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Registro palinológico del Holoceno y formación de turberas al noreste de Manitoba

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Résumé de l'article

Dans le nord-est du Manitoba, les tourbières occupent de vastes superficies peu accidentées et dont le substrat est imperméable. L'épaisseur de la tourbe varie entre 25 et 400 cm. À travers la région, le volume de tourbe moyen est de 1,5 x 10^6 m^3/km^2. Les principaux types de tourbières sont les tourbières minérotrophes, les plateaux palsiques arborés et les plateaux palsiques à polygones. Les dépôts les plus épais se trouvent dans les tourbières ombrotrophes à *Sphagnum* qui se sont développées sur des silts glaciolacustres ou marins. Des dépôts plus minces sont constitués de tourbe calcique ou de tourbe acide développées sur le till sableux. Il existe une relation positive entre l'épaisseur de la tourbe et le temps écoulé depuis l'émersion postglaciaire. On note également que les terrains récemment émergés sont dominés par la tourbe calcique, tandis que la tourbe acide est plus répandue sur les surfaces plus anciennes. L'analyse pollinique des carottes montre que les épinettes abondent depuis 6300 années. Des changements localisés quant au type de tourbe et à son taux d'accumulation résultent probablement de la variation du niveau de la nappe phréatique attribuable à la progression ou la dégradation du pergélisol. D'autres taxons caractéristiques des forêts boréales ont occupé des habitats semblables à ceux d'aujourd'hui, mais l'étendue des tourbières ombrotrophes et minérotrophes s'est accrue au fur et à mesure de l'entourbement .

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HOLOCENE POLLEN RECORDS AND PEATLAND DEVELOPMENT, NORTHEASTERN MANITOBA*

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ABSTRACT Peatlands cover extensive parts of northeastern Manitoba that have low relief and impermeable substrates, with peat thicknesses varying between 25 and 400 cm. Peat reserves average 1.5 x 10^6 m^3/km^2. Fens, forested plateau bogs, and polygonal plateau bogs are the prevalent peatland types. The thickest peat deposits consist of *Sphagnum* bogs that developed on glaciolacustrine or marine silt. Thinner deposits are composed of fen peat, or bog peat developed on sandy till. There is a positive relationship between peat thickness and time since postglacial emergence of the land. Also, recently emerged areas are dominated by fen peat, whereas bog peat is more prevalent on older surfaces. Pollen analysis of peat cores show that spruce trees have been abundant in the region south of Churchill for the past 6300 years. Local changes in peat type and accumulation rate occurred as bog and fen habitats changed, probably in response to changes in water table induced by aggradation and degradation of permafrost. Other taxa typical of boreal forest occupied suitable habitats similar to today, with bog and fen habitats increasing as paludification continued through time.

RÉSUMÉ *Les données polliniques de l'Holocène et le développement des tourbières, dans le nord-est du Manitoba.* Dans le nord-est du Manitoba, les tourbières occupent de vastes superficies peu accidentées et dont le substrat est imperméable. L'épaisseur de la tourbe varie entre 25 et 400 cm. À travers la région, le volume de tourbe moyen est de 1,5 x 10^6 m^3/km^2. Les principaux types de tourbières sont les tourbières minérotrophes, les plateaux palsiques arborés et les plateaux palsiques à polygones. Les dépôts les plus épais se trouvent dans les tourbières ombrotrophes à *Sphagnum* qui se sont développées sur des silts glaciolacustres ou marins. Des dépôts plus minces sont constitués de tourbe calcique ou de tourbe acide développées sur le till sableux. Il existe une relation positive entre l'épaisseur de la tourbe et le temps écoulé depuis l'émersion postglaciaire. On note également que les terrains récemment émergés sont dominés par la tourbe calcique, tandis que la tourbe acide est plus répandue sur les surfaces plus anciennes. L'analyse pollinique des carottes montre que les épinettes abondent depuis 6300 années. Des changements localisés quant au type de tourbe et à son taux d'accumulation résultent probablement de la variation du niveau de la nappe phréatique attribuable à la progression ou la dégradation du pergélisol. D'autres taxons caractéristiques des forêts boréales ont occupé des habitats semblables à ceux d'aujourd'hui, mais l'étendue des tourbières ombrotrophes et minérotrophes s'est accrue au fur et à mesure de l'entourbement .

RESUMEN *Registro palinológico del Holoceno y formación de turberas al noreste de Manitoba*. Las turberas cubren grandes zonas al noreste de Manitoba, éstas se caracterizan por un relieve bajo y substratos impermeables, con un grosor de musgos que varia entre 25 y 400 cm. La reserva de turba cubre alrededor de 1,5 x 106 m^3/km^2. Los principales tipos de turba son del tipo minerotrófica, de mesetas pantanosa forestal y de meseta pantanosa poligonal. Los depósitos más gruesos se encuentran en las turberas ombrotrófica de Sphagnum que se desarrollaron sobre limo glaciolacustre o marino. Los depósitos más delgados están constituidos de turba calcárea o de turba ácida desarrollada sobre limo arenoso. Existe una relación positiva entre el grosor de la turba y el tiempo transcurrido desde que sucedió la emersión postglaciar. Además, las zonas de emersión reciente están dominadas por turba calcárea mientras que la turbera ácida es más frecuente en áreas más antiguas. El análisis palinológico de muestras de turba pone en evidencia la presencia de abetos que fueron abundantes en la región sur de Churchill hace unos 6300 años. Los cambios locales en el tipo de turba y en la taza de acumulación ocurrieron a medida que las turberas calcáreas o pantanosas cambiaron, probablemente en respuesta a cambios del manto freático provocados por la elevación y degradación del gelisuelo. Otros taxa típicos del bosque boreal ocuparon hábitats similares al actual, con turberas ombrotróficas y minerotróficas que se fueron extendiendo a través del tiempo.

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INTRODUCTION

Coastal areas of northeastern Manitoba are part of the Hudson Bay Lowlands, one of the most extensive peatland areas on the globe. Past work in the area has focussed on identification of peatland forms (Radforth, 1969), terrain development on the York Factory Peninsula (Tarnocai, 1982), and general descriptions of peat in nearby areas (Klassen, 1986). A small inset map of peatlands was included in a geology report of northeastern Manitoba (Dredge and Nixon, 1992); thermal conditions of the peatlands and the evolution of thermokarst ponds were also described in that report (Dredge and Nixon, 1992). More recently, Rouse *et al.* (1995) considered methane emissions in wetlands at Churchill, and Kuhry (1998) interpreted macrofossils in two peat sections south of Churchill, For this study, several peat cores along the powerline right-of-way to Churchill have been made available by Manitoba Hydro. These cores lie near the northern limit of trees, and provide a record of vegetation changes in the area.

This paper describes the general distribution, thickness, and types of peatlands in northeastern Manitoba. The results of analyses on radiocarbon-dated pollen-profiles from the Hydro cores give insight into the vegetation succession of the region and the timing of these changes. Together with data presented on peat thickness, they provide information needed to address issues relating to climate change, such as whether or not organic terrain acts as a carbon source/sink that could affect global warming.

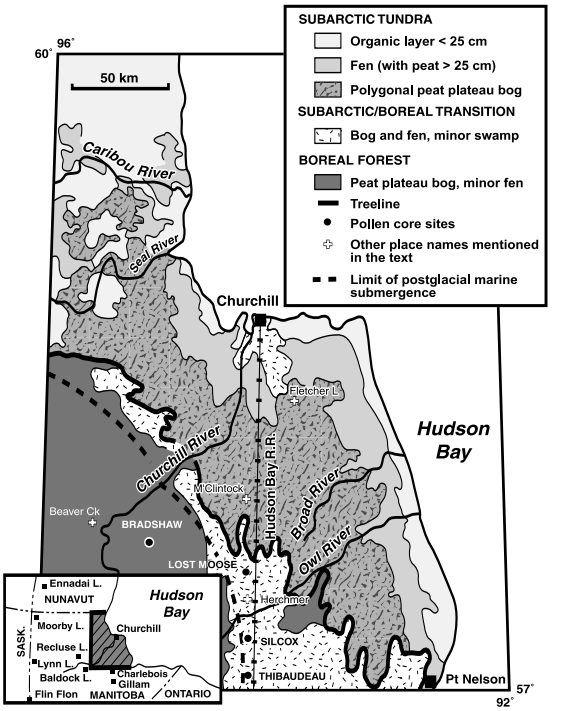

FIGURE 1. Vegetation zones, peat areas, and peatland classes in northeastern Manitoba. Terminology after Zoltai *et al.* (1988) and Warner and Rubec (1997).

