THE DEGLACIATION AND EARLY POSTGLACIAL ENVIRONMENTAL HISTORY OF SOUTHCENTRAL NEWFOUNDLAND: EVIDENCE FROM THE PALYNOSTRATIGRAPHY AND GEOCHEMICAL STRATIGRAPHY OF LAKE SEDIMENTS

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ABSTRACT

The Deglaciation and Early Postglacial Environmental History of Southcentral Newfoundland: Evidence from the Palynostratigraphy and Geochemical Stratigraphy of Lake Sediments

The purpose of this thesis is to reconstruct the chronology of deglaciation and early Holocene environmental change in southcentral Newfoundland. Previous palynological studies have helped to define the timing of deglaciation and the sequence of postglacial environmental change in certain parts of Newfoundland, but a firm chronology of events for the entire island has not yet been established.

Radiocarbon dating, pollen analysis and geochemical analysis have been carried out on sediment cores from four ponds, including three within the proposed limit of the main Newfoundland ice cap and one from the Hermitage Peninsula, which was apparently affected by a smaller local ice cap. The pollen, sediment and geochemical stratigraphies of the basal sediments of these cores confirm that the basal radiocarbon dates represent early stages in the postglacial sequences. The basal dates from Northwest Gander River Pond (10,200 ± 240 BP; GSC-5027), Moose Pond (10,000 ± 170 BP; GSC-5029) and Pool's Cove (9710 ± 120 BP; GSC-4945) are therefore considered minimum ages of deglaciation, but it is difficult to determine when the Conne River site became ice

free since the basal date of 11,300 ± 100 BP (GSC-3436; Blake, 1983) is suspected of being too old.

All four sites were apparently ice covered during the Late Wisconsinan, and there is no evidence that deglaciation occurred before the Younger Dryas episode. It is inferred that all three sites within the limit of the main Newfoundland ice cap were ice free before 10,000 BP, and that deglaciation progressed by downwasting, possibly beginning by 10,500 BP in areas of high elevation.
The basal date of 9710 ± 120 BP (GSC-4945) from Pool's Cove Pond on the Hermitage Peninsula provides a minimum date of deglaciation, but this site may have been ice free by 10,100 BP.

The reconstruction implies that deglaciation of southcentral Newfoundland began in the middle of the Younger Dryas cold period, and can therefore only be considered tentative, especially in light of doubts about the accuracy of bulk sediment radiocarbon dating of basal lake sediments.

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Chapter 1

Introduction

The extent of Late Wisconsinan ice on the island of Newfoundland and the timing and mode of the last deglaciation have been debated for decades. While mapping of geomorphological features and sedimentological studies have provided considerable evidence that the island had its own restricted ice cap with many coastal and highland nunataks, there is also conflicting evidence of Late Wisconsinan glacial activity offshore, suggesting more extensive glaciation.

A firm chronology of ice recession on the island has not yet been established, because of a paucity of reliable radiocarbon dates. Radiocarbon dating and pollen analysis of basal lake sediments have helped in the reconstruction of the deglacial chronology and the sequence of postglacial environmental change on the island (Macpherson, 1981, 1982; Anderson, 1983; Macpherson and Anderson, 1985; Dyer, 1986). Only two sites, one from the Burin Peninsula (Anderson, 1983) and the other from the north coast of the island (Macpherson and Anderson, 1985) have so far yielded evidence of a late glacial climatic oscillation corresponding to that identified at numerous locations in the Maritime Provinces. Basal radiocarbon dates from several other sites suggest deglaciation before or during the Younger Dryas episode, but many of these dates are now suspected of being too old (Macpherson, 1990).

The purpose of the current study is to help define the late glacial and early postglacial chronology for Newfoundland by investigating the sequence of events in the southcentral part of the island, including the area adjacent to the Bay d'Espoir highway (Route 360) and the Hermitage Peninsula. Mapping of geomorphological features and surficial geology in the area has provided evidence that the main Newfoundland ice cap did not extend to the Hermitage Peninsula, which was apparently affected by a separate smaller ice cap (Leckie and McCann, 1983), and that deglaciation of at least part of the study area occurred by downwasting of a stagnant ice mass (Proudfoot et al., 1990). The main objective of the present study is to help determine the timing and pattern of deglaciation of this part of the island, and possibly to provide some evidence of the extent of ice on the south coast during the Late Wisconsinan.

Radiocarbon dating as well as pollen and geochemical analysis has been carried out on basal lake sediments from four ponds, including one from the Hermitage Peninsula and three from within the proposed limits of the main Newfoundland ice cap. If they are accurate and represent an early stage in the postglacial sequence, the basal radiocarbon dates may be considered as minimum estimates of the age of deglaciation of each of the four sites. The general sequence of early vegetational changes inferred from pollen analysis is used to help evaluate the validity of the radiocarbon dates and determine how much time elapsed between ice recession and the deposition of the dated sediments, to approximate the actual time of deglaciation. The geochemical stratigraphy provides supporting information about changes in lake catchment soils and lake productivity, which helps to confirm if the basal sediments were indeed deposited during early postglacial time. If the age of ice recession at each of the sites can be established with a reasonable degree of confidence, then inferences can be made about the regional pattern of deglaciation.

A review of relevant literature is presented in Chapter 2 as a background to the nature of this research. The main characteristics of the geology, climate, soils and vegetation of the study area are discussed in Chapter 3. Chapter 4 outlines the methods used, and the physical characteristics of each of the four sites are described in Chapter 5.

The sedimentary stratigraphy, radiocarbon dates, and the results of the loss-on-ignition, pollen and geochemical analyses from each site are presented in Chapter 6. In the final chapter (Chapter 7) the results are interpreted, and the validity of the radiocarbon dates is evaluated. Inferences are made about the timing of deglaciation at each site and the regional pattern of ice recession.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter provides the background information necessary for an understanding of the purpose and nature of the thesis, beginning with a review of relevant palynological research in Atlantic Canada, with an emphasis on studies concerned with deglaciation chronologies and late glacial/ early postglacial environments. Secondly, evidence and theories of Late Wisconsinan ice extent and retreat on the island of Newfoundland, and in particular in the study area in southcentral Newfoundland, are summarized. This is followed by a review of the advantages and problems associated with the use of pollen analysis and radiocarbon dating in the reconstruction of deglaciation patterns. The final section is a discussion of the potential usefulness of lake sediment geochemistry in the interpretation of late glacial/ early Holocene paleoenvironments.

2.2 Relevant palynological research in Atlantic Canada

2.2.1 Introduction

Pollen analysis of peat and lacustrine sediments, supported by radiocarbon dating, has been an important tool for the reconstruction of late glacial and Holocene environments. Early workers used mainly peat, but since peat development did not immediately follow deglaciation or emergence their records are often truncated at the base. Lake sediment records more commonly extend further back in time, and for this reason recent workers have tended to prefer the analysis of lake sediments.

A considerable amount of palynological research has been conducted in the Atlantic provinces in recent years. Some of this work has dealt with purely paleobotanical considerations of the patterns of plant migration and succession (eg. Anderson, 1980), or with the reconstruction of climatic changes throughout the Holocene (eg. Macpherson 1985), and is not particularly relevant here. Emphasis in the following discussion is therefore on studies in which pollen analysis has been used to decipher local or regional chronologies of deglaciation and environmental conditions during and following ice recession.

2.2.2 Newfoundland and Labrador

a) Labrador

Within the province of Newfoundland and Labrador, palynological research has been more extensive in Labrador than on the island. The earliest palynological studies in the province of Newfoundland and Labrador were carried out by Wenner (1947) in eastern Labrador and on the northernmost tip of the Northern Peninsula. Wenner's work predated the development of radiocarbon dating, and therefore lacks absolute dating control, but he developed a relative chronology based on peat stratigraphy of 75 sites from Sandwich Bay to Okak Bay and inland in Labrador, and reported a pollen sequence indicating an early transition from tundra or birch-alder shrub to conifer-dominated forest-tundra vegetation.

Later work, beginning with Grayson's (1956) analysis of four peat bogs in the central interior plateau of Labrador, confirmed this broad vegetational sequence and attempted to assign an absolute chronology by radiocarbon dating samples from selected levels in the sediment cores. Grayson's radiocarbon dates lacked precision, but he suggested that deglaciation of the plateau occurred during the interval 8000-6000 BP. He identified three pollen zones, beginning with tundra, followed by a birch-alder association, and then a boreal woodland dominated by spruce which he concluded had been dominant for the past 4000 to 5000 years.

Basal dates from ten peat bogs sampled by Morrison (1970) in the Churchill Falls area range from 5575-5255 BP, leading him to suggest late deglaciation, despite the fact that he identified a transition from tundra to birch-alder scrub at around the time of his earliest basal date, suggesting deglaciation must have predated this level. Morrison determined that a boreal woodland had developed in the area by about 5200 BP with only minor fluctuations in the pollen record after this date.

From the pollen stratigraphy of five lake sites in the Hamilton Inlet - Lake Melville area, Jordan (1975) determined that the coastal area had been deglaciated before 8600 BP. He identified initial sedge-shrub and subsequent lichen-heath tundra episodes that existed until 7200 BP, followed by an alder-birch shrub episode and then a period of open birch-fir vegetation before forest became established at ca. 6000 BP inland and 5200 BP at the coast.

Short and Nichols (1977) found that the earliest organic sedimentation in lakes in northeastern Labrador-Ungava began at 10,300 BP, providing a minimum date for deglaciation of the region. Deglaciation was followed by an initial prolonged tundra episode. Short (1978) determined that the postglacial period of tundra vegetation lasted until approximately 6500 BP in northern Labrador-Ungava, with a transition to shrub tundra dominated by Alnus and Betula and an increase in lacustrine organic sedimentation rates. An open spruce woodland became established between 4500 and 4000 BP.

In southeastern Labrador, a similar transition to birch-alder shrub tundra occurred much earlier, at about 9000 BP, replacing a tundra vegetation that had been present since ca. 10,500 BP (Lamb, 1980). Trees invaded the shrub tundra at 6000 BP, with the initial forest community being a park tundra of Picea glauca with abundant fir, and some Betula papyrifera. The fir later declined in favour of Picea mariana, a change explained by Lamb as resulting from a deterioration of soil conditions.

Subsequent work in southeastern Labrador by Engstrom and Hansen (1985) indicated that the area was ice free by 11,000 BP. The pollen record from their Lake Hope Simpson site was similar to that reported by Lamb, with an initial predominantly non-arboreal assemblage between 10,500 and 9500 BP, characterised by low pollen accumulation values dominated by Salix, Gramineae, Cyperaceae, and various herbaceous taxa. This was followed by a domination of shrub Betula, ericads and Alnus crispa until 8000 BP, when a rise in Picea, predominantly P. glauca, occurred, followed by an increase in Abies and a subsequent decline of P. glauca in favour of *P. mariana* by 6000 BP. The authors attributed this succession of conifer species to changing soil conditions, favouring the more edaphically tolerant *P. mariana*.

b) Island of Newfoundland

While a relatively dense network of sites has been investigated in Labrador over the last forty-five years, it is only recently that palynology has been used to much extent to investigate the late glacial and postglacial history of the island of Newfoundland. Following Wenner's (1947) investigations on the Northern Peninsula, the first pollen analytical work on the island was done by Terasmae (1963), who published pollen records from three bog sites in the north-central region of the Avalon Peninsula. The earliest date reported by Terasmae was 8420 ± 300 BP (I[GSC]-4), which served only as an absolute minimum date for deglaciation, since the dated sample was from more than 1 m above the base of the core and contained a pollen spectrum indicating that spruce had already migrated into a shrub tundra vegetation dominated by shrub birch and grass, which had itself replaced an earlier sedge/grass meadow.

Later work by Macpherson (1981, 1982) on the Avalon Peninsula has extended the record back by some 1600 years, giving a better approximation of the time of deglaciation.

A core from Golden Eye Pond on the central upland of the peninsula yielded a basal date of 10,000 ± 250 BP (Macpherson 1981), while evidence from a core from Sugarloaf Pond north of St. John's indicated a later deglaciation of the coast around 9700 BP, leading Macpherson to conclude that final deglaciation of the peninsula proceeded by downwasting rather than recession. This theory is supported by the basal pollen sequence from Sugarloaf Pond, which indicated an early shrub dominated tundra type vegetation with fairly high pollen concentrations, implying that tundra-like vegetation was present in the area to colonize the catchment of Sugarloaf Pond as it became free of ice (Macpherson 1982). While Picea pollen was present from about 9300 BP concentrations were not high enough to suggest local presence of spruce until 8500 BP, and Abies balsamea arrived in the area about two centuries later. For about 3000 years after the arrival of balsam fir the vegetation on the Avalon Peninsula appears to have remained an open woodland of spruce, balsam fir, trembling aspen and probably tree birch (Macpherson, 1982).

The pollen sequences of the lowest portions of cores from two lakes in the Pouch Cove area, as well as the local glacial geomorphology, were studied by Mellars (1981) with the objective of determining the extent of Late Wisconsinan ice on the northernmost part of the St. John's Peninsula and the timing of deglaciation of the area, but she was unable to obtain firm evidence of either. The basal dates recorded in Mellar's study (8540 ± 90 BP [GSC-2985]; 8370 ± 110 [GSC-2961]) were considered to be too young to date ice retreat.

Macpherson (1987) compared the pollen stratigraphy of a dated core segment from St. John's Harbour with radiocarbon dated pollen sequences from three lake sites in the vicinity, and used the results to make inferences about both sea level changes and final wasting of the ice mass in the vicinity of the harbour. She concluded that after 10,000 BP a stagnant ice mass occupied the valleys which presently drain into St. John's Harbour, with a lake in the deepest part of the harbour basin draining across the sill in the Narrows to the adjacent shoreline. The lake received pollen from vegetation on higher areas which were already ice-free, and on possible small coastal ice-free areas.

In southwestern Newfoundland, Brookes (1981) obtained a date of ca. 10,600 BP from basal lake sediment containing a sedge-dominated tundra pollen assemblage (identified by J.H.McAndrews) when he attempted to date the Robinson's Head Moraine. Because of poor chronological control only the sequence and not the timing of vegetational events could be determined with any certainty. The tundra phase gave way to a shrubby vegetation, principally of _Betula_, _Salix_ and _Myrica gale_ which developed ca. 8000 BP and was followed by the invasion of Picea, Abies balsamea and Betula papyrifera by ca. 7000 BP.

The sequence of vegetational changes represented by the pollen records from two lakes on the Baie Verte Peninsula, northcentral Newfoundland indicated that Late Wisconsinan ice covered the Peninsula and probably extended to its northern terminus (Dyer, 1986). Basal sediment dates indicated that the northern highlands of the peninsula were deglaciated as early as 11,800 BP and dissipation of the ice progressed by downwasting and ice recession toward the interior of the peninsula. Dyer concluded that pioneering communities of Gramineae and herbs were replaced by a dwarf shrub tundra after 11,800 BP. The immigration of trees began with Picea after 9500 BP and the closing of the forest canopy in this area occurred after 6700 BP with the development of a white birch-black spruce forest.

The oldest pollen records found on the island so far come from the Burin Peninsula (Anderson 1983), and from Leading Tickles, Notre Dame Bay (Macpherson and Anderson 1985), with basal dates of 13,400 $\pm$ 140 BP (GSC-3559) and 13,200 $\pm$ 300 BP (GSC-3608), respectively. Analysis of these pollen sequences yielded evidence of a Late Wisconsinan climatic oscillation on the island, indicated by an inferred three-fold sequence of vegetational changes at both sites. During the first stage, pioneer plants became established by ca. 13,500 BP, developing to shrub tundra at the Burin site (Anderson 1983); and by 13,200 BP, developing to a herb-dwarf shrub tundra at the Leading Tickles site (Macpherson and Anderson 1985). This phase, interpreted to indicate an initial late glacial warming, was followed by a reversion to sparse herb tundra at the north coast site, and to herb-shrub tundra at the Burin site, dated at 11,300 BP (Anderson, 1983), somewhat earlier than a similar vegetation reversion recorded in the Maritime Provinces at 11,000 BP. The reversion in both cases is ascribed to cooler summers with longer lasting snow beds, which lasted until the major postglacial warming led to the development of a tall shrub tundra at both sites (Macpherson and Anderson 1985), beginning ca. 10,000 BP according to radiocarbon dates. Macpherson and Anderson (1985) suggested that the climatic fluctuation inferred from the pollen sequence may be correlated with the paleoclimatic reconstruction proposed by Ruddiman and MacIntyre (1981a, 1981b) from studies of the adjacent Atlantic marine sedimentary record, associated with the Allerod/ Younger Dryas event in Europe. Similar evidence for a late glacial climatic oscillation from palynological studies elsewhere in Atlantic Canada will be discussed in the following section.

2.2.3 The Maritime Provinces

Palynological investigations have been used in numerous studies concerned with the reconstruction of late- and postglacial environments in the Maritime Provinces, beginning in the 1950s. Livingstone and Livingstone (1958) found a clay layer interrupting the basal gyttja at Gillis Lake, southern Cape Breton Island, in which initial rises in *Picea* and *Betula* are retarded and Cyperaceae reaches maximum values. A date of 10,340 ± 220 BP (Y-524) on the gyttja above the clay layer provides an age for the regional spruce rise. These authors were the first to use vegetational shifts inferred from pollen analysis to postulate a significant late glacial climatic event in eastern Canada related to the classic Allerod/ Younger Dryas oscillation of Europe. Further evidence for this climatic fluctuation was later presented by Mott *et al.* (1986), Ogden (1987), Jetté and Mott (1989), and Stea and Mott (1989).

Mott *et al.* (1986) used the results of several workers from some fourteen sites throughout Atlantic Canada to suggest that the record of late glacial climatic changes in Atlantic Canada is broadly parallel to the classic Allerod/Younger Dryas climatic oscillation of Europe. This oscillation involved a warming trend before 11,000 BP, expressed by increasing organic sedimentation and pollen sequences indicating the development of vegetation by primary succession, which was interrupted by a distinct and abrupt cooling beginning at 11,000 BP, evidenced by a reversion of vegetation, as well as a reversion to dominantly mineral sedimentation in lakes as a result of thinning vegetation, which destabilized soils. The cold period persisted until the major Holocene warming around 10,000 BP, which is indicated by a return to dominance of organic deposition and a renewed proliferation of vegetation.

Mott <u>et al.</u> (1986) suggested that the correspondence of the late glacial climatic record of Atlantic Canada with that of Europe may be linked to movements of the Arctic Polar Front. Studies of deep sea cores from the North Atlantic (Ruddiman and MacIntyre, 1981) have shown that the deglacial warming that began about 13,500 BP was accompanied by a gradual retreat of the Arctic Polar Front from its full-glacial east-west position at about 40°N to a position near Greenland and Iceland at 9200 BP. This warming trend was interrupted when the polar front moved southeastwards again to near its full-glacial position between 11,000 and 10,000 BP (Ruddiman and MacIntyre, 1981a, 1981b).

The exact cause of this climatic reversal in the late glacial period is not fully understood. While modelling by Rind <u>et al.</u> (1986) shows that Atlantic Canada as well as Europe would be affected by the movements of the Arctic

Polar Front in the North Atlantic, as theorized by Ruddiman and MacIntyre (1981), recent suggestions that the event may be recorded further inland in central North America (Wright, 1984; Shane, 1987; Lewis and Anderson, 1989) suggest that the cooling trend may not have been simply a North Atlantic regional phenomenon resulting from ice shelf breakup, meltwater diversion, reorientation of atmospheric flow or deepwater production, as was originally suggested. Instead, it seems that the underlying cause or causes may be more complex than has been thought, and global cooling may be implicated, as suggested by Broecker et al. (1985), who proposed that this oscillation was due to a change in the rate of deep water production in the North Atlantic and may have had global consequences.

Whatever the cause of the climatic fluctuation, evidence described by Ogden (1987), Jetté and Mott (1989) and Stea and Mott (1989) augments data from many other sites which led Mott et al. (1986) to the conclusion that a climatic oscillation equivalent to the Allerod/Younger Dryas event of Europe occurred in Atlantic Canada.

Ogden (1987) determined that organic sedimentation had begun in lakes in the Halifax area by ca. 12,000 BP, with early pollen assemblages dominated by shrub birch, pine, spruce, willow and ericaceous pollen. The results of Ogden's study imply an initial climatic amelioration preceding a cold stage marked by a decrease in forest pollen productivity and a period of predominantly minerogenic sedimentation from ca. 11,500-10,500 BP, followed by a renewed warming as indicated by predominance of forest pollen and increasing pollen accumulation rates.

Further evidence of a late glacial climatic oscillation was found by Jetté and Mott (1989) who investigated the late glacial and Holocene palynostratigraphy of a site near Chance Harbour lake, Nova Scotia. A basal layer of pink clay was overlain by 18 cm of black silt with marl layers, representing an early period of organic accumulation. The silt/marl interval contained a pollen succession from an initial herb taxa, to a dominance of shrub taxa, then *Populus*/*Juniperus* and finally *Picea*, which Jetté and Mott interpreted as the vegetational response to the initial postglacial warming. The organic sedimentation was interrupted by a layer of clay containing pollen spectra indicating the replacement of *Picea* by *Betula*, *Salix*, and *Alnus*, while Gramineae and Cyperaceae representation also increased. Gyttja overlying the clay layer represented a second period of organic sedimentation with the same initial pollen succession as the basal organic silt. The four lowest of the seven radiocarbon dates obtained from this sequence are considered to be too old (Jetté and Mott, 1989).

Stea and Mott (1989) presented further evidence for a Younger Dryas age climatic reversal based on work on Cape Breton Island. Peat beds deposited during the interval 12,700-10,500 BP overlie glacial and fluvial deposits and are overlain by deposits of various origins. Pollen in these peat beds records the migration of spruce into the region indicating climatic warming, and a subsequent deterioration of climate is recorded by the return of a tundra-like vegetation. Stea and Mott concluded that at least some of the overlying mineral deposits are glacigenic, indicating that glaciers were still active in Nova Scotia until approximately 10,000 BP, although dates on glaciomarine deltas suggest that deglaciation began in the Bay of Fundy as early as 14,500 years ago.

The best record of the Younger Dryas found in Canada to date is from the Splan Pond (Basswood Road Lake) site in New Brunswick, originally studied by Mott (1975), where the Younger Dryas is represented by an interval of 60 to 80 cm of thixotropic clay that is underlain and overlain by organic sediments (Cwynar in Seaman et al., 1991 p.87). Recently, AMS radiocarbon dates have been obtained on macrofossils from close to the Younger Dryas boundaries at this site and others in New Brunswick and Nova Scotia, indicating that the cooling event began between 10,770-11,060 BP (Mayle and Cwynar, 1991), considerably later than indicated by bulk sediment conventional radiocarbon dates from some previous studies. The end of the Younger Dryas has been dated at 10,100 BP by both conventional (Mott, 1975) and AMS ^{14}C dating (Cwynar in Seaman et al., 1991).

Not all palynological investigations in the Maritime Provinces have revealed evidence of this oscillation. Pollen records from some sites do not extend back far enough in time to indicate late glacial climatic conditions (Livingstone and Estes, 1967; Livingstone, 1968; Anderson, 1980), while others that do extend to the end of the late glacial (Green, 1981) yield no evidence of a reversion of vegetation in response to the cooling event that is suggested to have begun at approximately 11,000 BP in the region. Basal dates at such sites may be too old.

2.3 Late Wisconsinan ice limits and final deglaciation of the island of Newfoundland

2.3.1 Extent of Late Wisconsinan ice

a) Island of Newfoundland

The extent of Late Wisconsinan ice on the island of Newfoundland has been debated for the past century, as outlined in reviews by Tucker (1976), Grant (1977b, 1989), Ives (1978), Brookes (1982) and Rogerson (1982, 1983).

Murray (1883) was the first to hypothesize that the whole island had been glaciated, and suggested that the ice had come from a combination of local and external sources. Since then a variety of controversial theories has been put forward concerning the numbers and ages of separate ice advances, the relative roles of Labrador or Laurentide versus island-based ice, and the vertical and areal extent of the ice sheets (Grant, 1989). These issues are still under debate, largely because of opposing interpretations of differentially weathered glacial terrains and crustal warping patterns, paucity of radiometric control, incomplete knowledge of surface deposits, and limited stratigraphic analysis (Grant, 1989), but systematic mapping and lithostratigraphic correlation of sedimentary sequences has led to the delimiting of four or more successive ice advances. The latter two are known to be Late Wisconsinan, and the earlier ones probably predate the last interglaciation (Grant, 1977b; Brookes, 1977b; Tucker and McCann, 1980; Rogerson, 1982, Grant and King, 1984; Grant, 1989).

In recent years, the hypothesis of limited ice extent, leaving many coastal areas ice free, has been widely accepted, largely due to the work of Grant (1969a, 1969b, 1972, 1973, 1974, 1975a, 1975b, 1976, 1977a, 1977b, 1989) and other researchers (Brookes, 1969, 1970, 1975, 1977a; Tucker and McCann, 1980), involving mapping of morphological features such as moraines, marine features, and meltwater channels, differential weathering zones (Brookes, 1977a; Grant, 1977a) and stratigraphic exposures.

According to the now widely accepted "minimum" model of Late Wisconsinan ice cover, the island of Newfoundland had its own restricted ice cap, with certain coastal and highland areas remaining ice-free. Grant (1977b) suggested that Late Wisconsinan glaciers spread weakly towards, and in many cases not beyond, the present coast throughout the Atlantic region, fed by a complex of small ice caps located on broad lowlands and uplands. His map (1977b) of the inferred limit of Late Wisconsinan glaciers in Atlantic Canada at the stadial maximum suggests that substantial areas of the island remained ice-free, including coastal nunataks and enclaves along the west and northeastern coasts, the Burin Peninsula and the extremities of the Avalon Peninsula, and interior nunataks such as the Topsail Hills, the Buchans Plateau and the Annieopsquotch Mountains. According to this reconstruction, Newfoundland was affected only by island-based ice with the exception of the northern tip of the Northern Peninsula, to which Labrador ice extended across the Strait of Belle Isle.

Grant (1989) later modified his interpretation of the extent of Late Wisconsinan ice in Newfoundland by moving the glacial limit northward to include Fogo Island, off the northeast coast, as well as including a small ice cap on the

Burin Peninsula and omitting the small nunataks he had previously suggested existed in the central uplands of the island.

While Grant (1989) contended that his "minimum model" of ice extent adequately accounts for most observed geomorphic, stratigraphic, and ice flow features, he admitted that it has some weaknesses, in that there is no direct chronometric control on the proposed limit or in the supposed extraglacial areas, and that it conflicts with most offshore reconstructions which require grounded ice in the Gulf of Maine and in the Gulf of St. Lawrence, including even the deepest parts of the Laurentian Channel. Therefore, Grant (1989) also presented an alternative or "maximum model", resembling that depicted by Mayewski et al. (1980), and favoured by researchers working offshore (e.g. King and Fader, 1986). This model envisages a coherent regional ice mass contiguous with, if not an integral part of, the Laurentide Ice Sheet, flowing more or less uniformly to the continental margin.

A number of workers investigating the continental shelf have attempted to define how far ice extended offshore during the various glacial stages. Slatt (1974) concluded that sediments indicate that ice once existed on the Grand Banks but provided no evidence of when this occurred or whether the ice was of island or independent origin. By contrast, Piper and Slatt (1977) concluded that Late Wisconsinan ice did not extend over any significant part of the Banks. However, Fader and Miller (1986) reported the presence of a 30 m thick deposit of till and glaciomarine sediment along the southwestern edge of the Grand Banks, along with rounded boulders and gravel dominated by Avalonian lithologies on the southern area of the Banks, as evidence that glaciers extended across the entire area at some time, possibly during the Wisconsinan. Other studies have favoured limited ice extent on the Grand Banks (Grant and King, 1984). King and Fader (1986) found evidence in Downing Basin and Whale Basin in the northcentral and southwestern Grand Banks, and Fader et al. (1982) on the St.Pierre Bank and Placentia Bay to support an interpretation that ice advanced at least to these areas sometime during the Wisconsinan. The problem of ice extent is complicated by the late Pleistocene-Holocene transgression of the Grand Banks, which effectively eroded previously deposited evidence for glaciation, such as glaciomarine sediments and tills.

While most authors conclude that during the Late Wisconsinan glacial ice had retreated to approximately the present coastline of the Atlantic Provinces (Grant, 1977b, King and Fader, 1986), Bonifay and Piper (1988), based on seismic reflection profiles, foraminiferal analysis, and radiocarbon dating of shells, suggested possible Late Wisconsinan glacial activity on the upper continental slope. They concluded that a late ice surge in the Halibut Channel, corresponding in age (11,500-12,000 BP) to the late readvance recognized by Brookes (1977a) in southwestern Newfoundland, and to the Younger Dryas readvance in the Maritimes (Mott et al., 1986), extended across the continental shelf to the continental slope off St. Pierre Bank. In the continuing debate on the limit of the Wisconsinan ice sheet, the observations of Bonifay and Piper (1988) support some of the 'maximalist' arguments rather than the currently favoured 'minimalist' interpretations.

Figure 2.1. illustrates suggested minimum and maximum limits of Late Wisconsinan ice on the island of Newfoundland, compiled from the reconstructions of a number of workers (Grant, 1977b, 1989; Ives, 1978; Mayewski et al., 1980; Rogerson, 1981, 1982; Prest, 1984; Dyke and Prest, 1987a, 1987b). Quinlan and Beaumont (1982) found that the two extreme models of Late Wisconsinan ice cover in the Atlantic region produce hypothetical postglacial sea levels that bracket actual observations of sea levels, and concluded that Late Wisconsinan ice limits must have been intermediate between the two proposed reconstructions.

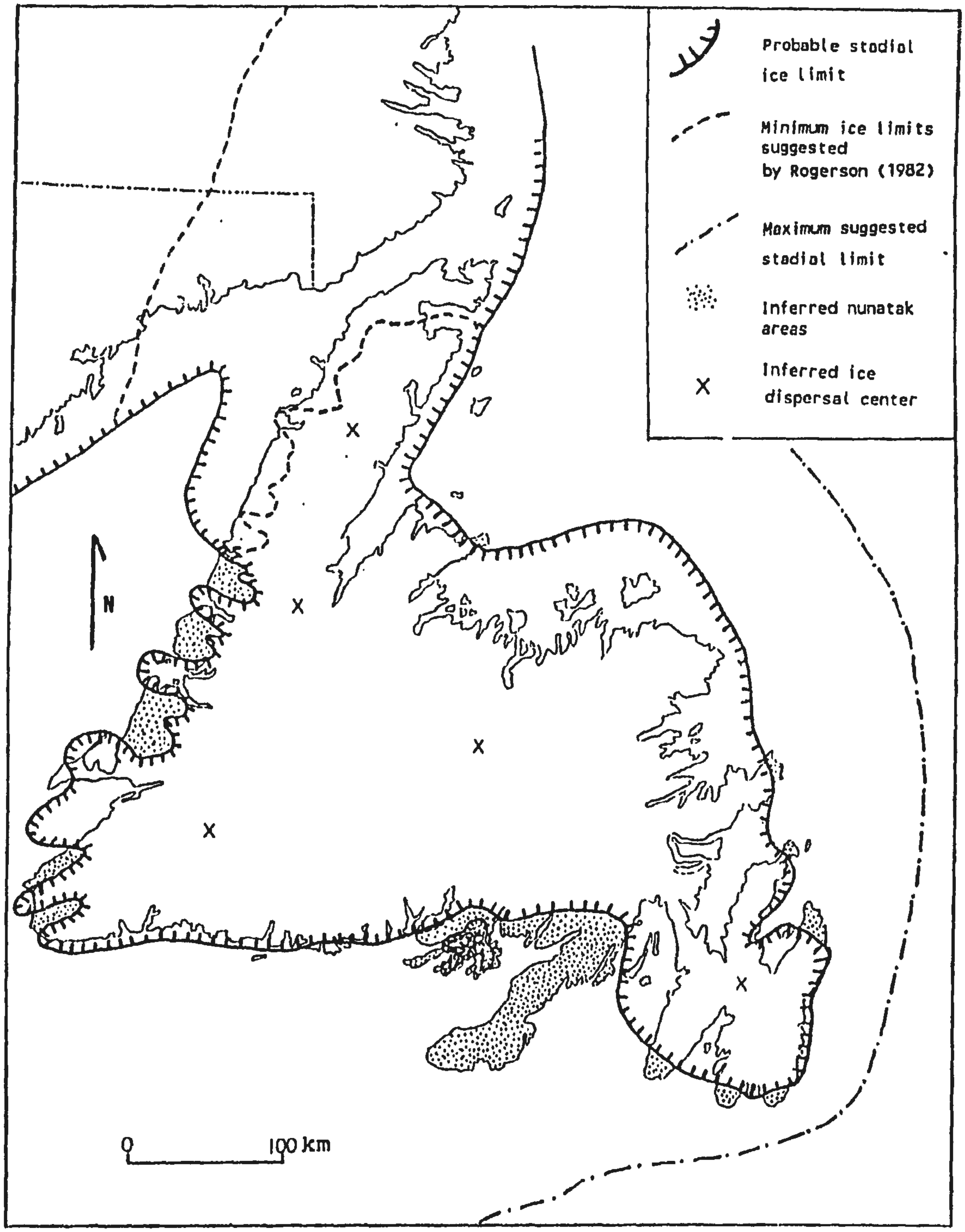

Figure 2.1 Proposed Late Wisconsinan ice extent, island of Newfoundland, after Grant (1989) and other sources (see text).

b) Southcentral Newfoundland

Widmer (1950) concluded that at some time during the Wisconsinan, the whole Hermitage Bay - Fortune Bay region was glaciated by a Newfoundland based ice cap, which extended southwards beyond the Burin Peninsula and then retreated to a position north of the Hermitage Bay area, with a recurrence of glaciation in Late Wisconsinan time when tongues of Newfoundland ice extended into Bay d'Espoir and Hermitage Bay from the northwest, and local valley glaciers occupied Northeast Arm, Old Bay and Salmonier Cove Pond. However, no absolute chronology was assigned to this sequence of events.

According to Grant (1975b), during ice recession onshore from Fortune Bay, there appears to have been a pause when the ice lay along the present coast indicated by end moraines with outwash graded to higher (+27 m) water levels. These ice marginal deposits, which display wave-planed distal parts and kettled proximal areas, are found at Fortune, Grand Bank, Garnish, Bay L'Argent, Hermitage, and Harbour Breton. Grant suggested that the ensuing postglacial fall of water level cut lower terraces, while Widmer (1950) had concluded that these were the result of a former proglacial lake in Fortune Bay. There is, according to Grant (1975b), no direct evidence as to whether the water body was marine or lacustrine, and the distribution of the many different shorelines had not been examined for tilt or relationship to ice masses.

Based on a study of the surficial deposits on the Burin Peninsula and the islands of St. Pierre and Miquelon, Tucker and McCann (1980) described the Late Wisconsinan limit as a very clear margin running across the Gisborne Basin, north of the Burin Peninsula, while local ice affected the central spine of the Peninsula.

Leckie and McCann (1983) concluded that the northern part of the Hermitage Bay area was glaciated by the main Newfoundland ice cap, and the southern part by a small, upland ice cap, broken by nunataks (Figure 2.2). It had previously been suggested (Grant, 1975) that a late ice mass on the Garrison Hills in the Hermitage area may have fed narrow tongues terminating in several bays.

