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Organic and Mineral Soils of the Southwestern James Bay Coastal Zone in Relation to Landform and Vegetation Physiognomy

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PREFACE

In 1972, Environment Canada, through the Canadian Wildlife Service (CWS), initiated surveys of migratory birds in the James Bay Region of Ontario and Quebec. The studies were partly in response to hydroelectric development projects underway on the Quebec side of James Bay (e.g., the Baie James Project) as well as other projects being planned for other parts of the Hudson/James Bay regions. During their studies, CWS recognized the significance of the coastal areas of James Bay to migratory birds. At that time, little was known about ecological processes within the Hudson Bay Lowland (HBL), particularly as they affected wildlife habitats.

The concern for possible impacts on migratory and resident wildlife as a result of various development proposals, resulted in a multidisciplinary study of the coastal portions of the HBL. Studies were conducted primarily by scientists from the federal Departments of the Environment and Forestry. Coastal marshes, fens and intertidal mud flats became the focus for the federal agencies because these were the areas most utilized by migratory birds. As well, it was the estuaries and marshes of the HBL coast that would be most heavily impacted by major developments upstream.

The primary objective of the HBL studies were to establish baseline values for the condition of the natural environment, particularly of migratory bird populations and habitat characteristics as they related to ecological processes, as a basis for long-term monitoring of environmental change. Field studies were conducted along the Ontario coast of Hudson and James Bays from 1977 to 1980. This report summarizes some results of vegetation, water chemistry and pedological studies for the southwestern James Bay coast.

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ABSTRACT

Soil profile descriptions from 117 sites in the coastal zone of the southern Hudson Bay Lowland are discussed. These include 71 profiles classified as organic soils (i.e., peat depth ≥40 cm) and 46 classified as mineral soils. The soils were grouped into peatlands, wetland mineral soils, and uplands. These groups were further subdivided on the basis of vegetational physiognomy into:

1. graminoid fen, low shrub fen, *Sphagnum*-rich treed fen, graminoid-rich treed fen, bog and conifer swamp;
2. brackish meadow marsh, freshwater meadow marsh, and thicket swamp; and
3. upland thicket and forested river levees, and upland forested beach ridges.

Soils representing the Organic, Regosolic, Gleysolic, Brunisolic and Podzolic orders are described. Organic and gleysolic soils are the most widespread, with gleysols occurring in the active marine zone and immediately inland in the broad freshwater marshes, as well as on stream banks and low river levees. Marsh gleysols give way to organic soils of the expansive fen and bog complexes of the Lowland. Brunisols and podzols are restricted to well drained sandy beach ridges, and brunisols occur most frequently on the best-developed river levees.

The soils are described, along with water chemistry, floristics and landform features, for each physiognomic type. The relationships among vegetation, soils and landforms of the southwestern James Bay Coastal Zone are discussed.

RÉSUMÉ

Les profils pédologiques prélevés à 117 sites dans la zone côtière du sud de la région des basses terres de la baie d'Hudson sont décrits. Les profils comprennent 71 échantillons de sols classés comme étant organiques (c'est-à-dire que l'épaisseur de la tourbe y est ≥40 cm) et 46 échantillons de sols minéraux. Les sols échantillonnés, classés en trois groupes, provenaient de tourbières, de sols minéraux de terres humides et de bas plateaux. Ces groupes ont été subdivisés en fonction de la physionomie végétale de la manière suivante :

1. Fen à espèces graminoïdes, fen à arbustes bas, fen arboré riche en *Sphagnum*, fen arboré riche en espèces graminoïdes, bog et marécage à conifères;

2. Marais herbeux (saumâtre), marais herbeux (eaux douces) et marécage à bosquets et

3. Levées naturelles à couvert forestier dense et plus clairsemé de bas plateaux et crêtes de plage boisées de bas plateaux.

Les auteurs décrivent des sols appartenant aux ordres suivants : organique, régosolique, gleysolique, brunisolique et podzolique. Les sols organiques et gleysoliques sont les plus répandus; les gleysols s'observent dans la zone d'influence de la mer et dans la zone intérieure immédiate des larges marais d'eau douce, ainsi que sur les rives des cours d'eau et les basses levées naturelles. Les gleysols de marais cèdent la place aux sols organiques des vastes complexes de fens et de bogs de la région des basses terres. Les brunisols et les podzols n'apparaissent que sur les crêtes de plage sableuses bien drainées, et les brunisols s'observent le plus souvent sur les levées naturelles les plus évoluées.

Pour chaque type physionomique, les sols ainsi que la chimie de l'eau, la composition floristique et les formes de terrain sont décrits. Il est question des rapports existants entre la végétation, les sols et les formes de terrain du sud-ouest de la zone côtière de la baie James.

TABLE OF CONTENTS

(cont'd)

DISCUSSION

ORGANIC AND MINERAL SOILS OF THE SOUTHWESTERN JAMES BAY COASTAL ZONE IN RELATION TO LANDFORM AND VEGETATION PHYSIOGNOMY

INTRODUCTION

The Hudson Bay Lowland (HBL) is a large coastal plain located between the Canadian Shield and the shores of Hudson and James Bays (Fig. 1). The HBL stretches approximately 1,400 km from Churchill, Manitoba, to the Rupert River in Quebec and has a maximum width of 520 km. It has an area of 325,000 km^2, of which 260,000 km^2 lie within the province of Ontario. The Sutton Ridges, located southwest of Cape Henrietta Maria, are the only features that break the monotony of the coastal plain. It otherwise has a gradient of only 0.65 to 1.0 m/km from the shield to the sea (Riley 1982).

The HBL is underlain by Paleozoic carbonates (limestone and dolomite) and sandstones of the Hudson Geologic Basin. The entire region was glaciated during the Pleistocene. Deglaciation occurred 7,000 to 8,000 years ago when marine waters invaded from the northeast to form the Tyrrell Sea (Craig 1969). Up to 150 m of uplift has since taken place. Uplift remains active, and the shoreline is undergoing one of the fastest rates of isostatic rebound in the world, at between 0.7 and 1 m/100 yr (Lee 1962, Webber et al. 1970).

The gentle gradient, in combination with a high water table and a cool, humid climate, has resulted in an extensive and essentially unconfined peatland complex. The organic deposits vary in depth from nonexistent at the coast to more than 6 m inland. They overlay substrates of marine clays and silts, coarse beach materials, glacial till and bedrock. Other than the Sutton Ridges, the only upland areas that occur inland of the coast are large, raised, beach ridge complexes, levees along the major rivers and occasional rock outcrops. Such features occupy in the order of 10 to 15% of the area (Riley 1982).

Soil formation is thus dominated by the growth and decay of organic materials. Paludification is very active and only the highest beach ridges and levees are capable of developing mature mineral soil profiles.

The major rivers of the Hudson Bay Lowland are the Churchill, Nelson, Severn, Winisk, Attawapiskat, Albany, Moose and Harricana. It is along these rivers and their largest tributaries that well developed levees, generally more typical of nonglaciated southern terrains, are found. They form the only significant barriers to the peat complex.

Annotated bibliographies of literature on the HBL have been prepared by Cowell (1982) for the earth sciences, Sims et al. (1979) for vegetation and vegetation ecology, and Merriman et al. (1982) for water resources. Other references pertaining to the HBL have been organized by subject area and listed by Haworth et al. (1978).

The objective of this report is to summarize the results of investigations of soils as they relate to vegetational physiognomy, landform and groundwater chemistry. These investigations were conducted in the southwestern James Bay portion of the HBL Coastal Zone.

The Coastal Zone was defined on LANDSAT imagery and represents a relatively youthful area located between the waters of Hudson and James Bays and the mature peatlands of the interior HBL (Fig. 1, Cowell et al. 1979). It is characterized by minerotrophic wetlands, including relatively shallow peatlands and

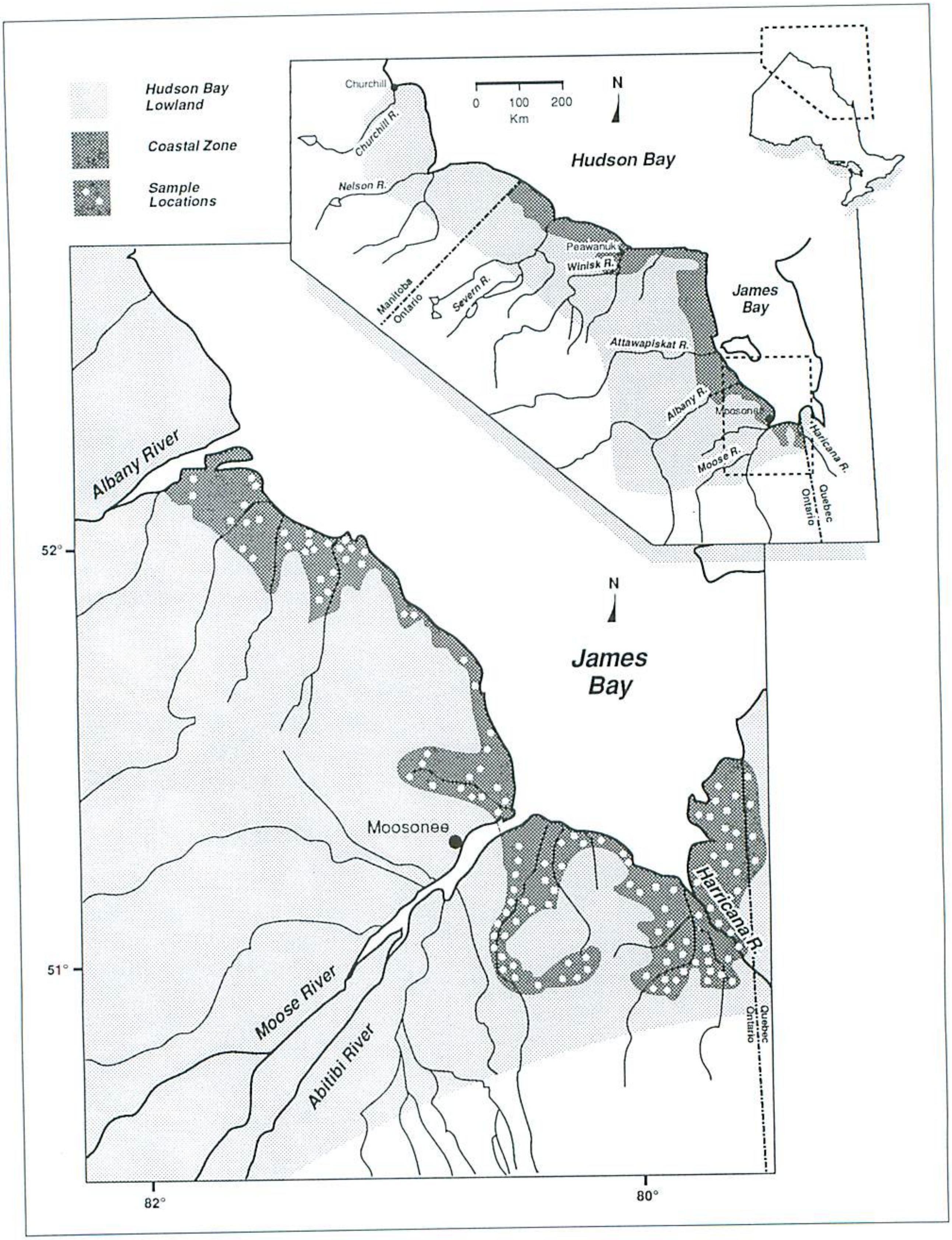

Figure 1. The Hudson Bay Lowland, showing the Coastal Zone boundary and sampling locations.

mineral landforms such as wide tidal flats, river levees and active and raised storm beach ridges.

STUDY AREA

The study area occupies an area of 4,000 km^2 within the Coastal Zone of southwestern James Bay between the Quebec border and the Albany River (Fig. 1). Field studies were conducted at 154 sites between 26 July and 31 August 1977. Mineral and organic soils were described at 117 sites, of which 46 were classed as mineral soils (i.e., <40 cm peat).

The climate of southern James Bay is the B3 humid microthermal type described by Sanderson (1948) and is strongly influenced by proximity to the bay. The average annual temperature is -1.0°C, with mean daily temperatures for January and July of -20°C and 15°C, respectively (Chapman and Thomas 1968). The southern limit of discontinuous permafrost, as defined by Brown (1967), occurs within the study area. Seasonal ice may occur in the peatlands as late as August and small palsas (circular to elongated mounds of peat with a permafrost core that rises 1 to 7 m above the surrounding wet peatland) are common inland of the Coastal Zone (Cowell et al. 1978). The growing season averages 140 days and the mean dates for last and first frosts are in mid-June and early September, although frosts can occur in any month. The mean annual precipitation is 750 mm, of which approximately one-third is snow.

The flora of the study area contains boreal elements, with subarctic and maritime elements becoming important along the James Bay shoreline. Floristic data have been tabled by Dutilly and Lepage (1963), with more recent studies being made of the phytogeography of the coastal flora (Riley and McKay 1980; Sims et al. 1982a,b) and the vegetational ecology of coastal marshes (Ringius 1980, Ewing and Kershaw 1986, Glooschenko and Martini 1987, Earle and Kershaw 1989). The flora of the area is remarkably rich, despite the cool climate and lack of relief (Sims et al. 1979). Good-quality forest land is confined to the largest levees and raised beach ridges. These forests approach the quality and composition of those within the northern Clay Section of the Boreal Forest Region (Rowe 1972). However, the remainder of the area is occupied by immense peatlands and mineral soil wetlands that are typically open or support sparsely stocked stands that would yield poor-quality, unmerchantable timber.

The wetlands of the study area form the southernmost extent of the Low Subarctic Wetland Region defined by the National Wetland Working Group (Anon. 1986). Zoltai et al. (1988) summarized the flora, climate, physiography and wetland characteristics of the area within the context of Canadian subarctic wetlands. Within the HBL, this wetland region is characterized by ribbed and horizontal fens with marshes and shallow waters. Peat plateau bogs and palsa bogs are common in the northwestern part of the region. Ribbed fens are rare within the Coastal Zone, which is characterized by horizontal fens, marshes and physiographically controlled swamps.

LITERATURE REVIEW

The HBL has only recently been studied in detail. The interior is accessible only by aircraft and, hence, the region is the least known in Canada. One of the earliest detailed accounts of the physical character of the HBL's interior peatlands was provided by Hanson and Smith (1950). Although primarily a wildlife investigation, they provided descriptions and a preliminary peatland classification for large areas between the major rivers.

A broad outline of the phytogeographical problems that occur in the HBL was provided by Hustich (1957), who discussed plant habitat and occurrence in terms of edaphic, climatic and hydrological controls. The dynamic character of the HBL is viewed in terms of permafrost, fire, paludification, vegetational succession and their interactions. Hustich noted that the evolution of peatlands here is more dynamic than the evolution of upland forest types as a result of the fast growth of organic material and the slower mineral soil-forming processes. Well developed upland forests occur primarily on the banks of the large rivers. In the southernmost portion of the HBL, these forests are characterized by white spruce (*Picea glauca*), white birch (*Betula papyrifera*), balsam fir (*Abies balsamea*) and balsam poplar (*Populus balsamifera*). Hustich reported white spruce up to 32 m in height (100 cm in diameter at breast height, DBH) and balsam poplar up to 25 m tall (50 cm DBH) in these southern levee forests. Black spruce (*Picea mariana*) occurs primarily on peatlands and as lichen woodland forests on raised beach ridges. Well grown black spruce on coarse sandy ridges in the southern portion of the HBL can reach 20 m in height.

Sjörs (1959, 1961, 1963) provided the first detailed accounts of chemical, hydrological and vegetational characteristics and controls in peatlands of the HBL. His 1959 paper, describing studies at Hawley Lake, included a description of a podzolic soil profile. Sjörs introduced many of the Scandinavian definitions and concepts for peatland minerotrophy, ombrotrophy and classification. His descriptions pertain primarily to the mature bog and fen complexes of the interior lowland, north of the study area.

