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LATE-WISCONSIN GLACIATION OF SOUTHWESTERN NEWFOUNDLAND (WITH SPECIAL REFERENCE TO THE STEPHENVILLE MAP-AREA)

(Report, 13 figures and Map 15-1973)

I. A. Brookes

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I. A. Brookes

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

Western Newfoundland is unique in Appalachian Canada for the variety and grandeur of its largely glacial landforms. The recent establishment of Gros Morne National Park acknowledges the scenic attraction of this strongly glaciated region of diverse relief situated in a predominantly coastal environment.

The major findings relate to the age and direction of glacier movements, the pattern and chronology of glaciomarine overlap, and the origins of landforms and sediments associated with glaciation and deglaciation.

The area covered in detail in the report is an irregular one since attention was focused, for reasons of interest and accessibility, on the coastal and riverine lowlands. Field work in the highlands was limited by access, but areas not visited have been covered by airphoto interpretation.

RÉSUMÉ

L'ouest de Terre-Neuve constitue une région unique dans les Appalaches canadiennes à cause de la diversité et de la grandeur du relief en majeure partie glaciaire.

La récente création du Parc national de Gros Morne reconnait la beauté de cette région que les glaces ont façonneé dans un milieu surtout littoral.

Les principales observations se rapportent à l'âge des glaciers et à la direction de leur mouvement, au modelé et à la chronologie du recouvrement glacio-marin et aux origines du relief et des sédiments associés à la glaciation et à la déglaciation.

La région qui fait l'objet du rapport est irrégulière puisque pour des raisons d'intérêt et d'accessibilité on a mis l'accent sur le bas-pays, près de la côte ou des cours d'eau. Les difficultés d'accès des régions élevés ont limité les travaux sur le terrain mais les régions qui n'ont pu être atteintes font l'objet d'une description fondée sur l'interprétation de photographies aériennes.

LATE-WISCONSIN GLACIATION OF SOUTHWESTERN NEWFOUNDLAND (WITH SPECIAL REFERENCE TO THE STEPHENVILLE MAP-AREA.)

INTRODUCTION

LOCATION OF THE AREA

The area covered in this report is outlined in Figure 1. Approximately 3,500 square miles are included. Access to the coastal fringe is excellent via gravel roads branching off the Trans-Canada Highway which is primarily an interior route. The Canadian National Railways line also crosses the area but this no longer offers a passenger service (1973). A variety of services are available in the towns of Corner Brook, Deer Lake, and Stephenville, and more limited services are found in the smaller towns of St. George's and Stephenville Crossing, and larger villages such as Robinsons, Port au Port, and Woody Point.

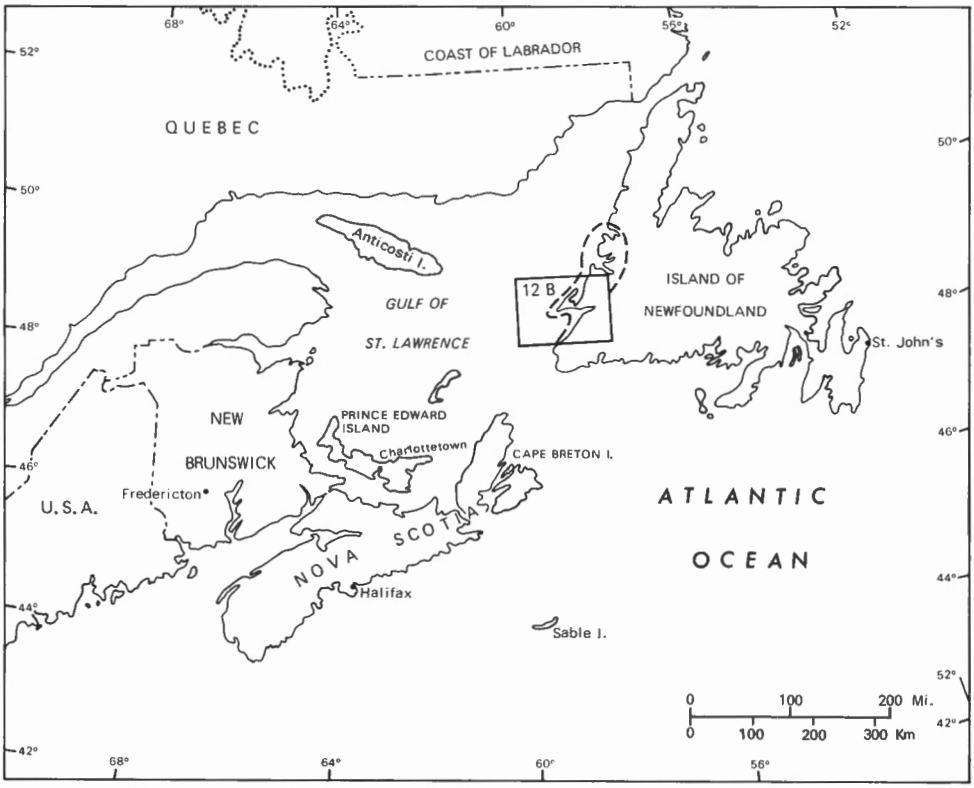

Figure 1. Location of study area.

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PREVIOUS INVESTIGATIONS

The glaciation of the island of Newfoundland has drawn the attention of many glacialists since the late-nineteenth century (Brookes, 1970). The works of Bell (1884), DeGeer (1892), Chamberlin (1895), Fairchild (1918), Daly (1921), Tyrrell (in Fairchild, 1918), Coleman (1926), Flint (1940), MacClintock and Twenhofel (1940), Jenness (1960), Lundqvist (1965) and Grant (1969a, 1969b) comprise the significant contributions to present knowledge.

Investigations have focused on two main topics: the relative ages and directions of glacier movement, and postglacial isostatic warping. Both relate to the overall problem of whether the island of Newfoundland supported its own ice cap at the maximum of the last glaciation ("classical Wisconsin"), or was overridden, partly or wholly, by ice of the Labradorean sector of the Laurentide Ice Sheet.

Bell, DeGeer, Chamberlin, Fairchild, Daly, Tyrrell, and Coleman all concluded that the island did support an independent ice cap at the last glacial maximum. The evidence upon which this conclusion was based would be considered tenuous today, drawn as it was from easily accessible ice flow and raised shoreline features; but Fairchild's general statement is an eloquent testament to the popularity of the notion:

> All available information on the glacial geology of Newfoundland favours an independent ice-cap, with radial flow. And when we consider the large area and mountain heights of the island; the northern position; exposure to ocean on all sides; and location in the paths of the cyclonic storms of America, it appears certain that the island was the locus of heavy snow precipitation and a massive ice-cap – the Newfoundland continental glacier.
>
> (Fairchild, 1918, p. 229)

In 1940, Flint expressed the view that the north-northwestward rise of isobases in western Newfoundland, tentatively drawn on the highest marine features, was due to an invasion of at least the west coast of the island by Labradorean ice. MacClintock and Twenhofel (1940) simultaneously presented evidence of predominantly radial flow over the island. However, they found crossing glacial striae on limestone bedrock beneath till in the Port au Port area and interpreted them as showing that ice first crossed the Port au Port Peninsula from northerly points and later flowed from east to west. They harmonized their evidence of radial flow with Flint's view of invading Labradorean ice by suggesting that:

> Newfoundland was at first affected by ice from Labrador and later had its own outward-radiating ice-cap.... The ice which moved southward may have been either Labrador ice or Newfoundland ice which, farther north, moved out into the Gulf of St. Lawrence, there encountered south-moving Labrador ice, and was pushed southwards by it.
>
> (MacClintock and Twenhofel, 1940, p. 1753).

They further stated (p. 1750) that:

> ... glaciation from Labrador took place at the climax of the Wisconsin stage, when ice may well have passed not only over Newfoundland but out to deposit the well-known drift of the Grand Banks.... As the Labradorian [sic] glacier waned part of it may have persisted on Newfoundland, acquired radial motion as impeding ice melted away from its margins, and thus became a local ice-cap whose movement would have largely obliterated any earlier striae.

The notion of overriding Labradorean ice has since become popular. Jenness (1960), for example, speculated that such an ice sheet was responsible for the trend of isobases produced by extending those he drew on east coast marine features to those drawn by Flint (1940) on the west coast of the island. Lundqvist (1965) suggested that Labradorean ice moving southeastwards would account for striae in northeastern Newfoundland which he had found difficulty in assigning to movements of local ice masses.

Evidence presented in this paper strongly indicates that ice flowed from the western mountains of Newfoundland into the Gulf of St. Lawrence at the last glacial maximum (before about 14,000 years B. P.) and that no Labrador ice invaded the Stephenville region.

BEDROCK GEOLOGY, TOPOGRAPHY, AND DRAINAGE

The area discussed can be divided into three topographic categories, broadly equivalent to the tectonic zones resulting from a complex Paleozoic geosynclinal history. Mountain areas (Fig. 2) that include the Long Range Mountains, constitute the most extensive tectonic-physiographic zone. They comprise a belt of predominantly acidic, metasedimentary and igneous rocks formed during the mid-Devonian Acadian Orogeny, although equally strong deformation occurred in the mid-Ordovician, Taconian Orogeny. A fault-line scarp forms a prominent margin to the mountains in the Codroy Valley region south of the map-area, but east of St. George's Bay, steep-sided, river-cut valleys, that have been modified by glaciers, have reduced its expression. The surface of these mountains, at 1,100-2,200 feet, is "Shield"-like in aspect, with an irregular knob-and-basin terrain, patches of low, hummocky moraine, isolated streamlined till hills, and disorganized or angular drainage with abundant lakes and ponds. North of Bonne Bay at the southern end of the Great Northern Peninsula, similar terrain is developed on Precambian metamorphic rocks.

