MRR 2005-6
(digital)

New Nouveau Brunswick

Natural Resources
Minerals, Policy and Planning

Mineral Resource Report

TILL GEOCHEMISTRY OF SOUTHWESTERN NEW BRUNSWICK

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ISSN 1718-2484
ISBN 1-55396-368-7
Price $10.00

2005

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Cover illustration: *Submerged megaflutes at Spednic Lake, southwestern New Brunswick, showing glaciated terrain typical of the Magaguadavic Highlands.*

Photograph courtesy of Martin Marshall, New Brunswick Department of Natural Resources.

Translation: Toute les traductions ont été préparées par le Bureau de traduction, Ministère de l'Approvisionnement et des Services du Nouveau-Brunswick. All translations were provided by the Translation Bureau, New Brunswick Department of Supply and Services.

Recommended citation:

Allard, S., Seaman, A.A., Pronk, A.G., and Boldon, G.R., 2005. Till geochemistry of southwestern New Brunswick. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Resource Report 2005-6, 69 p.

This report has been prepared by:

Minerals, Policy and Planning Division
Department of Natural Resources
Province of New Brunswick

Hon. Keith Ashfield
Minister of Natural Resources

December 2005

ABSTRACT

Between 1990 and 2003, 2122 basal till samples were collected in southwestern New Brunswick and subjected to geochemical analysis using a variety of laboratories and analytical techniques. The resulting data set (26 elements) underwent a comprehensive levelling procedure before being compiled into regional-scale till geochemical contour maps. Multivariate-element-association contour maps were plotted for indicators of precious-metal mineralization, base-metal mineralization, tin–tungsten mineralization, nickel–cobalt–copper mineralization, rare-metal mineralization, and rare-earth element concentration. Individual-element contour maps were plotted for As, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, and Zn. When overlain on regional bedrock geology maps, these contour maps effectively highlight areas of potential mineralization at a regional scale and facilitate comparison of the magnitude of anomalies across the report area.

RÉSUMÉ

Des données géochimiques nivelées (26 éléments) tirées d’échantillons de till de fond prélevés dans le sud-ouest du Nouveau-Brunswick (1990–2003) sont fournies. Des cartes en courbes de niveau d’associations d’éléments multiples faisant état des indicateurs de minéralisation de métaux précieux, des indicateurs de minéralisation de métaux communs, des indicateurs de minéralisation d’étain–tungstène, des indicateurs de minéralisation de nickel–cobalt–cuivre, des indicateurs de minéralisation de pegmatite à métaux rares et des éléments de terres rares, sont offertes. Des cartes en courbes de niveau individuelles visant l’As, le Ba, le Co, le Cr, le Cs, le Cu, le Fe, le Hg, le Mn, le Mo, le Ni, le Pb, le Rb, le Sb, le Th, l’U, le W et le Zn, sont offertes. Ces cartes en courbe de niveau qui recouvrent la géologie du substrat rocheux régional servent à mettre en relief les secteurs de minéralisation prometteurs à une échelle régionale et permettent une comparaison de la magnitude des anomalies dans différentes parties de la région.

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ACKNOWLEDGEMENTS

The authors would like to thank the many field assistants who aided with the considerable fieldwork surrounding this project. Eric Grunsky and Robert Garrett, both from the Geological Survey of Canada, deserve credit for providing the authors with pertinent levelling resources. Mike Parkhill and Les Fyffe critically reviewed the original manuscript.

INTRODUCTION

In New Brunswick, approximately 90% of the land surface is covered with unconsolidated materials that were either deposited directly by the action of Wisconsinan glaciers or derived from wasting of the ice masses (Pronk and Ruitenberg 1991). A comprehensive understanding of these unconsolidated materials is important to a number of applications including mineral exploration, forestry, agriculture, and land-use planning.

The current report describes an ongoing till geochemistry program being conducted in southwestern New Brunswick (Fig. 1) by the New Brunswick Department of Natural Resources (NBDNR). The program began in 1990 and has substantially increased the knowledge base of surficial geology in the province. The primary objective of the program is to identify new mineral exploration targets. Subsidiary objectives are to 1) assess baseline till geochemistry, 2) categorize till on the basis of features such as grain size, lithology, colour, and compactness for the future production of multipurpose surface materials maps (see Pronk et al. 2005), and 3) delineate the glacial transport trajectories in this area of complex ice-flow history.

Basal till is the most common glacial sediment used for drift prospecting and is the focus of this investigation, although ablation till samples were collected where basal till was unavailable. By the end of the 2003 field season, 2568 till samples had been collected from the 21 G and 21 J map areas (Fig. 1). Of these samples, 2122 are basal tills comprising lodgement till, basal melt-out till, and/or deformation till, as classified by Brodzikowski and Van Loon (1987). Seaman (2001a) and Allard (2003) provide a complete description of the sampling methodology.

The 2568 till samples were subjected to geochemical, granulometric, and lithological analyses. Geochemical analyses were performed using Instrumental Neutron Activation Analysis (INAA), Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (partial data set), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (partial data set), and Atomic Absorption Spectrometry (AAS) (partial data set) on the < 63 μm fraction of each sample. Granulometric analysis was conducted on the < 2 mm fraction, and lithological analysis was conducted on the 2 cm to 10 cm fraction.

The data set for the 2122 basal till samples was compiled into a series of regional-scale till geochemical contour maps that depict either multivariate-element-association plots or single-element plots. To create the maps, data for 26 elements (As, Au, Ba, Ce, Co, Cr, Cs, Cu, Eu, Fe, Hg, La, Lu, Mn, Mo, Ni, Pb, Rb, Sb, Sm, Tb, Th, U, Yb, W, and Zn) were subjected to a comprehensive levelling procedure. The current report presents the contour maps, interprets specific multivariate-element anomaly patterns, and identifies potential target areas for follow-up exploration.

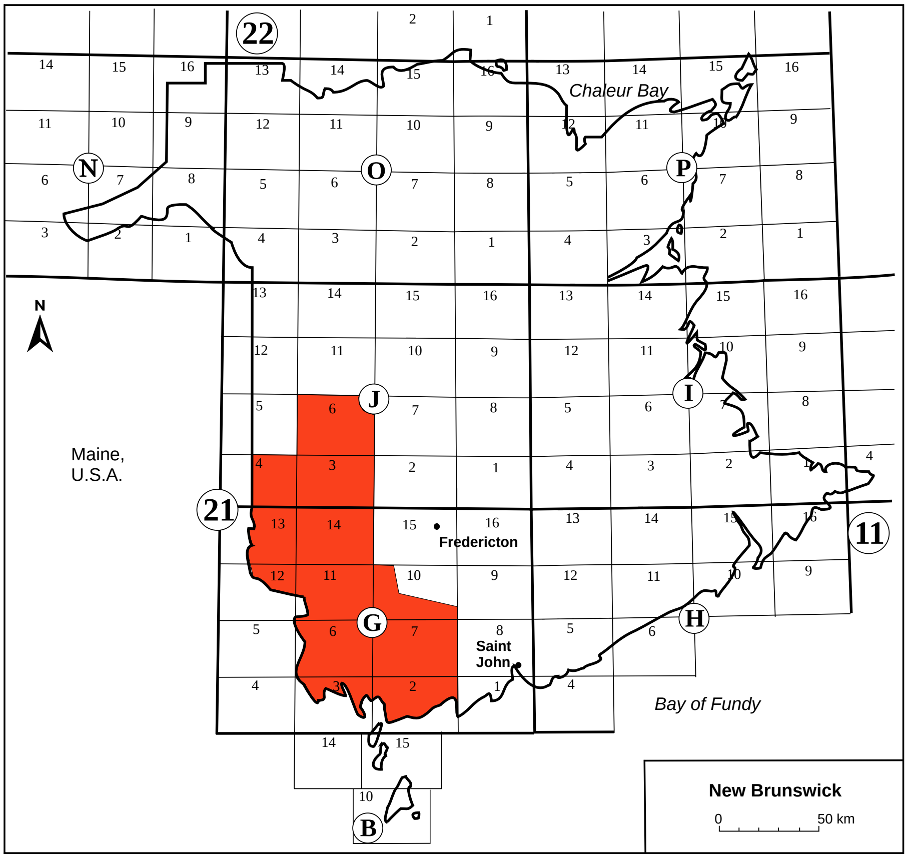

Figure 1. Location of report area in southwestern New Brunswick, showing NTS map sheets.

Location and Access

The report area comprises parts of twelve 1:50 000 NTS map sheets in southwestern New Brunswick (Fig. 1; Table 1). It is confined on the west by the Canada–U.S.A border with the State of Maine and on the south by the Bay of Fundy (Fig. 2). Notable communities in the district include Woodstock, McAdam, St. Stephen, St. Andrews, and St. George. Much of the region has a low population density. The New Brunswick capital city of Fredericton and the active seaport of Saint John are both located near the report area (Fig. 2).

The northern part of the report area is transected by the Trans-Canada Highway (No. 2) and the southernmost part by Highway No. 1 (Fig. 2). Many secondary highways, plus a network of logging and other private roads, also intersect the area. Where no roadway exists, access can be gained by footpaths, cutlines, transmission corridors, railroads, and the Maritimes–Northeast Pipeline route.

Past-producing mines are situated 30 km north of St. George at Mount Pleasant (Sn, W) and 20 km west of Fredericton at Lake George (Sb) (Fig. 2). Recent gold discoveries near Clarence Stream in the Rollingdam map area (NTS 21 G/06) and near Poplar Mountain in the Forest City map area (21 G/12) have renewed exploration interest in this part of the province (Fig. 1, 2).

Table 1. Till geochemical data for southwestern New Brunswick.
* Partial data set.

Map Sheet (1:50000)	NTS #	Sampling Year	Reference Source	Method	Laboratory	Digestion
St. George	21 G/02	2003	Pronk et al. (2004)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
St. Stephen	21 G/03	2002	Pronk et al. (2003a)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
Rollingdam	21 G/06	2001	Allard (2003) Pronk et al. (2002)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
McDougall Lake	21 G/07	2000, 2001	Pronk et al. (2002)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
Fredericton Junction	21 G/10	2002	Pronk et al. (2003b)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
McAdam	21 G/11	1991, 1992 1993, 1994	Stumpf (1995) Seaman (2003a)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	aqua regia
Forest City	21 G/12	1990	Seaman (1992, 1993b, 1999a)	INAA	ACTLABS	n/a
				AAS*	DNR	aqua regia
Fosterville	21 G/13	1990, 1992 1993	Seaman (1993a, 1994, 1999a)	INAA	ACTLABS	n/a
				ICP-OES*	ACTLABS	aqua regia
				AAS*	DNR	aqua regia
Canterbury	21 G/14	1990, 1991 1995	Balzer (1992) Seaman (in press)	INAA	ACTLABS	n/a
				ICP-OES*	ACTLABS	four-acid
				AAS*	DNR	aqua regia
Millville	21 J/03	1995, 1996 1997, 1998	Seaman (1999b, c)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid
Woodstock	21 J/04	1999	Seaman (2000)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid
Coldstream	21 J/06	1998, 2000 2001, 2002	Seaman (2001, 2002, 2003b)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid

PHYSIOGRAPHIC SETTING

The report area lies primarily within the New Brunswick Highlands of Bostock (1970), which Rampton et al. (1984) separated into three physiographic divisions: the St. Croix, Miramichi, and Caledonian (more recently referred to as Caledonia) highlands. Most of the area is situated in the St. Croix Highlands and the Miramichi Highlands (Fig. 3).

As well, parts of the Woodstock (21 J/04), Coldstream (21 J/06), and Millville (21 J/03) map areas are located in the Chaleur Uplands physiographic division, and parts of the McAdam (21 G/11) and Fredericton Junction (21 G/10) map areas lie within the New Brunswick Lowlands physiographic division (Rampton et al. 1984; Fig. 1, 3).

