

LANDSCAPE FEATURES, VEGETATION AND DEVELOPMENTAL HISTORY OF A PATTERNED FEN IN SOUTH-EASTERN LABRADOR, CANADA

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SUMMARY

(1) A general description of landforms, vegetation and environmental characteristics of Leech Lake Peatland, a patterned mire complex located on the Eagle Plain south-eastern Labrador, is presented. Particular emphasis is given to the developmental history of a minerotrophic mire, Leech Fen, and to the process of pattern (string-flark) formation.

(2) Nine floristic assemblages are recognized by the releve method. The nodes are characteristic of specific landforms related to a gradient of substratum height above the water table.

(3) The water chemistry is typical of poor fens: pH 4.7–6.1, $\text{Ca}^{2+} < 2.0 \text{ mg l}^{-1}$, conductivity $4.5\text{--}11 \mu\text{S cm}^{-1}$.

(4) Lateral water movement down the slope of patterned fens occurs through four pathways: sheet flow across the fen surface, surface flow in narrow channels along fen margins, surface flow in channels in strings, and percolation through near-surface layers of peat.

(5) The development of surface patterns is largely dependent on topography and water movement. Steep slopes with large inputs of water have terraces of alternating strings and deep pools, whereas gentle slopes or areas with little water movement are generally unpatterned. Substratum topography and the distribution of surface features are unrelated.

(6) The lower part of Leech Fen developed in a shallow bay of Leech Lake with the present shoreline stabilized by a forested ice-push ridge. In the upper part of the fen, peat growth progressed slowly up the slope. Most of the initial peat accumulation in the fen occurred after 4500 B.P. Sedges dominated the early vegetation, with shrubs increasing in importance later. Pattern formation did not occur until after the shrub vegetation had become established.

(7) A proposed process for the development of the surface pattern of strings and flarks includes three parts: (i) development of an irregular surface of hummocks and hollows, (ii) gradual expansion and joining of depressions across the slope controlled by differential rates of peat accumulation, (iii) expansion and coalescence of pools through active peat degradation, which can be observed in Leech Lake Peatland at present. Once formed, pools are permanent features on the mire surface in which degradative processes remove all allochthonous and autochthonous materials.

INTRODUCTION

Patterned fens (aapamires) are prominent landforms in the boreal and subarctic regions of North America, northern Europe and Siberia. Striking surface features on the mires consist of alternating peat ridges (strings) and depressions occupied by sparse, weakly peat-forming vegetation or by open water (flarks or pools). These features stretch across the slope perpendicular to the direction of water movement.

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With increasing latitude within the boreal zone there is a progressive replacement of a gentle string-flark pattern of slight relief by deep pools dammed by firm and robust strings. This trend is reversed in the far north where permafrost disrupts pattern development and the shorter growing season restricts the depth of peat accumulation.

Investigations of patterned fens in Fennoscandia have provided much of the terminology, and established numerous classification schemes for this mire type based on such characteristics as water chemistry, floristics, vegetation and the nature of the landforms (Sjörs 1950a; Ruuhijarvi 1960). Early Scandinavian investigators were primarily responsible for the discovery of the variety and extent of peatlands in central and eastern North America (Osvald 1928; Auer 1930; Wenner 1947; Sjörs 1959, 1961a, 1963, 1965; Kalela 1962, 1963).

Few studies, however, have been made on the development of patterned fens and the origins of the striking surface features. The prominence and diversity of peatlands on the Eagle Plain in south-eastern Labrador, Canada presented an opportunity to investigate pattern development in an undisturbed area. Leech Lake Peatland, the site chosen for investigation, is an extensive mire complex in which a variety of patterned fens as well as other mire types provide substantial variation in landforms, vegetation and developmental history ideally suited for the present study.

STUDY AREA

The Eagle Plain (350–450 m above sea level) lies centrally on the Mecatina Plateau which extends from the Gulf of the St Lawrence and the Labrador Sea to the edge of Lake Melville (Fig. 1) (Bostock 1970; Greene 1974). The plateau occupies the eastern part of the Precambrian Canadian Shield in which the bedrock is predominantly quartzo-felspathic gneisses with intrusions of granite and granodiorites (Greene 1974).

