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An Interpretation of Late Quaternary Glacial Flow Indicators in the Baie des Chaleurs Region, Northern New Brunswick

L'interprétation des mouvements glaciaires du Quaternaire supérieur à partir d'indicateurs glaciaires présents dans la région de la baie des Chaleurs, nord du Nouveau-Brunswick

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Résumé de l'article

On a déterminé la séquence des événements géologiques du Quaternaire supérieur survenus dans le nord du Nouveau-Brunswick à partir de l'analyse des stries tirée de diverses sources. Au sud de la baie des Chaleurs, l'évolution glaciaire complexe du Wisconsinien supérieur peut être retracée à partir des formes d'érosion glaciaire dont les clouures, les crag-and-tails miniatures, les cicatrices de toutes sortes, les stries et les fractures. La rareté des sédiments et des matériaux pouvant être datés excluent toute interprétation fondée sur la stratigraphie. En s'appuyant sur plus de 1000 sites de stries, on croit que la région a connu quatre épisodes glaciaires pendant le Wisconsinien supérieur: 1) le premier mouvement, de faible importance, s'est fait vers le SE en provenance des Appalaches; 2) le deuxième écoulement glaciaire vers PE démontre la force des glaces laurentidiennes au nord du Nouveau-Brunswick; 3) le troisième mouvement glaciaire vers le NNE pourrait être une réaction à l'affaissement qui s'est produit dans la baie des Chaleurs; 4) le dernier mouvement multidirectionnel s'est fait à partir de calottes localisées pendant les derniers stades de la glaciation wisconsinienne. On explique l'absence des blocs erratiques dans le nord du Nouveau-Brunswick par un écoulement des glaces le long du chenal laurentien interrompant l'Inlandsis laurentidien s'écoulant vers le sud. Les débris glaciaires de fond (y compris les blocs erratiques du Bouclier) ont apparemment été tronqués et enlevés par un courant glaciaire oblique, épurant ainsi la glace qui pénétrait en Gaspésie, puis au Nouveau-Brunswick.

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AN INTERPRETATION OF LATE QUATERNARY GLACIAL FLOW INDICATORS IN THE BAIE DES CHALEURS REGION, NORTHERN NEW BRUNSWICK

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ABSTRACT A sequence of late Quaternary geologic events in northern New Brunswick is determined from striation analysis derived from published data, open file reports, and field research conducted by the authors since 1985. These data are integrated with clast provenance and clast fabric trend analysis, as well as information from other studies in the surrounding area. South of the Baie des Chaleurs, a complicated Late Wisconsinan glacial history is preserved in the form of erosive features including nailhead striae, miniature crag-and-tails, and various scars, striations, and fractures. The rarity of sedimentary deposits and datable materials precludes simple stratigraphic interpretation. Based on over 1,000 striation sites, we conclude four major phases of glacial flow affected the area during the Late Wisconsinan: 1) an early flow to the southeast which reflects local Appalachian ice; 2) a second phase of glacial flow to the east indicating a Laurentide ice influence in western New Brunswick; 3) a third phase of glacial flow to the north-northeast, which may represent ice response to drawdown in the Baie des Chaleurs; and 4) a final multidirectional flow indicating localized ice response during the last stages of Late Wisconsinan glaciation. The absence of Canadian Shield erratics in northern New Brunswick is explained in terms of ice streaming along the St. Lawrence channel beneath a southward-flowing Laurentide Ice Sheet. Basal ice debris (including Shield erratics) was apparently truncated and removed by the obliquely flowing ice stream, leaving relatively clean ice in the Ice Sheet as it entered Gaspésie and ultimately New Brunswick.

RÉSUMÉ *L'interprétation des mouvements glaciaires du Quaternaire supérieur à partir d'indicateurs glaciaires présents dans la région de la baie des Chaleurs, nord du Nouveau-Brunswick.* On a déterminé la séquence des événements géologiques du Quaternaire supérieur survenus dans le nord du Nouveau-Brunswick à partir de l'analyse des stries tirée de diverses sources. Au sud de la baie des Chaleurs, l'évolution glaciaire complexe du Wisconsinien supérieur peut être retracée à partir des formes d'érosion glaciaire dont les clouures, les crag-and-tails miniatures, les cicatrices de toutes sortes, les stries et les fractures. La rareté des sédiments et des matériaux pouvant être datés excluent toute interprétation fondée sur la stratigraphie. En s'appuyant sur plus de 1000 sites de stries, on croit que la région a connu quatre épisodes glaciaires pendant le Wisconsinien supérieur: 1) le premier mouvement, de faible importance, s'est fait vers le SE en provenance des Appalaches; 2) le deuxième écoulement glaciaire vers l'E démontre la force des glaces laurentidiennes au nord du Nouveau-Brunswick; 3) le troisième mouvement glaciaire vers le NNE pourrait être une réaction à l'affaissement qui s'est produit dans la baie des Chaleurs; 4) le dernier mouvement multidirectionnel s'est fait à partir de calottes localisées pendant les derniers stades de la glaciation wisconsinienne. On explique l'absence des blocs erratiques dans le nord du Nouveau-Brunswick par un écoulement des glaces le long du chenal laurentien interrompant l'Inlandsis laurentidien s'écoulant vers le sud. Les débris glaciaires de fond (y compris les blocs erratiques du Bouclier) ont apparemment été tronqués et enlevés par un courant glaciaire oblique, épurant ainsi la glace qui pénétrait en Gaspésie, puis au Nouveau-Brunswick.

SAMENVATTING *Een Interpretatie van Laat-glaciale Ijsbewegingsindicaties in de Chaleur Bay Regio, Noord New Brunswick.* De Kwartair geologische kartering van noord New Brunswick begon met de studies van Robert Chalmers aan het einde van de 19e eeuw. Sindsdien zijn verschillende pogingen gedaan om de glaciale geschiedenis van dit gebied te ontravelen en uiteindelijk zijn Chalmers ideeen herontdekt en aangepast aan moderne theorien en modellen van glaciale processen en isostasie. De afwezigheid van stratigrafische secties en de aanwezigheid van vele glaciale erosieve en morphologische vormen heeft geleid tot de ontwikkeling van een "erosie-stratigrafie". Deze informatie wordt gesteund door till lithologische en gesteente orientatie studies. Het resultaat van dit gedetailleerde karterings project is de herkenning van 4 verschillende ijs-bewegingen. Datering van deze gebeurtenissen is een probleem vanwege een gebrek aan dateerbare materialen. Een eerste zuidoostelijke ijsbeweging is geregistreerd in het oostelijke deel van het gebied en in de Chaleur Coastal Plain. De tweede en sterkste gebeurtenis geeft een oostwaartse ijsbeweging te zien, die waarschijnlijk gedurende het gehele Wisconsinan (Weichselien) en mogelijk het gehele Pleistoceen van belang kan zijn geweest. Een derde ijsbeweging is in noord-oostelijke richting in de Baie des Chaleurs. In een latere fase, lokale ijsbewegingen vonden plaats in verschillende richtingen vanaf de hooglanden en mogelijk vanuit Baie des Chaleurs. Er is een poging gedaan deze gebeurtenissen in een regionale context te plaatsen, waarin de interactie van de Laurentide Ice Sheet met het Appalachian Ice Complex en het concept van een Laurentian ijsstroomkanaal centraal staan.

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INTRODUCTION

A review of recent mapping in the northern Appalachian region (Chauvin *et al.*, 1985; David and Lebuis, 1985; Newman *et al.*, 1985; Lowell, 1985; Lowell and Kite, 1986; David and Bédard, 1986; Lortie and Martineau, 1987; Lamothe, 1987; Rappol, 1988; Pronk and Lamothe, 1988) is presented within the framework of generally accepted glacial models and processes (*e.g.*, Weertman, 1957, 1961; Paterson, 1981; Boulton, 1971, 1985; Hughes *et al.*, 1977; Thomas, 1977; Whillans, 1978; Genes *et al.*, 1981). An explanation is given for the absence of Canadian Shield erratics in the Baie des Chaleurs region (Fig. 1).

