Géographie physique et Quaternaire

# Inferences on glacial flow from till clast dispersal, Waterford area, New Brunswick

# La détermination des flux glaciaires à partir de la dispersion des cailloux du till dans la région de Waterford, au Nouveau-Brunswick

# Die Bestimmung des glazialen Fließens ausgehend von der Dispersion der Kiesel des Tills im Gebiet von Waterford, Neu-Braunschweig

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Résumé de l'article

Les patrons de dispersion des cailloux du till sont comparés aux affleurements d'origine afin de reconstituer les principales directions de l'écoulement glaciaire dans une région où les stries montrent des directions multiples et discordantes. Pour les tills de la dernière glaciation, les patrons de dispersion s'étirent vers le sud et l'est. Certains cailloux ont été remaniés localement. La longueur des traînées de dispersion varie généralement de 4 à 10 km en ce qui a trait au matériel du till de fond, mais peut s'allonger sur 26 km en cas de transport intraglaciaire. Des cailloux de roche intrusive ainsi que felsitique et métavolcanique intermédiaire se trouvent dans le till à certains sites situés au nord des plutons affleurant sur le plateau central. Le till recouvre une partie du bassin carbonifère et son matériel a été remanié, en partie, du conglomérat sous-jacent. Étant donné que ces unités de conglomérat renferment des fragments des régions avoisinantes, y compris du plateau central, elles sont devenues une source secondaire de certaines lithologies au cours de la glaciation. L'érosion glaciaire d'unités sous-jacentes de conglomérat peut expliquer la présence de cailloux particuliers dans le till trouvés dans d'autres régions des basses terres du Nouveau-Brunswick, qui témoignaient, croyait-on, d'un flux glaciaire vers le nord.

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# INFERENCES ON GLACIAL FLOW FROM TILL CLAST DISPERSAL, WATERFORD AREA, NEW BRUNSWICK

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ABSTRACT Dispersal patterns for till clasts from the Waterford area, New Brunswick, are compared to source outcrops and used to confirm dominant ice-flow directions in a region reported to show multiple and conflicting striae directions. The results demonstrate that the last glaciation produced elongated south and eastward trending dispersal patterns, indicative of the dominant ice-flow directions. Clasts have been derived locally. Train lengths generally vary from 4 km to about 10 km for material in basal till, but can achieve distances up to 26 km because of transport in englacial positions. Felsic and intermediate metavolcanic and intrusive clasts occur in till at locations north of outcropping plutons on the Central Plateau. The till overlies part of the Carboniferous Basin and has been derived in part, from underlying conglomerate bedrock. Since these conglomerate units contain fragments from the surrounding areas including the Central Plateau, they provided a secondary source for some lithologies during glaciation. Glacial erosion of underlying conglomerate units may account for occurrences of distinctive till clasts found at other areas of the New Brunswick lowlands, previously thought to imply northward glacial transport.

RÉSUMÉ *La détermination des flux glaciaires à partir de la dispersion des cailloux du till dans la région de Waterford, au Nouveau-Brunswick.* Les patrons de dispersion des cailloux du till sont comparés aux affleurements d'origine afin de reconstituer les principales directions de l'écoulement glaciaire dans une région où les stries montrent des directions multiples et discordantes. Pour les tills de la dernière glaciation, les patrons de dispersion s'étirent vers le sud et l'est. Certains cailloux ont été remaniés localement. La longueur des traînées de dispersion varie généralement de 4 à 10 km en ce qui a trait au matériel du till de fond, mais peut s'allonger sur 26 km en cas de transport intraglaciaire. Des cailloux de roche intrusive ainsi que felsitique et métavolcanique intermédiaire se trouvent dans le till à certains sites situés au nord des plutons affleurant sur le plateau central. Le till recouvre une partie du bassin carbonifère et son matériel a été remanié, en partie, du conglomérat sous-jacent. Étant donné que ces unités de conglomérat renferment des fragments des régions avoisinantes, y compris du plateau central, elles sont devenues une source secondaire de certaines lithologies au cours de la glaciation. L'érosion glaciaire d'unités sous-jacentes de conglomérat peut expliquer la présence de cailloux particuliers dans le till trouvés dans d'autres régions des basses terres du Nouveau-Brunswick, qui témoignaient, croyait-on, d'un flux glaciaire vers le nord.

ZUSAMMENFASSUNG *Die Bestimmung des glazialen Fließens ausgehend von der Dispersion der Kiesel des Tills im Gebiet von Waterford, Neu-Braunschweig.* Die Dispersions-Muster der Kiesel des Tills im Waterford-Gebiet, Neu-Braunschweig, werden mit den ursprünglichen Ausstrichen verglichen, um Hauptrichtungen des Eisfließens in einem Gebiet zu bestätigen, wo mannigfaltige und diskordante Schrammen-Richtungen auftreten. Die Ergebnisse zeigen, daß die letzte Vereisung langgezogene süd- und ostwärts gerichtete Dispersionsmuster bewirkte, welche auf die Hauptrichtungen des Eisfließens weisen. Die Kiesel sind örtlich umgeschichtet worden. Die Länge der Bahnen reicht im allgemeinen von zwischen 4 km bis zu 10 km für Grundtill-Material, kann aber bei intraglazialem Transport Entfernungen bis zu 26 km erreichen. Intrusiv- und Felsit-Kiesel sowie metavulkanische Kiesel befinden sich im Till an einigen Plätzen nördlich von plutonischen Aufschlüssen auf dem zentralen Plateau. Das Till überlagert einen Teil des kohlehaltigen Beckens und ist teilweise von dem darunterliegenden Konglomeratgestein umgeschichtet worden. Da diese Konglomeratseinheiten Fragmente von den umliegenden Gebieten einschließlich dem zentralen Plateau enthalten, sind sie eine sekundäre Quelle für einige Lithologien während der Vereisung geworden. Glaziale Erosion darunterliegender Konglomeratseinheiten könnte das Vorkommen unterschiedlicher Kiesel erklären, die man in anderen Gebieten der Niederungen von Neu-Braunschweig gefunden hat und die man früher auf ein Eisfließen nordwärts zurückführte.

## INTRODUCTION

In New Brunswick, efforts to reconstruct Quaternary history have been hampered in part by a scarcity of datable sediments and lack of pre-Late Wisconsinan glacial artifacts (Prest, 1977). From glacial landforms and striae, Chalmers (1890) identified strong southeast trending ice-flow patterns in southern New Brunswick and deduced that local ice caps once existed on some upland and plateau areas. Evidence of divergent ice-flow directions found within relatively small areas suggested that both a large external ice source and local ice-caps were simultaneously active in parts of New Brunswick (Chalmers, 1890). Conversely, Goldthwait (1924) attributed all glacial features in southeastern New Brunswick to ice sheets from external sources.

