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QUATERNARY GEOLOGY OF ST. ANTHONY – BLANC-SABLON AREA, NEWFOUNDLAND AND QUEBEC

Douglas R. Grant

1992

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Cover description

Hay Cove, near L'Anse aux Meadows National Historic Park, at the forest/tundra transition. The area emerged from the sea in the last few thousand years, leaving gravel-covered slopes, a rock platform at about 10 m, and a fossil cliff just above tide level. Photo by D.R. Grant. (GSC 1992-201)

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Preface

The surface deposits in the St. Anthony – Blanc-Sablon area are important in the interpretation of Quaternary history because they record a succession of glacial advances of both the Laurentide Ice Sheet over Quebec and an independent satellitic maritime ice cap over the island of Newfoundland. Consequently, directions of glacial transport vary widely in different parts of the area and knowledge of these can be applied to the practice of mineral exploration using float. Information on recent environmental change, such as the history of shoreline displacement, gives an added dimension to the interpretation of conditions at L'Anse aux Meadows National Historic Park where a Norse settlement, known to be the earliest in the New World, has been designated a World Heritage Site by the United Nations. Terrain conditions and surface materials in the Strait of Belle Isle area are important considerations for economic development, such as a proposed power transmission line from Labrador.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

Les sédiments de surface dans la zone de St. Anthony et Blanc-Sablon ont un rôle important à jouer dans l'interprétation de l'histoire quaternaire de cette région du fait qu'ils témoignent d'une série d'avancées glaciaires de l'inlandsis Laurentidien au-dessus du Québec et d'une calotte glaciaire maritime satellite mais indépendante au-dessus de l'île de Terre-Neuve. Par conséquent, les directions du transport glaciaire varient grandement dans différentes parties de cette zone et leur détermination peut servir aux travaux d'exploration minérale basée sur les mineraux d'altération. Des données sur des modifications environnementales récentes, notamment sur le déplacement du littoral, viennent ajouter une nouvelle dimension à l'interprétation des conditions observées au Parc national historique de L'Anse-aux-Meadows où se trouve le plus ancien village du Nouveau Monde, fondé par des Scandinaves, que les Nations-Unies ont désigné comme Site du patrimoine mondial. Les conditions de terrain et les matériaux de surface de la zone du détroit de Belle Isle sont des facteurs importants à considérer dans les projets de mise en valeur économique, comme la traversée proposée d'une ligne de transport d'électricité en provenance du Labrador.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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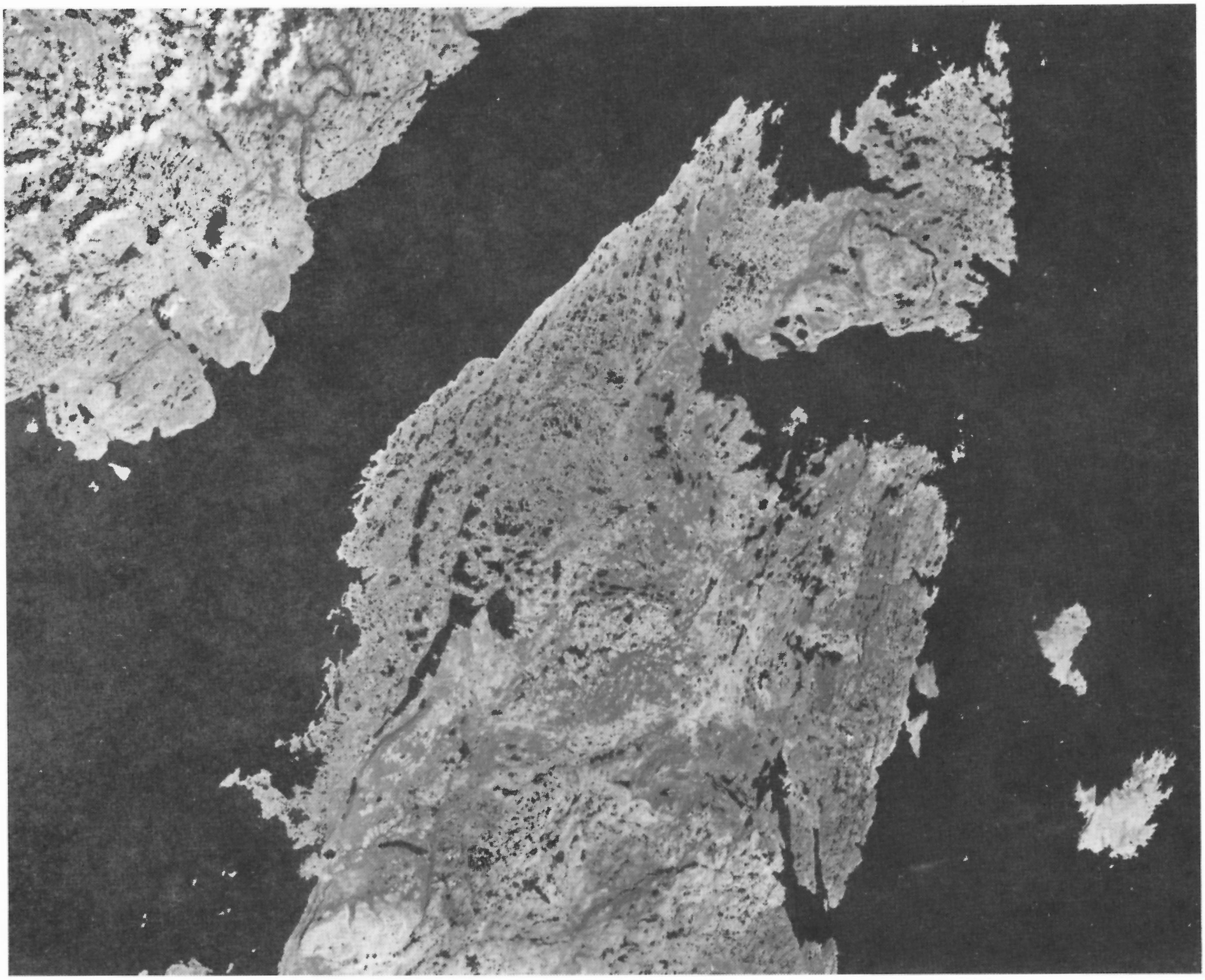


Frontispiece. Satellite image of Strait of Belle Isle. Major physiographic divisions are expressed as variations in lake density (black tone), forest cover (medium grey), and till and bog cover (light grey); barren White Hills and Highlands of St. John are white. (LANDSAT E 1429-14112; Bands 5, 6, 7)

QUATERNARY GEOLOGY OF ST. ANTHONY – BLANC-SABLON AREA, NEWFOUNDLAND AND QUEBEC

Abstract

The area is a complex of highland plateaus, uplands, and lowlands representing Tertiary planation levels; one surface is a paleoplain with largely inherited glacial relief, which has been exhumed from Cambrian cover strata. Straddling the Appalachian/Shield margin, the area records the interplay of two ice domains – the Newfoundland ice cap complex and the Laurentide Ice Sheet. Glacial terrains of different geomorphic maturity are attributed to three main glaciations. The oldest (St. John Zone) records a maximal Laurentide invasion; from relative stream entrenchment, it may be 400-500 ka (oxygen isotope stage 12). The intermediate-age terrain or Doctors Zone may be stage 6 (Illinoian). It shows that ice from the Canadian Shield merged with local ice, but left nunataks above 590 m; on Grey Islands, local glaciers occupied cirques that are now submerged 40 m.

The last main glaciation (Long Range Zone) is dated to Late Wisconsinan time by marine deposits. Crosscutting ice flow features define six phases. First, Shield ice crossed Strait of Belle Isle, overran White Hills, and merged with Newfoundland ice below 500 m along an interlobate moraine near the head of Esquiman Channel. Retreat by calving in deglacial Goldthwait Sea produced 400 De Geer moraines. Glaciers stabilized by 12.6 ka: Long Range ice built the Piedmont Moraines, while Shield ice built the Bradore and Belles Amours moraines at the 150 m marine limit. When the Polar Front shifted, causing a climatic reversal, Long Range ice readvanced and built the Ten Mile Lake Moraine at 11 ka. The resulting gravitational marine stillstand cut a rock platform (Bay of Islands Surface). A fossil cliff near tide level records a late Holocene transgression; emergence is now slow or complete. Sporadic ice wedges and palsas are relict from the Little Ice Age, but solifluction and nivation continue above 400 m; cryoturbation is active at sea level. Faulted glacial pavements suggest neotectonic stress release.

Résumé

Cette zone est constituée d'un ensemble complexe de plateaux, de hautes et basses terres correspondant à des niveaux d'aplanissement tertiaire; l'une des surfaces est une paléoplaine à relief glaciaire principalement hérité qui se trouve maintenant exhumée de couches sédimentaires cambriennes. Chevauchant la marge entre le Bouclier et les Appalaches, cette zone témoigne donc du jeu combiné de deux domaines glaciaires: la calotte glaciaire de Terre-Neuve et l'inlandsis Laurentidien. Les terrains glaciaires de maturité géomorphologique différente sont attribués à trois glaciations principales. La plus ancienne (zone de St. John) atteste d'une invasion maximale de l'inlandsis Laurentidien; à partir de l'encaissement relatif des cours d'eau, on peut la dater à 400 à 500 ka (12^{e} stade basé sur les isotopes de l'oxygène). Le terrain d'âge intermédiaire (zone de Doctors) pourrait remonter au 6^{e} stade (Illinoien). Il révèle que la glace en provenance du Bouclier canadien et la glace locale ont conflué mais la première a laissé des nunataks au-dessus de 590 m tandis que, sur les îles Grey, des glaciers locaux ont découpé des cirques qui se trouvent maintenant submergés à 40 m.

Des sédiments marins ont permis de dater la dernière glaciation principale (zone de Long Range) au Wisconsinien supérieur. Le recoupement de traces d'écoulement glaciaire permet de définir six phases. Le glacier du Bouclier a traversé le détroit de Belle Isle, dépassé les collines White et s'est fusionné avec le glacier de Terre-Neuve au-dessous de 500 m, le long d'une moraine interlobaire près de la partie amont du chenal Esquiman. Le recul par vêlage dans la mer de déglaciation Goldthwait a produit 400 moraines de De Geer. Les glaciers se sont stabilisés avant 12,6 ka: le glacier de Long Range a construit les moraines de Piedmont tandis que le glacier du Bouclier a produit les moraines de Bradore et de Belles Amours à la limite marine de 150 m. Lorsque le front polaire s'est déplacé, causant un renversement climatique, le glacier de Long Range s'est remis à avancer et a construit la moraine de Ten Mile Lake à 11 ka. L'immobilisation gravitaire du niveau marin qui en a résulté a découpé une plate-forme rocheuse (surface de Bay of Islands). Une falaise fossile située près du niveau de marée témoigne d'une transgression au cours de l'Holocène supérieur; l'émersion est actuellement lente ou complète. Les coins de glace et les palses sporadiques datent du Petit Âge glaciaire mais on observe actuellement des phénomènes de solifluction et de nivation au-dessus de 400 m; la cryoturbation est active au niveau de la mer. Des pavages glaciaires faillés laissent supposer un relâchement des contraintes de nature néotectonique.

SUMMARY

Strait of Belle Isle area is significant for understanding regional Quaternary events because it illustrates the interplay of two ice domains – the Laurentide Ice Sheet and a Newfoundland highland ice cap (Appalachian Glacier Complex). Crosscutting ice flow patterns record a succession of marine-based, regional, and local ice regimes; these reconstructions are applicable to mineral exploration by drift prospecting. Certain areas with anomalous geomorphic maturity lay beyond the last glacial limit; their ages are estimated by relative rock dissection. Active cryogenic features place the area at the southern limit of sporadic permafrost. Deglacial crustal movement, as recorded by relative sea level change, reflects ice load and retreat pattern. Postglacial faults indicate neotectonic stress.

The major physiographic units correspond to different lithotectonic terranes. In Quebec/Labrador, the 300 m *Mecatina Plateau* is a southward-sloping bevel on Proterozoic crystalline rocks. As the exhumed sub-Cambrian unconformity, the relict surface is a paleoplain. Its knob and basin glacial topography extends under the cover rocks and is thus largely inherited. Denuded by the Laurentide Ice Sheet, it features two major end moraines. The mesa-like *Forteau Tablelands* at 200-300 elevation are remnants of Cambrian strata carved into giant rock drumlins and crag-and-tail hills.

In Newfoundland, the *Long Range Mountains* are an upthrust basement block of Precambrian granite gneiss which forms a plateau at 300-500 m. The surface is an uplifted, tilted, and dissected late Tertiary peneplain; Precambrian paleoplains form small west- and north-sloping bevels. An ice cap cut fiords and scoured the plateau; the ice divide area has old cirques and immature till. The *Interior Midlands*, at about 200 m elevation, correspond to resistant sedimentary strata which form hogbacks, cuestas, and sinuous solution valleys. *Highlands of St. John*, a downfaulted slice of Cambrian strata, are two domical summits at 530 m and 610 m, the highest in the area. The surface is till and rubble smoothed by solifluction. Its geomorphic maturity suggests it was not overrun by the last glacier. The *West Newfoundland Coastal Lowland* (and adjacent floor of Strait of Belle Isle) lies below 50-70 m. It is a low-relief, west-sloping plain cut across Cambro-Ordovician carbonate rocks by late Tertiary planation. It was scoured by local and regional glaciers; dissolution features and minor (De Geer) moraines are common.

Three areas are thrust sheets of resistant rock. *Coastal Uplands* are flat topped hills at 150-250 m composed of sandstone and volcanic rocks, with a window to the underlying carbonates. They represent

SOMMAIRE

L'étude de la zone du détroit de Belle-Isle contribue dans une large mesure à une meilleure compréhension des événements quaternaires régionaux du fait qu'elle permet d'examiner le jeu combiné de deux domaines glaciaires: l'inlandsis Laurentidien et une calotte glaciaire de hautes terres à Terre-Neuve (complexe glaciaire Appalachien). Des tracés glaciaires entrecroisés témoignent d'une succession de régimes glaciaires marins, régionaux et locaux; ces reconstitutions peuvent servir aux travaux d'exploration minérale basée sur la prospection glacio-sédimentaire. Certaines zones de maturité géommorphologique anormale s'étendent au-delà de la dernière limite glaciaire; leur âge est déterminé en se basant sur l'érosion relative des roches. La présence de formes cryogènes actives situe cette zone à la limite sud du pergélisol sporadique. Le mouvement de la croûte dû à la déglaciation, attesté par le changement relatif du niveau de la mer, reflète une longue histoire de chargement et de recul glaciaires. Des failles post-glaciaires témoignent de la présence de contraintes néotectoniques.

Les principales unités physiographiques correspondent aux différents terranes lithotectoniques. Au Québec et au Labrador, le *plateau de Mécatina*, haut de 300 m, a une surface plongeant vers le sud et repose sur des roches cristallines protérozoïques. À l'instar de la discordance sous-cambrienne exhumée, la surface résiduelle est une paléoplaine. La topographie irrégulière se prolonge sous les roches de couverture et est par conséquent principalement héritée. Sur la surface dénudée par l'inlandsis Laurentidien se dressent deux importantes moraines terminales. Les *plateaux Forteau*, en forme de mésas de 200 à 300 m d'altitude, sont des vestiges de couches cambriennes sculptées dans des drumlins rocheux géants et des collines de type crag-and-tail.

À Terre-Neuve, les *monts Long Range* sont constitués d'un bloc de socle soulevé de gneiss granitique précambrien formant un plateau à 300 à 500 m. La surface est une pénéplaine redressée, inclinée et découpée datant de la fin du Tertiaire; des paléoplaines précambriennes forment de petites surfaces plongeant vers l'ouest de la nord. Une calotte glaciaire a découpé des fjords et décapé le plateau; la zone de partage glaciaire comporte d'anciens cirques et du till immature. Les *terres intérieures*, de 200 m d'altitude environ, correspondent à des couches sédimentaires résistantes formant des crêtes monoclinales, des cuestas et des vallées de dissolution sinueuses. Les *hautes terres de St. John*, lambeau de couche cambrienne faillée, sont constituées de deux sommets en forme de dômes de 530 m et 610 m, soit les plus hauts de la région. La surface se compose de till et de blocaille aplanis par solifluction. Sa maturité géomorphologique indique qu'elle n'a pas été recouverte par la dernière glaciation. Les *basses terres littorales de l'ouest de Terre-Neuve* (et le fond voisin du détroit de Belle Isle) s'étendent au-dessous de 50 à 70 m. Il s'agit d'une plaine basse plongeant vers l'ouest dont les roches carbonatées cambro-ordoviciennes sont recoupées transversalement par un aplanissement de la fin du Tertiaire. Elle a été décapée par des glaciers locaux et régionaux; des formes de dissolution et quelques moraines (De Geer) sont généralement présentes.

Trois zones sont composées de nappes de charriage de roche résistante. Les *hautes terres littorales* sont des collines à sommet plat de 150 à 250 m d'altitude composées de grès et de roches volcaniques, avec une fenêtre sur les roches carbonatées an intermediate Tertiary erosion level. The *White Hills* area is a block of barren ultrabasic rocks at 250-300 m that was initially overrun by Laurentide ice, then anchored a late-stage, marine-based glacier. Offshore, granitic and metamorphic rocks underlie *Grey Islands*, a plateau remnant at 300-400 m with partly submerged cirques. The degraded glacial terrain predates the last glaciation.

Surficial materials comprise bedrock terrains, and deposits of glacial, glaciofluvial, marine, fluvial, colluvial, and organic origin. Each physiographic unit has a distinctive assemblage. Bedrock-dominated terrain includes bare as well as vegetated rock, and minor small patches of thin till. It dominates areas of resistant rocks and at higher elevations (Mecatina Plateau and Long Range Mountains) which were ice dispersal centres where glacial erosion was more effective. Areal scouring has sculpted the surface and etched out the pattern of fracture lineaments and stratification trends.

Glacial till deposits vary depending on age, provenance, substrate, and facies. Three ages are inferred from terrain maturity and dating: Late Wisconsinan tills with fresh morainic topography, which are dated by associated marine deposits, and two older tills with a much more mature geomorphic aspect. The three glacial terrains are in sharp contact, but the tills were not seen in superposition. The two pre-Late Wisconsinan tills occur on Highlands of St. John and Atlantic islands. The most mature till terrain (St. John Zone) occurs on summit surfaces graded by solifluction and now devoid of glacial relief. The till consists of local sedimentary rocks with various Precambrian erratics; patches of rubble mark weathered outcrops. Bell Island has an outlier. In contrast, the intermediate-age till terrain (Doctors Zone), also rich in Long Range erratics, has undulating, subdued morainic topography. Its upper limit slopes westward from 600 to 380 m. Outliers occur on Horse Islands and Groais Island.

The Late Wisconsinan till (Long Range Zone) has virtually unmodified morainic topography and ice-moulded forms. It is subdivided according to thickness and continuity. A till plain, deposited by Long Range ice in the Interior Midlands, is a bilobate fan of drumlins, flutings, and crag-and-tail hills bounded by the arcuate Ten Mile Lake Moraine and associated Leg Pond Moraine. The till, up to 25 m thick, is derived from local sedimentary rocks; introduced Long Range erratics decrease northward exponentially. Till blanket, 2-5 m thick, occurs widely as a swath along the plateau ice divide, as De Geer moraine fields in the lowlands, and as two intersecting ice marginal deposits on Mecatina Plateau (Bradore Moraine, Belles Amours Moraine). Till veneer, 1-2 m thick, occurs as minor moraines and as patches in karst terrain.

sous-jacentes. Elles représentent un niveau d'érosion tertiaire intermédiaire. La zone des *collines White* est un bloc de roches ultrabasiques dénudées de 250 à 300 m d'altitude qui a été recouvert par l'inlandsis Laurentidien avant qu'un glacier de stade final débouchant sur la mer ne s'y fixe. Au large, des roches granitiques et métamorphiques reposent sous la surface des *îles Grey*, un vestige de plateau de 300 à 40 m d'altitude avec des cirques en partie submergés. Le terrain glaciaire érodé précède la dernière glaciation.

Les matériaux de surface sont notamment composés de terrains de socle et de dépôts d'origine glaciaire, fluvioglaciaire, marine, fluviale, colluviale et organique. Chaque unité physiographique comporte un assemblage caractéristique. Le terrain où prédomine le socle comporte, entre autres, des roches avec et sans végétation et quelques petites plaques de till mince. On le retrouve surtout dans les zones de roches résistantes et les zones de haute altitude (plateau de Mécatina et monts Long Range) qui étaient des centres de dispersion glaciaire où l'érosion glaciaire a été des plus efficaces. Le décapage a sculpté la surface et dessiné la configuration des linéaments de fracture et les directions de stratification.

Les dépôts de till varient selon l'âge, la provenance, le substratum rocheux et le faciès. On a déduit, à partir de la maturité et de l'âge du terrain, l'existence de trois tills d'âge différent: des tills du Wisconsinien tardif à topographie morainique récente qui ont été datés à partir de dépôts marins associés, ainsi que deux tills plus anciens d'aspect géomorphologique beaucoup plus mature. Les trois terrains glaciaires sont nettement en contact mais les tills ne se retrouvent pas en position superposée. Les deux tills antérieurs au Wisconsinien tardif sont situés sur les hautes terres de St. John et sur des îles de l'Atlantique. Le terrain dont le till est le plus mature (zone de St. John) se trouve sur des surfaces sommitales nivelées par solifluction, donc débarrassées de leur relief glaciaire. Le till se compose de roches sédimentaires locales et de divers blocs erratiques précambriens; des plaques de blocaille marquent l'emplacement d'affleurements érodés. L'île Bell comporte un lambeau de recouvrement. Par contrastre, le terrain à till d'âge intermédiaire (zone de Doctors) contenant également de nombreux blocs erratiques de Long Range, présente une topographie morainique ondulée et adoucie. Sa limite supérieure plonge vers l'ouest de 600 à 380 m. Des lambeaux de recouvrement s'observent sur les îles Horse et l'île Groais.

Le till du Wisconsinien tardif (zone de Long Range) présente une topographie morainique pratiquement non modifiée et des formes moulées par la glace. Il est subdivisé en fonction de son épaisseur et de sa continuité. Une plaine de till déposé par le glacier de Long Range dans les plaines intérieures a la forme d'un cône à deux lobes ponctués de drumlins, de cannelures et de collines de type crag-and-tail que délimite la moraine arquée de Ten Mile Lake et la moraine associée de Leg Pond. Le till, mesurant jusqu'à 25 m d'épaisseur, provient de roches sédimentaires locales; le nombre de blocs erratiques de Long Range diminue exponentiellement vers le nord. Une nappe de till, de 2 à 5 m d'épaisseur, couvre une grande étendue sous forme d'une bande longeant la zone de partage glaciaire du plateau, sous forme de champs de moraines de De Geer dans les basses terres et sous forme de deux dépôts de contact glaciaire s'entrecroisant sur le plateau de Mécatina (moraine de Bradore, moraine de Belles Amours). Le placage de till, de 1 à 2 m d'épaisseur, se présente sous forme de petites moraines et de plaques en terrain karstique.

Glaciofluvial deposits are rare. Ice contact deposits include a network of crevasse fillings behind Leg Pond Moraine and scattered small eskers and kames in the Québec/Labrador moraine belts. An outwash train fills Pinware Valley and a few occur in Long Range valleys.

Marine deposits occur locally below the 150 m limit of postglacial submergence. Stony mud, generally fossiliferous, is a deepwater facies of meltwater sediment discharged near ice margins. It is common around Pistolet Bay and south of Hare Bay; pockets occur near Plum Point, along Bradore Bay, and in lower Pinware River, among others. Blankets and veneers of sandy gravel occur as beach ridges, terraces, and deltas. They originated in situ by littoral reworking of till and outwash and are commonly fossiliferous in carbonate terrain. The largest is the submarine extension of Belles Amours Moraine.

Fluvial deposits are rare as 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, notably on Forteau Tablelands, Highlands of St. John, and Grey Islands. Till on the highest areas is soliflucting, but mappable quantities have not accumulated. Cliffs on Grey Islands are failing locally by deep-seated creep ("sagging").

Organic deposits of peat and muck occur on slopes and depressions in rock and till. Lowland rock pavements have large tracts of plateau bog, rocky terrain has innumerable small basin bogs, and smooth till surfaces have ribbed fens.

Ground ice and cryoturbation features occur sporadically from 0 to 600 m elevation and are noteworthy at this latitude. Ice wedges occur in peat and till on Highlands of St. John and in gravel around Pistolet and Bradore bays. Ice lenses have produced palsa mounds in peat in Québec/Labrador and L'Anse aux Meadows National Historic Park. Mud boils occur locally in till and gravel.

The Quaternary history is mainly a sequence of glacier flow phases and postglacial relative sea level changes. They are reconstructed from the position of glacial terrains, the pattern of ice movement indicators and end moraines, and the age and elevation of littoral deposits. Three major glaciations of decreasing extent occurred; the last had six main phases.

Les dépôts fluvio-glaciaires sont rares. Les dépôts de contact glaciaire comprennent notamment un réseau de matériaux de remplissage de crevasses derrière la moraine de Leg Pond et de petits eskers et kames disséminés dans les zones morainiques du Québec et du Labrador. Un épandage fluvio-glaciaire remplit la vallée Pinware et s'étend, par endroits, dans les vallées de Long Range.

Les dépôts marins se manifestent localement au-dessous de la limite de 150 m de la submergence post-glaciaire. Une boue caillouteuse, généralement fossilifère, est un faciès d'eau profonde de sédiments d'eau de fonte déversés près des marges glaciaires. On le retrouve fréquemment autour de la baie Pistolet et au sud de la baie Hare; des poches de ce facès s'observent, par exemple, près de la pointe Plum, le long de la baie Bradore et dans le cours inférieur de la rivière Pinware. Des nappes et des placages de gravier sableux prennent la forme de crêtes de plage, de terrasses et de deltas. Ils résultent d'un remaniement littoral sur place de till et de matériaux d'épandage fluvioglaciaire et sont, en général, fossilifères lorsque situés en terrain carbonaté. Le plus étendu est le prolongement sous marin de la moraine de Belles Amours.

Les dépôts fluviaux sont rares du fait qu'il y a peu de matériaux disponibles et que les cours d'eau régularisés sont peu nombreux. Des terrasses post-glaciaires et des cônes et deltas contemporains s'observent çà et là le long de quelques vallées importantes.

Les dépôts de colluvions comprennent des plaines et cônes de blocaille sous des falaises rocheuses instables, notamment sur les plateaux Forteau, les hautes terres de St. John et dans les îles Grey. Le till sur les zones les plus élevées se déplace par solifluction mais aucune quantité cartographiable ne s'est accumulée. Les falaises dans les îles Grey sont instables par endroits due à une reptation profonde ("affaissement").

Les dépôts organiques de tourbe et de sol humifère (muck) se retrouvent sur des pentes et dans des dépressions, dans la roche et le till. De larges bandes de tourbières de plateau traversent les pavages de blocs dans les basses terres, d'innombrables petites tourbières de bassin ponctuent le terrain rocailleux et des tourbières (fens) ondulées occupent la surface lisse de tills.

De la glace dans le sol et des phénomènes de cryoturbation s'observent sporadiquement de 0 à 600 m d'altitude et sont d'ailleurs remarquables à cette altitude. Des coins de glace ont été repérés dans de la tourbe et du till dans les hautes terres de St. John et dans du gravier autour des baies Pistolet et Bradore. Des lentilles de glace ont produit des monticules de tourbe gelée (palses) dans des tourbières du Québec et du Labrador et dans le Parc national historique de l'Anse-aux-Meadows. Des ostioles se manifestent par endroits dans du till et du gravier.

L'histoire quaternaire se résume à une séquence de phases d'écoulement glaciaire et de fluctuations post-glaciaires relatives du niveau de la mer qui sont reconstituées à partir de la position des terrains glaciaires, la configuration des indicateurs de mouvement glaciaire et des moraines terminales, ainsi que l'âge et l'altitude des dépôts littoraux. Trois principales glaciations d'étendue décroissante ont eu lieu, la dernière comportant six phases principales.

The oldest main glaciation, recorded by the St. John Zone, was Laurentide. It covered the area and deposited Shield erratics on Grey Islands. Valleys in bedrock in this terrain are about 50 times larger than within the area deglaciated 10 ka ago, so this glaciation is correlated with oxygen isotope stage 12 (440 ka), also indicated by local deep-sea cores to be the first major regional glaciation.

The next glaciation, estimated to be 100-150 ka (stage 6 or Illinoian), involved radially flowing Newfoundland ice that left a west-sloping trimline (Doctors Zone) and extended eastward offshore to Groais Island. The submerged cirques on Grey Islands may date to this glaciation.

Glacial events referred to the Wisconsinan Stage began with a southeastward Laurentide (Labradorean) ice invasion across Strait of Belle Isle. It overtopped White Hills, merged with Long Range ice at 250-300 m, but did not reach Grey Islands. Later thinning produced two southwestward ice streams and an interlobate moraine trending to Esquiman Channel, a calving bay in Goldthwait Sea. Eventually, recession separated the two ice domains; Labrador ice calved northward and Newfoundland ice shrank eastward to an ice cap anchored by White Hills, leaving 400 annual (De Geer) moraines. Retreat ceased as Long Range ice built the western lowland Piedmont Moraines at 12.6 ka. Laurentide ice stabilized when it regrounded at marine limit, building the Bradore Moraine and, shortly after, the crosscutting Belles Amours Moraine. Laurentide ice retreated out of the study area while Newfoundland ice shrank onto the Long Range plateau. A climatic reversal at 11 ka (by a Polar Front shift) caused the ice cap to surge 30 km into Goldthwait Sea, plowing up marine sediment into the Ten Mile Lake and Leg Pond moraines. Final retreat of plateau ice built the Cloud River Moraines 8-9 ka. On Highlands of St. John, small moraines may date to the Little Ice Age; nivation continues there today.

Postglacial relative sea level changes result from deglacial isostatic crustal rebound and reflect glacier disposition and retreat patterns. Isobases on marine limit rise northwestward from 122 to 148 m, showing that Laurentide ice dominated crustal deflection, although Long Range ice imparted the slight curvature. Late ice on White Hills produced anomalously low values (107-122 m) there. Shoreline displacement history since 14 ka is documented by dated littoral features and depicted in two ways. A shoreline relation diagram shows the upwarp of shorelines at 1000 year intervals in relation to ice retreat. A sea level curve shows the changing regression rate: the initial maximum peaked at 4.3 m/100 years; a stillstand at 60-80 m at 11 ka (induced gravitationally by the readvance) cut a rock bench that is correlated with the

La glaciation la plus ancienne révélée par la zone de St. John est celle de l'inlandsis Laurentidien. Elle a recouvert la zone et déposé des blocs erratiques provenant du Bouclier sur les îles Grey. Les vallées taillées dans le socle de ce terrain sont environ 50 fois plus larges que dans la zone d'où les glaces se sont rétirées il y a 10 ka. Une corrélation peut donc être établie entre cette glaciation et le 12^{e} stade basé sur les isotopes de l'oxygène (440 ka), correspondant également, tel qu'indiqué par des carottes prélevées localement en mer profonde, à la première glaciation régionale importante.

La glaciation suivante, remontant à 100 à 150 ka (6^{e} stade ou Illinoien) est en partie due à un glacier de Terre-Neuve à écoulement radial qui a quitté une ligne de contact plongeant vers l'ouest (zone de Doctors) et qui s'est avancé vers l'est en direction de l'île Groais. La formation des cirques submergés dans les îles Grey remonte peut-être à cette glaciation.

Les événements glaciaires correspondant au stade Wisconsinien ont commencé avec l'invasion d'un glacier Laurentidien (Labradoréen) vers le sud-ouest, à travers le détroit de Belle Isle. Le glacier a recouvert les collines White, a fusionné avec le glacier de Long Range à 250 à 300 m mais n'a pas atteint les îles Grey. Un amincissement ultérieur a produit deux langues glaciaires s'écoulant vers le sud-ouest et une moraine interlobaire se dirigeant vers le chenal Esquiman, une baie de vêlage dans la mer de Goldthwait. Par la suite, un recul a séparé les deux domaines glaciaires; le glacier de Labrador a vêlé vers le nord et le glacier de Terre-Neuve a rétréci vers l'est en une calotte glaciaire ancrée par les collines White laissant 400 moraines (De Geer) annuelles. Le recul a cessé lorsque le glacier de Long Range a construit les moraines de Piedmont dans les basses terres de l'ouest il y a 12,6 ka. Le glacier Laurentidien s'est stabilisé lorsqu'il a échoué de nouveau à la limite marine, construisant la moraine de Bradore et, peu de temps après, la moraine transversale de Belles Amours. L'inlandsis Laurentidien a reculé hors de la zone à l'étude tandis que le glacier de Terre-Neuve a reculé jusque sur le plateau de Long Range. Un renversement climatique il y a 11 ka (causé par un déplacement du front polaire) a provoqué une brusque avancée glaciaire de 30 km dans la mer de Goldthwait, charriant des sédiments marins qui ont été incorporés aux moraines de Ten Mile Lake et de Leg Pond. Le recul final du glacier de plateau est à l'origine de la formation des moraines de Cloud River il y a 8 à 9 ka. Sur les hautes terres de St. John, de petites moraines remontent peut être au Petit Âge glaciaire; des processus de nivation s'y observent encore aujourd'hui.

Les changements post-glaciaires relatifs du niveau de la mer ont été causés par un rebondissement isostatique de la croûte suite à la déglaciation et reflètent les modes de formation et de recul des glaciers. Les isobases sur la limite marine augmentent vers le nord-ouest de 122 à 148 m, indiquant que l'inlandsis Laurentidien a été le principal facteur de déflexion de la croûte bien que le glacier de Long Range ait causé la légère courbure observée. Le glacier le plus récent ayant recouvert les collines White a produit des valeurs anormalement basses (107 à 122 m) à cet endroit. Le déplacement de la ligne de rivage depuis 14 ka se traduit par des formes littorales dont on connaît l'âge et s'illustre de deux façons. Un diagramme des relations littorales montre le bombement des littoraux à des intervalles de 1000 ans correspondant au recul du glacier. Une courbe du niveau de la mer montre la vitesse changeante de régression: le taux maximal initial a atteint 4,3 m/100 ans; une période d'immobilisation survenue entre 60 et 80 m il y a 11 ka

"Bay of Islands Surface" farther south; since 5 ka the rate has slowed to 0.14 m/100 years, although several terraces below 10 m imply small fluctuations. A prominent fossil rock cliff at 2-3 m was cut about 2 ka by a small transgression possibly caused by migration of the glacial crustal forebulge. At present, sea level is stable, if not rising.