In the late 1800's, Robert Chalmers helped pioneer geologic studies in Atlantic Canada by mapping the surficial geology of northern New Brunswick (1881, 1882, 1886, 1887, 1895, 1898). Since then, several others have continued researching the Quaternary geologic history of the region. Among them are Alcock (1936) Lee (1955, 1959, 1962), Gauthier (1978a, b, 1979, 1980, 1982, 1983), Seaman (1985), Rampton *et al.* (1984), Rappol (1986a, b, 1988), Pronk (1986, 1987), Lamothe

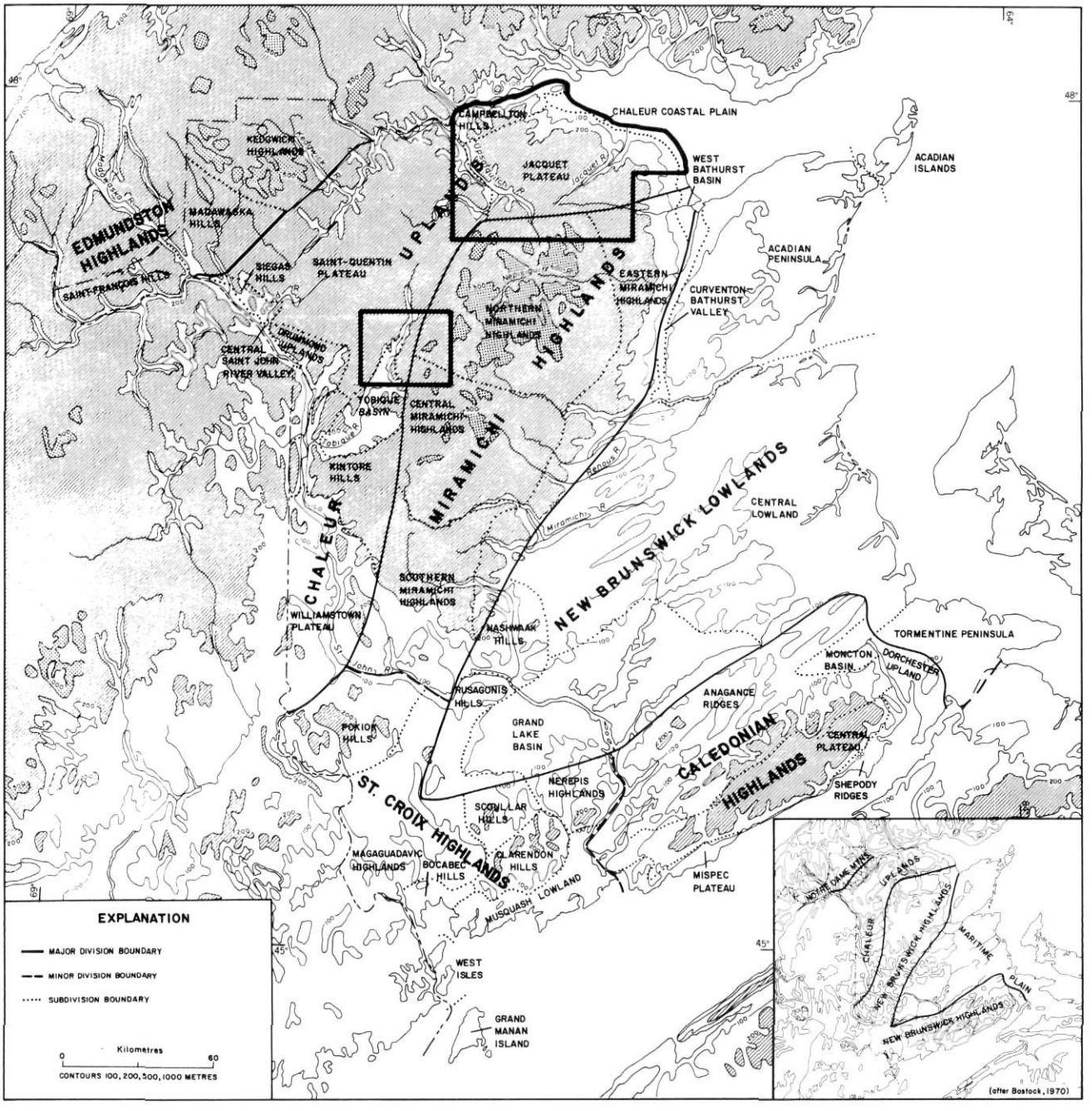

FIGURE 1. Physiographic regions of New Brunswick (from Rampton *et al.*, 1984) with study areas.

Régions physiographiques du Nouveau-Brunswick (de Rampton et al., 1984) et régions à l'étude.

(1986), Bobrowsky *et al.* (1987) and Pronk and Lamothe (1988). Current theories and models of ice sheet growth, flow behavior, erosion, transportation and deposition has required only minor modification of Chalmers' (1895, 1898) ideas.

The critical questions requiring further resolution include the timing and influence of Laurentide ice in the study area, the manner in which this ice sheet interacted with local ice centres, and the vertical and horizontal extent of these ice centres. Although access to field locations and availability of raw information pertaining to the Quaternary of northern New Brunswick has increased dramatically during the last century, a lack of absolute dates for the numerous events limits our interpretive precision. Nonetheless, this paper provides a sequence of late Quaternary geologic events based on published data, open file reports and field research conducted by the authors since 1985 (Fig. 2).

PHYSIOGRAPHY OF THE STUDY AREA

Physiographically, the province of New Brunswick can be divided into four broad zones. Figure 1, adapted from Rampton *et al.* (1984) illustrates the study areas in relation to these zones. The areas are situated on the northern margin of the Miramichi Highlands and the northeastern part of the Chaleur Uplands (Fig. 3). It encompasses part of the Northern and Eastern Miramichi Highlands, Saint-Quentin and Jacquet Plateaus, Campbellton Hills, Chaleur Coastal Plain, and West Bathurst Basin.

In the Miramichi Highlands, relief is commonly between 210 and 250 m, with summits between 450 and 640 m. The core of the Highlands, south of the study areas, exhibits higher relief with peaks as high as 820 m. To the east, Highlands generally lie below 365 m elevation, with a relief rarely exceeding 60 m. The Highlands are underlain by metamorphosed rocks of the Cambro-Ordovician Tetagouche Group and volcanic and sedimentary rocks of the Devonian Tobique Group (Davies, 1977).

The Saint-Quentin and Jacquet plateaus have gently undulating surfaces, with relief between 30 and 60 m. The plateaus slope from 400 m in the south to 60 m in the north and display a gradient break approximately 15 km from the edge. The Saint-Quentin Plateau averages 300 m elevation with peaks up to 483 m. Major streams and tributaries are incised in V-shaped valleys, 75 to 180 m below the upland surface. The Campbellton Hills are a group of structurally controlled ridges along the northern edge of the Saint-Quentin Plateau. The Chaleur Coastal Plain and west Bathurst Basin are gently sloping to undulating plains bordering the Baie des Chaleurs and for the most part lie below 70 m elevation.