Rampton and Paradis (1981) suggest that subsequently, during the Early to Middle Wisconsinan (their Caledonia phase), a larger ice mass flowing south-southeastward from the northwest probably engulfed smaller local glaciers and covered the study area (Fig. 1), as indicated by pervasive 120°-155° striae and by the presence of Mississippian sandstone clasts in till south of its source area. They suggest that the deeply-weathered bedrock and strongly oxidized soils in the northeastern Caledonia Highlands imply that the area has been ice-free since the Middle Wisconsinan (Rampton and Paradis, 1981)

From a regional analysis of cross-cutting striae, Rampton *et al.* (1984) divided the Late Wisconsinan into six successive phases, although glaciation of the Central Plateau was thought to have occurred earlier. Foisy and Prichonnet (1988, 1991) correlated local till deposits in the north and south Caledonia Highlands, with regional glacial phases identified by Rampton *et al.* (1984). They suggest that the Caledonia Highlands (and Central Plateau) were in fact glaciated during the Late Wisconsinan and that a shrinking local ice cap with radial outflow existed during deglaciation (Foisy and Prichonnet, 1988, 1991).

A compilation of published striae data for New Brunswick was assembled by Seaman (1989). In the study area, south-southeast directions dominate (Fig. 2), although many east-west trending striae and some northward flow indicators have been reported to occur in adjacent map sheets (Seaman, 1989; Foisy and Prichonnet, 1991). Northwestward directed striae (300°; Fig. 2) were reported to occur at one location in our area (Foisy, 1989). Rare north-northwest directed rat tails on the northern flanks of the highlands, and boulders found north of their source area, have been interpreted as evidence that small northward flowing glaciers may have occupied the Caledonia Highlands during the Early Wisconsinan (Foisy and Prichonnet, 1991).

Recent studies (*e.g.* Broster, 1986; DiLabio, 1990; Broster and Huntley, 1995) demonstrate the efficacy of employing till clast provenance in assessments of glacier dynamics and to confirm ice-flow direction(s). Dispersal is partly controlled by physiographic influences, size and frequency of source units, elevation of the source, and number of ice-flow events (Hornibrook *et al.*, 1993). Nonetheless, spatial plots of concentration contours of a component can form a well-defined dispersal pattern or "train" showing a down-ice decrease in content, from its "head" to its "toe" (Shilts, 1976). Such trains are commonly elongated parallel to the most recent ice-flow direction and can be constructed to identify occurrences of unique lithologies or "indicators" from known sources (*e.g.* DiLabio, 1990; Broster and Huntley, 1995).

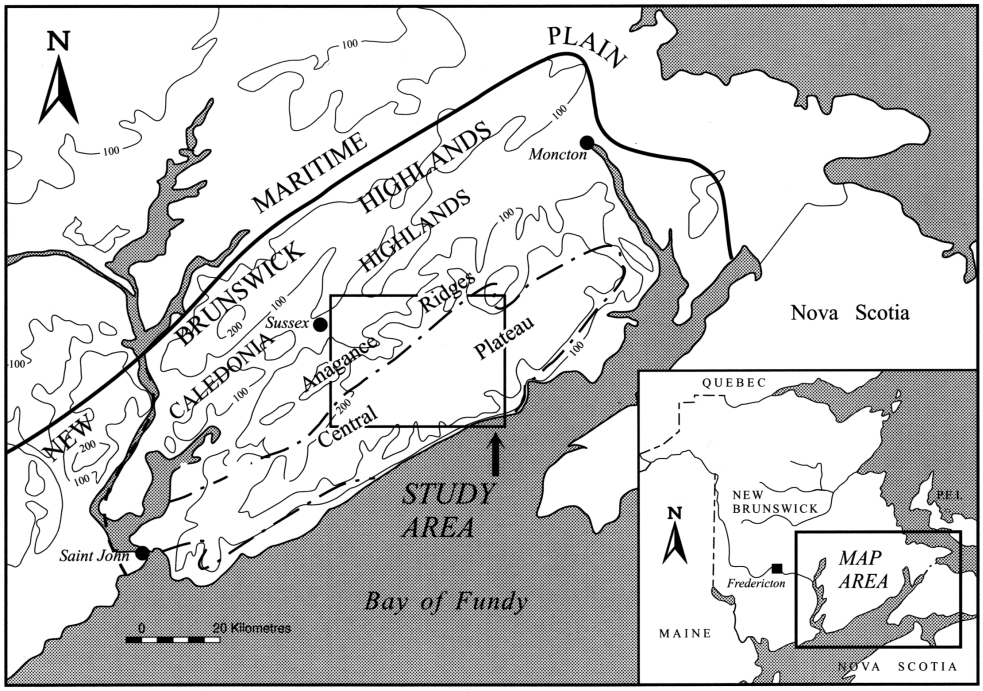


FIGURE 1. Location of study area with physiographic subdivisions after Rampton *et al.* (1984).

*Localisation de la région à l'étude et subdivisions physiographiques, selon Rampton* et al.*(1984).*

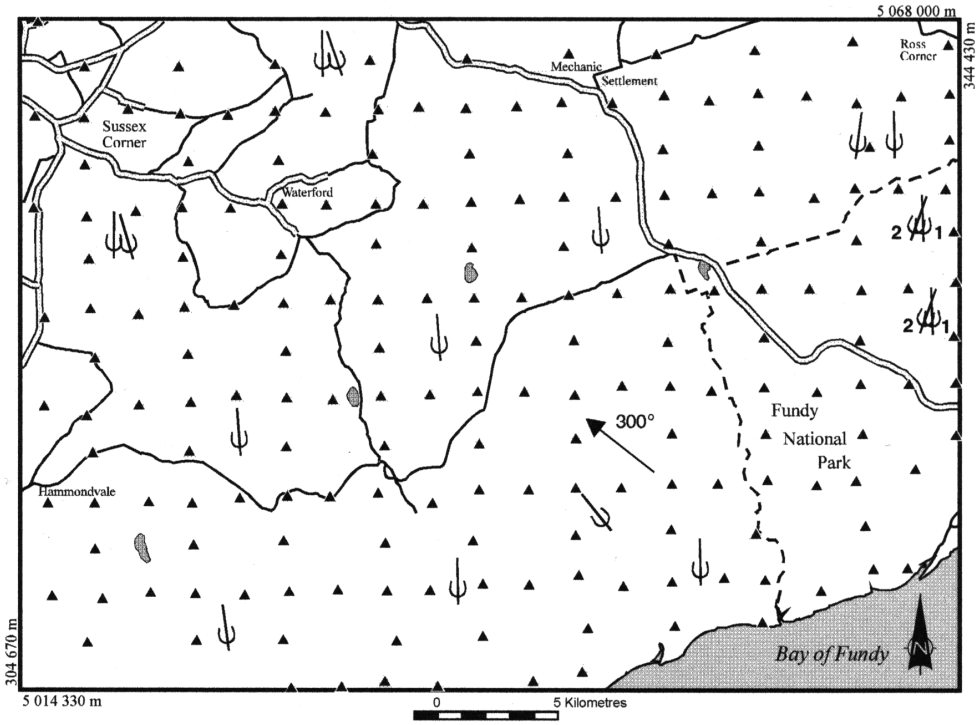


FIGURE 2. Locations of till clast sample sites and dominant striae directions. Arrow indicates orientation of older northwest directed striae to 300° reported by Foisy (1989).