Apparent offsets of glacial rock pavements seem to indicate postglacial faulting. A 10 cm upthrow occurs near Ten Mile Lake and others of more than a metre with the same east-west trend occur north of Strait of Belle Isle. All might represent failure due to differential stress caused by rapid ice load removal during calving, but presently there is strong ENE/WSW compressive crustal stress which has been implicated in modern seismicity and surface rupture elsewhere in the region.

(provoquée gravitationnellement par la réavancée), a découpé une terrasse rocheuse corrélée avec la «surface de Bay of Islands» qui se trouve plus au sud; depuis 5 ka, la vitesse a diminué à 0,14 m/100 ans, bien que la présence de plusieurs terrasses au-dessous de 10 m laissent supposer de petites fluctuations. Une falaise rocheuse fossile proéminante au niveau de 2 à 3 m a été découpée il y a 2 ka par une petite transgression probablement causée par la migration de l'avant-bourrelet crustal glaciaire. À l'heure actuelle, le niveau de la mer est stable à moins qu'il n'augmente.

Des décalages apparents des pavages de blocs glaciaires semblent indiquer la formation post-glaciaire de failles. Un soulèvement de 10 cm a eu lieu près du lac Ten Mile et d'autres mesurant plus d'un mètre dans la même direction est-ouest se sont produits au nord du détroit de Belle Isle. Tous pourraient correspondre à une rupture due à une contrainte différentielle causée par une rapide diminution de la charge glaciaire au cours du vêlage; mais on observe actuellement une forte contrainte de la croûte exercée par compression et orientée ENE/WSW, qui s'est d'ailleurs révélée dans des données sismiques et des données sur les ruputres de surface recueillies dans d'autres zones de la même région.

INTRODUCTION

The area includes the northern extremity of Northern Peninsula of the island of Newfoundland, south to 51°45′N, and part of Quebec and Labrador across Strait of Belle Isle (Fig. 1). It thus includes the margin of the Canadian Shield and the terminus of Long Range Mountains, a crystalline massif that forms the western highland spine of the island, together with fringing lowlands developed on carbonate rocks.

The study was prompted by a need for data on terrain conditions, soil materials, and glacial transport, which was required for mineral exploration, for the planning of a hydroelectric transmission corridor, for bedrock mapping, for forest inventory, and for land capability studies. A secondary reason for beginning a program of surficial mapping in this part of Newfoundland was the paucity of Quaternary geological information in a key area about which early reports debated the extent of glaciation, and where airphoto reconnaissance by the author in 1965 for the Glacial Map of Canada (Prest et al., 1968) revealed significant new glacial and marine formations. This study was co-ordinated with Operation Strait of Belle Isle (Bostock et al., 1983).

Data and preliminary interpretations for a variety of aspects have been reported previously (Grant, 1969a, b, 1970, 1972a, b, 1973a, b, c, 1974a, b, c, 1975, 1976, 1977a, 1980, 1987; Cumming and Grant, 1974). This report synthesizes earlier accounts, enlarges on certain aspects in the light of new data and concepts,and puts the results in a regional context (Grant, 1989).

Field work was conducted mainly in 1969, with brief topical studies in small areas in 1972 and 1974. Mapping was initiated using airphoto interpretation and was checked where possible on the ground by observation along roads and coasts. In addition limited helicopter transport helped in a few isolated areas, and one fixed-wing reconnaissance was made (Fig. 2). The mapping is considered reasonably well

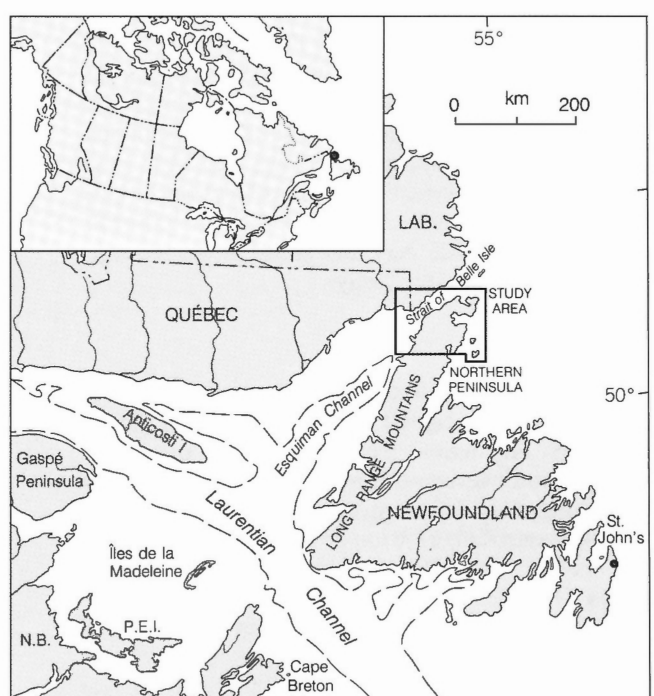


Figure 1. Index map.

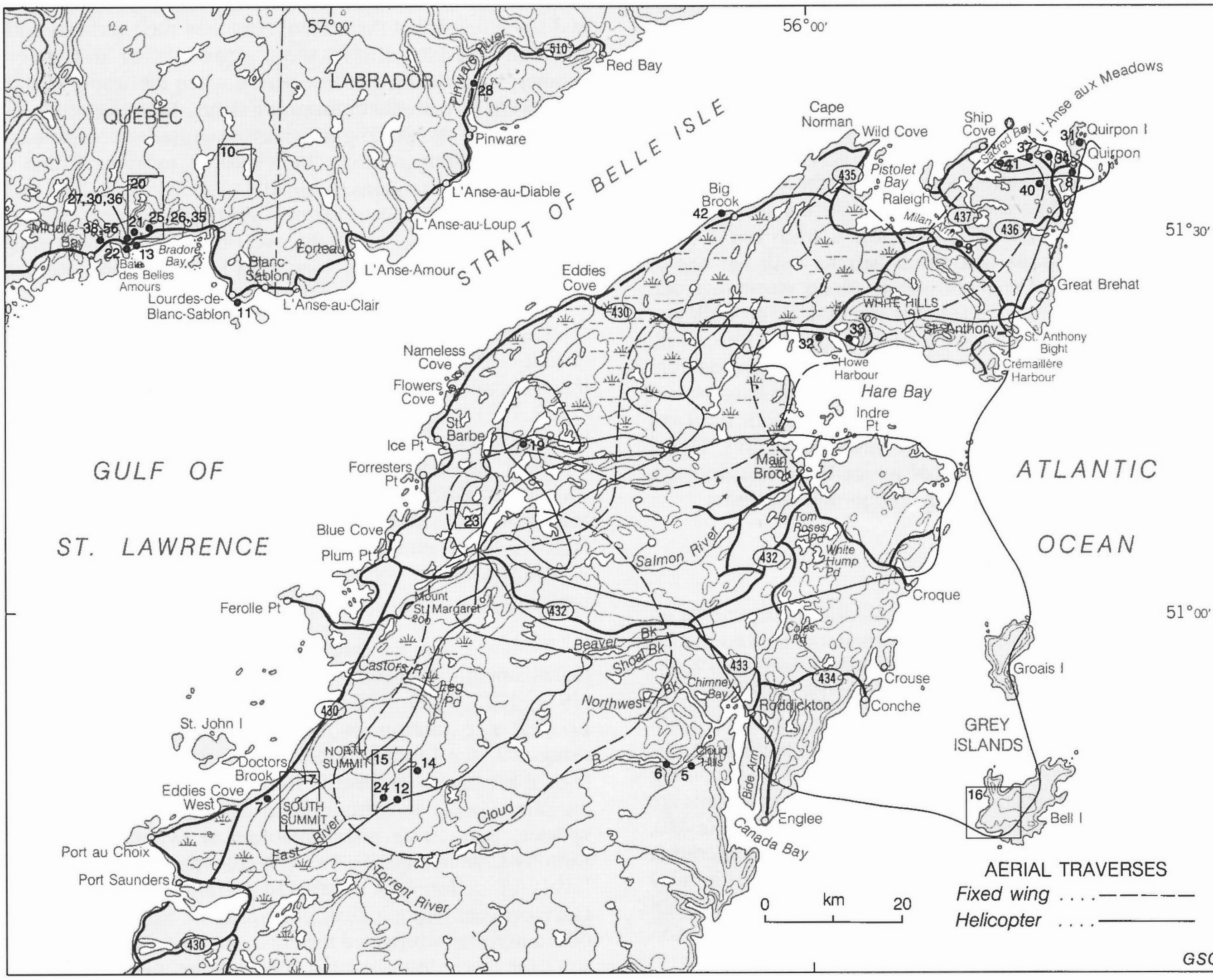


Figure 2. Localities mentioned in the texdt, roads travelled, aerial traverses flown, and locations of photo illustrations.

controlled because forest cover is sparse or absent over much of the area. The map shows important geomorphological features and classifies areas in terms of genesis, composition, and surface form. Where appropriate, thickness and texture are a basis for subdivision. Map units are arranged in approximate stratigraphic order. Relief elements are shown in some detail, including those attributable to bedrock structure. This report describes the areal, stratigraphic, and chronological relations of deposits and features and interprets the mode and sequence of formation. It also considers some practical applications of the knowledge to construction and resource development.

Climate and vegetation

An appreciation of climate may be useful for understanding certain geomorphic features and surficial materials, the style of glaciation, and the type and distribution of vegetation. According to Hare (1952), the climate is near-arctic and is comparable to areas much farther north, such as the Labrador coast, southern Keewatin, and the Mackenzie region. The arctic aspect reflects the shift of isotherms toward the equator in areas of prevailing westerly winds, but it is further intensified by the Labrador Current, a near-freezing stream of polar water. Indeed, Hare (1952) remarked that "nowhere else on earth does the Arctic verge drive so far south into the middle latitudes". The mean annual temperature at St. Anthony is 1-2°C. Pack ice persists until July and icebergs drift by all summer, giving a mean annual maximum temperature of less than 10°C. May 5 is the average date for the beginning of continuous thaw and there are 175 frost-free days on average. The growing season lasts 100-125 days beginning June 10-20. Precipitation and snowfall are lowest in Newfoundland, less than 900 mm, because moisture arrives on southerly winds and the area lies in the lee of Long Range Mountains where precipitation falls mainly as snow. The Blanc-Sablon area is even cooler. As summarized by Dionne (1983) the mean annual temperature is 0.5°C, and there are 210 days of frost and 120 frost-free days.

Soil climate data further underline the coolness of the area. Much of the region is classified as cryoboreal, with mean annual soil temperatures of 2-8°C. Moreover, local areas of sporadic permafrost further reduce the temperatures in organic materials.

These rigorous conditions account for the arctic aspect of the vegetation. Most of the area lies in the forest-tundra ecotone of Rowe (1972, p. 59-62), a transitional zone characterized by moss and shrub barrens with patches of stunted spruce and tamarack mainly along waterways and inland shores. In contrast, the lower slopes of White Hills and Long Range Mountains have a northern boreal forest with commercial stands of spruce and fir. Treeline descends from 300 m on Long Range Mountains in the south to near sea level on the northern coast, so trees are near their climatic limit and are therefore sensitive to drainage and local factors. Forest patterns facilitate recognition of minor relief and drainage differences related to surficial materials and landform.

Settlement, industry, and access

Settlement is mainly in small coastal villages dependent on inshore fishing. The offshore fleet works out of Roddickton (population 1234 in 1976) and St. Anthony (population 2987) which also serves as the administrative, medical, commercial, and supply centre for the region, including Labrador. Until recently, Main Brook was the major dispatch point for forest products, mainly pulp logs. Apart from the few remaining isolated coastal hamlets, called outports, most settlements are now served by paved roads, which connect with Route 430, the trunk highway of the Northern Peninsula. The interior is unsettled, with no road access except for the branch highway that crosses the peninsula to Roddickton. Since the mapping was completed, new roads now link the major outports such as Conche, Croque, and Great Brehat; the trunk route to St. Anthony, Highway 430, has been relocated via an interior corridor from Eddies Cove on the Strait of Belle Isle past the head of Hare Bay where a new regional airport was constructed in 1987. By sea, Canadian National and private companies operate regular passenger and freight service to St. Anthony. A summer ferry between St. Barbe and Blanc-Sablon is the main surface link with Quebec-Labrador. Air Canada provides scheduled service to St. Anthony and Quebecair serves Blanc-Sablon.

Previous work

Debate about the glaciation of Newfoundland began with the commencement of geological exploration. Since that time, opinion has varied on the fundamentals as well as on the details. The subject has been reviewed by Tucker (1976), Grant (1977a, 1989), Brookes (1982), Rogerson (1983), and Grant and King (1984). Little was known of the regional Quaternary geology of the area prior to this study, except for oblique references to the style of glaciation based on a few observed striations, and to the amount of marine submergence measured from raised shorelines. First reports date from early days of the glacial theory, though few deal directly with the map area. Milne (1874) adhered to the "diluvialist" school and so believed that the barren, scratched rock surfaces and the scattered boulders were products of a former submergence during a colder period when the whole island was swept by currents transporting debris-laden icebergs, as now pass its shores. Higher areas supported a complex of radially spreading ice fields. In its broadest meaning, Milne's original concept remains essentially valid. Ideas evolved and Murray (1883) and Chamberlin (1895) believed that after the island had been completely overridden by east-flowing external glaciers; it later supported local ice caps. Recent work essentially supports that general sequence.

The pattern of postglacial upwarp as evidenced by raised beaches led De Geer (1892) to postulate that Newfoundland had a separate ice cap throughout the last glaciation. Daly (1902, 1921) concurred on the basis of the elevation of raised beaches and the submergence limit around St. Anthony and southern Labrador. Fairchild (1918) supplemented these theories with measurements throughout Gulf of St. Lawrence region and concluded that Newfoundland had supported a large ice cap. Their inferences from glacioisostasy are largely substantiated by systematic mapping and numerical modelling.

Evidence that the latest glaciers failed to overtop the higher summits first came from biological studies by Fernald (1911, 1925, 1930) who reported plant assemblages on the Long Range summits which seemed to require ice free refugia. Later Lindroth (1963) gave supporting entomological arguments. Recently, Belland (1981, 1987) reached the same conclusions from the distribution of certain moss species. Supporting geomorphological evidence was put forth by Coleman (1920, 1926, 1930) who recognized three levels of differently weathered terrain. Using classical Davisian geomorphological principles, he reasoned that the different terrains reflected the duration of subaerial exposure since they were last glaciated. The least weathered zone was the extent of the last ice sheet, and it was smaller than the previous two. He speculated that the Labradorean glacier did not reach Strait of Belle Isle. This report and accompanying Map 1610A are the first description and delineation of the so-called "weathering zones."

However, Tanner (1940), who conducted the first aerial glacial geological survey, observed the degraded terrains but discounted their significance as relicts of former glaciations, as did MacClintock and Twenhofel (1940). Flint (1940) analyzed raised shorelevels and, from the northwestward tilt of marine limit, concluded that Labradorean ice had inundated Newfoundland completely during the last glaciation. His view supplanted the earlier concept and remained unchallenged until recently.

New evidence now suggests that the stratigraphic sequence records more than one glacial phase and that glaciation of Newfoundland was mainly by island-centred ice caps which, during the last glacial maximum, attained relatively low elevations near the coast and extended only a short distance offshore. This hypothesis has been revived by studies in Newfoundland by Grant (1977a), Brookes (1970, 1977b), and by Tucker and McCann (1980). Similar conclusions are being reached for New Brunswick and

Anticosti Island. Recent mapping corroborates the pattern of retreat depicted by Prest (1969) and underlines the fact that Newfoundland glaciers belonged to an assemblage of local ice caps, the Appalachian Glacier Complex (Prest, 1984), that was essentially independent of Laurentide ice emanating from the Canadian Shield. Moreover, the extent of glaciers at various times provokes an ongoing debate. Fulton and Hodgson (1979) made a surficial reconnaissance of southern Labrador and postulated that the Late Wisconsinan glacial limit lies far inland. Rogerson (1981, p. 40; 1982) adopted their view and showed most of the Strait of Belle Isle as unglaciated. Their interpretations are difficult to reconcile with the results of this study, and both conflict with the reconstructions of Mayewski et al. (1981) who adhered to the traditional maximalist school of thought and placed the last glacial limit far offshore.

Bedrock mapping has provided much valuable incidental information. Heyl (1937) found evidence favouring a small independent ice cap on the Northern Peninsula. Cooper (1937), mapping in the Hare Bay area, noted striations and erratics on White Hills, from which he concluded the Labradorean ice had flowed over the northern area while a separate ice cap spread from Long Range Mountains. Baird (1957) measured glacial, erosional features and terrace elevations in the Conche area. Waitt (1981) reported ice flow data that confirmed a major glacier emanating from Long Range Mountains. Inland from Blanc-Sablon where glacial limits are in question, Bostock et al. (1983, p. 5 noted a large area of possibly relict, disintegrated bedrock and, in central Long Range Mountains, a belt of subdued relief and drift that coincides with the supposed centre of ice dispersal.

Physiography and bedrock geology

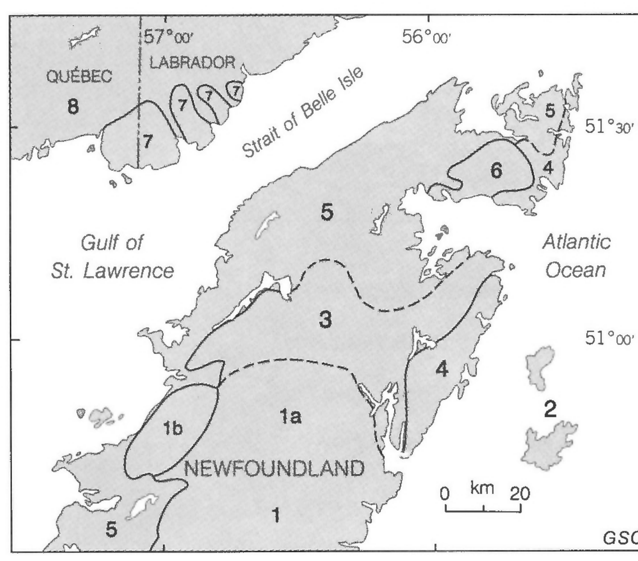
The area straddles the juncture of the Laurentian and Appalachian physiographic regions and, exclusive of submarine portions, comprises nine subdivisions (Fig. 3). Each corresponds to a separate lithotectonic unit (Fig. 4), lies at a different average elevation, has a characteristic geomorphological character, and has a distinctive assemblage of surficial materials. Their influence on the nature and extent of glaciation and marine submergence largely determined sediment distribution, thickness, and texture. The major units correspond to those proposed by Sanford and Grant (1976), but additional smaller subdivisions seem warranted. All references to bedrock lithogy, age, and structure pertain to Bostock et al. (1983).

Great Northern Highlands

Great Northern Highlands project into the area from the south to form the bulk of Northern Peninsula. They include the terminal segment of Long Range Mountains and a small appendage, Highlands of St. John. Long Range Mountains, a term commonly used and found on all topographic maps, front the west coast and form the backbone of Newfoundland. They are significant for glaciation both as a site for local accumulation and as an obstacle to possible invasion by external ice. The mountains form a roughly rectangular, high-standing block, usually described as a dissected tilted peneplain (e.g., MacClintock and Twenhofel, 1940), which, in this area, rises westward from 300 m to 500 m. The plateau has a rolling local relief of 100 m on Precambrian rocks, mainly granitic gneisses ribbed with diabase dyke ridges. A basaltic pile forms hogbacks in the vicinity of Cloud Mountain (Fig. 5). The plateau margins are incised by deep gorges (Fig. 6) and glacial troughs with rock basins such as Chimney Bay (Canada Bay). On the east, Long Range Mountains are bounded by a fault-line scarp, indented by fiords, which descends into a submarine channel excavated to 300-400 m in a basin underlain by weak Carboniferous strata. Everywhere, the surface is glacially scoured: rock basins abound and the bare hills are littered with erratics, except for a narrow medial zone in the headwaters of Cloud River where shallow drift mantles broad, domed bedrock undulations. A group of rounded, eroded, cirque basins occur in the medial zone. All features seem attributable to the action of a local ice cap.

Highlands of St. John

The crystalline block is abutted on the west, along a fault-line valley, by Highlands of St. John (Fig. 7). These two broad, nearly featureless domes called North Summit and South Summit (or Doctors Hill) are the highest prominences in the area at 610 m and 530 m, respectively. The prairie-like expanses are underlain by Cambrian-age, subhorizontal, Hawke Bay quartzite and Forteau limestone. Except for rare outcrops and subdued slope inflections marking the edges of the resistant beds, the summits are smooth surfaces composed of till and rock rubble. Cryoturbation has arranged the blocks



1 *Great Northern Highlands*
1a *Long Range Mountains*
1b *Highlands of St. John*
2 *Grey Islands*
3 *Interior Midlands*
4 *Coastal Uplands*
5 *West Newfoundland Coastal Lowland*
6 *White Hills*
7 *Forteau Tablelands*
8 *Mécatina Plateau*

Figure 3. Physiographic divisions (modified after Sanford and Grant, 1977).

into stripes and circles; patches of till are patterned with mud boils. Peat veneer is broken by frost polygons. Within the rubble are large granite erratics. The highest areas are devoid glacial basins and hummocks and these anomalously featureless summits, like others in western Newfoundland, have provoked a controversy about the limits of former glacial cover. Results of this study support earlier notions that they are ancient, degraded glacial terrains.

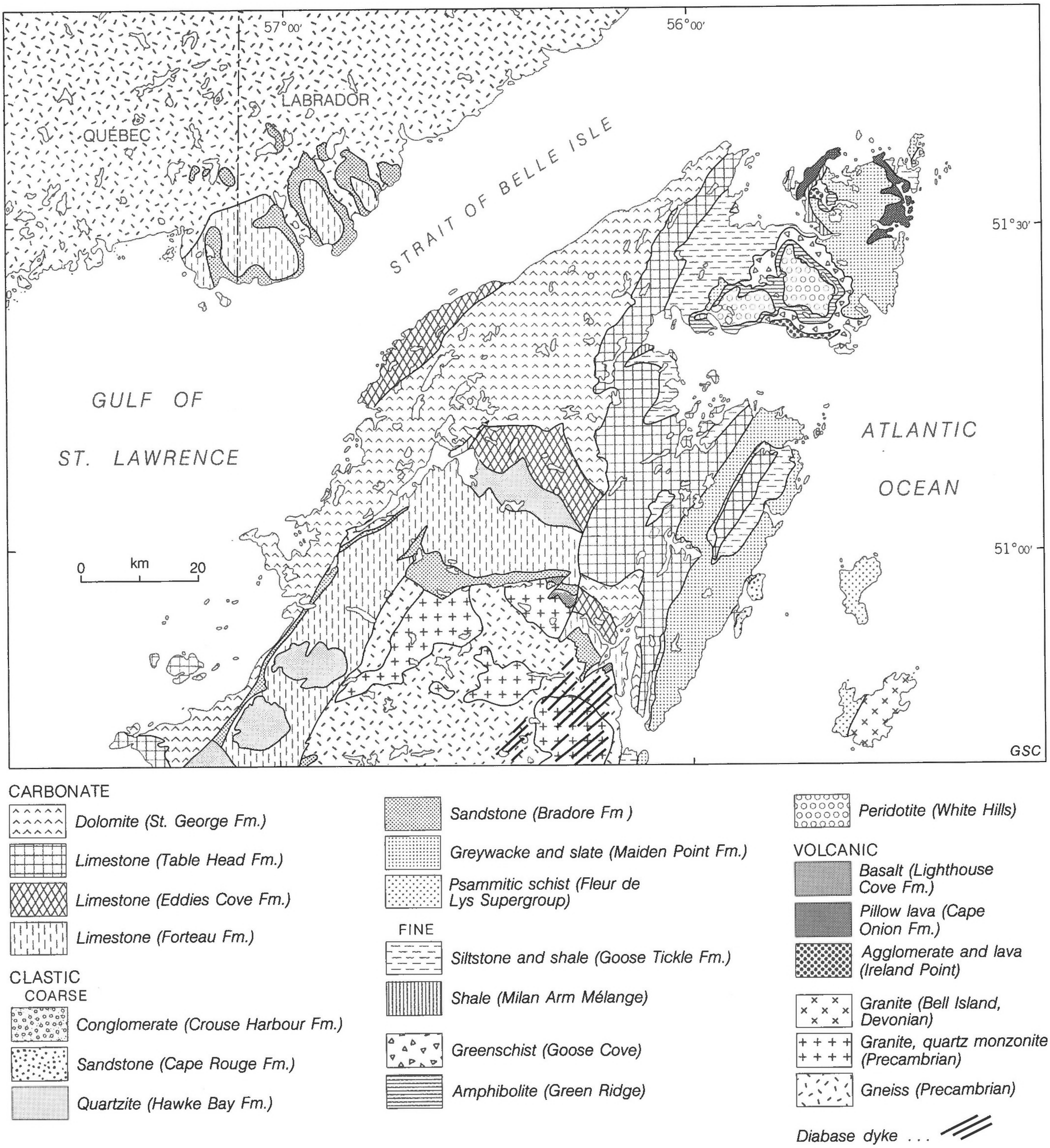


Figure 4. Bedrock geological units (adapted from Bostock et al., 1983).

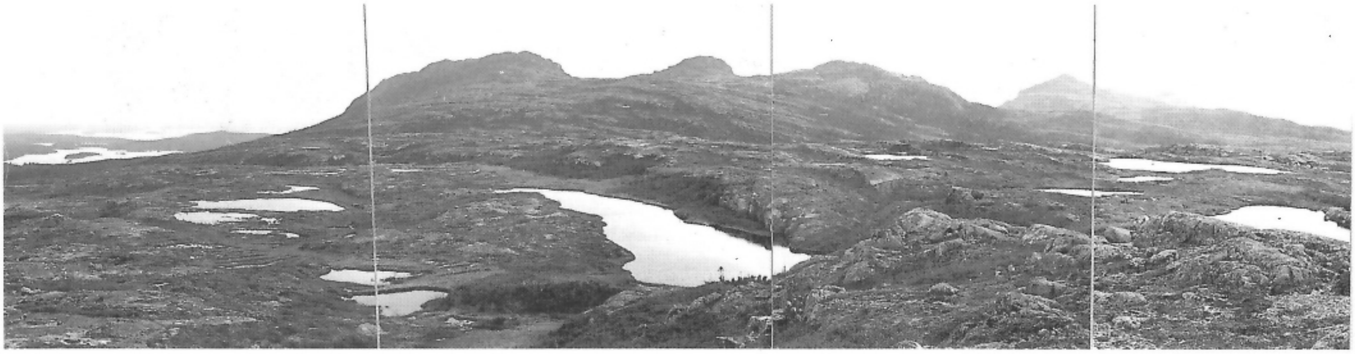


Figure 5. Typical scoured terrain of northern Long Range Mountains, where a basaltic sequence is draped over an anticlinal structure in gneisses, showing that some of the present relief is inherited from a Late Proterozoic surface. Forest obscures bedrock in protected locations (Unit Rb, Map 1610A). Canada Bay is in the background. (Composite of GSC 157966 to 157969, courtesy H.H. Bostock).

Figure 6. View looking eastward down Cloud River canyon Long Range Mountains, showing the denuded aspect of Unit Ra on Map 1610A. (GSC 157971, courtesy H.H. Bostock).

Figure 7. View of the seaward face of Highlands of St. John, South Summit (Doctors Hill). Cliffs with talus front a smooth summit mantled with till and felsenmeer (Unit 1a). Nivation has etched terraces along the stratification. (GSC 203284-S)

Grey Islands

Grey Islands (Bell and Groais), 20 km out in the Atlantic Ocean, are ringed by sheer cliffs. The margin of Bell Island in particular is scalloped by amphitheatre-shaped basins with floors about 40 m below sea level. These are interpreted to be partly submerged cirques. The cliffs rise to rolling uplands at 200-300 m, which are perhaps an extension of the highlands peneplain. The surface is a mosaic of glacial landforms but the terrain seems more mature than the adjacent nearby highlands. Their remoteness to glaciers from either Newfoundland or Labrador suggests that they too may record earlier glaciations.

Interior Midlands

The surface of Long Range Mountains declines northward from 200 m to 50 m across a gentle ramp of forested ridges, which is here informally termed "Interior Midlands," a transitional belt of variable width and undulating 100 m relief. The eastern part has alternating narrow ridges and karstic belts corresponding to interbedded slate and carbonate rock, whereas the western and central parts have cuestas of tilted Hawke Bay quartzite. The cuestas seem to rest on a sloping facet on the Long Range, which may be the exhumed sub-Cambrian unconformity. The gross glacial landforms of the midlands indicate that they were overrun by a Long Range glacier.

West Newfoundland Coastal Lowland

The midlands merge northward into the West Newfoundland Coastal Lowland, which generally lies below 50-70 m elevation and has a local relief of less than 10 m. Its width varies onshore from a narrow strip at the foot of Highlands of St. John to a broad expanse west of Hare Bay. It probably includes the floor of the bay, which is less than 50 m deep and is a broad basin presumably caused by constricted glacial flow. The lowland is underlain by gently inclined Ordovician dolomite and limestone of the St. George and Table Head formations, which form lengthy, nearly barren strike ridges separated by a myriad of shallow ponds and bogs. The limestone terrain in particular has a variety of solution features, including extensive karst depressions, disappearing lakes, and marl deposits. A zone of steeper tilting extending south from Cape Norman creates a belt of low, forested ridges pocked with solution basins that vary in size from tiny pits or dolines to large, unroofed caverns or poljes. West of White Hills, the lowland is a muskeg-covered shale plain, which slopes gently beneath Hare Bay and Pistolet Bay as a muddy, boulder-strewn tidal flat (Fig. 8). The lowland features ice flow markings and moraines produced mainly by Newfoundland glaciers.

Coastal Uplands

The midlands are joined on the east by a range of hills here termed the Coastal Uplands, which also extend north of Hare Bay. They are underlain mainly by resistant, Maiden Point metasandstone and minor volcanics that comprise an allochthon that has been thrust westward over the lowland carbonates. In fact, a large window of limestone in the sandstone was first recognized as an area having ponds floored with white marl. The uplands give the area a narrow eastern rim that declines northward from 250 m to 150 m. The surface is glacially denuded and unvegetated near the coast but slightly drift covered and forested inland. The strongly rolling fracture-lineated surface of 50 m relief produces a ragged coastline that harbours many small fishing settlements (Fig. 9). The uplands were scoured mainly by glaciers of Labradorean origin.

White Hills

Rising abruptly from the north side of Hare Bay are White Hills, so named because the two barren summits at 250-300 m are underlain by a sheeted block of ultramafic and ultrabasic rocks that inhibit vegetation. The surface is mainly rock knobs and basins with strong southeastward stoss and lee asymmetry. Areas of fluted till contain numerous Labradorean erratics and slate from Pistolet Bay. The landscape bears the clear imprint of Laurentide ice.

Figure 8. Intertidal mudflat (southern Milan Arm of Pistolet Bay) overlies rock platform on shale and is studded with large granite erratics, partly dropped from icebergs during deglaciation and partly concentrated downslope from winnowing of ablation moraine. (GSC 203284-R)

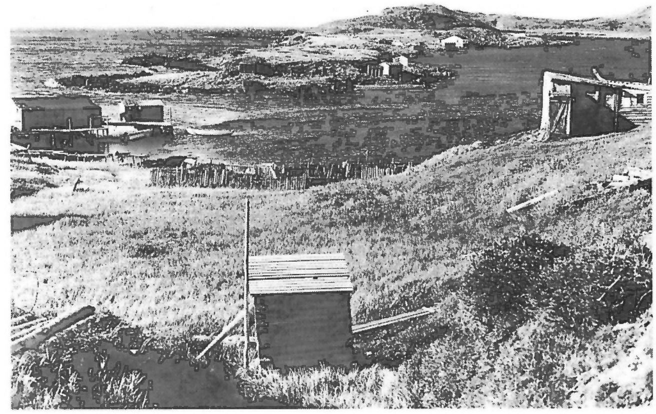


Figure 9. The ragged edge of the Coastal Upland shelters numerous small fishing settlements; Jacques Cartier Island near Quirpon. (GSC 204024-B)

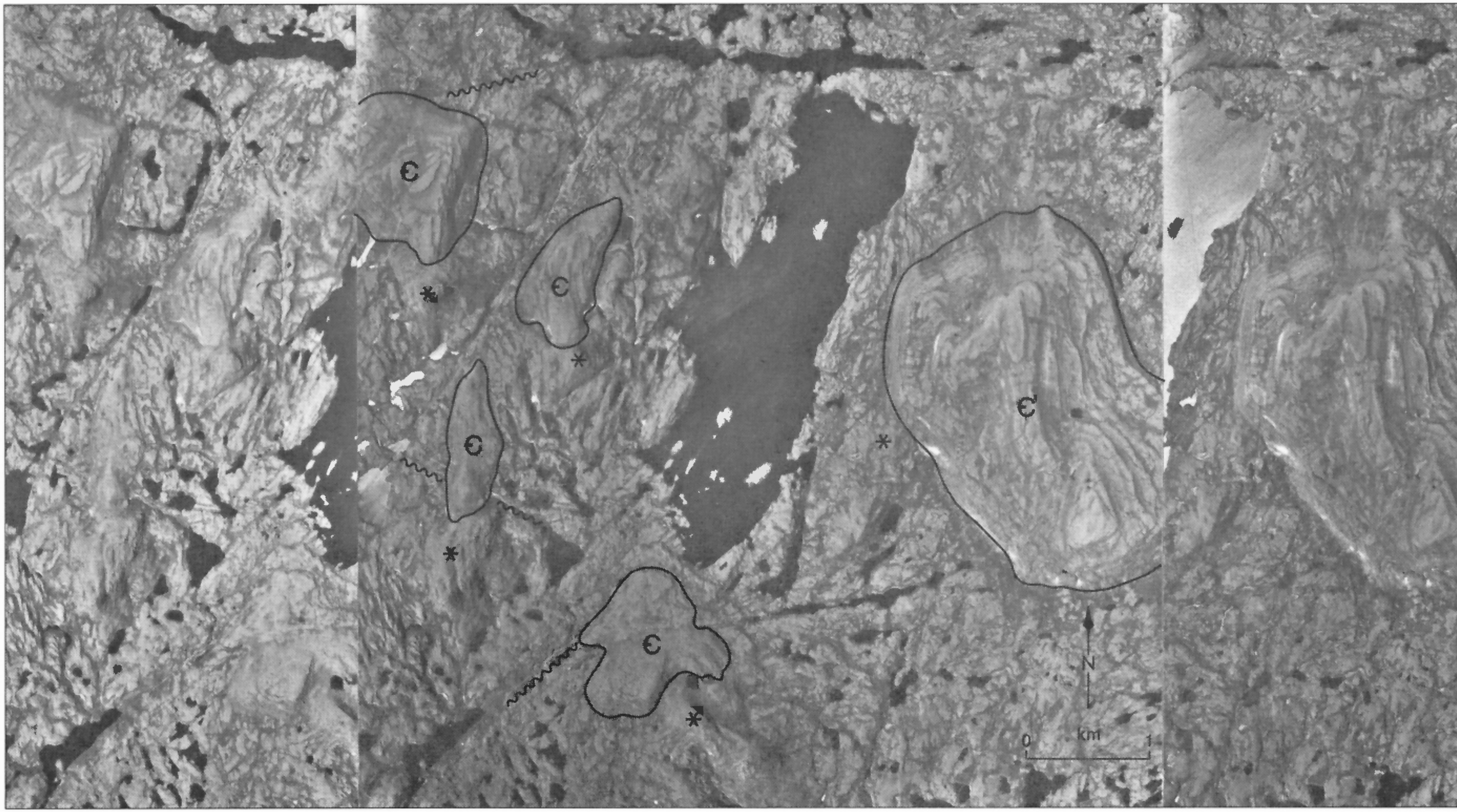
Forteau Tablelands

The lowland terrain descends under Strait of Belle Isle, forming part of the bare ridged channel floor. It terminates against the Labrador coast, which features a row of four flat summits here called Forteau Tablelands. Composed of Cambrian limestone and sandstone, the mesa-like plateaus are denuded and etched by glacial scour so that the strata as sinuous ledges. Elongate basins and perched crystalline erratics show the effect of Laurentide ice.