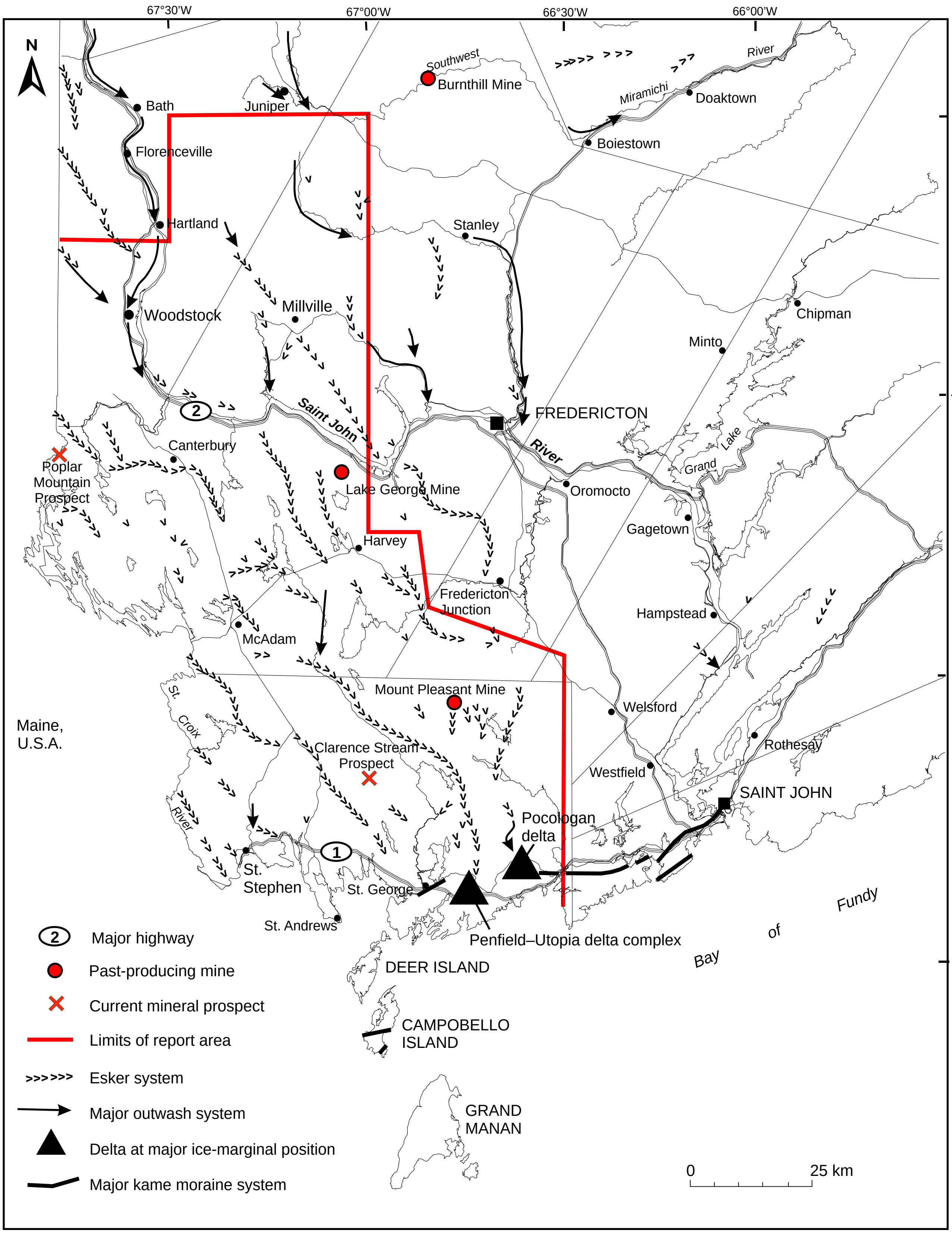

Figure 2. Selected past-producing mines and current mineral prospects in the report area. Map also shows general infrastructure and distribution of major eskers and ice marginal positions in southwestern Brunswick.

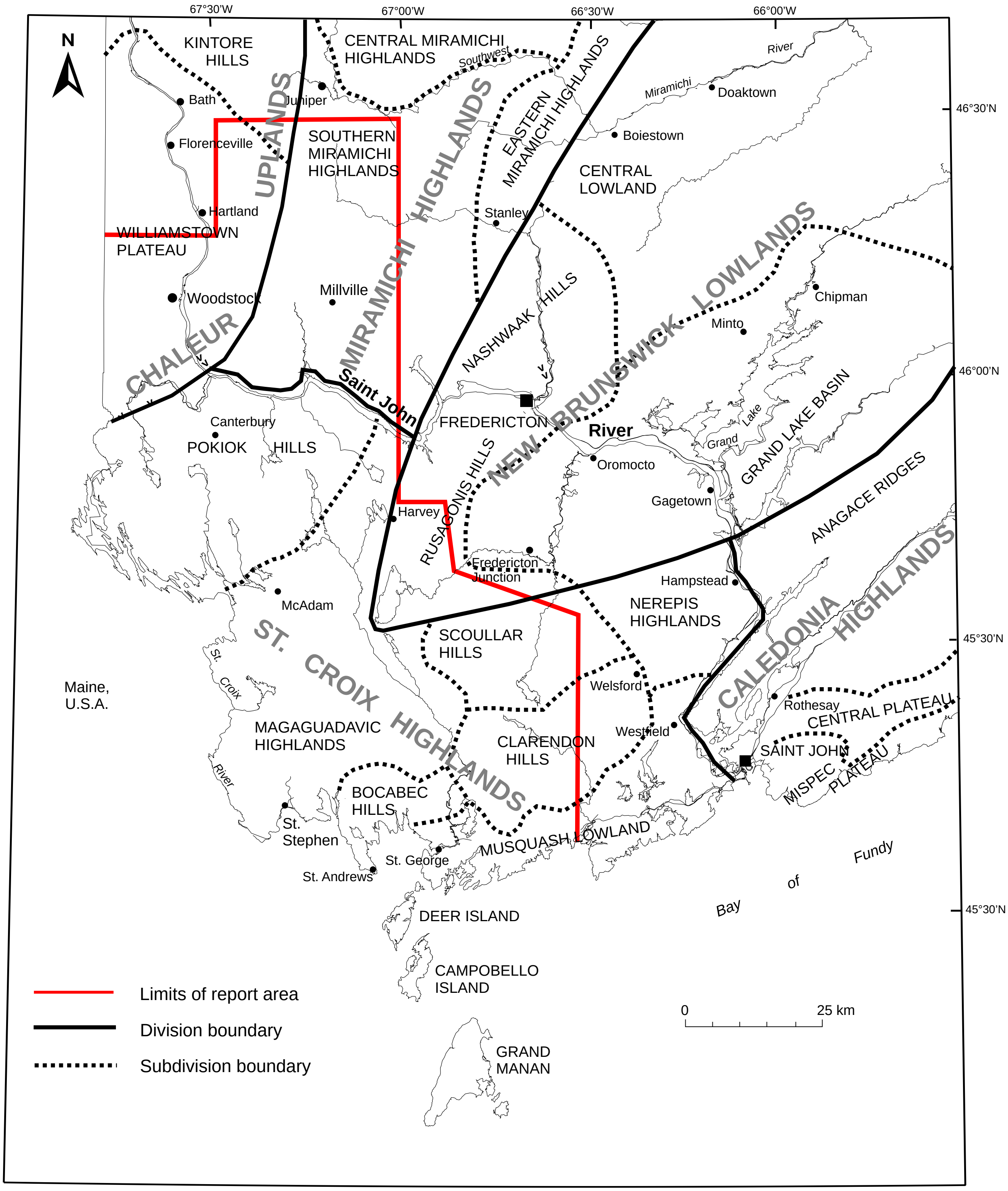

Figure 3. Physiography of southwestern New Brunswick, modified from Rampton et al. (1984). The Caledonia, St. Croix, and Miramichi highlands together represent the New Brunswick Highlands of Bostock (1970).

St. Croix Highlands

The St. Croix Highlands cover much of southwestern New Brunswick (Fig. 3). They are bound by the easterly flowing section of the Saint John River west of Fredericton and the southerly flowing section of the same river north of Saint John (Rampton et al. 1984). The St. Croix Highlands are elevated relative to the Bay of Fundy to the south and the New Brunswick Lowlands to the northeast (Fig. 3). Within the report area, the St. Croix Highlands achieve maximum elevations of between 300 m and 350 m (Rampton et al. 1984). Local relief ranges from tens of metres up to 150 m or more in some localities.

Much of this division, namely the Magaquadavic Highlands subdivision, typically consists of an undulating ridge-and-valley terrain. Ridges tend to be streamlined into megaflutes aligned northwest–southeast, reflecting the high degree of glacial erosion characterizing this part of the province. Parallel drainage patterns are common as most major rivers, secondary streams, and tertiary streams are constricted by the ridges. In poorly drained broad depressions, the drainage pattern is deranged (Rampton et al. 1984).

Miramichi Highlands

The report area encompasses only the southern part of the Miramichi Highlands (Fig. 3). This region of rolling hills and broad depressions features local relief averaging 60 m to 90 m. Maximum elevations here range from 300 m to 350 m. The area typically is well drained and characterized by an irregular dendritic drainage pattern (Rampton et al. 1984).

Chaleur Uplands

The Chaleur Uplands (Fig. 3) form a plateau that locally is dissected by major streams and interrupted by clusters of hills. The uplands comprise several subdivisions, two of which lie within the report area: the Williamstown Plateau and the Kintore Hills (Rampton et al. 1984).

The Williamstown Plateau (Fig. 3) is lower in elevation than the adjacent Miramichi Highlands and consists of gently rolling hills showing minor relief (30 m to 60 m). Areas of higher relief reach up to 150 m and occur along the deeply incised Saint John River valley and its tributaries. The area predominantly is well drained and exhibits a dendritic drainage pattern, except in valley bottoms and local depressions blocked by glacial sediments.

The report area includes only the southernmost part of the Kintore Hills subdivision, east of Florenceville (Fig. 3). Here, the southern boundary of the subdivision coincides with a bedrock-controlled scarp 150 m to 245 m in height (Rampton et al. 1984). Local relief throughout the Kintore Hills averages 120 m to 200 m, reaching up to 270 m along the Saint John River valley. Because of the substantial relief, much of the area is well drained by a pronounced dendritic drainage pattern.

New Brunswick Lowlands

The area extending from near the Village of Harvey to Fredericton Junction, and encompassing Oromocto Lake, forms part of the Rusagonis Hills subdivision of the New Brunswick Lowlands (Fig. 3). Rolling hills formed by incision of the Saint John River and its tributaries dominate the landscape. Local relief in upland areas tends to be low (10 m to 15 m) but can increase substantially near streams (Rampton 1984 et al.). The elevation of ridges and hills commonly crests near 210 m. The area is well drained except for broad, shallow depressions north of Oromocto Lake. Both dendritic and deranged drainage systems have developed.

GEOLOGICAL SETTING

Bedrock Geology

The bedrock geology of New Brunswick comprises part of the northeastern Appalachian Orogen, which has been divided into several tectonostratigraphic zones based on their unique stratigraphy and deformational history (Fig. 4). Belts of early Paleozoic and older rocks within the orogen are divided into zones reflecting their relative position to, or within, the early Paleozoic Iapetus Ocean (Williams and Hatcher 1982).

Three of these belts — the Avalon, Gander, and Dunnage zones — occur in New Brunswick. Fyffe and Fricker (1987) provide a comprehensive tectonostratigraphic analysis of the province. The Avalon Zone is underlain by Precambrian volcanic rocks of Gondwanan affinity; the Gander Zone is underlain by sedimentary sequences deposited off the Gondwanan continental margin; and the Dunnage Zone is underlain by tracts of Iapetan ocean floor, island arcs, and back-arc basins. Rocks of all three zones were deformed and successively accreted to the Laurentian continental margin during closure of the Iapetus Ocean.

The Avalon Zone in New Brunswick is referred to as the Caledonia Zone (Fig. 5; Fyffe 1994). It is underlain by a Middle Neoproterozoic quartzite–carbonate sequence and a succession of Late Neoproterozoic volcanic and associated intrusive rocks. A Cambrian–Early Ordovician platformal sequence containing distinctive Acado–Baltic trilobite fauna unconformably overlies the Precambrian rocks. The Caledonia Zone is generally considered to represent a fragment rifted from the continental margin of Gondwana during opening of the early Paleozoic Iapetus Ocean.