Zoltai (1973) generally assessed forest and soil conditions in the HBL. With respect to tree productivity, Zoltai noted that excess soil moisture appears to be the main cause of slow tree growth, but in the vicinity of Hudson Bay, colder climate appears to be the chief cause. The best tree growth occurs on the well drained frozen peat plateaus and palsas and not on the surrounding fens. Good drainage, rich alluvial soils, and protection from exposure, as occurs along the major river valleys, results in vegetation similar to the boreal forest much farther south. Zoltai reported that white spruce may reach a height of 22 m, with diameters of 50 cm in these locations.

Tarnocai (1982) provided a detailed description and analysis of terrain and soil conditions along an 18-km transect in the HBL Coastal Zone in the York Factory area. This site lies within the continuous permafrost zone defined by Brown (1967) and Tarnocai noted that soil-forming processes here are dominated by glacial rebound, coastal, fluvial, cryogenic and permafrost processes, and peat-forming (biological) processes. He described soils, landforms and the dominant vegetation that occurred along the transect. The inland end of the transect represents about 2,100 years of development since emergence from the sea. The youngest soils were Rego Gleysols occurring at 0 to 4 km from the coast. Peat accumulation began after 600 years (based on radiocarbon dating), with peaty-phase Rego Gleysols occurring at about 2 to 4 km from the coast. Over the next 400 to 600 years, these soils became Terric Mesisols (occurring at about 4 to 16 km along the transect) occupied by fens and having a lower pH. Permafrost soils occur as close as 4 km to the coast in fens (regosolic static cryosols), and reach their greatest development beyond about 9 km (Terric Mesic Organic Cryosols in palsa fens and Terric Fibric Organic Cryosols in bog palsas and peat plateaus).

Nutrient status (pH, calcium and magnesium) in soils and surface waters decreases with distance along the transect toward the interior. Tree growth was very limited, consisting primarily of stunted tamarack (*Larix laricina*) and spruce (*Picea* spp.) in the fens, with somewhat better growth of black spruce on peat plateaus.

Cowell et al. (1982) briefly described frozen podzolic soils under a black spruce canopy on raised beach ridges southwest of Peawanuck, Ontario. These soils developed in a sequence from freely drained Orthic Regosols (near the coast) to well developed Orthic Humic Podzols and Orthic Ferro-humic Podzols under black spruce/lichen woodland. Surface organic layers thicken (LFH becoming Of/Om with perched water tables) on the lower-relief ridges, resulting in sufficient insulation at about 10 km from the coast that the mineral soil becomes frozen for most or all of the year and podzolization processes are halted. Based on radiocarbon dating reported for the York Factory area

(Tarnocai 1982), this evolution would equate to about 1,400 years of development.

Previous reports on soils of the southwestern James Bay Coastal Zone include those of Glooschenko and Clarke (1982), Protz (1982a,b) and Protz et al. (1984, 1988). Majcen (1973) and Jurdant et al. (1977) described organic and mineral soils from the Quebec side of James Bay.

The most relevant work to the present study is that of Protz (1982a,b) and Protz et al. (1984, 1988). The first two papers summarize the results of investigations of gleysolic (1982a) and podzolic soils (1982b) conducted along Hudson and James Bays over a period of 5 years. Detailed physical and chemical descriptions were provided by the author in earlier technical reports (see Protz 1982a). The other papers focused on the rate of podzolic soil development with increasing distance from the coast in the northern HBL of Ontario (Protz et al. 1984) and in the southwestern HBL (Protz et al. 1988).

The gleysols (Protz 1982a) represented a sequence along the immediate shore and ranged from Orthic Gleysols on the lower tidal flats (essentially sedimentary sequences with no organic accumulation or oxidation) to Orthic Humic Gleysols in the uppermost tidal flats. The latter soils had Ahg and Bg horizonation. Based on a rate of uplift averaging 1 m/100 yr, Protz concluded that these soils are all less than 200 years old and, further, that this age represented the beginning of organic soil accumulation. He also noted that gleysols are common for up to several kilometres from the coast and are not shown on current soil maps of Ontario.

Podzolic soil development was described by Protz (1982b) and Protz et al. (1984, 1988). Raised beach ridges were examined sequentially with increasing distance from the coast, representing up to 5,000 years of development. These were all calcareous storm ridges generally less than 1.5 m above the surface of the surrounding swales. The sequence is Orthic Regosol through eluviated Eutric Brunisol and Orthic Humic Podzol to Orthic Humo-Ferric Podzol, associated with gradually thickening LF/LFH horizons. Organic matter translocation and eluviation results in the formation and expansion of Ae, Bh and, eventually, Bf/Bfh horizons. Soil horizons are generally low in sodium pyrophosphate-extractable Fe and Al and show strong pH gradients from B to C horizons (4.0 to 7.5 in one case). Generally thin Bh horizons and low pyrophosphate-extractable Fe+Al in many of the transitional profiles result in a classification to the Brunisol Order of the Canadian System of Soil Classification (Anon. 1978). However, Protz (1982b) pointed out that this does not convey the proper concept of pedological processes in the area. He suggested reconsideration of these criteria for the classification of soils that are clearly in the process of podzolization.

Protz et al. (1988) described a sequence of ridges representing 3,000 years of soil development (based on radiocarbon dating) located in the southern HBL between the Albany and Moose Rivers. They related higher average annual temperature and precipitation in this area, in comparison with the more northern ridges (Protz et al. 1984), to podzolization processes that are up to two times faster. This was demonstrated by significant correlations between distance/age and depth of carbonate leaching, mass of organic matter and mass of vermiculite. Interestingly, most of their correlations showed a break in slope, offset or reversal at 20 to 25 km, which corresponds to an age of about 2,200 years. This was not fully explained by the authors, although, in the case of mass of organic carbon, they related this break to a hiatus in organic matter accumulation 2,000 years (3,000 years in the northern ridges) before decomposition.

METHODS

One soil pit was opened at each of the 112 sites. Morphological descriptions were recorded on data cards, and each soil pit was classified at the sub-group level of the Canadian System of Soil Classification (Anon. 1978).

Soil pits were dug in the mineral soils to expose the C horizon. In the gleysols, high water tables (especially in the marsh sites) prevented descriptions deeper than about 40 cm below organic material. Each distinctive horizon was described with respect to its boundaries, mottling (amount and color), matrix color, texture, structure, consistence, stoniness, and reaction to hydrochloric acid (HCl). The latter was a subjective assessment of carbonate reaction to 10% HCl: no reaction, weak, moderate, strong, and very strong reactions were recorded. Horizon and mottle colors were recorded under field conditions (wet or moist) using the Munsell Soil Colour Chart (Anon. 1975). Notes were also made on the angularity of soil material, stratification, rooting depth, and other distinct features.

Forty-three horizons from 16 profiles were bulk sampled for chemical and grain-size analyses. Chemical analyses included pH in $CaCl_2$; cation-exchange capacity; exchangeable Mg, Ca, K and Na; organic carbon (C); inorganic C; total N; and extractable Fe and Mn. These analyses were performed using the standard soil analysis methods of McKeague (1978) and Richards (1954). Total N was obtained with the induction-furnace technique of Wong and Kemp (1977). Grain-size analyses were carried out by the sieve and short-pipette method to separate the major fractions (gravel, sand, silt and clay).

Organic soils are defined as having ≥40 cm of peat. At these sites, the upper 40 cm of peat was described in detail from a block of material cut from the surface. Water samples, pH and measures of depth to water table were taken in the soil pit. On hummocky sites, pits were located in medium-sized hummocks. The peat below 40 cm was described from samples obtained with a modified Hiller side-opening sampler (Mott 1966). Color, peat type (sedge, *Sphagnum*, non-*Sphagnum* moss or forest peat), peat pH (in deionized water), temperature, von Post decomposition stage and the abundance of root and wood remnants (Taylor and Pohlen 1970) were recorded for each identifiable horizon. The designation of fibric, mesic, or humic for classification purposes was based on the 10-point von Post scale, as follows: 1 to 3, undecomposed to very weakly decomposed; 4 to 6, weakly to strongly decomposed; and 7 to 10, strongly to almost completely decomposed. The underlying mineral substrate was sampled and described in the same way as in the mineral soil descriptions. Where sufficient material could be obtained, the substrate was sampled for grain-size analyses.

Water samples were collected from each wetland site, and field pH was recorded with a Metrohm portable pH meter. Conductivity, salinity and temperature were measured directly in the soil pit with a YSI Model 33 meter. Analyses for Ca, Mg, Cl, K, Na, SO_4, Fe, Mn, total Kjeldahl N and soluble silica were conducted on the water samples by means of standard techniques (Anon. 1979).

Vegetation was described at each site in three to six 1- x 1-m quadrats used to estimate vegetation cover. Other species present in the immediate vicinity were recorded. Voucher specimens of plants were deposited in Forestry Canada's Great Lakes Forestry Centre herbarium in Sault Ste. Marie, Ontario. Nomenclature follows that of Hulten (1968) and Porsild and Cody (1980) for the vascular plants, and that of Ireland and Cain (1975) for the mosses.

Vegetation cover, averaged by site, was ordinated by means of detrended correspondence analysis with the Cornell Ecology Program DECORANA (Hill 1979). DECORANA performs a reciprocal-averaging algorithm (Hill 1973) modified to avoid quadratic relations of the second axis to the first, thereby minimizing "arch" effects (Gauch et al. 1977). This analysis allowed a check on the initial physiognomic classification of site types used in the field program, and permitted evaluation of vegetation ("stands") with respect to known environmental gradients including moisture and nutrient status.

Soil-vegetation relationships, as represented by physiognomic types, have been utilized in this report to group soils for purposes of description and discussion. Physiognomic types are based partly on the wetland classification system of

Jeglum et al. (1974). This system utilizes four main wetland units at its most general level: bog, fen, freshwater marsh and swamp. Upland and brackish marsh physiognomic types have been added (Sims et al. 1988).

RESULTS

Site-type Classification

The sites are grouped into three major classes based on landform and subdivided by physiognomic type: (1) peatlands, which are subdivided into graminoid fen, low shrub fen, *Sphagnum*-rich treed fen, graminoid-rich treed fen, bog, and conifer swamp physiognomic types; (2) wetland mineral soils, including brackish meadow marsh, freshwater meadow marsh, and thicket swamp types; and (3) uplands, including upland thicket levees, forested river levees and upland forested beach ridge types.

Site types were easily delineated by means of the DECORANA ordination (Fig. 2). The results of this analysis confirmed the initial physiognomic classification with respect to vegetation. The axes of the ordination are directly related to nutrient status and moisture regime. Hence, there is clearly a strong relationship between

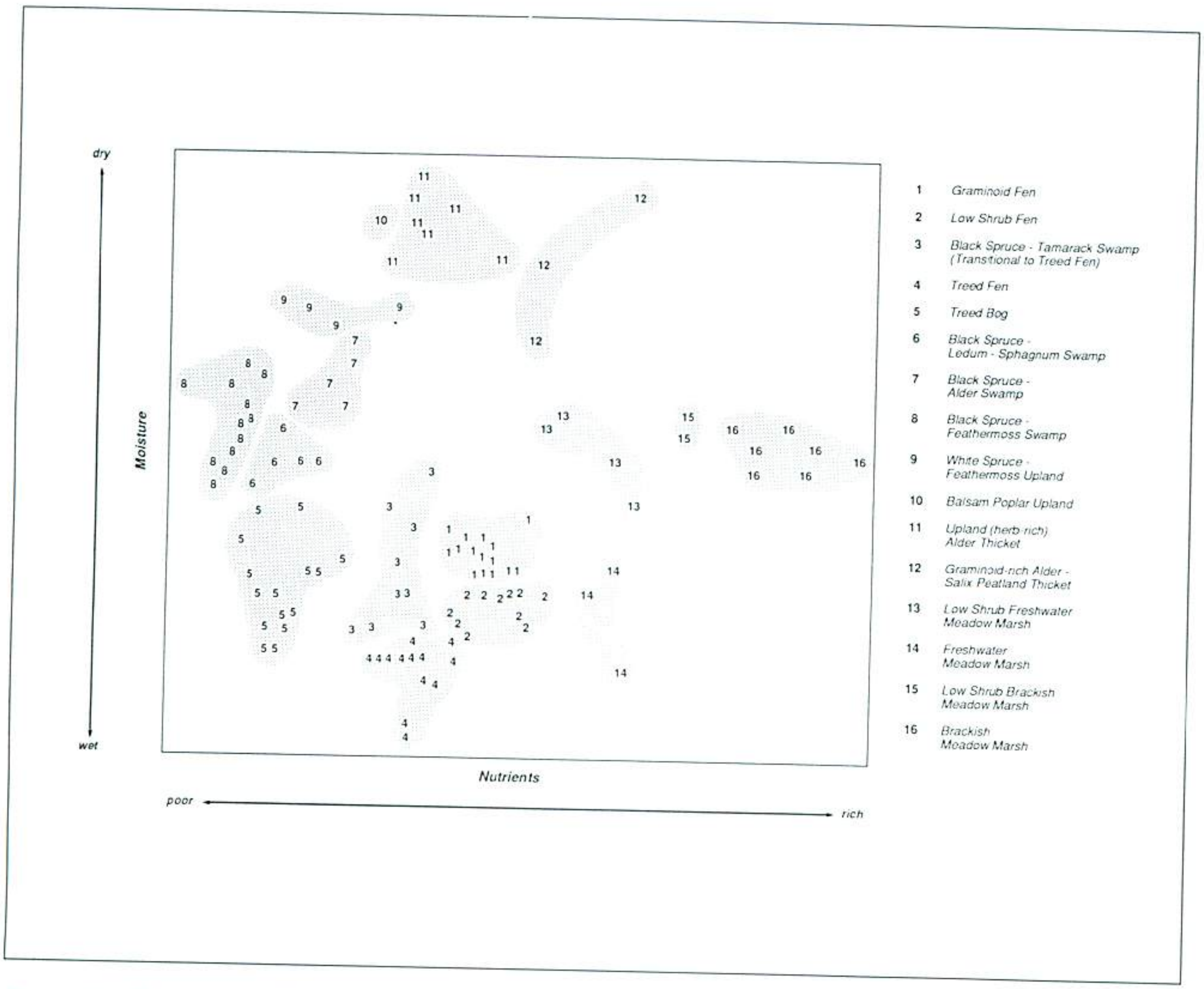

Figure 2. Ordination diagram (detrended correspondence analysis) of 127 vegetation stands in the southwestern James Bay Coastal Zone, Hudson Bay Lowland. Analysis was based upon averaged percentage-cover estimations in three to six quadrats per stand for all tree, shrub, herb, graminoid, bryophyte and lichen species encountered in the vegetation survey.

vegetation and landform in the southwestern James Bay Coastal Zone. It should be expected therefore that soils will also show a strong correlation with physiognomy. Detailed results of the ordination analyses have been discussed by Sims et al. (1982a) for fen types and Sims et al. (1982b) for treed peatland types.

Site-type Characteristics

Table 1 provides a summary of the basic soil information, including occurrence of soil subgroups for each physiognomic type. Peatland soils occur in the fen, bog and conifer swamp types, which are predominantly characterized by Terric and Typic Mesisols, although Fibrisols are common. Marshes and thicket swamps have little (<40 cm) or no peat accumulation and are dominated by Rego and Orthic Gleysols. Upland soils are predominately Orthic Humic Podzols on beach ridges and Humic Gleysols and Gleyed Brunisols on river levees.

Table 2 provides means and standard deviations of pH, conductivity and major ions for nine peatland and mineral-soil wetland types. Results show a strong minerotrophic gradient in the following sequence: treed bog < *Sphagnum*-rich treed fen < graminoid-rich treed fen < low shrub fen ≈ graminoid fen < conifer swamp < freshwater marsh < brackish marsh. (Brackish marsh is not shown in Table 2).