Mecatina Plateau

The stratiform tablelands rest unconformably on granitic gneisses of the Precambrian Shield, which, in southwestern Labrador, forms the Mecatina Plateau. Where the coastal fringe of sedimentary rocks is being stripped from basement, the tilted exhumed unconformity (or "paleoplain") forms a facet on the rolling upland, like the ramp along the north slope of Long Range Mountains. It rises from sea level to more than 300 m and exhibits a typical rock-basin landscape of areal scouring. Inset slightly below the level of the supposed paleoplain is an oddly rolling terrain noted by Bostock et al. (1983, p. 50) as having deeply distintegrated bedrock. If the grus represents a weathered mantle, perhaps the basinal area was stripped of its Cambrian cover rock at a much earlier stage than the coastal paleoplain.

The scoured rock-basin landscape is generally assumed to be the product of glacial action during Quaternary time. However, it is instructive to compare the outlying topography to the unconformity where it emerges from beneath the cover rocks. Figure 10 demonstrates that the limestones are clearly draped over a high-relief, sub-Cambrian, knob and basin landscape that has essentially the same form as the present terrain. The same is evident along the margins of the glacial troughs extending inland from Forteau, L'Anse-au-Loup, and L'Anse-au-Diable. Hence the present glacial aspect of the Shield in the Blanc-Sablon area may be largely the product of a Precambrian glaciation. This view was put forward for other parts of the Shield by Lawson (1890), Low (1897, p. 263L),



Cambrian cover rocks .... Є

Hill on Precambrian paleoplain .... *

Exhumed faultline scarp ...

Figure 10. Stereogram showing outliers of Bradore Formation sandstone on Precambrian granite gneiss, 19 km north of Lourdes-de-Blanc-Sablon. The outlier at the top is draped over a faultline scarp, and the present glacial knob and basin topography appears to pass under the cover rock. Much of the modern Shield relief may be inherited. Scale bar is 1 km. (NAPL A16617-48, 49).

Wilson (1903), Christie (1951), and Ambrose (1964). Supposed pre-Paleozoic glacial grooving near Lourdes-de-Blanc-Sablon (Fig. 11) is mentioned by Swett (1981). Whatever the pre- Quaternary glacial history of the Precambrian Shield, the latest southward flow by Laurentide ice has left an essentially barren surface, except for perched boulders and two major end moraines.

SURFICIAL DEPOSITS AND GEOMORPHOLOGICAL FEATURES

The generally unvegetated surface makes geomorphological features comparatively obvious. Hence the composition of surficial materials can be readily inferred from airphotos even though much of the area could not be reached and observed directly with the transport available. The map units are thus differentiated on the basis of distinctive patterns of landform and vegetation. To this two-dimensional areal classification, the age of formation and stratigraphic sequence were inferred from observed lateral justaposition and vertical superposition. Surficial units are therefore treated in general order of decreasing age. They are further subdivided into the following 19 classes according to texture, morphology, and thickness: *rock terrains* in three classes according to degree of cover by vegetation and drift; *glacial deposits*, including two older tills and one till of the last glaciation in three thickness and texture classes; *glaciofluvial deposits* in three geomorphological categories; *glaciomarine and marine* deposits in four texture and thickness phases; *fluvial deposits* undivided; *colluvial deposits* undivided; and *organic deposits* undivided.

Terrain composed essentially of bedrock

Bare exposed bedrock (Ra)*

The most easily identifiable surficial material is visible rock outcrop which makes up about 25% of the map area. It is a typical glacial landscape of areal scouring, with knobs and basins having fresh striations, grooves, and polish. The structural fabric of all rock types is etched out as stratification and foliation ridges, and as narrow, linear depressions following fracture lineaments (Fig. 12). Bedrock elements are included on Map 1610A to illustrate the structural fabric and to minimize ambiguity where drift features are superimposed. Erratic boulders of all sizes litter the surface (Fig. 13). Bare bedrock occurs throughout the area on all rock types but is generally found in higher areas and near the coast. Large tracts occur in Quebec-Labrador and around the margin of Long Range Mountains where they correspond roughly to areas above local treeline at 300 m.

The ice scoured rock surface preserves abundant evidence of the sequence and direction of glacier movements; a variety of ice flow marking can be observed. On airphotos, glacial sculpture has produced a clearly visible stoss and lee asymmetry to outcrop shapes on the Precambrian Shield, Long Range Mountains, Coastal Uplands, White Hills, and Grey Islands. On the ground, smaller features such as striations, grooves, and miniature crag and tail invariably have the same trend, except that additional early movements are also preserved that are not evident as larger forms. Abundant ice flow features show the activity of both

Figure 12. Aerial view of the interior plateau of Long Range Mountains showing typical landscape of areal scouring, which etches out the structural fabric. The terrain is littered with large blocks and patches of ablation till. (GSC 203284-Q)

Figure 11. At the fishing hamlet of Lourdes-de-Blanc-Sablon, gneiss is cut by large channels trending 160° which are attributed to a Late Precambrian glaciation (Swett, 1981). They are crossed by shallow Quaternary-age grooves trending 185° under building on right. (GSC 204024-4)

Figure 13. Typical Shield terrain littered with thin ablation debris near the Belles Amours Moraine, Quebec. (GSC 203284-U)

Laurentide and Newfoundland ice masses and have enabled a series of glacial phases to be recognized. These phases are discussed in the section on *Quaternary history*.

Areas of bare rock resulting from wave action are common along the coast. Below 150 m elevation and especially on steeper slopes, the combined effect of postglacial marine submergence and modern storm swash has stripped away glacial debris and weathering products.

The highest areas, namely Highlands of St. John, have a fringe of exposed bedrock at 450-520 m cut as a shoulder into the quartzite bedrock. The headwall now shelters semipermanent snowbanks or névé (Fig. 7). The planation and the removal of till and weathered rock is therefore attributed to the process of nivation.

Bare bedrock obscured by forest (Rb)

The second major type of rock terrain is tree-covered areas inferred to be underlain by bedrock with little or no overlying surficial sediment. It is recognized by numerous outcrops and by structural relief patterns that are almost as clearly visible as in areas of exposed bedrock. The distinction is made for practical purposes – partly for considerations of forest capability, and partly for geological exploration when it is necessary to know where bedrock might be exposed if vegetation were not present versus where it is actually visible. Surficial sediment may be present in thin patches and in depressions. Forested rock terrain usually occurs at intermediate elevations and marginal to bare rock areas. Large expanses occur in sedimentary rock terranes where trees can root in little or no soil.

Bare bedrock with undifferentiated till patches (Rc)

Large areas are occupied by bedrock-dominated terrain mantled with discontinuous veneers of till and other surficial materials, which comprise up to 40% of the map unit. This terrain is mostly forested and is recognized on airphotos by clear but subdued patterns of bedrock relief that belie a sediment cover, usually till. It generally occurs below 200-300 m elevation and in basinal areas. In addition, small undifferentiated patches of marine sand and mud may occur in lower areas below the 150 limit of submergence.

The limit of this terrain against rock or till units is gradational, so assignment to this category may be arbitrary in some cases. Moreover, the 40% sediment cover should be regarded as a rough estimate, because distribution varies with rock type, relief, and direction of glacier flow in relation to slope and topography. Major areas occur on the Forteau Tablelands, on the limestone window in the Coastal Uplands, and along the medial zone of Long Range Mountains where the ice divide of the plateau glacier was located. Smaller tracts occur on the Coastal Lowland where till is heaped on bedrock as small but discrete morainic ridges.

Glacial deposits and ice flow features

All of the study area was overrun by glaciers at various times, which produced a variety of depositional and erosional effects. Several associations of sediments and landforms have important practical applications as well as demonstrating the main events in the glacial sequence. The depositional aspects are therefore treated first. The evidence, however is not everywhere in the form of mappable deposits. A related body of data, in the form of erosional features oriented both longitudinally and transversely to ice flow direction, constitute an essential complement to the assemblage of mappable deposits. The ice flow indicators reveal individual patterns of dispersal and a sequence of secondary flow phases. Together both sets of data are the basis for reconstructing the history of glaciation whether for application to economic development or for understanding climatic change.

Of the areas covered by glacial deposits, there are major differences in geomorphological aspect. Fresh, virtually unaltered glacial terrain covers 99% of the area. Morainic

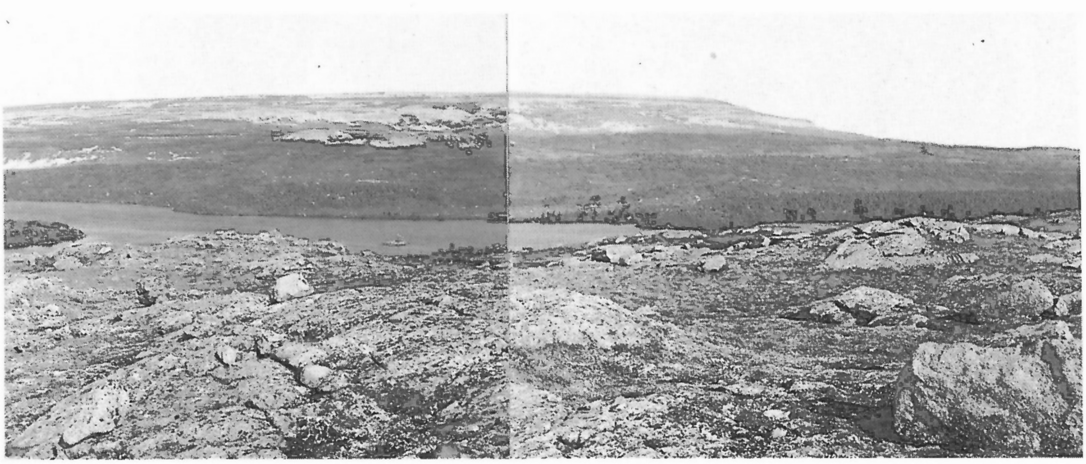


Figure 14. View westward from Long Range Mountains toward Highlands of St. John showing the contrast between the freshly ice-scoured gneiss in the foreground and the maturely graded slopes on sedimentary rock behind. (GSC 158006-7, courtesy H.H. Bostock)

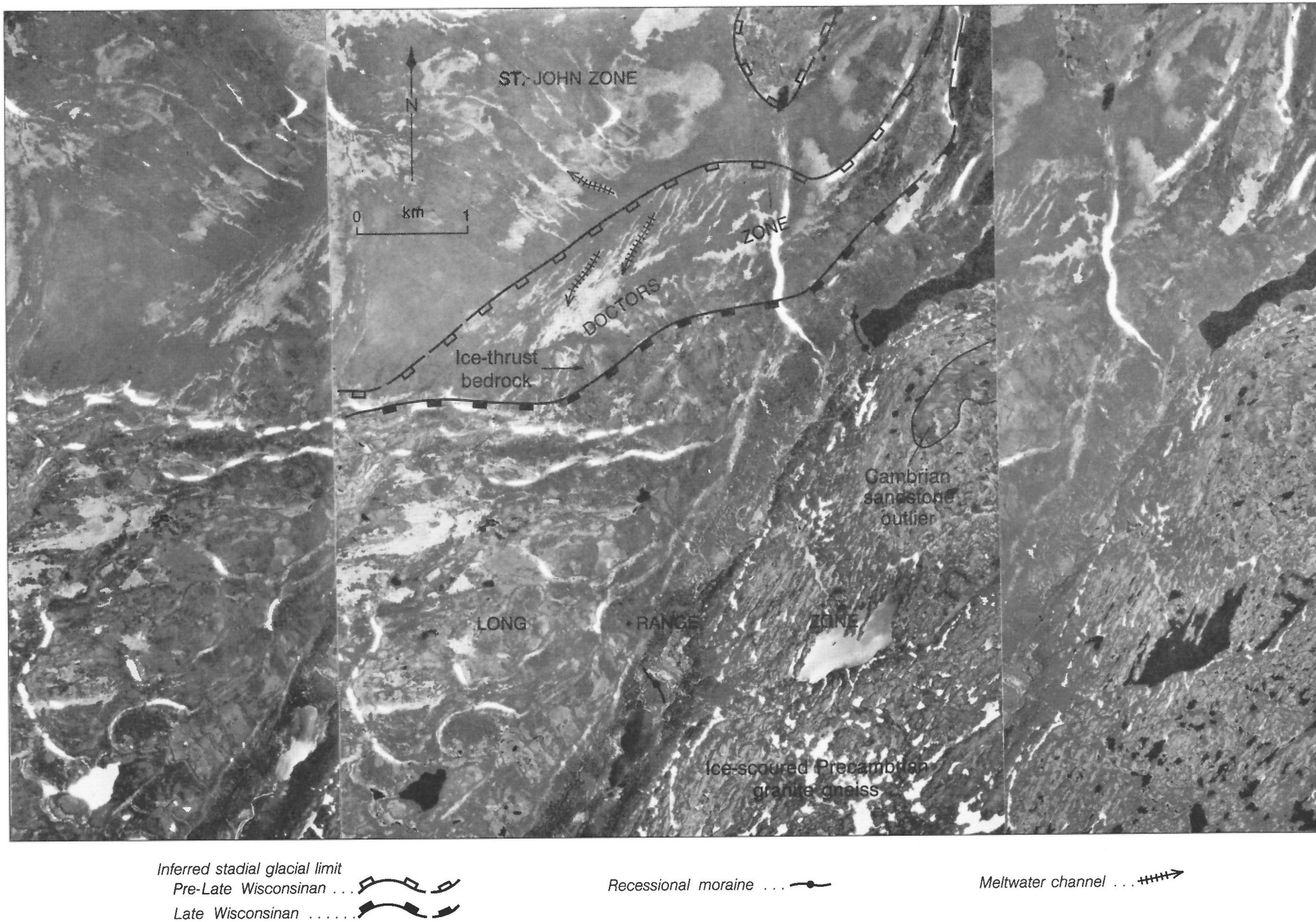


Figure 15. Stereogram showing the limits of three different ages of glacial terrains. The oldest and most mature forms the smooth summit of Highlands of St. John (1a), an intermediate zone shows as a subdued but eroded swath on the southern flank (1b), the youngest shows as deeply scoured terrain on both sedimentary rocks (Rb) and on granite gneisses (Ra). Note that a Cambrian sandstone outlier (X) has the same scoured aspect as the surrounding gneiss, yet is higher than the corresponding ice limit on the Cambrian plateau down ice. Symbols: N = nivation hollow; small arrow = ice-flow direction from stoss and lee forms; beaded line = recessional moraine. Scale bar is 1 km. (NAPL A21038-47, 48)

topography has angle-of-repose slopes, and bedrock surfaces are intact with fresh striations and polish. The glacial aspect is as youthful as anywhere in Canada. In sharp contrast, the remaining 1% has a distinctly more mature character in terms of slope evolution and the condition of surface debris. The latter areas lie above or beyond the youthful terrains, namely on the summits of Highlands of St. John (Fig. 14) and on Grey Islands. Till and other glacial features are present, but slopes are flattened and bedrock is disaggregated to varying degree. The same contrasts can be found on a variety of rock types on other highlands in western Newfoundland, and elsewhere in eastern Canada, notably in Gaspésie, New Brunswick, and Cape Breton Island. In northern Labrador and Baffin Island, the differences are attributed to duration of subaerial exposure and are radiometrically dated. The more mature terrains were glaciated prior to Late Wisconsinan time.

The degraded areas are therefore lithostratigraphic units, and the Newfoundland examples are tentatively given comparable status, although absolute dating has not yet been achieved. The older glacial terrains in this area are ranked according to the inferred degree of obliteration of glacial features. Two primary subdivisions are made qualitatively in terms of the destruction of rock knolls and infilling of rock basins by in situ accumulation of weathering debris, and by the grading of till slopes by solifluction, cryoturbation, and general mass wasting.

Older till terrains (1)

Till and blockfields with mature slope degradation (1a)

Highlands of St. John are two gently domed summits rising to more than 500 m, but are less than 50 m higher than adjacent Long Range Mountains. The highest parts are obscured locally by heath and thin peat, but large unvegetated areas show that surficial material is mainly angular blocky quartzite rubble (felsenmeer) produced from the fractured Hawke Bay Formation by frost action. The rubble is arranged in stone circles and stripes by cryoturbation. Conspicuous in the grey rubble are various igneous erratics, notably pink-weathering granodiorite similar to that in southern Labrador. Locally, mud boils reveal that some areas are composed of till that contains melanocratic gneisses from Long Range Mountains. The till and felsenmeer are graded by solifluction into gentle continuous slopes. Rare outcrops form low rises.

The till and erratics prove that the summits were glaciated, yet the surface is devoid of glacial landforms. The summit area contrasts sharply with a slightly lower terrain, also on quartzite, which has basins and knobs with 10-20 m relief (Fig. 15). There is no lithological or structural difference between the two terrains, they are at virtually the same elevation, and they are only marginally higher than the freshly glaciated Long Range area. Therefore, it is concluded that the St. John summits owe their anomalous maturity to prolonged mass wasting. The implication is that they escaped the glaciations that affected the lower quartzite area and Long Range Mountains. For the sake of discussion, the mature glacial terrain is hereafter referred to as the "St. John Zone." Estimates of the age of this earliest glaciation are made in a later section.

Grey Islands also display anomalously mature glacial terrain. On Bell Island, above marine limit, large till areas appear to be smoothed by solifluction, judging by the stone stripes and absence of morainic topography (Fig. 16). Large erratics of Cambro-Ordovician sandstone and dolomite from Northern Peninsula, together with gneisses that might have come either from Long Range Mountains or from Labrador, show that the glacier flowed eastward, as shown also by the trend of stoss and lee forms on lower wave-washed bedrock. The underlying massive granite does not explain the smooth slopes because it has a hummocky surface where stripped of till below marine limit. The till terrain of Bell Island is correlated tentatively with the St. John Zone.

Till terrain with intermediate-stage degradation (1b)

The St. John Zone abuts a second glacial terrain which lies about 10-15 m lower. It comprises till and bedrock areas that have a less degraded aspect (Fig. 17). Also developed on Hawke Bay quartzite, the terrain is characterized geomorphologically by broad, shallow basins containing ponds and bogs. The depressions are assumed to have been excavated glacially, although it is remotely possible that some of those seen in Figure 17 are collapse structures reflecting karst development in the calcareous Forteau Formation lying at depths of 50-100 m. Rock outcrops are common, but they are noticeably subdued and are being buried in situ by a kind of residuum composed of fine, frost-shattered debris (grus) in which various igneous erratics are scattered. The generally rocky terrain is interspersed with patches of till, which have a flattened, subdued, morainic topography.

On the northeast side of South Summit (Doctors Hill) the bedrock strata are contorted (Fig. 17). The quartzite ledges outcrop in complex, curvilinear, strike ridges with inclinations that are steeper than the gentle attitudes elsewhere on the summit. As there is no localized folding or faulting that could explain the structures, they are attributed to thrusting at the margin of the glacier that produced the basinal terrain, perhaps by freezing of ice to the substrate.

The upper limit of this intermediate-stage terrain against the mature St. John Zone is a fairly distinct line where it is not obscured by modern nivation. On the southern flank of North Summit, the contact descends from 600 m to 380 m over 12 km, or about 20 m/km (Fig. 17). On the northern flank, the slope is comparable though less continuous. Its lower limit, where truncated by the youthful glacial terrain, is clearest where it traverses the southern slope of South Summit (Doctors Hill). There, it descends from 400 m to 300 m over 8.5 km, or about 12 m/km.

This terrain occurs also on Grey Islands, specifically on Groais Island where the 180-240 m plateau presents a knob and basin topography on greywacke and schist. The rock shows a more advanced granular disintegration than do comparable rocks at similar elevations nearby, such as on the Coastal Uplands. Also, the till areas are somewhat smoothed by mass wasting, but not enough to destroy the linear, ice moulded flutings and crag and tail hills. These record a clear sense of eastward ice movement.

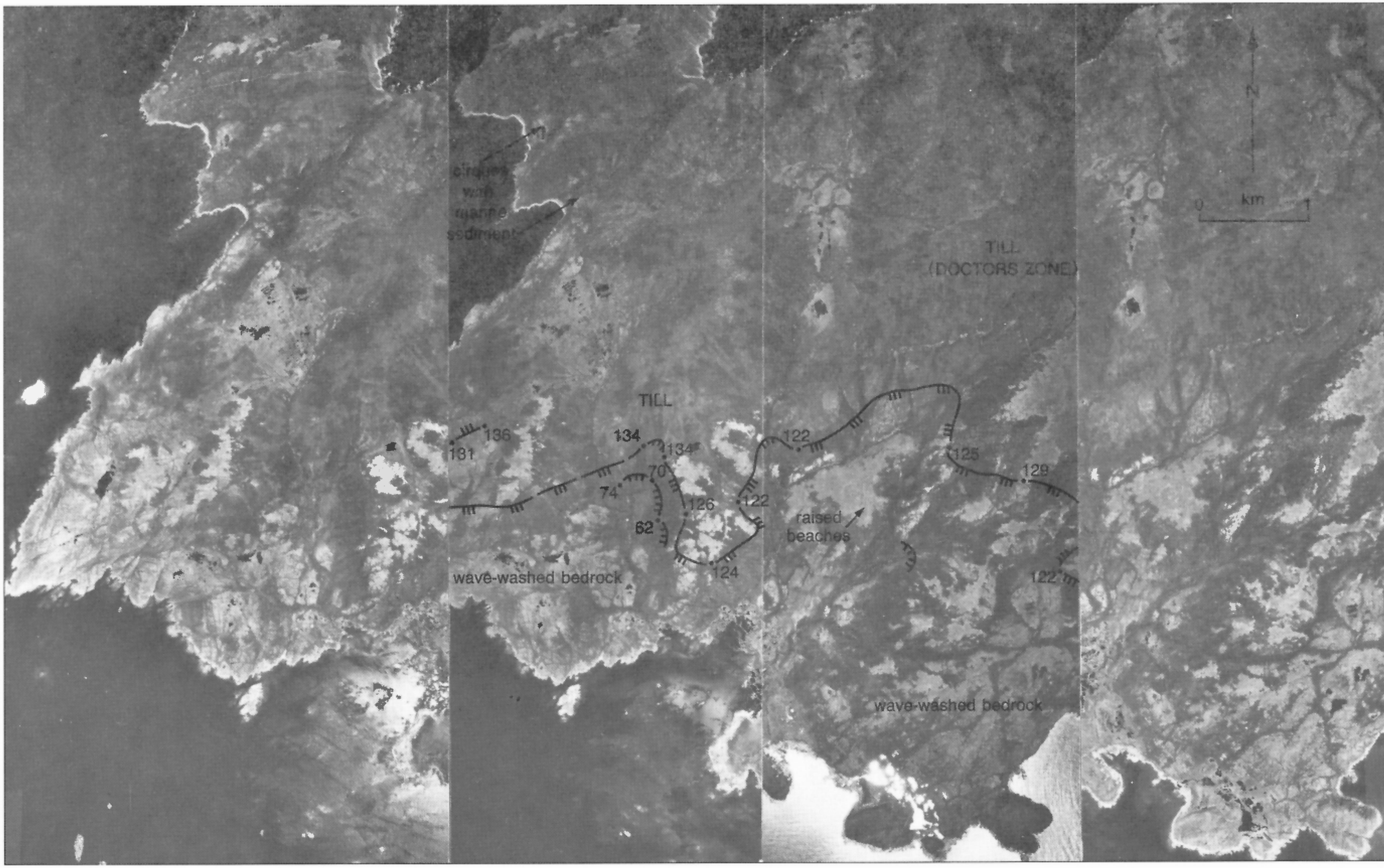
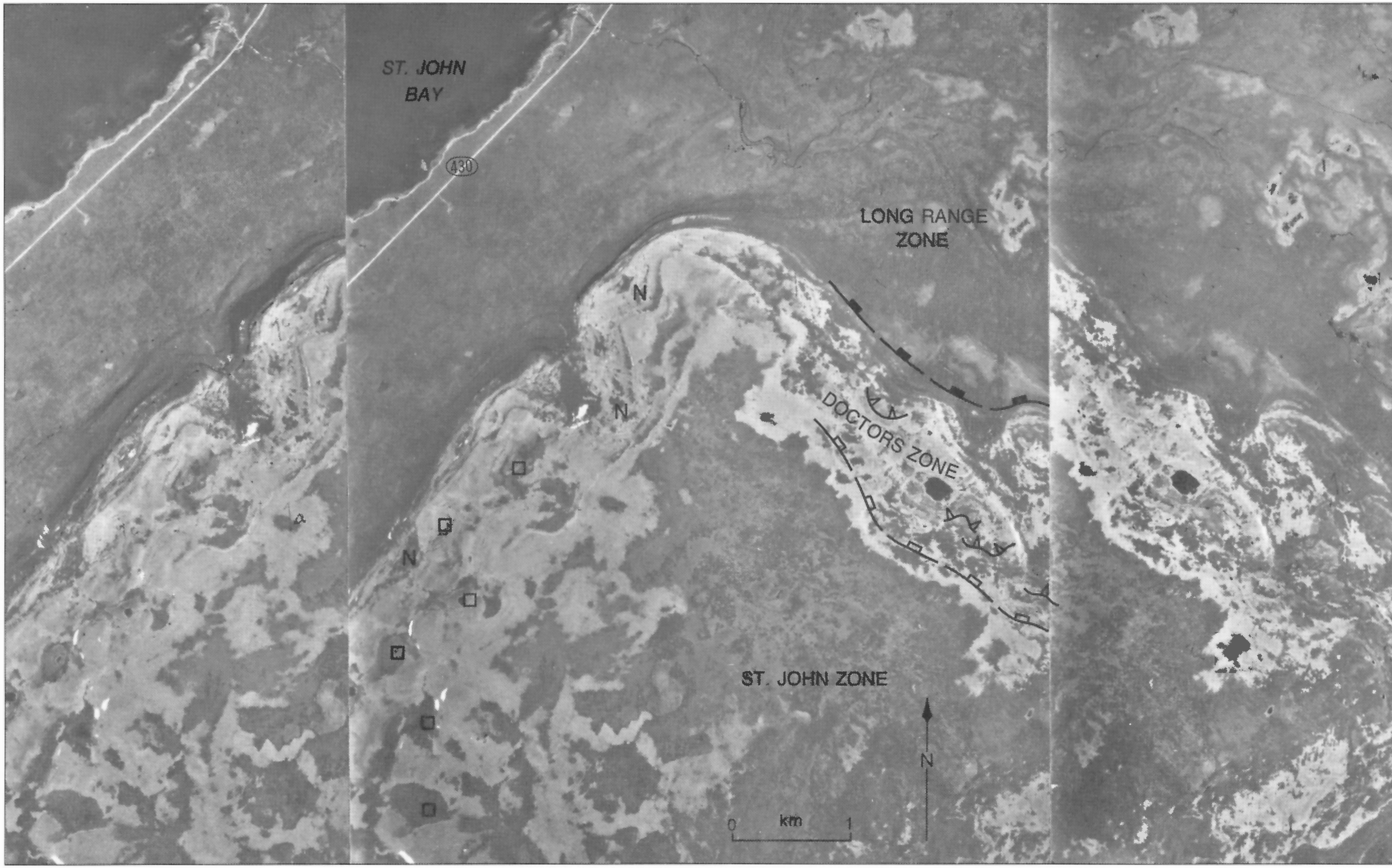


Figure 16. Stereogram of southern Bell Island (Grey Islands) showing marine limit with washed bedrock terrain below (Ra) and mature solifluncted till above (1a). Note talus cliffs (arrow) and emerged and submerged cirques (X). Scale bar is 1 km. (NAPL A20564-2, 3, 4)



Stadial glacial limit
Pre-Late Wisconsinan . . .
Late Wisconsinan . . . . . .

Ice thrust ridge . . . .

Nivation hollow . . . . N

Solution depression . . . . □

Figure 17. Stereogram of the north slope of North Summit, Highlands of St. John, showing most mature (oldest?) glacial terrain (1a) on plateau, flanked by degraded intermediate-age glacial terrain (1b) with ice-thrust bedrock ridges (toothed line) and rock basins (*). Note nivation hollows (N). Scale bar is 1 km. (NAPL A21038-49, 50, 51)

As both the upper and lower limits are seen on South Summit or Doctors Hill, the intermediate-age glacial terrain is informally named the "Doctors Zone."

Submerged and overridden cirques

A feature of Grey Islands are the well formed cirques that indent the plateau margin. The coastal cliffs are deeply embayed by at least eight amphitheatre-shaped basins that rise from floors 20-40 m below sea level (Fig. 16). They are 1-2 km in diameter, U-shaped in plan and profile, and have headwalls rising 200-300 m to the tablelands. Two with floors above sea level have marine terraces and deposits. By all appearances, they were last occupied after regional glaciation but before the glacioisostatic marine submergence.

Other cirque-like forms occur on Northern Peninsula within the area of the youthful glaciation, but as they have been glacially overridden they must predate it and are therefore discussed here. Bowl-shaped basins with floors submerged at depths similar to those on Grey Islands are found along the northern coast of Hare Bay. Each is backed on three sides by steep cliffs with glacially rounded upper edges. A second group of four basins forms Howe Harbour and nearby, low-level lakes named Long Pond, Three Brooks Pond, and Brimstone Pond. In addition, the outlines of St. Anthony Harbour, St. Anthony Bight, and Crémaillière Harbour also suggest ancient, much modified, drowned cirques.

A third group is in Long Range Mountains in the headwaters of Beaver and Cloud River valleys where eight basins are separated by narrow arêtes. There the plateau margin at 400 m is scalloped by basins 1-2 km in diameter, with floors at about 300 m. Similar basins farther northeast in the headwaters of Shoal Brook and Northwest Brook bottom out at 200 m. All have been rounded by overriding ice that moved eastward. There is no evidence that they harboured later cirque glaciers. The age of formation is discussed in the section on Glacial history.

Youthful till terrains (2)

With exception of the degraded areas already discussed, the greater part of the study area displays fresh glacial landforms, whether as ice flow lineaments, large and small end moraines, or disintegration topography. Ice moulded longitudinal forms include small flutings, drumlinoids, and crag and tail hills, all of which serve to indicate three distinct phases of ice advance. Moraines, on the other hand, record discrete episodes during both advance and retreat phases and help to define ice sheet configuration. Together with ice flow markings they are the basis for deducing most of the glacial history.

Till covered areas are widely distributed at all elevations, but the drift is generally shallow, and thick deposits are mainly present as ice marginal accumulations. Glaciers flowed mainly from harder rock uplands to sedimentary rock lowlands, with the result that higher areas are glacially denuded and grade downslope to areas of deeper drift. Thus, glacial debris from crystalline highlands has been spread onto the carbonate lowlands, although there are important exceptions. In the absence of systematic textural data, till cover is subdivided for practical purposes on the basis of thickness, as inferred from depositional features and the degree of masking of bedrock relief. The three categories are till veneer, till blanket, and till plain with large end moraines.

Till veneer (2a)

Thin discontinuous drift cover less than 1-2 m thick with numerous outcrops is termed *till veneer*. Its shallowness is evident on airphotos because the underlying bedrock relief is almost as readily discernible as in outcrop areas. This unit covers relatively small areas, but as it is intermediate in continuity and thickness between rock with till patches (Unit Rc) and till blanket (Unit 2b), detailed mapping might show that portions of the latter two actually belong in this category. Till veneer occurs on the Coastal Lowlands west of Hare Bay where it corresponds to karstic terrain and to fields of minor till ridges or De Geer moraines.