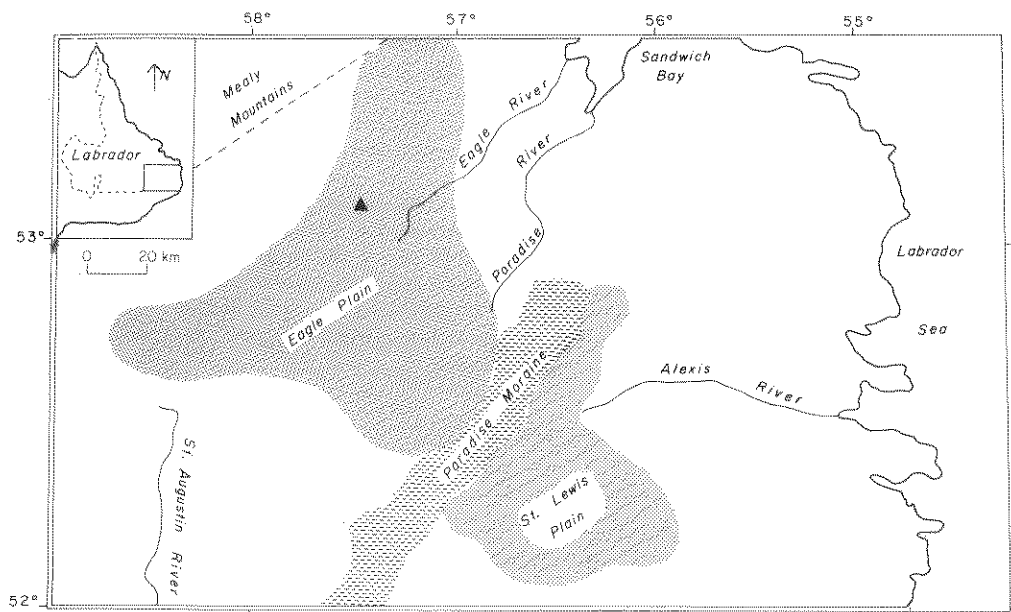


FIG. 1. Map of south-eastern Labrador showing the location of Leech Lake Peatland (triangle) on the Eagle Plain.

Peatlands and lakes cover a quarter of the Eagle Plain. Soligenous fens predominate and frequently form extensive mire complexes (*sensu* Sjörs 1948) several km² in area between intervening mineral uplands. Drainage is complex as fens merge or bifurcate downslope. Individual fens may be 100 m or more in width and several times that in length, but vary greatly.

The climate of south-eastern Labrador is one of extremes with long, cold winters and short, warm summers. On the Eagle Plain, annual precipitation averages between 1100 mm and 1200 mm with over 500 cm snowfall—the greatest amounts recorded for Labrador. The mean annual temperature, approximately -2.5°C , is the lowest in south-eastern Labrador excluding the Mealy Mountains. The growing season is brief. Lakes and peatlands freeze between mid-November and early December and scattered snow covering the lake ice may persist into mid-June (Peach 1975).