Sedimentary rocks of the Ordovician-Silurian Matapedia and Grog Brook groups and sedimentary and volcanic rocks

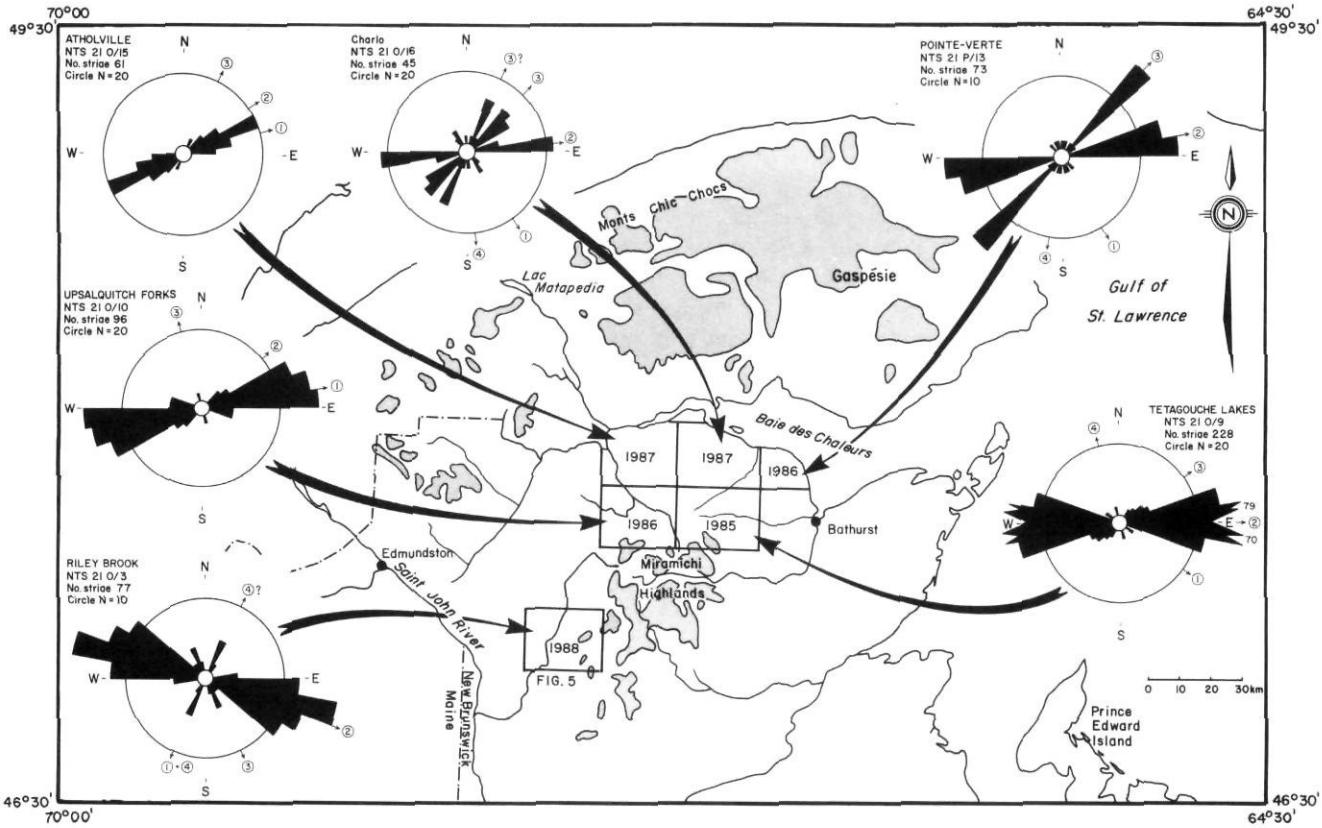

FIGURE 2. Location of study areas with NTS code, year of mapping, recorded striae patterns, and regional topography. Shaded areas are over 500 m in elevation (since topographic data is from several sources, some discrepancies may occur).

Localisation des régions à l'étude, leurs codes du S.T.N., l'année de la cartographie, l'orientation des stries et la topographie régionale. Les zones en grisé s'élèvent à plus de 500 m d'altitude (en raison de la diversité des sources, il peut y avoir des écarts entre les données topographiques).

FIGURE 3. Southward view from the Campbellton Hills across the Chaleur Uplands with the Miramichi Highlands in the background.

À partir des collines de Campbellton, vue vers le sud au travers des hauteurs des Chaleurs, avec les hautes terres de Miramichi à l'arrière-plan.

of the Silurian Chaleurs Group and Devonian Dalhousie Group underlie the Chaleur Uplands. These rocks are locally intruded by Devonian felsic and mafic rocks (Davies, 1977).

Several major rivers drain the region. The Baie des Chaleurs is fed by the Matapedia, Restigouche, and Upsalquitch rivers in the west and Jacquet, Tetagouche and Nepisiguit rivers in the east. Further to the south, the Miramichi River and its various tributaries empty directly into the Gulf of St. Lawrence.

SYNTHESIS OF PREVIOUS INTERPRETATIONS

The study areas are situated in a region that developed a local ice cap prior to the direct influence of the Laurentide Ice Sheet (Vincent and Prest, 1987). Chalmers' (1898) introduction of the "Appalachian complex of glaciers" demonstrated that he was aware of this phenomenon. North of the St. Lawrence River, striae are consistently oriented south and southeast (Prest *et al.*, 1968), whereas opposing directions occur south of this major topographic low, in the Eastern Townships of Québec (Lortie and Martineau, 1987), the Gaspésie (David and Lebuis, 1985; David and Bédard, 1986), northern Maine (Lowell and Kite, 1986; Lowell, 1985; Newman *et al.*, 1985), northwestern New Brunswick (Gauthier 1980; Rappol, 1986 a, b, 1988), and the Baie des Chaleurs region (Gauthier, 1982; Bail, 1985; Pronk, 1987; Bobrowsky *et al.*, 1987). Marine incursions into the coastal area (Rampton *et al.*, 1984; Bobrowsky *et al.*, 1987), and periglacial features in the Highlands (Gauthier, 1983; Seaman, 1985) are associated with the glaciation.

In northern Maine, a "zone of no erosion" (Lowell *et al.*, 1986) adjoins a zone of deeply fractured bedrock ("no data zone" of Rappol, 1986a) in northwestern New Brunswick and an area of "monolithologic till, deeply weathered bedrock, no glacial erosion" in the Gaspésie (David and Lebuis, 1985). West and north of this zone, there is evidence of ice flow reversal throughout the Late Wisconsinan and a shifting ice divide that was influenced by Laurentide as well as Appalachian ice masses (Figs. 6, 7). The presence of Laurentide ice in New Brunswick and the interaction with Appalachian ice has been a point of discussion (and contention) beginning with Chalmers (1898). Moreover, many workers (McDonald and Shilts, 1971; Shilts, 1981; Lamothe, 1987; Lortie and Martineau, 1987) recognize northeast, southeast, and southwestward flowing ice in the upper St. Lawrence River valley.

To fully understand the behavior of Laurentide ice during the Late Wisconsinan in northern New Brunswick, we propose to examine the configuration of the Laurentide Ice Sheet through time (Dyke *et al.*, 1982; Fisher *et al.*, 1985; Vincent and Prest, 1987; Dredge and Thorleifson, 1987; Dyke and Prest, 1987) relative to certain concepts of ice movement (*e.g.*, Weertman 1957; Thomas, 1977; Hughes *et al.*, 1977). We stress that a consensus on the physical definition of the Laurentide Ice Sheet in the Atlantic region of Canada and northeastern United States is complicated by opposing opinions on whether the Appalachian Ice was a separate entity (Grant, 1977; Dyke *et al.*, 1982) or not (Fisher *et al.*, 1985).

Chalmers' (1895, 1898) ideas of local glaciers were generally ignored in the decades that followed his original study. Later, Goldthwait's (1924) concept of continental ice sheets and two major flow phases across the Maritime Provinces was put forward at a time when the theory of continental ice sheets was generally accepted. His model was thought to be correct, despite the extensive amount of contradictory field data collected by Chalmers. Flint (1951) reopened the discussion with his description of highland centres of glacial flow in the Maritime Provinces. Studies by Lee (1962) on the Saint John River valley also suggested the presence of local ice caps. Recently, detailed work, carried out throughout the Maritimes and adjacent areas, support the interpretation that glaciation was predominantly a local phenomenon (for references, see introduction). In particular, Grant and Prest (1975) emphasized the difference in style of glacial dynamics that can be expected in a region of uplands that is cut by deep marine channels compared to a relatively flat shield area with one major ice centre.