Till blanket (2b)

Thin but continuous cover of drift 2-5 m thick is called *till blanket* because bedrock is completely covered and submask relief is only vaguely discernible as large strike ridges and major fracture lineaments. Till blanket occurs in three areas. The largest skirts the northern Long Range Mountains where presumably the till has become lodged by transverse ridges of sandstone and limestone. Although very stony, the till is streamlined into small drumlins, flutings, and crag and tail hills. The matrix has been generated in situ because it is brownish by comminution of Bradore sandstone and is locally calcareous by uptake of Forteau limestone. In contrast, the larger clasts and all the surface blocks are from Long Range Mountains. To quantify the transport, a count was made of crystalline erratics larger than 20 cm exposed along the verge of Highway 432 west of Ten Mile Lake. Figure 18 shows the number of stones in each of 33 km starting from the west edge of the dispersal train, plotted against the distance down ice from the contact as measured in a direction 015° which is the mean of observed striations. Judging from the visual best-fit trend line, the dispersal appears to decrease exponentially as expected.

On Long Range plateau, till blanket occurs in the medial zone surrounded by bare, scoured rock. The till is an immature rubbly drift without sign of appreciable transport. No ice moulded forms are visible on drift or rock and the terrain is a peculiar, nondescript undulating landscape without any glacial imprint. As all ice flow trends radiate outward from this interior area, it is assumed to be the general location of the ice divide where little basal sliding took place. Bostock et al. (1983), however, reported that diabase boulders from the dykes east of the medial zone are found in the western half of the plateau, so at one time the divide was located east of the median. Still, the medial drift-covered zone extends the full length of Longe Range plateau over nonglacial undulating terrain and maintains its central position in relation to diverging ice flow trends (Grant, 1986).

De Geer moraines. On West Newfoundland Coastal Lowland, till blanket forms extensive tracts of minor moraines arranged in groups from Ferolle Point to Hare Bay; about 400 occur over 90 km. The moraines are small, parallel, bouldery ridges usually less than 5 m high, 30-50 m wide, and spaced fairly regularly about 200 m apart. They are best seen in lakes as spits, islands, and shoals (Fig. 19), or where surrounded by bog. They may be continuous or segmented in 1 km arcs and are grouped in fields that generally occupy lower areas such as around lakes and in valleys. They do not occur above the limit of postglacial marine inundation. According to Elson's (1968) survey of moraine terminology, these are identical to the type first described in Sweden by De Geer (1889) as "annual" or "winter" moraines that form by seasonal pulses of an ice front retreating in a water body.

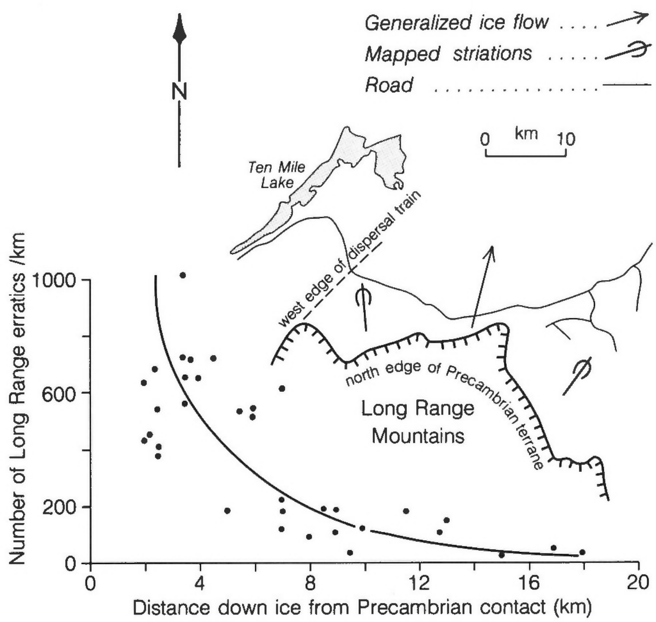


Figure 18. Diagram showing glacial transport of crystalline erratics northward from Long Range Mountains.

Figure 19. Aerial view of a field of De Geer moraine ridges truncated by the Ten Mile Lake Moraine (lower right). (GSC 203284-P)

Hoppe (1959) named them De Geer moraines, and Prest (1968) has adopted this usage in reference to their wide occurrence in several areas of Canada of which this one was found to be typical during preparation of the Glacial Map of Canada (Prest et al. 1968). In size and form they are identical to those shown in Prest (1983).

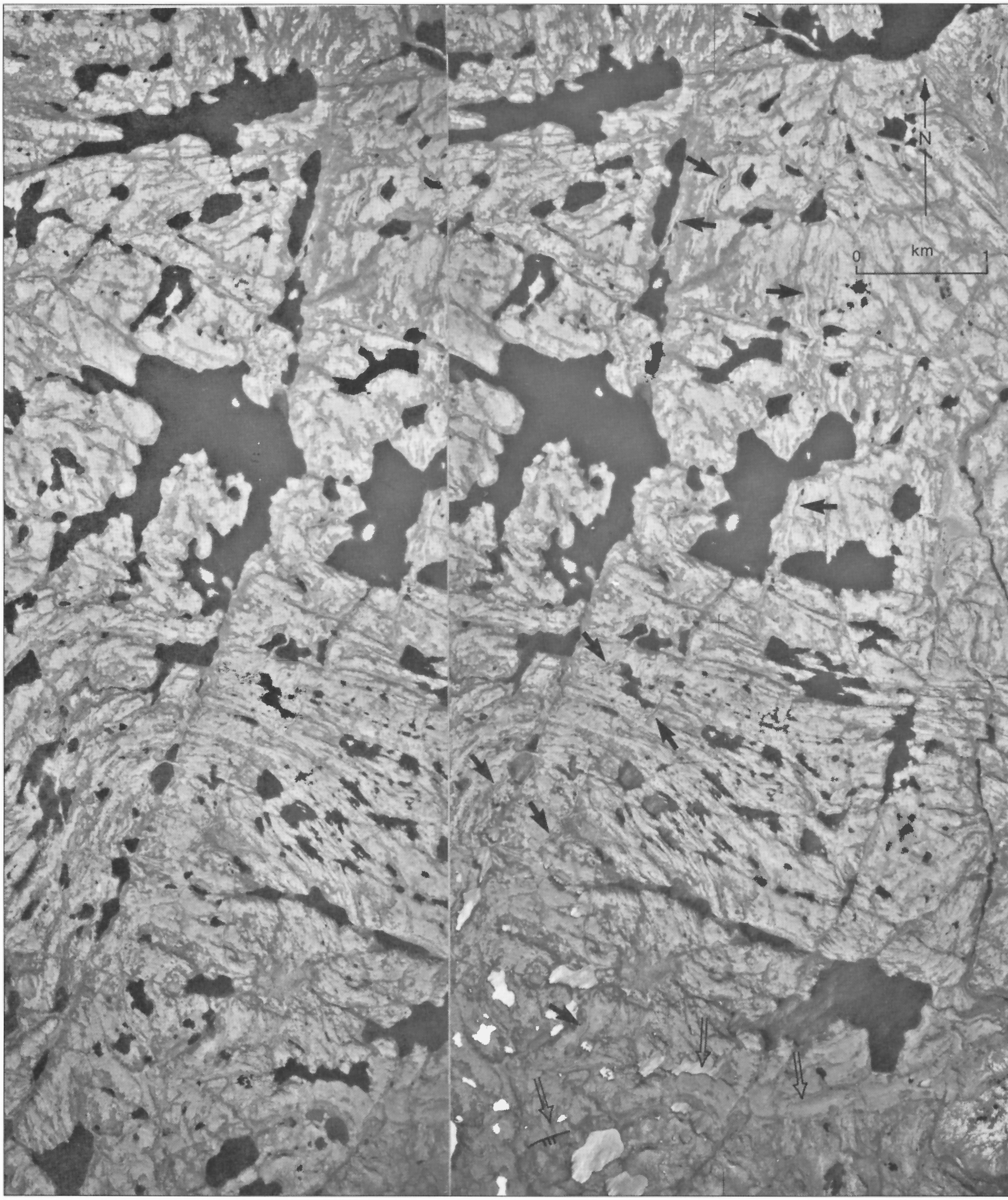
Belles Amours Moraine. In Quebec-Labrador, large till deposits are uncommon, but a notable exception is a broad northeastward-trending belt of shallow bouldery till, which is organized into a number of small sinuous moraines (Fig. 20). The swath has about ten ridges, each a few metres high and a few tens of metres wide, that snake over and around bedrock knobs. Despite their miniscule dimensions (Fig. 21), they continue for many kilometres from the Gulf of St. Lawrence to the north edge of the study area. At the coast the moraine belt is linked to two large gravel headlands (Fig. 22) that enclose Baie des Belles Amours. Accordingly the complex is here informally termed the Belles Amours Moraine. It cuts across another large ice marginal deposit, the Bradore Moraine, which is described in a later section.

Two other areas of till blanket deserve mention. First, the col between North Summit and South Summit is floored with locally ridged till in a morainal form that may have been produced by an outlet glacier from Long Range ice cap. Second, thick drift covers the lowland between Chimney Bay (Canada Bay) and Hare Bay and may be the product either of voluminous erosion of shale interbeds in Table Head limestone, or of lodgment on high-relief karst. Most of the remaining areas of till blanket are simply the shallower marginal phase of thick till plains.

Till plain with large end moraines (2c)

The drift mantle attains its thickest development as a continuous blanket more than 5 m thick in the form of extensive plains, bulky end moraine complexes, and miscellaneous masses. It covers bedrock completely except for rare outcrops, but the larger bedrock features remain visible, partly because of groundwater effects enhanced by vegetation. The largest is at the foot of Long Range Mountains where a gently undulating boggy plain overlies limestone and quartzite. The surface is ornamented with low flutes and shallow grooves up to several kilometres long. Short drumlinoids are lodged on stoss and lee sides of bedrock ridges. Outliers or extensions of the fluted plain occur around Ten Mile Lake and in Castors river – Leg Pond valley. The fluting is like that typically developed on cohesive fine grained till (Boulton, 1976) such as would be produced from the underlying limestone. Additional fine textured surface sediment in the form of marine mud might also be present in this area because the glacier is inferred to have readvanced across the sea floor during the late glacial phase of higher sea level.

Smaller areas of thick till occur in Cloud River and East River valleys, in the karstic depressions around Coles Pond and White Hump Pond, and on White Hills. Significantly, the latter deposits contain Labradorean erratics and slate from Pistolet Bay. In Labrador, north of Forteau Valley large till



Bradore moraine ...   *Belles Amours moraine* ...   *Marine limit* ...

Figure 20. Stereogram showing the large linear east-trending Bradore Moraine (black arrows) truncated by the northeast-trending belt of narrow sinuous ridges that constitutes the Belles Amours Moraine (white arrows). Both are mantled with bare granite boulders, which is why they are well camouflaged against the exposed bedrock terrain. Scale bar is 1 km. (NAPL A14478-38, 39)

Figure 21. Typical view along one of the bouldery ridges of the Belles Amours Moraine. (GSC 188726)

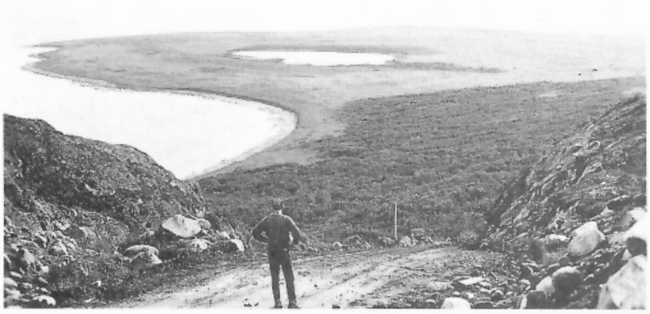


Figure 22. Large foreland of raised beaches composed of subaquatic outwash gravel that accumulated in Goldthwait Sea as a submarine extension of Belles Amours Moraine. (GSC 203284-N)

masses are lodged on the north or stoss side of bedrock hills to produce a "ramp and crag" effect, an ice-moulded rock and till landform that has apparently not been described before.

Ten Mile Lake Moraine. Some of the thickest deposits take the form of large end moraines of which two major systems are recognized. On Northern Peninsula, the largest is named the Ten Mile Lake Moraine after the lake it has created. The main segment is a nearly perfect semicircular embankment 10-30 m high. Its southern end bifurcates and the two arms further divide into two and three ridges that form islands and peninsulas in Angle Pond (Fig. 23). The central part of the arc is a single massive rampart that truncates a field of De Geer moraines; the eastern part is an irregular mass of hummocky moraine.

The internal composition is seen in cutbanks where the moraine juts into Ten Mile Lake. A brownish silt till is composed largely of local dolomite and quartzite plus a few crystalline erratics. The till contains abundant broken marine shells dominated by Mya truncata, which dated 10 900 ± 160 BP (GSC-1277). A feature of the deposit is cubic-metre sized "blocks" of pure barnacle (Balanus spp.) debris, which gave a virtually concordant date of 11 000 ± 160 BP (GSC-1324.)

The end moraine continues eastward as a second arc of hummocky ridges. Near Main Brook, the central part of the eastern arc is ridged with gravel beaches. This arc also bifurcates and subdivides where it terminates against the Coastal Uplands at White Hump Pond. The moraine disappears where it rises through the local marine limit at 130 m.

Leg Pond Moraine. In Castors River valley, south of Mount St. Margaret, a short, bulky, double-ridged end moraine is termed the Leg Pond Moraine after the lake it dams. Composed of a gravelly mixture of lowland and highland rock types, it is deeply kettled, and the summit is flattened as a terrace at about 60 m. Marine beaches and terraces notch the distal slope.

An unrelated ice marginal deposit occurs in the headwaters of East River where an area of thick till with kames and sidehill meltwater channels has several small end moraines that dam lakes (Fig. 24).

Bradore Moraine. In Quebec the Belles Amours Moraine truncates a narrow linear series of small, thick till bodies (Fig. 15) that lie along the escarpment fronting Bradore Bay. The deposits block numerous small valleys in an otherwise barren Shield terrain (Fig. 25) and are localized at marine limit. Borrow pits reveal either bouldery sandy, till (Fig. 26) or current-bedded, ice contact gravelly sand (Fig. 27) with a boulder armour that extends up to the 140 m washing limit. The feature was clearly built at an ice margin standing at a shoreline. Termed the Bradore Moraine after the nearby deepwater Bradore Bay, the feature can be traced eastward to the edge of the map area as a series of isolated ice marginal features: kame deltas at marine limit at the head of Forteau Valley, sidehill meltwater channels inland of L'Anse-au-Loup, and deltas and kames inland of Red Bay. It crosses Pinware River valley as a large kame and kettle deposit underlying outwash (Fig. 28).

Indicators of glacial movement

Longitudinal erosional markings

Although much of the area is devoid of mappable glacial deposits, evidence of the trend and sequence of ice movements is everywhere abundantly present as a variety of direction indicators (Fig. 29). Small-scale linear markings such as striations and grooves are ubiquitous and inscribed on all rock types. Miniature crag and tail, or "pressure shadows" are common on rock types with more resistant parts, such as porphyritic gneisses, crystal schists, and conglomeratic sandstones. Crescentic gouges, chattermarks, and related arcuate fractures are locally abundant on dense, silicic rock types and on certain carbonate types, such as at the mouth of Doctors Brook. All these are seen on most exposed bedrock surfaces in a virtually unweathered form, commonly with associated polish. On carbonate rocks they are quickly obliterated by plant acids but are preserved where protected either by water or by even a few centimetres of till. The small markings are invariably parallel to larger oriented forms, which, on till, take the form of flutings and small drumlinoids. On rock terrain they include rôches moutonnées, stoss and lee topography, and crag and tail hills. These collectively impart a strong directional asymmetry to the terrain fabric, which can readily be mapped from airphotos at 1:50 000 scale. For example, the diabase dykes of eastern Long Range Mountains stand in sharp relief above the gneissic country rock and have a plucked, east-facing cliff and a west-facing ramp leading up to the crest. Waitt (1981, p. 836) noted a similar large-scale propensity for one end of a lake basin to be heavily abraded

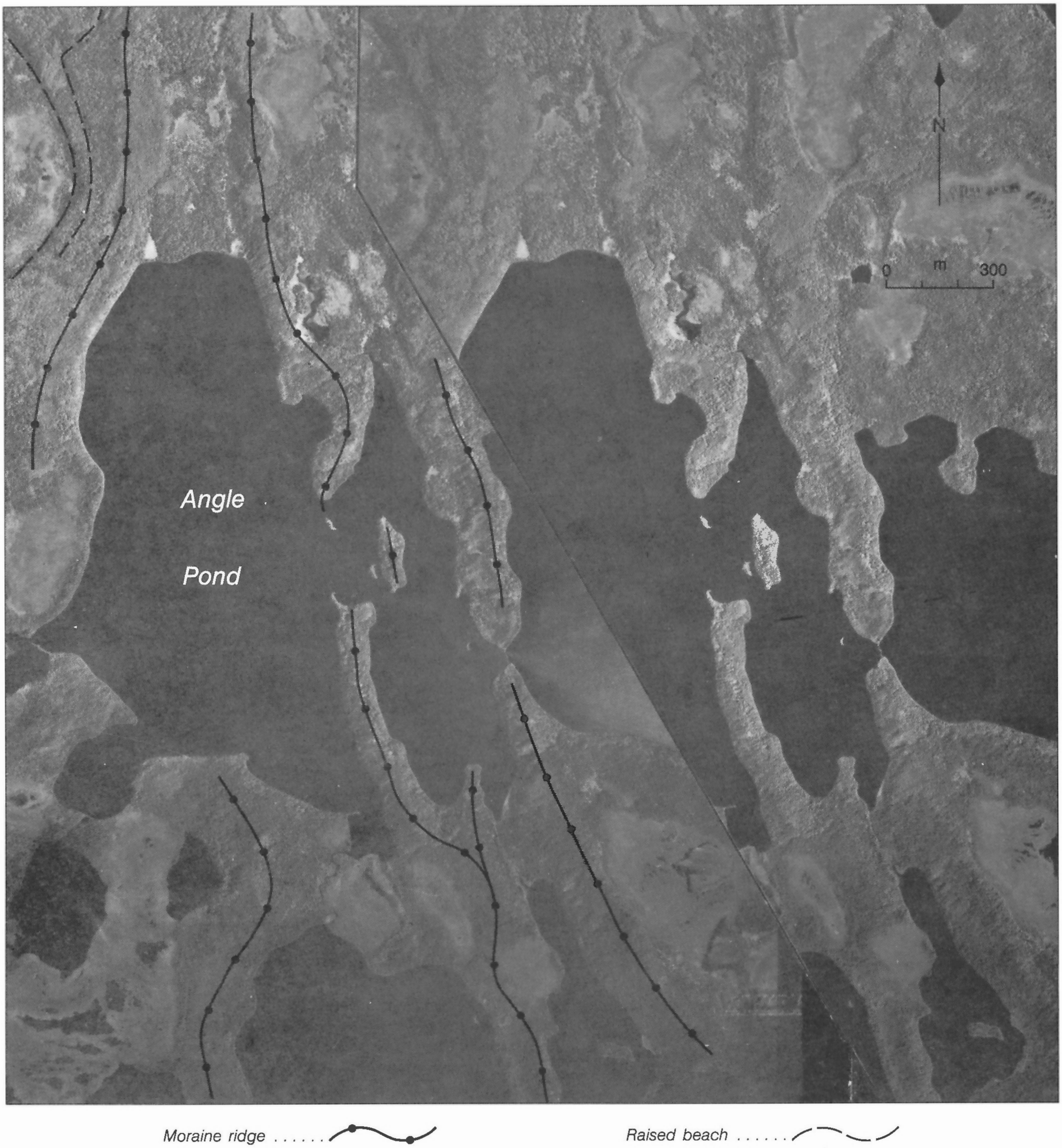


Figure 23. Stereogram of the Ten Mile Lake Moraine showing two of its five constituent ridges in Angle Pond. (NAPL A20533-31, 32)

whereas the other was scarcely marked. The stoss slopes face toward the medial line of the plateau as do the ice flow indicators.

Erratics

Erratics are dispersed in trends that corroborate the erosional indicators. The southward spread of Shield erratics onto the Forteau Tablelands is an expected consequence of the general southward movement of the Laurentide Ice Sheet, but they are also found on White Hills, Coastal Uplands, and Grey Islands as evidence that Shield ice also invaded northern Newfoundland. On the other hand, the northward dispersal of Long Range stones onto the carbonate terrane (Fig. 18) and westward dispersal of White Hills ultrabasics are conspicuous signs of an independent Northern Peninsula glacier. Bostock et al (1983, p. 4) interpreted diabase erratics on western Long Range to mean that a plateau ice cap was, at one time, centred east of the median line.

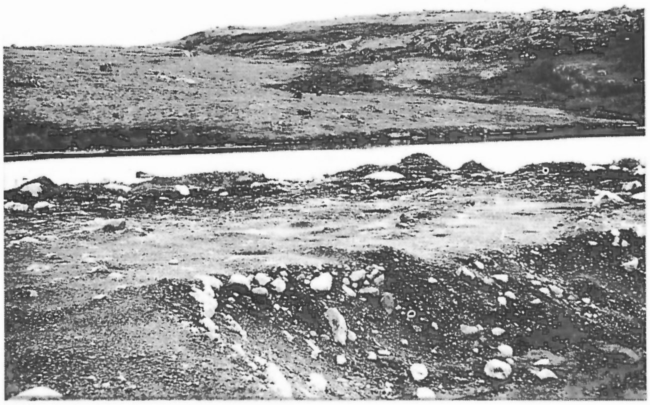


Figure 26. Close-up view of the same locality showing bouldery till and kettle lake in the foreground. In the background a wave-planed slope on the moraine rises to marine limit, which is marked by the lower limit of perched erratics. (GSC 203284-Y)

Figure 24. Aerial view of a small, recessional end moraine damming a pond in the headwaters of Castors River. (GSC 204024-A)

Figure 27. Internal composition of the Bradore Moraine showing marine boulder lag over cut-and-fill ice-contact sand deposited subaquatically. Outcrop on skyline with perched boulders is above the local marine limit at 140 m. (GSC 188743)

Figure 25. Ground view of a typical segment of the Bradore Moraine blocking a rock gorge. The till ridge impounds a former ice-block depression and is covered with beach gravel up to marine limit. (GSC 188749)

Figure 28. Internal structure of an ice contact, gravel mass in Pinware River valley believed to mark an ice-frontal position correlative with Bradore Moraine. (GSC 188743)

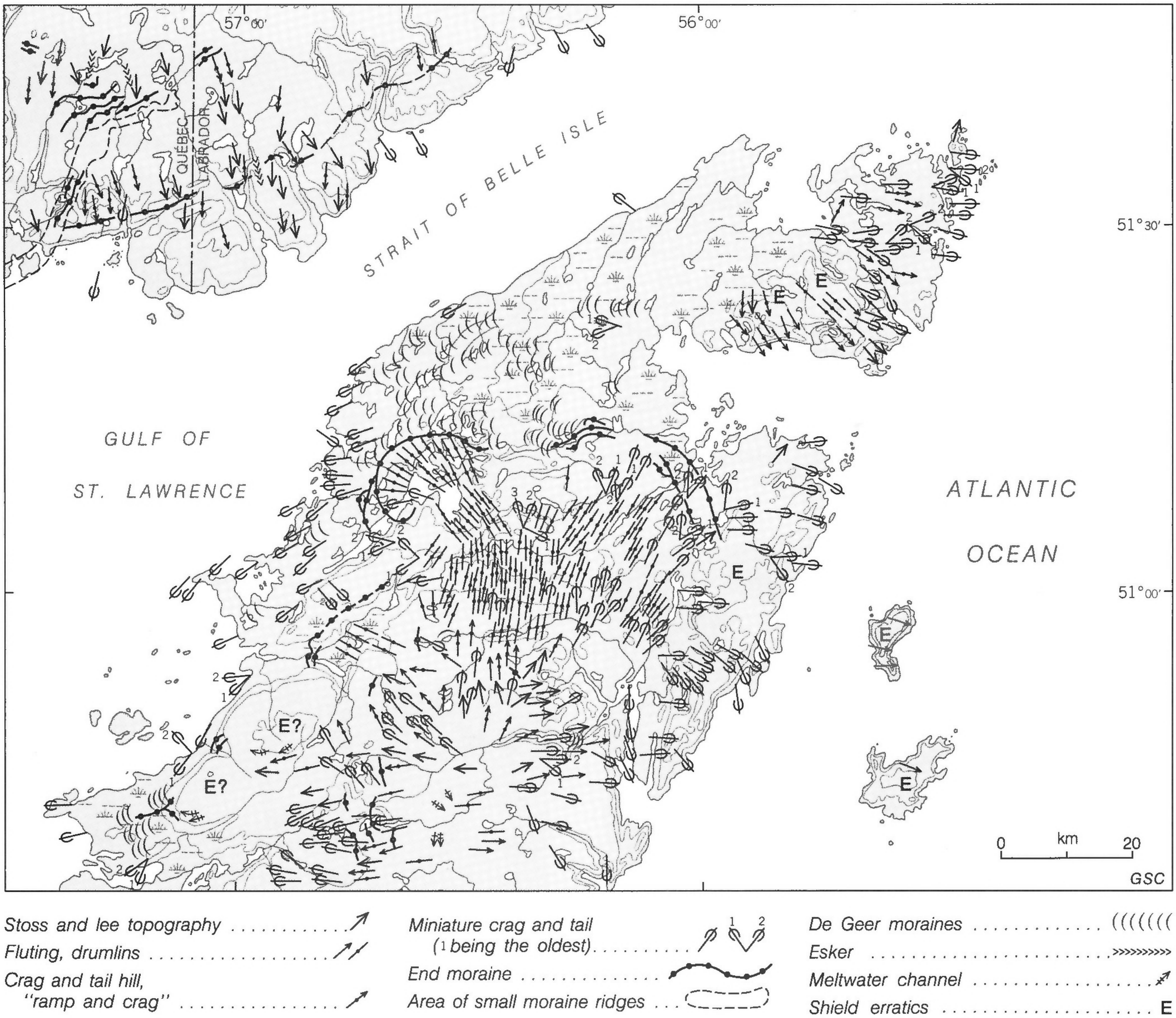


Figure 29. Indicators of ice-flow direction.

Transverse morainal features

In addition to the direct ice flow indications given by longitudinal features, transverse elements provide corroborative evidence. Marginal moraine ridges are invariably perpendicular to mapped ice flow, and their trend also delineates ice frontal shape. The trend of eskers and meltwater channels gives similar directional indications because they are generally directed down the regional hydraulic gradient that usually corresponds to glacier thickness which, in turn, drives ice flow.

In sum, these data are combined with the evidence from till deposits to deduce the sequence of ice flow phases detailed under Glacial Succession.

Glaciofluvial deposits and meltwater direction indicators

Sediments deposited by glacial meltwater are a minor surficial material partly because little debris was entrained in the ice (as reflected by the meagre till development), and partly because there was free drainage during general uphill retreat. They have little relation to present drainage and may occur on hilltops, valley sides, or beneath lakes. Nonetheless, the deposits are locally important for their commercial potential and as paleo-environmental indicators.

Glaciofluvial deposits

Glaciofluvial deposits are identified by their distinctive surface form, either as ridges and hummocks or as aggraded and channelled surfaces, which in turn are indicative of depositional environment. They thus reveal glacier flow and ice marginal position and reflect useful differences in thickness, grain size, and sorting. Lithology generally matches the associated till sheet and is a similar mixture of local and distant clasts. The groupings are crevasse fillings, kames, and outwash plains.

Crevasse fillings (3a)

The largest glaciofluvial deposit covers 25 km^2 in upper Castors River valley as a network of bouldery ridges 5-10 m high. They are situated behind the Leg Pond Moraine and are interpreted to be crevasse fillings that formed amidst a stagnant fragmented ice lobe.

Kames (3b)

Areas of gravelly hummocks and ridges (kames) occur mainly in Quebec-Labrador. At the north edge of the map area a large kame field forms a segment of the Belles Amours Moraine. In addition, small bouldery eskers lead up to the moraine and patches of gravel veneer, with low hummocks and shallow, dry, anastomosing channels, remain where till was washed by meltwater flowing amongst stagnant ice blocks.

Outwash plains (3c)

Sediment deosited in glacial rivers accumulated in relatively few valleys during ice retreat. Small outwash plains occur on the distal side of the Belles Amours Moraine and, although a few have kettles signifying rapid burial of glacier ice, most are smoothly graded plains that are present as short segments in rock gorges. Most lie 2-10 m above present stream level. The largest system, along Pinware River, comprises three inset terraces, each extending upstream to a kettled ice contact mass that marks a former ice front. On Northern Peninsula, much smaller deposits occur along Doctors Brook and Castors River.

Meltwater direction indicators

In the absence of ice flow features, landforms showing the discharge direction of meltwater give an equally meaningful indication of ice mass disposition during retreat. Proglacial channels, such as those in a bare-rock area in the northwest corner of the study area show that the Laurentide ice front swung around to a more east-west alignment after formation of the Belles Amours Moraine. Sidehill meltwater channels, such as those in the medial drift-covered area of Long Range Mountains, indicate that the last vestiges of the stagnant ice cap were located in upper Cloud River basin near the relict cirques.

Marine deposits and paleoshoreline indicators

Following glacial retreat much of the land area below the present 150 m contour was submerged by a marine inundation because the crust was glacioisostatically depressed. As relative sea level returned to its present position due to crustal rebound, various erosional and depositional processes modified the surface and produced a range of effects. The various sedimentary facies units, although not extensive, are locally important both as resources and hazards. They are therefore treated first. The deposits aspect is complemented by a related body of data in the form of a suite of erosional features that were produced at former shorelines, namely trimlines, washed zones, strandlines, benches, terraces, and platforms. In the absence of deposits, these define the exact initial extent of the submergence, as well as possible regressional stillstands and fluctuations. Where dated, directly or indirectly, shoreline features are used to reconstruct a history of relative sea level change for the ultimate purpose of understanding the root causes of the changes of level and then adapting that understanding to practical considerations pertaining to crustal movement and coastal evolution.

Marine deposits

At the former shoreline, erosion by wave action had different effects depending on substrate material and exposure. Where there was only a veneer of loose, bouldery, ablation debris over bedrock, it was washed away completely, leaving a stripped zone with a sharp upper boundary at the upper reach of the former sea, so-called marine limit. Where till was thick, wave action winnowed away the finer fraction and left a coarse, bouldery mantle usually about 1-2 m thick, which armoured the surface and prevented further erosion. Wave action thus removed thin drift and truncated thick drift.

The eroded material was deposited at depth depending on grain size. The gravel and sand fractions were laid down nearshore in proximity to the source and were redeposited at progressively lower levels during offlap. Hence, where the glacier discharged outwash directly at the former shoreline, gravelly ice contact deltas were built. Where drift cover is extensive, a coarse surface veneer has developed downslope. The finer fraction of silt and clay put in suspension at the shoreline, together with that discharged by meltwater streams, accumulated at greater depths. Thus, a mud blanket, found in lower areas usually about 100 m below marine limit, is thickest and most extensive in sheltered settings, near meltwater streams, and where subsequent erosion was ineffective. During regression the deep water mud commonly became buried by littoral deposits, so its true extent is probably much larger than its present outcrop expression. To both coarse and fine deposits, material was added from melting icebergs; ice-rafted clasts are a noticeable component of the deep water mud. Fossils of marine shells occur in all grades and are most common in those composed of carbonate debris, which buffers the leaching action of acidic groundwater; in granitic deposits, they are present only in the finer sediments where groundwater movement is presumably restricted.

Table 1. Fossils identified in emerged marine deposits, northern Newfoundland

Age (ka BP)	13				12						11							10								9						8	gap	5			3	2			1		0
<u>Pelecypoda</u>																																											
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				
<u>Gastropoda</u>																																									—		
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																																											
<u>Brachiopoda</u>																																											
Hemithyris psittacea				—								—			—	—														—													
Glaciarcula spitzbergensis										+																			—														
<u>Cirripeda</u>																																											
Balanus sp.												*							?												*												
Balanus cf. *crenatus*				*				*				?				*	*			*										*	?												
Balanus cf. *balanoides*								*							*	*																							*				
Balanus hameri												*																															
<u>Other</u>																																											
Bryozoans												*																									*				?		
? Echinoderm teeth																																					*						

— 0-15%
\+ 16-25%
x 26-40%

X 40%
* present but not included in calculation

The marine deposits represent a wide spectrum of depositional environments operating throughout postglacial time. Texture therefore varies from very coarse to very fine, and age ranges from glacial to modern. The map units have been chosen primarily to identify the main depositional facies because these carry distinctive attributes of texture. Secondary subdivisions are made on the basis of thickness. Thus, marine deposits consist not only of fine-grained deep water muds, both as a continuous blanket and as a discontinuous veneer, but also of the coarse nearshore and littoral sands and gravels, subdivided into a thin phase to show discontinuous beach veneers and a thick phase to show terraces and deltas. The finer facies is put first in the sequence partly because it includes some of the oldest deposits, but mainly because the coarse facies continued to form until the present.

Blanket of (glaciomarine?) stony mud (4a)

The fine grained sediment is massive and has about equal proportions of sand, silt and clay, which give it sticky plastic consistency. The fine texture indicates deposition in quiet, relatively deep water. It is medium grey and highly calcareous, showing that the matrix was derived locally by winnowing of tills from the extensive carbonate terranes. In addition, abundant ice-rafted clasts, mainly of crystalline rocks and ranging from grit to boulders, show that most of the rainout fraction was contributed by calving Laurentide glaciers.

The stony mud blanket is rarely found above 30 m elevation and usually below 15 m. Exposures are numerous along Salmon River valley and, because the mud commonly has a gravel veneer, it may be more extensive under younger marine units. Sizeable deposits are inferred along the southern Hare Bay coast and in front of Leg Pond Moraine. Smaller pockets occur in rocky terrain southeast of Pistolet Bay, at St. Anthony, in the vicinity of Plum Point, and along the shore of Canada Bay. In Quebec-Labrador only small occurrences were seen at Middle-Bay and under the lower terraces of Pinware River.