The Gander Zone in New Brunswick includes the St. Croix and Miramichi zones (Fyffe and Fricker 1987). The St. Croix Zone (Fig. 5) is characterized by Late Cambrian–Middle Ordovician black shale and quartz-rich turbidites that presumably were deposited off the

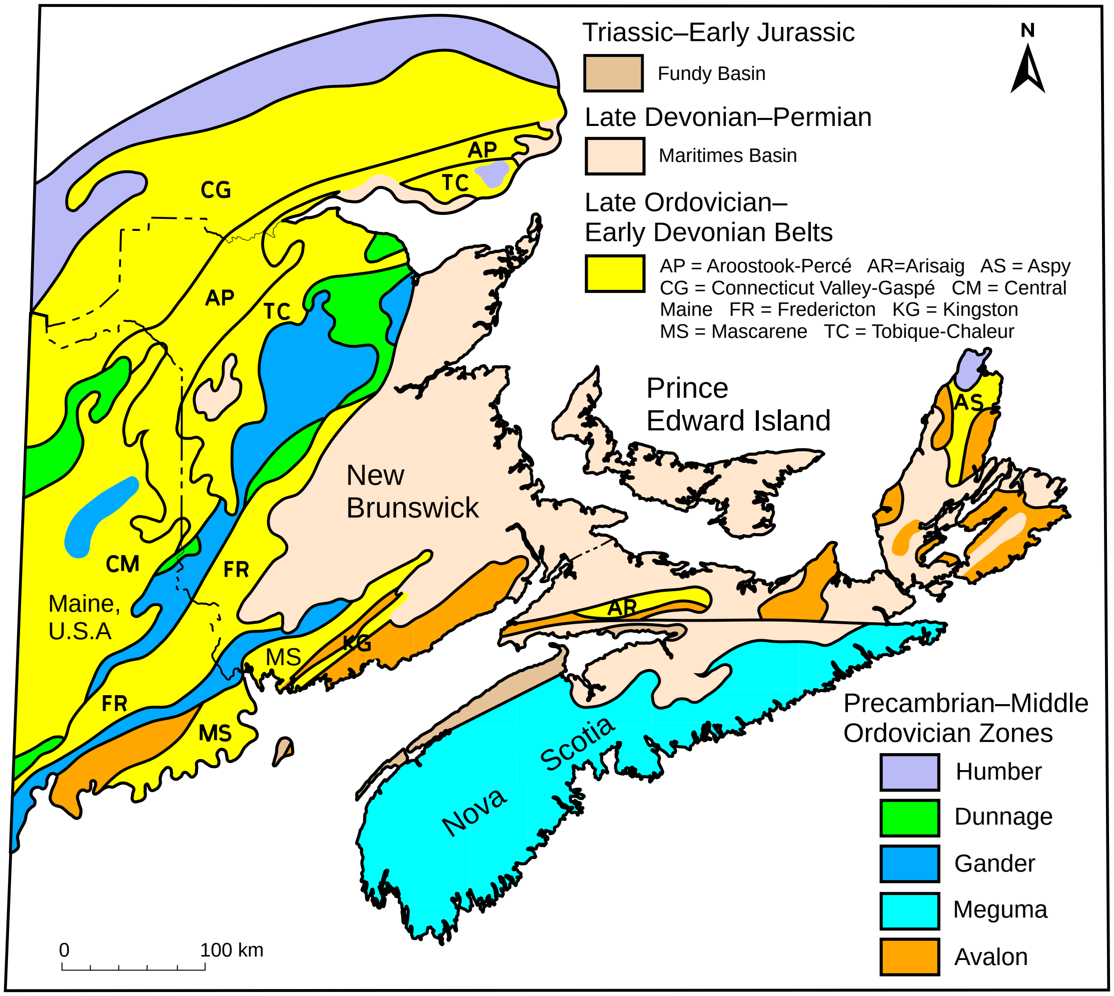

Figure 4. Tectonostratigraphic zones of the northeastern Appalachian Orogen.

Gondwanan continental margin. The Miramichi Zone (Fig. 5) comprises Early–Middle Ordovician volcanic rocks built upon the thick substratum of Late Cambrian–Early Ordovician quartz-rich turbidites.

The Dunnage Zone in New Brunswick is referred to as the Elmtree Zone (Fig. 5; Fyffe and Fricker 1987) and is underlain by an Ordovician ophiolitic suite. Volcanic rocks in the Miramichi and Elmtree zones possess arc and back-arc signatures and are interpreted to have been generated during the Late Ordovian–Silurian contraction of the Iapetus Ocean (van Staal and Fyffe 1991).

New Brunswick also includes belts of Late Ordovician–Early Devonian bedrock developed following closure of the main part of the Iapetus Ocean in the early Paleozoic. These comprise the Restigouche, Fredericton, Tobique–Chaleur, and Mascarene zones (Fig. 5) of Fyffe (1994). The Restigouche and Fredericton zones contain thick successions of calcarous and siliciclastic turbidites that range in age from Late Ordovician to early Devonian. These deep-marine sedimentary sequences likely were deposited in foredeep basins developed in front of the rising nappes during closure of the Iapetus Ocean and subsequent collision of the Gondwanan and Laurentian continental margins.

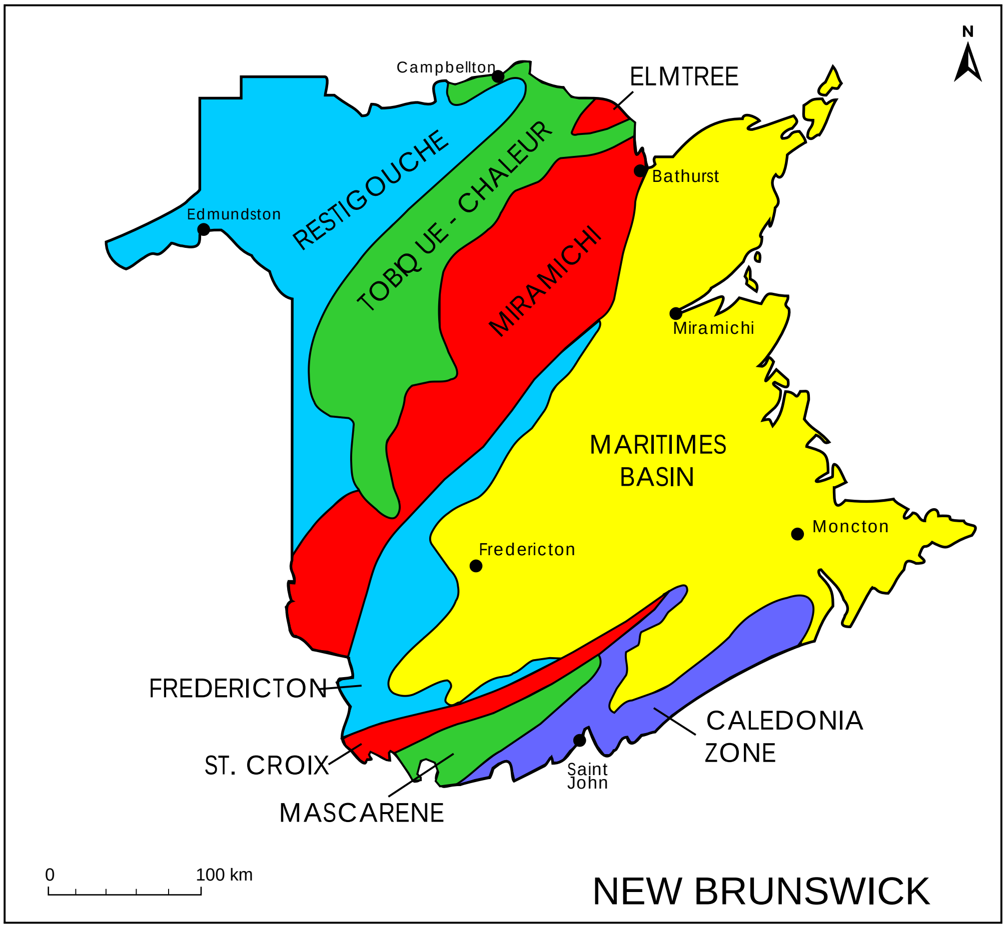

Figure 5. Geological zonation of New Brunswick.

The Tobique–Chaleur and Mascarene zones are underlain by Silurian–Early Devonian volcanic rocks interbedded with shallow-marine to fluviatile sedimentary rocks. The volcanic rocks show intraplate chemical signatures and probably erupted in transcurrent basins that formed as a result of oblique continental convergence. Thickening of continental crust generated bimodal batholithic suites that were emplaced between the Late Silurian and Middle Devonian.

The Maritimes Basin in New Brunswick (Fig. 5) includes Late Devonian–Carboniferous fluviatile conglomerate and sandstone sequences, shallow-marine limestone and evaporites, lacustrine oil shales, and subaerial volcanic rocks. These rocks were deposited in a successor basin within the uplifted Appalachian Orogen and are undeformed except along fault zones in southern New Brunswick.

The regional, 1:250 000-scale bedrock geology of the report area is documented by Fyffe (1982) and McLeod et al. (1994). The 1:500 000-scale bedrock geology of the entire province is illustrated on Map NR-1, *Bedrock Geology of New Brunswick* (NBDNRE 2000). Figure 6 is excerpted from Map NR-1 and shows bedrock in the report area; Table 2 lists the bedrock units marked on Figure 6.

Table 2. Bedrock units in southwestern New Brunswick.

	Intrusive Rocks		Stratified Rocks	
Age	**Code**	**Unit**	**Code**	**Unit**
Early Jurassic	EJC EJMI	Caraquet Dyke Ministers Island Dyke		
Late Carboniferous			LCP	Pictou Group
Early Carboniferous			ECMA	Mabou Group
Late Devonian– Early Carboniferous			DCHO	Horton Group
Late Devonian	LDBH LDK LDMB LDMD LDPR LDSR LDTR	Beech Hill Kedron Stream McDougall Brook Mount Douglas Pleasant Ridge Sorrel Ridge True Hill	LDHV LDPI	Harvey Group Piskahegan Group
Early Devonian	EDA EDB EDBA EDBL EDH EDHP EDHT EDJL EDMA EDNW EDPK EDSL EDSS EDTH EDU	Allandale Bocabec Baring Becaguimec Lake Hawkshaw Howard Peak Hartfield John Lee Brook Magaguadavic Nashwaak Parks Brook Skiff Lake St. Stephen Tower Hill Utopia	EDMS EDT	Mascarene Group Tobique Group
Late Silurian	LSAB LSCU LSEB LSFO LSJL LSM	Allen Brook Cutler East Branch Brook Foster Lake Jake Lee Mountain Mohannes	LSK LSMS LSPE	Kingsclear Group Mascarene Group Perham Group
Early Silurian	ESWBR	West Branch Reservoir	ESK ESMS ESPE	Kingsclear Group Mascarene Group Perham Group
Late Ordovician– Early Silurian			OSMA OSMS	Matapedia Group Mascarene Group
Late Ordovician			LOCK LOMD	Cookson Group Meductic Group
Middle Ordovician	MOLC	Little Clearwater Brook	MOCK MOMD	Cookson Group Meductic Group
Early Ordovician	EOBT EOGI	Benton Gibson	EOCK EOMD EOW	Cookson Group Meductic Group Woodstock Group
Late Cambrian– Early Ordovician			ЄOCK ЄOTL ЄOW	Cookson Group Trousers Lake Metamorphic Suite Woodstock Group
Cambrian			ЄEL ЄSJ	Ellsworth Group Saint John Group
Late Neoproterozoic– Middle Cambrian	ZЄG	Golden Grove Suite		
Late Neoproterozoic	LZNR	New River Suite	LZC	Coldbrook Group
Early Neoproterozoic			EZGH	Green Head Group

