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QUATERNARY GEOLOGY OF PORT SAUNDERS MAP AREA, NEWFOUNDLAND

Douglas R. Grant

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Cover description

View of the 650-m high Long Range Mountains from across the West Newfoundland Coastal Lowland. The road follows an inter-lobate moraine formed by outlet glaciers of a plateau ice cap that skirted these smoothly rounded weathered hills north of Parsons Pond. GSC 204634-C

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QUATERNARY GEOLOGY OF PORT SAUNDERS MAP AREA, NEWFOUNDLAND

Abstract

Pre-Quaternary uplift and differential planation cut lowlands and submarine deeps on sedimentary rocks, leaving Long Range Mountains as an isolated tilted Tertiary peneplain on an upthrust crystalline basement block, with a locally exhumed sub-Cambrian unconformity with glacial topography. Three major Quaternary glaciations by two ice domains, the Laurentide Ice Sheet and the Newfoundland Ice Cap complex, are documented by morphostratigraphy (terrain maturity), ice flow patterns, glacial trimlines, and relative sea-level changes.

During an early maximal glaciation, represented by a mature summit glacial terrain (St. John zone), Laurentide and Newfoundland ice extended beyond Grey Islands. Relative rock dissection suggests a Middle Pleistocene age. Coastal cirques, now submerged 40 m, were probably initiated then and occupied during the onset of later glaciations. During a second major glaciation (Doctor's zone) of presumed late Middle Pleistocene age, ice overran Groais Island, Horse Islands and Baie Verte Peninsula and left seaward-sloping trimlines at 600 m on nunataks. A Long Range ice cap dominated then and during later glaciations judging by an ice divide area preserving preglacial landforms surrounded by a scoured belt and radiating troughs.

A fresh glacial terrain (Long Range zone) with trimlines at 400-550 m records six Late Wisconsinan events. Laurentide abutted Long Range ice, extended eastward to Atlantic Ocean and converged southwestward on Esquiman Channel calving bay ≈14 ka. Highland nunataks divided western Long Range ice into confluent piedmont lobes which deposited calcareous till with seaward-decreasing highland erratics. Tidewater lobes stabilized in Goldthwait Sea ≈12.8 ka, building the Piedmont Moraines which grade laterally to glaciomarine drift and mark the lift-off line. During retreat, seasonal pulses plowed up marine sediment into De Geer or "winter" moraines, while icebergs and meltwater discharge deposited stony deepwater mud. A Long Range ice readvance, probably during a climatic reversal 11-10 ka, built Leg Pond Moraine and ice-contact marine deltas. Remnant plateau ice left the Cloud River Moraines (≈9.7 ka?). Cirque moraines and talus glaciers may be Neoglacial. Nivation and cryoturbation continue above the mean annual 0°C isotherm at ≈400 m.

Marine limit rises northwestward from 70 m to 142 m, reflecting Laurentide loading. Shorelevel displacement curves and a shoreline-profile diagram with 1000-year intervals illustrate postglacial sea-level recovery. In the north sea level fell continuously, except for a possible stillstand induced gravitationally by the 11 ka readvance, whereas in the south, it fell below present level by 8 ka and continues to rise because of subsidence, causing coastal erosion. A low fossil cliff may reflect a fluctuation ≈2 ka due to forebulge migration. Fractures which displace glacial pavements suggest deglacial faulting, perhaps by release of glacially stored compressive crustal stress.

Practical applications include adapting the radial dispersal model to mineral exploration, contending with unstable marine clay and karstic terrain in foundation sites, rationalizing development of scarce granular resources, taking account of coastal erosion, and monitoring the effects of possible crustal movement on hydroelectric installations.

Résumé

Le soulèvement préquaternaire et l'aplanissement différentiel ont entaillé des basses terres et des fosses sous-marines dans les roches sédimentaires, réduisant ainsi les monts Long Range à une pénéplaine tertiaire isolée et inclinée située sur un bloc soulevé du socle cristallin, et mettant en évidence une discordance sous-cambrienne exhumée et présentant une topographie glaciaire. La morphostratigraphie (maturité du terrain), les schémas de l'écoulement des glaces, la zone de transition forestière et les variations relatives du niveau de la mer témoignent de trois grandes glaciations survenues au Quaternaire et générées par deux domaines glaciaires, l'inlandsis Laurentidien et le complexe de la calotte glaciaire de Terre-Neuve.

Durant une première glaciation maximale, représentée par un terrain glaciaire sommital de type mature (zone de St. John), les glaces laurentidiennes et terres-neuviennes s'étendaient au-delà des îles Grey. La dissection relative des roches suggère qu'elles datent du Pléistocène moyen. Les cirques le long de la côte, qui maintenant se trouvent dans une profondeur d'eau de 40 m, se sont probablement formés à cette époque et ont été occupés par les glaces au début des glaciations ultérieures. Pendant une seconde glaciation majeure (zone de Doctor's) qui remonterait au Pléistocène moyen, les glaces ont envahi l'île Groais, les îles Horse et la péninsule de Baie Verte et laissé des zones de transition forestière à 600 m d'altitude sur des nunataks. La calotte glaciaire de Long Range a été prédominante à ce moment-là et au cours des glaciations ultérieures, puisqu'une ligne de partage des glaces conserve les reliefs préglaciaires environnés d'une zone d'affouillement glaciaire et d'auges glaciaires rayonnantes.

Un terrain glaciaire à roche fraîche (zone de Long Range), où la zone de transition forestière se trouve de 400 à 500 m d'altitude, témoigne de six épisodes glaciaires remontant au Wisconsinien supérieur. Les glaces laurentidiennes arrivaient en bordure des glaces de Long Range, se prolongeaient vers l'est jusqu'à l'océan Atlantique puis convergeaient vers le sud-ouest dans la baie de vêlage d'icebergs du passage Esquiman il y a approximativement 14 ka. Les nunataks des hautes terres ont divisé les glaces de l'ouest de Long Range en lobes confluents de piémont qui ont déposé un till calcareux avec blocs erratiques issus des hautes terres, de moins en moins nombreux à mesure que l'on se rapproche de la mer. Les lobes qu'atteignaient les marées se sont stabilisés dans la mer de Goldthwait il y a approximativement 12,8 ka, et ont édifié les moraines de piémont qui passent latéralement et graduellement à un diamicton glaciomarin, et marquent la limite de soulèvement des glaces. Pendant le retrait des glaces, des épisodes saisonniers d'avancée et de recul ont labouré des sédiments marins et les ont entraînés dans des moraines de De Geer ou moraines «hivernales», tandis que les icebergs et les eaux de fonte des glaces ont déposé des boues caillouteuses en mer profonde. Une réavancée des glaces de Long Range, probablement survenue pendant un changement climatique il y a 11 à 10 ka, a permis la formation de la Moraine de Leg Pond et de deltas marins de contact glaciaire. Les glaces de plateau résiduelles ont déposé les moraines de Cloud River (il y a approximativement 9,7 ka?). Il est possible que les moraines de cirque et les glaciers de talus soient d'âge néoglaciaire. Les processus de nivation et de cryoturbation se poursuivent encore au-dessus de l'isotherme moyenne annuelle de $0^{o}C$ à approximativement 400 m d'altitude.

La limite marine s'élève vers le nord-ouest de 70 à 142 m, sous l'effet de la charge des glaces laurentidiennes. Les isolignes du déplacement du niveau du trait de côte et un diagramme du profil de la ligne de rivage à des intervalles de 1 000 ans illustrent la compensation post-glaciaire. Au nord, le niveau de la mer a continuellement baissé, sauf pendant une période où il est resté stationnaire sous l'effet du poids des glaces de la réavancée survenue il y a 11 ka, mais au sud, il est tombé au-dessous du niveau actuel dès 8 ka et continue à baisser sous l'effet de la subsidence, et ceci favorise l'érosion littorale. Une falaise fossile basse reflète peut-être une fluctuation survenue il y a approximativement 2 ka, en raison de la migration d'un bombement crustal périphérique. Les fractures qui déplacent les pavages glaciaires semblent indiquer la formation de failles résultant de la déglaciation, peut-être lorsque les efforts de contrainte s'exerçant dans la croûte, et jusque-là confinés par les glaces, ont été libérés.

Parmi les applications pratiques de cette étude, on note l'adaptation du modèle de dispersion radiale à l'exploration minérale, la mise au point de méthodes permettant de travailler dans des argiles marines instables et dans des terrains karstiques sur les sites de fondations, la rentabilisation de la mise en valeur des rares ressources en granulats, en tenant compte de l'érosion littorale, et la surveillance de mouvements crustaux éventuels sur les installations hydroélectriques.

SUMMARY

The Port Saunders area (12 I and 2 L) is significant in several ways for understanding Quaternary processes and regional events. It illustrates the interplay of two ice domains, the Laurentide Ice Sheet and a Newfoundland highland ice cap of the Appalachian Glacier Complex. A succession of partly marine-based regional and local ice masses, is recorded by crosscutting ice-flow patterns and these glacial reconstructions are applicable to mineral exploration by drift prospecting. A morphostratigraphic feature is a number of summits having advanced maturity that is attributed to lengthy periglacial exposure when they were nunataks; their ages are estimated by relative rock dissection. The area is evidently at the southern limit of sporadic permafrost judging by active cryogenic features. Deglacial crustal movement, as recorded by relative sea-level change, reflects ice load and retreat pattern.

Six physiographic units correspond to different lithotectonic terranes. The *Long Range Mountains* are an upthrust basement block of Precambrian granite gneiss topped by a 300-500 m plateau representing an uplifted, tilted and dissected Late Tertiary peneplain. The plateau has a steep marginal bevel, regarded as an exhumed sub-Cambrian unconformity or paleoplain, with a knob and basin glacial topography that implies Late Proterozoic glaciation. A Quaternary ice cap cut fiords and scoured the plateau, except for an ice divide area with preglacial landforms, old cirques, and immature till. The *Interior Midlands* at ≈200 m correspond to resistant sedimentary strata which form hogbacks, cuestas, and solution valleys. *Highlands of St. John*, an upfaulted slice of Cambrian strata, are two domed summits at 530 and 610 m, the highest in the area, which have a smooth, soliflucted, cryoturbated surface of till and rubble. The *West Newfoundland Coastal Lowland* (and adjacent floor of Strait of Belle Isle) is a low-relief, west-sloping plain below 50-70 m developed on Cambro-Ordovician carbonate rocks by Late Tertiary planation. It features tracts of De Geer moraines, large interlobate moraines, and abundant karst features. The flat-topped *Coastal Uplands* at 150-250 m, a thrust slab of sandstone and volcanics with a window to the underlying carbonates, represent an intermediate Tertiary erosion level. Offshore *Grey Islands*, composed of granitic and metamorphic rocks, are a plateau remnant at 300-400 m with partly submerged cirques and a degraded glacial terrain which predates the last glaciation. Surrounding submarine deeps are are Late Tertiary fluvial lowlands developed on nonresistant sedimentary rocks.

SOMMAIRE

La région de Port Saunders (12 I et 2 L) est importante à plusieurs égards pour la compréhension des processus qui ont eu lieu pendant le Quaternaire et des épisodes régionaux de cette période. Elle montre l'interaction de deux domaines glaciaires, l'inlandsis Laurentidien et une calotte glaciaire des hautes terres de Terre-Neuve, cette dernière faisant partie du complexe glaciaire des Appalaches. Des configurations d'écoulements glaciaires transversaux mettent en évidence une succession de masses régionales et locales de glace à base partiellement marine, et les reconstructions glaciaires peuvent servire à l'exploration minérale par la prospection du drift. Plusieurs sommets de maturité avancée, attribuée à une longue exposition à des conditions prériglaciaires, à l'époque où ils constituaient des nunataks, sont un élément morphostratigraphique remarquable; on estime leur âge d'après l'état relatif de dissection de la roche. La région se trouve de toute évidence à la limite du pergélisol sporadique si l'on en juge par les caractères cryogéniques actifs. Les mouvements crustaux dus à la déglaciation, et indiqués par les variations relatives du niveau de la mer, traduisent la charge glaciaire et la configuration du retrait des glaces.

Six unités physiographiques correspondent à divers terranes lithotectoniques. Les *monts Long Range* sont un bloc soulevé du socle, composé de gneiss granitique précambrien recouvert à son sommet par un plateau de 300 à 500 m qui représente une pénéplaine soulevée, basculée et disséquée, datant du Tertiaire supérieur. Ce plateau comporte un biseau marginal fortement incliné, considéré comme une discordance ou une paléoplaine sous-cambriennes exhumées, avec une topographie glaciaire en bosses et creux qui laisse supposer une glaciation survenue au Protérozoïque supérieur. Une calotte glaciaire d'âge quaternaire a recoupé les fjords et affouillé le plateau, excepté une zone de partage glaciaire contenant des formes de relief préglaciaires, d'anciens cirques et un till immature. À approximativement 200 m, les *moyennes terres intérieures* correspondent à des strates sédimentaires résistantes qui forment des hogbacks, des cuestas, et des vallées karstiques. Les *hautes terres de St. John*, tranche de strates précambriennes appartenant au compartiment supérieur d'une faille, sont deux sommets en forme de dôme, qui à 530 et 610 m d'altitude sont les plus hauts de la région; ils ont une surface lisse, modelée par la solifluxion et la cryoturbation et composée de till et de débris. Les *basses terres littorales de Terre-Neuve* (et les fonds marins adjacents du détroit de Belle-Isle) constituent une plaine de relief peu prononcé, inclinée vers l'ouest, située au-dessous de 50 à 70 m, formée par aplanissement des roches carbonatées cambro- ordoviciennes dès le Tertiaire supérieur. Elle contient des traînées de moraines de De Geer, de vastes moraines interlobées, et d'abondantes structures karstiques. Les *hautes terres côtières* à sommet plat, d'altitude de 150 à 200 m, représentent une nappe de charriage composée de grès et de roches volcaniques, dans laquelle une fenêtre révèle les carbonates sous-jacents, et correspondent à un niveau érosionnel intermédiaire datant du Tertiaire. Les *îles Grey* extracôtières, composées de roches granitiques et métamor- phiques, sont un plateau résiduel situé de 300 à 400 m d'altitude, qui comporte des cirques partiellement submergés et un terrain glaciaire dégradé plus ancien que la glaciation antérieure. Les fosses sous-marines environnantes sont des basses terres fluviatiles du Tertiaire supérieur formées sur des roches sédimentaires tendres.

Surficial materials consist of bedrock and deposits of glacial, glaciofluvial, marine, fluvial, colluvial, and organic origin. Bedrock, including bare and vegetated rock and minor patches of thin till, dominates the Long Range plateau where areal glacial scouring has denuded and sculpted the resistant bedrock and etched out the pattern of fracture lineaments and stratification trends. Some sharp-edged lineaments which appear to vertically offset the glaciated surface may be postglacial faults.

Tills vary in surface form, thickness, and texture depending on age, topographic setting, rock substrate, and depositional facies. Three ages of glacial till terrain, which are in sharp contact, although the tills were not seen in superposition, are inferred on the basis of relative geomorphic maturity and dating. That dated to the Late Wisconsinan by associated marine deposits has fresh morainic topography; the two more mature till terrains at higher elevation and outlying islands are inferred to be pre-Late Wisconsinan. The most mature till terrain (St. John zone), which occurs on summits of Highlands of St John, the western Long Range Mountains, and Bell Island, has a solifluction-graded surface that is devoid of glacial relief. The till consists of local sedimentary rocks with various Precambrian erratics; patches of rubble mark weathered outcrops. The intermediate-age till terrain (Doctor's zone) is also rich in Long Range erratics but has undulating, subdued morainic topography. Its upper limit slopes westward from 600 m to 380 m. Outliers occur on Horse Islands and Groais Island. The Late Wisconsinan till has virtually unmodified morainic topography and ice-moulded forms. It is the product of a plateau ice cap and is subdivided according to thickness and continuity. *Till blanket* on the northern lowlands is a drift sheet with northward-decreasing Long Range erratics and a bilobate fan of drumlins, flutings and crag and tail hills ending at the Leg Pond Moraine. On the western lowlands, it forms the arcuate and interlobate Piedmont Moraines complex. *Till veneer* 2-5 m thick occurs on the western lowlands as a drift sheet in which Long Range erratics decrease linearly westward. It features innumerable De Geer moraines composed of plowed up marine sediment. *Discontinuous till veneer* 1-2 m thick covers the medial part of the plateau along the former ice divide.

Rare *glaciofluvial deposits* feature a network of crevasse fillings behind Leg Pond Moraine, and kames, kame moraines, and outwash trains where Long Range outlet glaciers coalesced and terminated in escarpment troughs and fiords. *Marine deposits* are variably developed below the 70-142 m limit of postglacial submergence. A generally fossiliferous stony mud, which

Les matériaux de surface se composent du substratum et de sédiments d'origine glaciaire, fluvioglaciaire, marine, fluviatile, colluviale et organique. Le substratum, comprenant la roche nue et la roche couverte de végétation et de petites étendues sporadiques de till de faible épaisseur, constitue la majeure partie du plateau de Long Range, où l'érosion glaciaire a dénudé et sculpté la roche de fond résistante fait ressortir par décapage de cette roche les linéaments de fractures et les directions générales de la stratification. Quelques linéaments à angles vifs qui apparemment décalent verticalement la surface englacée sont peut-être des failles post-glaciaires.

Les tills présentent des variations de leur configuration superficielle, leur épaisseur et leur texture, selon leur âge, leur contexte topographique, la nature de la roche en place, et les faciès sédimentaires. De la maturité géomorphologique relative du terrain et des datations réalisées, on a déduit qu'il y avait eu trois époques de formation des tills, lesquels se trouvent en contact net les uns avec les autres, mais n'apparaissent pas superposés. Le till daté du Wisconsinien supérieur à partir des sédiments marins qui lui sont associés se caractérise par une topographie de moraines non érodées; les deux terrains de till plus mature qui se situent à une altitude plus élevée et sur les îles environnantes sont sans doute d'âge antérieur au Wisconsinien supérieur. Le terrain composé du till le plus mature (zone de St. John) qui se situe sur les sommets des hautes terres de St. John, dans l'ouest des monts Long Range et dans l'île Bell, présente une surface aplanie par la solifluxion, sans relief glaciaire. Le till se compose de roches sédimentaires d'origine locale accompagnées de divers éléments erratiques d'âge précambrien; des étendues sporadiques de débris marquent les affleurements érodés. Le terrain formé de till d'âge intermédiaire (zone de Doctor's) est également riche en éléments erratiques provenant des monts Long Range, mais présente une topographie morainique onduleuse et modérée. Sa limite supérieure s'incline vers l'ouest, et passe de 600 m d'altitude à 380 m. Il existe des buttes témoins dans les îles Horse et Groais. Le till du Wisconsinien supérieur montre une topographie morainique virtuellement intacte, et des formes modelées par les glaces. Il a été formé à partir d'une calotte glaciaire de plateau et se laisse subdiviser selon son épaisseur et sa continuité. La *couverture de till* des basses terres septentrionales est une nappe de drift contenant des quantités, progressivement plus faibles vers le nord, de blocs erratiques provenant des monts Long Range et un éventail bilobé de drumlins, de cannelures et de collines rocheuses (crag-and-tail) se terminant contre la moraine de Leg Pond. Dans les basses terres occidentales, elle forme le complexe arqué et interlobaire des moraines de piémont. Une *mince couche de till*, de 2 à 5 m d'épaisseur, apparaît dans les basses terres occidentales sous forme de nappe de drift dans laquelle les blocs erratiques de Long Range diminuent linéairement vers l'ouest. Elle contient d'innombrables moraines de De Geer composées de sédiments marins raclés du fond marin. *Une mince couche discontinue de till* de 1 à 2 m d'épaisseur recouvre la partie médiane du plateau le long de l'ancienne ligne de partage glaciaire.

De rares *sédiments fluvioglaciaires* forment un réseau de dépôts de remplissage de crevasses derrière la moraine de Leg Pond, ainsi que des kames, des moraines de kames, et des traînées fluvioglaciaires, là où les glaciers émissaires de Long Range avaient fusionné et aboutissaient à des dépressions bordant des escarpements et à des fjords. Les *dépôts marins* se sont accumulés de façon variable au-dessous de la limite de submersion post-glaciaire occurs near present sea level in association with the outer Piedmont Moraines, is a deepwater facies of meltwater sediment discharged near ice margins. Blankets and veneers of sandy gravel occur as marine limit ice-frontal deltas with associated outwash terraces and as fossiliferous beach ridges developed by reworking of till. *Fluvial deposits* are rare because there is little source material and few graded streams. Postglacial terraces, modern fans and deltas occur sporadically along a few major valleys. *Colluvial deposits* comprise rubble aprons and fans below failing rock cliffs along much of the highland and upland margins. The frequency and rate of slope processes range from numerous landslides and avalanches over talus slopes, local slumps in marine clays, to wide- spread solifluction of till at the highest elevations. A Grey Islands cliff that is sagging by deepseated creep. *Organic deposits* of peat and muck occur both on slopes and in depressions on rock and till. Plateau-type bog is extensive on lowland rock plains, innumerable small basin bogs occupy rocky terrain, and ribbed fens cover smooth till surfaces. Solifluction and cryoturbation are active above 400 m, converting bedrock to rubble and sorting till into stripes, terraces, lobes, and mud boils. *Ground ice* may be present in peat and till on Highlands of St. John.

comprise entre 70 et 142 m. Des boues pierreuses généralement fossilifères, qui se trouvent à proximité du niveau actuel de la mer, associées aux moraines de piémont extérieures, représentent un faciès de mer profonde avec sédiments déposés par les eaux de fonte près des marges glaciaires. Des couvertures et placages de graviers sableux constituent des deltas de front glaciaire correspondant à la limite marine, avec terrasses de débris fluvioglaciaires associées, et des levées de plage fossilifères résultant du remaniement du till. Les *sédiments fluviatiles* sont rares en raison du manque de matériaux d'origine et de cours d'eau à profil d'équilibre. Les terrasses post-glaciaires, les cônes alluviaux et les deltas récents apparaissent sporadiquement dans quelques grandes vallées. Les *colluvions* comprennent des plaines d'épandage et cônes de débris alluviaux au-dessous de falaises en voie d'écroulement sur une grande partie des marges des hautes terres et des hauts plateaux. La fréquence et la vitesse des mouvements le long des pentes se traduisent par de nombreux glissements de terrain et avalanches sur les pentes des talus d'éboulis, des écoulements locaux de gravité dans les argiles marines, une solifluxion massive du till aux altitudes les plus élevées. L'une des falaises des îles Grey montre un affaissement causé par la reptation des couches profondes. Des *dépôts organiques* tourbeux et vaseux existent à la fois sur les pentes et dans les dépressions présentes dans la roche et dans le till. Les tourbières hautes occupent de vastes étendues dans les plaines rocheuses des basses terres, d'innombrables petites tourbières de bassin occupent les terrains rocheux, et des tourbières cannelées recouvrent les surfaces lisses de till. La solifluxion et la cryoturbation sont actives au-dessus de 400 m, convertissant la roche de fond en débris et triant le till qui forme alors des bandes, des terrasses, des lobes et des ostioles. Il peut y avoir de la *glace souterraine* dans la tourbe et le till des hautes terres de St. John.

The Quaternary history features a multiphase glacial sequence, reconstructed from differentially degraded glacial terrains, from end moraine patterns, and from crosscutting ice-flow indicators. Postglacial sea-level recovery is documented by the age and elevation of shell-bearing littoral deposits. Three main glaciations of decreasing extent are recognized; the last was Late Wisconsinan and had six phases. During the earliest major glaciation, recorded by the summit terrain, Laurentide ice that covered the area, depositing erratics on Grey Islands. Coastal cirques, now submerged 40 m, were occupied during low relative sea levels. presumably during the onset of each glaciation. Valleys cut in bedrock in this terrain are about 50 times larger than within the area deglaciated 10 ka and thus may date from the Middle Pleistocene. If so, it probably correlates with the greatest glaciation in the region which deepsea cores date to oxygen isotope stage 12 (440 ka BP). The next major glaciation featured radially-flowing Long Range ice which extended eastward to Groais Island, Horse Islands, and Cape St. John on Baie Verte Peninsula and left a trimline sloping west to Gulf of St. Lawrence. It is estimated geomorphologically to be about ten times older than postglacial time and thus possibly late Middle Pleistocene.

L'histoire du Quaternaire englobe une séquence glaciaire multiphasée, que l'on a reconstituée à partir de terrains glaciaires dégradés de façon différentielle, à partir des schémas des moraines frontales et d'indicateurs de l'écoulement glaciaire tranversal. La remontée post-glaciaire du niveau de la mer est décrite d'après l'âge et l'altitude des sédiments coquilliers littoraux. On a identifié trois grandes glaciations d'étendue progressivement réduite; la dernière remonte au Wisconsinien supérieur et comportait six phases. Pendant la plus ancienne des glaciations majeures, dont témoigne le terrain sommital, les glaces laurentidiennes qui recouvraient la région ont déposé des blocs erratiques dans les îles Grey. Des cirques littoraux, maintenant immergés dans 40 m d'eau, ont été occupés pendant des périodes de niveau de la mer relativement bas, sans doute au commencement de chaque glaciation. Sur ce terrain, les vallées entaillées dans la roche en place sont environ 50 fois plus vastes que dans la région déglacée il y a 10 ka, donc elles pourraient dater du Pléistocène moyen. Si tel est le cas, elles présentent probablement une corrélation avec la plus grande glaciation de la région, que l'examen de carottes prélevées en mer profonde permet de dater du stade isotopique 12 (440 ka BP). La glaciation majeure suivante comprenait les glaces de Long Range qui s'écoulaient radialement, et se prolongeaient vers l'est jusqu'à l'île Groais, aux îles Horse et au cap St.John dans la péninsule de Baie Verte et ont laissé une ligne de transition forestière s'inclinant vers l'ouest jusqu'au golfe Saint-Laurent. On estime que géomorphologiquement, elle est environ dix fois plus ancienne que l'époque post-glaciaire, donc pourrait dater de la fin du Pléistocène moyen.

Glacial events referred to the Wisconsinan Stage probably began with re-occupation of the now-submerged cirques. Next, probably during Late Wisconsinan time, Laurentide ice crossed Strait of Belle Isle but did not reach Grey Islands. It merged with Long Range ice at ≈300 m, producing southwestward flow toward Esquiman Channel, a presumed calving bay in Goldthwait Sea. Eventually, the two ice domains were separated by recession and by incursion of Goldthwait Sea. As Laurentide ice disappeared from the area, Long Range ice, in a series of coalescent tidewater glaciers, calved landward across the lowlands. Temporary stabilization built the interlobate Piedmont Moraines complex approximately 12.6 to 12.8 ka BP, renewed recession ca. 12.3 ka produced the De Geer moraines as marine sediment plowed up during successive annual winter pulses. Leg Pond Moraine, an extension of nearby Ten Mile Lake Moraine which was built about 10.9 ka, represents a re-expansion of Long Range ice that is attributed to a climatic reversal 10-11 ka when the Polar Front shifted. Final retreat of Long Range ice built the Cloud River Moraines ≈8-9 ka. Small moraines on Highlands of St. John may date to the Little Ice Age. Nivation and cryoturbation continues above 400-600 m.

Postglacial relative sea level changes result mainly from deglacial isostatic crustal rebound and thus reflect the gross distribution and retreat pattern of ice masses. Marine limit elevation increases northwestward from 70 to 142 m, showing that Laurentide ice dominated crustal deflection, although Long Range ice imparted a slight doming. Dated littoral features document shorelevel displacement since 14 ka. Initially the sea regressed at 4.3 m/100 a, with a possible stillstand at 11 ka (induced gravitationally by the Leg Pond readvance?) that produced larger beaches and sand plains at 60-70 m which may correlate with a rock platform south of the area ("Bay of Islands Surface"). The sea in the northern part regressed continuously to its present level, although terraces below 10 m imply small fluctuations. Since 5 ka the rate has slowed to 0.1 m/100 a. Sea level in the southern part apparently passed below its present position about 8 ka and has subsequently risen. A fossil cliff at 2-3 m, bracketed to ≈2 ka, represents a small transgression. It and the relative rise are tentatively attributed to crustal subsidence due to migration and collapse of the glacial crustal forebulge.

Les épisodes glaciaires désignés du nom de stade wisconsinien ont probablement débuté par la réoccupation des cirques maintenant submergés. Ensuite, probablement au cours du Wisconsinien supérieur, les glaces laurentidiennes ont traversé le détroit de Belle Isle, mais n'ont pas atteint les îles Grey. Elles ont fusionné avec les glaces de Long Range au niveau approximatif de 300 m, et produit un écoulement vers le sud-ouest en direction du passage Esquiman, qui était sans doute une baie de vêlage des icebergs dans la mer de Goldthwait. Finalement, les deux domaines glaciaires ont été séparés par le recul et par l'incursion de la mer de Goldthwait. À mesure que disparaissaient de la région les glaces laurentidiennes, les glaces de Long Range, formant une série de glaciers d'estran coalescents, ont vêlé des icebergs en direction des terres à travers les régions basses. Une stabilisation temporaire a édifié le complexe interlobaire des moraines de piémont il y a approximativement 12,6 à 12,8 ka BP; un retrait ultérieur survenu il y a environ 12,3 ka a généré des moraines de De Geer à mesure que les sédiments marins étaient ramenés à la surface du sol par les glaces au cours de phases hivernales successives et annuelles. La moraine de Leg Pond, prolongement de la moraine de Ten Mile proche formée il y a environ 10,9 ka, témoigne d'une réavancée des glaces de Long Range, attribuable à un changement climatique daté de 10 à 11 ka, survenu pendant le déplacement du front polaire. Le retrait final des glaces de Long Range a édifié les moraines de Cloud River il y a approximativement 8 à 9 ka. Les petites moraines des hautes terres de St. John pourraient remonter au Petit âge glaciaire. La nivation et la cryoturbation se poursuivent au-dessus de 400 à 600 m.

Les variations relatives post-glaciaires du niveau de la mer résultent principalement de la compensation isostatique qui a suivi la déglaciation et reflètent ainsi la distribution générale et la configuration du retrait des masses de glace. L'altitude de la limite marine augmente vers le nord-ouest de 70 à 142 m, et montre que les glaces laurentidiennes ont le plus influencé la déflexion crustale, même si les glaces de Long Range ont causé un léger bombement du terrain. Les structures littorales qui ont fait l'objet d'une datation témoignent d'un déplacement du niveau de la ligne de rivage depuis 14 ka. Initialement, la mer a reculé à la vitesse de 4,3 m par siècle, et il y a peut-être eu stagnation des glaces il y a 11 ka (commandée par la charge glaciaire qu'a produite la réavancée des glaces de Leg Pond ?); ainsi se sont formées des plages et des plaines sableuses plus étendues à l'altitude de 60 à 70 m, qui se laissent peut-être corréler avec une plate-forme rocheuse située au sud de la région ("Bay of Islands Surface"). Dans la partie nord, la mer a continuellement régressé jusqu'à atteindre son niveau actuel, mais des terrasses situées au-dessous de 10 m suggèrent de petites fluctuations. Depuis 5 ka, la vitesse a ralenti et n'est plus que de 0,1 m par siècle. Dans la partie sud, le niveau de la mer est apparemment passé au-dessous de sa position actuelle il y a environ 8 ka et est ensuite remonté. Une falaise fossile située de 2 à 3 m, d'âge approximatif 2 ka, indique une modeste transgression. Celle-ci et la montée relative du niveau de la mer sont provisoirement attribués à la subsidence crustale résultant de la migration et de l'affaissement du bombement crustal périphérique.

INTRODUCTION

The study area corresponds to two maps at 1:250 000 of the National Topographic System (12 I and 2 L). It covers most of Northern Peninsula of Newfoundland between latitudes 50°00′ and 52°00″ (Fig. 1), embracing the northern end of the Long Range Mountains together with fringing uplands and lowlands. Adjacent submarine areas are not included in the study, but figure in the interpretation.

This report presents the final results of surficial mapping of this area of Newfoundland at 1:250 000 scale. This work, the second phase of a systematic Quaternary reconnaissance, began on the west coast because airphoto reconnaissance by the author for the Glacial Map of Canada (Prest et al., 1968) revealed an assemblage of glacial and marine features which indicated that the area held the best potential for developing a stratigraphic framework for the Quaternary history of the island. The first phase dealt with northern end of the peninsula

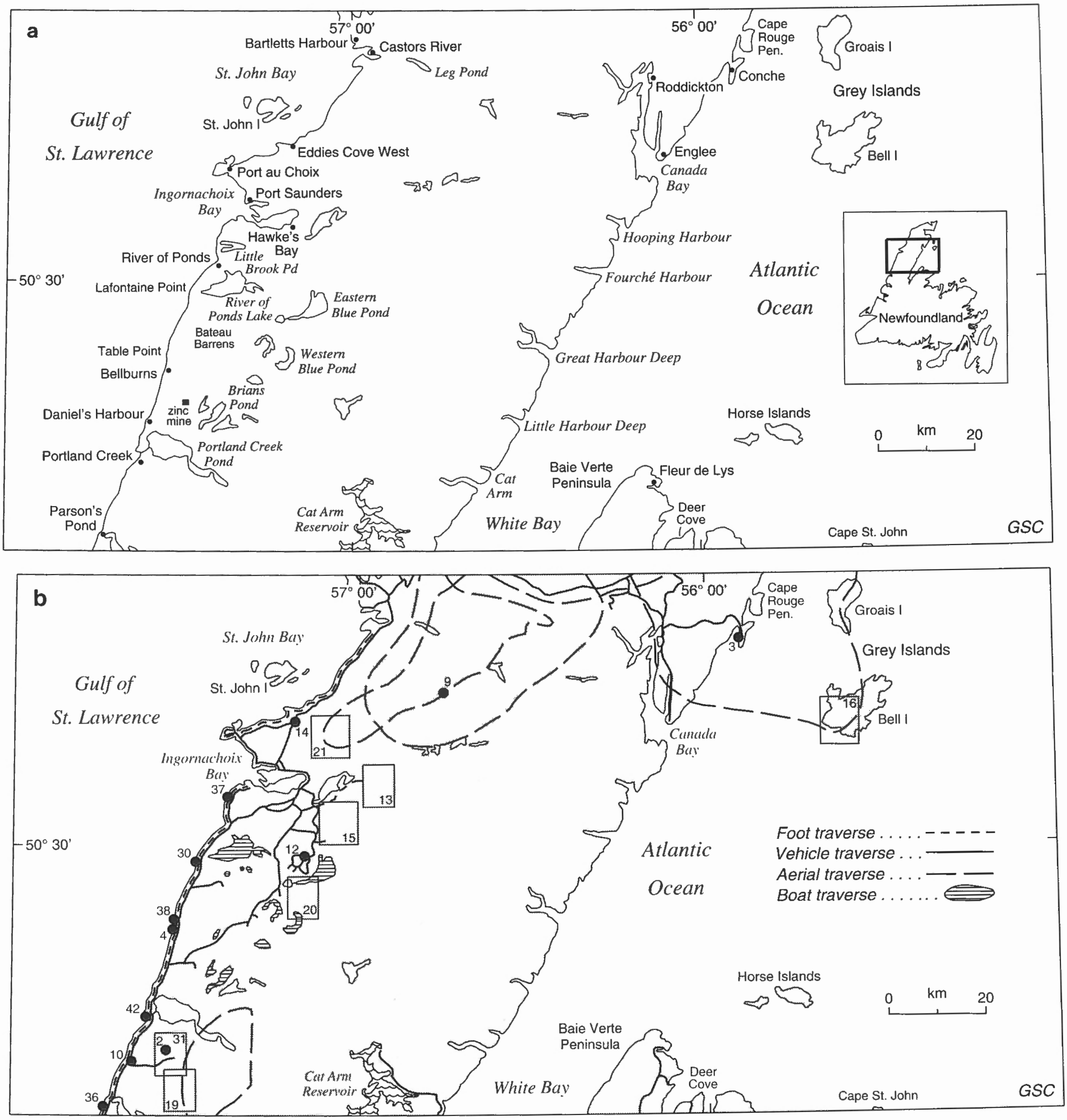


Figure 1a, b. Place names and localities mentioned in the text and field traverses made by foot, vehicle, boat, and air. Photo illustrations indicated by numbered boxes and dots.

(Grant, 1986a, 1992) and was affiliated with the Strait of Belle Isle Project (Bostock et al., 1983), which determined its scope and its 1:125 000 scale. The present study incorporates and adapts the southern quarter of that earlier work.

Systematic mapping of this area grew out of a local, detailed, surficial geology study near Daniels Harbour (Grant, 1972a). That study was part of a multidisciplinary pilot project to test the value of Quaternary mapping as a component of regional geochemical surveying aimed at detecting mineral occurrences in drift-covered areas (Hornbrook et al., 1975). The objective was to map the surficial materials at 1:50 000 scale to assess how dispersal patterns in glacial and derived sediments related to known bedrock sources of zinc mineralization. Further impetus for wider reconnaissance mapping was given by the emerging need for regional data on terrain conditions, surficial materials, and glacial transport for a variety of applications, among them a proposed hydroelectric transmission corridor from Labrador (Lower Churchill Development Corporation, 1979).

Preliminary interpretations of a variety of aspects have been reported in other contexts (Grant, 1969a, b, 1970, 1972a, b, c, 1973a, b, c, 1974a, b, c, 1976, 1977a, b, c, 1980, 1987, 1992; Prest et al., 1968; Cumming and Grant, 1974; Grant and King, 1984; Proudfoot et al, 1988). Surficial geology maps were open filed in preliminary form at 1:50 000 scale (Grant, 1973c) and in final form at 1:250 000 scale as GSC Maps 1610A and 1622A (Grant, 1986a, 1986b).