Table 3 lists specific soil data for each peatland site (fen, bog and conifer swamp types). Table 4 lists soil chemistry results for the upland mineral soils. Figures 3a to 3c show characteristic profiles along with average peat and water pH, average-grain-size analyses, and peat/LFH thickness for each physiognomic type. Several example photos of sites and related soils are shown in Fig. 4.

Peatlands

Graminoid Fen

Soils were described on 11 sites that were classified as graminoid fen. These sites are dominated by grasses, sedges and non-*Sphagnum* mosses. Characteristic vegetation includes *Scirpus hudsonianus, Carex limosa, C. exilis, Scheuchzeria palustris* var. *americana, Menyanthes trifoliata, Equisetum fluviatile, Rhynchospora alba* and *Scorpidium scorpioides*.

Average pH and Ca levels (Table 2) indicate that these 11 sites are the most minerotrophic of all fen and bog peatland types. Ca concentrations in excess of 18 mg/L are considered "rich fen" as opposed to "poor fen" (Moore and Bellamy 1974). Interestingly, the three sites with the lowest nutrient status (sites 30, 31 and 55; Table 3) had the deepest peats and were located the furthest inland, which suggests they may be transitional to poor fen or bog.

All but one of the 11 sites occurred on organic soils. The mineral soil site is a Rego Gleysol with only 32 cm of peat and a floating root mat over strongly gleyed clayey silt of high carbonate content (strong reaction to HCl). The organic soils are primarily Terric and Typic Mesisols, although there are two Terric Fibrisols (Table 3). Only three profiles have peat depths in excess of the Canadian System of Soil Classification's (Anon. 1978) control section of 160 cm (i.e., "typic"). Peat material consisted primarily of weakly decomposed sedges, although five profiles showed an upward transition to undecomposed *Sphagnum* or non-*Sphagnum* moss peats (usually with sedges intermixed; Fig. 3a).

On average, peat pH and water pH are similar (6.6 and 6.5, respectively), with surface peat pH ranging between 4.8 and 7.9 and water pH ranging between 4.4 and 7.3 (Table 3). Peat pH averages 6.6 (average of at least three values including top and bottom horizons), and ranges between 5.7 and 7.0.

The depth to the water table averages a fairly shallow 4.6 cm, and ranges from 19 cm above the surface to 21 cm below. In the only two cases in which the water table reached the peat surface, it was above the peat surface.

Table 1. Summary of parent-material characteristics, peat depth, peat pH, LFH thickness and soil subgroups by physiognomic types.

Physiognomic type	Parent material texture/decomposition (von Post)	Origin	Organic matter			Dominant soil subgroup(s) (% occurrence)
			Peat depth (cm)	Peat pH	LFH (cm)	
PEATLANDS						
Fen						
Open Fen						
Graminoid Fen	D2-D5	predominantly sedge peat	32-216	4.8-7.9	-	Terric Mesisol (50%) Typic Mesisol (30%) Terric Fibrisol (20%)
Low Shrub Fen	D1-D5	predominantly sedge peat overlain by *Sphagnum* and other moss peats	35-207	4.7-8.2	-	Terric Fibrisol (60%) Terric Mesisol (30%) Terric Fibric Mesisol and Fibric Mesisol (10%)
Treed Fen						
Sphagnum-rich Treed Fen	D1-D6	predominantly sedge peat overlain by *Sphagnum* peat	61-183	4.8-6.8	-	Terric Fibric Mesisol (40%) Terric Mesisol (30%) Typic Mesisol (30%)
Graminoid-rich Treed Fen	D1-D5	predominantly sedge peat	52-203	6.6-7.7	-	Terric Fibric Mesisol (40%) Terric Mesisol (30%) Typic Mesisol and Mesic Fibrisol (30%)
Bog						
Open Bog						
Graminoid Bog (1 only)	D2-D5	predominantly sedge peat overlain by *Sphagnum* peat	159	4.6-6.4	-	Mesic Fibrisol
Low Shrub Bog (1 only)	D2-D4	*Sphagnum* peat	186	4.5-6.2	-	Typic Mesisol
Treed Bog						
Graminoid Treed Bog (2 only)	D2-D6	predominantly *Sphagnum* peat	66-205	-	-	(Terric) Mesic Fibrisol
Shrub-Rich Treed Bog	D1-D5	predominantly *Sphagnum* peat (in some cases overlying sedge peat)	52-193	4.2-6.8	-	Terric Mesisol (40%) Typic Mesisol (30%) Terric Fibrisol and Mesic Fibrisol (30%)
Conifer Swamp	D1-D5	predominantly forest peat	27-123	4.2-7.2	-	Terric Mesisol (50%) Terric Fibrisol (25%) Rego Gleysol (5%)

(cont'd)

Table 1. Summary of parent-material characteristics, peat depth, peat pH, LFH thickness and soil subgroups by physiognomic types. (concl.)

Physiognomic type	Parent material texture/decomposition (von Post)	Origin	Organic matter			Dominant soil subgroup(s) (% occurrence)
			Peat depth (cm)	Peat pH	LFH (cm)	
MARSH AND THICKET SWAMP						
Brackish Meadow Marsh	silty clay and fine sand	supratidal deposits	5-25	-	-	Rego Gleysol (100%)
Freshwater Meadow Marsh	silty clay/D4-D6	supratidal/sedge peat	25(?)-40 40-65	6.6	-	Rego Gleysol (70%) Terric Mesisol (30%)
Thicket Swamp	silty clay and silts	supratidal deposits and minor tidal undulations (ridges)	25-34	-	2-28	Rego Gleysol (50%) Orthic Gleysol (50%)
UPLANDS						
Beach Ridge						
Forested	sand, coarse sand and gravelly sand	longshore transport and storm-wave construction	-	-	1-41	Orthic Humic Podzol (80%) Orthic Regosol (20%)
Levee						
Thicket	silt loam	overflow banks of stream	-	-	3	Rego Humic Gleysol (cumulic)
Forested	silt and silt loam	overflow banks of stream	-	-	2-31	Rego and Rego Humic Gleysol (60%) Gleyed Brunisol and Orthic Humo-Ferric Podzol (40%)

The mineral substrates beneath the peat profiles are generally fine-textured, well sorted silty clays. Only one had coarse material (gravel). The substrates are all strongly gleyed, as would be expected (Munsell colors 5Y5/1, 5/2, 4/1 and 2.5YR5/10), although carbonate content is varied (nil to strong reactions with HCl), indicating that leaching by organic acids has occurred to various degrees. Generally, the weakest reactions occur under the deepest peats.

Low Shrub Fen

Soils were described at 16 low shrub fen sites. These sites are distinguished from graminoid fens by the height of their shrubs—at least 25% are shorter than breast height. *Salix pedicellaris*, *Myrica gale* and *Betula glandulifera* are the most common shrub species. *Scirpus hudsonianus* can be an important sedge under *Salix pedicellaris*, *S. candida*, *Myrica gale*, *Potentilla fruticosa*, or scattered, low tamarack.

Groundwater chemistry for this type is, on average, fairly comparable to that of graminoid fens (Table 2), although below the poor fen/rich fen limit. Concentrations of Na and Cl tend to be the highest of all peatland types, which likely reflects their predominance closer to the coast. In contrast to graminoid fens, low shrub fens tend to occur on poorly drained plains away from drainageways. Marine influence could be indirect, as a result of sea spray (local precipitation effects) or as a residual from the soil.

Fifteen sites had organic soils and one had a mineral soil. The mineral soil was a Rego Gleysol. It had 35 cm of sedge peat over

Table 2. Groundwater chemistry for eight wetland types, southwestern James Bay Coastal Zone, Ontario (means, with standard deviations in brackets).

Wetland type	pH	Specific conductivity (μmhos)	Major ions (mg/L) Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}
Freshwater Marsh	7.0	976.0 (463)	55.2 (18.5)	23.3 (9.9)	98.9 (60.9)	3.7 (2.2)	179.9 (197.4)	2.6 (2.2)
Thicket Swamp	6.4	287.5 (214)	28.5 (3.5)	8.2 (4.5)	37.7 (46.2)	1.7 (1.5)	62.3 (80.3)	6.6 (7.0)
Conifer Swamp	6.0	216.1 (103.2)	21.7 (14.3)	5.2 (4.4)	10.2 (10.3)	1.6 (0.9)	18.4 (18.8)	3.2 (1.9)
Graminoid Fen	6.5	140.3 (74.8)	19.3 (13.2)	4.1 (2.1)	8.7 (8.6)	1.1 (0.4)	12.6 (10.2)	2.1 (1.6)
Low Shrub Fen	6.1	200.4 (183.4)	16.6 (12.5)	5.4 (5.3)	20.3 (15.9)	2.6 (1.7)	46.2 (55.5)	1.6 (1.2)
Graminoid-rich Treed Fen	6.1	91.0 (66.7)	16.5 (16.3)	2.7 (2.6)	5.5 (3.6)	2.0 (0.6)	8.4 (6.0)	1.9 (1.3)
Sphagnum-rich Treed Fen	5.4	52.3 (26.4)	6.9 (3.4)	1.3 (1.0)	3.8 (3.9)	1.7 (0.6)	8.0 (6.7)	3.3 (1.7)
Treed Bog	3.9	45.3 (13.0)	3.3 (4.0)	0.6 (0.4)	1.9 (0.9)	1.3 (0.5)	5.3 (1.9)	7.2 (3.9)

Table 3. Summary of soil data for fens, bogs and conifer swamps.

Physiognomic type and site no.	Peat thickness (cm)	Soil type[a]	Depth to water table (cm)	Peat type[b]	Surface peat pH	Average peat pH of profile	Water pH	Basal temp. (°C)	Substrate texture	HCl reaction[c]	Distance from coast (km)
Graminoid Fen											
30	181	TM	21	Sp/Se	4.8	5.8	5.3	12	silty clay	VW	40
31	216	TM	18	Sp/Se	5.4	5.7	4.4	9	silty clay	VW	43
48	88	TeM	12	M/Se	-	-	6.6	-	silty clay	Mod	7
55	179	TM	0	Se	6.4	6.6	6.6	10	silty clay	VW	36
64	65	TeF	0	M	7.4	7.0	6.8	-	silty loam	W	1
76	130	TeM	2	Se	6.7	6.6	6.9	9	silty clay	NR	52
84	90	TeF	14	Se	7.6	7.0	-	12	silty clay	St	5
113	56	TeM	-19	Se	-	-	-	-	coarse sand	W	16
126	32	RG	-11	Se	6.2	6.6	6.9	11	silty clay	St	4
139	70	TeM	12	Sp/Se	6.7	7.0	6.6	14	loam	W	2
142	97	TeM	4	M/Se	7.9	7.0	7.3	12	silty clay	NR	29
Mean	109.5		4.6		6.6	6.6	6.5	11.1			21.4
Shrub Fen											
1	66	TeF	1	Sp/Se	6.9	6.7	6.5	13	silt loam	VW	6
4	74	TeM	20	Sp/Se	5.9	6.7	6.6	12	sandy loam	NR	6
5	77	TeM	10	M/Se	7.5	6.9	6.5	14.5	sand	VW	3
9	59	TeF	0	M/Se	7.4	7.1	6.3	-	-	-	6
12	67	TeF	11	M/Se	8.2	7.3	6.9	15	silty clay	Mod	7
13	81	TeF	10	M/Se	7.3	6.6	6.4	15	silty clay	W	12
14	79	TeM	20	Sp/Se	6.4	6.4	6.1	12	silt loam	VW	17
16	64	TeF	15	Sp/Se	6.0	6.0	5.5	14	silt loam	W	15
41	83	TeFM	9	-	-	-	4.2	-	-	W	11
42	87	TeF	9	M/Se	7.0	6.5	5.7	12	silty clay	NR	6
43	81	TeM	17	Sp/Se	6.4	6.4	5.6	13	silty clay	NR	8
46	75	TeF	3	-	-	6.0	-	-	silty clay	NR	5
51	207	FM	19	Sp/Se	4.7	5.7	6.0	9	silty clay	VW	25
63	72	TeF	-6	M/Se	7.1	6.8	6.6	-	silt loam	VW	3
89	35	RG	12	Se	7.9	-	6.4	13.0	silt	St	3
140	54	TeF	5	M/Se	7.3	6.8	6.6	15.5	silty clay	W	16
Mean	78.8		10.3		6.9	6.6	6.0	13.2			9.3

(cont'd)

Table 3. Summary of soil data for fens, bogs and conifer swamps (cont'd).

Physiognomic type and site no.	Peat thickness (cm)	Soil type[a]	Depth to water table (cm)	Peat type[b]	Surface peat pH	Average peat pH of profile	Water pH	Basal temp. (°C)	Substrate texture	HCl reaction[c]	Distance from coast (km)
Sphagnum-rich Treed Fen											
16A	71	TeFM	17	Sp/Se	6.8	6.2	5.6	13	silty clay	W	15
19	115	TeFM	15	Sp/Se	6.6	6.3	5.7	11	silty clay	NR	13
25	159	TM	22	Sp=Se	4.8	5.6	5.3	11.5	silt loam	NR	22
28	163	FM	15	Sp=Se	-	-	4.9	-	silty clay	VW	28
39	159	TM	16	Sp//Se	-	-	4.8	-	silty clay	VW	22
40	103	TeM	19	Sp/Se	-	-	5.4	-	-	Mod	14
54	183	TM	17	Sp/Se	-	-	4.2	9	-	NR	35
56	128	TeM	16	Sp/Se	-	-	6.7	-	silty clay	VW	25
69	150	TeFM	16	Sp/Se	4.8	5.4	4.6	10	silty clay	NR	25
83	72	TeM	19	Sp/Se	6.1	6.3	5.7	10	silty clay	NR	28
95	122	TeM	12	Sp/Se	6.7	6.6	6.4	10	silty clay	St	24
135	61	TeM	23	Sp=Se	4.8	6.1	5.9		silt loam	NR	8
Mean	123.8		17.3		5.8	6.1	5.4	10.6			21.6
Graminoid-rich Treed Fen											
10	112	TeM	16	Sp/Se	7.3	6.7	6.7	13	silty clay	Mod	11
34	203	TM	18	Sp/Se	-	-	5.1	-	silty clay	W	31
74	143	TeFM	14	Sp/Se	-	-	5.8	-	silty clay	VW	34
77	195	MF	16	Sp/Se	7.3	6.6	5.9	9	silty clay	VW	43
86	81	TeFM	15	Sp/Se	6.2	6.3	5.8	10.5	silty clay	St	13
100	52	TeM	13	Sp/Se	7.7	7.4	6.9	-	-	-	2
131	120	TeFM	10	Sp/Se	6.9	6.7	6.2	15	silt	St	19
Mean	129.4		14.6		7.1	6.7	6.1	11.9			21.9

(cont'd)

Table 3. Summary of soil data for fens, bogs and conifer swamps (cont'd).