2.3.2 Deglaciation

According to the reconstruction of Dyke and Prest (1987a, 1987b, 1987c) the Newfoundland Ice Cap was much divided and diminished by 11,000 BP, but retreat had been delayed on the island compared with that on the south side of the Gulf of St. Lawrence, possibly due to the cooling effect of the Labrador Current. Ice centred on the Long Range Mountains readvanced at ca. 10,900 BP or later, but by

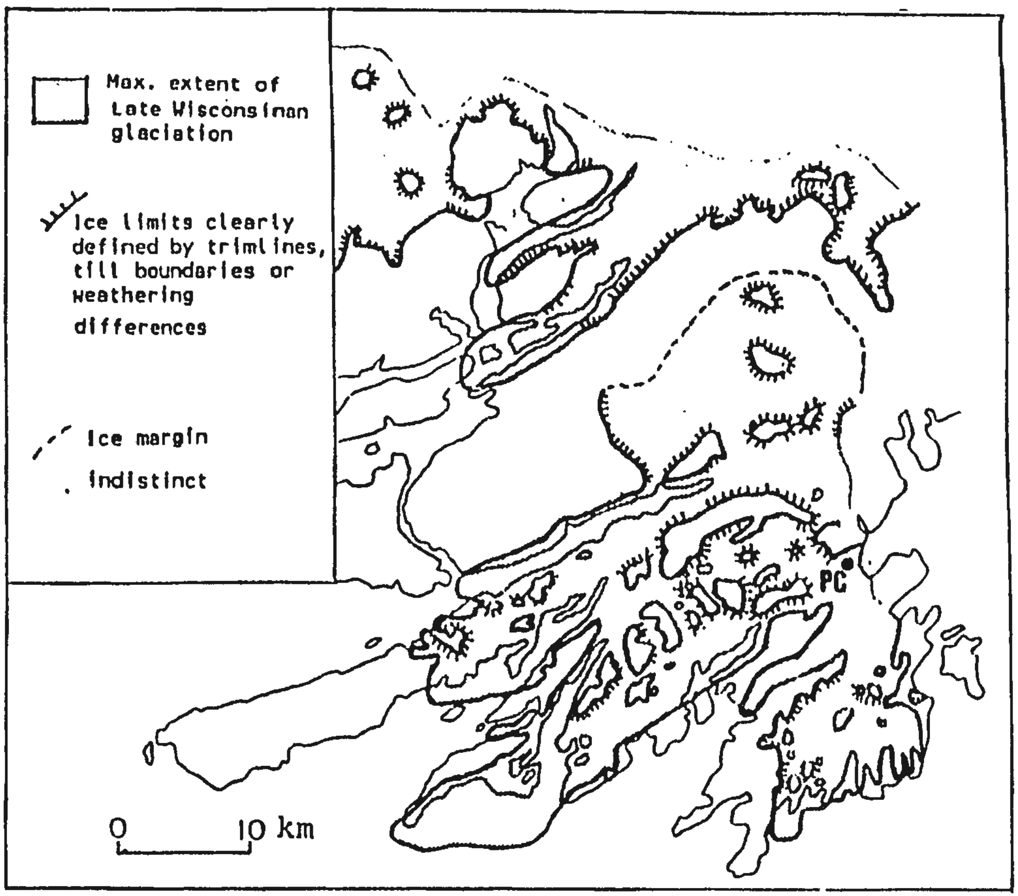

Figure 2.2 Late Wisconsinan ice limits in the Hermitage Peninsula area (redrawn from Leckie and McCann, 1983).

10,000 BP the Newfoundland Ice Cap persisted only as five small remnants.

Dyke and Prest (1987a) show the Burin Peninsula and the southern part of the Hermitage Peninsula as being ice free during the late glacial. Ice retreated gradually inland beginning by 13,000 BP or earlier near the coast, until by 10,000 BP only a few small residual ice masses remained, including one in central Newfoundland just north of the study area.

Dyke and Prest's depiction of Late Wisconsinan glacial retreat on the Avalon Peninsula, indicating withdrawal of the eastern margin of the Avalon ice cap from coastal sites by 13,000 BP and final melting of ice caps from the interior plateau between 12,000 and 11,000 BP, is in conflict with the results of Macpherson's research, which indicates that deglaciation of the coast near St. John's did not occur until ca. 9700 BP, about 400 years after deglaciation of the interior upland of the peninsula (based on basal dates of 9270 ± 150 BP [GSC-2601] from Sugarloaf Pond, and 10,100 ± 250 BP [GSC-3136] from Hawke Hills), leading Macpherson to suggest that deglaciation occurred by downwasting (Macpherson, 1982; 1988a).

The timing of ice retreat from most parts of the island has not yet been well established. Basal lake sediment dates have been obtained from numerous sites throughout the

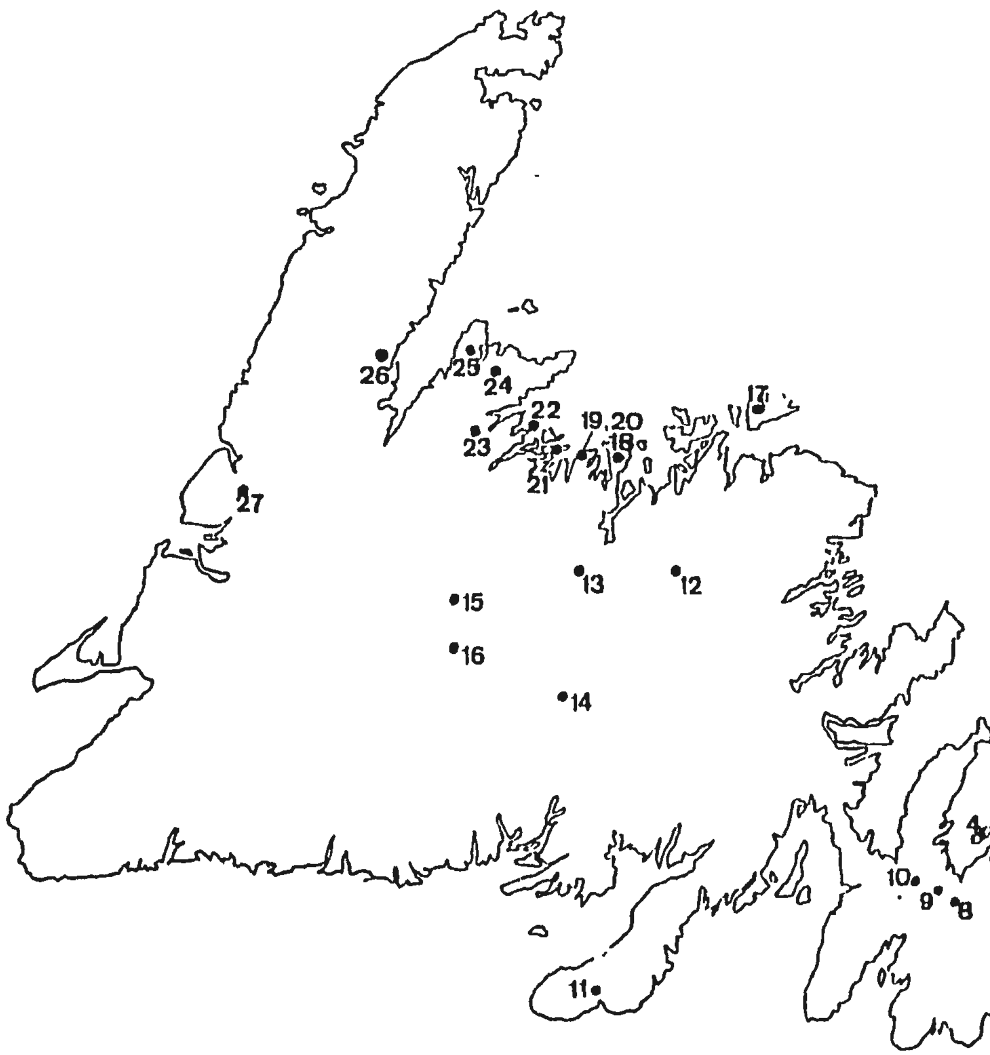

Figure 2.3 Location of radiocarbon dated basal lake sediments. See Table 2.1 for list of sites.

Table 2.1 Radiocarbon dates from basal lake sediments, island of Newfoundland.

Site	Date & Lab.No.	Reference
1. NE Pouch Cove Pond	8370±110 (GSC-2961)	Mellars, 1981 Lowdon & Blake, 1981
2. Pouch Cove	8480±90 (GSC-2985)	Mellars, 1981 Lowdon & Blake, 1981
3. Sugarloaf Pond	9270±150 (GSC-2601)	Blake, 1978 Macpherson, 1982
4. Bell Island	9240±190 (GSC-3166)	Lowdon & Blake, 1981
5. Kenny's Pond	8570±90 (GSC-3618)	Blake, 1983
6. Kents Pond	7350±130 (GSC-4605)	GSC Paper 89-7
7. Oxen Pond	9440±360 (GSC-3182)	Lowdon & Blake, 1981
8. Golden Eye Pond	10,100 (GSC-3136)	Lowdon & Blake, 1981
9. Nevilles Pond	11,800±150 (GSC-4829)	J.Macpherson, pers.comm.
10. Whitbourne	8420±3000 (I[GSC]-4)	Teresmae, 1963
11. James Pond	13,400±140 (GSC-3559)	Anderson, 1983 Blake, 1983
12. East Twin Pond	11,700±160 (GSC-4327)	J.Macpherson, pers.comm.
13. Bishop's Falls	11,800±200 (GSC-3647)	Blake, 1983
14. Conne River	11,300±100 (GSC-3634)	Blake,1983
15. West Twin Pond	9340±140 (GSC-4231)	J.Macpherson, pers.comm.
16. Noel Paul's Brook	9300±170 (GSC-4186)	J.Macpherson, pers.comm.
17. Freeman's Pond	11,000±260 (GSC-3973)	Blake, 1987
18. Cottrell's Pond	10,500±160 (GSC-4840)	J.Macpherson, pers. comm.
19. Leading Tickles	13,200±300 (GSC-3608)	Blake, 1983
20. Leading Tickles II	11,100±210 (GSC-4657)	J.Macpherson, pers.comm.
21. Triton Island	10,900±160 (GSC-4636)	J.Macpherson, pers.comm.
22. Gull Pond	12,000±130 (GSC-4588)	J.Macpherson, pers.comm.
23. King's Point	11,800±200 (GSC-3957)	Blake, 1987
24. Ming's Bight	10,400±160 (GSC-3966)	Dyer, 1986
25.Compass Pond	11,700±180 (GSC-3891)	Dyer, 1986
26. Cat Arm	8380±100 (GSC-4192)	J.Macpherson, pers.comm.
27. Comb Pond	7770±190 (GSC-2483)	Lowdon & Blake, 1979

island, as indicated in Figure 2.3 and Table 2.1. However, several of the earliest of these dates are now suspected to be too old because: 1) some are from samples with $\delta^{13}C$ ratios less negative than -25‰, suggesting aquatic photosynthesis and the incorporation of old, inert carbon; 2) in some cases, interpolated dates calculated using the radiocarbon dates indicate the arrival of spruce on the island prior to its establishment on Cape Breton Island; and 3) although several sites yielded basal dates of >11,000 BP, evidence for the Younger Dryas age climatic deterioration has been found only at one site on the Burin Peninsula (Anderson, 1983) and at Leading Tickles (Macpherson and Anderson, 1985) (Macpherson, 1990).

Radiocarbon dating of marine shells has also been used to infer the timing of deglaciation in some areas of Newfoundland, but none are available from the south coast for comparison with the basal lake sediment dates from the current study.

2.4. The recognition of glacial limits and retreat from palynological data.

Certain problems are inherent in the radiocarbon dating of basal lake sediments which should be considered in using this method to establish deglaciation chronologies. First of all, it should be recognized that the radiocarbon age of a sample is not equivalent to its true age even assuming no contamination by older or younger carbon (Bradley, 1985). Another consideration in using basal lake sediments to date deglaciation is that doing so requires the assumption that the earliest sediments at a site can be located and sampled, and that the earliest sediments lie in the deepest part, but this may not always be the case, and even when it is, sampling instruments cannot always be relied upon to locate the deepest parts (Tipping, 1988). King (1985) notes two other important considerations. The first of these is that the reported age of the sample may not be the true radiocarbon age of that sample, due to possible errors in the measurement process, or to contamination of the sample by older or younger carbon. Secondly, it must be determined whether the dated sample was deposited during deglaciation or some time later.

Various sources of contamination by older or younger carbon can result in erroneous reported radiocarbon ages. A major source of error is the "hard-water effect" that occurs when the organic material to be dated has taken up carbon from water containing bicarbonate derived from old inert sources (Shotton, 1972; Berglund, 1979; Bradley, 1985), causing ages to be overassessed. Contamination by older carbon is a problem particularly in newly deglaciated terrain where older carbon is released from rocks through glacial scouring and washed into newly formed lakes by glacial meltwater (Sutherland, 1980). Uptake of this old carbon by algae and its subsequent sedimentation would make the radiocarbon age of early postglacial sediments seem older than they actually are.

While carbonate bedrock in particular contains large amounts of carbon, some may be contained even in granites and metamorphosed sedimentary rocks. Because the basal sediments which are dated to determine the time of deglaciation are typically low in carbon content, even the average carbon concentration of granitic rocks may result in serious dating errors when it is made available for incorporation into the sediment being dated. For example, a dated sample with only 1% carbon, only 0.06% of which is derived from bedrock, would give a date 500 years too old (King, 1985).

Macpherson (1990) has suggested that many of the basal radiocarbon dates from Newfoundland may have been affected by this error, based on $\delta^{13}C$ values less negative than the normal -25%. for gyttja, indicating the possibility of aquatic photosynthesis (cf. Pennington, 1977; Blystad and Selsing, 1989; Aravena, 1990), which may have involved the utilization of bicarbonate containing old inert carbon by

Chlorophyte algae (e.g. Pediastrum) and other aquatic organisms.

In most cases the late glacial period was a time of soil instability, as indicated by pollen preservation studies which show that higher fluxes of recycled pollen grains characterise late glacial sediments (eg. Birks, 1984; Tipping, 1984; Lowe and Walker, 1986; Paus, 1988; Clark et al., 1989). Presumably other organic detritus, as well as mineral carbon derived from increased erosion of local soils and bedrock, was washed into lakes at that time, creating a 'reservoir effect' (Lowe et al., 1988). For example, in one sample Paus (1988) found old reworked microfossils making up 10% of the pollen sum, and assuming old organic carbon in the sample represented 10% of the total carbon, calculated that the apparent age of the sample would be increased by 850 years.

Younging errors in basal organic lake sediments can also occur, resulting from factors such as the downward percolation of humic acids (Terasmae, 1984), undetected bacterial or fungal growth on the sample (King, 1985), introduction of younger organic carbon into the sample by the accidental transfer of material either during field sampling or laboratory procedures (Lowe and Walker, 1980), penetration of sediments by modern roots (Olsson, 1979), and the dating of vertically thick samples (Sutherland, 1980).

Even if a radiocarbon date does represent the actual age of the basal sediment sample, it may not necessarily give an accurate estimation of the timing of deglaciation of area (King, 1985). The history of the sedimentation of the lake basin and the relative position of the dated sample in the stratigraphic sequence must be considered in deciding if a basal lake sediment does represent deglaciation time. For example, sedimentation may not have begun at the time of the local deglaciation if stagnant ice persisted in the lake basin for some time after the area was deglaciated. Lakes below the maximum marine limit in an area will also not have early postglacial sediments, and dates of the basal sediments of these lakes will not represent local deglaciation time (King, 1985).

If the basin was open during the final stages of deglaciation, the basal sediments are likely to be largely of glacial origin and will have a low organic content, making accurate dating difficult because of the low carbon content. In such lakes, basal samples for dating are usually taken from the sediments where organic content is higher, and give a date that is more representative of the beginning of deposition of organic sediments at the site than it is of local deglaciation time (King, 1985). Such dates can only be used to infer the minimum age of deglaciation, and not the absolute timing of the event.

Relatively slow rates of sediment accumulation are common in late glacial successions, making rapid environmental changes difficult to resolve because radiocarbon dates may represent several hundred years of sedimentation, especially if it is necessary to date vertically thick samples because of low organic content (Lowe et al., 1988; Ammann & Lotter, 1989).

It is impossible to either detect or remove all sources of error, and radiocarbon dates as indicators of the timing of deglaciation are likely to be in error to some extent. However, many of the problems associated with the use of radiocarbon dates for developing deglacial chronologies can be overcome as long as they are recognised and accounted for in the interpretation of the results, as King (1985) demonstrated in his detailed study of the history of deglaciation in southern Labrador and Quebec.

Some of the problems of obtaining accurate dates on basal lake sediments may be avoided if accelerator mass spectrometry (AMS) dating is used. The AMS radiocarbon dating of hand-picked organic material was used by Cwynar and Watts (1989) to date late glacial events at Ballybetagh, Ireland. Several of their dates were based on terrestrial plant remains, thus eliminating errors due to the hard water effect. However, there is still the possibilty that the remains of terrestrial macrofossils are reworked from older deposits. Ammann & Lotter (1989) suggested that this problem can be avoided by selecting morphologically identifiable terrestrial plant remains of taxa that occur in pioneer vegetation for AMS dating.

A major advantage of AMS measurements is that the residual radiocarbon content can be determined from minute amounts of sample carbon, so that various components of sedimentary organic matter, such as lipids, amino acids and humic acids, can be separately assessed. Several recent studies have attempted to identify possible sources of error in radiocarbon dated samples by AMS dating of different fractions of the sediments (Lowe et al., 1988; Paus, 1988; Blystad and Selsing, 1989; Lowe and Lowe, 1989). These studies have not yielded any conclusive evidence that any particular chemical fraction of the sediment provides accurate dates in all cases, but they have all confirmed the occurrence of old and presumably wrong dates resulting from 'mineral carbon' or 'hard water' errors where dates were obtained from sediments with low organic content, such as those accumulated in recently deglaciated terrain.

Brown et al. (1989) demonstrated for the first time the radiocarbon dating of pollen concentrate samples by AMS, which has the potential to provide more reliable radiocarbon chronologies for paleoenvironmental studies than have ever been obtainable by bulk sediment dating.

Unfortunately, it was not possible to obtain AMS dates on the basal lake sediments used in this study, so it is important to carefully assess the validity of the conventional bulk sediment dates, taking into account the various factors described above, and using the results of the pollen analysis.

2.5 Geochemical stratigraphy of lake sediments

While pollen analysis has been the most widely used method for reconstructing paleoenvironments from lake sediments, analysis of the geochemical stratigraphy may in some instances provide additional information, particularly about changing soil characteristics in the lake catchment. Since lake sediments are formed from a combination of material supplied from the terrestrial surroundings of the lake and material synthesized in the lake water, the chemistry of a given lake sediment is a function of the characteristics of both the lake water and the materials in the catchment.

Engstrom and Wright (1984) provide a comprehensive review of the use of lake sediment geochemical stratigraphy as a tool in reconstructing past environments. They note that sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) are among the major constituents of common silicate minerals and occur in most lake sediments primarily in allogenic clastics eroded from the catchment soils and rocks. Because detrital minerals are little altered in the lake environment, their distribution in sediments is particularly useful in assessing weathering, soil development and erosion in the catchment. This was the basic thesis of Mackereth's (1965, 1966) pioneer work on the geochemical stratigraphy of lake sediments in the English Lake District.

Mackereth hypothesised that both the erosive transport of soil particles and the progressive leaching of mineral matter _in situ_ could be reconstructed from the sedimentary profiles of the alkali and alkaline earth elements, and that these two processes should produce contrasting patterns in the sediments. During periods when the landscape is not fully stabilized, intense erosion should result in mass transport of raw unleached soils to the lakes, recorded in lake sediments by a higher proportion of mineral versus organic matter and high levels of the alkali metals Na and K. On the other hand, when the land surface is stabilized by vegetation, deep weathering of mature soils profiles should diminish the content of these elements in the mineral material prior to its erosive removal and sedimentation, (Mackereth 1966). Mackereth (1966) thus concluded that sedimentary Na and K, being primarily associated with detrital mineral materials, directly reflect the intensity of erosion and weathering in the catchment. He also noted that Mg has a distribution similar to that of the alkali metals, and is clearly associated with the mineral products of erosion (Mackereth, 1966).

Engstrom and Wright (1984) classed the components of the sediment according to their origin as allogenic if formed outside the lake (including mineral particles and humous material washed into the lake from the erosion of catchment soils), or authigenic if precipitated from aquatic solution or formed diagenetically within the sediments (including biochemically precipitated carbonate minerals, metal (Fe and Mn) oxyhydroxides, sulphides, and phosphates, biogenic silica, and sorbed or co-precipitated elements). Because different environmental information is contained within each of these sedimentary components, Engstrom and Wright recommend an analytical separation to help decipher the geochemical history of heterogeneous lake muds.

While the relative intensity of soil erosion is generally reflected in the concentrations of elements primarily associated with clastic minerals, such as Na, K and Mg, estimates of soil weathering based on these elements in the mineral matter (inorganic ash) may be seriously confounded by variations in the sedimentation of biogenic silica and authigenic oxides (Engstrom and Wright, 1984). In nutrient rich lakes, diatoms are common, and part of the silica which after leaching is transported into the lake by the inflowing water becomes assimilated by diatoms for the forming of frustules. Considerable amounts of silica can in this way be removed from the lake water, but at the same time release by dissolution of the frustules of dead diatoms also takes place, since after death the algae lose their buoyancy and the frustules settle rapidly on the lake bottoms. In some sediments diatom frustules are preserved for long periods, while in others dissolution and diagenetic processes make the existence of diatom silicon rare even though the deposition can be high (Hakanson and Jansson, 1983).

Fe and Mn are found in lake sediments as a component of authigenic oxides, sulfides (Fe), carbonates, and organic complexes as well as in the mineral lattices of allogenic clastics. Because a number of independent environmental factors control the delivery and sedimentation of these various minerals, Fe and Mn are difficult to interpret. Iron and manganese may reach lakes as constituents of mineral particles, and may therefore represent the severity of geological erosion in the same way as do the alkaline and alkaline-earth elements (Engstrom and Wright, 1984). The content of authigenic forms of Fe and Mn is also affected by soil development, because the solubility of these elements is dependent on oxidizing-reducing conditions and because humic materials produced by the microbial decay of terrestrial plant materials play an important part in their mobilization from catchment soils (Hakanson and Jansson, 1983; Engstrom and Wright, 1984). Other factors such as pH, sediment mixing and spatial patterns of sediment deposition across the basin can also influence Fe and Mn profiles. The abundance of these two elements is therefore determined by conditions both in the catchment and in the lake.

In general, sediment geochemistry may yield an estimate of the history of landscape stability as it responds to climatic changes and soil development. Elements that should normally have peak concentrations in early postglacial sediments, including Na, K, and Mg, are those that occur in lake muds primarily as allogenic silicate minerals, derived from the erosion of barren soils under the pioneer tundra vegetation of the early Holocene. With the gradual revegetation of barren deglaciated soils and the subsequent invasion of conifers, there should be a decline in those elements and an increase in the concentrations redox-pH sensitive elements such as Fe, Al, Mn and P, of authigenic origin, in response to the decreased erosion of clastic minerals and increased mobilization of organometallic complexes from waterlogged soils produced through humus accumulation under coniferous vegetation (Engstrom and Wright, 1984).

Engstrom and Hansen (1985) used palynological and geochemical analysis of Holocene lake sediments to evaluate long-term interactions between soils and vegetation in southeastern Labrador, and found that the changing composition and structure of catchment soils as inferred from the chemical stratigraphy of lake muds closely parallels the vegetational history of the area reconstructed from pollen analysis.

CHAPTER 3

REGIONAL SETTING

3.1. Location and Topography

The study area is located in southcentral Newfoundland, between latitudes 47° 25'N and 48° 45'N, and longitudes 55° W and 56° 20'W, extending approximately 30 km east and west of Routes 360 and 362 (Figure 3.1), for a total area of approximately 9000 km^2. This includes parts of the areas covered by NTS map sheets 2D/3, 2D/4, 2D/5, 2D/6, 2D/11, 2D/12, 1M/11, 1M/12, 1M/13 and 1M/14.

The region of the study area north of Bay d'Espoir forms part of the Central Newfoundland Plateau (Roberts, 1983), and has a gently rolling hummocky topography. Elevations range from less than 100 m asl in the Northwest Gander River valley to more than 300 m on top of Middle Ridge and the hills north of Jeddore Lake, but average approximately 250 m throughout most of this region. Ridges and valleys are generally parallel to the northeast-southwest structural grain of the underlying bedrock. The major drainage networks in the north (eg. Northwest Gander River, Southwest Gander River, Terra Nova River) tend to drain towards the northeast, while those in the south (eg. Conne River, Little River, Bay du Nord River) drain south to

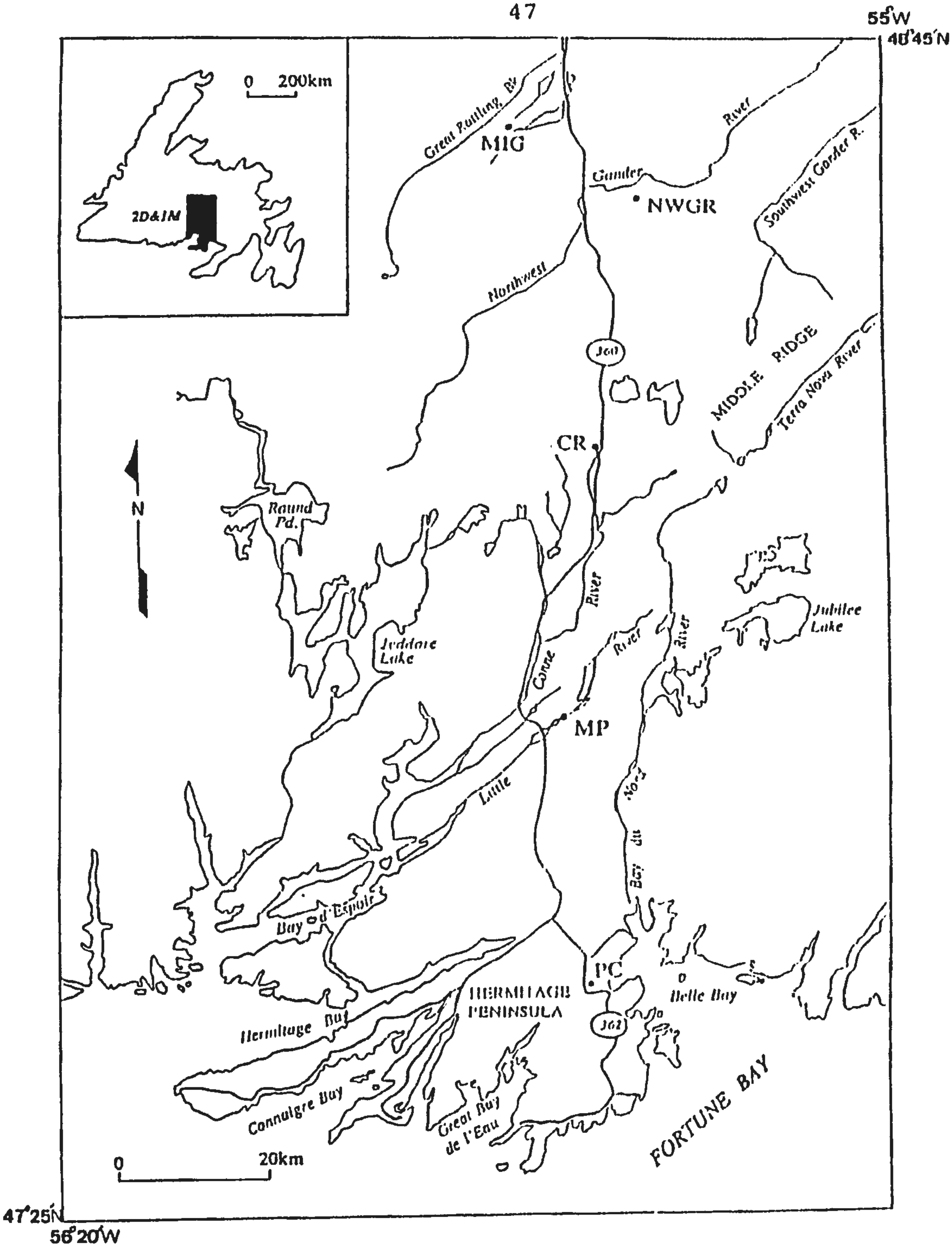

Figure 3.1 Location map. NWGR = Northwest Gander River Pond, CR = Conne River site, MP = Moose Pond, PC = Pool's Cove Pond.

southwest. Many small lakes are scattered throughout the area as a result of glacial derangement of drainage.

The remainder of study area, including the Hermitage Peninsula and the adjacent coastal region, forms part of the South Coast Highlands (Roberts, 1983) and is characterized by barren, rugged bedrock outcrops and deep, steeply sided coastal fiords. Average elevation is approximately 250 m, but hills rise locally to 350 m. Drainage patterns are strongly influenced by the complex structure of the underlying rock, and are irregular, especially on the Hermitage Peninsula.

3.2. Geology

The island of Newfoundland represents the northeastern limit of the Appalachian Mountain system, and has been the focus of considerable geological investigations because it is believed to represent the consequences of Paleozoic continental drift and collision (Wilson, 1966; Williams, 1979).

Four major tectonic zones have been identified on the island which can be traced throughout the Appalachian Orogen (Williams, 1979; Williams et al., 1988). The study area includes parts of three of these tectonic divisions (see Figure 3.2, inset). The Dunnage Zone, which represents a remnant of the Iapetus Ocean, is characterized by Cambrian

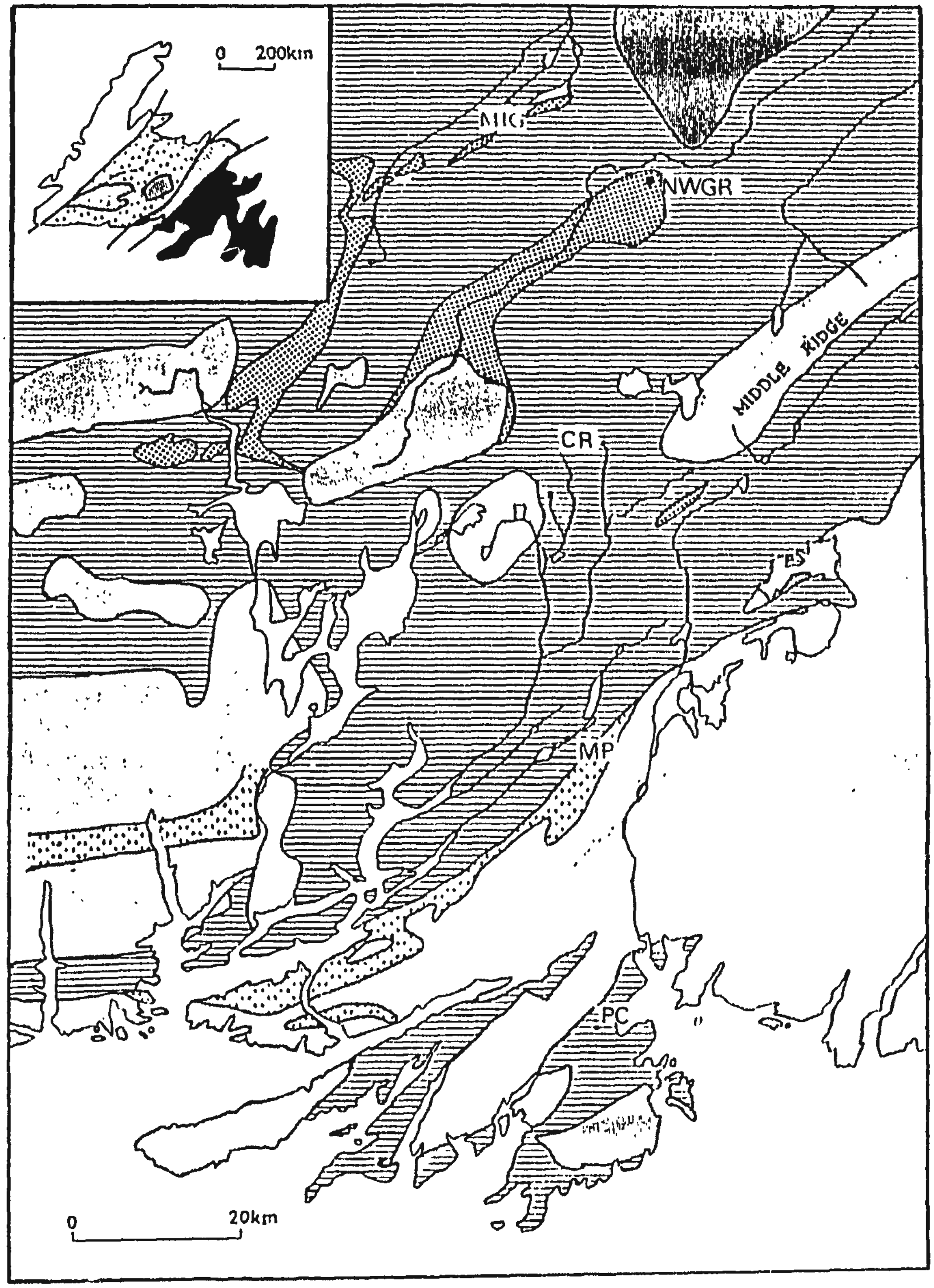

Figure 3.2 Generalized geology map of the study area, after Colman-Sadd & Swinden (1982) and Colman-Sadd <u>et al.</u> (1990). Inset: Tectonic divisions of the island of Newfoundland (Williams, 1979; Williams <u>et al</u>., 1988). See following page for key.

Figure 3.2, Key

Gneisses of uncertain age and origin

Ophiolites representing Ordovician or earlier oceanic crust

Late Proterozoic to Silurian & probably Devonian sedimentary & volcanic rocks

Intrusive rocks

INSET:

Humber Zone

Dunnage Zone

Gander Zone

Avalon Zone

to Middle Ordovician submarine volcanic rocks and Early Ordovician ophiolite suites, overlain in the Exploits subzone by black shales of Middle to Late Ordovician age, passing upwards into Late Ordovician to Early Silurian turbidite deposits and shallow marine and non-marine Silurian strata.

The Gander Zone contains quartz-rich siliciclastic sedimentary rocks of probable Cambrian and Ordovician age, and volcanic rocks are rare. Numerous granite plutons were intruded in the Dunnage and Gander Zones during the Acadian orogeny (375 Ma) (Strong 1980).

The Hermitage Peninsula represents the southwestern extremity of the Avalon Zone, which contains Late Proterozoic submarine and non-marine volcanic rocks and sedimentary rocks, overlain by a Late Proterozoic and Early Paleozoic shallow marine succession.

The bedrock geology of the study area is complex but may be summarized by classifying the outcropping rocks into four main groups (see Figure 3.2), following Colman-Sadd and Swinden (1982) with slight modifications to include parts of the study area not covered by their publication:

1) Gneisses of uncertain age and origin;
2) Ophiolites, representing Ordovician or earlier oceanic crust, which form a basement to lower Paleozoic oceanic deposits and were tectonically emplaced into present positions during the Late Silurian or early Devonian;

3) Sedimentary and volcanic rocks of Late Proterozoic to Silurian and probable Devonian age;

4) Intrusive rocks, most of which are granitoid in composition but range from gabbronorite to granite, mostly of Silurian or Devonian age, with the exception of mafic intrusions on the Hermitage Peninsula of Late Proterozoic to Cambrian age (Colman-Sadd et al., 1990).

3.3. Surficial geology and geomorphology

Most of the study area is covered by a blanket of glacially derived diamicton (till) more than 1.5 m thick, which forms a hummocky terrain over large areas, incorporating landforms described as hummocky moraine as well as ribbed moraine, cross-valley moraine and Rogen moraine (Liverman and Taylor, 1990b) (Figure 3.3). The origin of the hummocky moraine, which covers most of the area north of Bay d'Espoir, is controversial, but it is commonly believed to form beneath stagnating ice (Liverman and Taylor, 1990a).

The coastal area, including the Hermitage Peninsula, has little surficial cover and consists mainly of exposed or vegetation-concealed bedrock with scattered patches of thin till veneer (less than 1.5 m thick), glaciofluvial gravel and sand, and marine deposits.