Mollusc fossils are abundant and typically include such deep water species as *Balanus hameri* (often attached to clasts) and *Hemithyris psittacea*. However, others of shallower water affinity and coarser facies, such as *Mya truncata* and *Mya pseudoarenaria* occur on and in the surface of the mud. They probably date from the later regression. Many other species are fragmented and have been broken either by the impact of ice-rafted clasts or by impinging icebergs, or have been washed down from higher levels. No detailed paleoecology has been done, but Robertson (1987) has identified the faunal assemblage in 56 samples from the project area and has noted that the initial low diversity arctic fauna dating from about 11 000 BP was replaced by more boreal species by 8000 BP (Table 1).

Dates on shells in mud range from 11 000 BP, when glaciers were still present, to about 7000 BP, long after deglaciation (Table 2, dates 9, 12, 25, 28, 29, 33). The dates correspond to the fall of sea level from 80 m to 20 m above present. Although none of the observed deposits can be directly related to an ice front (because little is known of deglacial chronology), at least some of the deposits around Long Range Mountains must be the product of turbid meltwater discharge. The bulk of this material, however, is presumed to be the sort of offshore, deep water sediment that is presently deposited in this area. It represents the accumulation of suspended sediment originating by littoral and fluvial erosion of pre-existing deposits, supplemented by a coarse fraction introduced by ice rafting.

Veneer of stony mud (4b)

Associated with the mud blanket is a veneer of stony pelite occurs either in patches interspersed with numerous rock and till mounds or as a thin sheet draped over rock and till. It commonly has a gravelly surface. Massive phases occur southeast of Pistolet Bay 15-50 m above sea level. As the elevation corresponds to that of the nearby mud blanket, it is regarded as simply a thinner lateral equivalent. Elsewhere the material is poorly stratified, with sand and gravel interbeds as in Salmon River valley. This facies likely represents shallower water conditions when bottom currents operated. As it laps onto adjacent deposits of mud blanket, it may be partly reconstituted from them. Age of included shells range over the same interval, 11 000 - 7000 BP. Hence, except for its lesser thickness and lack of areal continuity, the mud veneer and the mud blanket could be combined for practical purposes.

Thick gravel beaches, terraces, and deltas (4c)

As stated, coarse sediment was deposited at or near the former marine shoreline as it receded from 150 m to its present level. Although the range of thickness and extent is great, it is useful to distinguish between miscellaneous thin or discontinuous gravelly veneers, which may result from a variety of unspecified conditions, and those thick deposits which, apart from their greater resource potential, may give important paleoenvironmental indications. Accordingly, the class of large thick gravel deposits includes former deltas, some of them ice marginal, and complexes of beach ridges, the flat relief of which indicates deep cover over rock or till. The latter type is found usually either in the vicinity of bulky source deposits, such as outwash fans and end moraines, or at lower elevations where it represents the combined product of a lengthy offlap process. Where no adjacent source exists, the thick beach deposits imply that they have been generated in situ by reworking of an underlying source.

The largest emerged marine gravel deposits occur in Quebec-Labrador. A major body of raised beaches composed of granite boulders forms two large headlands (Fig. 22) that represent a mass of reworked outwash deposited along the submarine extension of the Belles Amours Moraine. Other large terraced masses mark ice marginal deltas formed along the littoral margin of the Bradore Moraine, such as northeast of Bradore Bay, at the head of Forteau Valley and inland of Pinware Bay. Large aprons mantle the slopes of Forteau Tablelands and seem to be the product of downslope accumulation of reworked glacial debris and direct erosion of

Table 2. Radiocarbon ages relating to deglaciation and sea level change

Site No.[1]	Age (^{14}C years BP)[2]	Laboratory number[3]	Elevation(m)[4] (error, ±m)[5]	Material[6]	Location[7]	$^{12}C/^{13}C$ correction[8] ‰	Reference
1	12 800 ± 150	BGS-1080	130 ?	Intact pelecypod shells in sand, in till	"Bowaters Road"[9] 50°18.8'N 57°25.5'W	-	Proudfoot and St. Croix (1987)
2	12 600 ± 160	GSC-1600	115* (±5)	**Mytilus edulis** in beach gravel	Flat Pond[9] 52°24.03'N 57°16.15'W	-	Lowdon et al. (1977)
3	12 400 ± 360	GSC-1485	106 (±5)	**Hiatella arctica** whole valves in sand	"Zinc Lake[9]" 50°17.15'N 57°28.05'W	-	Lowdon et al. (1977)
4	12 000 ± 170	GSC-1601	90 (±10)	**Mya truncata** whole valves in gravel veneer	Eastern Blue Pond[9] 50°27.83'N 57°10.80'W	-	Lowdon et al. (1977)
5	12 000 ± 160	GSC-1605	85 (±10)	**Mya truncata** in growth position in beach gravel	River of Ponds[9] 51°31.00'N 57°13.20'W	-	Lowdon et al. (1977)
6	11 000 ± 180	GSC-2919	75 (1)	**Mya truncata**	Bustard Cove[9] 50°42.86'N 57°11.61'W	-	Blake (1983)
7	11 000 ± 160	GSC-1324	60* (±7)	**Balanus** spp. in till of Ten Mile Lake Moraine	Ten Mile Lake 51°04.87'N 56°42.63'W	-	Lowdon et al. (1971)
8	10 900 ± 160	GSC-1277	60* (±7)	**Mya truncata** in till of Ten Mile Moraine	"[10]	+1.7	Lowdon et al. (1971)
9	10 900 ± 140	GSC-2825	9 (±1)	**Mya truncata** fragments in deep water silts	Pinware River 51°31.53'N 56°43.80'W	+1.5	Lowdon and Blake (1979)
10	10 800 ± 110	GSC-3316	24 (±1)	**Mya truncata** fragments on till	Croque 51°03.36'N 55°50.78'W	+1.4	Blake (1983)
11	10 700 ± 170	GSC-1334	60 (±2)	**Astarte crenata** intact valves in silty sand below beach gravel	St. Anthony 51°22.28'N 55°37.35'W	-	Lowdon and Blake (1973)
12	10 500 ± 150	GSC-1343	17 (±1)	**Mya truncata** intact in stony pelite[10]	Quirpon 51°28.58'N 55°36.71'W	-	Lowdon and Blake (1973)
13	10 400 ± 120	GSC-4175	85 ?	**Mya arenaria** intact in stony pelite[10]	Forteau 51°29.30'N 56°58.60'W	-	Unpublished (D.G. Vanderveer, personal communication 1986)
14	10 300 ± 120	GSC-4283	163 ?	**basal gyttja;** beyond Bradore Moraine, above marine limit	"Isabelle Lake" 51°44.77'N 56°30.59'W	-25.0	Unpublished (T.W. Anderson, personal communication 1987)
15	10 100 ± 160	GSC-1270	60* (±7)	**Mya truncata** whole valves in beach gravel	Ten Mile Lake 51°03.85'N 56°45.00'W	+2.6	Lowdon et al. (1971)

1. Refer to Fig. 43.
2. Based on a half life of 5568 ± 30 years. Additional data on sample preparation and analysis can be found in Geological Survey Radiocarbon Date Lists XIII and XVII (Lowdon and Blake, 1973.
3. GSC = Geological Survey of Canada
   BGS = Brock University Department of Geological Sciences, St. Catharines, Ontario.
   T = Trondheim University, Norway
   I = Isotopes Inc., Westwood, New Jersey, U.S.A.
   SI = Smithsonian Institution, Washington D.C., U.S.A.
4. All elevations are related to modern high tide and were determined by repeated observation with aneroid altimeter, except those marked with an asterisk (*) which are interpolated from topographic maps with 50 foot contours with a standard accuracy of ±25 feet.
5. An estimate combining instrumental reproducibility and uncertainty of datum.
6. All materials are marine shells in marine beach or other marine formations, except otherwise noted.
7. Exact locations are plotted on Map 1610A; informal names are given in quotation marks; note that, where possible, coordinates are specified to 0.01 minute.
8. This correction for isotopic fractionation, relative to the PDB standard, is based on "normal" value of 0.0‰ for marine carbonate. The date given includes the correction.
9. This site is located just outside the map area but has been included because it is necessary for interpretation.
10. Ditto marks indicate that the age has been determined by another laboratory on the same material, or by the GSC laboratory on different material at the same site.
11. Stony pelite is sublittoral offshore mud containing ice-rafted clasts; relationship to corresponding sea level is indeterminate.

Table 2 (cont'd.)

Site No.[1]	Age (^{14}C years BP)[2]	Laboratory number[3]	Elevation(m)[4] (error, ±m)[5]	Material[6]	Location[7]	$^{12}C/^{13}C$ correction[8] ‰	Reference
16	9 861 ± 76	BGS-53	60* (±5)	**Mya truncata** in gravel veneer over end moraine	"Ten Mile Crossing" 51°02.98'N 56°46.70'W	-	Unpublished
17	9 820 ± 110	SI-3137	98 ?	Basal gyttja in lake basin	"Whitney Gulch" 51°30.10'N 57°18.31'W	-	Lamb, 1980
18	9 600 ± 90	GSC-3328	48 1	**Mya truncata** whole valves in situ, in beach ridge	Tom Roses Pond 51°07.64'N 55°58.50'W	+1.2	Blake (1983)
19	9 190 ± 150	GSC-1312	50 5	**Mya truncata** in growth position in beach bar over stony pelite[1]	Southwest Brook 51°04.48'N 56°05.36'W	-	Lowdon and Blake (1973)
20	9 035 ± 73	BGS-54	45 3	**Mya truncata** whole valves in gravel veneer	Main Brook 51°10.95'N 56°09.10'W	-	Unpublished
21	9 000 ± 80	GSC-3998	34 (1)	**Mytilus edulis** in mussel bank	Port Saunders[9] 50°39.00'N 57°17.38'W	-	Blake (1986)
22	8 970 ± 120	GSC-4278	141 ?	Basal gyttja in kettle pond in Bradore Moraine	"Triangle Lake" 51°30.41'N 57°18.51'W	-	Unpublished T.W. Anderson, pers. comm.)
23	8 930 ± 80	GSC-3325	2 1	**Mya pseudoarenaria** whole valves in situ in offshore sand	Lac Salé de l'Est 51°26.9'N 57°41.6'W	+1.8	Blake (1983)
24	8 760 ± 150	GSC-1307	30 2	**Mesodesma deaur-atum** whole valves in sand	Pistolet Bay 51°32.47'N 55°58.12'W	-	Lowdon and Blake (1973)
25	8 572 ± 71	BGS-52	10.5 0.5	**Chlamys islandicus** fragments in stony pelite[1]	Blue Cove 51°06.30'N 56°51.68'W	-	Unpublished
26	8 560 ± 80	GSC-4323	18 (±1)	**Mya truncata uddevalensis** in gravel	Airport 51°22.7'N 56°05.7'W	+1.2	Blake (1988)
27	8 530 ± 150	GSC-1470	30* 5	**Mya truncata** in growth position in gravel bar	Main Brook 51°10.57'N 56°02.20'W	-	Lowdon et al. (1977)
28	8 400 ± 150	GSC-1472	15 1.0	**Venericardia borealis** in stony pelite[1]	Pistolet Bay 51°31.90'N 55°56.55'W	-	Lowdon et al. (1977)
29	7 472 ± 67	BGS-55	" "	**Astarte** sp. whole valves in stony pelite[1]	"[10]	-	Unpublished
30	8 300 ± 200	GSC-1768	7.6 0.5	**Mya pseudoarenaria**(?) fragments in sand veneer on gravel terrace	La Fontaine Point[9] 50°28.30'N 57°28.60'W	-	Lowdon et al. (1977)
31	8 100 ± 160	GSC-4276	129 ?	**Basal gyttja** in kettle pond in Belles Amours Moraine	"Three Lobe Lake" 51°29.38'N 57°23.49'W	-24.7	Unpublished (T.W. Anderson, pers. comm. 1986)
32	7 500 ± 150	T-501	32 1	Basal organic layers in pond	"West Saddle Hill Pond" 51°35.32'N 55°31.18'W	-	Henningsmoen (1977)
33	7 220 ± 120	I-8365	3 0.5	Fragments of several mollusc species in stony silt under sand terrace at 15 m elevation	Middle Bay 51°28.00'N 57°29.28'W	-	de Boutray and Hillaire-Marcel (1977)
34	7 000 ± 130	GSC-4253	112 ?	Basal gyttja in pond just below marine limit	Crémaillière Hill 51°21.05'N 55°37.10'W	-28.0	Unpublished T.W. Anderson (pers. comm. 1986)

Table 2 (cont'd.)

Site No.[1]	Age (^{14}C years BP)[2]	Laboratory number[3]	Elevation(m)[4] (error, ± m)[5]	Material[6]	Location[7]	$^{12}C/^{13}C$ correction[8] ‰	Reference
35	6 610 ± 150	T-532	20 1	Basal organic layers in rock basin lake	"Skin Pond" 51°35.2'N 55°32.3'W	-	Henningsmoen (1977)
36	6 420 ± 130	T-502	52 1	Basal organic layers in shallow pond in peatland	"Ship Cove Pond" 51°35.18'N 55°40.70'W	-	Henningsmoen (1977)
37	5 680 ± 120	T-816	20 1	Basal organic layers in shallow pond on marine mud	"Mosquito Pond" 51°35.18'N 55°38.15'W	-	Henningsmoen (1977)
38	5 320 ± 60	T-820	4.75 0.1	Fen peat at base of 1.75 m thick palsa	"Palsa bog" 51°35.75'N 55°32.00'W	-	Henningsmoen (1977)
39	4 690 130	GSC-1403	6.1 0.3	**Mya pseudoarenaria** in growth position in beach berm	Port au Choix[9] 50°42.45'N 57°21.58'W	-	Lowdon and Blake (1973)
40	3 110 ± 130	GSC-1318	4.5 0.3	**Mya arenaria(?)** in growth position	"[10]	+3.4	Lowdon and Blake (1973)
41	4 290 ± 110	I-3788	6.1	Charcoal in archeological site on raised beach	Port au Choix[9] 50°42.54'N 57°21.58'W		Tuck (1971)
42	3 410 ± 100	I-4677		Human bone in Maritime Archaic archeological site on raised beach	Port au Choix[9] 50°42.5'N 57°21.5'W		Tuck (1971)
43	3 230 ± 220	I-4380		Bark in Maritime Archaic archeological site on raised beach	Port au Choix[9] 50°42.5'N 57°21.5'W		Tuck (1971)
44	3 890 ± 110	T-500	3.90 0.1	Basal gyttja over silt in pond on marine terrace	"L'Anse aux Meadows Pond" 51°35.85'N 55°32.07'W	-	Henningsmoen (1977)
45	3 490 ± 130	GSC-1527	5.2 0.5	(?) **Lithothamnion** sp. calcareous algae in beach ridge	Big Brook 51°31.25'N 56°10.48'W	-3.8	Lowdon et al. (1977)
46	3 400 ± 220	GSC-2040	6.5 0.5	**Mytilus edulis** in growth position in sand beach ridge	Wild Bight 51°36.50'N 55°53.25'N	-	Lowdon et al. (1977)
47	3 200 ± 130	GSC-1552	4.5 0.5	**Thais lapillus** in beach gravel	Nameless Cove 51°18.76'N 53°43.48'N	+3.8	Lowdon et al. (1977)
48	3 189 ± 57	BGS-50	" "	"	"[10]	-	Unpublished
49	2 460 ± 70	GSC-4021	84 ?	Wood (modern; spurious; see GSC-4175)	Forteau 51°29.30'N 56°58.60'W	-25.5	Unpublished (D.G. Vanderveer, pers. comm. 1985)
50	2 500 ± 60	GSC-1987	2.5 0.1	Wooden artifact under peat bog on raised beach	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Blake (1988)
51	2 170 ± 130	GSC-2086	0.75 0.2	**Mytilus edulis** fragments in gravel beach ridge	L'Anse aux Meadows 51°35.89'N 55°32.20	-	Lowdon et al. (1977)
52	2 150 ± 60	GSC-2076	2.2 0.1	Driftwood under peat bog	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Kuc (1975); Mott (1975)
53	2 010 ± 100	T-906	3.90 (0.1)	Gyttja	L'Anse aux Meadows Pond 51°35.85'N 55°32.07'W	-	Henningsmoen (1977)

Table 2 (cont'd.)

Site No.[1]	Age (^{14}C years BP)[2]	Laboratory number[3]	Elevation(m)[4] (error, ± m)[5]	Material[6]	Location[7]	$^{12}C/^{13}C$ correction[8] ‰	Reference
54	1 960 ± 90	T-503	1.4 0.1	Basal gyttja over marine clay in rock basin	"Straitsview Pond" 51°35.15'N 55°29.90'W	-	Henningsmoen (1977)
55	1 810 ± 50	GSC-2048	2.1 0.1	Basal peat over beach gravel	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Kuc (1975); Mott (1975)
56	1 790 ± 130	GSC-1331	1.75 0.3	**Volsella** sp. intact valves in gravel beach ridge	Ice Point 51°13.66'N 56°47.06'W	+3.7	Lowdon and Blake (1973)
57	1 780 ± 280	GSC-2071	2.7 0.1	Top of basal peat under driftwood layer	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Kuc (1975); Mott (1975)
58	1 600 ± 60	GSC-2069	2.4 0.1	Driftwood under peat bog	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Kuc (1975); Mott (1975)
59	1 590 ± 50	GSC-2055	2.6 0.1	Rhizome peat under driftwood layer	L'Anse aux Meadows 51°35.75'N 55°32.10'W	-	Kuc (1975); Mott (1975)
60	1 590 ± 260	GSC-2057	4.5 0.5	**Mya arenaria** and **Thais lapillus** fragments in sand veneer on terrace gravel	Raleigh 51°33.15'N 55°44.75'W	-	Lowdon et al. (1977)
61	1 480 ± 100	T-533	5.5 m 0.5	Basal peat on marine terrace	L'Anse aux Meadows 51°35.75'N 55°32.10'W		Henningsmoen (1977)
62	1 470 ± 60	GSC-2088	2.2	Wood in peat over raised beach	L'Anse aux Meadows 51°35.75'N 55°32.10'W		Unpublished
63	1 340 ± 60	GSC-2059	3.0 0.1	Sedge peat over driftwood in bog	L'Anse aux Meadows 51°35.75'N 55°32.10'W		Kuc (1975); Mott (1975)
64	1 290 ± 80	T-819	3.90 (0.1)	Gyttja	"L'Anse aux Meadows Pond" 51°35.85'N 55°32.07'W		Henningsmoen (1977)
65	1 130 ± 70	T-324	5.0 0.1	Charcoal in Norse house (representa-tive of several)	L'Anse aux Meadows 51°35.75'N 55°32.10'W		Kuc (1975)
66	1 080 ± 80	I-8254	1.5 0.3	**Mytilus edulis** paired valves in sandy beach ridge	Raleigh 51°33.15'N 55°44.75'W	-	Unpublished
67	990 ± 130	GSC-1602	1.5 0.5	**Mytilus edulis** fragments in gravel beach ridge	Eddies Cove West 50°46.04'N 57°09.15'W	-	Lowdon et al. (1977)
68	940 ± 60	GSC-2136	2.8 0.3	**Mytilus edulis** fragments in gravel beach ridge	L'Anse aux Meadows 51°35.89'N 55°32.20'W	-	Lowdon et al. (1977)
69	840 ± 80	QU-1313	4-5 m	Peat cut rbyict frost polygons	Lourdes-de-Blanc-Sablon 51°26'W 57°12.5'N		Dionne (1983)
70	640 ± 50	GSC-2051	2.6 m 0.1	Log at top of drift-wood layer under rhizome peat	L'Anse aux Meadows 51°35.75'N 55°32.10'W		Kuc (1975); Mott (1975)
71	460 ± 80	T-905	6.2	Sphagnum peat over ice in palsa	"Palsa bog" 51°35.75'N 55°32.00'W		Henningsmoen (1977); Vorren (1972)
72	370 ± 80	I-8253	0.1 0.3	**Mytilus edulis** paired valves in sandy beach ridge	Raleigh 51°33.15'N 55°44.75'W	-	Unpublished

the friable sedimentary rock slopes. In the coastal parts of those deposits, sand forms a major fraction judging by the stabilized dunes and blowouts near Lourdes-de-Blanc-Sablon, L'Anse-au-Loup, L'Anse-au-Diable, and Pinware. As the deposits lie at lower elevation than do the gravel beaches in that area, perhaps the sediment was initially deposited in the sublittoral zone.

On Northern Peninsula, ice frontal gravel aprons are associated with the Leg Pond Moraine, the eastern arc of Ten Mile Lake Moraine, and the inferred morainal mass in Doctors Brook valley. Most of the others are clearly the result of local downslope accumulation, such as on Bell Island, at Conche and Crouse, on the west flank of White Hills, and as pocket beaches along Strait of Belle Isle. A few remaining deposits, strung between rock knolls around Sacred Bay and Pistolet Bay, suggest a buried source such as till or submarine outwash at an unrecognized ice margin.

Fossil shells, some in life position, are common in gravels formed from carbonate rocks. Radiocarbon dates on these range from 10 000 BP to the present and have been used to trace the course of changing relative sea level in the study area (Table 2, dates, 15, 16, 18, 19, 20, 21, 24, 27, 45, 46, 47, 51, 56, 66, 67, 72).

Gravel veneer and scattered beach ridges (4d)

In general, littoral sediment is thin and sparse, so the coarse marine sediment in the area occurs mainly in the form of isolated patches and small groups of beach berms. As stated, about half the area has been subjected to marine action, but, because the overburden is generally thin or absent, marine derivatives are even more restricted. The elevational upper limit of mappable beach veneers is about 10-15 m below local marine limit.

In Quebec-Labrador the gravel veneer occurs widely on the slopes of the Forteau Tablelands because ample source material is present at all levels. Lithology is mainly sedimentary rocks but the Precambrian component increases markedly within a few kilometres of the Shield margin, as it does in glacial drift. In Northern Peninsula, however, where sources are meagre, gravel veneer occurs mainly at lower levels where littoral action has operated longer. An almost continuous although narrow, belt of gravel along Strait of Belle Isle coast is almost wholly composed of carbonate rocks. Around Pistolet Bay and Hare Bay, coastal beach deposits occur farther inland and contain a large proportion of clastic and crystalline rocks. Raised beach deposits are relatively rare around Canada Bay, except perhaps in major Long Range valleys.

Like the associated thicker deposits, gravel veneer and scattered beaches have both scientific value as a source of data on changing sea level and economic value as granular resources. To date the major potential of both aspects has been exploited.

Indicators of former shoreline position

Past sea levels can be recognized by former shorelines, which, in the study area, take the form of erosional features such as washing limits, trimlines, fossil cliffs, platforms, and benches, as well as by depositional features, such as aggradation levels and beach berms. The uppermost level of submergence, or marine limit, is uniquely registered in the extensive rocky terrain as the upper limit of rock surfaces that have been washed clean of ablation debris by wave action. The washing limit is visible even on airphotos where boulders are sufficiently plentiful that there is a tonal contrast with bare bedrock, as on the Shield and the White Hills – St. Anthony area. Where the drift forms a till sheet, as on Bell Island, the stripped zone is clearly visible (Fig. 16). Marine limit is also registered as a trimline where wave action has truncated morainic topography. The marine-washed bouldery lag forms a smoothly graded apron that is sharply delimited against the unmodified till surface above, as on the Bradore Moraine (Fig. 30). Platforms and benches backed by fossil cliffs are developed locally because of exposure, rock type, and duration of sea level stand. On Quirpon Island at the northernmost extremity of Northern Peninsula, marine limit is registered at 133 m as a bench cut in bedrock on the north summit (Fig. 31) presumably because it was an isolated

Figure 30. Marine limit trimline at 130 m cuts the proximal side of the Bradore Moraine; unmodified till surface remains above trimline; wave-planed, boulder lag surface is below. (GSC 203284-T)

Figure 31. Small cliff marking marine limit encircles north summit of Quirpon Island at 133 m and is coincident with lower limit of unmodified drift, represented in foreground by Shield erratic. First recognized as marine limit by Daly (1921). (GSC 204024)

pinnacle exposed to the open Atlantic Ocean in all directions. It matches the lower limit of unmodified till on other hills and was first reported by Daly (1921). A prominent fossil cliff and bench occur at an intermediate elevation between marine limit and present sea level. It is well developed at 75 m on several hills around Howe Harbour on the north side of Hare Bay (Fig. 32, 33), and elsewhere on the Coastal Uplands near St. Anthony and Conche. A similar platform at about 80 m is reported by de Boutray and Hillaire-Marcel (1977) on the Forteau Tablelands, where it may be confused with the stepped slopes on the Cambrian strata.

A few metres above present tide level around most of the coast, a prominent dead cliff is either cut in bedrock (Fig. 34) or forms a terrace scarp in raised marine deposits. Although its age is not precisely fixed, the feature is judged to indicate a recent interruption in the general regression.

Aggradation levels such as deltas and terraces are depositional surfaces that have been graded up to a former water plane where there was sufficient sediment and/or time to establish an equilibrium surface. In places, the Bradore Moraine is an ice contact delta built up to a level that coincides exactly with the 145 m marine limit determined by the lower limit of perched boulders (Fig. 35). Similarly, the Belles Amours Moraine is locally a delta plain aggraded to the local marine limit at 130 m (Fig. 36). Other marine limit deltas at have been mentioned in connection with the Leg Pond Moraine and Doctors Moraine. Below marine limit, terraces are rare except near present sea level in areas of thick gravel. Along Pistolet Bay an extensive terrace at 8 m is fronted by scarp with its foot at 5 m. In L'Anse aux Meadows National Historic Park (Fig. 37), terraces occur at 16, 10.5, and 4 m, the latter being the site of nine Norse buildings, which date about 1000 AD. The lowest construction and erosional level is the modern intertidal platform, which truncates rock, till, and marine mud. It is commonly edged with a modern ice-push rampart (Fig. 38).

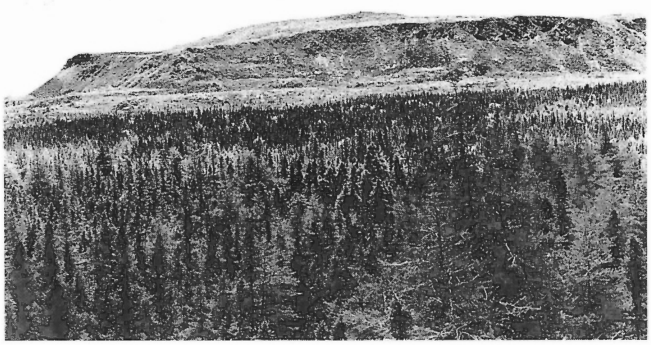


Figure 32. Mount Mer on northwest side of Hare Bay is ringed by a 55 m high rock cliff. Top of cliff at 130 m against unmodified till surface is marine limit; foot of cliff and cobble beach at 75 m is a prominent regressional level first noted by Cooper (1937). (GSC 204024-E)

Figure 33. Direction Mountain is encircled by a wave-cut rock bench at 75 m, which corresponds to 90 m marine limit on the Ten Mile Lake Moraine. (GSC 204024-D)

Figure 34. Dead cliff a few metres above tide level fronted by raised beaches, Maria Bay, L'Anse aux Meadows National Historic Park. (GSC 203284-G)

Figure 35. Wave-truncated sublittoral seaward face of Bradore Moraine extends up to 145 m marine limit marked by lower limit of perched erratics (on skyline). (GSC 188750)

Figure 36. Ice contact delta on Belles Amours Moraine is aggraded up to local 130 m marine limit marked by perched boulders. (GSC 188722)

Fluvial deposits

Mappable deposits of postglacial alluvium are relatively few largely because of the paucity of source material, and also because of the disorganized and youthful drainage. From both economic and paleoenvironmental points of view, it is useful to differentiate between the deposits of modern floodplains and those of former higher stream levels, which now appear as abandoned terraces.

Postglacial alluvial terraces (5a)

Terraces are the degradational remnants of formerly thicker fluvial deposits. Conditions for aggradation prevailed in relatively few rivers and only in rare reaches along them, primarily because of the minimal throughput of sediment. Incision followed as load decreased, perhaps because of afforestation and perhaps because base level was lowered during marine regression. The few alluvial terraces in Northern Peninsula are along rivers draining Long Range Mountains such as Beaver, Shoal, and Northwest brooks. They occur just below marine limit downstream from thick marine deposits where copious sediment was available. In Labrador, the largest set of terraces is a system along the Pinware River, which carried meltwater from a large area of the retreating Laurentide Ice Sheet for about 1000 years.

Figure 37. View of Norse archeological site circa 1000 AD situated on 4 m raised terrace, L'Anse aux Meadows National Historic Park. (GSC 203284-I)

Figure 38. Modern ice-push rampart composed of glacial boulders concentrated at edge of tidal bench, Baie des Belles Amours, Quebec. (GSC 188719)

Modern floodplains and deltas (5b)

At present, most watercourses transport little sediment. They flow either in rock gorges or in narrow, shallow meandering channels in till or marine sediment. Thus, floodplains are rare except where the stream gradient is flattened by rock or drift thresholds, and where infilling and aggradation occur. As sites of seasonal inundation, floodplains are easily recognized by their shrub or sedge vegetation, instead of trees. They are composed of sandy fine-to-medium gravel washed mainly from till and marine deposits.

Most alluviation therefore takes place where watercourses debouch into lakes and at the coast, where they deposit deltas. The largest mappable deltas, in order of size, are those of Pinware, Salmon, and Castors rivers; others occur around Canada Bay and Pistolet Bay.

Colluvial deposits and indicators of slope processes (6)

Colluvium is sediment that has collected at the foot of slopes, having been delivered by gravity processes such as by falling, sliding, or flowing. The latter two, although operating in the form of solifluction and cryoturbation on highlands surfaces, have not produced mappable accumulations. Yet there is an anomalous area of large solifluction lobes on till north of Three Brooks Pond, at the base of White Hills. As the till is composed of ultrabasic rocks that inhibit vegetation, perhaps the movement has resulted from a combination of fine texture, steep slope, and waterlogging.

Otherwise, the main class of colluvial deposits is rock rubble that has accumulated as talus or scree in fans and aprons at the foot of failing rock cliffs. In Labrador, the only such colluvial slopes are along coastal headlands of the Forteau Tablelands where exposure and deepwater promote active erosion. Similarly, on Northern Peninsula the only example (although too small to map) is also on Cambrian terrane inland along the western faultline scarp of Highlands of St. John where frost action is degrading the glacially oversteepened, fractured rocks (Fig. 7). Otherwise the Atlantic coastal cliffs, though higher, are glacially rounded and evidently are stable despite the exposure and deep water.

In contrast, Grey Islands have precipitous cliffs that are retreating as a narrow submarine platform widens (Fig. 16). The talus is forested, though clearly in metastable equilibrium as waves undercut the base and avalanches replenish the deposit from above. If the exposure and the rock types are considered comparable to those on the adjacent Coastal Uplands shore, then the development of the Grey Islands cliffs might be explained as the product of greater age, given that they have not been glacially abraded by the last glaciation to affect Northern Peninsula.

Slope processes

Gravity-induced movement of material on slopes is indicated by stone stripes, as on Highlands of St. John, solifluction lines, as on Bell Island, and solifluction lobes, as at the foot of White Hills.

In a few places along the Grey Islands' cliff line, an unusual colluvial process is operating. Best seen on the northern tip of Groais Island, several massive incipient block slumps each occupy an area of about 0.1 km. Gaping tension fissures more than 100 m inland of the edge define large, coherent units that are moving downward en masse by the process of deepseated gravitational creep. The shoulder of the plateau has in effect begun to sag, hence the term "sackung" has been applied in Europe where they are a common feature in rugged alpine terrain (Eisbacher and Clague, 1984, p. 19). There are many examples in western Newfoundland and Grant (1974a) has described the largest one, which has a volume of about $10^9 m^3$. It is not clear whether they are simply a normal, large-scale adjustment of oversteepened slopes, or whether they indicate some kind of internal stress that is being manifest only in certain rock terranes.

Organic deposits

Accumulations of vegetal matter exist under bogs, fens, and marshes of which mappable deposits cover about 5% of the area. This muskeg terrain has a variety of forms and a range of thicknesses depending on elevation and substrate, but differentiating each type was not within the scope of this study.

However, Wells and Pollett (1983) have classified peatlands in all areas of Newfoundland, so their results (Fig. 39) are adapted to this survey. The rocky basinal terrain of the Shield, Long Range Mountains, Coastal Uplands, Whitehills, and Grey Islands are characterized by innumerable small *basin bogs*, which are topographically confined and which are composed of mainly sphagnum peat in considerable thicknesses. The medial part of Long Range Mountains has more overburden and supports the *Atlantic ribbed fen*, which is recognized by its anastomosing grassy ridges oriented transverse to slope, and which is composed of a thin veneer of sedge peat. On the Interior Midlands, the blanket of till and marine sediment supports more and larger peat deposits in two forms, neither topographically controlled but rather expanding at the expense of forest. One, the *domed bog*, is an ombrotrophic (precipitation-fed) sphagnum deposit growing upward and, therefore, thicker than the other type, the *slope fen*, which is fed by nutrient-rich mineral water on a seepage slope and which rarely has more than 2 m of sedge peat.

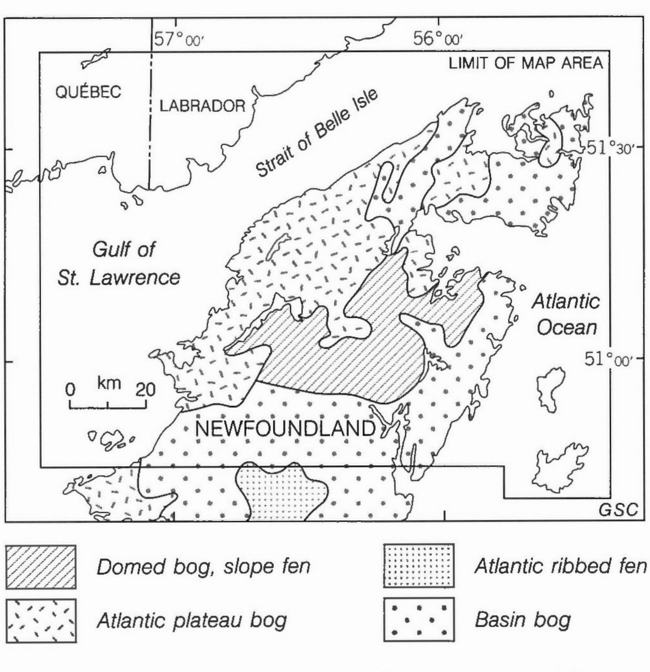


Figure 39. Distribution of peatland types (after Wells and Pollett, 1983, Fig. 3, p. 213).