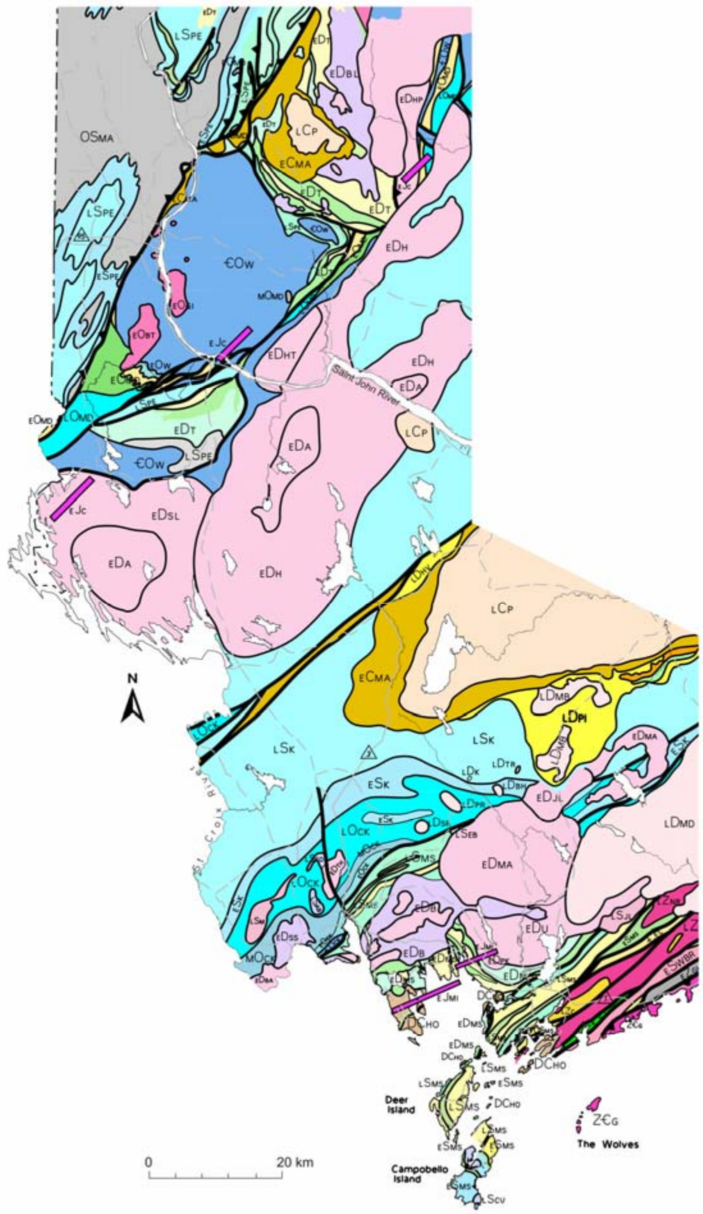

Figure 6. Bedrock geology of southwestern New Brunswick, as excerpted from Map NR-1 (NBDNRE 2000). To ensure optimal use of contour maps in this report, refer to the original Map NR-1, which provides higher quality reproduction of bedrock unit boundaries.

Mineral Deposits

As a result of its complex geological history, New Brunswick contains a wide diversity of mineral deposits. Mining has contributed significantly to the New Brunswick economy since shortly after coal was first exported from Grand Lake in 1643. Metallic mineral deposits were found later in association with plutons that intruded the various geological zones of the province. Among these deposits were an antimony mine in the Fredericton Zone near Lake George in 1861, a nickel prospect in the St. Croix Zone near St. Stephen in the late 1880s, a tungsten mine along Burnthill Brook in the Miramichi Zone in 1907 (Martin 2003), and a tungsten prospect near Welsford in the Mascarene Zone (Fig. 2, 5) in 1940 (McLeod 1990).

New Brunswick became a major mineral producer following discovery of the volcanic-hosted base-metal sulphide deposits in the Miramichi Zone near Bathurst in 1952. Two years later, tin and tungsten were discovered in the Mount Pleasant volcanic complex along the margin of the Maritimes Basin. Potash was discovered in the Maritimes Basin near Sussex in 1971, tungsten and molybdenum in the Miramichi Zone at Sisson Brook in 1977, and tin at Todd Mountain in 1981 (Ruitenberg and Fyffe 1982; Ruitenberg and McCutcheon 1982; MacLellan et al. 1990).

Gold exploration recently has become the focus of prospectors and junior mining companies operating in southwestern New Brunswick. Significant gold mineralization was discovered in a thrust belt at Cape Spencer in the Caledonia Zone in 1980 (Ruitenberg et al. 1990; Watters 1993), in a subvolcanic stock at Poplar Mountain in the Miramichi Zone in 1994, and at Clarence Stream along the margin of the Saint George Batholith in the Mascarene Zone in 1998 (Chi and Watters 2002; Thorne et al. 2002).

Surficial Geology

Previous Work

Lee (1962) was among the first to systematically map surficial materials in southwestern New Brunswick. Earlier regional soil surveys conducted by Stobbe and Aalund (1944) and Wicklund and Langmaid (1953) provided some information regarding glacigenic sediments and their relevance to the genesis and physical attributes of overlying soils. More recent works by Gadd (1973) and Rampton and Paradis (1981) describe the composition and extent of surficial materials in the report area and present an interpretation of glacial history.

Rampton et al. (1984) produced a comprehensive overview of the glacial history and surficial geology of New Brunswick, compiling their report from existing data sources, aerial photograph interpretation, and minor supplementary mapping. They revived the "Appalachian system of glaciers" concept of Chalmers (1890) by suggesting that four local ice centres affected New Brunswick during the Wisconsinan episode of glaciation. The Laurentide ice sheet may not have penetrated southwestern New Brunswick during the Late Wisconsinan but might have been a driving force behind the New Brunswick glaciers (see Lamothe 1992).

More recently, Seaman (1989a) and Seaman et al. (1993) documented the complexity of New Brunswick's glacial history by conducting an extensive analysis of striated outcrops.

Seaman (1989b, c) and Lamothe (1992) discussed glacial stratigraphy in specific locations within the report area. These studies approximately coincided with detailed fieldwork in the region by the NBDNR, studies that included geochemical surveys performed between 1990 and the present (e.g. Seaman 2002). In light of evidence derived from these recent investigations, it became apparent that some earlier interpretations by Rampton et al. (1984) needed revision. Seaman (2004) addresses these issues and summarizes the current knowledge base of Quaternary geology in New Brunswick.

Surface Materials

The report area is covered primarily by a single basal till unit of regional extent. A few multiple till sections have been documented, but further work is needed to determine their exact nature and relevance (Seaman 2004).

The basal till unit comprises lodgement till, basal melt-out till, or deformation till (as classified by Brodzikowski and Van Loon (1987)), or any combination of these three members. Typically, a given locality features only a single member. However, some exposures display one member grading into another: basal melt-out till into lodgement till, for example, or lodgement till into deformation till. The basal till unit occurs mainly as a blanket or veneer covering large parts of the landscape, commonly reflecting the texture, lithology, and colour of local bedrock. Thickness of the unit generally ranges from 0.5 m to 1.5 m. In some areas, mainly on the lee side of topographic highs, the unit can reach thicknesses of about 5 m; elsewhere, it forms a veneer measuring only a few decimetres.

Rapid deglaciation is recorded by glaciofluvial deposits found mainly in overdeepened river valleys and glacial spillways, and by discontinuous disintegration moraine (ablation till deposits with associated ice-contact deposits) found in topographic depressions. Deglaciation in this region did not produce a recognizable sequence of end moraines. Rather, it appears to have caused ice-mass stagnation and in-place wastage (Seaman 2004). Figure 2 shows the distribution of eskers and major kame moraines in southwestern New Brunswick.

DATA SET PROPERTIES AND LEVELLING SCENARIOS

Till geochemical investigations in southwestern New Brunswick began in 1990 and are ongoing today (2005). The current report deals only with basal till geochemical data obtained between 1990 and 2003. The 2122 basal till samples were collected from the 21 G and 21 J map areas (Fig. 1) and represent a sample density of 1 sample/4 km^2.

Till geochemical data gathered over the 13-year period was obtained from several laboratories that used a variety of analytical techniques (Table 1). In the case of some elements, the resulting data set is characterized by systematic variations. The variations are systematic in that elemental values obtained from standard reference materials in one survey tend to differ consistently from values obtained from the same standards in another survey: that is, the variations have similar parametric characteristics (Grunsky, in press).

To mitigate the effects of these inconsistencies and to produce a more accurate regional data set, levelling corrections can be applied. Levelling is the practice of applying a correction factor to the values of one survey to make them comparable to the values of another. Several scenarios in this data set warranted a levelling correction and are discussed in detail below. (Also see *Appendix 1*.)

Surveys conducted under the direction of Toon Pronk (NBDNR) employed Acme Analytical Laboratories Ltd., Vancouver, British Columbia, for ICP-MS analysis and Becquerel Laboratories Inc., Mississauga, Ontario, for INAA analysis. Surveys conducted by Allen Seaman (NBDNR) used Activation Laboratories Ltd. (Actlabs®), Ancaster, Ontario, for both INAA and ICP-OES analyses. In addition, surveys for the Fosterville, Forest City, and Canterbury map areas used AAS to determine base-metal concentrations. AAS was conducted by NBDNR staff prior to closure of the Department's AAS laboratory in 1993. Table 1 lists all publications related to the foregoing analyses.

The NBDNR conducted the first parametric levelling of its geochemical data in 2003 (Allard 2004). Prior to that time, the data were collected, analyzed, and published as reports and associated maps based on individual map-area projects. The approach successfully targeted new areas for exploration, and the resulting data proved useful to prospectors and junior mining companies operating in southwestern New Brunswick. However, comparisons made between non-levelled data sets potentially can result in misleading conclusions. Data levelling therefore is necessary when seeking to compare results from multiple surveys or to produce regional compilation maps and reports. Such compilation maps can be an excellent tool for assessing large-scale geochemical trends or delineating zones of high mineral exploration potential.

The current report presents levelled data for the following 26 elements: As, Au, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, Zn, and the combined rare-earth elements (Ce, Eu, La, Lu, Sm, Tb, and Yb). Data for these elements were levelled to represent Actlabs® INAA values, except for Cu, Mn, Ni, Pb, and Zn, which were levelled to represent Actlabs® ICP-OES values. *Appendix 1* describes the levelling methodology used.

Levelling corrections were applied where significant variations in data were observed due to one or more of the following circumstances.

1. *Different analytical techniques.* Where different analytical techniques were used in the report area, levelling was conducted to create a new, coherent data set. In this report, data obtained from AAS by NBDNR staff was levelled to fit data obtained from ICP-OES by Actlabs®. Quantile analysis of standard data indicates that values

obtained from both methods have systematic parametric characteristics and therefore can be levelled. No AAS–ICP-OES levelling was required for Cu. On the other hand, ICP plots for Mn, Ni, Pb, and Zn all required some degree of AAS–ICP-OES levelling.

Data from ICP-MS by Acme, which used aqua regia (hydrochloric and nitric acids) partial extraction, were also levelled with data from ICP-OES by Actlabs®, which used near-total, four-acid (hydrochloric, nitric, perchloric, and hydrofluoric acids) digestion. The levelling procedure yielded regional data for Cu, Mn, Ni, Pb, and Zn. Again, quantile analysis of standard data indicated systematic parametric characteristics that permitted levelling of the data.

2. *Consistent analytical technique but different laboratories*. Two laboratories used INAA: Becquerel and Actlabs®. Standard data indicated that values obtained from each method were comparable for most elements. Minimal levelling was required, and only for the elements Cr, La, Lu, Rb, Sm, Ta, and Yb.

3. *Consistent analytical technique and laboratories but changes in detection parameters or digestion.* Laboratory techniques have altered considerably over the duration of this project. Since 1990, for instance, detection limits, accuracy, precision, and control over digestion conditions have been improved. Levelling corrections thus were applied as required to take into account the consequences of these technological and analytical advances.

   In a few cases, different digestion methods were used, although the same laboratory and technique were employed. Specifically, two runs of ICP-OES (for the Fosterville and McAdam map areas) used aqua regia rather than four-acid digestion. Four-acid digestion is a substantially stronger dissolution than aqua regia digestion, but the results for some elements, including base metals, tend to be comparable (Hoffman 1999). Only Cu, Mn, Ni, Pb, and Zn are reported as ICP contour plots, and no notable discrepancy was observed at map boundaries, except in the case of the McAdam map sheet.

   On the McAdam map sheet, Pb and Zn concentrations were considerably lower than on the surrounding map sheets. Noticeable edge effects were apparent in preliminary contour plots but could not be attributed solely to the variation in digestion techniques. Data for the Fosterville map sheet, for example, also were obtained using aqua regia digestion but did not show a similar discordant relationship. Therefore, the anomalously low Pb and Zn values (below background levels) for the McAdam map area must be due to variations in the detection parameters or digestion conditions for that specific run. This discrepancy was accounted for in the levelling process.

CONTOURING METHODS

The contour maps in this report show the geochemical relief (variations in concentration) across the surveyed area for individual elements (listed below) and for specific multivariate-element-association groupings (also listed below). The geochemical contours are displayed on page-sized maps (Fig. 7–11, 20–38) over a bedrock background that was derived from the 1: 500 000 *Bedrock Geology of New Brunswick* (NBDNRE 2000; also see Fig. 6 and Table 2). This visual presentation allows for enhanced recognition of anomalous zones, dispersal patterns, and bedrock-controlled geochemical trends. The maps can be used as a quick reference to distinguish areas with greater mineral exploration potential from those that are less favourable.