The objective of the work was to map, describe, and explain the unconsolidated deposits and landforms to provide areal knowledge of geology and terrain as background information relative to land-use planning, mineral exploration, location of granular deposits, community water supply problems, forestry, urban and industrial development, and various aspects of engineering construction, and to determine the Quaternary history. Map units were delineated by interpreting airphotos at 1:50 000 scale; additional detail on the lowlands was gleaned from 1:13 500 scale, infrared airphotos in black and white.

The airphoto interpretation is ground-controlled by observing natural exposures accessible by various modes of ground and air transport (Fig. 1). Field work focused on the western and northern lowlands because transport was largely limited to vehicle, boat and foot traverse. On the lowlands, we walked all of the coast, circumnavigated the larger lakes by boat, and traversed the network of forest roads and trails. Observations in the highland interior were limited to foot traverses of Highlands of St. John and to two helicopter flights and one fixed-wing reconnaissance of parts of the western highlands and Grey Islands. Delineation of map units is considered to be reasonably well controlled over the entire area because, where surficial deposits are thickest and most complex, as in the lowlands, access is good and exposures numerous; where overburden is thin or absent, as in the highland interior, the surficial geology is readily visible on airphotos because of sparse or absent vegetation.

Information from parts of the western and northern lowlands is adapted from 1969-1972 studies (Hornbrook et al., 1975; Grant, 1992). In connection with work in adjacent areas, new exposures were briefly examined in 1975, 1980, and 1984 to address stratigraphic and geomorphological questions. Guidebooks prepared for field excursions to the area on behalf of the International Union for Quaternary Research (Grant, 1987) and the Geological Association of Canada (Proudfoot et al., 1988) greatly advanced the interpretation and provided a basis for this account. Malacological study of the author's marine-shell collections by Robertson (1987) provided insight into the paleoecology. After field work for this study was completed, detailed surficial mapping began in part of the northwestern lowlands (Mihychuk, 1986; Proudfoot and St. Croix, 1987), yielding findings that generally support these results, but differ in some details.

The accompanying Map 1622A classifies surficial materials in terms of genesis, composition, and surface form. Where appropriate, these are subdivided as to thickness and texture. Map units are arranged in approximate stratigraphic order based on superposition and dating. Also shown are various geomorphic features, including those attributable to bedrock structure. Based on the map information, this report describes the extent, stratigraphy, and chronology of deposits and landforms. For certain small summit areas that have problematical form and composition, various alternative interpretations are advanced. Major practical applications of the information are suggested. The surficial geology map provides an inventory of surficial materials and landforms that could be used, for example, for reforestation planning and for alignment and costing of hydroelectricity transmission corridors and inground communications cables. The data on glacier flow directions and transport are pertinent to geochemical surveying and drift prospecting for minerals. The occurrence of good-quality granular materials (glaciofluvial and coarse marine deposits) is pertinent to groundwater exploitation and provision of construction materials. The identification of karstic areas and of slopes and materials subject to rock creep, landsliding, and soft-sediment slumping, could be of interest to those concerned with foundation instability.

Climate, vegetation and soils

Climate

Regional oceanographic and atmospheric circulation

Present climate helps us to understand certain geomorphic features and the local style of glaciation. It determines , which in turn is a useful indicator of substrate. The climate of Northern Peninsula is surprisingly cool (subarctic according to the Köppen classification) considering the latitude. It is essentially continental and most air masses arrive from the interior, despite its maritime location and frequent incursions of oceanic air (Hare and Thomas, 1974).

Local climate varies greatly because proximity to the sea induces a pronounced coastal effect and because the high relief produces a strong elevational gradient (Hare, 1952; Energy, Mines and Resources Canada, 1985). The area is chilled by a near-freezing stream of polar water, Labrador Current and its branches, which encircle Newfoundland. The 0°-5°C water maintains frigid conditions throughout the year on the Atlantic side. The west coast of the island is only slightly warmer (10°C), except in winter when Gulf of St. Lawrence is frozen over. The degree of chilling differs with the season and latitude on either coast because of temperature contrasts and sea ice extent.

Temperature

Average temperature decreases northward and inland onto the central highlands (Environment Canada, 1975a, b). At Daniels Harbour, the only station in the area, mean annual temperature is 3.4°C and mean daily temperature ranges from -7.4°C in February to +14.6°C in August. Through the year, mean daily temperature maxima range from -0.7° to +17.6°C; mean daily temperature minima from -11.6° to +11.6°C. The mean annual maximum and minimum are 6.8° and 0.1°C, respectively. Thaw begins April 25 in the south and ends November 15; it begins May 3 in the north and ends November 5, giving 200 frost-free days in the south and frost-free 180 days in the north (10 days fewer on the highlands). The vegetative season lasts 120-150 days (10 days fewer on the highlands).

The position of the mean annual 0°C isotherm provides an approximate boundary for ground ice is thus useful in understanding geomorphic processes such as cryoturbation, gelifraction and solifluction. Although no measurements were made in this area, elevation of thi sisotherm is interpolated from measurements at two stations outside the area. St. Anthony and Stephenville are both 200 km equidistant to the north and south of Daniels Harbour and have mean annual temperatures that are 1.5°C lower and higher, respectively. At St. Anthony the mean annual 0°C isotherm lies just above sea level; at Stephenville it lies at 470-550 m (Titus, 1965). Assuming the 0°C isotherm slopes regularly between these two points, it is estimated to intercept the land surface at about 300 m in the south and about 150 m in the north part of the study area. Comparable figures were obtained by Schmidlin (1988) from empirical data.

Precipitation

Precipitation in the study area is the lowest in Newfoundland because moisture arrives mainly on southerly winds and the area lies in the lee of the central Newfoundland highlands. It decreases northward from 940 mm at Daniels Harbour and increases on the highlands to more than 1100 mm. Precipitation is fairly evenly distributed through the year; November is the wettest month, April the driest. About one third of precipitation falls as snow; the Atlantic coast gets more than the Gulf coast.

Wind, fog, and cloudiness (Middleton, 1935) reflect the moisture advection patterns and the interplay of maritime and continental air masses. Wind is light to moderate throughout the year, swinging from westerly in summer to northwesterly in winter; above 500 m winds are strong and southwesterly. In winter, strong, cold, dry winds from the northwest minimize accumulation on exposed western summits. Fog shrouds the coast about 20% of the time, mostly in summer. Ceiling height is below 300-600 m about 30% of the time.

Vegetation

The rigorous conditions are reflected in a northern boreal forest which grades northward and upslope to tundra (Hare, 1950; Rowe, 1972). The western and northern lowlands support a closed forest of black spruce balsam fir increases to the south. Along the eastern maritime fringe, white spruce is an accessory. On exposed sites, such as along the coast, fog and salt spray promote stunted forms which, because of wind stress during the growing season, are sculpted into streamlined and almost prostrate forms called tuckamore (krummholz). Extensive bogs and fens occupy rock and morainal depressions and cover large areas of poorly drained, fine grained, till and marine sediment.

The forest thins out and becomes stunted on the steep margins of Long Range Mountains (Fig. 2). Above about 400 m, it is gradually replaced by barrens of mosses and shrubs (tundra) with patches of stunted spruce and tamarack mainly along waterways and inland shores. Treeline is thus fairly distinct and reflects the average elevation of cloud ceiling height and freezing level. On the western Long Range summits treeline descends northward from 600 to 300 m; on the eastern margin, it is about 100 m lower. Because they are at or near their climatic limit throughout the area, the trees are sensitive to site factors such as drainage and soil type, so forest patterns facilitate recognition of minor relief and drainage differences related to surface material and landform.

Soils

Pedology of the study area has not been surveyed, except for Damman's study of the northern lowland (1963). Humo-ferric and ferro-humic podzols are the most common soils developed on till and waterlaid sediment. Lithic regosols occur on the small areas of disintegrated bedrock.

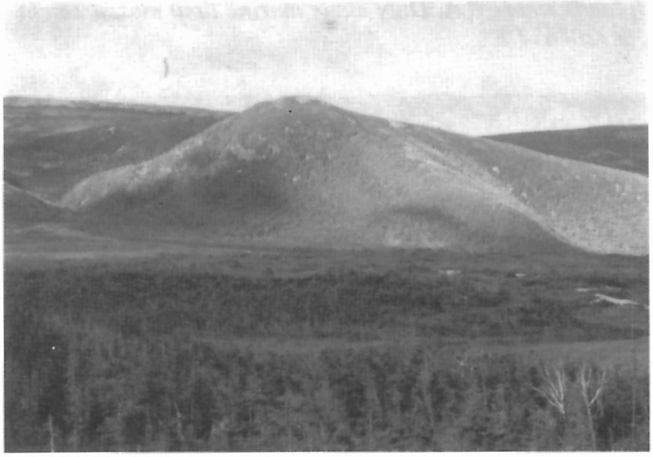


Figure 2. *Long Range fault-line escarpment separating coastal lowland (foreground) from highland plateau; note position of treeline. GSC 204634-J*

Settlement, industry and access

According to recent census data (Statistics Canada, 1988), population is concentrated in five towns: Englee (1012), Roddickton (1223), Port au Choix (1291), Port Saunders (822), and Daniels Harbour (566) where fish processing plants for the offshore fleet are located, along with medical and industrial service facilities. Forest products from extensive woods operations are handled in Hawke's Bay (547). The rest of the population is dispersed in numerous small coastal villages (Fig. 3) and hamlets (Fig. 4) and depend on the inshore fishery. Newfoundland Zinc Company operates a mine near Daniels Harbour and Newfoundland Hydro maintains a hydroelectric generating facility which impounds several plateau rivers near Cat Arm. Except for a few isolated villages in the eastern fiords, which are served by coastal freighters, all settlements are linked by paved roads that connect with the Trans-Canada Highway at Deer Lake. The interior is unsettled and without roads except that to the Cat Arm reservoirs and the branch highway across the northern lowlands to Englee. The study area lies midway between the two major airports at Deer Lake and St. Anthony, but there are emergency landing strips at Portland Creek and Port au Choix.

Figure 3. *Conche looking toward faultline scarp of Coastal Uplands where R.A. Daly made marine limit measurement. GSC 204634-E*

Figure 4. *Bellburns, a typical Gulf coast fishing hamlet. GSC 204634-M*

Previous work

Quaternary features in western Newfoundland have provoked debate about glaciation and sea-level change since the advent of geological exploration. As reviewed by Tucker (1976), Grant (1977a, 1992), Rogerson (1981, 1982, 1983), Brookes (1982), and Grant and King (1984), controversy arose whether the area was glaciated by Laurentide Ice Sheet or by independent local Newfoundland ice cap(s) (Murray, 1883; Chamberlin, 1895). Debate continues about whether and when Newfoundland may have been invaded by Laurentide ice (e.g., Mayewski et al., 1981). On western coastal summits, including Highlands of St. John in this area, botanists found isolated relict plants (Fernald, 1911, 1925, 1930, 1933) and certain beetle species (Lindroth, 1963), which were thought to have survived the last glaciation in ice-free refugia. Coleman (1920, 1926, 1930) provided geological support for this nunatak hypothesis, noting summit glacial terrains just south of the area that have greater geomorphic maturity than on the adjacent lowlands. He recognized three altitudinal levels of differently weathered terrain and reasoned that the differences reflected the duration of subaerial exposure since they were last glaciated; the least weathered type represented the extent of the last ice sheet. Tanner (1940), however, discounted their significance as relicts of former glaciations. The biological basis for the nunatak hypothesis has been recently reaffirmed in several areas of the region (Belland, 1981, 1987; Hamilton and Langor, 1987).

A century ago, emerged Pleistocene shorelines were also being interpreted as a measure of the extent and thickness of former ice sheets. From the regional upwarp pattern De Geer (1892) postulated a separate ice cap on Newfoundland during the last glaciation, its effect being superimposed on a general northwestward tilt toward the Laurentide centre of loading. Daly (1920, 1921) concurred on the basis of additional measurements, including a few near Conche. Fairchild (1918) further suggested that Newfoundland glaciers were large enough to produce a domical upwarp pattern.

The controversy prompted the Geological Society of America in 1939 to fund a three-part reconnaissance of landforms, glaciation, and emerged shorelines in western Newfoundland. Twenhofel and MacClintock (1940) drew attention to smooth, mature-surfaced summits (just south of the area), which contrasted with strongly glaciated valleys. MacClintock and Twenhofel (1940) attributed the smoothness to complete Late Wisconsin glacier cover on Newfoundland. Richards (1940) catalogued marine fossils in the area. Flint (1940) noted emerged shorelines that were tilted up to the northwest and proposed that Labradorean ice had inundated Newfoundland completely during the last glaciation. However, he later thought that Long Range Mountains had supported local ice caps before and after the regional glaciation (Flint, 1951). These views, particularly those of Flint, supplanted the earlier concept and remained unchallenged until the first geological surveys.

The area was the first to provide evidence of ice cap glaciation in Newfoundland. Bedrock mapping, particularly the earliest surveys, reported radially oriented ice flow markings and drift dispersal (Foley, 1937; Heyl, 1937; Betz, 1939; Watson, 1947; Fritts, 1953; Oxley, 1953; Nelson, 1955; Baird, 1957; Woodard, 1957; Waitt, 1981; Bostock et al., 1983).

Reconnaissance airphoto interpretation (Grant 1970, 1972a) revealed a radial ice flow imprint, as well as a central belt of nonglacial topography thought to mark one of several ice divides on the island (Grant, 1974b). Data from various areas fostered a hypothesis that Newfoundland was glaciated largely by local ice caps which, during the last or Late Wisconsinan advance, reached to only relatively low elevations near the coast and extended only a short distance offshore (Grant, 1977a; Brookes, 1977a; Tucker and McCann, 1980; Prest, 1984). Offshore work on the adjacent Northeast Newfoundland Shelf has yielded stratigraphic and chronometric evidence for limited Late Wisconsinan glacier extent (Slatt, 1974; Dale, 1979; Haworth et al., 1976a, b; Piper et al., 1978; Dale and Haworth, 1979; Mudie and Guilbault, 1982; Scott et al., 1984). Dating and pollen analysis of lake sediment cores on Baie Verte Peninsula (Dyer, 1986) and the western and northern lowlands (T.W. Anderson, personal communication, 1987) help constrain reonstructions of lateglacial ice retreat.

Few Quaternary features had been mapped prior to this study; data were limited to sparse indications on two glacial maps of Canada. The 1958 Glacial Map of Canada showed postglacial submergence of the western lowland and striations radiating from the highlands (Wilson et al., 1958). The 1968 Glacial Map of Canada refined the submergence limit and showed end moraines and De Geer moraines noted on airphotos (Prest et al., 1968). Interim results of this study pertaining to glacier extent during the last glacial maximum (e.g., Grant, 1977a, 1987, 1989) have been incorporated in a recent map compilation (Dyke and Prest, 1987).

The study area features a suite of three glacial terrains at different elevations and with different apparent geomorphic maturity. They resemble surfaces termed weathering zones elsewhere in eastern Canada. Most authors now regard these as relict glacial terrains that have been subaerially altered because they were not glaciated during the last advance. Others, however, (e.g., Mayewski et al., 1981, p. 82) explained the differences in terms of the varying effect of cold- and warm-based ice beneath an all-encompassing regional ice sheet. Thus, the question remains whether they simply reflect basal thermal regime or whether, according to classical Davisian geomorphological principles, the maturity

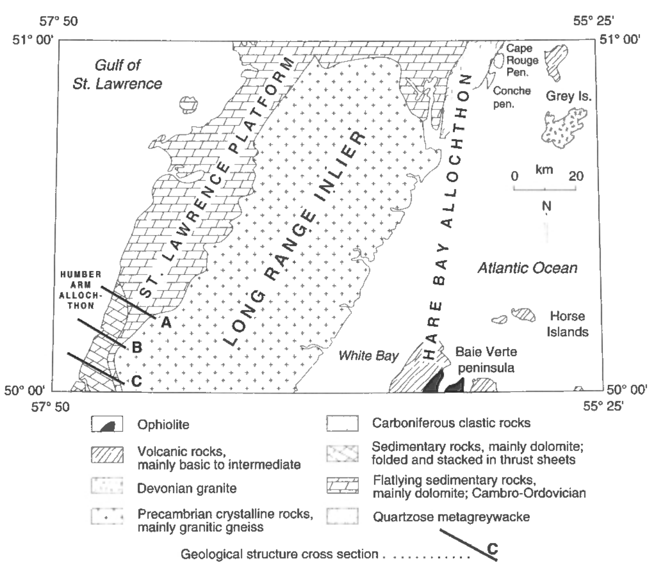


Figure 5. Generalized bedrock geology (adapted from various sources).

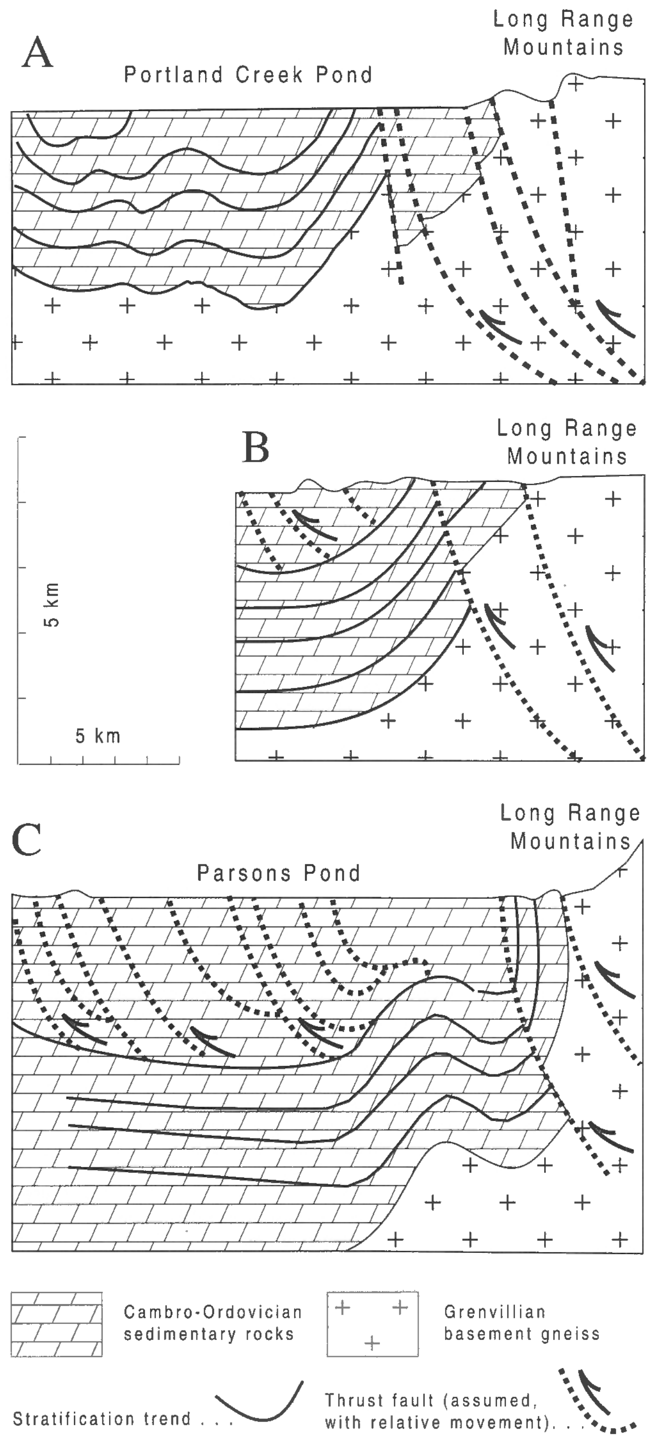


Figure 6. Structural cross-sections located on Figure 5 (from Cawood and Williams, 1986b).

reflects either structure (in terms of rock susceptibility to disintegration), process (as a function of the vigour of mass wasting at higher elevations), or time, meaning the duration of subaerial exposure since last glacier cover. The mapping delineates the boundaries of the glacial terrains in relation to rock type and elevation and thus addresses this important Quaternary issue. Mapping does suggest that time was a contributing factor, although it does not definitively answer the questions of origin and age.

BEDROCK GEOLOGY

The Great Northern Peninsula is part of the Appalachian Orogen where plate collision has assembled three broad, contrasting rock groups or lithotectonic terranes: a crystalline massif, a fringing sedimentary rock assemblage, and an outlying allochthon, or overthrust sheet, of volcanosedimentary rocks (Williams, 1978) (Fig. 5, 6). Each has characteristic landforms and suites of surficial sediment.

Crystalline rock terrane

The highlands are a block of cratonic basement composed of Precambrian gneiss intruded by granitic plutons and a swarm of diabase dykes (Bostock et al., 1983; Erdmer, 1984, 1986). Termed the Long Range Inlier, it was thrust up, together with its cover rocks, against, and locally onto, the sedimentary platform during the final phase of the plate collision, the Acadian Orogeny. The cover rocks were eroded during Cenozoic time.

Sedimentary rock terrane

About 3 km of Cambro-Ordovician sedimentary rocks underlie the lower ground; outliers form a few western highland summits (Knight and Boyce, 1984; Knight, 1985, 1987). Laid down on the edge of the proto-Atlantic Iapetus Ocean, the lower part consists of resistant Bradore Formation sandstone and Hawke Bay Formation quartzite, with an intermediate recessive unit of Forteau Formation limestone. The upper part is nonresistant dolostone, limestone and shale of the St.

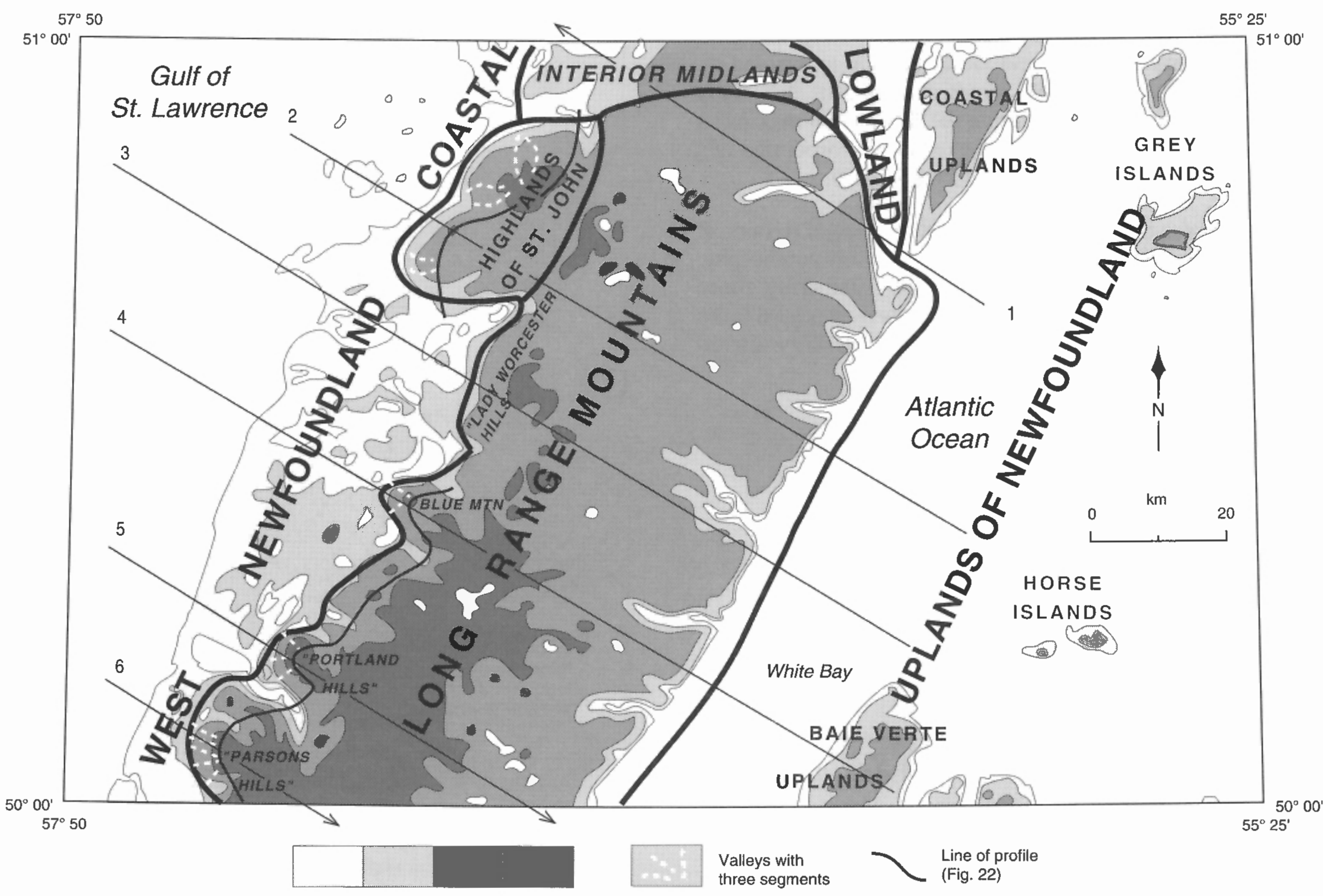


Figure 7. *Relief (adapted from NTS 12 NE and Hydrographic Chart 801) and physiographic divisions (after Sanford and Grant, 1976) showing location of topographic profiles (Fig. 11) (informal names italicized).*

George, Table Head, and Goose Tickle Formations. Late Paleozoic plate collision produced varying structural styles (Fig. 6). Strata in the southwest have been folded, faulted, and stacked in slices to form a complex thrust assemblage called the Humber Arm Allochthon, whereas the remainder, called the St. Lawrence Platform, remains flatlying to gently warped (Williams et al., 1985; Cawood and Williams, 1986a, b; Cawood et al., 1987).

Metamorphic volcanic sedimentary terrane

The eastern part of the area belongs to a second thrust assemblage, the Hare Bay Allochthon, which was emplaced by westward transport during the later Taconic Orogeny. Pebbly metagreywacke underlies the high ground north of Canada Bay; outliers of Carboniferous sandstone and shale form Conche and Crouse Peninsulas (Bostock et al., 1983). Grey Islands are composed of Devonian granite and Paleozoic pelitic and psammitic schist (Kennedy et al., 1973). Baie Verte Peninsula and outlying Horse Islands are composed largely of ophiolites and basic to intermediate volcanic rocks (Baird, 1951).

PHYSIOGRAPHY AND GEOMORPHOLOGICAL HISTORY

The area belongs to the Appalachian Physiographic Region and (excluding adjacent submarine portions) is a mosaic of eight strongly differentiated areas of highlands, uplands and lowlands (Fig. 7). Names of the major divisions are according to Bostock (1972) and Sanford and Grant (1976); five smaller informal physiographic units are added for discussion purposes. Each division corresponds to a separate lithotectonic unit, lies at a different average elevation, and has a distinctive suite of landforms and surficial materials.

Long Range Mountains

Long Range Mountains, part of the Great Northern Highlands that form the backbone of Newfoundland, are a rectangular block about 50 km wide and 100 km long bounded by steep escarpments. The eastern margin along White Bay is a faultline scarp (Fig. 3) that descends more than 1000 m to the floor of a submarine channel, which has been excavated 300-400 m into a graben of Carboniferous sedimentary rocks.

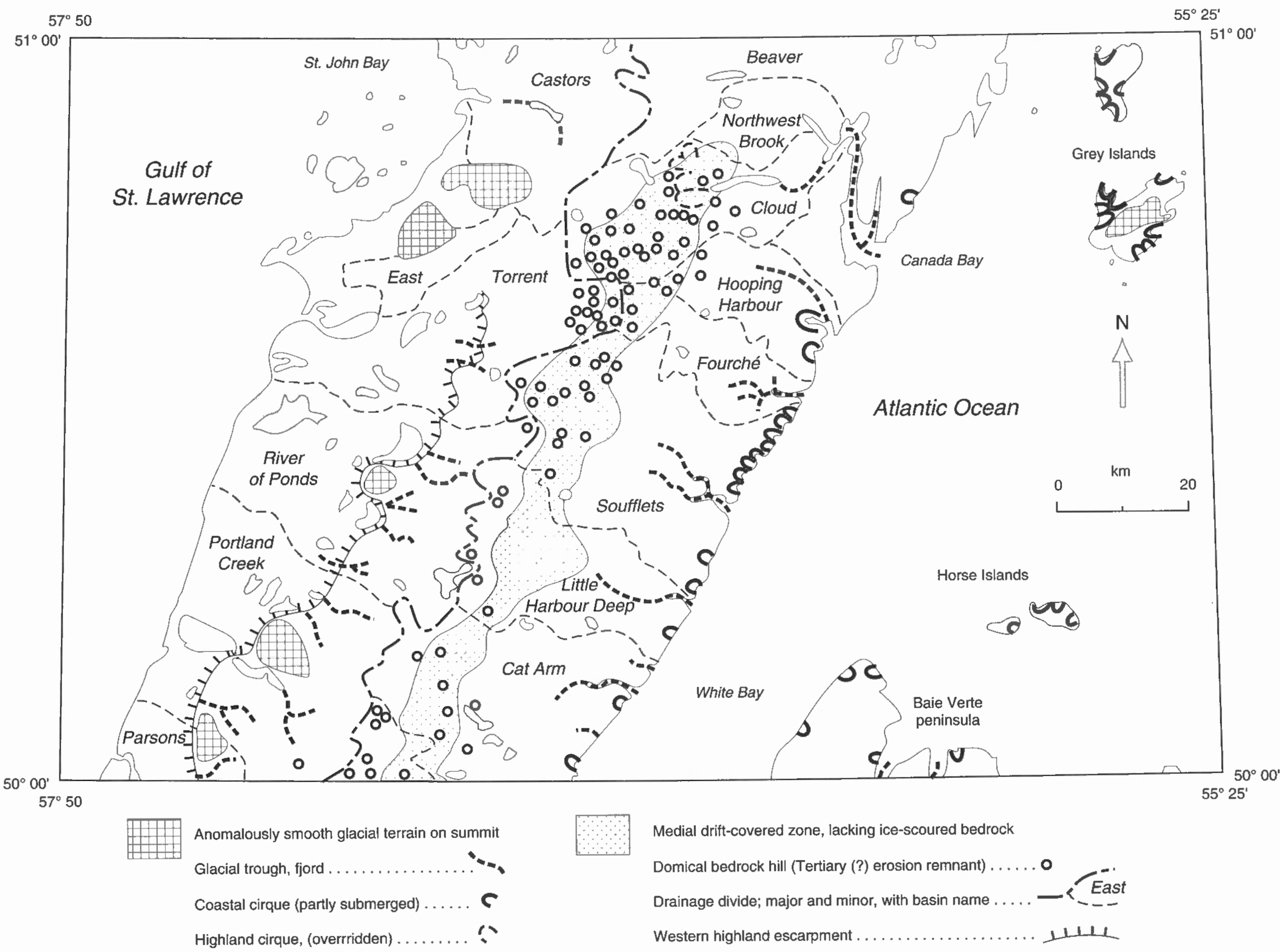


***Figure 8.** Selected physiographic and geomorphic features.*

The scarp, gently curved in two broad, symmetrical arcs, that perhaps reflect warping of the fault plane, is incised by spectacular sinuous, dendritic fiords and indented by cirques whose floors are now 20-40 m below sea level (Fig. 8). The western Long Range escarpment changes form from north to south, reflecting major differences in its structure. North of Blue Mountain, the escarpment forms a relatively gentle ramp that declines under the sedimentary cover rocks. South of Blue Mountain, it is a steep 600-m escarpment that closely follows the boundary thrust fault and thus has not been backwasted appreciably. The southern segment has a peculiar scalloped outline with semi-circular salients 10-20 km across which occur only on that portion of the basement block which is overthrust on the sedimentary terrane (Williams et al., 1985; Cawood et al., 1987) (Fig. 6). The promontories are therefore suggested to be original and characteristic features of the western thrust front of the Humber Arm Allochthon. The promontories are separated by glacial troughs (Fig. 8), the deepest of which is >700 m, and are incised by large V-shaped gorges (Fig. 8), which are noteworthy in that they comprise two or three segments increasing in size upstream and appear to correspond to different glacial terrains (described later). Their possible chronological significance is treated under "Quaternary history".

Surface character

Only a 10 km wide marginal zone is deeply dissected to 300-600 m; the interior presents an undulating to rolling plateau, with local relief of generally less than 100 m (Twenhofel, 1912). Locally, it is rugged, dissected, and ribbed with diabase dyke ridges. Outlying remnants of Cambrian strata form mesa-like hills, such as Blue Mountain, and hogbacks and flatirons e.g. "Lady Worcester Hills" (informal name). Generally, the rock surface is rugged, glacially scoured, and denuded. The structural fabric is etched out as a network of depressional lineaments; rock basins abound, and the bare hills are littered with erratics (Fig. 9). In sharp contrast, on the western margin, there are a few summits, also composed of the same crystalline rock, have a smoothly rounded form, notably Gros Paté, "Parsons Hills" (informal name), and "Portland Hills" (informal name) (Fig. 10). The age and origin of these surfaces is problem- atical, and their possible

Figure 9. *Long Range surface showing westward-stossed outcrop (G. Dewar, pilot, is scale figure). GSC 203284-W*

Figure 10. *The anomalously smooth, rounded summits ("Parsons Hills" area) typical of the highest part of the Long Range Peneplain. The road follows one of the interlobate moraines. GSC 204634-C*

significance is discussed under "Quaternary history". The medial zone has generally level rock terrain that is obscured by shallow drift and muskeg and interrupted by peculiar elliptical and circular bedrock hills (Fig. 8) 1-2 km wide and 50-70 m high. Therse hills are typical of granitic terranes in Newfoundland and may be relicts of pre-Quaternary weathering. Six cirque-like basins, with rounded headwalls and floors at 200-300 m, occur in upper Cloud River valley (Fig. 8).

Long Range Peneplain

The plateau level, though moderately dissected, has generally accordant summits rising from about 300 m on the eastern margin to about 600 m on the western margin (Fig. 11). The highest hills are generally isolated, smooth-topped prominences, which are situated at the brink of the western escarpment and have remarkably similar summit elevations (e.g., Highlands of St. John (625 m), Blue Mountain (648 m) (Fig. 12), Gros Paté on "Portland Hills" (656 m), and "Parsons Hills" (≥655 m)).

The sloping plateau is the western and highest remnant of an ancient erosion surface or planation level, termed the Long Range Peneplain (Twenhofel and MacClintock, 1940), which extends across Newfoundland. Grant (1987) correlated it with a similarly extensive, uplifted and tilted peneplain in Maritime Provinces, namely the Fundy Surface (Bird, 1972) (Fig. 11). Mathews (1975) suggested that it was cut, raised, then put in relief by middle to late Tertiary erosion of the adjacent weaker rocks. This age assignment is supported by the fact that it is at a marked angle to the sub-Cretaceous basement unconformity and has the same inclination as Tertiary unconformities in the shelf sequence (Grant 1987, 1989).

Possible exhumed unconformities

Parts of the Long Range plateau depart from the generally eastward-sloping peneplain level, forming north- and west-sloping ramps or facets inland of the highest summits (1 in Figure 11). The northern ramp is 15 km wide and slopes ≈10 m/km, whereas the western ramp is 5 km wide and slopes

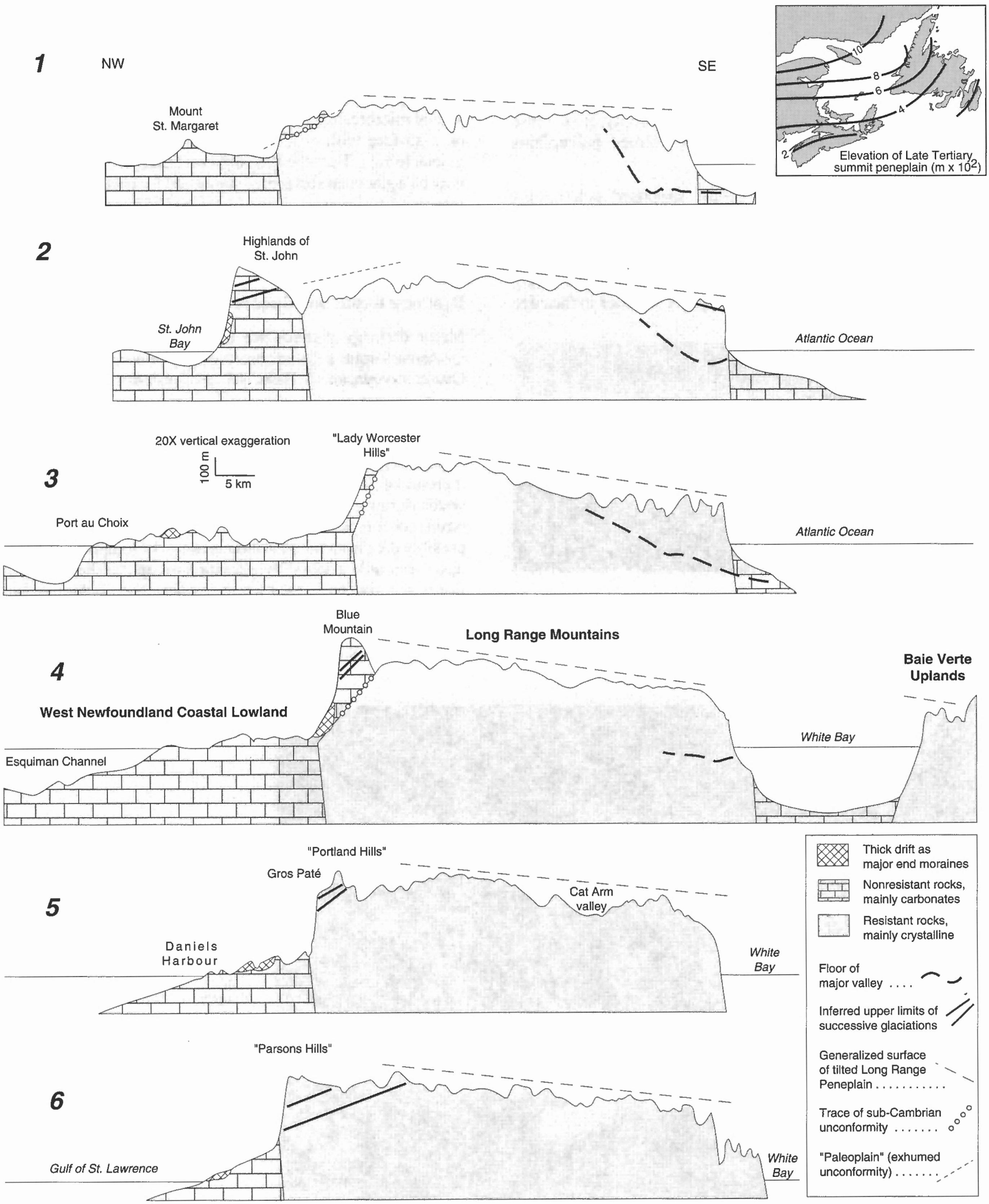


***Figure 11.** Topographic profiles, including submarine areas.*

≈200-300 m/km. Because their attitudes are comparable to those of sub-Cambrian basement unconformity, as can be seen from the trace of the edge of the Bradore Formation (Fig. 13) and its contact with the overlying Forteau Formation (Bostock et al., 1983, Map 1495A), he ramps may represent unroofed portions of the basement unconformity. If so, these exhumed erosion surfaces would be termed paleoplains (Ambrose, 1964).

