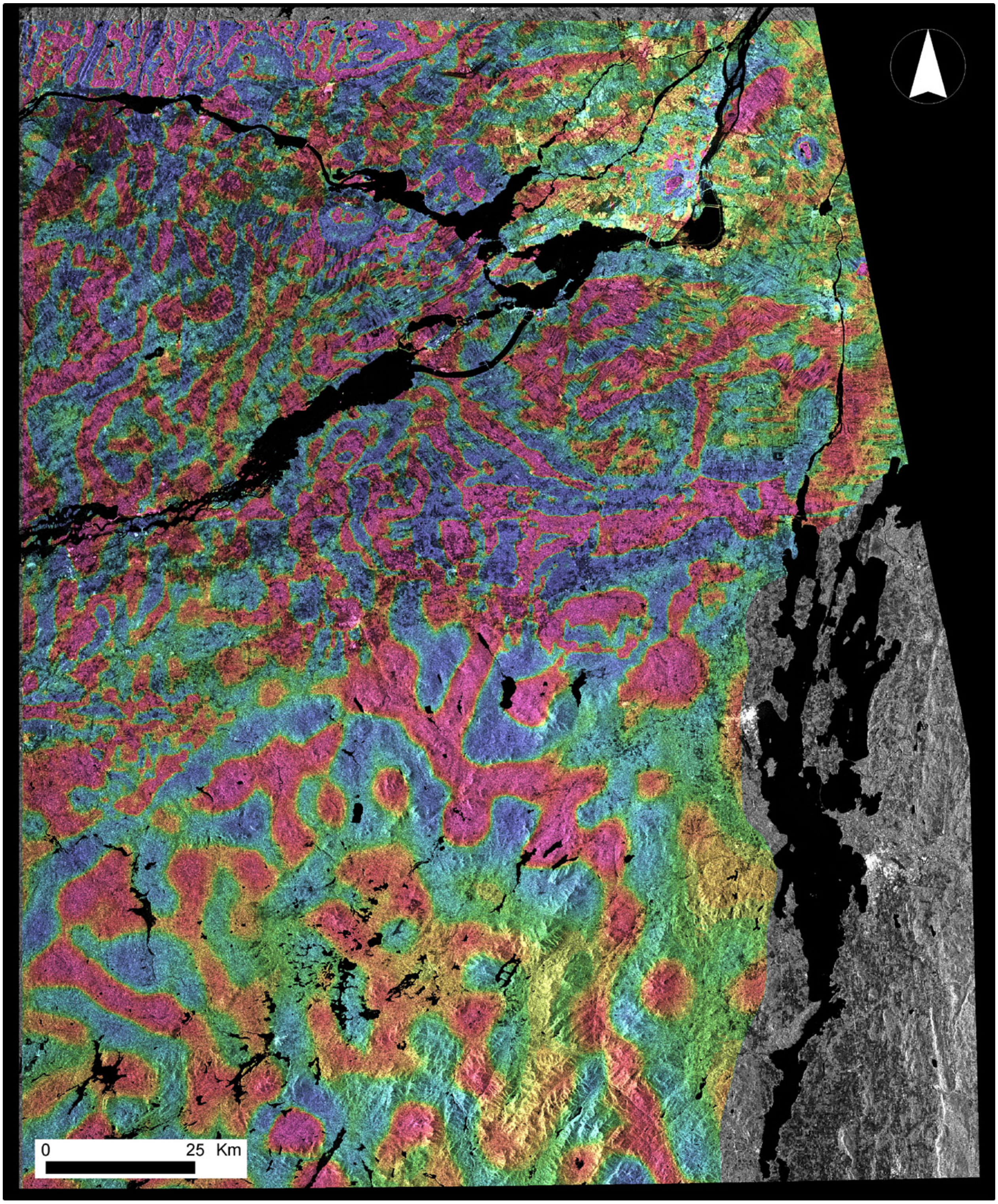


Figure 3-5 **Map Showing Integrated RADARSAT ScanSar and Magnetic Vertical Gradient.**

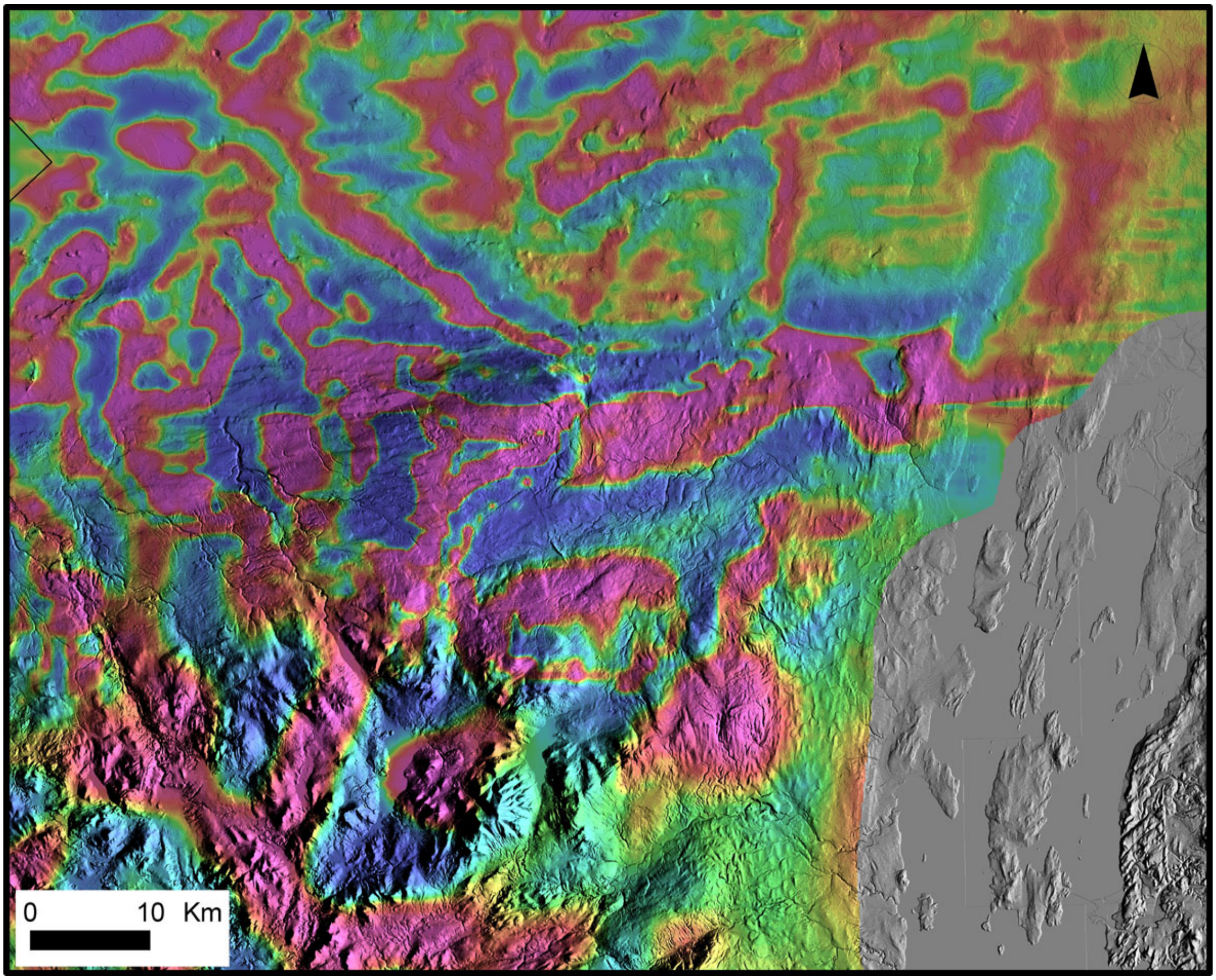


FIGURE 3-6 Map Showing Integrated Topographic Relief and Magnetic Vertical Gradient in the Target zone.

3.2.2.2 Geological Data

For New York State, vector layers were produced for lithologies and faults. Data from the New York State Geological Survey were converted into ArcView format, then were re-projected into the common Universal Transverse Mercator (UTM) map coordinates, and a preliminary geologic legend was produced for the different stratigraphic units mapped in the target zone. Attributes concerning the age, stratigraphy and general geologic descriptions were attached to the existing lithological codes. Interrogation of each lithological polygon within the target area then permitted retrieving all information on the specific lithologies, including related formation and group names and ages. For Quebec, faults and folds were digitized from the scanned geological map of Globensky

(1987) and then were used to validate the regional lineaments interpreted from remotely sensed data.

The earthquake epicentral locations were reformatted through the use of a word processor and database software in order to make them compatible with ArcView. Latitudes and longitudes were converted from geographical coordinates to UTM coordinates and the interpreted lineaments were extracted from the 1:250,000 scale Landsat-7, RADARSAT ScanSar and shaded relief images and digitized. Digital information was categorized as: (1) regional lineaments, (2) bedding or foliation, (3) fractures and the data were integrated into the ArcView database.

Chapter 4 ANALYSIS OF REMOTELY SENSED AND REGIONAL GEOPHYSICAL DATA

4.1 TOPOGRAPHICAL LINEAMENTS

RADARSAT-1 and Landsat data, along with existing topographical, geological and geophysical information, were employed to identify fault zones, whether expressed as topographical, geological or geophysical lineaments, in order to identify potential gas traps and to compare the results with previously mapped or interpreted faults. For the region the lineament analysis required the use of 1:250,000 scale prints of remotely sensed and shaded relief images of the topography whereas, for the target zone, 1:100,000 scale topographic imagery was applied (Figure 4-1). Overall linear and curvilinear features, related to ductile and brittle deformation in both the region and the target zone, were extracted and classified into the following three categories (Figures 4-1 and 4-2):

- *First order lineaments* – Faults or lithologic contacts
- *Second order lineaments* – Bedding or foliation
- *Third order lineaments* - Fractures

4.1.1 First Order Lineaments – Faults or Lithologic Contacts

First order or regional lineaments (Figure 4-1) correspond to topographic discontinuities associated with scarps or hydrographic patterns and correlate with the main fracture trends which may have formed during the Grenvillian orogeny. They commonly have a strong topographic expression within the basement rocks of the Adirondacks and are principally oriented north-south, north-northeast, east-northeast, east-west and southeast (Figures 4-1 and 4-2). In the target zone west-northwest and north-northwest fractures appear to be more prominent, whereas the north-south, east-west and southeast fractures diminish somewhat in number. The actual topographic expression of most of the lineaments probably reflects at least one period of reactivation along earlier formed fault zones developed within the basement.

The east-northeast oriented lineaments are very prominent and parallel the tectonic fabric in the exposed Precambrian basement, and extend into the St. Lawrence Lowlands of southern Quebec. In the lowlands they are more subtly expressed and are interpreted to have formed by the upward propagation of fractures and faults from the underlying basement. East-west trending lineaments are associated with the elongate, fault-bounded Covey Hill, (see Chapter 5) and are also present within the St. Lawrence Lowlands. In the latter location they coexist with members of the north-south set, which are also dominant within the Paleozoic rocks along Lake Champlain. North-northwest striking lineaments, albeit not the most abundant, occur predominantly within the Adirondacks though they, too, extend into the St. Lawrence Lowlands. Some members of that set are strongly suspected of being major faults, particularly those in the northwestern corner of the project area (Figure 4-1, north of 44°45'N and west of 74°W).

4.1.2 Second Order Lineaments – Bedding or Foliation

Second order lineaments are signatures of relatively short features that are interpreted as expressions of bedding or foliation (Figure 4-1). In the metamorphosed Precambrian basement of the Adirondacks and in the Paleozoic rocks underlying the St. Lawrence Lowlands of southern Quebec, they have an east-northeast trend. Along Lake Champlain and in adjacent southern Quebec north-south to north-northeast-trends, commonly associated with the Appalachian structural fabric, prevail. An east-west set, present in the platform rocks just north of the Adirondacks and near the New York-Quebec border, may be an expression of either slightly tilted rock layers or terrace boundaries. Besides the linear second-order lineaments, sub-circular features were identified and are inferred to be associated with the emplacement of intrusive igneous massifs.

4.1.3 Third Order Lineaments – Fractures

Third order lineaments (Figure 4-1), present throughout the entire study area, are related to small linear topographic discontinuities, such as ridges or streams, and have the same trend as first order, or regionally extensive, lineaments (Figure 4-2). They are commonly short and are interpreted as fractures or small faults with minor displacements resulting from different deformation episodes. Members of the east-northeast set are dominant in the Adirondacks. Northwest and northeast sets are also present in the Adirondacks, but appear in the St. Lawrence Lowlands as well, whereas the north-south and east-west sets seem to be more abundant within the St. Lawrence Lowlands.

4.2 MAGNETIC DISCONTINUITIES AND SEISMIC ACTIVITY

Magnetic data (Figures 4-3 and 4-4) show complex anomalies, most of which represent contrasts in basement lithology. At the New York - Quebec border there is a sub-circular anomaly, nearly 100 km in diameter, which is comprised of alternating high and low magnetic susceptibilities, and resembles mafic to ultramafic layered complexes (Figure 4-3). The core of the anomaly probably represents a leucocratic massif, such as an anorthosite, rimmed by magnetite. Magnetic lineaments within and bounding that anomaly (Figure 4-4) are parallel to topographical lineaments suggesting the upward propagation of faults. North-south and east-west magnetic discontinuities in the exposed and subsurface Precambrian basement are also suspected of being faults, some of which appear to be currently active because of the alignment of earthquake epicenters along, or parallel to, a few which are oriented northeast and northwest.

4.3 RELATIONSHIP TO PREVIOUSLY MAPPED FAULTS

Topographical lineaments correlate with many previously mapped faults, including those oriented northeast and northwest in the Adirondacks and others which trend north-northeast to north-south along Lake Champlain (Figure 4-5). Those along Lake Champlain seem to define two distinct sets instead of continuous structures, as previously interpreted, and in Quebec they are parallel to major Appalachian structural trends. In addition east-northeast and northwest oriented lineaments in the Lake Champlain area appear to be continuations of mapped faults. North-northeast-trending lineaments in the exposed Precambrian basement do not correlate with known faults, though they, themselves, may also be faults. In the western part of the area, there are prominent and parallel north-northwest striking lineaments which continue from the exposed basement into the Paleozoic cover rocks (Figure 4-1, north of 44°45'N and west of 74°W). Though no independent geological evidence was uncovered, due to lack of exposure, they are suspected of being faults that experienced at least one period of tectonic rejuvenation subsequent to Cambro-Ordovician sedimentation. East-northeast and west-northwest oriented lineaments are interpreted as incipient conjugate strike-slip faults, with the latter presumably related to the Ottawa-Bonnechère graben. North of the target zone lineaments, which strike north-south, parallel the similarly oriented portion of the curvilinear Havelock fault zone (Figure 4-5). Near Montreal east-west and northwest oriented lineaments appear to correspond to mapped faults and south of Montreal the northwest striking Delson fault zone is spatially related to a parallel magnetic discontinuity in the underlying basement.

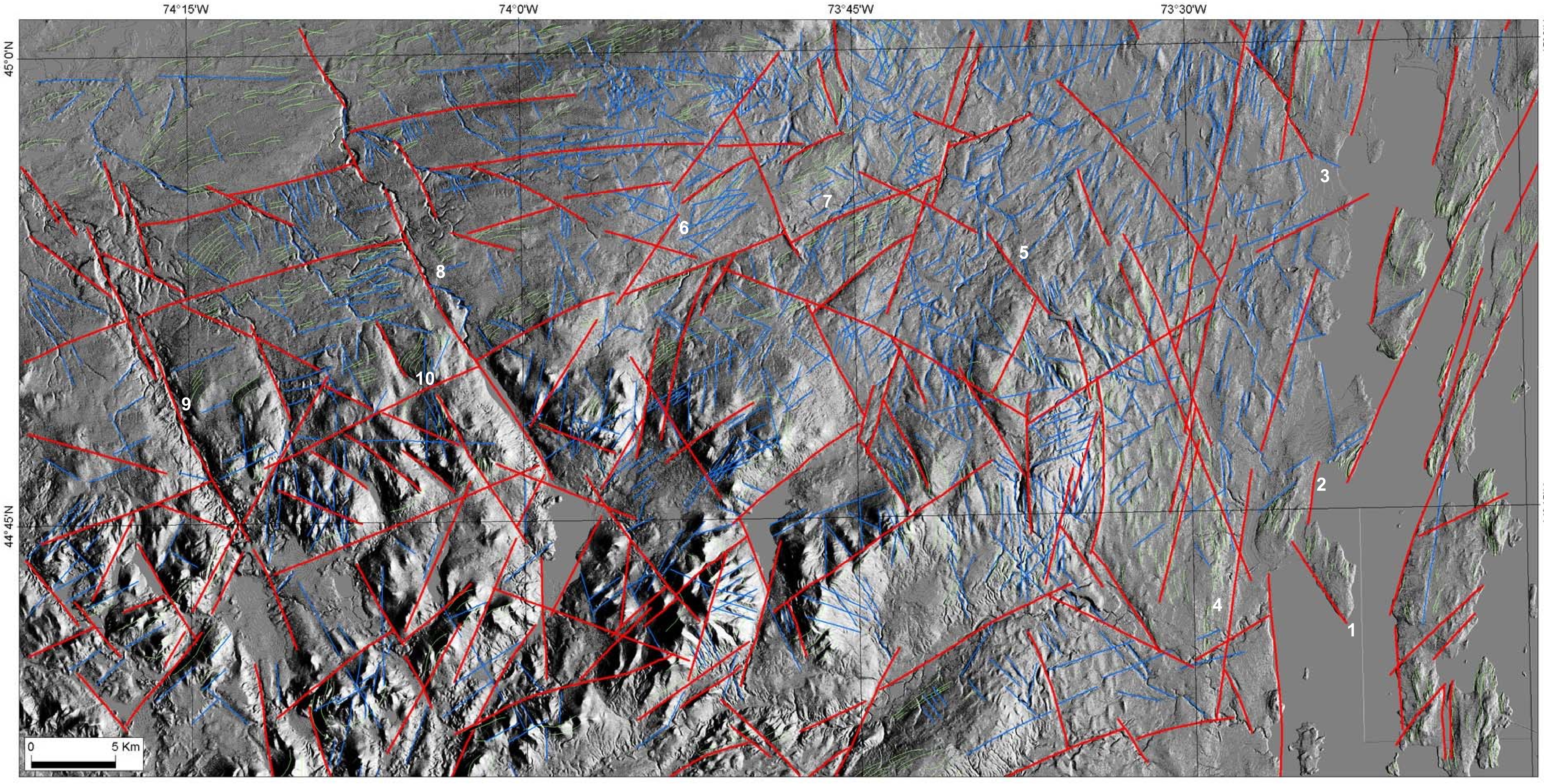
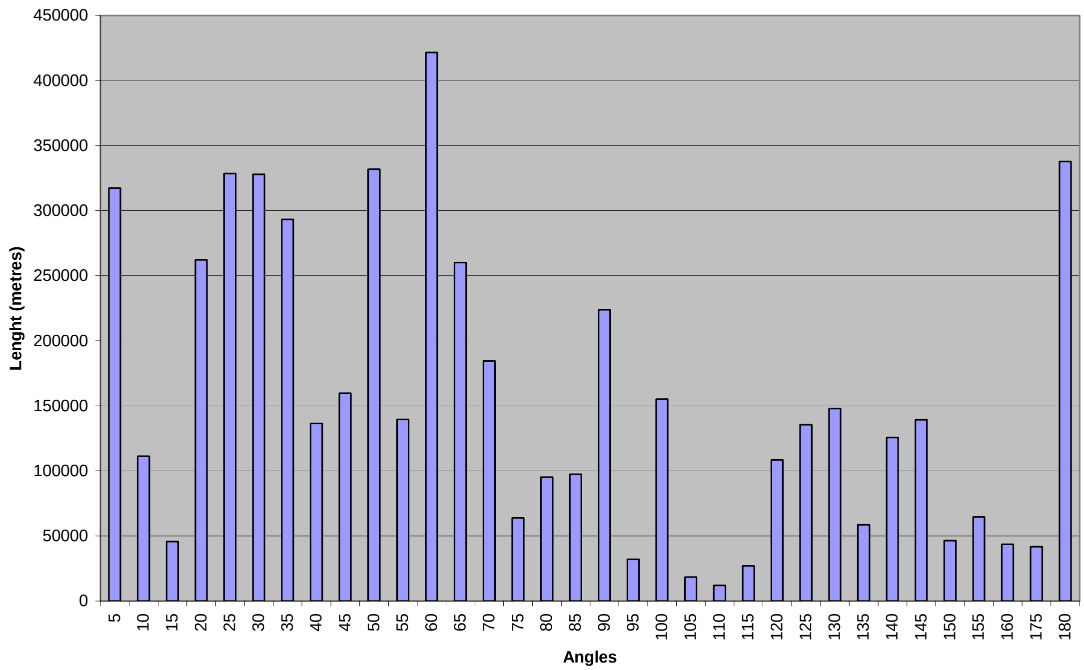