Les zones de végétation, les espaces couverts de tourbières et les types de tourbières dans le nord-est du Manitoba. Terminologie d'après Zoltai et al. *(1988) et Warner et Rubec (1997).*

THE PEATLAND ENVIRONMENT

GEOLOGIC SUBSTRATES AND TIME CONTROLS

The area depicted in Figure 1 consists of plains that rise gently from sea level to an elevation of about 210 m in the west, although there are spot heights of 250 m. Below an elevation of 110 m, the land slopes uniformly at a rate of about 1 m/km. Above this elevation, relief is less regular, and rises at a rate closer to 3 m/km. The relief and substrate are controlled by deposits of the last glaciation and the postglacial period. Areas north of Seal River were covered by south-flowing glaciers that deposited a permeable sandy granitic till, while areas to the south were covered by ice from Hudson Bay that deposited less permeable silty, calcareous till. Relief features created by glaciers include small rib moraines north of Seal River, and larger, broad arcuate moraines, plus a few eskers farther south. The southwestern part of the region was later covered by Glacial Lake Agassiz, the water body that inundated the region as glaciers retreated. Lake Agassiz drained about 7800 radiocarbon years ago when the ice centre in Hudson Bay collapsed (Dredge and Nixon, 1992) leaving a layer of lake bed deposits of brown silt and clay. The rest of the area, which lies below an elevation of 140 m (the dashed line on Fig. 1), was initially inundated by the postglacial Tyrrell Sea. As the land rebounded from the glacial load, this sea regressed to its present position. Marine deposits, consisting of a sand layer underlain by silty clay or stony silt that filled in irregularities in the underlying topography, were exposed during marine regression. Raised beaches provide local relief, and a large raised beach complex built on an old moraine is a major landscape feature near the marine limit. The peatlands shown on Figure 1 correspond to the extensive areas of impermeable silty substrate that have low relief.

Radiocarbon dates on marine shells provide some control on the rate of land emergence at the sites in this paper. The sea level curve for this region (Dredge and Nixon, 1992) indicates that the Bradshaw site emerged 7800 radiocarbon years ago, as soon as Lake Agassiz drained, and the Thibaudeau, Silcox and Lost Moose sites emerged from the sea 7400, 7600 and 6800 radiocarbon years ago, respectively. These are the earliest possible dates for the beginning of vegetation growth and peat accumulation for the sites mentioned.

CLIMATE AND PERMAFROST CONDITIONS

Churchill experiences a maritime subarctic climate with an annual mean daily air temperature of -7.3 °C. Daily means range from 12 °C for July to -27 °C for January. The frost-free period is 110 days. Precipitation averages 412 mm at Churchill airport, about 235 mm of which falls as rain. Prevailing winds are from the northwest, both in winter and summer, at an average velocity of 21 km/h (Environment Canada, 1982). The

area is sufficiently cold that organic deposits do not readily decompose, but warm enough in summer to support healthy vegetation growth, and thus substantial peat accumulation over the region. The northeastern part of the area lies within the zone of continuous permafrost, with annual ground temperatures equilibrating at -4 °C in bedrock at Churchill, and at -1 °C in marine clay. Depth of thaw rarely exceeds 60 cm, particularly where dry peat is present. To the southwest, permafrost becomes discontinuous; where peat is dry and thick, permafrost is present, but it is absent where peat is thin or where there is standing water.

SURFACE VEGETATION

Regional descriptions of vegetation communities have been reported by Ritchie (1960a, b; 1962). Most of the area north of Seal River shown in Figure 1 is sparsely vegetated with subarctic herb-tundra communities. Farther south, the vegetation of the coastal area consists of wet meadows of grass and sedge. Moss-lichen-heath vegetation covers tundra areas inland from the coast (Kuhry, 1998). Clumps of stunted spruce cover small areas, and sedge is common along drainageways. An open shrub/scrub forest transition runs diagonally across the region, and an outlier with transition vegetation occupies the vicinity of Churchill. The isolated forest-tundra transition areas near Hudson Bay support patches of stunted forest, predominantly white spruce (*Picea glauca*), with some black spruce (*P. mariana*) and tamarack (*Larix laricina*) in wet areas (Rowe, 1972; Rouse *et al.*, 1995). In the open shrub/scrub forest transition farther inland, trees are more abundant and show better growth, with forest cover increasing until closed forests prevail.

The vegetation of the southwestern part of the study area is boreal forest. Black spruce is the dominant species on peat-covered landscapes, along with tamarack, whereas white spruce characterizes better drained upland areas and river banks with better drainage. Better drained sites may support some balsam fir (*Abies balsamea*), trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*) and white birch (*Betula papyrifera*). Among the shrubs, speckled alder (*Alnus incana rugosa*) and various species of willow (*Salix* spp.) are common, along with dwarf birch (*B. glandulosa*). Green alder (*A. viridis crispa*) occurs on some drier sites in the south and southwest. Sedges (Cyperaceae) and grasses (Gramineae) are common in sedge meadows and fens. An understory of Labrador tea-sphagnum-blueberry (*Ledum-Sphagnum-Vaccinium*) is widespread on peaty substrates.

PEAT TYPES, DISTRIBUTION AND THICKNESS

Peat deposits are the most abundant surficial material in the study area. The type and thickness of peat vary over the area shown in Figure 1. North of Caribou River, where sandy till, or till modified by postglacial marine processes is the main surface veneer, organics are localized, and take the form of shallow veneers commonly less than 5 cm thick. Between Caribou River and Seal River, organic terrain covers about half the land surface. Most peat deposits form flat fens (terminology of Zoltai *et al.*, 1988; Warner and Rubec, 1997) or wet meadow terrain, and are generally less than 25 cm thick, but some areas of thicker and more continuous raised peat plateau bogs, which contain ice wedge polygons, have thicknesses in the range of 100-150 cm.

South of Seal River, peat deposits cover most of the land surface. The thickness of peat varies considerably across the region but reaches a maximum measured thickness of 550 cm. Areally generalized peat thicknesses, based on cores from 400 sites, are shown on Figure 2.

Peat accumulation is thin within about 5 km of the modern coast (Fig. 2). An adjacent zone of flat fen meadows with local palsa fen is covered with peat that varies in thickness from about 25 cm closest to the coast, to 50 cm farther inland to the west. Maximum thickness is 150 cm. In this zone, peat is prevalent on relatively flat, fine-grained marine deposits, but is absent on beach ridges.

Farther inland, in areas north and east of treeline, the land surface is covered with polygonal peat plateau bogs, extensive peat deposits whose surfaces are incised by ice wedge polygons and dotted with shallow thermokarst ponds that do not penetrate into the underlying mineral substrate. The shape and size of the ponds change from year to year as a result of

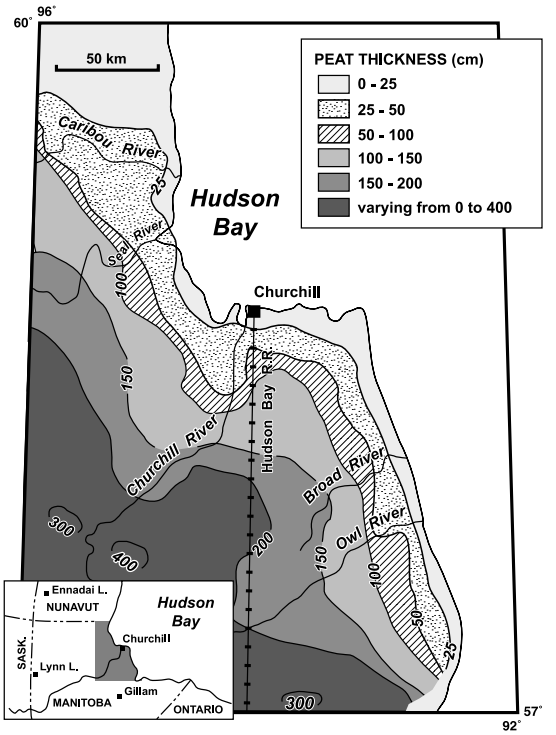

FIGURE 2. Generalized peat thicknesses in northeastern Manitoba, based on data at 400 sites.

