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**LENNOXVILLE GLACIATION OF THE MIDDLE CHAUDIERE AND
ETCHEMIN VALLEYS, BEAUCE REGION, QUEBEC.**

by

Andrée Blais, B.Sc.

A thesis submitted to
the Faculty of Graduate Studies
in partial fulfilment of
the requirements for the degree of
Master of Science

Department of Earth Sciences
Centre Géoscientifique d' Ottawa-Carleton
Ottawa-Carleton Geoscience Centre

Carleton University

Ottawa, Ontario

December 1989.

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The undersigned hereby recommend to
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Frontispiece. Largest boulder observed in the study area; located east of Vallée-Jonction.

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La réalisation de cette thèse n'aurait pu avoir lieu sans les soutiens financier et technique de la Commission Géologique du Canada. J'aimerais remercier le Dr. W.W. Shilts de la Commission Géologique qui m'a offert ce projet de cartographie dans une région unique du Québec. Toujours disponible, le Dr. Shilts a su partager ses connaissances. Je lui suis très reconnaissante. Son encouragement, sa patience et sa contribution aux discussions sur le terrain et à l'édition de ce manuscrit ont été fortement appréciés. J'aimerais aussi remercier mon directeur de thèse, le Dr. F.A. Michel de l'Université Carleton pour ses bons conseils lors de sa révision du présent manuscrit et son appui.

Le Dr. M. Rappol, le Dr. P. Henderson, et Inez Kettles m'ont enseigné des techniques de terrain qui ont amélioré la qualité du travail de recherche. De plus, j' ai profité de l'aide technique de Denyse Blais-Saydeh, de Stéphane Péloquin, de Josée Samson, de Pierre Blais et de Leslie Grignon. J'ai aussi participé à de bonnes discussions sur le terrain avec plusieurs gens. Toutefois, j'aimerais souligner l'apport du Dr B.R. Rust, de Dave Sharpe, de Geoff Burbidge et de Stewart Hamilton. De plus, Rob Burns, le Dr. L. H. Thorieifson, Alain Plouffe ont pris le temps de m'aider avec plusieurs logiciels.

Bref, j'ai apprécié le soutien moral de ma famille, de Heather, d'Alain, de Stewart et de Jennifer.

ABSTRACT

The objective of this study was to interpret the late-Wisconsinan glacial and deglacial events in the central Chaudière Valley. To achieve this objective a 1:50 000 scale map was compiled of glacial and post-glacial sediments. In addition to the sediment mapping, glacial striae were measured and compiled, geochemical dispersal was mapped for the surface till, and till stratigraphy was defined by measuring sections and determining fabrics. Texture, structure and paleocurrents of ice-contact stratified drift were studied to determine the style of deglaciation in the region.

Northward ice flow, that was previously known in the study area, was believed to have been caused by a calving bay penetrating up the St. Lawrence channel, producing in the ice sheet an embayment that interrupted southeastward ice flow across the St. Lawrence depression, even west of where the bay actually existed. Ice left south of the channel was thought to have flowed northward as a result, toward the axis of drawdown.

On the basis of previous work and field observations made during this study, a model for the last Wisconsinan Lennoxville glaciation has been synthesized.

1) Southeastward ice flowed across the Appalachians during the major part of the Lennoxville glaciation, probably to the sea in New England and New York.

2) With a warming climate, deterioration of the ice sheet caused sea level to rise, forming a calving bay in the lower St. Lawrence Estuary. To replace ice that was wasting rapidly in the bay, ice from progressively farther up the depression was redirected northeastward along the depression toward the point of enhanced wastage. This caused ice south of the channel, formerly flowing southeastwardly across the Appalachians, to be redirected northward, towards the St. Lawrence depression.

3) Ice flow reversal caused the supply of Laurentide ice to be cut off from the Appalachians which eventually caused the ice sheet to split, along the Appalachian Front, into two ice masses: 1) the Laurentide ice mass and 2) the Appalachian ice mass.

4) The Laurentide ice mass, resting against the northward facing front of the Appalachians prevented the Champlain Sea from invading the western St. Lawrence Lowlands and ponded drainage of northward flowing, south shore tributaries such as the Chaudière and Etchemin Rivers to form a proglacial lake. The southward retreating front of the shrinking remnant of Appalachian ice mass was submerged in these proglacial lakes and left behind ice-contact stratified deposits that were deposited in part subaqueously.

5) With renewed, but brief, climatic deterioration, the Laurentide ice mass readvanced as long, narrow lobes up the two major valleys and against parts of the highlands west of the Chaudière River, in the latter case forming deposits that make up portions of a complex formerly mapped as the Highland Front Moraine.

6) As the lobes retreated, subaqueous outwash and related sediments were deposited at irregular intervals in front of the lobes and along lower parts of the highlands. At Vallée-Jonction, a massive subaqueous fan deposit at one time filled the entire Chaudière Valley with over 50 m of coarse-grained sediments.

7) As Laurentide ice retreated north of the St. Lawrence channel from the narrows of Québec City, the incursion of the Champlain Sea into the St. Lawrence Lowlands took place.

RESUME

Le but de cette étude était d'interpréter les épisodes de glaciation et de déglaciation dans la partie centrale de la vallée de la rivière Chaudière durant la fin de la période wisconsinienne. Dans la poursuite de ce but, il a fallu dresser la carte des sédiments glaciaires et post-glaciaires de la région de Saint-Joseph-de-Beauce (SNRC 21L/7; 1:50 000). De plus, il a fallu mesurer les directions des stries glaciaires, dresser les cartes des traînées de dispersion géochimique dans le till de surface et définir la stratigraphie des tills en mesurant les coupes stratigraphiques et en déterminant la structure des tills. Pour déterminer le mode de déglaciation dans cette région, la texture, la structure et les paléocourants des dépôts de contact glaciaire ont été étudiés.

Auparavant, on croyait que dans la région étudiée, l'écoulement glaciaire vers le nord avait été causée par une baie de vêlage pénétrant en amont le chenal Saint-Laurent et produisant un enfoncement dans l'inlandsis, ce qui avait interrompu l'écoulement glaciaire vers le sud-est. A cause de l'interruption, la glace demeurant au sud du chenal Saint-Laurent s'écoulait vers le nord, en direction du chenal.

Selon les études précédentes et selon les recherches de l'auteur entreprises dans cette région, la synthèse d'un modèle de la dernière glaciation wisconsinienne (la glaciation Lennoxville) a été faite.

1) La glace s'écoulant vers le sud-est a envahi les Appalaches durant la majeure partie de la glaciation Lennoxville, probablement jusqu'à la mer en chevauchant les états du Nouvel Angleterre et celui de New-York.

2) Le climat s'est réchauffé. La fonte de l'inlandsis a produit une élévation du niveau de la mer qui, par la suite a formé une baie de vêlage dans l'estuaire Saint-Laurent. Dans la dépression, l'écoulement de la glace de l'inlandsis a été renversé pour compenser au dépérissement rapide causé par la baie de vêlage. De plus, la glace localisée au sud du chenal, sur les Appalaches, s'écoulant antérieurement vers le sud-est a renversé vers le nord son écoulement en direction du chenal Saint-Laurent.

3) Ce renversement d'écoulement glaciaire a coupé l'alimentation de l'inlandsis vers les Appalaches, ce qui a éventuellement causé l'incision de l'inlandsis tout au long du front appalachien. La glace demeurant au sud du front appalachien a été nommée la calotte glaciaire appalachienne.

4) La glace laurentidienne reposant contre le front appalachien et faisant face à ce dernier a empêché la mer Champlain d'envahir les basses terres du Saint-Laurent et a barré l'écoulement des eaux vers le nord, des rivières Chaudière et Etchemin et de leur tributaires. En recul vers le sud, la marge glaciaire appalachienne a été submergée dans des lacs proglaciaires et a laissé des dépôts de contact glaciaire formés dans des conditions de déposition en partie subaquatique et en partie subaérienne.

5) Avec un bref refroidissement du climat, une réavancée de la glace laurentidienne sous forme de deux longs lobes étroits dans les vallées (Chaudière et Etchemin) et aussi sur une partie des hautes terres à l'ouest de la rivière Chaudière a eût lieu formant des dépôts morainiques. Ces derniers étaient anciennement associés à une partie de la moraine Highland Front.

6) Lors du retrait des lobes, des sédiments formés dans des conditions subaquatiques ont été déposés à différents intervalles dans les deux vallées et au bas d'une partie des hautes terres. De même qu'à un moment donné, à Vallée-Jonction, un épandage subaquatique massif remplissait toute la vallée de la Chaudière avec plus de 50 mètres de sédiments à gros grains.

7) En recul vers le nord, la glace laurentidienne dépassant l'étranglement du fleuve Saint-Laurent situé à Québec a permis à la mer Champlain d'envahir les basses terres du Saint-Laurent.

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TABLE OF CONTENTS

	PAGE
TITLE PAGE	i
ACCEPTANCE SHEET	ii
ABSTRACT	v
RESUME	vii
ACKNOWLEDGEMENTS	ix
REMERCIEMENTS	x
TABLE OF CONTENTS	xi
LIST OF FIGURES	xv
LIST OF PLATES	xx
LIST OF MAPS	xxii
LIST OF TABLES	xxii
 CHAPTER I: Introduction	 1
1.1 Location of Study Area	1
1.2 Physiography	1
1.3 Economic Potential in the Beauce Region	6
1.4 Objective and Purpose of Study	7
1.5 Methodology	10

CHAPTER II: Geology	11
2.1 Bedrock Geology	11
2.1.1 Regional Setting	11
2.1.2 Local Setting	14
2.2 Previous Work and Historical Development of the Quaternary Stratigraphy	16
2.2.1 Quaternary Stratigraphy from Pre-1960's	16
2.2.2 Quaternary Stratigraphy from the mid 1960's to early 1970's	19
2.2.3 Quaternary Stratigraphy from the mid 1970's to Present Day	23
CHAPTER III: Results	26
3.1 Surficial Geology of the Saint-Joseph Map Area	26
3.2 Erosional Evidence of Ice Flow Directions	36
3.2.1 Glacial Striae Measurements	36
3.2.2 Availability of Outcrops on which to Observe Striae	42
3.2.3 Statistical Representation of Glacial Striae	47
3.2.4 Chronology of Glacial Striae	47
3.3 Depositional Evidence of Ice Flow directions in Till	50
3.3.1 Fabrics in Till Sections	50
3.3.2 Glacial Dispersal	66

3.3.3 Geochemistry of <63 Micron Fraction of Surface Till	68
i) Nickel Geochemistry	69
ii) Chromium Geochemistry	72
iii) Cobalt Geochemistry	74
iv) Copper Geochemistry	74
v) Arsenic Geochemistry	76
vi) Tin Geochemistry	78
3.4 Depositional Evidence of Ice Flow Directions in Ice-Contact Stratified Drift	81
3.4.1 Paleocurrents in Sand and Gravel Deposits	81
3.4.2 Pebble Lithology in Gravel Deposits	82
3.4.3 Esker Systems	88
3.4.4 Subaqueous Outwash Deposits, Eskers and Rhythmites	89
3.4.5 Low Altitude Silt and Clay Rhythmites	90
CHAPTER IV: Discussion of Events during Lennoxville Glaciation	92
4.1 Evidence of Southeastward Glacial Flow from Striae and Till Deposits	92
4.2 Northward Ice Flow and the Calving Bay Model	95
4.2.1 Striation Directions, Till Deposits and the Calving Bay Theory	94
4.2.2 Québec Ice Divide	97
4.2.3 Eskers and Subaqueous Outwash Deposits	99

4.3 Southward Ice Flow, a Glacial Readvance	102
4.3.1 Eskers and Subaqueous Outwash Deposits	102
4.3.2 Striae Directions	105
4.3.3 Deposits overlying Lennoxville Till	105
4.3.4 The Southward Readvance in Relation to the Champlain Sea	106
4.4 The Study Area in Relation with the Highland Front Morainic System	107
4.5 Other Late-Wisconsinan Readvances	112
 CHAPTER V: Summary and Conclusions	 114
REFERENCES	115
 APPENDIX 1 Striae Measurements	 125
Rose Diagram of Striae Indicating True Direction of Ice Flow	 132
 APPENDIX 2 Results from Geochemical Analyses	 133
Map of Till Sample Sites and Numbers	137

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
1	Location of study area.	2
2	Physiographic regions of southeastern Québec, modified from Stockwell, 1957.	4
3	Hypsometric tints of the relief in southeastern Québec and drainage pattern. Arrows indicate possible proglacial outlets; Famine/Daquaam River valleys in north, Chain Lakes/Dead River valleys in south. Numbers 1, 2, 3, indicate three highest peaks in the study area: Monts Frampton, O'Neil, Orignal, respectively.	5
4	Tectonic structural domains of southeastern Québec, modified from Gauthier 1988b and St-Julien and Hubert, 1975.	13
5	Bedrock geology map of Saint-Joseph-de-Beauce map area (NTS 21L/7), north and south, Beauceville map area (NTS 21L/2), modified from Slyvitsky et St-Julien (1987).	15
6	Highland Front Morainic System. Modified from Gadd, 1964b. Note deposits at Vallée-Jonction are included in this end moraine. The two other lines represent end moraines of the Laurentide Ice Sheet deposited after the HFMS: south of the St. Lawrence, the Drummondville Moraine and north of the St. Lawrence, parts of the St-Narcisse Moraine.	20
7	Rose diagram of glacial striae measurements divided into five groups numbered according to order of formation.	48
8	Rivière des Fermes diagrammatic till section. Southeastward ice flow inferred from presence of ultramafic clasts derived from outcrops northwest of the section.	52

FIGURE	DESCRIPTION	PAGE
9	St-Hubert diagrammatic till section. Southeastward ice flow inferred at the base and middle of section. The upper till-like unit may be related to glacial readvance.	54
10	Industrial Park till section. Base of section exposes till with southeastward fabric overlain by water laid sediments, which in turn are overlain by a diamicton. The diamicton and the southeastward deposited till appear to have been deposited in two separate episodes intercalated with ice free conditions. The diamicton may have been deposited during a late-glacial readvance. Fabrics suggest northward flow but proximity of ice divide (within a few km) makes it more likely that deposition was from southward readvancing ice.	55
11	Rivière Fraser till section. Ultramafic-rich till found just south of the ophiolite belt is believed to be Lennoxville Till that has been glaciotectonically disturbed. It is overlain by proglacial lake sediments and a clayey till. The last two units are interpreted as being deposited during a glacial readvance.	57
12	Motel Jaro diagrammatic till section. Ultramafic-rich till found just south of ophiolites. Fabric is roughly parallel to SE-trending striations on a 1.5 m boulder exposed during excavation. Upper stratigraphic layers are interpreted as being deposited during ice free conditions (water laid sediments) and a glacial readvance (overlying till).	61
13	Rivière Nadeau diagrammatic till section. Located north of ophiolite belt, the presence of ultramafic clasts and a strong fabric indicate northeastward ice flow.	62
14	Calway River till section. Located just north of the ophiolite belt, the till is ultramafic-rich. Fabrics at the base and top of the section indicate northward ice flow. Intermediate fabric has no clear dip but probably represents NW flow.	63

FIGURE	DESCRIPTION	PAGE
15	Diagrammatic section south of Saint-Georges. Northward fabric is in clayey till overlain by southwestward subaqueous outwash. The only known site where a "northwestward" till is overlain by an ice marginal deposit from southwestward flowing water from a southward advancing glacier.	65
16	Perspective of nickel dispersal in the silt and clay fraction of the surface till in southeastern Québec (modified from Shilts and Smith, 1989). The most northeasterly of the trains reflects southeastward dispersal from sources along Rivière des Plante.	67
17	Nickel dispersal in surface till. The long arrow indicates southeastward transport and the short arrow indicates northward transport in relation to ophiolite outcrops.	71
18	Chromium dispersal in surface till. The long and short arrow indicate southeastward and northward (respectively) dispersal in relation to ophiolite outcrops.	73
19	Cobalt dispersal reflects slight southeastward ice flow in relation to ophiolite outcrops (indicated by arrow).	75
20	Copper negative dispersal train in relation to ophiolites. Where there is high nickel, there are low concentrations of copper.	77
21	Arsenic concentrations. Together with cobalt and copper enrichments in the northwestern corner of the study area, they probably outline an unmapped stratabound mineralization.	79
22	Tin concentrations in surface till. May be related to hydrothermal activity during faulting.	80
23	Percentage of Precambrian erratics in ice-contact stratified drift.	86

FIGURE	DESCRIPTION	PAGE
24	Model for Lennoxville glaciation and deglaciation. Southeastward ice flow during the major part of the Lennoxville glaciation. Laurentide Ice Sheet invading southeastern Québec and northern part of the United States.	93
25	Supply of ice was stopped over southeastern Québec by a calving bay in the lower St. Lawrence channel. The lack of ice caused southeastward flowing ice to be diverted towards the point of drawdown, down the St. Lawrence channel. Southeastward flowing ice north of the channel shifted flow NE, down the channel; ice cut off from its northern supply and trapped south of the St. Lawrence developed a divide and flowed back toward the channel - northwards.	98
26	Eventually both ice masses split into 1) Laurentide ice mass and 2) Appalachian ice mass in which the ice divide had formed at the time that flow from the Laurentide ice mass was cut off. The split was not caused by a retreating calving bay into the St. Lawrence channel but because of a lack of supply of Laurentide ice to the remnant trapped over the Appalachians, in a climatic zone that caused the ice surface to be mostly below the local equilibrium line.	100
27	Cross-Section. Decrease in size of the Appalachian ice because a lack of ice supply caused it to gradually melt away. Laurentide ice, still sitting at the foot of the Appalachians, caused drainage to be ponded and subaqueous conditions of deposition for the outwash deposited by the Appalachian ice mass.	101
28	Once the Appalachian ice mass disintegrated, Laurentide ice readvanced as lobes up major valleys and into the lower parts of the Appalachian highlands in the Saint-Sylvestre map area (Gadd, 1978).	104

FIGURE	DESCRIPTION	PAGE
29	Ice-marginal features of the Highland Front morainic system in Saint-Sylvestre map-area, after Gadd, 1978. Note: northward glacial features are found north of some of the Highland Front moraine deposits.	109
30	Laurentide ice retreated once more leaving minor ice front deposits south and north of the major subaqueous outwash deposit at Vallée-Jonction. During the retreat, the Highland Front morainic system was also deposited within a narrow altitudinal and geographical band. When ice retreated from the narrows at Québec City, westward incursion of the Champlain Sea took place.	111

LIST OF PLATES

PLATE	DESCRIPTION	PAGE
Frontispiece	Largest boulder observed in the study area; located east of Vallée-Jonction.	iv
1	Facsimile of the McDonald nugget usually on display at the entrance of the Geological Survey of Canada in Ottawa. The nugget was found in Rivière Gilbert, a tributary of Rivière Chaudière (Obalski, 1908).	9
2	Ice-contact stratified drift showing abrupt changes in grain sizes and intercalated debris flow (arrow).	30
3	Ice-contact stratified drift showing high angle reverse faults caused by melting of ice blocks within or under layers of drift.	30
4	Ice-contact stratified drift showing intense folding and faulting due to collapsing of sediments during ice block melting.	32
5	Kettle in ice-contact stratified drift. External expression of sediment collapse due to melting of ice blocks.	32
6	South-dipping foreset beds of a subaqueous outwash deposit in Etchemin Valley, just north of the map area. Lack of topset beds indicates that level of water body was above the deposit.	35
7	Dropstone resting on subaqueous outwash deposit with continuous clay layers, indicating quiescent deposition, deformed by boulder's impact.	35

PLATE	DESCRIPTION	PAGE
8	Mantle of dense boulders overlying compact basal till, on the west side of Rivière Chaudière, near the north edge of the map area. Shilts (1973) has called this ablation mantle.	38
9	Rat-tail striae. Direction of ice flow indicated by arrow.	41
10	Striae parallel to shape of roche moutonnée. Direction of ice flow indicated by arrow.	41
11	Cross-cutting striae. True direction of second (youngest) set of striae determined by orientation of striated facets of first set of striae (oldest). North-facing facets of first set is protected from glacial erosion, and south-facing facet is striated by northward flowing ice. True direction indicated by arrow.	44
12	Stoss and lee relationship. Oldest set of striae found parallel to glacial molding of the outcrop protected in the down-ice side of second set of striae found on the surface.	44
13	Looking down on lunate ripple crests. Direction of paleocurrent indicated by the pen point.	84
14	Sand foreset beds. Direction of paleocurrent indicated by handle of knife.	84

LIST OF MAPS

MAP	DESCRIPTION	
1	Surficial geology of the Saint-Joseph 1:50 000 scale map area, NTS 21L/7.	Map pocket
2	Compilation of: paleocurrents in ice-contact stratified drift, glacial striae measurements, and fabrics in till stratigraphic sections; NTS 21L/7, 21L/2	Map pocket
3	Bedrock Geology Map (modified from Slivitsky et St-Julien, 1987)	Map Pocket

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
1	Quaternary stratigraphic column, southeastern Québec, modified from McDonald and Shilts (1971).	21

CHAPTER I: Introduction

1.1 Location of Study Area

During parts of the summers of 1987, 1988, and 1989, field work was carried out by the author in the central Chaudière Valley for the Geological Survey of Canada. The study area includes Saint-Joseph-de-Beauce and Beauceville map areas (1:50 000 scale; NTS 21 L/7 and 21 L/2, respectively). It is located in the Appalachian Mountains of southeastern Québec in a region known culturally as the Beauce. The north edge of Saint-Joseph map area is approximately 60 kilometres south-southeast of Québec City (figure 1).