Other mountains occur in four separate massifs with steep, commonly fault-controlled, bounding slopes rising to undulating plateau surfaces at 1,800-2,600 feet. These are, from north to south, Table Mountain massif, Bonne Bay; North Arm Mountain – Mount St. Gregory massif, Bay of Islands; the massif including Blow-Me-Down hill, south of Bay of Islands; and the Lewis Hills, north of St. George's Bay. These massifs are all composed of mafic and ultramafic igneous rocks forming part of a large 'klippe' slice that moved westwards along with Ordovician clastic sedimentary rocks during

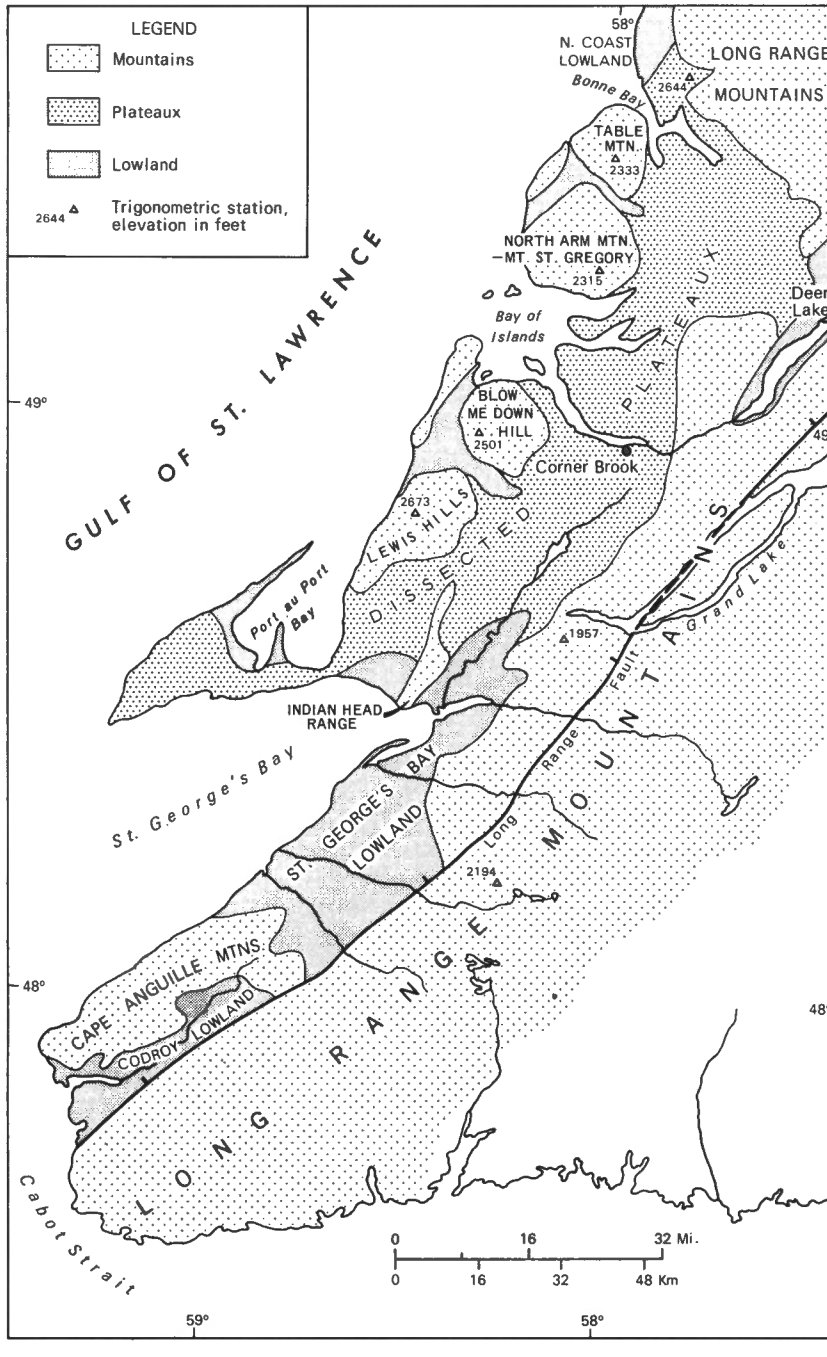

Figure 2. Topographic regions of southwestern Newfoundland.

the Taconian Orogeny (Rodgers and Neale, 1963). Where the ultramafic rocks outcrop, plateau surfaces are strewn with blockfields. Deep, glacially-modified valleys and peripheral cirques have high, frost-riven cliffs and bare talus aprons developed in them.

The Cape Anguille Mountains in the southwest of the map-area display a remarkably smooth surface comprising several bevelled slopes developed across the upturned edges of Mississippian sandstones and conglomerates, at 1,300-1,750 feet. Streams have cut steep, V-shaped valleys into the margins of this plateau, developing headwards along the southwest-northeast strike, with poorly-formed cirques and better-formed nivation hollows at their heads, particularly along the more exposed western margin.

Over the Port au Port Peninsula and in the area between the mafic-ultramafic massifs and the Long Range Mountains, terrain is more dissected than on the well-preserved plateau surfaces of the "mountains" of the map-area. Ordovician limestone and sandstone strata have been folded and faulted along southwest-northeast trends, and differential erosion has imparted a pronounced "grain" to less extensive plateau remnants that occur at 700-1,300 feet elevation between steep-sided valleys.

The lowlands of the area consistently reflect the inferior resistance of Mississippian and Pennsylvanian clastic sedimentary rocks of the Codroy and Barachois groups, with their minor shale, coal, and evaporite beds. Within the map-area, the St. George's Bay Lowland narrows from 16 miles in the south to six miles in the north near St. George's where there is a west-projecting salient of the Long Range Mountains. Outside the map-area, the Deer Lake lowland occupies a synclinal trough of Carboniferous rocks between the prominent plateaux of the Long Range Mountains.

The plateau aspect of upland areas in this and many other regions in Appalachian Canada is the result of Mesozoic and pre-Quaternary Cenozoic fluvial planation accomplished by antecedents of modern river systems; this planation most likely occurred under a humid subtropical climate and within a diastrophic environment characterized by intermittent small epeirogenic uplifts. The stepped form of many plateau surfaces and interfluves attests to fairly regular interruption of denudation. Preglacial drainage lines have been reconstructed from the slopes of these surfaces and are shown in the map of preglacial and present drainage (Fig. 13). Glacial modifications of that pattern are also shown; those in the lower Humber River and at the western end of Grand Lake are by far the most significant.

ACKNOWLEDGMENTS

J. T. Parry of McGill University supervised the preparation of the Ph. D. dissertation which forms much of the basis of this report. V. K. Prest, as the supervisor of the field project for the Geological Survey of Canada, provided useful advice through all stages of the work. In addition, D. R. Grant and J. M. Shearer of the Geological Survey gave assistance through discussions of their own work in Newfoundland. J. T. Andrews, University of Colorado, has given assistance in the application of his work on isostatic recovery. McGill University provided research facilities in the early stages of the work, while York University, Toronto, as the author's employer since 1965, has provided secretarial, cartographic, and laboratory facilities, as well as an income, while the work was being completed. Field work was carried out during the summers of 1964 to 1968 inclusive.

QUATERNARY GEOLOGY AND LANDFORMS

INTRODUCTION

The following three sections deal with the deposits and landforms of three distinct late-Wisconsin events. The deposits were given the names "St. Georges [sic] River Drift," "Bay St. George Delta," and "Robinsons Head Drift" in the St. George's Bay area by MacClintock and Twenhofel (1940). These names are retained here for the sake of continuity in the literature, but no attempt is made to extend the terms outside the type area because of the general uncertainty of geological time within each event. It should be borne in mind, therefore, that where the above terms are used, they refer to rock-stratigraphic, rather than time-stratigraphic, units.

ST. GEORGE'S RIVER DRIFT

Till and Ice-Contact Deposits

The St. George's River Drift is the oldest Quaternary unit in the area and was given its name by MacClintock and Twenhofel (1940) because of the relatively extensive surface exposures of the deposits north and south of St. George's River, near the head of St. George's Bay. The drift is best exposed in the cliffs around that bay, between Port au Port and Highlands, where it overlies Carboniferous and Ordovician bedrock (Fig. 3). It usually occurs in the cliff base, but may rise to 80 feet above sea level where bedrock rises high in cliff faces. Elsewhere in the area this drift occupies a basal position in Quaternary sequences preserved in isolated coves along predominantly steep bedrock coasts, and its equivalent thinly mantles the lower slopes of the fiord valleys of Bay of Islands and Bonne Bay. It is not found at any distance inland or on higher plateau surfaces. Plateau-top erratics, however, were probably emplaced during the glacial episode in which this drift was deposited.

The St. George's River Drift typically comprises a 3 to 15-foot-thick layer of compact lodgement till which develops near-vertical faces in coastal cliffs. The till varies in colour from greyish pink, where Carboniferous fragments predominate in the matrix, to grey in all other cases. The compact structure is related to the relatively high proportion (13-17%) of combined clay and silt in the till matrix, and derived from fine-grained clastic sedimentary and metamorphic rocks. Clasts are usually of more resistant, often far-travelled, crystalline rocks which are of value in determining till provenance.

Along the north shore of St. George's Bay and at Robinsons Head hummocky pockets of coarse, ice-contact stratified drift overlie St. George's River Drift till (Fig. 4). These indicate ice-stagnation during deglaciation of the present coast.

Ice-Flow Directions

The most significant conclusion reached in this paper arises out of the determination of ice-flow directions over western Newfoundland at the last glacial maximum. Abundant evidence of several types is available bearing on regional and local ice movements prior to marine overlap. Some of this is discussed by Brookes (1970).

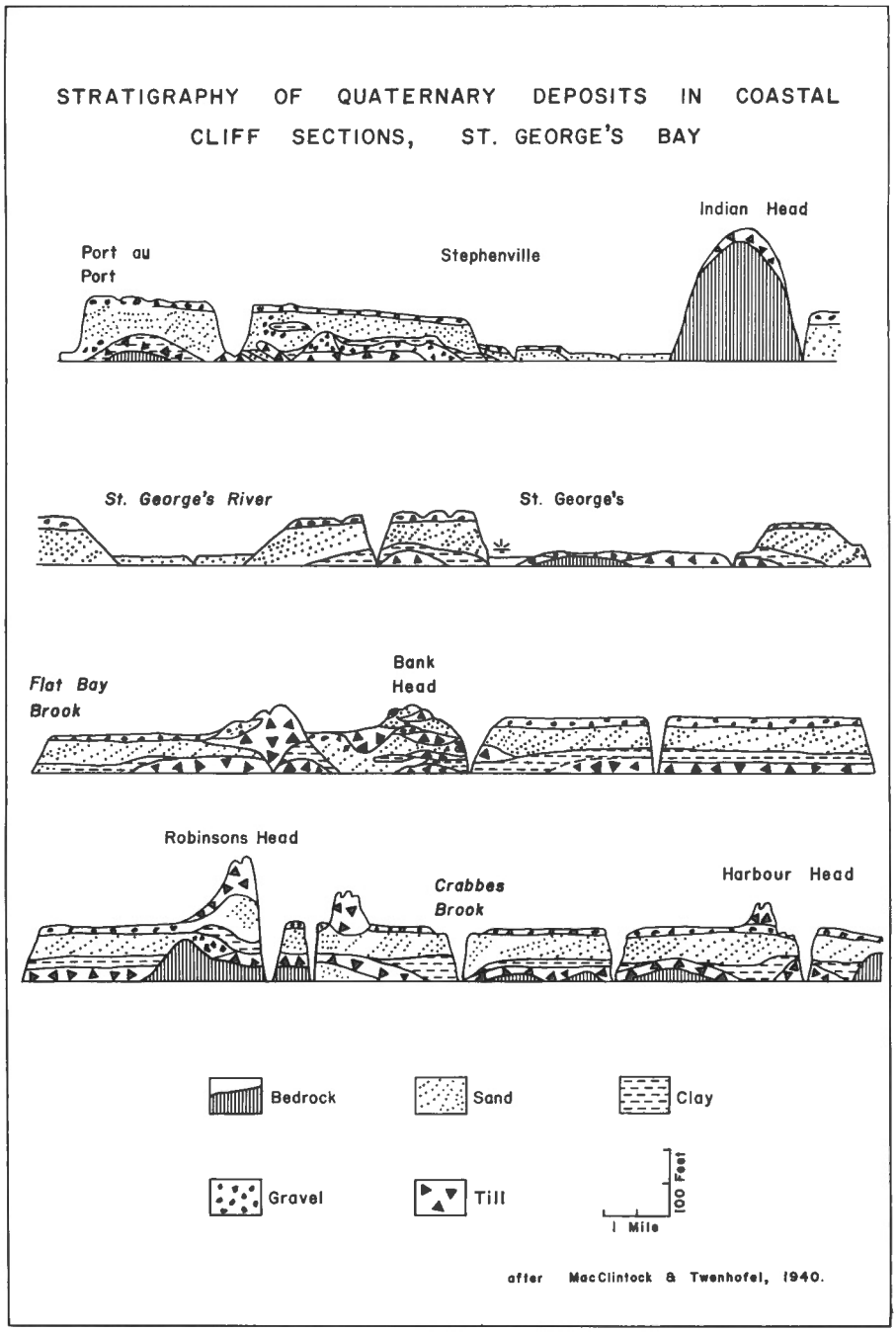

Figure 3. Stratigraphy of Quaternary deposits in coastal cliff sections, St. George's Bay.