Épaisseur généralisée de la tourbe dans le nord-est du Manitoba, fondée sur les données provenant de 400 sites.

the aggregation or degradation of massive ground ice. The peat surface is exceedingly wet in spring, but tends to dry out in summer. Bogs with thicknesses between 50 to 200 cm (maximum 300 cm) cover most of the area, although fens with shallower peat occupy drainageways.

Peat deposits in the southwestern boreal forest area form extensive areas of relatively dry forested plateau bogs interspersed with wet areas with floating bog mats or with fens. String fens, ribbed fens and swamps are common in the transition area near tree line. The thickness of peat is highly variable. Peat is thin or absent over old moraine ridges, eskers, and raised beaches, but is as much as 4 m thick in flatter areas underlain by glaciolacustrine clay. Peat thicknesses in the range of 50 to 150 cm were commonly encountered during coring operations.

Based on the thickness map (Fig. 2) and the ecotones, the peat reserves for the region can be estimated. The coastal zone, with 0-10 cm thickness of peat contains an estimated peat volume of <0.1 x 10^6 m^3/km^2. The volume of thicker peat in the fen zone is estimated at 0.37 x 10^6 m^3/km^2, and in the polygonal peat plateau zone at 1.5 x 10^6 m^3/km^2. In the boreal zone where peat thicknesses are highly variable, reserve estimates range from 0.2 x 10^6 to 4.0 x 10^6 m^3/km^2, with a conservative average volume estimate of 1.0 x 10^6 m^3/km^2.

Some insight into peat accumulation rates can be gained from the age/depth relationships for Lost Moose, Thibaudeau and Silcox sites (Fig. 3). The initial rate at Thibaudeau is 0.054 cm/yr, declines above 60 cm depth to 0.007 cm/yr, and increases in the top 40 cm to 0.034 cm/yr. The basal 32 cm at Silcox of 0.015 cm/yr increases in the upper 40 cm to 0.035 cm/yr, similar to the upper value at Thibaudeau. Lost Moose site has an accumulation rate of 0.026 cm/yr in the basal peat. The rate decreases between 70 and 52 cm to 0.011 cm/yr, increases sharply between 52 and 42 cm to 0.076 cm/yr, and increases further in the upper peat to 0.144 cm/yr.

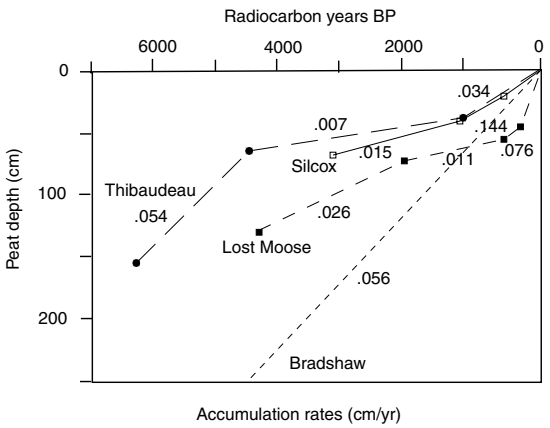

FIGURE 3. Peat accumulation rates in cm · yr^{-1}.
Taux d'accumulation de la tourbe en cm · a^{-1}

POLLEN PROFILES

METHODS

For the regional mapping project (Dredge and Nixon, 1979a, b), peat was sampled using either a Hoffer coring device with a 2.5 cm core barrel, or a SIPRE (CRREL) power drill with an 8 cm diameter core barrel (Veillette and Nixon, 1980). The cores near the railway that are reported in this paper were drilled by Manitoba Hydro in 1984 with a SIPRE corer. The Bradshaw core, used for comparison, is from the earlier regional mapping project. The sediment stratigraphy of the cores was described by Manitoba Hydro when the cores were extruded. When subsamples for pollen analysis were removed several years later it was noted that some shrinkage had occurred, probably as a result of desiccation. Any discrepancy noted in the length of the cores at the time of subsampling was justified by relating the stratigraphy and subsampling position to the field measurements.

A 1 cm^3 volume of peat determined by displacement of water in a graduated cylinder was used for all treatments, as the peaty sediments were too friable to otherwise measure a volume. A measured volume of exotic pollen (*Eucalyptus globulus*) suspension was added to each sample prior to treatment using a hypodermic syringe (Benninghoff, 1962). The concentration of the exotic mixture was determined by an haemacytometer as 102 700 grains/cm^3. Chemical treatment of each sample involved digestion in concentrated hydrofluoric acid, 10 % potassium hydroxide, dilute hydrochloric acid (10 % and 50 %), dilute nitric acid (10 %) and acetolysis (a 9 : 1 ratio of acetic anhydride to sulphuric acid) followed by dehydration in tertiary butyl alcohol. The residue was stored in glass vials with silicone oil until microscopic analysis.

A minimum of 300 pollen grains and spores was identified and counted. Pollen percentages were calculated using a pollen sum (a minimum exceeding 100 grains) excluding Cyperaceae pollen and all spores, which were so high that they overwhelmed values of the other taxa used in interpretation. Pollen accumulation rates (PAR) were calculated based on the sum of the taxa used for percentage calculations, and the radiocarbon dates available for each site. Pollen diagrams were plotted using the programs TILIA and TILIAGRAPH (E. Grimm, Illinois State Museum, Springfield, Illinois).

Conventional radiocarbon dates on peat (5 or 10 cm increments) and wood included in this report were provided by the Geological Survey of Canada Geochronology Laboratory (Table I and pollen diagrams). All dates used throughout are in radiocarbon years BP The emergence times in Table I include a 400 year marine reservoir correction on normalized ages on marine shells.

RESULTS

Overall, peat cores taken during the regional mapping program were found to contain large amounts of dark brown fibrous sphagnum peat, with a layer of sedge peat and/or wood at the base. In polygonal peat plateau bogs, however, interlayers of sphagnum peat and amorphous, yellowish sedge peat were commonly encountered. The peat contained large amounts of segregated ice and ice coated particles, with a

TABLE I

Radiocarbon dates on peat samples for sites shown on Figure 1

Locality (elevation m)	Depth (cm)	Material	^{14}C date	Lab number	Accumulation rate (cm/yr)	Comments	Emergence time (yrs BP)
Lost Moose (110 m)	40-45	Peat	290 ± 80	GSC-5321	0.144	Spruce to Sphagnum	
	50-55	Peat	420 ± 90	GSC-5226	0.076	Start of Ericaceae	
	68-73	Peat	1990 ± 70	GSC-5284	0.011	End of Cyperaceae	
	125-135	Peat	4270 ± 70	GSC-5221	0.026	Basal date	6800
Silcox (135 m)	20-25	Peat	550 ± 50	GSC-5265	0.045	End of Cyperaceae	
	38-43	Peat	1010 ± 60	GSC-5266	0.035	Start of Cyperaceae	
	65-70	Peat	3120 ± 60	GSC-5245	0.015	Basal date	7600
Thibaudeau (125 m)	15-20	Peat	–			Graminae spike	
	38-43	Peat	1140 ± 80	GSC-5219	0.034	Spruce to Sphagnum	
	65	Wood	4560 ± 110	GSC-5285	0.007	Spruce wood layer	
	150-160	Peat	6240 ± 80	GSC-5213	0.054	Basal date	7400
Bradshaw (215 m)	350	Peat	6280 ± 90	GSC-5240	0.056	Basal date	7800
Herchmer (105 m)	165-170	Peat	5970 ± 90	AECV-1715		Kuhry, 1998	6700
M'Clintock (85 m)	160-166	Wood	5810 ± 90	AECV-1718		Kuhry, 1998	5800
Fletcher L (49 m)	324	Peat	3430 ± 60	GSC-3988		Blake, 1986	3800
Beaver Ck	400	Peat	5960 ± 100	BGS-980		Dredge and Nixon, 1992	7800
Charlebois (100 m)	unknown	Peat	6280 ± 80	GSC-2760		Dredge and Nixon, 1992	6600

Other dates from basal peat in northern Manitoba

Site	^{14}C date	Lab number	Elevation (m)	Location	Reference
Recluse Lake	6490 ± 170	GSC-1738	185	56° 52' N; 95° 47' W	Lowdon and Robertson, 1977
Baldock Lake	6920 ± 150	GSC-1818	305	56° 21' N; 97° 57' W	McNeely and Mott, 1973; Lowdon and Blake, 1975
Moorby Lake	6040 ± 80	GSC-2759	190	59° 28' N; 101° 13' W	Lowdon and Blake, 1979
Flin Flon	8080 ± 150	GSC-1825	305	54° 45' N; 101° 41' W	Lowdon and Blake, 1975
Lynn Lake	6530 ± 130	WIS-72	–	56° 50' N; 101° 03' W	Nichols, 1967
Ennadai Lake	5780 ± 100	WIS-67	–	60° 50' N; 101° 30' W	Nichols, 1967

layer of massive ice 3-4 cm thick separating peat from mineral substrate.