Henceforth, the terms "map area" will mean strictly Saint-Joseph-de-Beauce map area and "study area" will include Saint-Joseph, Beauceville and adjacent map areas.

The Beauce is of economic interest because one of the first placer gold mines in Canada (Tyrrell, 1915) was operated there. It is of interest in glacial geology because: 1) the glacial history has not been resolved fully and 2) the source for gold in its pre-glacial gravels and the overlying till deposits has not been found in the local bedrock.

1.2 Physiography

Southeastern Québec has been divided into four physiographic regions (Stockwell, 1957; Bostock, 1964). These are: 1) Eastern Québec Uplands, 2)

Figure 1. Location of study area.

Notre-Dame Mountains, 3) Green Mountains, and 4) Megantic Hills (northeastern extension of White Mountains in New England). The study area is located in the Notre-Dame Mountains and Eastern Québec Uplands (figure 2).

The three highest peaks in the map area are Mont Frampton, 636 metres (2100 feet), Mont O'Neil, 606 metres (2000 feet), and Mont Orignal, 545 metres (1800 feet). The lowest point, 180 metres (600 feet), outlines the shore of the Chaudière River through most of the study area. The drainage pattern follows the general northeast-southwest trend of the Appalachian bedrock into the two major rivers, the Chaudière and Etchemin, which transect the bedrock topography and drain northward into the St. Lawrence River (figure 3).

In the Chaudière Valley, it is important to keep in mind that any time ice blocked the St. Lawrence River, northward drainage of the Chaudière and Etchemin Rivers was ponded and proglacial lakes formed. Outflow of the proglacial lakes depended on the position of the ice front relative to possible outlets. If the ice front rested against the Appalachian front, the possible outlets were at 394 metres (1300 feet) through the Famine River/Daquaam River valley, eastward into the St. John River (assuming Rivière St-François (100 km from study area) was also blocked), and if it rested south of the 394 m outlets, outflow was at 424 metres (1400 feet) through the Chain Lakes/

Figure 4. Tectonic structural domains of southeastern Québec, modified from Gauthier 1988b and St-Julien and Hubert, 1975.

Figure 3. Hypsometric tints of the relief in southeastern Québec and drainage pattern. Arrows indicate possible proglacial outlets; Famine/Daquaam River valleys in north, Chain Lakes/Dead River valleys in south. Numbers 1, 2, 3, indicate three highest peaks in the study area: Monts Frampton, O'Neil, Orignal, respectively.

Dead River drainage of central Maine (figure 3). Therefore, the elevation of a proglacial deposit is a constraining parameter in determining whether the environment of deposition was subaqueous or subaerial (Mackay, 1921; McDonald, 1967; Shilts, 1970, 1981; McDonald and Shilts, 1971).

1.3 Economic Potential in the Beauce Region

In 1987, the Beauce celebrated its 250th anniversary. Having been always in the political shadows of the more densely populated St. Lawrence Lowlands, the Beauce people built, around large families, distinctive political and cultural micro-systems. Consequently, they developed an aptitude and reputation for doing good business and eventually became self-sufficient. Hence, the Beauce area is known as the kingdom of small business.

Manufactured goods are the main contribution to the Beauce economy; as much as 85.5% of the products are exported. In decreasing order of profitability, metal products, sawmill and wood products, transport materials, foods and beverages, and textile manufacturing provide most of the annual income (Rancourt et Fournier, 1988).

Throughout the last century, the mining industry has contributed inconsistently to the Beauce economy. Gold, copper, asbestos, chromium, platinum and silver were the main minerals sought for exploitation.

In 1834, placer gold was discovered in the Chaudière Valley near the mouth of Gilbert River (figure 1). One of the largest nuggets collected was the fist-sized McDonald nugget on display at the entrance of the Geological Survey of Canada in Ottawa. It weighed approximately 1.3 kilograms (45 ounces) (Obalski, 1908) (plate 1). Thus in 1847, the year before gold was discovered in California (Tyrrell, 1915), gold mining operations began in the Beauce and flourished in the period between 1875 and 1885 (Cirkel, 1911). Subsequent mining operations were sporadic.

Although the demand for asbestos has diminished, exploration continues for gold and other precious metals, i.e., platinum, silver, chromium, etc. (Shilts and Smith, 1986a,b, 1987; Gauthier, 1985; Maurice, 1986; Gauthier *et al.*, 1987; 1989).

1.4 Objective and Purpose of Study

The main objective of the study was to interpret the late-Wisconsinan, Lennoxville, glacial and deglacial events in the Central Chaudière Valley.

The purpose of this study is to provide a base for utilisation of the land, whether it is for mineral exploration, construction, agricultural purposes, establishing groundwater resource potential, or other earth resource purposes.

Plate 1. Facsimile of the McDonald nugget usually on display at the entrance of the Geological Survey of Canada in Ottawa. The nugget was found in Rivière Gilbert, a tributary of Rivière Chaudière (Obalski, 1908).

1.5 Methodology

The techniques used to reconstruct the late glacial history of the Central Chaudière Valley were: 1) conventional surficial geology mapping of the 1:50 000 scale Saint-Joseph sheet, 2) compilation of glacial striae measurements, 3) defining till stratigraphy and measuring fabrics, 4) tracing geochemical dispersal in surface till, and 5) interpreting the sedimentology of ice-contact stratified drift. A description of the techniques will be made in the introductory paragraph(s) of each section dealing with the results (CHAPTER III).

CHAPTER II: Geology

2.1 Bedrock Geology

2.1.1 Regional Bedrock Setting

Southeastern Québec is located in the northern section of the Appalachian structural province. The northwestern limit of the Appalachians is characterized by a major thrust fault named Logan's Line. The northeasterly trending structure of the Appalachians is a result of at least two orogenic episodes, the Taconian and the Acadian orogenies. In pre-Taconian time, the Late Proterozoic Hadyrnian period (800 Ma) was marked by the birth of the Iapetus Ocean. This ocean developed due to rifting of the North American-European Supercontinent. The following Taconian orogeny lasted throughout the Late Cambrian and the Ordovician. It was "...responsible for almost all the deformation that we now observe in the Cambrian and Ordovician rocks of the Québec Appalachians" (St-Julien and Hubert, 1975, p. 356.). Finally, the Devonian Acadian orogeny marked the closing of the Iapetus Ocean by the collision of the North American continent with the European continent. Appalachian bedrock has generally been subjected to low-grade metamorphism (Poole and Rodgers, 1972).

In southeastern Québec, rocks affected by the Taconian orogeny are divided, from northwest to southeast, into two major tectonic domains, 1) the autochthonous domain containing rocks which have not been tectonically moved

and 2) the allochthonous domain containing rocks which have been tectonically transported. The latter are subdivided into: a) the external domain, made up of an outer belt of thrust imbricated structures and an inner belt of nappes emplaced by gravity sliding, b) the internal domain, represented by metamorphosed and igneous rocks, overlying a Grenville-like basement (St-Julien and Hubert, 1975), and c) the oceanic domain, represented by similar metamorphosed and igneous rocks, overlying an oceanic crust (St-Julien *et al.*, 1983; Slivitsky et St-Julien, 1987) (figure 4).

Hence, the first two allochthonous tectonic domains consist of a sedimentary succession, which represents, from northwest to southeast, shelf, continental slope, and continental rise depositional environments, where sediments accumulated on a Grenville-like basement (St-Julien and Hubert, 1975). The last tectonic domain consists of remnants of the oceanic crust (ophiolites) and deep sea sediments mixed with volcanic assemblages.

In the study area, northwest of the La Guadeloupe Fault, the bedrock belongs mainly to the internal and oceanic domains of the Taconian orogeny (St-Julien and Hubert, 1975) (figure 4). Southeast of the fault, the bedrock was affected by the Acadian orogeny and is mainly composed of allochthonous shelf to deep sea metasediments.

Figure 4. Tectonic structural domains of southeastern Québec, modified from Gauthier 1988b and St-Julien and Hubert, 1975.

2.1.2 Local Bedrock Setting

For the past century, many geological studies have been conducted in parts of the map area (Ells, 1887, 1889; Mackay, 1921; Tolman, 1936; Gorman 1954, 1955; Benoit 1958; Cousineau 1982). Although the tectonic history of the map area has been resolved, mapping of different lithologies has not been completed. Slivitsky and St-Julien (1987) suggested that the bedrock geology of this area be mapped systematically but have inferred, from a compilation of previous studies, the types of rocks found locally.

As mentioned above, rocks of the map area belong mainly to the allochthonous internal domain and the oceanic domain. According to Slivitsky and St-Julien's compilation (1987), the rocks vary in age from lower Cambrian to mid-Ordovician, but some units may be as old as Precambrian and as young as Devonian. Fine to medium grained metasedimentary rocks, including mudstone, siltstone, sandstone, shale, slate, phyllite, and schist comprise the dominant lithologies in the map area and they vary in colour from dark grey, to grey, to green, to red. Metavolcanic or volcanoclastic rocks make up a lesser percentage of the bedrock and range in composition from mafic to felsic.

The most distinctive lithologies in the area are found in an ophiolite complex which is part of the oceanic domain. Largely ultramafic in composition, they outcrop sporadically across the map area as serpentinized pyroxenites and peridotites (figure 5). These are distinct from surrounding

Figure 5. Bedrock geology map of Saint-Joseph-de-Beauce map area (NTS 21L/7), north and south, Beauceville map area (NTS 21L/2), modified from Slyvitsky et St-Julien (1987).

crustal lithologies in their appearance, mineralogy, geochemistry, and magnetic signature. The ultramafic lithologies are intimately associated with pillow lavas of various hues and with a distinctive granitoid intrusive.

When mapping surficial geology, the distinctive bedrock units within the ophiolite complex provide helpful criteria for identifying major glacial flow patterns, as well as for correlation of drift sheets. For example, in this part of southeastern Québec, where ice sheets have repeatedly overridden the ophiolitic bedrock, they have left dispersal trains which are recognizable lithologically, mineralogically, and chemically for significant distances down ice from their source outcrops (Shilts, 1976b). Further details on indicator lithologies are discussed in CHAPTER III.

2.2 Previous Work and Historical Development of the Quaternary Stratigraphy

2.2.1 Quaternary Stratigraphy from Pre 1960's

Chalmers (1898) was the first geologist to attempt to unravel the glacial stratigraphy of southeastern Québec. He based his stratigraphic interpretations on glacial striations and lithologic composition of stratigraphic sections along rivers. His method of measuring relative ages of striae was based on the relative freshness of bedrock outcrops. Defining true directions of glacial striae was based on the hypothesis that the ice only striated the stoss side of a

bedrock outcrop. From observations of northward trending striae and a lower till that lacked Canadian Shield erratics from the north, Chalmers concluded that there had been at least two glaciations in southeastern Québec: 1) an Appalachian glaciation and 2) a Laurentide glaciation. He thought that the oldest or Appalachian glaciers emanated from ice caps located in the mountains of New Hampshire. Glaciers draining New Hampshire ice caps were thought to have produced a northward ice flow in southeastern Québec. On the other hand, the Laurentide glaciation, the youngest, would have given rise to an ice sheet invading southeastern Québec from north-northwest toward south-southeast. During retreat of the Laurentide glacier, Chalmers speculated that local ice caps remained in the highlands. Although his work has been well regarded, further development in Quaternary geology has revealed that his approaches were misleading.

Mackay (1921), who mapped both the bedrock and surficial geology of the Beauceville map area (figure 1), also recognized that there may have been northward ice flow, but unlike Chalmers, he believed that there was little evidence that an ice sheet moved northward prior to the "Laurentide" glaciation. Others, such as Cooke (1937), Clark (1937), and Gorman (1954) inferred that there had been some northward ice flow based on observations of northerly trending glacial striae and/or northward dispersal of distinctive glacial erratics.

Like Chalmers, Flint (1951, 1957), suggested ice caps had formed in the New England Highlands, but he believed they were formed in late glacial time, rather than before "Laurentide" glaciation. Borns and Hagar (1965) also inferred the presence of late glacial ice caps in Maine on the basis of outwash overlying marine deposits, but they did not discuss implications for southeastern Québec.

Nevertheless, during the early stages of systematic surficial geology mapping from 1960 until 1971, the general opinion was that there had not been northward ice flow in southeastern Québec. For instance, Gadd (1960, 1964a, b, 1965, 1967), in the course of mapping several areas in the St. Lawrence Lowlands and the Beauce region, observed that at least two continental glaciations occurred in southeastern Québec during the Wisconsin Stage, he thought that both ice sheets originated from the north, flowed southeastward, and retreated northwestward. This concept did not involve the formation of ice caps in the Appalachian Highlands with ice flow northward into southeastern Québec; rather, it was analogous to pulling down a window blind (south to the glacial limit) and letting it roll back up with pauses. Consequently, Gadd (1964b) proposed that a series of end moraines, composed of ice-contact gravel with southward paleocurrents were deposited late-glacially. The most prominent of these morainic systems rests at the foot of the Appalachian Highlands and is called the Highland Front Moraine (Gadd,

1964b) (figure 6). The massive ice-contact deposits at Vallée-Jonction (figure 1) were included in this morainic system and are discussed further in CHAPTERS III, IV, and V.

Even though Gadd did not observe evidence of northward ice flow, the map of surficial geology for the Beauceville map area (1964a) shows some northward striae. Gadd *et al.* (1972b) later suggested that these were editorial errors even though subsequently they had found northward flow to be a reality.

2.2.2 Quaternary Stratigraphy from the Mid-1960's to Early 1970's

During this period, McDonald (1966, 1967, 1968, 1969) described three glacial episodes and confirmed the absence of northward ice flow in the Sherbrooke area of southern Québec. His work was influenced by and reflected similar conclusions to that of Stewart and MacClintock (1964) in adjacent Vermont. Following McDonald's work, Shilts (1970) also observed evidence of at least three glacial episodes (maybe four) in the Lac Mégantic area (figure 2) during the Wisconsinan. Consequently, McDonald and Shilts (1971) combined their research in a paper that established the first modern framework for Quaternary stratigraphy of southeastern Québec (table 1).

McDonald and Shilts summarized the glacial events as follows: 1) the oldest recognized continental glaciation, which deposited Johnville Till, had a southeastward ice movement from the Canadian Shield across southeastern

Figure 6. Highland Front Morainic System. Modified from Gadd, 1964b. Note deposits at Vallée-Jonction are included in this end moraine. The two other lines represent end moraines of the Laurentide Ice Sheet deposited after the HFMS: south of the St. Lawrence, the Drummondville Moraine and north of the St. Lawrence, parts of the St-Narcisse Moraine.

Time-Stratigraphic Unit		Rock-Stratigraphic Unit	Chronologic Control
Wisconsin stage	late	post-Lennoxville sediments	12,640 $\pm$ 190 (GSC 312; peat) 12,570 $\pm$ 220 (GSC-419; peat) 12,000 $\pm$ 230 (GSC-936; marine shells) 11,500 $\pm$ 160 (GSC-475-2; marine shells)
		Lennoxville Till	
	middle	Gayhurst Formation	> 20,000 B P. (GSC-1137) ca. 4000 varves
		Chaudière Till	
	early	Massawippi Formation	> 54,000 B P. (Y-1683) > 41,500 B P. (GSC-507) > 40,000 B.P. (GSC-1084)
		Johnville Till	
pre-Wisconsin stage(s)		pre-Johnville sediments	

Table 1. Quaternary stratigraphic column, southeastern Québec, modified from McDonald and Shilts (1971).

Québec; 2) its retreat was followed by an interstadial event (Massawippi Formation) during which there was free drainage in the St. Lawrence River and its Appalachian tributaries; 3) the second glaciation, which deposited Chaudière Till, originated from the northeast or east of the Chaudière Valley in Maine or the Maritime Provinces. Ice flowed southwestward until it collided with and was displaced eventually by continental ice advancing southeastward from the Canadian Shield. Ice flow directions were towards the east or southeast where the Chaudière glacier was overwhelmed by Laurentide ice. Retreat of the Chaudière glacier only as far north as the Appalachian front was accompanied in the Appalachians by an interstadial period during which the Gayhurst Formation was deposited in a large proglacial lake that filled the Chaudière and St-François River valleys; and 4) during the final glaciation, Lennoxville Till was deposited by an ice sheet that flowed southeastward to the glacial limit in the United States. The front of the ice sheet retreated northwestward across New England and Québec. This stratigraphic model did not include northward ice movement during the last glaciation, primarily because the area in which McDonald and Shilts worked did not contain strong evidence, if any, of northward ice flow. Nevertheless, the search for evidence of northward ice movement did not stop with the completion of their research.

While mapping bedrock geology of the Thetford Mines area (45 km west of the study area), Lamarche (1971) noticed glacial striae with northward

trending, miniature crag and tail features (rat-tail striae of Lortie et Martineau, 1987). Superposition of this evidence of northward ice flow on features formed by southeastward ice flow led Lamarche to believe that there had been a remnant ice cap in the Appalachian Highlands after Laurentide ice had retreated (Lamarche, 1971; Gadd *et al.*, 1972 a,b). Further regional observations of striations indicating northward ice flow were made by Lamarche (1974), Gauthier (1975), Lortie (1975, 1976), and LaSalle *et al.* (1977a) among others (for a detailed summary, the reader is referred to Lortie et Martineau, 1987). These observations contributed to the theory that late glacial northward ice flow was initiated by the development of a calving bay in the St. Lawrence Estuary, leaving an opening for the incursion of the Champlain Sea (Gadd, 1976; Shilts, 1976a; Thomas, 1977). Therefore, by the mid-1970's, late glacial northward ice flow was confirmed and the calving bay theory had been accepted among most Quaternary geologists working in southeastern Québec.

2.2.3 Quaternary Stratigraphy from the Mid-1970's to Present day

Although the calving bay theory was accepted, researchers were still left with a paradox: Ice marginal sediments, apparently deposited by ice standing to the north and associated with the Highland Front Moraine (e.g. Vallée-Jonction) were found to lie at or south of the latitudes of many bedrock outcrops with northward glacial striae. This would imply that there may have

been a glacial readvance after the northward flow. Suggestions of glacial readvance were not compatible with incursion of the Champlain Sea inferred from the theory of a calving bay penetrating deeply into the St. Lawrence Lowlands.

