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QUATERNARY MAPPING, ROBERT'S ARM, LITTLE BAY ISLAND AND SPRINGDALE AREAS (NTS 2E/5, 2E/12 and 12H/8)

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ABSTRACT

Mapping of the Quaternary geology of the Robert's Arm, Little Bay Island and Springdale areas shows an ice-flow history dominated by north to northeast ice flow perturbed by topographic drawdown during deglaciation. Till cover is extensive inland, but the coastal areas are dominated by glaciomarine and marine reworking of sediment in falling sea levels following deglaciation. A regional geochemical sampling program has collected about 400 samples from surficial sediment, concentrating on the area of outcrop of the Roberts Arm Group.

Use of till as a sampling medium for geochemical exploration in the area is hampered by a lack of till in coastal regions, and the probability of reworking by marine processes below 58 to 75 m asl (metres above sea level). Most diamictons in low-lying coastal areas appear to be glaciomarine rather than glacial, as shown by the common occurrence of fossils, and conventional drift-prospecting methods cannot be applied. Farther inland, till sampling was more successful due to the combination of good sampling media, and a comparatively simple ice-flow history.

INTRODUCTION

The area lying between Buchans, Springdale and Point Leamington in the east has a long history of successful mineral exploration. Numerous showings, prospects and mines have been located in this area, mostly hosted in the volcanic dominated rocks of the Robert's Arm, Lushs Bight, Cutwell and Wild Bight groups. In 1994, the Geological Survey instituted a new project using a multi-disciplinary approach, focusing on the Roberts Arm Group. This project involves extensive compilation of existing information as well as new field work. The Quaternary geology component of the project consists of mapping the Robert's Arm (NTS 2E/5) and Little Bay Island (NTS 2E/12) map sheets (Figures 1 and 2), including regional sampling of surficial sediments for geochemical analysis. Extensive regional sampling and geochemical analysis of till was undertaken by Klassen *et al.* (1994) in the southern part of the Buchans–Robert's Arm belt. Sampling is extended to the northern part of the belt including the eastern part of the Springdale map area (NTS 12H/8), specifically that area lying east of the Trans-Canada Highway. This area was mapped by Liverman *et al.* (1991), but sampling coverage was sparse.

PREVIOUS WORK

Regional ice-flow patterns have been outlined by Lundqvist (1965), Rogerson (1982), Grant (1989) and St. Croix and Taylor (1991). Lundqvist (1965) examined striae over a wide area of north-central Newfoundland and suggested that major ice flow was generally from southwest to northeast. Considerable local variation in flow direction was attributed to the effects of local topography during deglaciation. Radial flow from an ice-accumulation centre in the region of the Topsail Hills was described by Rogerson (1982) and Grant (1989). St. Croix and Taylor (1991) and Liverman (1992) postulated a four-phase sequence of deglaciation to explain a complex pattern of ice movement deduced from striation mapping in northeast Newfoundland. They suggested, that at the glacial maximum, ice, which flowed from central Newfoundland, was deflected to the east due to coalescence with ice from the Long Range Mountains along the coast of Notre Dame Bay. Retreat of Long Range Mountains ice, resulted in northeastern flow from an ice divide located in the central Newfoundland uplands. As deglaciation progressed, a number of smaller remnant ice caps developed. A minor ice cap in the Twin Lakes area was identified in the final stages of deglaciation (St. Croix and Taylor, 1991). O'Donnel (1973) studied boulder trains originating from the Gullbridge mine site, and postulated two ice-flow phases of the same advance, an earlier northeastward flow shifting to a later northwestward movement.

Hornbrook *et al.* (1975) discussed the results of a pilot geochemical study east of the study area, in the New Bay Pond area (the southeastern part of NTS 2E/5), and concluded

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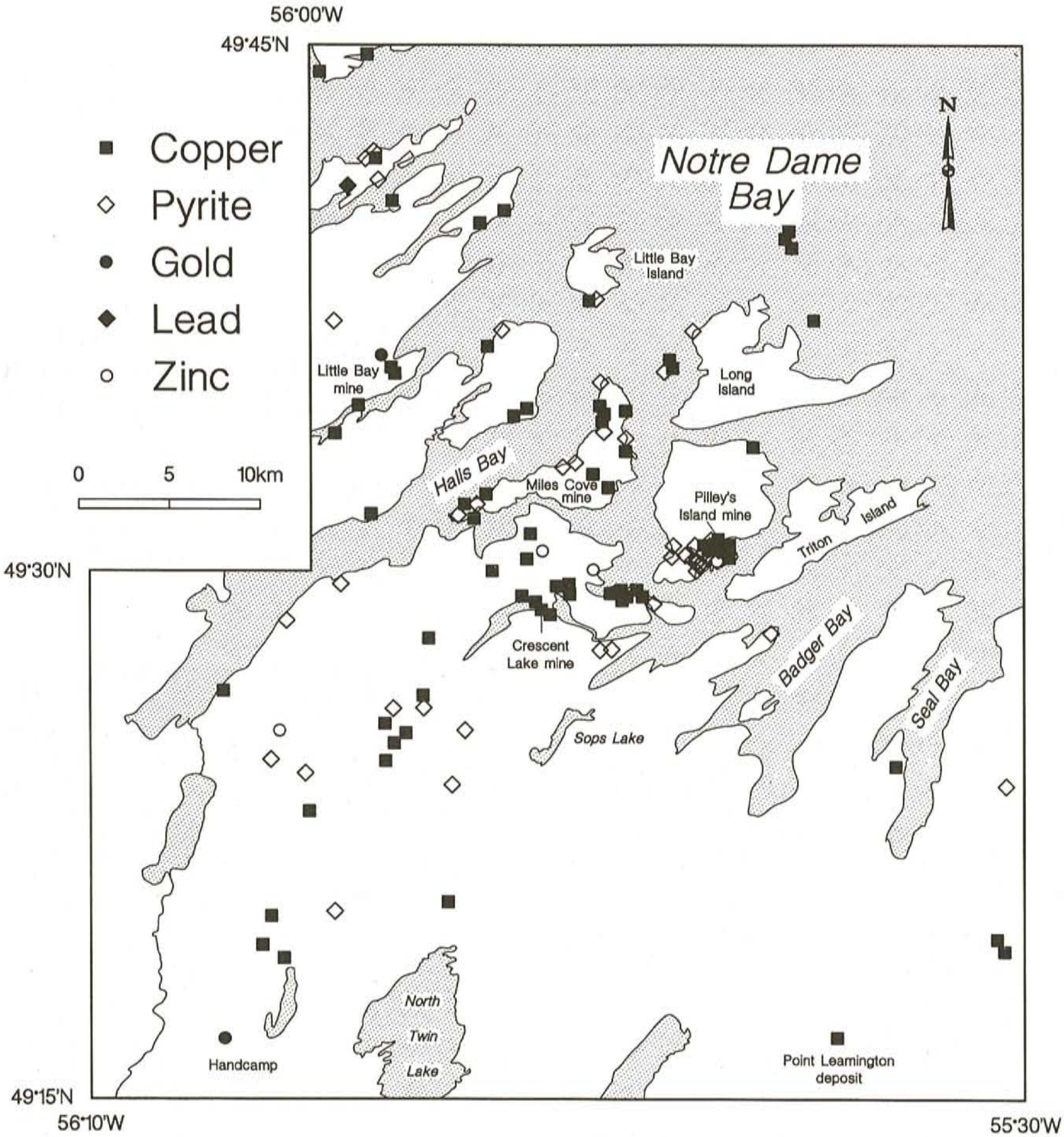

Figure 1. *Study area, showing locations of mines, prospects and showings, organized by primary commodity (data from MODS, Stapleton and Parsons, 1991).*

that soil and upper till sampling were less effective than basal till sampling in identifying bedrock mineralization. Grant (*in* Hornbrook *et al.*, 1975) described the surficial geology of the New Bay Pond area. Ice flow in this area, as indicated by striations and ice-sculpted bedrock, was dominantly north-northeast, with a later ice flow to the east.