Figure 4-1 **Map of Different Scale Lineaments in the Target Zone. Red - Regional Discontinuities, Green - Bedding or Foliation, Blue - Fractures. White Numbers Signify Examples of Lineaments That Correspond to Faults in Figure 5-1.**

Discontinuities



Fractures

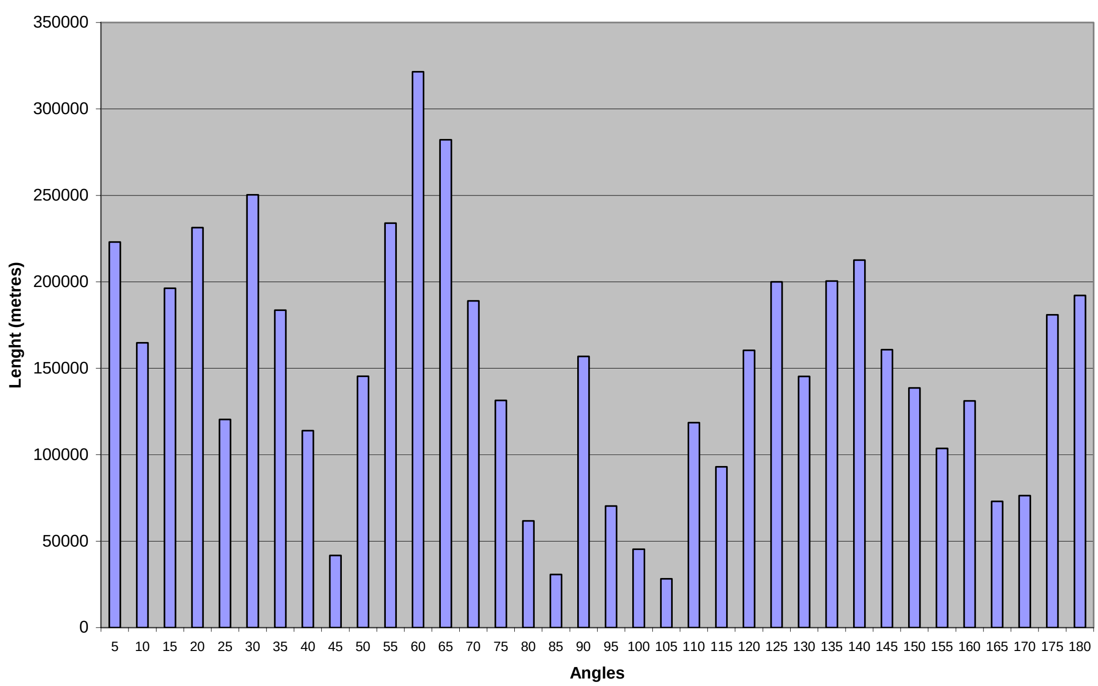
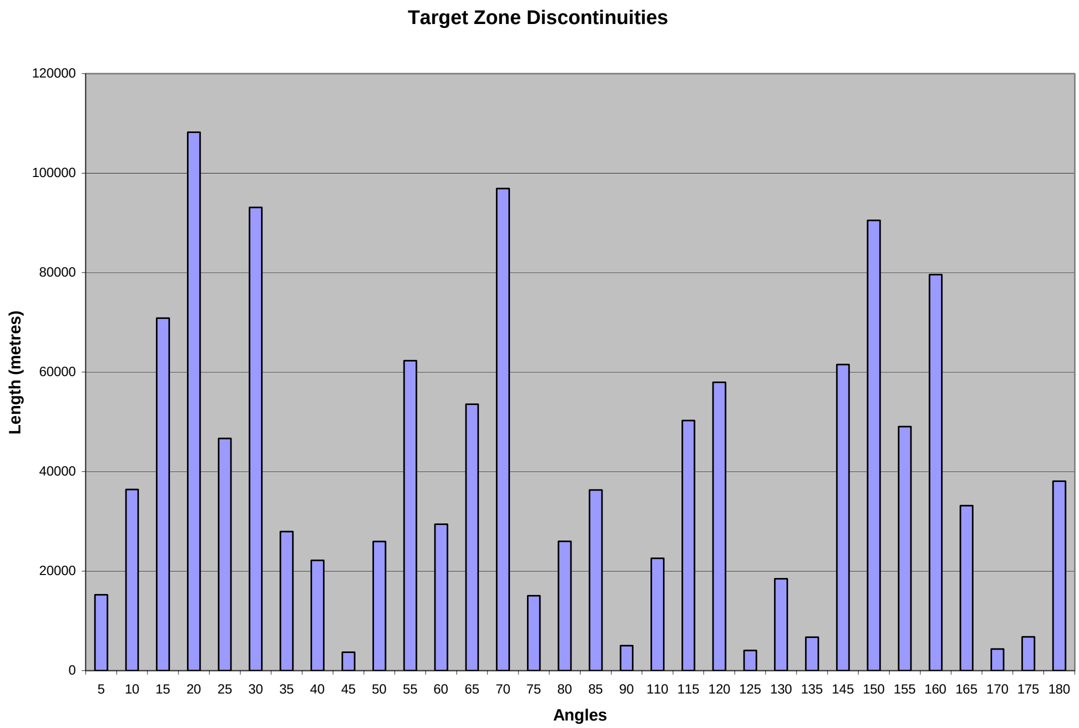


Figure 4-2a Histograms of Regional Lineament Orientations.



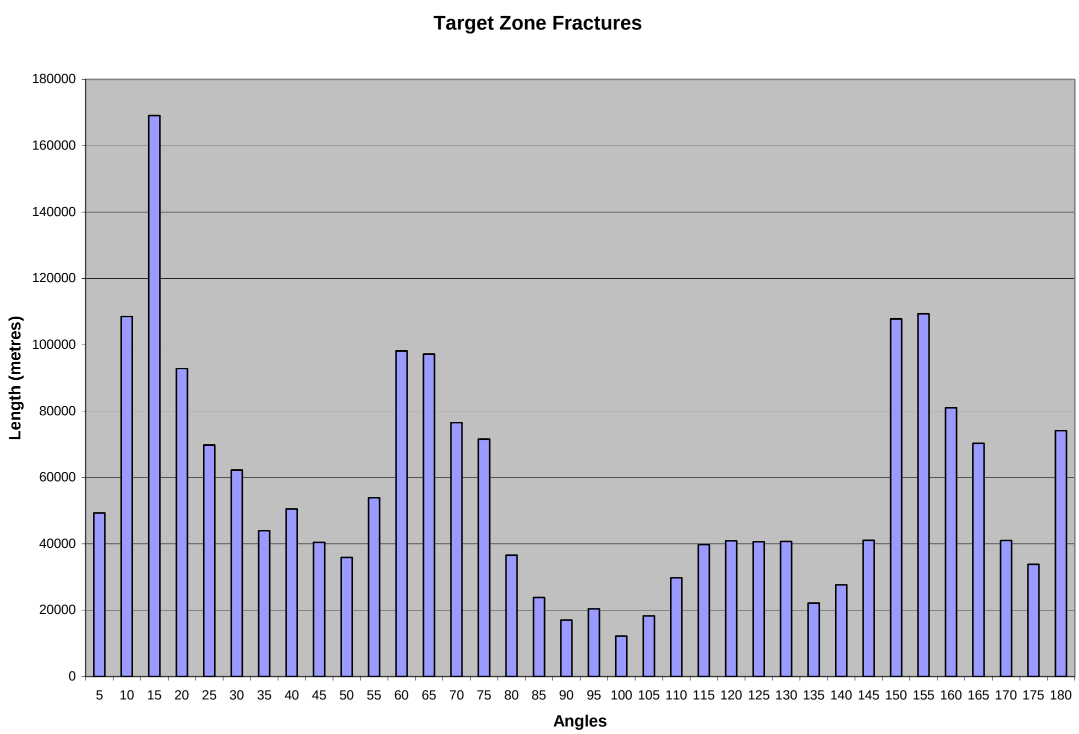


Figure 4-2b Histograms of Lineament Orientations in the Target Zone.

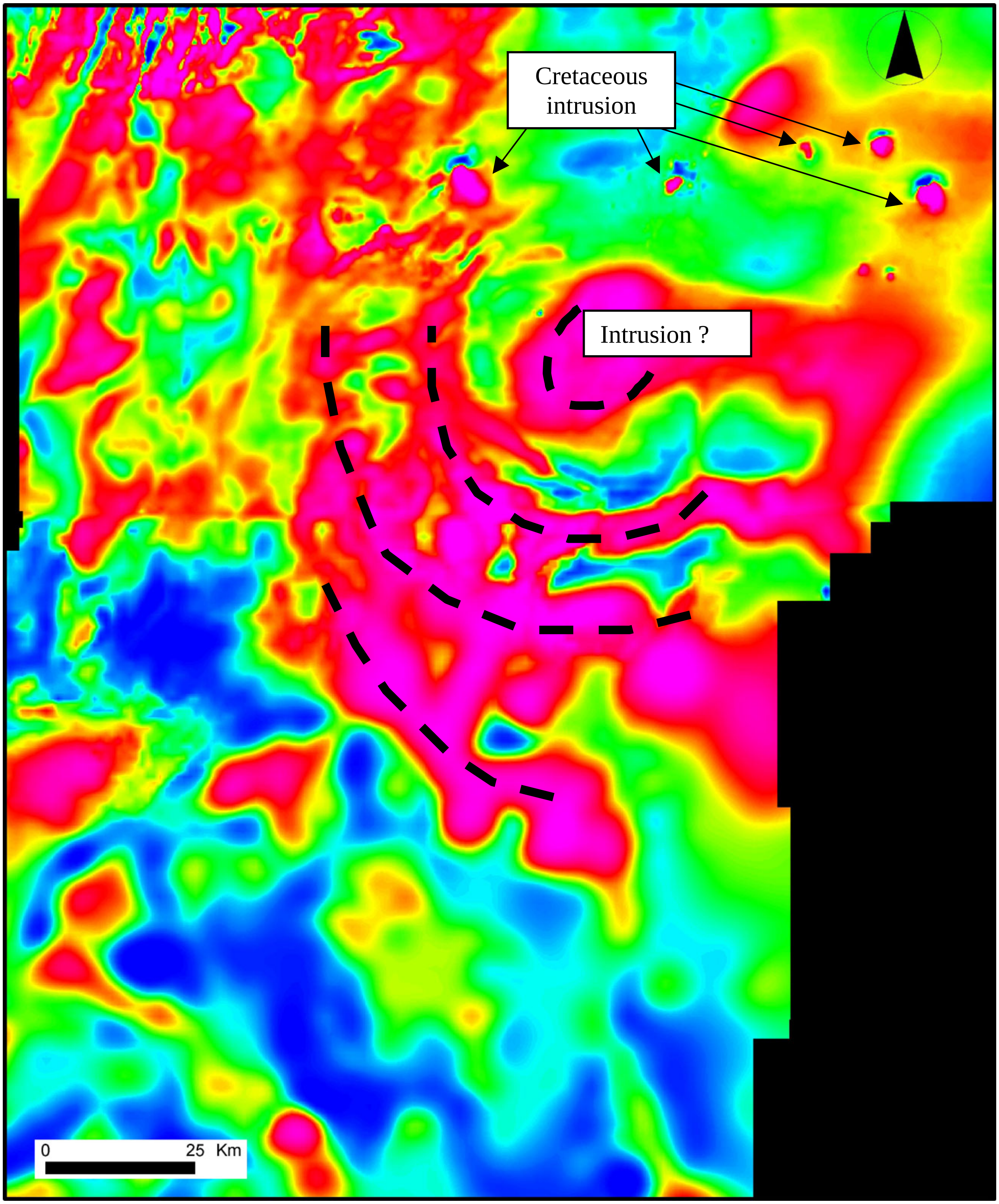


Figure 4-3 Total-Field Magnetic Map. Regional Coverage.

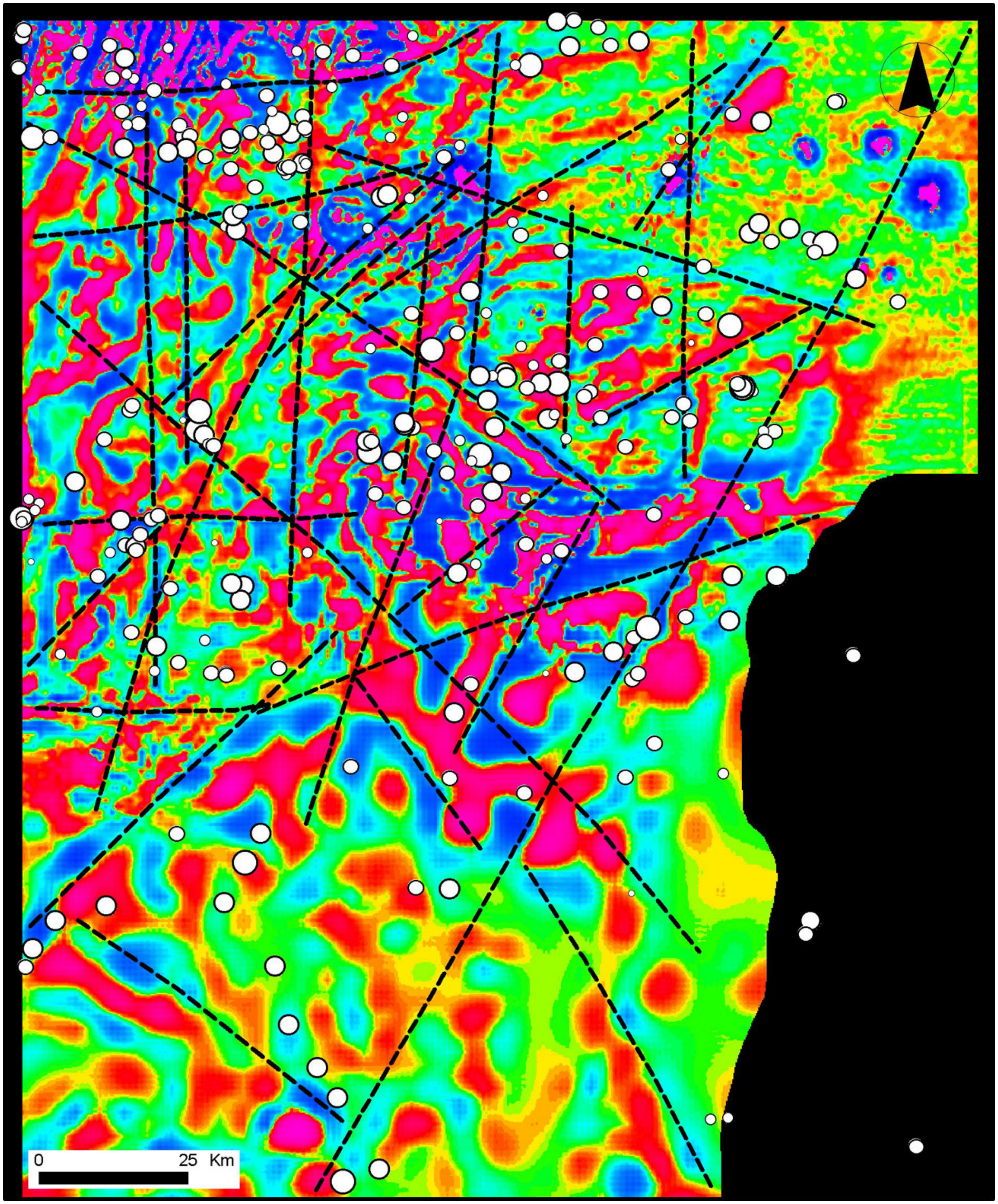


Figure 4-4 Magnetic Vertical Gradient with Superimposed Earthquake Epicenters. Regional Coverage.

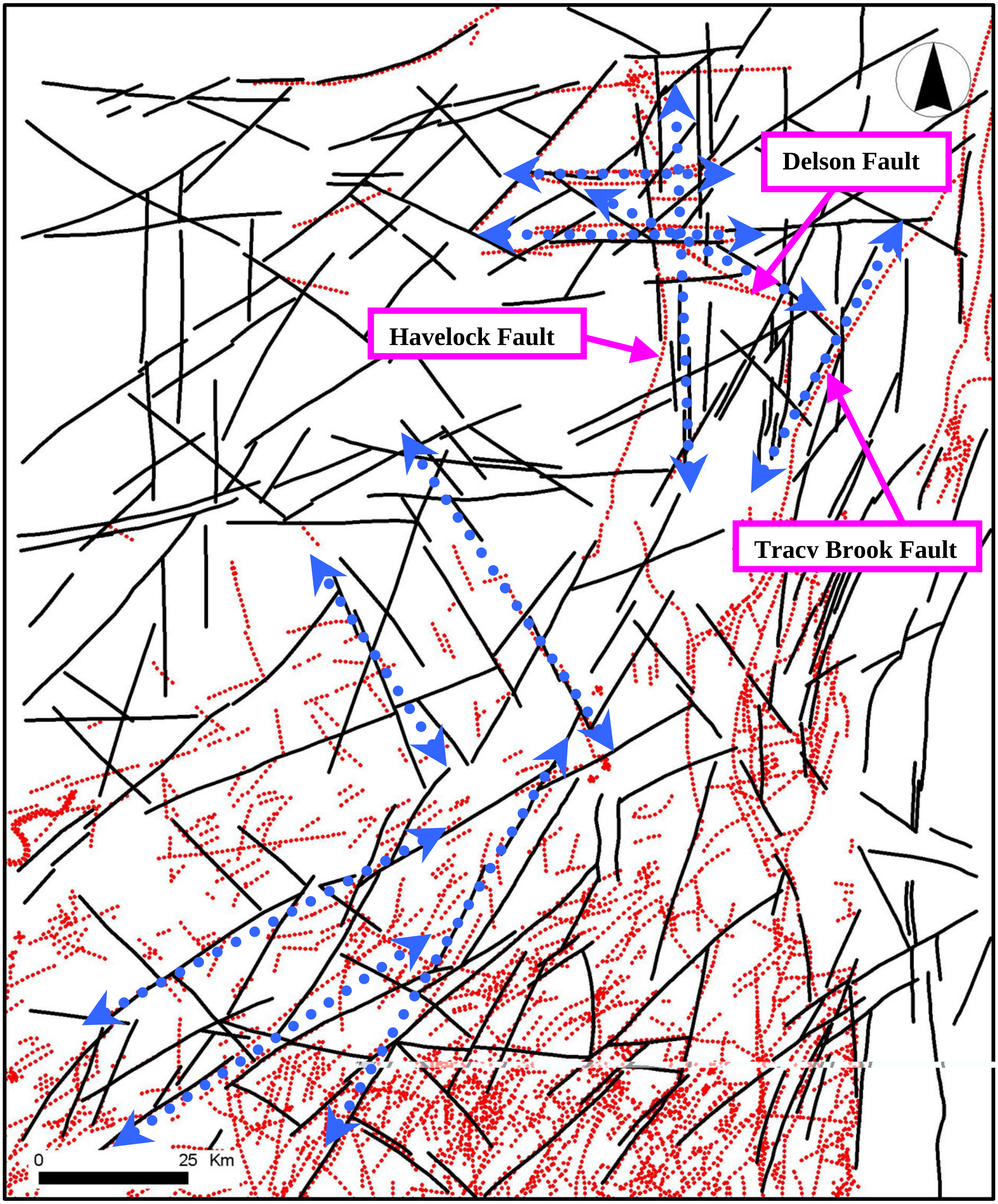


Figure 4-5 **Regional Lineaments (Solid Black) and Previously Mapped Faults (Dashed Red). Positive Correlations Between Interpreted Lineaments and Fault Zones are Shown by Blue Arrows. Fault Traces Were Recovered From the 1:250,000 Scale Geological Map of Globensky (1987) and the Digital Fault Data From the USGS Website.**

Chapter 5 GEOLOGY

5.1 INTRODUCTION

To supplement the remote sensing work bedrock mapping was undertaken in the Paleozoic cover rocks both north and east of the Adirondack Mountains in which the Precambrian basement is exposed. An integral component of the mapping was the measurement of bedding attitudes and elevations, particularly in order to locate folds and faults. Outcrop-scale structures were also documented because rocks deform at all scales, therefore those structures can be very revealing in terms of the large-scale geological framework and history. The data are summarized in Tables 5-1 and 5-2, with bedrock geology and outcrop locations shown in Figure 5-1 and 5-2, respectively.