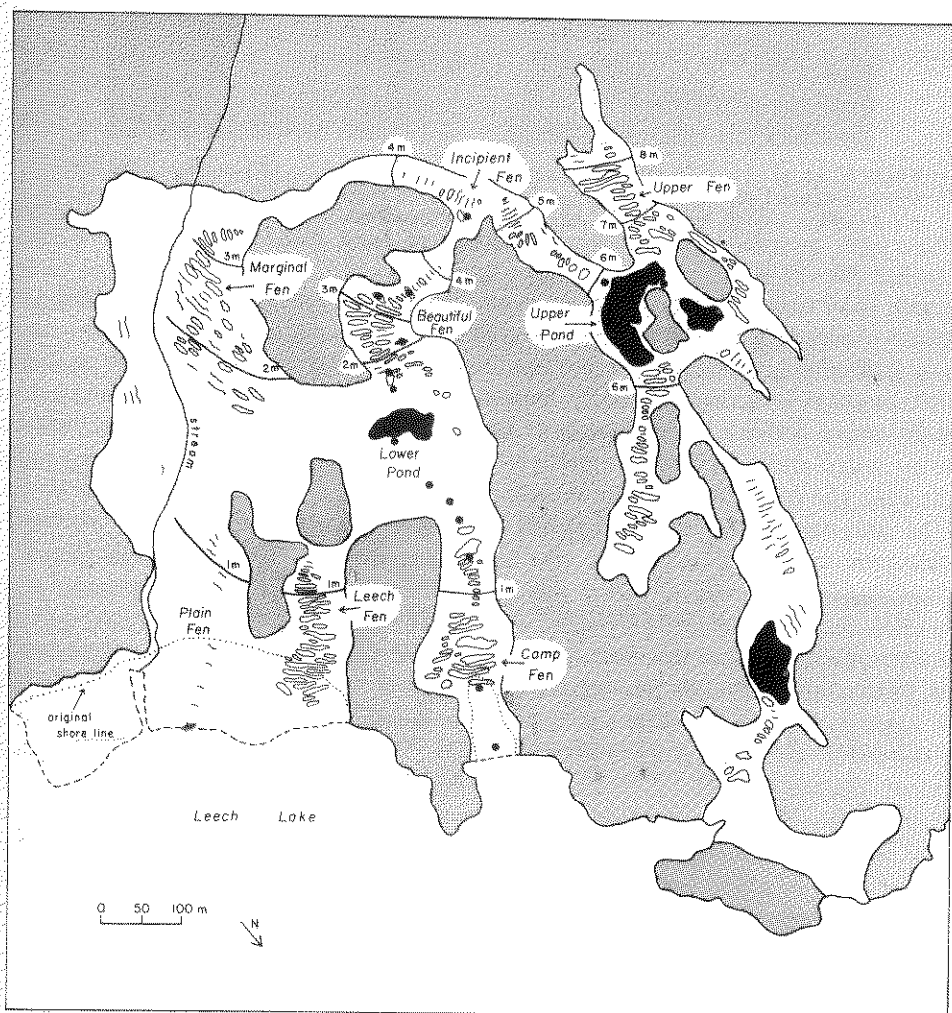


FIG. 2. Map of Leech Lake Peatland, Labrador: (□) Upland areas; (□) peatlands; (■) open-water tarns; metre contours of altitude relative to the lake surface are drawn (solid line) across the fen slopes; (---) shoreline composed of peat; (—) shoreline composed of till; (....) original shoreline. Pools on the surface are enclosed, wavy lines mark sedge or *Sphagnum* flarks. Core locations outside Leech Fen are indicated by large dots.



PLATE 1. Aerial view of the lower portion of Leech Lake Peatland, Labrador, from Lower Pond (right) to Leech Lake (left), a distance of 350 m. Note the extensive floating mat around Lower Pond and the well-developed string-flark pattern on Camp Fen and Leech Fen. See Fig. 2 for orientation and scale. Photograph by D. R. Foster.

Leech Lake Peatland (900 × 900 m) is on the south-western shore of Leech Lake (360 m above sea level), a dark-stained lake averaging 1 m in depth (Fig. 2). Peatland occupies nearly 20% of the catchment area and fens frequently extend down to the water producing a peat shoreline irregularly raised by ice action into ridges. Leech Lake Peatland has six well-developed patterned fens, four large tarns (*sensu* Sjörs 1948) bordered by extensive floating sedge mats, numerous unpatterned fens, a stream that borders the area to the south east, and over 300 m of lake shoreline (Plate 1, Fig. 2, Table 1). Approximately half of the area comprises mineral uplands with sparse black spruce (*Picea mariana*)–*Pleurozium* vegetation.

Aerial photography, mapping, and surveying

Aerial photographs of the mire complex were taken from 3000 m and a topographic map was compiled from the photographs and ground survey. At Leech Fen (see Table 1

TABLE 1. Landform characteristics in Leech Lake Peatland, Labrador. The height rise is the height difference between the foot and top of a fen.

		Length (m)	Height rise (cm)	Slope (cm m ⁻¹)	Area (ha)	
Landform					Water	Floating mat
Leech Fen	patterned fen	220	147	0.67	—	—
Camp Fen	patterned fen	250	174	0.70	—	—
Beautiful Fen	patterned fen	170	270	1.59	—	—
Incipient Fen	patterned fen	200	211	1.06	—	—
Upper Fen	patterned fen	180	209	1.16	—	—
Marginal Fen	patterned fen	260	—	—	—	—
Plain Fen	patternless fen	330	—	—	—	—
Ice-push Ridge 1	(base of Leech Fen)	220	—	—	—	—
Ice-push Ridge 2	(base of Camp Fen)	45	—	—	—	—
Lower Pond	tarn	—	—	—	0.15	1.25
Upper Pond	tarn	—	—	—	0.21	0.17

and Fig 2 for descriptions and locations of landforms) the altitude of the water table, water depth, and the thickness of the underlying sediment were measured at each pool

Vegetation sampling

The vegetation was sampled according to the phytosociological methods of Braun-Blanquet (Mueller-Dombois & Ellenberg 1974) All species were recorded in 9-m² plots subjectively placed in homogeneous stands of vegetation Visual estimates of cover-abundance were assigned on the 10-point Domin scale