Physiognomic type and site no.	Peat thickness (cm)	Soil type[a]	Depth to water table (cm)	Peat type[b]	Surface peat pH	Average peat pH of profile	Water pH	Basal temp. (°C)	Substrate texture	HCl reaction[c]	Distance from coast (km)
Open Bog											
75 (shrubs)	186	TM	13	Sp	4.5	5.3	4.1	10	silty clay	VW	48
82 (graminoid)	159	MF	13	Sp/Se	4.6	0.2	4.2	10	silty clay	W	31
Graminoid-rich Treed Bog											
52	205	MF	29	Sp	-	-	3.7	-	silty clay	VW	29
79	66	TeMF	30	Sp//F	-	-	3.4	-	silty clay	-	38
Shrub-rich Treed Bog											
17A	103	TeMF	18	Sp=Se	4.3	5.0	3.9	12	silt loam	W	17
27	52	TeMF	31	p=F	-	-	4.0	-	silt	NR	30
29	193	TM	37	Sp/Se	4.2	4.4	3.4	9	silty clay	NR	38
33	193	TM	27	Sp/?	-	-	3.5	-	-	-	37
37	168	TM	23	Sp	-	-	3.7	-	silty clay	W	26
50	178	MF	26	Sp//Se	4.6	5.1	3.7	6	silty clay	W	21
111	76	TeF	33	Sp	4.8	5.0	3.9	-	fine sand	St	10
112	86	TeF	33	Sp	4.2	5.7	-	-	sand	St	16
132	59	TeM	-	F+Sp	4.7	5.1	-	-	loam	St	22
141	69	TeM	27	Sp	-	-	6.3	-	sandy loam	NR	31
Mean	128.1		26.2		4.5	5.1	4.1	9.4			28.1

(cont'd)

Table 3. Summary of soil data for fens, bogs and conifer swamps. (concl.)

Physiognomic type and site no.	Peat thickness (cm)	Soil type[a]	Depth to water table (cm)	Peat type[b]	Surface peat pH	Average peat pH of profile	Water pH	Basal temp. (°C)	Substrate texture	HCl reaction[c]	Distance from coast (km)
Conifer Swamp											
3	42	TeF	19	Sp=F	5.4	6.6	6.5	9	loam	NR	2
6	95	TeF	26	Sp	4.4	5.9	6.6	8	loam	NR	4
23	24	RG	4	-	-	-	-	-	silty clay	St	7
44	42	TeM	0	Se	6.5	-	6.2	-	silty clay	V	3
53[d]	76	TeF	0	Sp/F	4.2	-	-	-	silty clay loam	NR	31
57	43/24	CuM	16	F	6.7	-	6.5	-	loam	NR	38
59	54	TeM	24	Sp/F	5.0	5.8	5.9	-	silt	W	45
60	123	TeM	20	Sp/Se	5.3	6.4	6.1	10	silt	N	33
80	114	TeFM	14	Sp/F	5.6	6.0	5.7	9	silty clay	NR	36
81	91	TeFM	26	Sp/F	4.6	5.6	4.7	9	-	NR	34
93	82	TeF	21	Sp/F	5.0	-	5.2	-	silt	St	23
94	78	TeM	16	Sp/F	5.4	6.3	5.7	8	silt	NR	27
102	32	RG	18	Sp=F	5.0	-	6.9	-	loamy sand	St	1
116	27	RG	32	F	-	-	-	-	sandy loam	St	4
203[e]	58	TeM	15	Sp/F	6.5	6.7	5.5	8	silt	St	14
204	33	RG	9	F	-	-	6.4	-	fine sand	St	6
Mean	64.9		17.3		5.4	6.2	6.0	8.7			19.3

Legend

[a]Soil type: M - mesic/mesisol; F - fibric/fibrisol; T - typic; Te - terric; RG - rego gleysol; R - regosol; Cu - cumilic

[b]Peat type: Sp - *Sphagnum* peat; Se - sedge; F - forest peat; M - non-*Sphagnum* moss peat

/ - overlying peat type thinner than underlying
// - overlying peat type thicker than underlying
= - about equal thickness

[c]HCl reaction: NR - no reaction; VW - very weak reaction; W - weak reaction; Mod - moderate reaction; St - strong reaction

[d]site 53 - no water table above mineral soil
[e]site 203 - disturbed site near Moosonee airport

Table 4. Chemical analyses for sampled mineral-soil horizons.

Site no.	Soil profile	Depth (cm)	$CaCl_2$ pH	Cation-exchange capacity (meq/100g)	Exchangeable cations (meq/100g)			Organic C (%)	Inorganic C (%)	Total N (%)	C/N ratio	Pyrophosphate extractable (%)	
					Mg	K	Na					Fe	Mn
Brackish Marsh													
77 - 137	Ah	0 - 2	7.4	66.3	17.58	1.14	6.09	15.33	1.46	1.28	11.98	0.378	0.028
	Ah2	2 - 4	7.1	62.0	17.84	0.86	8.48	11.41	1.21	1.13	10.10	0.308	0.012
	Bhfg	4 - 7	7.2	32.8	12.12	0.76	6.7	5.63	2.40	0.60	9.40	0.175	0.006
	Ckg	7+	7.4	17.0	5.54	0.68	5.0	1.58	3.10	0.11	14.40	0.060	0.003
Thicket Swamp													
77 - 15	Ah	0 - 5	5.9	52.2	10.23	0.19	0.91	9.64	1.90	1.03	9.40	0.275	0.005
	Bfg	5 - 15	7.2	11.5	2.84	0.15	0.35	0.49	3.77	0.07	7.00	0.050	0.002
	Bgk2	31 - 41	7.2	10.0	1.95	0.19	0.57	0.26	4.20	0.06	4.30	0.031	0.001
77 - 21	Ah	0 - 5	6.9	87.0	2.82	0.23	0.74	4.70	3.58	0.37	12.70	0.118	0.011
	Bgk	5 - 19	6.9	66.3	1.54	0.10	0.22	0.50	5.11	0.11	4.50	0.031	0.002
	Ckg	19+	7.1	41.3	0.71	0.06	0.26	0.50	4.90	0.05	10.00	0.037	0.002
77 - 78	Bgk	1 - 36	6.9	15.0	4.17	0.23	0.17	0.55	1.46	0.08	6.90	0.080	0.003
Thicket Levee													
77 - 20	Ahk	0 - 13	6.7	25.0	2.67	0.21	0.13	4.74	2.61	0.41	11.66	0.108	0.009
	II Ahkb	13 - 28	7.1	7.0	0.72	0.13	0.13	2.16	3.94	0.19	11.40	0.084	0.006
	III Ckg	28 - 63	7.1	5.4	0.58	0.07	0.09	0.23	4.60	0.03	7.70	0.033	0.001
77 - 201	Ahk	0 - 5	7.1	23.5	1.47	0.41	0.61	3.73	4.13	0.30	12.40	0.121	0.010
	II Ahgkb	5 - 26	7.1	15.0	1.09	0.17	0.61	2.20	2.78	0.23	9.60	0.058	0.001
	III Ckg	26+	7.3	10.4	1.28	0.17	0.57	0.95	4.27	0.09	10.60	0.046	0.001

(cont'd)

Figure 4. Photographs of representative sites and soil profiles, southwestern James Bay Coastal Zone, Hudson Bay Lowland:

a. An unconfined wetland complex consisting of Fen, Bog and Swamp peatlands and open-water pools about 50 km west of the southwestern James Bay coast, near the Albany River; peat depths near the interior margin in the Coastal Zone range up to about 2 m. [photo: R. Sims]

b. A Terric Fibric Mesisol located in a *Sphagnum*-rich Treed Fen near the interior margin of the Coastal Zone, south of the Albany River; excavation shows a portion of the fibric peat located above the standing water level on a small hummock. Depth of peat was 59 cm. [photo: D. Cowell]

c. Open-water pool in foreground, supporting *Menyanthes trifoliata* and *Utricularia intermedia*, and behind and somewhat elevated, an unmerchantable and depauperate stand of black spruce-dominated Treed Bog; 55 km north of Moosonee, Ontario. [photo: D. Cowell]

d. The soil profile of the Treed Bog in Fig. 4(c) is a Terric Fibrisol with a *Sphagnum*-derived peat overlying a *Carex*-derived peat; the depth to standing water was 20 cm and the depth to a clayey silt-textured mineral soil (Ckg horizon) was 88 cm. [photo: R. Sims]

e. Brackish Meadow Marsh with vegetation mats dominated by *Puccinellia phryganoides* and *Plantago maritima* (foreground), water pools with *Hippuris tetraphylla* growing along the margins, and an open meadow marsh dominated by *Carex paleacea*, *C. mackenziei* and *Senecio congestus* (behind, adjacent to a sparsely vegetated beach ridge); located on the southwestern James Bay coast just above the normal high-tide limit, 15 km south of the Albany River mouth. [photo: R. Sims]

f. A well sorted, fine-textured and strongly gleyed Orthic Gleysol supporting *Hippurus tetraphylla* vegetation cover in a Brackish Meadow Marsh; the soil profile lacks an Ah or a Bt horizon but significant gleying occurs within 10 cm of the surface. [photo: R. Protz]

g. Freshwater Marsh dominated by *Carex aquatilis*, *C. paleacea* and *Petasites palustris*; in the background is a Thicket Swamp with *Salix* spp. cover; located 0.3 km inland from the southern coast on Shipsands Island, a waterfowl sanctuary located in the Moose River estuary. [photo: R. Sims]

h. Fine-textured Rego Gleysol soil profile in a Freshwater Marsh; little horizonation is evident other than some minor organic accumulation at ground surface and a thin (3-4 cm), discontinuous buried organic horizon located about 15 cm from the surface and resulting from alluvial activity. [photo: D. Cowell]

i. Forested Beach Ridges occur perpendicular to the coast and are often still recognizable near the interior margin of the HBL Coastal Zone; these ridges, located midway between the Albany and Moose Rivers, are about 15 km from the present James Bay coast, and support mainly black spruce (and sometimes white spruce), often with a well developed ericaceous and feathermoss ground layer. [photo: R. Sims]

j. An Eluviated Eutric Brunisol occupying a raised beach ridge about 10 km inland from the current James Bay coast; a thin Ae horizon (about 2-3 cm) overlays a Bm horizon somewhat affected by podzolization processes. The soil is composed of stratified and sorted sands and gravels. [photo: D. Cowell]

k. A densely stocked and well developed jack pine stand occupying a major inland beach ridge near Kinoje Lake, 70 km northwest of Moosonee, Ontario; the understory is dominated by *Cladina* spp. lichens, *Vaccinium angustifolium* and the feathermoss *Pleurozium schreberi*. [photo: R. Sims]

l. This Orthic Humo-Ferric Podzol profile on the Kinoje Lake beach ridge has a thick forest-humus form (i.e., a fibrimor) overlying a thick, tonguing Ae horizon and a well-developed Bf horizon; the soil texture is medium sand. [photo: R. Protz]

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Fig. 4e

Fig. 4f

Fig. 4g

Fig. 4h

Fig. 4i

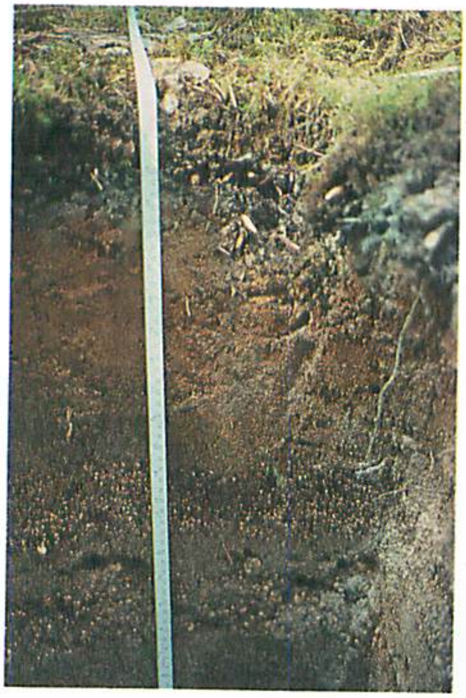

Fig. 4j

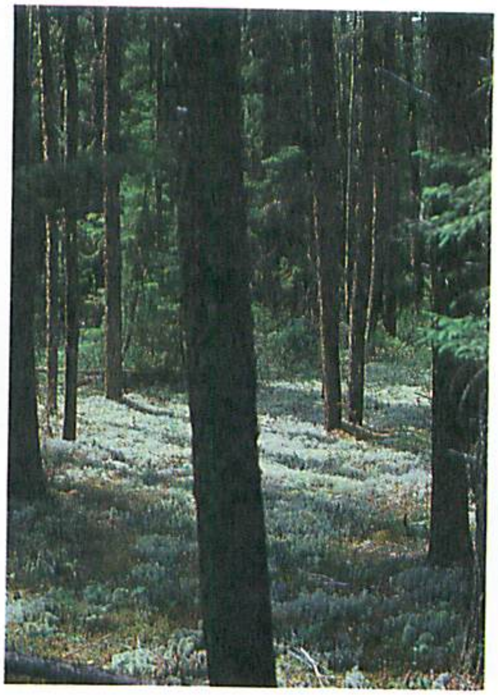

Fig. 4k

Fig. 4

Table 4. Chemical analyses for sampled mineral-soil horizons (cont'd).

Site no.	Soil profile	Depth (cm)	$CaCl_2$ pH	Cation-exchange capacity (meq/100g)	Exchangeable cations (meq/100g)			Organic C (%)	Inorganic C (%)	Total N (%)	C/N ratio	Pyrophosphate extractable (%)	
					Mg	K	Na					Fe	Mn
Forested Levee													
77 - 24	Ahgk	0 - 5	7.0	43.5	1.88	0.10	0.13	0.73	3.34	0.11	6.60	0.089	0.008
	I,II Ckg	5 - 31	7.0	47.8	1.23	0.10	0.13	0.63	3.69	0.12	5.30	0.061	0.004
	III Ckg	31 - 60	7.1	43.5	1.06	0.10	0.13	0.30	3.46	0.09	3.30	0.059	0.002
77 - 32	Aej+Bmgj	0 - 49	4.8	47.8	-	0.04	0.04	0.42	0.42	0.11	4.00	0.243	0.010
	Bmgj2	49 - 62	7.0	60.9	1.93	0.04	0.04	0.23	1.38	0.08	2.90	0.090	0.008
	Ckg	62+	7.1	29.3	1.48	0.04	0.04	0.15	1.74	0.06	2.50	0.064	0.004
77 - 35	Bf	2 - 6	3.5	23.5	0.92	0.14	0.04	0.71	0.43	0.06	11.80	0.321	0.005
	Bf2	6 - 21	4.4	20.7	1.68	0.19	0.04	1.57	0.29	0.12	13.10	0.392	0.012
	Bgj	21+	7.1	29.3	5.86	0.20	0.04	0.27	2.67	0.08	3.40	0.085	0.002
77 - 85	Ahk	0 - 9	7.1	7.6	1.76	0.14	1.59	3.26	4.48	0.31	10.50	0.094	0.006
	IIAhkb	9 - 18	7.3	15.0	1.31	0.09	0.15	1.91	4.57	0.19	10.10	0.072	0.003
	III Ckg	18+	7.4	7.6	0.95	0.06	0.13	0.42	4.78	0.06	7.00	0.049	0.001
77 - 138	Ah	0 - 3	4.3	30.7	1.37	0.19	0.17	4.12	1.93	0.32	12.90	0.535	0.007
	II Ahb	0 - 28	5.1	19.3	1.89	0.14	0.17	1.46	0.34	0.16	9.10	0.098	0.003
	III Ckg	28+	7.1	9.6	2.02	0.16	0.17	0.14	3.66	0.06	2.30	0.189	0.008

(cont'd)

Table 4. Chemical analyses for sampled mineral-soil horizons. (concl.)