Table 5-1 Data From Exposures North of the Adirondacks

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING STRIKE/DIP
AL-1	18 607 190	49 78 930	360	110	Theresa	300/04
AL-2	18 599 828	49 74 794	647	197	Nepean	205/03
AL-3	18 607 489	49 75 630	451	138	Nepean	020/04
AL-4	18 602 164	49 75 300	561	171	Nepean	280/05
AL-5	18 606 129	49 70 511	660	201	Nepean	235/03
AL-6	18 606 954	49 71 427	587	179	Nepean	
AL-7	18 607 553	49 75 171	478	146	Nepean	060/06
AL-8	18 604 900	49 72 691	620	189	Nepean	303/03
AL-9	18 602 346	49 73 096	676	206	Nepean	250/10
AL-10	18 602 060	49 71 946	729	222	Nepean	310/02
AL-11	18 599 432	49 75 691	677	206	Nepean	230/04
AL-12	18 599 401	49 79 574	670	204	Nepean	140/05
BR-1	18 573 377	49 67 130	1512	461	Precambrian	
BR-2	18 574 489	49 68 779	1397	426	Precambrian	195/15
BU-1	18 565 785	49 71 731	899	274	Nepean	255/05
BU-2	18 565 430	49 72 473	820	250	Nepean	288/03
CF-1	18 567 630	49 64 113	1433	437	Precambrian	
CF-2	18 566 954	49 67 703	1210	369	Nepean	245/26
CF-3	18 567 819	49 68 996	1125	343	Nepean	155/10
CF-3 ALSO	18 567 812	49 69 069	1105	337	Nepean	155/10
CF-4	18 567 795	49 69 094	1099	335	Nepean	125/24
CF-5	18 567 998	49 68 956	1086	331	Nepean	245/05
CHA-1	18 571 838	49 72 751	997	304	Nepean	240/06
CHA-2	18 578 831	49 79 488	1030	314	Nepean	195/03
CHA-2 ALSO	18 578 778	49 79 604	1014	309	Nepean	195/03
CHA-3	18 572 117	49 73 438	886	270	Nepean	155/02
CHA-3 ALSO	18 572 140	49 73 376	928	283	Nepean	155/02
CHA-4	18 572 219	49 73 528	951	290	Nepean	185/05

Table 5-1 Data From Exposures North of the Adirondacks (Continued)

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING STRIKE/DIP
CHA-5	18 572 147	49 73 432	984	300	Nepean	147/05
CHA-5 ALSO	18 572 072	49 73 205	1004	306	Nepean	147/05
CHA-6	18 572 045	49 73 117	1059	323	Nepean	
CHA-7	18 572 025	49 73 010	1086	331	Nepean	170/05
CHU-1	18 585 876	49 70 137	1296	395	Covey Hill	
CHU-1A	18 585 348	49 70 049	1379	420	Covey Hill	
CHU-2	18 584 315	49 77 184	1208	368	Nepean	228/03
CHU-3	18 583 518	49 83 199	870	269	Nepean	087/04
CHU-4	18 582 737	49 81 990	943	288	Nepean	268/08
CHU-5	18 581 184	49 76 195	1170	357	Nepean	
CHU-6	18 581 656	49 71 344	1351	412	Nepean	300/04
CO-1	18 555 775	49 74 121	397	121	Ogdensburg	264/07
CO-2A & -2B	18 555 274	49 75 139	364	111	Nepean	220/03
CO-3	18 555 230	49 82 168	239	73	Ogdensburg	035/01
CO-4	18 551 572	49 74 034	380	116	Nepean	335/08
CO-5	18 553 696	49 71 879	466	142	Nepean	292/04
DA-1	18 600 224	49 54 024	1985	605	Precambrian	
DA-2	18 599 948	49 52 964	1525	465	Precambrian	
EC-1	18 580 630	49 66 767	1807	556	Precambrian	
EC-2	18 585 161	49 65 502	1594	486	Precambrian	
ED-1	18 596 210	49 73 222	771	235	Nepean	305/02
ED-2	18 590 136	49 69 895	1141	348	Covey Hill	328/04
ED-3	18 593 907	49 71 267	934	285	Nepean	340/04
ED-4	18 594 501	49 70 984	969	295	Nepean	246/03
ED-5	18 594 241	49 79 461	912	275	Covey Hill	303/09
ED-5A	18 594 556	49 78 002	860	262	Nepean	
ED-5B	18 590 915	49 79 343	1042	318	Nepean	300/07
ED-5C	18 591 428	49 79 433	991	302	Nepean	H
ED-5D	18 589 743	49 79 189	1089	332	Nepean	265/09
ED-6	18 594 490	49 78 358	827	252	Nepean	H
ED-6A	18 593 135	49 76 775	943	288	Nepean	157/06
ED-7	18 595 059	49 74 729	943	288	Nepean	
ED-8	18 595 248	49 73 385	818	249	Nepean	
ED-9	18 595 811	49 69 857	1046	319	Nepean	275/04
ED-10	18 598 376	49 83 072	742	226	Nepean	
ED-11	18 597 236	49 79 213	792	241	Nepean	
ED-12	18 595 555	49 77 612	840	256	Nepean	230/10
EM-1	18 592 105	49 56 185	1601	488	Precambrian	
EM-2	18 595 939	49 57 505	1572	479	Precambrian	
EM-3	18 596 031	49 68 406	1193	364	Nepean	
EM-4	18 593 181	49 65 010	1630	497	Covey Hill	
MA-1	18 550 376	49 66 060	751	229	Precambrian	
MA-2	18 550 981	49 63 108	997	304	Precambrian	
MA-3	18 557 087	49 60 489	1128	344	Precambrian	
MO-1	18 618 081	49 72 396	253	90	Nepean	310/02
MO-2	18 615 522	49 75 058	262	80	Nepean	285/07
MO-3	18 612 041	49 79 382	244	74	Nepean	275/03
MO-4	18 613 126	49 79 347	228	70	Nepean	260/05

Table 5-1 Data From Exposures North of the Adirondacks (Continued)

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING STRIKE/DIP
MO-5	18 615 724	49 70 627	417	127	Nepean	255/02
MO-6	18 614 909	49 72 049	376	115	Nepean	295/07
MO-7	18 616 928	49 81 774	196	60	Theresa	035/05
MO-9	18 615 414	49 81 345	256	78	Nepean	255/03
MO-10	18 614 290	49 70 114	478	146	Covey Hill	298/04
MO-11	18 612 853	49 76 017	323	98	Nepean	241/12
MO-12	18 610 124	49 78 132	336	102	Nepean? C. Hill?	240/04

Table 5-2 Data From Exposures East & North of the Adirondacks

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING STRIKE/DIP	FAULTS	FAULT TYPE
BE-01N	18 625 387	49 69 429	185	56	Valcour	000/00		
BE-01S	18 625 435	49 69 315	191	58	Valcour	000/09		
BE-02	18 624 548	49 67 636	185	56	Day Point	239/10		
BE-02A	18 624 144	49 67 418	196	60	Day Point	017/09		
BE-02B	18 623 300	49 67 390	206	63	Crown Point	?		
BE-03	18 624 484	49 66 945	170	52	Day Point	290/07		
BE-03A	18 624 164	49 65 783	150	46	Crown Pt??	354/23		
BE-04	18 624 777	49 59 010	174	53	Oxford	000/00		
BE-04A	18 624 476	49 59 992	148	45	Oxford	274/09		
BE-05	18 625 030	49 58 180	177	54	Cumberland Head	215/23	Along cleavage	Upthrusts
BE-06	18 622 279	49 69 982	184	56	Crown Point	024/10		
BE-07	18 622 190	49 69 444	183	56	Crown Point & Valcour	106/03		
BE-08	18 622 303	49 68 757	171	52	Valcour	000/00		
BE-09	18 624 316	49 56 860	181	55	Cumberland Head	213/17		
BE-10	18 624 410	49 56 849	186	57	Cumberland Head	204/23		
BE-11A	18 620 646	49 58 283	210	64	Oxford	170/23		
BE-11B	18 619 160	49 60 752	281	86	Oxford	195/08		
BE-11C	18 620 687	49 57 832	182	55	Oxford	154/11		
BE-12	18 620 097	49 67 483	270	82	Day Point	Pavement outcrop		
BE-13	18 620 637	49 68 320	205	63	Day Point	000/00		
BE-14	18 627 445	49 60 110	167	51	Cumberland Head	270/14		
BE-15	18 624 756	49 69 386		0	Crown Point	Pavement outcrop		
BE-16	18 627 258	49 60 704	164	50	Oxford	000/00		
BE-17	18 626 327	49 66 881	116	35	Day Point?	Gentle N dip		
BE-18	18 626 749	49 67 870	130	40	Crown Point	235/08		
BE-19	18 623 026	49 62 683	228	70	Oxford	355/10		
BE-20	18 622 932	49 62 789	230	70	Oxford	?		
BE-21	18 622 037	49 62 072	229	70	Ft. Cassin?	280/02		
BE-21A	18 621 986	49 62 448	242	74	Oxford	275/03		
BE-22	18 628 316	49 59 977	123	38	Cumberland Head	049/14		

Table 5-2 Data From Exposures East & North of the Adirondacks (Continued)

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING	FAULTS	FAULT TYPE
BE-23	18 623 848	49 64 413	171	52	Oxford	272/06		
BE-24	18 624 594	49 65 375	157	48	Day Point	281/14		
CH-01	18 622 729	49 84 591	193	59	Theresa	227/04		
CH-02	18 625 270	49 83 669	240	73	Oxford	000/00		
CH-02A	18 625 265	49 83 520	225	69	Oxford	063/12		
CH-02A	18 625 221	49 83 454	220	67	Oxford	063/12		
CH-03	18 623 718	49 83 516	244	74	Oxford	133/07		
CH-04	18 622 809	49 79 680	213	65	Nepean	000/00		
CH-05	18 622 259	49 70 672	175	53	Day Point	015/23		
CH-06	18 623 165	49 76 259	198	60	Nepean	270/04		
CH-07	18 623 409	49 72 324	155	47	Nepean	000/00		
CH-08	18 623 162	49 70 881	170	52	Crown Point	049/13		
CH-08A	18 623 383	49 70 904	166	51	Crown Point	025/10		
CH-09	18 624 142	49 70 574	173	53	Crown Point?	Pavement outcrop		
CH-10	18 624 579	49 70 571	133	41	Valcour	282/05		
CH-11	18 624 785	49 70 575	148	45	Valcour	000/00		
CH-12	18 625 066	49 73 786	128	39	Valcour?			
CH-13	18 626 470	49 77 609	117	36	Valcour			
CH-14	18 620 531	49 83 410	152	46	Nepean	255/04		
CH-15	18 627 423	49 77 793	113	34	Valcour	010/14		
CH-15A	18 627 275	49 77 759	126	38	Valcour	?		
CH-16	18 627 867	49 78 693	109	33	Valcour	000/00		
CH-17	18 628 001	49 78 857	111	34	Valcour	000/00		
CH-18	18 626 062	49 80 156	163	50	Valcour	005/07		
CH-19	18 627 115	49 79 696	131	40	Valcour	H		
CH-20	18 622 187	49 79 788	244	74	Nepean	292/04		
CH-21	18 623 381	49 73 895	189	58	Theresa			
CH-22	18 625 948	49 80 294	157	48	Valcour	?		
CH-23	18 621 549	49 79 991	267	81	Theresa	306/02		
ED-03	18 593 907	49 71 267	934	285	Nepean	313/04		
ED-04	18 594 489	49 70 981	965	294	Nepean	246/03		
ED-10	18 598 309	49 83 144	747	228	Nepean	197/04		
ED-13	18 589 064	49 72 032	1,106	337	Covey Hill	158/04		
ED-14	18 589 017	49 70 697	1,053	321	Covey Hill			
JE-01	18 601 549	49 68 014	971	296	Nepean	140/03		
JE-02	18 606 234	49 65 520	1194	364	Covey Hill			
JE-03	18 605 432	49 69 668	800	244	Nepean	290/05		
JE-04	18 607 555	49 65 482	1062	324	Covey Hill	305/10		
JE-05	18 605 142	49 62 498	1242	379	Jericho	010/05		
JE-06	18 606 978	49 60 323	1416	432	Jericho			
JE-07	18 599 369	49 62 704	1226	374	Covey Hill	H		
JE-08	18 604 306	49 64 042	1088	332	Jericho			
KE-01	18 623 970	49 41 161	106	32	Day Point	330/02		
KE-02	18 622 365	49 31 219	307	94	Nepean	028/06		
KE-03	18 621 058	49 29 472	380	116	Nepean	035/08		
KE-04	18 619 272	49 39 112	270	82	Covey Hill	212/10		
KE-05	18 621 014	49 40 223	188	57	Oxford	219/05		
KE-06	18 623 952	49 39 741	99	30	Oxford	318/09		

Table 5-2 Data From Exposures East & North of the Adirondacks (Continued)

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING	FAULTS	FAULT TYPE
KE-07	18 622 014	49 35 066	212	65	Oxford	000/00		
MO-01	18 618 328	49 72 073	230	70	Nepean	000/00		
MO-05	18 615 734	49 70 640	419	128	Covey Hill	248/04		
MO-10	18 614 290	49 70 114	478	146	Covey Hill? / Nepean?	298/04		
MO-11	18 612 853	49 76 017	323	98	Nepean	241/12		
MOR-01	18 614 416	49 42 800	394	120	Nepean	315/11		
MOR-02	18 609 246	49 51 133	725	221	Nepean	337/03		
MOR-03	18 618 329	49 47 307	277	84	Oxford?	325/10	245/70	Normal
NH-01	18 629 494	49 61 525	101	31	Oxford	039/08		
NH-02	18 628 990	49 63 074	123	38	Crown Pt??	261/03		
NH-03	18 628 994	49 63 261	101	31	Crown Pt??	274/05		
NH-05	18 629 522	49 62 395	99	30	Ft. Cassin?	?		
NH-05A	18 629 578	49 61 906	107	33	Ft. Cassin?	?		
NH-06	18 628 833	49 64 070	96	29	Oxford			
NH-07	18 629 139	49 62 870	108	33	Ft. Cassin?	?		
NH-08	18 630 616	49 65 270	106	32	Oxford	205/04	205/04	Bedding slip
NH-09	18 631 715	49 66 196	99	30	Oxford & Day Pt	?	WNW-trending	
NH-10	18 631 968	49 65 936	97	30	Mega Breccia	Chaotic		
PL-01	18 624 683	49 55 550	152	46	Cumberland Head	220/10		
PL-02	18 624 459	49 54 856	159	48	Cumberland Head	030/08		
PL-03	18 623 283	49 45 328	157	48	Day Point	015/15		
PL-04	18 623 662	49 45 519	185	56	Day Point	053/10		
PL-05	18 623 967	49 45 089	108	33	Day Point	000/00		
PL-06	18 623 874	49 45 569	131	40	Day Point	000/00		
PL-07	18 624 278	49 56 340	180	55	Cumberland Head	035/15		
PL-08	18 620 042	49 44 183	198	60	Oxford	000/00		
PL-09	18 620 940	49 52 786	210	64	Crown Point & dike	338/11		
PL-10	18 620 291	49 53 210	280	85	Oxford	Pavement Outcrop		
PL-11	18 619 540	49 47 380	218	66	Oxford	026/03		
PL-12	18 625 949	49 52 596	91	28	Cumberland Head	331/04		
PL-13	18 625 585	49 52 987	98	30	Cumberland Head	005/07		Bedding slip
PL-14	18 621 115	49 54 283	158	48	Day Point	302/12		
PL-15	18 623 032	49 43 692	145	44	Day Point	005/04		
PL-16	18 623 139	49 42 814	105	32	Day Point	343/05		
PL-17	18 621 217	49 53 782	185	56	Crown Point?	325/10		
RP-01	18 633 204	49 73 961	108	33	Cumberland Head	269/40	010/25	Reverse
WB-01	18 620 223	49 25 790	550	168	Anorthosite			
WC-01	18 615 750	49 68 866	516	157	Covey Hill	275/03		
WC-02	18 616 369	49 68 938	411	125	Covey Hill	H		

Table 5-2 Data From Exposures East & North of the Adirondacks (Continued)

STATION	UTM EASTING	UTM NORTHING	ELEVATION (FT)	ELEVATION (M)	FORMATION	BEDDING	FAULTS	FAULT TYPE
WC-03	18 617 878	49 64 290	280	85	Oxford	268/02		
WC-04	18 617 212	49 62 332	334	102	Granite			
WC-05	18 617 331	49 61 419	354	108	Anorthosite			
WC-06	18 609 699	49 64 098	964	294	Covey Hill	305/06		
WC-07	18 612 571	49 61 992	802	245	Gneissic anorthosite			
WC-08	18 616 944	49 68 144	366	112	Covey Hill			
WC-09	18 612 670	49 61 878	790	241	Gneissic anorthosite		075/90	Dextral
WC-10	18 613 202	49 64 127	639	195	Red sandy ls			
WC-10A	18 613 590	49 64 176	618	188	Jericho			
WC-11	18 614 374	49 64 172	500	152	Covey Hill			
WC-12	18 613 796	49 64 152	573	175	Jericho	355/09		
WC-13	18 612 443	49 63 655	782	238	Nepean			
WC-14	18 611 737	49 63 573	866	264	Covey Hill			
WC-15	18 610 304	49 63 728	993	303	Covey Hill	275/03		
WC-16	18 609 821	49 58 353	1,442	440	Metagabbro	046/90?		
WC-17	18 611 762	49 62 600	873	266	Jericho			

5.2 NORTH OF THE ADIRONDACKS

5.2.1 Stratigraphy

North of, and in proximity to, the Grenvillian basement there are two distinct basal sedimentary units of commonly cross-bedded quartz sandstone. Following the criterion applied by Fisher (1968) and Globensky (1985), those sandstones were distinguished on the basis of the presence or absence of potassium feldspar clasts and were, therefore, mapped as distinct formations, herein named the Covey Hill and Nepean. Where the clasts are present the unit was identified as Covey Hill, but where absent it was mapped as Nepean. The Covey Hill, the older of the two, is light to pinkish gray, quartz cemented and locally conglomeratic (Figure 5-3), whereas the Nepean is light gray to white and quartz cemented (Figure 5-4), though its upper beds are more likely to be calcite cemented. Overlying, and possibly transitional from, the Nepean is the Theresa Formation, which marks the base of the Beekmantown Group. The Theresa is composed of an interlayered sequence of generally light to medium gray sandy limestone or sandy dolostone and quartz- or calcite-cemented quartz sandstone. The Theresa is overlain by the Oxford, which is predominantly a fine-grained dolostone, although that formation also embraces layers of dolomitic limestone and calcilutite. A summary of the units and their characteristics is given in Table 5-3.