Features and sediments indicating raised postglacial sea level have been widely identified in the study area (Richards, 1940; McLintock and Twenhofel, 1940; Lundqvist, 1965; Tucker, 1973, 1974; Scott *et al.*, 1992). A number of deltaic bodies have been identified with a marine limit of 75 m asl (metres above sea level). Barnacles collected from marine clays near South Brook by D.R. Grant gave a radiocarbon

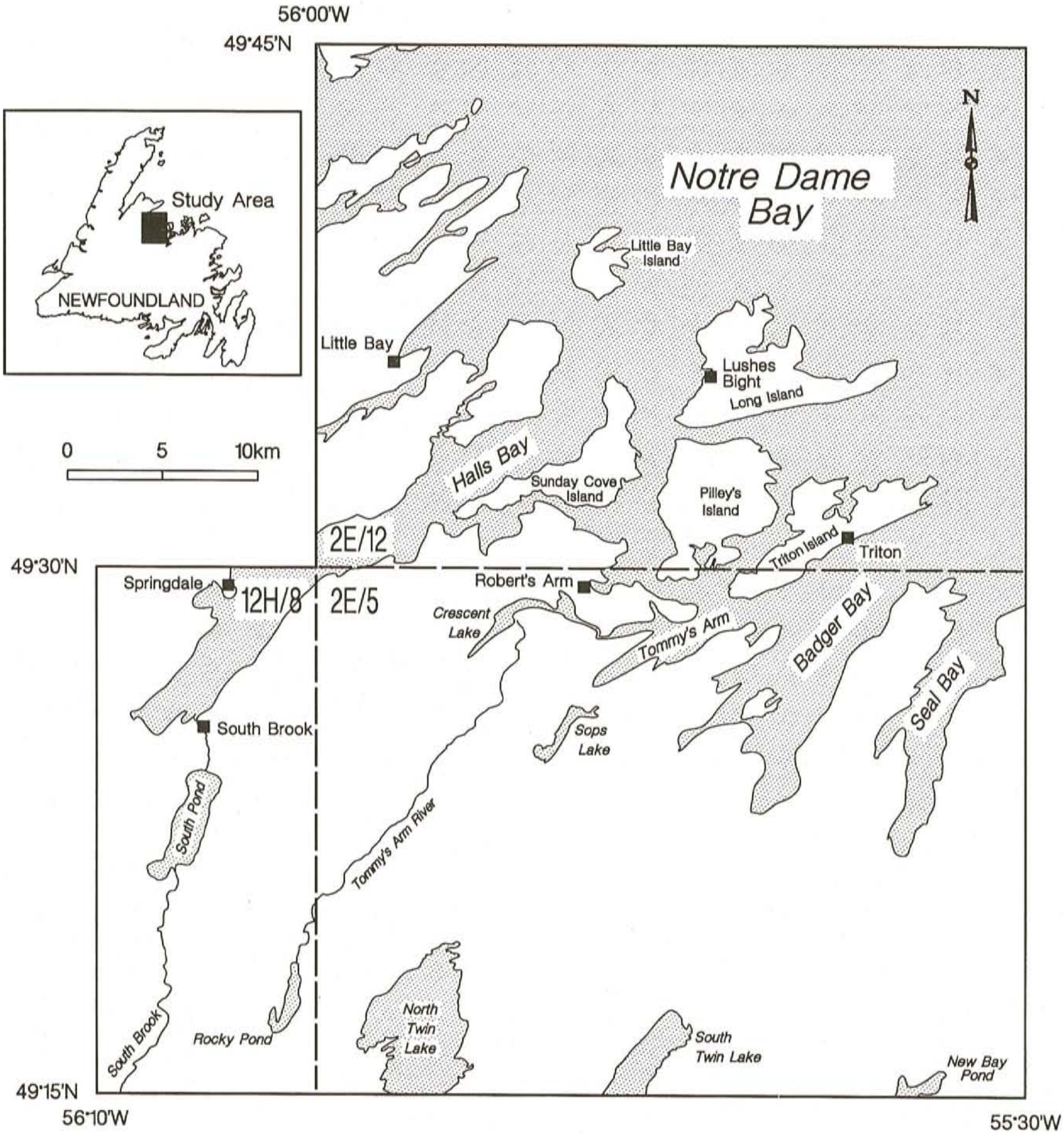

Figure 2. *Location of study area.*

date of 12 000 ± 220 years BP (GSC-1733); *Mya truncata* and *Hiatella arctica* shells collected from the same area by C.M. Tucker were dated at 11 000 ± 190 years BP, and were interpreted as representing a minimum date for deglaciation and dating the delta formation (Tucker, 1974; Lowdon and Blake, 1975). Scott *et al.* (1992) dated fossils from up to 10 km inland of the Springdale delta at between 11 300 ± 120 years BP (GSC-5140) and 12 470 ± 380 years BP. Scott *et al.* (1992) suggested that the highest deltas probably predate 12 470 years BP, and also identified small deltas at 50 m asl in the South Pond valley, representing a still-stand in sea-level fall. Marine limit is marked at the eastern extreme of the study area by deltas in the Bay of Exploits at up to 58 m asl (Mackenzie and Catto, 1993).

Macpherson (*in* McNeeley and McCuaig, 1991) reported a radiocarbon date of 12 000 ± 130 years BP on gyttya from

Gull Pond on Little Bay Island at 52 m asl, which was interpreted as marking the isolation of the lake from marine influence. A second date of 10 900 ± 160 years BP (GSC-4636) was reported from Triton Island at an elevation of 23 m asl, and was also interpreted as showing isolation of the lake basin as sea levels fell (Macpherson, *in* McNeeley and McCuaig, 1991). However, the absence of pollen reflecting the Younger Dryas climatic cooling event suggests that these dates may be anomalously old through contamination (J. Macpherson, Department of Geography, Memorial University, personal communication, 1992).