Figure 4. Coastal cliffs west of Stephenville, showing marine clay-silts draped over surface of St. George's River Drift. GSC photo 202291-A

The lithology of the St. George's River Drift till gives a general indication of ice movements. Along the east shore of St. George's Bay, the till is rich in Carboniferous fragments and the reddish matrix derives from the friable Carboniferous rocks underlying the adjacent lowland. On the south shore of the Port au Port Peninsula Ordovician limestone clasts are plentiful, indicating a derivation from the bedrock of this peninsula. In the Bonne Bay area the till overlying bedrock on the east shore of East Arm is notably reddish in colour; the nearest red rocks are in Deer Lake lowland to the southeast of the northern part of the Long Range plateau. Erratic boulders in the till and isolated erratics on wave-washed till surfaces and the tops of high plateaux, provide further evidence of former ice movement. The distribution and provenance of these, shown in Figure 5, gives only a general indication of ice-movement directions because the outcrops of bedrock source areas are usually extensive, but the pattern is the same as that shown by till lithology.

Glacial striae provide a more detailed picture in some areas, but they are either absent or inaccessible in others (see Map 15-1973). Along the north shore of St. George's Bay, crossing glacial striae are interpreted as indicating an early ice movement ranging from the east and southeast to west and northwest, succeeded by movements towards the southwest and south (Brookes, 1970). The latter movements are related to a change in the orientation of the ice front, from generally north-south trending at the maximum, to generally east-west trending off the north shore of St. George's Bay, as a calving bay developed during deglaciation. The distribution of erratics around the north shore of St. George's Bay can also be better understood by reference to this change in ice-flow directions.

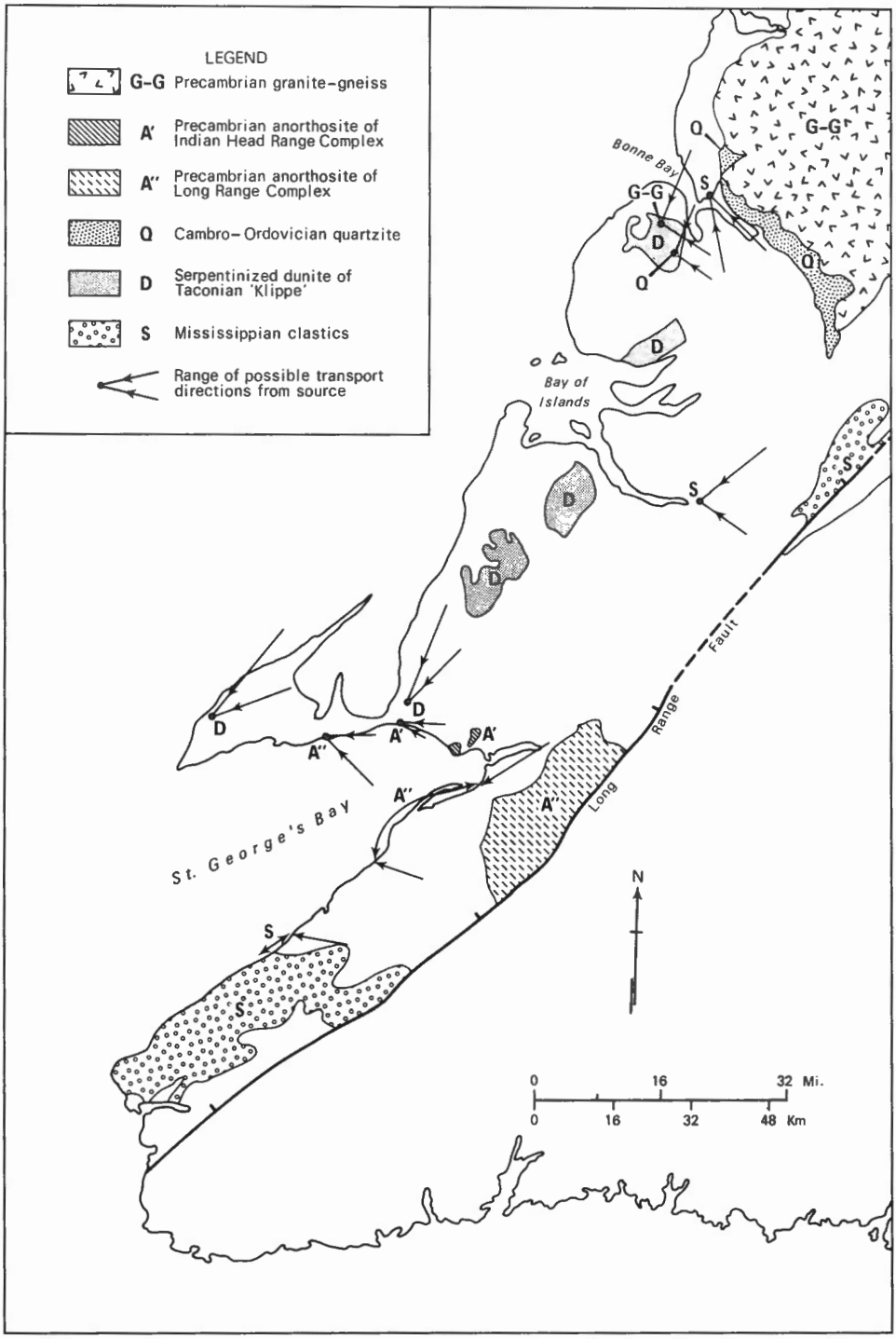

Figure 5. Provenance of glacial erratics in southwestern Newfoundland.

In the Trout River - Bonne Bay area, striae have been found only in valley-side situations and thus, by themselves, can be expected to indicate late-glacial flow directions; but, from studies of till lithologies and erratic provenances, an earlier pattern can be reconstructed. On the sides of fiords and the through-valleys of Trout River Gulch and Trout River Ponds, north and south of Table Mountain respectively, striae show ice moving towards the sea. On the east side of East Arm, Bonne Bay, the Carboniferous derivation of till associated with striae parallel to the valley indicates that this down-valley movement was characteristic of the main stage of the island ice cap, at least near the base of the ice. Precambrian granite-gneiss and Paleozoic quartzite erratics atop Table Mountain were probably also derived from the southeast, although the nearest source is to the east. The striae along the east side of East Arm, and along the Wiltondale - Rocky Harbour road indicate that, following the main northwestward movement, ice flow became progressively more normal to the fiord-side as the sea calved the fiord glacier inland, leaving ice masses isolated on surrounding highlands.

A further conclusion to be drawn from the presence of southeasterly-derived erratics on Table Mountain, Bonne Bay, is that they were moved at least 350 feet vertically over a maximum transport distance of 25 miles. Hence, this plateau at 2,500 feet, standing at least 300 feet higher than the plateau east of Grand Lake above which the ice divide probably lay, did not act as an ice outflow centre at the last glacial maximum. In fact, till lithology around the eastern margin of this block, though only poorly known, suggests that even in late-glacial times, ice did not actively flow far from the margins of the plateau. It is more probable that with the deglaciation of fiords in the Bonne Bay area, and by extension in the Bay of Islands, the westernmost plateau surfaces emerged from the ice at 2,000 - 2,500 feet and active ice remained in deep peripheral valleys and cirques before stagnating.

Till fabric was analyzed at three sites around St. George's Bay and at two sites on South Arm, Bonne Bay. In the former area, the two fabrics from the north shore of the bay indicate that pebbles were oriented by the final ice movement over the sites, since they do not conform to the known west-east movement of the maximum glaciation (see Map 15-1973). In Bonne Bay, the expectable down-valley ice movement is indicated.

No terminal features have been found within till of the St. George's River Drift. It is concluded, therefore, that the margin of the Newfoundland Ice Cap stood some distance offshore on the present floor of the Gulf of St. Lawrence. For any reasonable ice-surface profile to be drawn over the glaciated summits of the 2,500-foot plateau north and south of Bay of Islands, the ice margin must have stood near the edge of "Esquiman Channel" in the Gulf of St. Lawrence. Shearer (pers. comm.) has identified a possible end moraine in this position from air-gun reflection profiles through bottom sediments.

The presence of apparently fresh erratic boulders on the highest summits in the area, and the corollary that active ice transported them there, adds a point to the debate over the origin of extensive blockfields on such summits. Actively forming blockfields are best developed over plateaux that are only thinly vegetated and underlain by well-jointed, strong rock. Such plateaux are seen in the massifs north and south of Bay of Islands underlain by serpentinized dunite, the Mg-rich composition of which is toxic to plants; also on Gros Morne (2,644 feet) and other sterile Cambrian quartzite

summits north and east of Bonne Bay. These erratic-covered, active block-fields could have begun to develop in this area about 12,000-14,000 years ago.

THE BAY ST. GEORGE DELTA AND GLACIOMARINE OVERLAP

General Description

Although raised marine landforms are remarkably well developed in isolated coves, most evidence of marine overlap in western Newfoundland comes from the sediments themselves. Following deglaciation in this region, the sea flooded a narrow strip inland of the present coast to an elevation of up to 140 feet in St. George's Bay, 160 feet in Bay of Islands and to 230 feet near the mouth of Bonne Bay. At the head of St. George's Bay "late" ice delayed overlap until the sea had regressed to 100 feet near Stephenville. In places around the north and east shores of St. George's Bay, readvancing ice has obliterated most of the landform evidence of the earliest invasion of the sea, leaving regressional marine terrace features close to 85 feet high at the junction with the end moraine of the readvance.

The sedimentary record of glaciomarine overlap is best preserved in basal, shelly, marine clays and silts and in an overlying deltaic unit around St. George's Bay, in isolated coves on the Port au Port Peninsula, and in Bay of Islands and Bonne Bay. Along straight sections of steep, bedrock coastlines, evidence of overlap is restricted to wave-washed till surfaces with winnowed boulders. An upper limit of marine action is usually only faintly discernible as a junction between such surfaces and more irregular, unwashed till.