Site no.	Soil profile	Depth (cm)	$CaCl_2$ pH	Cation-exchange capacity (meq/100g)	Exchangeable cations (meq/100g)			Organic C (%)	Inorganic C (%)	Total N (%)	C/N ratio	Pyrophosphate extractable (%)	
					Mg	K	Na					Fe	Mn
Upland Beach Ridges													
77 - 11	Ae	0 - 3	3.6	5.0	0.17	0.05	0.09	0.44	0.06	0.07	6.30	0.033	0.001
	Bhc	3 - 11	6.2	43.5	9.05	0.25	0.57	9.64	1.62	0.40	24.10	0.424	0.004
77 - 49	Bh	9 - 51	5.2	10.9	0.91	0.07	0.04	0.51	0.63	0.09	0.57	0.147	0.007
	Ck	51+	7.2	24.3	0.63	0.07	0.04	0.01	1.83	0.07	0.14	0.017	0.001
77 - 61	Ahe	0 - 2	4.0	12.8	0.81	0.12	0.09	1.43	-	0.00	47.70	0.093	0.001
	Bhk	2 - 17	6.9	15.0	1.19	0.04	0.74	0.80	2.59	0.08	10.00	0.089	0.002
	Ck	17+	7.4	22.2	0.48	0.02	0.04	0.08	3.37	0.01	8.00	0.013	0.001
77 - 103	Bh	1 - 17	7.1	15.0	2.62	0.10	0.13	2.03	1.88	0.12	16.90	0.068	0.004
77 - 105	Ahej+Bhk	1 - 6	7.1	5.0	0.81	0.04	0.13	1.31	2.60	0.15	8.70	0.051	0.002
	Bhjk	6 - 17	7.2	2.7	0.61	0.04	0.13	0.49	3.58	0.09	5.40	0.022	0.001
	Ck	17+	7.3	2.6	0.52	0.03	0.13	0.20	3.76	0.08	2.50	0.017	trace

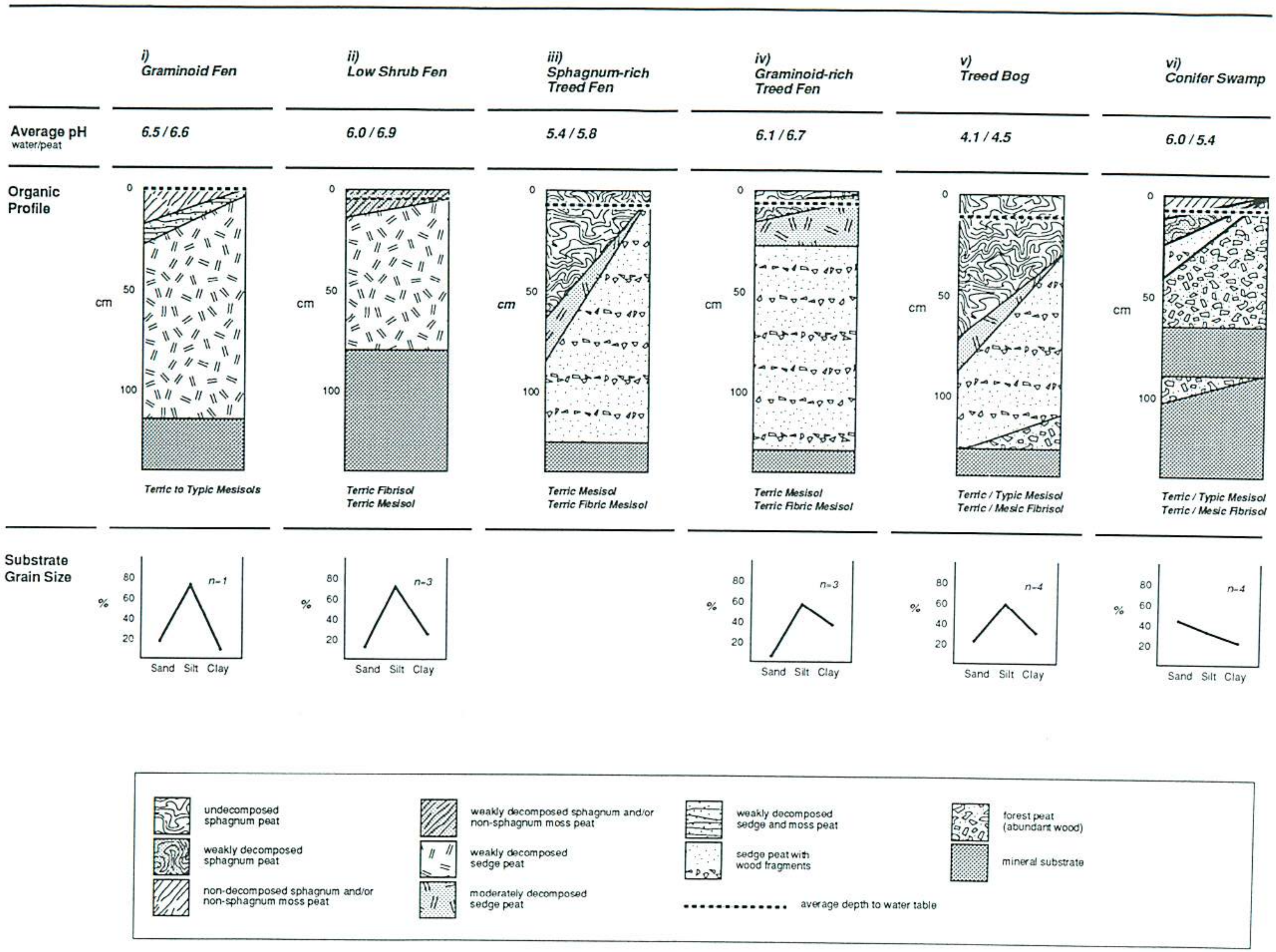

Figure 3a. Characteristic profiles, average water and peat pH, peat/LFH thickness and average-grain-size analyses or each physiognomic type.

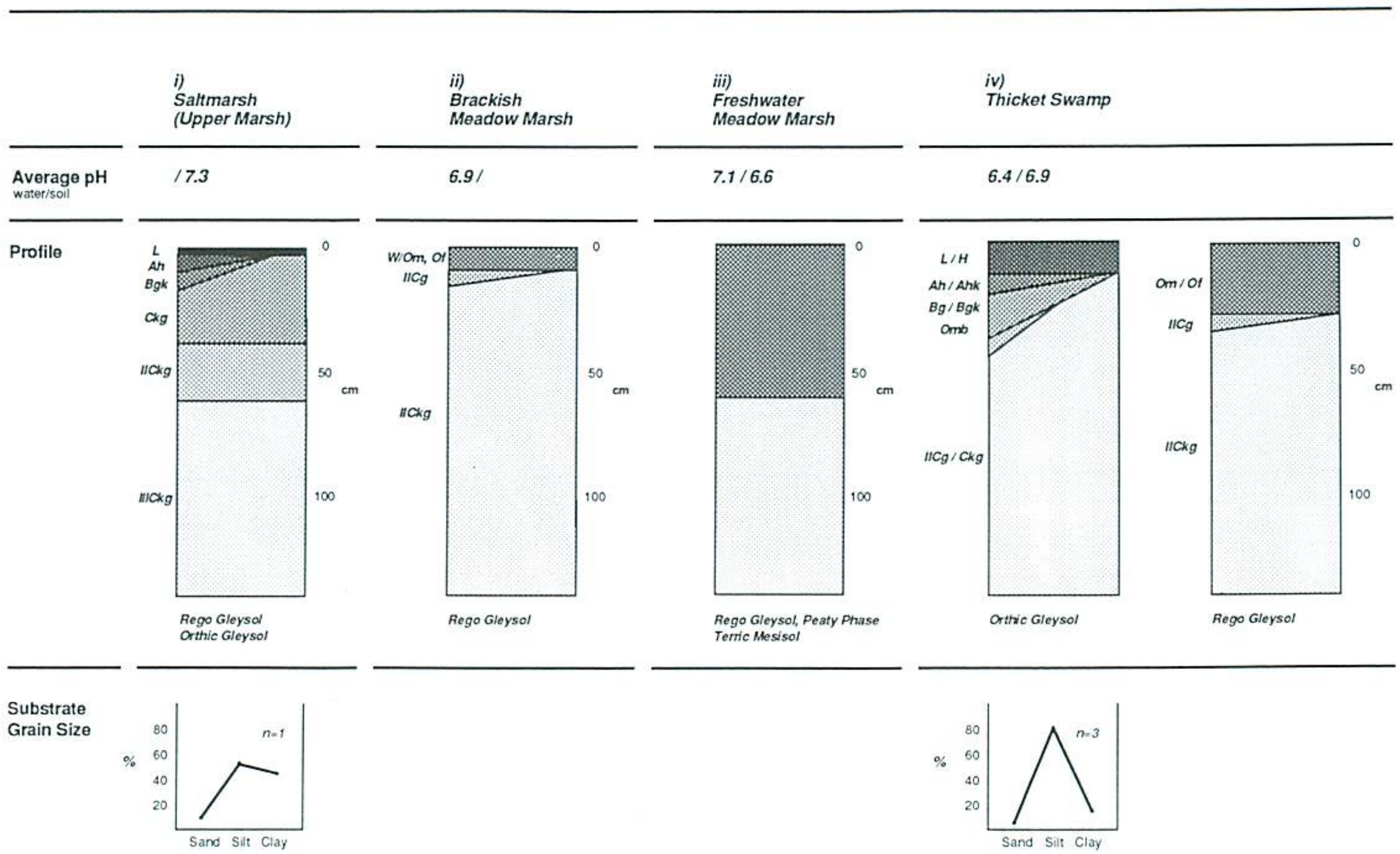

Figure 3b. Characteristic profiles, average water and peat pH, peat/LFH thickness and average-grain-size analyses or each physiognomic type.

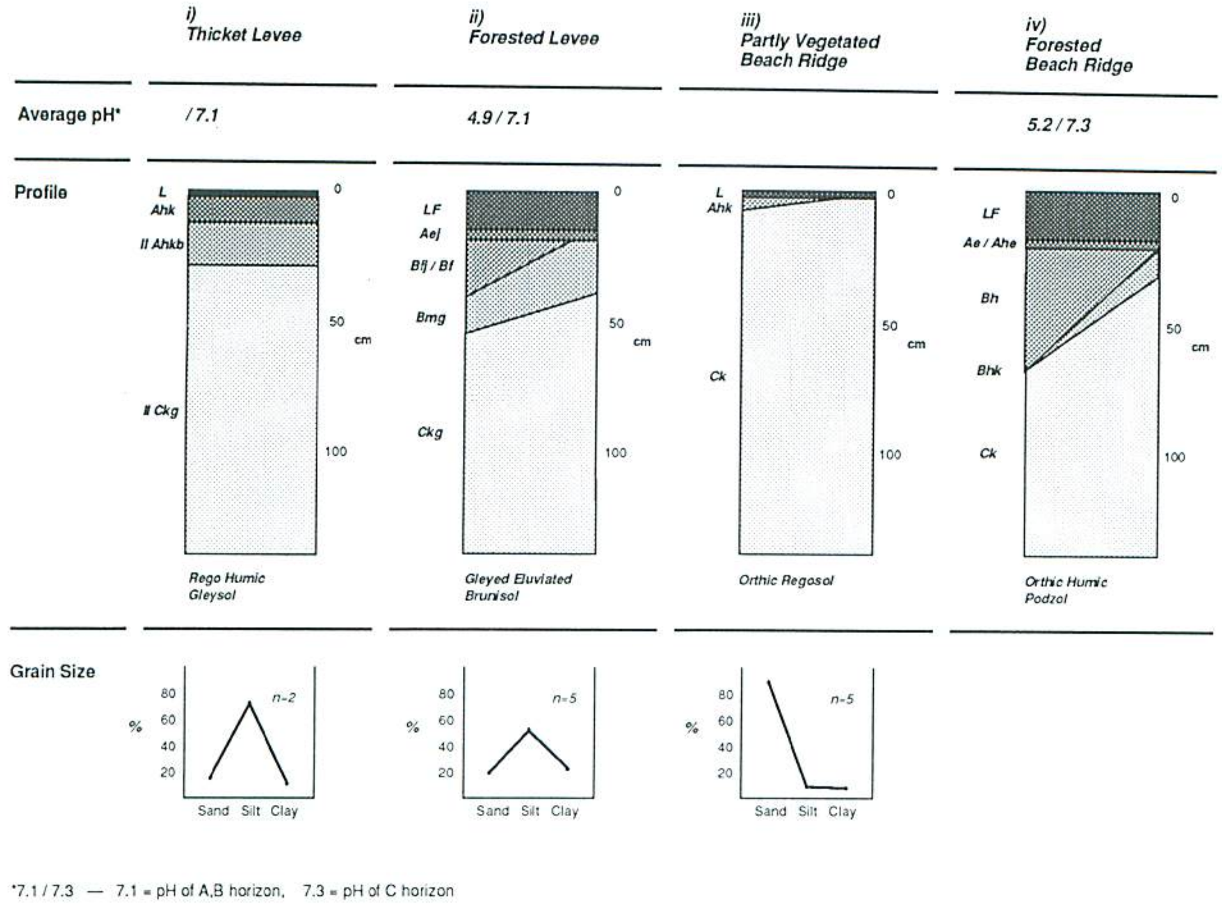

Figure 3(c). Characteristic profiles, average water and peat pH, peat/LFH thickness and average-grain-size analyses for each physiognomic type. Uplands.

strongly gleyed, well sorted silt. The presence of carbonate material was indicated by a strong reaction to HCl.

Organic soils were fairly evenly divided between Terric Fibrisols and Terric Mesisols. Except for one site (51), low shrub fens tended to be characterized by shallow peat accumulations within a narrow range of about 35 to 85 cm. This type has the second-lowest average peat thickness, next to conifer swamps, of all the organic soils and falls within the narrowest range of peat depths. The reason for this is uncertain but may be related to rooting and hydrological controls.

Soil characteristics of low shrub fens were similar to those of graminoid fens in the case of peat type (predominantly weakly decomposed sedge peats) and peat pH (Table 3). Water, however, was slightly more acidic on average in low-shrub fens (pH 6.0 as opposed to 6.5). As well, water tends to be more acidic than either the surface peat or the average for peat at each site.

The depth to the water table averaged 10.3 cm, only slightly deeper than for graminoid fens, and ranges from 6 cm above the surface to 20 cm below.

The mineral substrates had very fine textures (silty clays), with only one site (site 5) having sands and gravels. Reaction to HCl was mainly very weak to weak, indicating the presence of some carbonate, but generally less than is found beneath graminoid fens.

Graminoid-rich Treed Fen

Soils were described from seven sites classified as graminoid-rich treed fen. Treed fens are distinguished by the presence of a tree stratum which, without exception, is dominated by tamarack. Other dominants of treed fens include the shrubs *Betula glandulifera* and *Chamaedaphne calyculata*, as well as *Equisetum fluviatile* and *Carex chordorrhiza*. This type differs from *Sphagnum*-rich treed fen by having more of the graminoids *Carex limosa* and *Scirpus hudsonianus*, with characteristic bryophytes *Drepanocladus vernicosus* and *Scorpidium scorpioides*. The most common *Sphagnum* in this type is *Sphagnum warnstorfii*.

Nutrient status in these peatlands is intermediate between *Sphagnum*-rich treed fen and low-shrub fen (Table 2). Concentration of Ca ions and pH are just below the calcareous water limit that separates rich fen from poor fen (Moore and Bellamy 1974).

Graminoid-rich treed fens had soil types and characteristics similar to those of *Sphagnum*-rich treed fens with respect to peat thickness, soil classification and depth to water (Table 3; also see below). Peat type was similar; however, weakly decomposed sedge peat was the dominant type in each profile, and undecomposed *Sphagnum* peat was less significant than in *Sphagnum*-rich treed fens (Fig. 3a). This was also reflected in higher peat and water pHs, which were more characteristic of the graminoid fen type. In fact, on average, the surface peat pH was the highest of all peatland types. The reason for the relatively high surface peat pH in graminoid-rich treed fen is not certain, but may be a result of the presence of minerotrophic surface waters (such as from nearby beach ridges). *Sphagnum*-rich treed fens may occur in similar physiographic positions, but farther away from minerotrophic influence.

The reaction of the mineral soil to HCl varies from very weak to strong. Limited leaching of carbonate material suggests that the substrate has experienced predominantly reducing conditions since emerging from the marine zone. Substrate texture is commonly a silty clay.

Sphagnum-rich Treed Fen

Twelve sites classified as *Sphagnum*-rich treed fen had soil-profile descriptions prepared. *Sphagnum*-rich treed fen has tree and shrub vegetation similar to that of graminoid-rich treed fen but differs in the grass and ground layers. Bryophytes in the *Sphagnum*-rich treed fens are dominated by *Aulacomnium palustre*, *Sphagnum warnstorfii*, *S. fuscum* and *S. angustifolium*.