Thibaudeau (core 127B)

Stratigraphy. The Thibaudeau site is the most southerly of the five sites studied and is located in an area of forest/tundra (57° 4.5' N; 94° 9.5' W; Fig. 1) at an elevation of 125 m. The top 11.5 cm of the 160 cm core is dark brown fibrous peat that overlies brown fibrous peat to 30 cm. From 30 cm to a sharp contact at 55 cm the peat is mossy and black to dark brown. Well decomposed black peat occurs from 55 to 135 cm. A piece of wood at 65 cm used for dating was identified as *Picea* spp. (spruce) (GSC Wood Identification Report 90.82, unpublished). Dark brown to black peat occurred below 135 cm to the base of the core at 160 cm. The substrate is grey clayey silt.

Palynology. Pollen results shown in Figure 4 are based on 29 samples taken at 5 cm intervals, except for the basal two samples, which were 15 cm apart. Three pollen zones have been delineated, based on the contrast between bog and fen dominated assemblages. Zone T-I, although having high but declining percentages for *Picea* (spruce), is characterized by low Cyperaceae (sedge) and Poaceae (grass) pollen and abundant *Sphagnum* spores and some bog taxa, *i.e.* Ericaceae (heath plants). Zone T-II has somewhat greater values for *Picea*. Cyperaceae pollen is abundant, whereas *Sphagnum* spore percentages are lower. *Sphagnum* spores increase in zone T-III along with Ericaceae and Poaceae pollen and *Picea* declines to its lowest percentages. *Picea* pollen percentages from 50-65 % dominate throughout except for the upper 20 cm where levels drop to below 40 %. *Pinus* (pine) grains rarely exceed 20 %, and *Betula* (birch) and *Alnus* (alder) rarely

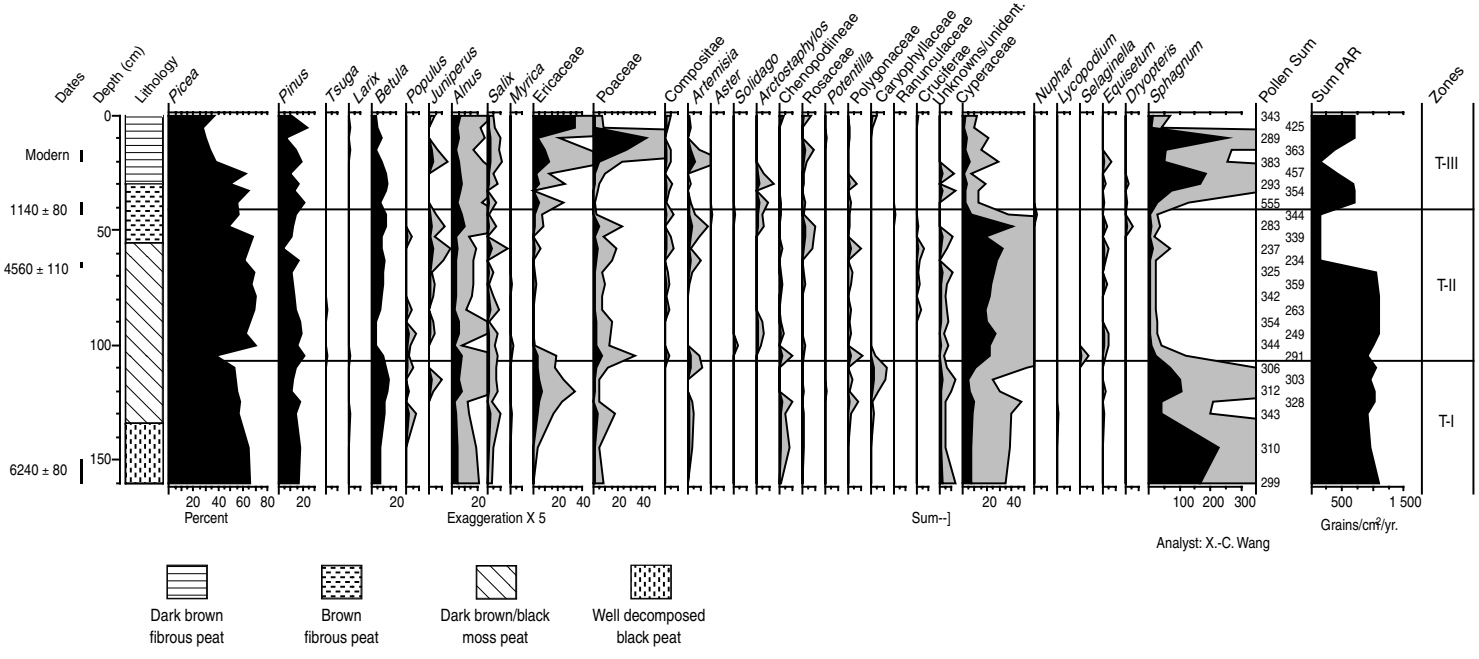

FIGURE 4. Summary pollen percentage diagram for Thibaudeau site, peat core 127B, Manitoba. Shaded curves are X5 exaggerated.

Diagramme abrégé des pourcentages polliniques du profil Thibaudeau, carotte 127B. Les courbes tramées sont exagérées 5 fois.

exceed 10 % and 5 % respectively. Other tree taxa have values of <1 %. Among the shrub taxa, Ericaceae pollen is most abundant near the top of the core, where it reaches about 30 %. Other shrubs are represented by values of <1 %. Cyperaceae percentages are low (<10 %) below 110 cm but rise to about 20 % before declining to around 5 % above 50 cm depth. Poaceae pollen values reach peak levels of 40 % at 10 cm below the surface. There are trace levels of other herb pollen including *Artemisia* (sage). *Sphagnum* (sphagnum moss) spore representations are exceedingly abundant below 100 cm and between 10 and 35 cm, but are very low between these intervals. Other spores occur in low numbers.

The Thibaudeau site shows pollen accumulation rates (based on pollen sum) in zone T-I and part of T-II of approximately 1 000 grains/cm^2/yr. Rates decline dramatically at the top of T-II. The abrupt decline coincides with a layer of brown peat whose undecomposed, fibrous nature suggests a rapid rate of accumulation, and probably a short time interval. PARs increase in zone T-III, but there is not enough chronological control in the upper 40 cm of the profile to provide reliable pollen accumulation rates.

Silcox core 52

Stratigraphy. Silcox site is located less than 20 km north of Thibaudeau (57° 10.0' N; 94° 14.2' W) in a similar forest/tundra environment at an elevation of 135 m. The top 4 cm of this 76 cm core is slightly decomposed brown woody peat with deciduous leaf fragments. Between depths of 4 and 22 cm is a brown moss peat that is moderately decomposed. Below is 15 cm of yellowish brown moss peat that is slightly decomposed, overlying 3 cm of a more decomposed brown moss peat. Dark brown to black, lightly decomposed, fibrous peat from 40 cm to 56 cm depth is underlain by 9 cm of dark brown to black, highly decomposed, silty peat. The basal 11 cm of the core is grey silt with pebbles.