Where thick marine sediments overlie St. George's River Drift the surface of the drift is gently undulating (Fig. 4). The marine sequence typically begins with a 1 to 2-foot layer of current-winnowed till or kame gravel over which lie up to 10 feet of massive, blue-black, occasionally red-brown, clay and silty clay with shells of marine pelecypods, gastropods, and barnacles. An echinoderm test was found in this clay at Benoit's Cove, Bay of Islands, and lobster 'claw' fragments were recovered there and at Lark Harbour on the same bay. These basal clays frequently contain numerous pebbles and pieces of till that indicate the presence of icebergs or ice shelves during deglaciation.

These marine sediments are typically overlain by, but may be replaced by 3 to 10 feet thick rhythmites of silty clay and sandy silt, which are interpreted as delta bottomset beds. They are never as rich in fauna as the massive sediments and contain much less till material. The colour of the sediments closely reflects that of the underlying till, further confirming origin by fluvial transport. These deposits are fine grained and thick in the hollows, and thin and coarser grained on the hummocks of the till surface. Above them is a thicker unit of delta foreset beds which, where the original delta surface is intact, are capped by subhorizontal topsets or terrace gravels. These coarser sediments have yielded marine shells in only a few localities. Around St. George's Bay the delta unit is a composite of many delta segments built into St. George's Bay by rivers draining an ice front only one quarter to one mile from the present shoreline. Modern rivers such as Crabbes Brook and Robinsons River are descendants of these, incised through surficial deposits into bedrock channels.

TABLE 1. RADIOCARBON DATES FROM SOUTHWESTERN NEWFOUNDLAND

Locality	Latitude Longitude	GSC Lab. No.	C^{14} Age (yrs)	Material	Collector	Elevation (ft)	Elevation (metres)	Marine Limit (ft)	Marine Limit (metres)
Highlands*	48° 10' 58° 56'	598	13,420±190	Shells; *Macoma calcarea*	B	12	3.7	85	26
Robinsons Head*	48° 15' 58° 47'	1200	13,500±210	Shells; *Macoma calcarea*	B	116	32.4	140	43
Robinsons Head*	48° 15' 58° 47'	1350	10,600±150	Bog-bottom plant detritus	P	93	28.4	140	43
St. George's* (Turf Point)	48° 26' 58° 28'	1145	7,340±220	Bog-bottom plant detritus	B	0	0	85	26
Abrahams Cove*	48° 13' 58° 55'	968	13,600±180	Shells; *Hiatella arctica*	B	20	6.1	140	43
Abrahams Cove*	48° 13' 58° 55'	1074	13,700±230	Shell fragments	B	134	41.0	140	43
Port au Port*	48° 34' 58° 43'	1187	13,400±290	Shells; *Balanus* sp.	S	6	1.8	130	40
Rocky Point* (Port au Port Bay)	48° 39' 58° 58'	937	13,200±220	Shells; mainly *Mya arenaria*	S	12	3.7	100	30
Little Port	49° 07' 58° 25'	1462	12,000±320	Shells; *Mytilus edulis*	B	125	38.2	155	47
Cox's Cove (Bay of Islands)	49° 07' 58° 05'	868	12,600±170	Shells	P	110-120	35.0	160	49
Bonne Bay	49° 27' 57° 45'	1575	10,500±300	Shells; *Macoma calcarea*	B	12	3.7	115-140	35-43

Collectors: B – I.A. Brookes; P – V.K. Prest; S – J.M. Shearer.
* Locality in Stephenville map-area.

Detailed Sections

Radiocarbon dates from marine sequences in southwestern Newfoundland are shown in Table 1, together with the relevant information pertaining to them. Some of these sections were described and conclusions were drawn by Brookes (1969). These dated and other undated sites will be described below (from south to north) and conclusions drawn about the nature of marine overlap.

Highlands, St. George's Bay

The Quaternary deposits and landforms at Highlands, St. George's Bay, are shown in the inset of Map 15-1973. Bedrock is overlain by St. George's River Drift till, above which fine-grained marine deposits enclose shells, C^{14}-dated at 13,420±190 years B.P. (GSC-598). This date refers to the onset of marine overlap and registration of a marine limit. Delta bottomset and foreset beds succeed the shell-bearing sediments vertically. The latter are overlain by coarse gravels in the cliff top at 85 feet above HHWL[1], but over a short distance along the cliff face the foresets are overlain by pinkish lodgement till which builds a moraine ridge approximately at right angles to the coast. The flanks of the moraine have been washed by waves that winnowed boulders from the till matrix when sea level stood at 85 feet. The relation of the 85-foot terrace set into the delta foreset beds to the wave-washed till at the same level indicates that the building of the moraine ridge was contemporaneous with a sea level stand at 85 feet. This is the highest level at which evidence of marine activity is seen today because evidence of higher marine features has been obliterated by readvancing ice. This situation is related to that seen in the Robinsons Head section described below, where shelly clays occur to 116 feet, and possible delta foresets occur to 145 feet, but the terrace contemporaneous with the Robinsons Head Drift and moraine is at 85 feet. Local differences in the depth to which readvancing ice affected marine sediments account for the differences in stratigraphy between Highlands and Robinsons Head.

Robinsons Head, St. George's Bay

Quaternary deposits and landforms at Robinsons Head are shown in the inset of Map 15-1973. Due to a rise in the bedrock surface St. George's River Drift deposits are higher here than elsewhere around St. George's Bay. Shells in silty clay above these glacial deposits are found at 114-116 feet above HHWL, and the date on them of 13,500±210 years B.P. (GSC-1200) probably refers to the first invasion of the sea. Sediments above the shelly layer up to 145 feet bear some resemblance to delta foresets but it is difficult to be more positive about their origin; if they are delta foresets, the marine limit stands close to 145 feet. Above these beds, the sediments abruptly change to cobbly kame gravels with pockets of sandy till, representing a return of ice-marginal conditions as far as the present coast at the Robinsons Head Drift stage (Fig. 6).

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[1] High high water level.

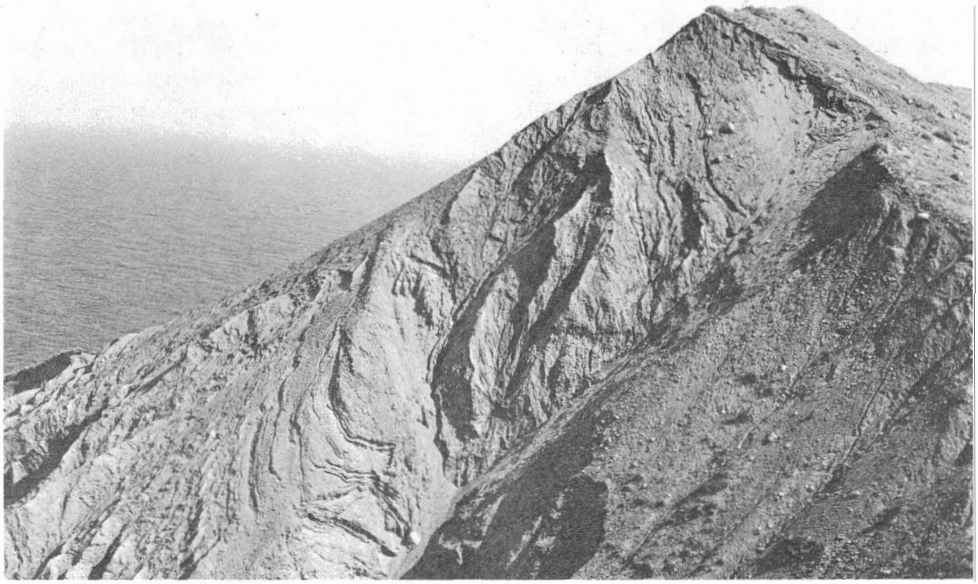

Figure 6. Landward-dipping kame sediments of Robinsons Head Drift end moraine at Robinsons Head. GSC photo 202291.

At Stinking Cove, about 500 feet to the north of the section from which the shells were recovered at Robinsons Head, plant debris from the basal inch of a 2-foot layer of peat 90 feet above sea level was dated at 10,600±150 years B. P. (GSC-1350). The debris contains transported fragments of vascular plants and mosses of tundra affinity. The peat layer overlies grey marine clay assumed to belong to the same unit from which the shells were recovered. For organic deposition to have occurred here, sea level must have fallen from its highest stand of at least elevation 115 feet (and possibly 145 feet) above sea level, attained 13,500±210 years B. P., to below 90 feet before 10,600±150 years B. P.

Turf Point, St. George's, St. George's Bay

At this locality, where the aerial bucket line of the Flinkote Company crosses the east side of St. George's harbour, waves are eroding the seaward side of a peat bog developed on top of the St. George's River Drift till. The base of the bog is at mean tide level. From a sandy layer between till and peat, plant detritus has yielded a C^{14} date of 7,340±220 years B. P. (GSC-1145). For peat growth to begin at this site, sea level must have fallen below its present level during regression from the marine limit. That the bog is presently being eroded by the sea suggests that peat accumulation occurred during an interval when sea level was lower than present, probably as the sea was slowly rising from a low stand, when isostatic rebound had slowed to less than the rate of eustatic sea level rise. The C^{14} date provides a theoretical maximum age for the regression of the sea below present sea level.

Harrys River Lowland

In the lower part of the Harrys River lowland, northeast of the head of St. George's Bay, wide glaciofluvial outwash terraces, built of torrentially-bedded, cobbly gravel, flank the eastern edge of the Indian Head Range. They occupy a distal situation with respect to end moraine fragments of the Robinsons Head Drift near Black Duck, and the proximal margin of the uppermost terrace merges with the distal end of an esker complex. The uppermost terrace is contemporaneous with the end moraine-esker complex; it must be at least partly estuarine in origin and related to the onset of marine overlap in this lowland. Certainly, the arcuate bluffs bounding successively lower terraces west of Harrys River and the abrupt change in stream directions at those bluffs suggest estuarine channels initially prograding, and later incising, themselves as sea level fell. No undoubted marine features have been identified in the lowland, but it is concluded that sea level must have been at about elevation 120 feet where it is marked by the proximal edge of the highest terrace near Long Gull Pond, and at which time the ice margin stood near Black Duck and "dead-ice" moraine was deposited.

Abrahams Cove, St. George's Bay

The Quaternary deposits and landforms at Abrahams Cove are shown on Map 15-1973. The dates of 13,600±180 years B. P. (GSC-968) for the lower part of the marine sequence and 13,700±230 years B. P. (GSC-1074) for the upper, show that as the island ice cap receded northward across the present shoreline, late-glacial marine waters flooded the cove to an elevation of 140 feet. The comparability of the two dates points to an important fact relating to glaciomarine overlap in this area, namely, where datable materials cannot be found close to the marine limit, a date on the more abundant shells in the basal marine sediments may serve to fix the age of the maximum overlap. The marine sequence may be viewed as a penecontemporaneous wedge of sediment deposited rapidly into the sea upon the flooding of an isostatically-depressed area.

Port au Port, Port au Port Bay

The map inset shows the Quaternary deposits and landforms at Port au Port. The sandy transition layer above the till contains cobbles on which scars of barnacles are preserved; barnacles are also abundant throughout the sand. Barnacle scars are found on only one side of the cobbles suggesting that the animals grew on the underside of cobbles embedded in the base of floating glacier ice. The cobbles fell to the sea floor as the glacier melted and became incorporated in current-winnowed glacial till.