Several authors attempted to answer these questions. There developed basically three schools of thought about the sequence of late glacial events: 1) the hypotheses put forth by Gauthier (1975), Lortie (1976), Shilts (1976a, 1981, 1982), and Lortie et Martineau (1987), proposed that after the calving bay bisected the Laurentide ice mass and left the Appalachian ice mass isolated, the Laurentide ice sheet expanded once more to readvance and deposit parts of, if not the whole Highland Front Moraine. This was also implied, but not asserted by Gadd (1978) and Bouchard *et al.* (1987); 2) LaSalle *et al.* (1976, 1977a, b) suggested that there was no evidence for glacial readvance in southern Québec and proposed a model in which a reentrant penetrated along the highlands (on solid ground rather than at the lowest point of relief) which in turn, produced simultaneous southward and northward ice marginal deposits on both sides of the reentrant; 3) a third approach to southeastern Québec Quaternary stratigraphy, which avoided the necessity of a readvance, was made by Parent (1987a, b) and Parent and Ochietti (1988). From work done in the Asbestos region (50 km west of the study area), Parent believed that during the Chaudière glaciation, an Appalachian-based ice sheet produced a prominent

westward ice flow which lasted throughout most of the episode and was followed by a northward ice flow. He did not believe that coalescence with the Laurentide ice sheet produced a southeastward ice flow following westward ice flow. In addition, Parent maintained that during Lennoxville glaciation, southeastward ice flow occurred but was not followed by northward ice flow, at least not in the Asbestos region. However, this scenario did not correlate with observations made by other authors who have worked in the area (Bouchard *et al.*, 1987; Lortie et Martineau, 1987; Turcotte *et al.*, 1989).

CHAPTER III: Results

3.1 Surficial Géology of the Saint-Joseph Map Area

In the map area, virtually all public and many private roads were traversed with a four wheel drive vehicle, and observations of surficial units were recorded on the 1:50 000 sheet. Where confirmation was needed, the surficial feature was examined carefully by foot traversing.

Along road traverses, stops were made to measure the direction of glacial striae wherever a bedrock outcrop revealed a polished surface. In addition, if till was well exposed in road ditches or in river sections, it was sampled for later geochemical analysis, its relationship to subjacent sediments sketched, photographed, and described, and its fabric was measured in many cases.

This procedure was carried out during the summer of 1987. In 1988, the approach was somewhat different, once the roads had been covered and air photo¹ interpretation was accomplished, more time was spent at specific areas of interest for a more in-depth study.

There are six principal surficial geology units of Quaternary age described in the legend of map 1. In approximate order from youngest to oldest, these units are: (6) alluvium, (5) bog and lake deposits, (4) fluvial terrace deposits, (3) proglacial lake sediments, (2) ice-contact stratified drift,

¹ Photos from National Air Photo Library (1962 and 1978).

subdivided into (2a) esker and (2b) sub-aqueous outwash deposits, (1) Lennoxville Till, and (1a) till veneer over bedrock surface. Also, briefly described in the legend and in greater detail in CHAPTER II is the bedrock unit (R) comprising several lithologies of Lower Paleozoic age.

6) Alluvium: Composed of modern flood plain silt, sand, and gravel with organic fragments and lenses. Alluvium includes all the areas inundated during normal overbank flooding.

5) Bog and lake deposits: Mainly composed of sphagnum and sedge peat, they are sparsely treed. The deposits can reach depths of 1 m on poorly drained slopes and to greater than 3 m on poorly drained depressions.

4) Fluvial terrace deposits: Paired and unpaired terraces capped by silty sand, sand and gravel of former flood plains. These deposits comprise 1 to 2 metre thick beds lying unconformably on older Quaternary sediments.

3) Proglacial lake sediments: Composed of silt and clay laminae which are either flat-lying or convolute. Where observed on land, they are usually less than 2 m thick. Clay layers can be interbedded with fine sand. but rarely.

2) Ice-contact stratified drift (ICSD): These deposits were built upon or immediately adjacent to glacier ice. Commonly a hummocky bench or ridge, ICSD possesses distinctive internal and external features, which are: 1) extreme range and abrupt changes in grain size, 2) presence of flow tills from supraglacial mudflows and debris flows, interstratified with normal fluvial

sediments, 3) individual clasts are less well abraded than in outwash, they often retain striae because of their emplacement directly into meltwater streams from glacier ice, and 4) high angle reverse faults caused by melting of ice blocks deposited within or under layers of drift; ice block melting also produces intense folding due to either gravity sliding, compression in collapsing sediments, or catastrophic sediment dewatering. Plates 2, 3, 4, and 5 represent internal and external features of ICSD observed in the map area. Based on distinctive internal structures and morphologies of the ICSD has been subdivided into: 2a) esker deposits and 2b) subaqueous outwash deposits.

2a) Esker deposits: They are differentiated from other types of ICSD by their ridgelike, sinuous appearance or linear morphology. They are produced in a subglacial or englacial tunnel of a stagnant or retreating glacier, and are left behind when the ice melts. In the map area, the esker's width to height ratio is generally 10:1. Eskers are located primarily in the Chaudière and Etchemin Valleys and the valleys of some of their tributaries.

2b) Subaqueous outwash deposits: These are formed where " glacial fluvial sediments are discharged directly from a glacial meltwater conduit into a standing water body, forming a depositional fan (subaqueous fan) well below the effects of the water surface" (Cheel and Rust, 1986, p. 78, Rust and Romanelli, 1975).

Plate 2. Ice-contact stratified drift showing abrupt changes in grain sizes and intercalated debris flow (arrow).

Plate 3. Ice-contact stratified drift showing high angle reverse faults caused by melting of ice blocks within or under layers of drift.

Plate 4. Ice-contact stratified drift showing intense folding and faulting due to collapsing of sediments during ice block melting.

Plate 5. Kettle in ice-contact stratified drift. External expression of sediment collapse due to melting of ice blocks.

Plate 9. Rat-tail striae. Direction of ice flow indicated by arrow.

Plate 10. Striae parallel to shape of roche moutonnée. Direction of ice flow indicated by arrow.

Essentially, the internal features observed in a subaqueous outwash deposit would be the same as those observed in a glaciofluvial delta, except for the lack of topset beds overlying the foreset beds, indicating that the deposit was not built to the surface of a standing body of water (plate 6).

In the field, when examining pitted ice-contact stratified drift deposits, it may be difficult to determine whether the sediments were laid down subaerially or subaqueously. Consequently, internal features that distinguish subaqueous conditions are sought, such as: interruption of sand and gravel sequences by continuous silt and clay layers (rhythmites) that indicate settling in a standing body of water, massive sand flows, and features such as dropstones (plate 7). In the Chaudière and Etchemin River valleys, glacial conduits through which sediment was transported to the subaqueous outwash deposits at the ice front, are commonly marked by discontinuous eskers.

1) Lennoxville Till: The surface till is a result of the Lennoxville glaciation. Its basal facies is compact, but supraglacial facies may be loose. Although its colour changes with the amount of weathering, from grey when unoxidized to brown or tan when oxidized, till can be red or have reddish grey hues where derived partially from red or hematite-rich bedrock. The till matrix contains subequal amounts of sand, silt, and clay. Where the glacier was advancing through a lake, its till may in places be very clayey, being composed

Plate 6. South-dipping foreset beds of a subaqueous outwash deposit in Etchemin Valley, just north of the map area. Lack of topset beds indicates that level of water body was above the deposit.

Plate 7. Dropstone resting on subaqueous outwash deposit with continuous clay layers, indicating quiescent deposition, deformed by boulder's impact; located about 10 km east of Vallée-Jonction.

almost entirely of reworked lake clays. Compact basal till is commonly mantled by a dense cover of boulders (plate 8).

1a) Till veneer: A thin layer of Lennoxville Till, commonly weathered, buff coloured, and less than 1 to 2 metres thick, drapes bedrock in much of the map area. It may be pierced by scattered bedrock outcrops making up as much as 20% of the surface.

R) Bedrock: This unit is defined by either closely spaced bedrock outcrops, covered by less than 1 m of sediment, usually till, or by areas with more than 80% bedrock outcrop. It commonly has a striated or polished surface, is only slightly weathered, and is fresh when covered with vegetation or unconsolidated material.

3.2 Erosional Evidence of Ice Flow Directions

3.2.1 Glacial Striae Measurements

Using a declination of 17° W, glacial striae were measured¹ at 193 sites in the study area. As striae were measured, the type of bedrock on which they were preserved was recorded. Their age relationship was also noted carefully if more than one set were present. Striation measurement often involved scraping the moss or till off the bedrock surface and recording the direction of glacial movement on outcrop facets oriented in various directions, so that older striae on a face protected from younger ice movement would not

Plate 8. Mantle of dense boulders overlying compact basal till, on the west side of Rivière Chaudière, near the north edge of the map area. Shilts (1973) has called this ablation mantle.

be missed. To ensure that all the facets were observed, considerable excavation was required at some sites.

The true direction (not just the trend) of a glacial striation was determined when: 1) a rat tail (Lortie et Martineau, 1987) was observed, 2) a stoss and lee relationship was established, or 3) striae were seen to be formed preferentially on outcrop facets most exposed to the striating ice. Appendix 1 contains a table of striae measurements for the study area.

Rat tails are formed by differential glacial erosion where a hard mineral, a clast, or a quartz vein imbedded in relatively softer, finer grained matrix, shields its down-ice side leaving a tail of uneroded rock trending down ice (plate 9).

Frequently, glacial striae are not associated with rat tails, but if a stoss and lee relationship can be established between the striae and the shape of the striated bedrock, ice flow direction can be deduced. The phrase "stoss and lee" refers to the asymmetrical aspect of glacial erosion that produces, on a large scale, roches moutonnées. When ice advances over bedrock, it abrades the stoss side and either plucks the lee side, or leaves it ragged and uneroded. If the lee side of an outcrop or protuberance on an outcrop was already subjected to glacial erosion, the stoss side may be smooth and be marked by

Plate 9. Rat-tail striae. Direction of ice flow indicated by arrow.

Plate 10. Striae parallel to shape of *roche moutonnée*. Direction of ice flow indicated by arrow.

striae of the older ice flow.² If glacial striae are found parallel to the stoss side of an outcrop and not found on the lee side, the ice flow direction can be inferred from the shape of the outcrop (plate 10). Such a relationship between rounded and angular parts of outcrops can be seen even on surfaces with relief of 1 cm or less. Sometimes south facing sides of E or SE-trending grooves that were cut during main Lennoxville flow have fine northward striae cut into them while their north-facing sides have none (plate 11). The relationships of multiple striation directions to outcrop form, facet orientation, and small scale glacial erosional features such as grooves and rat tails give in most cases a reliable estimate of age relationships of striating events. For example, striae formed preferentially on south-facing flanks of eastward-trending rat tails give not only a direction of ice flow (northward) but indicate that northward flow post-dated the eastward flow (plate 12).

3.2.2 Availability of Outcrops on which to Observe Glacial Striae

Access to striated outcrops depends on many factors, some of which are:

1) thickness of glacial drift cover, 2) type of eroded bedrock, 3) exposure to weathering conditions, and 4) relative intensity of glacial event that produced specific striae.

²In this region, where earlier flows were SE or E, and later ones generally northerly, northward facing facets of outcrops, which were on the lee side during northward flow, often have the earlier SE striae preserved on them.

Plate 11. Cross-cutting striae. True direction of second (youngest) set of striae determined by orientation of striated facets of first set of striae (oldest). North-facing facets of first set is protected from glacial erosion, and south-facing facet is striated by northward flowing ice. True direction indicated by arrow.

Plate 12. Stoss and lee relationship. Oldest set of striae found parallel to glacial molding of the outcrop protected in the down-ice side of second set of striae found on the surface.

In the study area, Shilts (1970, 1981), Shilts and Smith (1986a, b, 1988), and Smith and Shilts (1987) have drilled into buried valleys filled with glacial and interglacial drift and have described stratigraphy of glacial sediments along Rivière des Plante (1987) (figure 1). Since most major valleys have been filled with thick glacial and interglacial sediments, bedrock outcrops and glacial striae reflecting earlier ice flow directions are difficult to find.

Preservation of glacial striae depends on the type of bedrock the glacier overrode. In the Beauce region, the abundant slaty bedrock was easily erodable and in general preserves striae well. Consequently, maps 1 and 2 reflect a high number of striated bedrock surfaces. Map 2 contains striae from all measured sites.

As a general rule, the more siliceous (harder) the bedrock, the better the striae are preserved. However, if cleavage is well developed on vertically dipping slaty or schistose bedrock, as in the Rosaire Group (figure 5), the rock may deform at the ice-rock interface rather than being clearly cut and striated. Maps 1 and 2 appear to reflect the variability in bedrock composition by the pattern of striation measurements found parallel to northeasterly strike. For example, keeping in mind that all the roads have been traversed (on map 1 only), it can be seen that striae measurements are more abundant in the southeastern corner of the Saint-Joseph sheet than they are in its northwestern corner. This is because, in the southeastern corner, the slaty bedrock is

siliceous, hard, and coarsely cleaved as opposed to the northwestern corner, where bedrock is phyllitic and was easily deformed by glacial drag.

Preservation of glacial striae also depends on the amount of time striated surfaces have been exposed to weathering and the composition of bedrock. The author has found exposed bedrock surfaces that did not show any striae when uncovered for a relatively long period of time, but did show well preserved striae when a layer of vegetation or till was removed from an adjacent portion.

Striae representing the last glacial episode are commonly better preserved than the striae representing older glacial events. However, the relative intensity of a glacial episode may affect the abundance of glacial striae. For example, some east-northeastward striae are younger but less abundant than the northward striae. This is believed to be due to less vigorous erosion by an ice sheet that was in the final stages of melting when its flow fluctuated east-northeastwardly. The 110° ice flow direction seems to represent more intense erosion than the later 130° and 000° directions because few older than 110° striae are preserved. The fact that both 130° and 000° striae are in many places preferentially preserved on the stoss sides of outcrop irregularities with as little as a few mm of relief suggests that these glacial phases accomplished much less erosion, i.e. were less "intense".

3.2.3 Statistical Representation of Glacial Striae

A total of 193 sites were examined in the study area, from which 346 sets of glacial striae were measured (map 2).

All measurements have been plotted on a rose diagram (figure 7). To plot the measurements of glacial striae that only indicated a trend, the author inferred the true direction from parallel neighbouring sets of striations that did indicate a true direction and commonly showed similar age relationships. In Appendix 1, a rose diagram of striae measurements indicating true directions was plotted for comparison and it reveals a similar pattern. There are five observable glacial directions, in order of increasing frequency: A) southwestward, B) east-southeastward, C) southeastward, D) north-northwestward to north-northeastward, and E) east-northeastward (figure 7).

3.2.4 Chronology of Glacial Striae

The least common glacial striae direction is southwestward (figure 7). Because of its rarity and because it is found in one case on a surface protected from younger southeastward striating events, it is believed that this southwestward (A) glacial direction represents the oldest distinguishable glacial movement in the area, the Chaudière glaciation. There may be glacial striae that represent older glacial movements (Johnville glaciation) but they are not

Figure 7. Rose diagram of glacial striae measurements divided into five groups labeled alphabetically according to order of formation.

distinguishable due to a lack of cross-cutting relationships and similar azimuths to striations cut during the later Lennoxville glaciation.

Further field investigations from summer of 1989 revealed that the southeastward direction can be divided into two groups: east-southeastward (B) at $100^{\circ} (\pm 15^{\circ})$ and southeastward (C) at $130^{\circ} (\pm 5^{\circ})$. Based on cross-cutting relationships, the east-southeastward is thought to be the second oldest movement and the southeastward, the third oldest. It is believed that these two ice movements are part of the early Lennoxville glaciation and that ice flow shifted from east-southeastward to southeastward. Alternatively the east-southeastward may date from the Laurentide (latest) phase of Chaudière glaciation.

The largest group of glacial striae indicates a general northward (D) direction. It ranges from north-northwestward to north-northeastward, i.e., $000^{\circ} (\pm 25^{\circ})$. Based on cross-cutting relationships, it is consistently and unequivocally younger than the southeastward directions. Within the northward group of striae, there are cross-cutting relationships that would indicate age relationships, but there is no clear indication of whether north-northwest striae are younger or older than north-northeast striae.

Lastly, the east-northeastward (E), $060^{\circ} (\pm 30^{\circ})$ glacial direction is less common than the northward direction but, in a few cases (map 2), the east-northeastward direction appears to be younger than the general northward

direction as also reported by Lortie et Martineau (1987). It is believed that the "unstable" northward ice flow during the late Lennoxville glaciation transitionally shifted towards the east-northeast direction because: 1) the east-northeastward striae are younger than northward striae and 2) there is no clear-cut break between the northward striae direction and the east-northeastward.

3.3 Depositional Evidence of Ice Flow Directions in Till

3.3.1 Fabrics in Till Sections

Fortuitously for the author, in mid-August of 1988, the Beauce region was subjected to torrential downpours which caused flooding that cleared river sections of slump, providing several new sites for till clast fabric measurements. Till clast fabrics were measured in stratigraphic sections that had been detected either by traversing or on air photographs³.

Two and three-dimensional fabrics were measured from elongate clasts (30 per site) of an average size of 5 cm ($\pm$ 2cm) with long to intermediate axial ratios of at least 2:1. For the three-dimensional fabrics, the plunge of the elongate clasts was also measured, but the reliability of the method, particularly where a-axis plunges varied little from the horizontal, was questionable in

³ At four important sections (A, B, C, D of maps 1 and 2), on Rivière des Plante, the author participated in an earlier sampling and fabric measuring program which ultimately resulted in BSc. theses by Poliquin (1987) and Paul (1987). The reader is referred to Shilts and Smith (1987) and Shilts and Blais (1989) for a detailed description of the sections.

several instances. As with other studies done in this region, the author has supported fabric data with other evidence of transport, such as lithologies of erratics and geochemistry of the till matrix, orientation of structures in overridden, stratified sediments, etc.

Compilation of the measurements was done by hand on a rose diagram (two-dimensional) or by computer on a lower hemisphere stereonet projection according to the method of Kamb (1959) at a contour interval of two sigma (three-dimensional). With two-dimensional fabrics, only a bi-direction of ice flow can be inferred whereas, with three-dimensional fabrics a uni-direction of ice flow sometimes can be inferred. The long axes of till clasts are oriented parallel to ice flow. Elongate pebbles also dip up-ice so that three-dimensional fabrics can be an indication of true ice flow direction.

Rivière des Fermes: (Section G on maps 1 and 2)

Although the till at the Rivière des Fermes section is poorly exposed, a two-dimensional fabric was measured (figure 8). The results indicate a NW-SE preferred orientation for the elongate clasts. This trend corresponds with both the major southeastward ice flow associated with the last glaciation in southeastern Québec (Lennoxville glaciation) documented by McDonald (1967), Shilts (1970, 1973, 1981), McDonald and Shilts (1971) and with northwestward late glacial flow documented by this study. However, because the section is

Rivière des Fermes Section

Figure 8. Rivière des Fermes diagrammatic till section. Southeastward ice flow inferred from presence of ultramafic clasts derived from outcrops northwest of the section.

located south of the ophiolite belt and contains ultramafic clasts, the fabric is assumed to represent southeastward Lennoxville glacier flow.

Northward ice flow has taken place in the area because surrounding bedrock outcrops have been striated by northward ice flow. It is possible that northward fabric could be found at this section if more sites were measured.

St-Hubert Section: (Section J on map 2)

Located in the town of Saint-Georges on route 173 in the back of a St-Hubert BBQ restaurant, this 8 m high man-made section was created in 1987. At the base, the section revealed a hard dark grey unoxidized till which graded upward abruptly to a brown, fissile, oxidized till about 4 m below the original surface (figure 9). Three-dimensional fabrics measured in unoxidized and oxidized parts of the till both indicate southeastward ice flow.