In the Coastal Lowlands, where bedrock is level, relief is low, and groundwater is at or near the surface, the *Atlantic plateau* bog forms an irregular and extensive, but generally shallow, peat veneer (Fig. 40). The thickness of commonly less than 1 m becomes evident in an average summer when the pools dry up and the rock floor is exposed. Hence, despite the fact that these bogs cover almost half the area, their thickness is insufficient to meet the 1 m minimum to qualify as a map unit. Nonetheless, the distribution is shown roughly by the marsh symbols on the topographic base. Within all three peatland types, local development of ground ice creates variants termed palsa bog, peat mound bog, and polygonal peat plateau bog.

Ground ice

Though not a mapped surficial deposit, the presence of segregated ice bodies and icy sediments is noteworthy, not only because it represents one of the southernmost occurrences in Canada, but also because it affords further indication of the geomorphological effect of a modern climate that is essentially periglacial in character.

Frozen ground features occur in various materials and settings. Palsa mounds in peatlands with ice at 30 cm depth were reported in L'Anse aux Meadows National Historic Park, at the northern extremity of the map area by Henningsmoen (1977). Nearby on low gravel beaches around Sacred Bay, frost polygons are common (Fig. 41). Dionne (1983) reported similar polygons in the peat overlying raised

Figure 40. Aerial view of extensive organic terrain in L'Anse aux Meadows National Historic Park, composed of Atlantic plateau bogs, locally with palsa mounds. (GSC 203284-J)

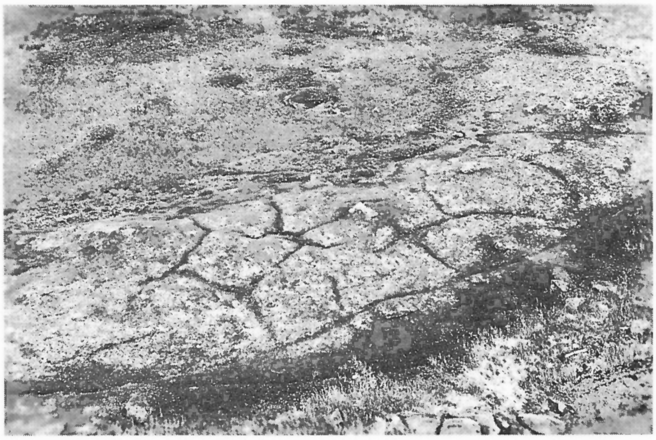


Figure 41. Ice-wedge polygons in peat on raised gravel beach; island in Sacred Bay, L'Anse aux Meadows National Historic Park. (GSC 203284-O)

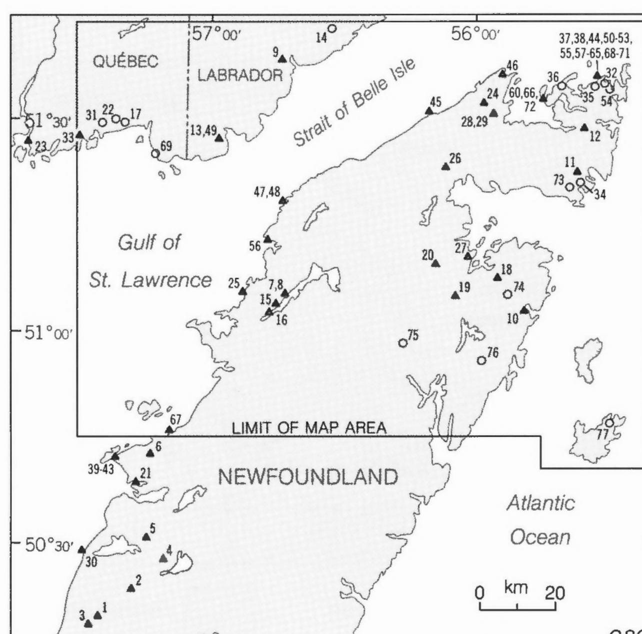
Figure 42. Sorted stone circles and mud boils in cryoturbated till and marine gravel, near mouth of Big Brook. (GSC 203284-B)

gravel beaches near Lourdes-de-Blanc-Sablon, although he found no ice and therefore considered them to be relicts of a former cold episode. Ice was found in these in late summer at depths of less than 1 m. Mud boils and stone circles are developing in till and marine sediment near sea level along Strait of Belle Isle (Fig. 42). Patterned ground has developed on the floors of borrow pits within two years. Polygons also occur on the highest summits in association with mud boils and stone circles. All these features indicate cryoturbation.

Frost action is to be expected in view of the near-freezing mean annual temperature of 1-2°C, the minimal snow cover, and the strong steady winter winds. But whether this climate implies permafrost is debatable. The area is just beyond the limit of sporadic, discontinuous permafrost in southern Labrador, as mapped from patterned fens and palsa mounds in peat terrain. The late R.J.E. Brown (personal communication, 1979) reported that upper-air temperatures in southwestern Newfoundland are low enough to induce permanently frozen ground at 750 m elevation. Theoretically then, the strait of Belle Isle area might have frozen ground at higher elevations, such as the summits of Highlands of St. John, if not also at lower elevations.

QUATERNARY HISTORY

The Quaternary history of this area is essentially a sequence of climatic changes manifest as glacial fluctuations. These in turn caused isostatic crustal deflections, which are expressed mainly as changes in relative sea level. Mapping has shown that all parts of the study area were overrun by glacier ice and that most of the area was submerged by former deglacial seas. The major events that are decipherable from the map information are a series of three main glaciations, of which the last had several secondary ice flow phases, and a general marine invasion and regression following the last glaciation. A sequence of glacial and marine stages has been reconstructed using data pertaining to: (1) the distribution and elevation of three glacial terrains of differing geomorphological stage ranging from youthful to mature; (2) ice movements associated with each as inferred from erosional and depositional indicators of ice flow direction such as striations and erratics; (3) end moraines of various sizes of which two mark important positions in ice retreat and one is a dated major readvance; and (4) shoreline features such as beaches and deltas, some of which are dated. As marine events result from deglaciation and continue to the present day, they are discussed after the glacial sequence.



Marine fossils ....▲ *Lake or bog sediment core ....o*

Figure 43. Location of radiocarbon dates.

Radiocarbon chronology

Absolute chronology is afforded by 72 radiocarbon age estimates on a variety of materials (Fig. 43, Table 2) of which 30 were acquired in connection with this study. The remainder derive from other studies on related aspects (Tuck, 1971; de Boutray and Hillaire-Marcel, 1977; Henningsmoen, 1977; Kuc, 1975; Mott, 1975; Lamb, 1980; Dionne, 1983; Proudfoot and St. Croix, 1987; T.W. Anderson, personal communication, 1986, 1987). Twenty-six dates are shown on Map 1610A; the rest are either of more recent vintage or are just outside the map area (within 50 km) and are cited because they are relevant and necessary for the interpretation. Not included are a large number on archeological materials from the Norse settlement at L'Anse aux Meadows circa 1000 BP, and from the Dorset sites on the Labrador coast (McGhee, 1976; McGhee and Tuck, 1975), which range less than 8000 BP. These are alluded to where relevant to geological history. The dated materials are in three main categories: marine fossils (41, of which 3 are in till); peat, wood, and lake sediment (27); archeological charcoal and so forth (4). The oldest date is less than 13 000 BP so the chronometric control pertains only to the last deglaciation and to the associated marine regression and climatic evolution.

The significance of the radiometric determinations depends on their validity, which is a function of laboratory dependability, contamination, and descrepancies resulting from isotopic fractionation. With respect to the laboratory factor, most were measured by the Geological Survey of Canada and are accepted as internally consistent. Dates from Brock University (BGS) agree closely with GSC replicates (47, 48 in Table 2, and elsewhere in the region). In one case, however, GSC and BGS dates from the same site (28, 29) differ by more than 1000 years. They were on different species in deep water mud, so the discrepancy could be either the result of differential isotopic fractionation or the result of a mixed population. Isotopes Inc. dates, though not cross-checked, are also accepted because they are in stratigraphic sequence at a single site (66, 72). The validity of shell dates, often questioned especially where carbonate terrain is involved, seems to present no cause for concern because they are nicely corroborated at Port au Choix (39-43) where charcoal from an archeological site on a raised beach is, as predicted by other data, just slightly younger than shells in the gravel substrate. In this connection it may also be noted that archeological dates similarly situated on raised beaches in Labrador (McGhee and Tuck, 1975) agree closely with the age of the associated sea level as inferred from shell dates. Moreover, gyttja dates from emerged freshwater basins (14, 17, 22, 31, 34) postdate the the time of deglaciation inferred from a sea level history based on shell dates. Although in some cases the difference is more than would be expected, it is possible that a depositional site might appear long before the first dateable organics could be deposited. Only at L'Anse aux Meadows is there a contradiction between the age of sea level based on shell versus freshwater dates. Still, most organics overlying raised beaches are younger than the shells. The problem may be simply that events of a few centuries duration cannot be resolved, given the inherent errors in counting and levelling. In sum, the dates seem internally consistent and are, therefore, used to establish the chronology of deglaciation and associated sea level recovery.

Glacial succession

The extent of three successive glaciations is recognized in terms of gross differences in geomorphological maturity and weathering products (Fig. 44). They are arranged in an elevational sequence on mountain sides. Figure 45 shows their vertical relationship in the type area by means of a profile across Northern Peninsula through Highlands of St. John. Note the westward slope as would be expected if they represent glaciation by an ice cap on Long Range Mountains. Indeed, the gradients of both trimlines is like the gradient of most outlet glaciers and not unlike the theoretical profile for large ice caps (Sugden and John, 1976, p. 65).

From highest to lowest, or from oldest to youngest, the first is characterized by moraine that has become flattened by solifluction and by rock that has broken down into blockfields or felsenmeer; the second has morainic topography that is noticeably subdued and bedrock that has disintegrated superficially to a fine gravelly debris or grus; the third is typified by fresh, high-relief, morainic topography and by sound, polished bedrock. For purposes of discussion, they are informally termed the "St. John Zone", the "Doctors Zone" and "Long Range Zone". Ages are estimated below.

Earliest glaciation ("St. John Zone")

The summits of Highlands of St. John preserve the most ancient glacial terrain. There are neither direct dates on the age of the glaciation nor pedological analyses of the glacial soil. Therefore, the terrain can only be assessed indirectly and qualitatively as to the duration of subaerial exposure since it was last overrun. One approach is the classical geomorphological test in which the depth of stream entrenchment is examined and compared with the depth of the same stream in the area uncovered since the last deglaciation. Given the same substrate and a uniform gradient, the volume of excavated material should be roughly proportional to the elapsed time.

Figure 46 shows variations in the depth and cross-sectional area of a valley, tributary to Castors River, that is cut in bedrock on the north side of North Summit. It is a relatively large gorge and represents a sizeable volume of rock, yet there is no sign of the debris as a cone or delta at the stream mouth. Therefore, it is reasonable to conclude that the upper, larger part of the valley was excavated prior to the last glaciation. The valley has three distinct segments, each corresponding to one of the mapped glacial terrains. The upper segment, cut in quartzite and corresponding to the vertical interval of the St. John Zone, is 100-150 m deep and about 750 m wide. In contrast, the lower segment, which is cut in dolomite in the Long Range Zone, is a mere 10-15 m deep and 100 m wide and represents the amount of incision

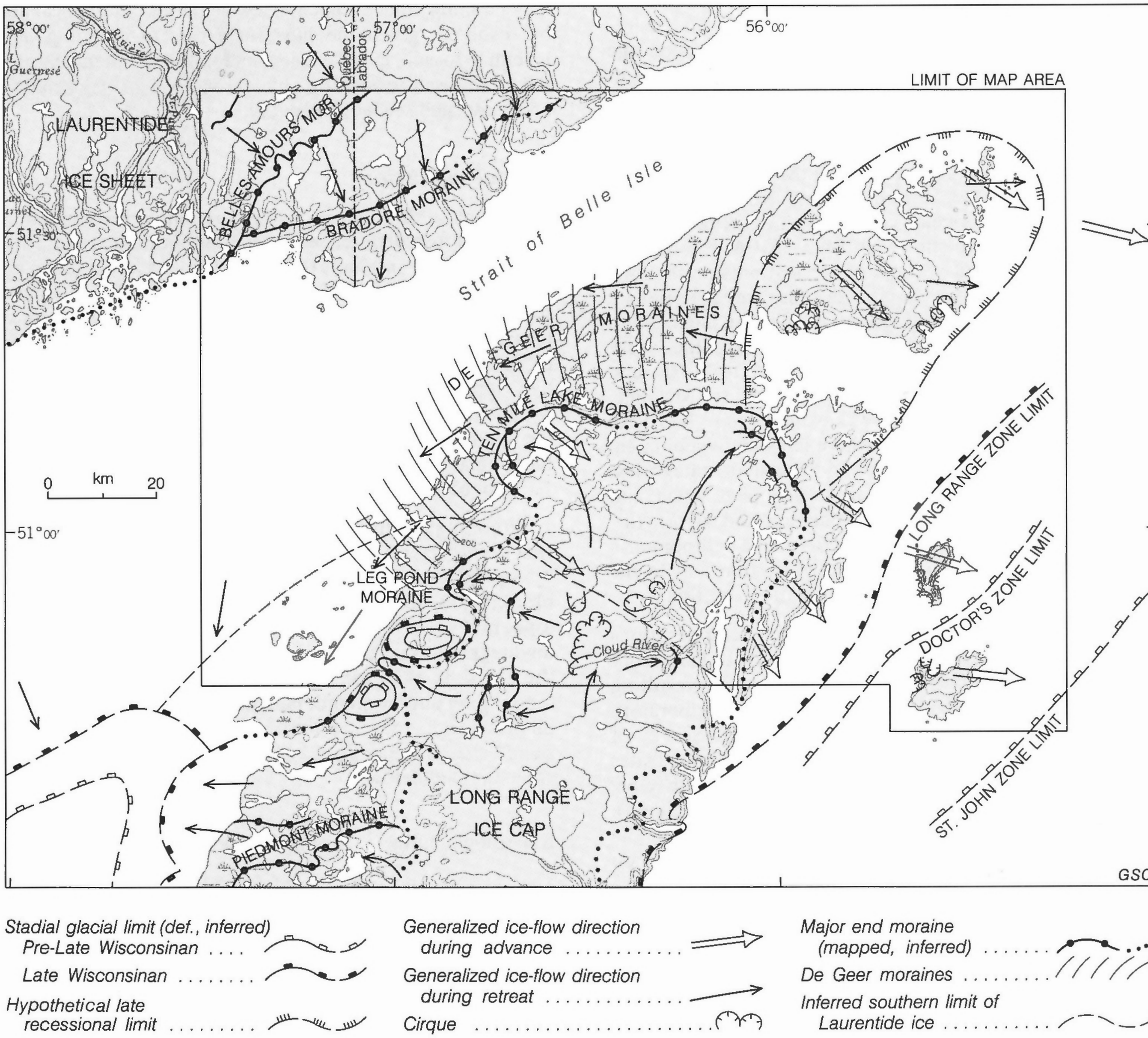


Figure 44. Extent of three major glaciations and configuration of six phases of Late Wisconsinan advance and retreat.

since deglaciation and marine regression in less than 10 000 years. Thus, the cross-sectional area of the St. John Zone segment is about 50 times the Holocene segment. The St. John Zone glacial terrain may therefore date from about 500 000 years ago.

This estimate is considered to be reasonable and perhaps conservative for three reasons. First, the rate of fluvial erosion is assumed to be constant with time, whereas it is more likely that the long-term rate has been slower than the Holocene nonglacial rate, because during much of Quaternary time under glacial conditions less surface water would have been present. Second, stream flow is assumed to be constant from headwater to mouth; in fact relatively less water would be operating in the upper reaches. Last, no correction is made for the greater resistance of quartzite compared to dolomite.

This age estimate for the area's greatest glaciation compares well with the results from independent studies. Alam et al. (1983) studied the rhythm of glacial input to deep sea sediments deposited on seamounts on the continental rise off Newfoundland, as reflected in the proportion of distinctive, red Carboniferous debris coming by glacial erosion from the Gulf of St. Lawrence area in the heart of the region. They found that the earliest maximal event occurred in oxygen isotope stage 12, about 440 000 years ago. If maximal erosion occurs during periods of greatest ice thickness, the St. John Zone can be tentatively correlated to stage 12, as Grant (1987, 1989) postulated.

The source of the glacier that overtopped Highlands of St. John and advanced into Atlantic Ocean beyond Bell Island can be judged from indicators of ice flow. Stoss and lee topography and crystalline erratics on Bell Island show that ice came from the northwest and crossed Northern Peninsula. Shield erratics on Highlands of St. John prove that it was an extension of the Laurentide Ice Sheet. It is the first event in the inferred succession of ice limits depicted in Figure 44.

Intermediate-age glaciation ("Doctors Zone")

At a slightly lower level, a second glacial terrain is recognized, which has a lesser geomorphological maturity in that rock basins and till knolls remain but are greatly subdued by mass wasting. By this qualitative assessment it would be intermediate in age between the ancient St. John Zone and the recent Long Range Zone. Referring to Figure 46, the valley segment in the Doctors Zone is about 50-60 m deep and at least 250 m wide. If the relative dissection yardstick were a valid measure of age, then the duration of subaerial exposure would be ten times the Holocene interval, or about 100 000 years. Thus, the Doctors Zone may represent either an Illinoian glaciation (oxygen isotope Stage 6) or perhaps a younger one, dating from Early Wisconsinan time.

Referring to the deep sea sediment record of Alam et al. (1983) for evidence of a second major pre-Wisconsinan glaciation, it is interesting to note again that they find Stage 6 to have been the next youngest maximal period of glacial erosion. There is, thus, independent support for the geomorphological age estimate of 100 000 years for the second oldest weathered glacial terrain.

The source of the glaciers that reached up to 500 m on Highlands of St. John and extended into Atlantic Ocean between Groais and Bell islands, can be inferred from ice flow indicators and from the slope of its upper limit. On

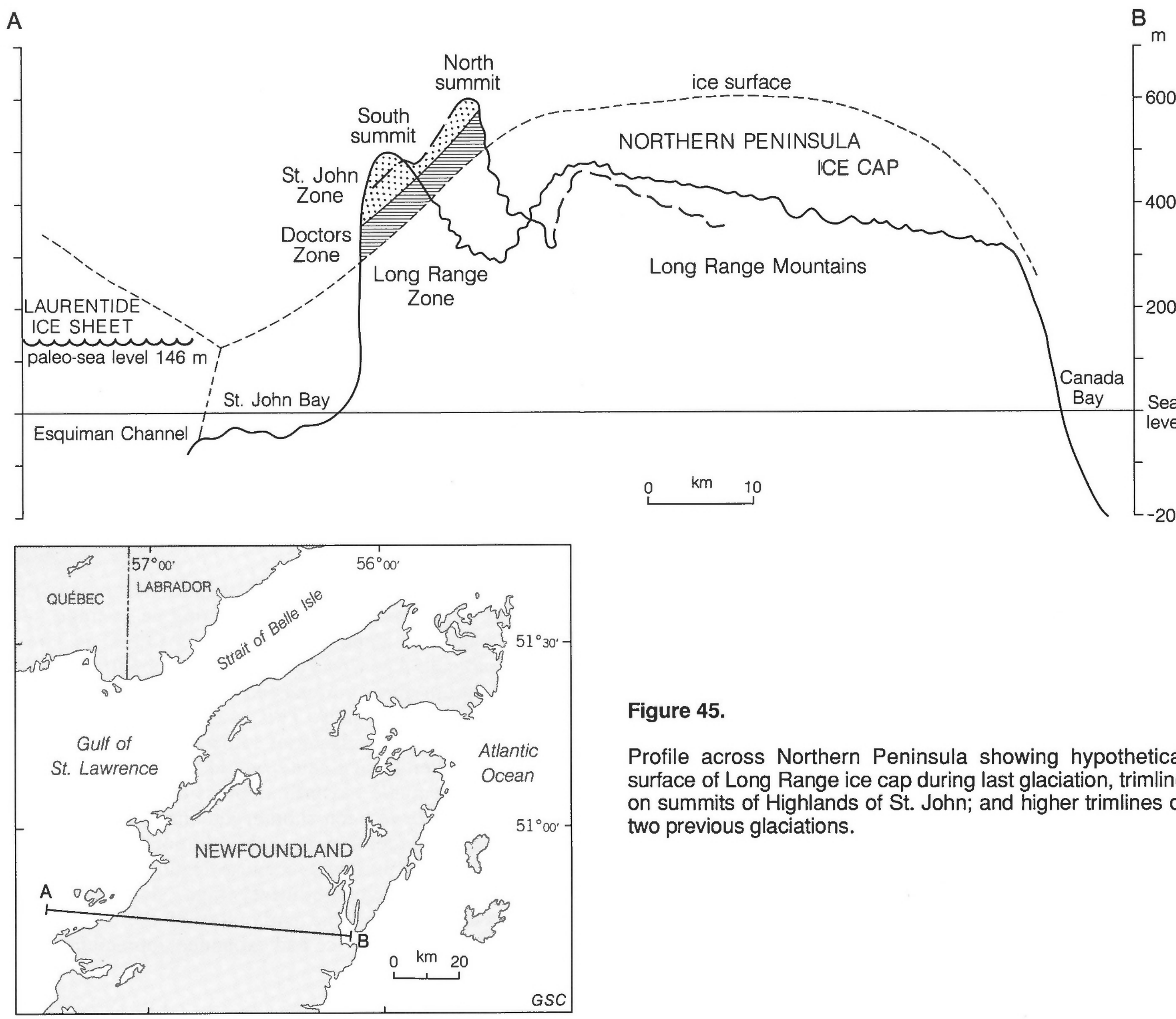


Figure 45.

Profile across Northern Peninsula showing hypothetical surface of Long Range ice cap during last glaciation, trimline on summits of Highlands of St. John; and higher trimlines of two previous glaciations.

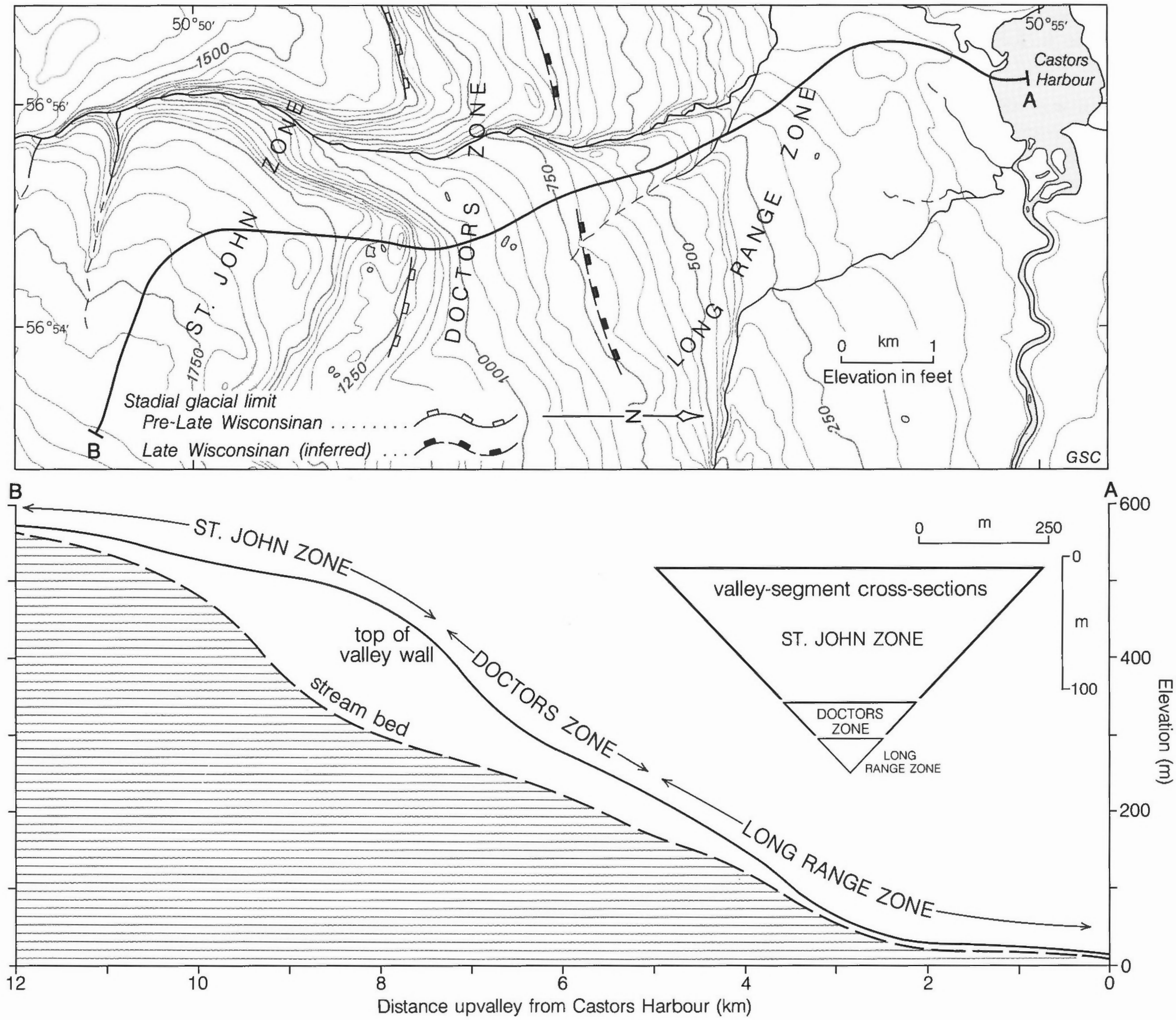


Figure 46. Map and profile of a stream on Highlands of St. John showing three segments with different depths of incision that correspond to three ages of glacial terrain.

Groais Island, crystalline erratics and east-trending stoss and lee topography show that ice came from the west in the direction of Northern Peninsula. The west-sloping trimline proves that an ice cap centred on Long Range Mountains was responsible.

Age of relict cirques

The overridden cirques on Northern Peninsula and the submerged cirques on Grey Islands were last occupied *after* the Doctors Zone glaciation because, on Bell Island, they are inset into that terrain, and they were cut *before* the last main advance (Long Range Zone) because they were eroded by it. If both drowned and overridden cirques belong to the same general period, they could only have been formed or occupied by ice when relative sea level was at least 40 m lower than at present. Not counting isostatic effects, if world sea level is lowered about 120 m during an average full glacial stage, the depths of the cirque floors on Grey Islands indicate that world glaciers were about one-third their maximum glacial dimensions during the period that ice occupied the cirques. This evidence suggests that they belong to a main glaciation rather than to a brief nival phase. Moreover, local glaciers would have been too small to effect appreciable isostatic depression, otherwise the cirques would have been submerged and unavailable as glacier sites. Hence, they probably do not date from the latter part of Illinoian time, because deglacial relative sea level would have been prohibitively high. More likely they were occupied during the early part of the Wisconsin glaciation, before local ice had expanded appreciably.

Late Wisconsinan or last glaciation ("Long Range Zone")

As stated, the most youthful glacial terrain, which covers most of the map area, is characterized by virtually unmodified rock and till surfaces. Exposed scoured bedrock retains fine striations and polish. Even on gneisses, which are the most susceptible to granular disintegration, relief of grains and quartz veins is only a few millimetres. Morainic landforms commonly have angle-of-repose slopes and soil depths of only a few decimetres. The age of this glaciation can be reasonably referred to Late Wisconsinan time, 25 000-10 000 BP, because not only the recessional and readvance moraines, but also the deglacial marine sediment and the postglacial lacustrine and paludal sediment all give ages less than 11 000 BP. Indeed, throughout Newfoundland, no dates on features of the last glaciation are older than 15 000 BP. On this evidence, all the land portion of the study area was covered by Late Wisconsinan glaciers, except possibly for Grey Islands and the top of Highlands of St. John.

Within the limits of this last glaciation, several distinct ice flow patterns truncate and crosscut one another. Five successive advance and retreat phases are demonstrated.

Direction and sequence of glacier movements

Various areas have contrasting suites of ice flow trends and alignments of ice marginal deposits. In the absence of sedimentary successions to record the sequence of depositional events, the historical framework discussed is deduced from crosscutting glacial erosional markings from superimposed depositional till lineaments, and from the course of changes in relative sea level.

Figure 44 generalizes data shown on Map 1610A and mentioned in the text and depicts the inferred succession of ice dispersal phases. Indications of ice extent come from the limits of geomorphologically distinct terrains. Evidence of flow direction comes from directional striations, till lineaments, and the transport of erratics. Evidence of ice-frontal configuration during advance or retreat comes from end moraines and meltwater channels. The sequence began with a regional ice flood which, during its waning stages, became reorganized into more local dispersal centres that experienced four moraine-building episodes.

Glacial phases

Regional ice flood (White Hills phase). Crosscutting striations and the topographical position of certain ice flow indicators show that the first movement was generally southeastward (140-160°). The first glaciers evidently crossed Coastal Uplands and White Hills, leaving a strongly stossed landscape. The latter summits above 250 m have distinctive erratics of western provenance, such as amphibolite and pink granite from Labrador and black slate from Pistolet Bay, which prove that Laurentide ice was responsible. Striations with the same trend are found above 150 m on Mount St. Margaret but were not seen on Long Range Mountains above 300 m, which suggests that a Longe Range ice cap prevented incursion above that level.

The outer limit of the ice sheet at this stage is undefined, but some inferences can be drawn from the relation of the ice flow trends to major relief features. The fact that the glacier moved uniformly and obliquely across the steep coast of Hare Bay and Atlantic Ocean, where the relief exceeds 300 m, suggests a regional ice flood that terminated well offshore, at least in the St. Anthony area. The more southward trend on the uplands east of Canada Bay suggest drawdown into White Bay basin and help to explain why Grey Islands were not reached at this stage.

Confluence of Laurentide and Newfoundland ice domains (Belle Isle phase). At a somewhat later stage, the ice sheet evidently underwent a partial reorganization because, along Strait of Belle Isle, the area between Laurentide and Newfoundland ice domains has striations that trend only southwestward. This direction is at right angles to both the southward flow of Laurentide ice and the northward flow of Newfoundland ice. It apparently represents a resultant direction by confluence of the two ice domains. Thus, in the southwestern corner of the map area all ice flow seems to have converged toward the head of Esquiman Channel, which implies that the 300 m deep channel was a calving bay that continually drained ice from that area.

Hence, the southern limit of Laurentide ice in Goldthwait Sea (Gulf of St. Lawrence area) is shown as a calving margin along the north side of Esquiman Channel where also Shearer (1973, p. 295) inferred an ice marginal stand based on thick till deposits in 70-90 m depths. From there, the hypothetical line of division between Laurentide and Newfoundland ice is shown on Figure 44 extending from the head of Esquiman Channel, through St. John Bay and across Northern Peninsula toward Canada Bay, the apparent limit of the Laurentide flow trend. South of the line only flow trends attributable to a Long Range ice cap occur.

Similarly, the western margin of the Newfoundland ice cap in Goldthwait Sea (Gulf of St. Lawrence) is assumed to have terminated along the eastern margin of the channel. In that area the Long Range glacier was divided into confluent streams by the St. John Highlands nunataks. One of the resultant interlobate or medial moraines trails westward from South Summit toward Port au Choix (Fig. 44).

This interval is termed the Belle Isle Phase after the marine area into which most of the combined ice sheets were evidently being drawn.

Recession to upland ice centres (Hare Bay phase). Ultimately glacial vigour waned and a pronounced episode of shrinkage began, as shown by a more topographically controlled ice flow direction and by series of recessional moraines. On the Atlantic coast a second set of striations, which cut across the southeastward set, trend directly coastward, rather than obliquely, down the regional slope at 070°-110°. This direction implies that the eastern ice front was becoming realigned, if not actually retreating.

Meanwhile, a major change was occurring in the west. The Goldthwait Sea expanded preferentially eastward from Esquiman Channel across Coastal Lowland to Hare Bay. The hundreds of eastward-concave De Geer moraines indicate the extent and pattern of retreat and demonstrate that marine water (Goldthwait Sea) was in contact with the ice sheet in this area and effectively separated the two ice domains. Laurentide ice presumably receded to a more stable position along the north slope of Strait of Belle Isle, while Newfoundland ice emerged as a separate entity. The retreat pattern shows that Northern Peninsula ice was reduced to two masses. One was the Long Range ice cap and the other was a remnant mass apparently covering Hare Bay and presumably anchored by White Hills and northern Coastal Uplands. The only evidence of ice emanating from the White Hills area, other than west-pointing striations on the lowlands, is a dispersal train of White Hills ultrabasic rocks spread westward across Highway 430 at the head of Hare Bay. Disjunct marine limits along northern Hare Bay show that relative sea level stood at about 130 m by the time the shrinkage stopped.

If the moraines were formed annually their number indicates that more than one-third of the glacier cover disappeared during the short span of 400 years. In this time, Belle Isle was deglaciated and the ice disposition changed completely. The reason for the sudden and rapid change from advance to retreat is assumed to be that most of the ice sheet was either marine based or grounded below sea level. Furthermore, because high relative sea levels caused by glacioisostatic crustal depression occur after the ice reaches its fullest extent, sea level will likely be rising during the beginning of thinning and retreat. Thus, the marine-based portion of the ice mass would be inherently unstable because ultimately a point would be reached at which the margin would become buoyant.

De Geer moraines were formed during the transition period as the ice sheet re-established a more stable configuration during the calving process. In effect, the glacier ceased to be marine based and became localized as land-based ice masses. This interval is termed the Hare Bay phase to signal the unexpected appearance of a remnant ice mass centred over that area. No direct date marks the beginning or end of the phase of De Geer moraine building, except that it occurred prior to 11 000 BP, the oldest date on marine sediment in the deglaciated area.