The marine limit at Port au Port is tentatively placed at 130 feet as a junction between wave-washed and untouched till. A prominent raised delta, kettled on the St. George's Bay side, abuts against the wave-washed till slope at 115 feet. Delta building was evidently delayed here until sea level had fallen 15 feet after deglaciation. Perhaps the delayed availability of a meltwater stream was responsible for this.

A date of 13,400±290 years B. P. (GSC-1187) on barnacles in the sand at the base of marine sediments suggests that delayed deglaciation might explain the difference between the marine limit elevation here and at Abrahams Cove, but the positions of all radiocarbon-dated sites with respect to the

direction of regional isostatic tilt must be known before positive conclusions can be drawn on the influences of deglaciation date and isostatic tilt on marine limit elevations.

Tea Cove (Rocky Point) West Bay, Port au Port Bay

The map inset shows the Quaternary sediments and landforms at Tea Cove, West Bay, Port au Port Bay. The stoniness of the basal marine deposits and the abundance of barnacles in them indicate the presence of floating ice masses over the site during the early part of marine overlap, but the deposits are limited and no delta was constructed. Shell fragments from 10 feet elevation in a 6-foot-thick band of marine clay overlying bedrock yielded a C^{14} date of 13,200±220 years B. P. (GSC-937). Small and faint beach ridges near the 100-foot level are identifiable on a till-covered knoll on the south side of the valley of Lourdes Brook. The restriction of high-level marine features in Port au Port Bay to the Tea Cove and Port au Port shell localities suggests that the bay was largely ice-filled at the time marine overlap was initiated in the south. With the northern end of the bay blocked by the receding glacier, the sea could only enter the bay near the two shell localities. At Tea Cove the sea entered from the west through the Lourdes Brook depression, and at Port au Port entered from the south across the gap now blocked by a modern tombolo bar.

Rope Cove Brook and vicinity, Gulf of St. Lawrence shore

The northwestern edge of the Lewis Hills drops steeply from 2,000 feet to hummocky morainic terrain at the mouth of Rope Cove Canyon. Seaward of this moraine, a wide outwash fan slopes gently to the top of a wave-cut bluff, the foot of which is at 130 feet above HHWL. This is the marine limit. Seaward a beach-ridged marine plain slopes to the top of the modern cliffs at 40 feet above sea level. Because of the general northeastward rise in the elevation of marine features in western Newfoundland, a limit higher than around St. George's Bay would be expected; however the relatively low elevation of the marine limit at this site suggests that deglaciation was delayed here, but no C^{14} dates are available to prove this assumption.

Lark Harbour, Bay of Islands

At Lark Harbour (north of map-area) on the east side of the promontory at the mouth of Bay of Islands and on the west side at Bottle Cove and Little Port, marine features are preserved in the seaward ends of lowland passes between high bedrock hills, and on exposed headlands at the entrances to these inlets (Fig. 7). At the heads of the inlets, shelly marine silts and clays occur up to 15 feet above sea level. At Lark Harbour village and between Bottle Cove and Little Port, delta foreset beds overlie these bottom sediments and form terraces that near Little Port, attain an altitude of 155 feet at the junction with a talus accumulation. From foreset beds at this latter site shells at 120 feet have been dated at 12,000±320 years B. P. (GSC-1462), and this is interpreted to be the age of the 155-foot marine limit. If this date can reliably be accepted as somewhat younger than that of 12,600±170 years B. P. for the 160-foot marine limit at Cox's Cove (see page 18), there

must have been some delay in deglaciation on the promontory at the mouth of Bay of Islands. Perhaps this may be attributed to ice lingering in the constricted valleys between the high hills of the promontory. In a fiord site such as Cox's Cove, the sea may have floated a glacier tongue into the fiord, permitting a molluscan fauna to colonize bottom sediments before ice actually left the immediate area of the fiord. But, in the Little Port area, foreset beds could not be deposited until ice had cleared the area.

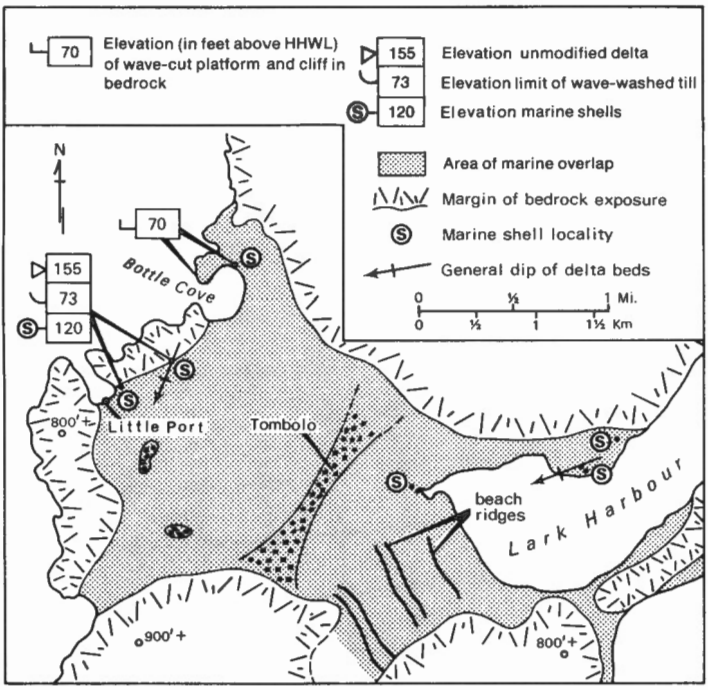

Figure 7.
Postglacial marine features in the Lark Harbour - Little Port area.

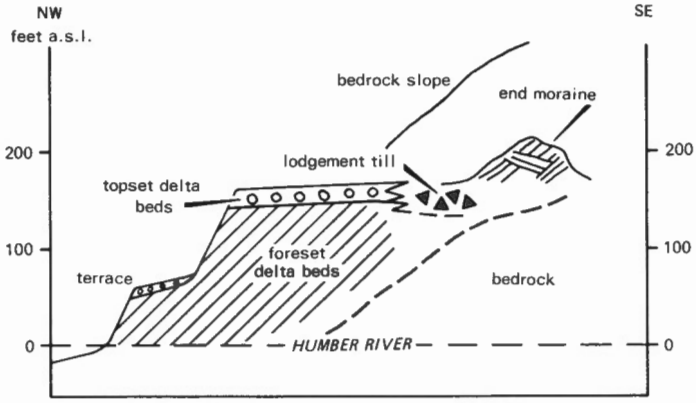

Figure 8.
Relation of glaciomarine delta and end moraine at mouth of Humber River, near Corner Brook.

Humbermouth, Corner Brook, Bay of Islands (east of map-area)

At the mouth of the Humber River, just east of Corner Brook, large fragments of a raised delta are preserved on each side of the head of Humber Arm. The surface of the delta is at 160 feet above HHWL and on the south side of the arm, the foresets were seen interfingering with massive lodgement till. The proximal edge of the delta surface on the north side of the mouth of the Humber River stands against an end moraine ridge in which ice-contact stratified sands and gravels are exposed (Fig. 8). These relations indicate that the snout of a valley glacier in the Humber Valley stood near the fiord head when a proglacial delta was being built into the sea at 160 feet. No dates are available on the feature but the fiord situation, and similar elevations of the marine limit here and at Cox's Cove, suggest an age of approximately 12,600 years B.P.

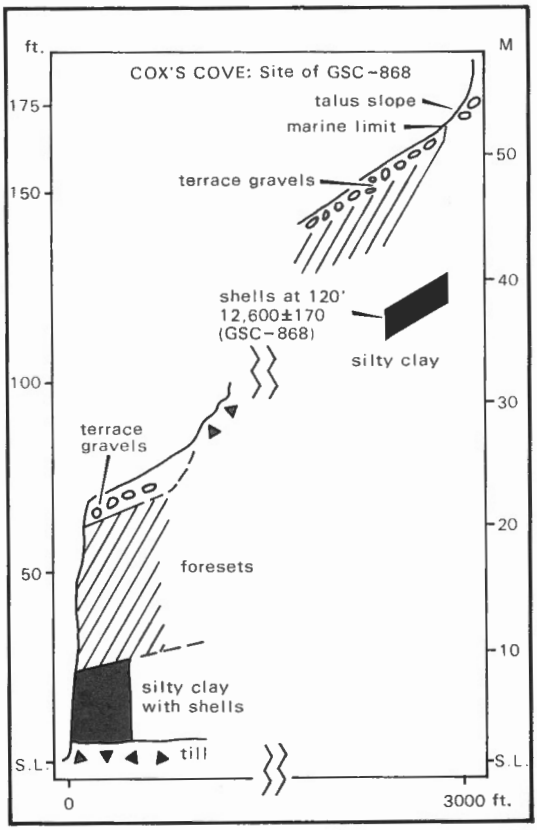

Figure 9. Quaternary stratigraphy at Cox's Cove, Bay of Islands.

Cox's Cove, Middle Arm, Bay of Islands

At Cox's Cover (north of map-area) Quaternary deposits once partially filled the lower part of a valley, cut in bedrock and leading into a fiord (see Fig. 9). During the fall of sea level from the marine limit these deposits were eroded and terraced so that they are now visible in separate exposures along the present shoreline and 3/4 mile inland.

The marine limit stands at 160 feet above HHWL and shells in laminated silts and clays at 110-120 feet have been dated at 12,600 ± 170 years B.P. (GSC-868). Similar shelly clays overlie a dark grey till near sea level along the shoreline. The date shows that deglaciation of this fiord was delayed by up to 1,000 years after development of the St. George's Bay shorelines. This delay is considered the result of activity of the valley glacier which was in closer proximity to an area of active outflow.

Trout River

A remarkable flight of ten raised marine levels is preserved at Trout River (north of map-area) eight miles along the coast south of Bonne Bay (Fig. 10). Glaciomarine sedimentation occurred around the lower slopes of hills following the retreat of ice inland from Trout River along major northeast- and southeast-trending topographic lows. The southeast valley, now occupied by Trout River Pond, was a salt-water fiord shortly after ice first cleared the coastline; a delta was built at its head, 11.5 miles from the present coast.

The marine limit in the Trout River area has been identified, with some uncertainty, at 230 feet at the foot of a low bluff against the distal side of an end moraine northeast of the village. Elsewhere in the area, this elevation is in thickly wooded terrain not amenable to survey, or lies against steep bedrock slopes where no landform is preserved if ever one was formed. Deposits of the end moraine, exposed in three small pits, indicate dead-ice conditions; kames were deposited and the associated topography is gently hummocky. On the basis of topography, the moraine can be tentatively extended to the northwest and southeast, as shown in Figure 10.