At the top of the section, the till unit is overlain by a thin diamicton (i.e. glacial origin cannot be determined). The orientation of the two stereoplots measured in this unit are NE-SW with no true direction indicated. At this point, the direction cannot be explained except that superficially similar stereoplots were measured in a diamicton overlying Lennoxville Till and laminated silty clay at the nearby Industrial Park Section (figure 10). Perhaps these fabrics represent a specific mode of deposition of till associated with a late readvance in the Chaudière Valley.

St-Hubert Section

Figure 9. St-Hubert diagrammatic till section. Southeastward ice flow inferred at the base and middle of section. The upper till-like unit may be related to glacial readvance.

Industrial Park Section

Figure 10. Industrial Park till section. Base of section exposes till with southeastward fabric overlain by water laid sediments, which in turn are overlain by a diamicton. The diamicton and the southeastward deposited till appear to have been deposited in two separate episodes intercalated with ice free conditions. The diamicton may have been deposited during a late-glacial readvance. Fabrics suggest northward flow but proximity of ice divide (within a few km) makes it more likely that deposition was from southward readvancing ice.

Industrial Park Section: (Section K on map 2).

This section is a construction excavation made in 1988 in the town of Saint-Georges, approximately 1 kilometre ENE of the confluence of Rivière Famine and Rivière Chaudière. The base of the section reveals a hard, unoxidized grey till deposited by southeastward flowing ice, a direction inferred from the stereonet plot. In the centre of the section, laminated silty clay fills a depression on the grey till surface. These sediments and presumably the SE till itself are overlain by an oxidized brown diamicton. The fabric measurements in the diamicton indicate a general NW-SE direction of ice flow with some scattering (figure 10). Since proglacial lake sediments may indicate ice free conditions, the upper diamicton may have been deposited during a different glacial event from the one that deposited the lower till. As mentioned in the discussion about fabrics in the St-Hubert (figure 9) and Jaro (figure 12) sections, the diamicton may be associated with a late readvance in the Chaudière Valley.

Fraser River Section: (Section F on maps 1 and 2).

The north-south striking face of the Fraser River section is about 8 metres high and was approximately 100 metres long in 1988, when it was well exposed by flooding (figure 11). An ultramafic-rich till unit at the bottom of the section is glaciotectonically tilted and sheared in a fashion similar to that

Fraser River Section

Figure 11. Rivière Fraser till section. Ultramafic-rich till found just south of the ophiolite belt is believed to be Lennoxville Till that has been glaciotectonically disturbed. It is overlain by proglacial lake sediments and a clayey till. The last two units are interpreted as being deposited during a glacial readvance.

observed at the base of section D on Rivière des Plante (Shilts and Smith, 1986b). Joint structures in the till appear to be dipping northeastward, suggesting deformation by overriding ice. Thin units of laminated sediments within the till, exposed in the bed of Rivière des Plante, indicate an almost vertical dip of the beds. The fabric measurement reveals a SW-NE direction with a concentration of elongate pebbles at the northeast edge of the stereonet, which normally would imply southwestward ice flow. However, since the till unit has been glaciotectonically deformed, the orientation of elongate pebbles probably has been disrupted or tilted by folding. Therefore, it is believed that this till unit is Lennoxville Till deposited by southeastward ice flow, a conclusion supported by the high concentration of ultramafic erratics from ophiolite bedrock that outcrops just northwest of the section.

At the south end of the section, the Lennoxville Till is overlain by a massive red clay layer which in turn is overlain by flat lying grey silt and clay rhythmites. The rhythmites grade upward into deformed rhythmites containing massive red clay clasts. The deformed rhythmites are overlain by a massive grey clay layer which passes upward into a clayey diamicton containing some stones as well as red clay clasts. The texture and relationship to underlying deformed laminae of this clayey diamicton is similar to the Drolet Lentil clay till that overlies rhythmites of the Gayhurst Formation and covers large parts of the upper Chaudière Valley (Shilts, 1970; 1973; 1981). The Drolet Lentil clay till

was produced by a glacial reworking of the proglacial lake sediments.

McDonald (1967) described a similar clay till overlying rhythmites over a large part of the upper St-François Valley, west of the study area. It is probable that the clayey diamicton exposed at Fraser River is a similar till deposited during a glacial readvance. Stratigraphy similar to this section was exposed in a ditch in the upland beside Fraser River about 1.5 km southeast of the Rivière des Plante and Fraser River confluence.

Motel Jaro Section: (section I on map 2).

This till section was created by excavation in 1987 behind a motel that was destroyed by fire the same year. It is located on the east side of Rivière Chaudière on route 173 a few kilometres south of both the confluence of Rivière des Plante and Rivière Chaudière and the outcrops of ultramafic lithologies in the ophiolite belt. At the base of the section, where the fabric was measured, a hard unoxidized ultramafic-rich till is exposed. The three-dimensional stereoplot indicates a general southeastward direction with a wide scattering of pebble orientations. The presence of ultramafic clasts and the fabric indicate a general southeastward ice flow as do the striations (125°) on a one metre-long boulder imbedded in the till.

Scattering of orientations of elongate pebbles in till may be explained by a number of factors influencing till genesis (Boulton, 1971). However, the

presence of younger northward glacial striae cross-cutting older southeastward striae near the section, and the presence of overlying till unit(s) lying on highly deformed, water sorted sand and silt suggest (figure 12) that the scattering in the southeastward fabric may reflect reworking by later, northward flowing ice followed by a readvance.

Rivière Nadeau Section: (Section H on map 1 and 2)

This badly slumped, 8 metre high section exposes a hard, unoxidized grey till near the top. The section is located north of the ophiolite belt and contains some ultramafic clasts in the till.

A lower hemisphere stereonet plot (figure 13) of the orientation of elongate clasts indicates a northeastward ice flow direction. Thus, combining the presence of a distinctive lithology in the till with the fabric, northward ice flow direction is confirmed at this section.

Calway River Section: (Section E on maps 1 and 2)

The Calway River section (figure 14) is located just north of the ophiolite belt. The till unit contains approximately 30% ultramafic clasts and two out of three fabrics indicate northward ice flow. Judging from the sequence of directions, a southeastward fabric direction would be expected to occur before (or below) evidence of northward ice flow, at the base of the

Figure 12. Motel Jaro diagrammatic till section. Ultramafic-rich till found just south of ophiolites. Fabric is roughly parallel to SE-trending striations on a 1.5 m boulder exposed during excavation. Upper stratigraphic layers are interpreted as being deposited during ice free conditions (water laid sediments) and a glacial readvance (overlying till).

Figure 13. Rivière Nadeau diagrammatic till section. Located north of ophiolite belt, the presence of ultramafic clasts and a strong fabric indicate northeastward ice flow.

Calway River Section

Figure 14. Calway River till section. Located just north of the ophiolite belt, the till is ultramafic-rich. Fabrics at the base and top of the section indicate northward ice flow. Intermediate fabric has no clear dip but probably represents NW flow.

section as seen at the Industrial Park section. For this reason, the southeast-northwest fabric that is physically between the two northward fabrics is thought to represent NW flow rather than SE. The exposure was not clean enough to place the laminated sediments, exposed in windows through slump, in stratigraphic perspective.

Section South of Saint-Georges: (Section L on map 2)

Approximately 10 kilometres south of Saint-Georges, under about 25 metres of subaqueous outwash, a clayey till unit with fabric indicating northwestward ice flow was found. The overlying subaqueous outwash contains a southwestward paleocurrent direction (see section 3.4.1 on paleocurrent directions). The opposite directions represent two different events in which southward ice flow with accompanying southwardly deposited subaqueous outwash would have occurred after northward ice flow (figure 15). There is no other unequivocal stratigraphic evidence of a glacial episode after the northward ice flow, especially that far south into the Chaudière Valley. This evidence contributes to the paradox related to the timing of deposition of the Highland Front morainic system and the glacial readvance hypothesis discussed further in CHAPTER IV.

Section South of Saint-Georges

Figure 15. Diagrammatic section south of Saint-Georges. Northward fabric is in clayey till overlain by southwestward subaqueous outwash. The only known site where a "northwestward" till is overlain by an ice marginal deposit from southwestward flowing water from a southward advancing glacier.

3.3.2 Glacial Dispersal

In southeastern Québec, glacial dispersal in till has been studied and evaluated by: 1) fabric orientation of elongate clasts, 2) the presence of distinctive clast lithologies such as the ultramafics associated with the ophiolite belt and the high grade metamorphic gneisses originating from north of the St. Lawrence River, and 3) chemical signature in the silt and clay fraction (< 63 microns) (Shilts, 1973; Rencz and Shilts, 1980). Although other parameters can reflect glacial dispersal, the one used systematically in this study is chemical signature in the silt and clay fraction.

Glacial dispersal is produced by a glacier overriding bedrock, carrying and depositing the bedrock material away from its source in the down ice direction. It is usually studied by mapping the concentration pattern of distinctive lithological, mineralogical, or geochemical components in till or other glacial sediments to reconstruct glacial movements. A dispersal train can be divided into two segments: 1) the head, located at or close to the bedrock source and contains relatively high concentrations of the component studied and 2) the tail, which trails away from the head and along which the dispersal component declines exponentially to relatively low concentrations (Shilts, 1976b). Figure 16, modified from Shilts and Smith (in press), shows a perspective view of nickel dispersal trains trailing from ultramafic sources in the Appalachian ophiolite belt. The most northeasterly of the trains reflects

Figure 16. Perspective of nickel dispersal in the silt and clay fraction of the surface till in southeastern Québec (modified from Shilts and Smith, in press). The most northeasterly of the trains reflects southeastward dispersal from sources along Rivière des Plantes.

southeastward dispersal from sources along Rivière des Plante. More detailed maps of this train are presented in the following section.

3.3.3 Geochemistry of <63 Micron (silt and clay) Fraction of Surface Till

Regional till sampling has been an on-going project in southeastern Québec since the first mapping in the region by Gadd and McDonald in the early 1960's. Collection of till samples from the study area has contributed to this regional sampling project. Till samples were collected wherever till was well-exposed to a depth below the post-glacial solum, mainly in excavations along roads. Usually, the C-horizon of till exposed at the surface was oxidized, but if the exposure was deep enough, sometimes, unoxidized till was also present. When both oxidized and unoxidized were seen, each was sampled separately so that the effects of weathering on mineralogical and geochemical compositions could be evaluated (Shilts, 1974; Shilts and Smith, in press; Shilts and Kettles, in press).

The silt and clay fraction of till samples was analyzed for 6 elements with standard procedures carried out by Bondar-Clegg Ltd. and Chimitec Ltd. The concentrations in parts per million (ppm) of nickel, cobalt, copper, and chromium⁴ were detected with atomic absorption spectroscopy (AA analysis) using a hot leach by HCl-HNO₃ (1:3). The concentrations of arsenic were

⁴Soluble chromium only.

detected by colourimetry using a leach of $\text{HNO}_3\text{-HClO}_4$ (1:1) and tin concentrations were determined by X-Ray fluorescence. Results of geochemical analyses along with a map of sample locations are annexed in Appendix 2.

The purpose of analyzing for chemical elements is two-fold: 1) geochemistry can serve as a surrogate for mineralogy of the sediments. A geochemical pattern of dispersal can indicate directions of ice flow across distinctive outcrops and can be a useful compositional parameter to use in correlating glacial sediments among scattered exposures; 2) geochemistry can be used to evaluate mineralization in drift-covered bedrock.

Fortuitously, the study area is crossed by an ophiolite belt (figure 5 or acetate⁵) that forms the bedrock along and north of Rivière des Plante. The ultramafic rocks of the ophiolite belt possess a distinctive chemistry because they are compositionally similar to the mantle and mantle rocks differ greatly in chemical composition from crustal rocks.

i) Nickel Geochemistry

The average content of nickel in ultramafic rocks of ophiolite suites of the Appalachians of Thetford Mines and Asbestos region is 2250 parts per million (ppm) (Laurent, 1975). Since ultramafic rocks have a high concentration of nickel, cobalt, and chromium, glacially comminuted ultramafic

⁵The legend for the acetate bedrock map is the same as the one for figure 5.

rocks should produce a similar chemical signature in the till. In other words, glacial deposits located down ice from ultramafic rock outcrops such as those of the Rivière des Plante ophiolite suite should contain high nickel, cobalt, and chromium concentrations, although the concentrations in drift, relative to the concentrations in source rocks are probably attenuated due to mixing with ground up crustal lithologies (Shilts, 1976b).

The nickel concentration for each till sample was plotted and contoured by hand (figure 17). If the acetate bedrock geology map (modified after Slyvitsky et St-Julien, 1987), is overlain on the contour map of nickel concentrations, it is observed that higher concentrations of nickel in the till correlate with the presence of ultramafic outcrops (stippled unit on the bedrock geology map).

There appear to be two nickel dispersal trains: 1) a major dispersal train with a general southeastward glacial ice flow pattern (indicated by large arrow on contour map) and 2) a minor dispersal train with northward distribution of nickel above background level (small arrow).

This pattern of dispersal seems to confirm observations that depositional evidence for northward ice flow is less abundant than for southeastward ice flow.

Figure 17. Nickel dispersal in surface till. The long arrow indicates southeastward transport and the short arrow indicates northward transport in relation to ophiolite outcrops.

ii) Chromium Geochemistry

Although chromium concentrations are lower than nickel concentrations, their dispersal pattern closely resembles the concentration pattern of nickel. In general, where there are nickel enrichments, there are chromium enrichments.

Like nickel, chromium is found in high concentrations in ultramafic rocks. The average for chromium in ultramafic rocks is 3000 ppm (Laurent, 1975). This implies that in till, concentrations of both elements should be similar. However, from figures 17 and 18, there is always less chromium than nickel in the silt and clay fraction. This can be explained since chromium usually occurs in the mineral form of chromite in Appalachian ultramafic rocks of Paleozoic age (Laurent, 1980), while nickel is concentrated in the structure of serpentine. Chromite, a resistant mineral, will not be as easily glacially comminuted as serpentine into the silt and clay fraction, nor will it be effectively attacked by the hot HCl-HNO₃ leach used routinely for those analyses. Rather, it will remain in sand size particles and only if it is in high concentrations will it show up in the silt and clay fraction (Rencz and Shilts, 1980).

Two glacial flows observed from the chromium dispersal pattern can be traced back to the ophiolite belt: 1) the southeastward ice flow (long arrow) and 2) the northwestward ice flow (short arrow) (figure 18).

Chromium concentrations (ppm) in $< 63\mu\text{m}$ fraction of till

Figure 18. Chromium dispersal in surface till. The long and short arrow indicate southeastward and northward (respectively) dispersal in relation to ophiolite outcrops.

foreset beds that indicated the same two-dimensional paleocurrent direction in order to eliminate possibility of measuring retrogressive ripples.

The purpose of using this approach was to determine the configuration of the ice mass that was responsible for depositing the sand and gravel. In other words, if the ice front of a glacier with a Laurentide source, i.e., ice flowing southward to a northward retreating ice front, paused long enough to accumulate an abnormal thickness of sediment, this sediment would have a southward paleocurrent direction. If the ice front was along the north side of a shrinking Appalachian ice mass, northward paleocurrent directions would be measured. Paleocurrents have been plotted on map 2, but the chronology of deposition has not been indicated and will be discussed further in CHAPTER IV.

3.4.2 Pebble Lithology in Gravel Deposits.

Along with measurement of paleocurrents, poorly sorted gravel samples were collected for pebble lithology identification. The objective of pebble counting was to attempt to associate provenance with paleocurrent measurements.

iii) Cobalt Geochemistry

Aside from the enrichment associated with the copper and arsenic enrichments discussed below, there is also some cobalt dispersal from outcrops along Rivière des Plante. The world average for cobalt concentrations in ultramafic rocks is 200 ppm compared with a typical crustal average of <80 ppm (Krauskopf, 1979). Glacial dispersal of cobalt from the ultramafic outcrops is only observed southeast from the outcrops and not north from them (figure 19). This probably indicates again that southeastward ice flow was stronger than northward ice flow and that dilution by cobalt-poor debris in the dispersal area has reduced the northward cobalt train to such low levels that it cannot be differentiated from background variations.

iv) Copper Geochemistry

In this region, when glacial dispersal of ultramafic clasts occurs, high nickel concentrations often coincide with low copper concentrations (Shilts and Smith, in press). To explain this observation Shilts and Smith suggest that copper-bearing components of the till are diluted by the high amount of nickel. Shilts (1984) has coined the term negative glacial dispersal train to explain dispersal patterns where some chemical elements are camouflaged by the presence of others.

Figures 17 and 20 reveal that where there is a high amount of nickel near ultramafic outcrops, there is the predicted low amount of copper.

Cobalt concentrations (ppm) in $< 63\mu\text{m}$ fraction of till

Figure 19. Cobalt dispersal reflects slight southeastward ice flow in relation to ophiolite outcrops (indicated by arrow).

Nonetheless, any copper present in the local bedrock may be hidden by the relative abundance of nickel down ice from ultramafic outcrops.

Copper enrichment is noticed in the northwest corner of the study area (figure 20) which seems to match with cobalt and arsenic enrichments found (in figures 19 and 21, respectively) in the same general area. Since the underlying metasedimentary bedrock is not thought likely to contain these high concentrations of cobalt, and the most recent compilation of bedrock units in southeastern Québec (Slyvitsky and St-Julien, 1987) suggests that this area needs to be re-examined, the author proposes that there may be an unmapped lithologic unit that hosts copper, cobalt and arsenic mineralization. Furthermore, approximately 30 km up-strike (NE) from the enrichment, in the Bennet schists-Caldwell Group, there are serpentinites that host copper, cobalt, and arsenic mineralization on colline St-Ronan (Gauthier, 1988a). Approximately 25 km down-strike (SW) from the enrichment, in the Rosaire Group, copper mineralization occurs at Harvey Hill (Gauthier, 1988a; Kirkham, personal communication, 1989). The strong northeasterly trend of the copper contours further suggest that stratabound mineralization or structurally controlled mineralization is responsible for the anomaly.

v) Arsenic Geochemistry

In addition to the sympathetic enrichment of arsenic with copper and cobalt, there is another less prominent arsenic enrichment overlying faulted

Figure 20. Copper negative dispersal train in relation to ophiolites. Where there is high nickel, there are low concentrations of copper.

slaty schists from the Magog Group. The latter enrichment may be related to mineralization from hydrothermal activity due to faulting (figure 21). These enrichments are close to the gold-bearing buried regoliths of the Beauceville area (Shilts and Smith, 1988; 1989) and may have some genetic significance for the origin of gold in the region.

vi) Tin Geochemistry

In the study area, there are small enrichments of tin. The highest concentration is 15 ppm (figure 22).

Cassiterite (SnO_2), being the most common tin-bearing mineral, is assumed to be the major contributor to the enrichments. Since cassiterite is a hard, resistate mineral, like chromite, it will not be easily weathered or abraded to silt and clay sizes. Therefore, evidence of enhanced concentrations of tin in the silt and clay fraction may be indicative of greater amounts in the coarser fractions.

The source of cassiterite or other tin-bearing minerals is not clear. The highest concentration (15 ppm) is found overlying rocks of the Magog Group (Ordovician age). The enrichment may originate from: 1) the underlying felsic tuffs and slates and related hydrothermal activity due to faulting, 2) hydrothermal activity from other events such as the intrusion of Devonian granites, or 3) an undefined hydrothermal event.

Figure 21. Arsenic concentrations. Together with cobalt and copper enrichments in the northwestern corner of the study area, they probably outline an unmapped stratabound mineralization.

Figure 22. Tin concentrations in surface till. May be related to hydrothermal activity during faulting.

Nevertheless, it may be interesting to explore coarser fractions of till samples that contain >10 ppm Sn to determine the origin of these concentrations.

3.4 Depositional Evidence for Ice Flow Directions in Ice Contact Stratified Drift

3.4.1 Paleocurrents in Sand and Gravel Deposits

During the summer of 1988, a systematic survey of paleocurrent directions in ice marginal deposits was undertaken. The regular procedure was: 1) to get a general paleocurrent direction from the angle at which the gravel pit faces cut into the dipping foreset beds, 2) to find ripple cross-laminated sand units that followed the general foreset dip direction, 3) to dig into the sand face to identify about 20-30 sets of ripple crests (in all cases, they were lunate (Collinson and Thompson, 1984) ripple crests)(plate 13), and 4) to record their direction of deposition. A total of 21 sites were measured systematically. Where sand ripple cross-laminae were absent, other paleocurrent features were measured, such as direction of dip in sand and gravel foreset beds (plate 14). Results from all measured sites can be seen on map 2.