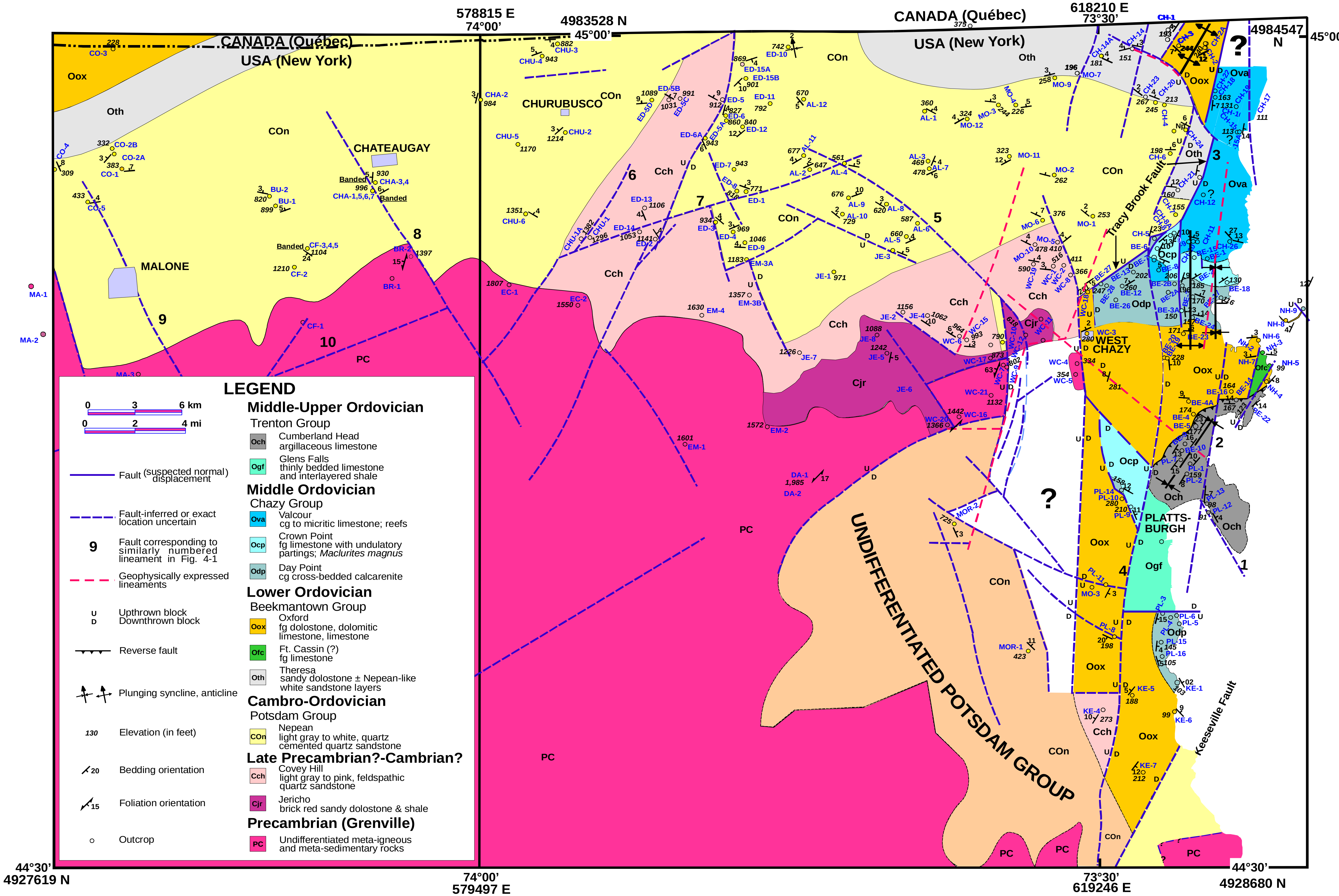


Figure 5-1 Geological Map

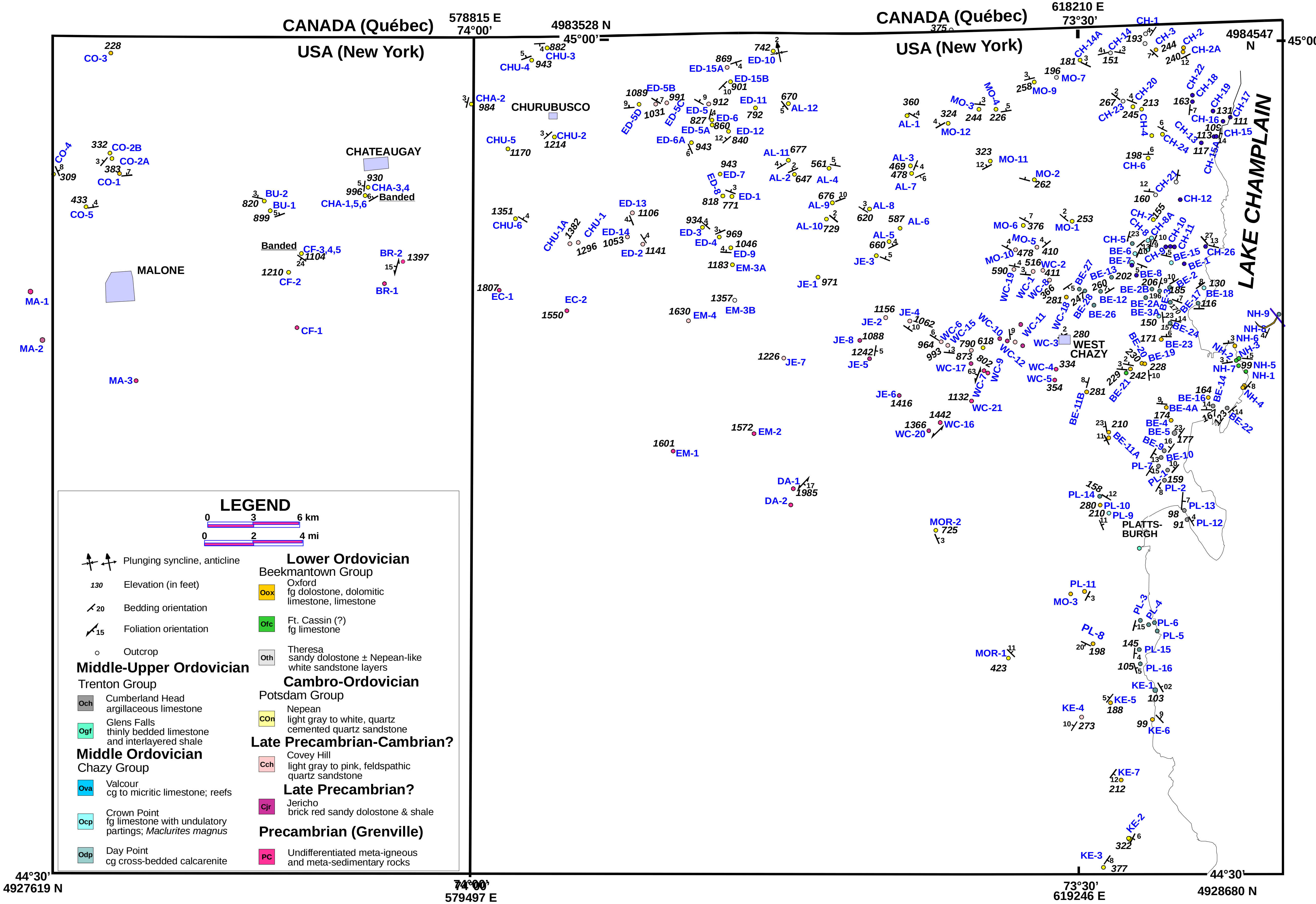


Figure 5-2 Outcrop Locations With Elevations (In Feet).

With increasing distance northward from the Grenvillian basement of the Adirondacks, the rocks exposed at the surface are progressively higher in the stratigraphic section, a reflection of the sedimentary strata dipping away from the basement. There is, however, some question about the Theresa Formation, which should occur between the Nepean and Oxford formations. It may do so, but thus far only one exposure along the north flank of the Adirondacks has been confirmed. Other exposures suspected of being Theresa, such as in the area of Constable (Stations CO-2a and 2b; Figures 5-1 and 5-2), are actually calcite cemented quartz sandstone, typical of either the upper Nepean or the Theresa. One reason for the difficulty may stem from the common occurrence of either pavement outcrops or relatively thin exposures afforded by stream cuts. The Theresa does contain layers of white quartz sandstone which are generally, but not uniquely, calcite-cemented and sandwiched between gray sandy limestone or sandy dolostone layers. The latter may be hidden from view, but without any core that supposition cannot be verified therefore, based on the observed lithology, the units have been assigned to the Nepean Formation. In the vicinity of Champlain, New York, however, sandy dolostone and interlayered sandy dolostone and quartz sandstone of the Theresa Formation were mapped (Figure 5-5).

Figure 5-3 Cross-Bedded, Pale Pinkish Gray, Covey Hill Feldspathic Sandstone.

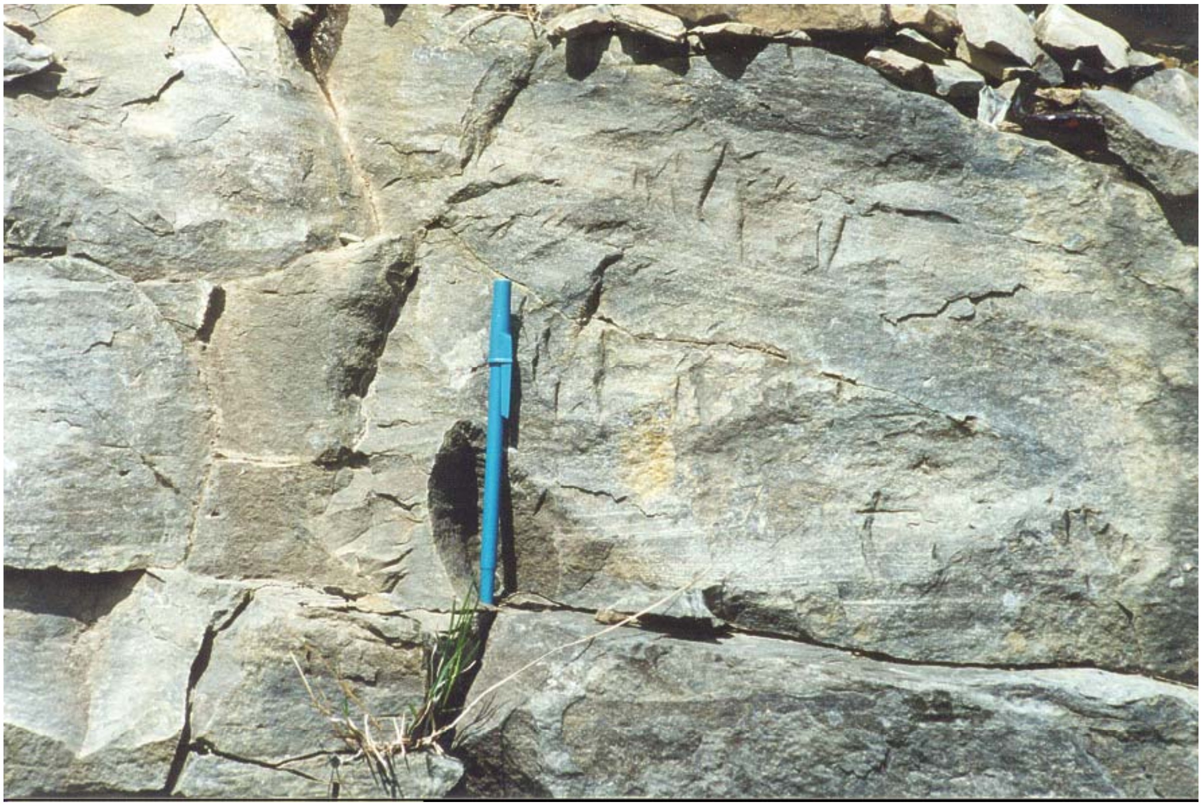


Figure 5-4 Cross Bedded Nepean Sandstone at Chazy, NY.

Table 5-3 Stratigraphic Units North of the Adirondacks

GROUP	FORMATION	CHARACTERISTICS
Beekmantown	Oxford	Buff to light brown weathering, light blue gray to gray dolostone; locally calcareous.
	Theresa	Sandy limestone or sandy dolostone, generally with layers of Upper Nepean lithology.
Potsdam	Upper Nepean	white to cream colored quartz sandstone.
	Lower Nepean	banded, pink, gray and white quartz sandstone.
	Covey Hill	Variously colored, dominantly quartz sandstone, but with grains of K-spar and possibly other, basement-derived minerals.

Figure 5-5 **Cross Section of the Theresa Formation North of Champlain, NY (Station CH-1). Lighter Gray Colored Layers are Quartz Sandstone, Identical to the Lithology of the Nepean Sandstone.**

Figure 5-6 **Cross Section of the Oxford Dolostone Northeast of Champlain, NY (Station CH-2). Note the Massive, Undulating Layers.**

5.2.2 Structure

Proximal to the exposed basement of the Adirondack Dome, the basal Paleozoic rock units dip in a generally northerly direction at up to about 30°, a reflection of tectonic uplift, not deposition. Further to the north the strata are horizontal to sub-horizontal. Based on topographic and geophysical lineaments, two of which cut both the basement and the Paleozoic cover, three north-northwest striking faults were interpreted and others, oriented east-northeast and northwest, were identified as a result of the distinction between the Covey Hill and Nepean formations (Figure 5-1). Because of tilting and stratigraphic position, with the older Covey Hill topographically higher than the younger Nepean, stretching of the Paleozoic crust is inferred which, if correct, implies that the structures are normal faults.

Folding was identified at one location, within the Nepean Sandstone, just south of the Canadian Border at Station ED-10 (Figures 5-1 and 5-2). There the opposite limbs are oriented 197°/03° and 324°/04°, and define a fold axis plunging 02° in the direction 349°.

5.3 EAST OF THE ADIRONDACKS

5.3.1 Stratigraphy

Along Lake Champlain the stratigraphy is more complex, with the addition of the Chazy Group of limestones sandwiched between the Beekmantown Group of dolostones and, allegedly, the limestone formations of the Black River Group. In the Beekmantown, Fisher (1968) identified several different dolostone formations. All, however, resemble the Oxford Formation, (also known as the Beauharnois, Ogdensburg, or Providence Island) thus in this work, all of those formations have been mapped as Oxford (Figure 5-6). Though dolostone predominates in the Oxford, the formation also comprises argillaceous dolostone, dolomitic limestone, and medium dark gray micrite, examples of which were found at the southern tip of Isle La Motte, Vermont, and in the Little Chazy River at West Chazy, New York.

Within the Chazy are three limestone formations (Table 5-4), two of which are readily identifiable. The third, the Valcour Formation is, at least in the study area, somewhat questionable. According to Fisher (1968) and Shaw (1969), the Valcour is a calcarenite, however where examined in this study, it was generally found to be a fossiliferous calcilutite, though calcarenite, resulting principally from bioclastic accumulation, was also seen. Reef structures and a multitude of fossils including sponges, bryozoa, trilobites and cephalopods were recognized by André Desrochers, a carbonate stratigrapher from the University of Ottawa, who visited some of the outcrops with JLW. At two locations the Valcour is a light- to medium-dark gray micritic limestone, with or without coarse-grained recrystallized calcite. At one of those locations that lithology can be seen in rather sharp contact with the underlying Crown Point Formation, therefore micritic limestone is considered to mark the base of the Valcour (Figure 5-7). The underlying Crown Point Formation is a fossiliferous calcilutite which commonly shows thin, sandy colored undulating laminae that resemble dolostone, but which effervesce vigorously with dilute HCl, and are, therefore, limestone. The oldest of the Chazy Group rocks is the Day Point Formation, which is a coarse-grained limestone quite commonly marked by cross-bedding (Figure 5-8). Near its base it is essentially a bioclastic calcarenite, but near its inferred top the unit is marked by interlayered calcilutite and calcarenite, suggesting sea-level fluctuations.

Stratigraphic distinctions within the Chazy Group are locally blurred owing to the existence of only pavement outcrops in some places and the interfingering of some units. At Station BE-7 (Figures 5-1 and 5-2) it appears that there were fluctuations in sea level at the time of deposition of the Crown Point and the overlying Valcour Formations because of the interlayering between the two. The gray, fine-grained fossiliferous calcilutite with the distinctive, irregular, thin sandy weathering laminae, indicative of the Crown Point, both overlies and underlies the lighter gray weathering, micritic, fossiliferous limestone of the basal Valcour. Similar occurrences were also recognized at or near the top of the Day Point Formation, as noted in the previous paragraph.

Thicknesses of the units within the Chazy Group are variable (Table 5-5). At Chazy, NY all three formations are thicker than at Isle La Motte, in Lake Champlain, where there is apparently no Valcour and the Crown Point has all but disappeared. The Day Point, however, is still rather thick albeit less so than at Chazy. The pattern is more difficult to generalize a bit further south. From southern Valcour Island, also in Lake Champlain, to South Hero, the Valcour thickens whereas the Crown Point thins, despite retaining a respectable thickness, and the Day Point is non-existent. Faulting or sedimentary pinching out may explain the differences, but that needs to be evaluated.

Figure 5-7 The Crown Point Formation, Showing its Distinctive Undulating Thin Laminae, and the Overlying, Micritic Valcour. Hammer Rests on the Contact.

Figure 5-8 Day Point Formation With Characteristic Cross Bedding.

Table 5-4 Stratigraphic Units East of the Adirondacks

GROUP	FORMATION	CHARACTERISTICS	THICKNESS (FEET)	THICKNESS (METERS)
Chazy	Valcour	Bioclastic calcarenite, but basal portion is calcilutite to micrite.	61-97	19-30
	Crown Point	Fossiliferous calcilutite marked by the gastropod Maclurites magnus. Also features thin, undulating, sandy-colored partings.	4-309	1-94
	Day Point	Cross-bedded calcarenite. Locally thin, undulating sandy-colored partings. Appears to interfinger with the Crown Point near the top.	115-222	35-67
Beekmantown	Oxford	Light blue gray to gray dolostone ± interlayered dark gray calcilutite	330	101
	Theresa	Sandy limestone or sandy dolostone, generally with layers of Upper Nepean lithology.	90	27
Potsdam	Upper Nepean	white to cream colored quartz sandstone.	470	143
	Lower Nepean	banded, pink, gray and white quartz sandstone.		
	Covey Hill	Variously colored, dominantly quartz sandstone, but with grains of K-spar and other basement-derived minerals.	35	11
	Jericho	Redbed sequence comprised of sandy dolostone ± quartz and feldspar clasts, and shale.	≥12	≥4

(Modified from Fisher, 1968)

TABLE 5-5 Thicknesses of Formations in the Chazy Group

FORMATION	THICKNESS (FEET)	THICKNESS (METERS)	FORMATION	THICKNESS (FEET)	THICKNESS (METERS)
Chazy, New York			Isle La Motte, Vermont		
Valcour	96.75	29.50	Valcour		
Crown Point	250.17	76.27	Crown Point	4.00	1.22
Day Point	134.83	41.11	Day Point	115.09	35.09
Southern Valcour Island, New York			South Hero Station, Vermont		
Valcour	60.75	18.52	Valcour	85.50	26.07
Crown Point	308.58	94.08	Crown Point	222.42	67.81
Day Point	221.92	67.66	Day Point		

(From Oxley and Kay, 1959)

Two units, the Stony Point and the Cumberland Head formations, assigned to the Trenton Group by Fisher (1968), are both thinly laminated argillaceous limestones and look exactly alike, at least where observed during this investigation. Moreover, they are described in a manner indicating them to be indistinguishable although in a table presented in Fisher (1968, Fig. 10), Erwin (1957), Hawley (1957) and Fisher (1967) showed the Stony Point as immediately overlying the Cumberland Head. Globensky (1987) described the Stony Point as a dark gray calcareous mudstone with thinly interlayered light gray, fine-grained shaly limestone and a negligible quantity of dark gray shale. Among the fossils contained therein are the trilobite *Triarthrus beckii*, numerous graptolites and a few, rare cephalopods. Globensky (1987, Fig. 20) also showed the Stony Point as having a well-developed fracture cleavage, which is also a common attribute of the Cumberland Head Formation. Interestingly other authors, identified in Fisher (1968, Fig. 10), did not even name the Stony Point Formation. Because of the foregoing, the Stony Point is not considered to be distinct from the Cumberland Head and, therefore, is not considered any further in this report.

Besides the aforementioned carbonate units, sandstones of both the Nepean and Covey Hill formations are also present. The former is light gray, cream colored or nearly white and is comprised almost exclusively of quartz grains that are quartz- or calcite-cemented. The Covey Hill is also richly quartzitic, but is more likely to be pinkish gray in color due to the presence of potassium feldspar clasts.

Spatially related to, but underlying, the Covey Hill is a red-bed sequence, either heretofore unrecognized or at least undocumented, consisting predominantly of sandy dolostone with lesser amounts of red shale. The sandy dolostone may be thinly laminated, locally cross-bedded and comprised of up to about 85% dolomite, but it also contains rounded to angular quartz grains and angular clasts of K-feldspar. Petrography shows that there are actually clasts of two K-feldspar phases, an untwinned perthite and microcline. The red sequence underlies the tiny village of Jericho, and much of the Jericho Quadrangle, thus it is, herein, informally named the Jericho formation. Sanford (1993) described a redbed clastic and volcanic sequence from western Newfoundland as representing the earliest formed deposits associated with Lower Cambrian rifting, though he equated that sequence to the Covey Hill Formation within the Québec Basin. Sanford's correlation may well be correct, however rip up clasts of dark red shales are enclosed in unequivocal Covey Hill conglomerates on Ile Perrot, near Montréal, indicating that the red shale is older than the lowest exposed conglomerate at that location.

5.3.2 Structure

5.3.2.1 Folds

Folding is implied, as deduced from changes in bedding orientations, but only two outcrop-scale folds were actually seen, one at Station BE-22 (Figures 5-1, 5-2 and 5-9) and the other at Station ED-10 (Figures 5-1, 5-2). On the macroscopic scale broad open fold patterns, which trend north-south to north-northeast, are outlined in the Beekmantown Group, near Champlain, and in the Chazy Group, both west and southeast of Chazy (Figure 5-1). They are contrasted by the much tighter folding inferred from the relatively abrupt dip reversals measured within the argillaceous limestone of the Cumberland Head Formation, just north of Plattsburgh (Table 5-6; Figure 5-1), which define horizontal fold axes that are oriented more northeasterly (035°).

5.3.2.2 Faults

Major faults are present throughout, as determined from the stratigraphy, but like most of the folds, none was actually observed directly, thus it is difficult to be precise about their number, geometry and specific locations. That point was punctuated by Hudson (1931) who, in commenting on his map, observed that: *"The faults as thus drawn are doubtless still incorrect in many details…"*. Quinn (1933) noted that all faults along Lake Champlain are normal, but added "*as far as can be determined…*". He also pointed out that almost all of them that trend approximately north-south are accompanied by displacements of east side down relative to the west side.