Palynology. The core was sub-sampled at 5 cm intervals, and 22 pollen and spore taxa were identified (Fig. 5). The Silcox and Thibaudeau profiles are characterized by the same taxa. The fluctuations of Cyperaceae pollen and *Sphagnum* spores, as well as the abundance of *Picea*, are seen in the three pollen zones shown in the profile. S-I has low values for Cyperaceae and relatively high percentages of *Sphagnum* with abundant *Picea*. *Picea* percentages remain high in zone S-II, but Cyperaceae increases and *Sphagnum* declines somewhat. Lower percentages for *Picea* in zone S-III accompany low Cyperaceae, higher *Sphagnum* and increased Ericaceae and Poaceae pollen. *Picea* percentages of 60 to 70 % in the bottom half of the profile decline to about 50 % above. *Sphagnum* spores are extremely abundant but variable throughout except where Cyperaceae pollen reaches a peak of >40 % at about 35 cm depth, where *Sphagnum* declines to approximately 10 %. At the top of the profile, Cyperaceae is replaced by increased amounts of Poaceae (up to 15 %) and Ericaceae (up to 30 %).

Pollen accumulation rates show a rising trend from the base of the profile to the top. This reflects increases in Ericaceae and Poaceae in the last 550 years. Although *Picea* percentages show a decline over the same period, the accumulation rates for *Picea* probably remained relatively stable.

Lost Moose core 128

Stratigraphy. Lost Moose site is approximately 35-40 km due north of Silcox site (57° 33.9' N; 94° 19.0' W) at an elevation of 110 m. The top 13 cm of undecomposed fibrous mossy peat overlies 9 cm of slightly decomposed dark brown peat. Light brown, fibrous mossy peat from 22-46 cm is underlain by 4 cm of dark brown woody peat. From 50 to 125 cm the dark brown to black peat is more decomposed and is underlain by 10 cm of well decomposed dark brown to black silty peat.

Palynology. Twenty eight samples from 5 cm intervals were analyzed for this 135 cm long core. In these samples 36 pollen and spore taxa exclusive of unidentified grains were identified and are profiled in Figure 6. Fluctuations in *Picea*, Cyperaceae, *Sphagnum* and Ericaceae characterize the three pollen zones in the profile. Zone LM-I has the highest percentages of *Picea*, and Cyperaceae pollen fluctuates around 20 %. Cyperaceae percentages decrease in the lower part of zone LM-II where *Picea* abundances are low, and decline as *Picea* increases again. *Picea* generally declines in zone LM-III as does Cyperaceae, whereas *Sphagnum* spores and Ericaceae pollen increase. In the lower part of the profile, *Picea* pollen is dominant, making up to 60 % of the assemblage. *Pinus* never reaches 20 %, *Alnus* remains <10 %, whereas *Betula* rarely exceeds 10 %. Cyperaceae fluctuates between about 10 and 20 %, and *Sphagnum* spores range between 10 and 12 %. All other taxa have minimal values. In the middle of the profile, *Picea* percentages decline to about 40 % or less as *Betula* reaches a peak of about 30 %. At 80 cm, Cyperaceae reaches a peak of 55 % and then declines to much lower levels. *Sphagnum* levels are less than 10 %. From 80 cm upwards, *Picea* increases to 50 % and then declines as Ericaceae increases to a peak of 35 % at 50 cm depth. *Sphagnum* then rises to extremely high percentages at 45 cm depth and remains abundant to the surface. *Picea* again rises at 35 cm depth to 45 % and then generally declines with fluctuating levels to the surface. Ericaceae also fluctuates, with a peak of 30 % near the surface. *Alnus* and *Betula* increase slightly toward the surface. Poaceae has somewhat higher values at some depths above 40 cm, whereas Cyperaceae percentages remain low.

Pollen accumulation rates at Lost Moose site are low in zone LM-I, decline in LM-II, and increase significantly in LM-III. The higher percentages in LM-III are influenced by the increase in Ericaceae.

Bradshaw site

Stratigraphy. The Bradshaw section (57° 41.8' N; 95° 9.5' W) is located in the boreal forest approximately 50 km to the northwest of the other sites, at an elevation of 215 m. A lakeside section exposed 350 cm of peat with the upper 100 cm being yellowish to light brown, poorly decomposed, fibrous moss peat and the lower 250 cm a light brown, slightly more decomposed, moss peat.

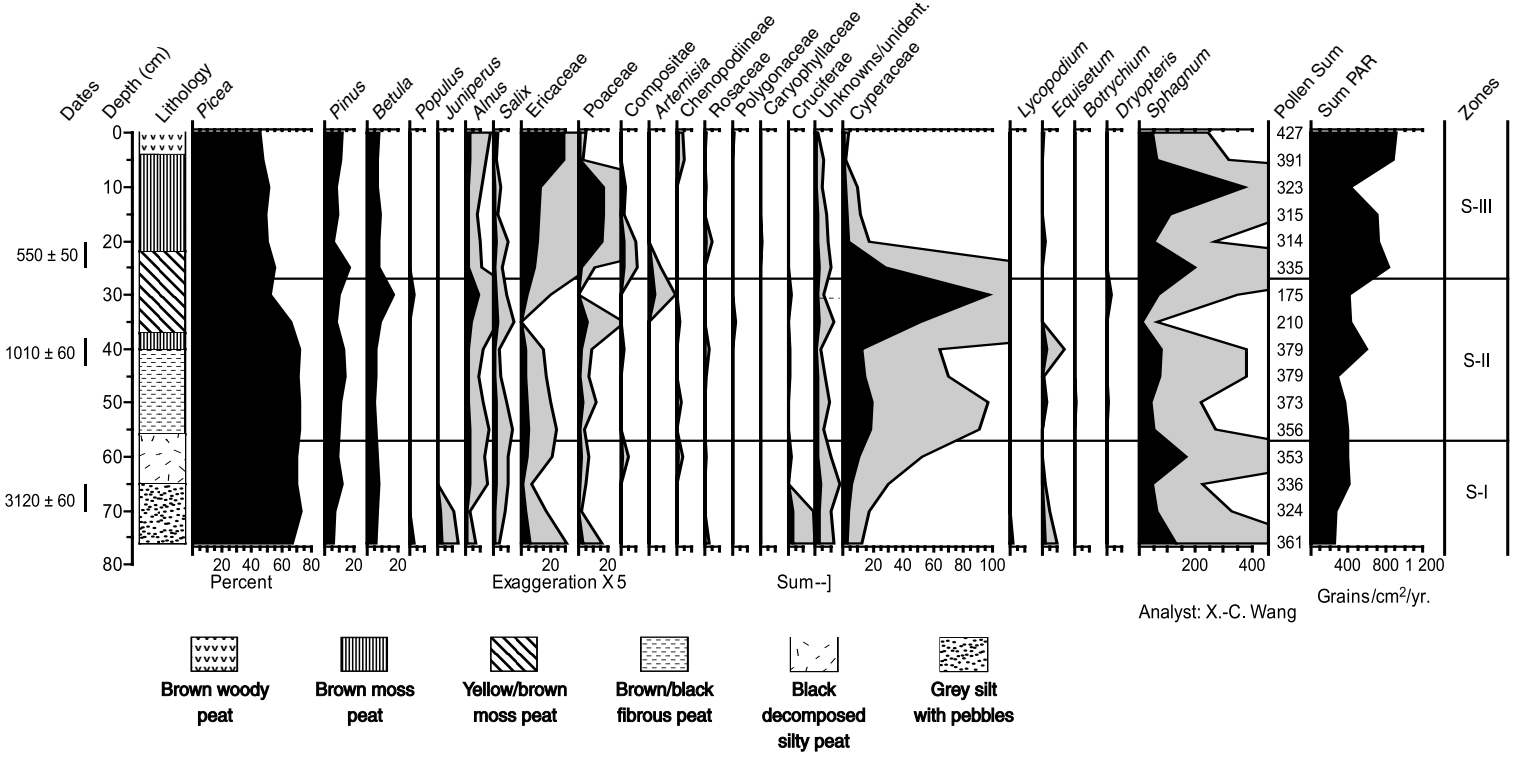

FIGURE 5. Summary pollen percentage diagram for Silcox site, peat core 52, Manitoba. Shaded curves are X5 exaggerated.