Map contours were generated by the Surfer® 8 software program using point kriging with a search radius of 8 km. Point kriging estimates values at grid nodes, employing a moving-average technique of contouring to compensate for the somewhat irregular spacing of sample sites. Statistically, kriging is based on *The Theory of Regionalized Variables*, wherein a variable is considered "regionalized" if it varies from one place to another with apparent continuity: in other words, trends are apparent in the data. Because such variation is evident in geochemical data, kriging is viewed as the method most suitable for geochemical contouring.

Surfer® 8 software allows the user to create an appropriate variogram model when gridding using the kriging algorithm. The variogram determines spatial continuity in the data set and measures how quickly values change with distance. It is a three-dimensional function that, when properly modelled and applied to the data, results in a more meaningful and natural representation of geochemical relief. By modelling the variogram through trial and error, and by employing Surfer's automated controls, the user allows the data to dictate the limits of reproducibility. All contour maps presented here have been subjected to variogram modelling (see *Appendix 2*).

The Multivariate Approach

The delineation of an anomaly with economic potential can often be enhanced by combining several geochemical parameters. In gold exploration, for instance, the values of not only gold, but also arsenic and antimony, among other pathfinder elements in till, should be considered. This is true, despite the fact that correlating the element values and defining element associations by examining data tables or single-element contour plots can be cumbersome and sometimes misleading, as exemplified by the so-called "nugget effect".

The odds of overlooking relevant anomalies can be significantly decreased by constructing multi-element pathfinder contour maps. The multivariate-element-association maps in this report (Fig. 7–11) are adapted from the element associations of Rose et al. (1979, p. 76:

Table 4.2). Equal weight is given to all constituents, whether they are major components or associated pathfinder components. The following steps demonstrate the data processing needed to determine an “indicator” value for contouring.

Step 1. The raw data are screened for “undetectables.” These are replaced with a value equal to half the detection limit for that particular element.

Step 2. The raw data are normalized by dividing the value of each element by its mean so that all elements are given equal weight in the resulting “indicator” value.

Step 3. The normalized values are summed (e.g. W + Mo + Cu + Rb + Cs = tin–tungsten indicator).

Step 4. The new “indicator” value is converted to its corresponding percentile value. This is the value that is contoured.

Multivariate-Element-Association Contour Maps

Five multivariate-element-association contour maps have been constructed to aid in identifying favourable areas for the types of mineralization expected to occur in southwestern New Brunswick. The maps show indicator contour plots for precious-metal mineralization (Fig. 7), base-metal mineralization (Fig. 8), tin–tungsten mineralization (Fig. 9), nickel–cobalt–copper mineralization (Fig. 10), and rare-metal mineralization (Fig. 11). Significant metal anomalies are marked on the contour maps by upper-case letters (e.g. A, B, C) and are discussed below.

Concentration contour maps (Fig. 20–37) also have been plotted for 18 individual elements (As, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, and Zn). These maps appear in *Appendix 3*, together with an indicator contour map for combined rare-earth-element concentrations (Fig. 38).

Although data levelling has produced an accurate representation of the till geochemical data, corrections cannot be made for specific naturally occurring phenomena. Caution thus should be exercised when comparing magnitudes of anomalies situated distal to one another in the report area. Variations in bedrock lithology and geochemistry (regional geochemical relief), differences in localized glacial dynamics, and till genesis all can affect the anomaly contrast with respect to source. Till in the report area presumably is locally derived, but differences in geochemical relief can (and likely do) result from varying degrees of till homogenization and reworking. For example, basal till overlying the Pokiok Batholith in the Forest City (21 G/12) map area has a locally derived sandy, granitic matrix, but a pebble fraction dominated by distally derived sedimentary and volcanic clasts (Seaman 1992).

Care also must be taken when comparing anomalies hosted in the different geological zones (Fig. 5). Allard (2003) has characterized background, threshold, and anomalous geochemical values using quantile analysis of 49 elements in the Fredericton Zone and St. Croix Zone for 272 till samples from the Rollingdam (21 G/06) map area. The Rollingdam data indicate that, for most elements, these parameters are noticeably lower in the Fredericton Zone than in the St. Croix Zone. In other words, transitions from one uniform geochemical "province" to another tend to be sharp and consistent with zone boundaries. Abrupt transitions attest to the dominantly local nature of the till and the efficiency of material incorporation and deposition by the ice mass.

Notwithstanding the foregoing limitations, the contour maps accompanying this report show anomalies that 1) have consistently high above-background concentrations, 2) display apparently high potential, and 3) can be readily discerned, regardless of setting.

Precious-Metal Mineralization

The precious-metal-mineralization indicator map (Fig. 7) represents a composite of normalized Au, Sb, As, Hg, Th, and U concentrations in basal till. The report area hosts numerous precious-metal anomalies. Some occur at sites of proven economic potential such as Clarence Stream (A on Fig. 7), Sorrel Ridge (B), Poplar Mountain (C; Seaman 1994), and Lake George (E). Other anomalies show surface expressions similar in magnitude to those at A, B, C, and E and occur in settings tectonically favourable for hosting potentially economic-grade deposits. However, these anomalies, which include ones at Sisson Brook (D) and Tower Hill (F; Allard, in press), have not undergone substantial follow-up work. Ruitenberg et al. (1990) present a summary guide to geological controls on precious-metal mineralization in the report area.

Smaller precious-metal anomalies on Figure 7 generally appear as "bull's-eye" and "amoeboid" shapes (Shilts 1975) or as small palimpsest configurations (Parent et al. 1996), all of which depict identifiable point sources. The larger, compound anomalies (e.g. A, B, and D) exhibit irregularly homogenized configurations that reflect the hybrid nature of the till. (Hybrid till was reworked by glacial flow paths, which "hybridized" the original till, redistributing its matrix and clast components. See *Considerations Relating to Glacial History,* below, for more detail.) These larger anomalies likely indicate proximal, multiple-point sources and areas of substantially higher background geochemical concentration related to underlying bedrock units.

Based on the precious-metal contour map (Fig. 7), several generalizations can be made concerning follow-up exploration targets. Many anomalies appear in close proximity to documented mineral occurrences, but other anomalies do not. Moreover, some anomalies coincide with mineral occurrences for commodities other than precious metals. For example,

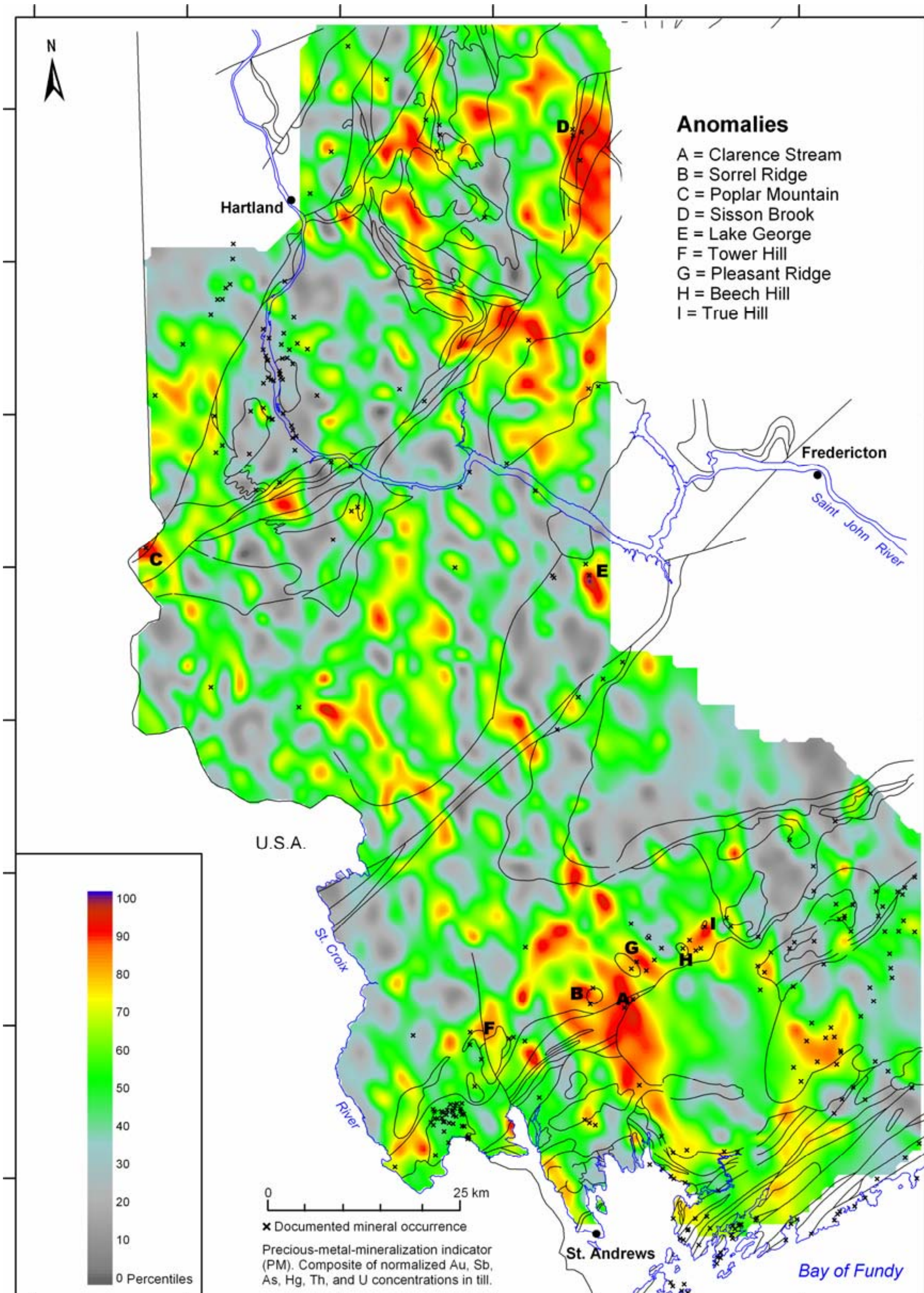

Figure 7. Multivariate precious-metal-mineralization indicator in basal till (< 63 μm fraction).

a significant precious-metal anomaly near Pleasant Ridge (G) overlays the eastern flank of the Late Devonian Pleasant Ridge pluton at its contact with sedimentary country rock. Documented mineral occurrences related to the intrusions describe base-metal and tin mineralization. This situation also pertains to anomalies associated with the Late Devonian Beech Hill (H) and True Hill (I) plutons.

Another factor to consider when examining anomalies near documented mineral occurrences is how the glacial dispersal direction relates to the position of the anomaly "head" (that is, the peak concentration contour) and mineral occurrence location. The Tower Hill (F) anomaly, for instance, occurs along the northwestern margin of the Tower Hill pluton, but the only known precious-metal occurrences lie east of the pluton. Glacial dispersal in the area is primarily toward the southeast. Because the surface anomaly expression is almost instantaneous in this region (as indicated by thin tills), it is unlikely (although not impossible) that an anomaly head oriented any distance north of a documented mineral occurrence could be related to that occurrence.

Overall, the precious-metal-mineralization indicator map shows a high potential for precious metals in southwestern New Brunswick. Many of the anomalies (Fig. 7) overlay areas that have undergone little mineral exploration and thus warrant follow-up work.

Base-Metal Mineralization

The base-metal-mineralization indicator map (Fig. 8) represents a composite of normalized Cu, Pb, Zn, Mn, As, Sb, and Au concentrations in basal till. As with the precious-metal contour map, the base-metal contour map shows numerous high-contrast anomalies. However, distribution of these anomalies is less sporadic than for precious metals and is more confined to specific geological zones.