Table 5-6 Bedding Orientations in the Cumberland Head Formation North of Plattsburgh (See Figure 5-2 for Station Locations)

STATION NUMBER	STRIKE	DIP
BE-5	215°	23°WNW
BE-9	213°	17°WNW
BE-10	204°	23°WNW
BE-14	270°	14°N
BE-22	049°	14°SE
PL-1	220°	10°NW
PL-2	030°	08°ESE
PL-7	035°	15°ESE
PL-12	331°	04°
PL-13	005°	07°E

Figure 5-9 A Normal Fault Cuts Through the Hinge of a Small Anticline, to the Right of the Hammer, in the Cumberland Head Formation at Station BE-22 (Figure 5-2).

Evidence of major faulting was furnished by both the distribution of stratigraphic units, with the older units topographically higher than, or at about the same elevation as, the younger units, and abrupt changes in strike directions. Additional evidence occurs locally in the form of tilted strata, which testify to predominantly, if not exclusively, dip-slip movements. One of the most prominent faults, the Tracy Brook (Fisher, 1968 and Globensky, 1987), is a major north-northeast to northeast-trending structure (Figure 5-1) recognized clearly and unequivocally on stratigraphic criteria. For example, in and near the village of Chazy the Cambro-Ordovician Nepean Formation and younger units of the lower Middle Ordovician Chazy Group are juxtaposed, with the former located to the west and northwest of the latter (Station CH-5, Figures 5-1 and 5-2). Accompanying the sharp stratigraphic break are dipping strata of the Day Point and Crown Point formations which, due to rigid body rotation, are inclined towards the east and southeast, away from the fault (Figure 5-10).

A second major fault occurs northwest of Plattsburgh and is marked by the Oxford Dolostone on the west and the inclined, but younger, Crown Point Formation limestone on the east. The Crown Point strata dip to the northeast and are cut by a west-northwest trending lamprophyre dike which has been emplaced within a fracture belonging to a network of similarly oriented closely spaced fractures (Figures 5-11 and

5-12). There are no clear-cut kinematic indicators of either of the aforementioned faults, at any scale, but due to stratigraphic relationships and tilted strata, their existence is unmistakable, and both are suspected of being normal faults, with the east side down relative to the west side. Other faults have been inferred, using the aforementioned criteria, some of which are similar to those interpreted by Fisher (1968).

In the southern part of the area, north-northeast faulting is indicated by the juxtaposition of the Nepean Sandstone and the Oxford Dolostone, with the latter unit younger, but topographically lower, than the former (Figures 5-1 and 5-2). Curiously, the strata in the Nepean dip towards the southeast suggesting that the northwest side of the fault, herein named the Keeseville fault (Figures 5-1 and 5-2), would have moved up relative to the southeast side, although the reverse is true. That suggests either that:

a) the dips there are independent of faulting, possibly due to folding,
b) there are at least two faults, one of which would have induced the rigid body, rotation producing the southeasterly dips in the Nepean,
c) there have been at least two periods of faulting, with one having caused the rotation or
d) the dip is the result of rollover or reverse drag[1]

Figure 5-10 Inclined Beds in the Day Point Limestone, East of the Tracy Brook Fault, Strike 015° and Dip 23° Towards the East-Southeast.

[1] Reverse drag, or rollover, is caused by the pulling apart of adjacent blocks involved in normal faulting. The leading edge of the hanging wall may collapse into the void created by the separation of adjacent blocks, thereby producing reverse drag.

Figure 5-11 **Darkly Colored, Deuterically Altered Diabase Dike Cutting the Crown Point Limestone of the Chazy Group. Located at Station PL-9, Just Northwest of Plattsburgh (Figures 5-1 and 5-2), the Dike Fills a Member of the Dominant Fracture Set There, the Average Orientation of Which is 289°/81°.**

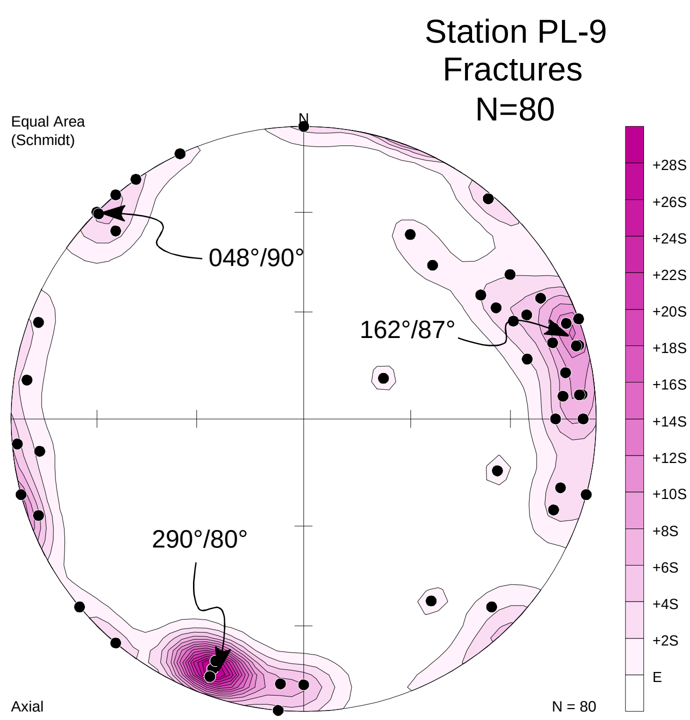


Figure 5-12 **Equal Area, Lower Hemisphere Projection of Poles to Fractures at Station PL-9 (Figures 5-1 and 5-2).**

(a)

Figure 5-13 (a) Rotated Cleavage in the Cumberland Head Formation, at Station PL-13, Indicating That The Upper Layers Moved to the Left (West) Relative to the Lower Layers.

(b)

Figure 5-13 (b) Closeup of Slickensided Vein Calcite Along Bedding. Pen Points N. Steps in Calcite (Left of Pen) Show the Movement of Upper Layers Towards the Bottom (West) Relative to the Lower Layers

East of the Adirondacks, the predominant fault trend varies from north-south to north-northeast. Nonetheless, just south of Plattsburgh, there is an east-west fault marked by a prominent cliff that presumably juxtaposes the thinly bedded limestone of the Glens Falls Formation (not exposed there, though it is just to the north) and the well exposed Day Point Limestone indicating that the south side moved up relative to the north side (Figure 5-1). In the same area, but a bit to the southwest is a curving, northwest striking fault entirely within the Oxford Dolostone. That fault follows a small river and is marked, like many others, by rigidly rotated strata showing that the northeast side moved up relative to the southwest side.

Smaller faults were observed at a few outcrops which, because rocks deform at all scales, yielded information on the geometry and kinematics of the larger structures. Bedding plane slip, resulting in stepped slickensided surfaces and rotated shear fractures, occurs along gently inclined surfaces oriented 005˚/07˚E in the Cumberland Head Formation at Station PL-13 (Figures 5-2 and 5-13) and 205˚/04˚W in the Oxford Dolostone at the southern tip of Isle La Motte, on the Vermont side of Lake Champlain (Station NH-8, Figures 5-2 and 5-14). In both cases the bedding plane slip formed in response to compression, with the hanging wall moving up and to the west relative to the foot wall. A northeast-striking normal fault was also identified in the Saranac River, west of Plattsburgh. Many of the major faults identified by, or inferred from, ground-based mapping coincide entirely or at least partially with major topographic lineaments identified during the remote sensing phase of the investigation (Examples are illustrated in Figures 4-1 and 5-1).

The Lacolle mélange, also referred to as the Lacolle breccia, was observed at two locations. In Chazy (Station CH-5; Figures 5-1 and 5-2) it occurs as a downward widening clastic dike which crosscuts the Nepean Formation (Figure 5-15). Dolostone from the Oxford Formation predominates among the fragments, although there are also a very few fragments of sandy dolostone from the Theresa Formation, all of which are set in a dark gray sandy matrix. The second occurrence is just east of Coopersville (Station CH-13; Figure 5-2), where it appears to be comprised largely of blocks of the country rock within a limy matrix, although other limestone formations are represented among the angular clasts. As such it is distinct from that occurring in Chazy. According to Globensky (1987) the composition of the breccia along a 12.5 km length in southern Quebec, just across the border from the study area, varies from north to south. In the southern part it is comprised of dolostone and sandy dolostone, but along the northern segment it contains more than 50 % limestone.

Fisher (1968) attributed the brecciation at both locations, and at others, to movement along the Tracy Brook fault, while noting that both of the aforementioned occurrences are spatially related to that structure. Globensky (1987) concluded the same for the origin of the polymictic breccia in the village of Lacolle, Quebec, also noting its proximity to the Tracy Brook fault. The characteristics of the mélange indicate tectonism, but do not support that interpretation, as illustrated by the exposure in Chazy. If the Tracy Brook fault were responsible for the brecciation there the fragments should be predominantly, if not exclusively, from the Nepean because it is that unit which is cut by the clastic dike. The fragments, however, are mostly from the Oxford, which is stratigraphically higher than the Nepean. Moreover, the Nepean shows no evidence of cataclasis. Those conditions suggest that bulldozing of autochthonous rocks associated with continental collision produced the breccia, and that high pore pressures drove the broken material downward into pre-existing fractures, thereby creating the clastic dikes. The existence of polymictic breccia at other locations also appears to contradict the notion of movement along a single fault as having been the cause of the brecciation. Stone (1957) interpreted the heterogeneous breccias in the Lake Champlain area, including the Lacolle breccia, in a similar manner, noting in particular that they formed in response to crushing and mixing along the soles of advancing thrust sheets.

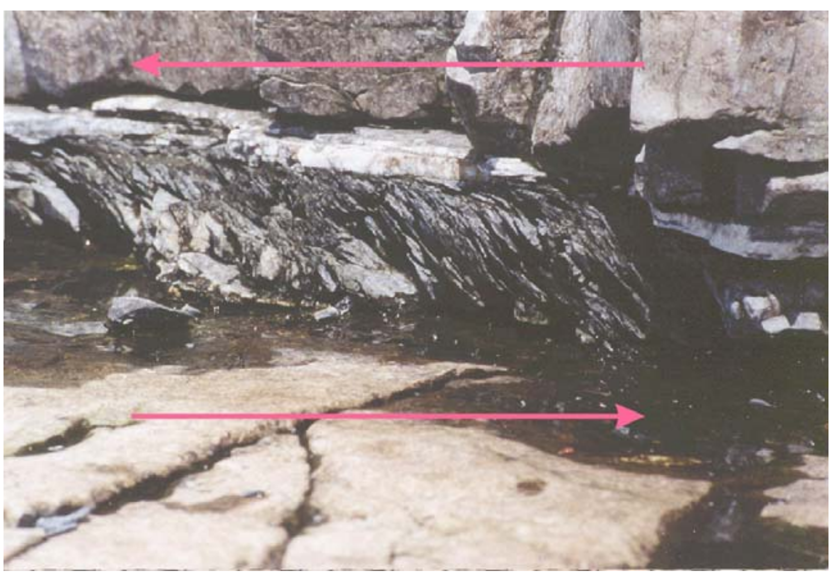


Figure 5-14 Rotated and Dragged Fracture Cleavage Indicating Tectonic Transport of the Upper Block of Massive Dolostone to the Left (West) Relative to the Underlying Block Represented by the Bedding Surface in the Lower Part of the Photo; a Small-Scale Overthrust. Located at the Southern Tip of Isle La Motte in Lake Champlain (Station NH-8, Figure 5-2).

5.3.2.3 Fracture Cleavage

Fracture cleavage, albeit a minor structure, deserves mention because, like fractures and faults, it may also serve as conduits for migrating hydrocarbons. The only unit within the study area that displays fracture cleavage is the laminated argillaceous limestone of the Cumberland Head Formation (Figure 5-16). Thin sections suggest that the cleavage formed initially as carbon-filled stylolites that were extended to produce a spreading center-transform fault geometry (Figure 5-17). The proposed origin of transform faults and, therefore, their relevance to the genesis of the fracture cleavage results from observations which are described in the next paragraph (p. 58).

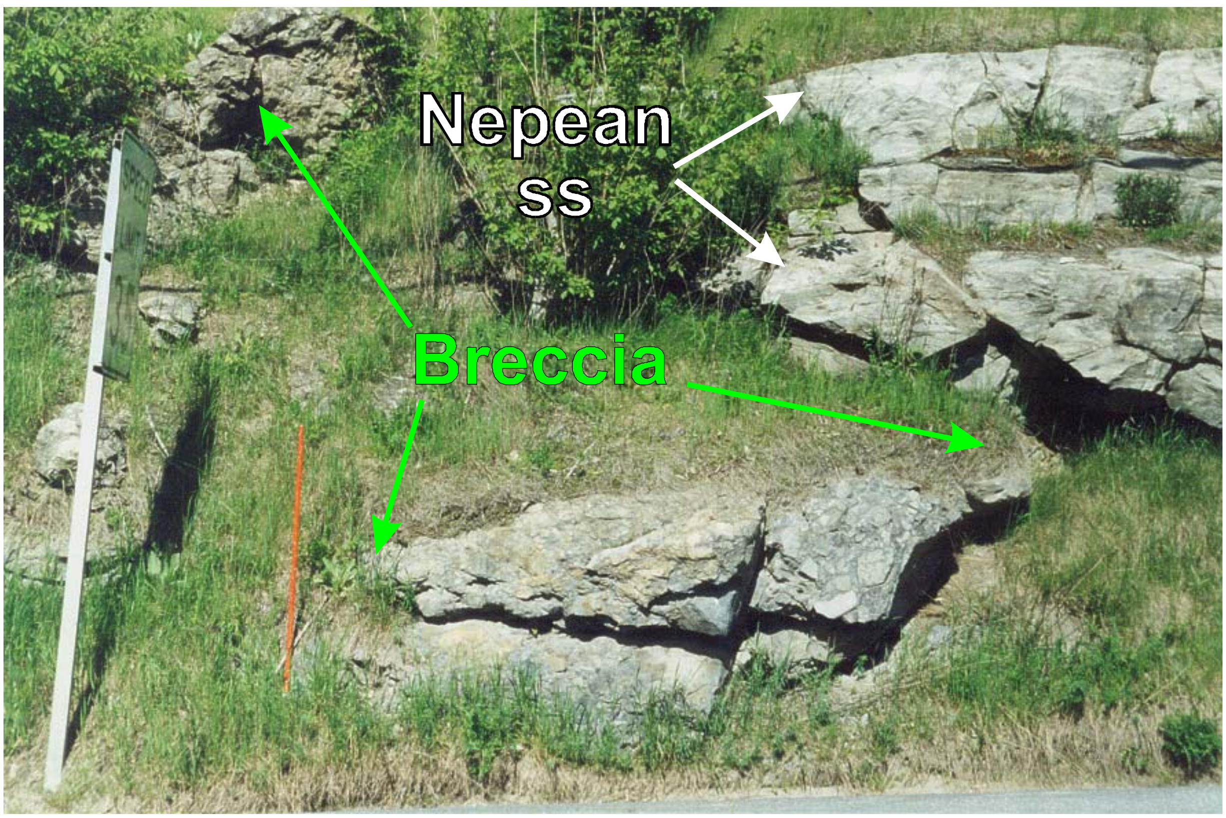


Figure 5-15 The Lacolle Breccia, a Clastic Dike Filled With Fragments of Oxford Dolostone, Cutting the Nepean Sandstone in Chazy, NY. The Orange Measuring Stick is 1.5 m high.

Figure 5-16 **Bedding (Dipping to the Left) and Fracture Cleavage (Inclined to the Right) in the Cumberland Head Formation.**

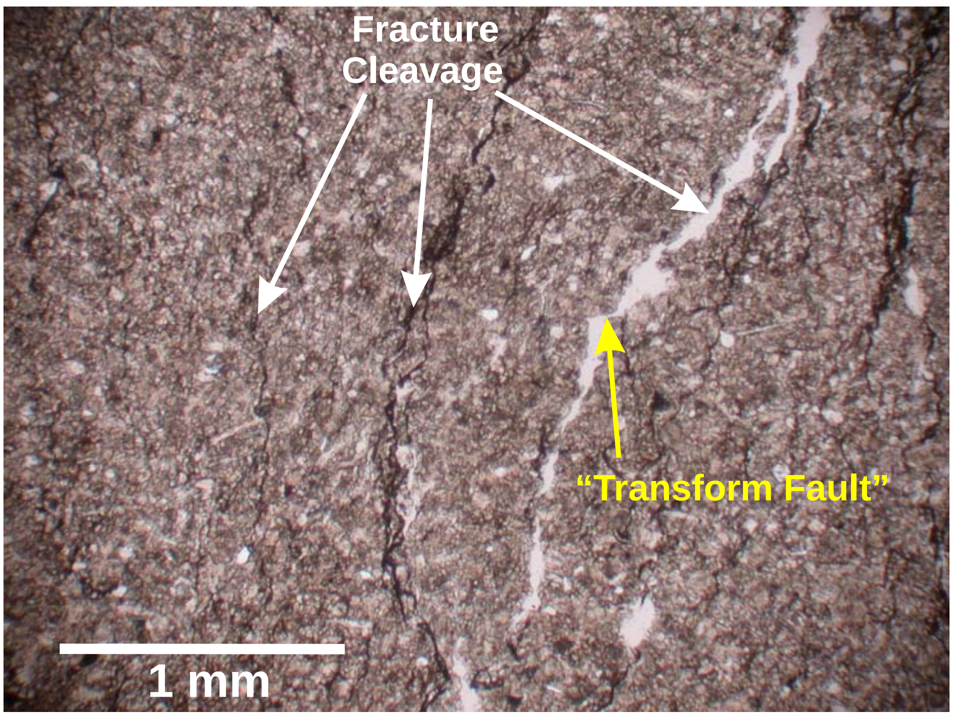
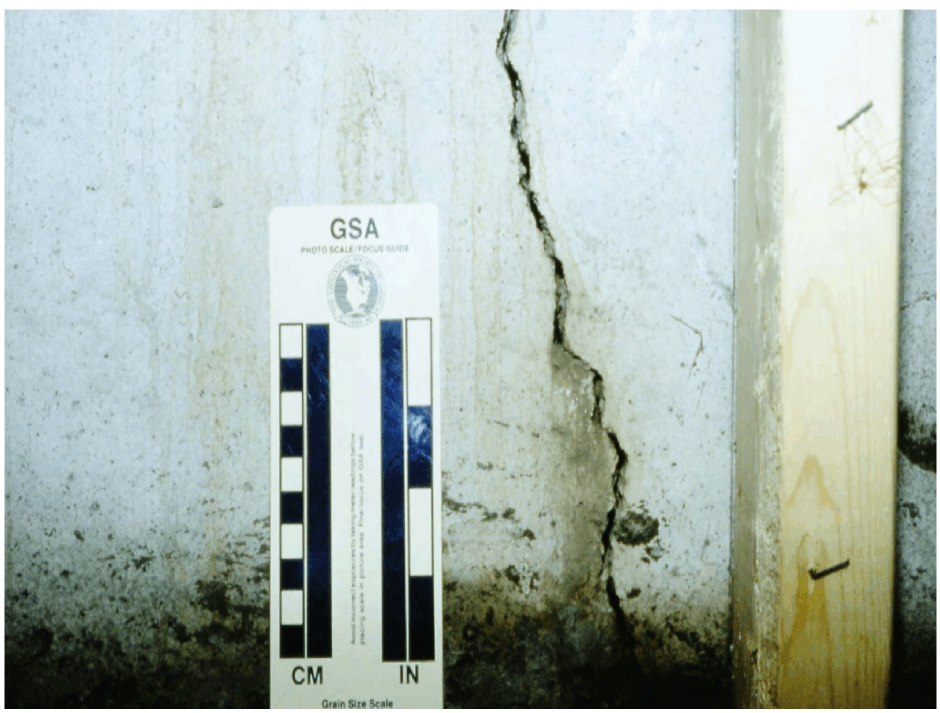


Figure 5-17 **Photomicrograph in Plane Polarized Light Showing Open and Carbon (?)-Filled Fracture Cleavage in the Cumberland Head Formation. The Thin Black Cleavages Appear to be Stylolites. Note the Tight "Transform Fault" in Contrast to the Wider "Displaced" Extension Fracture (White) Which, Collectively, Define "Spreading Center-Transform Fault" Geometry.**

(a)



(b)

Figure 5-18 "Spreading Center-Transform Fault Geometry". (a) Extension Created by Settling of Driveway and Consequential Tension Along the Hinge of an Anticline (b) Extension Along Basement Walls Due to Subsidence of House.

The "spreading center-transform fault" configuration was recognized on the basement walls of a house known to have settled and, consequently, lengthened due to inappropriate construction on weak water-laden clay (Figure 5-18). The driveway to the same house is beset with the same problem, settling, which has left a long ridge, or anticline, parallel to the driveway's length. The hinge area of an anticline is an area of tension, thus a series of “displaced”, open, axial planar extension fractures has formed along the hinge. Associated with those fractures are tight, transverse, transform faults, which "displace" the longitudinal extension fractures (Figure 5-18). It is, therefore concluded that lengthening is the mechanism of formation of transform faults and their associated longitudinal “displaced” fractures.