*Localisation des sites d'échantillonnage des cailloux de till et principales directions des stries. La flèche donne l'orientation à 300° vers le nord-ouest des plus anciennes stries signalées par Foisy (1989).*

The present study examines the dispersal of till clasts in a selected area of New Brunswick, with particular attention to bedrock source areas and evidence of northward glacial transport.

## LOCATION, PHYSIOGRAPHY AND GEOLOGY

The study area is situated in southeastern New Brunswick, midway between the cities of Saint John and Moncton (Fig. 1). The area comprises the whole of the Waterford topographic map sheet (N.T.S. 21 H/11, scale 1:50 000) and is bounded to the southeast by the Bay of Fundy. The area lies within the Caledonia Highlands physiographic subdivision of the New Brunswick Highlands (Weeks, 1957; Bostock, 1970), but can be subdivided further (Fig. 1) into: (a) a Central Plateau of mainly Precambrian rocks, and (b) the Anagance Ridges of folded and faulted Carboniferous sedimentary and metamorphic rocks (Rampton and Paradis, 1981). The Central Plateau and Anagance Ridges physiographic divisions are related, respectively, to the Caledonia Zone and Moncton Basin tectonostratigraphic zones of Rampton *et al.* (1984).

The boundary between the two physiographic areas provides a clear datum to assess local glacial dispersal. Several distinctive lithologies and mineral occurrences provide additional "point-source" targets for delineation of dispersal trains (Fig. 3). Only a cursory review of the major bedrock units and mineral occurrences will be discussed here.

### THE CENTRAL PLATEAU

The plateau is characterized by a gently undulating to level surface with hills typically 30 to 90 m high. Elevation of the plateau gently declines toward the southwest and ends abruptly along the Fundy coast where bedrock cliffs are locally more than 150 m in height.

The plateau is underlain by Upper Precambrian metavolcanic and metasedimentary rocks (Fig. 3). The Coldbrook Group volcanic rocks comprise about 25% of the area and include felsic and mafic lithic tuffs, pyroclastic breccias, vesicular basalts and rhyolitic flows, locally intercalated with poorly sorted sedimentary rocks (Ruitenberg *et al.*, 1979). The Broad River Group rocks are stratigraphic equivalents of the Coldbrook Group and comprise about 20% of the study area. Within the area the Broad River Group includes: (1) a mafic tuff unit with basalts and minor purple to grey siltstone, limestone, and arkosic sandstone; (2) a smaller unit of grey to pink tuffs and pyritiferous felsic tuff; (3) a unit of green to grey mafic tuffs with pink to grey felsites and; (4) a sliver of arkosic and pebbly sandstones with conglomerate, located between units (1) and (2) (McLeod, 1987; McLeod *et al.*, 1994; Ruitenberg *et al.*, 1977, 1979).

The Rose Brook Beds, of shallow marine sedimentary rocks with minor limestone and felsic tuffs, occur along the northwest and southeast margins of the Broad River Group (McLeod *et al.*, 1994). Distinctive lithologies here include maroon sandstone, siltstone and shale, and maroon and brown quartzite pebble conglomerate (Fig. 3).