Although ripple crest measurements may be the least reliable of paleocurrent indicators (Miall, 1974), the author chose to measure these within

foreset beds that indicated the same two-dimensional paleocurrent direction in order to eliminate possibility of measuring retrogressive ripples.

The purpose of using this approach was to determine the configuration of the ice mass that was responsible for depositing the sand and gravel. In other words, if the ice front of a glacier with a Laurentide source, i.e., ice flowing southward to a northward retreating ice front, paused long enough to accumulate an abnormal thickness of sediment, this sediment would have a southward paleocurrent direction. If the ice front was along the north side of a shrinking Appalachian ice mass, northward paleocurrent directions would be measured. Paleocurrents have been plotted on map 2, but the chronology of deposition has not been indicated and will be discussed further in CHAPTER IV.

3.4.2 Pebble Lithology in Gravel Deposits.

Along with measurement of paleocurrents, poorly sorted gravel samples were collected for pebble lithology identification. The objective of pebble counting was to attempt to associate provenance with paleocurrent measurements.

Plate 13. Looking down on lunate ripple crests. Direction of paleocurrent indicated by the pen point.

Plate 14. Sand foreset beds. Direction of paleocurrent indicated by handle of knife.

Gravel samples were dry sieved for an examination of the >6.7 mm pebble fraction. In a total of 29 samples, 300 pebbles were counted per sample.

The two lithologies compared were easily identified clasts of Precambrian erratics from the Canadian Shield north of the St. Lawrence River and ultramafic erratics from the ophiolite belt that strikes northeasterly through the study area.

Theoretically, deposits formed by a Laurentide ice mass would have southward paleocurrents along with a high content of Precambrian and no ultramafic erratics north of the ophiolite belt, but high amounts of ultramafics south of the ophiolite belt. Using similar reasoning, the Appalachian ice mass would have deposited only reworked Precambrian erratics but would have transported ultramafics north of the ophiolite belt, leaving only reworked ultramafic erratics from earlier southeastward flow south of the ophiolite belt.

The percentage of Precambrian erratics varies inconsistently from one deposit to another (figure 23). In addition, only two sample sites were observed to contain ultramafic erratics; one south of the ophiolite belt and the other north of it.

One factor that may explain the lack of ultramafic pebbles is the relatively low resistance to physical and chemical breakdown of ultramafic lithologies. Since most Precambrian pebbles are composed of granitic gneiss, they are relatively harder than the ultramafic erratics and they can be subjected

Figure 23. Percentage of Precambrian erratics in ice-contact stratified drift.

to higher energy levels of deposition without significant breakdown than can ultramafic erratics. Also, once deposited, ultramafic pebbles would probably react to meteoric waters and disintegrate relatively faster than the Precambrian pebbles. Therefore, fewer ultramafics would be present as coherent clasts in weathered samples.

The variability in percentage of Precambrian erratics or ultramafics also may be related to the varying hardness of the local bedrock. For instance, if the ice sheet paused above easily erodable bedrock such as slates, it would produce a high amount of local sediment and the amount of Precambrian pebbles may be camouflaged by the presence of local slates.

The lack of ultramafic erratics in ice-contact deposits of the Chaudière Valley from Sainte-Marie to Saint-Joseph is in sharp compositional contrast with till erratics on the adjacent uplands, reported by Gadd (1978) to be rich in ultramafics, an observation confirmed by the author. Likewise, work by Maurice (Canadian Mining and Metallurgy Conference, 1988) on geochemistry of heavy minerals in stream sediments in the region also showed low chromium concentration in the Chaudière Valley relative to streams traversing adjacent highlands. The contrasts noted by the author, Gadd, and Maurice comparable to the contrast between southward paleocurrents in deposits on the valley floor and northward striae and paleocurrents on flanking highlands. Combined with high percentages of Shield erratics in deposits in the Chaudière

Valley, the contrasting chromium and ultramafic erratic concentrations constitute lithological support of the depositional history deduced independently from morphology of the deposits in the valley and their paleocurrents, i.e., deposition of sediments in the valley was at the retreating front of a lobe of ice that had readvanced up the valley from the north.

3.4.3 Esker Systems

Eskers of the study area can be classified geographically into two systems. One system contains northward paleocurrents, the other southward paleocurrents. These paleocurrent discrepancies reflect deposition from two distinctly different ice masses: 1) the set of eskers with northward paleocurrents were formed within the Appalachian ice mass and 2) the set of eskers with southward paleocurrents were formed within the Laurentide ice mass. Eskers for which paleocurrent directions were not determined formed in either one of the two ice masses. Northeast of and within the study area, Gauthier (1975) and LaSalle *et al.* (1977b) noted northward paleocurrents in esker-outwash systems, but their techniques of measurement were not clearly discussed. Gauthier (1975) also recorded southward paleocurrents in the Vallée-Jonction deposits.

3.4.4 Subaqueous Outwash Deposits, Eskers and Rhythmites

As mentioned in Chapter I, in the Appalachians, any southward glacial outwash deposit below about 394m altitude is likely to have been formed in subaqueous conditions because, when ice blocks the St. Lawrence River, it forms proglacial lakes in the St. Lawrence's south shore tributaries. Consequently, any sediment deposited below this level in the Chaudière or Etchemin Valleys, must have had a subaqueous environment of deposition.

If no ice mass existed in the St. Lawrence Valley, drainage in the Chaudière and Etchemin Valleys should have been free above marine limit, which is unknown but probably <170m (550ft) (McDonald, 1967). Under such conditions of free drainage, ice-contact stratified drift with northward paleocurrents at any altitude above 170 m would be proglacial fluvial outwash and would not have been subaqueous. Several factors suggest that for both the deposits with northward paleocurrents and those with southward paleocurrents, deposition was into ponded drainage below 394 m. 1) A regional factor which helps to confirm subaqueous conditions of deposition is that sediments of ice-contact stratified drift with northward as well as southward paleocurrents possess, immediately downstream, a distal sedimentary facies of rhythmically laminated silt and clay thought to have been deposited in a proglacial lake (unit 3 of map 1). Taken together, the succession of esker, subaqueous outwash, and silt and clay rhythmites gives a general direction of

deposition; 2) High amplitude (>10 m) foreset beds were observed in deposits with both directions of paleocurrents, indicating lacustrine and not fluvial deposition. These foresets lack topset beds which indicates fan deposition below lake level; 3) Clay layers or beds of several silt-clay couplets within generally coarse-grained outwash represent periods of quiescent deposition at depth in a lake. Where present they confirm the sublacustrine environment of deposition of the coarse grained sediment package in which they occur. Continuous clay layers were observed in every northward ice-contact deposit, suggesting that a proglacial lake existed during retreat of the Appalachian ice mass. Therefore, there must have been ice in the St. Lawrence River blocking drainage of the Chaudière and the Etchemin Rivers as the Appalachian ice wasted. Clay layers were similarly observed throughout the deposits with southward paleocurrents; 4) In both Chaudière and Etchemin River valleys, the subaqueous outwash fan deposits (unit 2b of map 1) were fed by conduits marked by esker systems (unit 2a of map 1). Rust and Romanelli (1975) define a subaqueous outwash fan as being fed by a meltwater tunnel, but this process may or not preserve the esker at the upstream end of the fan.

3.4.5 Low Altitude Silt and Clay Rhythmites

In two places where there was a possibility that sediments interpreted to have been deposited in a proglacial lake may have been confused with

glaciomarine sediments because of their low altitude (<200m), undisturbed laminated silt and clay rhythmites were sampled for microfossil examination. The samples were boiled in stainless steel pots filled with water until clay particles were disaggregated fully. Then, samples were sieved (>63 micron fraction preserved) and dried under hot lamps. Once dried, the samples were separated in carbon tetrachloride (s.g. 1.56). The lighter grains were filtered and later searched for microfossils under a binocular microscope. No marine microfossils were found. Sites that were sampled are: 1) the silt and clay laminae overlying the Lennoxville Till in the Fraser River Section (figure 11 and section F on maps 1 and 2), and 2) the silt and clay laminae located in the town of Sainte-Marie (figure 1).

CHAPTER IV: Discussion of Events during Lennoxville Glaciation

4.1 Evidence for Southeastward Glacial Flow from Striae and Till Deposits

The oldest striation directions recognized are associated with the southwestward flow phase of Chaudière glaciation, but sites where these can be found are rare. Two main flow phases of Lennoxville glaciation are represented by southeastward glacial striae in southeastern Québec. Where both are preserved, a set at $100^{\circ} \pm 15^{\circ}$ is always the oldest, followed by a younger set at $130^{\circ} \pm 5^{\circ}$. Neither set of southeastward striae are as abundant as the younger sets (figure 7). Nevertheless, the southeastward striae represent the major part of the glaciation because their ice flow is responsible for glacially molding most of the bedrock hills into roches moutonnées oriented in a southeastward direction (figure 24). Consequently, southeastward ice flow probably lasted longer than the younger northward ice flow of the same glaciation. It is possible that the $100^{\circ} \pm 10^{\circ}$ phase of flow was formed late in the Chaudière glaciation when Laurentide ice displaced southwestward-flowing maritime ice in the study area. Shilts (1978; 1981) reported that the surface of the Chaudière Till beneath the Gayhurst Formation at Rivière Samson, 25 km south of Saint-Georges, is striated by ice flowing at 110° , which may support this hypothesis.

In stratigraphic sections, tills deposited by both southeastward and northward flowing ice have been observed, but their age relationship is not as

Figure 24. Model for Lennoxville glaciation and deglaciation. Southeastward ice flow during the major part of the Lennoxville glaciation. Laurentide Ice Sheet invading southeastern Québec and northern part of the United States.

clear as that between the various sets of glacial striae in the study area.

However, Shilts (1976b) has reported that late glacial ice flow reversal from southeastward to northward has been observed in Lennoxville Till exposed in a section near Petit Lac, located in the Thetford Mines area (45 km west of the study area), north of the ophiolite belt. At Petit Lac, the lower part of the till was deposited by southeastward flowing ice and is compositionally impoverished in ultramafic erratics, and in nickel, chromium and cobalt in the clay fraction. The upper part of the till has a north-northeast fabric and is enriched in ultramafic components derived from the south, which reflects the northward shift in ice flow direction as well as the relative age relationship of the two phases of flow.

As in the study area, the Petit Lac section, and other sites in the Thetford Mines area, the geochemistry of the silt and clay fraction of the surface till reveals well developed nickel, chromium, and cobalt dispersal trains trending southeastward from the ophiolite belt, but at the same time reflects a definite but weaker northward dispersal. Thus, it can be concluded that southeastward dispersal reflects a longer, more intense glacial event than the event characterized by northward flow.

4.2 Northward Ice Flow and the Calving Bay Model

4.2.1 Striation Directions, Till Deposits, and the Calving Bay Theory

As mentioned in the previous section, striation directions and till deposits indicate that northward ice flow followed southeastward ice flow during the Lennoxville glaciation. Northward ice flow appears to have been less vigorous in terms of: 1) erosion, because it did not erase evidence of southeastward ice flow and 2) deposition, because northward transport is less extensive than southeastward transport.

There seem to have been several phases of ice flow reversal. In the map area, northward striae are in some places cross-cut by younger east-northeastward striae which represent a slight shift in the ice flow towards the end of the glaciation. This was observed also by Lortie (1976) and Lortie et Martineau (1987).

It has been suggested by Gadd *et al.* (1972a) that a calving bay in the St. Lawrence channel caused the Laurentide Ice Sheet to stop the southeastward supply of ice, leaving a significant portion of the ice sheet "stranded" over the Appalachians. They suggested that the stranded ice eventually would have developed its own profile and would have started to flow northward toward the axis of drawdown in the St. Lawrence Valley.

After the calving bay hypothesis had been suggested, Thomas (1977) offered a glaciological explanation as to why the formation of a calving bay in

the St. Lawrence channel was a plausible model. In short, Thomas suggested that since ice was grounded in the St. Lawrence channel all the way out to the Gulf, a factor, such as a rise in the eustatic sea level because of melting of the Laurentide Ice Sheet as a result of warmer climatic conditions, may have caused the grounded ice margin to float and thereby form an ice shelf. He suggested that the ice shelf would eventually calve off icebergs which in turn would result in greatly accelerated wastage in the St. Lawrence channel, forming an embayment up the channel.

The embayment would have caused thinning of the ice sheet in the St. Lawrence channel and would have provoked ice from north of the St. Lawrence to flow northeastward towards the Gulf to compensate for the increased wastage. This northeastward redirection of Laurentide flow would have stopped the supply of ice to that part of the ice sheet that still covered the Appalachians. Consequently, because of drawdown, ice left over the Appalachians would have flowed back toward the St. Lawrence channel and then towards the north-northeast along the channel, parallel to the redirected Laurentide flow. This would have produced converging ice flows in the channel (figure 25).

The author thinks that such a model is plausible, but whether there was a calving bay in the lower St. Lawrence channel, or whether another mechanism stopped Laurentide ice from crossing into the Appalachians and

eventually caused the reversal of ice flow is not known. However, if the calving bay is the mechanism that caused the reversal of ice flow, it is not the mechanism that caused the splitting of the ice masses at the latitude of this study, as once thought by many authors, including Thomas (1977), Gauthier (1975), Lortie (1976), and LaSalle *et al.* (1977a, b). Such a mechanism would involve incursion of the Champlain Sea after northward ice flow. However, the evidence cited for a southward readvance up the valleys, discussed below, required ice resting continuously against the south side of the narrows between the Precambrian and Appalachian Highlands at and near Québec City, blocking the incursion of the sea. Likewise, evidence that the north edge of the shrinking Appalachian ice mass retreated in high level proglacial lakes requires a Laurentide ice mass resting against the Appalachian front, blocking drainage to the St. Lawrence.

4.2.2 Québec Ice Divide

Former mapping of glacial striations in southeastern Québec revealed that there were abrupt changes in the occurrence of northward versus southeastward directions (Lortie, 1976). It was thus suggested that the remaining ice cap had radiating ice flows out from its centre, i.e., away from the ice divide. This ice divide has been mapped roughly across the Québec Appalachians to the Maine border and has been called the Québec Ice Divide

Figure 25. Supply of ice was stopped over southeastern Québec by a calving bay in the lower St. Lawrence channel. The lack of ice caused southeastward flowing ice to be diverted towards the point of drawdown, down the St. Lawrence channel. Southeastward flowing ice north of the channel shifted flow NE, down the channel; ice cut off from its northern supply and trapped south of the St. Lawrence developed a divide and flowed back toward the channel - northwards.

(figure 25) (Shilts, 1976a, 1981). In Maine, Kite and Lowell (1986)⁶ refer to the divide as the North Maine Ice Divide. Further field investigations from the summer of 1989 have outlined the ice divide with more precision across the Chaudière Valley as far south as 10 km south of Saint-Georges (figure 1). Because the whole central Chaudière Valley was affected by the northward ice flow, if no glacial event followed northward flow, the last evidence of melting should be deposits with northward paleocurrent directions. However, the youngest glaciofluvial and glaciolacustrine deposits found in the Chaudière River Valley and in the central part of the Etchemin River Valley contain southward paleocurrent directions, suggesting that the last ice fronts in the bottoms of the valleys faced south.

4.2.3 Eskers and Subaqueous Outwash Deposits

Paleocurrent data reveal that some of the eskers and subaqueous outwash deposits have a northward direction of deposition. Since proglacial outwash deposits with northward paleocurrents had to be deposited in front of an ice margin, the ice mass responsible for northward flow had to have been split from the Laurentide Ice Sheet. The Appalachian ice mass probably split from the Laurentide Ice sheet due to a lack of and a lack of local alimentation required to maintain export of ice from the divide (figure 26 and 27).

⁶ 49th Annual Friends of the Pleistocene field trip.

Figure 26. Eventually both ice masses split into 1) Laurentide ice mass and 2) Appalachian ice mass in which the ice divide had formed at the time that flow from the Laurentide ice mass was cut off. The split was not caused by a retreating calving bay into the St. Lawrence channel but because of a lack of supply of Laurentide ice to the remnant trapped over the Appalachians, in a climatic zone that caused the ice surface to be mostly below the local equilibrium line.

Figure 27. Cross-Section. Decrease in size of the Appalachian ice because a lack of ice supply caused it to gradually melt away. Laurentide ice, still sitting at the foot of the Appalachians, caused drainage to be ponded and subaqueous conditions of deposition for the outwash deposited by the Appalachian ice mass.

The subaqueous conditions of deposition in the northward outwash complex imply that regular drainage had not resumed, i.e., there was still ponding which caused the ice margin from the Appalachian ice mass to be submerged into proglacial lakes. This ponding could have occurred only if the Laurentide Ice Sheet had split south of the St. Lawrence Valley, probably along the Appalachian front.

4.3 Southward Ice Flow, a Glacial Readvance

4.3.1 Eskers and Subaqueous Outwash Deposits

The Chaudière and the Etchemin Valleys contain southward deposited eskers and subaqueous outwash deposits (maps 1 and 2). In the Chaudière Valley, the most prominent subaqueous outwash deposits are at Vallée-Jonction, but several less prominent deposits occur along the valley as far south as south as the reach between Saint-Georges and Saint-Martin (map 2).

In the Etchemin Valley and in its tributaries, there are northward deposited eskers and subaqueous outwash in the upper part of the drainage basin. In the lower part of the valley, just north of the map area, a massive subaqueous outwash deposit occurs in a tributary of the Etchemin River. It has strong evidence of southward paleocurrents and is located less than 2 km north of subaqueous outwash deposits with northward paleocurrents located on

another tributary of the Etchemin River, the Pyke River. North of the Saint-Joseph map area (maps 1 and 2), there are a few other outwash deposits that have southward paleocurrents but have not been added to the map because they are too far out of the map area. The author suspects that systematic mapping and study of ice-contact deposits in the map area (NTS 21L/10) just north of the Saint-Joseph map area would shed further light on the nature of the retreat of the readvance lobe that filled the Chaudière Valley.

As noted by Gauthier (1975), Lortie (1975, 1976) Shilts (1982), and others, ice marginal deposits with southward paleocurrents are found only in the two major valleys. They are located throughout the valleys where they cut through the area striated by northward flowing ice and are probably correlative with similar deposits in the Rivière St-François Valley (Shilts, 1982). Because northward ice flow was the last event for which striae have been observed, the southward deposits at first seem to present a paradox. Since the last recorded ice flow should only have left deposits with northward paleocurrents, in the author's opinion, as well as Gauthier's (1975), Lortie's (1976), and Shilts' (1982), the timing of deposition of these southward ice marginal deposits occurred after northward ice flow. In other words, there must have been a glacial readvance to deposit the subaqueous outwash in the Chaudière and Etchemin Valleys (figure 28).

Figure 28. Once the Appalachian ice mass disintegrated, Laurentide ice readvanced as lobes up major valleys and into the lower parts of the Appalachian highlands in the Saint-Sylvestre map area (Gadd, 1978).

4.3.2 Striae Directions

The ultimate proof associated with the southward deposits found in the two major valleys would have been to find northward glacial striae being cross-cut by younger southward glacial striae. Unfortunately, at crucial locations such as at Vallée-Jonction (maps 1 and 2), the bedrock exposed is a friable phyllite that does not preserve striae well. Nevertheless, the latitudinal superposition of the northward erosional and depositional evidence found on the highlands versus the southward depositional evidence found only in the major valleys suggests that northward flow took place prior to a southward readvance (maps 1 and 2).