The geomorphic aspect of the supposed paleoplains appear similar to that of the unconformity where it is exposed at the edge of the Cambrian cover rocks. Where the paleoplain forms the present landscape it has the same high-relief, knob-and-basin glacial topography as elsewhere on the Long Range plateau. This glacial topography continues to the edge of the Cambrian cover rocks, which appear to fill up the hollows, as shown near Mount Hogan where glacial troughs cut through the "Lady Worcester Hills" (Fig. 13). On outcrops the hummocky surface varies from deeply weathered to cleanly polished (Bostock et al., 1983, p. 33-34) but show no glacial microfeatures. The Cambrian strata thus appear to rest on a surface with essentially the same form as the present glacial terrain. Thus the Precambrian basement unconformity may be a glaciated surface, as suggested for parts of the Shield margin (e.g., Lawson, 1890; Christie, 1951; Ambrose, 1964; Swett, 1981). If so, some part of the present glacial aspect is inherited from a Precambrian glaciation.

Figure 12. Dried-up marl pond; Blue Mountain, a sedimentary outlier and supposed nunatak in distance. GSC 204634-D

Drainage basins and divides

Major drainage patterns are primarily the product of pre-Quaternary uplift and incision, with only minor modification by Quaternary glaciation. Eastward- and westward-directed drainage basins are roughly comparable in size (Fig. 8), despite the fact that the former are restricted to the plateau and the latter extend onto a younger lowland. The main drainage divide has a regular trend and lies near the median line of the plateau where it presumably was shifted as the western basins expanded headwards during uplift and inception of the lowland. The eastern basins cover most of the peneplain and are of uniform size. They possibly date from the planation phase prior to uplift and, if so, have been little affected by glaciation except for the cutting of fiords and troughs in their lower reaches. The northern basins are larger and extend farther inland than those to the south to the north which influenced the timing and relative vigour of the outlet glaciers that followed them.

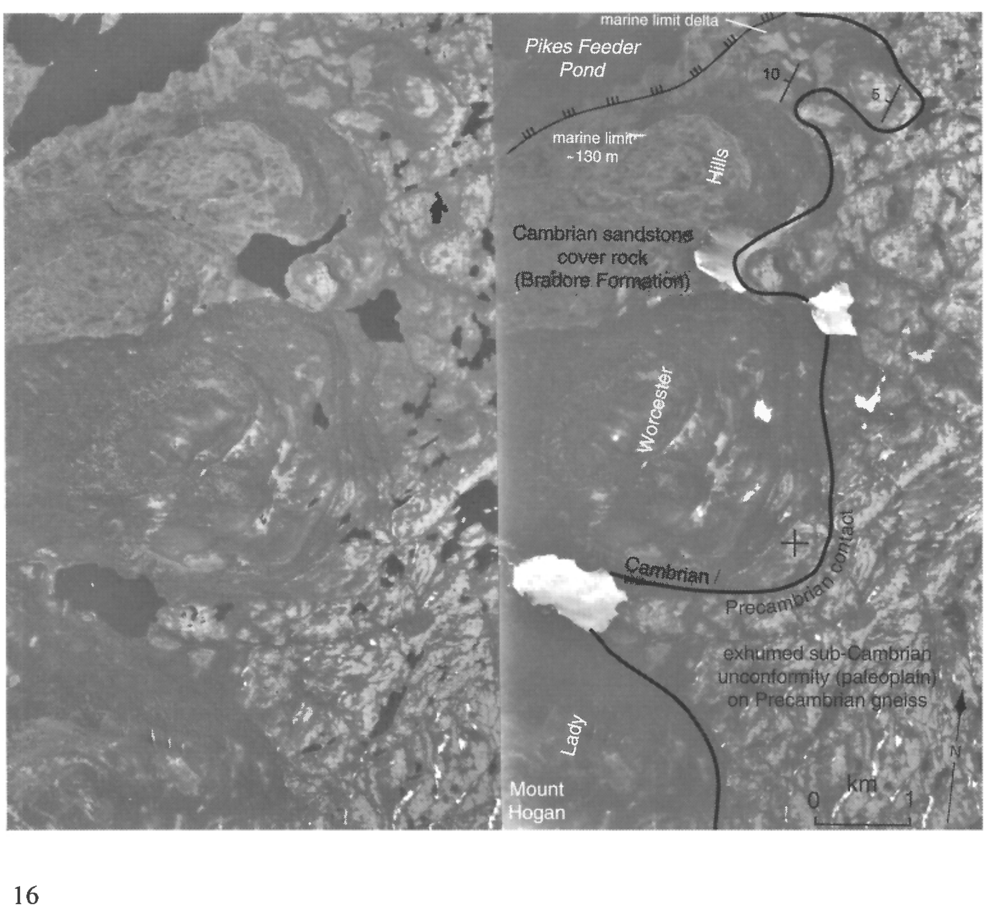


Figure 13.

Stereogram showing inferred exhumed sub-Cambrian unconformity on Precambrian gneiss, apparently showing original glacial relief, which forms a steep, secondary, west-facing facet on Long Range Peneplain; Mount Hogan area, "Lady Worcester Hills". NAPL A20003-29, 30

Uplift and dissection of the peneplain

Major valleys, like that of Soufflets River, are inset far below the peneplain. They seem graded to the adjacent submarine deeps (Fig. 11) suggesting that they date from when the submarine lowlands were excavated in later Tertiary time.

Highlands of St. John

The Highlands of St. John are prominent tablelands comprised of two smooth, domical hills called North Summit (625+ m) and South Summit or "Doctor's Hills" (504 m) which represent the northernmost extremity of the Long Range Peneplain (Fig. 11). Named the "High Lands of St. John" by Captain James Cook on the first nautical chart of western Newfoundland (British Admiralty, 1770), the hills are composed of flat-lying Cambro-Ordovician sedimentary strata which abut the Long Range crystalline block along a fault-line valley. The summits are underlain by quartzite of the Hawke Bay Formation and slope gently westward parallel to the stratification; the flanks are composed of Forteau Formation limestone. The top 50 m of each summit is a nearly featureless, prairie-like expanse; slightly lower, broad basins may be glacial or karstic, and subdued slope inflections mark the edges of resistant beds. The surface is composed mainly of till and rubble; rock outcrops are rare. Cryoturbation has arranged the frost-riven blocks into stone stripes and stone circles, patterned the till patches with mudboils, and broken the peat veneer into frost polygons. Large erratics of pink granite gneiss and other crystalline rocks are scattered in the rubble. The western face is a precipitous fault-line scarp partly covered with talus and etched at its top by nivation terraces (Fig. 14). Valleys cut in it have the same anomalous headward size increase (Fig. 7), as noted above for some Long Range summits. The possible glacial and chronological significance of the terrain contrasts and the peculiar valley development are discussed under "Quaternary history".

Figure 14. Highlands of St. John (South Summit or "Doctor's Hills"); solifluced till and rock rubble mantle the summits; nivation cuts terraces along the stratification. GSC 203284-S

"Interior Midlands"

A belt of ridges, of variable width and 100 m relief, here termed the "Interior Midlands" for convenience of discussion, lies at 100-200 m elevation as a transitional zone between Long Range Mountains and the Coastal Lowland (Fig. 7). The western and central parts have cuestas of tilted quartzite of the Hawke Bay Formation facing southward up the paleoplain, whereas the eastern part has alternating narrow ridges and karstic belts corresponding to interbedded slate and carbonate rock.

West Newfoundland coastal lowland

This narrow swath of lowland (Fig. 7) is the onshore part of a vast flat to gently undulating regional surface, the East St. Lawrence Lowland, which developed on Paleozoic sedimentary rocks largely underlying Gulf of St. Lawrence. It rises from below sea level to abut the highlands at about 150 m (Fig. 2) and its width ranges from 25 km to only 2 km at the foot of Highlands of St. John. Local relief is ≤50 m. It is underlain by Ordovician sedimentary strata – limestone and dolomite of the Table Head and St. George formations near the coast; sandstone and quartzite of the Bradore and Hawke Bay formations in the hinterland. Folding is greater inland and toward the north (Fig. 6) and is evident in the topography. Flat to gently inclined strata in the north produce gently rolling swells; crumpling and thrusting of the clastic beds near the Long Range front produces sinuous strike ridges (Fig. 15). Differential erosion in the south has left the more resistant quartzite, conglomerate and breccia beds at the base of each tilted thrust sheet as prominent linear strike ridges and isolated knobs like Portland Hill. Areas with carbonate rocks have various solution features, including karst lineaments along fracture lines, and innumerable depressions ranging from small sinkholes to large unroofed caverns. Most have ponds with distinctive white marl mud in shallow water (Fig. 12). Seasonal lakes, mainly near the coast, attest to fluctuating groundwater levels.

Uplands of Newfoundland

Defined as averaging 200 m elevation (Sanford and Grant, 1976), uplands are represented in this area by Baie Verte Peninsula, to which this report adds Grey Islands, Horse Islands, and a range of hills in the northeastern part of the area, here informally termed the "Coastal Uplands".

"Baie Verte Uplands"

This rugged, flat-topped range of hills rises to 150-300 m from submarine channels below -100 m and is bounded by steep cliffs that are indented by submerged cirques (Fig. 8). The summits decline in elevation eastward and are considered to be an extension of the Long Range Peneplain. The terrain is heavily scoured with little till and a northward stoss and lee topography.

Horse Islands

These two islands are similar to the "Baie Verte Uplands" in geology and topography and may also be an outlier of the Long Range Peneplain, although they are somewhat lower (100 m) than would be expected for their location. They too are indented by partly submerged cirque-like forms (Fig. 8).

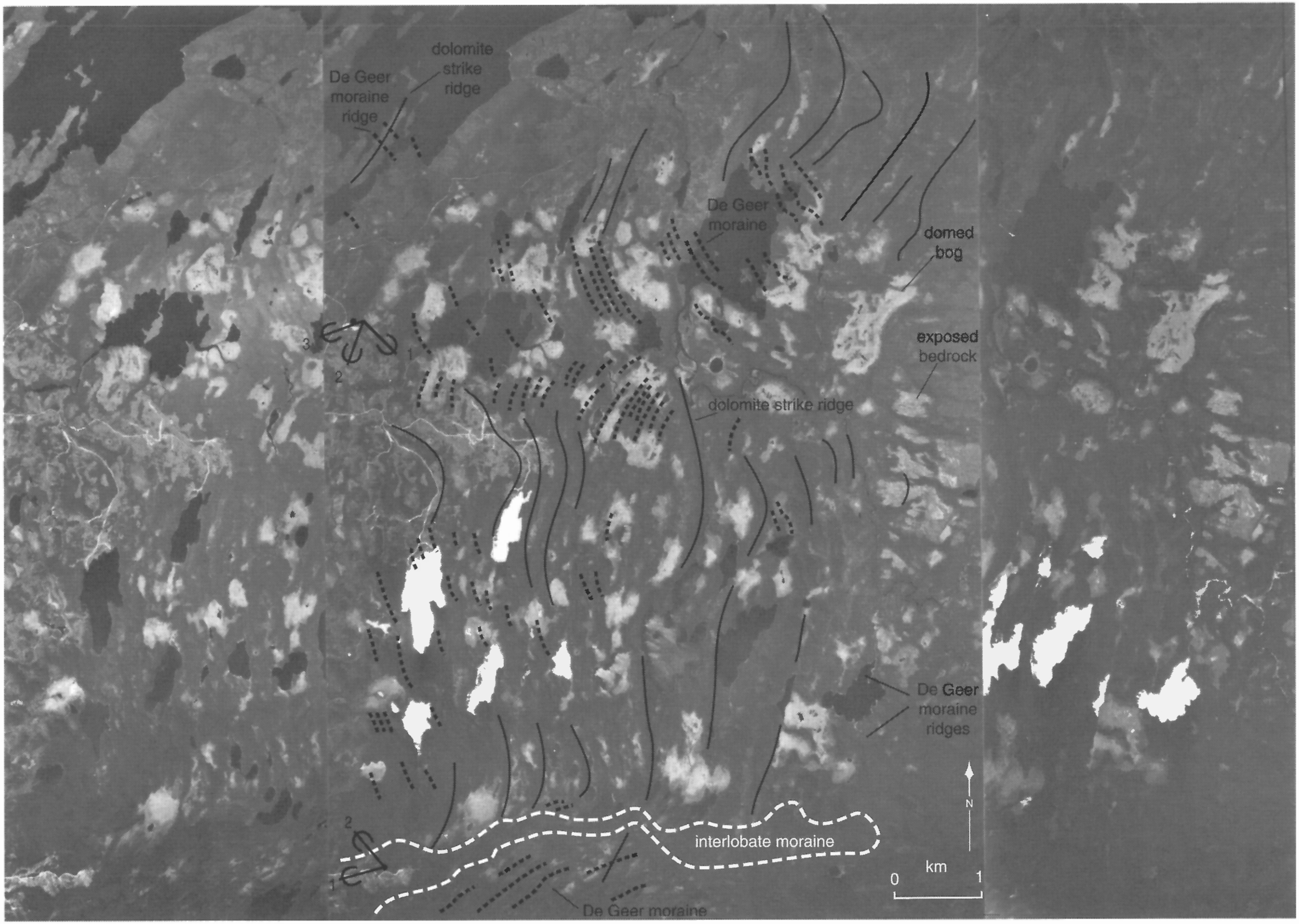


Figure 15. *Stereogram showing an interlobate moraine between fields of De Geer moraines, both superimposed on curvilinear dolomite strike-ridges. Note succession of ice flows recorded by striations. NAPL A20003-5, 6, 7*

Grey Islands

Bell and Groais islands, with sheer cliffs and rolling uplands at 200-300 m, appear to be outliers of the Long Range Peneplain, which became isolated when later preferential erosion cut the now submerged lowland on the weak Carboniferous rocks that underlie the intervening sea floor. Bell Island has a smoothly rounded till surface, whereas Groais Island has a scoured rocky surface. The cliffs, particularly of Bell Island, are embayed by eight large amphitheatre-shaped basins with sharp-edged, 200-300 m high headwalls (Fig. 8, 16). They are 1-2 km wide and U-shaped; their floors are 20-40 m below sea level. They appear to be partly submerged cirques. Two contain emerged marine sediment.

"Coastal Uplands"

A narrow range of hills at 250 m elevation is separated from the highlands by low ground along Canada Bay. The "Coastal Uplands" border Atlantic Ocean along a straight fault-line scarp that is interrupted by the Crouse and Conche peninsulas (Fig. 3), two promontories composed of Carboniferous sandstone. The strongly rolling surface of 50 m relief shows a network of fracture lineaments etched by glacial scouring.

SURFICIAL MATERIALS AND GEOMORPHIC FEATURES

Map 1622A shows the distribution of nine genetic types of surface materials and various landforms. Some units are further subdivided according to thickness or landform so as to convey important aspects of process and depositional environment. They are discussed here in order of relative age based on age estimates and/or stratigraphic succession as they appear on the legend. Their paleogeographic significance is discussed under "Quaternary history".

Pre-Quaternary units

Terrain composed mainly of bedrock

Bedrock-dominated terrain occupies about 40% of the area, chiefly on the highlands, as a broad swath surrounding the medial drift-covered zone (Fig. 17). It is characterized by a glacially scoured surface with deranged drainage systems, numerous lakes and ponds, rugged hummocky to hilly topography with numerous cliffs, and streamlined glacial erosional forms. Bedrock terrain is subdivided into three classes according to the amount of visible outcrop in relation to overburden as reflected in the degree of masking of structural relief.

Exposed bedrock (Unit Ra)[1]

Exposed bedrock, barren of vegetation except for lichens occupies about 20% of the area, mainly on the uplands and highlands above local treeline (300-600 m). Smaller areas occur along the west coast, on Grey and Horse Islands and Baie Verte Peninsula. Rock terrain typically displays a reticulate pattern of ridges and narrow linear depressions, which have been etched into the structural fabric by differential erosion. These structural features are shown on Map 1622A to emphasize their distinctiveness from glacial features and to supplement information on conventional geological maps. On crystalline rocks the pattern represents metamorphic foliation and fracture lines (Fig. 13); on sedimentary rocks, the ridges and lineaments pick out the stratification and joint trends. Some joint lineaments on the barren glaciated surface of the southeastern Long Range plateau have sharp edges unmodified by glaciation and appear to displace roches moutonées, mostly in an up-to-the-south direction. They may be postglacial faults.

Bare-rock areas have been denuded mainly by glacial erosion. The rock surface is streamlined into basins and knobs with stoss and lee asymmetry and it is commonly inscribed with various ice flow markings such as striations, miniature crag and tail, intersecting bevelled facets, and grooves that locally are large enough to be visible on airphotos. Erratic boulders of all sizes litter the surface. Other smaller areas of bare rock have been stripped by wave action during postglacial submergence, such as on Bell Island, and by nivation, as on Highlands of St. John.

Forested bedrock (Unit Rb)

Areas obscured by forest but inferred to be underlain by bedrock are recognized by numerous scattered outcrops and by structural relief patterns that are almost as clearly visible as in areas of exposed bedrock. Forested bedrock terrain occupies about 15% of the area, mainly in lower parts of the highland plateau. Like bare rock areas, it is the product of glacial scouring. Forested bedrock terrain is distinguished for practical purposes when it is necessary to know where bedrock might be exposed if vegetation was not present, such as in road construction, bedrock mapping, mineral exploration, and reforestation.

Bedrock with small undifferentiated till patches (Unit Rc)

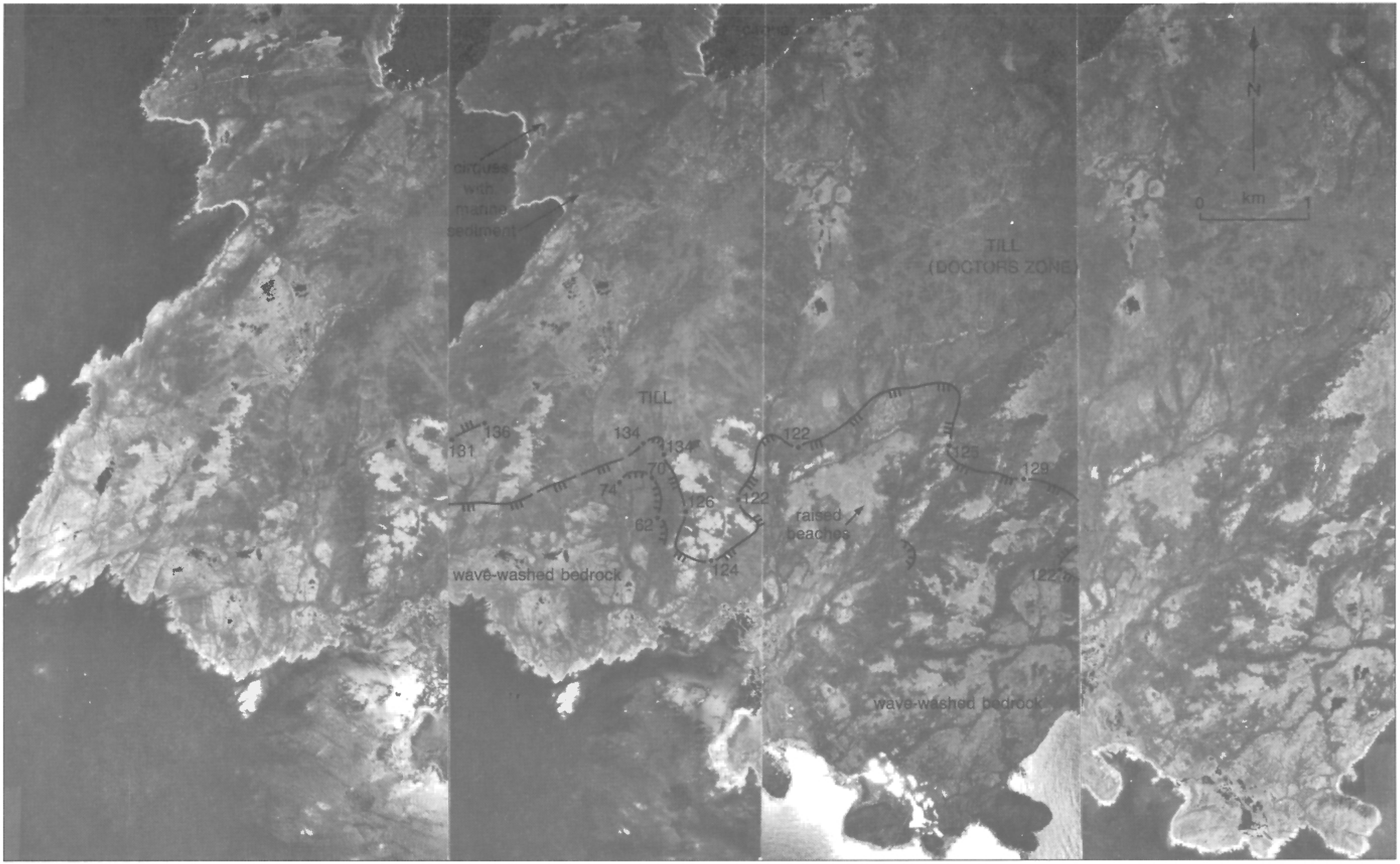
Bedrock-dominated terrain with patches of thin till covers about 5% of the area (Fig. 17). It is transitional between till and rock terrains with which its contacts are gradational. The till cover is inferred from distinctive morainal landforms, such as hummocks and ridges, and indirectly from its masking effect of the bedrock structural relief.

Pre-Quaternary and/or Quaternary units

Residuum (Unit 1)

Residuum (or regolith) is recognized only on the summits above ≈600 m of "Portland Hills" on the highland plateau (Fig. 18). It covers flat to very smoothly rounded areas that lack glacial landforms and that show no sign of the underlying Precambrian granitic bedrock structures so common in the

[1]Unit designator on Map 1622A.



Marine limit (defined, approximate, with elevation in metres) 140

Terrace (with elevation in metres) 75

Figure 16. *Stereogram of Bell Island showing old till surfaces stripped to bare bedrock by wave washing below marine limit. NAPL A20564-2, 3, 4*

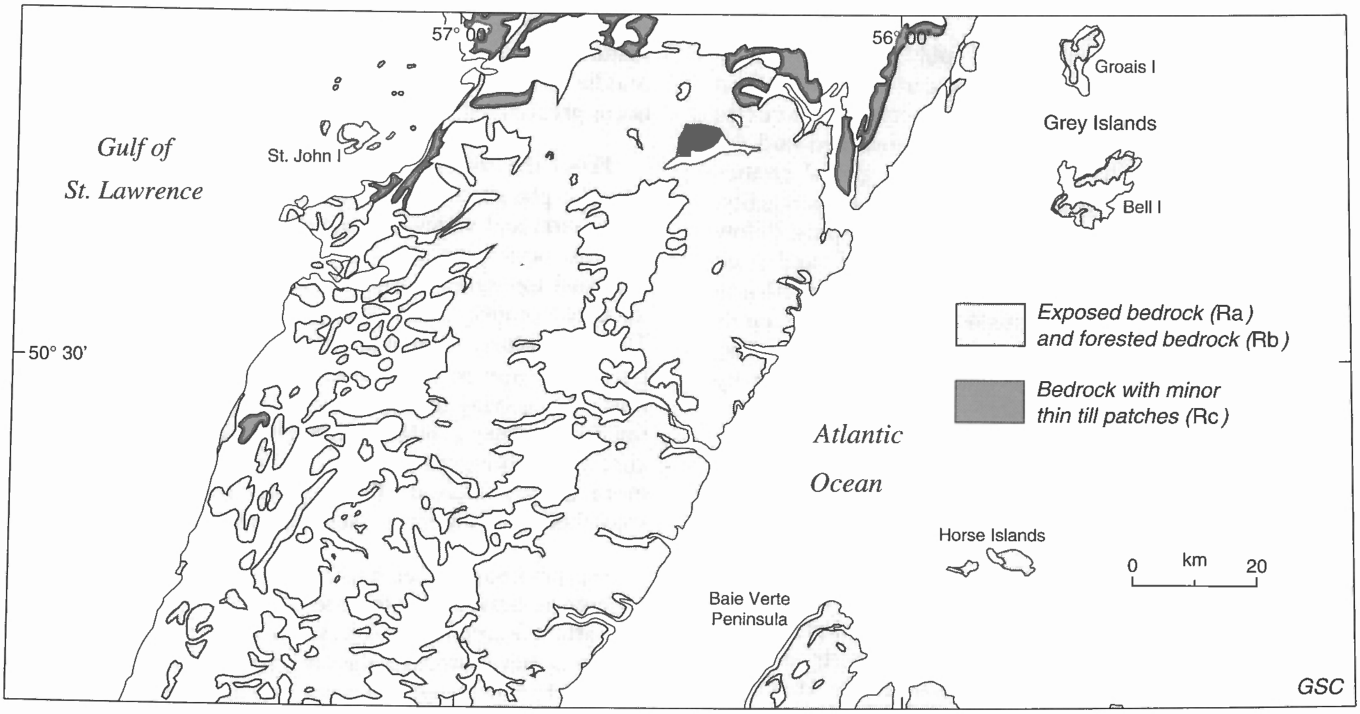


Figure 17. *Bedrock-dominated terrain (Units Ra (exposed) and Rb (forested); Unit Rc (with thin till patches). (After Map 1622A)*

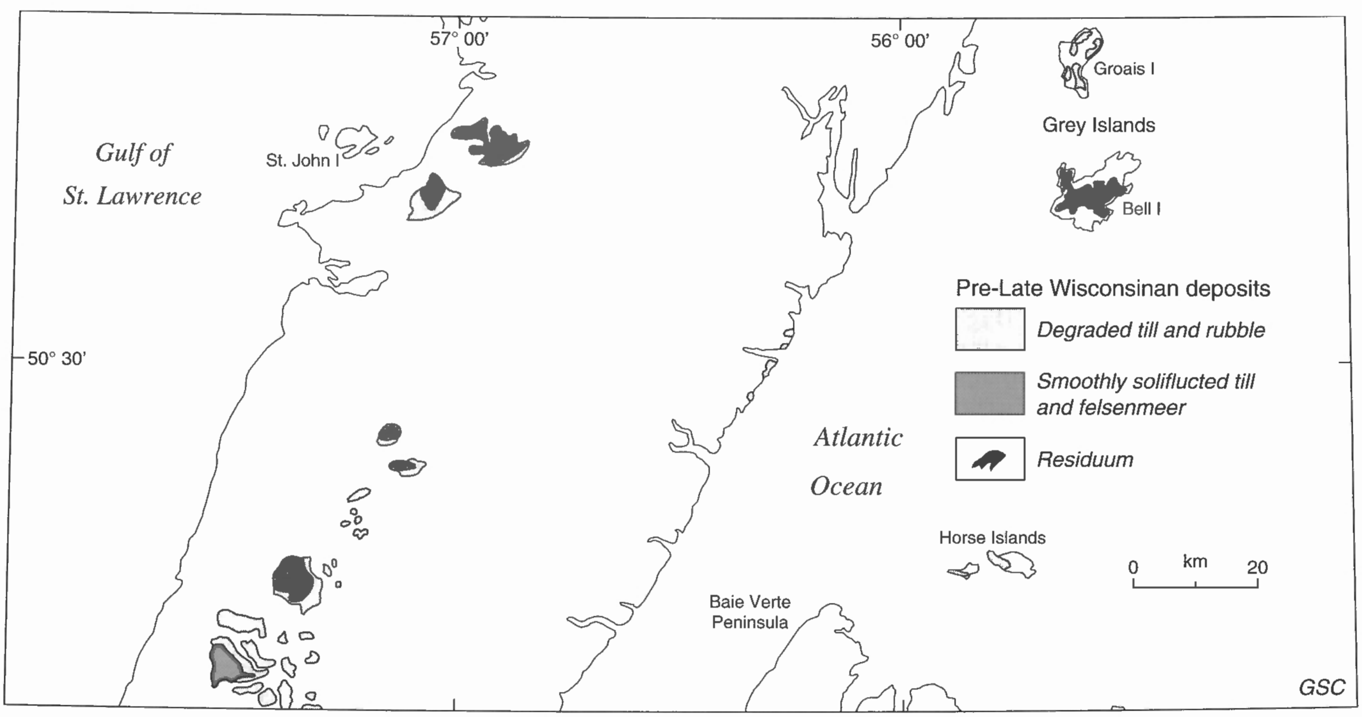


Figure 18. *Residuum (Unit 1) and pre-Late Wisconsinan glacial deposits (Units 2a; Unit 2b). (After Map 1622A)*

surrounding terrain. The surface is a blockfield ("felsenmeer") consisting of granitic rock rubble in the form of angular joint-bounded fragments produced in place by frost riving. Locally the rubble is arranged into crude stone circles and polygons, with the larger fragments sorted toward the margins, presumably by cryoturbation. No glacial erratics were seen. The fragments are virtually unaltered chemically, except for some superficial kaolinization of feldspars. Below a depth of -0.5 m, the rubble has a matrix of sand-sized mineral grains (grus) which is locally coated with reddish iron hydroxide. The rubble forms smooth, gently sloping aprons around summits where bedrock crops out as as crumbling knobs that may be tors. The contact is a slight declivity resembling a cryoplanation terrace.

The age and Quaternary paleoenvironmental significance of this terrain and its sediment cover is problematic. It depends on whether frost action has been sufficiently severe and vigorous during postglacial time to produce the observed effects. The residual terrain lies above the inferred elevation of the present mean annual 0°C isotherm (Titus, 1965; Schmidlin, 1988), so it is assumed that frost action operates during part of the year in this terrain and is thereby contributing to some degree to the production of rubble. However, the rate of frost riving is unknown, so it is impossible to judge how long it took to produce this terrain. The age and significance of this unit is discussed under "Quaternary history".

Quaternary units

Glacial deposits and ice flow indicators

Glacial deposits

Till-covered terrains are divided morphologically into three broad types according to the presence and relative relief of glacial landforms, as well as the degree of drainage integration and stream entrenchment into the underlying bedrock. Of the three glacial terrains, one is rugged, with minimal stream entrenchment; the other two (Fig. 18) are smoother and have deeper, more mature drainage systems. Each of the three glacial terrains maintains its distinctive morphological expression, whether on the granitic gneiss of (Fig. 19), the dolomite of Blue Mountain (Fig. 20), the quartzite of Highlands of St. John (Fig. 21), or the metasedimentary rocks on Groais Island. The three terrains are in contact and are arranged elevationally in the same order, locally within 50 m elevation of each other (Fig. 22). They encircle numerous western summits, being highest on the interfluves and sloping downvalley. Their upper limits range between 450 and 600 m, but there is no apparent difference from north to south. The boundary between the upper two is poorly marked or absent on the western highland escarpment, but the lower boundary is continuous around each hill group and appears to end at a moraine at 150-300 m elevation on the lowland.

Their mutual contacts vary from abrupt (i.e., the transition spans 10-20 ḿ) to blurred (200-500 m); nonetheless, they appear relatively sharp on airphotos where lengths of many kilometres around individual summits can be seen in a single view. The contacts decline seaward (radially) from the Long Range plateau. End moraine ridges and other ice-marginal features are common in the lower terrain, uncommon in the middle terrain, and rare in the highest terrain. They rarely occur precisely at the contact between terrains.

From the lowest to the highest of the three adjacent terrains, glacial relief decreases, whereas degree of stream integration and valley size increase. The lower of the three terrains, occupying about 98% of the area, has high-relief morainal topography, rugged and freshly scoured bedrock, deranged drainage, and minor stream incision in bedrock. The two higher, anomalously smooth and dissected glacial terrains occupy only ≈2% of the area on small western summits and outlying oceanic islands (Fig. 18). They have distinctly smoother, gentler and longer slopes. Bedrock outcrops are rare and drainage is more integrated and bedrock valleys more deeply incised. Two classes are recognized, one smoother and with better integrated drainage than the other.

It is not known whether there are large and significant age differences between the three terrains because the reasons for the variant morphologic expression are unclear. Although all three may have formed at the same time, they are nonetheless tentatively considered to represent a temporal sequence from highest to lowest by reason of their topographic position and the likelihood that deglaciation was not instantaneous. Whatever the provenance of the glaciers that covered the area, it is assumed that, during deglaciation, ice would retreat onshore from deep marine areas and thence inland to central higher ground. Hence, the outlying islands and the small western summits would be exposed before lower and more central terrain. Thus, the higher two glacial terrains were deglaciated before the lower rugged one and are therefore older. Accordingly they are discussed in order of assumed relative age. The reasons for the differences in topographic expression and estimates of their absolute age are discussed under "Quaternary history".

Anomalously smooth and dissected till terrains

Till and blockfields (felsenmeer) with smooth slopes (Unit 2a). The highest Long Range summits above 500-600 m (Fig. 21), and interior Bell Island, are largely till covered with broad undulations 100-1000 m wide (Fig. 19, 20). Relief features attributable to glacial erosion or deposition are absent or very vague. The ground surface in this terrain is generally smoothly rounded and gently graded, with slopes <3°. Rock basins are absent on the quartzite summit of Highlands of St. John; they are rare, dispersed, and shallow on the gneissic rocks of the Long Range plateau. Rock outcrops are rare; they occur as small knobs surrounded by rubble. Areas inferred to be underlain by bedrock are represented by loose, angular rubble with a few erratics. There is no morainic topography except for two small till ridges on the "Parsons Hills" resembling end moraines. Till surfaces on flat to gentle slopes are generally patterned with mudboils. Steeper slopes are typically ornamented with long solifluction stripes, stone gutters and large stone- and turf-banked solifluction lobes.