The Cumberland Head is structurally discordant to any of the adjacent autochthonous rock units and has been interpreted by Fisher (1968), and in this study, as an allochthonous thrust sheet. Furthermore, the unit has been subjected to internal compressional strain, undoubtedly related to the causative stresses that produced the overthrusting, which resulted in very tight folding, as discussed in section 5.3.2.1. Bedding thickness appears to be constant on the oppositely dipping strata within the Cumberland Head, suggesting that the folds formed by flexural slip. That mechanism is accommodated by layer-parallel slip along bedding which would, in turn, account for a shear couple leading to the development of extension fractures (cleavage) oriented obliquely to bedding.

Chapter 6 GROUND-BASED GEOPHYSICAL SURVEYS

6.1 INTRODUCTION

Outcrop control in the study area is rather poor, particularly in view of the complex geology, and the geophysical coverage there lacks detail. Consequently, in an attempt to identify subsurface structural features (particularly faults), besides those inferred from the geological investigations, and to provide additional geophysical information, ground-based magnetic and gravity surveys were undertaken. The target for those surveys was the northeastern portion of the study area, bounded on the north by the Canadian border and on the east by Lake Champlain (Figures 6-1 and 6-2).

6.2 PROCEDURES

The ground magnetic survey was undertaken using a GEM Systems Model GSM-19T proton precession magnetometer. Station spacing varied from 400 m (¼ mile), near and along Lake Champlain, to generally 800 m (½ mile) further to the west. Along the Northway (I-87) the stations were spaced at 1.6 km (1 mile).

Throughout the day, there are shifts in the magnetic field which must be accounted for in order to avoid the possibility of erroneous data. To correct for those diurnal variations and to calibrate the instrument, a main base station was established on day 1, but because of the size of the study area three satellite base stations were also set up at different locations. Readings at all satellite base stations were calibrated to those recorded at the first base station established on day 1 of the survey. Because only one magnetometer was available, it was necessary to return, periodically, to the base or satellite station nearest the area where the survey was being conducted on any given day. Readings were made at the base stations at various time intervals, but never more than two hours apart, and at the end of each day all readings were corrected for the drift. In order to be as consistent as possible, all readings were taken with the surveyor facing magnetic north and the sensor aligned in an east-west direction.

A Worden Educator Model # 567 gravimeter was used and, as in the case of the magnetometer survey, base stations were established for the purpose of calibrating the instrument. Unlike the magnetometer, however, the need to calibrate is not a result of diurnal changes in the gravity field, but is due to creep of springs or fibers which cause drift within the gravimeter (Dobrin, 1960). For the most part stations were located about 800 m (½ mile) apart, though across the Tracy Brook fault (Figure 5-1), station spacing was much closer.

6.3 RESULTS

Data from the surveys tended to substantiate much of what had been interpreted during the remote sensing and geological investigations, but they also revealed features that were heretofore unknown or which were, at best, suspected. By and large the resulting patterns from both geophysical surveys are similar throughout and are dominated by a generally north-northeasterly orientation, as exemplified by the linear magnetic and gravimetric depression cutting through the center of the map area (Figures 6-1 and 6-2). Furthermore, the geophysically expressed orientations are commonly consistent with those of the spatially related topography (Figure 6-1), although they may be locally discordant. For example, the aforementioned north-northeast oriented geophysical low underlies a north-south topographic grain (Figures 6-1 and 6-2), though north-south geophysical trends appear in the east-central portion of the area, near Lake Champlain (Figure 6-1; see also **A** in Figure 6-2a), and in the southwestern corner of the survey area. Discordance is also seen in the northwestern corner of the area where the topographic trend is distinctly northwest, but the geophysical trend is northeast (Figure 6-1). Nevertheless the latter hints at weak northwest trends where the magnetic contours pinch together, suggesting the existence of northwest trending structures that were superimposed on an earlier formed northeast fabric (see **B** in Figure 6-2a).

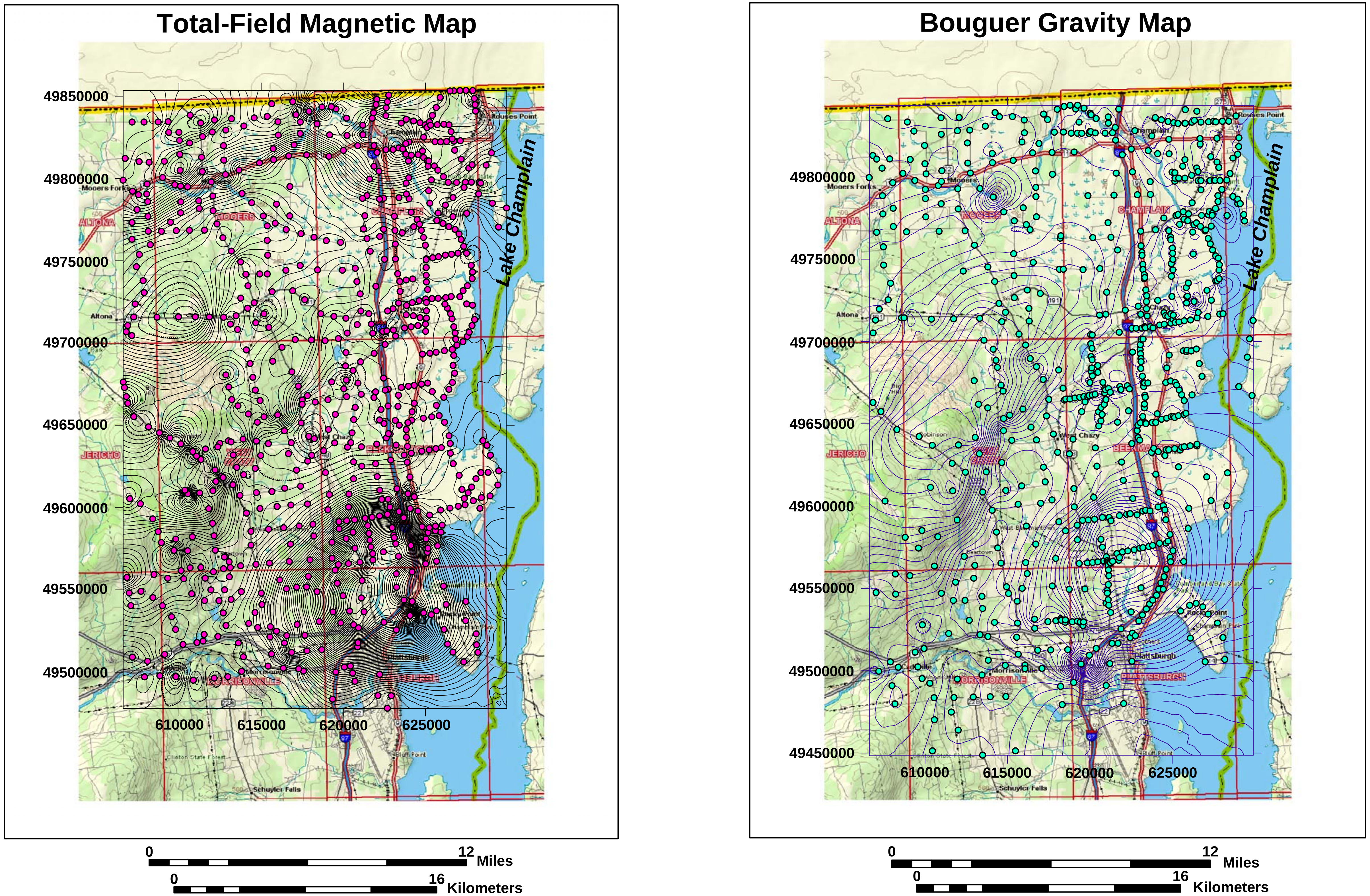
Across the northern part of the area a broad arcuate pattern is displayed by the magnetic data (see **C** in Figure 6-2a), but is only hinted at by the gravity data. There the magnetic pattern is marked by very steep gradients, suggestive of possible faulting, but it corresponds nicely to folding inferred from bedrock orientation data in the same area (Figure 5-1). Gravity data show the east-northeast trend west of the nose of that fold, but east of the nose, the northwest oriented fabric is not evident, though its presence is suggested (see **C** in Figure 6-2b). More conspicuous, however, is the truncation of that fold pattern by a nearly north-south gravity gradient that parallels the Champlain valley (see **D** in Figure 6-2b), and implies faulting. East of the fold there is a northwest oriented linear separation of two relatively high magnetic anomalies (see **E** in Figure 6-2a) that coincides with both a fault and a segment of the Great Chazy River (Figure 5-1). The same linear orientation is also recognizable on the gravity map (see **E** in Figure 6-2b).

Most prominent of the unexpected features are strongly expressed positive magnetic and gravity anomalies in the southeastern corner of the map area (Figures 6-1 and 6-2). Magnetic data reveal a triple maxima in the center of the approximately circular anomaly, the orientations of which are west-northwest and north-northeast (see **F** in Figure 6-2a). Gravity data do not show the triple maxima, rather the central portion is nearly symmetrical (See **F** in Figure 6-2b). Outward from the center the gravimetric pattern shows a slight north-northeasterly elongation of the anomaly, which becomes progressively more pronounced in the 0 to -6 milligal range (Figures 6-1b and 6-2b).

Near the center of those anomalies is a mafic dike which cuts the Crown Point Limestone (Figure 5-11). That dike was emplaced in one member of a fracture that trends west-northwest and is, therefore, parallel to the west-northwest orientation defined by two of the magnetic maxima. The presence of the mafic dike, and the shape and strength of the anomalies all suggest the existence of a subsurface basic intrusive, possibly gabbroic in composition, from which the dike emanated. The age of that intrusive is unknown, but because the dike cuts the Lower Ordovician Crown Point Limestone, and because reported igneous activity in the region is grouped as either Cambrian or Jurassic-Cretaceous in age (Isachsen et al, 1988), it is assumed that the intrusive would have been emplaced during the younger interval.

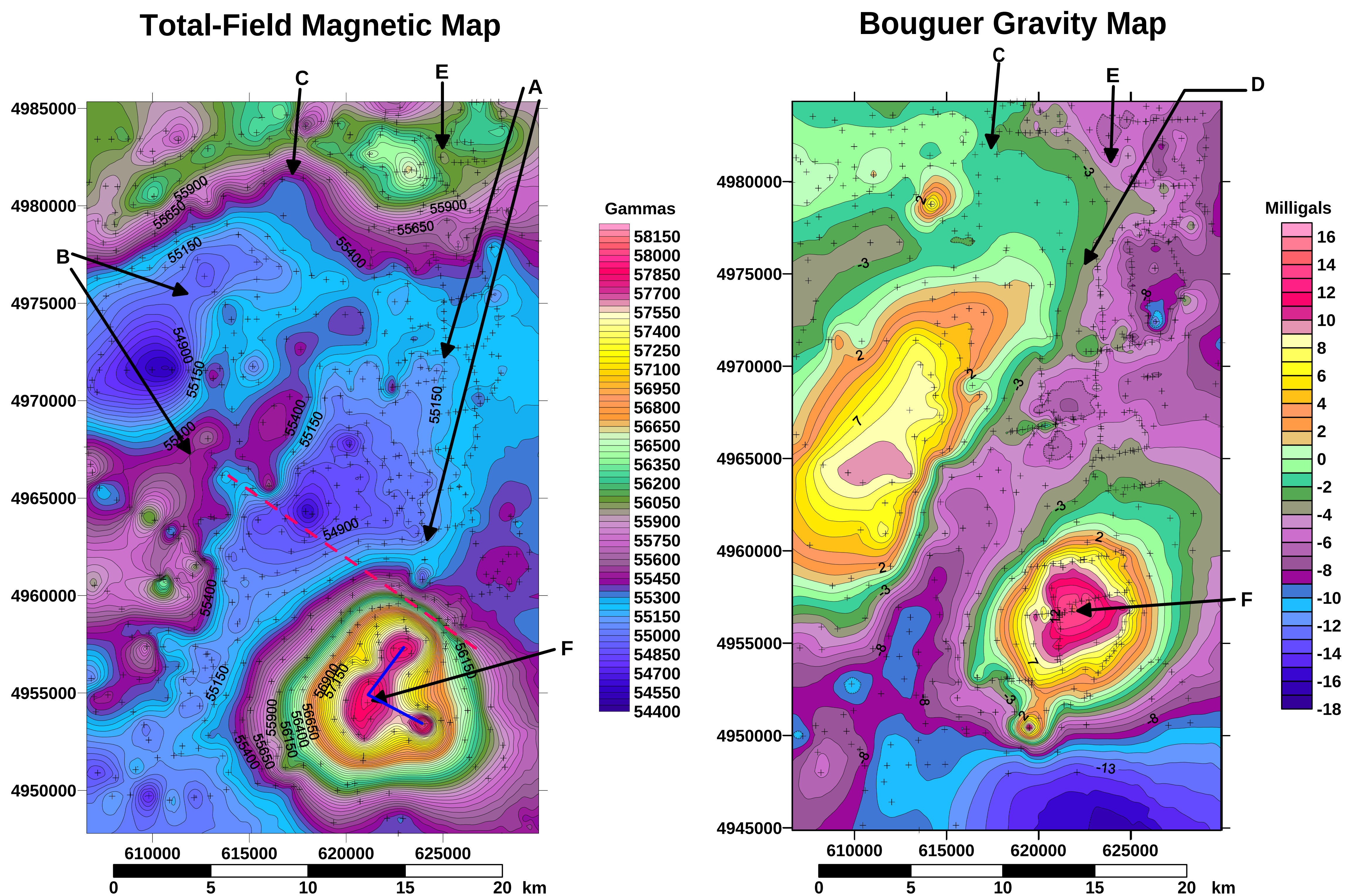
Northwest oriented faulting along the northern edge of the presumed pluton (dashed red line, Figure 6-2a) is suggested by the very steep magnetic gradient, but no clear-cut evidence of that inferred fault was recognized from the geological mapping on the surface at that location. On the other hand a parallel fault, located just to the south, was inferred from tilted bedrock in the Oxford Dolostone and is portrayed as marking the contact between the Oxford and the younger Day Point Limestone (Figure 5-1).

The shape of the inferred pluton and the west-northwest orientation of the spatially related dike suggest syntectonic igneous activity. In that scenario, a compressive stress field with the maximum horizontal compressive stress oriented west-northwest would have existed and would account for extension of pre-existing or newly created west-northwest fractures that, in turn, could serve as conduits for upwelling magma. That would also be consistent with a northwesterly shortening and northeasterly extension of the still warm intrusive mass. Alternatively the north-northeasterly alignment of two of the magnetic maxima and the somewhat north-northeasterly elongation of the anomaly might simply reflect the control of pre-existing structures on the overall emplacement pattern of the inferred pluton.



(a) (b)

Figure 6-1 Contoured Total-Field Magnetic Intensity (a) and Bouguer Gravity (b) Data From Ground-Based Surveys Superimposed on a Topographic Base Map. Coordinates are UTM 1983 NAD. Magnetometer Stations (Red Circles), Gravity Meter Stations (Green Circles); Magnetic Contour Interval – 50 gammas; Gravity Contour Interval – 1 milligal; Topographic Contour Interval – 50 Feet.



(a) (b)

Figure 6-2 Color-Filled Total-Field Magnetic Intensity (a) and Bouguer Gravity (b) Data From Ground-Based Surveys. Coordinates are UTM 1983 NAD. Note Prominent North-Northeast Lows in Center of Maps. A – North-South Magnetic Fabric, B – Pinched Contours Showing Northwest Trend, C – Arcuate Fold Pattern, D – North-Northeast Trending Gravity Fabric Truncating Possible Gravity Expression of Fold Seen in (a), E – Fault Along Great Chazy River, F Center of Inferred Gabbroic Pluton. Blue Lines in (a) – Triple Magnetic Maxima in Pluton. Dashed Red Line – Inferred Fault Truncating Pluton.

Chapter 7 EAST-WEST STRUCTURES

7.1 FAULTS

Immediately north of the international boundary lies Covey Hill, a prominent east-west trending mountain that dominates the local topography (Figures 7-1 and 7-2). The Covey Hill sandstone is exposed at the top and at lower elevations along the northern flank of the mountain, but further to the north, and at still lower elevations, the younger, white Nepean Formation is at the surface (Figure 7-3). South of, and lower than, the summit of Covey Hill, but at higher elevations then on the northern flank, the Nepean is also exposed at the surface (Figure 7-3). Thus, it appears that east-west faults bound Covey Hill, and have resulted in its uplift relative to the adjacent areas both to the north and south. The contours outlining Covey Hill give the impression that they truncate the northeast and north-south physiographic and structural trends of the area to the north and east (Figure 7-2) implying, therefore, that the east-west faults responsible for Covey Hill would have post-dated the development of those trends. East-west faulting also occurs along the Ottawa graben in the Montreal area (Clark, 1972) and marks the uplift of Rigaud Mountain, a Precambrian inlier located west of Montreal. At Station PL-6 on Lake Champlain, south of Plattsburgh (Figures 5-1 and 5-2), an east-west fault denotes a prominent cliff boundary between the Glens Falls Formation of the Trenton Group and the older, but topographically higher, Day Point Formation of the Chazy Group. Other small ones are also suggested from both relatively short topographic and magnetic lineaments, near Stations MOR-2 and WC-20 (Figures 5-1 and 5-2).

7.2 DIKES

During this study post-Grenvillian dikes were identified in different units within the Precambrian basement and in the Crown Point Limestone, the middle member of the Chazy Group (Figure 5-10). Other dikes were also recognized, both in the basement and in Paleozoic units, by Hudson and Cushing (1931), Fisher (1968), and Isachsen et al (1988), all of whom referred to yet earlier investigations. Isachsen et al (1988) described post-Grenvillian dikes located in the area of the northeast Adirondacks, included among which are diabases (±olivine), trachytes and lamprophyres. They noted that five lamprophyre dikes recorded K/Ar ages ranging from 146 to 123 ma, with one trachyte yielding an age of 113 ma. In alluding to previous works Isachsen et al (1988) reported

K/Ar ages of 588-542 ma for diabase and olivine diabase from the Rand Hill dike swarm, located just northwest of Plattsburgh.

Figure 7-1 View of the East-West Elongated, Fault-Bounded Covey Hill Looking Southwest Towards New York State.

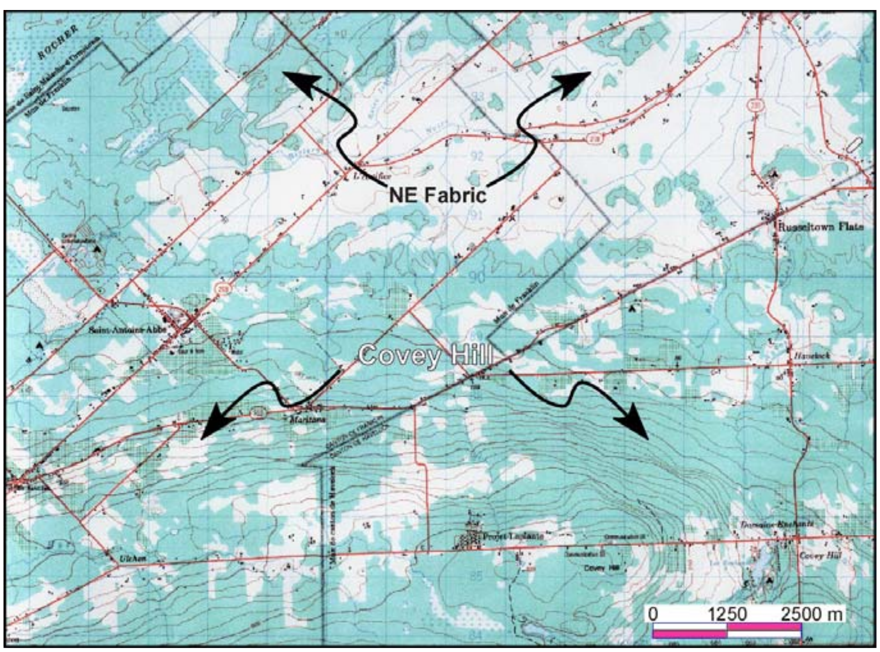


Figure 7-2 Topographic Map Showing the East-West Trend of the Contours of Covey Hill. The Contour Interval is 10 m (≈33 ft).