The main ice flow direction across the area, as reconstructed from striations on bedrock, was southward (160

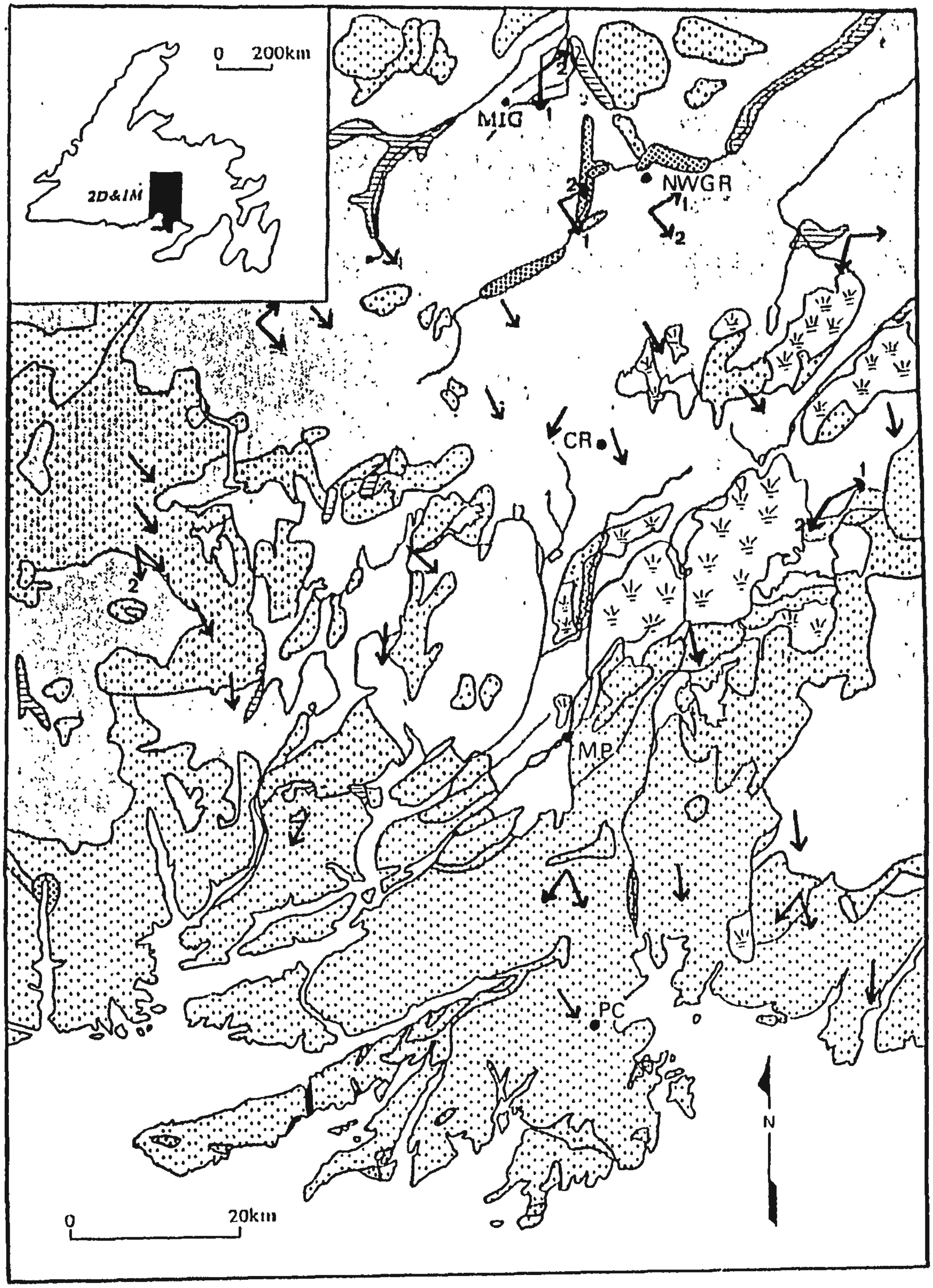

Figure 3.3 Generalized surficial geology map of the study area, after Liverman and Taylor (1990b). See following page for key.

Figure 3.3, cont'd

Key

Exposed bedrock & bedrock concealed by vegetation

Till blanket, including areas of hummocky terrain & ridged till (Till > 1.5 m thick)

Till veneer (< 1.5 m thick)

Glaciofluvial gravel & sand

Alluvium

Marine clay, sand, gravel & diamicton

Bog

Directions of glacial striations on bedrock (after Proudfoot et al., 1990).

to 190°), and most deviations from the south can be explained by local topographic deflections of ice (Proudfoot et al., 1990). North of Third Berry Hill Pond there are numerous sites where the north-south striations have been crosscut by striations indicating a more recent northeastward to eastward flow, (040-100°), but Proudfoot etal. suggest this later flow probably occurred during late-glacial stages as ice-flow centres shifted, rather than during a distinct glacial event. Near the south coast, the striations indicate ice flow to the south and southwest, following the deep fiords.

3.4. Climate

There is considerable climatic variation within the study region. The northern area is included in Zone 2 (Central Uplands) of Banfield's (1981) climatic classification of the island (Figure 3.4), which has a continental climate characterised by cold winters with heavy snowfall and persistent snow cover, and cool summers with frequent low cloud, especially in the southern part of the zone. Annual precipitation values vary from 1200 to 2000 mm within this zone.

The coastal region of the study area is greatly affected by its maritime location and belongs to Banfield's Zone 1 (South and south-east coasts and immediate

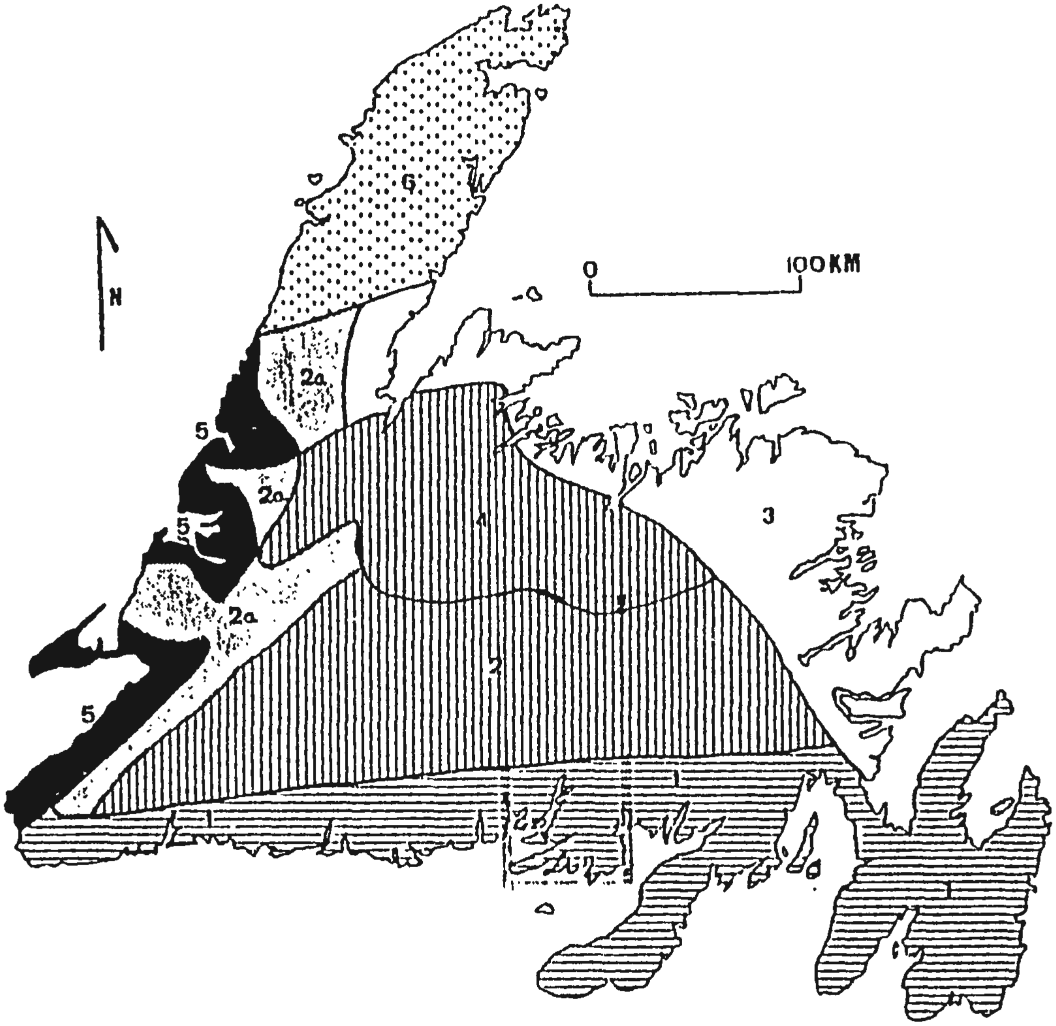

Figure 3.4 Climatic regions of the island of Newfoundland, redrawn from Banfield (1981). Location of study area is indicated. 1-South and southeast coast and immediate hinterlands, 2-Central Uplands, 2a-Western Mountains, 3-East coast and hinterlands, 4-Central lowlands, 5-West Coast, 6-Northern Peninsula.

hinterlands), characterised by relatively mild winters, cool summers, and the highest annual precipitation values in the province (1500-2000 mm). In the winter months snow cover is intermittent and less than half the precipitation falls as snow, while freezing rain is common in late winter. Sea fog is frequent in the summer months. The climate data from the Bay d'Espoir Generating Station (Table 3.1) is representative of this region.

3.5. Soils

A variety of soil types are found throughout the study area, reflecting variations in climate, parent material, topography, drainage and vegetation. The Central Plateau region includes parts of three of the Pedoclimatic Zones of Woodrow and Heringa (1987), the Central, Mountain and Jubilee Lake Zones (Figure 3.5), where Humo-Ferric and Ferro-Humic Podzols, Gleyed Podzols, Brunisols and Gleysols have developed on the glacial sediments. The soils are generally shallow, medium to coarse textured and stony, with poor drainage in many areas as a result of impermeable bedrock, hard indurated horizons and pans, or a high silt content. Organic soils, forming a variety of bogs and fens, are common throughout.

Table 3.1. Climatic data, Bay d'Espoir Generating Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily Max.Temp.	-0.9	-1.0	1.8	6.5	12.5	17.5	21.4	21.2	17.3	11.5	6.5	1.3	9.6
Daily Min.Temp.	-10.8	-11.2	-6.9	-1.7	2.1	6.8	11.1	11.5	7.1	2.7	-0.9	-7.1	0.2
Daily	-5.8	-6.1	-2.6	2.4	7.4	12.2	16.3	16.4	12.2	7.1	2.8	2.9	5.0
Rainfall	95.4	71.4	96.0	87.4	74.6	106.3	101.2	126.8	114.6	154.1	141.8	128.2	1297.8
Snowfall	46.6	42.3	35.2	18.7	0.8	0.0	0.0	0.0	0.1	1.0	7.8	41.9	194.4
Total ppt.	138.9	128.8	120.1	110.4	94.2	99.2	102.0	128.8	112.0	138.4	146.7	181.5	1501.0
Days with rain	7	5	8	10	12	12	12	13	13	14	13	10	129
Days with snow	10	9	9	4	0	0	0	0	0	0	2	9	43
Days with ppt.	16	14	15	14	14	14	13	15	15	15	15	18	178
Degree days above 5C	1.4	0.7	0.6	9.8	75.4	203.7	334.9	332.6	204.2	73.5	20.0	3.7	1260.5

Units:
Temperatures C
Rainfall mm
Snowfall cm
Total ppt. mm

Source: Canadian Climate Normals 1951-1980

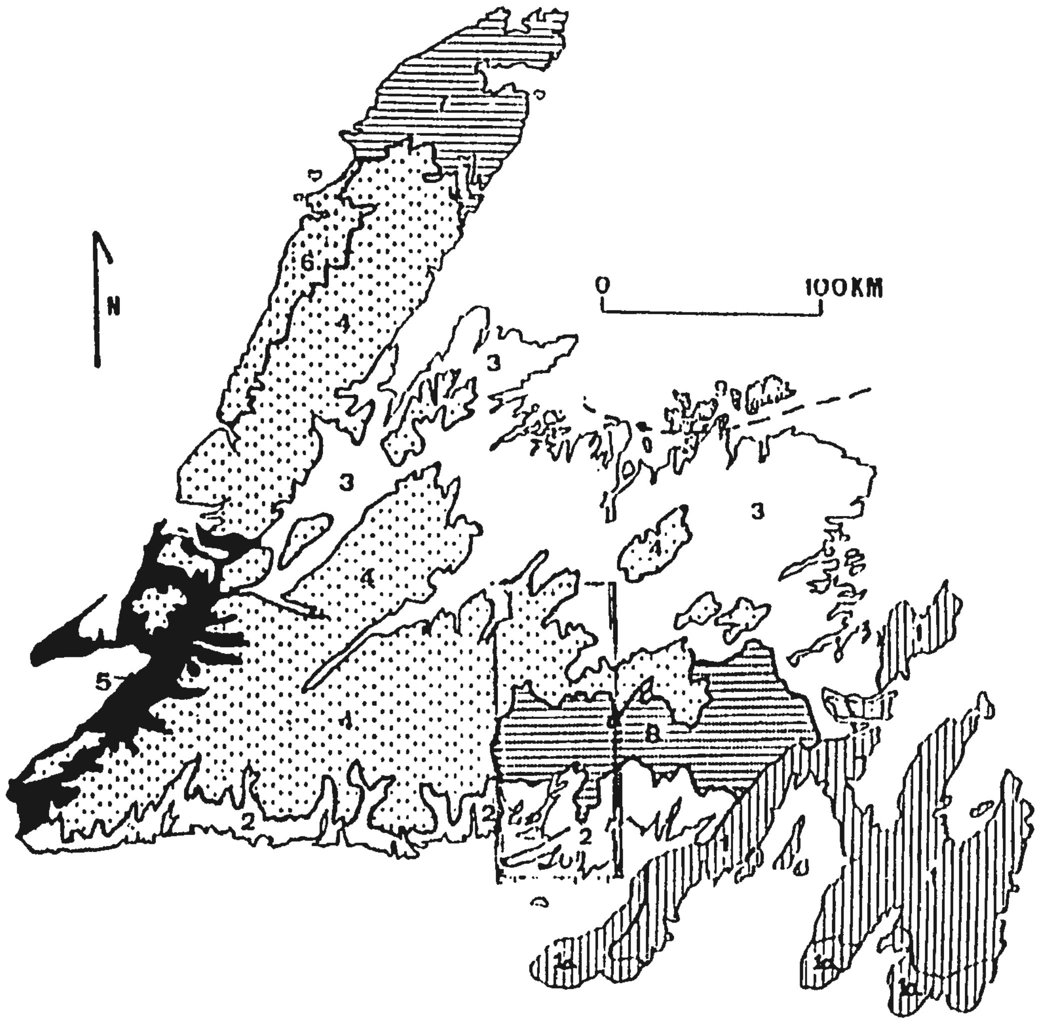

Figure 3.5 Pedoclimatic zones of the island of Newfoundland, redrawn from Woodrow and Heringa (1987). Location of study area is indicated. **1**-Atlantic, **1a**-South Atlantic, **2**-South Coast, **3**-Central Newfoundland, **4**-Mountain, **5**-Bay St. George, **6**-Gulf of St.Lawrence, **7**-North, **8**-Jubilee Lake, **9**-Northeast Coast.

The mineral soils of the South Coast Zone (see Figure 3.5) have developed on bedrock or very thin till veneer, in a harsh climate. They are classified mainly as Ferric-Humic Podzols and Humic Podzols which have iron pans with duric or cemented BC horizons, but Humo-Ferric Podzols and Gleysols also occur. Organic soils, including Terric and Typic Mesisols, occur usually as sloping bog or fen (Woodrow and Heringa, 1987).

3.6. Vegetation

Most of the study area falls into Damman's (1983) ecoregion VI (Maritime Barrens) (Figure 3.6) which is characterised by extensive barren areas consisting mainly of dwarf shrub heaths, bogs and shallow fens. Forest cover generally increases northwards and is most common in valleys, but also occurs occasionally on hilltops and slopes.

The dwarf shrub heath characteristic of the ecoregion is dominated by *Kalmia angustifolia*, especially on protected slopes where snow accumulates (Meades and Moores, 1989). *Kalmia* is replaced as the dominant species by *Empetrum nigrum* and *Vaccinium vitis-idaea* on exposed sites, and on very exposed sites where the vegetation cover is damaged by

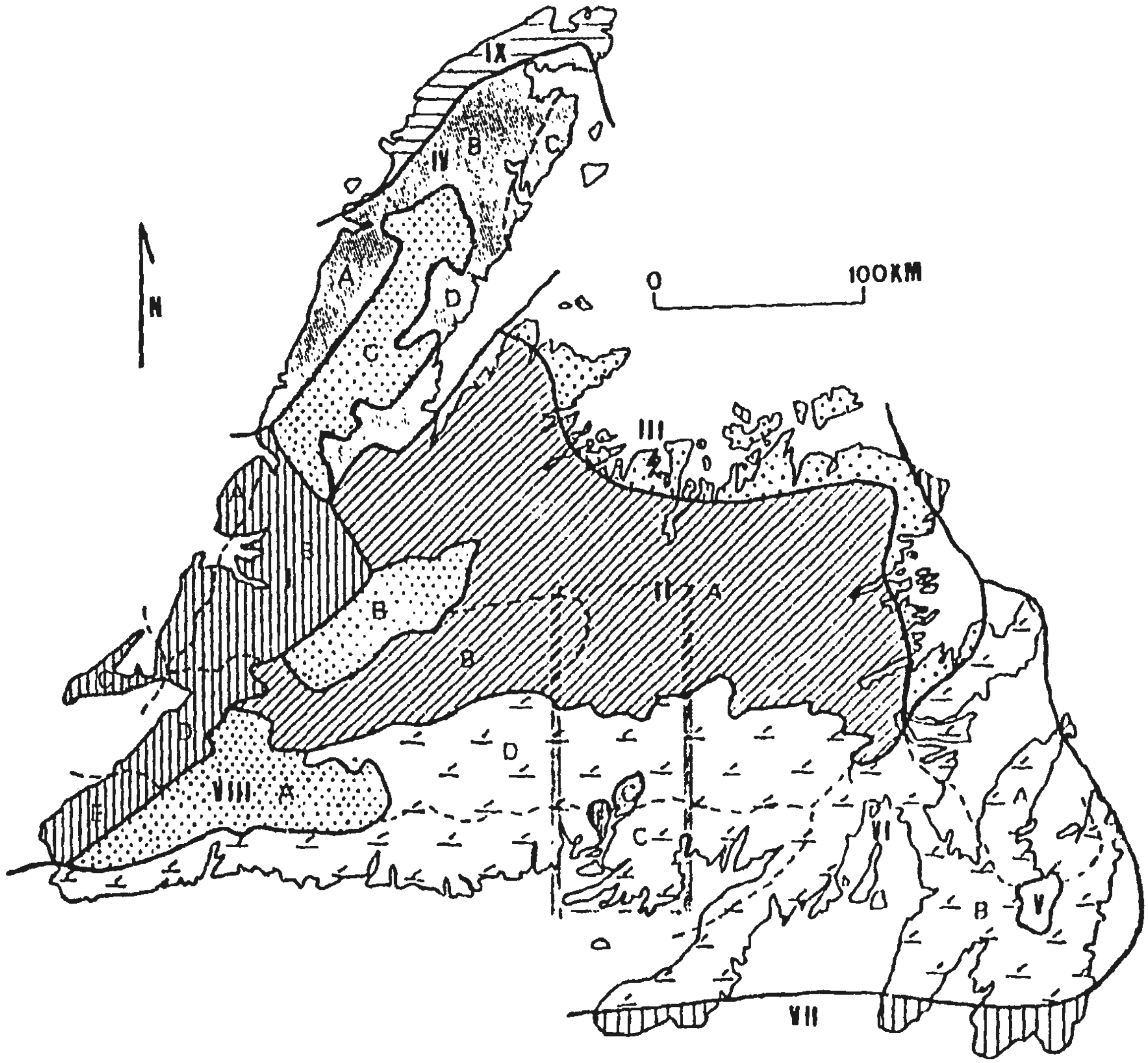

Figure 3.6 Ecoregions of the island of Newfoundland, redrawn from Damman (1983), with location of study area indicated. I-Western Newfoundland, II-Central Newfoundland, III-North Shore, IV-Maritime Barrens, V-Avalon Forest, VI-Maritime Barrens, VII-Eastern Hyper-Oceanic Barrens, VIII-Long Range Barrens, IX-Strait of Belle Isle. Letters indicate subregions (see Damman, 1983).

solifluction, frost heaving and wind erosion, an Empetrum eamesii vegetation develops. Other ericaceous shrubs such as Rhododendron canadense and Vaccinium angustifolium are also abundant. The moss layer is dominated by Pleurozium schreberi and Cladonia spp.

The most important tree in the scattered patches of forest is Abies balsamea, which often forms dense but stunted stands. The shrubs Nemopanthus mucronata and Viburnum cassinoides are abundant throughout the ecoregion, Larix laricina is common in the open barrens, and Sorbus decora often forms thickets in coastal areas. Forest patches of reasonable quality occur throughout the Central Barrens subregion, VI.D. (Figure 3.6), which experiences warmer summers, less frequent fog, and more reliable winter snow cover than the South Coast subregion (VI.C).

In contrast to the Maritime Barrens, ecoregion II (Central Newfoundland), which includes the northern portion of the study region and the isolated Twillick Steady subregion north of Bay d'Espoir (II.D) (see Figure 3.6), is characterized by forests dominated by Abies balsamea with a dense moss carpet of Hylocomium spendens. Forest fires are very frequent in this ecoregion (with the exception of subregion II.D) and fire stands of Picea mariana, and to a lesser extent Betula papyrifera and Populus tremuloides, cover large areas. Communities of dwarf-shrub heath dominated by Kalmia angustifolia have developed on nutrient-poor parent materials in areas affected by repeated forest fires. Raised bogs with more or less concentric rings of pools are common throughout this ecoregion, with scattered, low Picea mariana and Larix laricina trees usually growing on the strings.

Immediately to the south of subregion II.D is a small area classified by Damman as belonging to ecoregion I - Western Newfoundland (Bay d'Espoir subregion, I.F.), which occupies a deep, sheltered river valley at the head of Bay d'Espoir. This small area is climatically very favourable for plant growth, and is heavily forested, mainly by Abies balsamea, with Picea mariana stands on poorly drained sites and bedrock outcrops. Pinus strobus was apparently more common in this region in the past, but extensive logging of this tree in the late 19th and early 20th centuries depleted its numbers considerably (Cokes, 1973). According to Cokes, white pine (P.strobus) and tamarack (Larix laricina) combined make up less than 5% per unit area of the forest today, while Abies balsamea makes up more than 50% and Picea mariana 20-30%. Betula papyrifera and Betula lutea are also present, making up 10-20% and less than 5%, respectively, of the trees per unit area.

CHAPTER 4

METHODOLOGY

4.1 Field Work

4.1.1 Site Selection

Core samples were collected from a total of five ponds in southcentral Newfoundland. Initially, several possible sites were selected by studying 1:50,000 topographic maps and aerial photographs, and the final selection was made after visiting the various sites. Pollen analysis had previously been completed on a core from the Conne River site by Dr. Joyce Macpherson, but an additional core was collected from that pond for geochemical analysis. The following criteria were used in the selection of the other sites:

- one site should be located near the Late Wisconsin ice divide in the northern part of the study area, one near the south coast on the Hermitage Peninsula, and at least one site between these in addition to the Conne River site;
- ponds must be above the marine limit, which ranges from 25 m asl on the south coast to 30-40 m asl further north within the study area (Grant, 1980);
- there should be little or no inflow, in order to avoid sediment disturbance by through current;
- small ponds with sheltering surrounding slopes were preferred, to minimize the effects of wind on water circulation, thus reducing the processes of resuspension and differential deposition that affect the rate of pollen influx;

- for logistical reasons, sites should be accessible by road.

Coring of Miguels Pond produced over 5 m of sediment, but no basal mineral sediment was found after attempts in several different areas of the pond. The Northwest Gander River Pond site was then cored to ensure retrieval of a complete postglacial stratigraphic sequence from a site in the vicinity of the ice divide.

4.1.2 Coring

The cores were collected from two small aluminum boats bolted together and joined by a platform through which the coring was performed. The deepest areas of each lake were located with a plumb line prior to coring. A modified Livingstone piston corer was then used to raise core segments with a 5 cm diameter and 1 m length. The boats were securely anchored and a heavy plastic casing, extending from the platform to the sediment surface, was used to ensure the vertical positioning of the extension rods and coring tubes down through the sediment. Duplicate cores were extracted from each lake, so that one could be used for pollen and loss-on-ignition analyses and radiocarbon dating, and the other for geochemical analysis. At each site, the two cores were collected less than one metre apart to ensure a high degree of stratigraphic correlation.

The core segments were extruded in the field, placed in rigid plastic troughs, wrapped in plastic wrap and aluminum foil, labelled, and transported horizontally to the laboratory.

4.1.3 Vegetation survey

A reconnaissance survey of the modern vegetation of the drainage basin of each pond was carried out at the time of sample collection. Aquatic plants growing in the ponds, as well as herbs, shrubs and trees in the surrounding areas, were identified to species level whenever possible using field guides (Ryan 1978; Peterson & McKenny 1968). In addition, the composition of the local forest, in terms of the relative proportions of dominant arboreal species (*Picea mariana*, *P. glauca*, *Abies balsamea* and *Betula* spp.) was noted for the areas surrounding each site.

4.2 Laboratory techniques

4.2.1 Stratigraphy

In the laboratory, the sedimentology of the cores was described in terms of stratigraphic changes in physical properties such as colour, composition, and consistency. Because the outside surfaces of the core segments were smeared during extraction from the tubes, the cores were first cut in half vertically, and descriptions were made of the undisturbed centers of the cores.

4.2.2 Sampling

Samples were extracted from one core from each of Northwest Gander River Pond, Moose Pond, and Pool's Cove Pond for radiocarbon dating and loss-on-ignition analysis, as well as for pollen analysis. All samples were extracted from the centers of the split cores, to avoid contamination of the samples resulting from smearing of the outside surface of the core during extraction. Sediment samples for pollen analysis were extracted from one half of the core at 2.5 cm intervals, to allow a high degree of resolution at levels of dramatic changes in pollen composition. The samples were extracted using a small metal spatula, carefully cleaned between samples to avoid contamination, and stored in sealed, labelled glass vials until the chemical pollen extraction was carried out.

Samples of 1 cm vertical thickness were extracted from the other half of the core for loss-on-ignition analysis at 10 cm intervals, with the outside surface of each sample being carefully scraped away, again to avoid the possibility of contamination.

Core segments with a vertical thickness of 5 cm were extracted at selected levels and dispatched to the

Geological Survey of Canada for radiocarbon dating. Samples from the lowest levels with enough organic matter for accurate dating (as determined by loss-on-ignition analysis) were dated from each site to determine minimum ages of deglaciation. Additional samples were dated to determine the timing of spruce increase, provide control for the basal dates, and allow determination of influx rates.

4.2.3 Loss-on-ignition analysis

Loss-on-ignition analysis was performed to provide an approximation of the stratigraphic changes in organic content throughout the cores, which is useful in selecting levels for pollen analysis and dating. Samples which have a very low percent loss-on-ignition value contain only small amounts of organic matter and are thus not likely to contain much pollen or to be suitable for radiocarbon dating.

The procedure used for loss-on-ignition analysis is as follows:

1. Sediment samples were placed in crucibles of known weight and left overnight in an oven at approximately 100° C to dry.
2. The crucibles, with the samples, were placed in a dessicator to cool and then the weights of the crucibles plus the dried samples were obtained.
3. The dried samples were pulverized, returned to their crucibles, and placed in a furnace at 500-550° C for 2 to 4 hours for ignition of the organic matter. Samples were stirred after one hour to ensure full ignition, then returned to the furnace.

4. The samples were again cooled in a dessicator before being weighed to determine the crucible plus ash weight.

5. The percentage loss-on-ignition could then be calculated by the equation:

$$\frac{(b-a) - (c-a)}{(b-a)} \times 100 \qquad \text{or:} \qquad \frac{(b-c)}{(b-a)} \times 100$$

Where: a = weight of crucible
b = weight of crucible + sediment
c = weight of crucible + ash

4.3. Pollen analysis

4.3.1 Introduction

Pollen analysis was carried out on only the basal segments of the cores from the Pool's Cove, Moose and Northwest Gander River Ponds. The core from Miguel's Pond was rejected after examination of its stratigraphy and loss-on-ignition curve. This core is composed of organic lake mud (gyttja) with a high percentage of organic matter throughout its entire depth. Since the expected transition from mineral sediment at the base to organic sediment higher in the sequence is absent in this core, it was concluded that it might not represent the entire postglacial period, and therefore was not included in this study.

4.3.2 Chemical processing of samples for pollen analysis

The samples were prepared for analysis following a slightly modified version of the standard method outlined by Faegri and Iversen (1975) and Moore and Webb (1978), which involves treatment of the samples with various chemicals to remove most of the unwanted sediment matrix, leaving a residue rich in pollen and spores. A measured volume of a suspension of Eucalyptus pollen of known concentration was added to each sample prior to processing to serve as an exotic marker, to enable the calculation of 'absolute' pollen frequencies.

The method used can be summarized as follows:

1. Clay removal: Samples were washed repeatedly with a warm 5% sodium pyrophosphate ($Na_4P_2O_7$) solution to remove clay, and during the last wash the liquid was decanted back and forth between two beakers to remove sand particles. Very clay rich samples were subjected to a fine-seiving treatment, which involved resuspending the sample in $Na_4P_2O_7$ and filtering the clay particles through a 7 μm nylon mesh screen (Cwynar et al., 1979)

2. To deflocculate and remove humic acids, 10% potassium hydroxide (KOH) solution was added to the samples, which were then heated to boiling in a water bath. Samples were strained through Gooch crucibles to remove coarse organics, rinsing well with distilled water.

3. Hydrofluoric acid (HF) treatment to remove siliceous material: Samples were left in cold HF overnight and/or boiled with HF in a water bath for 5 minutes, followed by boiling with 10% HCl solution in a water bath for 5 minutes to remove colloidal silicates and silicofluorides.

4. Acetolysis to remove cellulose and hemi-cellulose: Samples were first washed with glacial acetic acid to dehydrate them before adding acetic anhydride and concentrated sulfuric acid. They were then boiled in a water bath for 5 minutes and washed again with acetic acid.

   Samples were washed with distilled water and centrifuged after each of the first four steps in the procedure.

5. After washing several times with distilled water the remaining pollen-rich residue was stained with safranin (an organic dye) to bring out the morphological characteristics of the grains, and dehydrated by rinsing with tertiary butyl alcohol.

6. Small amounts of the residue were mounted on microscope slides in silicone oil, for pollen identification and counting.

4.3.3 Microscopy

Pollen identification and counting was performed using a Carl Zeiss Jena binocular microscope at a magnification of x500 routinely, with magnification of x1250 and immersion oil used for grains that were difficult to identify. Traverses across the microscope slides were made at regular intervals of 2 mm over the entire area of the cover slip to avoid any bias that may have resulted from differential movement of various types of pollen grains on the slides. Pollen grains and spores were identified with the aid of several keys (Kapp 1969; McAndrews et al. 1973; Faegri and Iversen 1975; Moore and Webb 1978; Andrew 1984) as well as an extensive collection of reference slides of modern pollen samples.

A minimum pollen sum of 300 fossil grains plus at least 100 exotic grains was counted for most samples, except those where pollen concentrations were low. At these levels counts of 100 fossil grains were achieved. These low pollen counts were still considered to provide reasonable samples since five or more slides were counted for each. For the remainder of the samples a minimum of two slides was scanned.

Pollen and spores were identified based on size and shape as well as wall and aperture structuring. Grains were identified to genus level, except in the case of groups such as Ericaceae, Gramineae and Cyperaceae, which are difficult to distinguish beyond family level with much confidence.

Betula pollen grains were separated into grains less than 20 μm, taken to represent shrub birch, and larger grains, taken to represent arboreal birch (Ives, 1977; Dyer, 1981), to aid in the identification of tundra and forest assemblages. However, there is some overlap in size of modern shrub and tree birch pollen, making this separation a rough approximation only. Pollen of shrub birch species found in the study area (_Betula pumila_, _B. michauxii_) range in size from 18 μm to 26 μm, while pollen grains of the arboreal species _B.lutea_ and _B. papyrifera_ range from 25 μm to 35 μm. The overlap in size range between tree and shrub pollen is thus minimal, except that _B. cordifolia_ grains range in size from 20μm to 34 μm, making separation questionable for grains between 20-25 μm (Dyer 1981). However, in the samples analysed, very few birch grains in this size range were identified, and the separation of Betula grains greater than and less than 20 μm in diameter probably represents a close approximation of pollen from tree versus shrub birch.

Pollen grains of Picea glauca (white spruce) and P. mariana (black spruce) were differentiated on the basis of morphological characteristics (Hansen and Engstrom, 1985). This separation may strengthen the interpretion of the pollen records by providing information about changing soil conditions, since P. mariana is more tolerant of acidic, organic and waterlogged soils than is P. glauca (Lamb, 1980; Engstrom and Hansen, 1985).

4.3.4 Calculation of pollen frequencies and influxes

Because this study is concerned with the vegetational succession beginning with initial colonization after deglaciation, the pollen sums used for the calculation of percentage frequencies of the individual pollen taxa was comprised of the total of all land pollen including tree, shrub and herb taxa. The percentage frequency of each taxa (Y) within this group was then calculated for each sample as:

$$\frac{\text{grains of Y counted}}{\text{total land pollen count}} \times 100$$

For all other groups, including spores, aquatics and indeterminable grains, the percentages were calculated as percentages of their own sum plus the basic total land pollen sum. This method of calculation of all taxa outside the basic pollen sum is in accordance with the recommendation made by Faegri and Iversen (1975) that "the occurrence of any pollen category should be expressed in percentages of a universe of which it forms a part."

The concentrations, or absolute pollen frequencies, of each pollen and spore type was determined based on the exotic pollen counts and the known amounts of exotic pollen added to each sample, as follows:

$$\text{concentration of fossil pollen} = \frac{F}{E} \times \text{exotic pollen added}$$

Where: F = fossil pollen counted
E = exotic pollen counted

Sediment accumulation rates were calculated based on successive radiocarbon dates, and the annual pollen deposition rates, or pollen influx (grains/cm^2 of surface sediment/yr) were then calculated by multiplying the fossil pollen concentration by the sedimentation rate.

All percentage, concentration and influx calculations for the samples were performed using the POLSTA2 computer program (Green, 1985) after sample levels, radiocarbon dates and pollen counts for each taxon were read into the program.

4.3.5 Pollen diagram construction

All pollen diagrams were constructed using the POLSTA2 program. Pollen percentage and influx diagrams were both prepared because each provides a different set of information. Percentage diagrams, for example, illustrate the relative proportions of taxa present and therefore give an indication of the composition of plant communities, but do not account for changes in plant abundance, or for the effect a change in the input of one particular taxon may have on the relative proportions of all other taxa. Information about the absolute quantities of individual taxa and overall vegetation density can be obtained from pollen influx diagrams, but this information may easily be misinterpreted if changes in sedimentation processes are overlooked (Moore and Webb, 1978).

The depth below the water-sediment interface and the radiocarbon dates are indicated on the left axes of the diagrams. The sediment stratigraphy is illustrated to the left of each diagram. At the far right of each diagram is a curve indicating concentrations of total land pollen.

For ease of interpretation and discussion, the diagrams represent summaries of the results of the pollen analysis, designed to concentrate on those taxa which are most critical to the interpretation of the late-glacial-early postglacial environments. Thus, while individual pollen curves are presented for the most important taxa (including the coniferous trees, Betula, Alnus, pioneering herbs such as Rumex and Artemisia), certain types of pollen have been grouped together with other related taxa where little additional information would be provided by plotting individual curves.

For example, pollen of tree species which were present only in very small quantities were grouped together as "other trees". This category includes pollen of species such as Tsuga and Fagus which are not found in the area today, and are assumed to have been deposited in the lake sediments as a result of long-distance tranport from the mainland of North America.

Most herb taxa were present only in very small quantities, and have therefore been grouped as "other herbs". Only those herb taxa which are particularly important as indicator species, or which are present in relatively large proportions in some levels of the cores, are plotted individually.