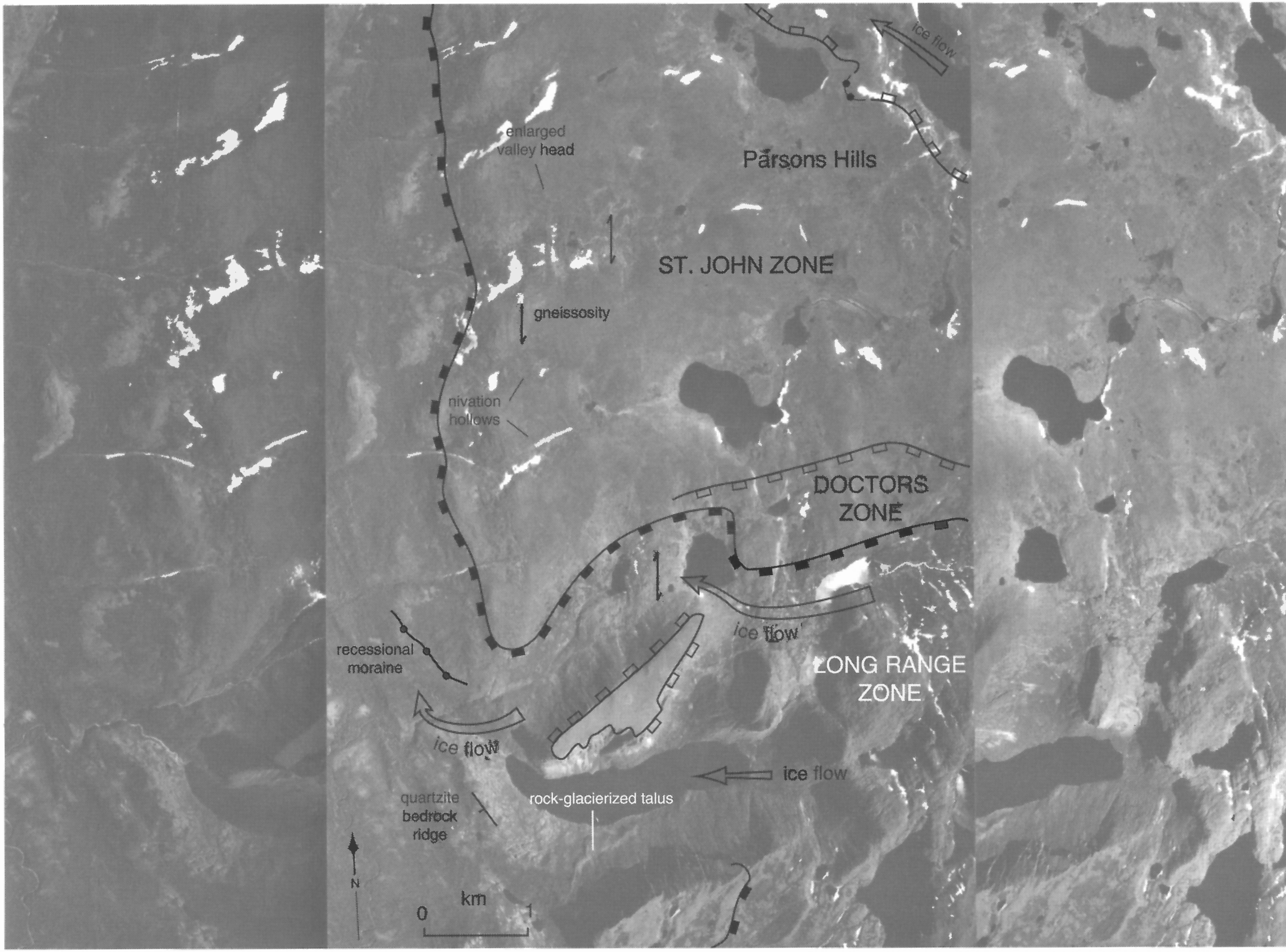


Figure 19. *Stereogram of glacial limits on Long Range Mountains summits ("Parsons Hills"); deep glacially scoured bedrock valleys separate summits with smoothly soliflucted till and rubble. NAPL A20564-43, 44, 45*

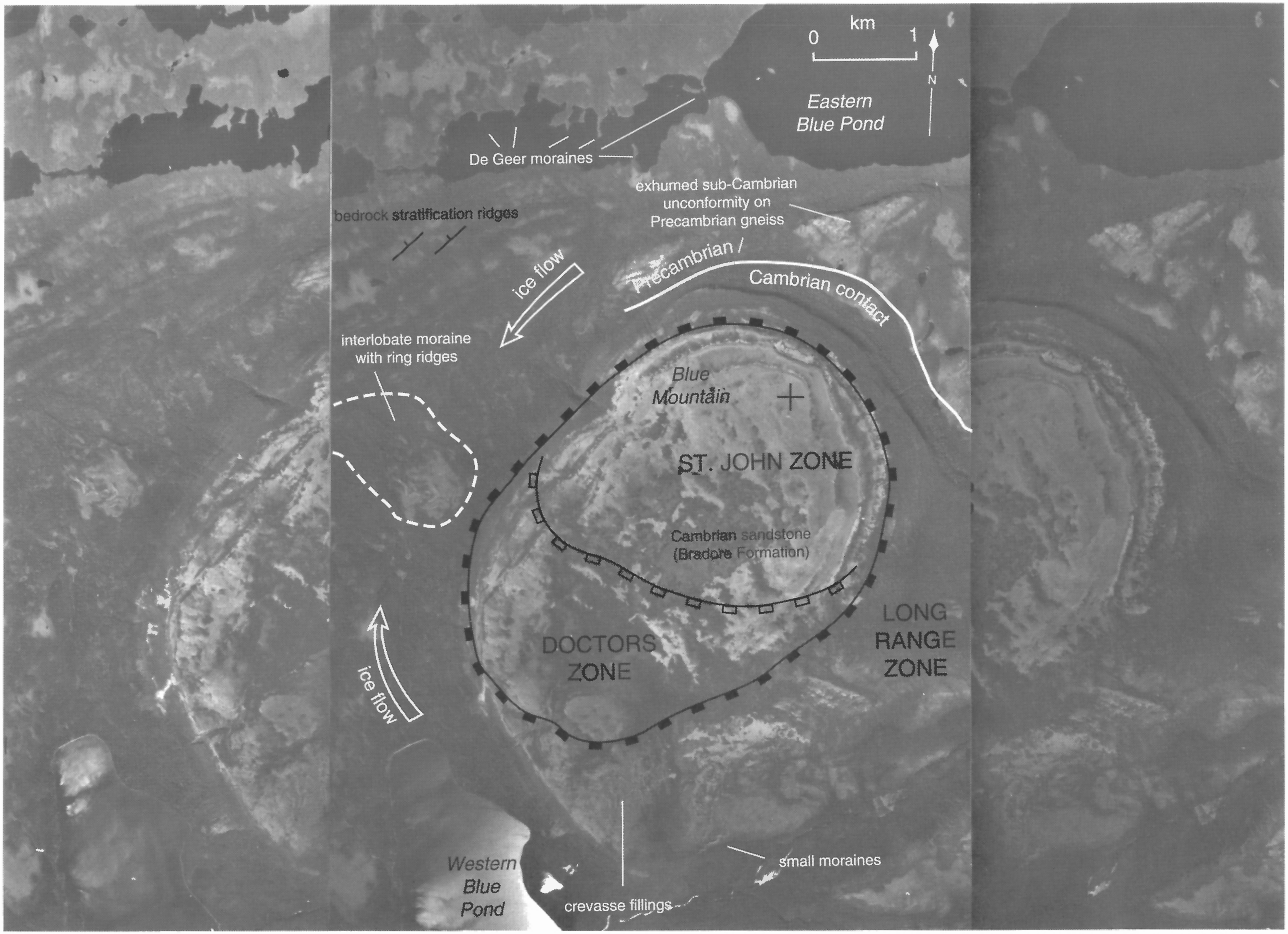


Figure 20. *Stereogram of the three glacial terrains expressed on Cambrian sandstone and Precambrian gneiss, Blue Mountain. NAPL A20567-102, 103, 104*

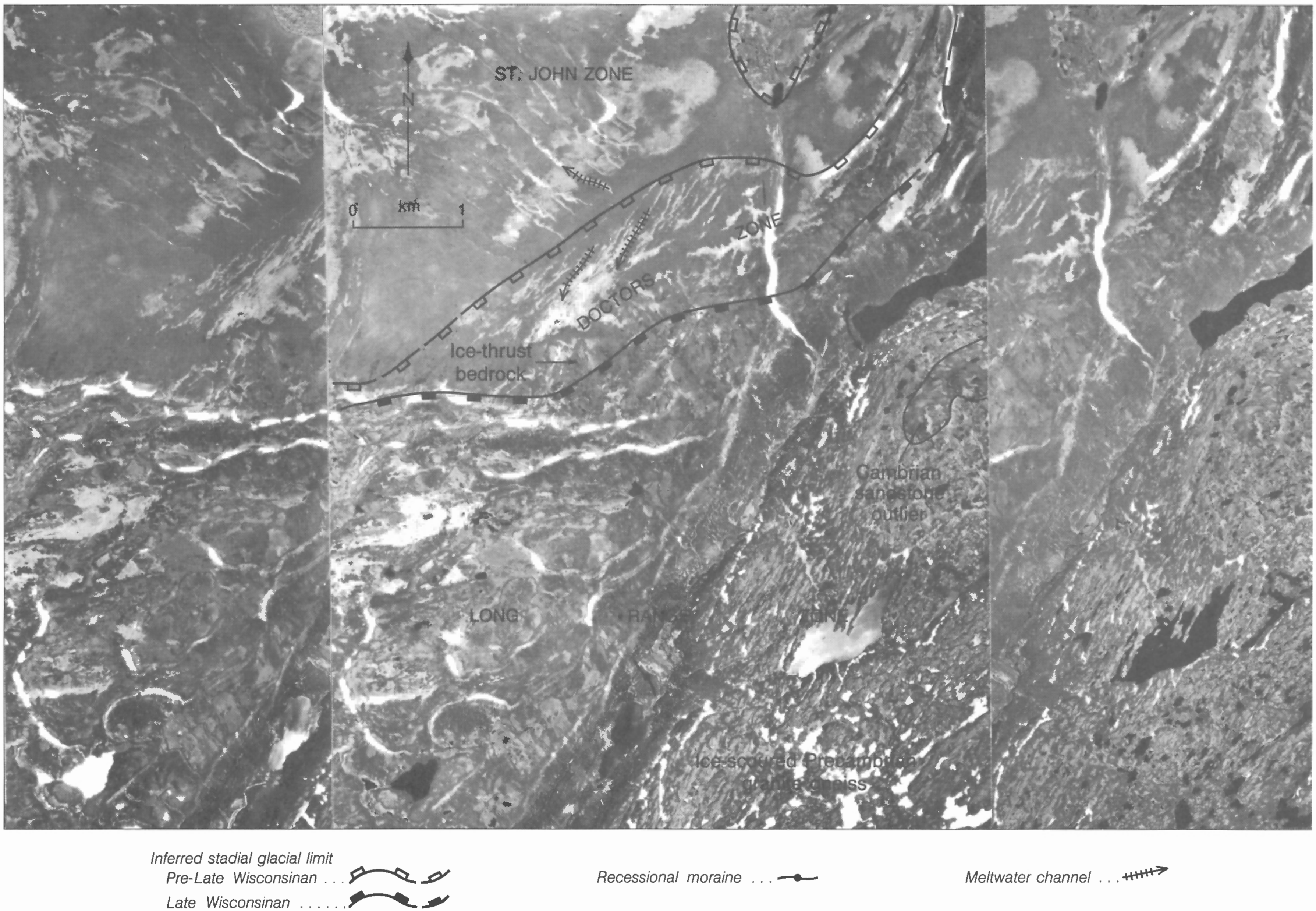


***Figure 21.** Stereogram of three morphostratigraphic glacial terrains at the proposed type locality of the St. John, Doctor's, and Long Range zones on South Summit of Highlands of St. John. NAPL A20003-40, 41, 42*

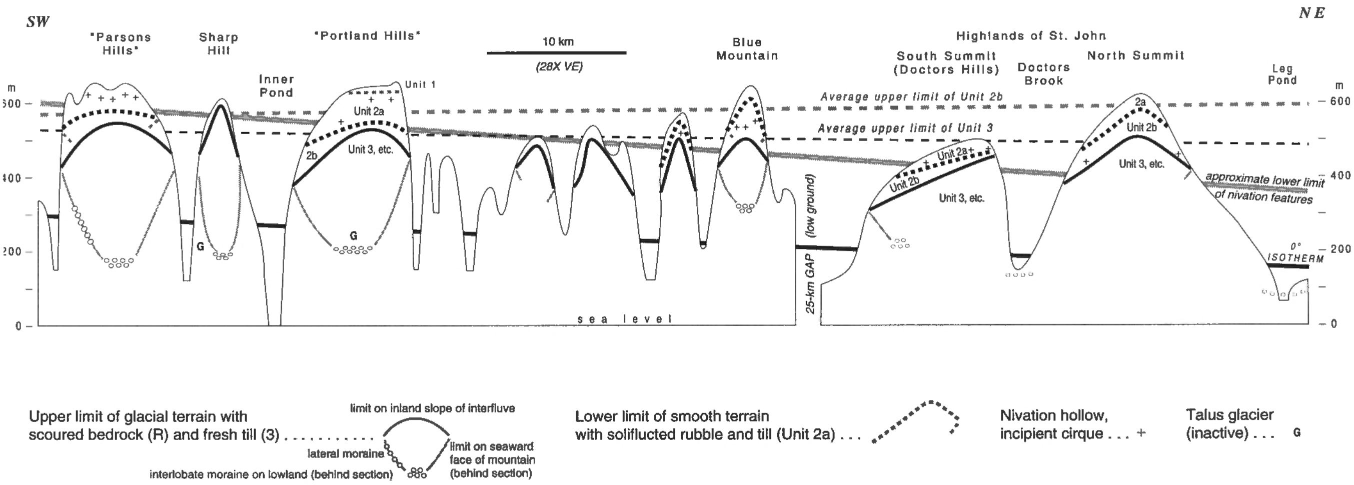


Figure 22. Elevational limits of the three glacial terrains in relation to moraines, nivation level and the present mean annual 0°C isotherm along a topographic profile through the western Long Range summits (see Fig. 7).

Erratics indicate that they were overrun by ice that moved generally southeastward. On Highlands of St. John, erratics of pink-weathering granodiorite from southern Labrador, as well as melanocratic gneisses similar to those in Long Range Mountains, occur in the rubble from the underlying quartzite and where mudboils expose patches of till. On Grey Islands the till surface is littered with erratics of Cambro-Ordovician sandstone from the Northern Peninsula lowlands, as well as gneisses from the Long Range Mountains or Labrador. On western Long Range summits areas of Unit 2a apparently contained only local crystalline material; neither erratics of certain Shield origin nor of lowland sedimentary rocks were noted.

Features believed to mark small ice-dammed ponds occur in this terrain on the east and south flanks of Gros Paté. Horizontal trimlines are incised into the till-covered slopes at 594, 550, and 495 m. The latter two lead to dry channels at the same elevation in the valley-head col, which evidently functioned as spillways or overflow channels. These features apparently represent small proglacial lakes impounded by glaciers wrapping around the hills. It is perhaps significant that the latter two glacial-lake trimlines are at the same elevation as the contact between this map unit and the adjacent lower glacial terrain, designated Unit 2b.

The valleys of those major streams, which cross all three glacial terrains (Fig. 7), typically show relatively abrupt decreases in valley cross-section as they pass from a higher terrain to a lower, such that three valley segments are evident (Fig. 23). Thus, the valleys in bedrock in this the highest of the glacial terrain are well integrated and much deeper than in the lower two. Drainage systems are large and well-developed, and the valleys are broad, flared gorges 100-150 m deep and 750-1000 m wide (Fig. 20). The origin and significance of the difference is discussed under "Quaternary history".

Till terrain with intermediate-degree dissection and morainic relief (Unit 2b). A glacial landscape with an intermediate degree of morainic development and relative stream integration and dissection is situated at intermediate elevations between the smooth, deeply dissected summit till terrain and the lower fresh-looking (Late Wisconsinan) terrain (Fig. 21, 22). In contrast to the smooth summit zone, it has glacial relief in the form of morainic till-covered surfaces and rocky areas with basins and outcrops. It differs from the lower, fresh glacial terrain in that morainic slopes are longer and only 3°-10°; rock surfaces lack polish and erosional microforms. Like the other two, this glacial terrain retains its distinctive intermediate morphological character, whether on the quartzite of Highlands of St. John (Fig. 21), on the dolomite of Blue Mountain (Fig. 20), on the granitic gneiss inland of "Portland Hills" (Fig. 19), or on the metasedimentary rocks on Groais Island.

The degree of stream integration and the degree of valley entrenchment in the bedrock of this terrain is intermediate in degree between that lying at higher and lower levels, as noted in major streams which cross all three glacial terrains (Fig. 7). Regardless of rock type, valley segments in a typical stream in this terrain are 50-60 m deep and about 250 m wide (Fig. 23).

The upper limit of this terrain, at its contact with the smoother glacial terrain above (Unit 2a), is of variable width and has a distinct slope. Its width ranges over a 10-200 m from relatively narrow and abrupt to wide and vague. It is unmarked by ice-marginal features such as moraines and meltwater channels, although, as described above, on Gros Paté it apparently locally coincides with the levels of proglacial lakes impounded in the terrain beyond. On the western summits the contact declines westward, i.e., downslope, as on South Summit of Highlands of St. John, where it descends from 400 to 300 m over 8.5 km, or about 12 m/km (Fig. 23). On Blue Mountain the slope is 23 m/km (Fig. 20). On Gros Paté, it declines westward from 570 to 490 m at 14 m/km.

A small area of supposed ice-thrust bedrock ridges occurs on South Summit of Highlands of St. John. Quartzite ledges crop out in complex curvilinear strike ridges, whereas they are generally flatlying elsewhere. The deformation is tentatively attributed to glacial thrusting, with the implication that the ice was cold-based thereby causing the bedrock to freeze onto the glacier sole.

After completion of Map 1622A a small area of anomalous till, which may be additional outlier of Unit 2b, was noted on Cape St. John, the eastern extremity of Baie Verte Peninsula. The volcano-sedimentary rock terrane has patches of a till composed almost entirely of far-travelled Long Range erratics. Moreover, the local ice flow trend is a strong southeastward stoss and lee which is perpendicular to that on most of the peninsula. Although the terrain is not noticeably different from that of the peninsula as a whole, the till in this area is tentatively assumed to record a glacial phase that predates the last glaciation of Baie Verte Peninsula as a whole; therefore it may correlate with the southeastward flow phase, which is represented by Unit 2b on Groais Island and Horse Islands.

High-relief, fresh-looking (Late Wisconsinan) glacial terrain

Most of the area is glacial terrain in which the surface of the till and the interspersed bedrock outcrops are virtually unmodified by subaerial weathering. About 30% of this terrain type is covered by till (Fig. 24). Fresh glacial landforms include streamlined, ice-moulded features such as fluting, drumlins and crag and tail hills produced by active flow, as well as hummocky to rolling morainic topography and end

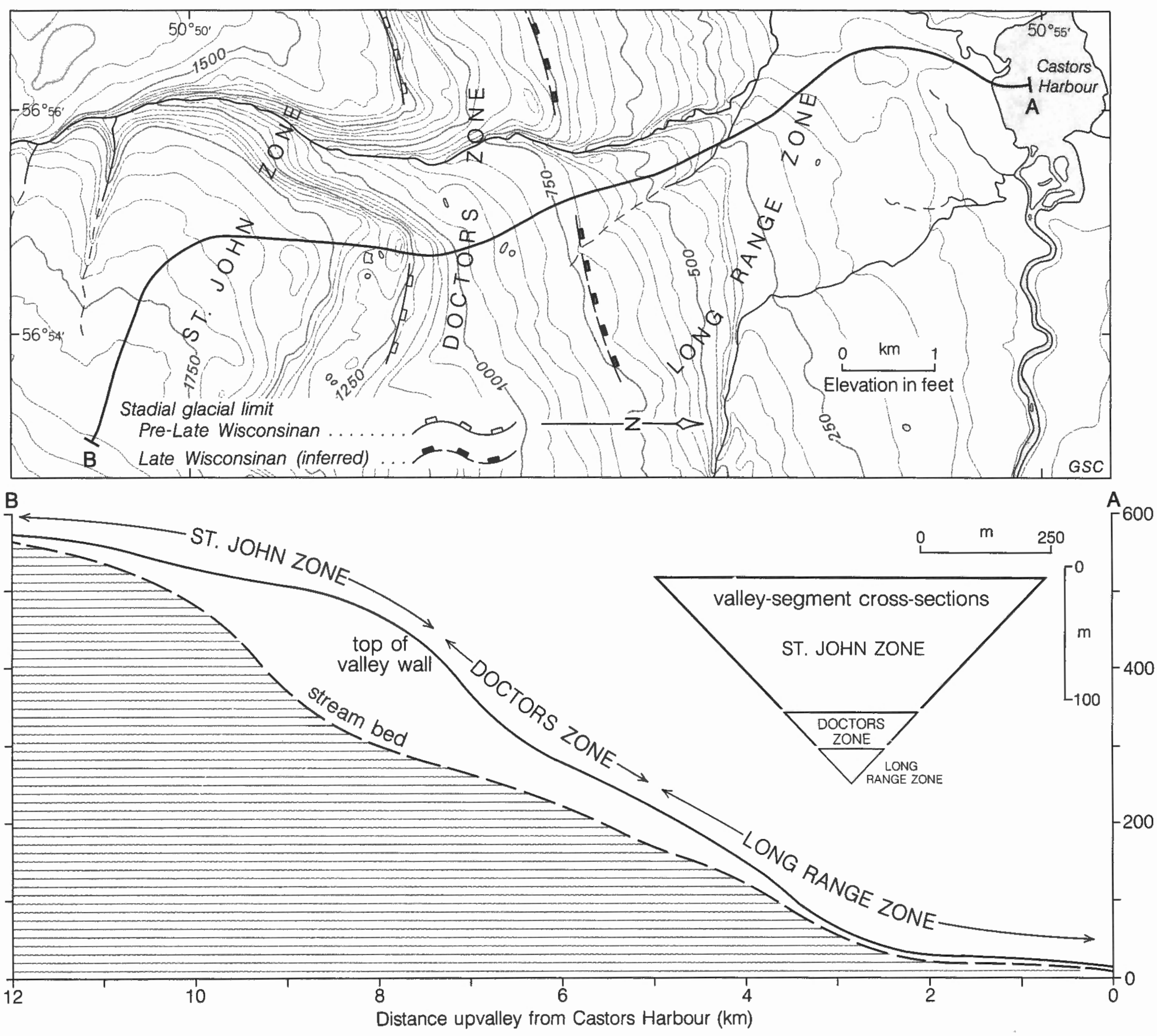


Figure 23. Profile of typical stream valley showing variation in valley cross-sectional area in the three glacial terrains, north slope of North Summit (from Grant, in press).

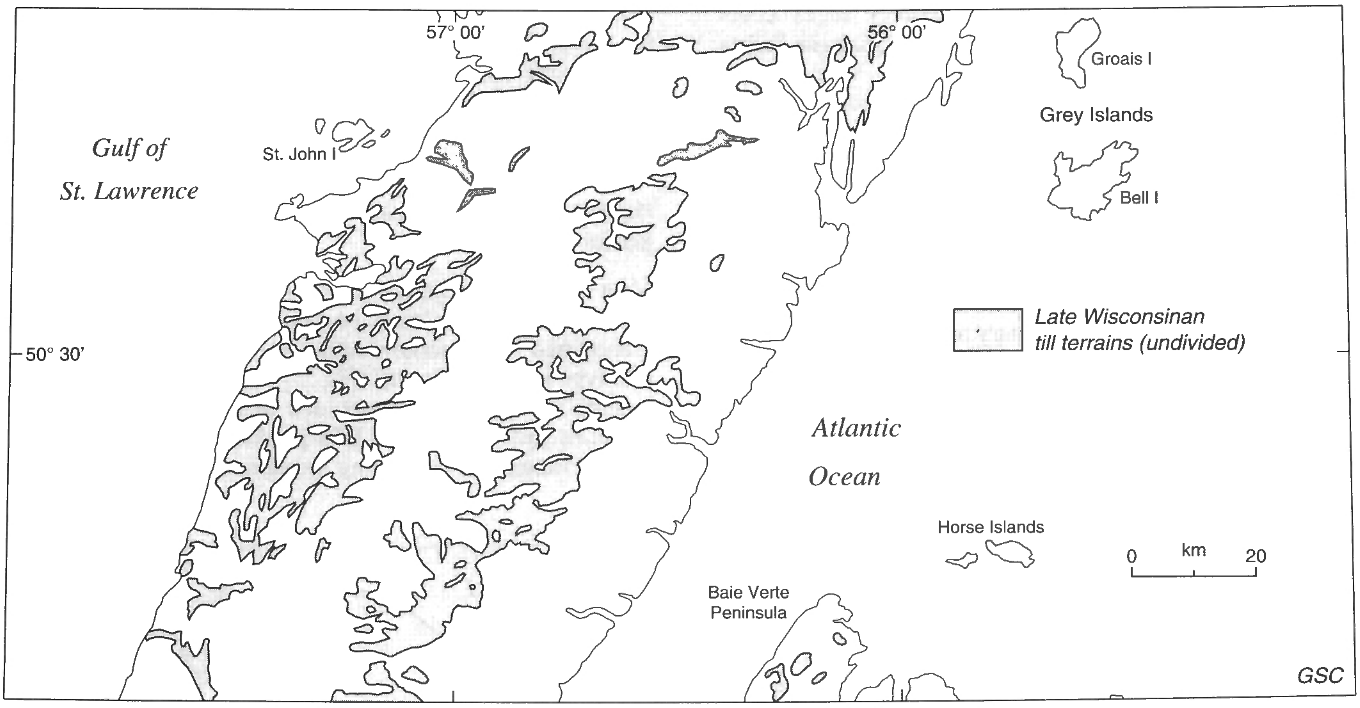


***Figure 24.** Late Wisconsinan till terrains (units 3a, 3b, 3c, undivided).*

moraines with angle-of-repose (30°-40°) slopes produced by ice stagnation and disintegration. Cryoturbation and solifluction features (such as mudboils and lobes) are rare and sporadic, in contrast to their general and ubiquitous occurrence in the two higher, geomorphologically different glacial terrains. Drainage is deranged and, as is particularly evident where streams cross all three terrains (Fig. 8), the valley segments in this terrain are noticeably smaller than in the higher two. Valleys in bedrock are typically ≈10-20 m deep and ≈100 m wide (Fig. 23). The upper limit of this terrain parallels the higher terrain contacts (Fig. 22).

This terrain is referred to glaciation of Late Wisconsinan age based on its association with shell-bearing till and deglacial transgressive marine deposits which are radiocarbon dated to ≤13 ka. It is subdivided in three categories according to continuity and average thickness, as inferred from the scale of depositional features and the degree of masking of bedrock relief.

Discontinuous till veneer (Unit 3a). This category denotes thin patchy drift <2 m thick with up to 40% interspersed rocky areas. It makes up about 15% of the area, chiefly in the medial zone of Long Range Mountains. The minimal thickness is inferred from the numerous interspersed large and small bedrock outcrops and from fact that submask bedrock relief is almost as clear as in bare-rock areas. Locally, however, the shallow smooth cover of slope fen (Wells and Pollett, 1983) gives the impression of greater thickness. The Long Range till is typically sandy, stony, locally derived and immature; clasts are subangular and show little wear. Streamlined forms occur only near the outer part of the unit. A westward-pointing erratics train (Bostock et al., 1983, p. 4) and radially disposed striations on the surrounding bare-rock terrain show that ice moved outward from this zone. In the central Long Range this till may be either of Late Wisconsinan age and have developed largely by in situ crushing along the ice divide area of a north-south elongated local ice cap, or it may be a relict till from a previous glaciation.

Continuous till veneer (Unit 3b). This thin mantle of till 1-2 m thick is interrupted only sporadically by small bedrock outcrops. Of its two main areas, a swath in the "Interior Midlands" has northward-pointing crag-and-tail hills anchored on quartzite cuestas. The matrix is comminuted sedimentary rock, but the clasts are of Long Range derivation.

The main area of till veneer covers most of the western lowland. Structural relief in the underlying bedrock shows as curved strike ridges and straight fault-line ridges (Fig. 15). Texturally it is sandy and stony (Fig. 25), with ≈30% carbonate debris in both matrix and clast fractions. The typically brown to grey matrix reflects the proportion of clastic and carbonate sedimentary rocks. As shown by lithological analysis of the 5-22 mm till-pebble fraction (Fig. 26) from several hundred samples, the content of introduced Long Range crystalline clasts decreases linearly westwards (Fig. 27) in the direction of ice flow. It matches the dispersal trend from local sources, such as the mineralized train from the Trapper Pb/Zn occurrence (Mihychuk, 1985, 1986).

De Geer moraines. Areas of till veneer north of Portland Creek Pond are characterized by fields of De Geer moraines. These small, closely spaced, parallel, arcuate till ridges are ≈5 m high, 20-40 m wide and 50-70 m apart (Fig. 15). They are arranged in trains of 200-300 separated by major east-west

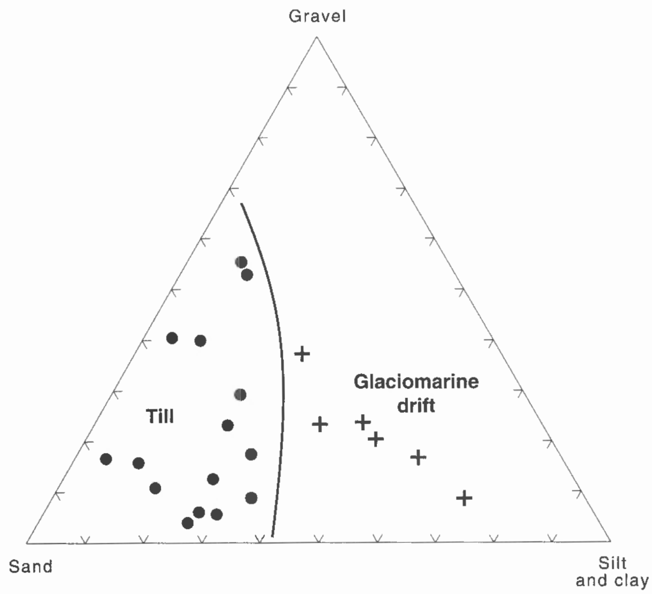


Figure 25. Ternary plot of gravel:sand:silt and clay for western lowland tills, with glaciomarine drift for comparison.

Figure 26. Washing mill being used to extract pebbles from till by A.S. Dyke (bottom left) and C.M. Tucker (top). GSC 203284-C

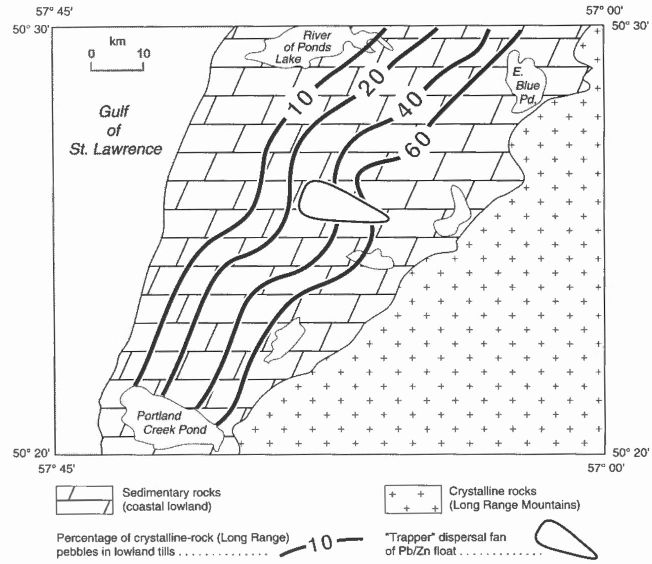


Figure 27. Westward-decreasing amount of Long Range erratics in lowland till (after Grant, in Hornbrook et al., 1975), with fan of Pb/Zn float from "Trapper" Prospect added for comparison (adapted from Mihychuk, 1986).

till ridges and are distributed between the present coast at Table Point and River of Ponds Lake 20 km inland. They are are not found above marine limit. The till is a chaotic mixture of large angular bedrock blocks in a sandy silty matrix with pods of marine shell bearing mud. The blocks commonly have only one striated face, the others being freshly broken, and they are locally bored by lithodomous shells, such as *Hiatella arctica*. An age of 12 300 ± 100 BP (GSC-4859) on such reworked shells gives a maximum date for moraine construction.

These till ridges are identified as De Geer moraines according to published criteria (Hoppe, 1959; Elson, 1968; Prest, 1968). They appear identical to those first described by De Geer (1889) who explained them as annual or "winter" moraines pushed up by minor seasonal pulses of a retreating ice front grounded below sea level (although yearly formation has not been demonstrated in this case). De Geer (1940, p. 118) further explained the blocks striated on only one side as having spalled by rock burst from the glacial pavement. It may be suggested here that the rupture was by sudden release of elastic compression possibly because of rapid deglacial unloading as the ice cliff retreated in deep water.

Till blanket (Unit 3c). Till blanket is a bulky drift sheet 2->10 m thick, which masks all but the larger bedrock relief features. Till blanket on the northern lowland is streamlined into flutings and elongated drumlins which fan out northward from the end of Long Range. Till blanket on the western lowlands mainly takes the form of major morainic ridges (Fig. 28). Two are arcuate, multi-ridged, transverse complexes located at the lower end of valleys at marine limit: one at the end of Leg Pond, the other in Doctor's Brook col

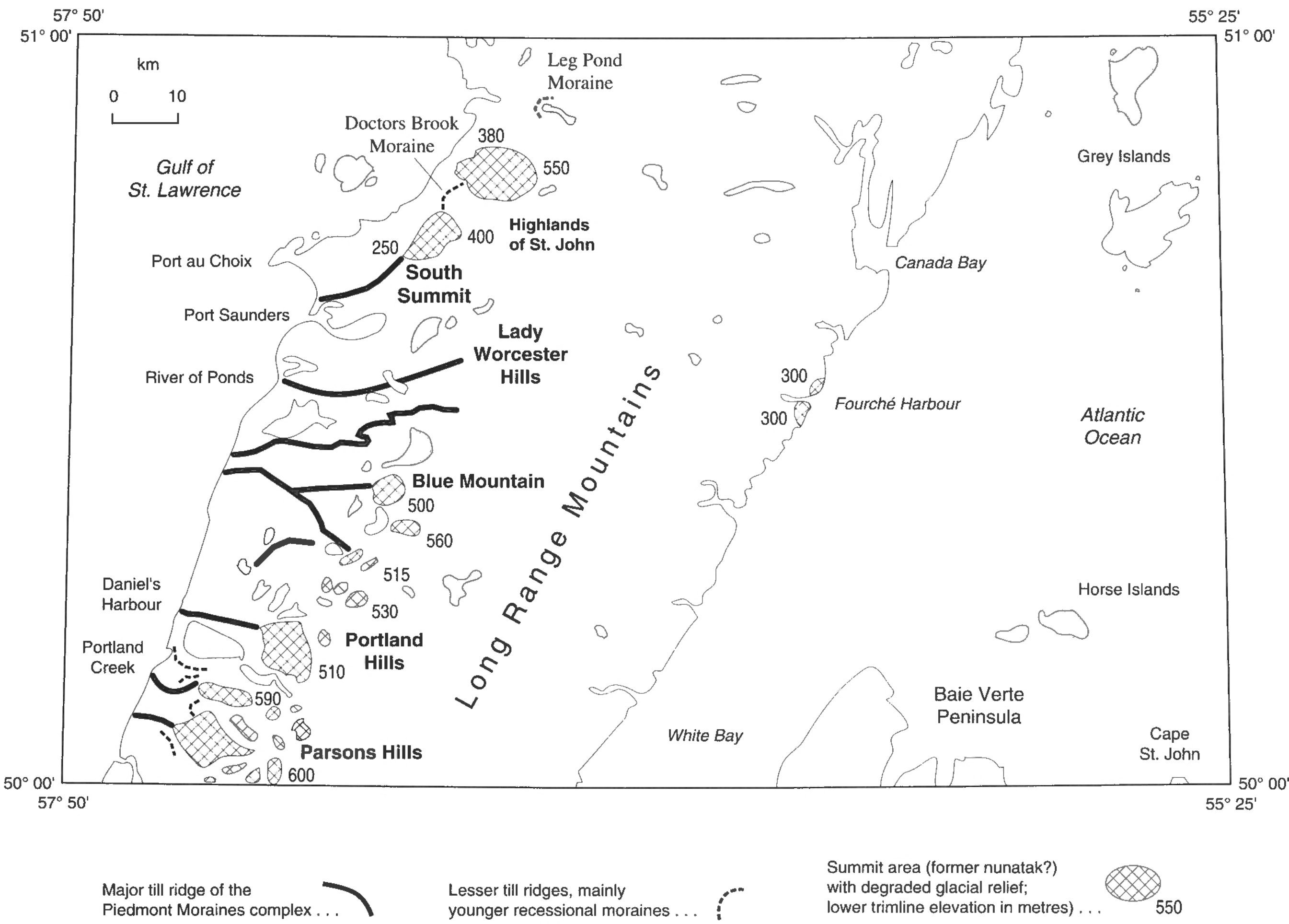


Figure 28. *Major end and interlobate moraines of the Piedmont Moraines complex and other recessional moraines in relation to postulated nunatak areas during the last glacial maximum.*

between North and South summits. The largest is the group of end and interlobate ridges collectively termed the Piedmont Moraines" (Grant 1969b, 1976).

Piedmont Moraines. These large, meandering, longitudinal till ridges up to 30 m thick and 1-2 km wide trail coastward downslope across the rock structure (Fig. 13) from each of the major western Long Range hill complexes (Fig. 28), such as Blue Mountain (Fig. 20) and South Summit, (Fig. 21). Striations are approximately at right angles to the moraine ridges, and De Geer moraines bend to merge with them.

The moraines show changes in form and composition depending on distance from the Long Range margin and elevation relative to marine limit. Above marine limit near the highland margin, the moraines are relatively narrow, steep-sided, strongly kettled, and composed of brown sandy stony till. Marine limit is a sharp trimline or terrace below which morainic topography is obliterated. Below marine limit, the surface form is smoothed and rounded by wave truncation. The ridges also become progressively broader and thicker. At the coast they cover several kilometres in width, are deeply mantled with marine sand and gravel, and appear to make up most of the local relief (Fig. 29). The sediment visible at Daniels Harbour, Bateau Cove (Fig. 30) and River of Ponds, although too poorly exposed to reveal contact relations, was silty (Fig. 26), and substratified and, in a few places, appeared to grade laterally to marine mud with dropstones and rare small shell fragments. The coastward ridges are thus seen as interlobate moraines that were deposited at the contacts of contiguous, marine-based, piedmont glaciers.

Subsidiary arcuate till ridges are nested within the longitudinal ridges, which in turn embrace fields of De Geer moraines. Examples encircling Portland Creek Pond and Brians Pond show the same textural progression as the larger ridges. A few exposures inland show that they locally contain reworked marine shells and rare pods of grey fossiliferous marine mud. The till of one such ridge, in a roadcut north of Zinc Lake, overlay compacted marine sediment with shells that dated 12 800 ± 150 BP (BGS-1080) (Proudfoot and St. Croix, 1987). The innermost moraines in this group take the form of marine-limit ice-contact marine deltas (Fig. 31).

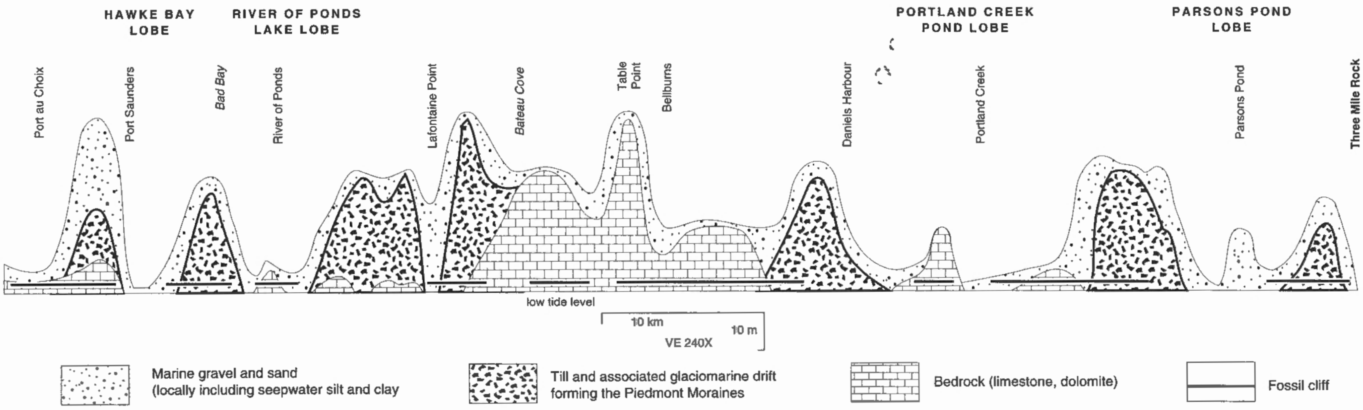


Figure 29. *Longitudinal stratigraphic section of the major surficial units exposed along the Gulf of St. Lawrence coast, showing relation of Piedmont Moraines (till ridges) to bedrock topography; extent of low fossil cliff also indicated.*

Figure 30. *Facetted outcrop overlain by till and glaciomarine drift composing ridge in "Piedmont Moraines" complex, cut by low fossil cliff; Bateau Cove. GSC 204634-N*

These arcuate ridges, together with the De Geer ridges, are seen as recessional moraines of spatulate piedmont ice lobes that retreated during marine transgression.