4.3.3 Deposits overlying Lennoxville Till

In many stratigraphic till sections of the study area, there are deposits of colluvium, diamicton, clayey till, or till directly overlying typical Lennoxville Till or overlying proglacial lake sediments which rest on Lennoxville Till. This stratigraphic evidence, along with the southwestward subaqueous outwash overlying a clayey till probably deposited by northward ice flow (figure 15), suggest that ice must have readvanced up the valleys, into ice-dammed lakes.

4.3.4 The Southward Readvance in Relation to the Champlain Sea

The glacial readvance must be reconciled with the timing and nature of the incursion of the Champlain Sea through the narrows at Québec City. If the Laurentide and remnant Appalachian ice masses had been split by the Champlain Sea transgressing westward through the narrows at Québec City, then any readvance must have been through marine water with an altitude of less than 170 m above present sea level. As far south as Vallée-Jonction in the Chaudière Valley, there is no evidence of marine incursion, nor is there any till containing reworked marine sediments in the Chaudière Valley. The laminated silt and clay sediments sampled do not contain marine microfossils.

There are two factors, mentioned previously, that suggest that Laurentide ice may have been blocking the incursion of the Champlain Sea. The first is that there has been no evidence of marine life as far south as the study area. The second is that the northward ice marginal deposits, along with proglacial lake sediments found north of them, suggest that the remnant Appalachian ice front was retreating in a body of water, undoubtedly glaciolacustrine, that had a surface well above any possible marine limit. Therefore the author suggests that 1) the Appalachian ice cap was split from the Laurentide ice mass along ridges that projected through the ice along the Appalachian front. The remnant ice melted away since it owed its existence to ice flowing from northern Québec and had little or no local source of alimentation. 2) On the

other hand, since Laurentide ice was still being supplied with ice from northern Québec, it was active enough to rest against the Appalachian front, blocking both marine incursion and northward drainage of south shore tributaries. Consequently, subaqueous (lacustrine) conditions were prevalent below 394m along the north edge of the melting Appalachian ice cap. The southward glacial readvance up both major river valleys probably resulted from a slight rejuvenation of the Laurentide Ice Sheet by climatic deterioration near its centre, resulting in a slight readvance into the highlands, and significant lobate readvances up the water-filled major valleys.

4.4 The Study Area in Relation to the Highland Front Morainic System.

As mentioned in section 2.2.1., in the 1960's, before northward ice flow was confirmed to have occurred after southeastward ice flow, the theory of emplacement of the Highland Front morainic system (Gadd, 1964b) along the northward retreating front of the Laurentide Ice Sheet was generally accepted. Ice was thought to have flowed southeastward at the glacial maximum and to have retreated towards the north, leaving a series of ice marginal deposits with southward paleocurrents. The most continuous and prominent of these was the Highland Front morainic system. However, with the confirmation of reversal of ice flow to the north after southeastward ice flow, neither the timing of

deposition, the paleocurrents, the configuration of glaciolacustrine deposits, nor the location (south of the northernmost northward striae) of the Highland Front morainic system seemed to be compatible with the last, northward glacial event.

In 1978, Gadd published a surficial geology report and map of the Saint-Sylvestre map area (NTS 21L/6) which adjoins the Saint-Joseph map area on the west. In the report, he describes the Saint-Sylvestre map area as the type area for the Highland Front morainic system, and comments on the timing of deposition. He says: (figure 29) "The sediments (of the Highland Front morainic system) occur well within the zone in which northward flow phenomena have been observed and recorded and, therefore, are considered the strongest evidence that the terrain was ice free and that northward ice flow had ceased before the Highland Front system and associated ponded sediments were formed." (p. 5.)

Although Gadd's observations imply that a glacial readvance of the Laurentide Ice Sheet took place after northward ice flow and deposited the sediments of the Highland Front Moraine, he did not propose a glacial readvance, because he could not visualize the Laurentide Ice Sheet readvancing across the Champlain Sea, especially if there was a lack of marine fossils in sediments from the type area. Nevertheless, Gadd did agree that the

Figure 29. Ice-marginal features of the Highland Front morainic system in Saint-Sylvestre map-area, after Gadd, 1978. Note: northward glacial features are found north of some of the Highland Front moraine deposits.

deposition of the Highland Front morainic sediments took place after northward ice flow (figure 30).

Gadd's observations are compatible with the author's observations that the northern margin of the Appalachian ice cap was deposited in a ponded body of water. This ponded body of water was probably not marine because its sediments lack marine fossils and its surface was well above marine limit (based on elevations of possible outlets, glaciolacustrine sediments, and subaqueous outwash).

Figure 30. Laurentide ice retreated once more leaving minor ice front deposits south and north of the major subaqueous outwash deposit at Vallée-Jonction. During the retreat, the Highland Front morainic system was also deposited within a narrow altitudinal and geographical band. When ice retreated from the narrows at Québec City, westward incursion of the Champlain Sea took place.

4.5 Other Late-Wisconsinan Glacial Readvances.

As mentioned in section 2.2.3 (Previous work), ever since the recognition of northward ice flow, the timing of deposition of the Highland Front Moraine has been in question. Consequently, some authors suggested glacial readvance, but because of the problem posed by necessity for readvance through to the Champlain Sea, most authors have tended to skirt around the problem.

There have been reports and suggestions of glacial readvances in adjacent areas of southeastern Québec; in the 1) Québec City area, 2) south of Québec City and, 3) Rivière-du-Loup area.

In and south of Québec City, LaSalle *et al.* (1976, 1977a, b) and LaSalle (1989) have described glacial readvances into the Champlain Sea with evidence of marine fossils found in till-like deposits. South of Québec City (and the St. Lawrence River), overlying marine sediments, marine macrofossils are included as erratics in glacial deposits which are associated with the St-Nicolas readvance (LaSalle, 1989). Deposits north of the Québec City area are part of the St-Narcisse Moraine, a readvance that is thought to post-date the St-Nicholas readvance.

Dr. Martin Rappol (personal communication, 1988) believes, after two seasons of field work in the Rivière-du-Loup area, that there may have been a

glacial readvance of the Laurentide Ice Sheet northeastward down the St. Lawrence channel.

The point in mentioning these glacial readvances is to indicate that the Laurentide Ice Sheet, while retreating, seemed to have been subjected to periods of climatic deterioration which caused the ice margin to readvance at different times. Thus, evidence of other glacial readvances make the readvance in the Etchemin and Chaudière Valleys plausible because it could be one of many fluctuations in the ice margin during general retreat.

CHAPTER V: Summary and Conclusions

There are six distinguishable directions of ice flow in the study area (from oldest to youngest):

- 1) Southwestward (Chaudière glaciation).
- 2) East-Southeastward (Early Lennoxville glaciation or Late Chaudière glaciation).
- 3) Southeastward (Early to mid- Lennoxville glaciation).
- 4) Northward (Late-Lennoxville).
- 5) East-Northeastward (Late-Lennoxville)
- 6) Southward Readvance (Late-late Lennoxville).

These six glacial events were defined by merging data from erosional evidence, such as glacial striae, and from depositional evidence, such as till units, till fabrics, and ice-contact stratified drift.

Building from work done by other authors and data from the six glacial events, a complex glacial and deglacial history was modeled for the Lennoxville glaciation in southeastern Québec. Integrated into the model is the deposition of the Highland Front morainic system and the incursion of the Champlain Sea.

REFERENCES

- Benoit, F.W.
1958: *Région de Saint-Sylvestre et de la moitié de Saint-Joseph, districts électoraux de Mégantic, de Lotbinière, de Dorchester et de Beauce*; Ministère des Richesses naturelles Québec, RP-359, 12 p.
- Borns, H.W., Jr., and Hagar, D.J.
1965: *Late-glacial stratigraphy of a northern part of the Kennebec River valley, western Maine*; Geological Society of America Bulletin, volume 76, pp. 1233-1250.
- Bostock, H.S.
1964: *A provisional physiographic map of Canada*; Geological Survey of Canada, Paper 64-35, Map 13-1964, 24 pages.
- Bouchard, M.A., Lortie, G., Turcotte, P., and Chauvin, L.
1987: *Thetford Mines-Asbestos area* in: Pleistocene stratigraphy in the St. Lawrence Lowlands and Appalachians of southern Québec: a field guide. Collection: Environnement et Géologie, Volume 4, p. 140-159.
- Boulton, G. S.
1971: *Till genesis and fabric in Svalbard, Spitzbergen* in: R. P. Golthwait (Editor) *Till, -A Symposium*; Ohio State University Press, p. 41-72.
- Chalmers, R.
1988: *Surface geology and auriferous deposits of southeastern Québec*; Geological Survey of Canada, Annual Report, volume 10, part J, 160 p.
- Cheel, R.J. and Rust, B.R.
1986: *A sequence of soft sediment deformation (dewatering) structures in late Quaternary subaqueous outwash near Ottawa, Canada*; Sedimentary Geology, volume 47, p. 77-93.
- Cirkel, F.
1911: *Alluvial gold deposits in Quebec*; The Engineering and Mining Journal, November 25, p. 1035-1038.

- Clark, T.H.
1937: *Northward moving ice in southern Quebec*; American Journal of Science, volume 34, p. 215-220.
- Collinson, J.D. and Thompson, D.B.
1982: *Sedimentary Structures*; George Allen and Unwin London, 194p.
- Cooke, H.C.
1937: *Further note on northward moving ice*; American Journal of Science, volume 34, p. 221.
- Cousineau, P.A.
1982: *Géologie d'une partie du quart SE de la région de Saint-Joseph-de-Beauce*; Ministère de l'Energie et des Ressources, Québec, DP 82-01.
- Ells, R.N.
1887: *Report on geology of a portion of the Eastern Townships, relating more specifically to the counties of Compton, Stanstead, Beauce, Richmond and Wolfe*; Geological Survey of Canada, Annual Report, volume 2, part J, 70 p.
- 1889: *Second report on the geology of a portion of the province of Quebec*; Geological Survey of Canada, Annual Report for the years 1887-1888, volume 3, part 2, p. 1K-120K.
- Flint, R.F.
1951: *Highland centers of former glacial outflow in northeastern North America*; Geological Society of America Bulletin, volume 62, p. 21-38.
- 1957: *Glacial and Pleistocene geology*; John Wiley and Sons, Inc., New York, 563 p.
- Gadd, N.R.
1960: *Surficial geology of the Bécancour map-area, Québec*; Geological Survey of Canada, Paper 59-8, 34 p.
- 1964a: *Surficial geology, Beauceville map area*; Geological Survey of Canada, Paper 64-12, 3 p.

Gadd, N.R. (continued)

- 1964b: *Moraines in the Appalachian region of Quebec*; Geological Society of America Bulletin, volume 75, p. 1249-1254.
- 1965: *Surficial geology, Chaudière River valley* ; in Report of Activities; Geological Survey of Canada, Paper 65-1, p. 115-117.
- 1967: *The pattern of glacial recession in southeastern Quebec* (Abstract); Geological Society of America, Northeastern Section Annual Meeting, p.28-29.
- 1976: *Quaternary Stratigraphy in southern Quebec*; in The Quaternary Stratigraphy of North America (Mahaney, W.C., Editor), Dowden, Hutchinson and Ross (Publishers), Stroudsbury, p.37-50.
- 1978: *Surficial geology of Saint-Sylvestre map-area*; Geological Survey of Canada, Paper 77-16, 9 p.

Gadd, N.R., LaSalle, P., Dionne, J-C., Shilts, W.W., and McDonald, B.C.

- 1972a: *Quaternary geology and geomorphology of southern Quebec*; 24th International Geological Congress (Montreal), Guidebook, Field trips A-44, C-44, 70 p.

Gadd, N.R., McDonald, B.C., and Shilts, W.W.

- 1972b: *Deglaciation of southern Quebec*; Geological Survey of Canada, Paper 71-47, 19 p.

Gauthier, C.R.

- 1976: *Déglaciation d'un secteur des rivières Chaudière et Etchemin*; thèse de M.A. inédite, Université McGill, Montréal, 180 p.

Gauthier, M.

- 1985: *Synthèse métallogénique de l'Estrie et de la Beauce*; Ministère de l'Energie et des Ressources, Québec, MB 85-20, 191 p.
- 1988a: *Les gîtes de la ligne Brompton-Baie verte-Livret guide d'excursion*; Ministère de l'Energie et des Ressources, MB 88-21, 51 p.

Gauthier, M. (continued)

- 1988b: *Les gîtes métallifères du complexe ophiolitique de Thetford-Mines et du complexe d'îles en arc d'Ascot-Weedon*, Ministère de l'Énergie et des Ressources, MB-01, 73 p.

Gauthier, M., Auclair, M., Durocher, M.

- 1987: *Synthèse métallogénique de l'Estrie et de la Beauce (Secteur nord, Annexe 1)*; Ministère de l'Énergie et des Ressources, Québec, MB 87-39, 223 p.

Gorman, W.A.

- 1954: *Région de Sainte-Justine, comtés de Bellechasse et de Dorchester*, Ministère des Mines, Québec, RP-297, 6 p.
- 1955: *Région de Saint-Georges-Saint-Zaccharie, comtés de Beauce et de Dorchester*, Ministère des Mines, Québec, RP-314, 6 p.

Kamb, N.B.

- Ice petrofabric observations from Blue Glacier, Washington, in relation to theory and experiment*; Journal of Geophysical Research, volume 64, pp. 1891-1909.

Krauskopf, K.B.

- 1979: *Introduction to geochemistry*, McGraw-Hill (Publishers), second edition, Toronto, 617 p.

Lamarche, R.Y.

- 1971: *Northward moving ice in the Thetford Mines area of southern Quebec*; American Journal of Science, volume 271, number 4, pp. 383-388.
- 1974: *Southeastward, northward and westward ice movement in the Asbestos area of southern Quebec*; Geological Society of America Bulletin, volume 85, pp. 465-470.

LaSalle, P.

- 1989: *Stratigraphy and glacial history of the Québec region*; in: *Friends of the Pleistocene-Guidebook*; 52nd Annual Reunion, Québec, p. 27-70.

LaSalle, P., Martineau, G., et Chauvin, L.

- 1976: *Géologie des sédiments meubles d'une partie de la Beauce et du bas Saint-Laurent*; Ministère des Richesses naturelles, Québec, DPV-438, 13 p.

- LaSalle, P., Martineau, G., et Chauvin, L. (continued)
- 1977a: *Dépôts morainiques et stries glaciaires dans la région de Beauce-Monts Notre-Dame-Parc des Laurentides*; Ministère des Richesses naturelles, Québec, DPV-515, 22 p.
- 1977b: *Morphologie, stratigraphie et déglaciation dans la région de Beauce-Monts Notre-Dame-Parc des Laurentides*; Ministère des Richesses naturelles, Québec, DPV-516, 74 p.
- Laurent, R.
- 1975: *Petrology of the Alpine-Type Serpentinities of Asbestos and Thetford Mines, Quebec*; Schweizerische Mineralogische und Petrographische Mitteilungen, volume 55, pp. 431-455.
- 1980: *Environment of formation, evolution and emplacement of the Appalachian ophiolites from Quebec*; in: Ophiolites; Proceedings, International Ophiolite Symposium, Cyprus, p.628-636
- Lortie, G.
- 1975: *Direction d'écoulement des glaciers du Pléistocène des Cantons de l'Est, Québec*; in: Report of Activities, Part A; Geological Survey of Canada, Paper 75-1A, pp. 415-416.
- 1976: *Les écoulements glaciaires wisconsinien dans les Cantons de l'Est et de la Beauce, Québec*; thèse M.A., non publiée, Université McGill, Montréal, 219 p.
- Lortie, G. et Martineau, G.
- 1987: *Les systèmes de stries glaciaires dans les Appalaches du Québec*; Ministère de l'Energie et des Ressources, Québec, DV 85-10, 45 p.
- Mackay, B.R.
- 1921: *Beauceville map-area, Quebec*; Geological Survey of Canada, Memoir 127, 105 p.
- McDonald, B.C.
- 1966: *Pleistocene geology studies, Richmond-Sherbrooke region, southeastern Quebec*; in: Report of Activities; Geological Survey of Canada, Paper 66-1, p.167.

McDonald, B.C. (continued)

- 1967: *Pleistocene events and chronology in the Appalachian region of southeastern Quebec, Canada*; unpublished Ph.D. dissertation, Department of Geology, Yale University, 161 p.
- 1968: *Deglaciation and differential postglacial rebound in the Appalachian region of southeastern Quebec*; Journal of Geology, volume 76, pp. 664-677.
- 1969: *Surficial geology of La Patrie-Sherbrooke area, Quebec, including Eaton River watershed*; Geological Survey of Canada, Paper 69-52, 21p.
- 1971: *Late Quaternary stratigraphy and deglaciation in eastern Canada*; in: The Late Cenozoic Glacial Ages, K.K. Turekian (Editor); Yale University Press, p. 331-353.

McDonald, B.C., and Shilts, W.W.

- 1971: *Quaternary stratigraphy and events in southeastern Quebec*; Geological Society of America Bulletin, volume 82, p. 683-698.

Maurice, Y.T.

- 1986: *Résultats et interprétation d'un levé géochimique de minéraux lourds, régions de l'Estrie et de la Beauce, Québec (21L, 17, 9, 10, 11, 13, 14, 15, 16; 21L/2, 3) ;* Commission Géologique du Canada, dossier public 1332.

Miall, A.D.

- 1974: *Paleocurrent analysis of alluvial sediments: A discussion of directional variance and vector magnitude*; Journal of Sedimentary Petrology, volume 44., p.1174-1185.

Obalski, J.

- 1908: *Gold in the Eastern Townships of the Province of Quebec*; Journal of the Canadian Mining Institute; Part of volume XI.

- Parent, M.
 1987a: *The Asbestos-Valcourt and Sherbrooke area*; in: *Pleistocene Stratigraphy in the St. Lawrence Lowlands and the Appalachians of southern Québec: a field guide*; Collection Environnement et Géologie, volume 4, p. 102-139.
- 1987b: *Late Pleistocene stratigraphy and events in the Asbestos-Valcourt region, southeastern Québec*; unpublished Ph.D. dissertation, Department of Geology, University of Western Ontario, London, 320 p.
- Parent, M., and Occhietti, S.
 1988: *Late Wisconsinan deglaciation and Champlain Sea invasion in the St. Lawrence Valley, Québec*; *Géographie Physique et Quaternaire*, volume 42, p. 215-246.
- Paul, J.
 1987: *Character and provenance of Lennoxville Till as exposed in two sections on Rivière des Plante, southeastern Québec*; Unpublished B.Sc. thesis, University of Waterloo, Waterloo, 66p.
- Poliquin, I.
 1987: *Stratigraphic and Sedimentological studies of sections from Rivière des Plante, southeastern Québec*; Unpublished B.Sc. thesis, University of Ottawa, Ottawa, 60p.
- Poole, W.H., and Rodgers, J.
 1972: *Appalachian geotectonic elements of the Atlantic provinces and southern Quebec*; 24th International Geological Congress (Montreal), Guidebook, Field excursion A63-C63, 200 p.
- Rancourt, L. et Fournier, C.
 1988: *Le grand Saint-Georges et sa région Beauce-Sartigan*; revue touristique, 25 p.
- Rencz, A.N. and Shilts, W.W.
 1980: *Nickel in soils and vegetation of glaciated terrains* in: *Nickel in the environment*, J.O. Nriagu (Editor), Wiley Interscience (Publishers), Toronto, p. 151-188.

Rust, B.R. and Romanelli, R.

- 1975: *Late Quaternary sub-aqueous outwash deposits near Ottawa, Canada*; in: A.V. Jopling and B.C. McDonald (Editors) *Glaciofluvial and glaciolacustrine sedimentation*; Society of Economic Paleontologists and Mineralogists, Special Publication 23, p.177-192.

St-Julien, P., and Hubert, C.

- 1975: *Evolution of the Taconian orogen in the Quebec Appalachians*; in: *American Journal of Science*, volume 275-A, p. 337-362.

St-Julien, P., Slivitsky A., and Feninger, T.