The fact that the St. Lawrence River valley lies between the Canadian Shield ("home" to the Laurentide Ice Sheet) and northern New Brunswick is of major importance in the development of glacial models for the region. The Laurentian Channel that extends to the edge of the continental shelf is shaped very much like a glacial valley (Shepard, 1931). The Chic-Chocs Mountains on the Gaspésie form a 600 m high mountain ridge that could have guided glacial flow into the Laurentian Channel. Major lows on the north shore of the St. Lawrence River, like the Saguenay valley, may have also deflected ice flow into a more easterly direction (Prest *et al.*, 1968). Gauthier (1978b) and David and Lebuis (1985) noted that a large part of the Laurentide ice was intercepted by an ice stream (Hughes *et al.*, 1977; Thomas, 1977) out to the shelf and if ice crossed the Gaspésie at all it would have been relatively "clean" ice. In this case, "clean" ice results from a transverse interception of the southward flowing ice sheet by the eastward moving ice stream and the concomitant incorporation of the debris-rich basal zone of the Laurentide ice by this pirating ice stream (Genes *et al.*, 1981).

As indicated by David and Lebuis (1985), Shield erratics should be present in the Baie des Chaleurs area, but they simply are not. In addition, Lortie and Martineau (1987) found little evidence of southeastward-trending striae that would indicate that Laurentide ice actually crossed the Gaspésie. In contrast, David and Bédard (1986) have shown southeastern transport of unique granitic erratics by ice from the central Notre-Dame Mountains to the Baie des Chaleurs; this unique distribution of erratics could have been accomplished by local ice. Farther to the northwest, Canadian Shield erratics seem to be restricted to low elevation "gaps" in the Notre-Dame mountain range (Lac Témiscouata-Edmundston and Matapédia Lake-River Lows) according to data from David and Lebuis (1985), Maurice (1986), and Bernier *et al.* (1987). The distribution of erratics in northern Maine (Newman *et al.*, 1985) and northern New Brunswick (Rappol, 1986b) shows less than 0.5 % Shield-derived clasts. Rappol (1986b) also indicates that more than one glacial/fluvial transport/erosion cycle was involved in the emplacement of these clasts since they are generally found adjacent to fluvial deposits. Genes *et al.* (1981) used a frozen bed/melted bed model to explain the distribution of erratics, but failed to explain the low percentages. Their second model shows an interfingering of local Appalachian ice with Laurentide ice.

Gauthier (1978b) used a similar model of drawdown for the Baie des Chaleurs region. The Baie des Chaleurs is a topographic feature of a lower rank, but has still influenced ice-flow directions in its coastal areas. Chalmers (1898) suggested that the general eastward ice flow was locally diverted to the northeast and southeast by the topography.

The concept of ice-streaming is also important to consider during the deglaciation phase, as it may be responsible for further drawdown in the St. Lawrence and consequential ice-flow reversal throughout northern Maine (Lowell, 1985), northwest New Brunswick (Rappol, 1986a) and the Gaspésie (David and Lebuis, 1985). Similar drawdown into the Baie des Chaleurs apparently initiated the regional northeast flow pattern (Jacquet River-Belledune Diversion of Rampton *et al.*, 1984). The regional shift in flow from east to northeast (Fig. 8) and the deposition of till assumes a change of the basal ice regime under the influence of drawdown in the bay.

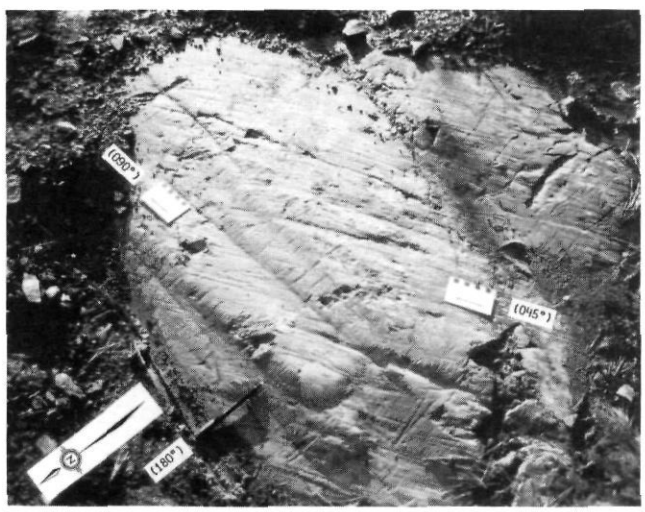

FIGURE 4. Glacial striae are the sole chronological control on the glacial events of northwern New Brunswick.

Les stries glaciaires sont les seuls éléments qui permettent de reconstituer la chronologie des événements glaciaires au Nouveau-Brunswick.

Another possibility is that the flow patterns toward the northeast mark a separate event (minor retreat and advance) within the Late Wisconsinan advance, akin to the classic Great Lake record (*cf.*, Karrow, 1984).

A third possibility is that the glacial flow patterns ascribed onto the bedrock might have existed throughout several periods of the Pleistocene in a similar configuration. However, in the study area, erosion and weathering tends to erase striations very rapidly and it is therefore assumed that all present features are of Late Wisconsinan age. The only older surficial features of the area are deeply weathered bedrock profiles, possibly dating back to Carboniferous, Cretaceous or Tertiary times (Rampton *et al.*, 1984), and a marine bench along the upper Baie des Chaleurs at ±5 to 7 m a.s.l. (possibly of Sangamonian age — oxygen isotope stage 5e, Mott and Grant, 1985; D. R. Grant, personal communication, 1988).

ICE-FLOW INDICATORS

The glacial features of northern New Brunswick are mainly erosional. The absence of accretionary deposits was noted by Chalmers who recognized the lack of stratigraphic sequences as an obvious research obstacle. Reconstruction of the glacial history has, therefore, relied considerably on geomorphic and erosional features (Figs. 1, 4), often based on aerial photographic interpretation. Our own discussion of the glacial history is based on supportive clast provenance analyses, till fabric data, directional information from striated bedrock localities and detailed sedimentologic mapping (Pronk, 1986, 1987; Bobrowsky *et al.*, 1987). Presentation of all the raw data is beyond the scope of the present discussion.

For most of Atlantic Canada and the contiguous United States, bedrock striation localities have provided the main source of information regarding Pleistocene ice flow histories. In northern New Brunswick, more than 1000 striae sites have been located, which viewed collectively, indicate glacial flow in all cardinal directions. Pattern recognition is, however, possible when a striation chronology is established and correlated to geographic locations. Many striation localities display some combination of nailhead striae, miniature crag-and-tails (rattail striae), stoss-and-lee forms and crescentic gouges/fractures that indicate a sense of ice-flow direction (*cf.*, Prest 1983; Fig. 4).