The forty-five relevés were sorted and a phytosociological table was compiled (Mueller-Dombois & Ellenberg 1974) Voucher samples of lichens and vascular plants are deposited in the herbarium of the University of Minnesota (MIN) Duplicates of all bryophyte collections are stored in the National Herbarium, National Museum of Canada (CAN) Nomenclature follows Fernald (1970) for vascular species, Stotler & Crandall-Stotler (1977) for liverworts, Ireland *et al* (1980) for mosses, and Hale & Culberson (1970) for lichens except *Cladonia*, which follows Ahti (1961)

Water chemistry

Seven water samples were collected in August 1980 and fifteen in August 1981 from pools along the central axis of Leech Fen Additional samples were collected at releve locations in the rest of Leech Lake Peatland from pools, flarks, or tarns Acid-washed, 250-ml polypropylene bottles were rinsed three times with water from the site before the sample was taken The pH was measured electrometrically in the field

Specific conductivity was measured with a platinum electrode standardized with a 0.001 N KCl solution, the data were normalized to 20 °C, and the conductivity due to hydrogen ions was subtracted to eliminate the effect of varying pH (Sjors 1950b) Cation concentrations were determined with a Spectraspan III DC-Argon Plasma Spectrophotometer

Stratigraphic analysis

Twenty-seven sediment cores were obtained with a modified Livingstone sampler of 5-cm diameter (Wright 1967) Where the peat was woody or extremely fibrous, surface samples 20 cm deep were cut with a knife and the underlying deposits were then cored with the Livingstone sampler Fourteen cores were taken and wrapped in plastic and aluminium foil for transport to the laboratory Cross stratigraphy was described in the field Plant macrofossils were picked from continuous 4-cm sections of five cores after dispersal with detergent and hot water and sieving through a 90- μ m mesh Samples for pollen analysis were taken from six cores and prepared using methods of Faegri & Iversen (1975) modified by E. J. Cushing (personal communication) Pollen percentages include all pollen and spores, except those of submerged aquatic plants Profiles of loss on ignition at 550 °C were determined for five cores Seven samples were radiocarbon dated

RESULTS AND DISCUSSION

Topography and drainage patterns

The surface of Leech Lake provided a reference point for the survey and all altitudes are relative to this surface The total rise of the mire complex is approximately 8.5 m (Fig 2), and is step-wise producing a complex drainage pattern Relatively steep slopes have well-developed patterned fens (e.g. Upper Fen, Beautiful Fen, Camp Fen, Table 1). These

end in fairly level unpatterned fens or extensive lawns surrounding open-water (e.g. Lower and Upper Ponds). Moderate slopes have poorly-developed string and flark patterns such as those found on the fens bordering the stream and in Plain Fen.

Water seeps in from the adjacent mineral-soil uplands and from the seasonal flow of numerous small brooks into the head of Upper Fen and the small fens northwest of Upper Pond. Drainage from Upper Pond is in two directions—north-east to the lake through two patterned fens, and south through Incipient Fen. At Incipient Fen this flow bifurcates, with the major portion of the water continuing south eventually into the stream, whereas the remainder is diverted through Beautiful Fen into Lower Pond. From Lower Pond the main drainage is south-east across the broad unpatterned fen north-east of Marginal Fen to the stream. Weaker flow occurs to the north into the top of Camp Fen and to the north-east around a large mineral upland into Leech Fen.

Surface and subsurface topography of Leech Fen

At Leech Fen the peat surface has an almost uniform slope in the middle of the fen, with a slight increase towards the upper margin, where the peat tapers to mineral upland (Fig. 3). Towards the lake shore a wedge of lake sediment lies between the peat and the mineral substratum.

In sharp contrast to the peat surface the substratum is extremely irregular. Troughs and ridges are unsystematically distributed and boulders (0.5–1.5 m across) break the sediment or water surface of some pools. There is no discernible relationship between the underlying topography and the distribution of pools and strings in the much smoother mire surface.