All spores have been totalled and plotted as one group, as have all aquatic pollen taxa. The "indeterminable" category includes all grains which could not be identified, either because they were obscured by other detritus on the slides, or were deteriorated too much to allow identification. A complete list of pollen counts for all taxa identified from each sample is presented in Appendix 1.

4.3.6 Pollen diagram zonation

Horizontal lines have been superimposed on the pollen diagrams, dividing them into pollen zones as numbered at the right of the diagram. These zones are intended to define sections of the core which are relatively uniform in pollen composition, and the boundaries were therefore drawn subjectively where there are notable changes in the curves. Moore and Webb (1978) recommend that the initial zonation of the diagram should be based upon "the inherent features of the data in question" without reference to other diagrams, which is the way the given zonation was derived. The purpose of this zonation is mainly to make description and interpretation of the pollen trends easier and to aid in the comparison and correlation of diagrams from different sites (Birks and Birks, 1980; Moore and Webb, 1978).

4.4. Geochemical analysis

Consecutive samples of 5 cm depth were extracted from the duplicate cores from each site, as well as samples at 20-25 cm intervals from the cores used for pollen analysis from Northwest Gander River Pond, Moose Pond and Pool's Cove Pond, for geochemical analysis. All processing of samples for geochemical analysis was carried out at the laboratory of the Department of Mines and Energy, Government of Newfoundland and Labrador, using the methods summarized below (C.Finch and P. Davenport, pers. comm.)

Proportions of major oxides (SiO_2, Al_2O_3, Fe_2O_3, K_2O, MgO, CaO, TiO_2, Na_2O, MnO, P_2O_5) were determined by fusion of 0.100 gram samples with lithium borate ($LiBo_2$) followed by digestion in hydrochloric acid (HCl) and hydroflouric acid (HF). Amounts were measured by Inductively Coupled Plasma (ICP) analysis.

Fractionation of organically sorbed cations, presumed to represent the authigenic fraction of various elements in the lake sediments, was achieved by digestion of 1 gram of sample in 30% hydrogen peroxide (H_2O_2) followed by 3N hydrochloric acid (HCl). This was followed by filtering through a 0.45 micron Millipore filter. The filtrate solution was used for analysis of organically sorbed cations (by atomic absorption analysis for some elements, ICP analysis for others), and the residue from the filter paper was digested in 0.2 N sodium hydroxide (NaOH) for determination of the content of biogenic silica.

The results are numerically represented in units of concentration, as weight percent of mineral matter, plotted using the POLSTA2 program for direct comparison with the pollen diagrams. Pollen zones are superimposed on the geochemistry profiles for each site for ease of comparison of geochemical and pollen stratigraphies.

Chapter 5

Site Characteristics

5.1. Northwest Gander River Pond

5.1.1 Location

Northwest Gander River Pond (48° 34'40"N, 55° 25'00"W; grid reference 6 168 54 814), is located 2 km south of Northwest Gander River, and 50 km south of the town of Bishop's Falls, Newfoundland. At an elevation of 160 m asl it is well above the marine limit, which is less than 50 m throughout the study area (Grant 1980). Access was possible using a logging road.

5.1.2 Topography

The pond lies in an area of irregular hummocky terrain underlain by ophiolites, with elevations ranging from approximately 60 m at the banks of Northwest Gander River to a maximum elevation of about 200 m (see Figure 5.1). Bogs and small ponds lie in the low areas between the hummocks, which are composed mainly of diamicton (Liverman and Taylor, 1990). The catchment is underlain by ophiolitic rocks of the Great Bend Complex, including peridotite and serpentized and magnesitized pyroxenite with interbedded gabbro and peridotite (Colman-Sadd and Swinden, 1982).

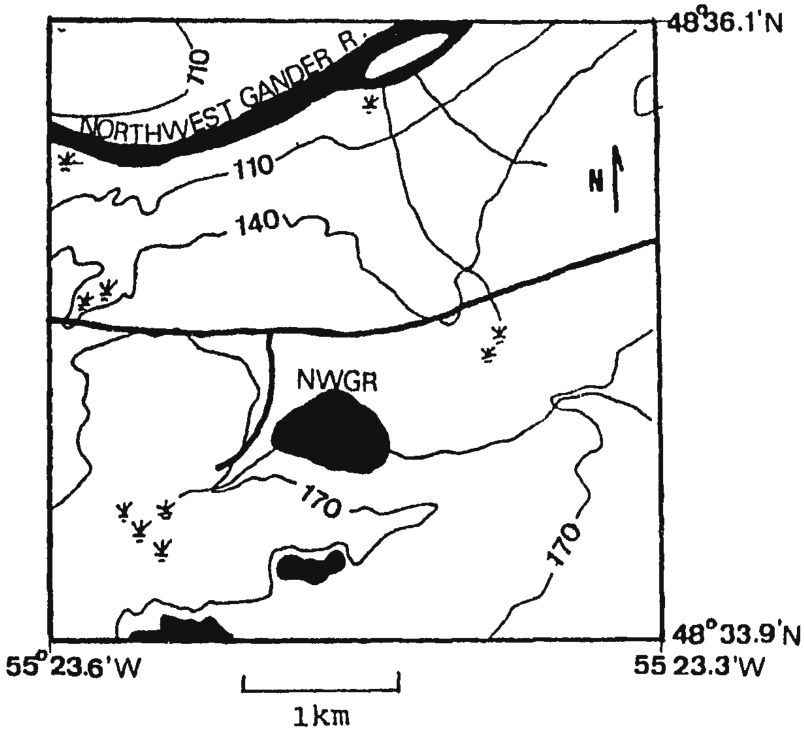

Figure 5.1 Topographic map of Northwest Gander River Pond area. Contour interval = 30 m. Source: NTS Map 2D/11, 1:50,000.

5.1.3 Lake Characteristics

The pond is roughly elliptical in shape, measuring approximately 700 x 500 m, with a surface area of approximately 23 ha. One small inflowing stream enters the pond from the southwest, and drainage is provided from the eastern end of the pond by a tributary of Bear Brook, which drains into Northwest Gander River. The catchment area is approximately 175 ha. The maximum water depth recorded in the pond was approximately 250 cm near the western end, but as this was considered to be too close to the inflow channel, coring was performed in the centre of the pond, where the water depth was 202 cm.

5.1.4 Vegetation

The only aquatic species identified in the pond was *Nuphar variegatum*, which was fairly abundant. Gramineae and Cyperaceae as well as a variety of herbs and shrubs, including *Iris versicolor*, *Rosa nitida*, *Myrica gale*, *Rhodora* spp., *Thalictrum polygamum*, *Ledum groenlandicum*,*Kalmia angustifolia*, *Vaccinium angustifolium*, and *Alnus crispa* are found along the water's edge.

This site falls within Damman's ecoregion II - Central Newfoundland (see Figure 3.6), and large areas of the surrounding forest have been affected by forest fires. *Picea mariana* is the dominant tree species in these areas,and large stands of Alnus crispa are common. Also found here are shrubs such as Kalmia angustifolia, Vaccinium angustifolium, and Rubus idaeus; a variety of herbs including Epilobium angustifolium and Saxifragaceae; and scattered large dead Betula papyrifera trees. The area has been harvested rather extensively by the pulp and paper industry, and Alnus crispa, Kalmia angustifolia, Salix spp., and Vaccinium spp. are common in the cutover areas. In the remaining undisturbed areas of the forest, Abies balsamea is the dominant tree species, while Picea mariana and Betula papyrifera are also common and scattered Picea glauca and Pinus strobus can be found.

5.2. Pool's Cove Pond

5.2.1 Location

The southernmost site, Pool's Cove Pond (47° 38'00"N, 55° 31'00"W, grid reference 6 119 52 760) is located on the Hermitage Peninsula, 8 km southwest of the community of Pool's Cove. Its elevation is approximately 150 m asl, well above the marine limit, which according to Grant (1980) is approximately 25 m in this coastal area.

5.2.2 Topography

The topography of the coastal highlands on which this site is located is variable, reflecting the complex geology. The pond itself is situated within the Pool's Cove Formation, made up of fluviatile and lacustrine, siliclastic and carbonate rock, and subaerial, bimodal volcanic rocks of Devonian and Carboniferous age. Elsewhere on the peninsula are found stratified marine sedimentary rocks; bimodal, mainly subaerial volcanic rocks; and granitoid and mafic intrusions (Colman-Sadd et al., 1990). In general the area is characterised by irregular rock knobs, exposed in places but mostly concealed by vegetation. Surficial deposits are absent with the exception of small patches of till or sand and gravel (Liverman and Taylor, 1990b), and bogs and small ponds are found in low lying areas. Pool's Cove Pond occupies a bedrock basin and is sheltered on all sides by hills of 200-250 m asl.

5.2.3 Lake characteristics

This irregularly shaped headwater pond has several basins (see Figure 5.2), with a total surface area of approximately 7.5 ha and a catchment area of approximately 60 ha. One small outflow stream drains the pond from the south-southeast. Duplicate cores were collected from the northern basin, where water depths were up to 680 cm, the

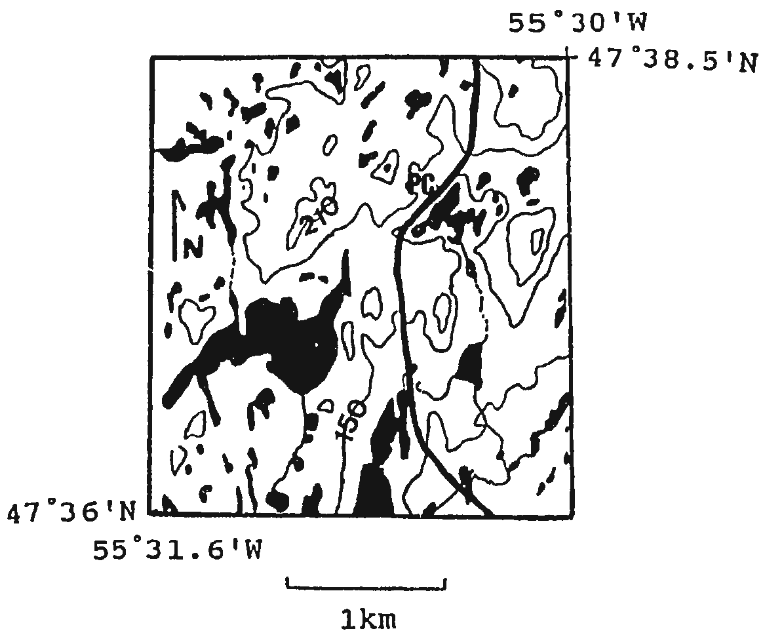

Figure 5.2 Topographic map of the Pool's Cove Pond area. Contour interval = 30 m. Source: NTS Map 1M/12, 1:50,000.

deepest recorded in the pond. An additional core was also collected from the southwestern basin (water depth 260 cm) but was not used in this study as it yielded only 70 cm of sediment, compared to the 280 cm of sediment collected from the northern basin.

5.2.4 Vegetation

No aquatic vegetation was found in this pond, which lies within subregion C (South Coast Barrens) of the Maritime Barrens ecoregion (Damman, 1983). *Rosa nitida*, Umbelliferae, *Achillea millefolium* (Yarrow), *Myrica gale*, *M. pensylvanica* and *Larix laricina* grow around the edge of the pond, while the surrounding bedrock ridges are mostly covered by *Sphagnum* mosses, with *Vaccinium* spp., *Betula michauxii*, *B. glandulosa*, and *Juniperus horizontalis*. Trees, including *Alnus crispa*, *Sorbus americana*, and stunted (1-1.5 m) *Abies balsamea* are restricted mainly to roadsides and sheltered areas. Stunted *Picea mariana*, in krummholtz form, grow near the pond and in scattered boggy sites.

5.3 Moose Pond

5.3.1 Location

Moose Pond (47° 56'00"N, 55° 33'30"W; grid ref. 6 077 53 096) is located 1 km from the entrance to Jipujijkuei Kuespem Provincial Park, at an elevation of 130 m asl, well above the marine limit which is less than 50 m according to Grant's (1980) reconstruction.

5.3.2 Topography

The structure of the underlying bedrock has a major impact on the landscape of the Moose Pond area (Figure 5.3), as evidenced by the northeast-southwest trend of most of the ridges and drainage lines in the area, reflecting the trend of the major geological units in the area. The bedrock consists of felsic and mafic volcanic tuffs and flows with interbedded gray-green shale and siltstone, graphitic slate, and coarse sandstone and conglomerate, making up the Isle Galet Formation (Colman-Sadd and Swinden, 1982). Moose Pond lies in a broad, gently sloping valley, with summits of approximately 220 m and 260 m to the north and southeast respectively. The pond itself lies within the southern extent of the hummocky terrain which covers most of the northern part of the study area, but within 2 km to the east and south, and 8 km to the west and southwest, the bedrock is either exposed, concealed by vegetation or in places covered by a thin till veneer.

5.3.3 Lake characteristics

Moose Pond is larger than the other ponds cored, with a surface area of approximately 50 ha, and measuring

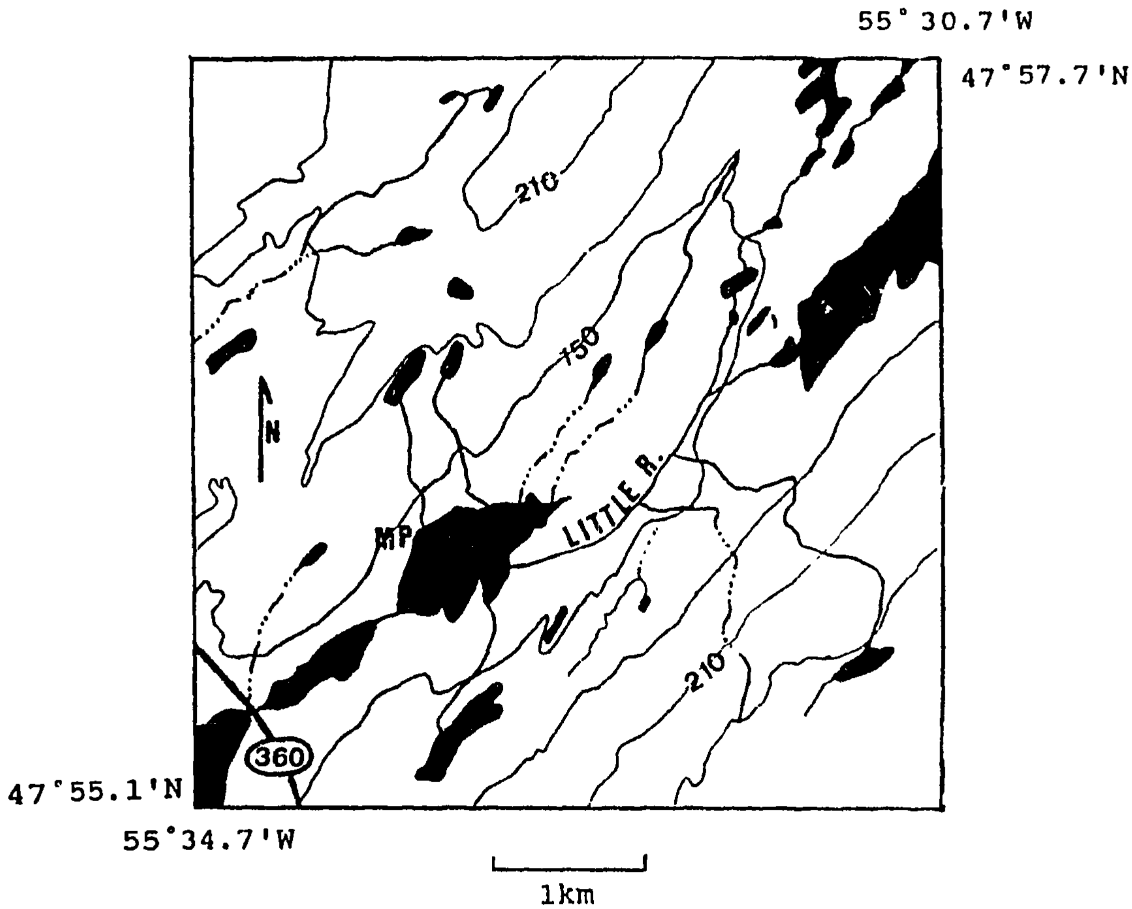

Figure 5.3 Topographic map of the Moose Pond area. Contour interval = 30 m. Source: NTS Map 1M/13.

1200 x 600 m with the longitudinal axis trending southwest.

The main inflow into the pond is in the southeast where Little River enters, draining from Little Spruce Pond to the northeast. Three other smaller streams and three ephemeral streams also drain into the pond. This makes the pond less than ideal for sampling, but unfortunately all other ponds in the area were either overgrown with vegetation, too rocky to core, or were inaccessible. The cores were collected from the northeastern end of the pond (water depth 288 cm), in an attempt to avoid areas most likely to be disturbed by the major inflow streams. The outflow stream is at the southwestern end of the pond, draining into another pond which in turn drains into River Pond and then lower Little River.

The catchment area, including the area that drains directly into Moose Pond as well as that drained by the system upstream from it, is extensive, totalling approximately 105 km^2.

5.3.4 Vegetation

The only aquatic vegetation identified in the pond was *Nuphar variegatum*. Gramineae, Filicales, *Thalictrum polyganum*, *Potentilla fruiticosa*, and thickets of *Alnus rugosa* grow around the water's edge. Alder thickets, *Salix* spp. and various herbs including *Heracleum maximum* (cowparsnip) occupy the sides of the rough logging road leading to the pond. The main forest species in this area, which is within Damman's Maritime Barrens ecoregion, are *Picea mariana* and *Betula papyrifera*, with the latter being particularly abundant in a large cut-over area north of Moose Pond.

5.4 Conne River site

5.4.1 Location

The Conne River site (Figure 5.4) is located at 48° 15' 00"N, 55° 29'40"W (grid reference 6 118 53 448), adjacent to Route 360 and approximately 86 km south of Bishops Falls, at an elevation of approximately 200 m asl, above the marine limit which is less than 50 m in this area. The pond was easily accessible from Route 360.

5.4.2 Topography

Like Northwest Gander River Pond, this site lies in an area of hummocky terrain with numerous bogs and small ponds. The underlying bedrock is interbedded volcanogenic sandstone and shale and conglomerates of the North Steady Pond Formation (Colman-Sadd and Swinden, 1982). Elevations in the area range from approximately 185 m asl at the banks of

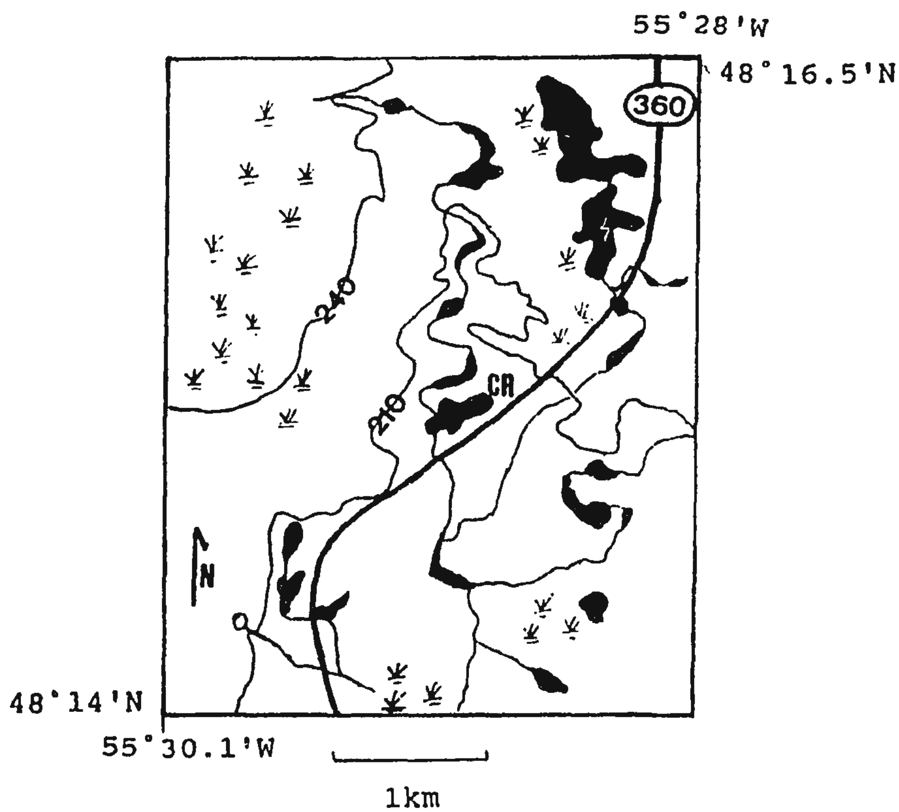

Figure 5.4 Topographic map of the Conne River site. Contour interval = 30 m. Source: NTS Maps 2D/5, 2D/6, 2D/13, 2D/14, 1:50,000.

Conne River to 275 m asl at the summit of a hill 3.5 km to the northwest of the pond.

5.4.3 Lake characteristics

This is one of a series of ponds linked by upper Conne River, and the entire system upstream from it drains an area of approximately 400 ha. The pond itself is small, with a surface area of only approximately 2 ha, measuring 200 x 70 m with the longitudinal axis trending approximately west southwest. A small inflow channel entering at the northwest end of the pond connects it to another pond to the north, and the only outlet is on the southwest shore. The throughflow is thus restricted to the western end of the pond, where it has carved a channel into the bottom sediments. The water depth in this channel was approximately 100 cm, compared with maximum depths of only approximately 50 cm in the rest of the pond. A core was collected from the centre of this pond for geochemical analysis, for comparison with the results of pollen analysis previously carried out on another core from the same pond by Dr. J. Macpherson.

5.4.4 Vegetation

Aquatic vegetation is abundant at this site, consisting mainly of *Nuphar variegatum* as well as a dense cover of

Cyperaceae over most of the lake bottom. Gramineae and Cyperaceae are abundant around the edge of the pond, along with *Thalictrum polyganum*, *Chrysanthemum leucanthemum*, *Ranunculus* spp., *Iris versicolor*, *Myrica gale*, *Alnus rugosa*, and *Kalmia angustifolia*.

The Conne River site is located within subregion D of Damman's Maritime Barrens ecoregion. The dominant species in the surrounding forest appears to be *Picea mariana*, with *Larix laricina* growing in the swampy areas near the pond, and scattered *Abies balsamea* found on better drained sites.

CHAPTER 6

RESULTS

6.1 Introduction

The results from each of the four sites are presented in this chapter, including descriptions of the stratigraphy of the cores, loss-on-ignition results, radiocarbon dates, pollen stratigraphies, and geochemical stratigraphies.

Because the main objective of the pollen analysis is to determine the validity of the basal radiocarbon dates in establishing the timing of deglaciation, and to reconstruct the sequence of environmental change immediately following ice recession, only summary pollen diagrams are presented here. All taxa which make significant contributions to the pollen sum are plotted, allowing reconstruction of the general nature of the vegetational succession that followed deglaciation. Certain other pollen types have been grouped together into categories such as "other trees", "other herbs" and "aquatics", while a few pollen and spore types, which were found only in one or two samples in very small quantities, have been omitted from the diagrams. A complete list of all taxa identified is given in Table 6.1, and the entire data set is presented in the Appendix.

TABLE 6.1. Fossil pollen and spore types identified

Pollen type	NWGR	PC	MP	CR
Trees				
Picea	Y	Y	Y	Y
P. glauca	Y	Y	Y	N
P. mariana	Y	Y	Y	N
Abies balsamea	Y	Y	Y	Y
Pinus	Y	Y	Y	Y
P. strobus	Y	Y	Y	N
P. banksiana/ resinosa	Y	Y	Y	N
Betula	Y	Y	Y	Y
Larix laricina	Y	Y	N	N
Populus	N	N	N	Y
Fraxinus	Y	Y	Y	Y
Quercus	Y	Y	Y	Y
Ulmus	Y	Y	N	Y
Acer	Y	Y	Y	Y
Juglans	Y	N	N	N
Carya	N	N	N	Y
Fagus	N	N	N	Y
Tilia	Y	Y	Y	N
Castanea	N	N	N	Y
Shrubs				
Corylus	N	N	N	Y
Myrica	Y	Y	Y	Y
Alnus	Y	Y	Y	Y
Juniperus	Y	Y	Y	Y
Salix	Y	Y	Y	Y
Ericales	Y	Y	Y	Y
Eleagnus	N	N	Y	N
Taxus	N	Y	Y	Y
Cornus	N	N	N	Y
Caprifoliaceae	N	N	Y	N
Herbs				
Gramineae	Y	Y	Y	Y
Cyperaceae	Y	Y	Y	Y
Artemisia	Y	Y	Y	Y
Ambrosia	N	N	N	Y
Chenopodiaceae	Y	Y	Y	Y
Compositae:				
Tubuliflorae	Y	Y	Y	Y
Liguliflorae	N	Y	N	Y
Cruciferae	N	N	N	Y

Table 6.1 (cont'd)

Pollen type	NWGR	PC	MP	CR
Caryophyllaceae	N	Y	Y	Y
Polygonaceae	Y	N	N	N
Plantago	Y	Y	Y	N
Ranunculaceae	N	Y	Y	Y
Rosaceae	Y	Y	Y	Y
Rumex/Oxyria	Y	Y	Y	Y
Saxifragaceae	N	N	N	Y
Thalictrum	Y	Y	Y	Y
Convolvulus	N	N	Y	N
Urtica	N	N	N	Y
Spores				
Sphagnum	Y	Y	Y	Y
Lycopodium	Y	Y	Y	Y
Selaginella	N	N	Y	Y
Filicales	Y	Y	Y	Y
Osmunda	N	Y	Y	N
Cryptogamma	N	N	Y	N
Pteridium	Y	N	Y	Y
Aquatics				
Equisetum	Y	Y	Y	N
Isoetes	Y	Y	Y	Y
Typha/Sparganium	Y	Y	Y	Y
Potamogeton	Y	N	N	Y
Myriophyllum	Y	Y	Y	Y
Nuphar	Y	Y	N	Y
Nymphaea	N	Y	Y	Y

NWGR = Northwest Gander River Pond
PC = Pool's Cove Pond
MP = Moose Pond
CR = Conne River site

The pollen sequences are described in terms of local pollen assemblage zones for each site, based on changes in pollen percentages and influx. These zones are then superimposed on the corresponding geochemical diagrams to allow direct comparison of the palynological and geochemical results.

Most emphasis is on the comparison of the results from Northwest Gander River Pond, which is furthest inland and closest to the suggested location of the Late Wisconsinan ice divide, and the coastal Pool's Cove Pond, which is believed to lie beyond the limit of the main Newfoundland Ice Sheet, and may have been affected by a smaller local ice cap (Leckie and McCann, 1983). The results from these two sites are therefore dealt with first, followed by the results from the intermediate Moose Pond and Conne River sites.

6.2. Northwest Gander River Pond

6.2.1 Stratigraphy and loss-on-ignition

The sediment stratigraphy of the two cores collected from Northwest Gander River Pond is described in Table 6.2. Core A, which was used for pollen analysis, consisted of a basal eleven centimetres of clay with pebbles (220-231 cm below sediment-water interface) overlain by a layer of

Table 6.2. Core stratigraphy, Northwest Gander River Pond

Core A

Depth (cm)	Description
0-167	dark brown fibrous gyttja
167-181	brown-grey silty clay-gyttja with fibrous material
181-193	dark grey clay-gyttja with fibrous material
193-200	light grey clay
200-220	light grey sandy clay
220-231	clay, with faceted and striated pebbles

Core B

0-117	dark brown gyttja
117-140	dark grey clay-gyttja, with thin layers of fibrous material at 135 cm & 139 cm
140-161	light grey clay
161-170	clay with faceted and striated pebbles

silty clay (193-220 cm), with a transition to a more organic clay-gyttja above 192 cm and then to a dark brown gyttja from 165 cm to the surface. Although the second core from this pond (Core B) measured only 170 cm, it has a stratigraphy similar to that of the first core, with the same units present, and only the gyttja unit shows a significant difference in thickness between the two cores.

The loss-on-ignition curve for Core A (Figure 6.1) shows a gradual initial rise in percent organic matter beginning at approximately 190 cm depth, corresponding roughly with the transition from clay to clay-gyttja, and a sharper increase from 10% to ca. 35% between 160 and 170 cm depth, at approximately the level of the transition to gyttja.

6.2.2 Radiocarbon dates

Two samples from this core were radiocarbon dated, one from just above the transition to clay-gyttja (185-190 cm), and one from 160-165 cm, just above the transition to gyttja and higher organic content. The lower sample, which was dated to provide an approximation of the timing of deglaciation, yielded a date of 10200 ± 240 BP (GSC-5027), while the 160-165 cm sample was dated at 8960 ± 120 BP (GSC-4951) (see Table 6.3).

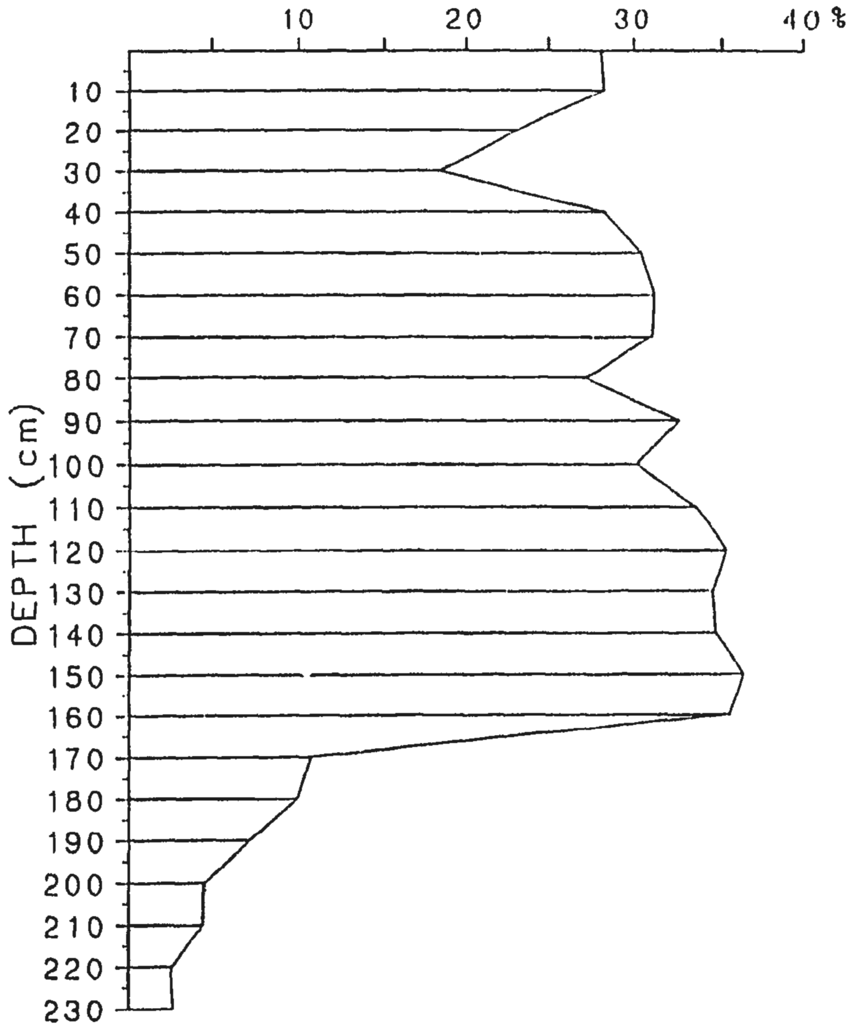

Figure 6.1 Loss-on-ignition, Northwest Gander River Pond, Core A.

Table 6.3 Radiocarbon dates

Depth	Lab No.	Corrected & (uncorrected) age (yr. BP)	δ13C(%.)	Sample size (Dry sed. weight,g)
Northwest Gander River Pond				
160-165	GSC-4951	8960±120 (8960±120)	-25.1	9.7
185-190	GSC-5027	10200±240 (10,100±240)	-18.3	33.7
Pool's Cove Pond				
210-215	GSC-5028	8300±120 (8320±120)	-26.1	13.4
245-250	GSC-4945	9710±120 (9680±120)	-23.1	17.0
Moose Pond				
335-340	GSC-4960	8660±110 (8680±110)	-25.8	19.1
365-370	GSC-5029	10,000±170 (10,000±170)	-25.1	44.5
Conne River site				(wet sed. weight, g)
341-346	GSC-4122	8530±120 (8540±120)	-25.7	36.1
395-405	GSC-3634	11,300±100 (11,400±100)	-26.7	166.9

6.2.3 Pollen stratigraphy

The pollen diagrams from this site (Figures 6.2, 6.3) are divided into three local pollen assemblage zones labelled, from the base upwards, NWG-1, NWG-2, and NWG-3.

Pollen assemblage zone NWG-1: Cyperaceae (below 175cm).

The lowest zone, dominated by sedge pollen, is divided into two subzones, NWG-1i, Cyperaceae-herbs (below 200 cm) and NWG-1ii, Cyperaceae-*Betula*-shrubs (175-200 cm).

Subzone NWG-1i: This subzone is dominated by Cyperaceae (28%), *Pinus* of distant origin (34% at 210cm), and herbs (27-32%). The most dominant herb at 210 cm is *Rumex/Oxyria* type (probably *Oxyria digyna*) (12%), while at 200 cm *Artemisia* and *Polygonum* make up 11% and 9%, respectively, of the pollen sum. *Betula* increases from 8% to 33%, with approximately 50% of grains measuring < 20μm in size (ie. probably shrub birch).

Pediastrum reaches highest frequencies in this subzone, and has a relatively high influx compared to that of pollen and spores, but it does not attain peak frequencies until higher in the core, in pollen subzone NWG-1ii. Pollen influx, as calculated using the rate of sediment accumulation extrapolated from between the two dated levels, is very low throughout (51 grains/cm^2/yr).

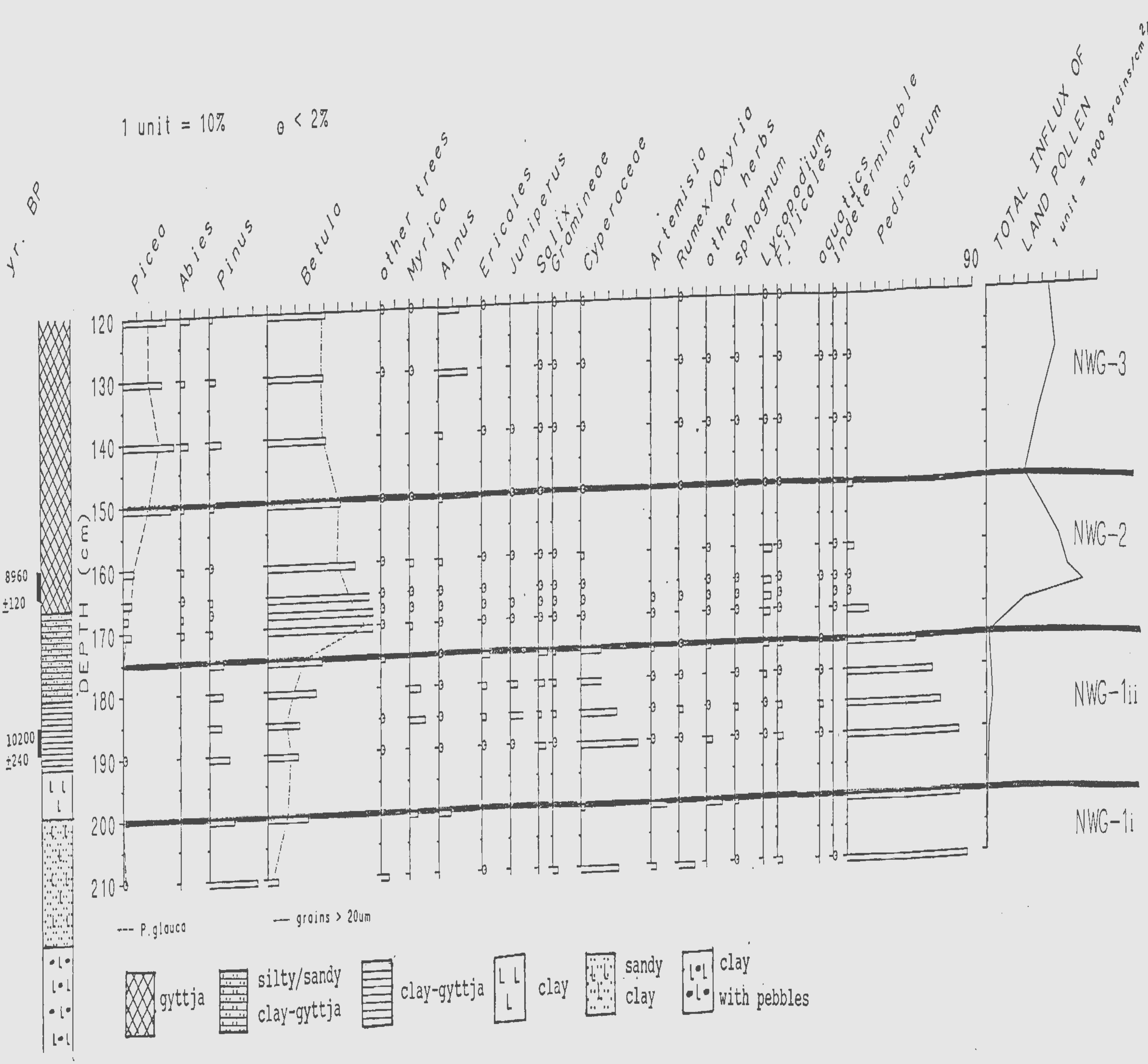

Figure 6.2 Pollen percentage diagram, Northwest Gander River Pond, Core A.