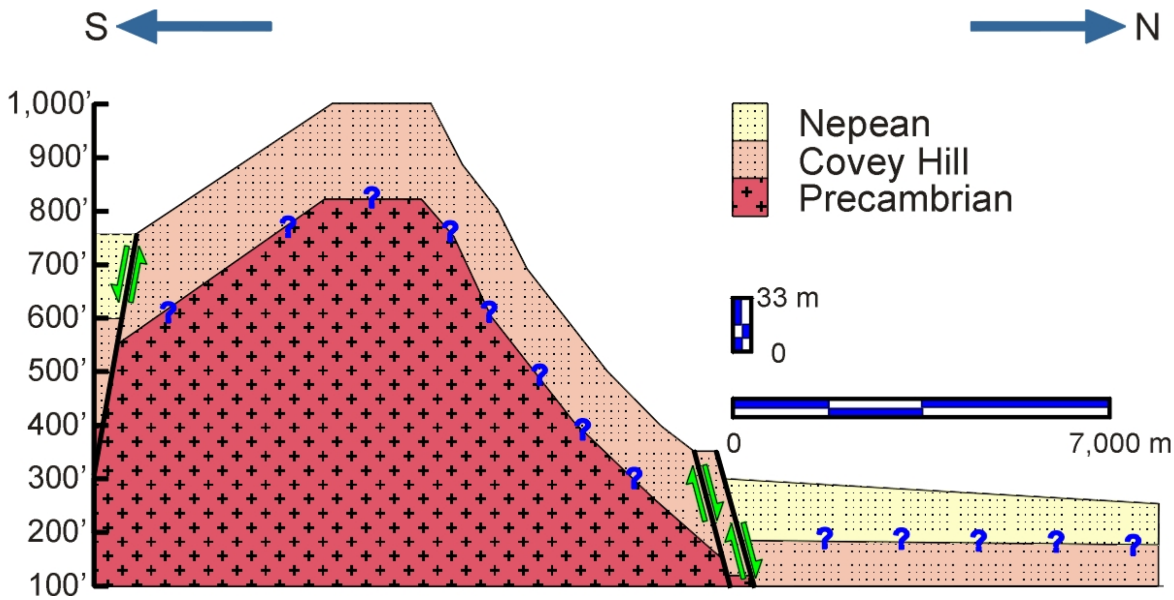
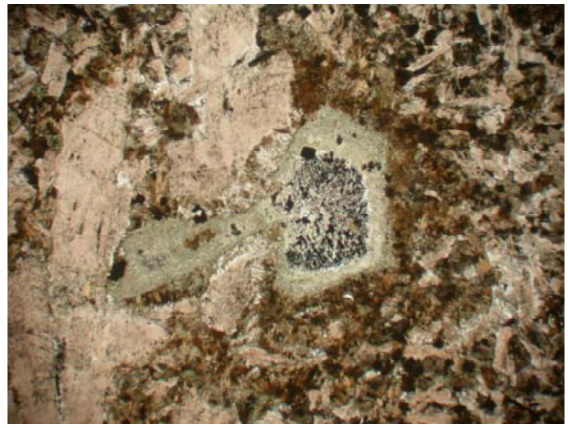


Figure 7-3 **Schematic North-South Cross-Section Through Covey Hill.**

Generally the dikes are porphyritic with an aphanitic groundmass. Most have been classified as lamprophyres, which are porphyritic rocks in which the phenocrysts are uniquely ferromagnesian, meaning that none are plagioclase. Nonetheless there were some mafic dikes which also had plagioclase phenocrysts (Figure 7-4). All dikes that were examined petrographically during this investigation appear to be alkaline and show varying degrees of deuteric alteration, though they are otherwise unmetamorphosed. Samples of thin sections from dikes of the Rand Hill swarm (Isachsen et al, 1988) were sent by Bill Kelly of the New York State Geological Survey and, like those assessed during this study, post-date the regional metamorphism and are deuterically altered.

Aside from biotite, ferromagnesian phenocrysts are generally completely to nearly completely altered. Consequently the original mineral can only be inferred from the preserved euhedral crystal outlines, though vestiges and some nearly pristine crystals of clinopyroxene were identified in thin sections of the mafic dike cutting the Crown Point Limestone at Station PL-9 (Figures 5-1, 5-2 and 5-11). Two minerals common to most of the dikes are plagioclase and biotite, both of which appear as phenocrysts and in the fine-grained matrix. Plagioclase phenocrysts vary from relatively fresh to substantially altered, and biotite may be either well preserved or completely altered to chlorite.

(a)



(b)

Figure 7-4 **(a) Thin Section of a Porphyritic, Deuterically Altered Ferromagnesian Dike, Which Cuts Anorthositic Gabbro at Station WC-9 (Figures 5-1 and 5-2). Randomly Oriented Plagioclase Phenocrysts and Pseudomorphs After Former Ferromagnesian Phenocrysts (Presumably Olivine) are Shown. (b) Closeup of the Red Rectangular Area in (a) Showing Plagioclase (Light Colored Mineral) and Pseudomorphic Ferromagnesian Phenocrysts, (Presumably Olivine) Altered to Chlorite (Green) and Iron Oxide (Black). Both in Plane Polarized Light.**

Dikes identified thus far fill pre-existing fractures oriented east-northeast and west–northwest (Figure 7-5), the geometry of which suggests that the fractures may have formed as conjugate strike-slip faults in response to east-west maximum horizontal compression. In many instances there are suggestions of slip having occurred along the fractures following dike emplacement, but kinematic indicators were identified at only one location (Station WC-9, Figures 5-1 and 5-2). There, stepped slickenlines, which pitch 18° on both the host gabbroic anorthosite and black lamprophyre dikes along fractures oriented 075°/90° and 262°/79°, indicate oblique dextral slip following emplacement of the dikes. A third fracture, also along a dike-host rock contact oriented 262°/79°, displays evidence of two episodes of oblique, right-lateral slip, with the older and younger showing pitches of 20° and 40°, respectively.

The dikes are important because of their tectonic implications, which may also be an important factor in assessing natural gas potential. There is, however, a question about the reported ages, cited above. The ages may be correct, but all of the dikes are deuterically altered and most are ferromagnesian. Thus, albeit not highly likely, it is possible that the dikes may all have been emplaced during the same geological event which would, therefore, imply that one set of the cited K/Ar dates is unreliable. The Cretaceous ages of the Monteregian Hills and associated dikes in the Montreal-Eastern Townships area of Quebec suggest, but by no means prove, that the older set of ages may be incorrect. It has been suggested that zircon ages would prove to be much more dependable, but dating the rocks was beyond the scope of this study.

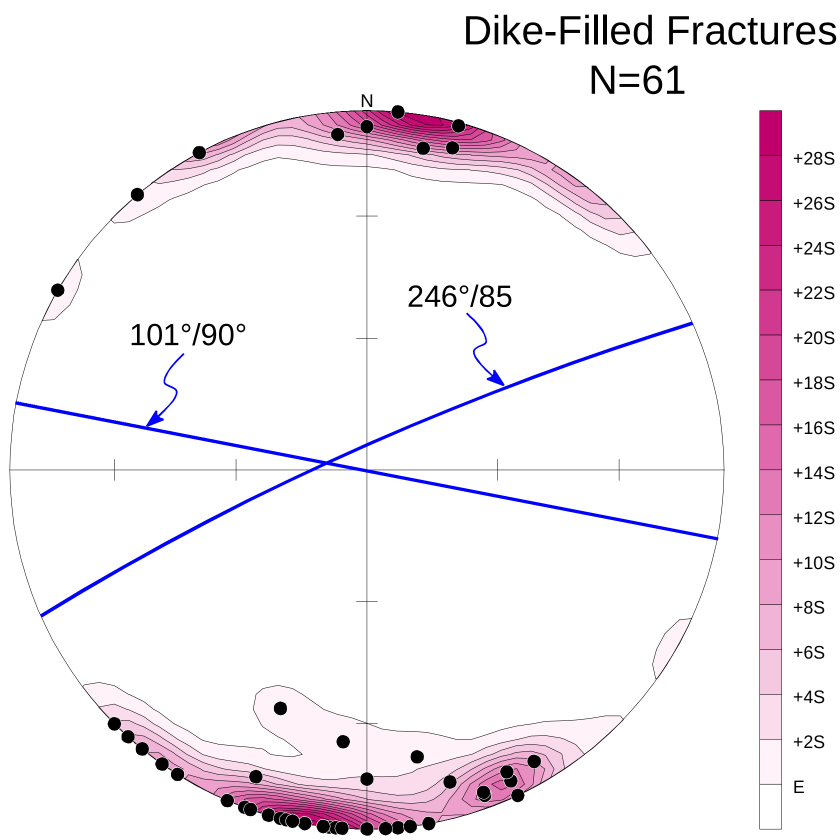


Figure 7-5 **Equal area, Lower Hemisphere Projection of Poles to, and Planar Surfaces Representing, Dike-Filled Fractures.**

Chapter 8 TECTONIC AGE RELATIONSHIPS

8.1 PALEOTECTONISM

Subsurface data show the presence of thrust sheets overlying and truncating approximately north-south trending normal faults (Figure 8-1), which suggests that those normal faults are the oldest identifiable Phanerozoic structures in the study area. That implies that the compression responsible for the approximately north-south trending folds and overthrusts, including the outcrop-scale bedding plane thrusts and the Lacolle Breccia (Figures 5-13 to 5-15), succeeded a period of crustal extension. Following the crustal compression was a second occurrence of normal displacements along north-south to north-northeast striking faults, inferred from the disruption of the fold pattern seen in Figure 5-1, although it is acknowledged that interpretation predominates over observations due to the scarcity of outcrops. Support for that interpretation, however, comes from outcrop scale observations made at Station BE-22 (Figures 5-1 and 5-2) where brittle normal fault movement has displaced layers within the inclined hinge of a flexural-slip fold (Figure 5-9). Additional and larger scale evidence comes from the area of Montmorency Falls, just east of Quebec City. There low angle reverse faults and associated asymmetrical folds in the Utica Shale have been rotated along with bedding as a consequence of drag along the major Montmorency normal fault which has juxtaposed Trenton Group limestone and the Utica Shale (Figure 8-2).

8.2 RECENT UPLIFT

Earthquakes and other expressions of neotectonic activity indicate that the region is not geologically tranquil. High horizontal stresses, with the greatest principal horizontal compressive stress oriented nominally northeast, have been documented by, e.g. McKay (1986), and displaced boreholes and pop-ups, both of which are kinematically congruent with the contemporaneous stress field, were discussed by Wallach et al. (1993). In and near the Adirondacks some of the most impressive earthquakes in New York State have occurred, including the 1944 Cornwall-Massena event, a magnitude 5.8, the 1983 Goodnow earthquake, a magnitude (m_b) 5.1 event and, most recently, the Ausable Forks earthquake in 2002 which registered about M=5.1. Fault plane solutions and geological observations of faults in the epicentral area of the Goodnow earthquake reveal excellent agreement, with both indicative of high angle reverse faulting along north-northwest-trending surfaces, again in kinematic agreement with the current ambient stress field. According to Dawers and Seeber (1990), reverse faulting with a small component of dextral slip along the interpreted rupture surface oriented 345°/60°W was responsible for the Goodnow earthquake. Moreover an outcrop within the epicentral area reveals seven faults which range in strike from 313° to 355° and in dip from 50°W to 89°E

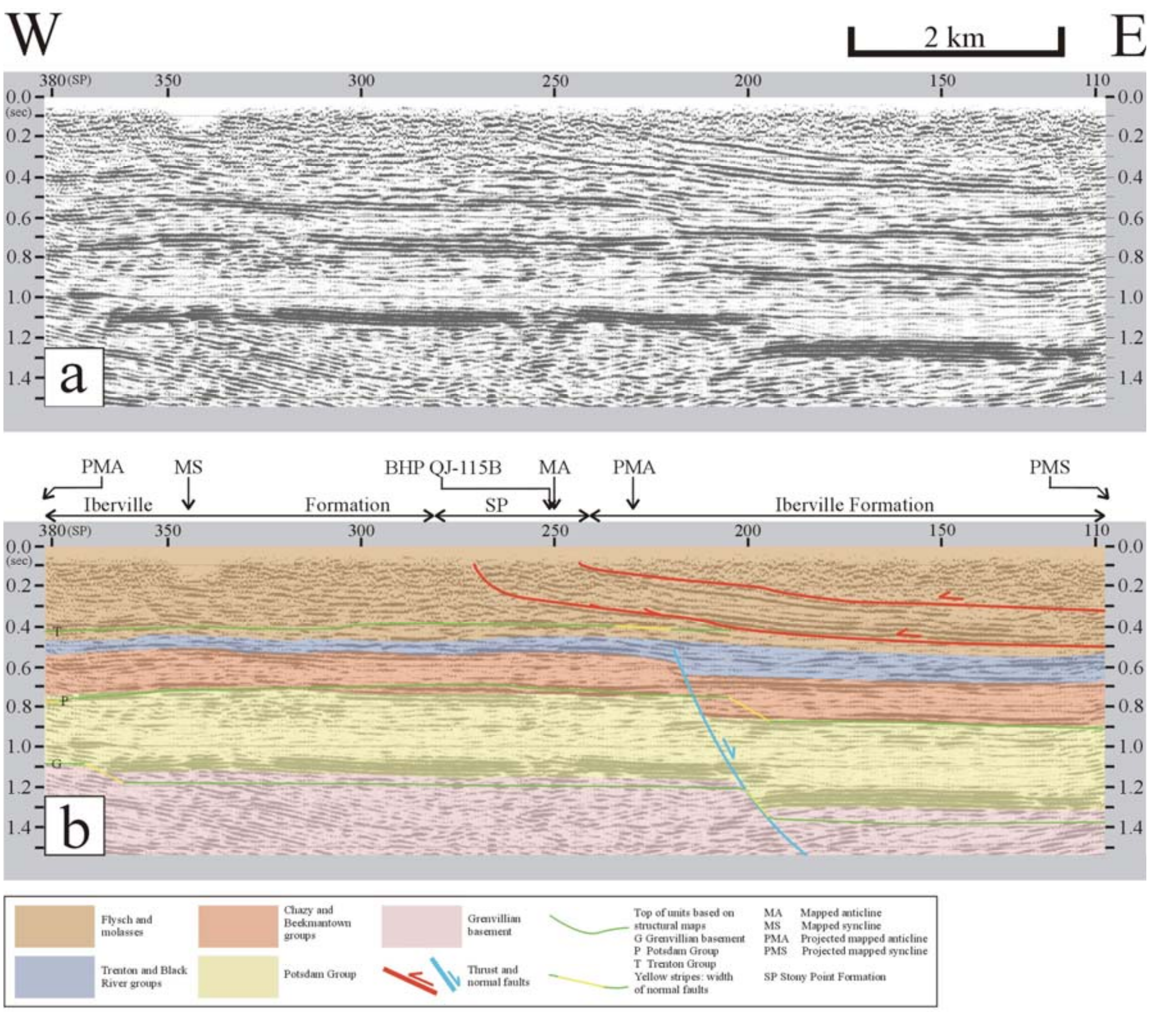


Figure 8-1 **East-West Seismic Profile Across Lac Missisquoi, the Northern Extension of Lake Champlain In Quebec. (a) Uninterpreted; (b) Interpreted. Note in (b) the presence of overthrust sheets (curving red lines) overlying and truncating the normal fault (curving blue line). (Interpretation by Stephan Séjourné)**

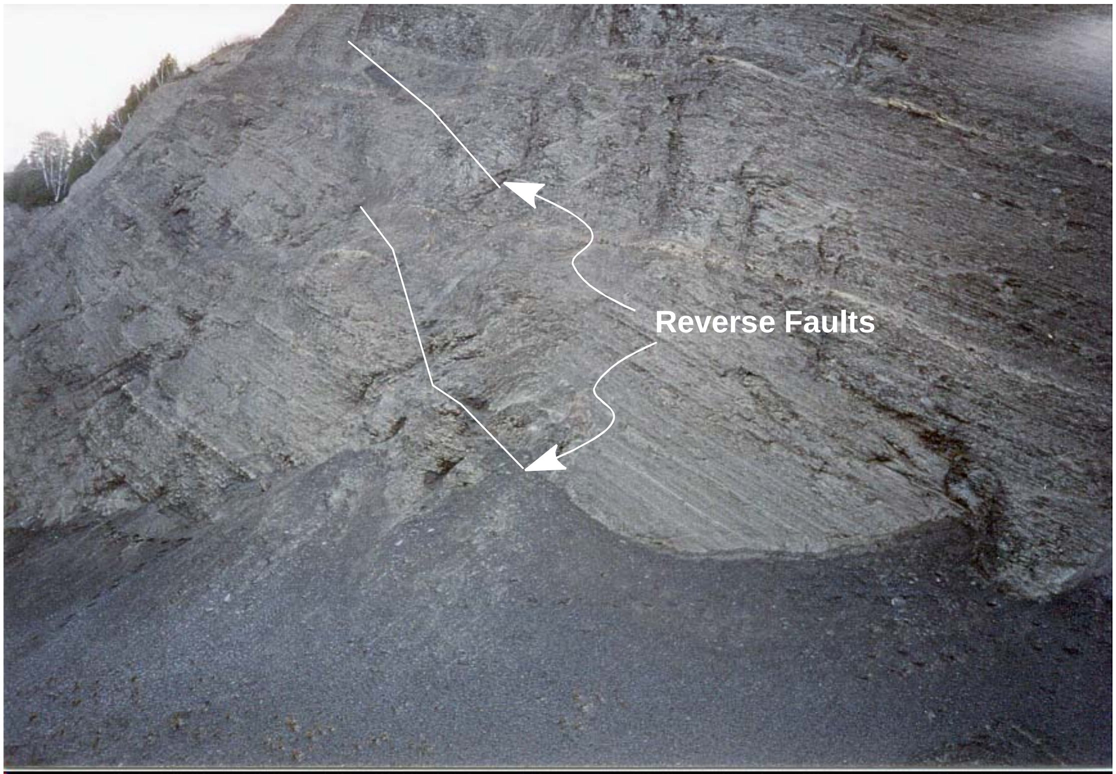


Figure 8-2 **Rotated reverse faults in the dipping Utica Shale at Montmorency Falls, Quebec City. Curving beds are drag along the hanging wall of the lower of the two faults. Rotation of the Utica is a consequence of drag along the Montmorency normal fault within the St. Lawrence fault zone.**

Besides the seismicity, terraces were identified along the northern rim of the Adirondack Mountains, in terrain underlain by the Nepean and Covey Hill sandstones (Figure 8-3). Adjacent to the Adirondacks those units, the oldest of the Paleozoic cover rocks in the area, are topographically higher than stratigraphically younger sedimentary rocks further to the north. Moreover, there are well developed terraces in the unconsolidated sediments overlying those sandstone units indicating that the area was under water, then subsequently uplifted.

Figure 8-3 **Terraces On Potsdam Group Sandstone With Suspected Fault (Green-Covered Slope) in Midground and the Adirondack Mountains in the Background. View Looking Southeast.**

Chapter 9 CONCLUSIONS AND RECOMMENDATIONS

High quality RADARSAT ScanSar, RADARSAT Standard Mode and Landsat ETM enhanced images were produced for an area bordering the northern and the eastern parts of the Adirondack dome in New York State. A database, consisting of value-added products of remotely sensed topographical and geophysical data, was generated and a systematic interpretation of lineaments was undertaken in order to extract a first level of structural information. In general magnetic and gravimetric discontinuities appear to correlate with topographical lineaments, though they may be locally discordant, and many of the topographic lineaments, in turn, represent surface expressions of the major faults. East-northeast, north-northeast and northwest striking lineaments originate within the Adirondacks and extend into the St. Lawrence Lowlands. North-south and east-west sets, however, seem to be largely restricted to the Lowlands or to the Paleozoic rocks along Lake Champlain

North-south to north-northeast trending normal faults dominate the structural landscape and constitute the principal elements of interest in attempting to fulfill the objective of this study. Those structures post-date both an earlier set of normal faults and later reverse faults, the latter having resulted from Paleozoic crustal compression. The younger normal faults have resulted in the blocks on the east side being down-dropped relative to those on the west. That is undoubtedly responsible for creation of the Champlain Valley and accounts for the Lower Paleozoic units at the surface in the Champlain Valley being younger than those exposed at the surface adjacent to the Adirondacks.

Though the north-south to north-northeast structures predominate there is another assemblage of faults comprised of apparently three distinct sets, oriented east-northeast, east-west and west-northwest. Aside from the current uplift of the Adirondack Dome and surrounding areas, it appears that reactivation of that nominally east-west system is among the youngest structural movements in the study area in that it is suspected of being Cretaceous in age. That does not, however, rule out differently oriented structures also having been reactivated either at that time or even more recently. In fact it was displacement along north-northwest and north-northeast striking faults which resulted in the 1983 Goodnow and 2002 Ausable Forks earthquakes, both of which exceeded magnitude 5.