NORTH-CENTRAL NEW BRUNSWICK

In northern New Brunswick, the oldest flow is weak and has a southeasterly trend (125-160°; Fig. 5). The second, most dominant trend indicates a due eastward glacial flow (080-110°; Fig. 6). A third flow trend is recorded by abundant striae; diamicton pebble fabrics oriented to the northeast (045-070°) are evident on the Jacquet River Plateau (Fig. 7). These general ice-flow directions are supported by both pebble fabric data and bedrock striae (Fig. 2). Late stage outflow of local

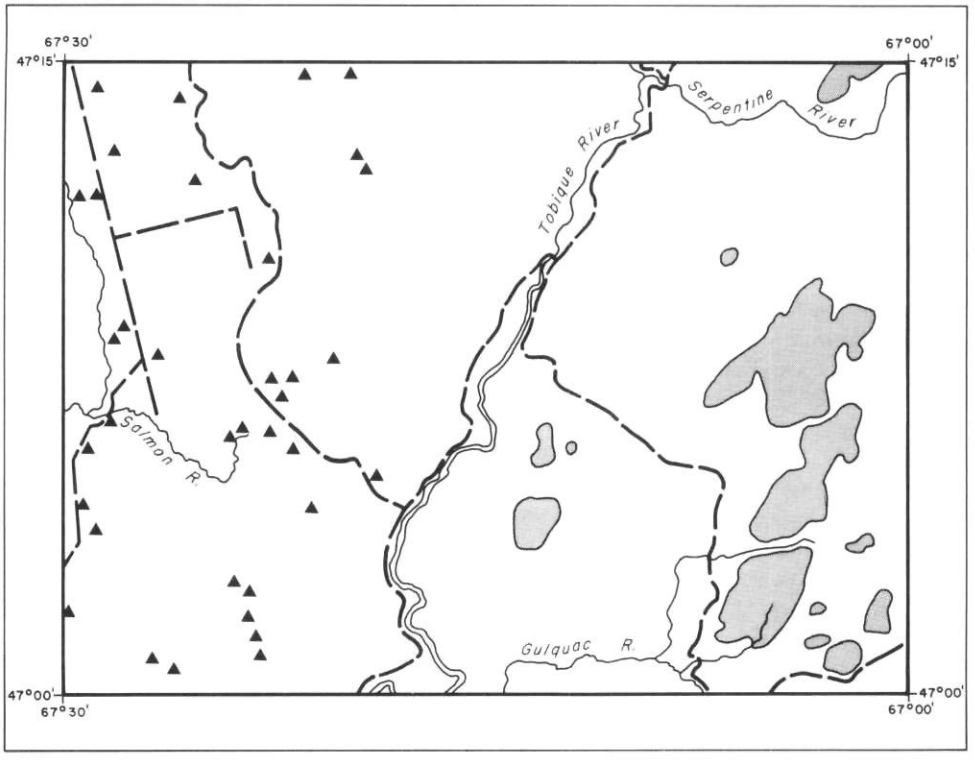

FIGURE 5. Earliest recorded ice flows in the northern Appalachian Region. Ice was from local sources (dashed lines). Data from Prest *et al.* (1967), Gauthier (1982), Rampton *et al.* (1984), David and Lebuis (1985), Lowell (1985), Newman *et al.* (1985), Lowell and Kite (1986), Rappol (1986a,b 1988), Lortie and Martineau (1987), and authors work (Fig. 1).

Premiers mouvements glaciaires rapportés dans le nord de la région des Appalaches. La glace provenait de sources locales (lignes tiretées). Les données sont de Prest et al. *(1967), Gauthier (1982), Rampton* et al. *(1984), David et Lebuis (1985), Lowell (1985), Newman* et al. *(1985), Lowell et Kite (1986), Rappol (1986a,b 1988), Lortie et Martineau (1987) et des auteurs (fig. 1).*

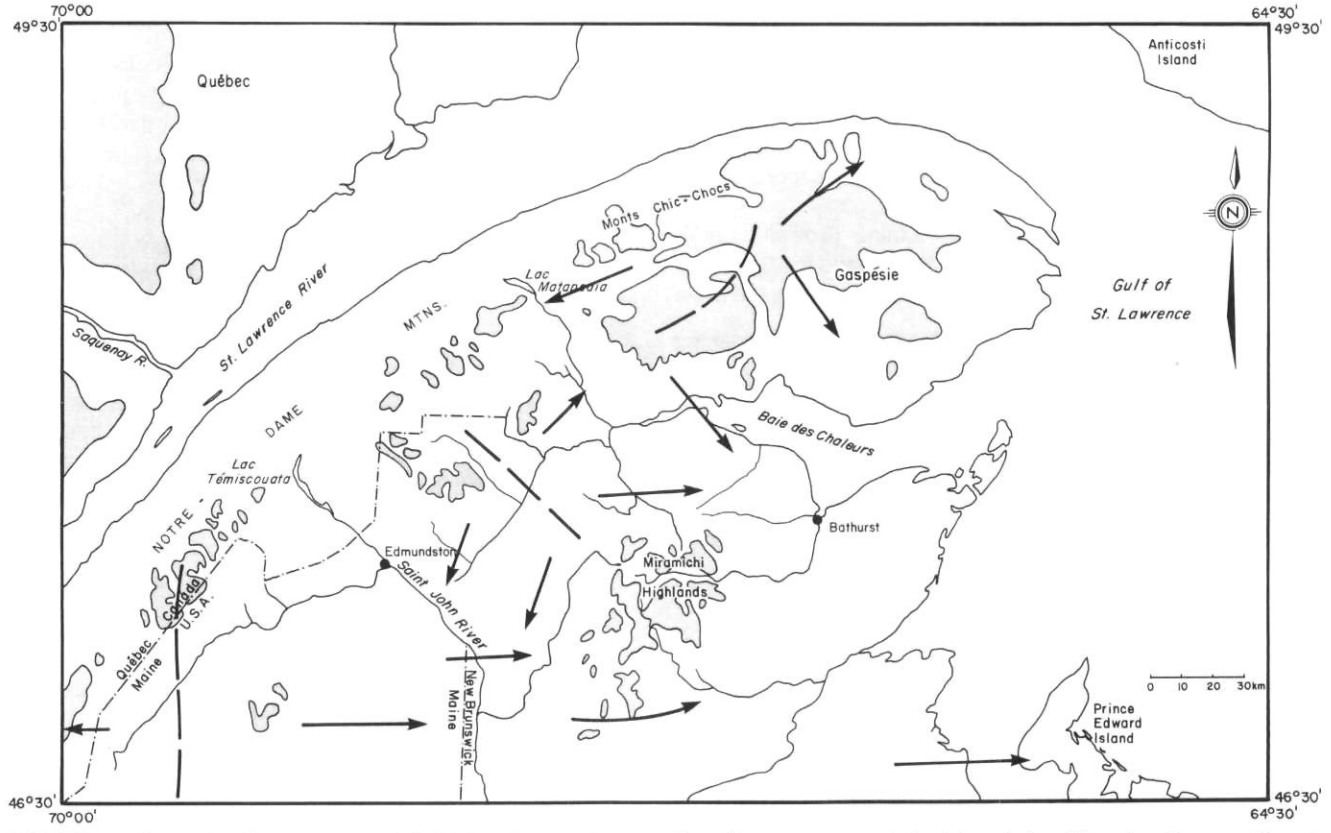

FIGURE 6. Secondary flow patterns and Shield erratics distribution (heavy dotted line). For sources see Figure 6. Note that the influence of Laurentide ice is channelled by topography and that flow patterns in northeast New Brunswick do not fit the Laurentide flow pattern (see text).

Deuxième mouvement glaciaire et répartition des blocs erratiques en provenance du Bouclier (ligne tiretée et pointillée). Voir la figure 6. À noter que la topographie détermine l'influence de la glace laurentidienne et que le mode d'écoulement dans le nord-est du Nouveau-Brunswick ne correspond au mode d'écoulement laurentidien (voir le texte).