Macpherson and Anderson (1985) reported the results of dating and pollen analysis from a core taken from Leading Tickles (lying just east of the study area). Two radiocarbon dates were obtained from the core, a basal date of 13 200 ± 300 years BP (GSC-3608), and a 10 500 ± 140 years BP date from 20 cm above the basal date (GSC-3610). The results of pollen analysis were interpreted as showing an initial colonization by vegetation commencing around 13 200 years BP in response to development of a favourable climate, followed by a cooling period lasting up to 10 500 years BP. Following this date, major postglacial warming led to the development of tall-shrub tundra at the site. Anderson and Macpherson (1994) suggested that this climatic trend may be related to the Younger Dryas cooling event recognized widely around the North Atlantic.

BEDROCK GEOLOGY

The bedrock geology of the area has been mapped by, amongst others, Dean (1977), Swinden and Sacks (1986), Kean and Evans (1987), Swinden (1987), Bostock (1988), Kean *et al.*, (*in press*) and Szybinski (1989). The focus of this project, the Roberts Arm Group, was mapped specifically by Bostock (1988), who described it as 'a Middle Ordovician, fault bounded, spilitized, bimodal volcanic to shallow plutonic assemblage within the northern Dunnage tectonostratigraphic zone' (Bostock, 1988, page 1). Common rock types in the Roberts Arm Group include calc-alkaline and tholeitic lavas, often pillowed, volcanoclastic rocks, and marine chemical and clastic sediments. The Lushs Bight Group is of similar lithology, dominated by pillow lavas. The Wild Bight Group also consists of a mix of volcanic and marine sedimentary rocks, containing tuff, agglomerate, mafic to acidic flows, pillow basalts, chert, sandstone and greywacke (Dean, 1977). The Cutwell Group consists of tuff, cherts, shales, tuff breccia, dacites, and pillow lavas (Syzbinski, 1989). Large intrusions cut all of these groups and include the Twin Lakes diorite complex, the Halls Bay pluton (granodiorite and granite), the Hodges Hill granite, the Woodfords Arm pluton (pink granite), the South Pond pluton (granitoid), the Loon Pond pluton (granite, syenite), the Mansfield Cove complex (mostly plagiogranite), the Long Island pluton (granodiorite, diorite and gabbro), and others (Dean, 1977; Swinden, 1987; Kean and Evans, 1987; Bostock, 1988).

Numerous mineral occurrences are scattered throughout the area (Figure 1) (Swinden *et al.*, 1990). Former mines were located at Little Bay (copper), Pilleys Island (sulphur and copper), and Crescent Lake (copper). Occurrences within the Roberts Arm Group are mostly of base metals of the 'Buchans type' (Cu–Zn–Pb association), with the notable exception of the gold-bearing Handcamp prospect. Mineralization is concentrated in the calc-alkaline rocks (Swinden, 1987). The Lushs Bight Group hosts many pyrite–chalcopyrite–(sphalerite) occurrences of the 'Cyprus' type (Bostock, 1988). Similar mineralization is found in the Cutwell and Wild Bight groups.

OBJECTIVES

The objectives of the 1994 field season were; 1, to examine ice-flow indicators with a view to expanding the existing ice-flow database; 2, to ground check aerial photograph interpretations of the surficial geology; 3, to sample surficial sediment for geochemical analysis over the outcrop of the Roberts Arm Group with a sample spacing of 1 to 3 km; 4, to sample areas outside the Roberts Arm Group within the NTS 2E/5 and 2E/12 map areas with a sample spacing of 4 to 6 km; 5, to examine sediment genesis and dispersal patterns, and 6, to determine the Quaternary history of the area with regard to providing data of use to mineral exploration.

METHODS

All roads and tracks were traversed by truck or all-terrain vehicle, samples obtained, and striations and other ice-flow indicators on bedrock were located and recorded. This was supplemented by helicopter sampling in remote areas. Natural sections, road cuts, gravel pits, exploration trenches and other exposures were examined and described when encountered. Ice-flow mapping consisted of examination and recording of ice flow as indicated by striations, rôche moutonées, crag-and-tail structures, and clast fabric. Most emphasis was placed on striation mapping with a view to supplementing existing coverage. Sediment sampling was mostly from hand-dug pits 0.3 to 1.3 m deep, where possible from the C-soil horizon of soils developed on glacigenic diamictons (tills). Where this was not obtainable, BC-soil or B-soil horizons were sampled. In some areas, till was absent, and marine diamictons, marine gravels, or residual soils were sampled to investigate the potential of using these media in drift exploration. Where present, collections were made of marine fauna preserved in sediments, and these were subsequently cleaned and identified. Selected samples have been submitted for radiocarbon dating.

RESULTS

ICE FLOW

Striation data for the area has been compiled by Taylor *et al.* (1993). The database contains more than 200 striations for this area. In the course of 1994 field work, a further 30 sites were located and described (Figure 3). The results from the ice-flow mapping (in the 1994 field season) did not substantially alter the interpretations made by Liverman