- 1983: *A deep structural profile across the Appalachians of southern Quebec*; in: *Contributions to the tectonics and geophysics of mountain chains*; Hatcher, R.D., Williams, H., Zietz, I.(Editors), Geological Society of America, Memoir 158, p. 103-112.

Shilts, W.W.

- 1970: *Pleistocene geology of the Lac Mégantic region, southeastern Quebec, Canada*; unpublished Ph.D. dissertation, Department of Geology, Syracuse University, Syracuse, 154 p.
- 1973: *Glacial dispersal of rocks, minerals, and trace elements in Wisconsinan till, southeastern Quebec, Canada*; Geological Society of America, Memoir 136, 189-219.
- 1976a: *Glacial events in southern Quebec -northern New England, a reappraisal* (Abstract); Geological Society of America, Abstracts with Programs, volume 8, number 2.
- 1976b: *Glacial till and mineral exploration*; in: *Glacial till, an inter-disciplinary study*; R.F. Legget (Editor) Royal Society of Canada, Special Publications, number 12, p.205-224.
- 1978: *Detailed sedimentological study of till sheets in a stratigraphic section, Samson River, Québec*; Geological Survey of Canada Bulletin 285, 30 p.
- 1981: *Surficial geology of the Lac Mégantic area, Québec*; Geological Survey of Canada, Memoir 397, 102 p.

Shilts, W.W. (continued)

1982: *The Highland Front Moraine Complex*: in: P. LaSalle, P.P. David, and M.A. Bouchard, (Editors), Guidebook of the 45th Annual Meeting of the Friends of the Pleistocene, Drummondville-Saint-Hyacinthe, Québec, Canada; Université de Montréal, p. 47-51.

1984: *Till geochemistry in Finland and Canada*; Journal of Geochemical Exploration, Elsevier Science Publishers, volume 21. p. 95-117.

Shilts, W.W. and Blais, A.

1989: *Saint-Joseph Area*; in: Friends of the Pleistocene, 52nd Annual Reunion, Québec, pp. 3-26.

Shilts, W.W. and Kettles, I.M.

1989: *Section 531, Geochemical/Mineralogical profiles through fresh and weathered till*; Handbook of glacial indicator tracing (in press).

Shilts, W.W. and Smith, S.L.

1986a: *Stratigraphy of placer gold deposits: overburden drilling in Chaudière Valley, Québec*; in: Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 703-712.

1986b: *Stratigraphic setting of buried gold-bearing sediments, Beauceville area, Québec*; in: Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 271-278.

1987: *Pleistocene stratigraphy in the Appalachians of southern Québec*; in: Pleistocene stratigraphy in the St. Lawrence Lowlands and the Appalachians of southern Québec: a field guide; Collection Environnement et Géologie, volume 4, p.72-101.

1988: *Glacial geology and overburden drilling in prospecting for buried gold placer deposits, southeastern Quebec*; in: Prospecting in areas of glaciated terrain-1988; D.R. MacDonald and K.A. Mills (Editors), The Canadian Institute of Mining and Metallurgy, p.141-183.

- Shilts, W. W. and Smith, S.L. (continued)
 1989: *Drift prospecting in the Appalachians of Estrie-Beauce, Québec*; in: *Drift Prospecting '89*; Geological Survey of Canada Paper Series, (in press).
- Slivitsky, A. et St-Julien, P.
 1987: *Compilation géologique de la région de l'Estrie-Beauce*; Ministère de l'Energie et des Ressources, Rapport MM 85-04, 40 p.
- Smith, S.L., and Shilts, W.W.
 1987: *Quaternary stratigraphy of the Noire River cores, Beauceville area, Québec*; in: *Current Research, Part A*; Geological Survey of Canada, Paper 87-1A, p.159-164.
- Stewart, D.P. and MacClintock, P.
 1964: *The Wisconsin stratigraphy of northern Vermont*; American Journal of Science, volume 262, p. 1089-1097.
- Stockwell, C.H.(Editor)
 1957: *Geology and Economic Minerals of Canada*; Geological Survey of Canada, Economic Geology Series, number 1, 4th edition.
- Thomas, R.H.
 1977: *Calving bay dynamics and ice sheet retreat up the St. Lawrence Valley system*; Géographie Physique et Quaternaire, volume 31, p. 347-356.
- Tolman, C.
 1936: *Lake Etchemin Map-Area, Quebec*; Geological Survey of Canada, Ottawa, Memoir 199, 22 p.
- Tyrrell, J.B.
 1915: *Gold-bearing gravels of Beauce County, Quebec*; American Institute of Mining Engineers, volume LI, February, p.673-683.
- Turcotte, P., Bouchard, M.A. et Chauvin, L.
 1989: *Stratigraphie du Pléistocène de la région de Thetford-Mines-Asbestos, Québec*; Géographie Physique et Quaternaire, volume 43, numéro 2, p. 131-146.

88-SJ-000 SJ=Saint-Joseph Map and adjacent areas

Legend: E=Easting; N=Northing; D=Direction; A=Age;

S= Sense: 1=True direction 2=No true direction;

F= Form: 1= Striae 4= Grooves

Stop #	E	N	D	A	S	F	Comments
88SJ 8	355275	5127150	020	0	2	1	Red slates
9	354500	5126400	028	0	1	1	Red slates;good tails
14	354950	5143850	005	1	1	1	Interlyrd slate+metasandstone
14	354950	5143850	070	2	1	1	Tails on intrlyrd sl.+sdstone
16	380575	5143275	100	1	1	1	Tails on red+green pillows
16	380575	5143275	015	2	1	1	Stoss+lee relationship
17	381125	5143875	100	1	2	1	red+green pillow basalts
17	381125	5143875	010	2	1	1	Stoss+lee relationship
18	381200	5144125	010	0	1	1	Stoss+lee relationship
19	382750	5146800	350	0	1	1	Red+green pillows;tails
21	382550	5141700	000	0	1	1	Grey slates;tails
22	383750	5142125	115	0	2	1	Metasiltstone
23A	383850	5142050	135	1	2	1	Metasiltstone
23B	383850	5142050	355	2	1	1	Large scale stoss+lee rel.
24	384900	5142000	350	0	2	1	Metasiltstone;fan 345-355
24	384900	5142000	105	0	2	1	Metasiltstone
25	377300	5140825	070	0	2	1	Red+green pillows; Mt Orignal
26	377425	5141050	115	0	1	1	Nice tails;Mt Orignal;fan 105-125
28	371800	5095950	000	0	2	4	Crude grooves;weathered slates
30	372050	5094750	110	0	2	4	Crude grooves;slates
31	363700	5118675	105	1	1	1	Metasiltstone;rat tails
31	363700	5118675	005	2	1	1	Metasiltstone;tails
43	351275	5151775	270	1	2	1	Feldspathic volcanics
43	351275	5151775	035	2	2	1	Feldspathic volcanics
75	357100	5145025	025	0	2	4	Sugary sandstone
90	358900	5125075	355	0	1	1	Metavolc.;nice tails;fan 350-000
93	361625	5119375	310	1	2	1	Grey slates
93	361625	5119375	350	2	1	1	Stoss+lee rel.;grey slates
94	367150	5110450	110	1	1	1	Tails+grooves intrlyrd slate+astone
94	367150	5110450	350	2	2	1	Intrlyrd slate+sandstone
95	366800	5112075	110	1	2	1	Coarse metavolcanics
95	366800	5112075	345	2	1	1	Nail-head; stoss+lee
99	363225	5117400	125	0	1	1	Stoss+lee; grey slates
99	363225	5117400	070	0	2	1	Metasiltstone=grey slates
101	362750	5117700	165	1	1	1	Stoss+lee; grey slates
101	362750	5117700	010	2	2	1	Grey slates
109	374075	5141025	010	0	1	1	Red+green slates; stoss+lee
113	376075	5145050	000	0	2	1	Red+green pillows
113	376075	5145050	280	0	2	1	Red+green pillows; asphalt plant
120	365450	5127450	350	0	1	1	Good tails;splay 345-355
129	369600	5110175	120	1	2	1	Splay 110-140; grey slates
129	369600	5110175	065	2	2	1	Grey slates below fresh till
132	373650	5084025	235	1	1	1	Stoss+lee; metasiltstone

Stop #	E	N	D	A	S	F	Comments
132	373650	5084025	120	2	2	1	Metasiltstone
140	344550	5145100	140	0	1	1	Intrlyrd metavolcanics;
140	344550	5145100	010	0	2	1	Intrlyrd metavolcanics
142	345025	5144900	140	0	1	1	Possibly 2 dir.;splay
144	356300	5128050	120	1	1	1	Good tails;Metacongl. of volcs+seds
144	356300	5128050	340	2	1	1	Tails; Metacongl. of volcs+seds
144	356300	5128050	105	3	2	1	No direction;
145	356275	5127825	345	0	1	1	Tails; Crude grooves=325-330
133	374350	5083150	120	1	1	1	Tiny rat-tails; grey slates
133	374350	5083150	320	2	2	1	Off-set striae;

87-SJ-000.

Stop #	E	N	Dir	A	S	F	Comments
87SJ 001	361925	5126600	175	0	2	1	Near intersection to Des Pl. riv.
87SJ 002	357150	5130925	180	0	2	1	Near St-Joseph
87SJ 005	354900	5134000	355	0	1	1	Steeply dipping black slates
87SJ 007	358350	5137475	180	0	2	1	
87SJ 008	359850	5134225	190	0	2	1	Red and green slates
87SJ 011	357325	5127650	000	2	1	1	Meta-volcanics
87SJ 011	357325	5127650	120	1	1	1	Meta-volcanics
87SJ 012	355950	5129700	050	1	1	1	Black slates
87SJ 012	355950	5129700	355	2	2	1	" "
87SJ 015	348950	5146925	145	1	1	1	Meta-sediments
87SJ 015	348950	5146925	000	2	2	4	Crude grooves
87SJ 015	348950	5146925	115	3	1	1	
87SJ 016	348600	5145150	135	0	2	1	Meta-volcanics
87SJ 016	348600	5145150	120	0	2	1	"
87SJ 017	352850	5142400	125	0	2	4	Grooves in schists
87SJ 018	358350	5144200	060	0	1	1	Good rat-tails
87SJ 020	360900	5140875	000	1	2	1	Slates;1 is on beveled surface
87SJ 020	360900	5140875	055	2	2	1	
87SJ 021	361450	5140300	180	0	2	1	Meta-volcanics
87SJ 022	361850	5139850	000	1	1	1	Good tails
87SJ 022	361850	5139850	020	1	1	1	
87SJ 023	368100	5116300	105	1	1	4	Grooves at N.-D. des Pins
87SJ 023	368100	5116300	140	2	1	1	
87SJ 023	368100	5116300	005	3	2	1	
87SJ 025	354550	5142700	100	0	1	1	Meta-volcanics; NW of Sts-Angeles
87SJ 026	352225	5145400	125	0	2	1	" "
87SJ 027	351325	5148450	120	0	2	4	Crude grooves
87SJ 028	347600	5145850	140	0	1	1	Schists
87SJ 029	344175	5150150	110	0	2	1	Red and green slates
87SJ 029	344175	5150150	145	0	2	1	" " " " ; weaker than 110
87SJ 031	368200	5110675	345	0	1	1	Good rat-tails on black slates
87SJ 032	361550	5117550	115	0	2	1	Black slates
87SJ 032	361550	5117550	130	1	2	1	" "
87SJ 032	361550	5117550	355	2	2	1	" "
87SJ 033	347250	5134750	020	0	1	1	Meta-sandstone
87SJ 034	365550	5136750	120	0	2	1	E of Beauceville
87SJ 035	366375	5127550	110	0	2	1	E of Beauceville

Stop #	E	N	D	A	S	F	Comments
87SJ 035	366375	5127550	175	0	2	1	
87SJ 036	366700	5127900	110	0	2	1	W of Lac-Etchemin
87SJ 036	366700	5127900	185	0	2	1	"
87SJ 037	379450	5138050	230	0	2	1	Class III till lying on it
87SJ 037	379450	5138050	180	0	2	1	
87SJ 038	376575	5140650	180	0	2	1	Red and green pillow basalts
87SJ 038	376575	5140650	160	0	2	1	Same set of striae fanning out
87SJ 039	376350	5140975	110	0	2	1	Red and green pillow basalts
87SJ 041	362900	5142150	035	0	1	1	Coarse-grained meta-volcanics
87SJ 041	362850	5142125	010	0	1	1	Ibid; on other side of road
87SJ 042	363950	5140775	090	0	2	1	Meta-volcanics
87SJ 044	367775	5123775	140	0	2	1	Meta-siltstone; E of St-Benjamin
87SJ 045	369100	5125050	135	1	2	1	E of St-Benjamin
87SJ 045	369100	5125050	165	2	2	1	
87SJ 046	369900	5125625	135	1	1	1	Soft meta-siltstone
87SJ 046	369900	5125625	165	2	1	1	Ibid
87SJ 047	370350	5126050	140	1	1	1	Meta-siltstone
87SJ 047	370350	5126050	170	2	2	1	Ibid
87SJ 048	370725	5126450	145	0	2	1	Meta-siltstone
87SJ 049	370775	5126600	120	0	2	1	Grooves at 120 on other side of rd
87SJ 049	370775	5126600	170	0	2	1	
87SJ 050	370825	5126800	230	1	2	1	
87SJ 050	370825	5126800	110	2	2	1	
87SJ 050	370825	5126800	155	0	2	1	A few metres away from other 2 dir.
87SJ 051	374250	5126925	225	1	2	1	
87SJ 051	374250	5126925	110	2	2	1	
87SJ 052	374700	5127425	110	1	2	1	Meta-siltstone
87SJ 052	374700	5127425	170	2	1	1	Ibid
87SJ 053	379350	5131600	110	1	2	1	Meta-volcanics
87SJ 053	379350	5131600	335	2	1	1	Ibid
87SJ 054	380450	5134650	235	1	2	1	
87SJ 054	380450	5134650	335	2	2	1	
87SJ 054	380575	5134775	350	0	2	1	A bit further along the same road
87SJ 055	382700	5137850	110	1	2	1	
87SJ 055	382700	5137850	000	2	2	1	Meta-siltstone
87SJ 056	382150	5137250	100	0	2	1	
87SJ 057	381650	5136900	240	0	2	4	Gouges
87SJ 057	381650	5136900	110	1	2	1	Meta-sandstone
87SJ 057	381650	5136900	000	2	2	1	
87SJ 059	379025	5134500	105	0	2	1	Soft meta-sediments
87SJ 059	379025	5134500	010	0	2	1	Ibid
87SJ 060	378900	5134300	105	0	2	1	
87SJ 060	378900	5134300	015	0	2	1	
87SJ 061	377750	5133250	110	1	2	1	Meta-siltstone
87SJ 061	377750	5133250	000	2	2	1	
87SJ 061	377750	5133250	240	0	2	4	Gouges
87SJ 062	376650	5132200	110	0	2	4	Gouges
87SJ 063	375550	5131300	110	0	2	1	
87SJ 063	375550	5131300	000	0	2	1	
87SJ 064	376250	5130975	110	0	2	4	Gouges
87SJ 064	376250	5130975	340	0	2	1	
87SJ 065	374950	5130650	335	0	2	1	Meta-siltstone

Stop #	E	N	Dir	A	S	F	Comments
87SJ 066	372550	5128600	110	0	2	1	Slates
87SJ 066	372550	5128600	355	0	2	1	
87SJ 067	371500	5127550	355	0	2	1	Meta-greywacke
87SJ 068	374875	5124375	110	1	2	1	
87SJ 068	374875	5124375	345	2	2	1	
87SJ 068	374875	5124375	010	2	2	1	
87SJ 069	375400	5124900	120	1	2	1	
87SJ 069	375400	5124900	350	2	2	1	
87SJ 070	376600	5138550	145	1	2	1	
87SJ 070	376600	5138550	000	2	2	4	Gouge
87SJ 070	376600	5138550	105	0	2	1	
87SJ 071	376725	5138550	140	0	2	1	
87SJ 071	376725	5138550	020	0	2	1	
87SJ 072	376250	5138250	340	1	1	1	Rat-tails
87SJ 072	376250	5138250	000	2	1	1	Meta-conglomerate
87SJ 073	375100	5137200	345	0	2	1	Ibid
87SJ 074	367925	5131500	110	1	2	1	
87SJ 074	367925	5131500	000	2	2	1	
87SJ 074	367925	5131500	335	3	2	1	
87SJ 075	366500	5131800	110	0	2	1	Meta-siltstone
87SJ 075	366500	5131800	345	0	2	1	
87SJ 077	363825	5134450	000	0	1	1	Red and green slates; check again
87SJ 077	363825	5134450	320	0	2	1	
87SJ 078	367275	5133000	350	1	2	1	Meta-siltstone
87SJ 078	367275	5133000	325	2	2	1	
87SJ 079	367825	5133000	000	0	1	1	Meta-siltstone
87SJ 080	368525	5133100	005	0	2	1	Ibid
87SJ 081	369500	5133750	010	0	1	1	
87SJ 083	370150	5136000	000	0	2	1	Red slates
87SJ 083	370150	5136000	015	0	2	1	
87SJ 084	369950	5135950	355	0	1	1	Tails; grooves also
87SJ 084	369950	5135950	335	0	1	1	Tails
87SJ 085	369325	5135350	110	1	1	1	Interlayered M-volc; greenish-white
87SJ 085	369325	5135350	000	2	1	1	
87SJ 085	369325	5135350	325	3	2	1	Faint striae
87SJ 086	370125	5138700	120	1	1	1	Grooves also; tails
87SJ 086	370125	5138700	000	2	1	1	Grooves also
87SJ 086	370125	5138700	320	3	2	1	Weak striae
87SJ 087	375250	5146350	005	0	2	1	Grooves and striae
87SJ 087	375250	5146350	320	0	2	1	Faint striae
87SJ 088	378600	5144875	110	1	1	1	Spectacular site on pillow basalts
87SJ 088	378600	5144875	000	2	1	1	Text-book e.g. of rat-tails
87SJ 088	378600	5144875	340	2	1	1	
87SJ 088	378600	5144875	020	2	1	1	No age relation to last first 3
87SJ 090	379350	5143225	140	0	1	1	Good tails on pillow basalts
87SJ 091	359650	5146250	020	0	2	1	Probably north due to shape of outcrop
87SJ 092	358100	5146225	070	1	2	1	
87SJ 092	358100	5146225	040	2	1	1	Good rat-tails on meta-siltstone
87SJ 093	356750	5148450	130	0	2	1	Faint striae
87SJ 095	366600	5147175	010	0	2	4	On Mont Frampton, weak grooves
87SJ 096	368575	5144950	000	0	1	1	Good tails on M. Frampton; r+gr. volc.
87SJ 097	371225	5108525	165	1	2	1	Fossil. outcrop; Rugosa, etc.