The treed fen types are the least minerotrophic of all fen types, and *Sphagnum*-rich treed fens are the poorest of all (Table 2). Their pH and Ca ion concentrations are above, but close to, the "mineral soil limit" that separates poor fen from bog (pH 4.0 and Ca 1 mg/L; Moore and Bellamy 1974). The four sites (28, 39, 54 and 69; Table 3) with the deepest peat accumulation and located farthest from the coast also have the lowest minerotrophy of this type (note the surface-water pH in Table 3). Groundwater chemistry in these four sites is comparable with that of bog types and it is likely that *Sphagnum*-rich treed fen, as a class, represents a transitional stage between poor fen and bog.

All sites had organic soil profiles and all were mesisols. The most common soil type was a Terric Mesisol, although Typic Mesisols, Terric Fibric Mesisols and Fibric Mesisols were encountered. Peat thickness ranged from 61 to 183 cm, and, on average (123.8 cm), was the third thickest after graminoid-rich treed fens (129.4 cm) and bogs (128.1 cm). Although weakly decomposed sedge peat quantitatively dominated the profiles of this type, each profile was capped with undecomposed *Sphagnum* peat. In some sites, sedge and *Sphagnum* peats were about equal in thickness (sites 25, 28 and 135; Table 3, Fig. 3a), although the sedge peats were probably compressed; in one case, *Sphagnum* peat dominated the profile (site 39).

Sphagnum-rich treed fens were, on average, the most acidic of fen types in terms of both water and peat. This is to be expected, because living *Sphagnum* spp. dominate the ground layer and these mosses are known to secrete organic acids (Sjörs 1963). Water tends to be more acidic (pH 4.2 to 6.7, averaging 5.4) than surface peat (pH 4.8 to 6.8, averaging 5.8) and the average peat pH (5.4 to 6.6, averaging 6.1).

The water table was at a medium depth from the surface, averaging 17.3 cm and varying within a narrow range between 12 and 23 cm. These depths were measured from medium-sized hummocks.

The mineral substrates for these sites are all fine-textured silty clays and silt loams. Carbonates are present in at least half of the substrates; however, they are leached more than beneath any other wetland type, as indicated by very weak or nil reactions to HCl.

Bog

The various bog types are discussed together because of the low number of graminoid, *Sphagnum*, low-shrub or graminoid-rich treed bog sites. Most sites (10 of 14) are shrub-rich treed bog and, thus, the following description pertains mainly to that type.

Bogs are dominated by the mound-forming *Sphagnums*, particularly *Sphagnum fuscum*. *Sphagnum rubellum* is also common in most bogs, and the feathermoss *Pleurozium schreberi* is common on raised hummocks in treed bogs. Woody shrubs include *Ledum groenlandicum*, *Chamaedaphne calyculata* and *Kalmia polifolia*. Black spruce is the only tree species found in bogs of the southwestern James Bay Coastal Zone. Lichens (*Cladonia* and *Cladina* spp.) are most abundant in bog types.

Bog water chemistry is distinct, with average pH and Ca clearly indicating ombrotrophic conditions (Table 2). These conditions reflect the absence of minerotrophic inputs either from underlying mineral soils or from groundwater. The living surface vegetation must derive virtually all nutrients from atmospheric sources. The average SO_4 concentration in bogs was the highest of all wetland types (Table 2). Gorham (1957) attributed high acidity in ombrogenous bog waters in Britain to the influence of free sulfuric acid. According to Gorham (1966), the source of this mineral acid is the oxidation of organic sulfur and contributions from atmospheric pollutants.

Bog soils were distinguished from fen and swamp primarily on the basis of peat type, which was dominated by undecomposed *Sphagnum* peat (Fig. 3a). In at least half the profiles, *Sphagnum* spp. contributed the only recognizable plant remains. Weakly decomposed sedge peat was the next most common peat type; however, unlike with the fen types, there was a strong forest peat component. In some profiles, forest peat (abundant wood fragments plus a mixture of sedge and non-*Sphagnum* spp. peat) formed the lowest recognizable peat. The sedge peats between this and the *Sphagnum* peat also contained a higher wood-fragment content, which suggests that a shrub/tree component was part of the living community throughout the history of most of these sites. Peat thickness was quite variable (52 to 205 cm) but, on average, was the thickest (128.1 cm) of the sites examined.

Bog types had the lowest peat and water pHs of all wetland types (Table 3). The pH of peat and water tended to be <5.0, although average peat pH was slightly higher as a result of the influence of the mineral soil on basal peats. Water-table pH and surface-peat pH tended to be similar, although the latter was consistently higher. The high pH value shown for site 141 (Table 3) is anomalous and does not reflect nutrient conditions for the living vegetation. This site was a small bog island within a large fen seepage. The groundwater sample reflected the minerotrophic fen that surrounds and appears to underlie recently formed bog hummocks. The hummocks have developed sufficiently to isolate a living community from the fen seepage.

The depth to the water table was the greatest of all wetland sites, ranging between 13 and 37 cm, and averaging 26 cm. Relatively deep water tables are common in bogs because of their very hummocky nature and relatively fast accumulation of *Sphagnum* peat.

Bog substrates were predominately fine-textured, but poorly sorted silt, sand and gravel substrates also occurred. Reaction to HCl varied, indicating that carbonates were not consistently leached from beneath bog peats.

Conifer Swamp

Soil descriptions were completed for 16 sites classified as conifer swamp. Standing water was common in the generally uneven surfaces, which were characterized by pools, channels and depressions. The conifers were dominated by black spruce, although tamarack was also common. Shrubs common to conifer swamps include *Ledum groenlandicum* and *Alnus rugosa*. Other characteristic vegetation includes *Smilacina trifolia, Rubus acaulis, Carex leptalea, Hylocomium splendens, Pleurozium schreberi* and *Sphagnum warnstorfii*.

The chemistry of conifer swamp groundwaters is highly variable, ranging from the low end of poor fen through rich fen. On average, the nutrient status of these sites falls between thicket swamp and graminoid fen (Table 2).

Characteristics of conifer swamp soils were also highly variable. There was a wide range of peat accumulation (24 to 123 cm), but on average these were the shallowest of peatlands (Table 3). Mineral soils were well represented, and the total range of soil types included Gleysols (4), Fibrisols (4) and Mesisols (8). *Sphagnum* peat dominated the upper portions of profiles, although forest peat was quantitatively the most significant type (Fig. 3a). This indicates that forest conditions have existed at these sites throughout their history.

Surface peat pH was low because of acids secreted by living *Sphagnum*, although average peat and water pH values were higher. *Sphagnum* was not, however, dominant in the living layer in conifer swamps. Feathermosses were generally more prevalent, and thus the dominance of *Sphagnum* peat in the upper portion of the profile is misleading. This condition may be related to the humification processes (i.e., *Sphagnum* spp. may humify more slowly). Average peat and water pH values were higher than for bogs, and thus the *Sphagnum* peat and living *Sphagnum* spp. typical of conifer swamps did not influence water pH as much as for bogs or *Sphagnum*-rich treed fens.

The ground surface in this type was characterized by numerous fallen trees, with feathermoss and *Sphagnum* moss hummocks on the logs. Pits and channels, many with standing water, are common because of the unstable character of the forest.

The substrate textures of conifer swamps were predominantly loams, silts and silty clays. This is indicative of their physiographic location, generally beside or near river and stream courses. Their substrates are thus primarily alluvium. In contrast, bogs and fens occur in interfluvial areas, and their substrates are either finer alluvium or marine clays. Overbank flooding is responsible for the alternating peat and silt layers in the profile of site 57 (Cumulic Mesisol), which was located immediately beside a stream. The substrates of conifer swamps contrast sharply between no reaction and strong reaction to HCl.

This physiognomic type is floristically and physiographically distinct; however, wide variations in groundwater chemistry and soil characteristics occur within this class. It would appear that the living community is most influenced by hydrological controls in the form of overbank flooding and/or frequent seepage along the back side of large levees. Wide variations in groundwater chemistry may be an artifact of sampling, reflecting time between flooding events rather than the long-term conditions that influence the vegetation.

Species that occur are those most adapted to these hydrological conditions, thus minimizing the influence of peat depth and type. Instability related to flooding is shown by the abundance of fallen and uprooted trees that form the characteristic pits and channels of conifer swamp floors. It is possible that these conditions give rise to many microsites that do not reflect the overall site condition. Hence, the placement of the soil pit and groundwater sampling location is most critical in these types.

Mineral-soil Wetlands

Brackish Meadow Marsh

Soils on six sites classified as brackish meadow marsh were described. These sites occurred on the uppermost parts of tidal flats, and their nutrient status, physiography and vegetation are transitional between salt marsh and freshwater marsh. They are thus gradational, ranging from typical salt marsh species at their lower end, along tidal channels and in tidal pools, to typical freshwater marshes at their higher end. Characteristic species described for this type include *Juncus balticus, Carex paleacea, Puccinellia phryganoides, Hippuris tetraphylla, Potentilla anserina, Triglochin maritima* and *Lathyrus palustris.*

Groundwater conductivity and salinity indicate brackish to slightly saline conditions as a result of periodic tidal inundation. Conductivity averaged 9,075 µmhos/cm, with a standard deviation of 5,712 µmhos/cm, and salinity averaged 7.1 parts/1000 with a standard deviation of 5.5 parts/1000. Samples were not collected at these sites for analyses of major ions.

Brackish meadow marshes were characterized by Rego Gleysols and Orthic Gleysols developed on mixtures of poorly sorted to well sorted clays, silts, sands and gravels (Fig. 3b). These soils are within the range of only the highest tides on the uppermost portion of the tidal flats.

Soils were alkaline (pH >7.0) and high in exchangeable bases, especially Ca, Mg and Na (Table 4). Organic carbon content tends to be high, especially in the upper 10 cm, because of dense rooting by marsh grasses and sedges. These soils were very strongly reduced within 20 cm of the surface, with wet colors of 2.5Y3/0 or darker. On the middle portions of the flats, below the salt marshes and in pans, the soils were strongly reduced within 1 cm of the surface (see Protz 1982a).

Freshwater Marsh

Soils were described for five sites classified as freshwater marsh. These sites were characterized mostly by freshwater species, although some species more common to brackish meadow marshes occurred (e.g., *Hippuris vulgaris*). Characteristic species include *Menyanthes trifoliata, Typha latifolia, Salix* spp., *Carex* spp., *Equisetum fluviatile* and *Petasites sagittatus.*

Freshwater marsh soils occurred above the high-tide limits, although their lower extremities may be inundated by unusually high tides. Tidal influence and/or residual saline effects are shown in their groundwater chemistry. Three sites had measurable salinities ranging from 0.5 to 1.0 parts/1000 (averaging 0.5 for five sites). Their ionic chemistry (Table 2) indicates that, overall, these sites are the richest of those wetlands found above the current high-tide limits.

Soils were Rego Gleysols developed on silty clays (Fig. 3b). The mineral soil was overlain by mesic and fibric organic material up to 24 cm thick, and the water table was generally at or above the organic surface. The soils were thus strongly gleyed. A weakly developed B horizon, as observed in some of the brackish meadow marsh profiles, was not observed in any of the freshwater marsh profiles. This reflects the extremely poor drainage of these marshes, even though they occur physiographically above the brackish marshes.

Abundant dead but undecomposed root material and strongly reduced, very dark gray bands of organic material in the mineral soils were relic features. They developed during earlier salt marsh/brackish marsh development, when these soils were within the range of regular tides. The silty clay material was probably deposited by high tides before these sites were gradually uplifted above the limit of regular tides. The substrates of the brackish meadow marshes tended to be coarser and more variable (see above).

One of the sites classified as freshwater marsh was an inland *Carex aquatilis* marsh that was, in fact, transitional to graminoid fen. The soil was a Terric Mesisol with 65 cm of moderately decomposed sedge peat (von Post 5) overlying a strongly gleyed silty clay. Peat pH was 6.6 and the water pH 7.1. Strongly reduced, dark gray bands similar to those of the supratidal marshes occurred in the mineral material.

Thicket Swamp

Soils representing 11 thicket swamps were described. These have an abundant cover of shrub species, particularly *Salix* spp. and *Alnus rugosa*. Understory vegetation typically consists of *Myrica gale* and *Carex* spp.

On average, thicket swamps have the second highest ionic concentration of all wetland types (Table 2). This is to be expected because these sites have the shallowest peat accumulations, and thus groundwaters are in close contact with mineral soils. Concentrations of Na and Cl suggest some residual influence from earlier tidal conditions.

Thicket swamp development is physiographically controlled, occurring: (1) near the coast on subtle rises in freshwater marsh areas; and (2) on the banks of small streams that are flooded periodically or continuously. Their soils were Rego Gleysols and Orthic Gleysols developed on silts and silty clays. In all cases, the water table was within 50 cm of the surface.

Rego Gleysols, with organic materials directly overlying C horizons (Fig. 3b), develop primarily where the water table is above the surface for most of the year (primarily situation 1, above). Orthic Gleysols develop under periodic flooding where the water table drops 30 to 60 cm below the surface for part of the year, permitting the development of weak Bg or Bgk horizons (situation 2, above). These B horizons are characterized by common to many distinct mottles beneath thin Ah horizons (Fig. 3b).

Three profiles (all Orthic Gleysols) were sampled for chemical analyses (Table 4). The chemistry of these soils reflects original sediment characteristics rather than pedological processes. The primary pedological process active at these sites is the accumulation of organic material and the formation of Ah horizons. Thus, for example, cation-exchange capacities below any A horizons reflect the dominance of silt over coarser material. The pH of the profiles are consistently near neutral (≈7.0, Table 4).

Uplands

Upland Thicket Levees

Soils from two upland thicket levee sites were described. Floristically, these sites were equivalent to thicket swamps, with shrubs dominated by *Alnus rugosa* and *Salix* spp.

Both sites described had Rego Humic Gleysol soils developed in silt loam on distinct river levees (Fig. 3c). They are cumulic, having buried Ah horizons that result from periodic overbank flooding. Soil development was minimal because of a high water table and periodic flooding, which deposits fresh alluvium. The C horizons (II or IIIC) occurred within 30 cm, and free carbonates were present throughout. Mottles were well developed (common to many) and contrasted distinctly with the matrix colors.

Both sites were sampled for soil chemical analyses (Table 4). Their chemistry is comparable to thicket swamp soils and also most likely represents original sediment characteristics.

As in the case of thicket swamps, overbank flooding plays a major role in site ecology and soil development. However, thicket levees were found on larger streams and thus were physiographically more pronounced. Hence, flooding is not as prolonged in these sites but individual flood events result in greater sediment deposition. This is shown by generally thicker A horizons (which have had a longer time for development and were not washed off the site), high carbonate content (i.e., the 'k' designation in Ahk, from the addition of fresh carbonate-rich silts), and the presence of buried Ahk horizons.

Forested Levees

Eight upland forested levee soils were described. Forested levees are generally higher than those that support thicket swamp-type vegetation. However, within this forested type was a range of site conditions that were demonstrated by soils and vegetation.

The four lowest and most frequently flooded sites all had gleysolic soils (three Rego Gleysols and one Rego Humic Gleysol). Vegetation on these sites included *Alnus rugosa*, which was characteristic of thicket swamps, as well as tree species such as *Picea glauca* and *Populus balsamifera*. *Hylocomium splendens* was the most common moss species.

The four higher, well developed levee sites were represented by a podzolic soil (Orthic Humo-Ferric Podzol), two brunisolic soils (a Gleyed Eluviated Dystric Brunisol and a Gleyed Eluviated Eutric Brunisol) and a gleysol (Rego Humic Gleysol). *Alnus rugosa* was absent from these sites. Tree species included *Abies balsamifera, Picea glauca* and *P. mariana*. Ground cover consisted of typical boreal plants including *Cornus canadensis* and *Gaultheria hispidula* and mosses such as *Pleurozium schreberi, Dicranum* spp. and *Hylocomium splendens*.