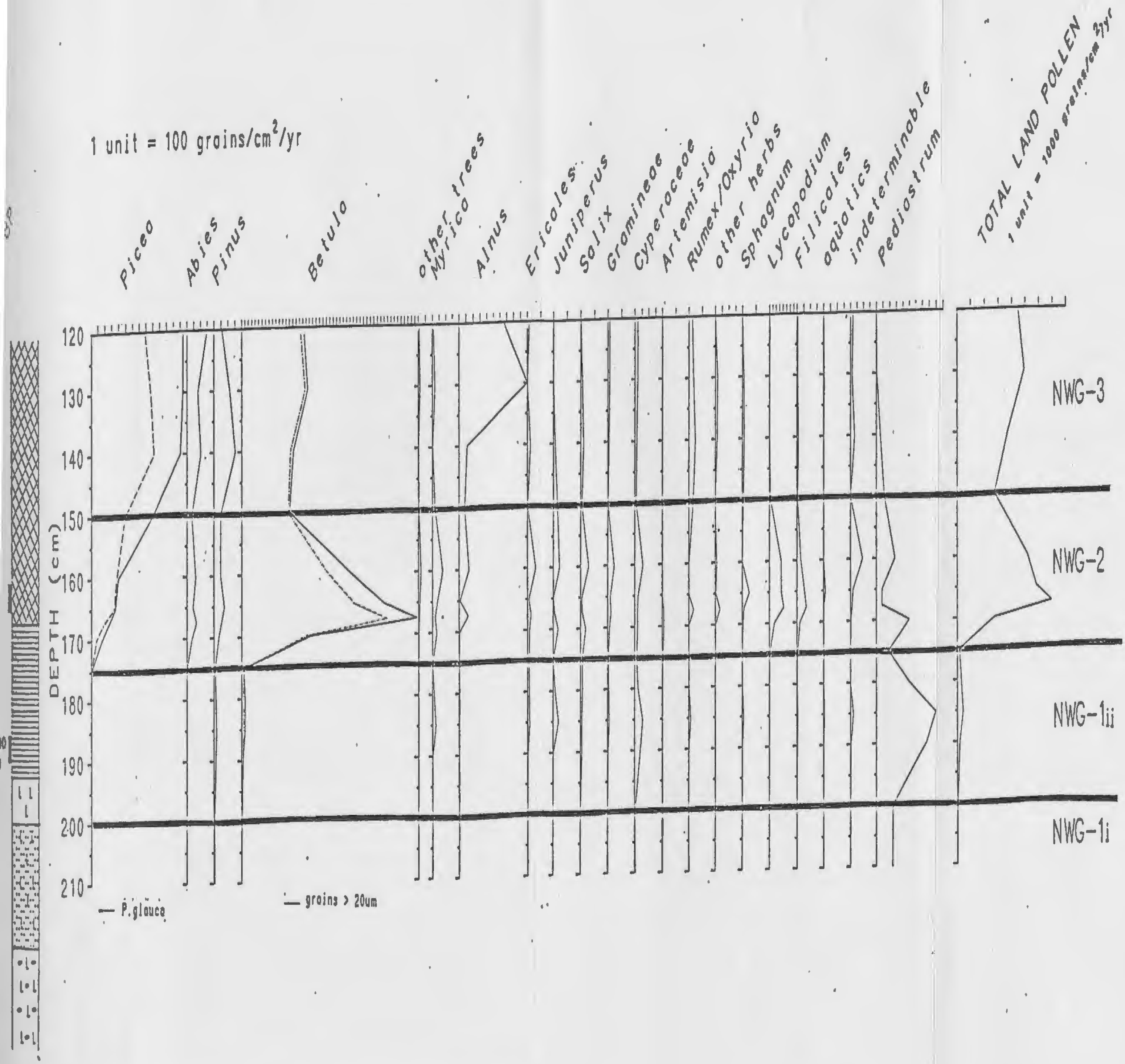

Figure 6.3 Pollen influx diagram, Northwest Gander River Pond, Core A.

<u>Subzone NWG-1ii:</u> The boundary between NWG-1i and NWG-1ii is defined by an increase in birch (up to 44%; 105 grains/cm^2/yr) and shrub pollen, with successive peaks in percentages of *Alnus*, *Myrica*, *Juniperus*, and *Salix* pollen; and by an initial small increase in total land pollen influx (up to 397 grains/cm^2/yr). Cyperaceae peaks in percentage at 190 cm (43%), and also shows a peak in influx at 185 cm. The influx of *Pediastrum* peaks in this zone (9 colonies/ cm^2/yr) and then begins to decline.

<u>Pollen assemblage zone NWG-2</u>: *Betula* (150-175 cm).

Betula pollen dominates this zone, peaking at 77% of the total land pollen at 167.5 cm, coinciding with a peak in *Betula* influx of 5166 grains/cm^2/yr. 79% or more of the birch grains are greater than 20μm in size and could therefore represent either trees or shrubs. Except for very low percentages of *Picea* found in two lower samples, both spruce (mostly *P. glauca* initially) and fir (*Abies balsamea*) first appear in this zone in high enough percentages and influx values to suggest local presence of these trees. Total land pollen influx peaks within this zone at 5920 grains/cm^2/yr at 167.5 cm, then declines above this level to a low of 2614 grains/cm^2/yr at the boundary with zone NWG-3. While shrubs and herbs make up relatively small percentages of the pollen sum throughout this zone, Ericales, Juniperus, Salix, Gramineae, Cyperaceae, and herbs all show peak influxes within this zone, as do Sphagnum, Lycopodium, Filicales spores and aquatic pollen.

Pollen assemblage zone NWG-3: Betula-conifers-Alnus (above 150cm).

This zone is separated from NWG-2 on the basis of increases in both the frequency and influx of Picea (up to 38%; 1341 grains/cm^2/yr), 60-70% of which was identified as P.glauca, as well as Abies balsamea, Pinus and Alnus pollen, and a decline in percentage (to < 45%) and influx (to <2000 grains/cm^2/yr) of Betula pollen. Approximately 95% of the Betula grains identified throughout this zone were greater than 20μm in diameter. The percentage and influx of all other pollen and spore types are very low.

6.2.4 Geochemical stratigraphy

The geochemical stratigraphy of Core A from Northwest Gander River Pond is illustrated in Figure 6.4, in terms of the common oxides of the major elements.

The most obvious changes in the stratigraphy of these major elements appear to correlate rather well with the pollen zone boundaries, which have been superimposed on the geochemistry diagram. Al_2O_3, MgO and K_2O all peak below

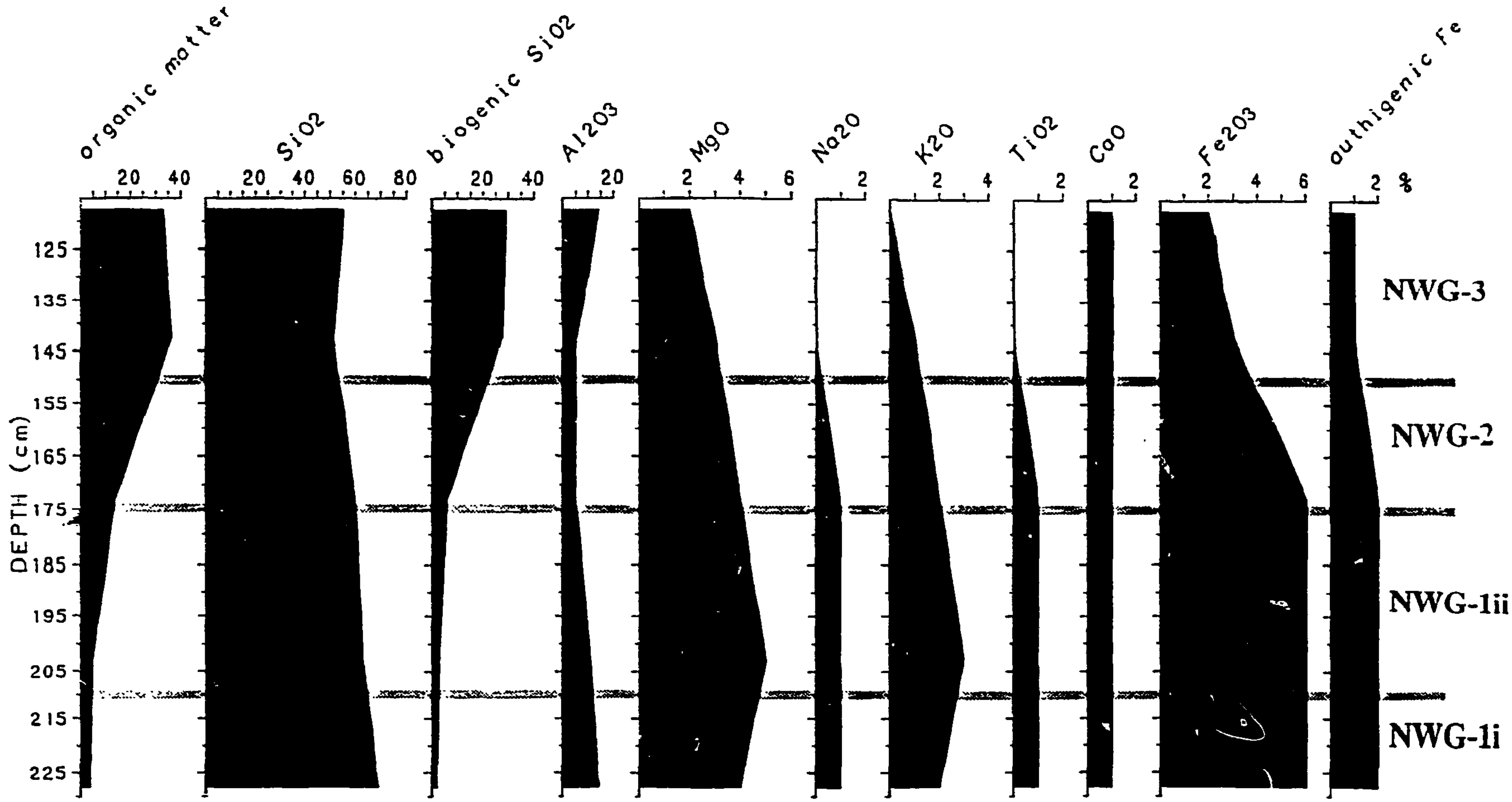

Figure 6.4 Geochemical stratigraphy, Northwest Gander River Pond, Core A. Major elements are represented by their common oxides, as percentages of total sediment weight.

190 cm, the boundary of pollen assemblage subzones NWG-1i and NWG-1ii, and decline upwards. The curves for Na_2O, TiO_2 and Fe_2O_3 are also highest at the bottom of the core, but maintain steady concentrations up to 167.5cm, near the boundary between pollen assemblage zones NWG-1ii and NWG-2, declining above this level. CaO values do not show any change throughout the core. Al_2O_3 declines from a maximum of 14% at the base to a minimum (5%) between 172.5 and 142.5 cm, coinciding approximately with the boundaries of pollen assemblage zone NWG-2, then begins to increase again above this level.

Total values of SiO_2, which makes up the largest proportion of the sediment, vary from 51-69%, while the proportion of biogenic (NaOH soluble) silica, representing diatom frustules, increases sharply above 172.5 cm, just above the boundary between pollen assemblage zones NWG-1i and NWG-2.

Fe_2O_3 makes up approximately 6% of the total dry sediment weight below 172.5, declining to 3% by 142.5 cm and to 2% at 117.5 cm. The proportion of the total iron content contributed by authigenic Fe (separated by acid solution) increases from 33% below 142.5 cm to 50% above this level.

6.3 Pool's Cove Pond

6.3.1 Stratigraphy and loss-on-ignition

Of the 4 cores retrieved from Pool's Cove Pond, the longest (North basin Core A, 280 cm) was used for pollen analysis. The base of this core (270-280 cm) was composed of a sandy clay, grading upwards into a sandy clay-gyttja (255-270 cm), overlain by a more organic silty gyttja (205-255 cm), and finally gyttja extending to the top of the core (Table 6.4).

The results of the loss-on-ignition analysis (Figure 6.5) indicates that organic matter makes up 4-10% of the sediment weight throughout the lower clay unit, increasing dramatically to a peak of almost 45% at 198 cm, coinciding approximately with the transition from silty gyttja to gyttja. Above this peak the loss-on-ignition averages approximately 30%.

6.3.2 Radiocarbon dates

Two samples from Pool's Cove Pond north basin, Core A, were submitted for radiocarbon dating (see Table 6.3). The lowest sample (245-250 cm depth), from just above the transition to organic sediment, was dated at 9710 ± 120 (GSC-4945), providing a minimum date for the deglaciation of this site. The second dated sample (210-215 cm) yielded an age of 8300 ± 120 BP (GSC-5028).

Table 6.4 Core Stratigraphy, Pool's Cove Pond (North basin)

Core A

Depth (cm)	Description
0-205	dark brown gyttja, with 0.5 cm-thick layer of fibrous material at 205 cm
205-255	dark brown silty/sandy gyttja, gradually becoming more minerogenic with increasing depth
255-270	light brown sandy clay-gyttja
270-280	light greyish brown sandy clay

Core B

181-261	dark brown gyttja
261-272	light brown clay-gyttja
272-281	light grey clay

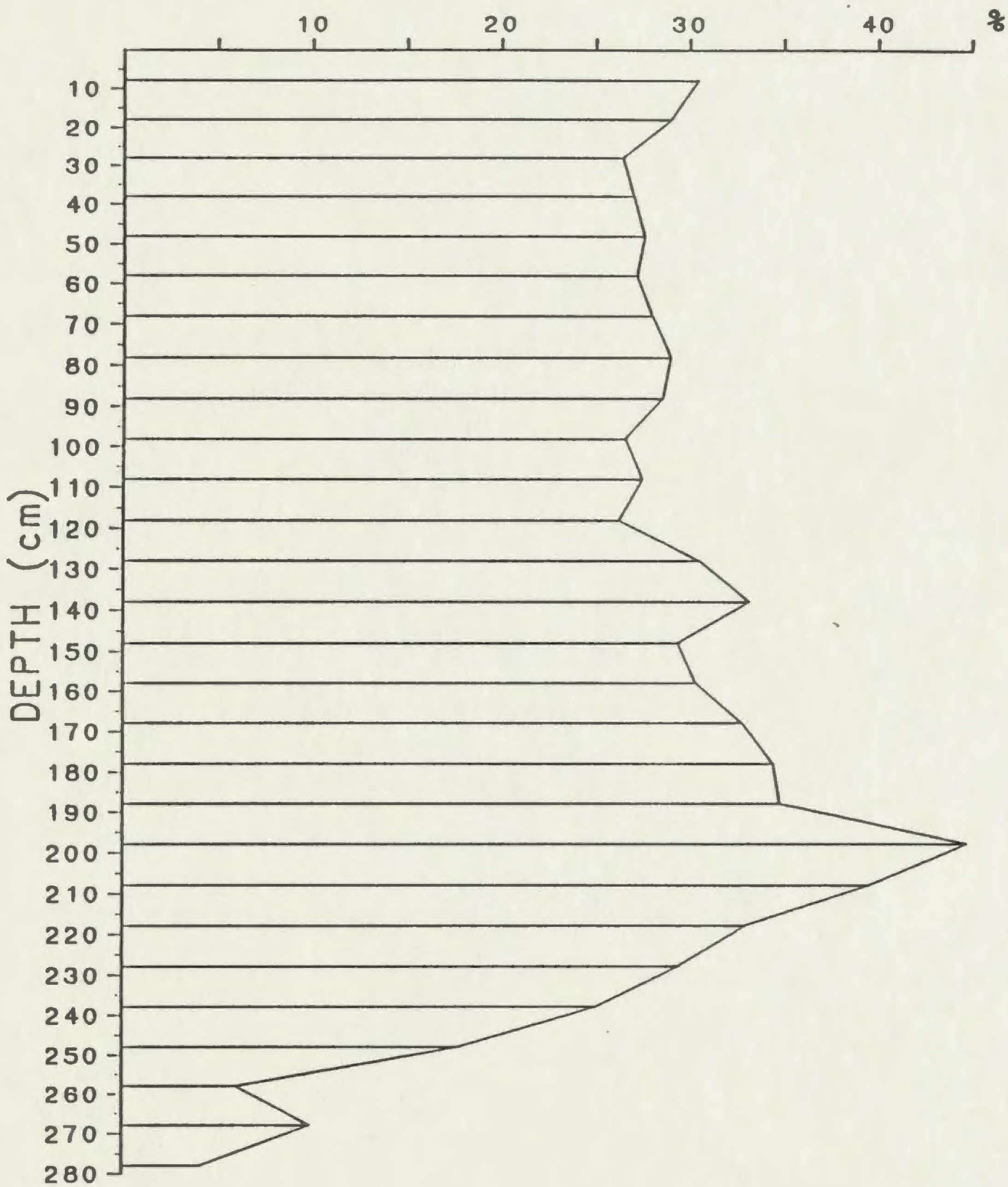

Figure 6.5 Loss-on-ignition, Pool's Cove Pond north basin, Core A.

6.3.3 Pollen stratigraphy

Three pollen zones can be identified in the basal sequence from Pool's Cove Pond (Figures 6.6 and 6.7):

Pollen assemblage zone PC-1: *Salix*-Cyperaceae zone (below 260 cm).

The basal zone is dominated by *Salix* pollen, which peaks at 49% of total land pollen at the base of the core, and has relatively high influx values (up to 309 grains/cm^2/yr, as calculated using the sedimentation rate extrapolated from between the dated levels). *Pinus* (of distant origin) contributes 10-25% of total land pollen in this zone, and percentages of Cyperaceae pollen are also high, peaking at 33% at the upper boundary of this zone. *Juniperus* has a maximum frequency of 15% at the base of the core and has an initial peak in influx (95 grains/cm^2/yr) in this zone, succeeded by a peak in Ericales, (34%; 188 grains/cm^2/yr) at the upper boundary of the zone. Peak percentages of herb pollen including *Artemisia* (5% at base) and *Oxyria/Rumex* type as well as *Sphagnum* spores (7-8%) occur in this zone. *Pediastrum* peaks in the bottom sample of the core, with an estimated influx of ca. 513 colonies/cm^2/yr. Total influx of land pollen throughout this zone is higher than in zone NWG-1, but still relatively low, ranging from 333 to 756 grains/cm^2/yr as calculated using extrapolated sedimentation rates.

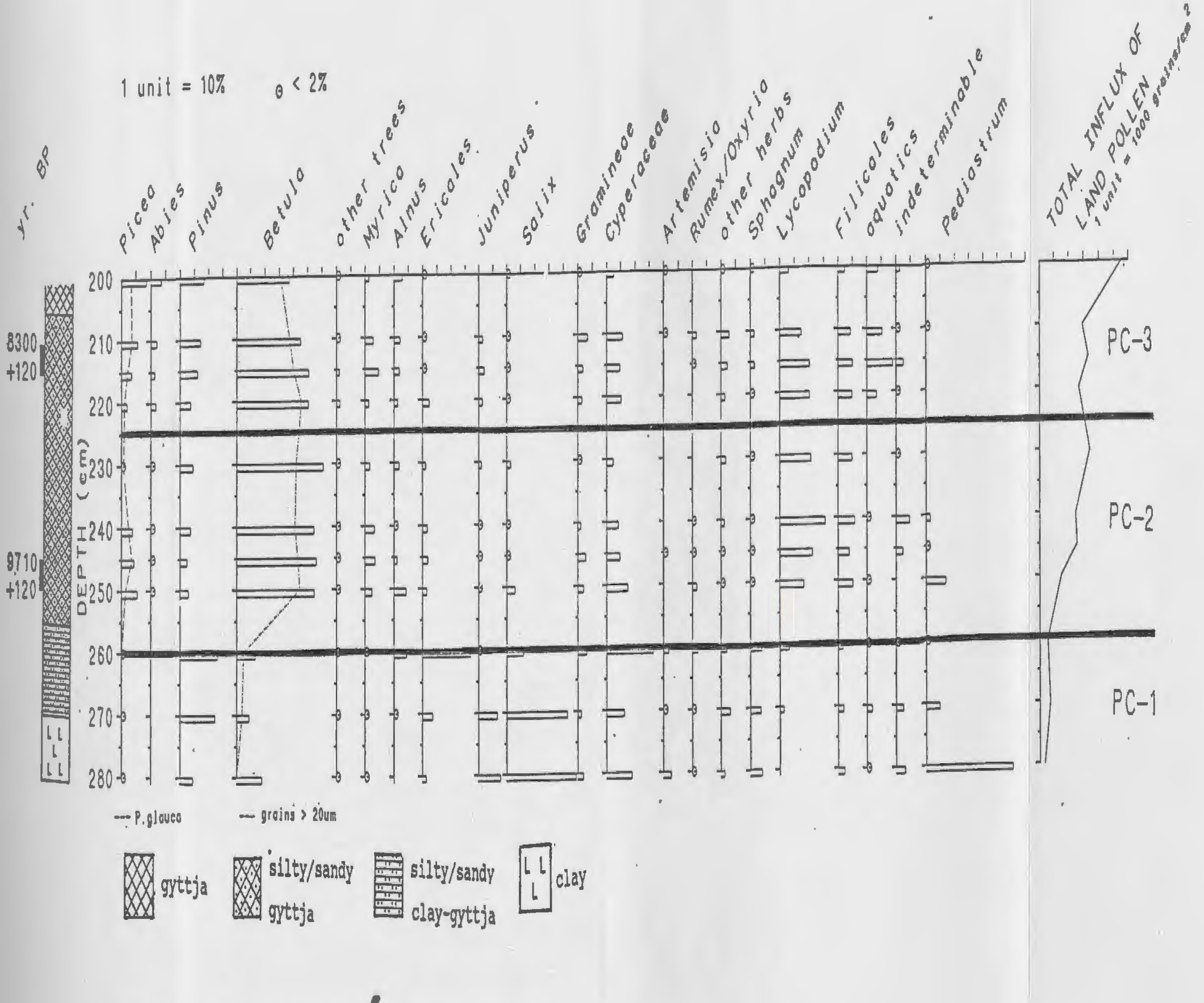

Figure 6.6 Pollen percentage diagram, Pool's Cove Pond north basin, Core A.

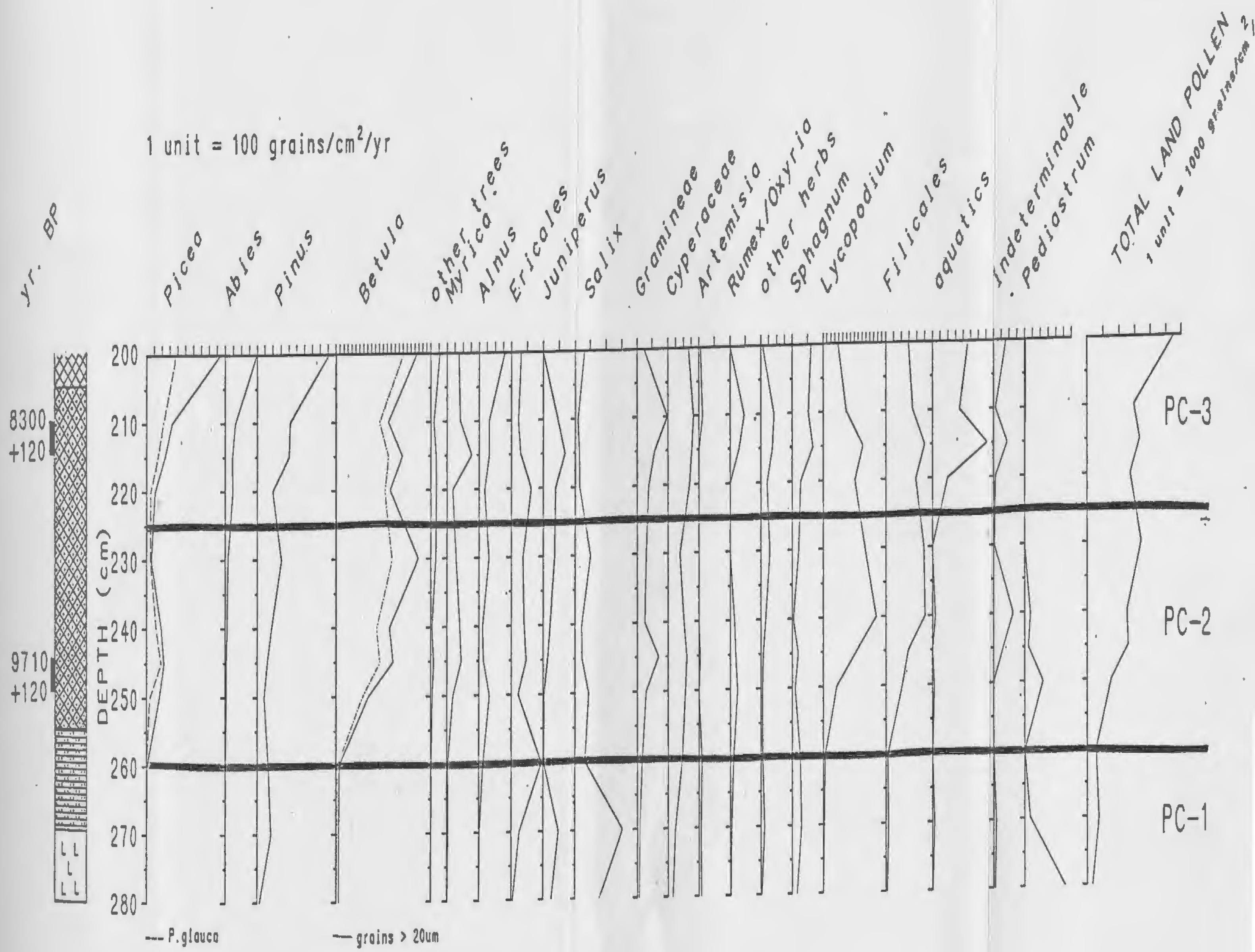

Figure 6.7 Pollen influx diagram, Pool's Cove Pond north basin, Core A.

Pollen Assemblage Zone PC-2: *Betula*-shrub (220-260 cm).

Increases in both the percentage and influx of *Betula* (up to 61%), *Myrica* (up to 7%) and *Alnus* (up to 9%), as well as an increase in total land pollen influx (550-3409 grains/cm^2/yr) characterize this zone. *Picea*, including grains of both *P.glauca* and *P.mariana*, exhibits an initial peak in both percentage and influx in this zone but then declines above 245 cm. High percentages and influx of *Lycopodium* (up to 31%; 1355 grains/cm^2/yr) and Filicales (up to 12%; 505 grains/cm^2/yr) spores are also attained in this zone.

Pollen assemblage zone PC-3: *Betula*-conifers (above 220 cm).

Increasing percentages and influx of *Picea*, *Abies* and *Pinus* pollen define this pollen assemblage zone. While *Picea* pollen influxes are not as high here as in zone NWG-3, (reaching a maximum of 939 grains/cm^2/yr), *Abies* and *Pinus* influxes are higher. The majority of spruce pollen grains in lower samples were identified as *Picea glauca*, but *P. mariana* is more dominant in the uppermost sample, contributing 60% of total spruce pollen (compared to about 45% black spruce in the top sample from Northwest Gander River Pond). *Betula* pollen maintains high frequencies, decreasing slightly near the top (51-37%), with 80-85% of the grains measuring more than 20μm in diameter. A peak in the frequency and influx of Myrica pollen occurs at 2.5 cm, and Alnus increases towards the top of the zone. Peak influxes of Juniperus, Gramineae, Cyperaceae, herbs, and aquatics also occur in this zone, and total land pollen influx increases sharply to a maximum of 5513 grains/cm^2/yr in the highest sample analyzed from this core (200cm).

6.3.4 Geochemical stratigraphy

The geochemical stratigraphy of the basal segment of Core A from Pool's Cove Pond (Figure 6.8) reveals trends for most of the major elements similar to those found in the Northwest Gander River Pond core, and again there is an apparent correlation between the pollen and geochemical stratigraphies.

Percentages of Al_2O_3, MgO, Na_2O, K_2O, TiO_2, total Fe_2O_3 are again all highest at the base, decreasing upwards. While Al_2O_3 values decline steadily but gradually upwards, other components diminish to almost negligible levels lower

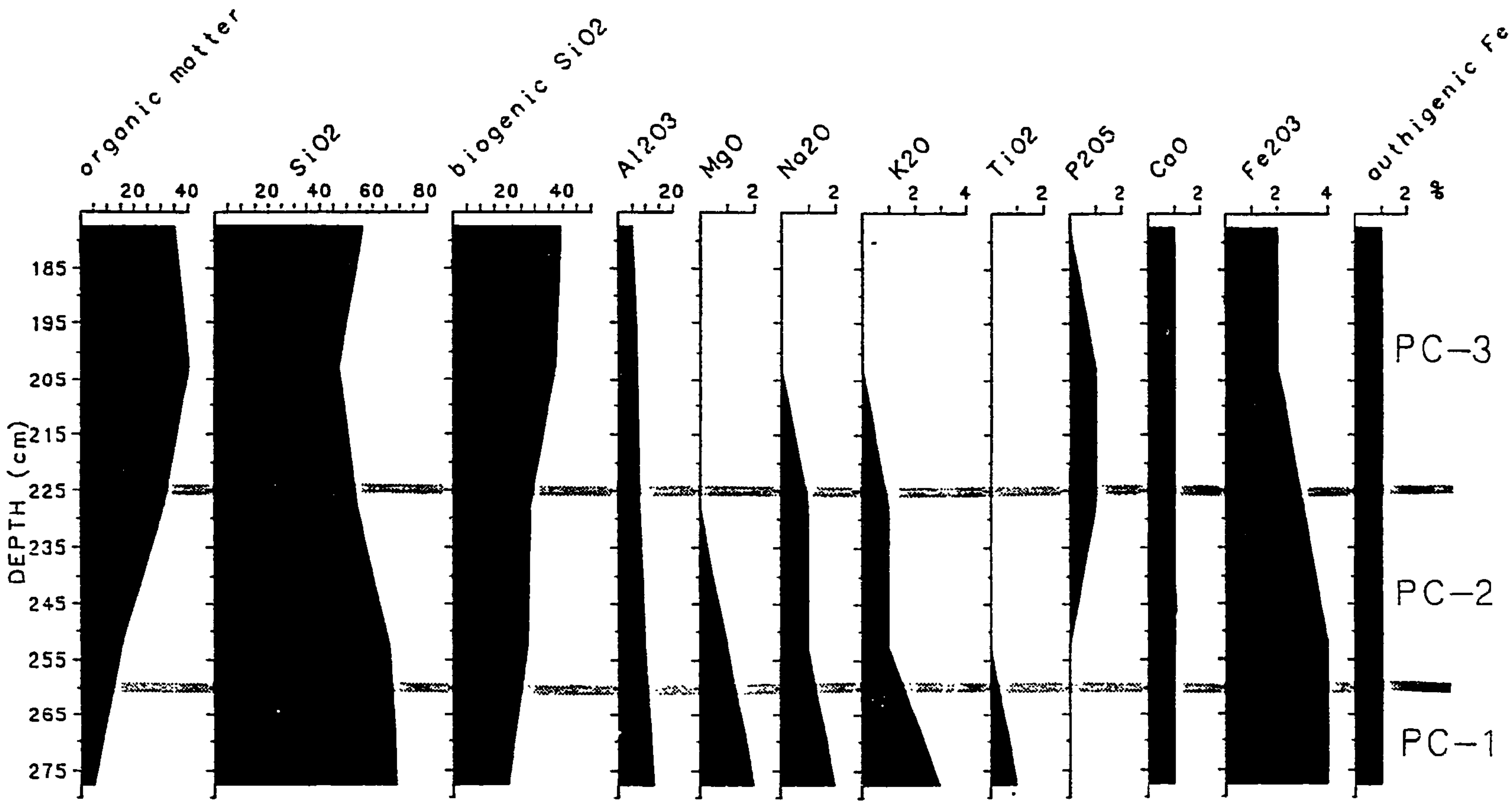

Figure 6.8 Geochemical stratigraphy, Pool's Cove Pond north basin, Core A. Major elements are represented by their common oxides, as percentages of total sediment weight.

in the core: TiO_2 by 252.5 cm, just above the boundary of pollen assemblage zones PC-1 and PC-2; MgO by 227.5 cm, near the PC-2/PC-3 pollen assemblage zone boundary; and Na_2O and K_2O by 202.5 cm, where significant expansions in influx of pollen, particularly of coniferous trees, occur.

Total Fe_2O_3 values decline from a maximum of 4% of dry sediment weight at the base of the core to 2% by 202.5 cm, while the input of authigenic iron remains constant at approximately 1%, making up 25% of total Fe_2O_3 at the base and 50% above 202.5 cm.

As in the Northwest Gander River Pond core, SiO_2 makes up the majority of the dry sediment weight (47-69%). Levels of biogenic SiO_2 are higher in this core however, comprising 20% of total dry sediment weight at the base, increasing steadily to 39% at the top of the basal core segment.

6.4 Moose Pond

6.4.1 Stratigraphy and loss-on-ignition

The first core collected from Moose Pond (Core A) consisted entirely of a dark brown gyttja, without the expected basal mineral sediment, but Core B, collected approximately 1 m away, contained a typical postglacial sequence beginning with clay at the base (373-400 cm), grading upwards into clay gyttja (358-373 cm), silty gyttja (348-358 cm) and finally dark brown gyttja above 348 cm

(Table 6.5). The latter core was therefore used in the analysis.

Loss-or-ignition was carried out only on the basal sediments, below 300 cm depth. The results (Figure 6.9) indicate a fairly steady increase in content of organic matter from 2.75% at the base to 25-30% above 330 cm.

6.4.2 Radiocarbon dates

The lowest sample dated from this core was extracted from just above the transition to clay-gyttja, at 365-370 cm, and yielded an age of 10,700 ± 170 BP (GSC-5029), providing a minimum date for deglaciation of the site. A second sample, from 335-340 cm, was dated at 8660 ± 110 BP, (GSC-4960), dating the rise in *Picea* as well as *Abies* pollen. (See Table 6.3)

6.4.3 Pollen stratigraphy

Three pollen assemblage zones are identified in the basal pollen sequences from this site (Figures 6.10 and 6.11):

Table 6.5 Core stratigraphy, Moose Pond

Core A

Depth (cm)	Description
0-295	dark brown gyttja, with: - wood fragments at 47cm & 55cm - 0.5cm-thick layer of sand at 70cm - piece of wood, 4 cm long at 70-74cm - black fibrous layer (peat?), 76.5- 78cm, containing a well preserved leaf and other macrofossils - piece of wood at 102 cm.