Ice flow indicators

The direction and sequence of glacier flow and retreat is recorded by various features including erosional markings on outcrops, by longitudinal and transverse drift forms, and by the dispersal trends of erratics. The main trends are summarized from Map 1622A (Fig. 32).

Rock-inscribed markings

Erosional features on bedrock range in size from large-scale landforms, such as roches moutonées and stoss-and-lee topography, to small-scale markings on outcrops, such as striations, grooves, and miniature crag-and-tail. Commonly the abraded surface has two or more superimposed sets of glacial striations. Locally, outcrops have two or three intersecting abraded facets. Such crosscutting relationships reveal three main flow phases and their relative age.

From 148 measurements, the area is seen to have experienced a general radial movement coastward from two areas, Long Range Mountains and Baie Verte Peninsula, but different parts of the area had distinctive flow histories (Fig. 33). The entire eastern part of the area, from Coastal Uplands, through Grey Islands, Horse Islands and Cape St. John was overrun by southeastward-moving (120°-160°) ice which, from the provenance of erratics, had its source in the Long Range Mountains, as well as farther to the northwest on the Shield. On the Interior Midlands and northern Coastal Lowlands, this southeastward movement was followed by a flow that fanned northward (320°-040°) from Long Range Mountains. Over the Strait of Belle Isle part of the Coastal Lowlands between Port au Choix and Ferolle Point, ice first flowed southeastward, then dominantly southwestward parallel to the coast, and finally northwestward from Long Range Mountains.

The western lowland south of Port au Choix experienced a generally westward movement stemming from Long Range Mountains. Discordant earlier and later movements are demonstrated by rare outcrops with three intersecting striated facets, but it is not clear whether the three sets belong to one glaciation or three because there is no evidence that they were subaerially exposed. A few outcrops in the River of Ponds area record an early southeastward invasion, possibly by the Shield glaciers which presumably emplaced the Precambrian erratics on nearby Highlands of St. John, although no Precambrian erratics or till are known on the lowlands. Next, ice moved coastward from Long Range Mountains, first maintaining an oblique southwestward flow across the lowlands and later a westward flow perpendicular to the coast and to the mountain front. The later phase appears to correlate with the construction of the major arcuate end moraines and De Geer moraines.

Longitudinal and transverse ice-moulded drift forms

Flutings, drumlins, drumlinoids, and crag and tail hills, although largely restricted to Long Range Mountains and the "Interior Midlands", together with several types of moraines, generally

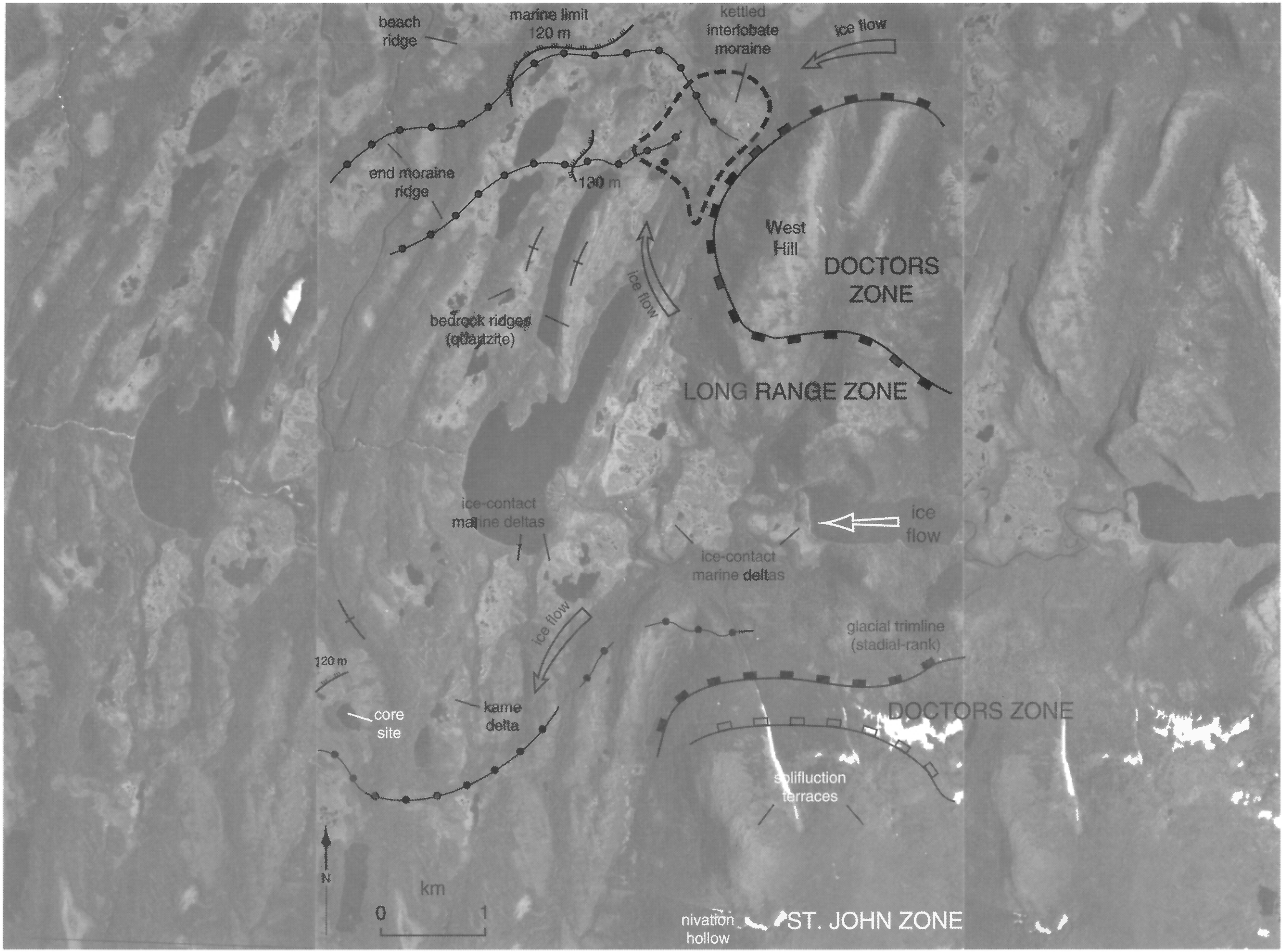


Figure 31. *Stereogram showing arcuate piedmont moraines, ice-contact delta, and morphostratigraphic glacial terrain boundaries; "Parsons Hills". NAPL A20564-13, 14, 15)*

corroborate the erosional ice flow evidence. They help define ice-marginal configuration and retreat pattern. Southeastward-pointing crag-and-tail hills and roches moutonnées on Horse Islands and Cape St. John evidently record an early maximal southeastward flow phase of an ice sheet that was grounded in the Atlantic submarine deeps. Rare ice-thrust ridges at the high-level glacial trimlines on Highlands of St. John possibly represent basal shearing in the marginal zone at an early stage in the expansion of Long Range ice. Interlobate moraines and end moraines on the western lowlands outline the contiguous piedmont ice lobes which issued from troughs in the Long Range escarpment (Fig. 15, 28). The multitudes of De Geer moraines (Fig. 15) record the subsequent eastward inland retreat by calving. Rare moraines on the highlands are restricted to the western half where the ice front retreated downslope to the median part of the plateau. They record late-stage glacial pauses prior to eventual stagnation along the Long Range ice divide.

Dispersal of erratics

Glacial displacement of distinctive indicator lithologies supports the evidence of ice flow trends from the other directional indicators. Shield erratics on Highlands of St. John, "Coastal Uplands" and Grey Islands, together with Long Range erratics on Horse Islands and Cape St. John, demonstrate an early regional southeastward flow by combined Newfoundland and Laurentide ice. Northward dispersal of inland lithologies over Baie Verte Peninsula demonstrate the activity of central Newfoundland glaciers. Westward-dispersal of diabase clasts on Long Range Mountains (Bostock et al., 1983, p. 4), and west and northward dispersal of highland crystalline rocks onto the adjacent lowlands (Fig. 27) document radial outflow by a plateau ice cap. The number of erratics decreases exponentially within a few kilometres north of the crystalline contact (Fig. 34).

Glaciolacustrine deposits and lake-level indicators

Sediments of glacier-dammed lakes (though not shown on Map 1622A) may occur in the basins of three small proglacial lakes which are inferred on the flanks of Gros Paté from horizontal trimlines incised into valley-head slopes at 594, 550, and 495 m. The 550 m trimline connects to a dry channel at the same elevation in the valley-head col which evidently functioned as spillway or overflow channel. It descends to the 495 m trimline in the adjacent valley which in turn connects to a similar assumed spillway in the col. These features apparently represent small ponds dammed by Long Range ice wrapping around the hills. Similar deposits may also exist in analogous settings on the highlands south of Portland Creek Pond, although no shorelines are evident.

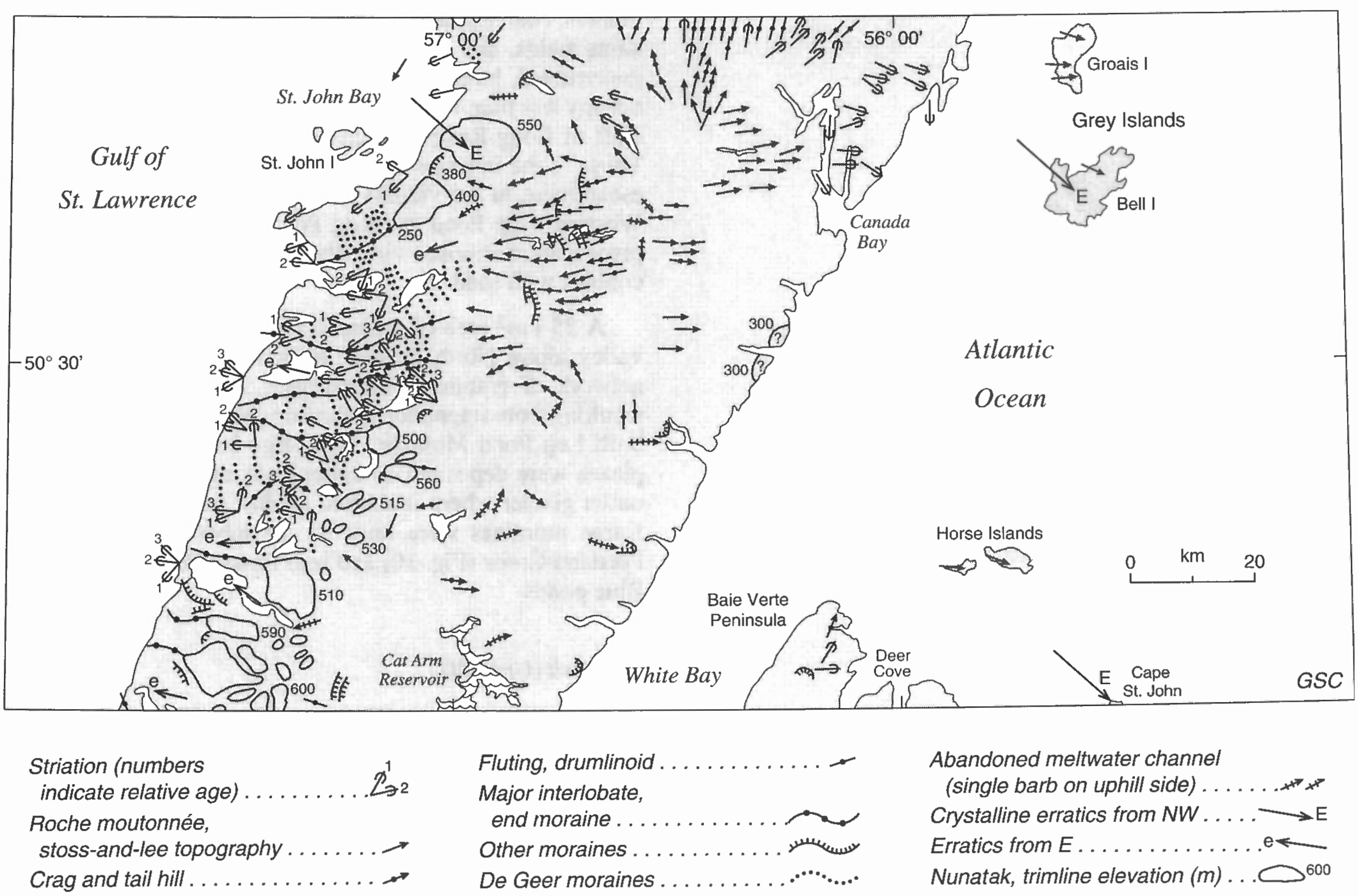


***Figure 32.** Summary of ice-flow indicators.*

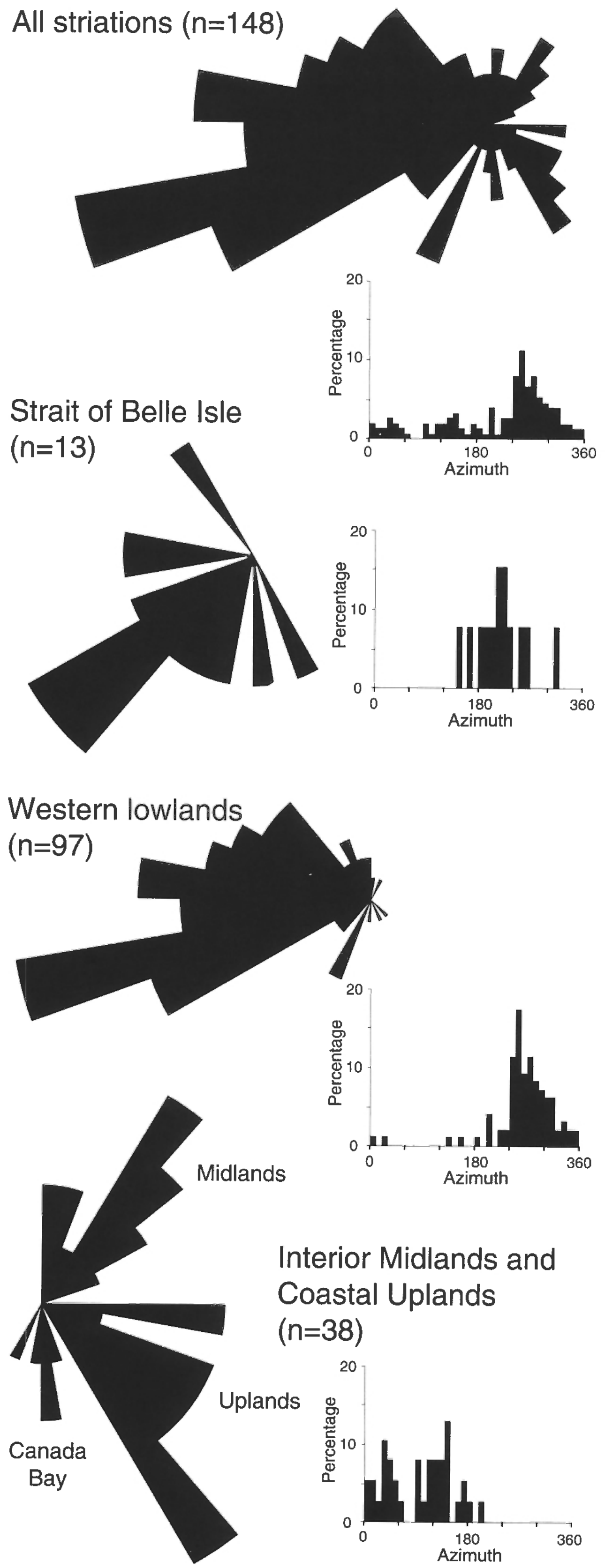


Figure 33. Rose diagrams of striation trends showing variation by area. Numbers of samples in brackets.

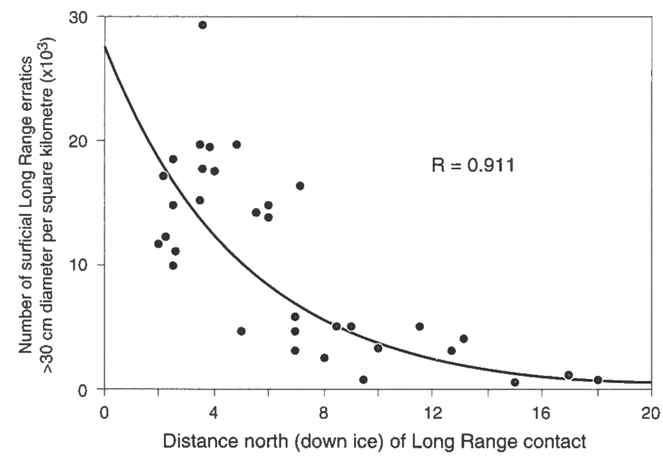


Figure 34. *Northward transport by Long Range ice showing decrease of glacially transported crystalline erratics onto lowlands (from Grant, 1992).*

Glaciofluvial deposits and meltwater direction indicators

Ice-contact stratified drift (Unit 4A)

Ice-contact deposits, which accumulated in ice-walled tunnels, channels and depressions, include crevasse fillings, kame fields, and kame moraines which are recognized by their ridged, hummocky, or depressional topography. They occupy less than 1% of the area (Fig. 35), mainly at the lower ends of Long Range troughs at or just above marine limit. Those at the inner part of the lowland near the Long Range escarpment in the vicinity of Portland Creek, Brians Pond, Western Blue Pond and Leg Pond, where observed in five places, are composed virtually entirely of coarse crystalline cobbles with sand.

A 25 km^2 area of crevasse fillings in the Castors River valley along North Branch, Middle Gulch Brook forms a network of granite boulder ridges 5-10 m high, probably resulting from stagnation of the Long Range outlet glacier that built Leg Pond Moraine. Two large kame and kettle complexes were deposited on either flank of the Portland Creek outlet glacier where it abutted against adjacent ice tongues. Kame moraines were built by ice lobes debouching near Portland Creek (Fig. 30) and into Eastern Blue and Western Blue ponds.

Outwash (Unit 4B)

Outwash forms scattered terraces (Fig. 35), mainly in Long Range troughs, where it is characterized by kettles and shallow, braided, dry channels. 'They grade downstream to marine limit and terminate upstream at kame moraines or relict ice-contact scarps.

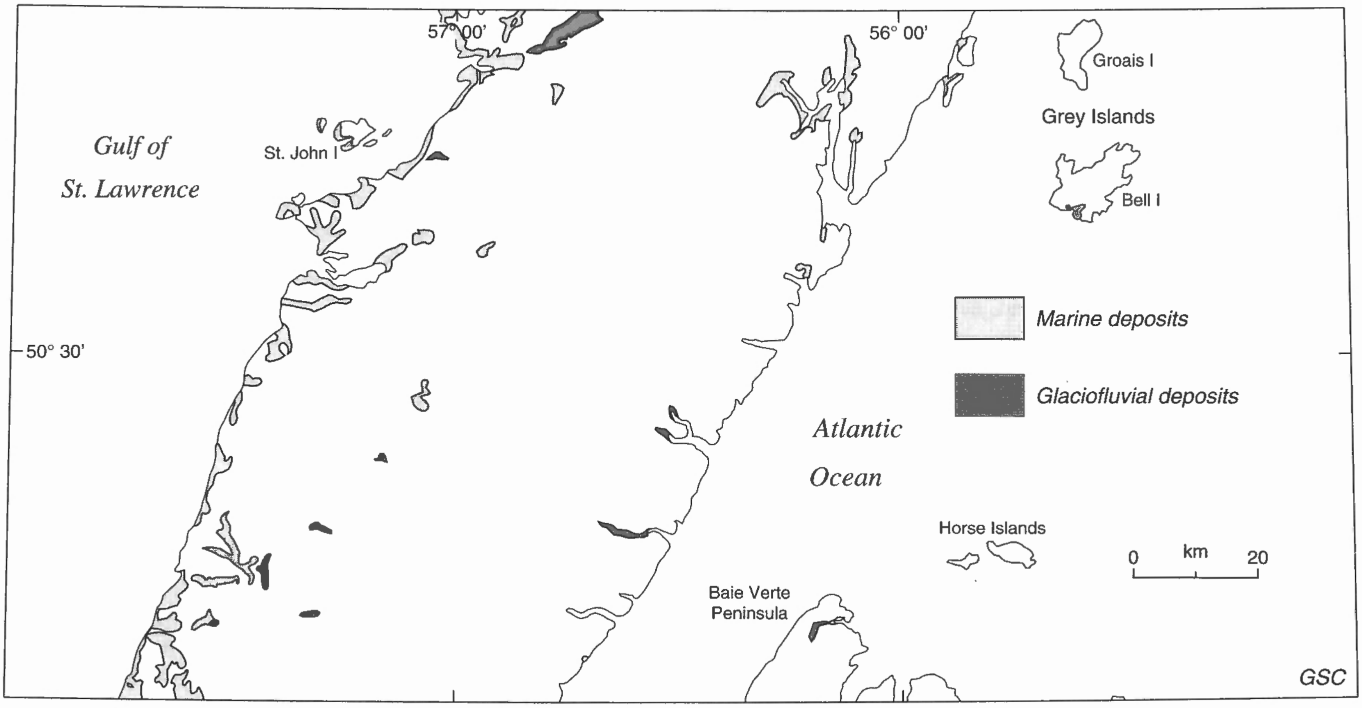


***Figure 35.** Glaciofluvial deposits and marine deposits (from Map 1622A).*

Meltwater direction indicators

The flow direction of glacial meltwater is given by the trend and gradient of subglacial and proglacial deposits and channels (Fig. 32). They indirectly indicate ice gradient and direction of retreat. Outwash trains and meltwater channels point radially seaward and thus illustrating the concentric retreat of two major ice masses, the Long Range ice cap and the Baie Verte Uplands ice cap.

Marine deposits and paleo-shorelevel indicators

Marine deposits are present in varying thicknesses over large areas below marine limit, which ranges up to 70 m on Baie Verte Peninsula, 136 m on Grey Islands, and 106-142 m on the "Coastal Lowlands". However, only those accumulations >2 m thick are shown on Map 1622A so that the identity of the underlying material not be obscured over too great an area. The deposits so mapped cover about 5% of the area (Fig. 35).

Blanket of glaciomarine stony mud (Unit 5A)

This sediment is generally massive and fine grained, with about equal proportions of sand, silt and clay (Fig. 25) giving it a sticky plastic consistency. Scattered matrix-supported clasts are considered to be dropstones. It is localized mainly below the present 20 m contour and outcrops in the Bartletts Harbour and Hawke's Bay areas. Thicknesses up to 20 m occur at or near the distal parts of major end moraines, notably on the slopes of Little Brook Pond and River of Ponds Lake and on the coastal zone at La Fontaine Point and Daniels Harbour. Scattered exposures elsewhere on the western lowlands suggest that it underlies large, flat areas of littoral sand and gravel. It may also underlie the large lowland bogs because its relatively low permeability creates a perched water table which promotes paludification. On the Atlantic coast, deposits occur at the head of Canada Bay, on Bell Island, and on Baie Verte Peninsula at Fleur de Lys and Deer Cove. It is relatively weak and fails readily by slumping, particularly where slopes are oversteepened by wave erosion, as near River of Ponds and Daniels Harbour.

Fossils are abundant and typically are deepwater shell species such as Balanus hameri (commonly attached to clasts), Hemithyris psittacea, and Chlamys islandica. Its upper contact with coarser marine sediment commonly has an accumulation of species from shallower-water, such as Mya truncata and Mya pseudoarenaria.

Glaciomarine ice-contact marine deltas (Unit 5B)

Emerged deltas recognized as ice-contact deposits have steep, distal (i. e. seaward-facing) foreset slopes, locally with beach berms; flat to gently sloping tops, commonly with kettles and braided distributary channels; and steep, inland-facing proximal slopes that are scalloped and kettled where formerly in contact with glacier ice (Fig. 31). They occur at marine limit and most are located at the lower ends of Long Range troughs on both coasts, although several are too small to be differentiated from the adjacent end moraine ridge on Map 1622A. Rare exposures show them to be composed of coarse sandy cobble gravel of Long Range lithology.

Gravel beaches and terraces (units 5c, 5d)

Gravel has accumulated below marine limit over various substrates as littoral beach ridges and terraces but is only mapped where >2 m thick. On the basis of thickness and continuity, it is subdivided into extensive thick sheets (Unit 5c) and patchy veneers with interspersed rock and till outcrops (Unit 5d). Both accumulated as wave action reworked pre-existing deposits of till and outwash, removed the fines, and generated an in situ lag of sandy gravel. Such gravel lags are ≤3 m thick inland, near marine limit and on hilltops, presumably because no additional material was added and because this thickness, once developed, acted as an armour that prevented further reworking of the substrate. Such lags thicken downslope because of accumulation during offlap and thus form a nearly continuous mantle at the present coast (Fig. 29).

Distribution and thickness largely reflect the availability of pre-existing erodable sediment. Thick deposits thus mantle the flanks of end moraines (Fig. 20) and ice-contact marine deltas (Fig. 31) and have accumulated where postglacial rivers reworked upstream deposits, as at East River. Others at the foot of bedrock slopes represent redeposited ablation debris, as for example on Grey Islands (Fig. 16) and in the Conche and Crouse areas. Near and at present sea level, thick gravel deposits commonly occur as large, compound, recurved spits and barriers at the mouths of large bays. Most have been greatly truncated by subsequent cliff retreat. Of those near River of Ponds, Daniels Harbour, and Parsons Pond, only the distal hook portions remain as landward-curved ridges in the peat terrain. Parsons Pond village is sited on the terminal recurve of one such inferred fossil barrier beach.

Discontinuous gravel veneers have been generated over extensive flat bedrock expanses at low elevation by the reconstitution of thin till cover and by accumulation of bedrock joint fragments, as on the flatlying dolomite terrane around Bartletts Harbour, Port au Choix, Bellburns and Parsons Pond.

***Figure 36.** Mytilus edulis mollusc shells. Fossil locality 101004, near Parsons Pond. GSC 204634-I*

Various fossil shells are common (Table 1), especially where the sediment lithology is calcareous. The sand facies and locally even fine gravel usually contains *Mya truncata*, often in life position. Also common are *Macoma* spp., *Astarte* spp., and *Mytilus edulis*, which generally occur intact in dense clusters (Fig. 36) resembling mussel banks. Age estimates on included shells (Table 2) help outline the course of sea-level change. The age of specific paleosealevels is fixed by dates on shells in life position in deposits judged to be littoral by virtue of their beach berm form. Beach berm sediments containing shells that are not in life position, but broken or disarticulated, provide only upper limits on dated sea levels, because the fossils are presumed to have been deposited above tide level by wave action. Conversely, shells in sublittoral deposits constrain the sea-level history by providing lower limits.

Modern coastal sediment and landforms

Sediments that are now accumulating at the present shore or in the intertidal zone include the modern beach berm, intertidal salt marshes, sand plains, and boulder flats. They are not shown on Map 1622A because they are too small and thin to differentiate from the adjacent deposits which are usually emerged Holocene marine sediment.

Intertidal salt marshes consist of narrow fringes of sand and mud <1 m thick. They support a grassy vegetation comprising salt-tolerant plants such as *Salicornia*, *Scirpus*, and *Carex*, which grow in parallel zones according to the frequency and duration of salt-water immersion (Thannheiser, 1984). The largest marshes occur in Parsons Pond (where they are included with adjacent peat terrain) and in Hawke's Bay and Cloud River estuary (where they adjoin emerged marine deposits).

A broad intertidal sand shoal in lower Parsons Pond has resulted from tidal-current redistribution of fine grained sediment winnowed from adjacent emerged sandy marine beds.

Boulder flats (Fig. 37) are subhorizontal intertidal benches armored with large round glacial boulders and commonly fronted by a boulder barricade pushed up on the seaward edge by grounding winter ice-floe packs. The boulders are usually only a thin veneer, ≈1 m thick, over till and glaciomarine drift which is commonly exposed where the

***Figure 37.** Intertidal boulder flat, with barricade at low tide level, developed on till by modern wave action. GSC 203284-F*

Table 1. List of marine fossil species in emerged marine deposits, arranged according to age (after Robertson, 1987).

Age (ka BP)	13				12						11							10								9						8	gap	5			3	2			1		0
Pelecypoda																																											
Mya sp.				X	x	X	X	—	—		x	X	X	X			X	X	X	X		X		X	X		x		+	X	x	X		+			x			X			
Mya pseudoarenaria				—	x			—	x			+				—	X	—		X	x			+	X	—	—	—	—	—	—												
Hiatella arctica									+																		+							X									
Macoma calcarea				+		+		—	—	+	x	—		—		—	—	—		—		X			—				—														
Macoma balthica		X			—			—	—				+	—	—		—				X								—	—													
Mytilus edulis																																											
Cyrtodaria siliqua			X						—														X			X					—				X			—	x	—	x	x	
Spisula sp.					—				—																	—		—			—												
Chlamys islandica					—															—								—			+												
Nuculana pernula						+		—				—								—							—		—														
Portlandia arctica								X																																			
Tridonta cf. *montagui*																																											
Tridonta sp.								+							X	—					—			—	—				—														
Macoma sp.														—																		+											
Tridonta cf. *borealis*																—																											
Serripes groenlandicus																		—									—		—		—												
Clinocardium ciliatum																		—		—	—						—				—												
Mesodesma arctatum																																											
Ensis directus																										—		X				—		—									
Spisula polynyma																										—																	
Cyclocardia borealis																										+					—												
Spisula solidissima																													+	—	—												
Mya arenaria																																		—					—				
Modiolus modiolus																																					x					—	
Placopecten magellanicus																																							X				
Gastropoda																																									—		
Buccinum undatum																																											
Buccinum scalariforme											+									—				—		—	—	—							x	—		—	—		?	X	
Cryptonatica clausa																		—																									
Euspira pallida					—			—		+							—											—	—								—	x		—		—	
Lepeta caeca																—																											
Boreotrophon truncatus										x																																	
Plicifusus kroyeri														—																													
Trichotropis borealis																	+								—		—	—	—														
Buccinum glaciale																								?					—														
Boreotrophon clathratus																													—														
Nucella (Thais) lapillus																													—														
Notacmea testudinalis																								?										—		X	—	—	+	x	—		
Littorina saxatilis																																					—	—		—			
Stagnicola elodes																																						x					
Valvata sincera																																											
Brachiopoda																																											
Hemithyris psittacea				—								—			—	—														—													
Glaciarcula spitzbergensis										+																			—														
Cirripeda																																											
Balanus sp.												*							?												*												
Balanus cf. *crenatus*				*				*				?				*	*			*										*	?												
Balanus cf. *balanoides*								*							*	*																							*				
Balanus hameri												*																															
Other																																											
Bryozoans												*																									*				?		
? Echinoderm teeth																																					*						

— 0-15%
+ 16-25%
x 26-40%
X 40%
* present but not included in calculation

Table 2. Radiocarbon age determinations and fossil localities, Port Saunders map area

Age[1] (^{14}C years BP)	Lab No.[2]	Elev.[3] (m)	Material[4]; stratigraphic setting	Locality[5]; latitude, longitude	Reference[6]	Coll.[7]	$\delta^{13}C$ Corr.[8]	Paleo. Coll'n. No.[9]	Site No.[10]
RADIOCARBON AGE DETERMINATIONS									
12 800 ± 150	BGS-1080	*130*	**SHELL** (unspecified fragments in till)	**Bowaters Road** 50° 18.8' 57° 25.5'	Proudfoot and St. Croix (1987)	DNP			5
12 600 ± 160	GSC-1600	*115*	**SHELL**; *Mytilus edulis* in life position as "mussel bank" in gravel barrier beach	**Flat Pond** 50° 24.03' 57° 16.15'	Lowdon et al. (1977)	DRG		100974	8
12 500 ± 120	GSC-4393	*100*	**GYTTJA**; in kettle lake in interlobate moraine (772.5-776.5 cm level in 852-cm core below marine limit)	**Portland lake** (interlobate moraine) 50° 05.64' 57° 35.35'	T. W. Anderson pers. comm. 1987; McNeely (1990)	TWA	-24.3		3
12 400 ± 360	GSC-1485	*106*	**SHELL**; *Hiatella arctica* valves and fragments in sand mantle	**Zinc Lake** 50° 17.75' 57° 28.05'	Lowdon et al. (1977)	DRG		101014	4
12 400 ± 110	GSC-4700	*72*	**SHELL**; *Hiatella arctica* intact valves in silt under till	**Deer Cove** ("Normans Pond") 50° 00.55' 56° 03.34'	M. Milner pers. comm. 1988; McNeely (1990)	MM	+0.8	104330	27
12 300 ± 100	GSC-4859	*85*	**SHELL**; *Hiatella arctica* reworked into till of De Geer moraine	**Forked Feeder Pond** 50° 30.28' 57° 13.05'	McNeely (1990)	DRG	+1.0	100981	10
12 000 ± 170	GSC-1601	*90*	**SHELL**; *Mya truncata* as separate valves in gravel lag	**Eastern Blue Pond** 50° 27.83' 57° 10.80'	Lowdon et al. (1977)	DRG		100986	9
12 000 ± 160	GSC-1605	*85*	**SHELL**; *Mya truncata* in life position in gravel (beach?)	***River of Ponds*** 50° 31.00' 57° 13.20'	Lowdon et al. (1977)	DRG		100983	11
11 700 ± 180	GSC-3891	*236*	**GYTTJA**; in rock basin lake (540-545 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986); Blake (1986)	JBM	-17.4		28a
11 600 ± 90	GSC-4538	*81*	**SHELL**; *Mya truncata* in life position in sand blanket	**Bateau Barrens** 50° 25.9' 57° 24.3'	McNeely (1990)	DRG	+2.2	101031 101041	7
11 000 ± 180	GSC-2919	*75*	**SHELL**; *Mya truncata* fragments in stratified silt	**Bustard Cove** (Highway 430) 50° 42.86' 57° 11.61'	Blake (1983)	DGV		101067	18
11 000 ± 160	GSC-1324	*60*	**SHELL**; *Balanus* spp. in till of Ten Mile Lake Moraine	**Ten Mile Lake** *51° 04.87'* 56° 42.63'	Grant (1969; 1986); Lowdon et al. (1971)	DRG	+1.7	100967	31a
10 900 ± 160	GSC-1277	*60*	**SHELL**; *Mya truncata* fragments in till of Ten Mile Lake Moraine	**Ten Mile Lake** 51° 04.87' 56° 42.63'	Grant (1969; 1986); Lowdon et al. (1971)	DRG	+1.7	100957	31b
10 800 ± 110	GSC-3316	*24*	**SHELL**; Mya truncata fragments as marine lag on till surface	**Croque** 51° 03.36' 56° 50.78'	Grant (1969; 1986); Blake (1983)	DRG	+1.4	100972	34
10 300 ± 90	GSC-5026	*8*	**SHELL**; *Mya truncata* uddevalensis in life position in sublittoral? sand over till	**Parsons Pond** bridge 50° 04.25' 57° 42.00'	this paper	DRG	+0.8	101043	36
10 200 ± 100	GSC-4006	*51*	**SHELL**; *Mytilus edulis* in life position in "mussel bank" in gravel beach ridge	**Parsons Pond** hill 49° 59.76' 57° 43.50'	Blake (1986); Grant (1989)	DRG	+0.7	101000	30
10 100 ± 160	GSC-1270	*60*	**SHELL**; *Mya truncata* in life position in gravel beach ridge	**Ten Mile Lake** 51° 03.85' 56° 45.00'	Grant (1969; 1986); Lowdon et al. (1971)	DRG	+2.6	100959	32
9 950 ± 150	GSC-3898	*236*	**GYTTJA**; in rock basin lake (495-500 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	JBM	-21.0		28b
9 930 ± 130	GSC-4214	*20*	**SHELL**; *Mya truncata* (juveniles) in life position in silty sand	**Fleur de Lys** (playground) 50° 07.10' 56° 09.55'	Blake (1988)	DRG		101018	26
9 870 ± 170	GSC-4577	*104*	**GYTTJA**; in rock basin lake below marine limit (702-712 cm level in core)	**Bell Island** 50° 46.0' 55° 32.8'	J.B. Macpherson (pers. com., 1988)	JBM	-18.6		24
9 720 ± 100	GSC-5025	*3*	**SHELL**; *Mya truncata* and *Mya truncata uddevalensis* in sand underlying gravel beach ridge	**Parsons Pond** shore 50° 03.43' 57° 42.35'	this paper	DRG	+0.7	101032	35

Age[1] (^{14}C years BP)	Lab No.[2]	Elev.[3] (m)	Material[4]; stratigraphic setting	Locality[5]; latitude, longitude	Reference[6]	Coll.[7]	^{13}C Corr.[8]	Paleo. Coll'n. No.[9]	Site No.[10]
RADIOCARBON AGE DETERMINATIONS									
9 620 ± 170	GSC-4629	*9*	**SHELL**; in stony marine pelite exposed on lake shore	**Little Brook Pond** 50° 32.82' 57° 23.46'	J. Shaw, D. Forbes (pers. comm., 1990)	DLF	+0.8		13
9 190 ± 150	GSC-1312	*50*	**SHELL**; *Mya truncata* in life position in beach ridge over stony mud	**Southwest Brook** 51° 04.48' 56° 05.36'	Grant (1986, in press); Lowdon and Blake (1973)	DRG	-0.1	100926	33
9 000 ± 80	GSC-3998	34	**SHELL**; *Mytilus edulis* in life position in "mussel bank" beneath offlap gravel	**Port Saunders** 50° 39.00' 57° 17.38'	Blake (1986)	DRG		101029	15
8 950 ± 90	GSC-4304	*10*	**SHELL**; *Mytilus edulis* in life position in "mussel bank" in gravel beach	**Parsons Pond** bridge 50° 04.25' 57° 42.00'	Blake (1988)	DRG		101042	2
8 650 ± 140	GSC-1762	*8.5*	**SHELL**; *Mytilus edulis* in life position in "mussel bank" in gravel ridge (barrier/spit?)	**Parsons Pond** village 50° 01.47' 57° 43.48'	Lowdon et al. (1977)	DRG		101001	1
8 400 ± 110	GSC-4861	*190*	**WOOD**; *(Salix)* extracted from detritus gyttja in rock basin lake above marine limit (387-390 cm level in core)	"Lily Pad Pond" 50° 55.12' 55° 59.15'	T. W. Anderson (pers. comm., 1989)	TWA			23
8 380 ± 100	GSC-4192	*384*	**GYTTJA**; basal organic sediment (153-155 cm interval) overlying boulders; section exposed on floor of artificially drained pond in hydroelectric development	Cat Arm River ("Pond No. 8") 50° 02.80' 56° 49.30'	McNeely (1990)	JBM	-23.8		29
8 310 ± 140	GSC-3992	*236*	**GYTTJA**; in rock basin lake (435-440 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	AD	-25.2		28c
8 300 ± 200	GSC-1768	*7.6*	**SHELL**; *Mya pseudoarenaria* fragments in sand of terrace	**La Fontaine Point** 50° 28.30' 57° 28.60'	Lowdon et al. (1977)	DRG		101064	6
6 280 ± 120	GSC-3902	*236*	**GYTTJA**; in rock basin lake (395-400 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	AD	-25.1		28d
4 690 ± 160	GSC-3903	*236*	**GYTTJA**; in rock basin lake (295-300 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	AD			28e
4 690 ± 130	GSC-1403	*6.1*	**SHELL**; *Mya pseudoarenaria* in life position in sand of upper raised beach (on site of Indian cemetery)	**Port au Choix** 50° 42.45' 57° 21.58'	Lowdon and Blake (1973)	DRG		100966	16a
4 290 ± 110	I-3788	*6.1*	**CHARCOAL**; oldest wood (from beneath bones) in Archaic Indian cemetery on upper raised beach)	**Port au Choix** 50° 42.45' 57° 21.58'	Harp (1964); Tuck (1971); Wilmeth (1978, p. 197)	WAR			16b
3 930 ± 130	I-4678	*6.1*	**BONE** (human); oldest skeleton in Archaic Indian cemetery (on upper raised beach)	**Port au Choix** 50° 42.45' 57° 21.58'	Harp (1964); Tuck (1971)	JAT			16c
3 310 ± 130	GSC-1318	*4.5*	**SHELL**; *Mya arenaria* in life position in lower raised beach (on site of Indian cemetery)	**Port au Choix** 50° 42.45' 57° 21.58'	Lowdon and Blake (1973)	DRG		100965	16d
3 050 ± 140	GSC-3906	*236*	**GYTTJA**; in rock basin lake (195-200 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	AD	-26.8		28f
2 294 ± 51	P-732	*4*	**CHARRED FAT**; oldest of 5 ages on such material in occupation layer in house "15" of middle Dorset (eskimo) settlement	**Cape Riche** 50° 42.98' 57° 23.20'	Wilmeth (1978); Harp (1964)	EJH			17a
2 050 ± 140	GSC-3910	*236*	**GYTTJA**; in rock basin lake (95-100 cm level in core)	"Compass Pond" 50° 02.05' 56° 11.78'	Dyer (1986), Blake (1986)	AD	-25.5		28g
1 736 ± 48	P-692	*4*	**CHARCOAL**; oldest of 13 ages on such material in occupation layer in house of middle Dorset (eskimo) settlement	**Cape Riche** 50° 42.98' 57° 23.20'	Wilmeth (1978); Harp (1964)	EJH			17b
1 585 ± 95	SI-2607		**CHARCOAL**; in Dorset (eskimo) living site	**Englee** 50° 43.5' 56° 06.3'	Wilmeth (1978, p. 194)	JAT			25

Table 2. (cont.)