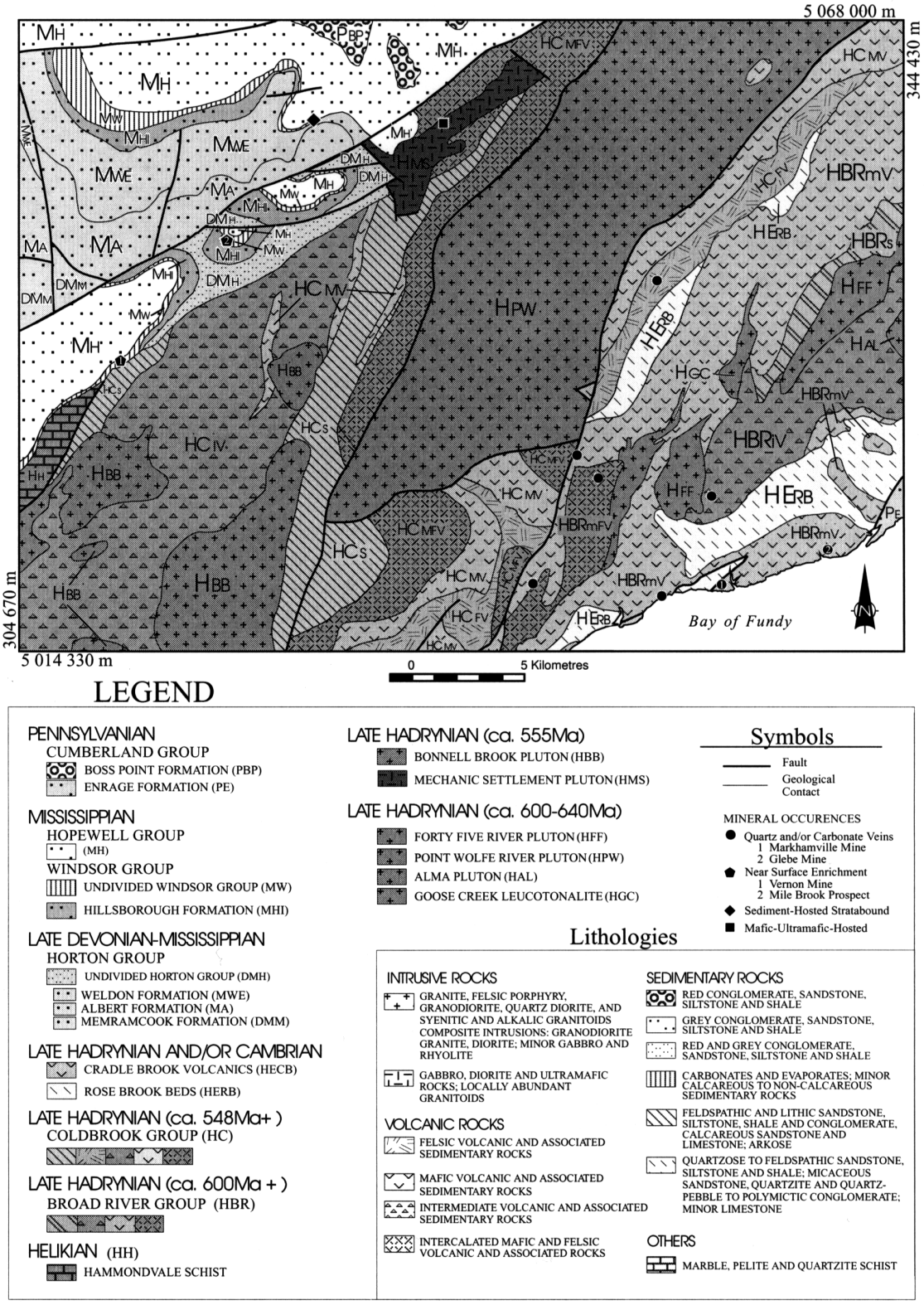


FIGURE 3. Known mineral occurrences and bedrock geology of the Waterford area (after McLeod *et al.*, 1994).

*Sites connus de minéraux et géologie du substrat rocheux dans la région de Waterford (d'après McLeod* et al., *1994).*

Several plutons intruded the Coldbrook Group and its equivalents (*e.g.* McLeod *et al.*, 1994; Fig. 3). The Point Wolfe River Pluton is the largest intrusion and underlies about 20% of the study area. Lithologies include, granodiorite, quartzdiorite, diorite and coarse granites (Ruitenberg *et al.*, 1979; Barr and White, 1988) that are intensely sheared in some outcrops (Barr, 1987). Other lithologically distinctive intrusions include: the Forty-Five River Pluton, a greenish granodiorite; the Goose Creek Leucotonalite, a greyish-white leucocratic rock consisting mainly of quartz and plagioclase; and the Bonnell Brook Pluton, a green-grey to pinkish grey, fine to medium-grained syenogranite, diorite to quartz diorite, and minor spherulitic rhyolite (Barr, 1987; McLeod *et.al.*, 1994).

Small mafic and ultramafic intrusions composed of gabbro, diabase, peridotite, and pyroxenite (Ruitenberg *et al.*, 1979) constitute about 5% of the rocks in the study area (Fig. 3).

THE ANAGANCE RIDGES

The Anagance Ridges occupy the northwest corner, representing about 20% of the entire study area (Fig. 1). This area is characterized by parallel northeast-southwest ridge-and-valley topography, related to local structural trends (Rampton and Paradis, 1981). Relief varies from about 20 m to over 300 m and divides drainage into northeastward- and westward-draining sections.

This part of the Moncton Basin is comprised of units of mid-Paleozoic sedimentary rocks (Fig. 3), that were folded and faulted by NW-SE compression, during the Carboniferous (Ruitenberg and McCutcheon, 1982). The Devonian-Mississippian age Horton Group (Fig. 3) includes formations consisting of red and grey-green polymictic conglomerates, arkosic sandstones, mudstones, oil shale, and minor non-marine evaporites (van de Poll, in press). Overlying Windsor Group units consist of marine limestone, grey to white gypsum and anhydrite, and interbedded grey-green mudstone and sandstone. These are in turn overlain by rocks of the Mississippian-age, Hopewell Group, consisting of red-brown polymictic conglomerate, and quartzo-feldspathic sandstone and mudstone. The conglomerates are characterized by the common presence of felsic volcanic clasts, and lesser amounts of granite, grano-diorite and diorite clasts, derived from Caledonia Zone source rocks (van de Poll, 1994).

Overlying Pennsylvanian Cumberland Group rocks are subdivided into the Enrage Formation and Boss Point Formation (Fig. 3). The Enrage Formation includes two conglomerates, a basal quartzite conglomerate and a polymictic conglomerate at the top of the unit both with a red medium-grained sand matrix, that separate beds of red sandstone and mudstone (van de Poll, 1994). Grey-green quartzose sandstone and quartz-pebble conglomerate, with minor red and grey mudstone, are lithologies typical of the Boss Point Formation.

MINERALIZATION

McLeod *et al.* (1994) identify twelve individual mineral occurrences of various types and styles in the southeast and northwest parts of the study area (Fig. 3). In the southeast mineral occurrences are mostly sulphide-bearing quartz and quartz-carbonate veins and some stratabound deposits hosted by the Broad River Group (Ruitenberg *et al.*, 1979; McLeod, 1987). In the northwest part of the area a disseminated sulphide occurrence is hosted by the mafic-ultramafic Mechanic Settlement Pluton (Rose and Johnston, 1990) and base metal concentrations are associated with the basal Horton-Windsor contact (van de Poll, in press).

SURFICIAL GEOLOGY

Several geological studies have included perfunctory discussions of the glacial features of the study area (*e.g.* Matthew, 1872; Chalmers, 1890). Greiner (1974) examined glacial and bedrock features along the Fundy coastline and reviewed the geomorphology of Fundy National Park. Rampton and Paradis (1981) mapped southeastern New Brunswick (Amherst 21/H) detailing surficial deposits and describing Late Wisconsinan glacial events. This work formed the basis for detailed surficial and bedrock maps prepared by McCutcheon and Thibault (1981). Local aggregate resources have been mapped by Seaman (1988).

## SAMPLE COLLECTION, PREPARATION AND STATISTICS

Till sampling was completed for New Brunswick Department of Natural Resources and Energy (NBDNRE) in conjunction with regional geochemical surveys and surficial mapping during the summers of 1993 and 1994. Although till colour changes from area to area, no evidence of multiple tills was found during field investigations. The colour change is interpreted as a reflection of underlying bedrock and the surface till unit is believed to represent deposition from a single glacial advance.

Two hundred and seventy samples obtained for matrix analyses will not be discussed at this time. Here we discuss the results of 194 samples of till clasts. We attempted to collect samples from unweathered basal till at natural exposures and from excavated sample pits (Fig. 2), but as the till was often less than 1.5 m thick some samples were unavoidably collected from englacial till (*sensu stricto*, Dreimanis, 1976). The tills commonly displayed a 0.7 m dense lower zone, interpreted to represent basal or englacial till, that graded upward into a loose diamicton interpreted as englacial and ablation till (see Dreimanis, 1976). Approximately 50 - 100 pebbles (clasts 2 cm-9 cm in diameter) were examined in each sample. Thirty five unique lithologies were identified that could be reduced to seventeen lithological groups, although only a few examples are discussed herein (see Munn, 1995, for complete data set).