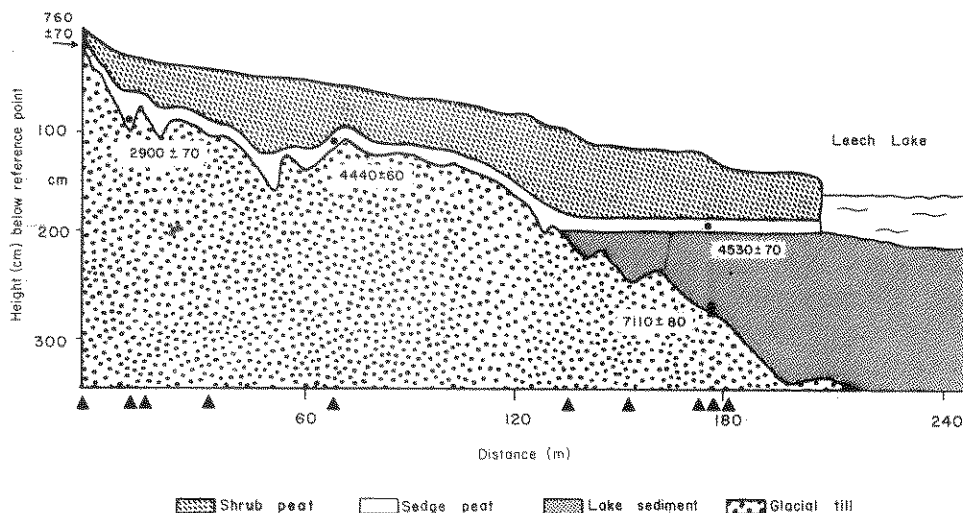


FIG. 3. Cross-section of Leech Fen, Labrador. Core locations are indicated by triangles at the base of the diagram (see also Fig. 6). Location of samples that were radiocarbon dated are indicated by large dots. Sedge peat overlying lake sediment includes a lower zone of peat detritus and an upper zone of sedge peat, both of approximately equal thickness (see Fig. 7).

Water movement in the patterned fens

Lateral water movement in the Leech Lake Peatland occurs through four pathways that vary in importance depending on the amount of input: sheet flow across the surface, surface flow in narrow channels along the margins, surface flow in small rivulets or channels across strings, and percolation through the surface layers of peat.

When the local water table is unusually high, after prolonged rain, or during spring melt, fens may become flooded and water movement occurs as sheet flow across broad areas. Low strings become submerged beneath 5 cm or more of water, and at the bottom of Leech Fen, where water becomes ponded behind the forested ice-push ridge, four or five pools may temporarily coalesce with submergence of the intervening strings.

As the water level falls, surface flow is confined to narrow channels along the margins of patterned areas and through low spots and interruptions in the strings. The marginal channels are narrow, fairly straight, and lack vegetation. Water movement is relatively rapid and unimpeded as long as the input remains high. These channels may have arisen as animal trails, for they are confined to the passable portions of the mire complex (cf. Sjors 1961a). The channels across strings may be initiated by the funnelling of water between sedge tussocks or along frost cracks; erosion at high water levels expands and deepens them. If sufficient erosion occurs the higher pool may drain considerably into the lower.

Percolation within the peat matrix also must occur. The surface peats are generally less compact and humified than deeper ones, and the bulk of the percolation may be confined to a relatively thin surface layer (Wickman 1951, Ingram 1967, Damman 1979).

Landforms and vegetation

Nine vegetation nodes were recognized (Table 2), many of which are characteristic of specific landforms within the mire complex. Where a node is associated with more than one landform it is first discussed under the one in which it is most common.

Ice-push ridge

Ice-push ridges of organic deposits (approximately 10 m wide) line the shores of lakes on the Eagle Plain wherever extensive peatlands abut them. At Leech Lake the lower slopes of Camp and Leech Fens end in such ridges, covered with well-grown conifers and a lush and diverse understorey (*Abies balsamea*–*Sphagnum girgensohnii* Nodum). The height of the trees gives the false impression that these sites are much higher than the adjacent peatland and water surface. The cross-section of Leech Fen (Fig. 3), however, shows that although the forested ice-push ridge ends in a near-vertical step of about 30 cm above the lake surface, there is only a slight fall from the forest to the lawn on the fen side. The present shoreline at Leech Fen represents the furthest advance of a floating mat that developed in a small bay of the lake (Fig. 2, see Peat Stratigraphy p. 130). Any further encroachment of the peatland across the bay is apparently prevented by ice and wave action.

Even the slight rise of the ice-push ridge may restrict drainage and impound water that flows off the mire behind it. Following heavy precipitation the lawn at the base of Leech Fen is inundated with 10 cm or more of water that ponds behind the ridge. During winter, large snow drifts form on this lawn, as the fringe of trees serves as an effective break to the driving winds that carry snow across the ice surface. The drifts, which may persist until June and long after other snow cover on the fen has melted, help saturate the lawns and may considerably shorten the growing season in these sites.