Age[1] (^{14}C years BP)	Lab No.[2]	Elev.[3] (m)	Material[4]; stratigraphic setting	Locality[5]; latitude, longitude	Reference[6]	Coll.[7]	^{13}C Corr.[8]	Paleo. Coll'n. No.[9]	Site No.[10]
RADIOCARBON AGE DETERMINATIONS									
1 502 ± 49	P-676	*4*	**CHARCOAL**; youngest of 13 ages on such material in occupation layer in house "5"of middle Dorset (eskimo) settlement	**Cape Riche** 50° 42.98' 57° 23.20'	Wilmeth (1978); Harp (1964)	EJH			17b
1 450 ± 70	GSC-4717	*-0.5*	**PEAT**; base of intertidal salt marsh	**Mosquito Cove** 50° 56.52' 56° 57.70'	J. Shaw, D. Forbes (pers. comm., 1990)	DLF	-24		20
1 220 ± 60	GSC-4868	*-0.4*	**PEAT**; base of intertidal salt marsh	**Mosquito Cove** 50° 56.43' 56° 56.80'	J. Shaw, D. Forbes (pers. comm., 1990)	DLF	-24		21
990 ± 130	GSC-1602	*1.5*	**SHELL**; *Mytilus edulis* fragments in first raised beach above tide level	**Eddies Cove West** 50° 46.04' 57° 09.15'	Lowdon et al. (1977)	DRG		100991	19
in progress	GSC-4644	*129*	**GYTTJA**; in pond behind Ten Mile Lake end moraine	"Hatters Pond" 50° 58.95' 56° 16.40'	T. W. Anderson (pers. comm. 1989)	TWA			22
in progress	GSC-4669	*9*	**SHELL** in clay (sample WNF-5)	**Bad Bay B** 50° 32.63' 57° 23.58'	Jean-Pierre Guilbault (pers. comm. 1990)	JPG			12
in progress			**WOOD**; in clay (sample WNF-4)	**Little East River** 50° 37.17' 57° 09.40'	Jean-Pierre Guilbault (pers. comm. 1990)	JPG			14
FOSSIL LOCALITIES									
		41	SHELL (various species)	**Ferolle** junction 50° 58.26' 57° 54.90'		DRG		100934	
		60	SHELL (various species)	**Roddickton** pit 50° 54.85' 56° 06.40'		DRG		100950	
		26	SHELL (various species)	**Northeast Brook** 50° 55.90' 56° 07.05'		DRG		100951	
		75	SHELL (various species)	**River of Ponds** 50° 26.15' 57° 13.70		DRG		100975	
		45	SHELL (various species)	**River of Ponds** 50° 26.65' 57° 13.70'		DRG		100976	
		40	SHELL (various species)	**River of Ponds** 50° 28.67' 57° 14.68'		DRG		100977	
		75	SHELL (various species)	**River of Ponds** 50° 29.12' 57° 14.65'		DRG		100978	
		115	SHELL (various species)	De Geer series 50° 30.52' 57° 12.40'		DRG		100979	
		80	SHELL (various species)	**Eastern Blue Pond** 50° 28.81' 57° 09.45'		DRG		100987	
		75	SHELL (various species)	Interlobate moraine 50° 30.44' 57° 07.98'		DRG		100988	
		30	SHELL (various species)	**Little Brook Pond** 50° 33.08' 57° 19.57'		DRG		100989	
		30	SHELL (various species)	**Hawke Bay** 50° 35.73' 57° 10.48'		DRG		100990	
		5	SHELL (various species)	**Cliffy Point** 50° 12.94' 57° 36.35'		DRG		100992 100993 100995	
		90	SHELL (various species)	Interlobate moraine 50° 31.43' 57° 13.70'		DRG		100996 100997	

Age[1] (^{14}C years BP)	Lab No.[2]	Elev.[3] (m)	Material[4]; stratigraphic setting	Locality[5]; latitude, longitude	Reference[6]	Coll.[7]	^{13}C Corr.[8]	Paleo. Coll'n. No.[9]	Site No.[10]
FOSSIL LOCALITIES									
		75	SHELL (various species)	**Bowaters Road** 50° 32.75' 57° 11.00'		DRG		100998	
		8.2	SHELL (various species)	**Parsons Pond** shore 50° 02.90' 57° 42.12'		DRG		100999	
		8.5	Shell (various species)	**Parsons Pond** village 50° 01.47' 57° 43.48'		DRG		101002	
		8.5	SHELL (various species)	**Parsons Pond** village 50° 01.47' 57° 43.48'		DRG		101003	
		2	SHELL (various species)	**Moulting Pond** 50° 00.76' 57° 44.00'		DRG		101004	
		37	SHELL (various species)	**Portland Hill** 50° 09.18' 57° 36.73'		DRG		101008	
		15	SHELL (various species)	**Torrent River** 50° 37.00' 57° 09.52'		DRG		101009	
		15	SHELL (various species)	**East River** 50° 38.10' 57° 09.75'		DRG		101010	
		30	SHELL (various species)	**Little Brook Pond** 50° 32.80' 57° 21.86'		DRG		101013	
		100	SHELL (various species)	**Bowaters Road** 50° 18.65' 57° 26.30'		DRG		101015	
		7.6	SHELL (various species)	**La Fontaine Point** 50° 28.30' 57° 28.60'		DRG		101016	
		9	SHELL (various species)	**Bad Bay A** 50° 32.63' 57° 23.58'		DRG		101030	
		30	SHELL (various species)	**Zinc Lake** road 50° 16.43' 57° 33.50'		DRG		101059	
		10	SHELL (various species)	**Daniels Harbour** 50° 15.48' 57° 34.48'		DRG		101060	
		30	SHELL (various species)	**Daniels Harbour** 50° 14.62' 57° 35.08'		DRG		101061	
		10	SHELL (various species)	**Moulting Pond** 50° 00.70' 57° 44.08'		DRG		101062	
		75	SHELL (various species)	**Bowaters Road** 50° 17.59' 57° 29.60'		DRG		101063	

1 Based on half life of 5568 ± 30 years. See Lowdon and Blake (1973) for data on chemical pretreatment and radiocarbon measurement.
2 GSC = Geological Survey of Canada; BGS = Brock University; Department of Geological Sciences; I = Isotopes Inc., P = University of Pennsylvania, SI = Smithsonian Institution.
3 **Datum is Present Mean Annual High tide Level.** (Mean Sea Level is about one metre lower). Elevations determined by aneroid or by leveling; those shown in italics were interpolated from topographic maps with 50-foot [≈15 m] contours.
4 **SHELL** = tests of marine pelecypods; **GYTTJA** = organic lake sediment; **CHARCOAL** and **BONE** are from archeological sites.
5 Boldfaced names are approved and official (on maps); all others are informal. **NB: Coordinates are to 0.01 minute, not seconds.**
6 Refers to previous publication of the data.
7 Initials refer to D. G. Vanderveer, D. L. Forbes, D. N. Proudfoot, D. R. Grant, E. J. Harp, J. A. Tuck, J. B. Macpherson, Jean-Pierre Guilbault, M. Milner, T.W. Anderson, W. A. Ritchie.
8 Value given is the ratio of ^{13}C in the sample to that in the PDB standard. It is used to compensate or "correct" for isotopic fractionation by normalizing to 0.0% for marine carbonate and to -25.0% for other organic matter. **The quoted age includes the correction.**
9 Numbers refer to samples in the GSC Paleontology fossil collection; most of these collection sites are shown on Map 1622A.
10 Numbers refer to sites on Fig. 46. Appended letters denote other ages at same site. **These sites are outside the map area** (they are included here in support of the interpretation).

boulders are sparse or where they have been bulldozed aside to create protective jetties for local fishermen. The underlying bouldery till or glaciomarine drift usually forms a cliff behind the flats (Fig. 30), so it is assumed that the boulders are a lag after wave removal of the fines. Indeed, the thickness of the lag is about what would be expected judging by the proportion of coarse sizes in the source sediment.

Paleosealevel indicators

Various deposits and shoreform features are diagnostic of former sea levels and, when dated by means of their included fossils, serve to outline the course of postglacial relative sea level change, as discussed under "Quaternary history". The upper limit of marine submergence (marine limit) is marked by nickpoints, trimlines, and washing limits (Fig. 16), and by the tops of ice-contact marine deltas (Fig. 31). In addition, marine limit is approximated by the uphill ends of the highest De Geer moraines, because it is evident from their relationship to other marine deposits and features that the glacier margin did not produce them where it extended above sea level (Fig. 15, 20). Sea levels intermediate between marine limit and present sea level are marked by various coastal forms, including gravelly beach berms representing raised beaches and spits, fossil cliffs and cutbanks (Fig. 38), and the inner limit of aggradational marine terraces.

Topography and forest cover prevent recognition of all but two discrete intermediate sealevel stands between marine limit and present sea level. A disproportionate abundance of aggradational marine terraces and relatively large, numerous, closely spaced beaches in the 60-75 m range, as also noted by Proudfoot and St. Croix (1987), may represent a more important sea-level stand. Examples are the 70 m sand plain of Bateau Barrens and the 60 m terrace on Grey Islands. The possible significance of this level and the fact that it corresponds to the elevation of marine limit (75 m) on Leg Pond Moraine is discussed under "Quaternary history".

Figure 38. *Fossil cliff near tide level (with few raised beaches at foot) cut during a recent transgression; Table Cove, near Bellburns. GSC 1994-017*

A second prominent feature indicative of a paleoshore is the virtually horizontal fossil cliff 5-10 m high, which lies just above present tide level along the west coast (Fig. 29) and possibly also on Bell Island. It is cut in materials ranging from marine mud to bedrock and, although its base is not exposed, it is onlapped by younger raised beaches that are banked in front ≈1-4 m above tide level (Fig. 30, Fig. 38). As an erosional feature it cannot be dated directly, but its age seems bracketed by the fact that it is cut in 4 ka beaches at Port au Choix and is onlapped by 1 ka beaches at Eddies Cove West. Its horizontality presents a problem for reconstructing crustal movement and sea-level fluctuation, as discussed under "Quaternary history".

Fluvial deposits (Unit 6)

Postglacial alluvium occurs as abandoned Holocene degradational river terraces and their active modern counterparts floodplains, deltas, and fans. In area, they are minor units mainly because there are few opportunities for deposition and preservation of material. Where streams are large and vigorous, as on the highlands and uplands, source material is scanty and valley bottoms too steep and narrow to permit accumulation. On the lowlands where source material is abundant, drainage is deranged and sluggish, so that streams are small and weak; the few large streams are actively downcutting rather than aggrading. Abandoned terraces occur along Castors River, Doctor's Brook, and East River. Most mappable deposits are deltas formed where streams debouch in sheltered lakes and bays, as in Canada Bay, most eastern fjords, all of the western trough ponds, and in coastal inlets such as Hawke's Bay and Portland Creek and Parsons ponds. Fans are steeper conical deposits of coarse waterlaid debris associated with colluvial slopes, notably the cliffs around Inner Pond.

Colluvial deposits and indicators of slope processes

Colluvial deposits (Unit 7)

Colluvium as mapped consists of rock rubble (talus or scree) as fans and aprons which have accumulated at the foot of the steepest cliffs of the Long Range Mountains, Highlands of St. John, Grey Islands, and Baie Verte Uplands (Fig. 39). It is being produced on slopes, oversteepened by glacial and modern marine undercutting, which are adjusting their profiles by disintegration. Colluvium is thus restricted to glacial troughs and exposed oceanic cliffs. Absence of colluvium on the Atlantic coast of Long Range Mountains may reflect rock competence or a gentler glacial profile than in otherwise comparable areas.

Indicators of slope processes

Colluvium has accumulated by several processes of slope failure. Cones and fans are mainly the product of small-scale frequent block fall (ravelling) from zones of weak-rock, whereas talus aprons result from landslides and avalanches, judging by the number of fresh scars through their forest cover. A large-scale, slow-moving type of rock-slope failure is the deepseated gravitational creep called "sagging". One case occurs on northern Groais Island where large slices of the cliff have slipped

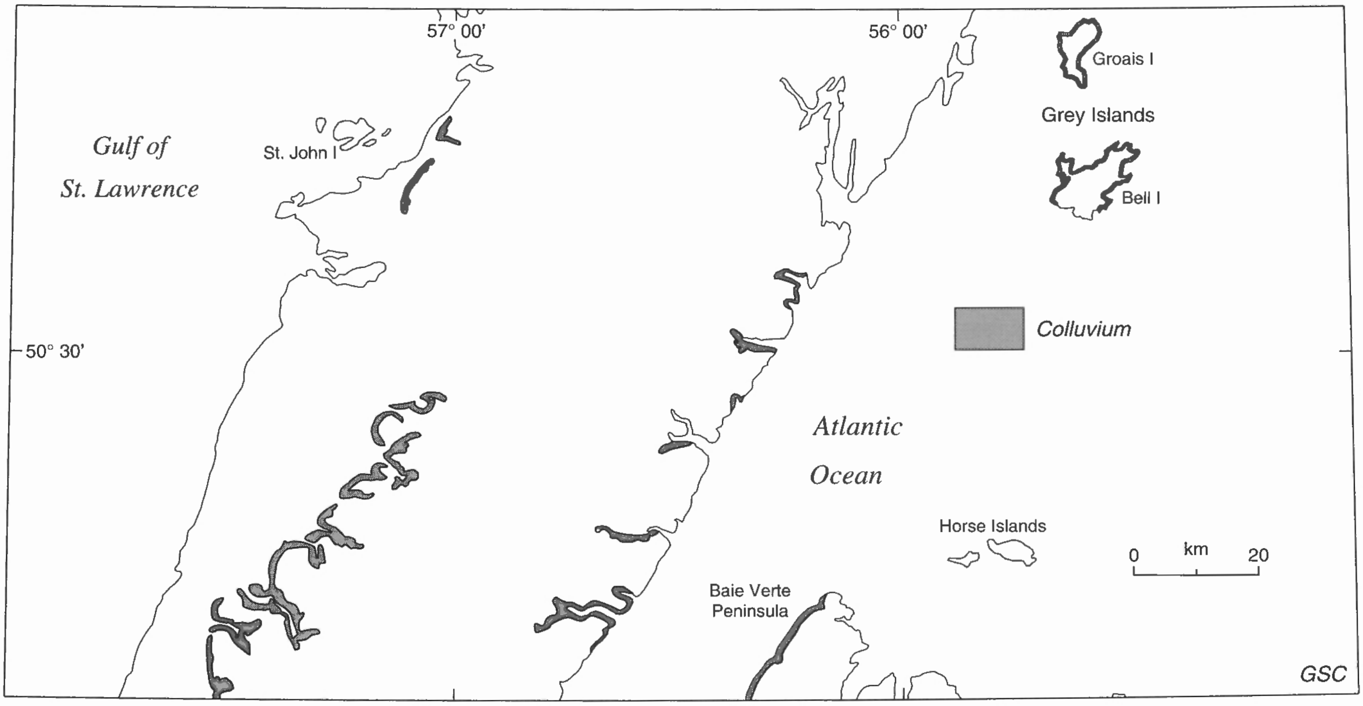


Figure 39. *Major colluvium deposits (after Map 1622A).*

along steep failure planes. Four unusual landforms, which are interpreted to be inactive rock glaciers, appear as forest-covered, ridged, hummocky, horseshoe-shaped bulges on the otherwise smoothly graded slopes of talus on the Long Range escarpment fronting "Parsons Hills" and "Portland Hills". They lie ≈300 m below the present level of nivation and quasi-permanent snowbanks, and about at the inferred elevation of the mean annual 0°C isotherm (Fig. 22). Small slumps and slides occur in weakly consolidated glaciomarine drift on the coast at Daniels Harbour and around River of Ponds Lake.

Organic deposits (Unit 8)

Deposits of vegetal matter 1-2 m thick, which have accumulated in bogs, fens, and freshwater marshes, cover a minor part of the area (Fig. 40). Five types are differentiated (Wells and Pollett, 1983) according to form and composition (Fig. 41). Each reflects specific climatic and substrate conditions. Slope bogs composed of sphagnum peat occur on the shallow, sloping, till-covered surfaces along the medial area of the Long Range Plateau where paludification results from high precipitation and seepage. Atlantic ribbed fen occupies steeper northern till slopes and is composed of sedge (e.g. Scirpus spp.) with Sphagnum only ≈1 m thick in a pattern of pools (flarks) separated by long, narrow, ridges parallel to slope. Basin bogs, composed of ≥2 m sedge-sphagnum sequences, occupy innumerable small depressions in the surrounding barren crystalline terrain. Atlantic plateau bogs, with 2-4 m sedge and sphagnum peat, have sloping margins and flat to undulating tops with numerous irregularly shaped pools. Sustained by abundant precipitation and a high moisture index, extensive tracts occur on the western lowland where drainage is poor because of impervious marine sediment flats and till plains interrupted by rock ridges oriented parallel to slope. On the northern lowland till plain, depressional areas support concentrically patterned domed bogs containing up to 10 m of sphagnum peat over a woody base. Small but nonetheless important areas of slope fen, not shown on Fig. 41, consist of 1-2 m of sedge peat on inclined, fluted, surfaces of calcareous till in the north where they are sustained by base-rich seepage.

Eolian deposits

Windblown sediments, though too small to show on Map 1622A, occur as 10-m high sand dunes which are advancing over the living forest at Ingornachoix Bay and Portland Cove. The sand is blown onshore from intertidal flats, which presumably owe their existence to the bulky glacial and marine deposits at those sites. Blowouts show that the modern dunes rest on buried forest levels (Fig. 42) which cut horizontally across older dune sands.

QUATERNARY HISTORY

The Quaternary history of the area is essentially one of glacier deployment from local and distant sources and of relative sea-level changes following the last deglaciation. A general sequence of events is inferred from areal relationships, stratigraphy, and limited radiometric age control. Ice flow during the latter glacial phases is reconstructed from the patterns and crosscutting relationships of directional features and moraines, but the nature of earlier glacial events is uncertain because the age and origin of the anomalously smooth,

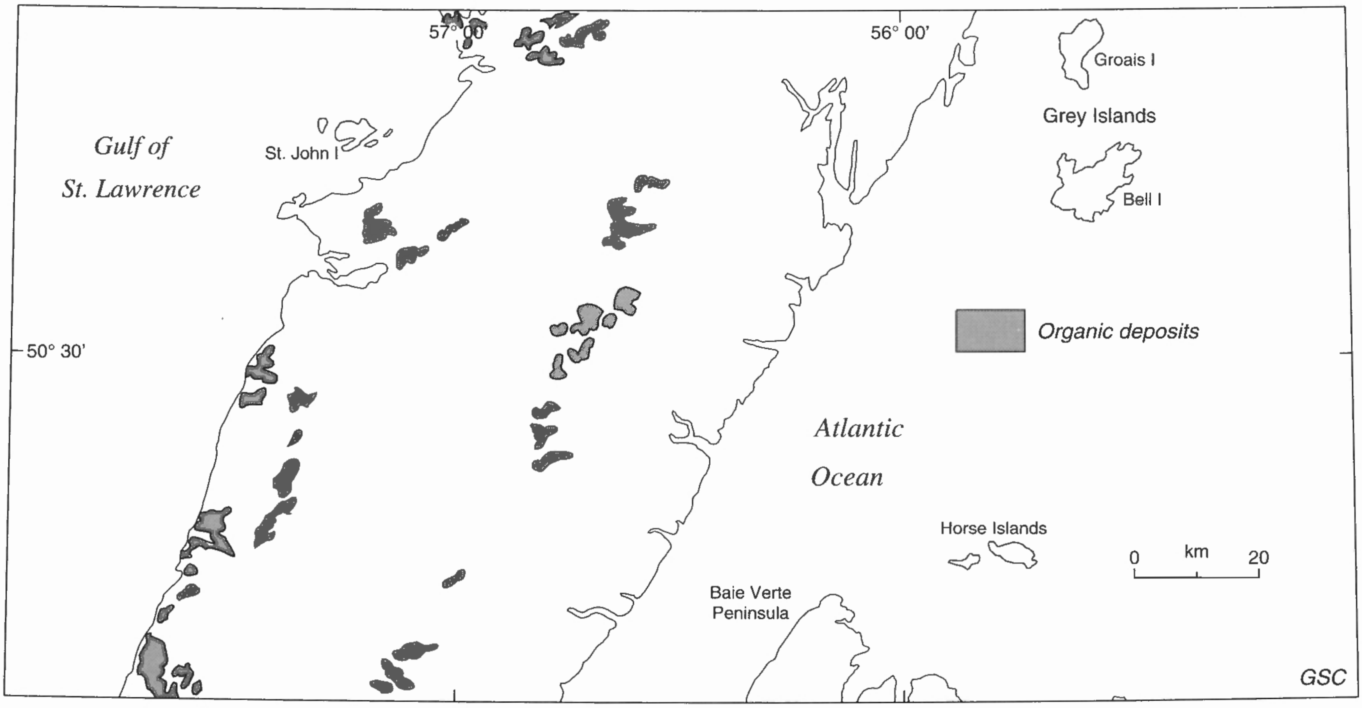


Figure 40. Major organic deposits (after Map 1622A).

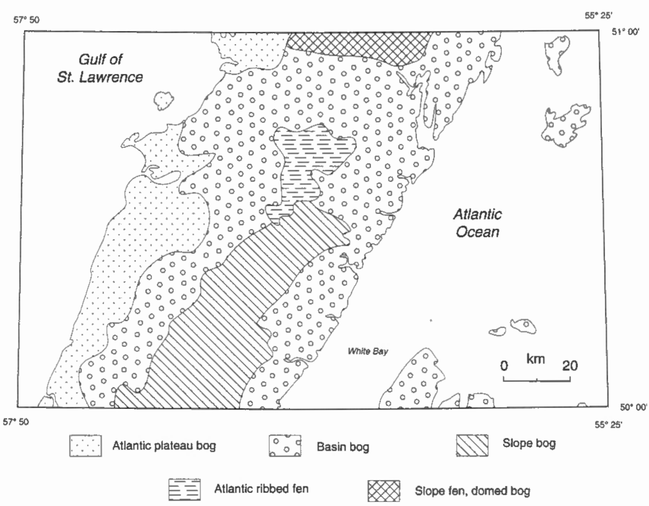


Figure 41. Peatland types (from Wells and Pollett, 1983).

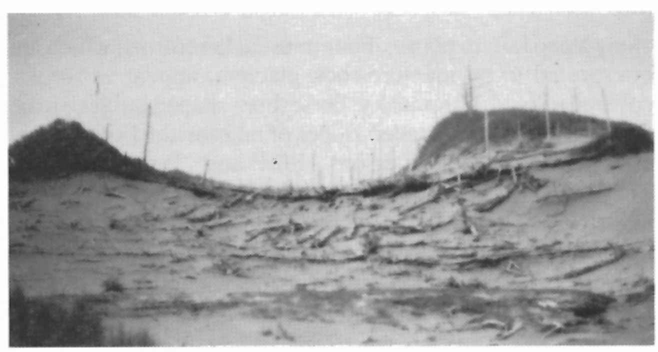


Figure 42. Modern coastal sand dunes with active blowouts exposing buried humic forest layers; mouth of Portland Creek. GSC 204634-B

lowlands. Relative sea-level changes are deduced from shoreline features, such as beaches and deltas, some of which are dated.

high-level terrains (Units 1, 2a, 2b) are problematical, as discussed below. The ages assigned to most of the glacial events therefore are relative and speculative because chronometric control pertains only to the last deglaciation. Mapping shows that virtually the entire area was overrun by glaciers. Geomorphology suggests that possibly three main glaciations, each with different flow regimes, were involved; the first two were possibly Middle Pleistocene. The last main glaciation was Late Wisconsinan, had five ice flow phases and was followed by marine submergence of much of the

Chronology

A suite of 36 radiocarbon age estimates on various materials provides an absolute chronology for deglaciation, marine regression and climatic evolution during the last postglacial period (Table 2; Fig. 43). Three main categories of material were dated: 18 on marine shells, of which 3 are in or under till; 12 on peat, wood, and lake sediment; and 6 on archeological materials (such as charcoal, fat, and bone). selected from more than 20 occurrences in three areas. The ages range from 12 800 BP to 240 BP and thus pertain to Late

Wisconsinan and Holocene times. Most were acquired in connection with this study. A few derive from related studies on geochemistry (Proudfoot and St. Croix, 1987), palynology (T.W. Anderson, personal communication, 1987), and coastal change (J. Shaw, personal communication, 1990). Most of the date locations are shown on Map 1622A; a few were obtained after publication of the map. Also listed as relevant to the interpretation are six additional dates from <10 km beyond the map area. Age citations are keyed to Figure 43 using locality names with site numbers in square brackets, with letter subscripts where there is more than one date at a given locality, e.g., Port au Choix [16c].

The validity of the radiometric determinations is a function of laboratory dependability, contamination, and discrepancies resulting from isotopic fractionation. Most ages were determined by the Geological Survey of Canada and are accepted as given, mainly because they are internally consistent. The validity of shell ages in a carbonate bedrock area is of concern, but this suite demonstrates concordance with associated carbonaceous material. For example, at Port au Choix ages on archeological bone and charcoal [16b, 16c] (Tuck, 1970) in graves on a raised beach were slightly younger than marine shells in the gravel substrate [16a, 16d]. As well, gyttja from an emerged freshwater basin [3] dated younger than the inferred time of sea level at that position [8] and the inferred age of deglaciation. The dates thus appear to provide a reliable chronology of sea-level change and thus help constrain the deglacial sequence.

Glacial succession

Origin of the morphologically different glacial terrains

In the study area, four major glacial terrains which are in mutual contact, are situated at different elevational intervals, and are characterized by distinctive drainage and relative freshness of glacial landforms. Unit 3, which covers most of the area, has youthful drainage, rugged scoured rock surfaces, and till forms with high relief. It is dated to Late Wisconsinan time by associated postglacial marine sediments. The other three units are restricted to high summits and outlying islands and have smooth slopes and more mature drainage. Unit 1 lacks glacial attributes; Units 2a and 2b have solifluction-graded till and frost-shattered bedrock. Their origin and age is problematical because there is not the necessary sedimentary evidence to ascribe them to separate glaciations (ice-marginal features at their boundaries, superposed till sheets and dated nonglacial deposits). A satisfactory explanation of the glacial terrains must account for 1) development on various rock types; 2) uphill decrease in glacial relief and the corresponding increase of stream integration and valley size; 3) concentric elevational arrangement within a relatively narrow vertical interval on all western coastal summits, as well as their occurrence on outlying oceanic islands; and 4) relatively sharp, parallel, seaward-sloping contacts.

The basic question is whether the different glacial terrains are the product either of *structure and process* (lithology, climate and glacial behaviour), *or of time*

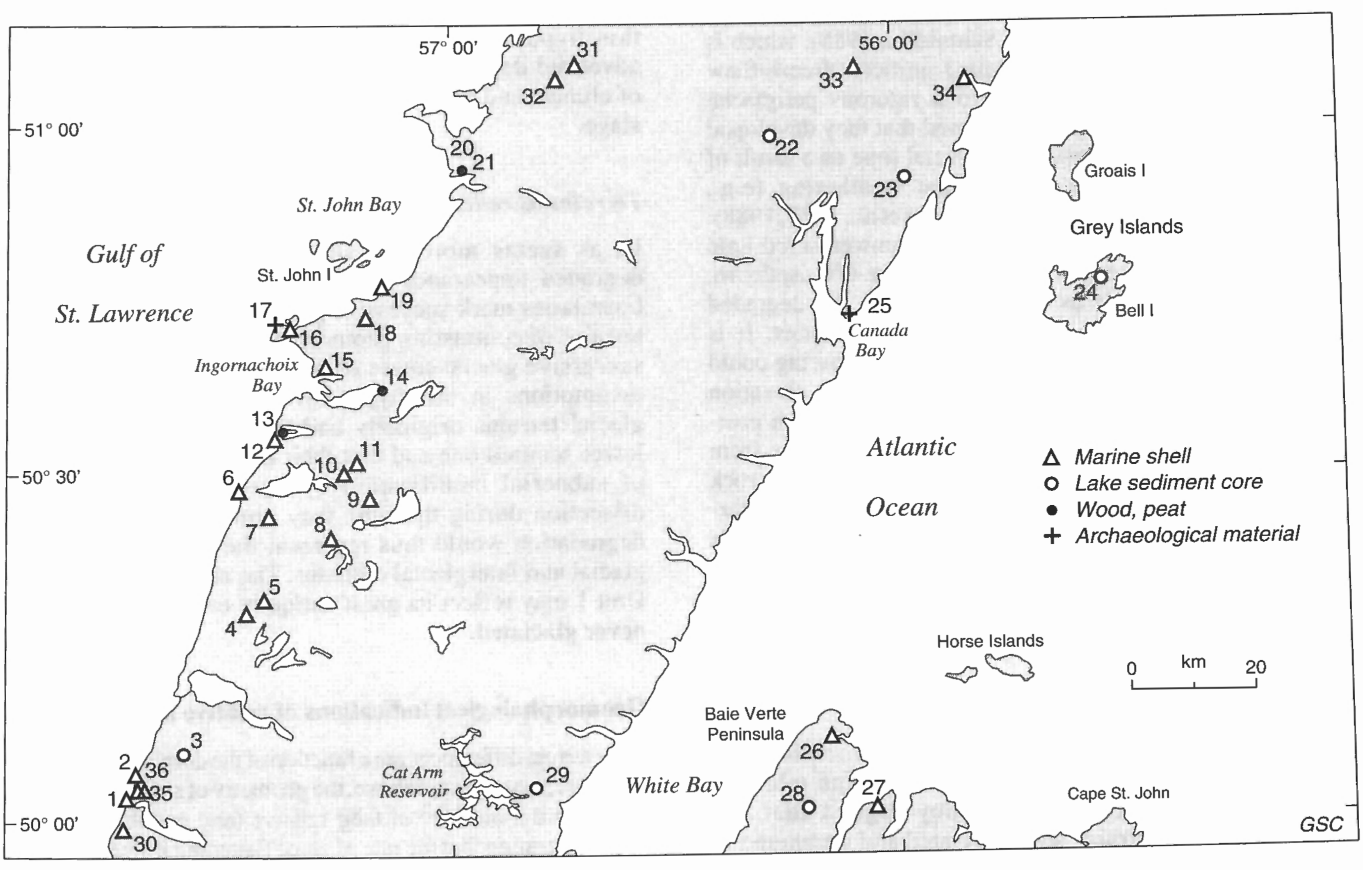


***Figure 43.** Location of radiocarbon age determinations. (Numbers refer to entries in Table 2).*

(the duration of subaerial exposure since they were last deglaciated). As discussed by Nesje et al. (1988), the various possible alternatives which can be envisaged to explain the problematical upper terrains (Units 1, 2a, 2b) are 1) they relate to lithology; 2) they result from intense, high-altitude climate after the last glaciation; 3) they pre-date the last glaciation but were covered and preserved by cold-based, nonerosive ice; 4) they reflect periglacial weathering during the last deglaciation, or 5) they are older glacial terrains that were not overridden during the last glaciation.

Terrains as lithological effects

That the four terrains relate to bedrock type, for example because of structural weakness, can be discounted because they are distributed independently of lithology or structure. Apart from the small areas of Unit 1 in gneissic terrane, the others occur on a variety of lithologies with no apparent common trait. They cut across lithological boundaries and maintain their distinctiveness on rock types ranging from quartzite to dolomite, granite, and gneiss. Rock type is evidently not the controlling factor, but whatever processes were responsible for the three terrains had similar effects on all rock types within a narrow elevation range.

Terrains as high altitude, postglacial climatic effects

The summits with the three anomalous terrains (Units 1, 2a, 2b) lie above the inferred level of the present mean annual 0° isotherm (Fig. 22) (Titus, 1965; Schmidlin, 1988), which is the generally accepted threshold for significant freeze-thaw activity. They are thus exposed to a rigorous periglacial climate. From this it might be supposed that they developed solely by masswasting during postglacial time as a result of cryoturbation, solifluction, and frost weathering (e.g., Dahl, E. 1955; Dahl, R., 1966; 1987; Nesje et al., 1987, 1988). However, the greater part of the virtually unweathered Late Wisconsinan glacial terrain is also above the 0°C isotherm, yet locally lies as little as 50 m lower than the degraded terrains with which it is in relatively sharp contact. It is therefore difficult to understand how frost weathering could be so vigorous and pervasive in the 400-600 m elevation range during the improving climates of the 10-12 ka post-glacial period. Not only would it have had to remove from Unit 1 all erratics and other loose material from the rock surfaces but also to produce Units 2a and 2b as two differentially degraded zones with relatively sharp contacts, while leaving part of the same rocky area virtually unaffected up to 500 m asl. Weathering during a single, short period does not seem to be a likely explanation.

Terrains as weathered relicts protected by cold-based ice

It has been suggested (e.g., Mayewski et al., 1981) that geomorphic differences among glacial terrains relate to basal thermal ice conditions. They argued that the smoother summit terrains were glaciated and weathered at some earlier time (or times), but that they were ice-covered during the last glaciation. They retained their ancient character because they were protected from erosion by cold-based ice, i.e., ice that was fixed and frozen to the substrate, whereas erosive, warm-based ice acted over the fresh-looking lower terrain. Thermal differences, while not impossible, do not, however, explain why Unit 1 has no erratics, or why the smooth-topped summits have different degrees of stream incision, or why the terrain boundaries are sharp, seaward-sloping, elevationally consistent, and of about equal spacing over a large area. Finally, the cold-based ice scenario only begs the questions of when these problematical terrains were last glaciated by warm-based ice and of how long they were subjected to subaerial degradation.