Raised marine levels below the marine limit at Trout River take the form of low bluffs cut in till at 195, 180, 157 and 130 feet, below which is the most prominent level at 115 feet, a wide delta surface. The delta is evident

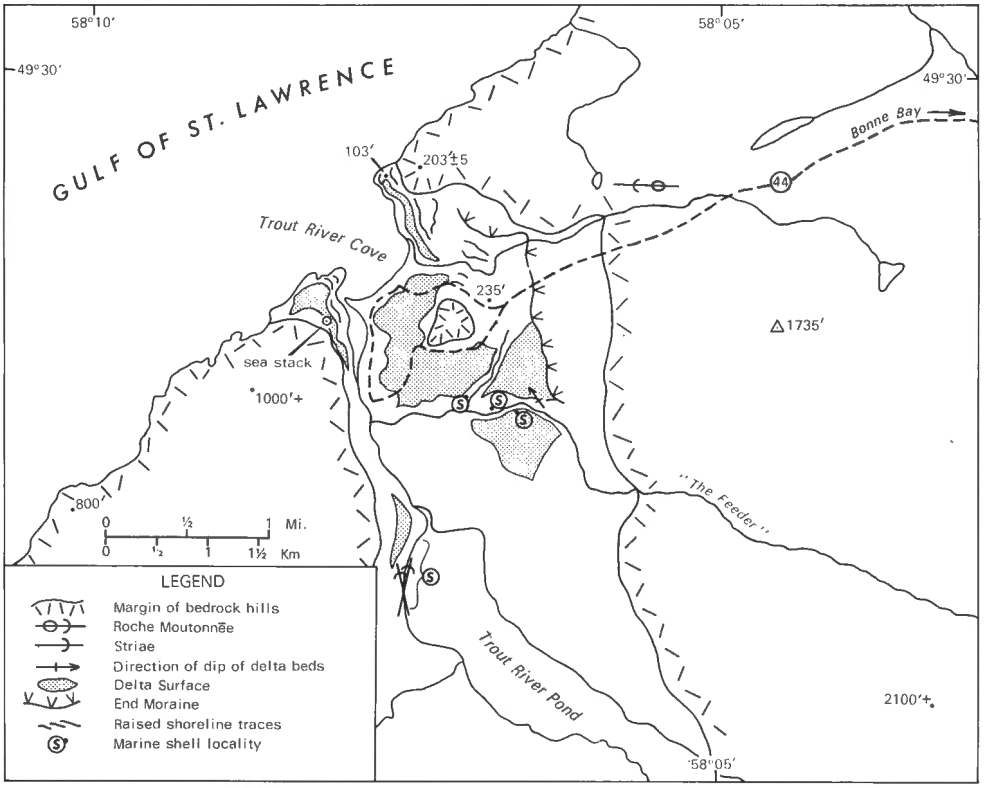

Figure 10. Glacial and raised marine features at Trout River.

around Trout River Cove but it is also represented at higher elevations farther inland. From the dip of foreset beds it appears that the stream entering Trout River from the east, and that entering the cove from the east, were responsible for building the delta. The present Trout River is, therefore, a recent stream cut through the delta, leading the waters of Trout River Pond to the sea. The stand of sea level at 115 feet is suggested to have been a major regressional stillstand, as a sea stack and wave-cut caves occur in friable bedrock at the back of the delta on the south side of the village. Below this level, minor regressional stands are marked by platforms around the cove and depositional terraces along Trout River at 85, 75-79, 69, 47, and 35 feet.

Marine shells are abundant in clay, silt, and sand deposited at or near the base of the deltaic wedge which is presently exposed at the northwest end of Lower Trout River, known locally as 'The Feeder'. At the head of the Upper Pond, 11.5 miles from the coast, a delta terrace is well exposed in a cliff section one mile up Middle Trout River, but only surface finds of marine shell fragments were made there. This feature is concluded to be of marine origin since it is improbable that sea birds or any other agent would have transported these fragments so far inland. The elevation of this terrace was not surveyed, but from a topographic map it is near the 200-foot contour.

Bonne Bay

Bonne Bay (north of map-area) is a magnificently scenic fiord with two arms joining to form a deep, two-mile-wide entrance to the open sea. The maximum depth is 750 feet in East Arm, and its eastern-shore mountains rise to 2,200 feet. Raised marine deltas are excellently preserved where larger modern streams enter the bay, commonly building their own deltas below the raised ones. The lodgement till is overlain by massive and/or laminated, shell-bearing, fine-grained sediments which are, in turn, overlain by delta foreset gravels that are poorer in shells. The highest part of a delta at 230 feet above sea level was located above Horseback Brook at the head of South Arm. In other places, deltas slope up gently into terrain which prevents accurate identification or survey of their higher reaches.

Between these deltas, along the west side of South Arm, marine landforms are only poorly defined as discontinuous wave-worn bluffs on a steep, till-covered slope. At Woody Point shorelines were located at 35, 70, 100, 135, 200, and 235 feet on a single traverse but sea levels possibly lie within 5 feet of each of these elevations through the entire settlement.

Near Lomond on the west side of East Arm, Bonne Bay and near its head end, shells from silt and sand rhythmites near present sea level have been C^{14}-dated at 10,500±300 years B. P. (GSC-1575; see Table 1). These sediments are overlain by delta foreset beds which have been truncated by a regressional terrace rising from 85 feet above the shoreline to 105 feet inland. The marine limit has been vaguely located at 115 feet where bouldery till has been wave-washed to leave a lag deposit, but it might stand 25 feet higher on the till slope where surface till boulders are less easily identifiable as wave-winnowed.

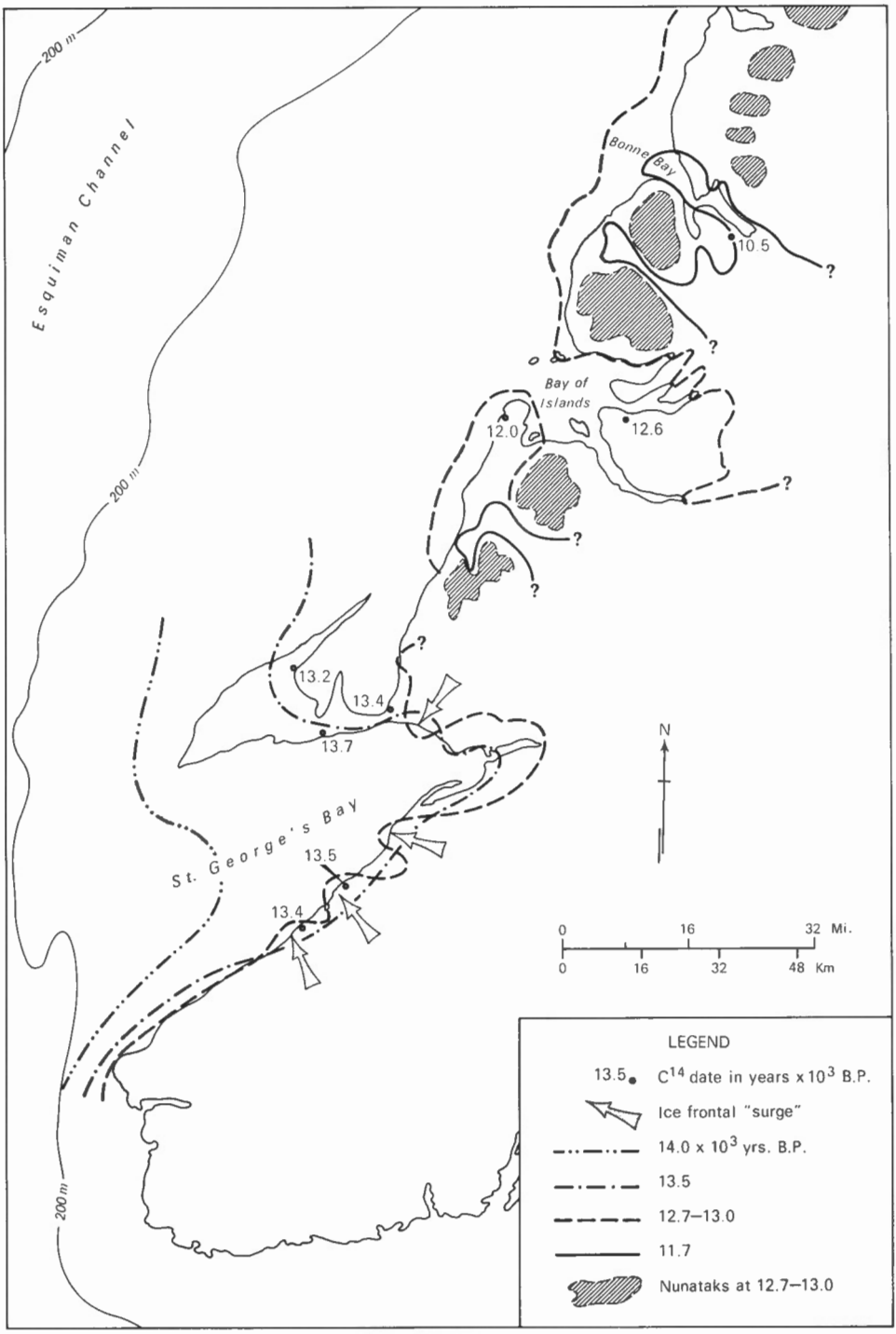

Figure 11. Speculative ice-marginal positions during deglaciation of south-western Newfoundland.

Summary

Upon deglaciation of a narrow coastal zone of western Newfoundland, the eustatically-rising waters of the Gulf of St. Lawrence overlapped the surface of an isostatically-depressed, but probably rapidly-uplifting land area. This overlap occurred at about 13,500 years B.P. to heights between 100 and 145 feet around St. George's Bay where a gently sloping ice margin had calved into a bay that opened southwest to the deep Laurentian Channel (Fig. 13). In Bay of Islands the sea did not flood the deep fiords until 12,500 years B.P. because glacier tongues were more active, being confined in valleys close to ice-dispersal areas; the marine limit is between 155 and 165 feet around this bay. Farther north at the mouth of Bonne Bay the marine limit was emplaced at 230 feet, but this event has not been dated. The head end of Bonne Bay, however, was not deglaciated until about 10,500 years ago by which time relative sea level had fallen to between elevation 115 and 140 feet. The 2,000-year delay in deglaciation between here and Bay of Islands is attributable to the strength of ice flow northwestwards from the Topsails Plateau, east of Grand Lake, through the relative topographic low between the Long Range and the Table Mountain-North Arm Mountain block.

The time-transgressive nature of deglaciation in western Newfoundland makes it impossible to determine directly the regional pattern of postglacial isostatic warping. Uplift curves are required for representative localities widely spread over the area before this complication can be eliminated. A hypothetical approach to the problem is offered in the section on glacio-isostatic rebound.

ROBINSONS HEAD DRIFT

The Nature and Extent of the Drift

The name "Robinsons Head Drift" was given by MacClintock and Twenhofel (1940) to a sheet of coarse till and ice-contact stratified deposits spread over the hinterland of St. George's Bay, with an outer limit marked by a kame moraine intersected in several places by the coastal cliffs. The moraine was identified as marking the limit of an advance of a lowland ice mass across a sea floor when sea level stood higher than at present. The drift sheet behind it was deposited during the retreat of ice inland into the plateaux surrounding St. George's Bay. These general conclusions are borne out by recent investigations and will be amplified here.