Stabilization of Laurentide and Newfoundland ice masses (Bradore/Piedmont phase). Absence of De Geer moraines east of the head of Hare Bay suggests an abrupt cessation of retreat of the remnant ice body anchored over White Hills, although no moraine marks the stillstand. In Quebec-Labrador, and in western Newfoundland south of the study area, large end moraines do signify a changed regimen. The Bradore Moraine marks a Laurentide ice margin when the flow trend was nearly southward. Situated essentially at marine limit, it reflects an equilibrium between marine invasion and extent of ice. Concordance between marine limits on the moraine and those registered beyond and behind the moraine signifies that retreat to the moraine position was rapid and was then followed by a stillstand while the sea regressed.

In contrast, the Belles Amours Moraine was built by Laurentide ice flowing southeastward. It cuts off the Bradore Moraine, crosses marine limit, and has a submarine extension. It thus signifies a resurgence into Goldthwait Sea by ice coming from a new outflow centre. It truncates the Bradore Moraine and therefore must be younger but, because marine limit on it is only 10 m lower, the age difference is slight. In fact, the rate of sea level change at that time (discussed later) suggests that only about 200 years elapsed between the two. The angle of divergence between the two moraines, although large, gives a separation of only 15 km, which would correspond to a retreat interval of less than 100 years if the average rate of calving of 250 m/a applies. On the other hand, the separation might not necessarily represent any ice-frontal retreat if the separation zone were actually occupied by a belt of dead ice and if the Belles Amours Moraine marked the margin of active ice. In any case, both moraines show that after the interval of widespread retreat Laurentide ice stabilized and possibly readvanced.

Neither moraine is dated directly, but the age can be estimated from two lines of evidence. Low-level regressional marine sediment at mouth of Pinware River, well beyond the Bradore Moraine dates 10 900 ± 140 BP (9 in Table 2). Postglacial lake-bottom gyttja an Whitney Gulch just beyond the Bradore Moraine dates 9820 BP (17). The base of the sequence is estimated at 11 000 BP (H.H. Lamb, personal communication, 1984) and the lake is 50 m below marine limit. The moraines, therefore, probably formed before 12 000 BP. On the west coast of Northern Peninsula, just south of the map area, large end moraines, the Piedmont Moraines (Fig. 44), were built by Long Range ice. Their age is bracketed to between 12 800 BP (1), based on shells reworked into till (Proudfoot and St. Croix, 1987), and 12 000-12 600 BP (2-5 in Table 2), based on shells deposited after retreat from the moraines (Grant, 1972b). The accordant marine limits on the Piedmont Moraines and on the Bradore and Belles Amours moraines invite correlation.

If the moraines are indeed linked by the 12 600 BP shoreline, its slope harmonizes with all others (see Fig. 48), whereas the correlation to the 11 000 year old Ten Mile Lake Moraine originally proposed by Grant (1969a) would require a shoreline tilted four times the slope of the others and would thus violate the progressive upwarp scheme.

Readvance of the Long Range ice cap (Ten Mile Lake phase). Laurentide ice had presumably retreated outside the study area after formation of the Belles Amours Moraine. Long Range ice, however, was still fairly extensive because the next event was a significant expansion that produced the Ten Mile Lake Moraine. It marks the limit of a readvance from the highlands onto the Coastal Lowlands. The marine sediment, which forms the bulk of the sediment in the moraine, shows that the ice advanced into Goldthwait Sea. Dates on the included marine shells are 10 900 ± 160 and 11 000 ± 160 BP (7, 8 in Table 2). Inasmuch as the shell masses and some of the shells themselves are intact, the marine sediment is considered to have been ploughed up right at the ice margin and not to have been transported any significant distance. An age of 11 000 BP is therefore assigned to the culmination of the readvance. Sea level at the time or moraine building was between 80 m, the elevation of strandlines cut into the distal slope (Fig. 23), and 90 m, the elevation at which the hummocky moraine surface is noticeably smoothed. A lower limit on the moraine age is 10 100 BP (15) from shells beyond it at 60 m. No marine sediment is found inside the moraine above 75 m. These relations indicate that about 11 000 BP ice from Long Range Mountains moved northward into a sea that stood 80 m higher than at present.

The history of shorelevel displacement, as detailed later, helps support the age estimated for the culmination of the readvance and further suggests that the stillstand was brief. Marine limit on the Ten Mile Lake Moraine is 80-90 m, or about 60-70 m below its level on the Bradore Moraine. If the latter is correctly dated at 12 600 BP, an 11 000 year date for the Ten Mile Lake Moraine agrees with the date on sea level at that time. Marine limit on the back of the moraine is 75 m, 15 m lower than on the front of the moraine. The difference would correspond to a few hundred years, so the moraine was abandoned shortly after 11 000 BP.

That the event was a real enlargement of the ice mass and not just a stabilization, is shown by the ploughed-up marine sediment and by the fact that the field of De Geer moraines is truncated and deeply embayed by the Ten Mile Lake Moraine lobe. This relationship suggests that the ice moved forward at least 20 km, although its pre-advance limit is unknown because the inner limit of overridden marine sediment is unknown. Thus, it is impossible to estimate how far inland the ice front was driven by the calving process of the previous phase. However, if Long Range ice stabilized at the 137 m local marine limit, as did Laurentide ice, then it might have been 30 km inland of the moraine position, or about at the position where the finely fluted terrain begins.

It is interesting to note that the shape of the end moraine appears to reflect the general structure of the Long Range ice cap. The moraine is in two arcs, and the reentrant seems to be an extension of the line of divergence between east- and west-trending ice flow indicators on the highlands.

The eastern limit of the readvance is not recognized on the Coastal Uplands, but the western flank is marked by the Leg Pond Moraine and the Doctors moraines in the valleys on either side of North Summit. Together, these three moraines document a major expansion of the Long Range ice cap. The event might have been a dynamic response to rapid calving, which would have oversteepened the ice profile and caused a surge. Alternatively, the advance was climatically induced. Its correspondence in age with a regional episode of cooling, discussed under sea level change points to the latter cause.

Final spasmodic retreat of the Long Range ice cap (Cloud River phase). After construction of the Ten Mile Lake Moraine, Long Range ice is presumed to have retreated into the highlands along the mapped ice flow trends. Striations and till lineaments behind each of the moraine arcs converge back onto the plateau. Thus, the ice shrank, not to the highest ground, which is located along the western edge, but to an ice divide located along the median line of the plateau in the general vicinity of the relict cirques. There broad, deep river basins presumably contained the remnant ice mass. The west side of the ice cap produced small end moraines in the headwaters of Cloud River, perhaps because ice flow was directed upslope. As well, diffuse belts of very bouldery terrain, shown on the map, may have similar meaning if they represent stagnant marginal zones. For the eastern flank of the ice cap, Waitt (1981) reported small arcuate end moraines in Cloud River valley, which he speculated might be about 8000-9000 BP. If correlative with the western moraines, they probably mark the penultimate stabilizations of the ice cap because both sets are within 10 km of the mapped ice divide.

After disappearance of the plateau glacier, small névé patches probably persisted on White Hills and Highlands of St. John. On North Summit a small moraine at the mouth of a large nivation hollow or shallow cirque might be very young, perhaps Little Ice Age or Neoglacial, because on airphotos it appears to have less lichen cover than the surrounding felsenmeer.

Sea level changes

Scattered deposits and features demonstrate that much of the area was submerged. Dates at various levels show that the former sea disappeared during a general regression back to present level. As the deposits represent only a small proportion of the area actually inundated, to understand the overall process in terms of the elevation and extent of the water level at any given time, it is necessary to reconstruct the changes of relative sea level by which the regression is defined. Only then is it possible to appreciate the factors that caused the process, whether they were real movements of sea level or of crustal position.

Extent and elevation of submergence

Marine limit configuration. The maximum extent of the former sea, as extrapolated from numerous marine limit determinations, is portrayed in Figure 47, together with later regressional phases and representative elevations. Marine limit is well defined from lengthy visible segments, along the Shield margin, on southern White Hills, and on Bell Island. On the mainly forested Coastal Uplands and slopes of Highlands of St. John, marine limit is inferred from isolated measurements. In general, the elevation rises northwestward across the area from 122-126 m on Bell Island to a maximum of 148 m in front of the Bradore Moraine, although it declines slightly northeastward along Strait of Belle Isle. Anomalously low values of 107-122 m occur on the north coast of Hare Bay in the area of an inferred remnant ice cap.

Later phases related to the Ten Mile Lake readvance are reconstructed from positions of moraines, together with some dates and elevations. Prior to the readvance the sea is assumed to have flooded inland along Castors and Salmon River valleys, up to 130 m level of local marine limit, except for the Canada Bay area where Long Range ice is assumed to have persisted owing to proximity to source. At the culmination of

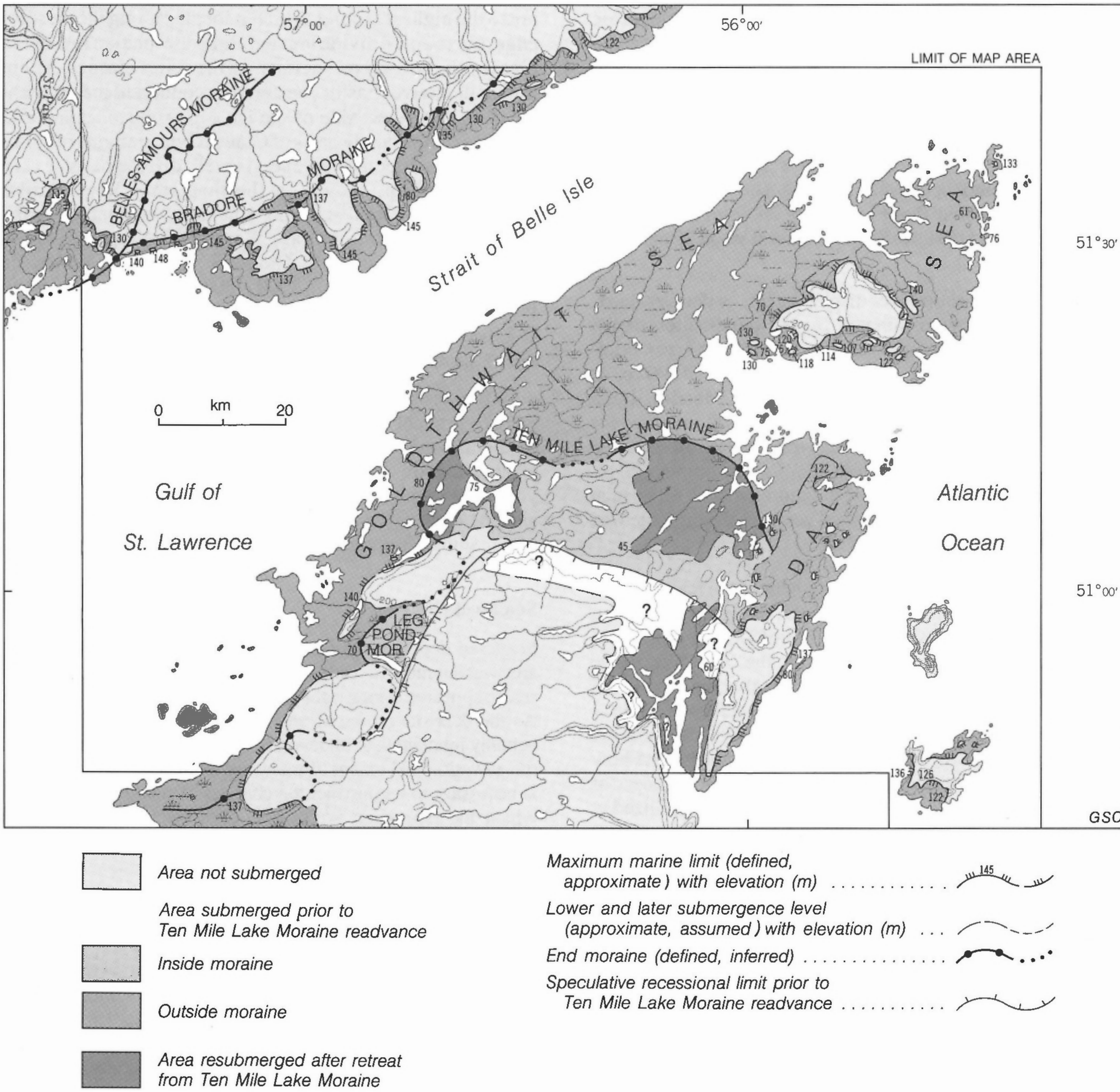


Figure 47. Extent of postglacial submergence of Goldthwait Sea and Daly Sea, showing marine limit, selected elevations, regression phases, and major moraines.

the readvance, the sea was at 90 m on the moraine, whereas at a distance from the ice front it stood slightly lower at 80 m on northern Strait of Belle Isle, 75 m on White Hills, 62 m at Conche, and 60 m on Grey Islands. Perhaps the reason for the differences was that these places were at some distance from the newly added ice mass where the geoidal effect on the water level by gravitational attraction would be much attenuated. After the glacier abandoned the moraine, the sea flooded in to progressively lower levels along the direction of ice retreat until, at its innermost reach, it stood at 45 m.

Shoreline relation diagram

The foregoing shows that the submergence reached different levels across the area and was time transgressive as the marine based part of the ice sheet disappeared. A shoreline relation diagram (Fig. 48) expresses the differential tilting and the relationship of changing sea levels to shrinking Laurentide and Newfoundland ice masses. On it are plotted the age and elevation of all sea level data from Table 2, projected onto a plane extending from the Bradore Moraine to Grey Islands, which is oriented southeastward parallel to the direction of

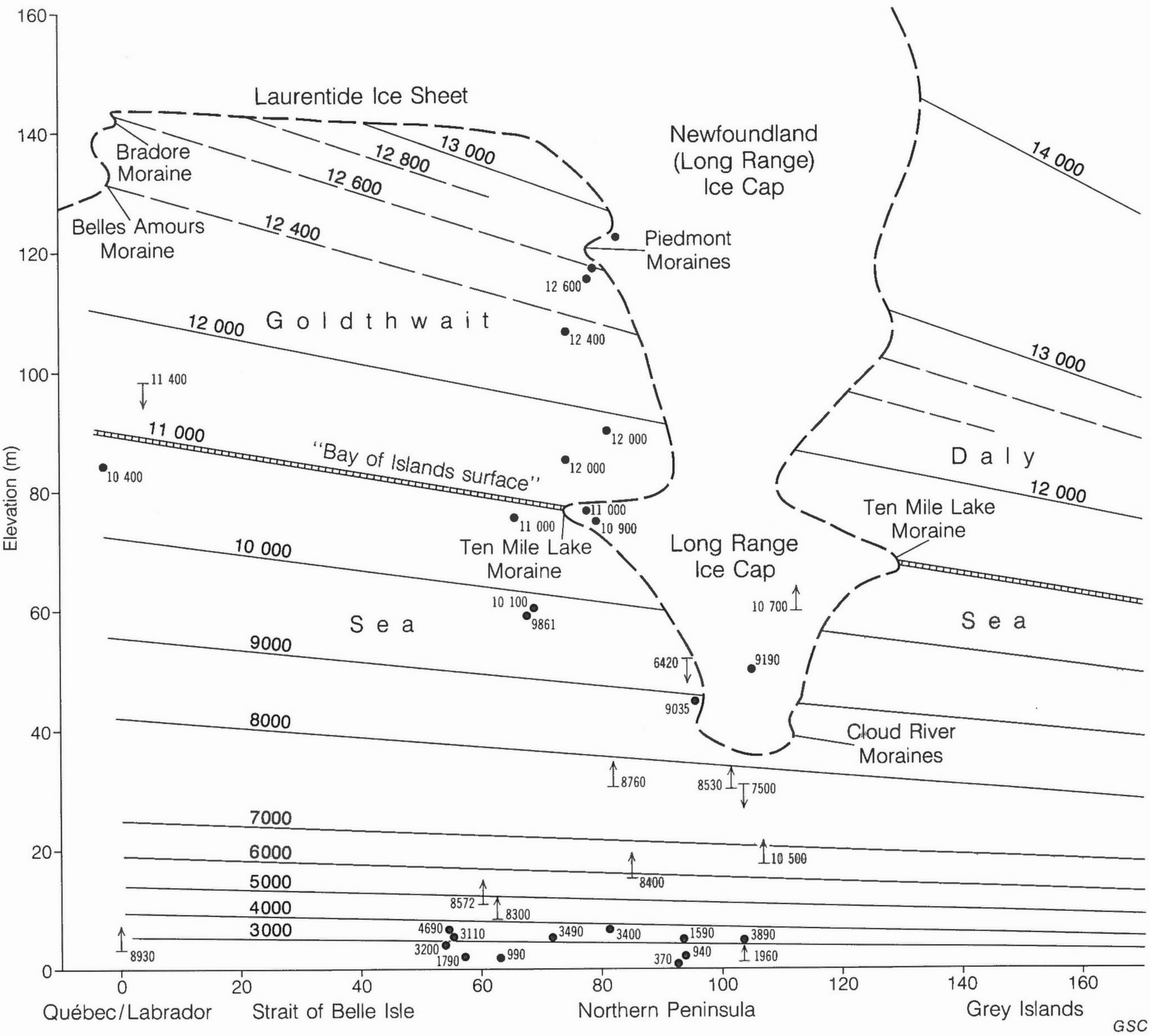


Figure 48. Shoreline relation diagram constructed along a line from Bradore Moraine, Quebec to Grey Islands, showing relation of hypothetical regressional levels to retreating Laurentide and Newfoundland ice masses.

maximum slope of marine limit. Both marine and freshwater dates are used and each has a different relationship to a hypothetical sea level. The dates are in three groups. Shells in life position in inferred beach deposits are assumed to date a paleosealevel and are shown by a dot. Deep water species or those in sublittoral mud are indicated by an arrow pointing upward to indicate that sea level was higher at that time. Conversely, freshwater dates are shown with a downward-pointing arrow to indicate that sea level was lower at that time. Hence, all dates serve to constrain a hypothetical scheme of gradual regression.

A series of hypothetical water planes at 1000 year intervals from 12 600 BP to the present is sketched that best fits the data. Superimposed is a conceptualisation of the separation and shrinkage of the two ice domains. Although no shoreline is dated at more than one point, no serious discrepancies or contradictions appear. The general pattern is an internally consistent series of delevelled water planes that are tilted up to the northwest in the direction of greatest ice load, as would be expected if the emergence were the product of glacioisostatic crustal rebound. In essence, the pattern shows that, in any interval, emergence was greater toward the north, and that the rate at any point decreased with time.

To begin with, the sequence is extrapolated to start at about 14 000 BP when the ice sheet stood near Grey Islands and sea level was at 136 m. About 13 000 BP, Goldthwait Sea invaded Strait of Belle Isle and separated the two ice sheets. At 12 600 BP, sea level is recorded at 115 m on the Piedmont Moraines (beyond the map area) and at 145 m on the supposedly correlative Bradore Moraine. Shortly after, at about 12 400 BP, the Belles Amours Moraine was trimmed off at 130 m. The next major event was the cutting of the rock bench corresponding to the climax of the Ten Mile Lake readvance at 11 000 BP. The broad development of this shoreline suggests a stillstand, if not a slight transgression, both of which might be explained as a geoidal effect by gravitational attraction and elevation of the sea surface by the sudden increase of glacier mass. Finally, glacier ice is shown disappearing from the area 8000-9000 BP and the assemblage of younger dates shows the continually decreasing rate of emergence. Sea level was below 10 m by 4000 BP. Thereafter it becomes difficult to resolve the pattern by this means. An alternative portrayal gives perspective on the actual rate of change of relative sea level with time.

Shorelevel displacement history

The data in Table 2 can be plotted as to elevation and age, irrespective of location, so as to show temporal variation in emergence rate (Fig. 49). As in Figure 48, the same convention is used for indicating the sea level affinity of each sample. The main reasons for the scatter of points is that some of the samples, like gyttja, originated far above sea level, and others far below – even some of those originally thought to be littoral. Excluding these gyttja and deep water shell dates, an envelope is sketched to outline the general trend of lowering sea level based essentially on beach deposits. The width of the envelope results partly from incorrect assignment of a sample to the beach environment, but mainly from the variations in sea level recovery within the area, just as Figure 48 reveals differential emergence.

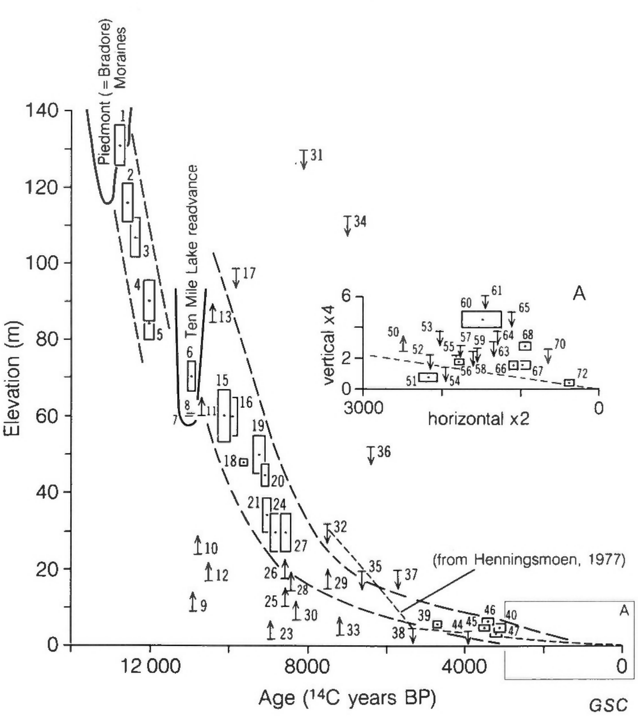


Figure 49. Shorelevel displacement curve for Strait of Belle Isle area, with earlier segment for area of Piedmont Moraines. Note Henningsmoen's (1977) curve (dashed line) based on the "isolation level" method.

The envelope of littoral dates shows a sea level recovery trend which has the familiar exponential form typical of isostatically rebounding areas that became ice free rapidly and late in the deglacial hemicycle. There are two trends before and after 8000 BP. The first phase began 12 800 BP in the western coastal lowland area with a rate of 4.3 m/century. That part of the curve clearly pertains to the area of the Piedmont Moraines and lies parallel to, but lower than, the trend for Strait of Belle Isle area. It is included to show the early part of the process and to demonstrate the effect of location. The record shows that sea level recovery in the map area per se began 11 000 BP with a rate of 2.5 m/century, which, in the first 3000 years, averaged 1.7 m/century until an abrupt change at 8000 BP.

Since 5000 BP, the average rate has been much slower at 0.14 m/century, but this figure is somewhat misleading as the actual trend is unclear. There is a contradiction between shell dates, which show a higher sea level, and freshwater sediment dates, which point to lower levels. The assemblage at L'Anse aux Meadows, shown in the inset on Figure 49, illustrates the point. Shells in beach ridges suggest that sea level was 1-2 m above present about 1000 BP yet peat overlying the raised beaches seems to indicate that sea level was below that position since at least 2000 BP. This interpretation is supported by Henningsmoen's (1977) curve (the dotted line on Fig. 49) for the Norse site, which comes from basal gyttja dates in emerged basins (the "isolation level" method). As there is more reason to accept the wood, peat, and gyttja ages, it is assumed that interpretation of the shells is in error and that they may have been deposited in storm beaches well above actual tide level.

From this curve an estimate can be made of the age of certain prominent low-level terraces, benches, and cliffs. In the L'Anse aux Meadows area, terraces at 16 m, 10.5 m, and 4 m would be about 7000, 6000, and 3500 years old, respectively. The low dead cliff a few metres above tide level, so extensive in western Newfoundland, unfortunately is not dated directly. However, beach ridges that lie at about the same level and seem to be extensions of the cliff line in depositional areas, give dates of about 3500 BP at Big Brook and Wild Cove. Raised beaches in front of the cliff, and at lower levels, give ages of 2000 BP and younger. The dead cliff is, therefore, estimated at 3000-2000 BP and is attributed to a small transgression, which is thought to be the only means by which the necessary erosion could be accomplished. The postulated rise of sea level could not in any case be registered by a beach-shell chronology.

The present rate and direction of sea level change is unclear. The trend of the past two millenia points to little if any change. The fact that 1000-2000 year old raised beaches are being truncated by the modern shoreline suggests that the general fall of sea has virtually ceased, if not actually reversed in recent time. Boulder barricades (Fig. 34) may indicate that sea level is now virtually stable or even rising. However, if the fossil cliff and terraces reflect nonsystematic fluctuations superimposed on the general regression, then the generalized curve in Figure 49 would not be a sound basis for interpreting small-scale events. The general and specific aspects of the local sea level chronology are put in a regional context in the next section on correlations.

DISCUSSION AND CORRELATIONS

The findings of this study generally support the Quaternary historical framework being developed for the Atlantic Provinces region. Certain aspects constitute key evidence bearing on the controversy about glacial age and extent. By the same token, inferences developed elsewhere lend credence to some of the propositions made herein. Although many uncertainties and even some outright contradictions remain, most interpretations parallel the results of similar studies elsewhere in Newfoundland and Nova Scotia and have been incorporated in regional syntheses.

Glacial features and sequence of events

Some individual features can be linked to comparable features in adjacent areas, and the general sequence as well as some of the separate events postulated for this area parallel findings elsewhere in Newfoundland and beyond. By the same token, results from other areas and from related studies in other disciplines, where for example chronometric control is better, lend confidence to the scheme presented here.

Threefold morphostratigraphic zonation

First, the tripartite sequence of major glaciations based on major differences in terrain maturity corresponds to that recognized in other highland areas along the eastern margin of the Laurentide Ice Sheet. Most important, this study confirms the reality of the weathered terrains initially reported by Fernald (1911), and described by Coleman (1926). Moreover, it reveals a parallel development to the

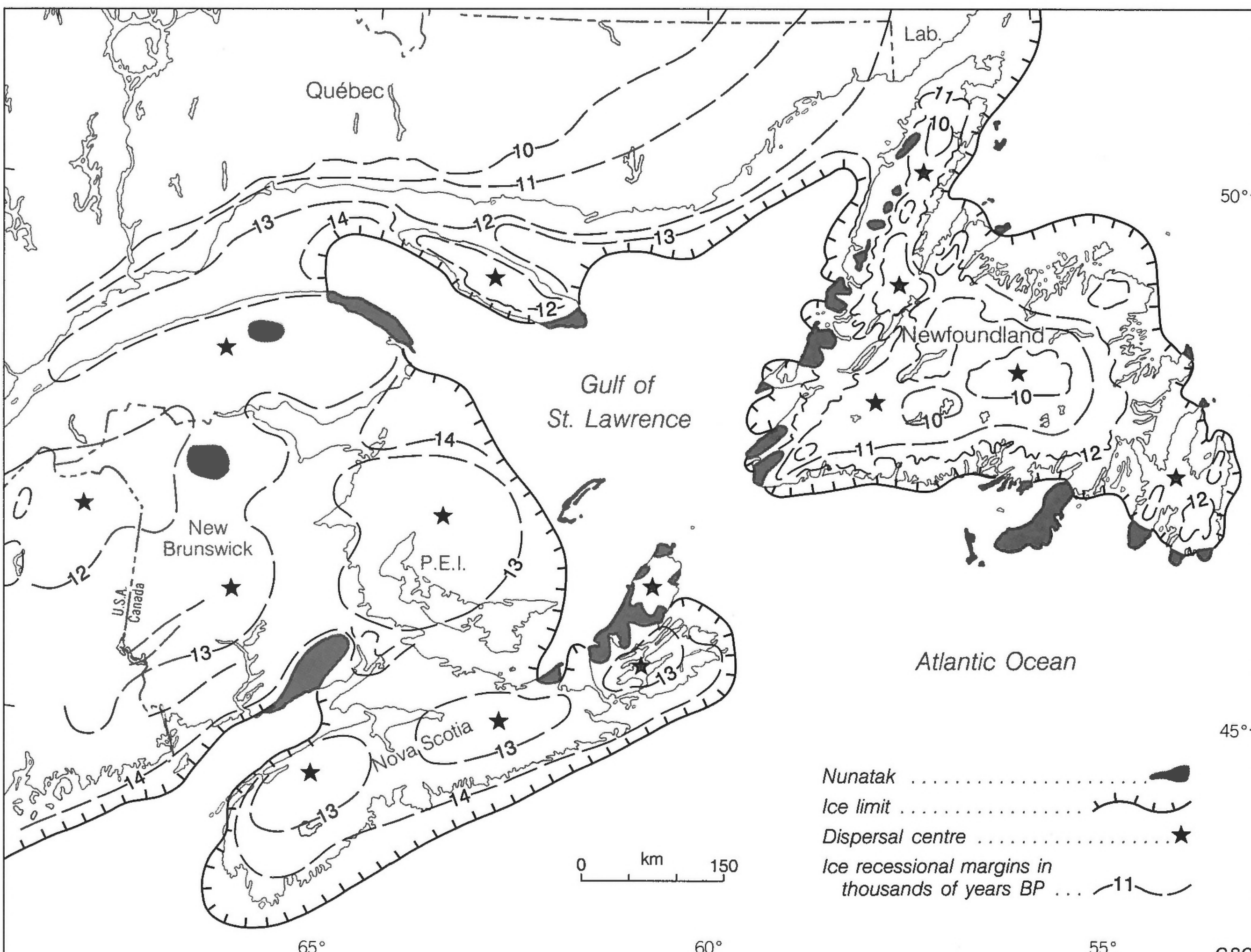


Figure 50. Hypothetical limit of the Late Wisconsinan glacier complex in the Atlantic Provinces region (from Grant, 1987).

zonation first delineated by Grant (1977b) in the Bonne Bay area of western Newfoundland. There, the three terrains are equally distinctive whether the rock type is quartzite, gneiss, or peridotite. Similarly, Brookes (1977b) portrayed an apparently comparable sequence in the Codroy area of southwestern Newfoundland where he also confirmed an additional summit zone that had no evidence of glaciation, as Coleman (1926) reported. Thus it seems that, over a wide area of western Newfoundland, three main glaciations can be discerned in terms of the degree of slope degradation. The lowest and most youthful glacial terrain represents the area covered by Late Wisconsinan glaciers, and the highest of the four may never have been glaciated.

This three- or four-fold zonation resembles sequences elsewhere in eastern Canada. For Shick Shock Mountains of Gaspésie, Coleman (1922) described comparable contrasts, but no modern work has mapped or evaluated the terrains. David and Lebuis (1985) postulated several glacial events there, but all are assumed to be Late Wisconsinan, and the degraded summit terrains are seen as older surfaces preserved beneath a recent, protective, cold-based ice sheet. For Torngat Mountains of northern Labrador, the four glacial terrains described by Ives (1958, 1975) are remarkably similar to those in Newfoundland. It is generally accepted that the Labrador zones represent successive glaciations, and recent work onshore and offshore is building a chronology. The lowest and freshest, Saglek Zone, is dated to the late Wisconsinan maximum about 18 000 BP. The middle or Koroksoak Zone predates 40 000 BP and has the incipient felsenmeer that is characteristic of the Doctors Zone. Baffin Island, where the term "weathering zone" was coined, has the best dating control (Boyer and Pheasant, 1974; Dyke et al., 1982). There the youngest terrain represents the maximal Wisconsinan advance; the oldest is estimated to be more than 600 000 years old and has mature felsenmeer like the St. John Zone. Hence, the tripartite, morphostratigraphic division of glacial terrains in Newfoundland is broadly matched in other areas over a wide range of latitude, and the age estimates are not inconsistent.

Late Wisconsinan maximal extent

The outer glacier limit in the Strait of Belle Isle area is postulated to lie just offshore; this concept accords with the regional model developed from other areas (Fig. 50). The hypothetical margin, portrayed as generally following the Gulf of St. Lawrence and Atlantic coasts of Nova Scotia and Newfoundland (Grant, 1977a), is becoming supported where ice margins can be dated, as for example on Anticosti Island (Gratton et al., 1984), and is essentially unmodified in recent portrayals (Dyke and Prest, 1987a). No submarine stratigraphic study of Gulf of St. Lawrence yet bears on the age and extent of glaciation, but, for the Atlantic side of Northern Peninsula, Northeast Newfoundland Shelf evidently did not have grounded glaciers during Late (and Middle) Wisconsinan time according to seismic surveys and coring by Alam et al., (1983), Piper et al. (1978), and Dale and Haworth (1979). The concept of relatively limited Late Wisconsinan glaciation in the region is given independent support from ice models derived from sea level data (Quinlan and Beaumont, 1982).

This study offers no support for the notion that southeastern Labrador was a large ice free area during the last glacial maximum. Whereas Coleman (1920) envisaged a narrow, extraglacial zone along the eastern coast on the basis of advanced weathering, Fulton and Hodgson (1979) placed the stadial limit far inland at the Paradise Moraine because till was sparse beyond the moraine and because of lake sediment dated at 20 000 BP near Aleksis River. Vilks and Mudie (1978) concurred because pollen in offshore sediment, thought to date from the glacial maximum, seemed to indicate an extensive tundra nearby. Ives (1978, Fig. 2) and Rogerson (1981, p. 40) also adopted the Paradise limit. This minimalist view can be challenged because the Aleksis River dates are judged to be spurious (King, 1985), and because the offshore total-carbon dates are unreliable according to Fillon et al. (1981) and Josenhans et al. (1986). The argument about lack of till being an indication of age is difficult to evaluate. Certainly in the map area the rocky terrain on both sides of the Bradore Moraine and Belles Amours Moraine (both of which would predate the Paradise Moraine in any reconstruction), is virtually fresh. There is thus no evidence to suggest that southeastern Labrador was not covered by the last main Laurentide advance. This position is adopted in a recent summary by Dyke and Prest (1987a, 1987b).

On the other hand, Mayewski et al. (1981) argued that no stratigraphic and chronometric proof exists that weathering limits can be interpreted as glacier margins. Accordingly, they attribute all features to the last glaciation, which they envisage as a monolithic ice sheet extending to the shelf edge (Fig. 51). All preserved sequences are merely phases of this single latest event, and the mature terrains are older landscapes preserved by cold-based ice. This hypothesis, though elegantly simple, has no single point of evidence in its favour, but would be a plausible scenario for one of the earlier glaciations, most likely the penultimate one.