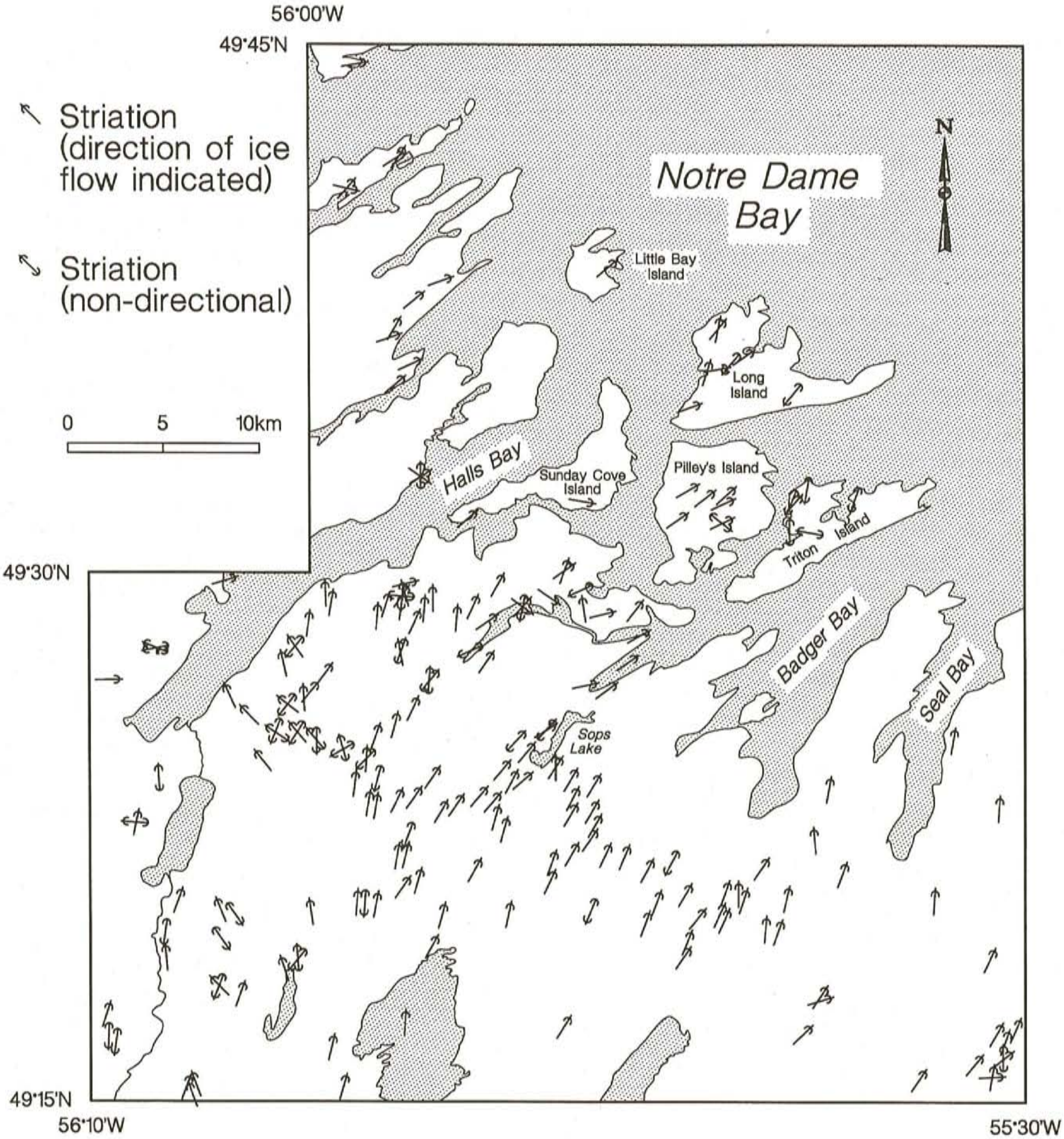

Figure 3. *Ice flow, Robert's Arm area. Data from Taylor* et al. *(1993), and 1994 field work.*

et al. (1991) and St. Croix and Taylor (1991). These show that over most of the area a single dominant north to northeast ice flow is recorded. Variation from this pattern is seen on the east side of Hall's Bay, where a more recent flow to the northwest is recorded; close to Tommy's Arm, where ice flow was eastward; and on the Springdale Peninsula, where fragmentary evidence of a late southeast flow is apparent. These variations are all attributed to late deglacial topographic drawdown. Evidence for the late eastward flow described in Hornbrook *et al.* (1975) was found only in the far southeastern limit of the map area. This suggests that the ice centre responsible for this flow lay somewhere in the Twin Lakes area, as suggested by St. Croix and Taylor (1991).

Few clast fabrics were recorded in the area in 1994, due to a lack of well-exposed sections. Those measured, indicated clast fabrics that were moderately to well oriented with girdle to unimodal distributions. Where interpreted as indicating ice flow, they generally accorded with regional striation trends.

SURFICIAL GEOLOGY

The surficial geology and geomorphology of the area is variable, with a strong contrast between coastal and inland areas. The coast is mostly rocky, with a few gravel-dominated 'pocket' beaches. In the coastal margin (including Long Island, Triton Island, Pilley's Island, Sunday Cove Island, and Little Bay Island, and extending up to 10 km inland), the topography is rugged, with mostly exposed or vegetated bedrock knobs interspersed with areas of bog and fen. Till is rare, and is restricted to small patches of till veneer. In small protected coves close to sea level, thick fossiliferous glaciomarine diamicton is sporadically found. This is commonly associated with gravels, deposited either in marine terraces, or as glaciofluvial deltas. Major deltas are located at the mouth of South Brook (cf. Scott *et al.*, 1992).

Inland from the coast, there is a variable cover of till, mostly as veneers or blankets, and large areas of hummocks. Bedrock is commonly exposed, and is often streamlined and stossed, particularly in the east of the study area; streamlined till is found in this area also. Wetlands are found throughout, some forming bogs up to 10 km long. Glaciofluvial gravels are sporadic, but extensive areas are found along the Tommy's Arm River, and along the west shore of South Twin Lake.

CLAST LITHOLOGY

Sampling of clasts from diamictons was limited to eight sites, because of time considerations. Rather than attempt a regional coverage, a few sites were selected with a comparatively large sample size (240 to 350 clasts at each site). The bedrock geology of the study area does not allow detailed examination of dispersal, due to the lithological similarity of many of the units. Intrusive rock types are readily identifiable in pebble-sized clasts, and yield some information as to dispersal (Figure 4). Significant numbers of mostly granitic clasts were found in samples on Sunday Cove Island, Long Island, and northeast of North Twin Lake. Comparison of the location of these sites to the outcrop of intrusive rocks suggests that many of these clasts have been transported considerable distances. Northeast of North Twin Lake, the sample site is approximately 10 km down-ice of the nearest outcrop of intrusive rocks, yet contains 46 percent intrusive rocks. The sample obtained from Little Bay Island contains comparatively few intrusive rocks, but had a number of red sandstones and conglomerates. No such rock types are mapped in the vicinity, and they resemble Carboniferous rocks in the Kings Point area. No outcrop of Carboniferous rocks is found nearby, so these clasts may be derived from Carboniferous basins offshore (cf. Haworth *et al.*, 1976).

SAMPLING AND SAMPLE QUALITY

Nearly 400 samples of surficial sediment were taken with the objective of achieving a complete regional coverage over the Roberts Arm and Lushs Bight groups, with a sample spacing of 1 to 3 km; and more general coverage outside of these areas (Figure 5). This objective was achieved, although coverage over the eastern part of the area was sporadic (Figure 5). The sampling target was the C-soil horizon of glacial diamictons. The distribution of surficial sediment meant that, particularly in the outer coastal zone described above, such diamictons could not always be located. An ideal sample was not obtained at 40 percent of sites. At half of these sites samples were obtained from the B-soil or BC-soil horizons, due to only a thin till cover being present. At the remainder of these problematic sites, till was not present and samples were obtained from colluvium, marine gravels, or residual soils over bedrock. Most of these problematic sites were located close to the coast, or on the islands offshore. It is likely that diamictons sampled close to the coast are of glaciomarine rather than glacial origin. This may make interpretation of results difficult, as dispersal processes may be somewhat different in these sediments, with ice rafting and debris flow being important.

Samples have been submitted for textural and geochemical analysis, and results are anticipated in 1995.

SEA LEVEL AND PALEONTOLOGY

Numerous features related to raised postglacial sea level are present in the area. Deltas in the South Brook area have upper elevations of approximately 75 m asl, and are thought to mark the marine limit in the western part of the study area (Tucker, 1973; Scott *et al.*, 1992). During the 1994 field work, small deltas were located at elevations of about 50 m asl in the vicinity of Sops Lake, and at about 12 to 15 m asl around Crescent Lake (Figure 6). Extensive deposits of fine gravel and sand along Tommy's Arm River at approximately 60 m asl also may relate to higher sea levels.