Contouring of lithological data was accomplished using SURFER® computer software. The Kriging geostatistical method was used, which calculates an autocorrelation

between irregularly spaced data points producing a minimum variance unbiased estimate. For our data grid nodes were established to be coincedent with sample locations and resulting contours were confirmed by comparison with original values. Pearson correlations were investigated using the Statistical Package for Social Sciences® (S.P.S.S.) but were unproductive, and hence, are not included herein.

## OBSERVATIONS AND INTERPRETATIONS

While several distinctive lithologies occur within the study area (see Munn, 1995), a simplification of the glacial dispersal process can be achieved by comparison of the gross differences between the dominant rock groups of the Central Plateau and those of the Anagance Ridges. For example igneous rocks are prevalent in the Central Plateau but do not outcrop within the Anagance Ridges. Also, the Carboniferous-Hadrynian contact between these areas forms a southeast-northwest boundary perpendicular to the dominant direction of glacial flow as indicated by striae. In addition, gabbro, diabase and mudstone lithologies are distinctive rocks that occur in small areas of outcrop and provide the best indicators for analysis of glacial transport direction.

A plot of the dispersal pattern for a combined felsic and intermediate intrusives lithologies group, demonstrates that most maximum concentrations are associated with the occurrence of plutons across the Central Plateau (Fig. 4). Concentrations decrease gradually towards the east and south and more abruptly towards the northwest. Areas of high concentration, vaguely reflect the shape of the source outcrop but are apparently displaced east and southeastward by approximately 5-8 km. This trend is repeated for most plutons. However, one anomaly occurs in the north-central area where concentrations of felsic and intermediate intrusive clasts are as high as 40% in till overlying conglomerates of the Cumberland Group, at a location approximately 2-3 km north of the Carboniferous-Hadrynian contact (Fig. 4). These general trends, including similar anomalous concentrations in the area north of the Carboniferous-Hadrynian contact were recognized in dispersal patterns for several individual felsic intrusive lithologies (see Munn, 1995).

Felsic and intermediate volcanic rocks outcrop on the Central Plateau only, but are found as till clasts throughout the area (Fig. 5). Plots of the felsic and intermediate extrusive lithologies group show maximum clast concentrations (commonly greater than 70%) overlying and southward of suspected source units. However, anomalous concentrations of up to 80% of this group occurs over Carboniferous sedimentary rocks northwest of units of similar lithologies.

Examination of dispersal patterns for mafic lithologies demonstrate east and southward dispersal trends, but no anomalous clast occurrences in till, north of suspected source areas. For example, maximum concentrations of diabase and gabbro clasts (Fig. 6) are found only south and eastward of their sources. These highly distinctive lithologies are restricted to a small source area and thus serve as the best "indicator" lithology in the area. Dispersal patterns for the diabase and gabbro clasts are twice the size of source areas and transport distances are less than 6km. Arguably, clast concentrations for basalt and basaltic tuff lithologies occur over, or to the southeast of, presumed source areas (Fig. 7).

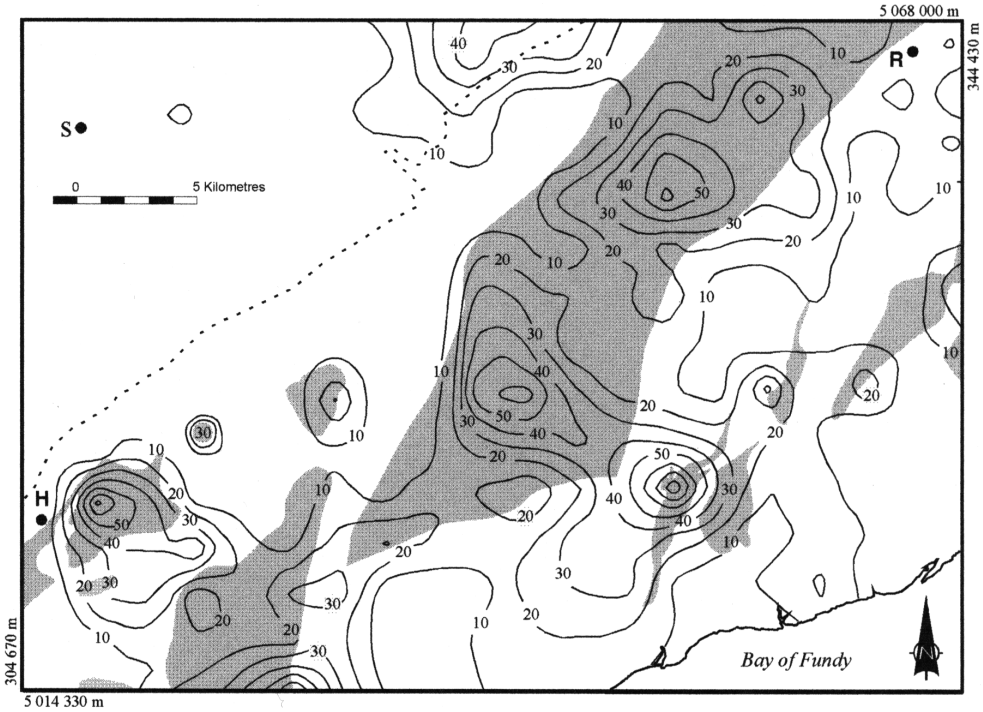


FIGURE 4. Dispersal pattern for percent felsic and intermediate intrusive clasts. Potential source units are indicated by shading, the dashed line designates the Carboniferous (northwest)/ Hadrynian (southeast) contact. The villages of Sussex Corner (S), Ross Corner (R) and Hammondvale (H) are indicated (•).

*Patron de dispersion des cailloux de roche felsitique et intrusive intermédiaire dans le till. Les sources possibles sont tramées ; le tireté identifie le contact entre le Carbonifère (au nord-ouest) et l'Hadrynien (sud-ouest). Les villages de Sussex Corner (S), Ross Corner (R) et de Hammondvale (H) sont indiqués (*).*