The drift comprises a coarse, loosely-structured till of englacial and supraglacial origin. Silt and clay content in the deposits is less than ten per cent due to the washing out of this fraction by meltwaters. Ice-contact stratified drift is also abundant in the form of kames, eskers, and sporadic outwash, particularly closer to present river valleys which follow courses inherited from outwash streams.

Deposits of the kame moraine marking the limit of the Robinsons Head Drift are stratified gravel and sand with minor silt and small irregular bodies of till. At Robinsons Head, the proposed type section for this unit, kame sand and gravel layers dip inland towards a kettle depression behind the 250- to 350-foot-high cliffs (Fig. 6). In places, as at Bank Head, the till in the moraine is dark grey and contains much more silt and clay than the

drift behind the moraine. This is due to the inclusion of grey-black marine silt and clay as the ice moved across the sea floor. At Harbour Head, marine delta foreset beds are overlain by a pink-grey lodgement till, indicating active ice flow across and into marine sediments.

Outside the St. George's Bay hinterland, lowlands and low dissected plateaux are thinly mantled with a generally coarse till, mostly of local derivation. In a few isolated localities terminal features are seen that are related to this drift sheet and they each mark a minor stillstand in ice retreat associated with the onset of marine overlap. These moraines are found (i) at the foot of the northwestern edge of the Lewis Hills, west of Serpentine Lake; (ii) inland of the curve of York Harbour, Bay of Islands (these being parts of one discontinuous morainal system); (iii) at the head of Humber Arm, Bay of Islands where an end moraine stands at the proximal edge of a glaciomarine delta at 160 feet (Fig. 8); and (iv) at the southwestern end of a valley leading into the cove at Trout River from the northeast, where a hummocky kame moraine stands immediately inland of the 230-foot marine limit (Fig. 10). The lower Humber end moraine is dated at about 12,600 years B.P. by reasoning that the associated delta, at 160 feet elevation, is also the same age as the marine limit at Cox's Cove (12,600±170 years B.P. - GSC-868).

The Relation of the Drift to Marine Overlap

Around the shores of St. George's Bay, east of Port au Port, the relationship between marine and younger glacial deposits is distinctly different from that found farther north in the area. Where the coastal cliffs of St. George's Bay are cut back into the lobate margin of the Robinsons Head Drift, there is good stratigraphic and topographic evidence bearing on the relation of the marine transgression and the succeeding glacial event. In the Robinsons Head area shelly marine silts occur up to an elevation of 116 feet, and overlie ice-contact stratified deposits of the St. George's River Drift. Shells from this layer are dated at 13,500+210 years B.P. (GSC-1200). Seaward-dipping, stratified sands and fine gravels overlie the shelly layer and it is possible, though not certain, that these are glaciomarine delta foreset beds. If they are marine, overlap can be extended up to 145 feet elevation – an altitude that accords well with marine limit determinations farther north near Bank Head and along the southern shore of the Port au Port Peninsula. Above these sands, kame gravels and pockets of coarse till of the Robinsons Head Drift extend to the cliff top at near 200 feet elevation (see inset on Map 15-1973).

At Jeffreys, one mile south of Robinsons Head, the same end moraine stands at 85 feet on the inland margin of a terrace set into the Bay St. George Delta. This terrace is prominent all along the east shore of St. George's Bay from Highlands to St. George's. The terrace is neither cut into nor overridden by the moraine and thus represents a regressional stillstand of sea level contemporaneous with the building of the moraines. The stratigraphy and topography at these two sites indicates that while marine overlap attained at least 115 feet and possibly 145 feet, sea level had fallen to 85 feet by the time the ice advanced to the Robinsons Head Drift end moraine.

At Harbour Head, near Highlands, an end moraine lobe is cut by sea cliffs in which lodgement till can be seen overlying delta foreset beds. On either side of the moraine crest the till is bevelled by a terrace at 85 feet

which continues along the cliff top across the foreset beds of the Bay St. George Delta. Again, the contemporaneity of an ice advance and an 85-foot sea level is indicated.

Inland of Stephenville Pond, a wide, pitted delta surface at 95 feet above sea level stands in front of the kame-and-kettle end moraine of the Robinsons Head Drift. Here, however, no readvance is in evidence and no indication is found that the sea ever stood higher than the delta surface. Therefore, in this area at the head of St. George's Bay, it appears that deglaciation was delayed until sea level had fallen to 95 feet and when ice cleared this part of the coast, retreat was temporarily arrested. This allowed for the deposition of a proglacial marine delta contemporaneous with the advance that is well documented along the east shore of the bay. A proposed sequence of events for the Stephenville area is shown in Figure 12.

The glacial event marked by the continuous Robinsons Head Drift end moraine did not take the form of a readvance all around St. George's Bay. Where more subdued sections of the end moraine front on a delta, as at Stephenville, or on a terrace set into a delta, as at Jeffreys and Highlands, the ice margin perhaps was not active at the time the terrace was formed. Between these localities, however, where the seaward-projecting lobes of the moraine are markedly hummocky, a readvance is firmly documented by the

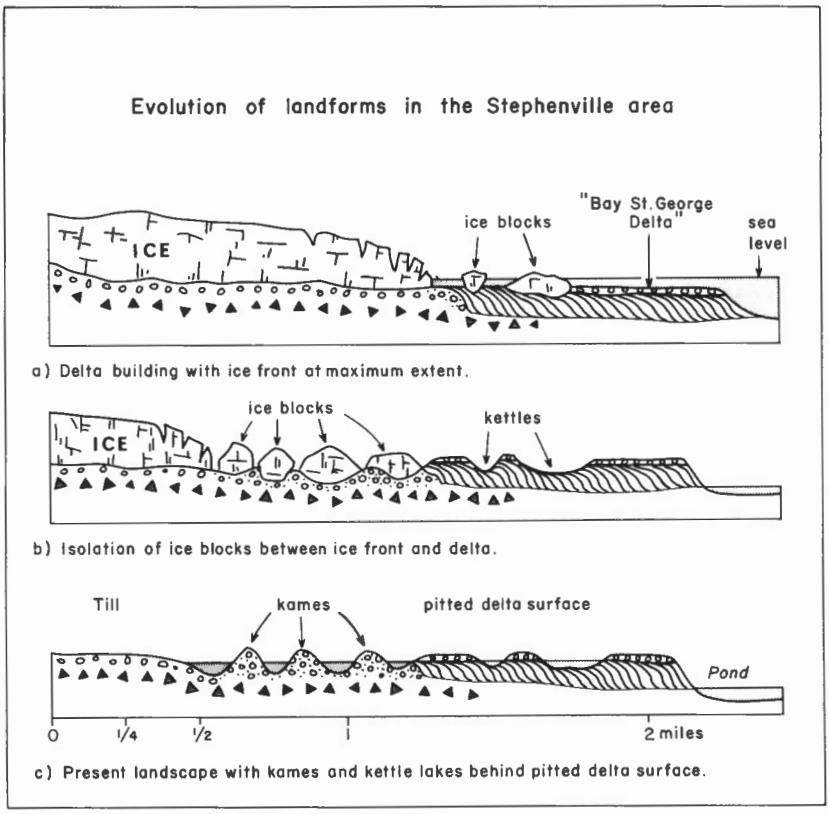

Figure 12. Evolution of glacial and associated landforms in Stephenville area.

occurrence of till and kame gravels overlying delta foreset beds. The ice, therefore, appears to have "surged" locally due to instability induced by the formation of calving bays along its front (Fig. 11).

No datable material has been recovered that would permit the precise age of the Robinsons Head Drift end moraine to be determined. At the north end of Robinsons Head, plant detritus from a thin gravel layer above marine clay at 90 feet above sea level is dated at 10,600±150 years B. P. (GSC-1350). This date provides a minimum age for the Robinsons Head Drift end moraine and the passage of sea level below 90 feet elevation, but consideration of postglacial uplift, to be discussed in the following section, enables the age of the moraine and associated terrace to be estimated at 12,500-13,000 years B. P.

North of St. George's Bay, several end moraine fragments stand at the proximal edge of raised marine features. There is no evidence that the sea was ever higher than the junction of each marine terrace and end moraine, indicating that each moraine represents a recessional stillstand of the ice front immediately after it receded inland of the present coastline. No readvances are evident in any of these localities.

The 160-foot raised delta at Humbermouth, Corner Brook, is interpreted here as contemporaneous with a feature at the same elevation at Cox's Cove, radiocarbon-dated at 12,600±180 years (GSC-868). The end moraine standing at the back of the Humbermouth delta is also of this age. The only other date bearing on the time of deglaciation between St. George's Bay and Bonne Bay is one of 12,000±320 years B. P. (GSC-1462) on shells from delta foresets relating to a marine limit at 155 feet at Little Port, near the mouth of Bay of Islands. At nearby York Harbour, an end moraine fragment cannot definitely be related to that date. If it is of the same age as the Little Port marine limit, it is necessary to consider the influence of "late" ice in the surrounding hills to delay marine limit registration for a minimum of 100 to 200 years, if not for about 600 years, after the sea had flooded Bay of Islands up to Cox's Cove and Corner Brook.

Although no radiocarbon dates are available on the other moraine fragments, those at the mouth of Rope Cove Canyon west of Serpentine Lake and at Trout River occur at the foot of high plateaux close to the present coastline, with marine features abutting on or close to their distal margins. A stillstand of an ice front can readily be envisaged in such situations where, having been calved eastward by the rising waters of the sea, irregular terrain immediately inland of the present coast arrested its orderly retreat. Stagnant ice conditions are attested to by kame-and-kettle moraine, and such conditions heralded the beginning of a general, down-wasting and recession of the land-based Newfoundland Ice Cap, and its break-up into smaller, separate masses. The influence of topography upon the regime of the glacier margin, would militate against simultaneous end moraine formation, but reasoning from rates of postglacial rebound and the altitudinal relations of end moraines to raised marine features, as discussed in the following section, provides some basis for assuming they are penecontemporaneous.

POSTGLACIAL CHANGES OF LEVEL

RAISED MARINE FEATURES

The form, location, and elevation of raised marine features are shown on Map 15-1973. The details of marine overlap and associated depositional conditions are discussed in the preceding section. In this section an attempt will be made to relate the elevation of marine features to the combined influences of time-transgressive deglaciation and postglacial isostatic warping.

The upper limit of postglacial marine submergence shows a general rise along the northeast-trending coast. Around St. George's Bay, the marine limit is at 140-145 feet at sites where deglaciation is dated at 13,700 years B. P., and at 95 feet where it is thought to be slightly younger. In Bay of Islands the marine limit at or near the heads of fiords stands at 160 feet, and is dated at about 12,500 years B. P. At Trout River and near the entrance to Bonne Bay the limit stands at 230 feet but has not been dated; near the head of East Arm, Bonne Bay, 13 miles from the open Gulf of St. Lawrence, the limit is at 115-140 feet and is dated at about 10,500 years B. P. Deglaciation of the present coast, therefore, occupied a 3,000-year interval. The effect of deglaciation date upon the amount of postglacial uplift can only be ascertained if the form of that uplift through that time can be determined.