Diagramme abrégé des pourcentages polliniques du profil Silcox, carotte 52. Les courbes tramées sont exagérées 5 fois.

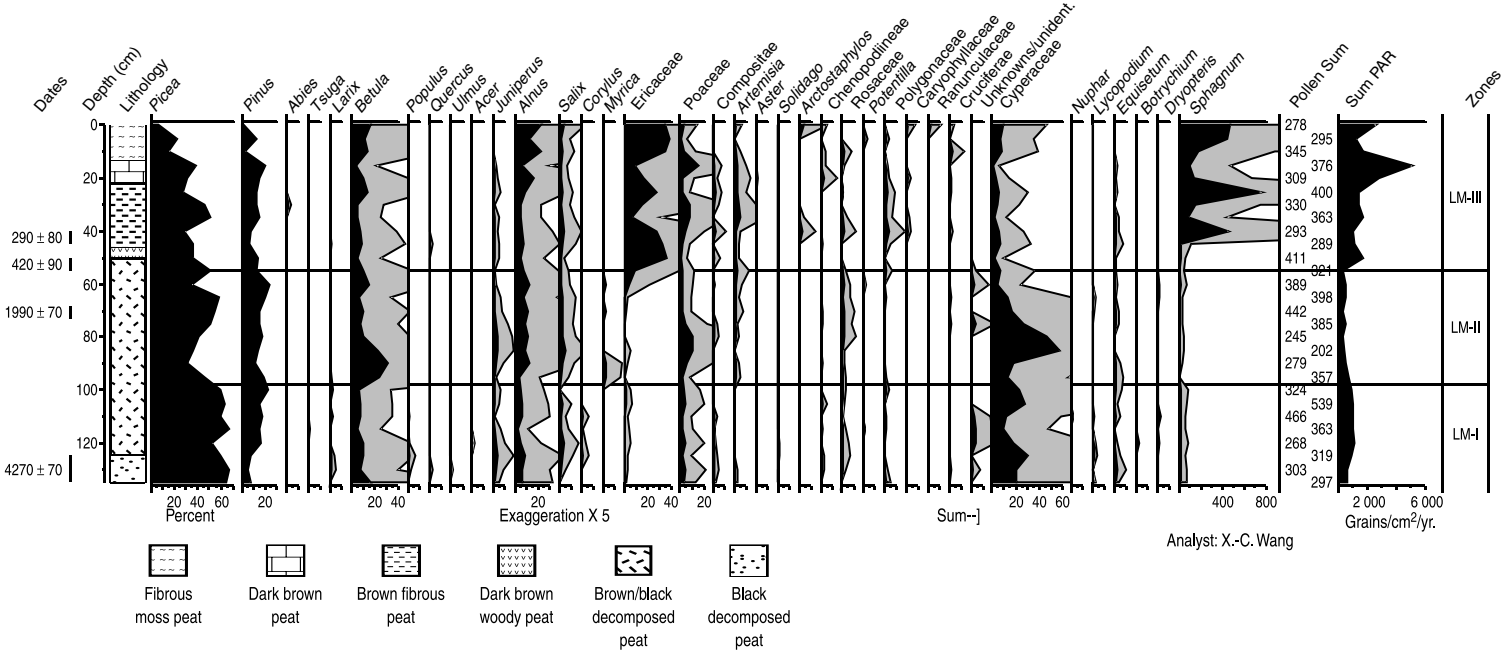

FIGURE 6. Summary pollen percentage diagram for Lost Moose site peat core 128, Manitoba. Shaded curves are X5 exaggerated.

Diagramme abrégé des pourcentages polliniques du profil Lost Moose, carotte 128. Les courbes tramées sont exagérées 5 fois.

Palynology. Eight bulk samples were collected from this exposed section at 50 cm intervals from the surface to 350 cm depth. Twenty four taxa were identified, as shown in Figure 7. The Bradshaw Lake Bog diagram was not zoned because of the lack of detail in the profile and the limited chronology. Some fluctuations in *Picea*, Cyperaceae pollen and *Sphagnum* spores are apparent as in the other profiles, but not enough levels were analyzed to judge the significance of these changes. The same taxa as the other sites characterize this forested peat plateau bog site. *Picea* is the dominant pollen taxon, ranging from about 30 % to more than 75 %. Its lowest level at 200 cm depth marks a peak in *Alnus* of about 40 % and a small peak in *Betula* of 15 % which otherwise show lower values. *Pinus* rarely exceeds 10 %, nor do the other characteristic pollen taxa Poaceae and Cyperaceae. Ericaceae percentages as well are low except at the surface where they reach 20 %. *Sphagnum* spores are extremely numerous except at the surface and 250 cm depth where they are 10 % or less.

Although good chronological control is not available for the Bradshaw site, pollen accumulation rates could be estimated using the basal date because the peat is fairly uniform. The lower part of the profile shows rates in the range of 500 to 800 grains/cm^2/yr. Above this the rates exceed 1 000 grains/cm^2/yr, but decline to 500 grains/cm^2/yr or less at the top of the profile.

INTERPRETATION

Pollen accumulation rates throughout the region are much lower than those seen at mid-latitudes, indicating the depauperate nature of the flora. The PAR data further indicate that spruce trees were the dominant taxon in the region. However, without more chronological control, especially for more recent times, it is difficult to say whether or not spruce trees increased or declined at any one site. For instance, Bradshaw Lake bog site is presently within a forested landscape and yet pollen accumulation rates are similar to those at Thibaudeau and Lost Moose sites, which are in the forest/tundra transition where spruce trees are stunted and less abundant. Silcox site has low pollen accumulation rates in zones S-I and S-II even though *Picea* pollen dominates the profile. Relative *Picea* percentages decrease in the upper part of the profile where pollen accumulation rates increase. This is partly due to increased Ericaceae and Poaceae, but the rates suggest that spruce trees remained as abundant as in lower zones, or increased somewhat. In contrast, PARs at both Lost Moose and Thibaudeau sites are lower near the tops of the profiles, coincident with declines in *Picea* percentages.

All sites show an abundance of *Picea* pollen from the earliest dated interval, suggesting that spruce trees were the dominant tree taxon throughout approximately the last six millennia. *Pinus* pollen, which rarely exceeds 20 %, can be attributed to long distance transport. Pine trees do not occur in the immediate vicinity of any of the sites which have *Pinus* percentages of 12 % or less. The nearest occurrences of pine trees are on dry ridge sites 50 km to the southwest. Therefore, although *Pinus* percentages approaching or slightly exceeding 20 % may indicate that pine trees were nearer to the sites in the past, they never became abundant, even in the southern part of the region. Low peaks in *Betula* and generally low *Betula* percentages throughout the profiles suggest that birch trees were never abundant but occupied small sites when conditions were suitable. Dwarf birch (*B. glandulosa*) may also account for some of the *Betula* pollen, as birch species were not identified. The low levels of *Alnus*, probably *A. incana rugosa* (speckled alder), indicate that this species was probably only locally abundant in habitats similar to those it occupies today. *Alnus* species were not differentiated, and it is possible that *A. viridis crispa* (green alder) may have been present on the drier upland sites. Percentages of other arboreal taxa are minimal, and may represent long-distance dispersal. Poplar/aspen, fir and tamarack in particular were never abundant and probably had occurrences similar to those at present.

Various shrubs, particularly willow, were present locally in low abundance throughout the postglacial. One exception is heath plants, which show increased abundance at almost all sites in the last several hundred years. This abundance coincides with extremely high values for *Sphagnum* spores, indicating a shift to bog conditions as opposed to wetter fen environments which are characterized by abundant sedges and grasses. Thibaudeau and Lost Moose sites show these shifts particularly well. The pollen accumulation rates also suggest a shift to bog conditions, with a decline in spruce trees locally as bogs became more prevalent.