Only the highest levees were represented by the profile in Figure 3c. Slight gleying in these higher leveé soils resulted from thick LFH layers under closed coniferous forest and seepage from adjacent peatlands. The stability of these levees has permitted relatively good horizonation, with leaching of carbonates resulting in more acidic upper horizons (Table 4). Well developed levees, such as those of the Harricana River, are rarely inundated, thus preventing the periodic deposition of fresh, carbonate-rich alluvium. Only three of eight forested levee sites exhibited cumulic horizons within 50 to 75 cm of the surface.

The soil chemistry of the higher levees (as represented by sites 32 and 35; Table 4) reflected their greater stability. Soils of levees undergoing seasonal flooding compare more with thicket levees and thicket swamps than with the higher levees. Soil pH, exchangeable cations and total N were lower, and pyrophosphate-extractable Fe was higher, in A and B horizons of the highest levees. This is expected, given their great stability and longer eluviation/illuviation history.

Although the high levee soils tended to be low in exchangeable K and in percent N, they are the most productive forest soils in the southwestern James Bay Coastal Zone. This is a result of their physiographic location in combination with moist loam soils. The levees invariably supported the best forest growth (based on height and circumference) in the study area.

Upland Forested and Partly Vegetated Beach Ridges

Soils were described from 10 beach ridges that ranged from immediately above the active shore to 21 km inland. Physiognomically, each ridge is classified as upland forest, even those closest to the coast, which have similar species but vary in abundance and ground cover. The dominant tree species on all ridges was *Picea mariana*, with ground cover including *Cornus canadensis, Vaccinium vitis-idaea, Linnaea borealis* and the mosses *Hylocomium splendens* and *Pleurozium schreberi*.

Beach-ridge soils develop in carbonate-rich coarse sand and gravelly coarse sand. Inland ridges commonly supported a white spruce forest with thick LFH horizons. Coastal ridges had sparser vegetation (thickets and saplings) with a very thin surface organic layer. Soils were well drained and lacked structure ("single grain") except for organic cementation in the B horizon of one site (site 11; Table 4).

Generally, soils ranged from Orthic Regosols, with little or no horizonation on the youngest ridges, to Orthic Humic Podzols on older ridges (Fig. 3c). Intermediate ridges are Orthic or Eluviated Eutric Brunisols with B horizons characterized by the accumulation of humus, but too thin to meet the requirements of a podzolic horizon (i.e., <10 cm). One ridge, located 21 km from the coast, though one of the oldest ridges of the Coastal Zone, still displayed a brunisolic rather than podzolic profile. Factors such as exposure, height, fire and flooding may inhibit soil development on some ridges. Otherwise, beach ridge soils of the southern Coastal Zone are undergoing active podzolization. Thicker surface organic layers supply more organic material and acids, which produce eluvial horizons (Ae) and podzolic B horizons (dominantly Bh). Four sites (11, 49, 61 and 103), located between 2 and 13 km from the coast, were classified as Humic Podzols (Table 4). Site 11 was an Ortstein Humic Podzol with a cemented horizon (Bhc). Another four sites (including site 105; Table 4), located 1 to 5 km from the coast, were considered transitional. Although technically brunisols, there is little doubt that they will develop into podzols. One ridge located immediately at the coast had virtually no horizon development (L and ABk horizons only) and was classified as an Orthic Regosol.

Beach ridge soils had the lowest total N and exchangeable cations of all mineral soils (Table 4). Their coarse texture and good drainage permit relatively rapid leaching of carbonates and downward movement of organic material. Pyrophosphate-extractable Fe is too low for the requirements of a Bf horizon in all cases except site 11.

DISCUSSION

Peatland Soils

Peatland soils in the Coastal Zone of southwestern James Bay are predominantly Terric and Typic Mesisols and Terric Fibric Mesisols. These soils occur in each physiognomic type (in some cases, along with peaty-phase Rego Gleysols) and hence it is not possible to distinguish physiognomic types using only the Canadian System of Soil Classification sub-group level.

The peats are almost undecomposed to moderately decomposed (von Post D2 to D5). No peats were found to be more decomposed than von Post D6. Shallow, weakly to moderately decomposed peats common to the Coastal Zone illustrate the "youthful" character of its peatlands. It is likely that the deeper, more mature peats of the interior are, on average, more humified.

Sedge peats are the dominant basal peat type for fens. These are generally transitional upward to *Sphagnum* and other moss peat types. Where surface peats and the living ground cover are dominated by *Sphagnum* spp., such as *Sphagnum*-rich treed fen, the nutrient status (as reflected by pH and Ca) is distinctly less minerotrophic. Peat and water pH of conifer swamps are between fen and bog, which illustrates the acidic influence of the *Sphagnum* spp. buffered by the presence of alluvium and/or periodic flooding by stream waters. In all types, however, the average peat pH of the profile is less variable than either surface peat pH or water pH. This reflects the buffering influence of the generally carbonate-rich substrates, which increases peat pH toward the base of deposits. Low surface peat pH is due to the presence of acid-secreting surface vegetation (Gorham 1966).

It is interesting that water pH is consistently lower than surface peat pH and the average peat pH of the profiles (except in conifer swamps) by up to an order of magnitude, even though the

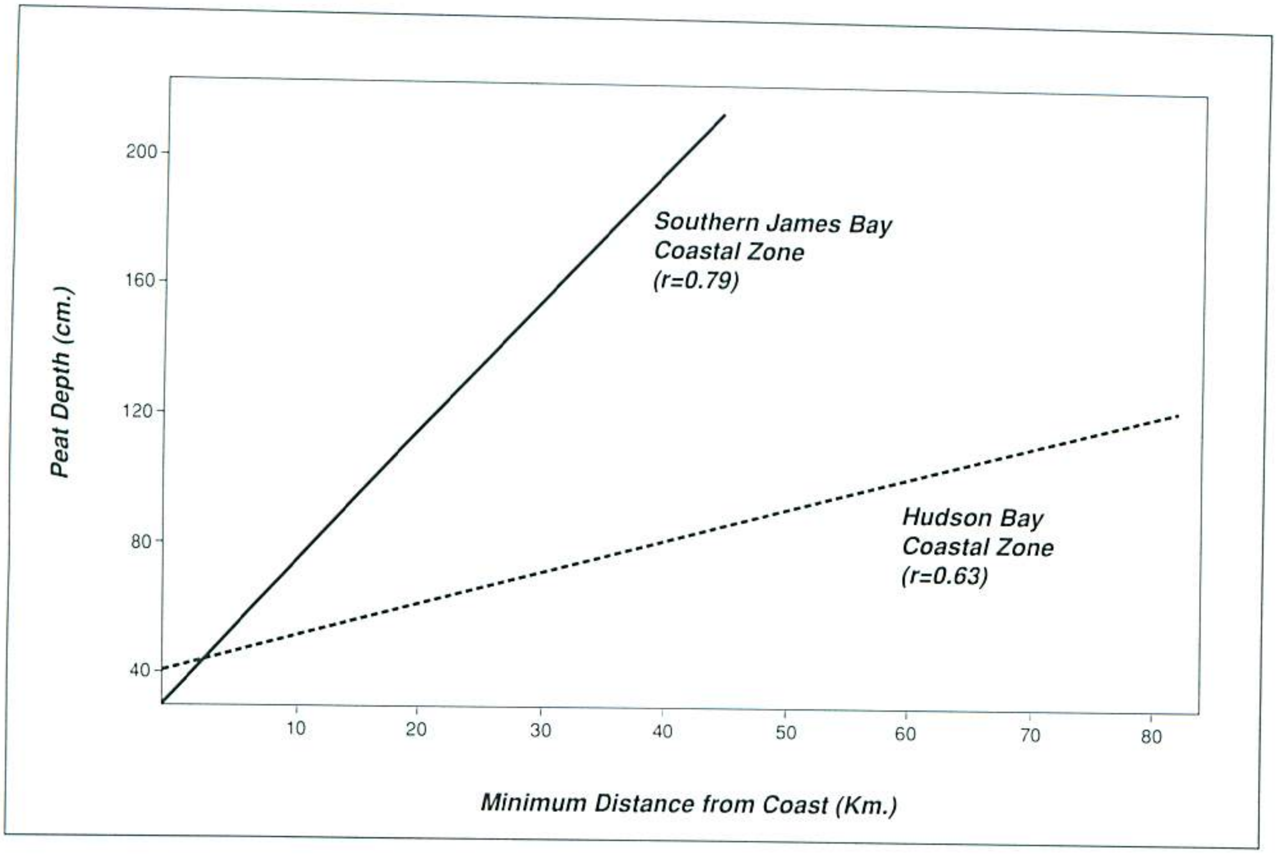

Figure 5. Regression correlation of distance from the coast versus peat depth for the southwestern James Bay and Hudson Bay Coastal Zones.

water table in most sites is within 20 cm of the living vegetated surface (Table 3). This supports claims by Sjörs (1963) and Gorham (1966) that peat material absorbs 10 to 100 times the concentration of cations dissolved in the surrounding water. In the case of conifer swamps, relatively higher water pH reflects periodic flushing and sediment contributions from minerotrophic surface streams.

Figure 5 shows the rate of increase in peat thickness from the coast up to 40 km inland. This correlation between thickness and distance (r = 0.79) indicates an accumulation rate of about 7.4 cm/km within the first 10 km. This is relatively rapid in comparison with the colder Hudson Bay coast (Wickware et al. 1980). The rate decreases with distance, most likely as a result of compression. The line intercept suggests that peat accumulation begins very close to the coast—probably within 200 years of uplift, as suggested by Protz (1982a), and much sooner than the 600 years that Tarnocai (1982) estimated for the York Factory area.

Cool, humid climatic conditions, regionally high water tables, and relatively thin peat accumulations are factors that limit the potential for large-scale peat extraction from the Coastal Zone of the HBL (Wickware et al. 1980, Cowell et al. 1983, Sims et al. 1988).

Mineral Wetland Soils

Gleysols are widespread on and near the coast of James Bay but become rare beyond about 2 km from the coast because of rapid peat accumulation. Coastal gleysols are primarily Rego Gleysols and Orthic Gleysols. Permanently saturated soils, which occur within the active tidal zone (up to and including salt marshes), show virtually no horizonation other than minor organic accumulation. These soils are basically wet marine sediments. Freshwater marsh soils are also permanently flooded and are also mostly Rego Gleysols. They are differentiated from the tidal soils on the bases of their peaty-phase organic surface horizon and relatively low salinity and conductivity. Gleysols of the uppermost tidal flats (i.e., those of the brackish meadow marshes) are predominately Orthic Gleysols. The water table in these soils fluctuates sufficiently to allow the development of thin Bg horizons.

Ringius (1980), Glooschenko and Clarke (1982), Price and Woo (1988), and Earle and Kershaw (1989) noted that somewhat higher salinity and conductivity is found in HBL soils of upper tidal flats, within the brackish marsh zone, than in soils of the active intertidal zone. This is partly explained by evaporation effects in the upper brackish zone. However, Glooschenko and Clarke (1982) also observed fairly rapid desalinization at all sites over the summer period, which they attributed to leaching by rainwater of salts deposited by high spring tides.

This rapid desalinization is also found spatially. Salinity and conductivity drop relatively rapidly inland from brackish marshes through freshwater marshes and shrub fens. Salt effects are thus relatively short-lived and are likely of little or no consequence in soil formation, as these substrates are soon elevated from marine influence. Also, the substrates beneath low shrub fens and graminoid fens immediately inland of freshwater marshes display the strongly reduced, very dark gray banding found on the present active tidal flats. Inland of these, however, gleysols are found only along small- to medium-sized streams, where periodic flooding inhibits significant peat accumulation.

These inland gleysols display a gradation from Rego Gleysols through Orthic and Orthic Humic Gleysols to Gleyed Brunisols. The Rego Gleysols occur on stream borders and very low levees nearest the coast, where flooding is virtually continuous. Orthic and Orthic Humic Gleysols occur on stream banks/levees that are high enough to limit flooding events. Gleyed Brunisols occur on relatively large levees, where overbank flooding may occur only during the spring freshet.

Upland Soils

Formation of upland soils within the southwestern James Bay Coastal Zone is represented by: (1) the podzolization of coarse sandy raised beach ridges, and (2) mixed brunisol, podzol and gleysol development on moist loams of high river levees. Collectively, upland soils form under the most productive forests of the HBL; however, they are limited in extent to less than 15% of the area.

Beach Ridge Soils

Beach ridges closest to the coast are essentially unweathered carbonate-rich sands and gravels (Glooschenko 1980, Tarnocai 1982, Sims et al. 1987). Podzolization progresses with time as vegetation becomes established, permitting surface leaching by downward-percolating organic acids and the translocation of organic matter and eventually forming strong podzolic Bh horizons. Bf horizons occur but are less common within the Coastal Zone. Limited Bf horizons may reflect the nature of the parent material, which is derived largely from the calcareous Paleozoic rocks.

The closest true podzol (i.e., with at least a 10-cm podzolic B horizon) was found at 2 km from the coast. Based on an uplift rate of 0.7 m/100 yr and a surface gradient of 0.5 m/km, the maximum age of this podzol would be in the range of 150 to 200 years. At least three podzols were found in the 2-3 km range; however, an Eluviated Eutric Brunisol was found on a low ridge 21 km from the coast (Bh 8 cm thick). The rate of podzolization is affected by specific site factors such as disturbance (fire, uprooting of canopy) and position of the water table (controlled by relief of the ridge and paludification).

Protz et al. (1988) noted that podzolization processes — in particular, carbonate leaching and the masses of organic matter and of vermiculite — are up to twice as rapid in southwestern James Bay as in a more northerly study area west of the Winisk River. They suggested that this is primarily a result of warmer temperatures and higher precipitation in southwestern James Bay.

Although temperature and precipitation are primary factors in soil development, another critical factor is time. Temporal control of soil development in the HBL is a function of isostatic rebound. Differential uplift rates, both temporally and spatially, are known to have occurred in this region (Wagner 1967, Craig 1969, Skinner 1973). Figure 3 in Protz et al. (1984) illustrates this as well; this figure plots radiocarbon dates against distance from the coast for both their study areas, and the resulting curves suggest different rates of uplift between their two transects as well as within each transect. In particular, the data for southwestern James Bay suggest a relatively abrupt decrease in uplift after about 2,200 years ago.

An overall faster rate of uplift in the more northerly transect would appear as slower soil formation than that along the more southerly transect if distance from the coast was considered in isolation from absolute time. Similarly, a decrease in uplift over time along one transect would result in younger ridges appearing to experience more rapid podzolization than older ridges. This is, in fact, shown by the plot of depth of leaching vs. distance presented as Figure 5 in Protz et al. (1988). Although temperature and precipitation are important, the differences in these two factors from south to north within the HBL may not be as significant in determining the rate of podzolization as was suggested by Protz et al. (1988).

In general, the rate of podzolization of these coarse sandy and gravelly coarse sandy beach ridge soils is very rapid, especially given that the parent material is highly calcareous. Evans (1980) observed increased podzolic morphological expression from south to north in a transect study north of Lake Huron on acidic parent materials. He related this northerly trend to an increased content of coniferous species. Water-soluble phenolic acids and carbohydrates, important as organic chelates of Fe and Al, were found to be higher in content under the more conifer-rich sites, and, hence, these sites may be more susceptible to podzolization. His results were tenuous given the limited extent of the study and the probable disturbance patterns of his sites. The rapid development of podzolic B horizons in calcareous parent materials under stable coniferous forests of the southwestern James Bay Coastal Zone supports his conclusions.