Marine limit features are further restricted to a zone, the width of which, orthogonal to the general trend of the coast, is narrow relative to its length. Therefore, even where marine limits are demonstrated or argued to be of the same age, isobases cannot be constructed between them over any convincing distance.

Bearing these factors in mind, a first attempt can be made to determine an isostatic warping trend using the available field evidence. In Bay of Islands the marine limit at Cox's Cove, on Middle Arm, is at 160 feet and has been dated at 12,600±170 years B. P. (GSC-868). A delta terrace associated with an end moraine at Humbermouth at the head of Humber Arm, is at the same elevation and its age is thus presumed to be about the same. Therefore an isobase can be drawn tentatively between these two points in a northwest-southeast direction.

In St. George's Bay, there are only two sites where the marine limit is at the same elevation and of approximately the same age. These are at Abrahams Cove (140 feet, 13,700±230 years B. P. – GSC-1074) and south of Bank Head (delta surface sloping from 130 to 150 feet, presumed to be the same age as the marine limit at Robinsons Head: 13,500±210 years B. P. – GSC-1200). An isobase drawn between these two sites has the same orientation as that between the Bay of Islands sites, although the two pairs of sites differ in age by 1,000 years.

Regressional marine levels are not useful at present in determining the trend of isostatic warping. Features are abundant and occasionally well marked, but none are dated. The terrace fragments at near 85 feet around St. George's Bay are contemporaneous with the end moraine of the Robinsons Head Drift, but they do not differ sufficiently in altitude to permit a warping pattern to be recognized. In Bay of Islands, terrace remnants at 65-75 feet are the most prominent regressional features; they probably belong on a warped plane also occupied by the wide delta – rock platform feature at

115 feet at Trout River and by delta and washed-till limits at 120 feet in Bonne Bay. But again, the areal distribution of features is not great enough to permit an accurate isobase trend to be established.

GLACIO-ISOSTATIC REBOUND

The changing position of sea level relative to the land in the postglacial period is a result of two primary influences: isostatic rebound and eustatic sea level change. In a region such as western Newfoundland where ice thickness at the glacial maximum was sufficient to cause considerable isostatic down warping, deglaciation would be accompanied by rapid recovery of the land and a less rapid eustatic sea level rise. The net effect in the early postglacial interval would be for sea level to fall relative to the land.

In this area, no C^{14} dates have been obtained on sea level positions below the marine limit. Several are available on the limit itself, and two give a minimum age for the fall of sea level below certain elevations at the respective sites (Table 1). Without these dates, no uplift curves can be constructed, and it becomes impossible to account directly for the difference in deglaciation dates in the determination of an isostatic warping pattern.

From a hypothetical consideration of uplift, the age of early postglacial marine features can be approximated at particular sites. But even hypothetical uplift rates cannot be applied between a site deglaciated late and one deglaciated early because the form of restrained recovery beneath ice at the former cannot be assumed to be the same as early postglacial uplift at the latter. If it could, marine limit elevations at sites deglaciated late could be "adjusted" to elevations that would have resulted had they become ice-free simultaneously with the earliest. Isobases could then be constructed. All that can be attempted here is the tentative determination of the ages of selected regressional features, employing general conclusions about isostatic recovery and eustatic sea level rise.

From his analysis of many uplift curves constructed for sites in Arctic Canada, Andrews (1968) concluded that, while the dates of deglaciation and the amounts of total postglacial uplift are different at each site, the form of the uplift was very similar at each. The similarity was so great that he was able to tabulate the percentage of uplift in each 1,000-year interval of postglacial time in the following manner.

Time Since Uplift Began ($x10^3$ yrs)	Mean % Uplift Accomplished	% Standard Deviation
0	0	-
1	33.0	4.4
2	56.0	5.7
3	70.4	5.8
4	80.2	5.4
5	86.5	4.5
6	91.1	3.7
7	93.9	2.9
8	94.6	3.0
9	97.4	1.9
10	100	-

(Andrews, 1968, Table II, p. 42)

Although there is probably some error in the assumption that isostatic balance is attained in 10,000 years following deglaciation, the percentages for the early postglacial period would not be significantly different if the duration of uplift was extended. It is the early postglacial uplift rate which is of concern for the present purpose.

In order to date the regressional 85-foot terrace associated with the end moraine around St. George's Bay, the rate of relative sea level fall from the marine limit to that elevation must be known. At Robinsons Head, the marine limit at 145 feet elevation is C^{14}-dated at 13,500±210 years B.P. (GSC-1200). Total postglacial uplift has thus been equal to that figure plus eustatic sea level rise since that time, in other words, 145+215, or 360 feet. If, in the first 1,000 years after deglaciation, one third of that amount is accomplished, then the rate of uplift is 12 feet per century. Sea level rise in that interval (from Shepard, 1963 and Mörner, 1969) amounted to 4 feet per century. Therefore, sea level was falling relative to the land at the rate of 8 feet per century and would have fallen 60 feet from the marine limit 750 years after the onset of marine overlap, i.e. at 12,750±210 years B.P. (the standard error of the C^{14} date on the marine limit is applied here).

This age for the terrace and the associated end moraine around St. George's Bay is very similar to that of the marine limit at Cox's Cove, Bay of Islands and by extension, to the age of the end moraine and delta at Humbermouth, Corner Brook. Therefore, the tentative isobases that were drawn on marine limit features regardless of age in St. George's Bay and Bay of Islands in the previous section can be shown to hold good for a synchronous plane occupied by the marine-limit features at the head of Bay of Islands and the 85-foot regressional terrace around St. George's Bay.

Similar reasoning applied to the Cox's Cove site on Bay of Islands gives an age of 11,700±170 years B.P. for the 90-foot regressional terrace. This terrace belongs on the same plane as features that are prominent between 65 and 90 feet above sea level, on headlands and in coves all around this bay, but these features need to be levelled more accurately to permit isobases to be drawn on them.

No radiocarbon date is available on the 230-foot marine limits at Trout River and lower Bonne Bay. The date of 10,500±300 years B.P. (GSC-1575) at Lomond in upper Bonne Bay relates to a limit at 115 to 140 feet. It may also date the prominent regressional terrace at 115 feet at Trout River, which therefore would not belong on the same water plane as the most prominent regressional features in Bay of Islands as would have been first assumed. In fact if the 115-foot terrace at Trout River is 10,500 years old, it is the marine limit at 230 feet which would more likely lie on the 11,700-year-old plane.

The tentative reconstruction of a northeastward rise of early postglacial water planes in western Newfoundland raises a question about the distribution of the ice loads that depressed the surface during glacierization. It is unreasonable to postulate a thickening of ice in that direction from what is known of ice dispersal patterns at the last glacial maximum. Possibly, glacio-isostatic depression beneath a Newfoundland ice sheet was interfered with by depression beneath Labrador-derived ice in the Gulf of St. Lawrence, and the northeastward trend of upwarp in western Newfoundland results from interfering rebound fields.

SUMMARY: LATE-WISCONSIN GLACIATION OF SOUTHWESTERN NEWFOUNDLAND

During the last Wisconsin maximum the western part of the island of Newfoundland was covered by an ice sheet centred somewhat east of the Long Range Mountains. West of the mountains ice flowed towards the Gulf of St. Lawrence, moving over the 2,500-foot summits north and south of Bay of Islands, but was strongly channelled through topographic lows such as Bay of Islands and that leading into Bonne Bay. General till lithologies, till fabrics, the distribution of specific erratics, and the trend of striae and other related microfeatures, all taken together, provide strong evidence for this general concept. No evidence of impinging Labradorean ice was found, forcing an abandonment of earlier notions that such ice had any influence on the glaciation of western Newfoundland south of Bonne Bay.

At this stage, the margin of the island ice sheet probably lay parallel to the present coast, close to the edge of "Esquiman Channel" in the Gulf of St. Lawrence. No age for this maximum can be provided from evidence in this area, but it is reasonable to suppose that it was close in age to the terminal stand of ice on the Scotian Shelf, tentatively placed at about 19,000 years B. P. (King, 1969).

Overlying the till and ice-contact sediments related to this early episode, marine sediments in western Newfoundland record marine overlap of a narrow strip of the present coast after deglaciation. Radiocarbon dates on shells from the basal marine sediments indicate that this overlap was in progress 13,700 to 13,500 B. P. around St. George's Bay, where proximity to deep offshore water, a gently-shelving coast zone, and distance from ice outflow areas contributed to early overlap. In Bay of Islands, marine waters had flooded up to the heads of fiords by about 12,500 years B. P. The 1,000-year delay in this area was due to more active ice flow in confined valleys and closer proximity to highland ice dispersal areas. In Bonne Bay the head of East Arm was not ice free until 10,500 years B. P., which may be accounted for by the vigour of northwestward ice flow through the lowland inland of the bay.

Around St. George's Bay the upper limit of postglacial submergence varies in altitude from 95 to 145 feet where, due to glacier activity, local differences in the date of deglaciation and the general trend of isostatic warping interfere and thus complicate any interpretation of marine overlap. In Bay of Islands the limit is less variable at 155 to 165 feet, but in Bonne Bay a marked decline in its elevation is recorded, from 230 feet near the bay-mouth to 115 to 140 feet at the head of East Arm. Deglaciation appears to have generally been later towards the north of the area, and this has strongly affected marine limit elevations. This complication makes it difficult to construct isobases on the marine limit water plane. No uplift curves are available from the area that would allow this effect to be accounted for in the determination of an isostatic warping pattern.

Shortly after the onset of marine overlap around St. George's Bay ice returned to positions a little beyond the coast in several lobate "surges" across the floor of a regressing sea. The outer limit of this Robinsons Head Drift readvance is marked by a prominent kame moraine. Stratigraphic and topographic relations between the moraine and marine sediments, well exposed at several places around the bay, permit a time correlation of this readvance with a stillstand of sea level at 85 to 90 feet, some 50 to 60 feet

below marine limit. From a hypothetical consideration of the form of rebound in the St. George's Bay area, the moraine and the 85- to 90-foot regressional stillstand of sea level are tentatively placed at 12,750 years B.P. – approximately synchronous with the deglaciation of fiord-heads in Bay of Islands.

Marine limit features in Bay of Islands and features belonging to the 85- to 90-foot sea level plane around St. George's Bay may, therefore, be used to approximate the regional pattern of postglacial isostatic warping. The pattern shows a northeastward rise of 1.3 feet per mile on a plane tentatively dated at 12,600 to 12,750 years B.P. This trend is difficult to relate to the regional distribution of ice thickness over western Newfoundland at the glacial maximum. It might have resulted from the interference of two warping trends: that associated with a Newfoundland Ice Cap and that related to Labrador-derived ice in the Gulf of St. Lawrence. Whatever its origin, the isobases trend at 90 degrees to those tentatively drawn by Flint (1940), from which he concluded that Labrador ice had invaded western Newfoundland.

The hypothetical postglacial uplift rates, derived from the general conclusions of Andrews (1968), permit some conclusions to be drawn about the fall of relative sea level after deglaciation in this area. Those conclusions are supported in two cases where radiocarbon dates on bog-bottom material provide minimum ages for sea level positions. The most pressing requirement in this area is the derivation of uplift curves from radiocarbon dates on regressional sea level positions.

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