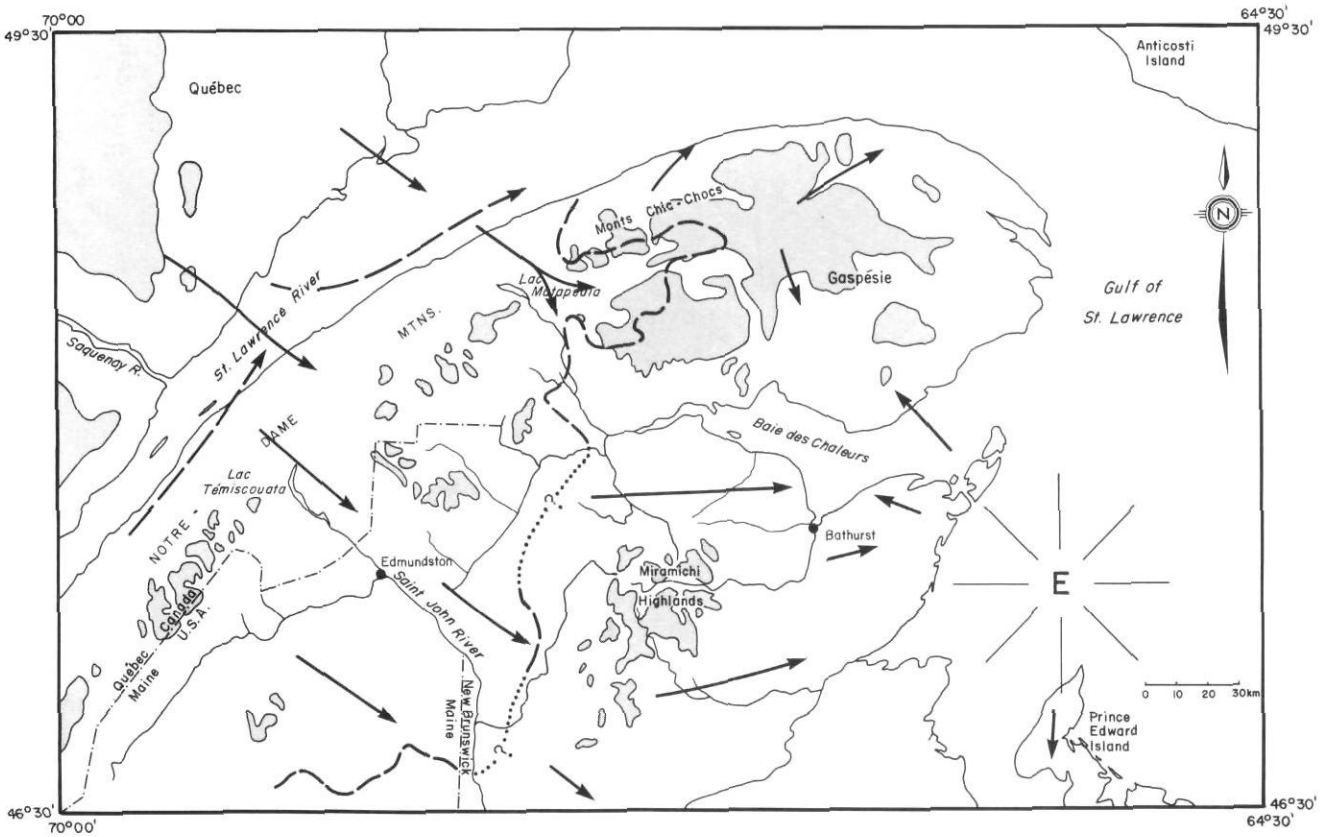

FIGURE 7. The Appalachian divide as visualized by Rappol (1986b, 1988) would fit the flow patterns influenced by marine downdraw in the St. Lawrence River and the Baie des Chaleurs (see text).

La ligne de partage des glaces appalachienne telle que déterminée par Rappol (1986b, 1988) concorderait bien avec les directions d'écoulement glaciaire déterminées par les affaissements qui se sont produits dans le Saint-Laurent et la baie des Chaleurs.

ice did not have significant influence on the material distribution (Fig. 8).

Clast provenance studies (Pronk and Lamothe, 1988; Pronk and Burton, 1988) reveal east-northeastward glacial transport. Frequently, pebble tracing indicates very local transport in the order of a few kilometres, but individual clasts are found up to 40 km down-ice (east-northeast) from their original source. The combined data indicate that glacial ice associated with the original eastward flow was primarily responsible for most glacial bedrock erosion and sediment transport. Patchy sediment and pebble distribution, and fabrics attest to this ice flow.

The present fabrics of glacial sediments are reflective of the subsequent northeastward flow regime. Different basal ice conditions are inferred to have existed at this time to allow significant reworking of pre-existing glacial debris by the northeastward flow regime. Minimal bedrock erosion occurred during the northeastward event which may have been responding to a drawdown in the Baie des Chaleurs. Local late-stage ice movements, such as the southern flow northwest of Bathurst (Fig. 8), did not significantly influence the redistribution of till, but remobilization is apparent from distorted and reoriented pebble fabrics. Throughout the north-central study area, the absence of shield erratics is evident.

The "Restigouche-Elmtree" moraine system south and southeast of Dalhousie was originally envisioned as being deposited in an interlobate position between two time-equivalent ice masses flowing south-southeast and east-northeast (Rampton *et al.*, 1984). This interpretation was based on a suggestion by Brinsmead (1979) that cross-beds dipping to the north and south occur at several locations. However, detailed sedimentological and structural mapping within these systems, as well as re-examination of the bidirectional localities, suggest that the "moraines" represent a late and postglacial series of nested, pitted deltas, intimately associated with offshore sediments (Bobrowsky *et al.*, 1987). They are, in effect, marking an episodic period of high meltwater expulsion during deglaciation. Numerous sections exposed within this system indicate that large scale deltaic foreset beds dominate the landforms, although fossiliferous shallow marine and ice contact deposits are also present. Paleoflow interpretations from the foreset beds, as well as pebble fabric data from approximately 100 sample locations (topset and foreset beds) indicate paleoflow occurred predominantly to the north. Thus, the suggestion that bed structures with paleoflow to the south are a product of sediment deposition off an ice mass located to the north are unsupported. Offshore echogram data by Syvitski *et al.* (1987) indicate that an unstratified constructional ridge of Pleistocene sediments up to 30 m thick skirts the northern shore of the Baie des Chaleurs. This ridge may, in fact, represent a Late Wisconsinan interlobate junction in the mid-bay region, since the sedimentological data indicate no sedimentation to the south occurred in the past.