There is abundant evidence of raised sea levels in the form of marine fossils found above the current sea level throughout the coastal part of the study area. In 1994, nine new localities were described, in addition to the four listed in the compilation of Batterson *et al.* (1992). Shell collections made at these sites showed a variety of species (Table 1). Reference to typical depth, temperature and salinity ranges of modern species allows some assessment of paleoenvironmental marine conditions (Wagner, 1970; Peacock, 1993). Most sites have a similar faunal assemblage, with typically *Hiatella arctica, Mya truncata, Macoma calcarea* and *Balanus crenatus,* with *Astarte striata,* and *Balanus balanus* also common. Site 70 (Table 1, Figure 6) stands out as having a different species composition, with *Mytulis edulis, Mya areneria,* and *Macoma balthica* present only at this site and *Hiatella arctica* and all *Balanus* species absent. Paleoenvironmental interpretations must be considered indications only, as many shells were recovered as fragments, and re-working is a distinct possibility in some sites. The usual *Hiatella–Mya–Macoma–Balanus* assemblage suggests water depths of at least 10 m, but more likely at least 40 m, given the depth preferences of *Balanus crenatus* (Wagner, 1970). The preferred range of *Mya truncata*

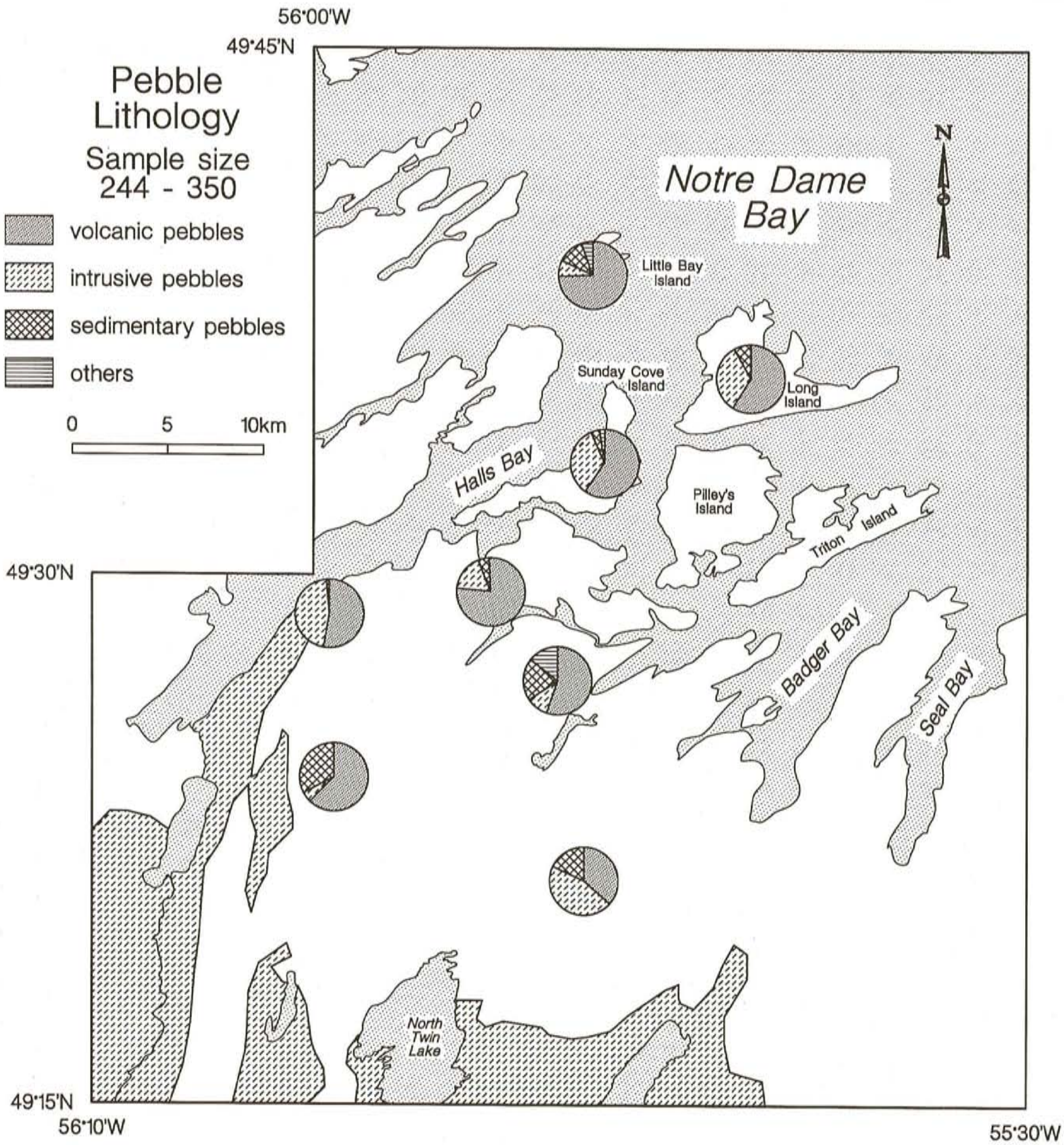

Figure 4. *Pebble lithology data, Robert's Arm area. Outcrop of intrusive rocks simplified from Dean (1977), Swinden and Sacks (1986), Kean and Evans (1987) and Swinden (1987).*

suggests that most of these samples were deposited in 40 to 50 m of water (Table 2; Peacock, 1993). Given the elevations of the sites and the likely marine limit, this appears reasonable (Figure 6, Tables 1 and 2). The presence of *Hiatella arctica* and *Mya truncata* indicates salinities not less than 8 to 17% (Wagner, 1970; Peacock, 1993) and the possibly stenohaline *Trichotropis borealis* also indicates moderate salinity. The species composition at site 70 suggests shallower water, as *Mytulis edulis* has a depth range of down to 10 m, and the various *Balanus* species are absent in this sample. The absence of *Hiatella arctica* and the presence of *Macoma balthica* also suggest a more brackish environment.