TABLE 2. Phytosociological table of relevés from Leech Lake Peatland, Labrador. Values 3, cover < 4%, frequent individuals; 4, cover 4–10%; 5, cover 10–25%; 6, cover

Relevé number	<i>Abies balsamea</i> – <i>Sphagnum</i> <i>girgensohnii</i> Nodum		<i>Sphagnum fuscum</i> Nodum						<i>Scirpus cespitosus</i> – <i>Lonicera villosa</i> – <i>Aulacomnium palustre</i> Nodum					<i>Scirpus cespitosus</i> – <i>Carex exilis</i> Nodum					
Number of species	3	4	16	45	44	41	18	25	10	12	1	5	46	48	37	31	26	30	42
	27	27	22	22	21	24	22	25	21	22	22	21	21	21	18	17	18	14	18
<i>Abies balsamea</i>	5	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Nephroma arcticum</i>	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Tridentalis borealis</i>	2	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lycopodium annotinum</i>	2	3	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
<i>Moneses uniflora</i>	3	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Sphagnum girgensohnii</i>	8	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Polytrichum commune</i>	3	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Dicranum fuscescens</i>	2	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Sphagnum pulchrum</i>	3	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Betula pumila</i>	6	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Potentilla palustris</i>	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Deschampsia flexuosa</i>	2	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Cornus canadensis</i>	2	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Gaultheria hispidula</i>	2	3	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Carex trisperma</i>	3	3	2	.	1	4	1	1	.	.	.	.	.	.	.	.	.	.	.
<i>Smilacina trifolia</i>	3	2	.	2	.	3	3	4	.	.	.	.	.	.	.	.	.	.	.
<i>Vaccinium uliginosum</i>	3	1	1	2	.	4	4	3	1	.	.	.	.	.	.	.	.	.	.
<i>Pleurozium schreberi</i>	5	6	.	2	3	.	1	2	.	2	.	.	.	.	.	.	.	.	.
<i>Polytrichum strictum</i>	2	3	.	3	1	1	1	1	.	.	.	.	.	.	.	.	.	.	.
<i>Ledum groenlandicum</i>	4	4	2	.	1	4	2	3	.	.	.	.	.	.	.	.	.	.	.
<i>Sphagnum fuscum</i>	.	.	7	8	7	8	7	4	.	.	.	1	.	.	.	.	.	.	.
<i>Mylia anomala</i>	.	.	3	3	2	2	2	3	2	.	.	.	.	.	.	.	.	.	.
<i>Sphagnum nemoreum</i>	.	.	2	2	3	1	4	1	.	.	.	.	.	.	.	.	.	.	.
<i>Carex pauciflora</i>	.	.	1	.	1	1	1	2	.	.	.	.	.	.	.	.	.	.	.
<i>Empetrum nigrum</i>	.	2	2	1	.	2	3	1	.	.	.	.	.	.	.	.	.	.	.
<i>Dicranum undulatum</i>	.	.	2	3	2	1	1	5	.	.	.	.	.	.	.	.	.	.	.
<i>Sphagnum rubellum</i>	.	.	4	2	2	1	2	2	2	5	.	2	6	.	.	.	1	1	.
<i>Sphagnum fallax</i>	.	.	.	.	.	.	.	.	4	.	3	.	4	.	.	.	2	.	2
<i>Sphagnum angustifolium</i>	.	.	.	.	.	.	.	.	3	3	4	3	2	2	2	.	.	.	.
<i>Lonicera villosa</i>	.	.	.	.	.	.	.	.	2	2	2	1	3	2	.	.	.	.	.
<i>Rubus acaulis</i>	.	.	.	.	.	.	.	.	1	1	1	2	2	.	1	.	.	.	.
<i>Aster radula</i>	.	.	.	2	.	2	.	.	2	2	1	2	3	1	.	2	.	.	.
<i>Aulacomnium palustre</i>	.	.	.	.	1	.	.	.	1	2	2	2	2	1	2	.	.	.	.
<i>Epilobium palustre</i>	.	.	3	.	.	.	.	.	3	2	3	1	3	4	3	3	2	3	3
<i>Carex exilis</i>	.	.	.	.	2	.	.	.	.	.	2	.	2	5	3	2	4	5	6
<i>Juncus stygius</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	2	2	2	2	.	1
<i>Menyanthes trifoliata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	2	4	2	2
<i>Cladopodiella fluitans</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Drosera anglica</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Carex limosa</i>	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
<i>Carex aquatilis</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Sparganium angustifolium</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Nuphar variegatum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Carex rostrata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Betula michauxii</i>	.	.	2	1	.	.	.	.	2	2	2	3	3	5	5	2	4	2	3
<i>Sphagnum lindbergii</i>	.	.	.	.	.	.	.	.	6	4	8	6	7	4	9	8	5	5	5
<i>Drosera rotundifolia</i>	.	.	3	2	2	1	.	3	3	2	2	2	3	3	2	2	3	1	3
<i>Scirpus cespitosus</i>	.	.	8	4	5	.	5	7	8	8	8	7	7	7	9	4	8	7	8
<i>Sphagnum magellanicum</i>	.	.	7	.	3	1	5	2	4	6	3	4	4	5	3	3	3	1	7
<i>Coptis groenlandicum</i>	2	2	1	3	2	.	2	2	2	2	1	2	.	1	3	2	2	3	1
<i>Picea mariana</i>	5	4	1	6	4	6	5	7	.	2	1	2	1	1	4	1	1	.	1
<i>Larix laricina</i>	2	4	.	2	1	4	4	4	2	1	1	4	1	2	4	.	2	.	1
<i>Vaccinium oxycoccos</i>	2	.	3	3	2	3	3	3	3	3	2	3	2	2	.	3	1	3	2
<i>Kalmia polifolia</i>	3	3	2	3	3	2	4	3	.	1	2	3	2	2	4	1	3	3	2
<i>Carex oligosperma</i>	2	3	2	4	2	5	1	3	5	3	5	3	3	5	.	2	.	5	4
<i>Chamaedaphne calyculata</i>	4	3	4	8	6	8	4	6	2	2	2	5	4	4	5	1	4	2	3
<i>Andromeda glaucophylla</i>	.	.	3	.	4	.	.	2	1	2	2	2	3	3	2	4	2	.	3