Upland Levee Soils

Soils of prominent river levees develop under mixed coniferous-deciduous forests on silt loams. Major rivers such as the Harricana, Moose and Albany have the best developed levees. These are characterized by steep slopes adjacent to the river and a gradually sloping distal surface that grades into the adjoining peatland.

The levees are moderately well to imperfectly drained. Gleying may occur near the surface due to: (1) water retention as a result of the high silt content of the alluvium; (2) thick LFH horizons under closed forest canopies, which limits evaporation; and (3) seepage from adjacent peatlands. Seepage is especially concentrated along the interface between the alluvium and underlying Tyrrell Sea marine clayey-silts, which serve as an aquiclude (i.e., an impermeable or slightly permeable barrier). The levees are currently being degraded by rotational slumping as a result of failure of the overlying alluvium at its contact with the wet Tyrrell Sea clays.

Soil development includes brunisols, podzols and gleysols. This likely reflects their overall youth and relative instability with regard to overbank flooding. All but the highest levees are flooded at least seasonally, which contributes fresh unweathered calcareous sediment to the profile.

Thus, buried Ah horizons and cumulic C horizons are common. Translocation of organic matter is not as prominent as in the coarser sands and gravels of the beach ridges, although one soil had well developed Bf horizons.

Soil, Landform and Vegetation Relationships

Physiographic controls on wetland and upland ecology and ecological succession models for the southwestern portion of the James Bay Coastal Zone have been discussed by Martini et al. (1980) and Wickware et al. (1980).

Figure 6 is a schematic cross section (toposequence) through the southwestern James Bay Coastal Zone. This figure summarizes relationships among soils, vegetation physiognomy and landforms. It can be compared with Figures 3a-c for soil-profile characteristics. Figure 6 illustrates the two main soil-forming processes in the southwestern James Bay Coastal Zone. These are the podzolization of coarse sands and gravelly coarse sands on raised beach ridges, and the growth of thick organic deposits in swales between ridges. On the left of the diagram (i.e., nearest the coast) the landscape is dominated by upland and mineral soil wetland-type vegetation and soils. On the right (i.e., toward the interior), the landscape is dominated by organic landforms and soils along with associated peatland vegetation. With time (i.e., to the right), the dominant process is clearly the paludification of the landscape including all but the highest raised beach ridges (and river banks) and the domination by peatland landforms in the form of expansive fen and bog complexes.

The successional gradients over time for each landform unit are shown conceptually in Figure 7. This figure is derived from observations of vegetational physiognomy on similar landforms with increasing distance from the coast (i.e., toward the bottom of the diagram). This diagram indicates the vegetation-landform association for three major landform units: (1) raised beach ridges and river levees; (2) low-relief beach ridges, low levees and riparian edges; and (3) raised tidal flats, including peatland seepageways.

The successional gradients indicate an overall direction toward mature bog and fen complexes (Fig. 7). The vertical axis identifies the major vegetation units with an overall gradient from tidal and supratidal communities to marsh and graminoid communities to shrub-rich communities and, finally, to forest communities. The overall direction in the successional gradients in this diagram is toward mature bog and fen communities (i.e., from no peat, nutrient-rich to deep peat, nutrient-poor conditions).

It is not suggested that succession on all landform units results in treed bog communities. Rather, this is the hypothetical succession, given continually increasing peat depths and isolation from nutrient sources. Depending on local hydrological, chemical and landform relief controls, most of the communities could represent a "climax" community. The communities that are never maintained through time are the tidal and supratidal freshwater marsh (including "low shrub marshes") and, possibly, low shrub fen (which, at least, becomes more restricted in extent with time).

The first landform unit (furthest right along the horizontal axis) in Figure 7 begins as upland thicket vegetation on unweathered coarse sandy (beach ridges) to silt and silt loam (levee) soils. Upland mixed forests replace the thickets and eventually give way to upland coniferous forests. Soils are podzols (beach ridges) and brunisols (levees). These upland forests are sustained if the landform has sufficient relief, otherwise paludification results in a sequence from conifer swamp (Gleysols and Terric Mesisols) to treed bog (Terric to Typic Mesisols). Thus, the frequency of raised beach ridges appears to decrease toward the interior. However, this may also reflect the fact that fewer ridges were constructed during earlier stages of uplift, especially as the rate of uplift was higher in the past.

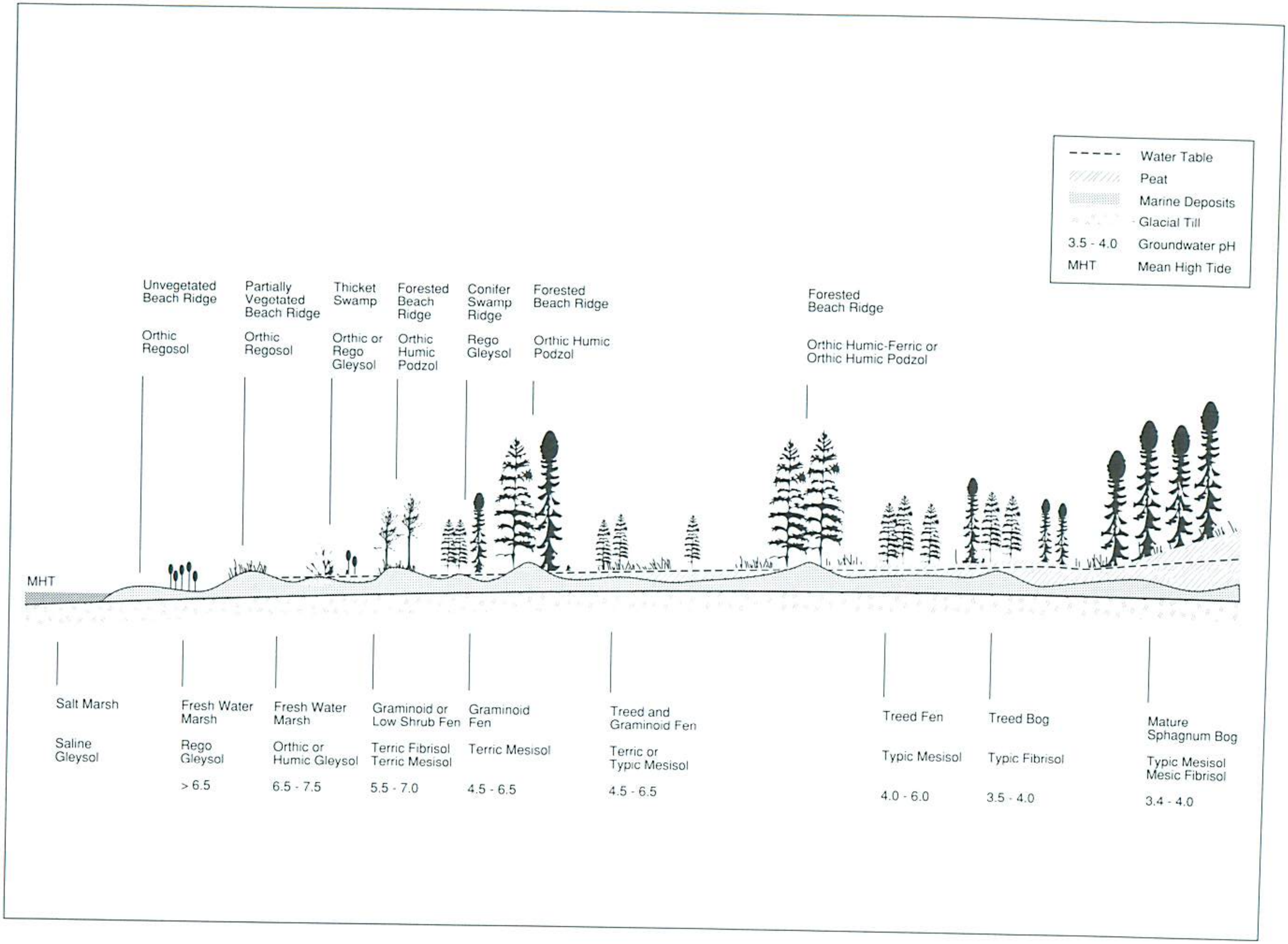

Figure 6. Schematic cross-section through the southern James Bay coastal zone.

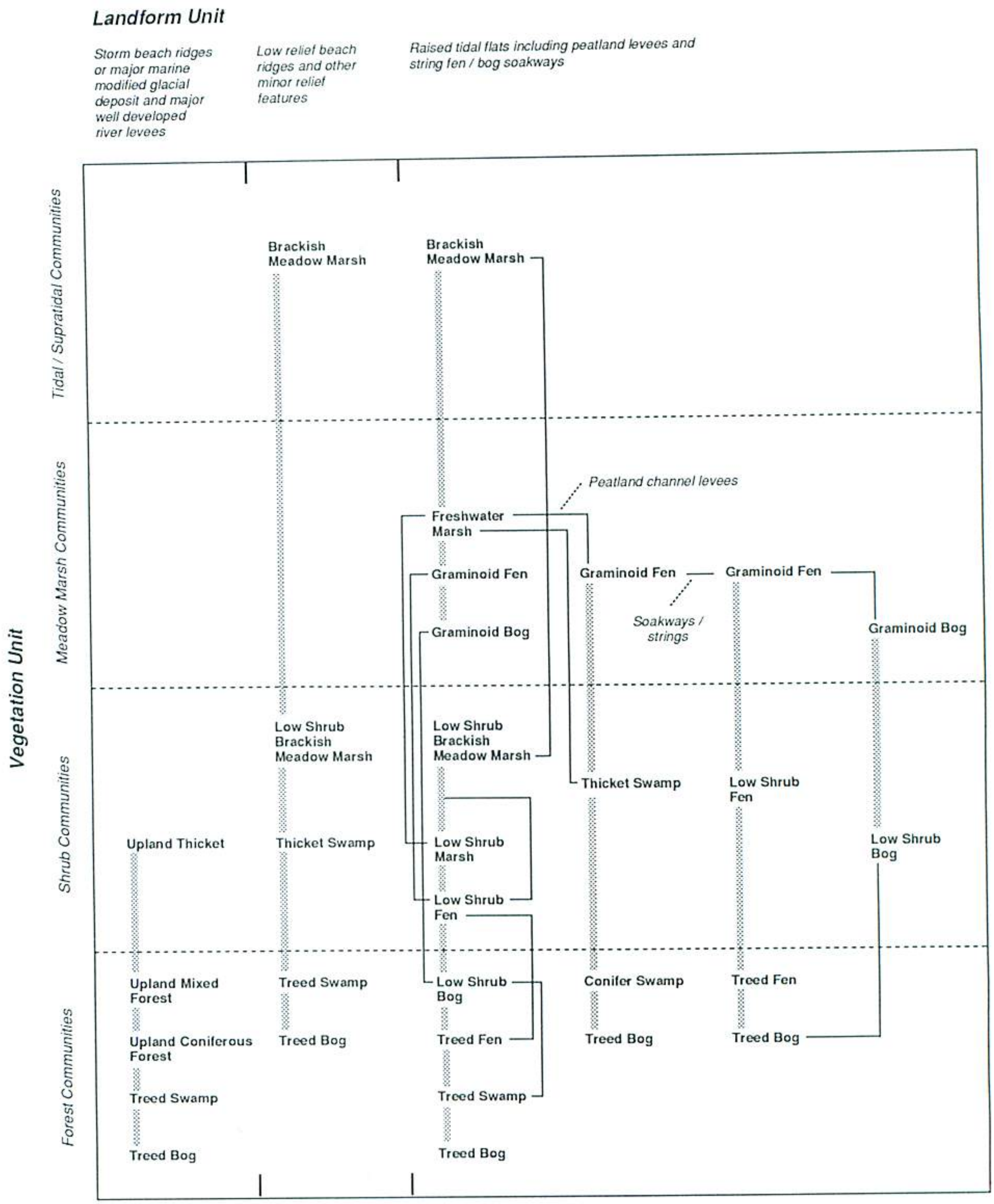

Figure 7. Vegetation-landform relationships, showing successional gradients with time and distance (from top downwards) from the coast. (Broader lines show main pathways, finer lines indicate common sequences that were observed in the field.)

A large beach ridge complex inland of the Coastal Zone, midway between the Moose and Albany rivers, supported a post-fire jack pine forest. The relief of the ridge was determined by means of a transit survey to be over 7 m in height. Likewise, river levees along the large rivers of the southwestern James Bay Coastal Zone may reach 7 to 10 m above river level.

The second landform unit in Figure 7 shows the successional development on low relief (i.e., <1-1.5 m) ridges and stream banks. These features are invariably completely paludified within the Coastal Zone. The only exception are streams that maintain sufficient flow to remain in contact with mineral material. These continue to support thicket swamp and/or treed swamp communities. Soils are predominately Rego Gleysols on permanently wet sites such as riparian edges (thicket swamp), and Orthic Gleysols where some water-table fluctuation occurs, such as low stream banks (thicket swamp), low ridges (thicket swamp) and the uppermost tidal flats (brackish meadow marshes).

The third landform unit in Figure 7 is more complex in terms of its successional gradient. This landform includes the tidal flats and raised tidal flats that are the most extensive of landforms in the HBL. The complexity is a result of the development of wide expanses of peatland and the development of peatland drainageways (patterned fens, soakways, seepageways). Specific peatland physiognomic types that develop (e.g., graminoid fen and bog, treed fen and bog, shrub bog) are controlled by peatland dynamics, influenced by local relief features (ridges, levees, rock outcrops) that affect drainage and nutrient supply.

Generally, soils evolve from Orthic Regosols (brackish meadow marsh) through Rego Gleysols-peaty phase (freshwater marsh) to Terric and Typic Mesisols (shrub, graminoid, treed fen and bog).

SUMMARY AND CONCLUSIONS

Soils of the southwestern James Bay Coastal Zone are diverse, with representation from the Organic, Podzolic, Brunisolic, Regosolic and Gleysolic orders. Gleysols and organic soils are the most widespread types in the southwestern James Bay Coastal Zone. Gleysols are found within the active shore zone and immediately inland in the broad freshwater marshes, as well as on stream banks and low river levees that develop along the dense, parallel drainage network of the HBL's Coastal Zone. Marsh gleysols give way to organic soils of the expansive fen and bog complexes of the emerged Coastal Zone and mature HBL.

Regosolic, brunisolic and podzolic soils characterize the many beach ridges of the HBL. Humic podzols are formed within a thousand years of uplift from the shore zone, almost the same amount of time it takes to establish a closed spruce forest and 15 cm of litter and humus. Brunisols are most prevalent on the most developed levees.

The soil subgroup level of classification is not suitable for distinguishing among physiognomic groups of the southwestern James Bay Coastal Zone. This is particularly true with regard to the peatland physiognomic types. The youthful nature of these deposits within the Coastal Zone results in thin, weakly decomposed peats, most of which are classified as Terric Mesisols.

Peat type and sequences are more descriptive of vegetation physiognomy (Fig. 3). As with the mineral soils, parent material is the most relevant variable in relation to vegetation physiognomy. Hence, classification of the HBL soils to at least the Family level for upland soils and Series level for peatland soils would differentiate the physiognomic types that have been identified. These types are readily interpretable on medium-scale aerial photography, and thus soil-landform-vegetation information should be readily obtainable from remote-sensing sources.

The potential for productive forest stands is very low because of the regionally high water table and associated paludification of all but the highest landform features. High-quality forests are restricted to high-relief raised beach ridges and river levees, which together constitute less than 10 to 15% of the southwestern James Bay Coastal Zone.

Soils within the Coastal Zone of the HBL are extremely dynamic. The climate of the study area is temperate and has not varied greatly during the 7,000 to 8,000 years since the area first emerged from the Tyrrell Sea. The land base is young, but displays a time gradient perpendicular to the coast. Such conditions provide an excellent opportunity to study oxidation, eluviation, illuviation and humification processes as well as the effects of relatively rapid organic accumulation.

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