Core B

Depth (cm)	Description
0-100	thixotropic, dark brown gyttja
100-348	dark brown gyttja
348-358	dark brown gyttja, with: - twig at 149 cm - 1 cm layer of fibrous material at 175 cm - wood fragments at 263 cm
358-373	clay gyttja
373-383	dark grey silty/sandy clay, oxidizing orange-brown
383-400	light grey clay

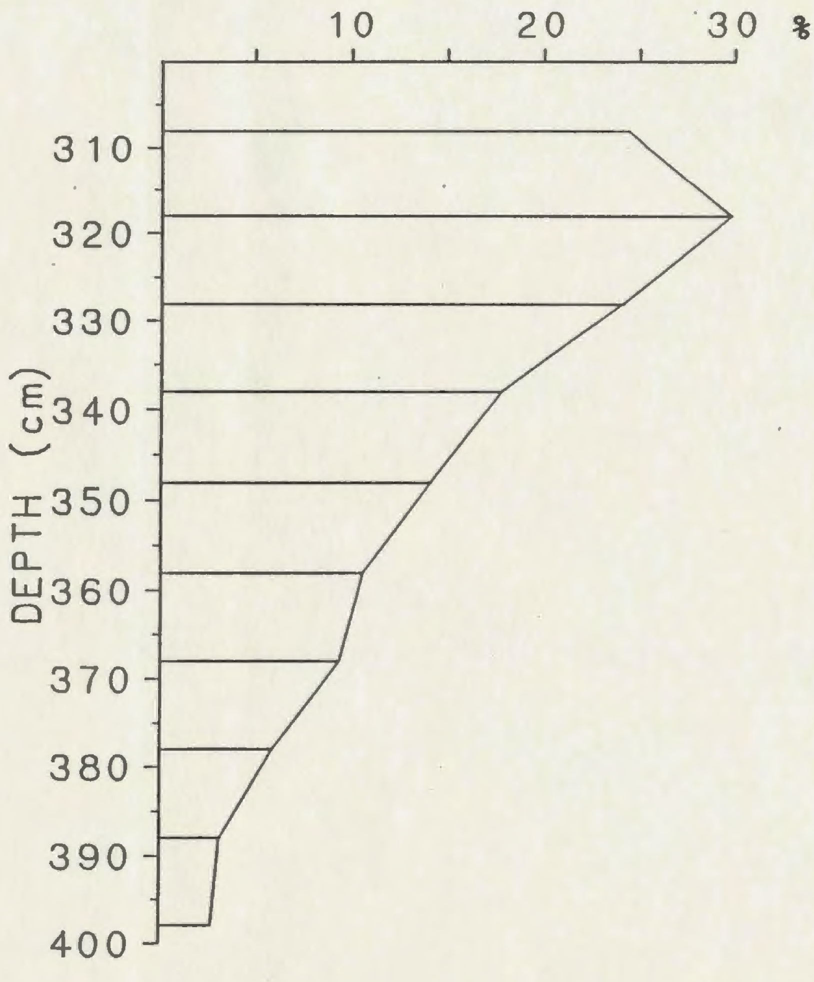

Figure 6.9 Loss-on-ignition, Moose Pond Core B.

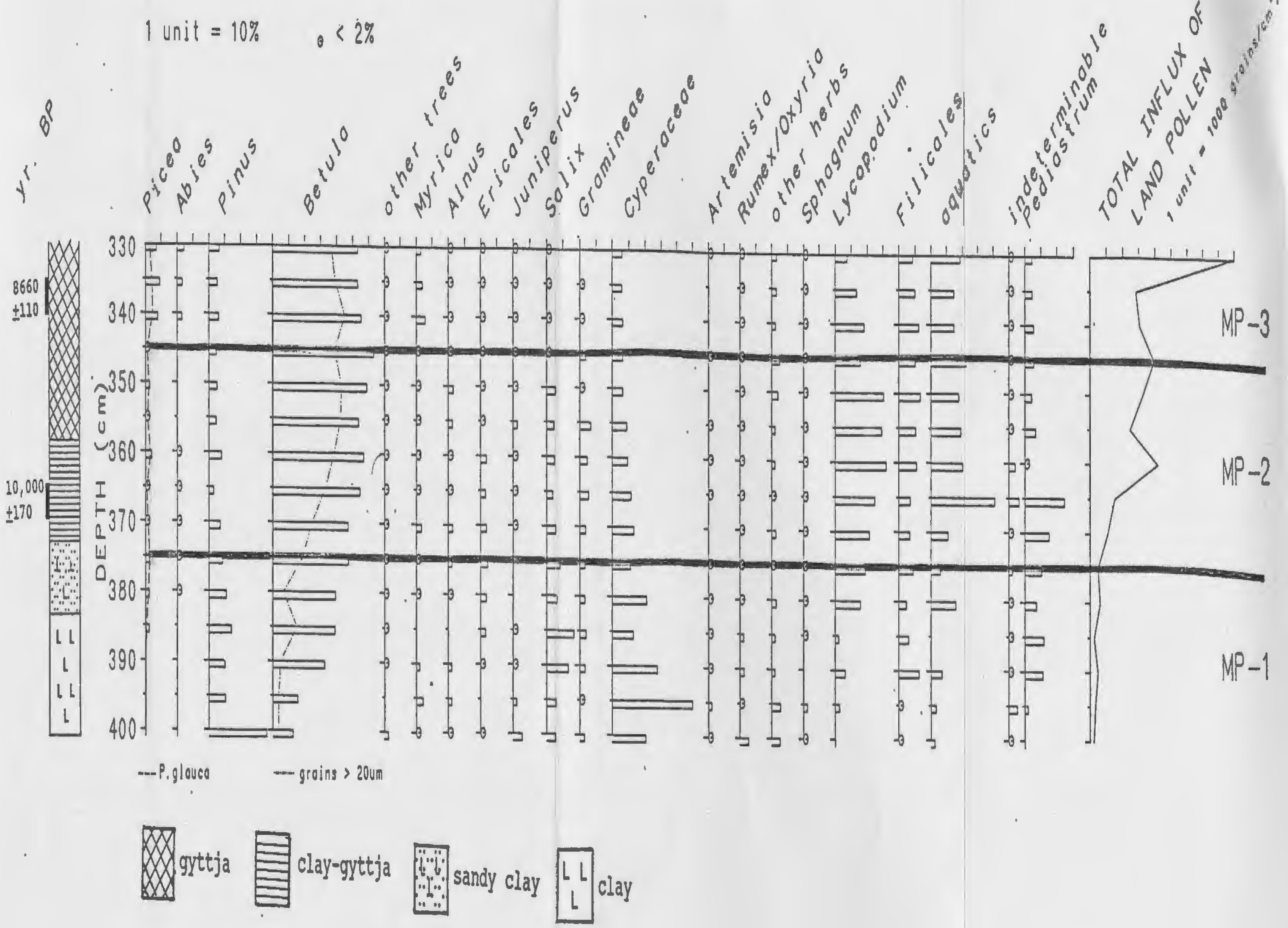

Figure 6.10 Pollen percentage diagram, Moose Pond Core B.

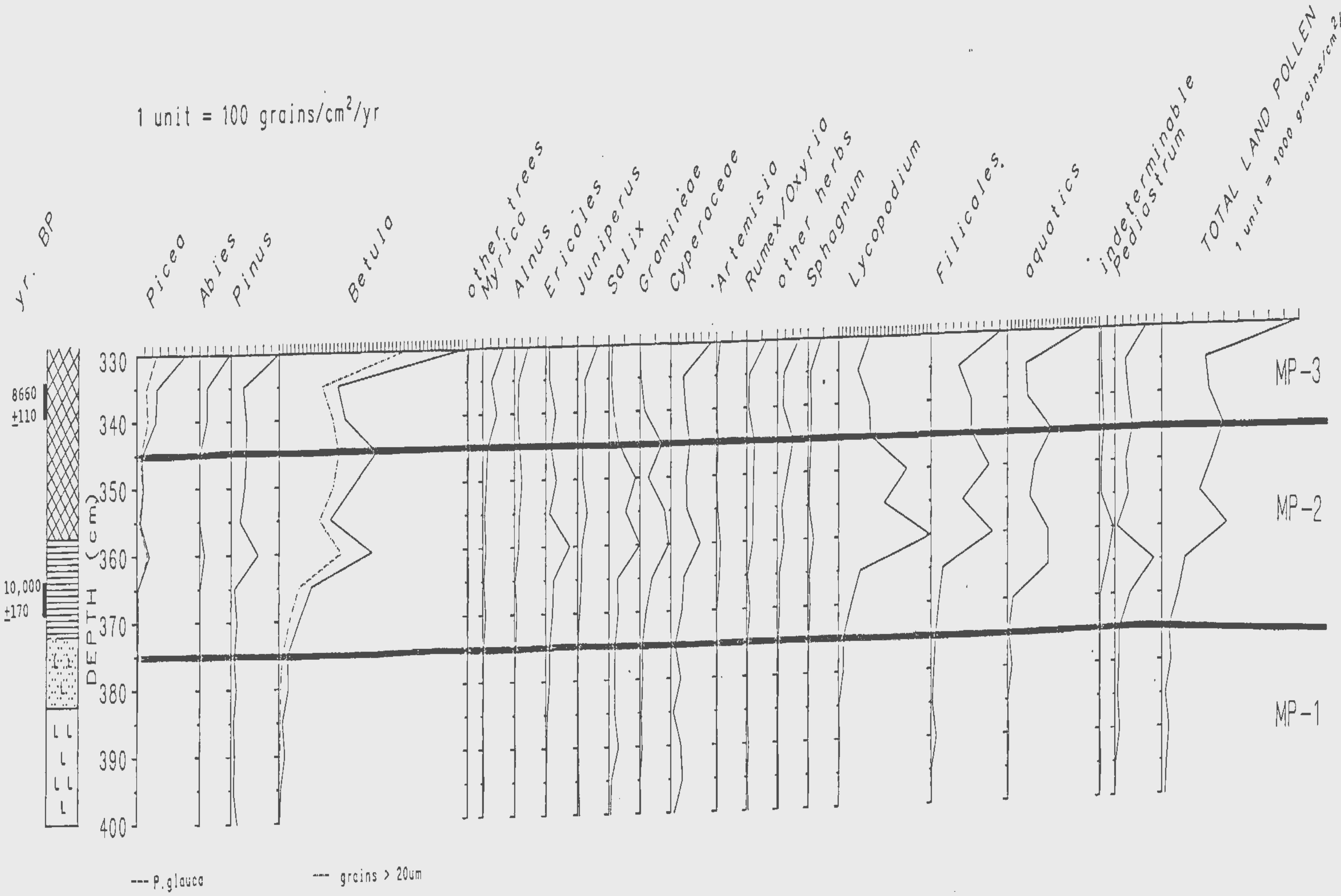

Figure 6.11 Pollen influx diagram, Moose Pond Core B.

<u>Pollen assemblage zone MP-1:</u> Cyperaceae-<u>Betula</u>-<u>Salix</u> (below 374 cm).

The pollen of <u>Betula</u>, Cyperaceae, <u>Salix</u>, and far-travelled <u>Pinus</u> dominate the basal zone. Cyperaceae, along with <u>Pinus</u>, is most prevalent at the base of the core, but after a peak of 52% at 395 cm the percentage of sedge pollen begins to decline in favour of increasing frequencies of <u>Betula</u> (12% at the base to 47% at the top of the zone) and <u>Salix</u> (which peaks at ca 16% at 385 cm). The majority (60% or more) of the <u>Betula</u> grains identified at all levels in this zone were less than 20 μm in diameter (ie. shrub birch). <u>Juniperus</u>, <u>Artemisia</u>, <u>Rumex/Oxyria</u> and 'other herb' percentages all climax at or near the base of this zone, and an initial peak in <u>Myrica</u> pollen frequency occurs at 395 cm. The overall influx of land pollen is very low throughout the zone and the only taxa which register significant influx values are <u>Pinus</u>, <u>Betula</u>, <u>Salix</u> and Cyperaceae. Influx of Ericales, Gramineae, and aquatic pollen, <u>Lycopodium</u> and Filicales spores, and <u>Pediastrum</u> all begin to increase near the top of this zone.

<u>Pollen assemblage zone MP-2:</u> <u>Betula</u>-<u>Lycopodium</u>-Cyperaceae zone (345-375 cm).

<u>Betula</u> pollen is dominant in this zone, making up 47-63% of the total pollen sum. Grains greater than 20 μm in diameter make up less than 40% of the total at the MP-1/MP-2

boundary but 66% or more higher in the zone. Highest percentages (up to 31%) and influx (up to 2386 grains/cm^2/yr) of Lycopodium are attained, as well as peaks in percentage and influx of aquatic pollen (up to 41%; 1059 grains/cm^2/yr) and Pediastrum (up to 495 colonies/cm^2/yr). Cyperaceae percentages are lower than in zone MP-1, declining gradually from a high of 13% at 370 cm to 6% at the top of the zone.

Low percentages of Picea pollen occur throughout this zone (mostly P.glauca), with influx of spruce pollen varying from 50-160 grains/cm^2/yr above 365 cm. Abies pollen is registered for the first time in this zone, but in percentages of less than 2% throughout, and influx of fir pollen is negligible except for a small peak of 91 grains/cm^2/yr at 360. Pinus pollen makes up 3-9% of total land pollen throughout the zone, with influx ranging from 42 grains/cm^2/yr at the base to 185 grains/cm^2/yr top of the zone, with a peak of ca 334 grains/cm^2/yr at 360 cm. Total land pollen influx increases from 481 grains/cm^2/yr at the lower boundary of this zone to 3953 grains/cm^2/yr at the upper boundary. A peak in total influx (ca 4179 grains/cm^2/yr) as well as most pollen and spore types, occurs at 360 cm.

Pollen assemblage zone MP-3: Betula-Picea-Abies (330 345 cm.

The boundary between this zone and MP-2 is defined by an increase in *Picea* pollen percentages (up to 9%), and influx (increasing throughout the zone from 66 grains/cm^2/yr at the lower boundary of the zone to 613 grains/cm^2/yr at 330 cm). The majority of the spruce grains are *Picea glauca* at the base of the zone, but *P. mariana* becomes increasingly important until at 330 cm it contributes almost 55% of all spruce pollen. *Abies balsamea* is persistently present for the first time in this zone, comprising 3-4% of the total pollen sum, with its influx increasing sharply to 380 grains/cm^2/yr in the topmost sample.

As in PAZ MP-2, *Betula* pollen is dominant in this zone, making up approximately 53% of the total pollen sum, with 70% or more of the birch grains measuring greater than 20 μm in diameter.

The total land pollen influx increases dramatically from 2826 grains/cm^2/yr at 335 cm to 8820 grains/cm^2/yr at 330 cm, and this increase is reflected in the influx curves for most pollen taxa, with coincident increases in influx of *Lycopodium*, *Sphagnum* and Filicales spores, aquatic pollen, and *Pediastrum*.

6.4.4 Geochemical stratigraphy

The main geochemical components demonstrate stratigraphical changes in the basal segment of the Moose Pond core (Figure 6.12) similar to those described above for the Northwest Gander River Pond and Pool's Cove Pond cores. As in the other cores, SiO_2 makes up most of the dry sediment weight, but decreases slightly, from 68% at base to 55% at 300cm. Biogenic silica makes up a minimum amount of the total silica (less than 3%) at the base of the core, but increases to a maximum 36% of total SiO_2 (19% of total dry sediment weight) at 327.5 cm.

As in the basal core segments from the other two sites, MgO, Na_2O, K_2O, and TiO_2 all have maximum values at the bottom of this core. MgO begins to decrease above 377.5 cm (near the MP-1/MP-2 pollen assemblage zone boundary) and levels off at approximately 1% above 352.5 cm. Na_2O, K_2O and TiO_2 all decrease above 352.5 (Na_2O and K_2O from 2-1%, TiO_2 from 1-0%), just below the 345 cm boundary of pollen assemblage zone MP-2 and MP-3.

P_2O_5 increases from negligible levels below 327.5 cm to approximately 1% by 300 cm. No change in CaO values occurs throughout this segment of the core, as was the case in the other two cores.

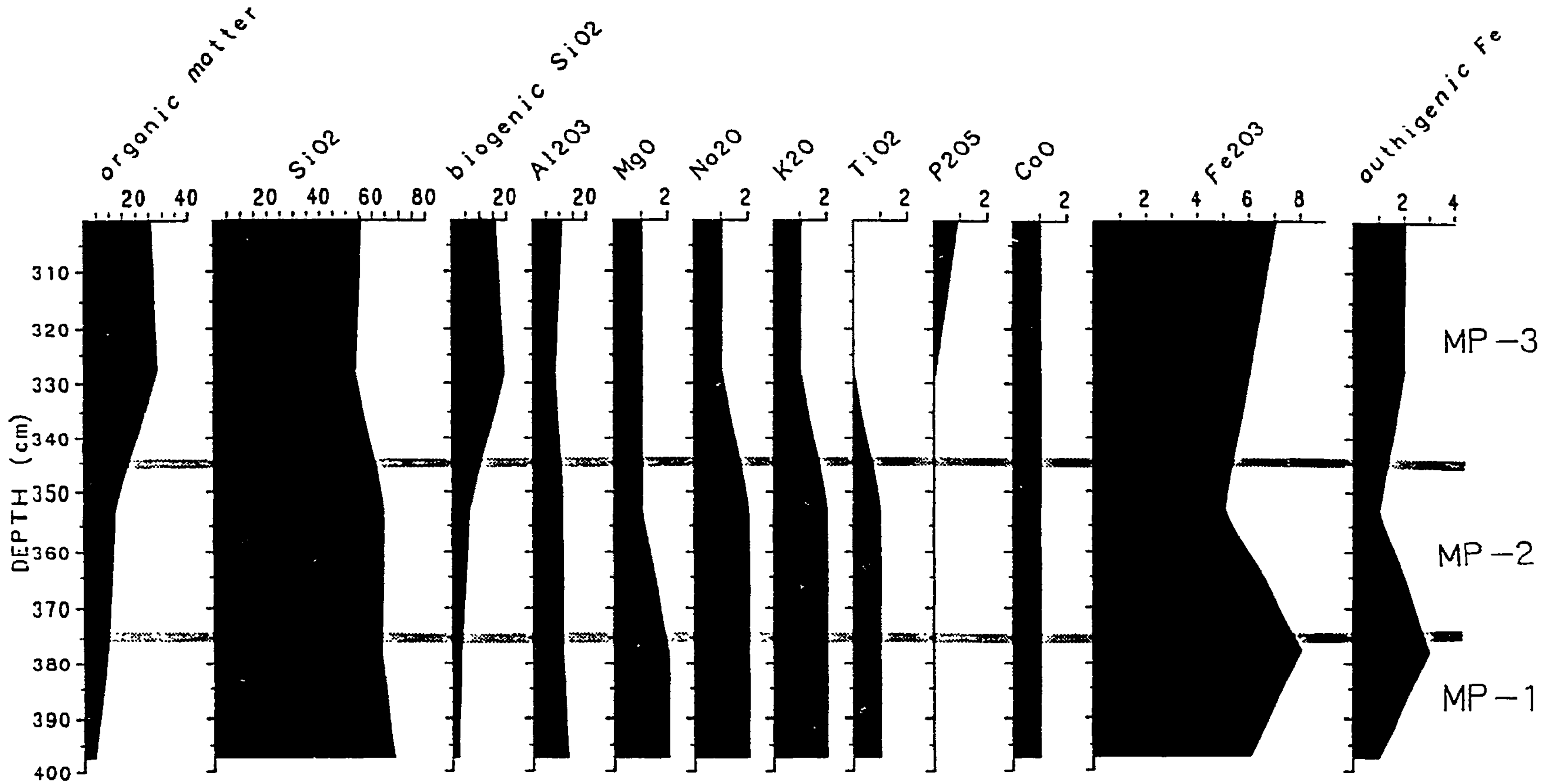

Figure 6.12 Geochemical stratigraphy, Moose Pond Core B. Major elements are expressed as their common oxides, in percentages of total sediment weight.

Fe_2O_3 (8%) and authigenic Fe both peak at 377.5 cm (with authigenic Fe making up a maximum 38% of total Fe_2O_3), then decline to minimum values at 352.5, and increase again above this level.

6.5 Conne River site

6.5.1 Stratigraphy and loss-on-ignition

The stratigraphy of the original core collected from the Conne River site by Dr. Joyce Macpherson in 1982, as well as that of the core collected by the author in 1989 to be used for geochemical analysis, is described in detail in Table 6.6. Dr. Macpherson's core contained what appears to be a very complete post-glacial sequence, beginning with a layer of black thixotropic clay overlying gravel at the base (below 433 cm), separated by a layer of black sand (432-433 cm) from a silty-clay unit which grades upwards into clay-gyttja (400-403 cm) and then gyttja (above 400 cm). It seems that the entire sequence was not successfully retrieved in the 1989 core, which measured only 300 cm, with 1 cm of clay at the base, clay-gyttja from 296-299 cm grading upwards into a sandy gyttja (242-286 cm), overlain by gyttja which extends to sediment surface, with alternating silty and fibrous layers.

The loss-on-ignition curve for the 1982 core is presented in Figure 6.13. The percentage of organic matter

Table 6.6 Core stratigraphy, Conne River site

1982 core (JCM)

Depth (cm)	Description
0-95	coarse medium to dark brown fibrous gyttja
95-105	medium brown, softer gyttja
105-145	dark brown, firm gyttja
145-200	greenish gyttja, oxidizing light-medium brown, with black streaks 165-185 cm & light-medium brown gyttja 190-195 cm
200-395	greenish gyttja, oxidizing dark-greenish - dark reddish; mineral content increasing below 365 cm
395-403	clay-gyttja
403-420	dark grey silty clay, oxidizing lighter, with more persistent layers of black clay-silt 404-406 cm
420-432	thixotropic silty clay, with some laminations
432-433	black sand
433-base (gravel)	black thixotropic silty clay

1989 core

Depth (cm)	Description
0-210	dark to medium-brown fibrous gyttja
210-242	light brown gyttja, with interbedded silty (210-220cm, 222-238cm) & fibrous (220-222cm, 238-242 cm) layers
242-286	sandy, darker brown gyttja
286-296	light brown-grey clay-gyttja
296-300	clay

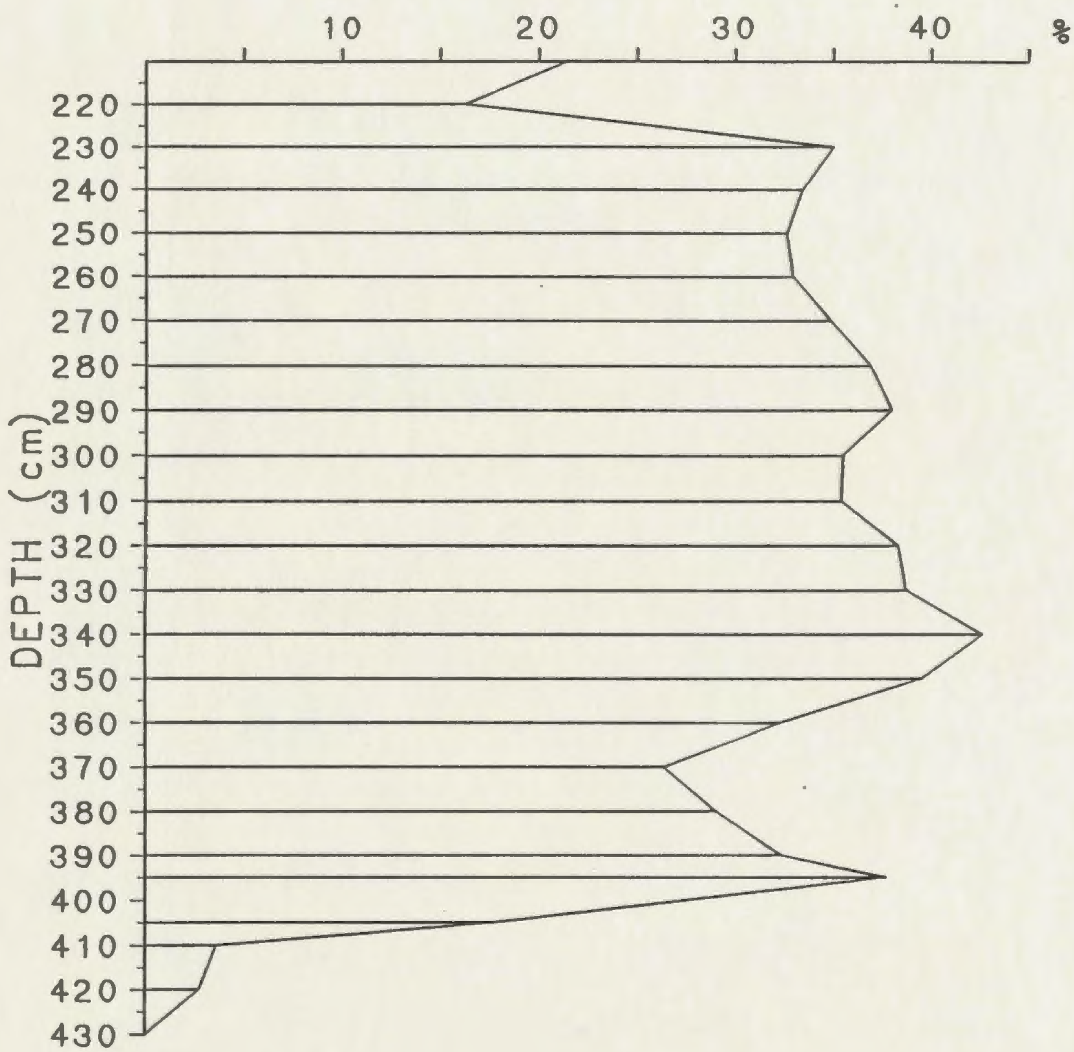

Figure 6.13 Loss-on-ignition, Conne River site, 1982 core.

is low at the base as expected, but increases sharply above 410 cm.

6.5.2. Radiocarbon dates

Two samples from the original core from this pond have been dated. The basal date, intended to provide a minimum age for deglaciation of the site, is 1100 years older than the oldest of the dates from the other three sites, at 11,300 ± 100 (GSC-3634) (Blake, 1983), and is thought to be erroneously old, as will be discussed in the following chapter. A date of 8530 ± 120 BP (GSC-4122) on a sample from 341-346 cm below the sediment surface dates the rise in *Picea* (mainly *P. mariana*) pollen.

6.5.3 Pollen stratigraphy

Summary basal pollen percentage and influx diagrams for the Conne River site (Figures 6.14 and 6.15) have been plotted, using Dr.Macpherson's data, for comparison with the results from Northwest Gander River Pond, Pool's Cove Pond and Moose Pond. *Picea* grains were not separated into *P.glauca* and *P.mariana*, and *Betula* grains were not separated into different size categories. Only those taxa plotted in the summary diagrams of the other sites have been plotted here.

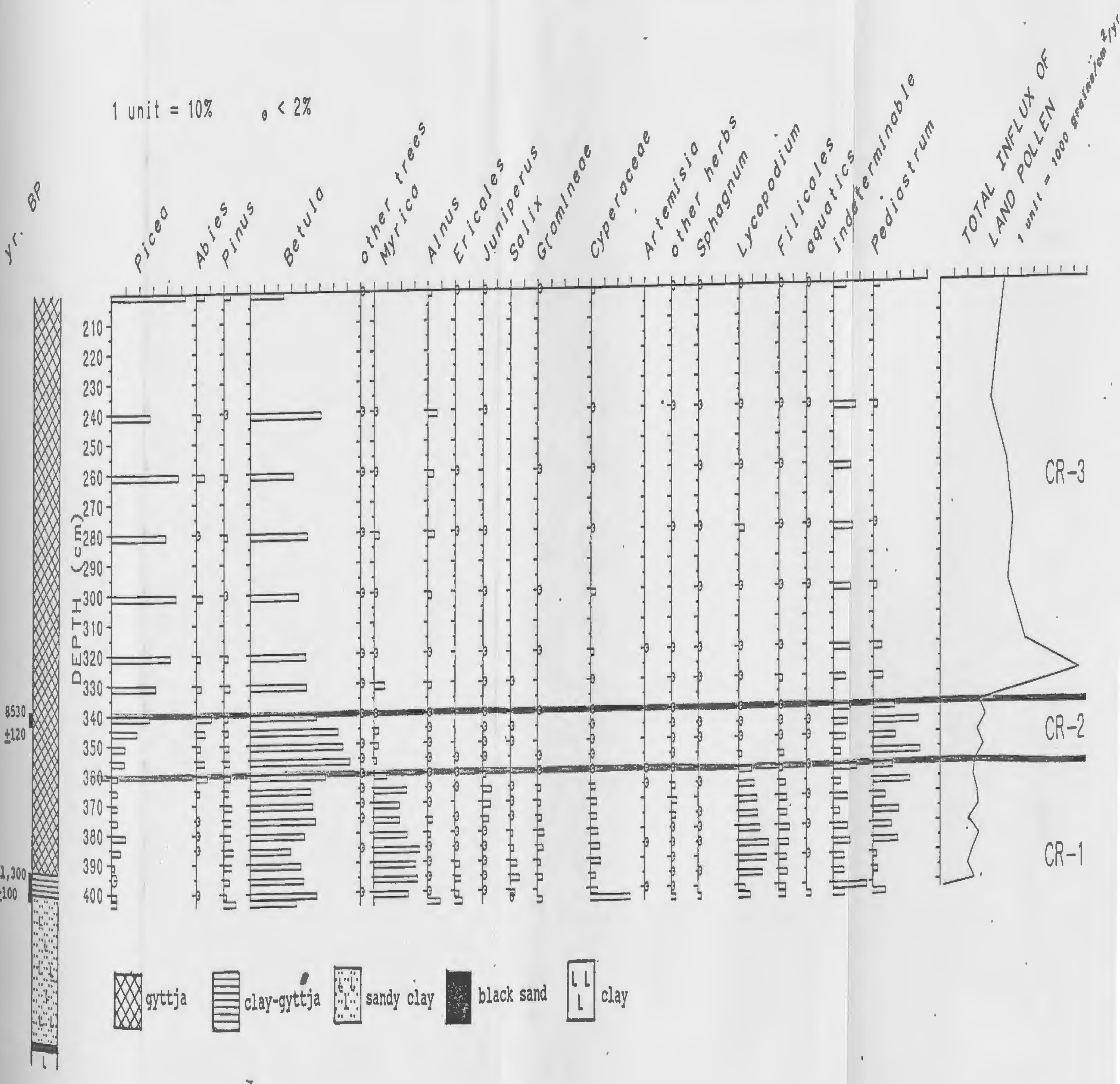

Figure 6.14 Pollen percentage diagram, Conne River site, 1982 core.

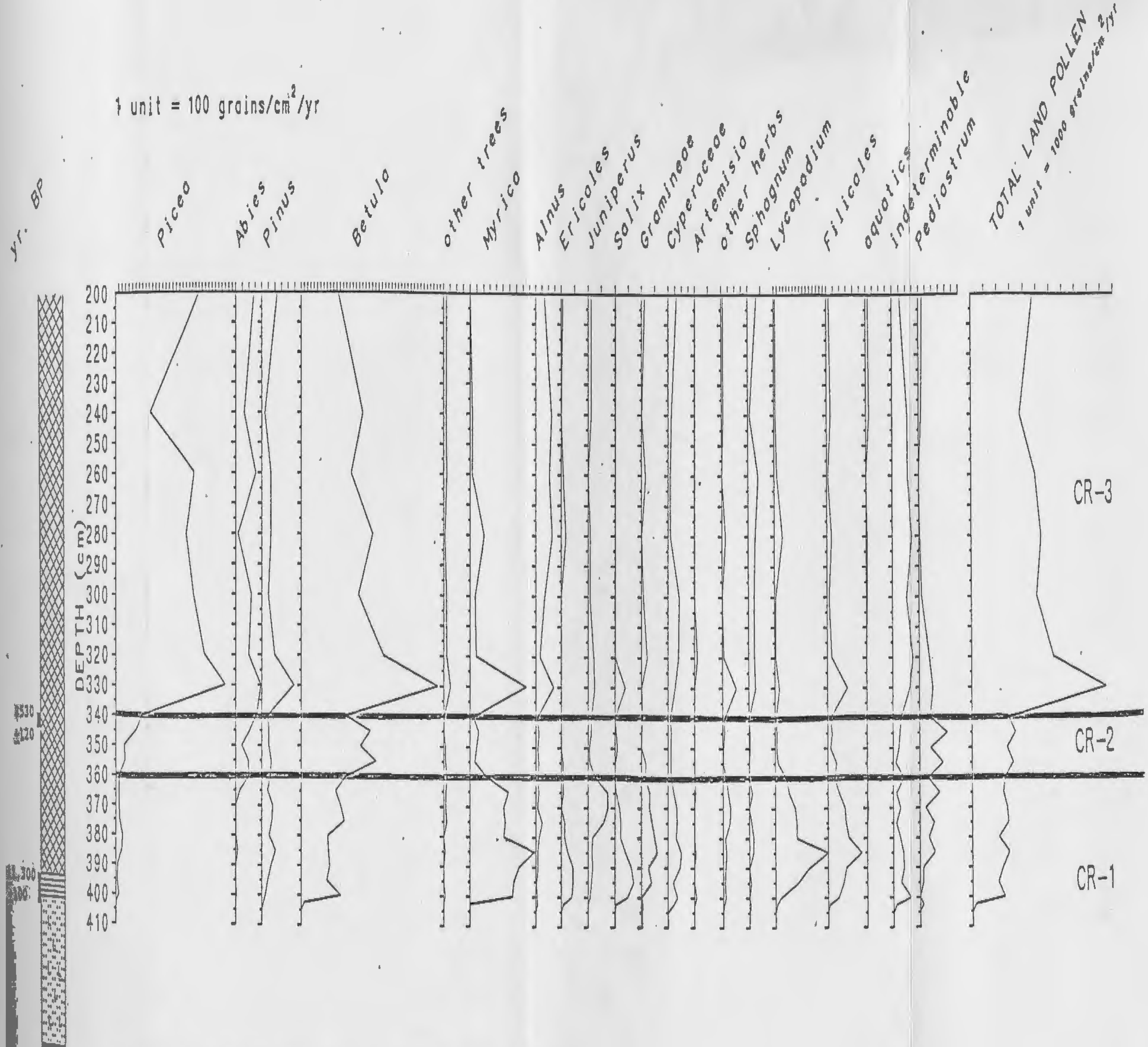

Figure 6.15 Pollen influx diagram, Conne River site, 1982 core.

Three pollen zones can be distinguished:

Pollen assemblage zone CR-1: *Betula*-*Myrica*-Cyperecaea (below 360 cm).

Betula (29-48%) and *Myrica* (19-34%) comprise most of the pollen sum throughout this zone. Cyperaceae peaks at 30% in the 402.5 cm sample but then declines to less than 10%. Successive peaks occur in influx of Ericales and *Salix*, then Cyperaceae, Gramineae, *Lycopodium* and Filicales, and finally *Juniperus*. *Picea* and *Abies* are present in this zone but not in high enough values to suggest local presence of these trees, and a peak in *Pinus* at the base must represent pollen from extraregional sources.

Total land pollen influx is fairly high throughout this zone compared with the basal zones of the other sites (up to 2856 grains/cm^2/yr).

Pollen assemblage zone CR-2: *Betula*-*Picea*-*Abies* (340-360 cm).

This narrow zone is distinguished by the initial increase in percentage and influx of both *Picea* and *Abies* to values high enough to suggest local presence of these taxa, and declines in both percentage and influx of all shrub and herb pollen, as well as *Lycopodium* and Filicales. A peak in *Betula* frequency (up to 72%) occurs at the base of the zone. *Pediastrum* attains its highest values (up to 418 colonies/cm^2/yr, 35%) in this zone as well.