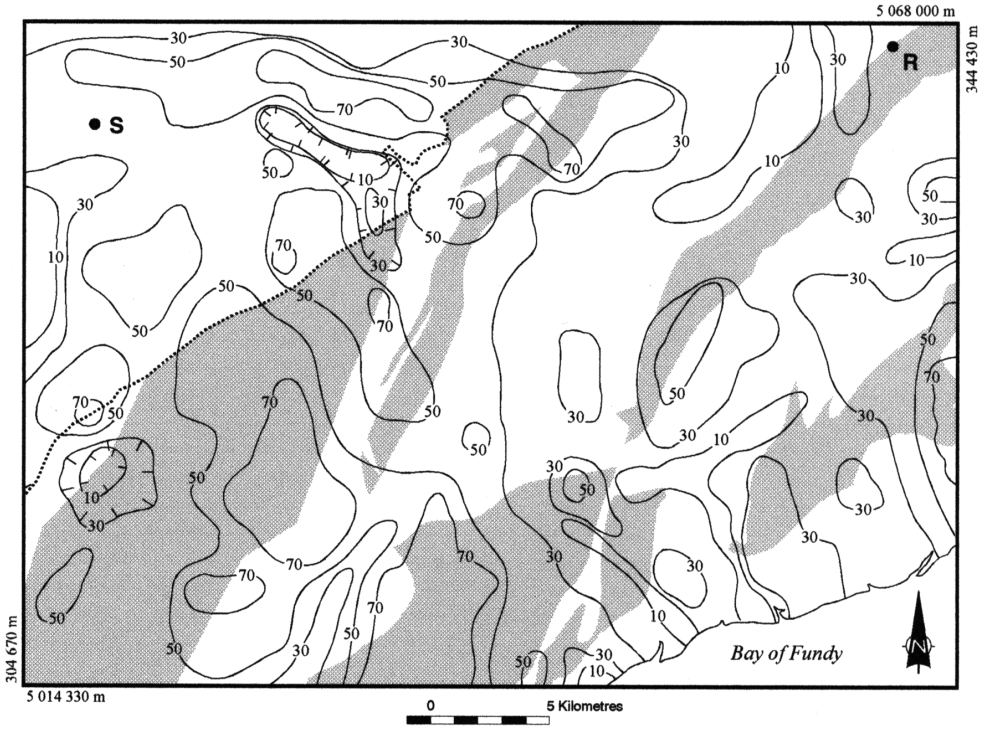


FIGURE 5. Dispersal pattern for percent felsic and intermediate volcanic till clasts. Potential source units are indicated by shading, the dashed line designates the Carboniferous (northwest)/ Hadrynian (southeast) contact. The villages of Sussex Corner (S), Ross Corner (R) and Hammondvale (H) are indicated (•).

*Patron de dispersion des cailloux de roche felsitique et volcanique intermédiaire dans le till. Les sources possibles sont tramées ; le tireté identifie le contact entre le Carbonifère (au nord-ouest) et l'Hadrynien (sud-est). Les villages de Sussex Corner (S), Ross Corner (R) et de Hammondvale (H) sont indiqués (*).*

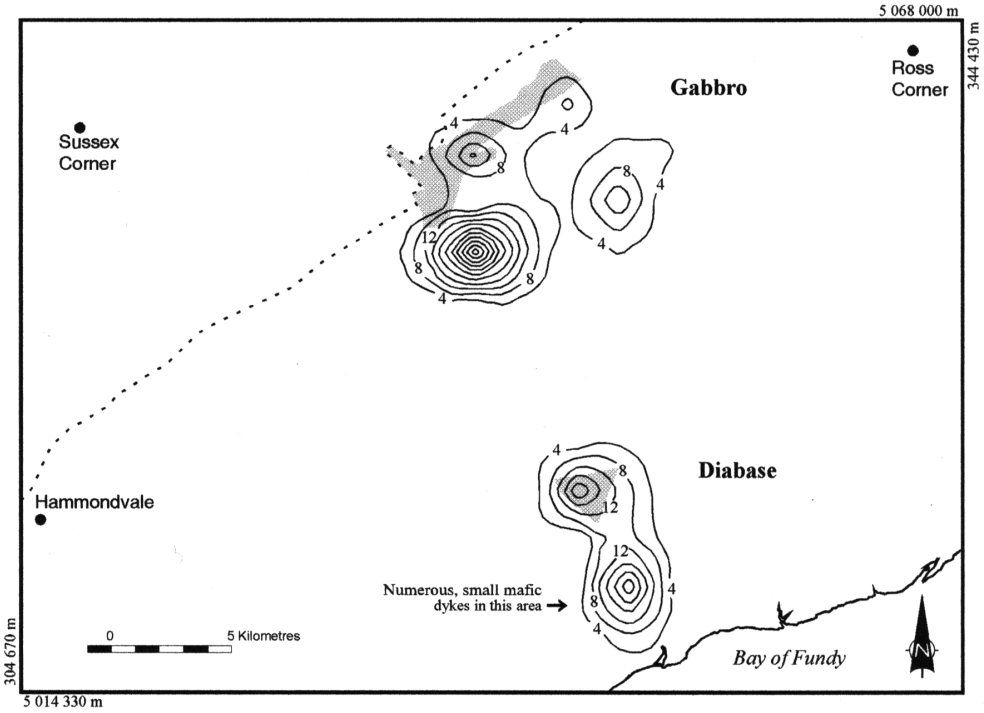


FIGURE 6. Dispersal pattern for percent mafic intrusive (diabase and gabbro) till clasts. The two most probable source units are indicated by shading (see bedrock units; Figure 3). The Carboniferous (northwest)/ Hadrynian (southeast) contact is indicated by a dashed line.

*Patron de dispersion des cailloux de roche mafique intrusive (diabase et gabbro) dans le till . Les deux sources possibles sont identifiées par une trame (voir fig. 3). Le tireté identifie le contact entre le Carbonifère (au nord-ouest) et l'Hadrynien (sud-est).*