DISCUSSION

CONTROLS ON PEAT DISTRIBUTION AND THICKNESS

Peat deposits dominate the landscape in this region, but they differ greatly in thickness, as can be seen from the data presented here. In areas of continuous organic terrain, peat ranges to 400 cm in thickness. On a regional scale, fen peat is considerably thinner (maximum 1.5-2 m) than bog peat (2-4 m). As well as peat type, the substrate type, topography, and time available for peat growth are other factors controlling thickness. For each major peatland class shown on Figure 1, peat is thickest on impermeable silty till, on glaciolacustrine clay and marine silt, and where terrain is flattest; data acquired through mapping shows that peat is thinnest on moraines and other sloping terrain, and absent on eskers, raised beaches, and sandy till.

There is some relationship between peat thickness and elevation above sea level, a measure of time available for peat accumulation since land emergence, although there is a considerable amount of site to site variation apparent on Figure 8, most of which is due to topographic factors. Areas near the coast that lie below an elevation of 15 m emerged less than 1500 years ago (Dredge and Nixon, 1992), and do not have substantive peat deposits, with peat thicknesses varying between 0 and 10 cm. Peat in areas between elevations of 15, 30, 60 , and 90 m that emerged about 1500, 2500, 4500, and 6000 years ago respectively, have corresponding increases in peat thicknesses from 25 to 50 to 100 to 150 cm respectively. Average peat thicknesses between elevations of 120 m and 140 m, the upper limit of postglacial marine emergence in the study area, are generally slightly lower, possibly because

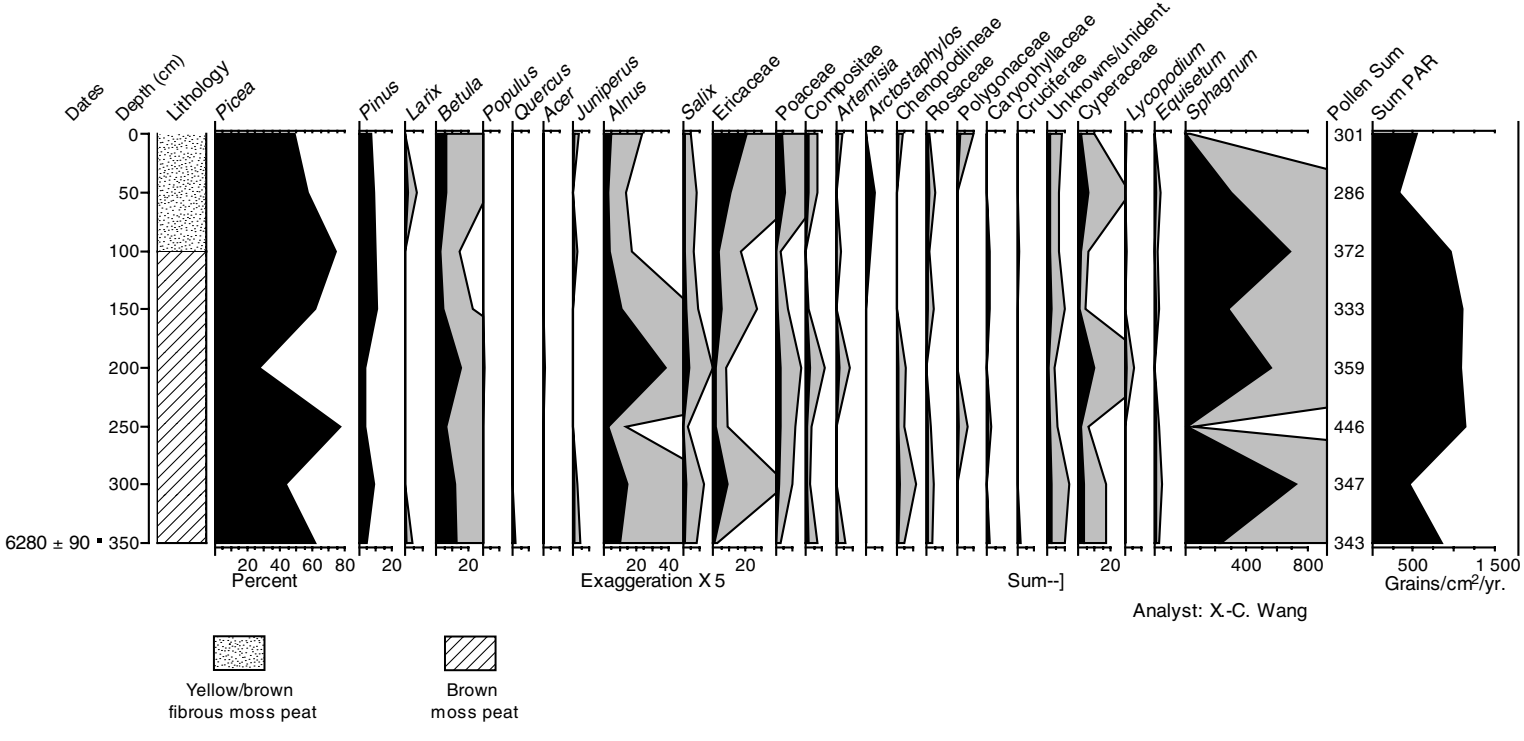

FIGURE 7. Summary pollen percentage diagram for Bradshaw Lake peat core, Manitoba. Shaded curves are X5 exaggerated.

Diagramme abrégé des pourcentages polliniques du profil Bradshaw. Les courbes tramées sont exagérées 5 fois.

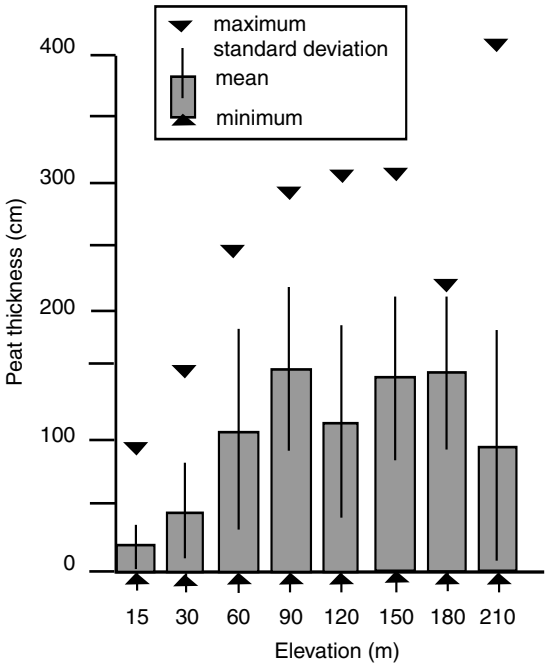

FIGURE 8. Measured peat thickness, plotted against height above sea level.

Relation entre l'épaisseur de la tourbe et l'altitude.

drainage is better due to a greater slope of the land, and the presence of large beach-ridge complexes. Above 140 m, peat thickness varies greatly due to local slope changes on broad moraines underlying Glacial Lake Agassiz clays.

Flat fens are the dominant peat type on terrain below an elevation of 30 m (*i.e.*, land that emerged less than 2500 years ago). Plateau bogs are common on older, higher terrain. This may be an areal expression of the same succession found in the vertical peat cores, discussed below. The time period for development of peat plateaus determined from the cores is similar to that proposed for development of bogs at Port Nelson (2000 years; Tarnocai, 1982), and the time of development of sphagnum bog at Herchmer (2200 years), although Kuhry (1998) attributed this change to climatic factors and permafrost development rather than to plant succession.

PEAT CORES

The peat cores show that time is only one of the factors controlling peat thickness. For instance, 160 cm of peat accumulated at the Thibaudeau site over a period of 6240 years, whereas 350 cm of peat accumulated at Bradshaw Lake bog over a similar period of time. These dated profiles indicate that peat type and rate of decomposition are also important; for example, at Bradshaw, fibrous moss peat predominates, whereas at Thibaudeau, more decomposed sedge peat comprises a considerable part of the core. When the peat accumulation rates on Figure 3 are compared to the pollen profiles, it is apparent that much faster rates of accumulation have occurred in the sphagnum peat than in the sedge peat. These findings are the opposite of those of Klinger and Short (1996), and Hilbert *et al.* (2000), who proposed faster accumulation rates in fens in their models for unfrozen peatlands, but the results of the present study are similar to those of Kuhry (1998) for this area, and for sites in northwestern Manitoba (Table I).