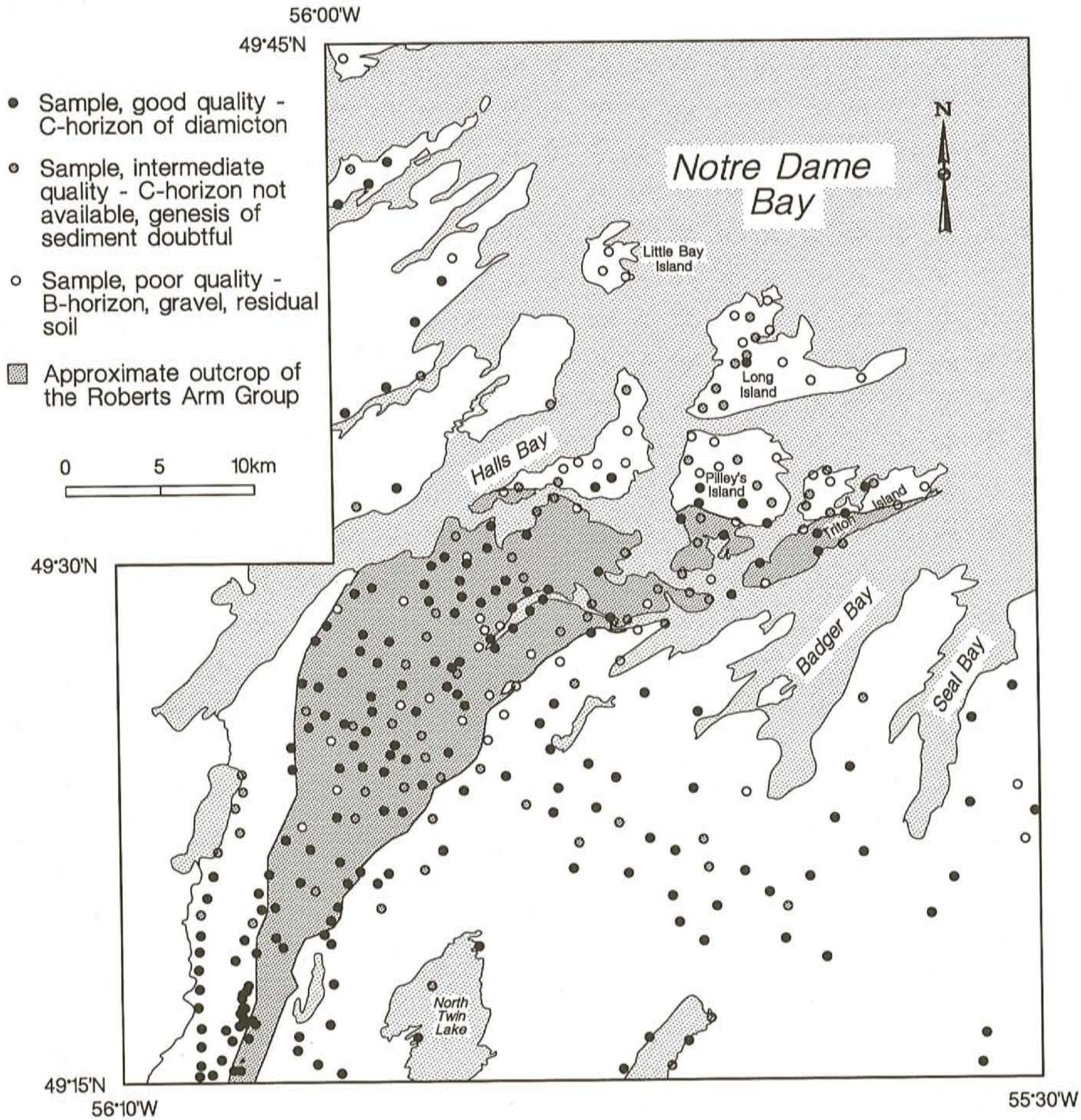

Figure 5. *Sampling and sample quality, Robert's Arm area.*

Shells from site 381 have now been dated at 12 200 ± 110 BP (GSC-5898).

QUATERNARY HISTORY

The pattern of sediment distribution and ice flow described above is consistent with previous interpretations of dominant ice flow from an ice centre located in central Newfoundland, likely in the Topsails area. Ice flow varied little in orientation from the last glacial maximum through deglaciation, with deviations mainly associated with drawdown toward Hall's Bay in the final stages. It is likely that only evidence of the last (Late Wisconsinan) glaciation are preserved. The areas of hummocks suggest stagnation of ice in the area of Rocky Pond, and North Twin Lake and South Twin Lake. This may be associated with the deglacial

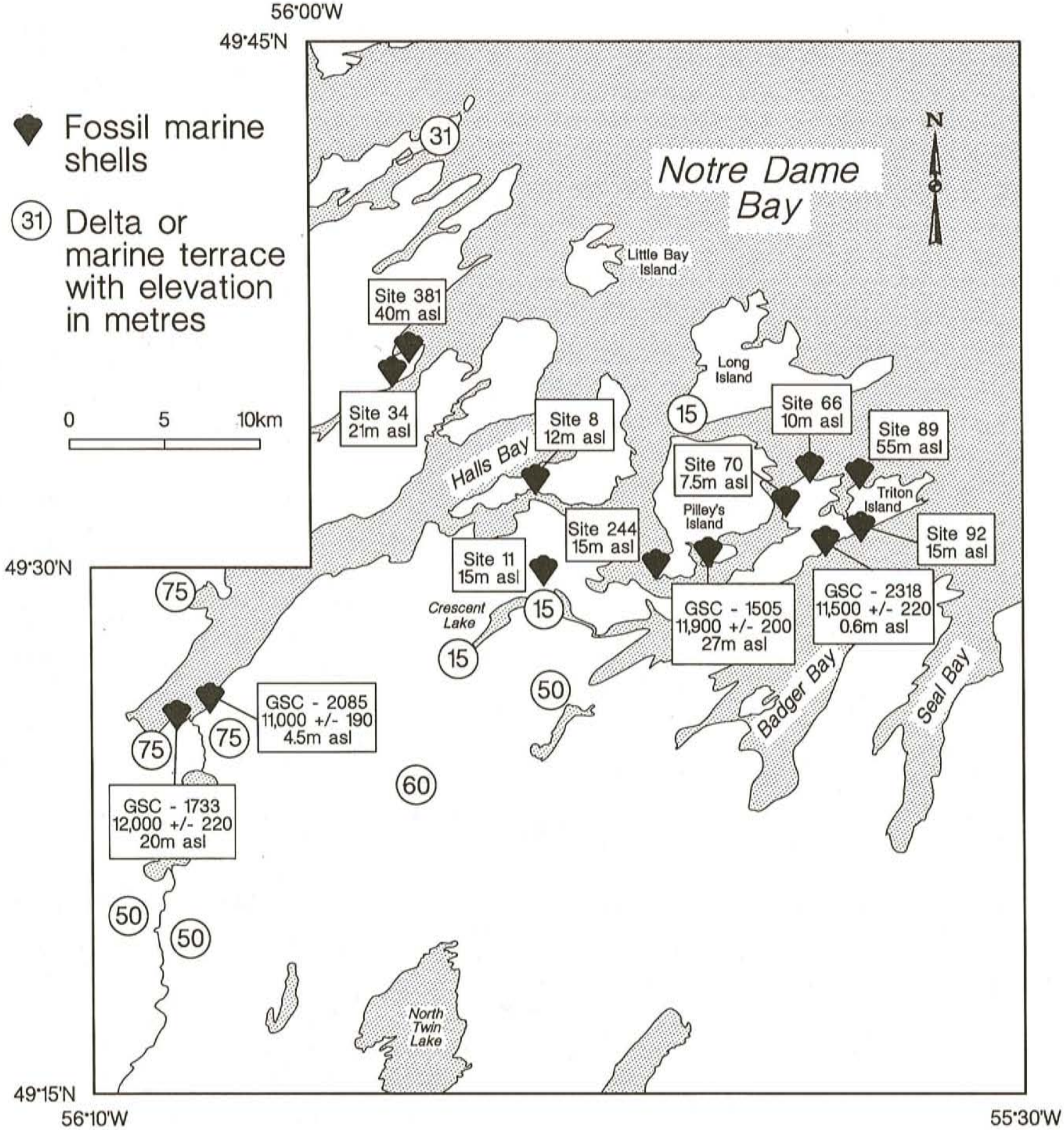

Figure 6. *Fossil localities and features related to sea level, Robert's Arm area.*

ice centre proposed by Grant (1974) in this area. Extensive gravels, apparently deposited in outwash fans on the west shore of South Twin Lake, suggest the ice centre was located west of there. It is possible that the late easterly flow reported by Hornbrook *et al.* (1975) is associated with late re-activation of this ice centre, although the absence of easterly oriented striations in the intervening area is puzzling.