Late Wisconsinan events

Within the youngest glacial terrain, the age of advance and retreat phases is less speculative and several correlations with adjacent areas seem evident. Within the map area both the Laurentide and Newfoundland ice domains built end moraines at about the same time. Newfoundland ice built the Piedmont Moraines about 12 600 BP and the Bradore and Belles Amours moraines of Laurentide ice are reasonable correlatives, based on accordant marine limits. The latter, in turn, are linked to other major moraines on the Gulf north shore by Dyke and Prest (1987a, 1987b). The Piedmont-Bradore phase is judged to be essentially coeval with the Robinson's Head Drift readvance in southwestern Newfoundland, which dates 12 600-12 700 BP (Brookes, 1977a) and with the lengthy moraine of the Millville-Dungarvon phase of the New Brunswick ice cap, which Rampton et al. (1984) date to 12 700 BP on the basis of shells in its marine marginal deposits in Chaleur Bay.

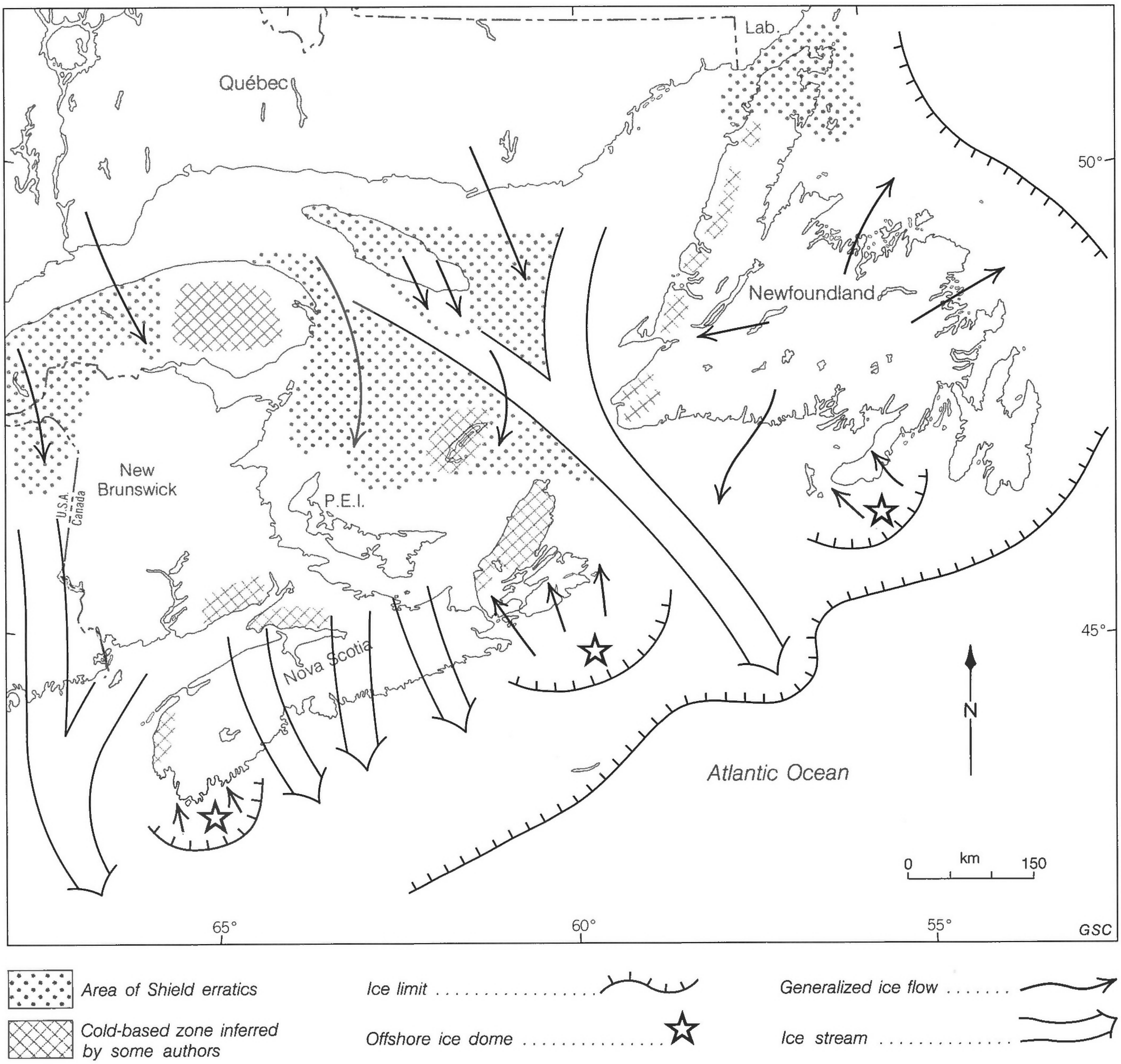


Figure 51. Hypothetical maximum extent of glacier ice during the Wisconsinan Stage (from Grant, 1987).

The Ten Mile Lake Moraine, a culmination of Newfoundland ice at or just after 11 000 BP, is essentially coeval with the major Laurentide stillstand or readvance that built the Paradise Moraine and the St.-Narcisse Moraine (LaSalle and Elson, 1975; Dyke and Prest, 1987a, 1987b). The synchrony of moraine building along an ice margin that was both land and marine based argues against these moraines being either "re-equilibration" phenomena or mechanical adjustments to oversteepening because of rapid calving, as Hillaire-Marcel et al., 1981 proposed. A regional climatic change would be implicated. Indeed, Mott et al. (1986) demonstrate from independent pollen-stratigraphic evidence from many sites in the Atlantic Provinces that about 11 000-10 000 BP tundra abruptly replaced boreal forest. They explain it by the sudden climatic cooling associated with a large southward shift of the Polar Front in the Atlantic Ocean (Ruddiman and McIntyre, 1973). If, as Ruddiman and McIntyre (1981) suggested, eastern North American glaciers should be sensitive to North Atlantic sea surface temperatures, then the Ten Mile Lake and related moraines can be seen as a natural glacial response to the climatic deterioration. Similarly, the Cloud River moraines of Waitt (1981) could correlate with the next most important ice-marginal stand of the Laurentide Ice Sheet according to Dyke and Prest (1987b), the Quebec North Shore Moraine system, which Dubois and Dionne (1985) date to 9700-9500 BP.

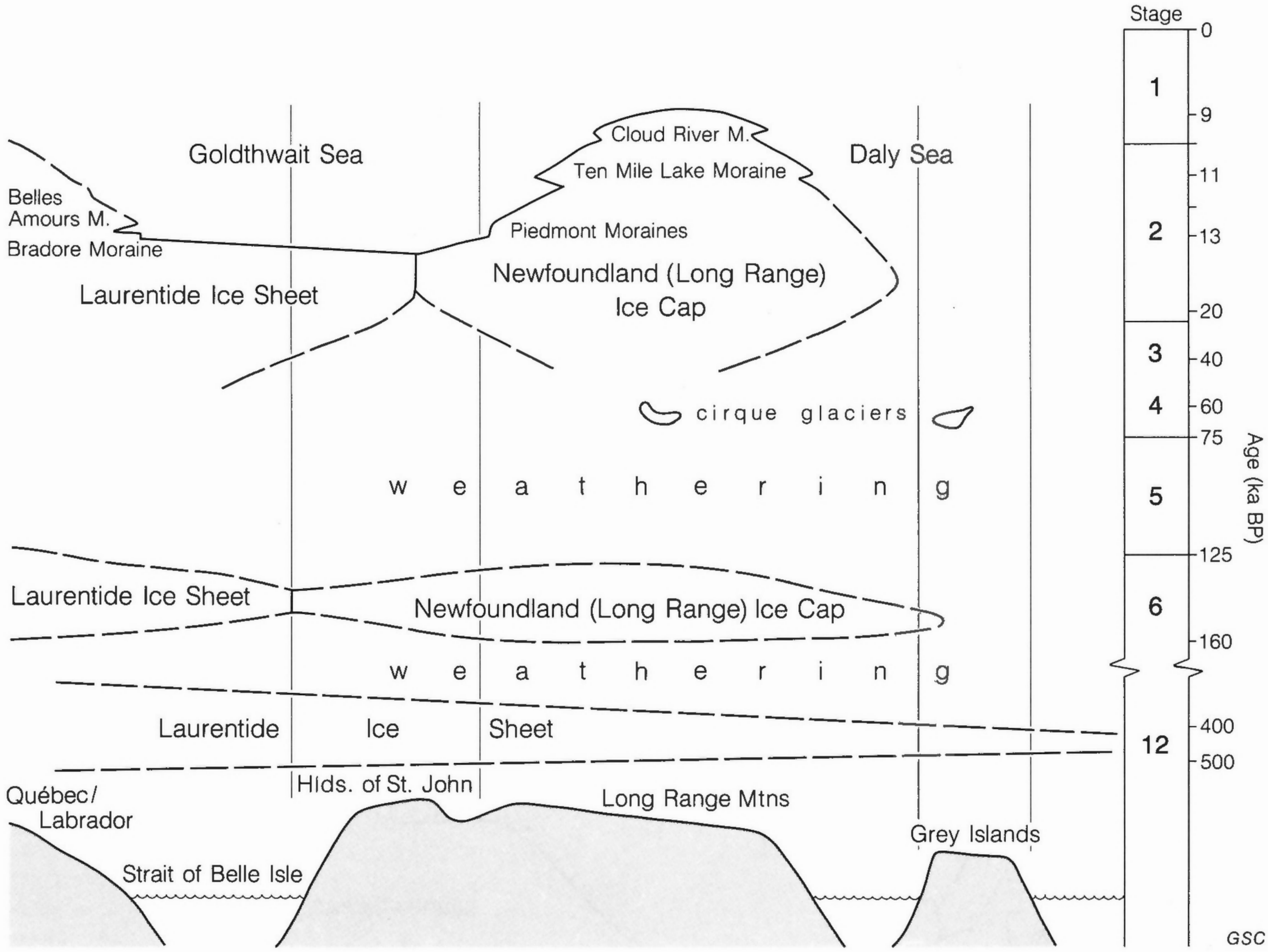


Figure 52. Time-space diagram of the inferred extent of Laurentide and Newfoundland glaciers in Northern Peninsula region during the Middle and Late Quaternary.

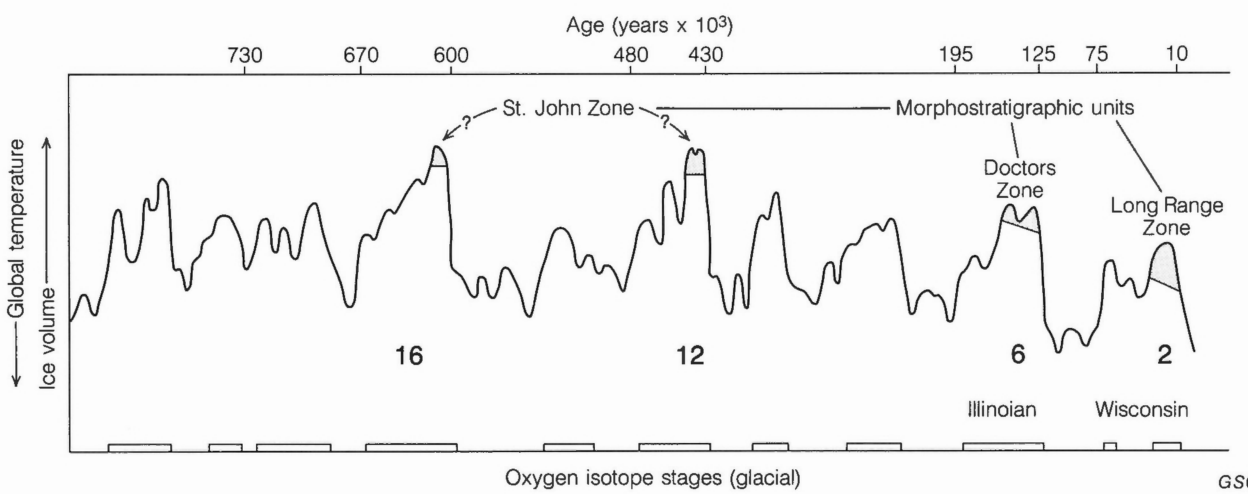


Figure 53. Correlation of the major cold phases deduced from the deep sea oxygen isotope chronology (Ruddiman and McIntyre, 1981) and the three main Newfoundland glaciations inferred from differently weathered glacial terrains (from Grant, 1987).

Good correspondence in times of major ice-marginal episodes between the Laurentide, Maritime Provinces, and Newfoundland ice masses suggests that, for the eastern Canadian region, glaciers responded to regional climatic changes. These changes are, in turn, driven by North Atlantic sea surface conditions, as Ruddiman and McIntyre (1981) supposed, and as Mott et al. (1986) demonstrated for the Younger Dryas-age cooling event.

To summarize the interpretation of changing areal extent of glaciers through time, and thus to show the inferred correlation of major ice-marginal features, a time-space diagram (Fig. 52) is constructed. It shows the three main glaciations deduced from weathering differences, the coalescence of Laurentide and Newfoundland glaciers, and, for the last deglaciation, the several positions of retreat as Goldthwait Sea and Daly Sea invaded the area.

Correlation of major glaciations to oxygen isotope record

The ages of the two previous glaciations have been estimated by comparing the depth of fluvial dissection in those areas to that in the last or Late Wisconsinan terrain, which is dated by means of associated shell-bearing marine deposits. The older two are stages 6 and 12; the last is stage 2. Independent evidence that those periods were times of maximal regional glaciation comes from offshore, where terrigenous sediment on seamounts in the deep sea points to maximal glacial erosion during those same isotope stages (Alam et al., 1983).

If maximal erosion corresponds to greatest extent, and, hence, with thickness or elevation, then the morphostratigraphically defined, weathered, glacial terrains, which are arranged in an elevational sequence, can be related to the deep sea oxygen isotope chronology of Ruddiman and

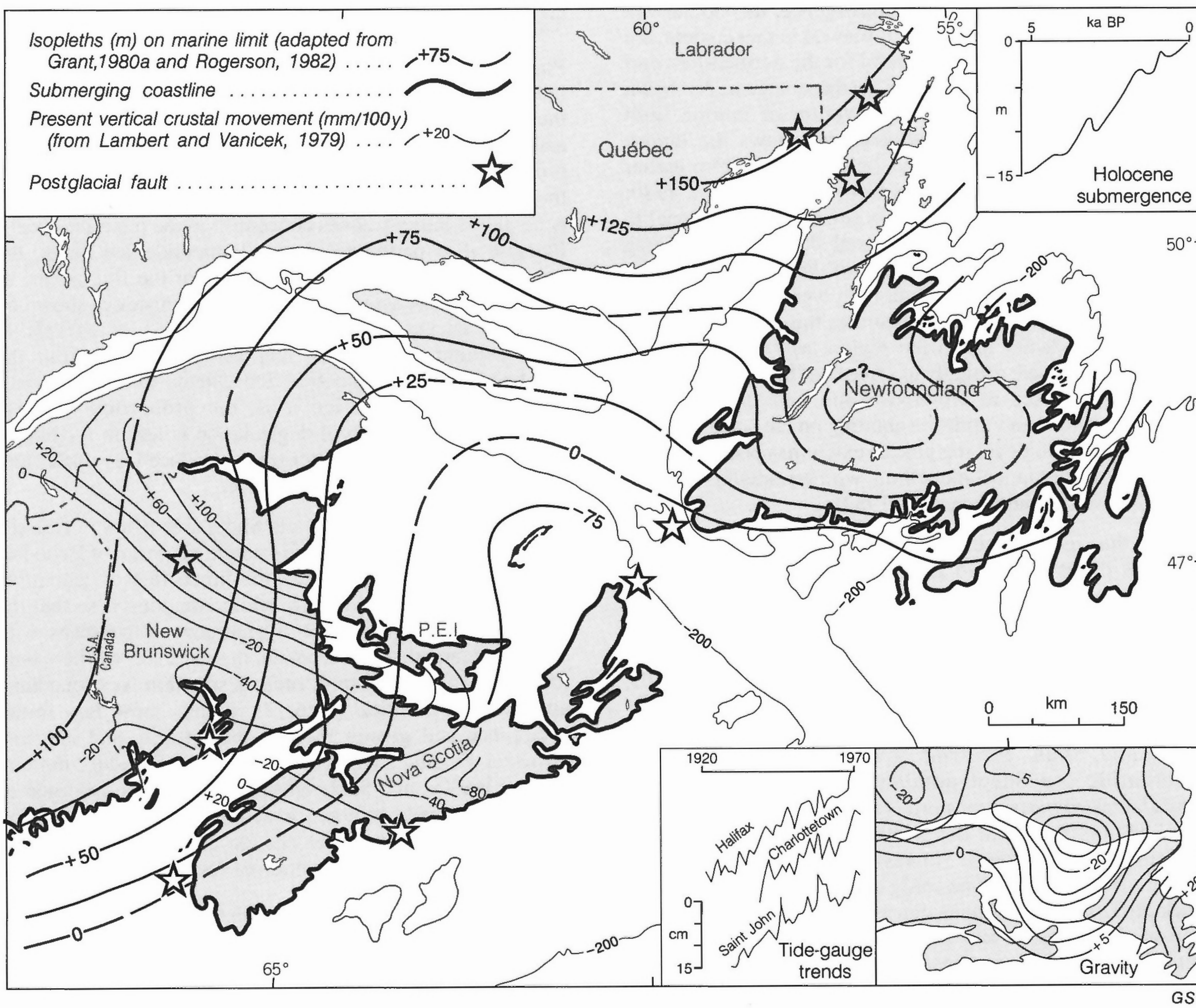


Figure 54. Regional variation in the maximum elevation of the postglacial Goldthwait Sea in Gulf of St. Lawrence, showing greatest submergence in Strait of Belle Isle area. Stars denote postglacial faulting (modified after Grant, 1989).

McIntyre (1981) (Fig. 53). According to that method the derived seasurface temperatures are a proxy measure of global ice volume. If the times of lowest global temperature were the periods of greatest ice volume, then the maximal Quaternary glaciations in decreasing order of magnitude were stages 16, 12, 6, and 2. If ice volume in this area corresponds to thickness or height of the Newfoundland ice cap as it flowed seaward between the coastal mountains, then those summits effectively served as inverted dipsticks to record the upper reaches of successive great glaciations. By this means, the last three or four maxima were registered as trimlines on the marginal nunataks.

Sea level changes and crustal movements

Regional variation of submergence level

Changes of relative sea level in Strait of Belle Isle area are part of a regional, postglacial submergence, the Goldthwait Sea (Elson, 1969; Dionne, 1977). Viewed in that context, the results of this study provide control for the northeastern part of the region and support findings in adjacent areas. As shown by variations in the regional elevation of marine limit (Fig. 54), northernmost Newfoundland shows the largest emergence. The pattern is only slightly altered from earlier reconstructions (Wightman and Cooke, 1978; Grant, 1980; Rogerson, 1982). As emergence is generally proportional to the amount of glacioisostatic crustal deflection, this area reflects the combined influence of Newfoundland and Laurentide ice masses, although both were near their limit. The regional isobase pattern illustrates the gross disposition of grounded glacier ice in the region, as De Geer (1892) originally surmised: a mainly ice-free Gulf between two main glacier complexes in Newfoundland and the Maritime Provinces, with Laurentide ice abutting on the north. The sea level approach to deducing glacier extent has been tested by computer mathematical modelling, with essentially the same results (Quinlan and Beaumont, 1982).

Of the younger sea level, which might reveal later patterns of upwarp, two give useful information despite deficient age and elevation control. In the study area, the 75 m rock bench cut during the Ten Mile Lake readvance is a prominent marker. First noted by Cooper (1937), it was found by Flint (1940) to correlate with a regionally extensive shorelevel which he called the "Bay of Islands Surface." It rises north- westward like the slope of marine limit and, thus, confirms that the vast bulk of the Laurentide Ice Sheet dominated the later phases of postglacial upwarp in western Newfoundland. Flint (1940, p. 1776) believed that the width of the bench required a stillstand of 5000 years. However, he was not aware that the modern shore is commonly a wide platform and high rock cliff, which have been cut, as shorelevel displacement history indicates, in less than 1000 years. The efficacy of intertidal planation in these latitudes, especially on thin bedded, jointed and cleaved rocks, is attributed to frost action that disaggregates the rock during exposure, combined with removal of debris by waves and shorefast ice. There is, thus, no necessity for a lengthy stillstand but, as the shorelevel is an anomalous erosional feature, it certainly required an interval of much slower emergence, if not a slight pause or transgression.

The second level is the low cliff estimated at 2000-3000 BP, which is found just above tide level along the west coast of the island. Its virtual horizontality across areas with quite different recent sea level history points to a cause unrelated to differential upwarp. A small transgression has been suggested. If so, it would require a broad, slight, crustal subsidence. As suggested by Newman and Grant (1987), a possible mechanism might be the passage through the area of the collapsing glacial forebulge whose migration up the Atlantic coast to the Gulf region has been traced mathematically by Pardi and Newman (1987). A similar extensive low terrace in upper St. Lawrence River estuary has been referred to a transgression 5800-4400 BP by Dionne (1988).

Variation of sea level change through the region

Postglacial shoreline recovery is the resultant of crustal rebound, general sea level rise as glacial meltwater returns to the oceans, and gravitational change as ice masses disappear and subcrustal movement proceeds. The dominant factor is proximity to glacier load and, as Clark et al. (1978) showed, the variation of sea level change over the globe can be generalized into six zones concentric to the main ice sheets. Because it is peripheral to the Laurentide Ice Sheet, the eastern Canadian region covers three of the five zones, as illustrated by the assemblage of sea level histories shown by the nine curves in Figure 55. The style of shorelevel displacement varies with increasing distance from the Quebec-centred Laurentide Ice Sheet. In other words, depending on initial ice load, the proportion of early emergence resulting from deglaciation is less in relation to the amount of later submergence produced by meltwater accession and by crustal subsidence.

Thus, like the Quebec North Shore area (Curve 1) the sea level history derived from this study in the Strait of Belle Isle area (2), having also been under the direct effect of Laurentide ice load, has emerged rapidly and continuously, so that the entire postglacial sequence is emergent. It contrasts with areas at greater distance from the main ice sheet, where only local ice caps are inferred, such as southern Newfoundland and New Brunswick (5, 6, 7), which show less initial emergence and greater recent submergence, and are now drowned. Finally, areas at or beyond the inferred ice margin, such as Halifax and Sable Island (8, 9), have submerged so much that the early emergence record is drowned completely. The variation of sea level change across the region thus expresses the general disposition of former glacier load.

To test the value of sea level history as a measure of ice load, Quinlan and Beaumont (1982) used some of the sea level data available in the region, including that for northern Newfoundland (Grant, 1972b), to model glacier extent and retreat. The result pointed to an ice sheet intermediate between the maximum and minimum concepts protrayed in Figures 50 and 51. Their rigorous mathematical approach, although deficient in some areas, is regarded as support for the geomorphologically defined ice limits in this work, and it further shows that glacial and sea level data must be congruent.

Recent crustal movement

Shorelevel displacement results primarily from glacio-isostatic crustal recovery. Hence the large and regionally varying emergence implies rapid differential uplift. A question is whether the strain everywhere is a smooth flexing or warping, or whether local faulting occurred and, if so, whether any such displacement can be detected. The prime evidence would be rupture and offset of glaciated bedrock surfaces. Two examples were seen on the ground. One, on the top of a rock hill at the south end of Ten Mile Lake where a 137 m marine limit trimline was measured, showed the grooved glacial pavement upthrown about 5 cm on each of two east-west joints. It is not unlike other faulted pavements that have been reported in Nova Scotia and New Brunswick (Grant, 1987, p. 15).

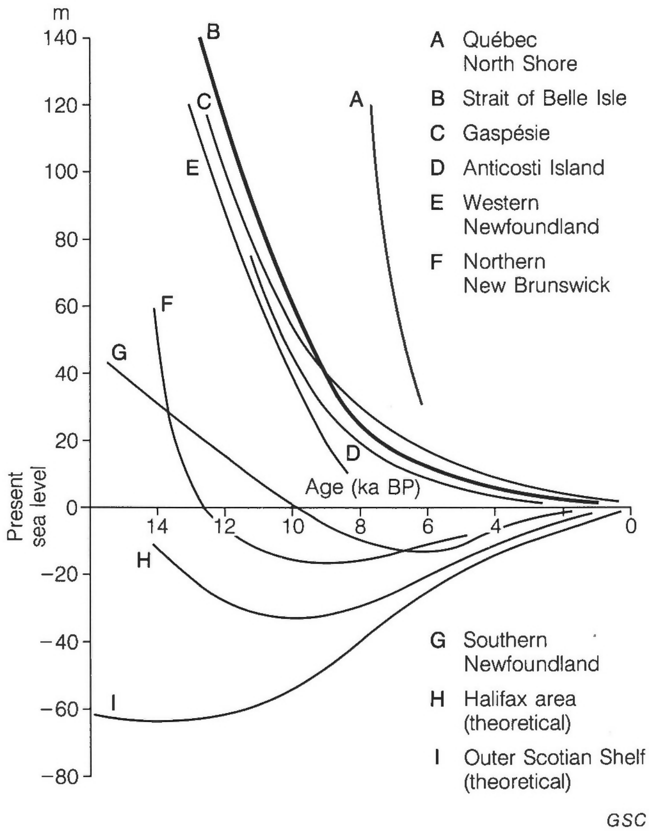


Figure 55. Comparison of postglacial shorelevel displacement history for the strait of Belle Isle with other sea level curves presented for the region (from Grant, 1989).

Figure 56. Possible postglacial fault scarp with up-to-the-south displacement of glaciated bedrock surface; Baie des Belles Amours. (GSC 188715)

The other, near Baie des Belles Amours, was a north-facing scarp several metres high that cut across a roche moutonnée (Fig. 56). The feature appears on airphotos as a distinct, sharp-edged lineament unlike most bedrock structural features, which are greatly eroded and smoothed by glaciation. Other sharp-edged lineaments were photo-mapped in the northwest part of the study area, as shown on Map 1610A, and northeast beyond Red Bay. Most show an apparent upthrow to the south. If they are true postglacial faults, they have the orientation and displacement that is consistent with the idea of isostatic and/or elastic rebound in front of a northwestward retreating ice mass. In any event, Plumb and Cox (1987) showed that the area is under horizontal compression from the northeast; this stress might be causing surface rupture.

Apart from discrete signs of surface rupture, crustal movement evidently continues, judging by the amount of shoreline displacement over the past few centuries. Lacking geodetic relevelling to reveal the absolute rates, general trends could be deduced from more detailed sea level studies, such as by dating the marine/freshwater transition in low level rock basins.

ECONOMIC GEOLOGY

Knowledge of the nature and origin of surface materials is essential for optimal land use. The surficial deposits and terrain data shown on the map have been chosen to emphasize the mosaic of rocky substrates interspersed with unconsolidated materials and to reflect the main differences in texture and thickness of deposits that are pertinent to a variety of land-based activities. For the foreseeable future the main applications pertain to settlement (for which foundation conditions and water supply are crucial), forestry (for which soil composition and hydrology are the limiting factors), mining (which uses information on rock structure and drift prospecting), and transportation (which requires both granular resources as well as general terrain data for roads and powerlines).

Engineering applications

Most settlements are located along the coast, which is underlain by either rock or gravel formations. Generally, these provide good sites for future expansion, free of stability problems. The small pockets of clayey marine sediment with low bearing strength can be easily avoided as they occur in depressional areas. No problems are anticipated for construction in till areas, although no geotechnical data were collected to support this belief.

Re-alignment and construction of new routes must contend with a variety of difficulties, primarily high water table, numerous lakes, and boggy conditions that prevail over large areas. The pronounced north-south topographic grain limits free choice of routes, but judicious use of natural ridges can minimize the amount of peat that has to be removed and backfilled. On the positive side, however, all substrates have good bearing strength except for small areas of marine mud that should be avoided. Many small unmapped occurrences will no doubt be encountered. Periodic flooding, which results from fluctuations of groundwater in the cavernous carbonate terrain, such as east of Big Brook, is a perennial hazard that can be avoided by noting signs of previous occurrence and by not altering the surface water flow with impervious embankments.

Granular materials for grading and asphalt production are in short supply except on the Quebec-Labrador coast. Moreover, on the carbonate plain the small deposits consist largely of unstable rock species. Prospecting for suitable sources will, therefore, have to be carried out using the mapped occurrences of marine and fluvial gravel as a starting point. Individual raised beaches have been found on the otherwise barren rock plain inland of existing highways, each of which would produce several miles of subgrade. However, long haulage distances are unavoidable. In addition large untapped areas of fluvial and marine gravel are believed to underlie Castors River and Doctors Brook valleys. These are within short haulage distance of the west coast highway and could become important reserves in an area now generally believed to be seriously deficient. For the proposed road link from Main Brook to the new airport, large deposits of marine gravel are associated with the Ten Mile Lake Moraine. Otherwise most reserves underlie the coastal settlements, presenting a land-use conflict between exploitation of a dwindling and valuable resource and urban expansion onto prime construction land.

When Labrador hydroelectric power is developed and brought to the island, the corridor will lie along Northern Peninsula. Both the Long Range plateau route and the coastal lowlands route present difficulties. A lowland route could skirt environmentally sensitive areas but would contend with small unmapped pockets of weak marine clay and must be localized on bedrock because the towers must be guyed. Fortunately, rock is at the surface or just below shallow patches of drift and bogs everywhere along the coast, from the probable terminus near Flowers Cove to Port aux Choix and beyond. However, each site should be drilled to test for caverns and other weakness in the carbonate strata.

Groundwater supply

In smaller communities most water is obtained by individual dug or drilled wells that tap shallow aquifers in rock or gravel; in larger communities impoundment of surface drainage is the current method. On the east coast adequate potential sites exist for expansion and construction of new systems because of the high relief and numerous good quality lakes. On the west coast, however, surface drainage is seasonally intermittent because of the karstic carbonate terrane and of low quality because it derives from extensive bog lands. The provision of municipal systems will require drilling to stratabound aquifers unless large catchment areas are reserved and isolated from contamination.

Forestry

The suitability of soils on various terrain materials over an area of the Central Midlands has been interpreted in detail by Damman (1963). As there is good correspondence between his mapping of parent materials and that of the present study, his criteria can be easily applied over the balance of the study area. Naturally, growth and regeneration is highest over the deeper unconsolidated materials where they occur in adequately drained settings such as till ridges or till veneer over rock ridges on the flanks of Long Range Mountains and White Hills. In addition, an important limiting factor is the seasonal groundwater fluctuation in carbonate areas along Salmon River and around Ten Mile Lake.

In general, soil lithology and texture corresponds to that of the underlying bedrock, even where tills or granular marine deposits occur. Locally, long-distance glacial transport has emplaced granitic materials over quartzite or carbonate rock terranes, as along the flanks of Long Range Mountains, but this admixture of coarser particles is probably beneficial because it offsets the normally heavy texture of carbonate tills. A fairly reliable interpretation of soil texture, lithology, and thickness can be made by using the terrain map in conjunction with the bedrock map (Bostock et al., 1983).

Mineral exploration and drift prospecting

Structural geological inferences

Airphoto interpretation of terrain relief elements was used to identify all manifestations of bedrock fabric. Map 1610A therefore shows many more inferred fracture and stratification lineaments than might be mappable from observation of outcrops alone. The patterns of folding and fracturing thus evident match the known features perfectly and serve to add much information about areas where bedrock is largely obscured. Most obvious on the carbonate plain is the pronounced northeast trend of both bedding and jointing. Disturbance by folding increases to the east from nearly flat-lying strata to steeply dipping contortions giving rise to higher hills. A conjugate ENE-NWN fracture system pervades this terrane. A zone of intense fracturing extends from Ten Mile Lake to Pistolet Bay. The Coastal Upland block on the other hand is cut by a dense system of fractures trending east and north-northeast. The Long Range block displays several fracture trends, some elements of which continue into the younger rocks. In Quebec-Labrador, fracture systems in the Shield and Cambrian areas are distinctly separate; the latter blocks have a pronounced northeast fragmentation that does not involve the basement rocks. In two areas of the Shield – northwest of Bradore

Moraine and northeast of Red Bay – long open crevices with sharp-crested upthrown southern sides, cutting otherwise smooth roches moutonnées (Fig. 56), seem to indicate postglacial disruption of bedrock. These trend northeast, parallel to the former ice front and could mark localized isostatic upheaval as the area was freed of ice. However, these largely photo-mapped occurrences need to be evaluated on the ground.

Zones of karstification are localized and could be dependent on structure. Belts of collapse topography trend mainly northeast in several areas: Mount St. Margaret, Bide Arm to Coles Pond, Tom Roses Pond to Indre Point, Northeast Arm to Southwest Brook, with the longest from Northwest Arm through Salmon River, past Hare Bay to Cape Norman. These could be ancient cavern systems unroofed during glaciation. It is believed that groundwater has exploited major fracture zones, a relationship that may be of economic significance if strata-bound sulphide bodies are also structurally localized.

Drift prospecting

Considerable effort was made to document the details of ice flow direction and sequence to facilitate the search for mineral sources using distribution of float and geochemical anomalies in drift-covered areas. Although the region records a total of five ice flow phases, smaller areas have been subjected to fewer effective directions of drift dispersal. The Quebec-Labrador portion was affected mainly by ice flowing south-southeast. Long Range Mountains and the adjacent midlands and lowlands as far as the Ten Mile Lake Moraine experienced radial, mainly northward, glacial erosion. Beyond, the carbonate plain was crossed by ice moving southeast with a later, though probably less effective, westward movement. Along the coast of St. John Bay only flow to the southwest is recognized. Finally, over White Hills and Coastal Uplands, erosion and transport was evidently only to the east and southeast.

The thickness and origin of secondary deposits over bedrock are an important consideration in the practice and assessment of geochemical surveying. Depending on the number and sequence of re-depositions, anomalies vary in their affinity to bedrock sources, ranging from direct first-order derivatives, such as residual weathered mantles, solifluction sheets, and modern lake sediment in rocky areas, to second-order derivatives, such as till veneer and thick till in end moraines, to third-order glaciofluvial derivatives of till, to distantly derived marine clay. The surficial deposits map should enable a better understanding of geochemical assays that are made on a mosaic of materials of widely differing origin and distance of transport.

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