Terrains as periglacial climatic effects in early deglacial time

It may be suggested that the higher terrains became nunataks as a regional ice sheet thinned. They were then degraded by masswasting during the intense periglacial climate, which presumably would have prevailed when it shrank to the area represented by the freshly scoured terrain (Unit 3). This hypothesis has merit in that it explains the geometry of the terrain boundaries, but not why there are two and why they are sharp, rather than blurred. It also poses the question of whether all this process could remove all erratics from Unit 1 and whether Unit 2a could be so deeply dissected during the same time. It also does not explain why the continuing periglacial climate did not later modify the lower terrain (Unit 3) to some degree. Although this hypothesis does not adequately account for the advanced degree of degradation, it does focus on the role of climate and implies that each terrain equates to a glacial stage.

Terrains as relicts of former greater glaciations

If, as seems more plausible from the foregoing, the degraded appearance is a weathering effect and if the boundaries mark successive glacier margins, then the four terrains of contrasting geomorphic maturity may represent successive glacial stages of greatly different age. Implicit assumptions in this hypothesis are that the higher two glacial terrains originally had the same character as the lower scoured one and that their differences are the result of subaerial modification by masswasting and fluvial dissection during the time they remained ice free. Their degradation would thus represent the combined effect of glacial and interglacial climates. The absence of erratics in Unit 1 may reflect its great antiquity or signify that it was never glaciated.

Geomorphological indications of relative age

If the terrain differences are a function of the duration of subaerial exposure, as suggested above, the geometry of slopes and valleys may afford a measure of their relative (and possibly absolute) ages. Assuming that the rate of slope flattening is linear and that upon deglaciation slopes on loose materials (till, gravel, rubble) in all terrains were equally steep (i.e., at angle of repose 30°-40°), comparing of the slopes on the higher smooth terrains suggests they may have been exposed many times longer than those on the lower fresh terrain. Whereas slopes in Unit 3, which has been exposed for about 10 ka, are still at or near maximal angles of repose, those in Unit 2b have been flattened to 3°-10° and those in Unit 2a have been reduced even further to <1° over large areas. If slope reduction is proportional to age and linear with time, the differences may suggest that Unit 2b has been exposed about 4-10 times longer than Unit 3, and Unit 2a for 10-40 times longer than Unit 3.

There are equally large differences between the terrains in terms of the amount of stream incision in bedrock, as exemplified by a valley on the north side of North Summit, Highlands of St. John (Fig. 23). The lower segment, which has been cut into Unit 3 since it became ice free about 10 ka, is a minor gully 10-15 m deep and ≈100 m wide. By comparison, the middle segment in Unit 2b, with a depth of 50-60 m and a width of at least 250 m, has a cross-sectional area about 10 times larger. In Unit 2a the upper segment, a broad gorge 100-150 m deep and ≈750 m wide, is about 50 times larger. If these size differences are function of time, they suggest that Unit 2a may have been deglaciated in the first half of the Middle Pleistocene and Unit 2b in the later Middle Pleistocene. These age estimates are hypothetical but may indicate the possible length of the glacial record in this area.

Inferred sequence of glacial phases

A succession of glacial events is reconstructed on the basis of mapped crosscutting ice flow indicators and the areal and vertical relationships of deposits and landforms. The changing paleogeography of ice, land and sea is depicted in a series of map views (Fig. 44), with a supplementary ice-surface profile for the last glacial maximum (Fig. 45). Three main glaciations and their limits are recognized morphostratigraphically as three till terrains with different geomorphic maturity which are in mutual contact. The ages of the first two main glaciations are inferred on geomorphological grounds as outlined above; the age of the last main glaciation can be specified as Late Wisconsinan from radiocarbon age estimates. Deposits and features demonstrate that glaciation of the area, from the earliest stages to the last, involved the interplay of two ice domains the southern margin of the Laurentide Ice Sheet and the Newfoundland Ice Cap complex which was represented in this area by two ice-dispersal centres one the Long Range plateau and the other on Baie Verte Uplands. Newfoundland ice became progressively more important than Laurentide ice, judging by the dominantly radial ice flow trends and the number of marginal troughs and fiords. The following scenarios incorporate the various alternative explanations of the problematical glacial terrains.

First and greatest major glaciation (early Middle Pleistocene?)

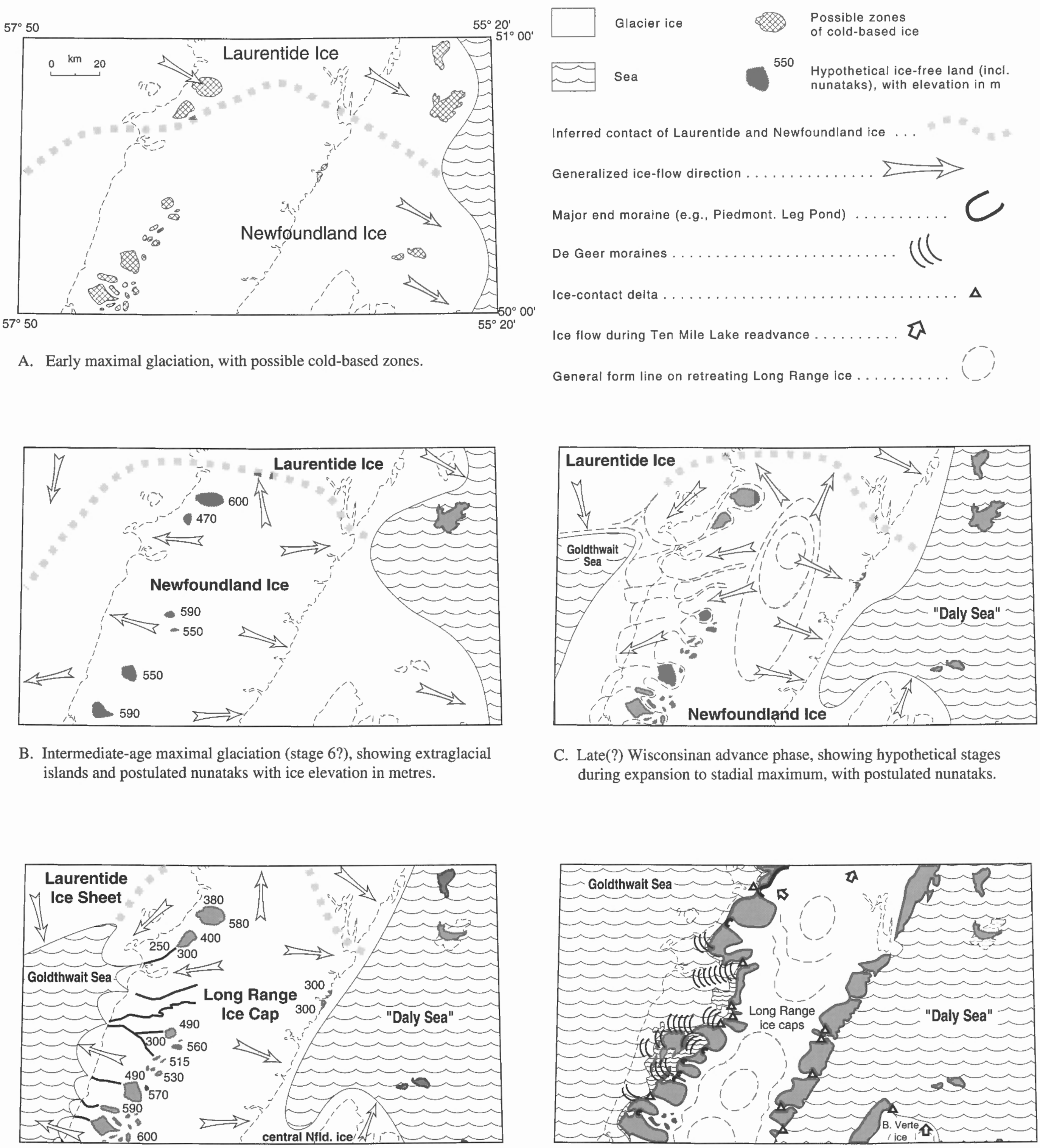
The earliest glacial phase (Fig. 44A) in evidence involved an ice sheet composed of Laurentide and Newfoundland components which abutted along the northern slope of Long Range Mountains, marked by the uphill limit of Shield erratics. The ice surface sloped southeastward and extended far offshore to the east. Its passage is recorded by the parallel ice flow features which trend obliquely across the ≥400 m relief of the steep Atlantic margin of Coastal Uplands and offshore islands. Laurentide ice invaded the northern part of the area, depositing Shield erratics on Highlands of St. John and Grey Islands and imprinting a strong ice-contact marine deltas topography on Coastal Uplands" and Bell Island. The ice sheet overtopped the highest Long Range summits and extended into Atlantic Ocean beyond Grey Islands, Horse Islands and Cape St. John. The smooth summit terrains (Units 1, 2a, 2b) may represent areas where, because it was thinnest and divergent over the highest ground, the glacier was cold-based. If the blockfields (Unit 1) are erratic-free because they were never glaciated, they would have projected through the ice sheet at that time, either as ice-free nunataks or with inactive ice carapaces.

If the apparent geomorphic maturity of the terrain belonging to this early glaciation is proportional to the length of time that has elapsed since it was deglaciated, then the age of the first major glaciation may range from as recent as Late Wisconsinan, if the summit terrains represent cold-based areas, to as ancient as the first half of Middle Pleistocene (Grant, 1987).

Age of submerged cirques and overridden cirques

The inception and last occupation of the submerged coastal cirques and the overridden highland cirques is uncertain because their stratigraphic context is ambiguous and because their elevations differ (200-300 m vs -40 m) probably representing different paleosnowlines. Moreover, their large size, particularly of the drowned cirques, represents the cumulative effect of many glaciations. Therefore, it is assumed that they began to form at least as early as during the first major glaciation. Ice last occupied the submerged cirques prior to the Late Wisconsinan glacio-isostatic inundation;. Ice last occupied the highland cirques prior to the last plateau ice-cap phase, which lasted perhaps until about 9 ka.

Their different topographic setting permits an inference about the time interval each was occupied during a given glaciation. The highland cirques were probably the first sites for glacierization as snowline fell to plateau level. The submerged cirques, likewise, could only have been glacierized during the early stages of each main glaciation because, for their formation, they require not only a very low glaciation level but also a relatively low sea level. The latter requirement is a particularly definitive constraint. The waning phase of any glacial hemicycle can be ruled out because sea level is relatively higher at that time because of glacioisostasy. A -40 m relative sea level requires that local glaciers be small and have negligible isostatic effect while global ice volume was about one-third its average maximum dimensions (corresponding to a sea-level lowering to -120 m). The drowned cirques were therefore probably ~~cut during~~ the early stages of each major glaciation, and last occupied during the Early Wisconsinan. The drowned cirques suggest that regional glaciation in this area peaked relatively late in each glacial phase.



A. Early maximal glaciation, with possible cold-based zones.

B. Intermediate-age maximal glaciation (stage 6?), showing extraglacial islands and postulated nunataks with ice elevation in metres.

C. Late(?) Wisconsinan advance phase, showing hypothetical stages during expansion to stadial maximum, with postulated nunataks.

D. Piedmont Moraines phase, with ice elevation around nunataks.

E. Ten Mile Lake readvance 11-10 ka, with associated end moraines and ice-contact marine deltas. Also shown are De Geer moraines formed during prior subaqueous retreat, and suggested formlines on subsequent retreat.

Figure 44. *Glacial phases showing interplay of Newfoundland ice caps and Laurentide Ice Sheet, with mapped ice-flow trends, major moraines and ice-contact marine deltas, postulated nunataks or cold-based zones, suggested diagrammatic advance and retreatal positions, and inferred calving bays.* ***A.*** *early maximal glaciation, with possible cold-based zones;* ***B.*** *intermediate-age maximal glaciation (stage 6?), with upper limit on postulated nunataks in metres;* ***C.*** *(Late?) Wisconsinan advance phase and stadial maximum with postulated nunataks and two diagrammatic configurations (profile shown in Fig. 45);* ***D.*** *Piedmont Moraines phase;* ***E.*** *Ten Mile Lake readvance 11-10 ka with end moraines and associated ice-contact marine deltas; also shown are De Geer moraines formed during prior retreat, and later stabilization phases during which Cloud River Moraines formed.*

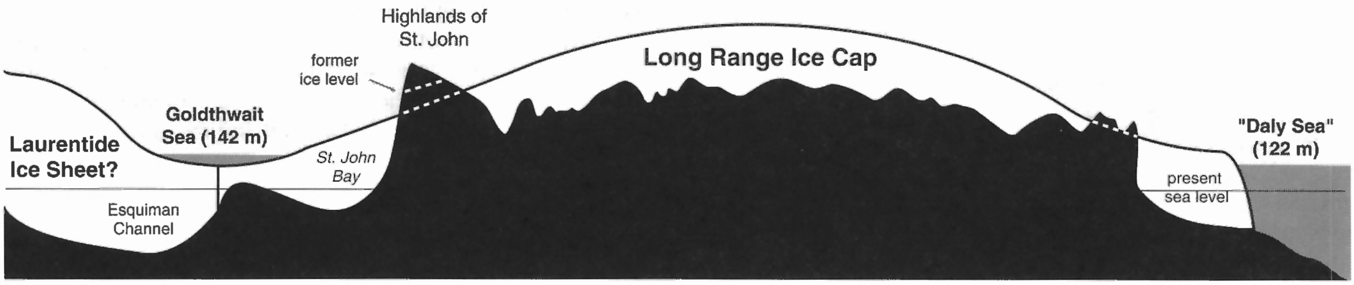


Figure 45. *Hypothetical profile across Long Range Ice Cap showing hypothetical upper limit, inferred calving bays, limit of Laurentide Ice Sheet, and relative sea level during the Late Wisconsinan glacial maximum (location shown in Fig. 44C).*

Second major glaciation (late Middle Pleistocene?)

The seaward-sloping contact of Unit 2b against the higher Unit 2a implies an ice-dispersal phase characterized by dominantly radial outflow from a Long Range ice cap (Fig. 44B). If the smooth terrains represent thermal zones, their seaward slopes indicate that ice thickness decreased from the plateau to the lowlands. If, on the other hand, their topographies reflect maturation by subaerial exposure, then the areas of Unit 2a were ice free at this time, either projecting as nunataks on the western summits or lying beyond the ice margin, in the case of Bell Island. It is assumed that Laurentide ice again abutted on the north because there is no evidence that Long Range ice ever expanded farther northeastward over Coastal Uplands and Grey Islands. The age of this phase could range from as recent as Late Wisconsinan, if the terrains are considered to represent thermal zones, to as old as late Middle Pleistocene (Illinoian?) (Grant, 1987), if the areas of Unit 2b, which were covered by this ice, subsequently were exposed to dissection and masswasting for 100 ka or more, as inferred above on the basis of their flatter slopes and deeper valleys.

Last major glaciation (Late Wisconsinan)

The extent and deployment of ice during the last glaciation (Fig. 44C, 45) is evidenced by the fresh-looking glacial terrain and flow features that characterize much of the area. Glacial terrains lacking this fresh aspect on the Long Range summits, Grey Islands, Horse Islands, and Cape St. John are therefore considered to represent extraglacial areas at this stage. This glaciation is referred to the Wisconsinan and most probably reached its climax during Late Wisconsinan time. After 12.8 ka (the oldest date on associated deglacial marine, lacustrine and paludal sediment) the western margin retreated across the area. The continued interplay of Newfoundland and Laurentide ice is evidenced by ice flow features and ice-marginal deposits. Five flow phases are differentiated, each characterized by distinctive regimes of retreat or stabilisation.

Advance phase and last glacial maximum

Long Range ice is presumed to have formed first on the northernmost part of the plateau, because a lower snow line would have glacierized that area first. In this area of the relict cirques, glaciers persisted longer in the final stages. Ice reaching the northern lowlands met southward-advancing Laurentide ice, which by then had overtopped "Coastal Uplands", and was deflected southwestward around Highlands of St. John where it reached 500 m. Laurentide and Newfoundland ice converged toward the head of Esquiman Channel causing southwestward flow over St. John Bay area, presumably because of drawdown into a deepwater marine calving bay. This condition probably persisted until the penultimate stages. As there is no evidence that Laurentide ice invaded western Newfoundland, its southern limit is positioned on the north side of Esquiman Channel (Fig. 45) where Shearer (1973, p. 295) postulated an ice-marginal stand based on the thick submarine till deposits at 70-90 m depth.

Falling snow line caused the Long Range ice cap to enlarge southward on the plateau. To the east ice moved freely downslope but, on the west, moved upslope, deployed around the high western summits, which remained as nunataks, and coalesced on the lowlands as a series of contiguous piedmont glaciers (Fig. 44C, 45). Torrent River valley probably contained the first outlet glacier because it is the northernmost and extends farthest inland. Reaching the lowlands this lobe was forced to expand mainly to the south because St. John Bay ice was already in place on its northwestern flank. This scenario explains why lowland ice advanced obliquely southwestward to the coast, as recorded by the first set of superimposed striations.

The Long Range ice cap elongated southward until it eventually became centred along the median line of the plateau (Fig. 45), producing the observed symmetrical pattern of ice flow and covering all but the highest hills, which projected as nunataks (Fig. 44D). With all western valleys then receiving comparable ice input, flow on the lowlands was realigned more directly seaward and thereby super- imposed a westward set of striations on the earlier set. The heights of the glacial trimline on the down-ice side of the nunataks suggest that the thickness of piedmont ice was less than 200-300 m. As it was marine-based when relative sea level was ≥100 m higher, the westward offshore extent of piedmont ice was therefore probably near the present 200 m isobath about 10 km beyond the present coast.

Piedmont Moraines phase

These large interlobate moraines were constructed at the margins of confluent coastward flowing glaciers. They mark an equilibrium phase either duringo the last glacial maximum or shortly thereafter. That their outermost portions appear to grade laterally to marine sediment indicates that they were formed by tidewater glaciers fronted by sea. They were constructed >12.6 ka, based on the age of the subsequent marine invasion.

At the last glacial maximum the Long Range ice cap lay between Laurentide ice on the north and an ice cap on Baie Verte Uplands. The general convergence of ice flow trends toward deep marine embayments suggests drawdown into permanent calving bays. Esquiman Channel thus effectively barred Laurentide ice from the western lowlands, and White Bay prevented Long Range ice from overwhelming Baie Verte Peninsula. Ice margins thus generally followed the coast, perhaps explaining why most fiords and troughs have sills at or near the highland and upland escarpments. The marine bodies that are inferred to have occupied the offshore areas are called Goldthwait Sea on the west and "Daly Sea" on the east.

Recession of western tidewater glaciers in Goldthwait Sea

Ultimately glacial vigour waned and the marine-based ice front calved inland, allowing Goldthwait Sea to transgress the lower ground (Fig. 44E). Laurentide ice retreated northward out of the area and stabilized on the Shield margin about 12 600 BP (Grant, 1992). Newfoundland piedmont glaciers similarly shrank inland, becoming spatulate lobes. As flow became more topographically controlled, it shifted more perpendicular to the mountain front, thereby inscribing the last set of striations in a northwestward direction on the earlier sets. Retreat was apparently faster or sooner in the southern part. The interlobate moraine near "Parsons Hills" was evidently abandoned well before 12 500 ± 120 BP (GSC-4393) [3], the age of basal gyttja in a kettle pond. Inside the interlobate complex near Zinc Lake, a large arcuate recessional moraine halfway between the coast and the mountains contains shelly till in one place dated at 12 800 ± 150 BP (BGS-1080) [5]. This date provides a maximum age on the time of construction, as well as a minimum age on the marine transgression. Marine transgression had reached almost to the mountain front by 12 600 ± 160 BP (GSC-1600) [8].

The submarine ice foot calved inland between the interlobate ridges, leaving fields of ≈300 arcuate De Geer moraines. Composed of reworked shelly marine sediment, the moraines demonstrate the stepwise, fluctuating retreat of a highly lobate ice cliff grounded on the sea floor. The general time of formation of the northern fields is suggested by age estimates of 12 300 ± 100 BP (GSC-4859) [10] on reworked shells in till and 12 000 ± 170 BP (GSC-1601) [9] on shells near the highland front. If the De Geer moraines represent small annual (winter) readvances during the general retreat, their number shows that the calving process removed about one-half of the ice sheet in a few centuries. This rapid retreat of the marine-based portion is presumably because the ice mass was thinning and retreating while relative sea level was still rising because isostatic recovery was incomplete, thus making the ice increasingly buoyant and instable.

Stabilization and readvance of ice caps

When the ice caps retreated inland of marine limit they stabilized, building moraines and deltas; in two places they readvanced (Fig. 44E). Baie Verte ice re-expanded into the sea after 12.5 ka depositing till over marine mud with shells of that age at Normans Pond near Deer Cove [27]. It involved a relatively small lobe reached neither as far north as Fleur de Lys [26] nor as high as Compass Pond site [28] at 236 m. The northern part of the Long Range ice cap also readvanced into the sea, plowing up marine sediment and culminating at the Ten Mile Lake Moraine about 20 km beyond the north boundary of the area (Grant, 1992). Dates on included shells show that the advance terminated at or just after 10.9 ka.[31]. Correlative end moraines in this area are the Leg Pond and Doctor's Brook moraines, based on proximity and similar 75 m marine limits. Elsewhere, the Long Range ice margin at this time is tentatively placed at the numerous heads of outwash and ice-contact marine deltas (with 60-75 m marine limits), which occur in most western troughs and eastern fiords (Fig. 44E). Although the Ten Mile Lake readvance may have been a simple mechanical response to an ice profile oversteepened by rapid calving, it is more likely to have been a real expansion of the ice cap in response to the sharp, regional climatic cooling between 10.5 and 11 ka during the Younger Dryas (Mott et al., 1986).

Halting retreat of remnant plateau ice caps

Long Range ice continued its retreat onto the highlands and separated into three ice-dispersal centres, as shown by radial patterns of ice flow indicators and meltwater channels. These centres were situated, not on the highest ground along the western edge, but along the median line of the plateau in upper Cat Arm basin, near Lake Michel, and in Cloud River basin over the relict cirques. The retreat was interrupted by still-stands, as evidenced by scattered small moraines connected by belts of bouldery stagnation moraine where ice flow was directed upslope on the western flank. The eastern flank of the ice cap built small arcuate end moraines in Cloud River valley, which Waitt (1981) speculated are about 8-9 ka.

Possible Neoglaciation

After the plateau glacier disappeared, small névé patches probably persisted on Highlands of St. John judging by the persistence of present-day snowbanks. On North Summit a small moraine at the mouth of a large nivation hollow or shallow cirque appears on airphotos to have less lichen cover than the surrounding felsenmeer and may therefore date from the Little Ice Age.

Relative sea level changes

Extent and elevation of submergence

Following the last deglaciation sea level was relatively higher than at present because of glacio-isostatic crustal depression and so inundated much of the lowland part of the area. The postglacial submergence is referred to as Goldthwait Sea in Gulf of St. Lawrence and "Daly Sea" on the Atlantic coast (Grant, 1992). There is no record of how sea level rose to the relatively higher elevations because available data pertains only to its subsequent fall to present level. The maximum extent (Fig. 46) is reconstructed from determinations of marine limit, represented by ice-contact marine delta tops, trimlines on moraines and other till surfaces, and washing limits of which lengthy segments are visible on Grey Islands (Fig. 16), Conche and Crouse peninsulas, and South Summit. Marine limit (Fig. 46) increases in elevation more or less regularly northwestward from ≈70 m on Baie Verte Peninsula to 142 m on the South Summit interlobate moraine. Anomalously low values relative to the general trend occur on Leg Pond Moraine, in Canada Bay, and on eastern Baie Verte Peninsula because lateglacial readvance in those areas obliterated the original levels and because the later submergence was less because of crustal rebound in the interim.

Shorelevel displacement history

As a result mainly of deglacial isostatic crustal rebound, sea level generally fell from its postglacial high to its present position. However, information is insufficient to reconstruct the areal extent of intermediate phases in the recovery. Instead, the trend of changing sea level can be expressed graphically by means of shorelevel displacement curves (Fig. 47) using the ages and elevations of marine as well as terrestrial deposits (Table 2). Datum points that are believed to relate most closely to sea level include shells in life position in inferred beach deposits and high-tide, salt-marsh peat. Upper limits on the position of sea level at a given time are provided by lake sediments and archeological materials, whereas lower limits are given by shells in till and by shells in deepwater deposits. Data for the southern part are differentiated from those in the north to address the question of whether there is a difference in sea-level history comparable to the twofold northward increase in marine limit noted above.

For the area as whole, sea level generally fell at a steadily decreasing rate; littoral and archeological data define an emergence trend that approximates closely to a simple exponential curve (regression coefficient ≈0.9). However, the data groups for the northern and southern halves of the area can be fitted better (visually) to two separate curves which indicate

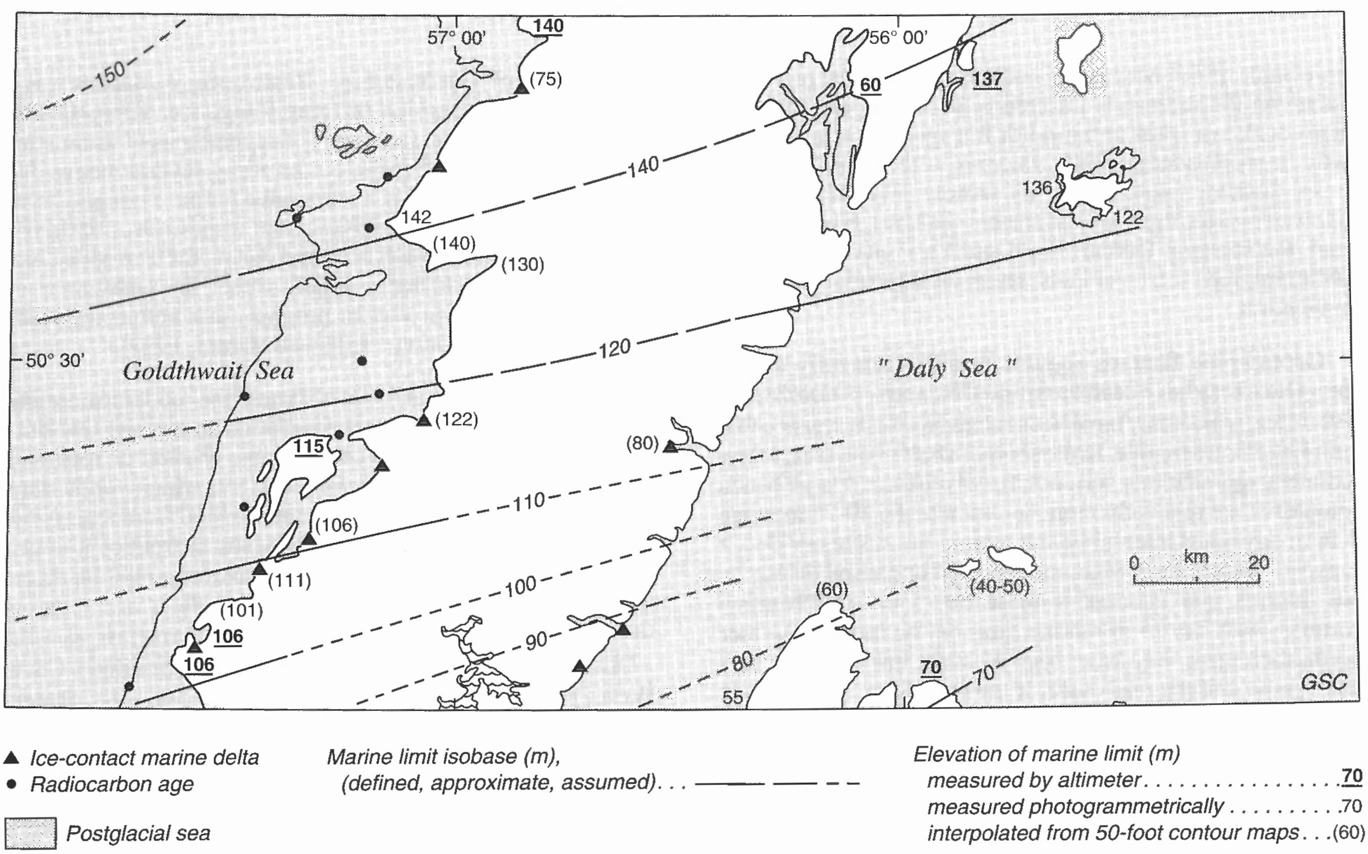


Figure 46. *Extent of postglacial Goldthwait Sea and "Daly Sea".*

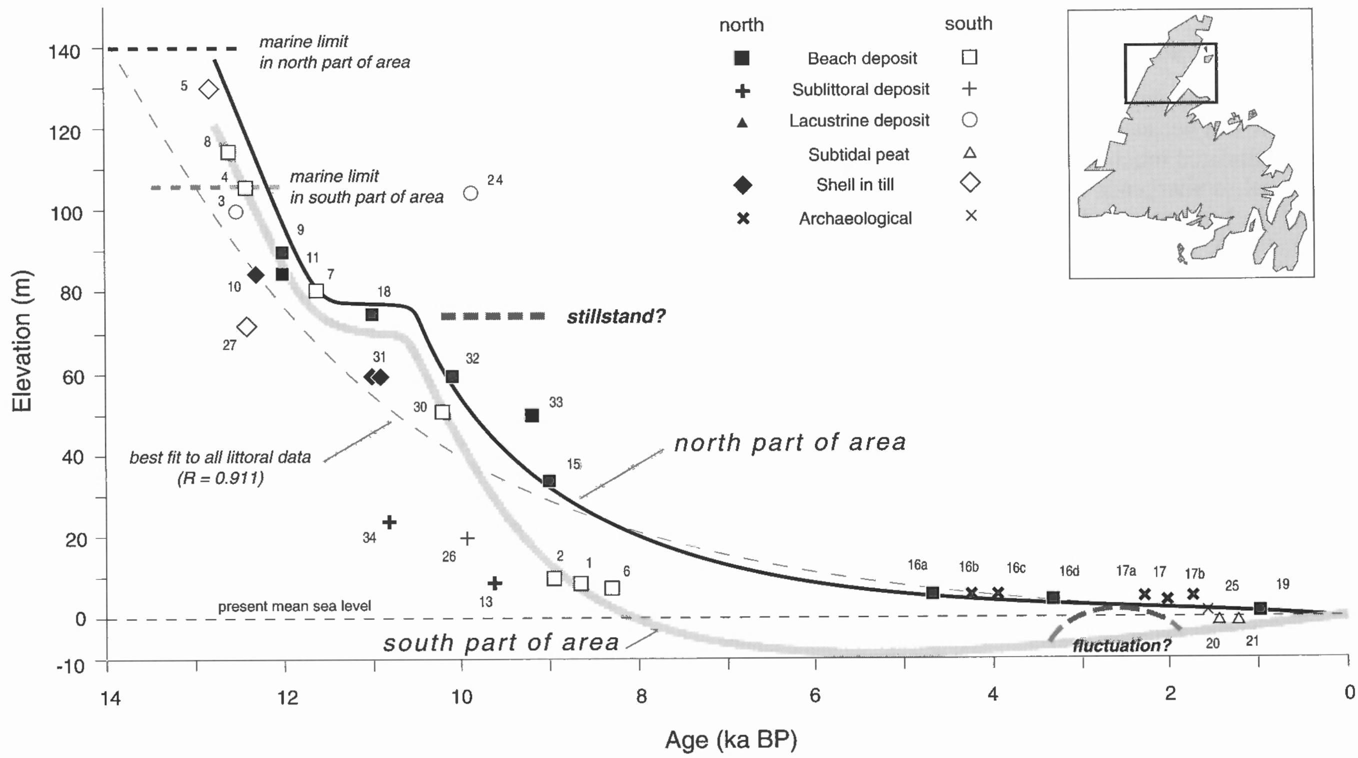


Figure 47. *Trends of local postglacial relative sea-level change (shorelevel displacement) (numbers refer to site numbers in Table 2 and Figure 43).*

appreciable differences in rate and style of sea-level recovery. Assuming the sediments inferred to be littoral are correctly interpreted, sea level in the north fell more or less continuously to its present position, whereas in the south sea level seems to have fallen below its present level about 8 ka, followed by a transgression to present sea level. If on the other hand, the shells at Parsons Pond and La Fontaine Point are sublittoral, then sea level in the south changed much as it did in the north.

Geomorphic features suggest that the generally steady emergence may have been interrupted by a sea-level stillstand ≈10-11 ka, which may have been related to the readvance that built Leg Pond Moraine. In the southern half of the area, major sediment aggradations, terraces, fossil cliffs, and large beach complexes are relatively more common in the 60-75 m range than in any other interval below marine limit. This evidence suggests that sea level regression slowed or paused during its fall through that interval. If these 60-75 m level features correlate with the 75 m marine limit on the moraine farther north, then there may have been a causal link between sea-level pause and the readvance. If the coincidence of levels is significant, perhaps they are the local manifestation of the so-called "Bay of Islands Surface," a raised rock platform, which Flint (1940) postulated is tilted up to 75 m along the west coast. Although that platform is not recognized as such in this area, perhaps the 60-75 m features are its depositional equivalents and thus indicate that there was little if any sea-level change in that time interval. If the sea-level pause did occur when Leg Pond Moraine was built during the culmination of Ten Mile Lake Readvance, perhaps it was a response to re-expansion of Long Range ice. Theoretically, an ice margin change (advance) of several tens of kilometres will deform the geoid (raise sea level) by several metres due to gravitational attraction, as suggested for the Younger Dryas readvance in Norway (Fjeldskaar and Kanestrøm, 1980). If a similar geoidal correction occurred during the Ten Mile Lake readvance, it would have largely offset the emergence of 3 m/100 year, which was in progress just before the readvance, thereby effecting a stillstand (Grant, 1992).

The low, horizontal fossil cliff near the modern shoreline (Fig. 38) implies a sea-level oscillation in the last few millenia. The cliff represents considerable erosion of rock and previously deposited regressive sediments which implies that the direction of sea-level movement changed from regression to transgression. The few raised beaches in front of it imply subsequent regression. The time of erosion cannot be dated directly but can be roughly bracketed by dates of 3.4 ka on the beaches into which it is cut at Port au Choix [16] and the ≈1 ka date of a beach deposited in front of it at Eddies Cove West [19]. An oscillation at ≈1-3 ka is therefore postulated (Fig. 47). The change from regression to transgression in late Holocene time indicates a sea-level oscillation which Pardi and Newman (1987) suggested would be the consequence of the.collapsing crustal forebulge migrating through an area The fossil cliff, whatever its age, is still problematical and difficult to accomodate in the sea-level trend because there is little time and because its horizontality from north to south contradicts the postulated latitudinal variations.

The present rate and direction of sea-level change is difficult to specify because there are no local tide-gauge measurements or geodetic relevelling; uncertainty about the meaning of the fossil cliff is a further complication. Nonetheless, an estimate can be extrapolated from general trends of the past few millenia. In the north, truncation of the 1000-2000 year-old raised beaches by the modern shoreline suggests that the general fall of sea has virtually ceased and may be rising very slowly. In the south, sea level is apparently rising, as suggested by the active modern coastal erosion, specifically the truncated barriers, the aggradation of salt marsh mud, and the construction of boulder barricades (Fig. 37). Indeed, two dates on high tide and freshwater peat now below tide level [20, 21] indicate that sea level has risen about 0.5 m in the last millenium (J. Shaw, personal communication 1990). This ongoing and relatively rapid sea-level rise is clearly responsible for the vigorous coastal erosion and deposition that prevails today.

ECONOMIC GEOLOGY

In this study area, for which continued future resource development and population growth seems likely, information on terrain features and Quaternary deposits and processes will be useful for various economic activities, including resource development, land-use planning, and hazard assessment. Existing terrain conditions and the processes that are presently modifying the landscape affect on land use by either beneficially or negatively. Some of these factors and the ways they may be managed are outlined in this section.

The surficial geology map, a detailed inventory of surficial materials and landforms, provides information on thickness and composition of overburden and the location and relief of landform elements such as scarps, rock ridges, and solution collapse features. Thus the map would be useful for planning any land-based activity such as reforestation programs; it permits preliminary selection and costing of route alignments for instalations such as hydro-electric transmission and for communication cables. The map is also a convenient reference to materials, such as peat and gravel, which have economic value or are important for other purposes such as water supply and waste disposal.

Mineral exploration

Mineral exploration and development using geochemical surveying and drift prospecting can be aided by reference to surficial materials and the sequence and direction of glacial transport. The mapped materials provide a background to evaluate the degree to which the host sediment is displaced from the bedrock source. For example, heavy metal anomalies in till are more closely related to the parent bedrock source than anomalies in stream and lake sediment, which are in turn derived from till. Mineralized float in till or as ablation debris on till or bedrock usually relates to the last direction of ice flow, especially on the Long Range plateau. However, on the lowlands, particularly the western part, where several discordant movements have occurred, there is the possibility of redeposition by successive movements; the anomaly may be in an unrecognized window to an older till bed.

Granular materials and peat

Sorted aggregates of gravel and sand are essential ingredients for fill and for making concrete and asphalt. Most deposits in the map area are concentrated near the coast and thus coincide with the populated areas where demand is greatest. Large deposits at the heads of unpopulated eastern Long Range fiords, where there is no local need, could be considered for direct shipping by barge to distant markets. Map 1622A outlines all deposits of sand and gravel regardless of composition, texture, and quality. Subsequent detailed assessments of all aggregate deposits (including suitable bedrock types) within 3 km either side of all highways and major resource access roads have been conducted (Kirby and Ricketts, 1983; Kirby, 1984, 1988) and presented on a 1:250 000-scale map with analyzed samples located (Kirby et al., 1983).