Much of the coastal part of the study area was covered by the sea following deglaciation as shown by the common occurrence of marine fossils above modern sea level. The chronology of sea-level change is uncertain. Previous radiocarbon dates from South Brook were interpreted as representing a minimum date for deglaciation and dating marine limit delta formation (Tucker 1973, 1974; Lowdon and Blake, 1975). Scott *et al.* (1992) suggested that the highest

Table 1. Fossil marine fauna, Springdale–Robert's Arm area

Site	**8**	**11**	**34**	**66**	**70**	**89**	**92**	**381**
Elevation (m asl)	12	15	21	10	7.5	5.5	15	40
Species								
Hiatella arctica	✓	✓	✓			✓	✓	✓
Mya truncata	✓	✓	✓	✓	✓	✓	✓	✓
Mya arenaria					✓			
Mytulis edulis					✓			
Trichotropis borealis	✓	✓						✓
Macoma calcarea	✓	✓	✓	✓	✓			✓
Macoma balthica					✓			
Astarte striata[1]		✓	✓					
Natica clausa[2]					✓			
Balanus crenatus	✓	✓	✓	✓		✓	✓	✓
Balanus balanus	✓	✓						
Balanus hameri		✓						✓
cf. Lunatia heros[3]					✓			
Acmea testudinalis[4]						✓		

[1] Equivalent to *Tridonta striata, Astarte montagui* complex of other authors; [2] Equivalent to *Tectonatica/ Cryptonatica clausa/affinis* of other authors; [3] Equivalent to *Euspira/ Polinices heros* of other authors; [4] Equivalent to *Notoacmea/Tectura testudinalis* of other authors

deltas probably predate 12 470 years BP and much of the dated material related to a lower stillstand. The data of Macpherson (*in* McNeeley and McCuaig, 1991) indicated sea level stood at 52 m asl at 12 000 years BP, and 23 m asl at 10 900 years BP (although these dates may be too old). The marine fauna located in this study are compatible with this interpretation. The maximum elevation at which shells were found was 40 m asl at Little Bay. Faunal composition suggests water depths of 40 m, indicating that these shells were deposited in association with marine limit deltas. Site 70, at 7.5 m asl is associated with fauna indicating water depths of up to 10 m. Therefore, it likely relates to a lower sea-level stand. Dating of these two sites may assist in more clearly delineating the sea-level history of the area. Regional considerations indicate that sea level fell below present at some time between 11 000 and 10 000 years BP (Liverman, 1994).

The marine limit in the area is between 58 and 75 m asl, decreasing to the east, and this occurred prior to 12 400 years BP. A major stillstand marked by deltas at close to 50 m asl likely relates to most of the dated fauna and thus occurred between 12 000 and 11 000 years BP. By 10 000 years BP, sea level fell below the present level, reaching a minimum of -17 m asl in the Bay of Exploits by about 8000 years BP (Shaw and Edwardson, 1994). Sea level is likely currently rising. It is hoped that radiocarbon dating of material collected in this project will aid in refining this picture.

CONCLUSIONS

IMPLICATIONS FOR DRIFT PROSPECTING

The ice-flow history of the area is comparatively simple, dominated by north to northeast flow. Dispersal distances of clasts associated with this flow appear to be comparatively great (kilometres, rather than metres), due to consistent ice-flow regions throughout the last glaciation. Dispersal trains produced by such a glacial history should be ribbon shaped and relatively long (cf. O'Donnel, 1973). It is likely that dispersal distances will differ between the areas of hummocky moraine, and those of streamlined till or till blankets. Hummocky moraines form in stagnant environments, and likely contain a great proportion of superglacial (and more far travelled) debris than basally deposited till.

Use of till as a sampling medium for geochemical exploration in the area is hampered by a lack of till in coastal regions, and the probability of reworking by marine processes below 58 to 75 m asl. Most diamictons in low-lying coastal areas are glaciomarine rather than glacial, as shown by the common occurrence of fossils, and conventional drift-prospecting methods cannot be applied in these areas. Sampling of residual soils is a possible alternative, although such samples likely represent only very local bedrock composition. Sampling of stream or overbank sediment may be a more rewarding approach. Farther inland, till sampling

Table 2. Proxy data derived from modern species tolerances

Species	minimum summer sea surface temperature (°C)	temperature range (°C)	salinity (normal minimum)	minimum salinity	Depth range (common) in metres	Depth range (total)
Hiatella arctica	-	-	20	11	1 to 75	1 to 120
Mya truncata	4.5	-2 to 17	17	8	1 to 50	1 to 70
Mya arenaria	12	-	6	-	1 to 50	1 to 70
Mytulis edulis	4	-10 to 30	7	normally 15 to 40	1 to 10	1 to 50?
Trichotropis borealis	14	-	stenohaline?	-	-	10 to 270
Macoma calcarea	5	-2 to 16 (11)	13	8	-	0 to 80
Macoma balthica	7	-2 to 22	2	tolerant of low salinity	down to 25	1 to 45
Astarte striata	-	intermediate temperatures	19	9	down to 70	down to 100
Natica clausa	-	-11	25?	-	-	4 to 2000
Balanus crenatus	-	eurythermal	14?	-	40 to 90 and 10 to 12	1 to 95
Balanus balanus	-	eurythermal	14?	-	20 to 45	1 to 200
Balanus hameri	-	above 1°	33?	-	>200	5->200
Acmea testudinalis	10	-	-	9	down to 10	1 to 50

Data from Pilsbury (1916), Wagner (1970), Nilsson-Cantell (1978) and Peacock (1993). Further research is in progress to assess the applicability of northeast Atlantic data to the northwest Atlantic.

will be more successful due to the combination of good sampling media, and a comparatively simple ice-flow history.

ENVIRONMENTAL GEOLOGY

A number of potential problems were noted in the course of field work, but not investigated in detail. Widespread cabin development and small-scale agriculture is taking place on the extensive areas of sand and well-sorted gravel adjacent to the upper Tommy's Arm River. The surficial material here is highly permeable and porous, and there is a possibility of contaminants (either sewage or agricultural chemicals) leaking into the river (a scheduled salmon river). The steep rocky coastline, and protected inlets means that coastal problems are rare in the area. In a few instances, communities lie behind gravel beaches, and may be impacted in severe storms. Rockfall problems have occurred in Springdale on the margins of the study area (see Batterson *et al., this volume*), and caution should be exercised in zoning or construction adjacent to steep slopes in other communities. Rockfall has also clearly occurred in steep road-cuts on Pilley's Island, and near to Robert's Arm, but is likely a minor problem.