Little is known about natural gas in the areas of New York State bordering the Adirondacks. North of the Canadian border, however, several licenses have been issued to different companies by the Quebec government for subsurface hydrocarbon exploration in the St. Lawrence Lowlands and along the northward projection of Lake Champlain (Figure 9-1). There are indicators of natural gas at a depth of about 480 m (1,580 ft) at the base of the Utica Shale in the Eastern Canada #1 well at St-Jean-sur-Richelieu, Quebec (Jean-Sébastien Marcil, personal communication; see Figure 9-2 for location). At Clarenceville, Quebec, JUNEX identified a domal structure which they plan to investigate and anecdotal information from Vermont suggests the presence of natural gas beneath Lake Champlain. In a joint press release issued in 2001 Ditem and Junex announced an insitu gas potential of 48.08 Bcf spread out among three different locations on the Lacolle Oil and Gas Property, located along the Canadian border (Figure 9-2). They added that the most promising potential reservoirs "*are fractured zones related to regional faulting, folding and hydrothermal alteration in the Paleozoic sedimentary sequence*" which comprises the interval from the Stony Point to the Potsdam, all of which they classified as formations. At the westernmost location, which they named the Lacolle Prospect, potential targets were identified in the Stony Point Formation and in the Beekmantown and Potsdam groups, whereas 4 km and 5.5 km to the east, respectively named the Noyan Prospect and Ash Island Lead, the Trenton and Chazy groups were added to the list of possible stratigraphic targets (Table 9-1).

Table 9-1 Estimated Potential of, and Depths to, Gas Reserves on the Lacolle Oil and Gas Property, Quebec (See Figure 9-2)

TARGET STRATIGRAPHIC UNIT	LACOLLE PROSPECT	NOYAN PROSPECT	ASH ISLAND LEAD
Stony Point	3.29 Bcf @ 670 m	0.59 Bcf @ 530 m	0.64 Bcf @ 470 m
Trenton		2.46 Bcf @ 1,130 m	1.75 Bcf @ 870 m
Chazy		2.84 Bcf @ 1,600 m	1.03 Bcf @ 1,200 m
Beekmantown	8.27 Bcf @ 1,000 m	7.35 Bcf @ 2,000 m & 4.45 Bcf @ 2,460 m	6.19 Bcf @ 1,860 m
Potsdam	3.75 Bcf @ 1,675 m	2.98 Bcf @ 3,330 m	2.47 Bcf @ 2,400 m

(Data from Ditem Press Release)

North of the Adirondack Dome, where the stratigraphy is less complex, there are porous rock units that are also known to be fluid bearing, i.e. the Covey Hill, Nepean and Theresa formations. From Covey Hill north to the Ottawa Embayment of the St. Lawrence Lowlands the units exposed are higher in the stratigraphic section, despite being at lower elevations than on and adjacent to Covey Hill. That implies that the blocks to the north have been downdropped relative to those to the south, presumably along normal faults, thereby leading to the deeper burial of the Covey Hill, Nepean and Theresa formations.

Natural gas has been discovered southwest of Valleyfield, Québec by Ditem Explorations Inc. of Montreal (Figure 9-3). According to another of their press releases, they drilled a borehole 422.8 m deep, which terminated in the Covey Hill Formation. They also conducted at least one seismic survey which, when combined with the drilling, led to the recognition of reservoirs in the Beauharnois (equivalent to the Oxford) and Theresa formations within a sequence of dolomitized, intensely fractured rock; Ditem stated that those reservoirs may contain economic quantities of natural gas.

As a consequence of the present investigation and the information available from southern Quebec, detailed studies of both the Champlain Valley in New York-Vermont and the St. Lawrence Lowland basin in Quebec, in the search for natural gas, are highly recommended. In New York the focus should be on subsurface work, whereas in Vermont and Quebec some reconnaissance and detailed remote sensing, geology and geophysical surveys at the surface are suggested prior to undertaking any subsurface investigations. With respect to the faults in the exposed Precambrian basement of the Adirondack Dome, emphasis should be placed on the north-northwest, west-northwest and north-northeast oriented sets which extend into the adjacent Paleozoic cover rocks. Some of those faults are currently active, as attested to by the spatially related seismicity. Depending on the properties of the active faults, asperities along them can result in their being opened which, all other conditions being equal, may contribute to hydrocarbon flow and the subsequent development of gas reservoirs. On the eastern side of the study area, along Lake Champlain, the probable extension of east-northeast and northwest oriented faults, which originate in the Adirondacks, should also be checked in addition to the aforementioned north-south and north-northeast faults.

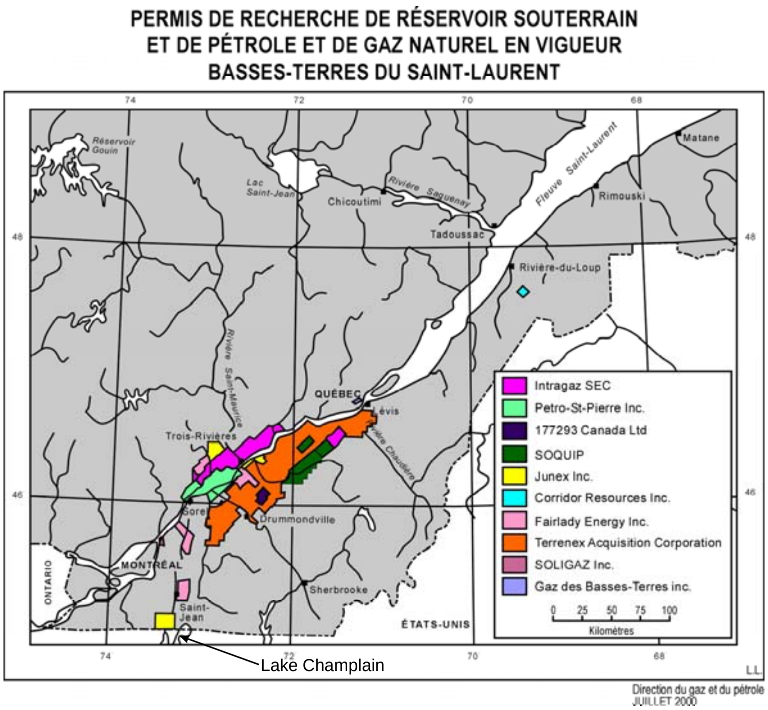


Figure 9-1 **Map of Properties Licensed by the Gas and Oil Directorate of the Quebec Department of Natural Resources for Subsurface Natural Gas and Oil Exploration. Issued July, 2000.**

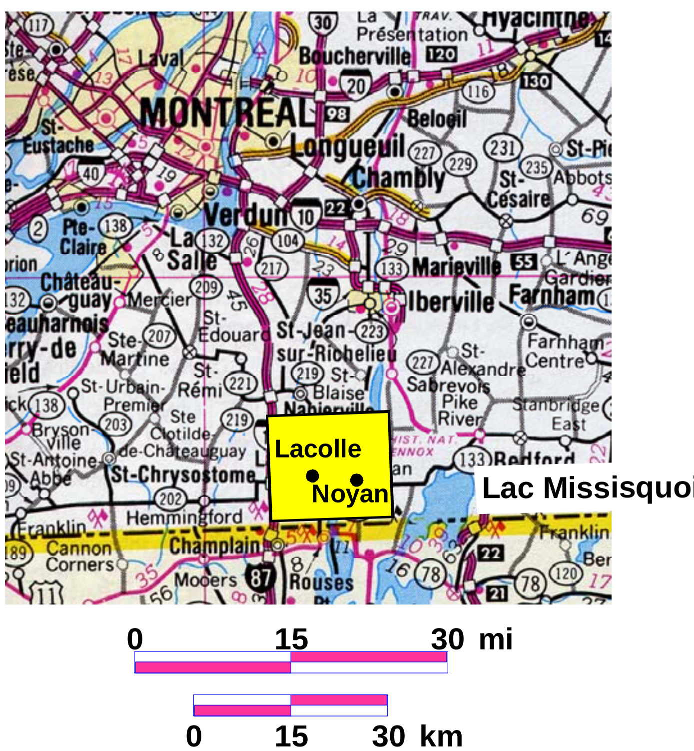


Figure 9-2 **Approximate Location of the Lacolle Oil and Gas Property in Quebec (gold-colored box), Just North of New York State (International Boundary Marked by Black Dashed Line and Golden Stripe).**

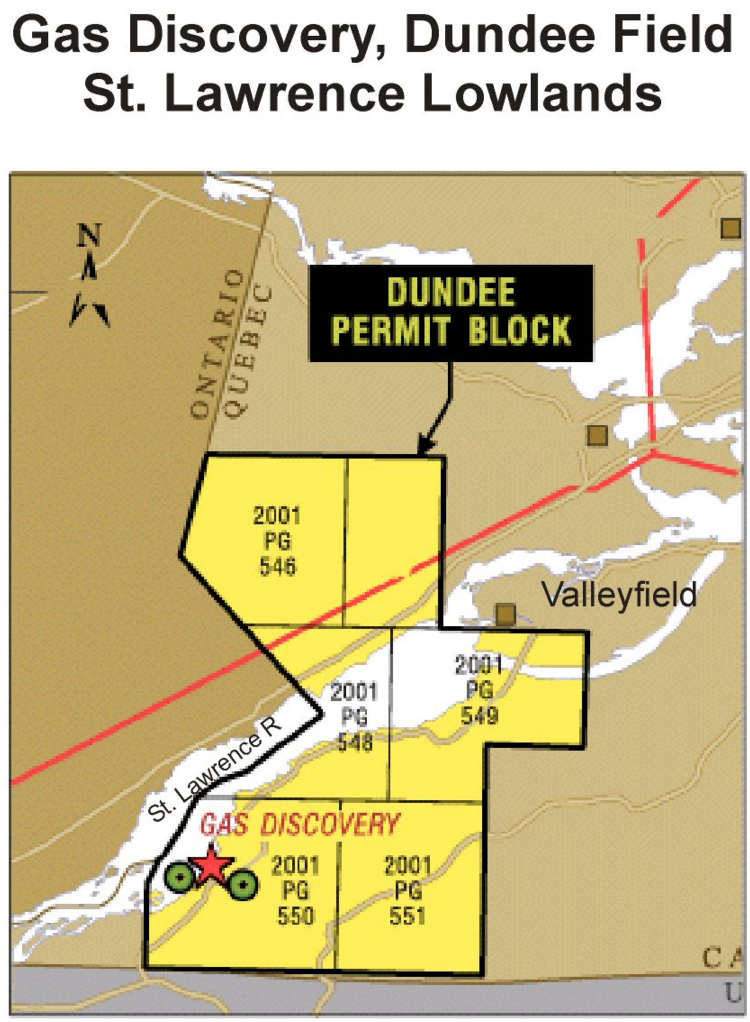


Figure 9-3 **Map of The Dundee Gas Field, Southwest of Valleyfield, Quebec, Just North of New York State.**

Chapter 10 SELECTED REFERENCES

Billman, D.A. and Fagan, J.P., 1998. Hydrocarbon potential of the St. Lawrence Lowlands of northern New York. American Association of Petroleum Geologists, v. 82, no. 9, p. 1765.

Buddington A.F., 1937. Geology of the Santa Clara Quadrangle. New York State Museum Bulletin, Number 309, 56 p.

Buddington, A.F. and Whitcomb, L., 1941. Geology of the Willsboro Quadrangle, New York. New York State Museum Bulletin, Number 325, 137 p. plus map.

Cadwell Donald H. and Pair, Donald L., 1991, Surficial Geological Map of New York at 1: 250,000, Adirondack Sheet, The University of the State of New York, the State Education Department.

Castonguay, S; Tremblay, D; Lavoie, D. Geologic compilation map : Montréal-Mégantic, Appalachian section : Geological Bridges of eastern Canada transect 1.

Castonguay, S; Dietrich, J R; Morin, C; Laliberte, J -Y., 2001, Structural architecture of the St. Lawrence platform and Quebec Appalachians: insights from reprocessed (MNRQ) seismic reflection data, Geological Survey of Canada.

Clark, T.H., 1972. Montreal area. Ministère des Richesses Naturelles, Geological Report 152, 244 p. plus map.

Dawers, N.H., and Seeber, L., 1991. Intraplate faults revealed in crystalline bedrock in the 1983 Goodnow and 1985 Ardsley epicentral areas, New York, Tectonophysics, v. 186, p. 115-131.

Dobrin, M.B., 1960. Geophysical Prospecting. McGraw-Hill Book Company, 446 p.

Dykstra, J.C.F. and Longman, M.W., 1995. Gas reservoir potential of the Lower Ordovician Beekmantown Group, Quebec Lowlands, Canada. American Association of Petroleum Geologists Bulletin, v. 79, pp. 513-530.

Erwin, R.B., 1957. The geology of the limestone of Isle La Motte and South Hero Island, Vermont. Vermont Geological Survey Bulletin, Number 9, 94 p. plus plates and map.

Fisher, D.W., 1968. Geology of the Plattsburgh and Rouses Point, New York – Vermont Quadrangles. New York State Museum and Science Service Map and Chart Series Number 10, 51 p. plus plates.

Globensky, Y., 1987. Géologie des Basses–Terres du St-Laurent. Ministère de l'Énergie et des Ressources du Quebec, MM 85-02, 63 p. plus map.

Hawley, D., 1957. Ordovician slates and submarine breccias of northern Champlain Valley in Vermont. Bulletin of the Geological Society of America, v. 68, pp. 55-94.

Hudson, G.H., 1931. The fault systems of the northern Champlain Valley, New York. New York State Museum Bulletin, Number 286, 77 p. plus figures

Hudson, G.H. and Cushing, H.P., 1931. The dike invasions of the Champlain Valley, New York. New York State Museum Bulletin, Number 286, pp. 81-112

Isachsen, Y. W. and Fisher, D.W., 1970. Geologic Map of New York, Adirondack Sheet. 1:250,000. The University of the State of New York, the State Education Department.

Isachsen, Y.W., Kelly, W.M., Sinton, C., Coish, R.A. and Heizler, M.T., 1988. Dikes of the northeast Adirondack Region – introduction to their distribution, orientation, mineralogy, chronology, magnetism, chemistry and mystery. In Olmstead, J.F., editor. New York State Geological Association, 60th Annual Meeting, Field Trip Guidebook, pp. 215-243.

Lavoie, D; Bolduc, A; Castonguay, S; Malo, M; Ross, M; Salad Hersi, O; Sejourne, S; Tremblay, A; Lauziere, K; McIntosh, 2001, A. The St. Lawrence Platform, Humber Zone, and Quaternary successions along Transect #1: Montreal-Appalachians, Geological Survey of Canada.

Loewenstein, S., 1997. Presentation at the 17th Annual Meeting of IOGANY, Amherst, N.Y., September 24.

McKay, D.A., 1986. Roblindale Quarry stress measurements: preliminary evaluation-Phase 1. Ontario Hydro Research Division, Report No. 86-43-P: 144 pp.

Oxley, P., and Kay, M., 1959. Ordovician Chazyan Series of Champlain Valley. New York and Vermont, and its reefs. Bulletin of the American Association of Petroleum Geologists, v. 43, pp. 817-853.

Quinn, A.W., 1933. Normal faults in the Lake Champlain Region. Journal of Geology, v. XLI, pp. 113-143.

Rocher, M.;Tremblay, A.;Nadeau, L.;Lavoie, D. , 2000, Analyse structurale et tectonique de la plate-forme du Saint-Laurent (Quebec, Canada): resultats preliminaires, Commission geologique du Canada.

Sanford, B.V., 1993. St. Lawrence Platform – Geology. Chapter 11 in Sedimentary Cover of the Craton in Canada, D.F. Stott and J.D. Aitken (eds.). Geological Survey of Canada, Geology of Canada, no 5. pp. 723-786.

Sanford, B.V., Thompson, F.J. and McFall, G.H., 1985. Plate Tectonics - A possible controlling mechanism in the development of hydrocarbon traps in southwestern Ontario. Bulletin of Canadian Petroleum Geology, v. 33, no. 1, pp. 52-71.

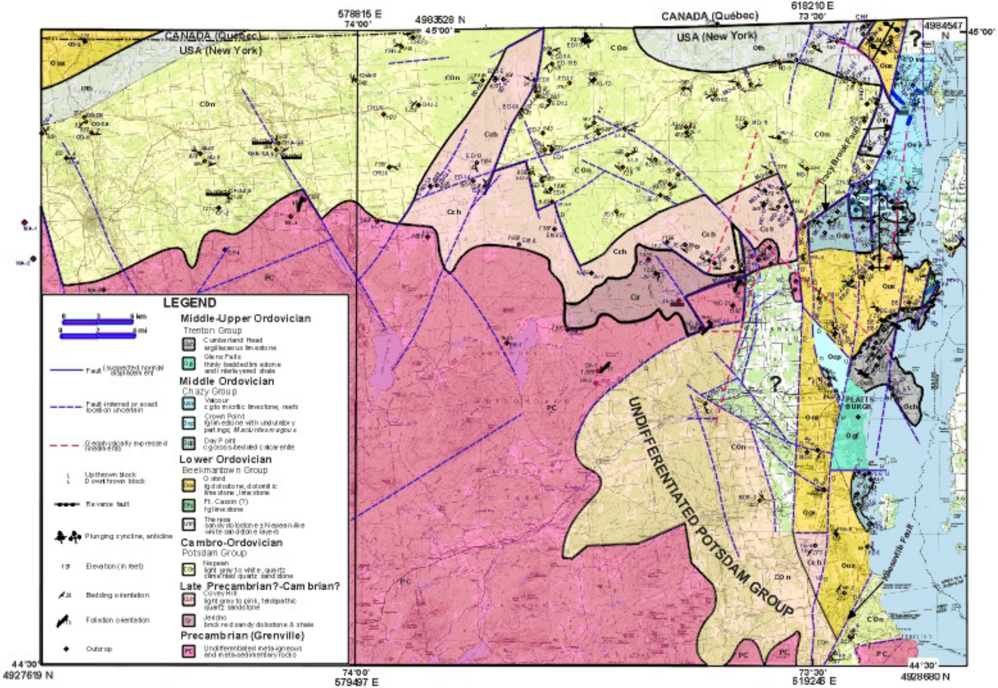
Séjourné, Stephane; Dietrich,Jim R. and Malo, Michel, 2002. New interpretation of industry seismic lines, southern Quebec Appalachians foreland. Geological Survey of Canada, Current Research, D1.

Shaw, F., 1969. Stratigraphy of the Chazy Group (Middle Ordovician). New York State Geological Association Guidebook to Field Excursions, 41st Annual Meeting. State University College of Arts and Science, Plattsburgh, New York, pp. 81-92.

Stone, D., 1957. Origin and significance of breccias along northwestern side of Lake Champlain. Journal of Geology, v. 65, pp. 85-97.

Wallach, J.L., 2002. The presence, characteristics and earthquake implications of the St. Lawrence fault zone within and near Lake Ontario (Canada-USA). Tectonophysics, v. 353, pp. 45-74.

Wallach, J.L., Mohajer, A.A., McFall, G.H., Bowlby, J.R., Pearce, M., and McKay, D.A. 1993. Pop-ups as geological indicators of earthquake-prone areas in intraplate eastern North America. In Neotectonics: Recent Advances. Edited by L.A. Owen, I. Stewart and C. Vita-Finzi. Quaternary Proceedings, **3**: pp. 63-79.



578815 E
74°00'
4983528 N
45°00'
CANADA (Québec)
USA (New York)
618210 E
73°30'
4984547 N
45°00'
?
Tracy Brook Fault
UNDIFFERENTIATED POTSDAM GROUP
PLATTSBURGH
Cumberland Head Fault
44°30'
4927619 N
74°00'
579497 E
73°30'
619245 E
44°30'
4928680 N
LEGEND
0 2 4 km
0 2 4 mi
Fault (suspected normal displacement)
Fault inferred or exact location uncertain
Geophysically expressed lineaments
Upthrown block
Downthrown block
Reverse fault
Plunging syncline, anticline
Elevation (in feet)
Bedding orientation
Foliation orientation
Outcrop
Middle-Upper Ordovician
Trenton Group
Cumberland Head argillaceous limestone
Glens Falls thinly bedded limestone and interlayered shale
Middle Ordovician
Chazy Group
Valcour c-gr to micritic limestone; reefs
Crown Point fg limestone with undulatory partings; Maclurites magnus
Day Point cg cross-bedded calcarenite
Lower Ordovician
Beekmantown Group
Oxford fg dolostone, dolomitic limestone, limestone
Ft. Cassin (?) fg limestone
Theresa sandy dolostone ± Nepean-like white sandstone layers
Cambro-Ordovician
Potsdam Group
Nepean light gray to white, quartz cemented quartz sandstone
Late Precambrian?-Cambrian?
Covey Hill light gray to pink, feldspathic quartz sandstone
Jericho brick red sandy dolostone & shale
Precambrian (Grenville)
Undifferentiated meta-igneous and meta-sedimentary rocks