Pollen assemblage zone CR-3: Picea-Betula-Abies (above 340 cm)

This zone is characterized by an increase in Picea pollen to 37-53% (3286 grains/cm^2/yr). Betula percentages are lower than in zone CR-2, but still high, between 24 and 51%, while the peak in Betula influx occurs in this zone at 330 cm, with a simultaneous peak in influx of most taxa and in total land pollen influx. Abies peaked in percentage in zone CR-2, but it attains maximum influx (382 grains/cm^2/yr) in this zone at 330 cm and a mean influx of approximately 200 grains/cm^2/yr throughout the rest of the zone. Alnus and Pinus contribute up to 8% and 5%, respectively, of the total land pollen sum, while all other pollen and spore taxa are present only in relatively small percentages, although some display small peaks in influx. Total land pollen peaks at 10,392 grains/cm^2/yr at 330 cm, just above the level of maximum percentage organic matter (see Figure 6.13), averaging approximately 5000 grains/cm^2/yr above this level.

6.5.4 Geochemical stratigraphy

The geochemical stratigraphy of the basal segment of the 1989 core from the Conne River site is illustrated in Figure 6.16. No curves are plotted for MgO, K_2O or TiO_2 because the data sets for these compounds were incomplete.

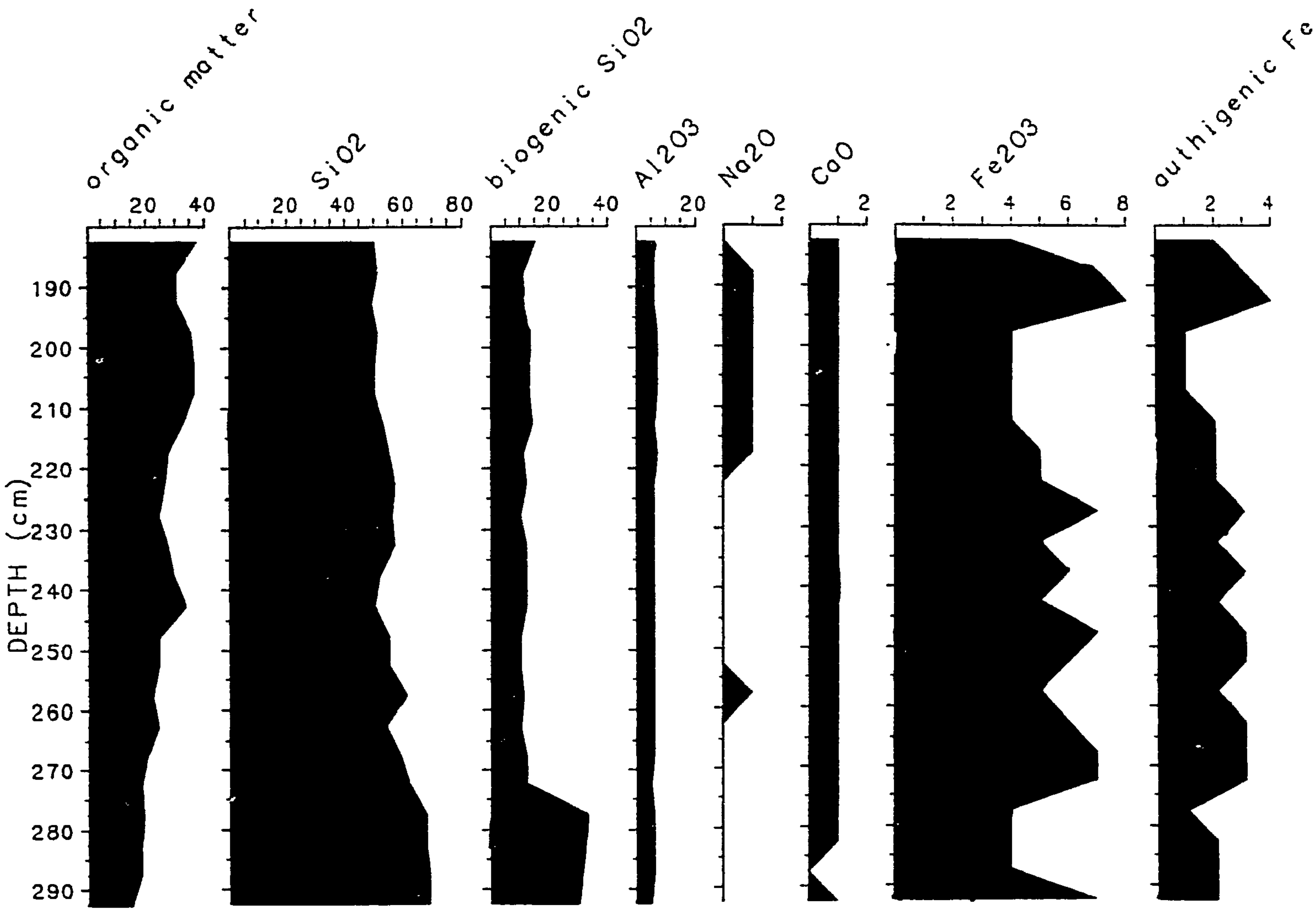

Figure 6.16 Geochemical stratigraphy, Conne River site, 1989 core. Major elements are represented by their common oxides, as percentages of total sediment weight.

SiO_2 makes up the majority of the sediment weight throughout, with biogenic SiO_2 peaking at the base, where it makes up approximately half of the total SiO_2.

The Na_2O curve from this core does not exhibit the expected peak at the base, but instead has minimum values at the base, with a brief peak at 257.5 cm and increased values again higher in the core, above 222.5 cm.

Both the total Fe_2O_3 and the authigenic iron curves are irregular, but authigenic Fe values are generally higher than in the cores from the other sites, averaging approximately 3% of the dry sediment weight.

CHAPTER 7

INTERPRETATION AND CONCLUSIONS

7.1 Introduction

In the following discussion, the emphasis is on using the results presented in the previous chapter to reconstruct the chronology of deglaciation and early postglacial events in the study area. First, the pollen stratigraphies from each of the four sites are used to reconstruct the sequences of local vegetational change that occurred while the basal sediments were being deposited. This is followed by a brief discussion of contemporaneous environmental changes in the lakes and their catchments, as inferred from the geochemical stratigraphies.

The radiocarbon dates are then evaluated in terms of their accuracy and how well the basal dates represent local deglaciation time. The basal date from the Conne River site is apparently too old, while those from the other three sites represent early stages in the vegetational succession of their respective catchments, and provide minimum estimates of the timing of local deglaciation. The approximate time represented by the sediments underlying the lowest dated levels from each of these sites is calculated and added to the basal radiocarbon dates to estimate the actual ages of deglaciation.

This leads to a discussion of the apparent pattern of deglaciation in the study area, with reference to uncertainties about the timing of events here and in other parts of Newfoundland and Atlantic Canada. In the final section, some possibilities for further related research are discussed.

7.2 Interpretation of pollen sequences

7.2.1. Introduction

The results of the pollen analysis are interpreted below primarily in terms of the general pattern of vegetational change, with particular attention to whether the basal pollen sequences indicate sequential deposition following ice retreat and confirm that the basal radiocarbon dates represent early stages in the vegetation succession.

A combination of techniques is used in interpreting the pollen sequences. A common approach to the interpretation of Holocene fossil pollen assemblages is to compare them with modern assemblages from different vegetation regions. However, finding modern analogues for late-glacial and early Holocene pollen assemblages is often a problem because the communities from which the pollen was derived were undoubtedly controlled by environmental factors (eg. edaphic conditions, competition, migration, changing climate) that were vastly different from those of the present day tundra regions, and were continually changing.

The earliest pioneer zones in particular do not appear to have any analogues in vegetation communities found even in the high arctic of North America today, and the best interpretations of the early pollen zones can perhaps be attained by comparison with communities found in areas that have recently experienced glacial retreat, in combination with reference to published early postglacial pollen sequences from other areas. In the following discussion, the well documented vegetation communities and corresponding modern pollen spectra of the Storbreen glacier foreland in southern Norway (Matthews, 1978; Whittaker, 1989; Caseldine, 1989), where ice has been retreating since 1750 A.D., will be considered in the interpretation of the lowest zones. These Scandinavian results cannot be directly extrapolated to earlier vegetation histories in areas as far away as Newfoundland, but they do provide valuable insight into early postglacial vegetation dynamics and the degree to which vegetation is represented by pollen assemblages.

The fossil pollen spectra cannot be translated directly into past vegetation assemblages because of differential patterns of pollen production and dispersal among species, and because certain types of pollen are more commonly deposited and preserved in lake sediments. However, comparisons of modern pollen spectra with the actual composition of the vegetation communities they represent have helped to overcome this problem to some extent. Macpherson (1982) and Dyer (1986) compared modern pollen spectra from lake sediments on the Avalon and Baie Verte Peninsulas, respectively, with the composition of the regional vegetation and found that some species, notably Abies balsamea, tend to be poorly represented by their pollen in lake muds, while others, especially Betula, are strongly overrepresented. In interpreting the fossil pollen sequences from this study, the discrepancies between the relative proportions of certain taxa in the modern vegetation of Newfoundland and of their pollen in lake sediments, as determined by Macpherson (1982) and Dyer (1986), are taken into consideration.

7.2.2 Northwest Gander River Pond

The basal core segment analyzed from Northwest Gander River Pond contained 20 cm of essentially non-polliniferous sediment at the base, from which two samples were analyzed but found to contain only very low concentrations of tree pollen (Pinus, Picea, Betula and Acer) probably transported to the area by wind, or perhaps released from the retreating ice.

The lowest samples with countable quantities of pollen (pollen subzone NWG-1i) contain high percentages of pollen (up to 40%) from pine and other tree species, most probably of distant origin. <u>Betula</u> percentages are also fairly high, but this does not necessarily imply the local existence of birch, which tends to be a prolific pollen producer (cf. Macpherson, 1982; Dyer, 1986). Caseldine (1989) concluded that high birch percentages in the pollen assemblages from present day pioneer communities in front of the retreating Storbreen glacier are largely due to long-distance transport from outside the glacier foreland area.

Excluding those pollen types which are likely to be of non-local origin, the lowest levels of the core are dominated by Cyperaceae pollen, with peaks of <u>Artemisia</u>, <u>Rumex/Oxyria</u>, Gramineae and 'other herbs', succeeded by the invasion of a variety of shrubs beginning with <u>Alnus</u>, followed by <u>Salix</u>, <u>Juniperus</u>, Ericales, and <u>Myrica</u>. <u>Betula</u> also increases, with a combination of grains measuring < 20μm in diameter (taken to represent shrub birch) and larger grains which may include shrub and tree birch. This initial increase may be interpreted as indicating the invasion of shrub birch into the area, perhaps with some input of extraregional tree birch pollen.

In the pioneer communities of the Storbreen glacier foreland, Gramineae is a major component of the vegetation, and makes up high percentages of the pollen spectra (Caseldine, 1989). While a small peak in the percentage of Gramineae pollen occurs at the base of the pollen sequence from Northwest Gander River Pond, Cyperaceae is much more dominant. At Storbreen, most sedge species growing in pioneer and snowbed communities apparently do not have a detectable pollen signature, and it is only when *Eriophorum* species are present that significant amounts of sedge pollen are recorded (Caseldine, 1989). The higher Cyperaceae values in the early pollen spectra from Northwest Gander River Pond may therefore simply indicate the presence of species of sedge which are more prolific pollen producers. However, they may also reflect differences in drainage conditions, since Watts (1979) noted that high sedge percentages are characteristic of recently deglaciated terrain with large areas of impeded drainage.

Matthews (1978) and Fredskild (1973) both recognise *Oxyria digyna* as a coloniser in recently deglaciated areas, and Caseldine (1989) reported the highest values for *Rumex/Oxyria* pollen in the Storbreen foreland from within pioneer communities in areas which had been deglaciated less than 50 years.

The lowest sample dated from this core was from 185-190 cm, so the pollen influx rates below this level, as plotted in Figure 6.2, are based on sedimentation rates extrapolated from between the dated levels and are of questionable validity. The estimated pollen influx rates are very low (< 60 grains/cm^2/yr) in the basal 30 cm of the core and increase only slightly in the next 25 cm (up to 175 cm depth), corresponding with low percentages of organic matter in the sediment, as determined by loss-on-ignition (Figure 6.1). This is attributed to high sedimentation rates due to rapid erosion of the sparsely vegetated landscape, combined with low organic productivity in the catchment.

The high percentages and influx of *Pediastrum* in pollen zone NWG-1 support the interpretation that this interval represents a time of discontinuous vegetation cover, causing slope instability and high inputs of mineral matter to the lake, providing the nutrients these algae need to flourish (cf. Lamb, 1980).

This early sequence fits well with Tipping's (1988) criteria for pollen sequences indicative of primary colonisation of newly deglaciated terrain in the British Isles, with high values of *Rumex/Oxyria* and *Artemisia* in the earliest pioneer communities followed by the invasion of *Juniperus*, *Betula*, *Empetrum* and other dwarf shrubs, and the eventual development of a birch-dominated assemblage. Ericales pollen was not differentiated in the present study, but may reasonably be assumed to include *Empetrum* spp., since _Empetrum nigrum_ and _Empetrum eamesii_ are found throughout Newfoundland today, growing well in barren, exposed habitats (Ryan, 1978). The beginning of the period of _Betula_ dominance in the Northwest Gander River Pond core has an interpolated date of 9680 BP. Since both radiocarbon dates from this core appear to be satisfactory, as explained later, this and other interpolated dates mentioned below are considered to be reasonably accurate.

The sharp increase of _Betula_ at the base of zone NWG-2 may represent the arrival of tree birch to the area. The high values of birch pollen (up to 75%) do not of course indicate that birch trees and shrubs completely dominated the landscape, considering that _Betula_, which makes up only 7% of the productive forest of the northeastern Avalon Peninsula, contributed 39% of the modern pollen spectra from the surface lake sediments of one of Macpherson's (1982) sites. Birch was undoubtedly present in the Northwest Gander River Pond area, however, and probably formed a significant component of the vegetation, which was developing into an open woodland, with a variety of shrubs still present according to the influx diagram.

The appearance and increasing percentages and influx of _Picea_ pollen throughout this zone suggest the invasion of spruce, beginning ca.9330 BP as interpolated from the two radiocarbon dates. The majority of the spruce grains were classed as P. glauca below 150 cm, with the exception of the lowest sample recording significant levels of spruce, where 14 of the 26 Picea grains were identified as P. mariana. If this represents the approximately simultaneous arrival of P. glauca and P. mariana, the former must have been more successful in the area at first, since while black spruce seems to be proportionately represented by its pollen, white spruce was found to be underrepresented in modern pollen spectra from lake sediments on the Baie Verte Peninsula (Dyer, 1986). A later expansion of black spruce begins at the boundary between pollen assemblage zone NWG-2 and NWG-3 (interpolated age 8270 BP).

Abies balsamea pollen first appears at the same level as Picea (ca.9330 BP), and although it attains only low percentage and influx values, its consistent presence suggests the existence of balsam fir in the area after this, especially since this tree is known to be poorly represented by its pollen in modern lake sediments from Newfoundland, comprising only 8% of the modern pollen on the eastern Avalon Peninsula, where it makes up 55% of the productive forest (Macpherson, 1982).

Declining influxes and very low percentages of most shrubs (with the exception of Alnus) after ca 8300 BP (pollen assemblage zone NWG-3) probably represent their competitive replacement by expanding tree populations as an open woodland developed. Betula percentages and influx are both lower in this zone with almost all grains now over 20μm in diameter, probably mostly tree birch. By about 7700 BP a spruce-fir forest, with birch trees and alder (probably forming thickets, especially near the pond), was established in the Northwest Gander River Pond area, including all the components present in the modern forest of the area.

7.2.3 Pool's Cove Pond

The expected postglacial successional sequence described by Tipping (1988) is not as obvious in the basal segment from Pool's Cove Pond. As in the Northwest Gander River Pond core, Artemisia and Rumex/Oxyria are present in the lowest samples, and Cyperaceae values are high, suggesting primary colonisation of freshly exposed ground. However, in this case the most dominant taxon in the lower samples is Salix, with high values of grains tentatively identified as Juniperus at the base and a sharp increase in Ericales to a brief peak at the top of the lowest zone.

In the Storbreen foreland, Caseldine (1989) found a very close relationship between frequencies of Salix and Ericales pollen and the local presence of these largely insect-pollinated taxa, reflecting their low levels of pollen dispersion. The high values of Salix in the two lowest samples of the core may thus be interpreted as representing the close proximity of willows at the time of deposition.

Anderson's (1983) pollen diagrams from the adjacent Burin Peninsula indicate the presence of significant amounts of Juniperus in pollen spectra from pre-Younger Dryas sediments, with lower levels during the Younger Dryas period and an increase (to 5-6%) in the early Holocene. There is little information in the literature concerning the dispersion of Juniperus pollen, so it is unknown whether its presence in fossil pollen spectra necessarily indicate the local presence of juniper shrubs. However, if the pollen was widely dispersed, Juniperus might be expected to be more prominent in Holocene pollen diagrams, so the high values of this taxa at the base of the Pool's Cove Pond sequence are tentatively interpreted to represent the local presence of juniper shrubs.

The basal pollen zone from this core may therefore represent the input of pollen both from pioneer herb communities on newly deglaciated areas near the basin, as well as from dwarf shrub communities growing on older ground nearby. Leckie and McCann (1983) suggested that the Hermitage Peninsula was affected during the Late Wisconsinan by a small separate ice cap, broken with nunataks. According to their reconstruction of the extent of Late Wisconsinan glaciation on the peninsula (Leckie and McCann, 1983, p401) Pool's Cove Pond lies within the proposed limits of the Hermitage Peninsula ice, but within 1 km of a clearly defined nunatak area to the north, and 2-4 km from others to the west, southwest and southeast (see Figure 2.3). The Salix and Juniperus pollen in the basal zone of the Pool's Cove Pond core may have originated from these nunatak areas, or other areas that had been ice covered but were deglaciated earlier than Pool's Cove Pond. These areas may have been vegetated by dwarf shrub communities.

The pollen succession in the higher zones indicates a transition to a heath community represented by a brief but significant peak in Ericales pollen, followed by the invasion of taller shrubs (including Myrica) and an expansion of birch, beginning at the base of the lowest dated sample (9710 ± 120 BP; GSC- 4945). Alnus shows an initial peak in percentages at this level as well, but this probably represents long-distance transport. Rumex/Oxyria values are higher in pollen zone PC-2 than at lower levels, but this is not difficult to explain since Matthews (1978) notes that Oxyria digyna tends to extend with a high frequency on to older ground than other pioneer species, and Caseldine reported significant quantities of Rumex/Oxyria in the pollen spectra from snowbed sites.

Spruce (both P.glauca and P.mariana identified) attains initial high values also beginning at the base of the lowest dated sample (ie. before 9710 BP), but later declines until at approximately 9000 BP it makes up less than 2% of the pollen sum, increasing again after about 8600 BP. This early expansion, decline and renewed expansion of spruce is not found in either the Northwest Gander River Pond or Moose Pond stratigraphies; the initial spruce rise has been dated by interpolation at 9330 BP at Northwest Gander River Pond and somewhat earlier, approximately 9670 BP, at Moose Pond, followed by more or less steady expansion in the pollen records. One possible explanation is that the lower Picea rise in the Pool's Cove Pond core represents long-distance transport of pollen, probably from Cape Breton Island, while the second increase, in zone PC-3, represents the actual arrival and expansion of spruce. This interpretation best accounts for the temporary decline in Picea percentages.

However, it is possible that Picea had migrated to the Hermitage Peninsula before 9710 BP, since it was apparently present on Cape Breton Island, the probable source area for spruce migration to Newfoundland, before then (Livingstone and Livingstone, 1958; Anderson, 1985). There is also evidence that Picea spread to sites on the north coast of the island after 9800 BP (Macpherson, 1988).

The early spruce rise may therefore alternatively be interpreted as representing the expansion of P.glauca, later declining in response to competition from expanding populations of Abies balsamea, which makes up only small percentages of the pollen sum, but does exhibit a gradual increase in influx coinciding with the decline in Picea. The high proportions of P. mariana in the 250 cm sample may be the result of either erroneous separation of spruce pollen, long distance transport from mainland sources, or the simultaneous arrival of both species, with white spruce being originally more successful on the nutrient rich, mainly inorganic tundra soils. Studies in southeastern Labrador have revealed a succession of conifer species beginning with P.glauca, followed by increasing dominance of Abies balsamea and later P.mariana, interpreted as a response to deteriorating soil conditions (Lamb, 1980: Engstrom and Hansen, 1985). The second Picea rise includes increasingly high proportions of grains identified as P.mariana, and probably represents the expansion of this species, although it does not seem to have competitively replaced P.glauca and Abies balsamea before the end of the period represented by the pollen sequence, since all three species expanded throughout pollen assemblage zone PC-3 (after 8800 BP). A mixed coniferous woodland seems to have developed, probably with white spruce and balsam fir inhabiting well-drained sites with richer soils, and the more edaphically tolerant black spruce occurring on sites with poorer soils and impeded drainage.

A significant increase in *Pinus* also occurs in pollen zone PC-3, suggesting the arrival of pine to the region. It is unlikely that pine grew on the Hermitage Peninsula, but *P.strobus* may have been present in small numbers in the sheltered valley at the head of Bay d'Espoir, which Damman (1983) identified as belonging to the Western Newfoundland ecoregion (subregion 1.F, Bay d'Espoir subregion). *Pinus* did not expand in the north-central interior of the island until approximately 6500 BP according to Macpherson (1988).

The persistence of shrub and herb taxa suggests that forest tundra vegetation remained at least until the end of the period represented by the basal 80 cm of the core, at approximately 7800 BP. However, the topmost sample analyzed records an increase in *Alnus*, and decreasing levels of other taxa including Ericales, *Juniperus*, and most herbs, contemporaneous with the alder increase in the Northwest Gander River Pond core, which has an interpolated date of ca. 7720 BP. This may mark the beginning of a transition to a more closed forest in the Pool's Cove Pond region.

7.2.4 Moose Pond

The lowest zone of the Moose Pond core is dominated by Cyperaceae pollen, with a high initial frequency of far-travelled pine, small peaks in *Rumex/Oxyria*, *Artemisia*, and 'other herbs', and increasing proportions of shrub *Betula* and _Salix_, resembling subzone NWG-1ii of the Northwest Gander River Pond sequence. The high percentages of herbs found at the base of the Northwest Gander River Pond sequence are absent from the Moose Pond pollen stratigraphy, indicating that the primary phase of colonisation of the area following deglaciation is not represented.

The sediments of this pond are apparently underlain by boulders, as rock was encountered at a variety of depths during both coring attempts and by probing in other areas of the pond. No mineral sediment was retrieved at all in the first sampling attempt (core A), and it is possible that the earliest sediments at both sampling sites were deposited between boulders and were therefore not retrieved by the corer.

Instead, the lowermost pollen spectra (from core B) seem to represent the period of invasion of shrubs into the pioneer herb tundra, beginning with _Salix_ and shrub birch, followed by heaths and later _Juniperus_, _Alnus_ and _Myrica_. If any earlier sediments are missing from the base of this sequence, they represent the time between deglaciation and the initial invasion of shrubs. In the Storbreen glacier foreland pioneer communities give way to 'heath' or 'snowbed' shrub communities approximately 50 years after ground is exposed by the retreating glacier (Matthews, 1978). The period between deglaciation and deposition of the basal sediments may have been as brief as 50 years if shrub communities had already been established in nearby earlier deglaciated areas, thus being readily available to colonise the Moose Pond catchment as soon as environmental conditions became favourable; it was probably longer if the shrubs had to migrate from further away.

Above the level of the basal date (10,000 BP) grains > 20μm in diameter make up increasing proportions of the steadily rising _Betula_ input, possibly representing the arrival of tree birch. Both radiocarbon dates from this core seem to be correct, so the interpolated dates given here are also assumed to be acceptable. _Picea_ (almost exclusively _P.glauca_ at first) is consistently present, though in small quantities, after ca. 9665 BP, probably representing the arrival of white spruce, which comprises most of the pollen identified in lower samples; an increase after 9000 BP, with approximately half of the grains identified as _P.mariana_, is interpreted as representing the expansion of black spruce. _Abies_ also arrived ca. 9000 BP, after which all the major forest components were present. _Alnus_ contributes only very small proportions of the pollen sum, but shows a small increase in influx in the topmost sample analyzed, dated at ca. 8480 BP. A sharp increase in total land pollen influx is also registered at this level, which may signal a sudden decline in sedimentation rates combined with increasing pollen productivity as the vegetation cover becomes more complete.

7.2.5 Conne River

The lowest levels plotted in the Conne River pollen diagrams are dominated by Betula and Myrica, with peaks in Alnus, Ericales, Salix, Lycopodium and Filicales. Only the lowest sample plotted (402.5 cm) contains high Cyperaceae percentages, Artemisia is present only in very small quantities, and Rumex/Oxyria was not recorded at any level in this core. Thus there is little evidence here of a successional sequence beginning with pioneer colonisation.

However, the segment of the core represented in the pollen diagram was underlain by 33 cm of largely non-polliniferous minerogenic sediment, with intermittent laminations, suggesting possible deposition by glacial meltwater. Two samples, from 405 and 410 cm below the sediment surface, were analyzed but have been omitted from the diagrams because pollen sums of only 9 and 14 grains, respectively, were achieved. This might be the result of unsuccessful chemical extraction of pollen or poor preservation of grains in the minerogenic sediment, but most probably represents a rate of sedimentation too high to register countable amounts of pollen, combined with the low pollen productivity of early postglacial plant communities (cf.Tipping, 1988). High sedimentation rates would certainly be expected if glacial meltwater was being washed into the lake, a theory which is supported by the fact that Pediastrum values are low at the very base of the pollen diagrams, peaking above 380 cm depth. The influx of glacial meltwater might create turbid conditions in the lake during the summer growing season, preventing these algae from flourishing despite the large quantities of nutrients that would have been made available by the high inputs of mineral matter to the lake.

It is worth noting that the few pollen grains found in these omitted samples included several Gramineae and Cyperaceae grains, as well as Saxifragaceae (some species of which are found in the pioneer communities of the retreating Storbreen glacier foreland) and Artemisia. Thus while the initial postglacial colonisation by pioneer communities is not evident in the Conne River pollen diagrams, as it was in the Northwest Gander River Pond pollen sequences, it is possible that it occurred during the time represented by the underlying minerogenic sediments. The shrub phase (pollen assemblage zone CR-1) is succeeded by a zone of Betula dominance (CR-2), as was the case in the pollen sequences from the other sites.

A small initial peak of Picea in the lowest zone (at 380 cm) is dated at 10300 BP by interpolation between the two radiocarbon dated levels of this core. This led Macpherson (1990) to reject the basal date from this core (11,300 ± 100 BP; GSC-3634) as being too old, since it is unlikely that spruce was present in Newfoundland before it arrived in Cape Breton Island. The arrival of spruce was dated at 10,160 BP at Gillis Lake, Cape Breton Island (Mott et al., 1986, p. 249). Since spruce was not present in Cape Breton Island before the climatic deterioration began, it probably did not arrive until after the end of the Younger Dryas, which occurred approximately 10,100 BP (Mott, 1975; Cwynar in Seaman et al., 1991). Thus even if the initial peak in *Picea* in the Conne River pollen sequence represents long-distance transport, it may still be argued that the interpolated date of 10,300 BP is too old, since the most likely source of wind-blown pollen is Cape Breton Island.

The consistent percentages and influx of *Picea* in the pollen percentage and influx diagrams after the initial increase suggest the presence of spruce in the Conne River area. This interpretation is supported by a rise in *Abies*, which arrived in most areas soon after spruce, just above the early *Picea* peak, and below the larger increase of spruce. A sharp increase in *Picea* suggesting a significant expansion of spruce begins at the level of the second radiocarbon date (8530 ± 120 BP; GSC-4122), which is assumed to be correct.

A spruce-fir forest developed in the region after this time, as evidenced by percentages of spruce of more than 30% throughout zone CR-3, and moderate levels of *Abies* (mean ca. 5%). Considering that on the Avalon Peninsula the proportion of balsam fir in the forest is almost 7 times the proportion of *Abies balsamea* in modern pollen assemblages from lake sediments (Macpherson 1982), this might translate to 30-35% balsam fir in the vegetation of the Conne River area during this interval. *Betula* and *Alnus* were apparently also present, suggesting that the forest remained somewhat open, although only negligible values for other shrub and herb taxa are recorded.

7.2.6 Regional pollen zonation

On the basis of the local pollen zonations ascribed to the sequences from the four sites, a provisional regional pollen zonation for southcentral Newfoundland has been devised (Figure 7.1).

Where the local pollen zone boundaries for the four sites fall between dated levels or between the upper dated

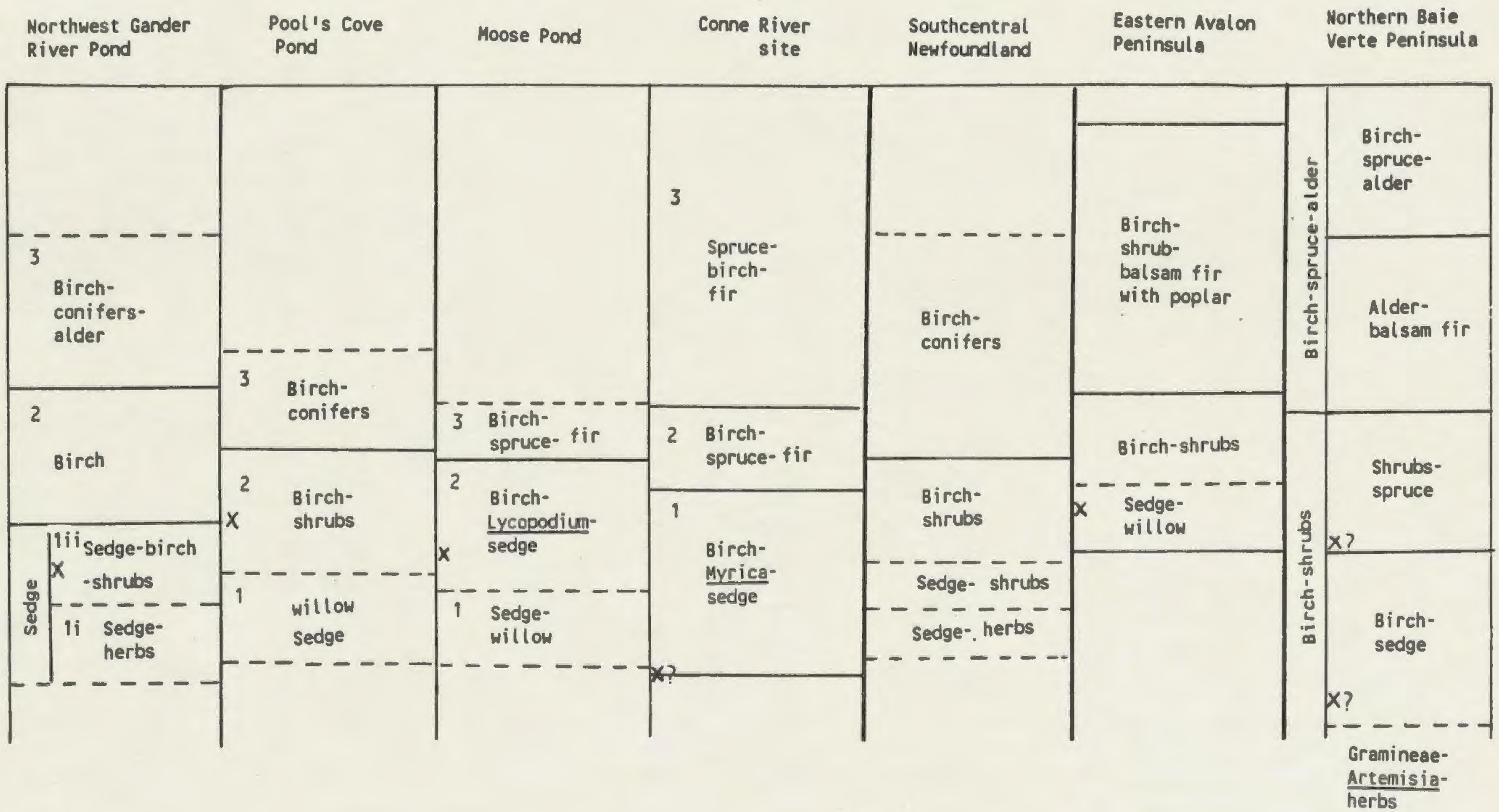

Figure 7.1 Proposed regional pollen zonation for the study area, based on the local pollen zones from the four sites. Regional pollen zones from the eastern Avalon Peninsula (Macpherson, 1982) and northern Baie Verte Peninsula (Dyer, 1986) are presented for comparison.
x = radiocarbon date, believed to be correct
x?= suspect radiocarbon date

level and the upper surface of the lake mud, their ages were interpolated based on average sedimentation rates, and are therefore only approximations of the actual ages. The radiocarbon dates from Northwest Gander River Pond, Moose Pond and Pool's Cove Pond appear to be satisfactory, so the interpolated dates are considered to be reasonably accurate, but this is not true for the Conne River dates.

Below the level of the basal dates, estimated ages can only be calculated using sedimentation rates extrapolated from between the dated levels. This method does not provide very reliable age approximations because sedimentation rates are unlikely to have been the same during deposition of the basal mineral sediments as they were after a vegetation cover developed in the catchment.

Probably partly because of the inaccuracy of interpolated, and especially extrapolated, zone boundary dates, and partly the result of actual differences in species colonisation times at different sites (due to factors such as local climatic differences, soil conditions, and migration patterns), there is not much synchroneity between the local pollen zones assigned to the four sites. This makes the chronological placement of regional pollen zone boundaries difficult, and as a result the legitimacy of the regional pollen zonation is questionable. The regional pollen zones shown in Figure 7.1 are intended to represent the average sequence of changes in the pollen stratigraphies from this study, and do not agree completely with the local pollen zones of any one site.

The general pattern of early postglacial vegetational succession in the region, as inferred from the pollen sequences, began with pioneer colonisation of freshly exposed ground by sedges and other herbs, which is recognizable only in the Northwest Gander River Pond pollen stratigraphy. This was followed sometime later by the invasion of various shrubs, forming a heath vegetation that probably underwent continuous changes in composition as new species arrived and some of the earlier colonisers were depleted because of increasing competition. The shrub tundra was gradually invaded by birch trees and conifers until an open woodland of spruce, balsam fir and birch trees, possibly with understories or thickets of shrubs, mainly alder, developed beginning ca. 9000 BP at the Pool's Cove Pond and Moose Pond sites, and somewhat later at Northwest Gander River Pond (ca. 8300 BP). The beginning of the major spruce expansion at the Conne River site is dated by interpolation as approximately 9370 BP, but probably occurred later than this since the basal date is considered to be too old.

Regional pollen zonations constructed by Macpherson (1982) for the eastern Avalon Peninsula, and Dyer (1985) for northern Baie Verte Peninsula, are also shown in Figure 7.1 for comparison. A general succession from herb and shrub dominated pollen assemblages representing pioneer tundra vegetation communities, through to a dominance of tree pollen suggesting the development of open woodland, is apparent in all three sequences, but the similarities end there. Differences in the pollen zones identified for the three regions are to be expected because of different environmental controls affecting migration and colonisation. The lack of synchroneity in the chronologies may be largely the result of different degrees of error in the radiocarbon dates. It is not unlikely that the sequence began later on the Avalon Peninsula than on the rest of the island, but since Dyer's (1986) basal dates from the Baie Verte Peninsula are suspected to be too old (Macpherson, 1990) the basal zones as shown in Figure 7.1 are probably also too old.

7.2 Geochemical stratigraphy

The geochemical stratigraphies (Figures 6.4, 6.8, 6.12) of the same basal core segments used for pollen analysis from Northwest Gander River Pond, Pool's Cove Pond and Moose Pond reveal a general relationship with the sequence of vegetation development inferred from the pollen diagrams. Elements which occur in lake muds primarily as components of allogenic clastic minerals (Na, Mg, K) have peak concentrations at the bases of all three cores, corresponding with the sparse vegetation of the early postglacial period identified in the lower zones of the pollen diagrams. High concentrations of these elements are characteristic of sediments derived from the unstable catchment soils typical of newly deglaciated terrain.