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REFERENCES

Anderson, T.W. and Macpherson, J.B.
1994: Wisconsinan late glacial environmental change in Newfoundland: a regional review. Journal of Quaternary Science, Volume 9, pages 171-178.

Batterson, M.J., Wareham, B.J. and St. Croix, L.
1992: Carbon-14 date list for Newfoundland and Labrador. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File NFLD (2190).

Batterson, M.J., Liverman, D. and Taylor, D.
This volume: The assessment of geological hazards and disasters in Newfoundland.

Bostock, H.H.
1988: Geology and petrochemistry of the Ordovician volcano-plutonic Robert's Arm Group, Notre Dame Bay, Newfoundland. Geological Survey of Canada, Bulletin 369, 84 pages.

Dean, P.L.
1977: A report on the metallogeny of the Notre Dame Bay area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-10, 17 pages, and accompanying maps.

Grant, D.R.
1974: Prospecting in Newfoundland and the theory of multiple shrinking ice caps. *In* Current Research, Part B. Geological Survey of Canada, Paper 74-1B, pages 215-216.

1989: Quaternary geology of the Atlantic Appalachian region of Canada. *In* Quaternary Geology of Canada and Greenland. *Edited by* R.J. Fulton. Geological Survey of Canada, Geology of Canada No. 1, pages 391-440.

Haworth, R.T, Poole, W.H., Grant, A.C. and Sandford, B.V.
1976: Marine geoscience survey northeast of Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 76-1A, pages 7-15.

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

Kean, B.F. and Evans, D.
1987: Geology and mineral occurrences, Little Bay Island area (NTS 2E/12). Newfoundland Department of Mines and Energy, Mineral Development Division, Map 87-07.

Kean, B.F., Evans, D.T.W. and Jenner, G.
In press: Geology and mineral deposits of the Lushs Bight Group. Newfoundland Department of Natural Resources, Geological Survey, Report 95-2.

Klassen, R.A.
1994: Till geochemistry and ice flow data, central Newfoundland (NTS 12A/10, 15, 16, 12H/1). Geological Survey of Canada, Open File 2823, 350 pages.

Liverman, D.G.E.
1992: The application of regional surficial geology mapping to mineral exploration, northeastern Newfoundland, Canada. Transactions of the International Association of Mining and Metallurgy, Section B, Volume 101, B89-98.

1994: Relative sea-level history and isostatic rebound in Newfoundland, Canada. Boreas, Volume 23, pages 217-230.

Liverman, D.G.E., Scott, S. and Vatcher, H.
1991: Quaternary geology of the Springdale map sheet (NTS 12H/8). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 29-44.

Lowdon, J.A. and Blake, W.
1975: Geological Survey of Canada Radiocarbon Dates XV. Geological Survey of Canada, Paper 75-7, 31 pages.

Lundqvist, J.
1965: Glacial geology in northeastern Newfoundland. Geologiska Foreningen i Stockholm Forhandlingar, Volume 87, pages 285-306.

MacKenzie, C. and Catto, N.R.
1993: Quaternary geology of the Botwood (NTS 2E/3) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 139-148.

MacClintock, P. and Twenhofel, W.H.
1940: Wisconsin glaciation of Newfoundland. Bulletin of the Geological Society of America, Volume 51, pages 1729-1756.

Macpherson, J.B. and Anderson, T.W.
1985: Further evidence of late glacial climatic fluctuations from Newfoundland: pollen stratigraphy from a north coast site. *In* Current Research, Part B. Geological Survey of Canada, Paper 85-1B, pages 383-390.

McNeeley, R. and McCuaig,S.
1991: Geological Survey of Canada Radiocarbon Dates XXIX. Geological Survey of Canada, Paper 89-7, 134 pages.

Nilsson-Cantell, K.A.
1978: Cirripedia Thoracica and Acrothoracica. Universitetsforlagat Oslo, Norway. 134 pages.

O'Donnel, N.D.
1973: Glacial indicator trains near Gullbridge, Newfoundland. Unpublished M.Sc. thesis, Department of Geology, University of Western Ontario, 258 pages.

Peacock, J.D.
1993: Late Quaternary marine mollusca as palaeoenvironmental proxies: a compilation and assessment of basic numerical data for NE Atlantic species found in shallow water. Quaternary Science Reviews, Volume 12, pages 263-275.

Pilsbury, H.A.
1916: The Sessile barnacles (cirripedia) contained in the collections of US National Museum: Including a monograph of the American species. Smithsonian Institution, United States National Museum, Bulletin 93, 366 pages.

Richards, H.G.
1940: Marine Pleistocene fossils from Newfoundland. Bulletin of the Geological Society of America, Volume 51, pages 1781-1788.

Rogerson, R.J.
1982: The glaciation of Newfoundland and Labrador. *In* Prospecting in Areas of Glaciated Terrain—1982. *Edited by* P.H. Davenport. Canadian Institute of Mining and Metallurgy, pages 37-56.

Scott, S., Catto, N.R. and Liverman, D.G.E.
1992: Sedimentology of Quaternary marine sediments in the Hall's Bay area, Newfoundland. Atlantic Geology, Volume 27, pages 181-191.

Shaw, J. and Edwardson, K.A.
1994: Surficial sediments and post-glacial sea-level history, Hamilton Sound, Newfoundland. Atlantic Geology, Volume 30.

St. Croix, L. and Taylor, D.M.
1991: Regional striation survey and deglacial history of the Notre Dame Bay area. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 61-68.

Stapleton, G. and Parsons, W.K.
1991: MODS-PC- Mineral Occurrence Data System for personal computers, users manual. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File Nfld. 2174, 80 pages and 4 discs.

Swinden, H.S.
1987: Geology and mineral occurrences in the central and northern parts of the Roberts Arm Group, central Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 381-390.

Swinden, H.S. and Sacks, P.E.
1986: Stratigraphy and economic geology of the southern part of the Roberts Arm Group, central Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 86-1A, pages 213-220.

Swinden, H.S., Evans, D.T.W. and Kean, B.F.
1990: Metallogenic framework of base and precious metal deposits, central and western Newfoundland. 8th IAGOD symposium field trip guidebook, Geological Survey of Canada, Open File 2156, 232 pages.

Szybinski, Z.A.
1989: Geology of the Cutwell Group, Notre Dame Bay, Newfoundland: a disrupted volcanic-volcaniclastic island-arc complex. *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 141-147.

Taylor, D.M., St. Croix, L. and Vatcher, S.V.
1993: Newfoundland striation database. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File NFLD 2195.

Tucker, C.M.
1973: The glacial geomorphology of west-central Newfoundland; Halls Bay to Topsails. Unpublished M.Sc. thesis, Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland, 132 pages.

1974: A series of raised Pleistocene deltas in Halls Bay, Newfoundland. Maritime Sediments, Volume 10, pages 1-7.

Wagner, F.J.E.
1970: Faunas of the Pleistocene Champlain Sea. Geological Survey of Canada, Bulletin 181, 104 pages.