Stop #	E	N	D	A	S	F	Comments
87SJ 097	371225	5108525	120	2	1	1	Good tails on conglomerate
87SJ 097	371225	5108525	010	3	1	1	Good tails
87SJ 099	381275	5122900	110	0	2	1	Meta-siltstone
87SJ 099	381275	5122900	350	0	2	1	
87SJ 100	376275	5124800	340	0	1	1	Black slates; scalloped surface
87SJ 101	376750	5127125	110	1	2	1	Black slates; crude grooves
87SJ 101	376750	5127125	020	2	2	1	
87SJ 101	376750	5127125	340	0	1	1	Rat-tails
87SJ 102	376600	5127350	345	0	1	1	Black slates; tails
87SJ 103	376350	5127650	090	0	1	1	In rock quarry; siliceous rk yet, slaty
87SJ 103	376350	5127650	355	0	1	1	Striae in all directions; preservation
87SJ 103	376350	5127650	020	0	1	1	from previous glaciations?
87SJ 103	376350	5127650	010	0	1	1	
87SJ 103	376350	5127650	030	0	1	1	
87SJ 104	375250	5130825	110	1	2	1	Black slates
87SJ 104	375250	5130825	340	2	2	1	
87SJ 105	375275	5130950	340	0	1	1	Black slates
87SJ 105	375275	5130950	110	0	2	1	
87SJ 105	375275	5130950	000	0	2	1	Pyritiferous slates
87SJ 106	374975	5131000	005	0	2	1	Pyritiferous slates
87SJ 106	374975	5131000	030	0	2	1	
87SJ 107	374850	5131500	340	0	1	1	Pyritiferous slates
87SJ 107	374850	5131500	010	0	2	1	
87SJ 107	374850	5131500	130	0	2	1	
87SJ 108	373650	5132350	095	0	2	1	Fine gr. interlayered meta-seds
87SJ 108	373650	5132350	335	0	2	1	
87SJ 108	373650	5132350	000	0	2	1	Slates
87SJ 109	372050	5134350	090	1	2	4	Grooves
87SJ 109	372050	5134350	110	1	2	4	
87SJ 109	372050	5134350	355	2	1	1	Large tails; field trip stop
87SJ 110	373825	5135850	120	0	2	1	Faint striae on black slates
87SJ 111	375700	5128100	120	1	1	1	Greywacke sandstone; good tails
87SJ 111	375700	5128100	000	2	2	1	Mafic rk; epidote and qtz veins
87SJ 112	377575	5126450	105	1	1	1	#1 is on beveled surface
87SJ 112	377575	5126450	005	2	1	1	
87SJ 115	364300	5130425	140	0	1	4	UM. Mega-grooves; shape indicates dir.
87SJ 115	364425	5130525	110	0	2	1	
87SJ 117	359900	5126750	000	0	2	1	Strong grooves and striae; weathered
87SJ 117	359900	5126750	140	0	2	1	Siliceous rk
87SJ 118	359600	5126500	015	0	1	1	Stoss + Lee shows direction
87SJ 119	359300	5126150	110	0	2	1	Meta-sandstone
87SJ 119	359300	5126150	000	0	2	1	
87SJ 120	360300	5131175	140	1	2	1	Red slates; faint striae
87SJ 120	360300	5131175	260	3	2	1	
87SJ 120	360300	5131175	005	2	1	1	
87SJ 121	360775	5130650	140	0	2	1	Red slates; faint str. bulldozer marks
87SJ 121	360775	5130650	005	0	2	1	
87SJ 122	361450	5129975	000	0	2	4	Grooves on weathered andesitic rk
87SJ 123	361500	5129800	100	1	2	1	Meta-volcanics; on protected face
87SJ 123	361500	5129800	000	2	1	1	
87SJ 124	354825	5129775	000	0	2	1	Grooves and striae; meta-volc.
87SJ 126	368250	5140025	140	0	2	1	Pillow lavas

Stop #	E	N	D	A	S	F	Comments
87SJ 133	368450	5110450	025	1	2	1	Siliceous hard meta-greywacke
87SJ 133	368450	5110450	320	2	2	1	and siltstone
87SJ 133	368450	5110450	350	0	2	1	
87SJ 133	368450	5110450	090	0	2	1	
87SJ 133	368450	5110450	245	0	2	1	
87SJ 134	368125	5111075	140	0	1	1	Bedrock has sinusoidal surface
87SJ 135	367975	5114300	000	0	1	1	"Tete de clou" indicates direction
87SJ 135	367975	5114300	090	0	2	1	
87SJ 139	354800	5127150	120	1	2	1	Fan from 110 to 130
87SJ 139	354800	5127150	000	2	2	1	Meta-sandstone
87SJ 141	365125	5117900	345	0	2	1	In gravel pit near Rapides du Diable
87SJ 141	365125	5117900	130	0	2	1	Pit is ICSD
87SJ 142	362100	5120000	350	0	2	1	Black slates
87SJ 142	362100	5120000	125	0	1	1	On protected face; bullet-shpd boulder
87SJ 142	362100	5120000	050	0	2	1	Chaudiere? Bill does not think so
87SJ 142	361975	5120100	110	1	2	1	Thought ages were reverse=readvance but
87SJ 142	361975	5120100	000	2	1	1	saw this situation with M. Rappol
87SJ 143	362450	5119700	110	1	1	1	Back of new duplex; good roche-moutonnee
87SJ 143	362450	5119700	355	2	2	1	Meta-siltstone; took Polaroids
87SJ 144	360700	5133200	000	1	1	1	F.gr. meta-volc with tails for both dir.
87SJ 144	360700	5133200	260	2	1	1	
87SJ 145	362075	5131800	000	1	1	1	Red and green slates
87SJ 145	362075	5131800	250	2	1	1	
87SJ 145	362000	5131750	100	1	1	1	Good tails; meta-siltstone
87SJ 145	362000	5131750	350	2	1	1	
87SJ 146	363200	5130475	110	1	1	1	Meta-sandstone; good tails, stoss+lee
87SJ 146	363200	5130475	000	2	1	1	Good tails
87SJ 146	363200	5130475	250	0	2	1	
87SJ 147	363000	5130650	000	0	1	4	Stoss + lee feature shows direction
87SJ 148	362825	5130100	000	0	2	1	Coarse-gr. meta-seds
87SJ 149	362750	5130975	000	1	2	1	Red slates; took pictures
87SJ 149	362750	5130975	265	2	2	1	
87SJ 149	362750	5130975	130	0	2	1	
87SJ 151	363975	5136725	130	0	2	1	Grooves also; on meta-seds
87SJ 152	366450	5138650	110	1	1	1	Pillow basalts; faint striae
87SJ 152	366450	5138650	000	2	1	1	Tails
87SJ 154	365225	5141525	005	0	2	1	Very soft phyllitic rk; weak striae
87SJ 155	365275	5141500	000	0	1	1	Chlorite schist; tails
87SJ 156	371025	5134600	100	1	2	1	Massive meta-siltstone str. and grooves
87SJ 156	371025	5134600	000	2	2	1	
87SJ 157	368200	5110675	345	0	1	1	Meta-siltstone
87SJ 157	368200	5110675	000	0	2	1	
87SJ 158	363950	5118600	125	1	2	1	Meta-siltstone
87SJ 158	363950	5118600	140	1	2	1	
87SJ 158	363950	5118600	005	2	2	1	
87SJ 159	363525	5118975	100	0	2	4	Grooves on coarse grained pyroclastics
87SJ 159	363525	5118975	350	1	2	1	To check again, readvance?
87SJ 159	363525	5118975	145	2	1	1	Sand-sized rat-tails
87SJ 160	363400	5118975	105	1	1	4	Grooves; direction shown by stoss+ lee
87SJ 160	363400	5118975	005	2	2	1	
87SJ 162	361150	5130125	080	0	2	1	Red slates; faint striae
87SJ 163	370525	5126300	355	0	2	1	Interlayered coarse and fine siltstone

Stop #	E	N	D	A	S	F	Comments
87SJ 164	370975	5126975	350	0	1	1	Bl. slates dir. shown by stoss + lee
87SJ 165	368050	5124975	005	0	1	1	Greywacke sandstone
87SJ 165	368050	5124975	135	0	2	1	
87SJ 166	373375	5121800	340	0	1	1	Coarse gr. wacke sst. tails and stoss + lee
87SJ 167	376925	5126300	110	1	2	1	On protected face; St-Benjamin
87SJ 167	376925	5126300	355	2	1	1	Coarse gr. wacke sst. tails
87SJ 168	380700	5131475	320	0	2	1	Green meta-volc.
87SJ 169	380400	5131775	110	1	2	1	Coarse green meta-seds; grooves also
87SJ 169	380400	5131775	000	2	2	1	
87SJ 169	380400	5131775	140	0	2	1	On other side of road
87SJ 170	380150	5132125	110	1	1	1	Grooves also; tails; stoss+lee
87SJ 170	380150	5132125	340	2	1	1	Tails; meta-volc.
87SJ 170	380150	5132125	005	3	1	1	Tails
87SJ 170	380150	5132125	020	4	1	1	Tails
87SJ 171	386025	5136350	110	1	2	1	On protected face
87SJ 171	386025	5136350	005	2	1	1	Tails
87SJ 172	384600	5133550	000	0	1	1	Tails on meta-volc. both sides of rd
87SJ 173	382400	5130100	135	0	2	1	Green meta-volc.
87SJ 174	382550	5129925	110	0	2	1	Coarse gr. bdrk
87SJ 175	382750	5129700	150	0	2	1	Fine gr. metavolc.
87SJ 177	362750	5147500	040	0	1	1	Tails on schist; bdrk hard to preserve
87SJ 178	364075	5149125	060	0	2	1	Schists; Sugary surface; str. ll to clvg
87SJ 179	364450	5149650	040	0	1	1	Stoss + lee
87SJ 184	369325	5148650	025	1	1	1	Grooves also
87SJ 184	369325	5148650	060	2	2	1	
87SJ 184	369325	5148650	340	0	2	1	Weak striae
87SJ 184	369325	5148650	010	0	1	4	Grooves; soft meta-seds
87SJ 185	373150	5143650	005	0	1	1	Red slates
87SJ 185	373150	5143650	000	1	1	1	Red and green slates
87SJ 185	373150	5143650	330	2	1	1	Where esker has been stripped
87SJ 186	372900	5143550	005	0	2	1	Red slates
87SJ 187	369050	5149600	355	0	1	1	Light green meta-volc.; sugary surface
87SJ 189	364850	5117275	260	0	2	1	Faint striae fanning from 260 to 290
87SJ 189	364850	5117275	290	0	2	1	Hard gr. wacke sandstone; Chaudiere?
87SJ 190	375750	5150400	350	0	1	1	Faint str.; stoss + lee; phyllite
87SJ 191	381300	5150900	015	0	1	1	Tails; stoss + lee; phyllite
87SJ 192	383350	5149200	350	0	1	1	Interlrd m.-f. gr. slates; Fan 340 to 000
87SJ 193	383500	5148925	075	1	2	1	Red and green slates
87SJ 193	383500	5148925	355	2	1	1	Tails make triangle; took pictures
87SJ 193	383500	5148925	020	3	1	1	Tails
87SJ 195	384525	5147875	110	1	1	1	Red and green pillow basalts; grooves;
87SJ 195	384525	5147875	000	2	1	1	Pictures; outcrop dug out in mid-road
87SJ 196	383375	5147625	110	1	2	1	
87SJ 196	383375	5147625	010	2	1	1	Stoss + lee shows direction
87SJ 197	381800	5147250	145	0	2	4	Meta-sandstone; weak grooves
87SJ 198	381350	5147750	010	0	2	4	Crude grooves
87SJ 199	379750	5147150	110	1	2	1	Green slates
87SJ 199	379750	5147150	000	2	1	1

Sample	EASTING	NORTHING	Ni (ppm)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Sn (ppm)
86018	361780	5116630	80	7	23	40	20	0
86019	362750	5115650	74	8	21	41	29	0
86040	362150	5124150	222	6	27	84	16	0
86041	362190	5124100	200	9	26	76	18	0
86042	380625	5119040	73	6	24	44	21	0
86043	380625	5119040	76	15	17	40	30	0
86059	371325	5111800	68	22	16	21	33	2
86076	375275	5116400	165	33	25	99	33	0
86078	371500	5111875	59	18	13	25	25	3
86079	370450	5117025	54	11	15	30	25	11
86080	369500	5116675	44	13	11	16	13	3
86081	368900	5116000	59	12	14	22	23	8
86082	365800	5111700	36	23	10	24	28	4
86083	363150	5110450	43	18	13	26	29	2
86084	359450	5118350	24	12	10	18	28	8
86085	360450	5112925	53	7	15	36	25	6
86086	367150	5130950	137	13	16	35	28	6
86087	384250	5116975	78	20	15	32	23	14
86088	370325	5127550	181	8	18	44	26	2
86089	370700	5127100	38	13	9	18	28	7
86090	371350	5127475	167	11	13	48	19	7
86091	371400	5127400	224	8	16	52	36	10
86092	374250	5130100	84	12	11	34	34	2
86093	374125	5126850	138	2	16	42	19	11
86094	373100	5125950	74	10	12	22	30	5
86095	368400	5112575	34	4	4	30	29	15
86096	369350	5113500	31	4	9	16	18	3
86097	372200	5116625	63	18	10	31	22	7
86099	371200	5119850	116	15	12	20	25	5
86124	368650	5129650	36	5	14	24	29	1
86125	371200	5130350	129	5	14	46	34	0.5
86126	375300	5130450	41	18	10	25	28	0.5
86127	376350	5129100	52	11	15	25	29	2
86128	375750	5128150	42	14	10	24	31	8
86129	387150	5126700	49	16	13	27	40	1
86130	379250	5128600	38	15	13	22	32	1
86131	380500	5131650	86	24	17	55	39	5
86132	367000	5126200	213	3	16	50	24	7
86133	367175	5126000	252	4	21	62	25	4
86134	368700	5124550	133	17	17	36	28	0.5
86135	370700	5126475	258	12	22	47	23	4
86136	369650	5132150	57	9	14	24	26	0.5
86137	349500	5135625	43	20	14	22	34	2
86138	348625	5133800	34	6	16	25	22	0.5
86139	347200	5132400	42	35	42	24	41	0.5
86140	347200	5132150	52	39	15	20	41	1
86141	346200	5131325	40	25	12	15	36	0.5
86142	348300	5128125	33	21	12	15	35	3
86143	348950	5127500	40	10	15	23	25	4

Sample	EASTING	NORTHING	Ni (ppm)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Sn (ppm)
86144	347100	5128200	38	18	12	16	29	3
86145	353525	5124900	40	20	14	18	32	4
86147	349850	5128550	39	20	12	13	30	0.5
86149	356900	5134850	28	7	8	20	21	0.5
86150	369025	5133300	36	26	13	22	24	3
86151	376250	5135100	32	15	11	20	33	7
86152	376550	5135500	30	5	13	16	29	5
86153	379150	5137650	58	10	10	24	28	6
86155	383950	5138250	37	21	14	22	45	4
86156	383675	5132700	45	15	12	19	30	5
86157	381825	5130700	33	26	9	19	29	3
86191	361150	5122025	81	9	12	33	18	0.5
86200	367700	5119425	66	23	11	27	21	7
86201	368075	5119625	74	14	11	24	34	1
86202	369725	5119775	52	47	11	21	14	2
86203	370650	5116550	53	16	7	24	22	9
86205	372025	5119850	98	29	9	40	38	9
86206	373250	5122025	186	17	15	43	28	7
86207	372900	5117125	81	16	11	24	22	4
86208	374875	5117700	91	15	5	27	23	4
86209	376125	5125050	87	19	10	28	28	1
86210	368750	5108850	36	3	6	28	11	5
86211	357750	5110325	33	15	9	16	27	5
86212	356800	5115225	31	60	11	31	30	2
86213	357550	5114100	40	10	14	17	27	6
86217	352750	5119175	43	18	7	33	22	3
86218	348050	5117625	48	27	10	36	48	4
86219	355550	5120375	37	9	14	24	27	10
86220	354150	5118300	35	19	12	16	36	3
86221	351550	5115975	82	14	13	48	37	4
86222	350050	5117850	46	25	10	33	36	4
86223	349625	5118550	23	13	8	15	34	6
86227	347800	5118750	57	17	12	44	28	6
86225	348000	5117275	51	30	15	33	49	0.5
86278	361775	5124550	76	8	12	32	19	4
86300	379940	5104945	44	10	13	36	26	0.5
86301	376465	5097820	40	8	12	32	34	0.5
86304	365045	5100840	31	7	14	30	34	0.5
86305	364295	5100250	40	8	18	30	32	0.5
86306	345750	5104655	66	9	18	50	44	0.5
86307	347290	5101850	63	11	20	44	38	1
86308	348450	5099390	59	6	18	38	36	3
86309	349400	5102730	46	10	12	40	38	3
86310	365875	5106000	31	5	11	28	24	1
86311	363250	5103205	34	5	16	32	26	3
86312	362210	5102475	34	5	16	29	30	3
86313	361255	5097150	40	8	15	32	31	2
86314	366825	5099355	40	4	20	34	32	0.5
86315	367950	5099215	40	6	18	30	36	1
86316	368035	5098440	37	6	12	22	35	0.5
86317	371360	5095390	37	3	13	31	25	3
86318	371525	5102750	42	5	19	32	34	4
86319	372150	5105310	39	7	15	28	26	4

Sample	EASTING	NORTHING	Ni (ppm)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Sn (ppm)
86320	363050	5105475	33	2	11	35	29	4
86321	355740	5107590	42	5	16	35	34	1
86323	346380	5109900	59	6	17	54	28	4
86324	347100	5106855	55	8	18	47	35	4
86325	347945	5103225	57	5	18	42	26	4
86326	351200	5098940	61	6	17	40	42	2
86327	350230	5101660	44	6	18	36	38	1
86328	353920	5100240	37	4	16	33	38	0.5
86329	354900	5199545	42	5	14	30	36	1
87200	356600	5135200	50	20	17	27	54	1
87201	365500	5143500	59	12	16	23	45	2
87202	355525	5139525	42	18	13	31	37	12
87205	379550	5137325	38	10	17	16	42	10
87207	370850	5135350	33	9	17	25	29	1
87208	379175	5143775	36	3	10	23	27	1
87210	348825	5146825	10	2	7	9	12	7
87213	365300	5128950	307	4	24	60	25	6
87214	363200	5129125	123	9	14	33	22	1
87215	360900	5127550	38	20	14	12	29	4
87216	368850	5137700	29	5	12	9	20	4
87217	367150	5141550	36	8	11	21	28	7
87218	365550	5143475	59	15	17	24	40	1
87219	359975	5149775	29	15	11	18	25	2
87220	365450	5146475	54	18	13	23	36	3
87221	369350	5143650	22	6	12	16	27	6
87227	361700	5129675	57	11	13	25	35	8
87229	365350	5148625	26	10	12	16	35	8
87230	366750	5147975	60	7	13	24	32	3
87231	367800	5149700	90	10	12	32	35	10
87232	377550	5145600	26	12	15	16	34	7
87233	384000	5148350	37	20	13	15	35	5
87237	353350	5144950	27	2	15	24	23	3
87239	346700	5150825	14	4	7	13	26	1
87240	358850	5137925	49	15	10	27	39	8
87241	360250	5138275	42	13	13	24	38	3
87245	347300	5137750	43	17	17	29	28	3
88001	353650	5140450	64	47	31	26	120	1
88002	352525	5146875	55	286	19	15	66	1
88003	346125	5129700	30	23	10	21	34	1
88004	378450	5123650	121	20	10	35	31	5
88005	376800	5129225	37	14	13	21	31	1
88006	357900	5123450	26	14	12	22	31	1
88008	348650	5127175	32	23	12	20	30	5
88009	382850	5141450	35	15	10	22	35	1
88010	382550	5141700	43	15	14	24	32	10
88017	348700	5139475	15	15	8	12	21	1
88018	348550	5138000	38	34	14	20	38	3
88019	348675	5138125	27	30	13	18	26	4
88021	348700	5136775	31	12	12	23	26	2
88022	349800	5136450	24	20	9	15	32	1
88023	360050	5143150	91	44	17	31	42	1
88024	364550	5144650	28	12	12	18	28	4

Sample	EASTING	NORTHING	Ni (ppm)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Sn (ppm)
88025	368075	5145500	25	13	10	18	29	6
88026	373125	5145875	28	18	9	18	38	3
88027	354625	5128250	31	18	10	19	33	1
88028	361625	5119375	41	18	11	32	31	1
88029	366800	5112075	33	16	10	22	26	2
88030	371350	5105275	37	14	10	30	30	1
88031	358300	5127100	54	11	9	26	20	2
88032	355175	5133700	32	13	11	20	27	9
88033	353525	5133350	17	23	7	11	27	1
88034	353425	5132900	20	13	8	17	14	1
88035	375550	5097750	40	8	11	28	22	1
88036	366200	5118475	143	15	13	40	27	1
88040	370275	5109025	31	15	8	13	19	1
88044	360650	5127900	31	9	13	38	25	1
88045	344800	5126975	35	22	16	18	25	1

TILL SAMPLE SITES AND NUMBERS

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