The *Abies balsamea*–*Sphagnum girgensohnii* Nodum on the ice-push ridge is floristically diverse. Below the discontinuous canopy of *Abies balsamea*, *Picea mariana* and scattered *Larix laricina* is a low shrub cover of *Betula pumila*, *Chamaedaphne calyculata*, *Kalmia polifolia*, *Ledum groenlandicum* and *Vaccinium uliginosum* (Table 2). The ground cover consists of a nearly continuous carpet of *Sphagnum girgensohnii* and *Pleurozium schreberi*, with scattered herbs—*Carex trisperma*, *Cornus canadensis*, *Deschampsia flexuosa*, *Lycopodium annotinum*, *Moneses uniflora*, *Smilacina trifolia*, and *Trientalis borealis*. A narrow fringe along the lake shore is composed of *Betula pumila*, *Myrica gale* and *Salix pedicellaris*, accompanied by *Carex aquatilis* and *Potentilla palustris*.

The floristic diversity of the vegetation and the presence of well-grown conifers on this landform contrasts with the rest of the peatland. Proximity to the lake undoubtedly results in a more favourable nutrient regime and enhanced aeration of the substratum, factors that may be limiting for tree growth on the main expanse of the peatland (Sjors 1950a, Watt & Heinselman 1965, Jeglum 1974). The lake has a higher pH and conductivity and greater concentration of dissolved ions than found elsewhere in the peatland (Table 3). A varied microrelief may also increase diversity; fallen trees and windthrow mounds provide dry microhabitats that are colonized by *Cladonia* spp. (*C. cornuta*, *C. deformis*, *C. ecmocyna*), *Dicranum fuscescens*, *Gaultheria hispidula*, *Lycopodium annotinum* and *Polytrichum juniperinum*.

TABLE 3 Concentrations of selected cations (mg l⁻¹) and silicate (as Si, mg l⁻¹), pH and conductivity (μS cm⁻¹) from surface water in the Leech Lake Peatland, Labrador. The values from Leech Fen and the plateau bogs are averages, and other samples are single measurements.

	pH	Conductivity	Ca	Mg	Fe	Si
Leech Fen (n = 14)	4.7–5.5	4.9	0.33	0.19	0.15	—
Lower Pond	5.2	9.3	0.78	0.40	0.20	0.89
Upper Pond	6.1	5.8	1.10	0.38	0.21	0.32
Leech Lake	6.1	10.2	1.60	0.54	0.28	1.45
Plateau Bog (n = 10)	3.8–4.4	3.1	0.20	0.14	—	—

Strings

Strings vary in width, length, shape, height, and degree of consolidation of the peat. In width, strings may range from 1 m to 2 m, whereas their length may exceed 75 m and extend across the breadth of a fen. Strings may be continuous strands separating long, narrow pools, or they may interconnect to create a network of smaller pools.

In cross-section, strings typically are asymmetric, the upslope and downslope margins are dissimilar in shape and vegetation (Lundquist 1951, Eurola 1962, Vitt, Achuff & Andrus 1975). Downslope, strings grade gently into the centre of the adjoining pool. The vegetation changes gradually from sedges and shrubs to a carpet community dominated by *Sphagnum lindbergii* and *S. magellanicum* adjacent to the pool. In sharp contrast, the upslope margin is a near vertical bank to the pool bottom 5–40 cm below. The shrub and sedge community with *Andromeda glaucophylla*, *Betula michauxii*, *Chamaedaphne calyculata*, and scattered shoots of *Carex limosa* and *Menyanthes trifoliata* covers the surface nearly to the water.