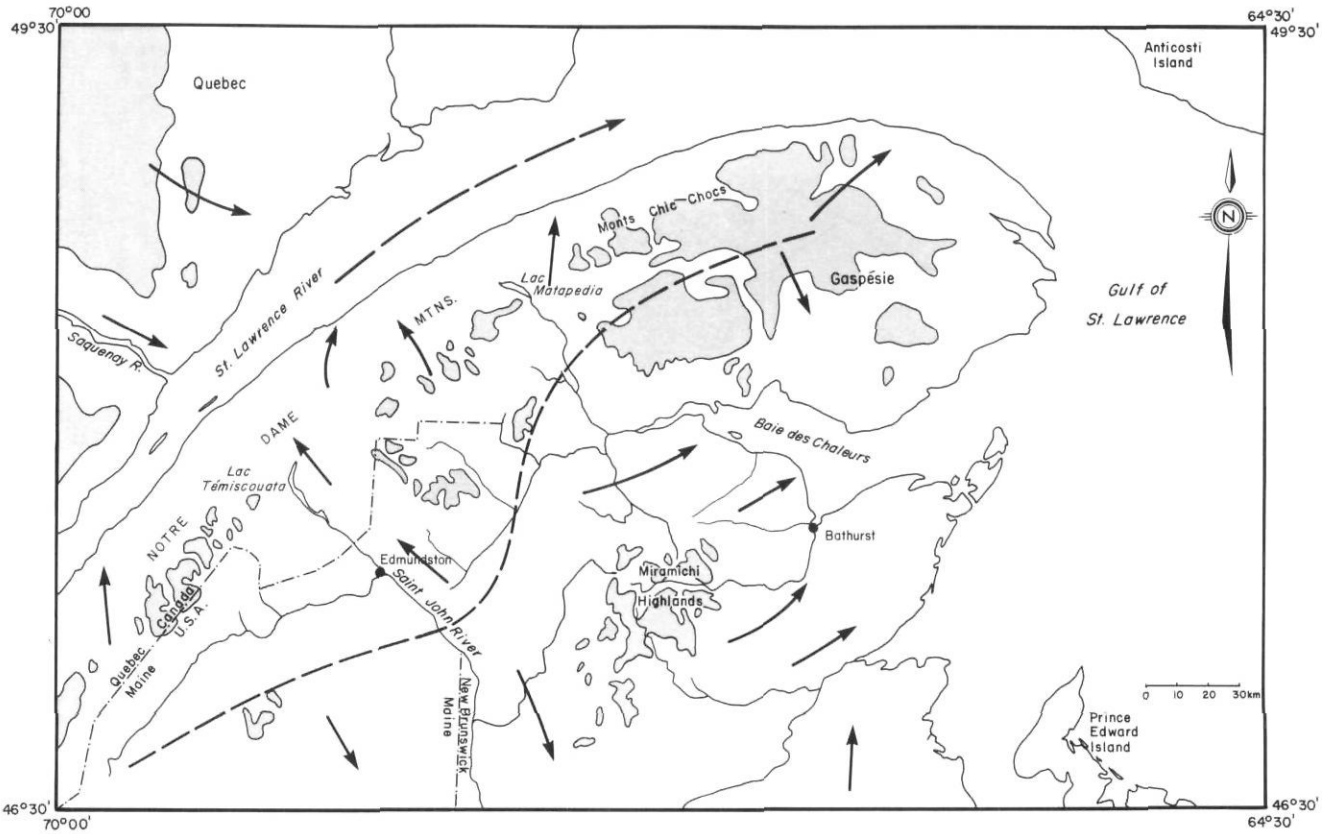

FIGURE 8. Local out flow of residual ice caps during deglaciation in northern New Brunswick.

Écoulement local des calottes glaciaires résiduelles au cours de la déglaciation dans le nord du Nouveau-Brunswick.

NORTHWEST NEW BRUNSWICK

An early west-southwestward ice flow was followed by a due east flow in the 1988 study area (see also Rappol, 1988). A subsequent east-southeastward flow took place under the influence of pressure from the Laurentide ice moving into the Appalachian region. Under this flow pattern, the Laurentide erratics were brought into this area (Figs. 6, 9). A late stage flow indicates both southward and northward flows from remnant ice on the west flank of the Highlands. Ablation material in this area reflects the downwasting of this remnant ice.

GLACIAL HISTORY IN A REGIONAL CONTEXT: A REVISED MODEL

In a hypothetical model for the northern Appalachian region, local ice started to build up five to six thousand years before Laurentide ice reached the St. Lawrence Lowland (Vincent and Prest, 1987), *i.e.*, in both Early and Late Wisconsinan times. This difference in timing between formation of regional mountain ice and the advancing continental Laurentide ice is not uncommon. A similar, but well dated situation exists for the Late Wisconsinan in the northern Rocky Mountains and northeastern plateau of British Columbia (Bobrowsky, 1989).

In the Appalachian Uplands of southern Québec (Lamothe, 1987), several Laurentide events are registered. An Early Wisconsinan till of Laurentide origin (Johnville Till) is overlain by St. Pierre sediments that are dated at ±70-65 ka BP. These sediments are overlain by Appalachian as well as Laurentide (Chaudière) tills, which in turn are overlain by the Gayhurst Formation. Rappol (1988) correlates the Chaudière tills with a lower till (Appalachian source) and an upper till (Laurentide source) in the upper Saint John River valley. Gayhurst sediments are topped by another till of Laurentide origin (Lennoxville till), which shows ice-flow reversal in its upper parts. It is obvious from this alternating influence of Appalachian and Laurentide ice that during the Wisconsinan, the Appalachian ice was present but asynchronous in terms of growth relative to Laurentide ice and could possibly have obstructed further advance of the Laurentide front. Glacial striae records (*e.g.*, Chalmers, 1898; Lortie and Martineau, 1987) confirm this possibility. Genes *et al.* (1981) describe a similar interaction of Laurentide and Appalachian Ice in northern Maine.

The major eastward ice flow recorded in northern New Brunswick possibly existed throughout the Wisconsinan and originated from the northern Maine-Notre Dame Ice Divide (Rampton *et al.*, 1984; Rappol, 1988) as its flow direction does not fit the regional Laurentide flow patterns. At times it may have been influenced by pressure from Laurentide ice.

East of the study area, there are indications of northwestward flowing ice. Gauthier (1978a) reported a northwestward fabric trend on the Acadian Peninsula and Bail (1985) reported a last ice flow onto the south shore of the

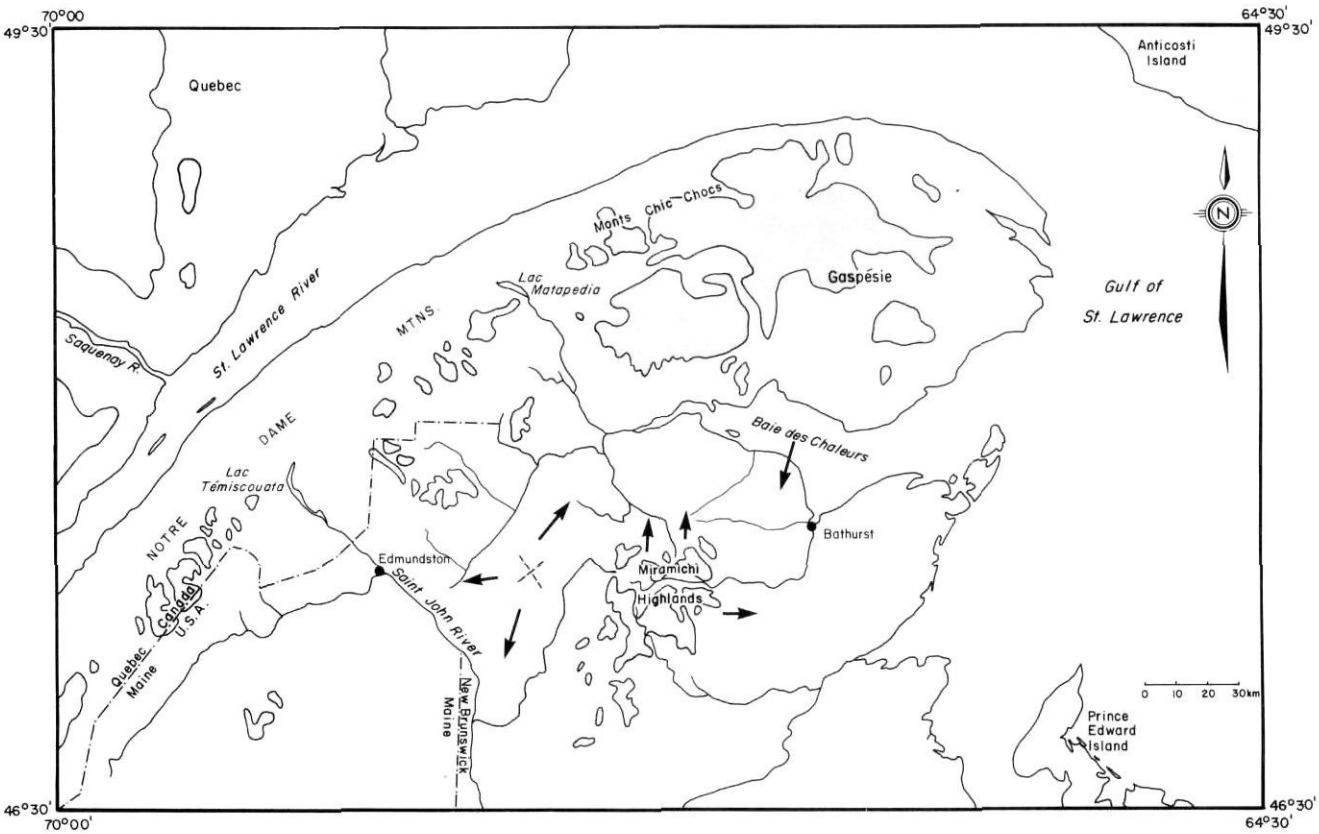

FIGURE 9. Distribution of Shield erratics (Precambrian granites and arnorthosites) in map area 21 0/3. The shaded area is above 450 m elevation and represents the western parts of the Miramichi Highlands. Source of the anorthosite boulders is likely to the northeast of Lac Saint-Jean, Québec (Prest and Nielsen, 1987) as that outcrop lies in the up ice extension of the Lac Témiscouata-Edmunston Low.