The few sand deposits are limited mainly to small areas of recent alluvium and a few dunes at the head of Canada, St. John, Ingornachoix, and Hawke bays, and along Portland Creek. Small and thin beds of marine sand occur locally near River of Ponds, Daniels Harbour and Parsons Pond and inland along River of Ponds. Composition is largely comminuted granitic rocks from Long Range Mountains.

Abundant gravel occurss as veneers and blankets in the form of extensive raised marine beaches mainly over the western lowlands and as thick ridges locally farther inland in the form of ice-contact stratified drift associated with interlobate moraines. Gravel composition and texture varies greatly, the proportion of crystalline versus carbonate rocks and the degree of sorting depending on the distance down-ice from Long Range Mountains.

Deposits of granular materials seem to be of adequate quantity and quality to meet most local requirements for some time to come. However, a land-use conflict may emerge in some areas where large, high-quality reserves are being effectively excluded from exploitation by being built over or degraded by use as landfill sites.

Widespread and locally quite thick deposits of peat are of economic grade and quality, though not yet commercially viable because of price in relation to distance from markets. Peat is an important component in the hydrological regime because it regulates fluctuations, especially because it blankets even gravelly areas. Basinal peat bogs may offer a better landfill medium for community waste disposal than gravel pits.

Water supply and waste disposal

Water requirements are presently met from surface and shallow subsurface flow using dug wells, streams and lakes. Most sources on the populous west coast exploit or flow through coarse marine deposits which provide good quality, dependable supplies. However, water in gravels is subject to contamination arising from current waste-disposal practices. Leachates are migrating from septic, sanitary, and commercial wastes that are disposed in gravel pits and quarries, as well as on coasts. The problem is exacerbated by the dense clayey tills and glaciomarine sediments, which typically underlie the gravels. An alternative disposal environment might be peat-filled depressions in clayey sediment where percolation could be contained and the peat could be applied as absorbant covering layers.

Hazards

The physical hazard with the greatest economic impact is shoreline recession and coastal alteration, which is being driven by the continuing sea-level rise. It poses the greatest risk because the damage affects property and thereby hampers economic activity by necessitating expensive remedial and defensive structures. The most vulnerable coastal type is unfortunately the most economically preferred, because it is composed of easily alterable materials, namely gravel and sand. No measurements of actual coastal erosion rates have been made, but anecdotal evidence, such as visible destruction of residential property and periodic road realignment and a cursory examination of airphoto coverages since 1953, suggests that shorelines composed of till and gravel are retreating up to 1 m/a along much of the populated Gulf coast. This rate of shoreline retreat is of the same order of magnitude as that predicted by the Bruun Rule by which shoreline retreat is a function of sea-level rise and coastal slope (retreat = sea-level rise/ tangent of coastal slope). Applying this rule of thumb to the nonresistant Gulf coast, which has an average regional slope of $\approx$1:100, the approximate present rise of 0.002 m/a (extrapolated from Fig. 47) would theoretically cause 0.2 m/a of retreat. This rate of erosion is sufficient to destroy the average-sized domestic property in one or two generations.

Other hazards are largely confined to slopes where various kinds of mass movement occur. Steep bedrock and colluvial slopes along the highlands escarpment are subject to periodic rockfall, landslide, and avalanche. A cursory examination of four successive airphoto coverages suggests that failures occur at the rate of one per decade per kilomtre of cliff. On steep till and colluvial slopes, the possibility should not be overlooked of large earth flows induced by abnormal precipitation, as they have occurred elsewhere in Newfoundland. Slumping of clay-silt marine deposits by mudflow and rotational failure has occurred periodically around River of Ponds Lake and in the vicinity of Daniels Harbour, suggesting that these sediments should be avoided as foundation sites. Near-surface subterranean cavities are suggested by the frequency of sinkholes (shown on Map 1622A) and disappearing lakes. Foundation integrity should therefore be ensured before siting large structures, such as transmission towers. Finally, slower mass move- ments, namely the processes of solifluction, cryoturbation, and frost disruption of bedrock, and possible ground ice are likely above 300-400 m elevation.

CONCLUSIONS

Highlights of the findings are mentioned here. The recommendations are aimed at resolving outstanding problems.

Bedrock geomorphology

Hitherto unrecognized physiographic aspects give insight into bedrock structural style, inheritance of landscapes, regional uplift and sedimentation, and the degree of Quaternary modification. The fact that much of the western Long Range escarpment has not backwasted appreciably inland of the fault trace indicates that it represents the original shape of the allochthon thrust front. Moreover, peculiar arcuate salients characterize the leading edge of the overthrust portion. If so, they may be useful indicators of thrust sheets where fault criteria are ambiguous.

The sub-Cambrian unconformity on Long Range crystalline terrane apparently has a knob-and-basin surface indistinguishable from the rest of the glaciated Long Range terrain. This unroofed paleoplain implies a Late Proterozoic glaciation, as has been inferred for other similar parts of the Shield margin (e.g., Swett, 1981). It thus raises the question of how much of the present glacial relief is the product of recent (Quaternary) glaciation and how much is relict from ancient glaciations. Closer inspection of outcrops of the unconformity seems warranted.

The area features strongly differentiated Tertiary planation levels which represent major episodes of crustal uplift and stability. They correlate regionally, but important height variations seem to offer a unique measure of broad-scale Cenozoic warping, much of which may have been an isostatic response to erosional unloading. Moreover, as the surfaces span the same period as the continental shelf depositional sequence, it would be fruitful to establish better onshore-offshore correlations to construct a regionally integrated picture of crustal movement and sedimentation.

Glaciation

The Port Saunders area is apparently one of only two in Appalachian Canada where the interplay of contemporaneous Laurentide ice and local upland glaciers can be demonstrated. There is no evidence that Shield ice invaded any more than only the northern extremity of Newfoundland during the last glaciation (apart from rare early southeastward striations explained as piedmont glacier lobations). This finding contrasts with regional interpretations (e.g. Mayewski et al., 1981) and those developed from offshore evidence (e.g., Piper et al., 1990). Some effort should be expended on resolving the contradictions and developing a model that incorporates all evidence.

The evidence that glacial terrains with different geomorphic maturity (or weathering zones) constitute morphostratigraphic units supports recent interpretations in the Scandinavian type area (Dahl, 1987; Nesje et al., 1987, 1988). It thus has implications for reconstructing glacier extent and thickness in other areas of the eastern Canadian margin where such terrains are developed. Still, documentation of their age is still deficient and could be improved by pedological analysis and by independent chronostratigraphic evidence from their offshore extensions.

Three progressively less extensive major glaciations are represented and are inferred to be of stage rank, based on geomorphic maturity as a measure of postglacial time. The first two may date from the Middle Pleistocene and the last is Late Wisconsinan. The geomorphological results thus offer independent support for interpretations based on offshore sediments that there were three major regional glaciations and that they correlate with oxygen-isotope stages 12, 6, and 3 (Alam et al., 1983).

Climatic change

The multiphase glacial sequence documented by direction indicators and ice-marginal forms demonstrates four main Late Quaternary events that are widely represented elsewhere in Newfoundland and the surrounding region: readvances at 12.7 ka and 10-11 ka (Brookes, 1977b; Dubois and Dionne, 1985); a stillstand 8-9 ka (Waitt, 1981; T.W. Anderson, personal communication, 1990); and reactivation of talus glaciers during the Neoglacial cold period when also permafrost re-formed at low elevation (e.g., Dionne, 1983). It is noteworthy that the 10-11 ka event correlates with the severe Younger Dryas climatic deterioration that affected northwestern Europe. The good correlation of local glacier responses underlines the sensitivity of Atlantic regional climate to North Atlantic oceanic conditions, as alluded to by Mott et al., (1986). Eastern Canadian climate, at least during the glacial mode, is evidently strongly coupled to sea-surface temperatures, but this relationship needs to be validated by pollen-sequence analysis.

Testing the possible climatic origin of morphostratigraphic units brought to light ample evidence of active solifluction, cryoturbation, and nivation. These processes are tentatively related to the mean annual 0°C isotherm, which is inferred to lie at relatively low elevation in the area. Fossil rock glaciers suggest a late Holocene lowering of the freezing level. These features invite further study of their age and rate of formation.

Stratigraphy and sedimentology

The work has developed an extensive geochronological database, assembled a rich mollusc collection, and brought to light numerous classic and accessible stratigraphic sequences which demonstrate the facies transitions between submarine and subaerial glacier margins. These resources present good opportunities for sedimentological modeling and for paleoecological, isotopic and amino-acid analysis of fossil material, such as by comparing mollusc assemblages (Robertson, 1987) with microfauna (Guilbault, 1984). Such opportunities are unparalleled in Atlantic Canada.

Sea level change

The different sea-level histories across the area demonstrate the strong gradient of crustal warping induced by Laurentide loading which typifies the Atlantic region. Especially instructive is the fact that the area straddles the Zone I/II boundary (of the global zonation by Clark et al., 1978), which is the transition between continuous emergence and continuous submergence. The refined trends materially improve the database used by Quinlan and Beaumont (1982) to model glacier extent from relative sea-level changes, which thus points up the need to update the modelling in the light of data added over the last 10 years.

Qualitative evidence of a temporary cessation of shoreline emergence (a relative sea-level stillstand) during the 10-11 ka glacial readvance, is a fact rarely adduced in other studies. It is suggested that emergence was offset by geoidal rise because of gravitational attraction by the enlarged ice mass. If this explanation were valid, the mechanism would account for unexplained deglacial stillstands in other areas.

The reconstructed sea-level trends document a strong relative rise during at least the last millenium, which explains the rapid coastal erosion prevailing today. However, projectiing future trends and their precise effects on shoreline change will require much more detailed dating of recent submergence rates, such as may be obtained from tidal marsh sequences. A horizontal fossil cliff, so widely developed throughout western Newfoundland, implies a late Holocene fluctuation, perhaps correlative to that in the St. Lawrence estuary (Dionne, 1990). The feature is nonetheless difficult to accommodate in the existing sea-level chronology, so its age must be established to substantiate the suggestion that migration of the crustal forebulge (Pardi and Newman, 1987) is responsible. Present coastal erosion rates should be measured using the sequence of airphoto coverages since 1953 and the results compared with rates of sea-level rise to test the Bruun Rule as a means of predicting coastal retreat rates where measurements are lacking.

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REFERENCES

Alam, M., Piper, D.J.W., and Cooke, H.B.S.
1983: Late Quaternary stratigraphy and paleo-oceanography of the Grand Banks continental margin, eastern Canada; Boreas, v. 12, p. 253-261.

Ambrose, J.W.
1964: Exhumed paleoplains of the Precambrian Shield of North America; American Journal of Science, v. 262, p. 817-857.

Baird, D.M.
1951: The geology of the Burlington Peninsula, Newfoundland; Geological Survey of Canada, Paper 51-21, 70 p.
1957: Carboniferous rocks of the Conchenorthern Grey Islands area; Newfoundland Department of Mines and Resources, Geological Survey, Report 12, 25 p.

Belland, René J.
1981: Ecology and phytogeography of the Bonne Bay region, western Newfoundland; Masters thesis, Memorial University of Newfoundland, St. John's, 133 p.
1987: The disjunct moss element of the Gulf of St. Lawrence region: glacial and postglacial dispersal and migrational histories; Journal of Hattori Botanical Laboratory, no. 63, p. 1-76.

Betz, F.
1939: Geology and mineral deposits of the Canada Bay area, northern Newfoundland; Newfoundland Geological Survey, Bulletin 16, 53 p.

Bird, J.B.
1972: The denudational eveolution of the Maritime Provinces, Canada; Revue de Géographie de Montréal, v. 26, p. 421-432.

Blake, W. Jr.
1983: Geological Survey of Canada radiocarbon dates XXIII; Geological Survey of Canada, Paper 83-7, 34 p.
1986: Geological Survey of Canada radiocarbon dates XXV; Geological Survey of Canada, Paper 85-7, 32 p.
1988: Geological Survey of Canada radiocarbon dates XXVII; Geological Survey of Canada, Paper 87-7, 100 p.

Bostock, H.H., Cumming, L.M., Williams, H., and Smyth, W.R.
1983: Geology of the Strait of Belle Isle area, northwestern insular Newfoundland, southern Labrador and adjacent Québec; Geological Survey of Canada, Memoir 400, 145 p.

Bostock, H.S.
1972: Physiographic subdivisions of Canada; in Geology and Economic Minerals of Canada, (ed.) R.J.W. Douglas; Geological Survey of Canada, Economic Geology Report, no 1, 5th edition, p. 9-30.

British Admiralty
1770: A chart of the west coast of Newfoundland surveyed by order of Commodore Pallisser, Governor of Newfoundland, Labrador &c&c by James Cook, Surveyor, 10 May 1770.

Brookes, I.A.
1977a: Geomorphology and Quaternary geology of Codroy lowland and adjacent plateaus, southwest Newfoundland; Canadian Journal of Earth Sciences, v. 14, p. 2101-2120.
1977b: Radiocarbon age of the Robinson's Head Moraine, west Newfoundland, and its significance for postglacial sea-level changes; Canadian Journal of Earth Sciences, v. 14, p. 2121-2126.
1982: Ice marks in Newfoundland: a history of ideas; Géographie physique et Quaternaire, v. 36, p. 139-163.

Cawood, P.A. and Williams, H.
1986a: Acadian basement thrusting, crustal delamination and structural styles in and around the Humber Arm Allochthon, western Newfoundland; Geology, v. 16, p. 370-373.
1986b: Northern extremity of the Humber Arm Allochthon in the Portland Creek area, western Newfoundland, and relationships to nearby groups; in Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 675-682.

Cawood, P.A., Williams, H., and Grenier, R.
1987: Geology of Portland Creek area (12 I/4), western Newfoundland; Geological Survey of Canada, Open File 1435.

Chamberlin, T.C.
1895: Notes on the glaciation of Newfoundland; Geological Society of America, Bulletin, v. 6, p. 467.

Christie, A.M.
1951: Geology of the southern coast of Labrador from Forteau Bay to Cape Porcupine, Newfoundland; Geological Survey of Canada, Paper 51-13, 19 p.

Clark, J.A., Farrell, W.E., and Peltier, W.R.
1978: Global changes in postglacial sea level: a numerical calculation; Quaternary Research, v. 9, p. 265-287.

Coleman, A.P.
1920: Extent and thickness of the Labrador ice sheet; Geological Society of America, Bulletin, v. 31, p. 319-328.
1926: The Pleistocene of Newfoundland; Journal of Geology, v. 34, p. 193-223.
1930: The extent of Wisconsin glaciation; American Journal of Science, Series 5, v. 20, p. 180-183.

Cumming, L.M. and Grant, D.R.
1974: Crustal delevelling in northern Newfoundland; in Report of Activities, Part B, Geological Survey of Canada, Paper 74-1B, p. 7-10.

Dahl, E.
1955: Biogeographic and geologic indications of unglaciated areas in Scandinavia during the glacial ages; Geological Society of America, Bulletin, v. 66, p. 1499-1519.
1987: The nunatak theory reconsidered; Ecological Bulletins, v. 38, p. 77-94.

Dahl, R.
1966: Block fields, weathering pits and tor-like forms in the Narvik Mountains, Nordland, Norway; Geografiska Annaler, Ser. A, v. 48, p. 55-85.

Dale, C.T.
1979: A study of high resolution seismology and sedimentology on the offshore Late Quaternary sediments northeast of Newfoundland; M.Sc. thesis, Dalhousie University, Halifax, 181 p.

Dale, C.T. and Haworth, R.T.
1979: High resolution reflection seismology studies on Late Quaternary sediments of the northeast Newfoundland continental shelf; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 357-364.

Daly, R.A.
1920: Oscillation of level in the belts peripheral to the Pleistocene ice caps; Geological Society of America, Bulletin, v. 31, p. 303-318.
1921: Postglacial warping of Newfoundland and Nova Scotia; American Journal of Science, Series 5, v. 1, p. 381-391.

Damman, A.W.H.
1963: A reconnaissance survey of ecological conditions in the forests of the Roddickton area, Newfoundland; Canada Department of Forestry, Forest Research Branch, St. John's, Mimeo 63-N-1, 90 p.

De Geer, G.
1889: Ändmoräner i trakten mellan Spånga och Sunbyberg; Geologiska Föreningen i Stockholm, Förhandlingar, v. 11, p. 395-396.
1892: On Pleistocene changes of level in eastern North America; Boston Society of Natural History, Proceedings, v. 25, p. 454-477.
1940: Geochronologia Suecica principles; Kungliga Svenska Vetenskapsakademiens Handlingar, Series 3, v. 18, no 6, 367 p.

Dionne, J-C.
1983: Reseaux reliques de polygones de tourbe, moyenne et basse Côte Nord du Soint-Laurent, Québec; Géographie physique et Quaternaire, vol. 37, p. 127-146.
1990: Observations sur le niveau marin relative à l'Holocène à Rivière-du-Loup, estuaire du Saint-Laurent, Québec; Géographie physique et Quaternaire, vol. 44, p. 45-53.

Dubois, J-M. M., and Dionne, J-C.
1985: The Québec North Shore Moraine system: a major feature of Late Wisconsinan deglaciation; Geological Society of America, Special Paper 197, p. 125-133.

Dyer, A.K.
1986: A palynological investigation of the late Quaternary vegetational history of the Baie Verte Peninsula, northcentral Newfoundland; Master of Science thesis, Memorial University of Newfoundland, 182 p.

Dyke, A.S. and Prest, V.K.
1987: Late Wisconsinan and Holocene retreat of the Laurentide Ice Sheet; Geological Survey of Canada, Map 1702A, scale 1:5 000 000.

Elson, J.A.
1968: Washboard moraines and other minor moraine types; in Encyclopedia of Geomorphology, (ed.) R.W. Fairbridge; Encyclopedia of Earth Sciences Series, v. III, Reinhold Book Corporation, New York, p.1213-1219.

Energy, Mines and Resources Canada
1985: National Atlas of Canada, 5th Edition.

Environment Canada
1975a: Temperature 1941-1970; Atmospheric Environment Service, Canadian Normals, v. l-SI.
1975b: Precipitation 1941-1970; Atmospheric Environment Service, Canadian Normals, v. l-SI.

Erdmer, P.
1984: Summary of field work in the northern Long Range Mountains, western Newfoundland; in Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 521-530.
1986: Precambrian geology of the northern Long Range Inlier, western Newfoundland; Geological Survey of Canada, Open File 1310.

Fairchild, H.L.
1918: Postglacial uplift of northeastern North America; Geological Society of America, Bulletin, v. 29, p. 187-234.

Fernald, M.L.
1911: A botanical expedition to Newfoundland and southern Labrador; Rhodora, v. 13, p. 109-162.
1925: The persistence of plants in unglaciated areas of boreal America; Memoirs of the American Academy of Arts and Sciences, v. 15, p. 239-336.
1930: Unglaciated western Newfoundland; Harvard Alumni Bulletin, 6 p.
1933: Recent discoveries in the Newfoundland flora; Rhodora, v. 35, p. 9-162

Fjeldskaar, W. and Kanestrøm, R.
1980: Younger Dryas geoid-deformation caused by deglaciation; in Earth Rheology, Isostasy, and Eustasy, (ed.) N-A. Mörner; John Wiley and Sons, New York, p. 569-574.

Flint, R.F.
1940: Late Quaternary changes of level in western and southern Newfoundland; Geological Society of America, Bulletin, v. 51, p. 1757-1780.
1951: Highland centers of former glacial outflow in northeastern North America; Geological Society of America, Bulletin, v. 62, p. 21-38.

Foley, F.C.
1937: Geology and mineral deposits of the Hawke BayGreat Harbour Deep area; Newfoundland Department of Natural Resources, Geological Survey, Bulletin 10, 22 p.

Fritts, C.E.
1953: Geological reconnaissance across the Great Northern Peninsula of Newfoundland; Newfoundland Department of Mines and Resources, Geological Survey, Report 4, 27 p.

Grant, D.R.
1969a: Surficial deposits, geomorphic features, and Late Quaternary history of the terminus of the Northern Peninsula of Newfoundland, and adjacent Quebec Labrador; Maritime Sediments, v. 5, p. 123-125.
1969b: Late Pleistocene readvance of piedmont glaciers in western Newfoundland; Maritime Sediments, v. 5, p. 126-128.
1970: Quaternary geology, Great Northern Peninsula, island of Newfoundland; in Report of Activities, Part A, Geological Survey of Canada, Paper 70-1A, p. 172-174.
1972a: Surficial geology, western Newfoundland; in Report of Activities, Part A, Geological Survey of Canada, Paper 72-1A, p. 157-160.
1972b: Surficial geology reconnaissance, Island of Newfoundland; in Report of Activities, Part B, Geological Survey of Canada, Paper 72-1B, p. 100.

Grant, D.R. (cont.)
1972c: Postglacial emergence of northern Newfoundland; in Report of Activities, Part B, Geological Survey of Canada, Paper 72-1B, p. 100-102.
1973a: Canada-Newfoundland Mineral Development Program – Project 6: Glacial geological-geochemical survey, glacial geology phase; in Report of Activities, Part A, Geological Survey of Canada, Paper 73-1A, p. 196-198.
1973b: Pleistocene and Recent history; in The Great Northern Peninsulaan archeological and geological history; Newfoundland Department of Tourism, Park Interpretation Publication 3, p. 28-31.
1973c: Surficial geology maps, Newfoundland; Geological Survey of Canada, Open File 180, scale 1:50 000.
1974a: Terrain studies of Cape Breton Island, Nova Scotia, and the Northern Peninsula, Newfoundland; in Report of Activities, Part A, Geological Survey of Canada, Paper 74-1A, p. 241-248.
1974b: Granular resources inventory, Island of Newfoundland; Geological Survey of Canada, Open File 194, scale 1:500 000.
1974c: Prospecting in Newfoundland and the theory of multiple shrinking ice caps; in Report of Activities, Part B, Geological Survey of Canada, Paper 74-1B, p. 215-216.
1976: Glacial style and the Quaternary stratigraphic record in the Atlantic Provinces, Canada; in Quaternary Stratigraphy of North America, (ed.) W.C. Mahaney; Dowden, Hutchinson and Ross, Stroudsburg, U.S.A., p. 33-35.
1977a: Altitudinal weathering zones and glacial limits in Newfoundland with particular reference to Gros Morne National Park; in Current Research, Part A, Geological Survey of Canada, Paper 77-1A, p. 455-463.
1977b: Workshop on sea-level rise and subsidence in the Maritimes; Geoscience Canada, v. 4, p. 144-146.
1977c: Glacial style and ice limits, the Quaternary stratigraphic record, and changes of land and ocean level in the Atlantic Provinces; Géographie physique et Quaternaire, v. 31, p. 247-260.
1980: Quaternary sea-level change in Atlantic Canada as an indication of crustal delevelling, in Earth Rheology, Isostasy, and Eustasy, (ed.) N-A Mörner; John Wiley and Sons, New York, p. 201-214.
1986a: Surficial geology, St. Anthony Blanc-Sablon, Newfoundland Québec; Geological Survey of Canada, Map 1610A, scale 1:125 000.
1986b: Surfical geology, Port Saunders, Newfoundland; Geological Survey of Canada, Map 1622A, scale 1: 250 000.
1987: Quaternary geology of Nova Scotia and Newfoundland; XII INQUA Congress, Ottawa, Canada, Excursion Guide Book A-3/C-3, National Research Council of Canada, Publication 27525, 62 p.
1989: Quaternary geology of the Atlantic Appalachian region of Canada; Chapter 5 in Quaternary Geology of Canada and Greenland, (ed.) R.J. Fulton; Geological Survey of Canada, Geology of Canada, v. 1, p. 391-440 (also Geological Society of America, The Geology of North America, v. K-l).
1992: Quaternary geology of St. Anthony – Blanc-Sablon area, Newfoundland and Québec; Geological Survey of Canada, Memoir 427, 60 p.

Grant, D.R. and King, L.H.
1984: A Quaternary stratigraphic framework for the Atlantic Provinces region; in Quaternary Stratigraphy of Canada, (ed.) R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 173-191.

Guilbault, J.-P.
1984: Late-glacial Foraminifera localities in raised marine sediments in western Newfoundland; Geological Survey of Canada, Open File 1003, 97 p.

Hamilton, K. G. A. and Langor, D. W.
1987: Leafhopper fauna of Newfoundland and Cape Breton Islands (Rhynchota: Homoptera: Cicadellidae); Canadian Entomologist, v. 119, p. 663-695.

Hare, F.K.
1950: Climate and zonal divisions of the Boreal Forest formation in eastern Canada; Geographical Review, v. 40, p. 613-635.

Hare, F.K. (cont.)
1952: The climate of the island of Newfoundland, a geographical analysis; Geographical Bulletin, v. 2, p. 36-87.

Hare, F.K. and Thomas, M.K.
1974: Climate Canada; Wiley Publishers, Toronto, 256 p.

Harp, E. Jr.
1964: The cultural affinities of the Newfoundland Dorset Eskimo; National Museum of Canada, Bulletin 200, 183 p.

Haworth, R.T., Grant, A.C., and Folinsbee, R.A.
1976a: Geology of the continental shelf off southeastern Labrador; in Report of Activities, Part C, Geological Survey of Canada, Paper 76-1C, p. 61-69.

Haworth, R.T., Poole, W.H., Grant, A.C., and Sanford, B.V.
1976b: Marine geoscience survey northeast of Newfoundland; in Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 7-15.

Heyl, G.R.
1937: The geology of the Sops Arm area, White Bay, Newfoundland; Newfoundland Department of Natural Resources, Geological Survey, Bulletin 8, 42 p.

Hoppe, G.
1959: Glacial morphology and inland ice recession in northern Sweden; Geografiska Annaler, Series A, v. 41, p. 193-212.

Hornbrook, E.H.W., Davenport, P.H., and Grant, D.R.
1975: Regional and detailed geochemical exploration studies in glaciated terrain in Newfoundland; Newfoundland Department of Mines and Energy, Mineral Development Division, Report 75-2, 116 p.

Kennedy, M.J., Williams, H., and Smyth, W.R.
1973: Geology of Grey Islands, Newfoundlandnorthernmost extension of the Fleur de Lys Supergroup; Geological Association of Canada, Proceedings, v. 25, p. 79-90.

Kirby, F.T.
1984: Detailed aggregate assessment project, insular Newfoundland; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, p. 288-289.
1988: Detailed aggregate resource assessmentsinsular Newfoundland; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 88-1, p. 373-377.

Kirby, F.T. and Ricketts, R.J.
1983: Aggregate Resource Map Series; Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 1287, Map 83-17.

Kirby, F.T., Ricketts, R.J., and Vanderveer, D.G.
1983: Inventory of aggregate resources in Newfoundland and Labrador: information report and index maps to accompany aggregate resource map series 1:250 000; Newfoundland Department of Mines and Energy, Mineral Development Division, Report 88-3, 36 p.

Knight, I.
1985: Geological mapping of Cambrian and Ordovician sedimentary rocks of the Bellburns (12 I/5/6)), Portland Creek (12 I/4), and Indian Lookout (12 I/3) map areas, Great Northern Peninsula, Newfoundland; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, p. 79-88.
1987: Geology of the Roddickton (12 I/16) map area; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, p. 343-357.

Knight, I. and Boyce, W.D.
1984: Geological mapping of the Port Saunders (12 I/11), St. John Island (12 I/14) and parts of the Torrent River (12 I/10) and Bellburns (12 I/6) map sheets, northwestern Newfoundland; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, p. 114-124.

Lawson, A.C.
1890: Notes on the Pre-Paleozoic surface of the Archean terranes of Canada; Geological Society of America, Bulletin, v. 1, p. 163-174.

Lindroth, C.
1963: The fauna history of Newfoundland illustrated by Carabid beetles; Opuscula Entomologica, Supplementum, v. 23, 112 p.

Lowdon, J.A. and Blake, W., Jr.
1973: Geological Survey of Canada radiocarbon dates XIII; Geological Survey of Canada, Paper 73-7, 61 p.

Lowdon, J.A., Robertson, I.M., and Blake, W., Jr.
1977: Geological Survey of Canada radiocarbon dates XVII; Geological Survey of Canada, Paper 77-7, 25 p.

Lower Churchill Development Corporation
1979: Lower Churchill Project Transmission Facilities, Project Description and Environmental Policy Statement.

MacClintock, P. and Twenhofel, W.H.
1940: Wisconsin glaciation of Newfoundland; Geological Society of America, Bulletin, v. 51, p. 1729-1756.

Mathews, W.H.
1975: Cenozoic erosion and erosion surfaces in eastern North America; American Journal of Science, v. 275, p. 818-824.

Mayewski, P.A., Denton, G.H., and Hughes, T.J.
1981: Late Wisconsinan ice sheets of North America; in The Last Great Ice Sheet, (ed.) G.H. Denton and T.J. Hughes; John Wiley and Sons, New York, p. 67-178.

McNeely, R.N.
1989: Geological Survey of Canada radiocarbon dates XXVIII; Geological Survey of Canada, Paper 88-7, 93 p.

Middleton, W.E.K.
1935: The climate of the Gulf of St. Lawrence and surrounding regions in Canada and Newfoundland, as it affects aviation; Canada Department of Marine, Meteorological Service, Memoir 1, 40 p.

Mihychuk, M.
1986: Quaternary mapping and exploration in the Bellburns map area (12 I/5 and 6) and Trapper Prospect areas; in Current Research (1986), Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, p. 271-282.

Mott, R.J., Grant, D.R., Stea, R.R., and Occhietti, S.
1986: A late glacial climatic oscillation in Atlantic Canada equivalent to the Aller-d/Younger Dryas event; Nature, v. 323, p. 247-250.

Mudie, P.J. and Guilbault, J.-P.
1982: Ecostratigraphic and paleomagnetic studies of Late Quaternary sediments on the Northeast Newfoundland Shelf; in Current Research, Part B, Geological Survey of Canada, Paper 82-1B, p. 107-116.

Murray, A.
1883: Glaciation of Newfoundland; Royal Society of Canada, Proceedings and Transactions, v. 1, p. 55-76.

Nelson, S.J.
1955: Geology of Portland CreekPort Saunders area, west coast; Newfoundland Department of Mines and Resources, Geological Survey, Report 7, 58 p.

Nesje, A., Anda, E., Rye, N., Lien, R., Hole, P.A., and Blikra, L.H.
1987: The vertical extent of the Late Weichselian ice sheet in the Nordfjord-Møre area, western Norway; Norsk Geologisk Tidsskrift, v. 67, p. 125-141.

Nesje, A., Dahl, S.O., Anda, E., and Rye, N.
1988: Block fields in southern Norway: Signficance for the Late Weichselian ice sheet; Norsk Geologisk Tidsskrift, v. 68, p. 149-169.

Oxley, P.
1953: Geology of the Parsons PondSt. Paul's area; Newfoundland Department of Mines and Resources, Geological Survey, Report 5, 53 p.

Pardi, R.B., and Newman, W.S.
1987: Late Quaternary sea levels along the Atlantic coast of North America; Journal of Coastal Research, v. 3, p. 325-330.

Piper, D.J.W., Mudie, P J., Aksu, A E., and Hill, P.R.
1978: Late Quaternary sedimentation, 50°N, North-east Newfoundland shelf; Géographie physique et Quaternaire, v. 32, p. 321-332.

Piper, D.J.W., Mudie, P J., Fader, G.B., Josenhans, H.W., MacLean, B., and Vilks, G.
1990: Quaternary geology; Chapter 10 in Geology of the continental margin of eastern Canada, (ed.) M.J. Keen and G.L. Williams; Geological Survey of Canada, Geology of Canada, v. 2, p. 475-607 (also Geological Society of America, The Geology of North America, v. I-l).

Prest, V.K.
1968: Nomenclature of moraines and other ice flow features as applied to the Glacial Map of Canada; Geological Survey of Canada, Paper 67-57, 32 p.

Prest, V.K. (cont.)
1984: The Late Wisconsinan glacier complex; in Quaternary Stratigraphy of Canadaa Canadian contribution to IGCP Project 24, (ed.) R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 21-36.
Prest, V.K., Grant, D.R., and Rampton, V.N.
1968: Glacial Map of Canada, Geological Survey of Canada, Map 1253A.
Proudfoot, D.N. and St. Croix, L.
1987: Quaternary geology of the Bellburns (12I/5 and 6) map area; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, p. 11-21.
Proudfoot, D.N., Grant, D.R., and Batterson, M.J.
1988: Quaternary geology of western Newfoundland; Geological Association of Canada, Annual Meeting, St. John's, Field Trip Guidebook A6, 53 p.
Quinlan, G. and Beaumont, C.R.
1982: The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea level record; Canadian Journal of Earth Sciences, v. 19, p. 2232-2246.
Richards, H.G.
1940: Marine Pleistocene fossils from Newfoundland; Geological Society of America, Bulletin, v. 51, p. 1781-1788.
Robertson, S.
1987: Quaternary and Recent marine fauna of western Newfoundland; B.Sc. thesis, Carleton University, Ottawa, Canada, 84 p.
Rogerson, R.J.
1981: The tectonic evolution and surface morphology of Newfoundland; in The Natural Environment of Newfoundland, Past and Present. (ed.) A.G. Macpherson and J.B. Macpherson; Memorial University of Newfoundland, p. 24-55.
1982: The glaciation of Newfoundland and Labrador; in Prospecting in Areas of Glaciated Terrain1982, (ed.) P.H. Davenport; Canadian Institute of Mining and Metallurgy, Geology Division, p. 24-55.
1983: Geological evolution; in Biogeography and Ecology of the Island of Newfoundland, (ed.) G.R. South; Dr. W. Junk Publishers, The Hague, p. 5-53.
Rowe, J.S.
1972: Forest Regions of Canada; Environment Canada, Ottawa, 172 p.
Sanford, B.V. and Grant, G.M.
1976: Physiography, eastern Canada and adjacent areas; Geological Survey of Canada, Map 1399A, scale 1:2 500 000 (4 sheets).
Schmidlin, T.W.
1988: Alpine permafrost in eastern North America: a review; in Proceedings, 5th International Conference on Permafrost, Trondheim, Norway; p. 241-246.
Scott, D.B., Mudie, P.J., Vilks, G., and Younger, D.C.
1984: Latest Pleistocene-Holocene paleoceanographic trends on the continental margin of eastern Canada: foraminiferal, dinoflagellate and pollen evidence; Marine Micropaleontology, v. 9. p. 181-218.
Shearer, J.M.
1973: Bedrock and surficial geology of the northern Gulf of St. Lawrence as interpreted from continuous seismic reflection profiles; in Earth Science Symposium on Offshore Eastern Canada, (ed.) P.J. Hood; Geological Survey of Canada, Paper 71-23, p. 285-303.
Slatt, R.M.
1974: Continental shelf sediments off eastern Newfoundland: a preliminary interpretation; Canadian Journal of Earth Sciences, v. 11, p. 362-368.
Statistics Canada
1988: Place Names Reference ListsAtlantic Provinces; Census Publication 92-121.
Swett, K.
1981: A probable sub-Cambrian glacial erosional surface in southern Labrador and eastern Québec; in Earth's Pre-Pleistocene Glacial Record, (ed.) M. J. Hambrey and W. B. Harland; Cambridge University Press, Cambridge, U.K., p. 772-773.
Tanner, V.
1940: The glaciation of the Long Range of western Newfoundland; Geologiska Föreningen i Stockholm, Förhandlingar, v. 62, p. 361-368.
Thannheiser, D.
1984: The Coastal Vegetation of Eastern Canada; Memorial University of Newfoundland, Occasional Papers in Biology, no. 8, 212 p.
Titus, R.L.
1965: Upper Air Climate of Canada; Canada Department of Transport, Meteorological Branch, 70 p.
Tuck, J.A.
1970: An Archaic Indian cemetery in Newfoundland; Scientific American, v. 222, p. 113-121.
Tucker, C.M.
1976: Quaternary studies in Newfoundland: a short review; Maritime Sediments, v. 12, p. 61-73.
Tucker, C.M. and McCann, S.B.
1980: Quaternary events on the Burin Peninsula, Newfoundland, and the islands of Saint Pierre and Miquelon, France; Canadian Journal of Earth Sciences, v. 17, p. 1462-1479.
Twenhofel, W.H.
1912: The physiography of Newfoundland; American Journal of Science, Series 4, v. 33, p. 1-24.
Twenhofel, W.H. and MacClintock, P.
1940: Surface of Newfoundland; Geological Society of America, Bulletin, v. 51, p. 1665-1728.
Waitt, R. B.
1981: Radial outflow and unsteady retreat of Late Wisconsin to Early Holocene icecap in the northern Long Range Upland, Newfoundland; Geological Society of America, Bulletin, v. 92, p. 834-838.
Watson, K. de P.
1947: Geology and mineral deposits of the Baie VerteMings Bight area; Geological Survey of Newfoundland, Bulletin 21, 48 p.
Wells, E. and Pollett, F.C.
1983: Peatlands; in Biogeography and Ecology of the Island of Newfoundland, (ed.) G.R. South; Dr. W. Junk Publishers, The Hague, p. 207-265.
Williams, H. (compiler)
1978: Tectonic Lithofacies Map of the Appalachian Orogen; Department of Geology, Memorial University, St. John's, scale 1:1 000 000.
Williams, H., James, N.P., and Stevens, R.K.
1985: Humber Arm Allochthon and nearby groups between Bonne Bay and Portland Creek, western Newfoundland; in Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 399-406
Wilmeth, R.
1978: Canadian archeological radiocarbon dates (revised version); National Museums of Canada, Archeological Survey of Canada, Paper 77, 218 p.
Wilson, J.T., Falconer, G., Mathews, W.H., and Prest, V.K.
1958: Glacial Map of Canada; Geological Association of Canada, scale 1:3,801,600.
Woodard, H.H.
1957: Geology of the Port Saunders Castors River area, west coast; Newfoundland Department of Mines and Resources, Geological Survey, Report 10, 45 p.