Most base-metal anomalies occur in the northern part of the report area within the Miramichi Zone and the southern extension of the Tobique–Chaleur Zone (Fig. 5). The peak anomaly (99^{th} percentile) overlays rocks of the Tobique–Chaleur Zone in an area targeted by Ruitenberg and McCutcheon (1982) as having high potential for stratabound massive-sulphide deposits. Anomaly A (Fig. 8) overlays Early Carboniferous sedimentary rocks of the Mabou Group. The anomaly "head" coincides with a contact between Early Devonian mafic volcanic rocks of the Tobique Group and Carboniferous rocks. A compound anomaly of almost equal magnitude (98^{th} percentile) occurs in the vicinity of Sisson Brook (B on Fig. 8). Anomaly B straddles multiple bedrock units including the Early Devonian Howard Peak pluton, Ordovician volcanic rocks of the Meductic Group, and Late Cambrian–Early Ordovician sedimentary rocks of the Woodstock Group. The position of the anomaly "heads" relative to nearby documented mineral occurrences suggests that additional sources of mineralization may exist nearby. Many other anomalies identified in the northern part of the report area also deserve further investigation (Fig. 8).

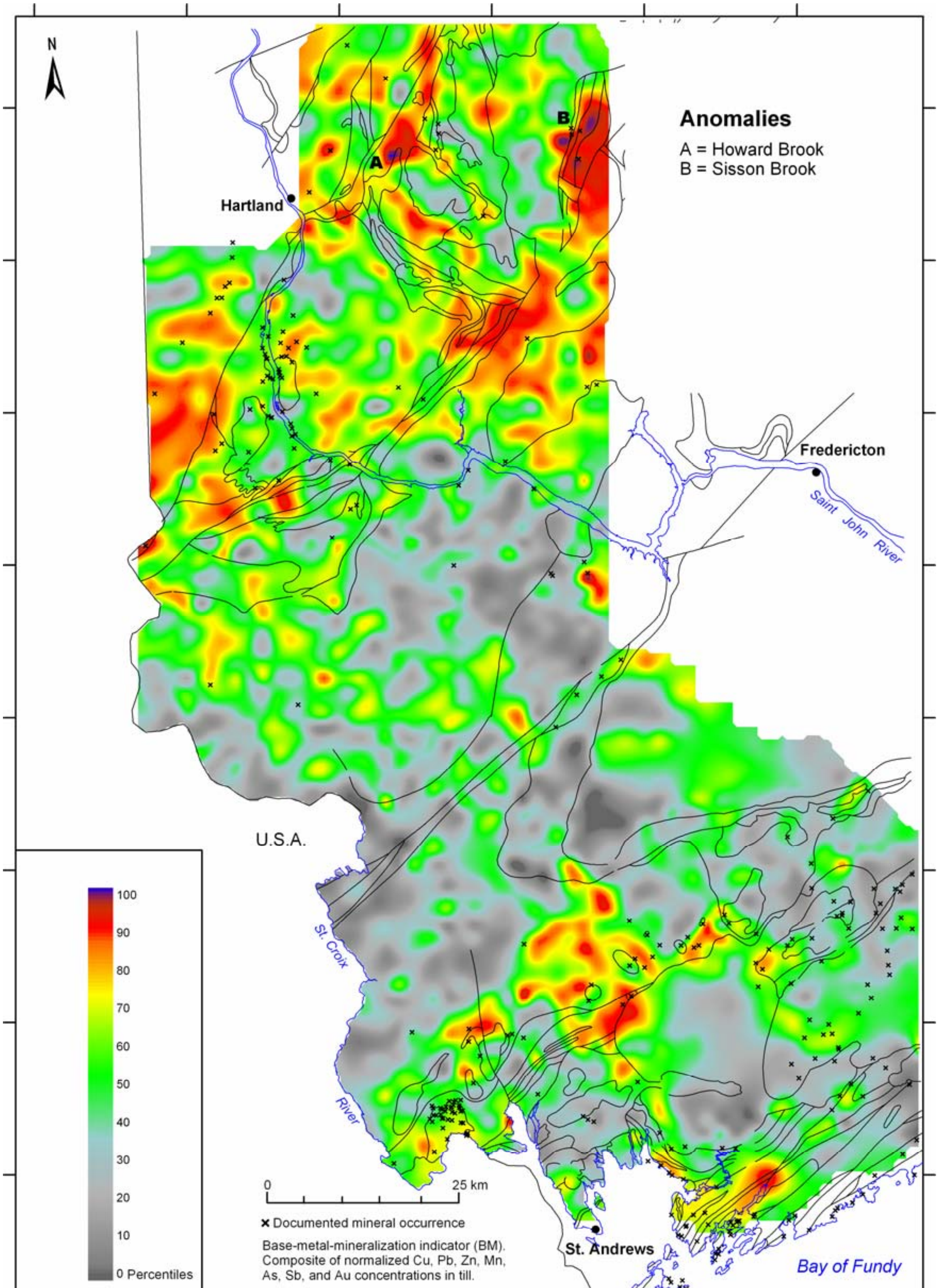

Figure 8. Multivariate base-metal-mineralization indicator in basal till (< 63 µm fraction).

Most base-metal anomalies in the southern part of the report area occur proximal to the boundary between the St. Croix Zone and the Mascarene Zone (Fig. 5). Although the area is not known for high base-metal potential, the anomalies here justify follow-up activity (Fig. 8).

Tin–Tungsten Mineralization

The tin–tungsten-mineralization indicator map (Fig. 9) represents a composite of normalized W, Mo, Cu, Rb, and Cs concentrations in basal till. Map anomalies are confined primarily to the Miramichi Zone and St. Croix Zone, situated in the northern and southern parts of the report area respectively (Fig. 5). Ruitenberg and McCutcheon (1982) describe tungsten–molybdenum mineralization in the region as being stockwork in greisen.

Peak tin–tungsten anomalies in the northern portion occur in the Coldstream (NTS 21 J/06) map area near Sisson Brook (A on Fig. 9) and in association with Early Carboniferous rocks of the Mabou Group (B). The compound anomaly at Sisson Brook forms a disjointed band of highly anomalous (> 98th percentile) values spanning several bedrock units. Related mineral occurrences have been documented but, again, configuration of this anomalous zone indicates high potential for additional sources of mineralization. Snow and Coker (1987) describe overburden geochemistry at Sisson Brook and relate it to known W–Cu–Mo mineralization in the area.

The source of anomaly B (Fig. 9) overlying Early Carboniferous sedimentary rocks of the Mabou Group is unknown; this attractive area deserves further investigation. Interestingly, a sizeable dispersal train emanates from the rock suite and extends southeast for approximately 20 km (Seaman 2001b). This indicates a significant displacement of material, assuming that no additional sources of mineralization are situated along the trajectory.

Although geochemical relief in the south part of the report area is less than in the north, the St. Croix Zone in New Brunswick (Fig. 5) historically has been a target area for tin–tungsten exploration. The region features numerous mineral occurrences containing tin–tungsten and related commodities, and many anomalies are associated with these occurrences (Fig. 9). One such deposit is the past-producing Mount Pleasant mine (Sn, W, In, and Bi) although, curiously, the mine site (C on Fig. 9) shows a lower than expected geochemical relief. Szabo et al. (1975) discuss Cu, Pb, Zn, As, and Sn in the Mount Pleasant area, as well as glacial dispersal of till pebbles.

Ruitenberg and McCutcheon (1982) describe host rocks for tin–tungsten mineralization in the report area as being Late Devonian high-silica granite stocks and associated contact aureoles. Some anomalies on the tin–tungsten contour map (Fig. 9) show definite associations with such intrusions including those in the areas of McDougall Brook (near C), Sorrel Ridge (near D), and Pleasant Ridge (near E). Conversely, other anomalies on Figure 9 show relief equal to that of anomalies C to E but appear not to be associated with granitic intrusions or aureoles.

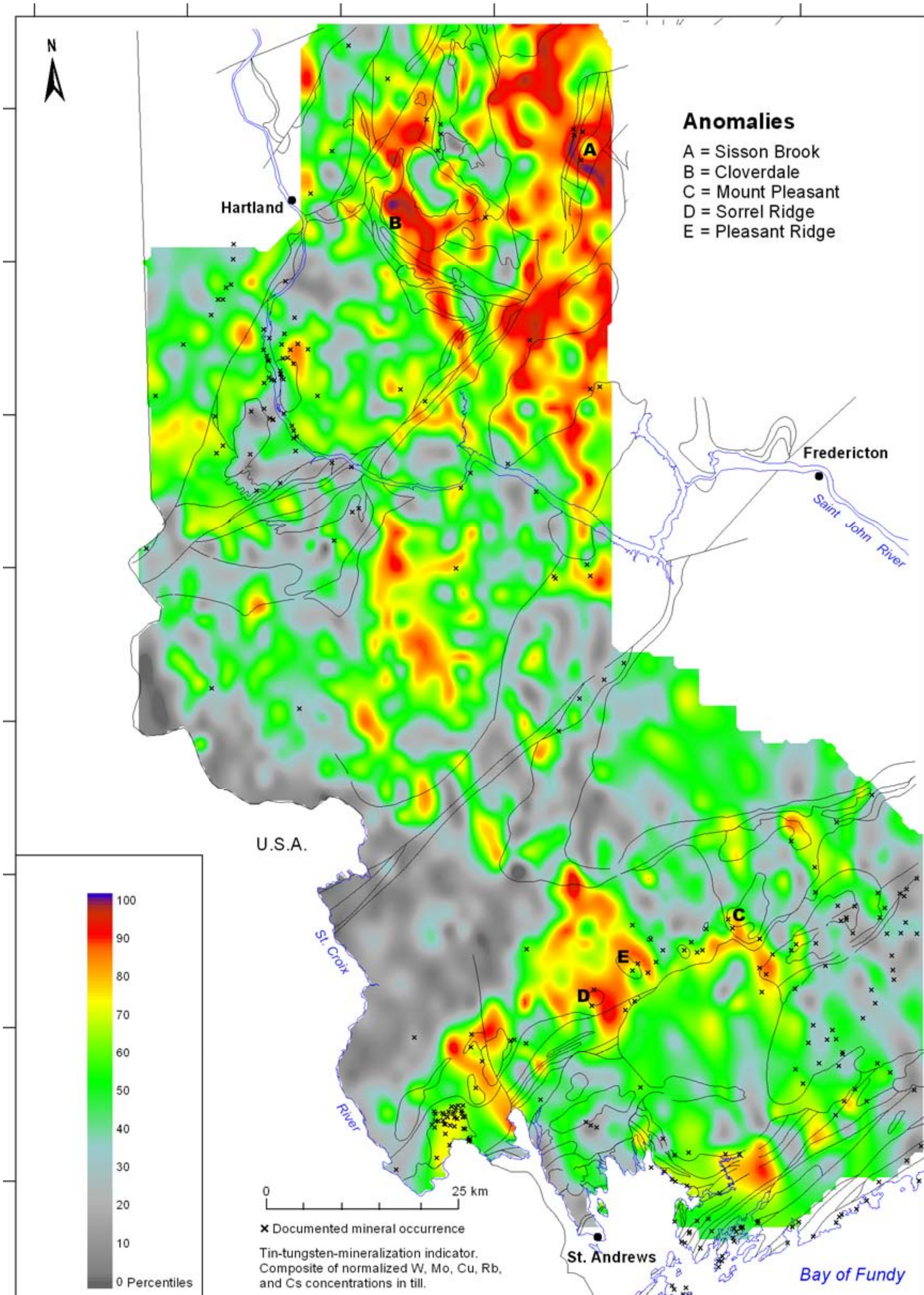

Figure 9. Multivariate tin–tungsten–mineralization indicator in basal till (< 63 μm fraction).

Nickel–Cobalt–Copper Mineralization

The nickel–cobalt–copper-mineralization indicator contour map represents a composite of normalized Ni, Co, Cu, and Cr concentrations in basal till (Fig. 10). High-contrast anomalies of this mineralization type are limited to the St. Croix Zone and Miramichi Zone located in the southern and northern parts of the report area respectively (Fig. 5).

Numerous mineral occurrences have been documented in ultramafic and mafic phases of the Late Silurian St. Stephen intrusion around St. Stephen (Fig. 10). Their associated anomalies expressed in the overlying basal till consistently show > 90^{th} percentile values. Anomalies in the St. Croix Zone include those at St. Stephen (A of Fig. 10) and two bull's-eye anomalies underlain by the Silurian Allen Brook (B) and Foster Lake (C) mafic intrusions. Another noteworthy anomaly occurs at Utopia (D) in association with mafic rocks of the Early Silurian Mascarene Group. Significantly, all five multivariate-element-association maps consistently show an anomaly at this location.