Répartition des blocs erratiques en provenance du Bouclier (granites et arnothosites précambriens) dans la région 21 0/3. Les zones en grisé s'élèvent au-dessus de 450 m d'altitude et constituent la partie ouest des hautes terres de Miramichi. La source des blocs d'anorthosite est probablement située au nord-est du lac Saint-Jean, au Québec (Prest et Nielson, 1987), cet affleurement se trouvant dans l'extension amont des terres basses de la région de Lac Témiscouata-Edmunston.

Gaspésie. This flow may have originated from the Escuminac ice centre which was apparently present in the Prince Edward Island area during the Late Wisconsinan (Rampton *et al.*, 1984; Stea, 1987).

In the Chaleur Coastal Plain, indications of southeastward moving ice are recorded (striae, fabric trends, Pronk, 1987; Bobrowsky *et al.*, 1987). This flow could have originated on the Gaspésie or on the Canadian Shield. It predates the early eastern flow at most sites (Pronk and Lamothe, 1988), but occasionally seems to postdate the eastward flow (Bobrowsky *et al.*, 1987). Throughout northern New Brunswick, a northeastward ice flow is recorded. Ice may have advanced well into the Baie des Chaleurs and joined with southeastward flowing ice in the bay itself. Under the influence of drawdown in the bay, a possible change in basal ice regime resulted in sediment remobilization and till deposition. The major trend in pebble fabrics along the coastal area attests to this northeastward oriented ice flow.

Unfortunately, timing of these events remains problematic in the absence of dateable materials. If the drawdown relates to a marine incursion there are two possible time intervals for the events. A major marine incursion took place sometime during the Middle Wisconsinan (Dredge and Thorleifson, 1987) throughout Maritime Canada and another one at the onset of Late Wisconsinan deglaciation (Rampton *et al.*, 1984). At the mouth of the Baie des Chaleurs, the latter is dated at 12,700 BP and in the Campbellton area is dated at 12,000 BP by a series of radiocarbon dates (Rampton *et al.*, 1984).

Late stage ice flow took place from local ice centres in the Highlands and uplands in almost every direction (Pronk, 1987; Rampton *et al.*, 1984; Gauthier, 1983), as well as from an area north of the Belledune coast to the south and southwest. Chalmers (1989) attributed the latter to sea ice action, but the extent and consistency of striae patterns indicate a more regional event (Pronk and Lamothe, 1988). South of the Highlands, two tills envelope a layer of organic silt (M. Lamothe, personal communication, 1987) that dates at 11,500 ± 150 years BP (GSC-4277). The overlying till may correspond to the late stage flows of the Highlands and the Younger Dryas climatic cooling that occurred throughout Atlantic Canada (Mott *et al.*, 1986). As a result of the early deglaciation of the Highlands, highland peaks were left as nunataks and periglacial features (polygons, tors, frost wedges) were formed (Seaman, 1985). Some of these forms have been formed in pre-Late Wisconsinan times and were simply not completely eroded

during glaciation of the area. Till on the highest peaks of the Highlands has similar characteristics as till on the Uplands of northern New Brunswick, and we have to assume glaciation of the Highlands during the glacial maximum.

Marine incursion into the area was contemporaneous with ice retreat (Rampton *et al.*, 1984) and is registered throughout the Chaleur Coastal Plain and West Bathurst Basin by glaciomarine deposits. The "Restigouche Kame" and "Elmtree Interlobate Moraine" (Rampton *et al.*, 1984) are related to the Chaleur and the end of the Bantalor phases, respectively. Bobrowsky *et al.* (1987) described these deposits as a shore-parallel series of nested, pitted deltas intimately associated with offshore marine sediments and give a minimum date of 12,450 ± 90 years BP (ISO-11341; corrected age) as the time of deglaciation near Dalhousie. Although all dates in this region are based on marine shells, we believe the majority are reliable given their congruence to a suite of amino acid ratios (Bobrowsky *et al.*, 1987).

DICUSSION AND CONCLUSIONS

If Laurentide ice crossed New Brunswick and Nova Scotia to deposit the Scotian shelf moraine complex (King, 1972), it was free of Canadian Shield debris because basal ice was intercepted by an ice stream in the Laurentian Channel (Thomas, 1977). Some Shield indicators (Genes *et al.*, 1981; Maurice, 1986; David and Lebuis, 1985) were transported across the Notre-Dame Mountains in a southeastward direction, but did not reach north-central New Brunswick (see also Bernier *et al.*, 1987). An interaction of Laurentide and Appalachian ice masses (Model I of Genes *et al.*, 1981) whereby Laurentide ice fuses with, as opposed to overrides, Appalachian ice, together with the drainage of dirty basal ice through the Laurentian Channel (Gauthier, 1978b) can satisfactorily explain this discrepancy (see below).

Local ice caps, built-up in the Appalachians some 5,000 to 6,000 years before Laurentide ice reached the St. Lawrence Lowlands, may have further obstructed the passage of Laurentide ice, eventhough Appalachian ice is commonly believed to have been thin, and Laurentide ice, at a Late Wisconsinan maximum, had an estimated thickness of 2,300 m (Thomas 1977) to 1,600 m (Fisher *et al.*, 1985) and as low as 1,000 m (Quinlan and Beaumont, 1982) just north of the St. Lawrence Lowland.

The St. Lawrence Lowland is more than 30 km wide directly northwest of the Québec-New Brunswick border and the Laurentian Channel is approximately 200 m deep, whereas the surrounding land masses rise up to 600 m a.s.l. This 800 m of relief would be a major obstacle to glacier overriding even without a local ice cap on the land masses. In most ice sheet models (*e.g.*, Paterson, 1981), the ice front quickly rises to one-third of its total thickness and then slowly climbs to its centre height. As the bulk of glacial debris is transported basally in an ice sheet (Whillans, 1978) and as the "Laurentian ice stream" would intercept the lower 400 m (1/2 of the total valley depth, 2/5 or less of ice thickness) of the sheet, most shield derived glacial debris would be funneled down the Laurentian channel and only "clean" ice would then override, push, or fuse with Appalachian ice. This clean ice would be indistinguishable from local ice and would probably not overprint the basal flow patterns of the local ice which were partially controlled by topography (*cf.*, Alley *et al.*, 1986; Blakenship *et al.*, 1986). Because of the effect of the Laurentian channel, Laurentide ice would impinge on Gaspésie and only penetrate further south through topographical lows in the mountain chains (Fig. 6). Erosive force of this ice would be minimal and only minor ablation material with few shield indicators would be deposited.

Farther to the west, where the mountain chain east of the St. Lawrence Lowlands is lower, the channel less wide and deep, and the frozen bed/melted bed model of Genes *et al.* (1981) might apply and explain the more abundant shield erratics in northern Maine.

We conclude that:

1. Four informal phases of glacial flow in northern New Brunswick can be recognized based on erosive directional indicators which we have observed at over 1,000 sites;
2. The earliest phase consists of a glacial flow to the southeast and probably represents erosion from local Appalachian ice;
3. The second oldest phase consists of a glacial flow to the east and indicates the influence of Laurentide ice in western New Brunswick;
4. The third phase of a glacial flow is to the north-northeast and may represent a response of the ice to drawdown in the Baie des Chaleurs;
5. A final phase of glacial flow provides multidirectional flow indicators and may represent local ice response during the Late Wisconsinan to several small ice centres such as the Escuminac ice accumulation to the southeast;
6. During the late Pleistocene, ice streaming occurred along the St. Lawrence channel oblique to the regional flow of the Laurentide Ice Sheet in that region;
7. The St. Lawrence ice stream pirated Canadian Shield erratics from the base of the Laurentide Ice Sheet, which resulted in relatively clean, "debris free" Laurentide ice crossing into Gaspésie.

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