All sites studied emerged between 7800 radiocarbon years ago (Bradshaw site) and about 6600 years ago (Lost Moose site). Since the oldest basal peat ages are about 6300 years, it is possible that the oldest organic deposits were not recovered from the sites. Tarnocai (1982), for instance, suggested that peat is established within a period of 600 years from the time of emergence. The basal peat dates at M'Clintock, Fletcher Lake and Charlebois (Table I), also suggest peat development within the 600 year period. Nevertheless, although it seems improbable that pioneer vegetation did not invade the area for 1500 yrs after the land was exposed, the scarcity of peat within 15 m elevation of the modern shore shows that this time interval may be necessary for substantive peat deposits to accumulate.

The pollen profiles and the presence of wood in the basal sediments show that spruce trees were abundant in the region 6300 years ago and remained so to the present. Plant communities similar to those of the present also characterized the region throughout the entire time interval represented, with areas shifting from fen to bog as conditions changed locally. Areas covered by organic deposits must have increased as paludification continued over time. A change to bog from fen conditions in the last millennium is apparent in the pollen profiles for some sites as are increased accumulation rates seen in the age/depth curves (Fig. 3). This change could be attributed to natural vegetation succession, according to models proposed by Sjors (1963), Tarnocai (1982), and Klinger and Short (1996), among others. However, below this transition at Thibaudeau, Silcox, and Lost Moose, the shifts from fen to bog conditions seen in the pollen profiles and the age/depth curves are not consistent in sequence or timing from one core to another, suggesting that factors other than succession are acting here. Local changes in the water table may be particularly important (Hilbert *et al.*, 2000). Although water table changes could theoretically be possible as a response to regional warming and melting of ground ice, or increased precipitation, the data suggests that the changes observed in the cores reflect more local factors. We suggest that the changes may be caused by local aggradation and degradation of ground ice, together with the development of collapse scar ponds, at different times. Aggradation of permafrost would raise peat surfaces above their local water table, and encourage bog development, while local melting of ground ice would create water-filled collapse scar depressions, promoting fens. Drainage or infilling of the thermokarst ponds, effectively lowering the water table, would cause a reversion to bog conditions. Also, what appears to be widespread changes may reflect a bias in sampling bog areas rather than wet fens, which cannot be traversed.

No changes in tree line, expected due to Nichols' conclusions based on sites farther north at Ennadai Lake (Nichols, 1967; Fig. 1), are apparent from the profiles, even though tree line presently passes through the region. It is possible that vegetation zonation from tundra to boreal forest in this region is controlled by its proximity to Hudson Bay and not to regional continental Arctic air mass movements, as suggested for the tree line changes farther north and inland (Nichols, 1967; MacDonald *et al.*, 1993).

CONCLUSIONS

Similar vegetation to today has characterized the boreal forest region south of Churchill, Manitoba, for the past 6300 years. Peatlands developed on areas previously occupied by Glacial Lake Agassiz and the Tyrrell Sea. On a regional scale, fen peat colonized recently emerged land, and bog peat developed later. Both peat type and peat thickness are related to time available since land emergence, and peat thicknesses to 550 cm were measured on the oldest land surfaces. Local changes in peat type occurred as bog and fen habitats shifted. Spruce was the dominant tree from early time as boreal forest invaded the region, although pollen accumulation rates suggest that at some sites the abundance of spruce trees may have declined locally as bogs proliferated. Other taxa typical of boreal forest occupied suitable habitats similar to today, with bog and fen habitats increasing as paludification continued through time. The results show that the vegetation zones and habitats remained relatively stable for the past six millennia, although local variations in peat type and peat accumulation rate are common.

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REFERENCES

Benninghoff, W.S., 1962. Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. Pollen et Spores, 4: 332.

Blake, W. Jr., 1986. Geological Survey of Canada Radiocarbon dates XXV. Geological Survey of Canada, Paper 85-7: 10.

Dredge, L.A. and Nixon, F.M., 1979a. Thermal sensitivity and the development of tundra ponds and thermokarst lakes in the Manitoba portion of the Hudson Bay Lowland. Geological Survey of Canada, Current Research, Paper 79-C: 23-26.

_____ 1979b. Thaw depths and permafrost in polygonal peat terrain, Hudson Bay Lowland, Manitoba. Geological Survey of Canada, Current Research, Paper 79-C: 27-30.

_____ 1992. Glacial and Environmental Geology of Northeastern Manitoba. Geological Survey of Canada, Ottawa, Memoir 432, 80 p.

Environment Canada, 1982. Canadian Climate Normals, 1951-1980. Environment Canada, Ottawa, SI-1 and SI-2.

Hilbert, D.W., Roulet, N. and Moore, T., 2000. Modelling and analysis of peatlands as dynamical systems. Journal of Ecology, 88: 230-242.

Klassen, R.W., 1986. Surficial Geology of North-central Manitoba. Geological Survey of Canada, Ottawa, Memoir 419, 57 p.

Klinger, L.F. and Short, S.K., 1996. Succession in the Hudson Bay Lowland, Northern Ontario. Arctic and Alpine Research, 28: 172-183.

Kuhry, P., 1998. Late Holocene permafrost dynamics in two subarctic peatlands of the Hudson Bay Lowlands. Eurasian Soil Science, 31: 529-534.

Lowdon, J.A. and Blake, W. Jr., 1975. Geological Survey of Canada, Radiocarbon Dates. Geological Survey of Canada, Ottawa, Paper 75-7, 32 p.

_____ 1979. Geological Survey of Canada, Radiocarbon Dates. Geological Survey of Canada, Ottawa, Paper 79-7, 20 p.

Lowdon, J.A. and Robertson, I.M., 1977. Geological Survey of Canada, Radiocarbon Dates. Geological Survey of Canada, Ottawa, Paper 77-7, 25 p.

MacDonald, G.M., Edwards, T.W.D., Moser, K.A., Pienitz, R. and Smol, J.P., 1993. Rapid response of treeline vegetation and lakes to past climate warming. Nature, 361: 243-246.

McNeely, R. and Mott, R.J., 1973. Radiocarbon dates from northern Manitoba. Geological Survey of Canada, Paper 73-1B: 145-147.

Nichols, H., 1967. The post-glacial history of vegetation and climate at Ennadai Lake, Keewatin, and Lynn Lake, Manitoba. Eiszeitalter und Gegenwart, 18: 176-197.

Radforth, N.W., 1969. Airphoto interpretation of muskeg, p. 53-77. *In* I.C. MacFarlane, ed., Muskeg Engineering Handbook. University of Toronto Press, 297 p.

Ritchie, J.C., 1960a. The vegetation of northern Manitoba IV. The Caribou Lake region. Canadian Journal of Botany, 38: 185-199.

_____ 1960b. The vegetation of northern Manitoba VI. The lower Hayes River region. Canadian Journal of Botany, 38: 769-788.

_____ 1962. A geobotanical survey of northern Manitoba. Arctic Institute of North America, Montréal, Technical Paper 9, 32 p.

Rouse, W.R., Holland, S. and Moore, T., 1995. Variability in methane emissions from wetlands at northern treeline near Churchill, Manitoba. Arctic and Alpine Research, 27: 146-156.

Rowe, J.S., 1972. Forest Regions of Canada. Canadian Forestry Service, Ottawa, Publication 1300, 172 p.

Sjors, H., 1963. Bogs and fens on Attawapiskat River, northern Ontario. National Museum of Canada Bulletin, 186: 45-133.

Tarnocai, C., 1982. Soil and terrain development on the York Factory Peninsula, Hudson Bay lowland. Le Naturaliste canadien, 109: 511-522.

Veillette, J. and Nixon, M., 1980. Portable Drilling Equipment for Shallow Permafrost Sampling. Geological Survey of Canada, Ottawa, Paper 79-12, 35 p.

Warner, B.G. and Rubec, C.D., 1997. The Canadian Wetland Classification System. Wetlands Research Centre, University of Waterloo, 68 p.

Zoltai, S.C., Tarnocai, C., Mills, G.F. and Veldhuis, H., 1988. Wetlands of Subarctic Canada, p. 55-96. *In* S.C. Zoltai, ed., Wetlands of Canada. National Wetlands Working Group, Canada Committee on Ecological Land Classification, Environment Canada, Ottawa, Ecological Land Classification Series 24, 152 p.