Declining concentrations of these clastic elements upcore, as organic matter (determined from loss-on-ignition) increases and the pollen records indicate the gradual expansion of shrubs and later coniferous trees, is interpreted as representing decreasing erosion rates as the catchment soils became more stabilised (cf. Mackereth, 1966; Engstrom and Wright, 1984; Engstrom and Hansen, 1985). Clastic minerals are also the primary source of titanium in lake sediments (Engstrom and Wright, 1984), so it is not surprising that peak concentrations of this element are also found at the base of the cores.

The only geochemical results available from the Conne River site are from the 1989 core, and cannot be directly compared with the pollen stratigraphy of the 1982 core. The lowest sediments appear to be missing from this core since the organic matter content (loss-on-ignition) is higher in the lowest sediments (17%) than in the basal sediments of either the other core from this pond or those of the other three sites, and the Na_2O curve does not show the expected peak at the base. (MgO, K_2O and TiO_2 stratigraphies are not plotted in Figure 6.16 because data for these oxides were missing for some levels and zero values were recorded for most others).

Stratigraphical changes in iron concentrations are more difficult to interpret because Fe is deposited in lake sediments in the lattices of allogenic clastic minerals, but may also be present as a component of authigenic oxides, sulphides, carbonates and organic complexes. Both Fe_2O_3 concentrations determined from total sediment digestion, and proportions of authigenic Fe, separated by acid solution, are plotted in the geochemistry diagrams. Allogenic Fe reaches the lake as a constituent of mineral particles and would therefore be expected to peak during times of maximum erosion intensity (ie. in the early postglacial sediments). This does seem to be the case in the Northwest Gander River Pond and Pool's Cove Pond cores, where maximum Fe_2O_3 values are registered below the levels where conifer expansion is indicated in the pollen stratigraphies.

The variations in iron and especially authigenic Fe content with depth in the individual cores, and between cores, may be the result of a combination of complex factors acting both within the lake and in the catchment soils, and their interpretation is beyond the scope of this thesis. It is interesting to note however, that levels of both total and authigenic Fe are somewhat higher in the Conne River core than in the others. This may be due to higher levels of iron sulphides, since pyrite nodules were plentiful in samples from the 1982 Conne River core processed for pollen analysis (Macpherson, pers. comm.), but were not found in the cores from the other sites. The occurrence of pyrite could be the result of anoxic conditions at the bottom of the pond, related to high productivity in the lake water above, since an abundance of oxygen consuming organic matter can lead to reduced conditions in the surface sediments (Hakanson and Jansson, 1983). However, according to Hakanson and Jansson (1983, p.102) pyrite deposition from allogenic sources is more common than from authigenic sources, so the high pyrite levels might instead indicate reducing conditions in the catchment soils.

Sodium hydroxide solution was used to separate the biogenic silica from the total silica concentrations determined by bulk sediment digestion. Biogenic silica represents the remains of diatom frustules in the lake sediments, which theoretically provide an index of lake productivity. However, previous attempts to interpret past changes in lake productivity from biogenic silica stratigraphy have not been very successful. Other evidence for high productivity and nutrient availability during the early phases of landscape development is contradictory with low levels of biogenic silica sometimes recorded in early postglacial lake sediments (Digerfeldt, 1972; Engstrom and Wright, 1984). The stratigraphies for Northwest Gander River Pond, Pool's Cove Pond and Moose Pond likewise show low concentrations of biogenic silica in the lower sediments. Dilution of silica inputs by high influx of allogenic clastics is probably at least partly responsible for this, but other factors may also be involved, including poor preservation of diatom frustules, and higher rates of frustule dissolution leading to removal of biogenic silica in outflow from the lake.

7.3 Evaluation of radiocarbon dates

With the exception of the basal dates from the Northwest Gander River Pond and Conne River sites, there is no evidence that the radiocarbon dates from this study were affected by any sources of error such as contamination by older or younger carbon, or errors in the measurement process.

The basal dated sample from Northwest Gander River Pond has a $\delta^{13}C$ ratio of -18.3‰, somewhat less negative than the accepted range for gyttja (-20‰ to -25‰). <u>Pediastrum</u> was abundant at the dated level, suggesting the possibility of aquatic photosynthesis which might have incorporated older carbon into the sediment, leading to an erroneously old date (cf.Pennington, 1977; Blystad and Selsing, 1989; Aravena, 1990; Macpherson, 1990). However, the date ascribed to this sample (10,200 ± 240 BP, GSC-5027) does not seem to be too old in the regional context, being younger than most previous basal lake sediment dates from central and northern Newfoundland, and only 200 years younger than the date from Moose Pond. It is therefore assumed that any aging effect introduced as a result of aquatic photosynthesis was minimal, and that the radiocarbon date is more or less correct. The $\delta^{13}C$ ratios of all other radiocarbon dated samples from this study were more negative or only slightly less negative than -25‰, and therefore do not appear to be affected by this source of error.

The basal date from Pool's Cove Pond may have been affected by contamination due to input of older carbon from the carbonate bedrock which underlies parts of the Hermitage Peninsula (Colman-Sadd <u>et al.</u>, 1990), making the radiocarbon date too old. The resulting degree of error is unknown, but since this date does not seem unreasonably old in the regional context, it is assumed that the contamination is minimal and that the date is satisfactory.

However, the basal date of 11,300 ± 100 BP (GSC-3634) from Conne River is suspected of being too old, because it leads to an interpolated age of 10,300 BP for the initial *Picea* rise, before its arrival in the Cape Breton, the probable source area (Macpherson, 1990). The interpolated age of the initial *Picea* rise at Pool's Cove Pond is 500 years later, at 9800 BP. Assuming that this is approximately the correct age of this event, and that it was more or less synchronous at both sites, the average sedimentation rate between the upper dated level (8530 ± 120 BP, GSC-4122; 341-346 cm) and the spruce rise at 380 cm depth in the Conne River core is 0.287 mm/yr. Extrapolating this sedimentation rate downwards yields a date of approximately 10,500 BP for the basal sample, but it is impossible to infer a corrected age with any certainty.

The basal dates from Northwest Gander River Pond, Pool's Cove Pond and Moose Pond are all from above the contact between basal mineral sediments and the lowest organic sediments, so the dated sediments are assumed to have been deposited sometime after deglaciation. Although these dates are all from relatively early stages in the vegetation sequences, none are from the period of initial primary colonisation following ice retreat. The basal radiocarbon dates can therefore only be accepted as minimum estimates of local deglaciation times.

Richard et al. (1982) and King (1985) suggest a method for correcting basal radiocarbon dates of lake sediments where pollen analysis is available and the dated sample is above the contact with mineral sediments. This method depends on two criteria:

1) vegetation, as inferred from pollen analysis, did not change while the undated organic sediment was being deposited;

2) at least two radiocarbon dates are available from the core.

If these two criteria are met, then a constant pollen influx is assumed for the basal organic sediments, and the average pollen concentration is then divided by the pollen influx in the dated sample, to determine the average deposition time of 1 cm of the undated organic sediment. The deposition time (in yr/cm) is multiplied by the thickness of the undated section to determine the time represented by the section; this value is added to the basal radiocarbon date to give an estimate of the age of the glacial contact. An additional 100 years, considered by King (1985) to be the minimal number of years represented by the glacial sediments, is added to give an estimated time of deglaciation.

Two radiocarbon dates were obtained for each core, thus meeting the second of the two criteria listed above. The Northwest Gander River Pond and Moose Pond pollen stratigraphies indicate little change in the vegetation during the period represented by the undated organic sediments, but this is not true for the Pool's Cove Pond core, where a significant change in vegetation is inferred from the pollen stratigraphy below the dated level. Thus although this correction method is applied to the basal dates of all three cores, the resulting estimated age of the glacial contact is probably less reliable in the case of Pool's Cove Pond.

The resulting estimates of deglaciation time are 10,464 BP for Northwest Gander River Pond; 10,094 BP for Pool's Cove Pond; and 10,248 BP for Moose Pond. If the period of primary colonisation by pioneering herbs is missing from the base of the Moose Pond as hypothesised, then the time of deglaciation may have been somewhat earlier, but perhaps by as little as 50 years, giving an approximate deglaciation time of 10,300 BP.

The Storbreen data suggest that the shrub stage is reached in about 250 years after deglaciation, while data from the Avalon Peninsula suggest that it took approximately 350 years there (Macpherson, pers. comm.). Therefore it may reasonably be assumed that deglaciation occurred no more than 400 years before the pollen sequences indicate the presence of birch and other shrubs. This provides a means of checking the validity of the deglaciation dates calculated above, assuming the radiocarbon dates are satisfactory.

In the Northwest Gander River Pond sequence, Betula makes up a significant proportion of the pollen sum above 200 cm, and other shrubs increase beginning at 190 cm, at the bottom of the dated level. A shrub community therefore seems to have been established by 10,200 BP. Adding 400 years to this date places the maximum date of deglaciation at 10,600 BP, so the estimated age of 10,464 BP, calculated using King's (1985) method, is probably legitimate.

The basal date from Pool's Cove Pond (9710 $\pm$ 120; GSC-4945) is from 245-250 cm depth, just above the beginning of zone PC-2, which is interpreted as representing a period of shrub vegetation including birch, Myrica, heaths, and possibly alder, beginning before 9710 BP, thus 10,100 BP may be considered a satisfactory estimate of the date of deglaciation of this site.

The pollen stratigraphy from Moose Pond indicates that a birch-dominated shrub vegetation had developed well before the basal radiocarbon date of 10,000 BP, so the estimated deglaciation date of 10,300 BP for this site is also considered to be legitimate. This approach is of no use in establishing the date of deglaciation of the Conne River site, since the shrub stage begins at the level of the questionable basal radiocarbon date.

7.4 Conclusions

The results suggest that all sites were ice covered during the Late Wisconsinan, and there is no evidence that deglaciation occurred before the Younger Dryas. According to the reconstruction of Leckie and McCann (1983), Pool's Cove Pond lies beyond the limit of the main Late Wisconsinan Newfoundland ice cap and within the area covered by the separate ice cap which affected the Hermitage Peninsula. The basal radiocarbon date of 9710 ± 120 BP (GSC-4945) is a minimum estimate of the age of deglaciation of this site; the 'corrected' age of 10,100 BP, though of questionable reliability for the reason explained above, probably provides a better estimate of the actual deglaciation time.

The Northwest Gander River Pond, Conne River and Moose Pond sites all lie within the proposed limits of the main Newfoundland ice cap. Moose Pond, with a basal radiocarbon date of 10,000 ± 170 BP and an estimated deglaciation time of 10,300 BP, seems to have remained ice covered longer than the other two sites. A basal date of 10,200 ± BP (GSC-5027) from Northwest Gander River Pond is the minimum age of deglaciation of this site and the corrected age of 10,465 BP probably provides a better approximation. The timing of deglaciation of the Conne River site is unknown since evidence suggests that the basal radiocarbon date of 11,300 BP is too old, but this site may have been exposed earlier than the others; based on comparison of the Picea curve from this core with that of Pool's Cove Pond, an age of approximately 10,500 BP is suggested for the age of the mineral/organic sediment contact, but this is at best a tentative guess. However, it does seem likely that the Conne River site was ice free earlier than either Northwest Gander River Pond or Moose Pond.

If the Conne River site (elevation 200 m asl) was indeed the first of these sites to be free of ice, followed by Northwest Gander River Pond (160 m asl) and later Moose Pond (130 m asl), the probable mode of deglaciation is by downwasting of stagnant ice rather than ice marginal retreat. This conclusion is supported by the surficial geomorphology of the area, since all three sites lie within an area covered by a blanket of diamicton with an irregular, hummocky surface (Liverman and Taylor, 1990b). Although its origin is somewhat controversial, it is commonly accepted that hummocky moraine is deposited by glacial stagnation, and most of the hummocky terrain on the island of Newfoundland is interpreted as having this origin (Liverman and Taylor, 1990a).

Proudfoot et al.(1990) inferred that the deglaciation of the Burnt Hill/Great Gull Lake area (NTS maps 2D/5 & 2D/6), within the study area, occurred by stagnation of a large ice mass in the southern part of that area. Downwasting of stagnant ice has also been inferred by Macpherson (1982) and Dyer (1986) for the Avalon and Baie Verte Peninsulas, respectively.

One significant problem arises from this reconstruction: why did deglaciation of this area begin during a time when the Maritimes, as well the north coast of Newfoundland and even the adjacent Burin Peninsula, were apparently affected by the deteriorated climatic conditions of the Younger Dryas? While there is considerable evidence that a late glacial - early Holocene climatic oscillation did occur in Atlantic Canada (Livingstone and Livingstone, 1958; Mott, 1975; Mott et al., 1986; Ogden, 1987; Jetté and Mott, 1989; Stea and Mott, 1989; Mayle and Cwynar, 1991), including parts of Newfoundland (Anderson, 1983; Macpherson and Anderson, 1985), the absolute chronology of events has not yet been firmly established.

Dates from two Newfoundland sites indicate that the period of climatic deterioration began by 11,300 BP and ended about 10,500 BP (Anderson, 1983; Macpherson and Anderson; 1985), which corresponds well with the apparent start of deglaciation in southcentral Newfoundland, assuming the basal radiocarbon date from the Conne River site is too old. However, in light of doubts over the accuracy of many basal dates from Newfoundland and the discrepancy between this chronology and the apparent later timing of the Younger Dryas in the rest of Atlantic Canada, Macpherson (1990) suggested that the dates from her north coast site, and possibly Anderson's (1983) Burin Peninsula site, may be too old.

The generally accepted sequence from Nova Scotia and New Brunswick involves a warming trend before 11,000 BP, interrupted by a cold period which lasted until approximately 10,000 BP when the major Holocene climatic amelioration began (Mott <u>et al.</u>, 1986; Stea and Mott, 1989), while Ogden (1987) dated the climatic deterioration as extending from 11,500-10,500 BP in the Halifax area. Recently, AMS radiocarbon dating of macrofossils from lake sediments in Nova Scotia and New Brunswick, presumed to be considerably more accurate than conventional radiocarbon dating of bulk sediments, yielded a range of 10,770 - 11,060 BP for the beginning of the Younger Dryas episode, suggesting that the bulk sediment dates may be too old (Mayle and Cwynar, 1991), and the Younger Dryas may have begun later than previously believed. The end of the Younger Dryas has been dated by both conventional and AMS radiocarbon dating at 10,100 BP at Splan Pond (Basswood Road

Pond) in New Brunswick (Mott, 1975; Cwynar in Seaman *et al*., 1991).

Recent studies involving AMS dating of hand-picked terrestrial plant macrofossils (Ammann and Lotter, 1989; Cwynar and Watts, 1989; Mayle and Cwynar, 1991) and even pollen concentrate (Brown *et al.*, 1989), indicate considerable discrepancies in many cases between these dates and conventional radiocarbon dates of bulk lake sediments. Since the AMS dates theoretically should be more accurate as long as material for dating is carefully selected, it seems likely that many of previous conventional radiocarbon dates from lake sediments, including those from the present study, are in error to some degree. Determinations of the timing of deglaciation and of events such as the Younger Dryas climatic reversal, based on conventional dates, should thus be considered only as tentative estimates of the actual chronologies.

7.5 Further work

Further palynological research, preferably involving the use of AMS dating, is needed to establish a firmer chronology of late glacial - early Holocene events in the study area and for the island of Newfoundland as a whole. It might prove useful, where feasible, to obtain both conventional bulk sediment radiocarbon dates and AMS dates of carefully selected terrestrial plant macrofossils (or better still, pollen concentrate), from basal organic sediments and other significant levels of lake sediment cores. Assessment of the amount of discrepancy between results from the two methods might allow evaluation of the degree of error in the conventional radiocarbon dates from this study and from other previously dated sites.

A considerable amount of data has been generated from the geochemical analysis of the lake sediments, only a small portion of which was used here. Further interpretation of this data is beyond the scope of this thesis, but more work on this is planned for the future.

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APPENDIX

RAW POLLEN DATA

NORTHWEST GANDER RIVER: COUNTS (Wisconsin format);
45 "taxa", 16 samples, 95,000 exotic

```
 45
 16
 120  1  140  109  64  38  24  9  140  9
 0  0  0  0  0  1  1  0  53  0
 0  1  2  1  3  0  0  0  0  0
 0  2  0  0  1  0  1  0  0  0
 0  3  0  0  367
 130  1  152  118  77  25  14  20  165  7
 0  1  0  0  0  1  2  1  88  0
 1  0  2  1  3  0  1  0  0  2
 0  3  0  1  0  0  1  0  0  0
 1  2  0  1  439
 140  1  253  191  135  46  30  45  210  13
 0  0  0  0  0  0  0  0  16  2
 3  3  1  1  3  0  0  0  0  2
 0  7  2  2  1  0  3  0  0  0
 0  2  7  9  544
 150  1  218  117  63  54  9  12  177  5
 0  0  0  1  0  0  5  0  10  4
 1  0  1  0  2  0  0  0  0  0
 0  4  0  1  5  0  1  0  0  0
 0  0  0  16  353
 160  1  166  34  32  2  11  8  221  58
 0  0  0  3  0  0  6  7  12  4
 5  5  2  4  10  0  0  0  2  0
 0  0  0  0  30  0  5  0  0  0
 0  4  12  24  454
 165  1  225  41  39  2  10  17  393  100
 0  1  0  1  0  0  8  0  1  0
 1  1  5  2  5  0  0  0  0  0
 0  0  1  6  41  0  13  1  2  0
 0  4  0  10  691
 167.5  1  165  22  15  7  12  9  369  76
 0  0  0  0  1  0  1  2  11  1
 1  2  0  2  3  1  0  0  0  1
 3  3  2  1  36  0  12  0  0  0
 0  2  0  7  600
 170  1  320  26  12  14  12  11  315  26
 0  0  1  0  0  0  6  4  1  6
 6  2  6  2  6  2  0  0  0  0
 0  0  1  1  24  0  7  0  0  0
 0  1  0  83  460
```

175 2 487 0 0 0 0 9 24 11
0 1 1 0 1 0 0 0 1 0
6 5 0 2 13 2 0 2 1 0
0 1 0 0 4 0 4 1 0 0
0 0 0 90 91
180 1.5 485 0 0 0 0 11 22 18
0 0 0 0 0 0 9 0 2 6
5 4 0 3 17 1 0 0 0 0
0 1 0 1 3 0 1 0 1 0
0 0 0 185 117
185 1.5 582 0 0 0 0 17 27 18
0 1 0 0 0 0 22 0 1 18
4 6 1 5 51 1 0 2 0 0
0 6 1 5 2 0 7 0 3 3
0 0 20 405 199
190 1.5 784 1 0 0 0 16 19 6
1 0 0 1 0 0 0 0 1 1
6 1 0 2 47 1 0 3 1 1
0 1 0 1 1 0 5 0 1 0
0 0 4 465 115
200 2 561 0 0 0 0 6 5 5
0 0 0 0 0 0 2 0 3 0
0 0 0 0 1 4 0 0 3 0
1 0 0 1 0 1 0 0 0 0
0 0 2 146 35
210 2 1270 1 1 0 0 17 2 2
0 0 0 1 0 2 0 0 0 0
0 1 0 2 14 2 0 0 0 0
0 6 0 1 0 0 2 0 0 0
0 1 0 325 53
220 2 600 1 0 1 0 0 1 1
0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 0
0 0 0 0 0 0 2 0 0 0
0 0 0 1 5
230 2 570 1 0 0 0 1 1 0
0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 1 0 1 0 0 1 0 0 0
0 0 0 4 5
depth in sediment (cm)
sample volume (ml)
exotic
total *Picea*
Picea glauca
Picea mariana
Abies
Pinus
Betula >20μ

Betula <20μ
Fraxinus
Quercus
Ulmus
Acer
Juglans
Tilia
coryloid (triporate lacking clear pore structure)
Myrica
Alnus
Juniperus
Salix
Ericales
triporate (deteriorated)
Gramineae
Cyperaceae
Artemisia
Chenopodiaceae
Compositae: Tubuliflorae
Polygonaceae
Plantago
Rosaceae
Rumex/Oxyria
Thalictrum
Sphagnum
Lycopodium
Selaginella
Filicales
Equisetum
Isoetes
Potamogeton
Nuphar
indeterminable
unknown
Pediastrum
total land pollen

POOLS COVE: COUNTS (Wisconsin format);
43 "taxa", 11 samples, 95,000 exotic
43
11
200 1 201 77 46 31 32 75 0 140
28 2 1 6 0 8 4 26 0 5
5 43 4 22 1 1 1 0 0 0
0 0 10 31 24 0 0 37 0 1
13 1 465
210 1 386 53 16 35 20 68 1 180
36 0 0 4 1 20 7 20 15 3
7 45 32 54 4 4 10 0 0 0
15 13 17 96 57 2 2 50 0 5
4 2 484
215 1 246 24 8 15 9 42 0 139
36 0 6 1 0 22 10 13 14 3
6 20 12 32 0 0 5 0 3 0
6 7 14 106 52 0 0 74 0 0
18 0 363
220 1 306 14 7 7 12 26 0 160
17 0 2 7 0 6 3 9 10 4
16 64 10 36 0 0 5 0 0 0
0 5 7 105 50 0 0 24 1 0
3 0 353
230 1 231 6 1 5 3 30 1 140
64 0 0 5 0 10 1 12 7 10
7 38 6 15 0 1 3 0 0 1
0 6 4 105 48 0 0 0 0 0
1 0 335
240 1 322 26 3 17 3 25 0 140
45 0 0 2 0 13 9 6 6 6
11 48 7 28 0 0 4 1 0 0
4 3 1 185 69 0 0 5 0 0
34 10 374
245 1 254 24 4 20 1 14 1 120
36 0 2 1 0 15 4 6 3 5
10 36 15 26 1 0 3 0 0 0
4 0 4 91 31 0 0 0 0 0
13 5 291
250 1 392 27 0 7 2 15 0 110
25 0 0 3 0 8 4 21 1 15
7 9 10 37 0 0 1 0 0 2
8 0 3 56 35 0 0 4 0 0
0 38 247
260 1.5 643 3 0 0 0 59 0 11
19 1 0 1 0 4 0 20 2 27
77 1 14 74 8 0 7 0 0 0
9 2 21 17 9 0 0 0 1 0
2 1 227

270 1.5 346 1 0 0 0 39 0 6
8 0 0 1 0 3 0 1 21 68
11 0 4 20 3 0 7 0 0 2
2 1 13 5 7 0 0 5 0 1
8 16 167
280 1.5 368 1 0 0 0 7 0 0
14 0 0 1 0 1 0 0 12 38
2 2 3 14 4 0 2 0 0 0
1 0 7 0 4 0 0 0 0 1
5 120 83

depth in sediment (cm)
sample volume (ml)
exotic
total <u>Picea</u>
<u>Picea mariana</u>
<u>Picea glauca</u>
<u>Abies</u>
<u>Pinus</u>
<u>Larix</u>
<u>Betula</u> >20μ
<u>Betula</u> <20μ
<u>Fraxinus</u>
<u>Quercus</u>
<u>Acer</u>
<u>Tilia</u>
<u>Corylus</u>
<u>Myrica</u>
<u>Alnus</u>
<u>Juniperus</u>
<u>Salix</u>
Ericales
triporate (deteriorated)
Gramineae
Cyperaceae
<u>Artemisia</u>
Chenopodiaceae
Compositae: Tubuliflorae
Compositae: Liguliflorae
Caryophyllaceae
Ranunculaceae
<u>Rumex/Oxyria</u>
<u>Thalictrum</u>
<u>Sphagnum</u>
<u>Lycopodium</u>
Filicales
<u>Osmunda</u>
<u>Equisetum</u>
<u>Isoetes</u>
<u>Typha/Sparganium</u>

<u>Nuphar</u>
indeterminable
<u>Pediastrum</u>
total land pollen

MOOSE POND: COUNTS (Wisconsin format);

```
48 "taxa", 15 samples, 95,000 exotic
 48
 15
 330  278  1  29  12  16  18  28  153  69
 0  0  1  0  10  2  8  6  1  1
 46  0  0  25  1  1  2  3  0  0
 0  0  0  6  7  4  38  43  0  0
 0  95  0  0  0  1  19  417
 335  280  1  34  16  16  12  20  146  52
 0  0  0  1  12  2  7  6  2  3
 40  0  1  21  0  1  1  2  0  0
 1  0  0  2  6  2  65  48  0  0
 1  62  0  0  2  1  17  374
 340  211  1  24  14  0  9  19  137  31
 0  0  0  1  15  2  4  5  3  6
 18  0  3  19  0  0  1  0  0  0
 1  0  0  1  5  2  79  53  0  0
 4  48  0  0  4  0  17  308
 345  226  1  7  5  2  0  20  162  103
 0  2  0  0  2  4  7  3  7  3
 32  0  15  26  1  0  4  9  0  0
 2  0  1  5  5  2  89  57  0  0
 0  121  0  0  6  0  24  426
 350  202  1  8  7  1  0  16  132  49
 0  1  0  0  2  2  9  3  16  6
 24  0  5  19  0  0  7  5  0  0
 0  0  0  4  0  1  168  72  0  0
 0  65  1  0  2  0  13  310
 355  321  1  7  5  1  0  17  156  42
 0  1  1  0  1  2  9  9  16  3
 34  0  24  32  1  0  1  4  0  0
 3  0  0  6  0  1  179  63  0  0
 0  86  0  0  3  0  26  372
 360  172  1  13  11  1  5  27  129  63
 0  1  0  0  0  3  4  2  16  12
 5  0  15  31  2  0  0  0  0  0
 1  3  1  3  2  3  193  65  0  0
 0  85  0  0  14  0  2  352
 365  464  1  3  3  0  1  10  108  71
 0  2  1  1  2  0  1  5  12  10
 38  0  17  37  4  0  3  0  0  0
 0  0  2  1  0  2  122  34  2  1
 1  228  1  1  10  12  108  339
 370  605  1  5  5  0  [illegible]  22  75  70
 1  0  0  1  5  5  8  3  17  11
 19  0  11  40  0  0  1  0  0  0
 0  6  1  6  0  4  93  29  1  0
 1  37  0  0  1  1  55  309
```

375 504 2 6 6 0 1 20 42 66
0 2 0 0 2 0 5 0 19 10
16 0 7 25 2 0 4 0 0 0
0 0 0 1 0 2 60 28 0 0
0 15 0 0 4 1 27 232
380 597 1 4 3 1 1 19 11 56
0 0 0 1 2 0 1 0 11 6
9 0 5 36 2 0 2 0 0 0
0 1 2 2 0 1 34 10 0 0
0 32 0 0 1 1 13 172
385 599 2 3 1 0 0 19 20 32
0 1 0 1 0 0 0 1 22 4
2 0 5 17 1 0 0 0 2 0
1 0 0 3 0 2 3 9 0 0
0 0 0 0 2 0 18 136
390 889 1 0 0 0 0 20 9 55
0 0 0 1 4 0 4 2 26 2
0 3 6 55 2 0 0 0 0 1
0 0 3 5 0 0 15 30 0 0
2 11 0 2 0 1 25 198
395 986 1 0 0 0 0 15 5 17
0 0 0 0 6 0 3 3 8 0
0 0 1 72 3 0 0 0 0 0
0 0 8 2 0 4 4 2 0 0
3 0 2 0 7 1 3 150
400 1094 1 0 0 0 0 41 4 10
0 0 1 2 1 0 1 6 6 1
0 0 3 23 2 0 0 0 0 0
0 0 5 6 1 1 0 2 1 0
0 0 3 0 1 0 0 114
depth in sediment (cm)
exotic
sample volume (ml)
total *Picea*
Picea glauca
Picea mariana
Abies
Pinus
Betula >20μ
Betula < 20 μ
Fraxinus
Quercus
Ulmus
Acer
Corylus
Myrica
Alnus
Juniperus
Salix

Ericales
triporate (deteriorated)
Caprifoliaceae
Gramineae
Cyperaceae
<u>Artemisia</u>
Chenopodiaceae
Compositae: Tubuliflorae
Caryophyllaceae
<u>Epilobium</u>
Polygonaceae
<u>Plantago</u>
Ranunculaceae
Rosaceae
<u>Rumex/Oxyria</u>
<u>Thalictrum</u>
<u>Sphagnum</u>
<u>Lycopodium</u>
Filicales
<u>Osmunda</u>
<u>Cryptogramma</u>
<u>Equisetum</u>
<u>Isoetes</u>
<u>Myriophyllum</u>
<u>Nymphaea</u>
indeterminable
unknown
<u>Pediastrum</u>
total land pollen

CONNE RIVER: COUNTS (Wisconsin format);

```
 53 "taxa"; 25 samples
 53
 25
 0   75.2   103   23   10   0   70   1   0   2
 0   0   0   0   0   0   8   12   12   26
 2   1   0   0   8   25   1   2   1   1
 0   0   0   0   0   0   0   0   95   7
 0   6   0   0   0   3   0   14   4   0
 10   14   308
 100   172.6   126   17   17   0   76   0   0   0
 1   0   0   0   0   0   6   5   14   40
 1   1   0   0   3   18   0   0   0   0
 0   0   1   0   0   0   1   0   127   13
 2   3   0   0   0   5   0   15   0   1
 3   11   327
 200   275.1   225   25   21   0   103   1   1   2
 0   0   0   0   0   0   20   0   1   12
 2   0   0   0   2   11   0   1   0   0
 0   0   0   0   0   0   1   0   6   3
 0   3   0   0   0   0   0   2   1   0
 10   5   428
 240   281.8   90   11   4   1   167   0   0   2
 0   0   0   0   0   0   18   3   0   22
 2   0   2   0   0   4   0   1   1   0
 0   0   0   0   0   0   0   0   1   3
 1   5   0   0   0   3   1   0   0   0
 20   3   328
 260   380.8   152   20   9   0   100   0   1   1
 1   0   0   0   0   0   15   2   1   14
 0   0   0   0   2   2   0   0   0   0
 0   0   0   0   0   0   0   0   5   5
 1   1   0   0   0   0   0   0   0   0
 15   0   320
 280   427.2   121   2   8   0   128   0   0   0
 1   0   0   0   0   0   15   12   2   15
 1   0   2   0   0   2   0   0   0   0
 0   0   0   0   0   0   3   0   3   14
 0   4   0   0   0   1   0   0   0   0
 17   1   312
 300   345.7   166   17   7   0   126   0   0   3
 0   0   0   0   0   0   12   5   0   10
 1   0   0   0   1   12   0   0   0   0
 0   0   0   0   0   0   0   0   3   2
 1   2   0   1   0   0   0   0   0   0
 15   3   360
 320   542   122   9   9   0   116   2   0   0
 0   0   0   0   0   0   12   4   0   3
 2   0   0   0   2   7   1   0   0   0
```

```
0 0 0 0 1 0 0 0 2 1
0 3 0 0 0 0 0 0 0 0
14 7 290
330 396.6 129 15 19 0 165 0 0 3
0 0 0 1 0 0 15 33 0 11
2 3 0 0 0 4 0 1 0 1
0 0 0 0 1 0 5 0 2 5
1 12 0 0 0 0 0 0 0 0
10 8 408
340 425.5 93 38 11 0 163 0 0 1
0 0 0 0 0 0 17 5 0 3
3 0 0 0 1 4 0 1 0 0
0 0 0 0 0 1 1 0 0 3
0 5 0 0 0 0 0 0 0 0
14 19 342
345 420.4 73 26 13 0 259 0 0 0
0 0 0 0 0 0 2 15 0 6
3 1 0 0 0 6 0 0 0 0
0 0 0 0 2 0 1 0 1 6
0 8 1 0 0 0 0 0 0 0
12 51 407
350 420.4 31 11 13 1 222 1 0 0
0 1 0 0 0 1 26 11 0 4
1 2 0 0 0 5 0 0 0 0
0 0 0 0 0 0 1 0 1 5
0 5 0 0 0 1 0 0 0 0
10 20 331
355 333.7 43 29 22 0 353 0 0 3
0 1 0 0 0 1 2 10 2 7
2 0 0 0 5 6 0 0 0 0
0 1 0 0 0 0 0 0 0 13
0 20 0 0 0 0 0 0 0 0
6 54 487
360 363.7 15 29 18 1 194 3 0 3
0 0 0 0 0 1 25 35 2 5
8 0 0 0 4 7 1 0 0 0
0 0 0 0 1 0 6 0 0 47
0 14 0 2 0 0 0 0 0 0
22 17 358
365 401.1 12 8 11 0 135 0 0 4
0 0 0 0 0 2 5 74 2 6
19 1 0 0 8 11 1 0 0 2
0 0 0 2 1 0 4 1 3 54
0 22 0 0 0 0 0 0 0 0
6 38 309
370 449 12 0 19 0 139 0 0 3
0 0 0 0 0 0 17 58 0 3
17 4 1 1 7 15 0 0 0 3
2 0 0 0 0 0 8 0 0 70
```

1 30 0 1 1 0 0 0 0 0
12 10 309
375 461 13 1 17 0 147 1 0 1
1 0 1 0 1 2 1 59 3 11
13 5 0 0 9 15 0 0 0 1
0 0 0 1 1 0 6 2 2 74
0 31 0 0 0 0 0 0 0 0
5 24 312
380 436 24 1 13 0 96 0 0 0
0 0 0 0 0 0 3 60 3 6
4 5 0 0 12 14 0 0 0 1
0 0 0 3 0 0 0 0 4 78
0 38 1 0 0 0 0 0 0 0
12 16 245
385 507 18 3 21 0 85 0 0 2
0 0 0 0 0 0 5 98 5 3
3 8 0 0 12 20 1 0 0 0
1 0 0 2 2 0 0 0 3 161
0 52 0 0 0 0 0 0 0 0
15 23 289
390 898 3 0 8 0 50 0 0 0
0 0 0 0 0 1 1 42 5 2
2 7 0 0 3 10 0 0 0 1
0 0 0 0 1 0 0 0 0 60
0 16 1 0 0 0 0 0 0 0
9 3 136
395 649 3 0 7 0 62 0 0 0
0 0 0 0 0 0 1 52 7 1
2 11 0 0 6 6 0 0 0 1
0 0 0 0 1 0 0 0 1 55
0 19 0 0 0 0 0 0 0 0
9 4 160
400 394 12 2 7 0 157 0 0 3
0 0 0 0 0 3 8 83 10 3
2 12 0 0 0 18 2 0 1 0
0 0 0 0 4 0 0 0 0 20
0 21 0 0 0 0 0 0 0 0
34 0 327
402.5 263 2 0 5 0 18 0 0 0
0 0 0 0 0 0 0 0 3 5
0 1 0 0 2 16 0 0 1 0
0 0 0 1 0 0 0 0 2 7
0 4 2 0 0 0 0 0 0 0
9 10 54
405 99 0 0 1 0 3 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 3 1 0 1 0 0
0 0 0 0 0 0 0 0 1 1
0 0 0 0 0 0 0 0 0 0

2	0	9							
410	76	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0
0	1	0	0	5	4	1	0	0	0
0	0	0	0	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3	8	14							

depth in sediment (cm)
constant (exotic added/exotic counted)
Picea
Abies
Pinus
Tsuga
Betula
Populus
Fraxinus
Quercus
Ulmus
Acer
Carya type
Fagus
Castanea
Corylus
coryloid (triporate lacking clear pore structure)
Myrica
Ericales
Alnus
Juniperus
Salix
Taxus
Cornus
Gramineae
Cyperaceae
Artemisia
Ambrosia
Chenopodiaceae
Compositae: Tubuliflorae
Compositae: Liguliflorae
Caryophyllaceae
Cruciferae
Ranunculaceae
Rosaceae
Saxifragaceae
Thalictrum
Urtica
Sphagnum
Lycopodium
Selaginella
Filicales

trilete spores (unidentified)
Pteridium
Myriophyllum
Nuphar
Nymphaea
Isoetes
Potamogeton
Typha/Sparganium
indeterminable/unknown
Pediastrum
total land pollen