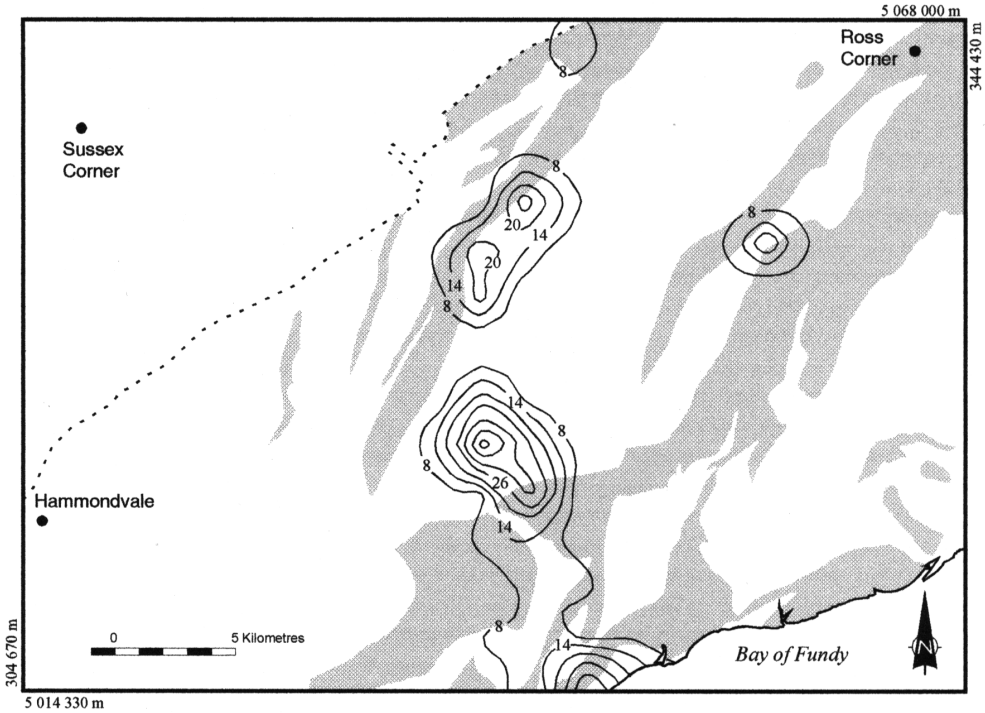


FIGURE 7. Dispersal pattern for percent mafic extrusive (basalt and basaltic tuff) till clasts. Potential source units are indicated by shading, the dashed line designates the Carboniferous (northwest)/ Hadrynian (southeast) contact.

*Patron de dispersion des cailloux de roche mafique extrusive (basalte et tuf basaltique dans le till. Les sources possibles sont tramées ; le tireté identifie le contact entre le Carbonifère (au nord-ouest) et l'Hadrynien (sud-est).*

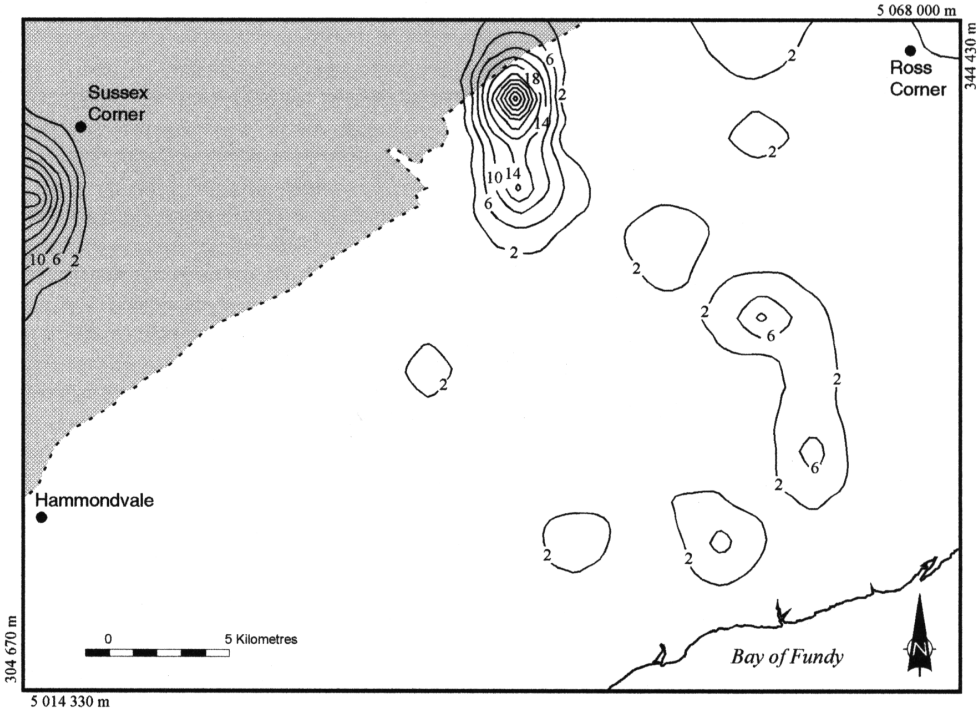


FIGURE 8. Southward-elongated dispersal pattern for percent mudstone till clasts. Known potential source units for mudstone clast occurs only in rocks north of the Carboniferous/ Hadrynian contact (dashed line).

*Patron de dispersion des cailloux d'argilite dans le till. Les sources possibles connues sont situées au nord du contact entre le Carbonifère (au nord-ouest) et l'Hadrynien (sud-ouest) identifié par le tireté.*

A few sedimentary lithologies (conglomerates with red-brown matrix) occur only within tills overlying Carboniferous source rocks in the northwest (see Munn, 1995). Red, brown and olive coloured mudstone clasts are derived solely from Carboniferous rocks. They occur in greatest abundance in tills near the Carboniferous-Hadrynian contact overlying mafic and felsic volcanic outcrops (Fig. 8). A continuous dispersal train, originating there, is elongated southward over a distance of 8 km (Fig. 8). Isolated occurrences of mudstone clasts, southeastward of the main train, suggests that the complete train extends over a length of 26 km (Fig. 8).

Sandstone outcrops mainly in the northwest and southeast parts of the study area. In the northwest concentrations decrease along the contact between source rocks and Late Hadrynian rocks to the southeast (Fig. 9). Sandstone clasts in southeastern tills are proximal to local sources and decrease south and eastward.

## DISCUSSION

In the southern part of the area, field examinations of the till clasts indicated that extrusive lithologies apparently vary inversely with intrusive lithologies within the till. However, statistical analysis of the complete data set did not confirm any significant correlation. This is likely because samples collected in the northwest area have "confused" the data set. Tills in the northwest area contain anomalous concentrations of felsic and intermediate intrusives as high as 40% at some locations, and up to 80% felsic and intermediate extrusive clasts at other locations. These concentrations are considered to be anomalous in that they occur in till overlying Devonian and Carboniferous sedimentary bedrock.

The occurrence of felsic and intermedate clasts in till north of known outcrops, implies significant northward transport of bedrock material, which at first glance might be considered as proof of northward glacial transport. At least three individual felsic and intermediate lithologies demonstrated this trend (Munn, 1995). Thus, the anomalous dispersal patterns are not an artifact of multi-lithological data-groupings, which as Shilts (1976) warns, can result in false dispersal patterns and confusion of more significant patterns formed by individual component lithologies.

The dispersal patterns of other major lithology groups and some distinctive "indicator" lithologies, do in fact contain features which indicate east and southward glacial transport only, as suggested earlier by Matthew (1872), Chalmers (1890), Prest (1977) and Rampton and Paradis (1981). For example, eastward and southward transport is demonstrated by mafic intrusive (Fig. 6) and extrusive (Fig. 7) lithologies and these igneous clasts were not found north of the Carboniferous /Hadrynian contact.