Delineating anomalous patterns of nickel–cobalt–copper mineralization in the northern portion of the report area is less straightforward than in the south. Although many anomalies overlay mafic volcanic rocks and mafic intrusions, another large group of anomalous values (E on Fig. 10) are associated with manganese-rich sedimentary rocks of the Silurian Perham Group. Considerable glacial dispersal to the east and south–southeast from this area has produced a zone of above-background concentrations. No occurrences of mineral commodities related to this mineralization type have been documented here. However, grab samples from bedrock in the area were analyzed using INAA and ICP-OES (four-acid dissolution) and showed above-background Ni and Co concentrations (Seaman 2000). Whether these elevated values in bedrock and the overlying till reflect a potential source of economic mineralization is unclear; the district warrants further investigation.

No relevant mineral occurrences have been documented at any of the nickel–cobalt–copper anomalies associated with mafic rock units in the northern part of the report area. Anomalies F, G, H, and I (Fig. 10) appear related to mafic rocks of the Early Devonian Tobique Group. The sizeable, high-contrast, bull's-eye anomalies J and K (Fig. 10) overlay the Early Devonian Becaguimec Lake mafic intrusion.

Rare-Metal Mineralization

Normalized Cs, Rb, U, Th, Ce, Eu, La, Sm, Tb, and Yb concentrations in basal till were used to compile the rare-metal-mineralization indicator map (Fig. 11). Peak concentrations are found in the northern part of the report area. Here, a broad zone of anomalous concentrations (A on Fig. 11) occurs in close association with Early Devonian intrusions (> 99^{th} percentile head) including the Nashwaak and Howard Peak plutons, and the northern extension of the Hawkshaw pluton.

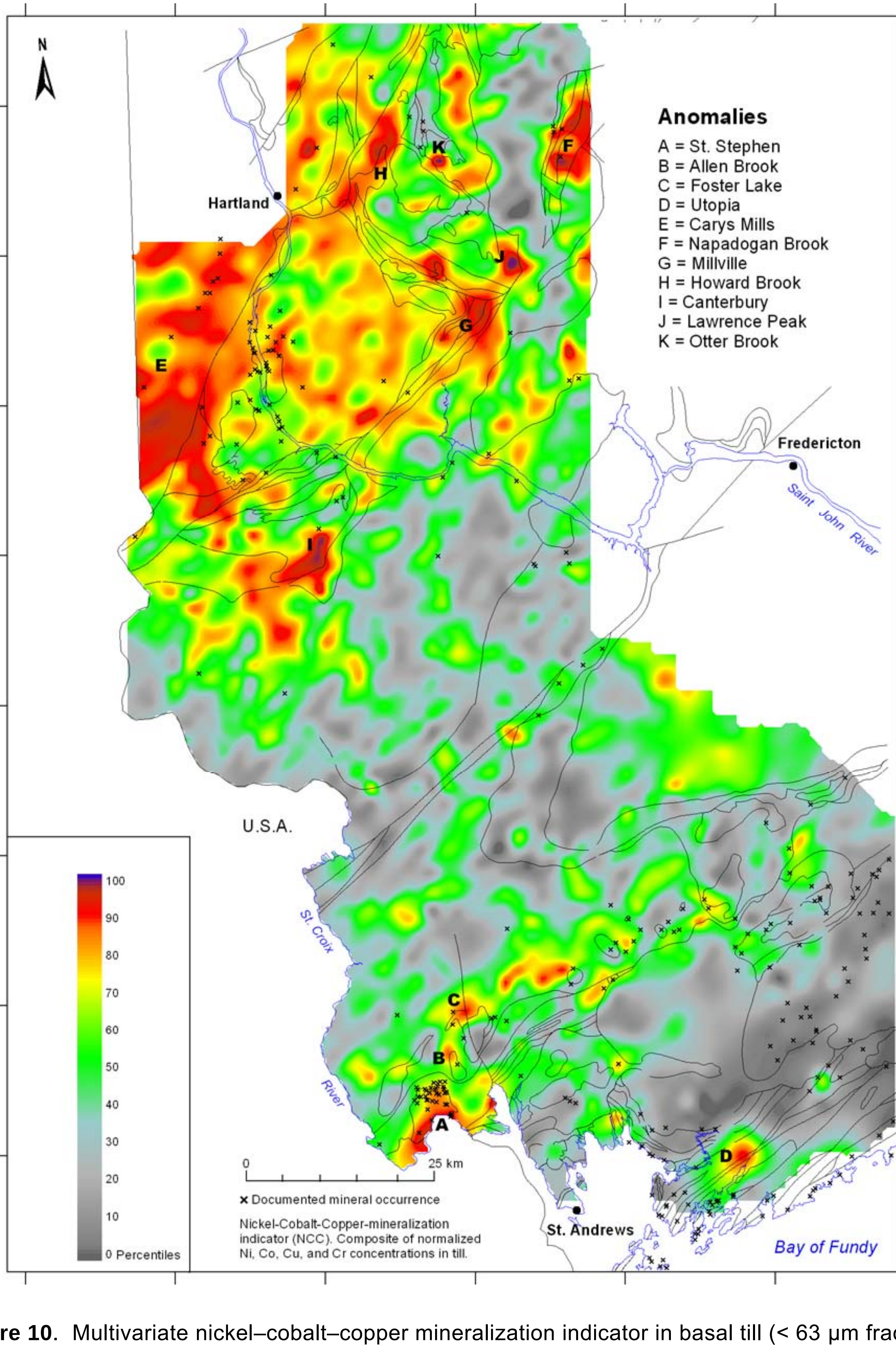

Figure 10. Multivariate nickel–cobalt–copper mineralization indicator in basal till (< 63 µm fraction).

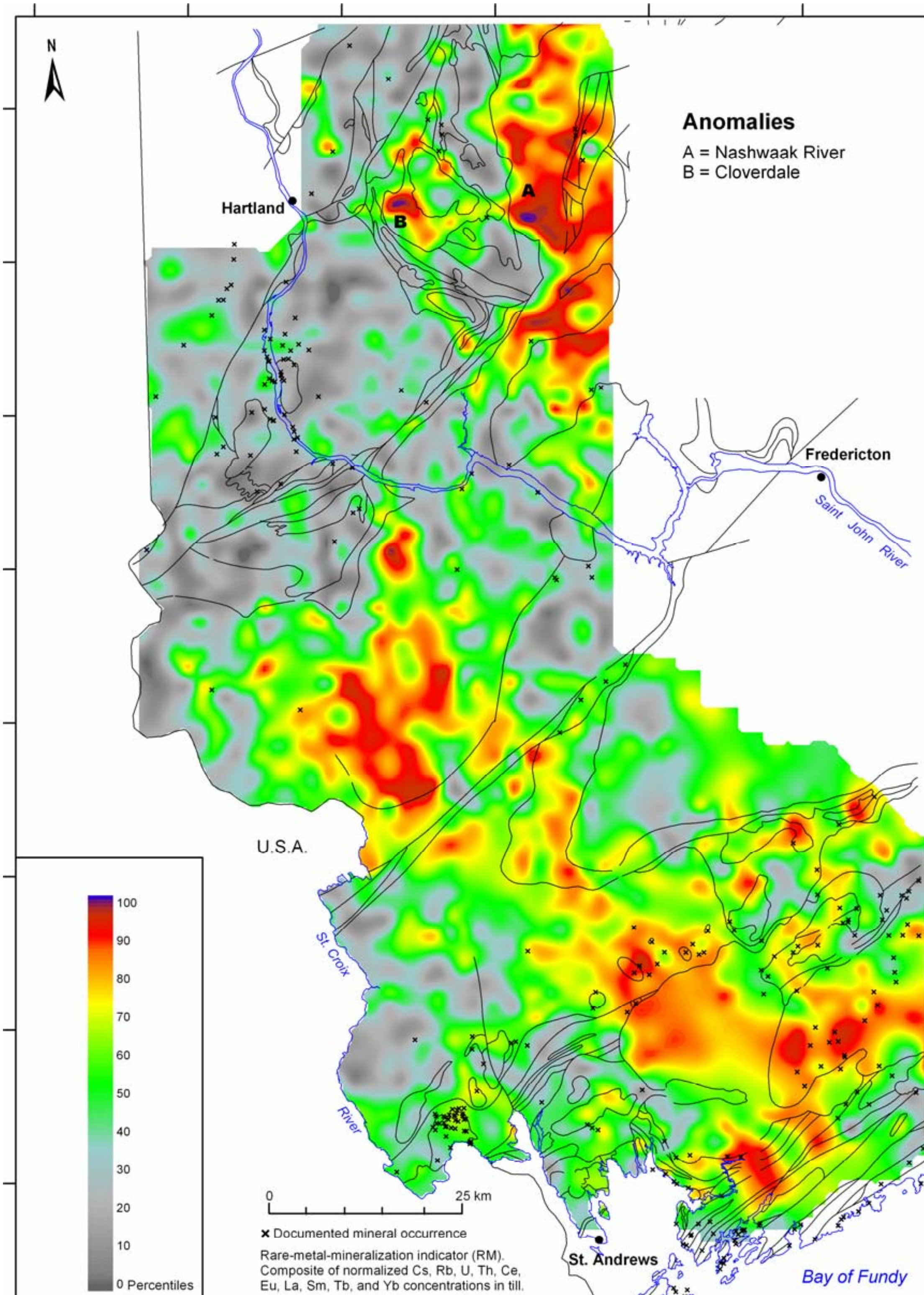

Figure 11. Multivariate rare-metal-mineralization indicator in basal till (< 63 µm fraction).

West of these sites, and of particular interest, is a high-contrast (> 99^{th} percentile), well defined, amoeboid-shaped anomaly (B on Fig. 11) that indicates a point source. Anomaly B overlays Early Carboniferous sedimentary rocks of the Mabou Group, even though anomalies of such extreme relief generally are not expected to occur diagenetically in sedimentary rocks. The anomaly may represent placer deposition of heavy minerals and deserves further investigation.

In the middle and southern parts of the report area, broad, diffuse zones of rare-metal anomalies occur in association with several Devonian and, to a lesser extent, Late Neoproterozoic felsic intrusions (Fig. 11).

CONSIDERATIONS RELATING TO GLACIAL HISTORY

The complex Wisconsinan history of New Brunswick and the resulting glacial landscape present unique challenges to interpreting the timing and orientation of glacial events (Parkhill and Doiron 2003). As such, they pose several problems related to drift exploration. The complex erosional record (Fig. 12) is difficult to interpret (Seaman 1989a; Seaman et al. 1993), till fabric studies are inconclusive (Seaman 1991; Seaman et al. 1993), and datable Quaternary organic material is rare. Compounding these issues is the fact that provenance studies via geochemical dispersal must take into account 1) the extensive Late Wisconsinan hybridization of the till, and 2) the diverse bedrock geology of the province and its associated varying background geochemistry.

The report area is dominated by a single stratigraphic basal till unit consisting of basal melt-out till, lodgement till and, in some districts, deformation till. The basal till unit likely was deposited during the Early–Middle Wisconsinan Caledonia Phase of glaciation (Table 3). The Caledonia Phase appears to have comprised an Early Wisconsinan east–southeast erosional phase followed by a Middle Wisconsinan south–southeasterly depositional flow event (Rampton et al. 1984; Stea et al. 1998; Seaman 2004).

After till deposition, the single till unit underwent extensive reworking and hybridization during a series of Late Wisconsinan ice-flow phases (Stea and Finck 2001; Allard 2003; Allard and Pronk 2003; Seaman 2003b). These phases (Table 3) represent shifts in outflow orientation within a common ice sheet, rather than multiple advances and retreats by individual ice masses (Seaman et al. 1993). In the Rollingdam map area, for instance, Allard (2003) interpreted some till dispersal patterns and palimpsest landforms as being related to a Late Wisconsinan ice-flow event that followed a south–southwest (200° to 220°: Chignecto Phase) flow trajectory (Fig. 13, Table 3). A few-degrees shift in outflow direction and a subsequent creep of ice mass along the new trajectory for only tens of metres apparently were sufficient to produce a new set of striae.

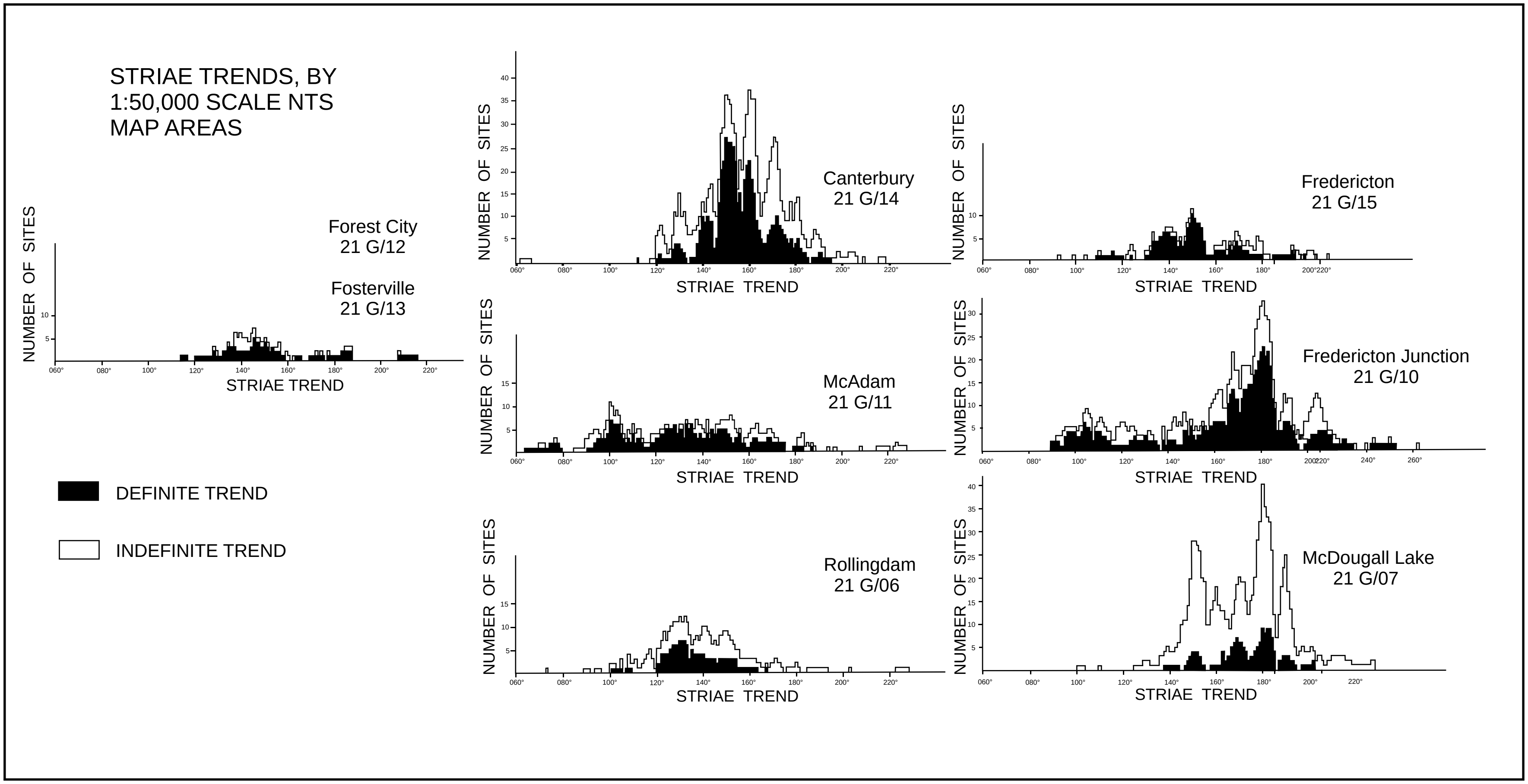

Figure 12. Histograms for observed striae trends in southwestern New Brunswick.

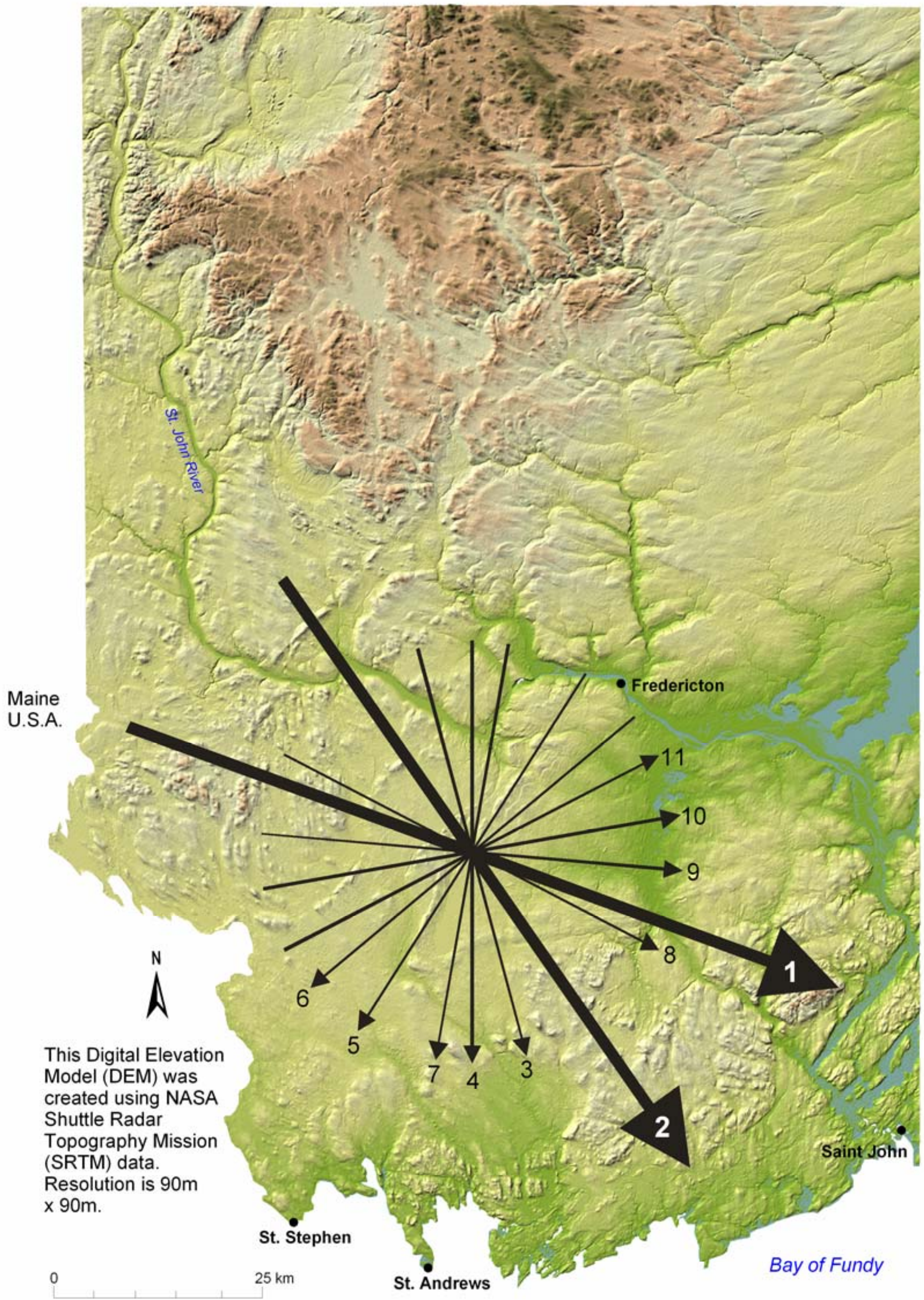

Figure 13. Ice-flow trajectories (No. 1 to 11) across southwestern New Brunswick. Diagram does not show the source area or terminal position. Table 3 lists glacial phase names and orientations associated with each numbered trajectory.

Table 3. Ice-flow chronology for southwestern New Brunswick.

Reference No. on Figure 13	Phase	Flow Trajectory	Inferred Age
11	Pollet River	55°–70°	Late Wisconsinan
10	Kent	70°–90°	Late Wisconsinan
9	Tuadook–Renous	90°–100°	Late Wisconsinan
8	Passamaquoddy	100°–135°	Late Wisconsinan
7	St. Martins	185°–195°	Late Wisconsinan
6	Port Elgin	220°–240°	Late Wisconsinan
5	Chignecto	205°–220°	Late Wisconsinan
4	Tantramar–Norton–Oromocto	175°–185°	Late Wisconsinan
3	Woodstock	155°–175°	Late Wisconsinan
2	Late Caledonia	135°–155°	Middle Wisconsinan
1	Early Caledonia	110°–120°	Early Wisconsinan

These variations in outflow orientation did not produce a recognizable till deposit. Instead, they altered the physical properties of the pre-existing till through increased homogenization, redistribution of the matrix and clast components, and re-alignment of the clast fabric. The result is a hybrid till with characteristics inherited from the multiple phases within one glacial episode (Allard and Pronk 2003; Seaman 2003b). The complex erosional landforms and striae patterns in southwestern New Brunswick record these Late Wisconsinan dynamics (Seaman 2004). Table 3 and Figure 13 summarize the current interpretation of ice-flow chronology in the region, based on striae crosscutting relationships and limited stratigraphy (Seaman 2004).

Despite the complex Late Wisconsinan glacial history, Early and Middle Wisconsinan trends remain discernable, albeit somewhat diffuse and homogenized. The predominant dispersal direction in southwestern New Brunswick (Fig. 13) is 135° to 155° (Late Caledonia Phase) and, to a lesser extent, 110° to 120° (Early Caledonia Phase). Transport distances are highly varied. Till clast provenance studies (such as Allard 2003) indicate that much of the till at a given location is of relatively local origin. In the report area, maximum transport distances for the clast component are approximately 20 km to 30 km (Allard 2003). The matrix component of the till would be expected to represent more distal sources but, as demonstrated on the contour maps (Fig. 7–11, 20–39), anomaly expression in the < 63 µm fraction of the till is almost instantaneous, as the anomaly head consistently occurs close to the presumed source. In the matrix component, geochemical dispersal trains tend to be diffused within 10 km of the presumed source. Many anomalies define bull's-eye patterns or slightly elongated amoeboid shapes with an exponential decrease in concentration down ice.

CONCLUSIONS

Till geochemical data from southwestern New Brunswick have been successfully combined and levelled using values from multiple surveys that employed several analytical techniques and different laboratories. This first attempt to level geochemical data represents a pilot project for the NBDNR. Future levelling methods are expected to improve through the possible use of a weighted regression quantile levelling technique similar to that used by Daneshfar and Cameron (1998). Their method allows more flexibility in weighting specific (heavily populated) quantiles than does the equal-weight linear regression technique.

The multivariate-element-association maps (Fig. 7–11, 38) represent a valuable aid in defining high-potential areas for particular types of mineral deposits. The maps reveal numerous till geochemical anomalies that warrant further investigation and, as such, will likely stimulate additional exploration activity in southwestern New Brunswick.

Production of mineralization indicator contour maps is a NBDNR priority, and future refinements are expected to improve usefulness of the maps. Meanwhile, the following recommendations have emerged as a result of this pilot project.

1. To minimize the need for levelling in the future, the number of analytical methods (including digestion conditions where applicable) and laboratories used should be kept to a minimum. Increasing diversity in the data set causes greater complexity of the levelling process and, in turn, lessens reliability of the levelled data.

2. Before beginning a regional or provincial levelling project, it may be beneficial to extract approximately 10 samples from each 1:50 000-scale survey for re-analysis in a single batch (one run) using the technique to which the data will be levelled (such as INAA, ICP-MS, and ICP-OES). The procedure would provide a solid baseline for parametric levelling of the data.

3. Parametric levelling should be the method of choice in adjusting values from adjacent surveys. Unlike quantile regression techniques, which require data selection on the basis of geographic location or bedrock characteristics, parametric levelling is based solely on the comparison of reference data in the form of duplicates or standards. Parametric levelling should yield excellent results as long as sufficient duplicate data are available over a wide range of concentrations (low register to high register).

4. To improve the status of ICP-OES–ICP-MS levelling in southwestern New Brunswick, an extraction of ICP-MS survey samples (~10–20) representing a wide range of concentrations should be re-analyzed using ICP-OES and vice versa. This would improve the reference set used in the levelling processes.

5. For the sake of consistency, an extraction of samples from southwestern New Brunswick surveys that used ICP-OES (aqua regia digestion) — that is, the McAdam and Fosterville surveys — should be re-analyzed using ICP-OES (four-acid digestion). This would improve the baseline for levelling and would offer additional insight into why base-metal concentrations for the McAdam survey are anomalously low.

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