Notwithstanding minor occurrences in the southeast, sandstone clasts are derived primarily from Devonian and Carboniferous rocks in the northwest (Fig. 9). The Carboniferous/Hadrynian contact also approximates the local physiographic boundary between the Central Plateau and the Annagance Ridges. Sandstone clast concentrations decrease progressively southeastward and extend south and eastward onto the Central Plateau (Fig. 9). The plateau decreases gradually in elevation toward the southwest,

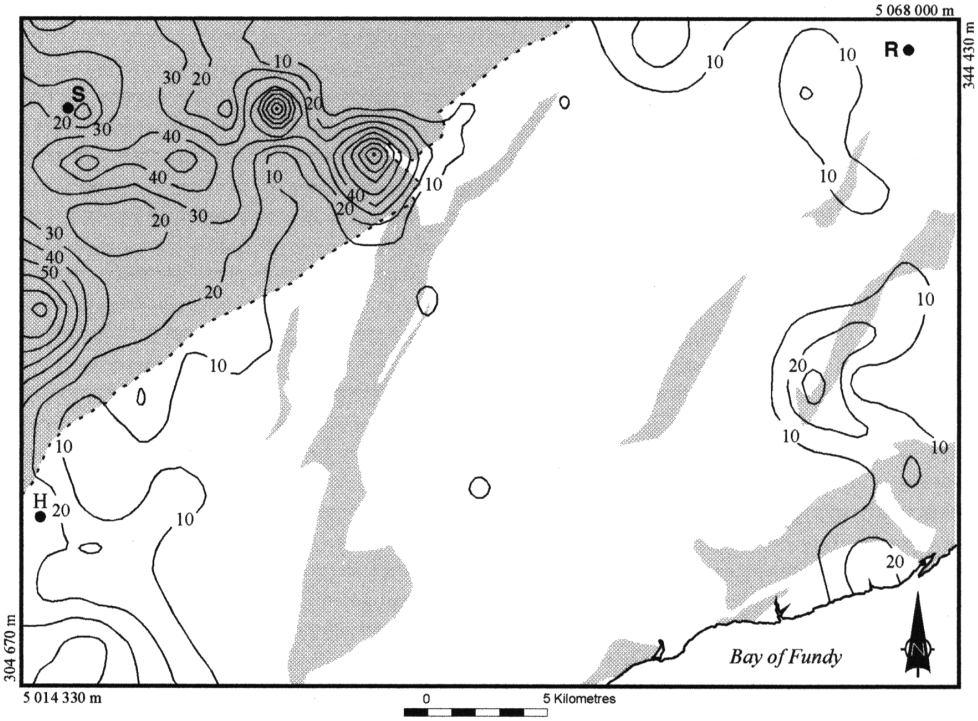


FIGURE 9. Dispersal pattern for sandstone till clasts, with potential source units indicated by shading. The concentration can be seen to decrease in a southwest direction at the contact (dashed line) between the Carboniferous units to the northwest and the Hadrynian. The villages of Sussex Corner (S), Ross Corner (R) and Hammondvale (H) are indicated (•).

*Patron de dispersion des cailloux de grès dans le till. Les sources possibles sont indiquées par une trame. On constate que la concentration diminue en direction sud-ouest au contact (tireté) entre les unités du Carbonifère (au nord-ouest) et l'Hadrynien. Les villages de Sussex Corner (S), Ross Corner (R) et de Hammondvale (H) sont indiqués (•).*

hence the sandstone dispersal pattern suggests that early glacier ice-flow could have been influenced by topography and at first deflected around the central core of the Highlands. Local southward directed striae and southward dispersal trains likely reflect late glacial regional flow patterns.

Mudstone bedrock is presumed to outcrop north of the Carboniferous/Hadrynian boundary, yet its clast dispersal train extends up to 26 km south of the contact (Fig. 8). This is the longest clast-dispersal train found in the study area and extends south of a location where glacial ice would have been required to flow up-hill onto the plateau (approximately 200 m higher in elevation). As has been recognized elsewhere, dispersal patterns are often larger in areal extent, behind hills (*e.g.* Hornibrook *et al.*, 1991) or in locations of ice-streaming (Broster and Huntley, 1995). It is plausible that glacier flow onto the plateau was accompanied by the shearing of material into higher positions in the ice, facilitating greater preservation and more distal transport; resulting in a larger dispersal train than that produced for lithologies acquired on the plateau.

The anomalous northern occurrences of felsic and intermediate till clasts probably represent glacial entrainment from underlying or adjacent Hopewell Group rocks. These units include conglomerates with clasts originally derived from the Caledonia Highlands (van de Poll, in press). The absence of anomalous mafic clasts may indicate that these lithologies are infrequent in conglomerate beds that experienced glacial erosion, or that erosive processes favored the preservation of felsic and intermediate lithologies. Over several million years, many of the plateau rocks experienced prolonged erosion and weathering. Some of the resulting sediments were transported northward and deposited within the Carboniferous Basin, forming the conglomerate units. After millions of years of weathering and erosion, the conglomerates were finally eroded by southward flowing ice. In this regard, some plateau lithologies that now occur as clasts within the conglomerate units have undergone multiple erosive, weathering and transportation events. As a result of multiple erosive processes the less-resistant clasts are reduced in size and volume while the more resistant felsic and intermediate igneous clasts become relatively more abundant.

## CONCLUSIONS

The results of this study demonstrate that in this area, occurrence of till clasts for unique individual lithologies show east and southward trending dispersal patterns elongated parallel to dominant southeastward ice-flow directions. Train lengths generally vary from 4 km to about 10 km, but can achieve distances up to 26 km where material has been transposed into higher ice-positions or experienced ice streaming. Glacial erosion and deposition was probably related to the Caledonia phase if Late Wisconsinan maximums did not reach plateau elevations, as suggested by Rampton and Paradis (1981).

Convincing evidence of northward glacial transport was not found. Rare striae interpreted as northwestward flow may indicate a much earlier glacial event. Hadrynian metavolcanic and intrusive clasts found north of outcrops on the Central Plateau have likely experienced multiple erosive and transportation events. These till clasts have probably been derived from conglomerate units or preglacial sediments, by southward-flowing ice. However the possibility of northward transport by glaciation preceeding the Late Wisconsinan can not be wholly discounted.

Our results suggest that till clast lithologies may display dispersal patterns of similar appearance while no significant statistical correlation exists. This should be expected for areas of complex geology where erosive products from older lithologic units can have been resedimented within adjacent younger units that subsequently provide secondary sources for younger erosive events. In addition, lithological content has been affected by differences in resistance to erosion and topography. Friable, soft or soluble lithologies can be rapidly comminuted and depleted in a resulting till. Conversely, resistant lithologies become preferentially enriched, producing obscured statistical correlations (*cf.* Broster, 1986) and disproportionate dispersal patterns. Difference in resitance and entrainment from multiple sources likely accounts for the disparity between occurrence of felsic and mafic till clasts in our study.

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