Communities are often indistinct on strings because of variation in microtopography along the length of a string and the gradient that occurs from pool margin to string crest. However, two nodes characteristic of elevated and low strings, respectively, have been

recognized, together with a third nodum that occupies a distinct zone at the downslope margins of strings and along the lateral edges of pools

The *Scirpus cespitosus*–*Lonicera villosa*–*Aulacomnium palustre* Nodum (Table 2) is characteristic of elevated and firm strings and of unpatterned areas on well-consolidated peat. The strings occupied by this nodum generally have a broad and solid central crest 1 m or more wide and are 15–30 cm above the water table. The nodum is dominated by shrubs, herbs, stunted *Larix laricina* and *Picea mariana* with *Aster radula*, *Lonicera villosa*, *Rubus acaulis*, *Sphagnum angustifolium* and *Aulacomnium palustre* (Table 2).

The *Scirpus cespitosus*–*Carex exilis* Nodum is most commonly found on low strings in patterned fens, and throughout the extensive unpatterned fens on consolidated peats adjacent to tarns and on gentle or short slopes. Tree cover is sparse and the sedge *Scirpus cespitosus* is dominant on elevated surfaces and across the central axis. *Carex exilis* and *C. oligosperma* are prominent on moist sites, near string margins and in depressions. *Carex exilis*, which is the only differential species in this nodum, is characteristic of the upslope edge.

The strings occupied by this nodum are generally low, and extend only 5–20 cm above the water surface. Frequently the peat is being eroded by water flowing between pools. The variety of microsites, ranging from exposed mud in erosion channels to hummocks around tree bases, accommodates a wide range of species. *Juncus stygius* and *Menyanthes trifoliata* typically occupy depressions and mud surfaces near the water table, whereas *Coptis groenlandicum*, *Epilobium palustre*, *Larix laricina* and *Picea mariana* are located on the relatively dry crests of the highest strings.

The *Sphagnum lindbergii*–*Carex limosa* Nodum forms a carpet occupying the transition zone along the upslope and lateral edges of pools, and overlies a saturated and very loose *Sphagnum lindbergii* peat approximately 10–15 cm thick. The community also occupies slightly raised sites on the floating mats surrounding the tarns, on relatively thin peat (10–30 cm thick) that is loosely consolidated within a matrix of *Carex limosa* rhizomes. In all sites *Sphagnum lindbergii* forms broad flat carpets just above the water table.

This nodum is differentiated by the nearly continuous cover of *Sphagnum lindbergii* and the prominence of *Carex limosa* and *C. oligosperma*. Shrubs occur only as very scattered and low individuals. This nodum is very similar to the mud-bottom community (*Carex limosa*–*Menyanthes trifoliata* Nodum, Table 2). The mud-bottom nodum, however, is found on exposed peat close to the water table and consequently is more frequently flooded, it differs in the absence of *Sphagnum lindbergii* and increased prominence of *Cladopodiella fluitans*, *Drosera anglica* and *Juncus stygius*.

Flarks and pools

There are two types of water bodies found within Leech Lake Peatland: tarns (Swedish 'tjarn', German 'Teich' *sensu* Sjors 1948), which are primary in origin and are underlain by lake sediment, and pools ('gol', 'Blanke', Sjors 1948), which develop secondarily upon the mire surface and have a bottom of flocculent peat. Tarns and pools generally also differ in water chemistry, slope position and size. Moreover, tarns gradually fill through encroachment of floating-mat vegetation, whereas pools are actively expanding their water-surface-area.

The elongated flarks and pools display similar variation in size and shape to that of the bounding strings. Pool width depends on the slope of the peat surface. Wide pools can only occur on very gentle slopes or where dammed behind tall and robust ridges. Steep slopes have very narrow pools arranged in terraces. Pool shape is also governed by developmental

history The sinuous form of many long pools, with narrow necks of water separating wider expanses, results from gradual coalescence of numerous pools located at slightly different positions on a slope

Pool bottoms have well decomposed flocculent underlying peat The pools are very clear and may heat up considerably on long sunny summer days, and although the water is apparently free from abundant algae, the peat bottoms may be covered with a thick algal film (Sjors 1950a, 1965, Lundquist 1951)

Shallow pools have sparse vegetation (*Carex limosa*–*Carex oligosperma* Nodum), and deeper pools even less except for widely scattered clumps of *Carex aquatilis*, *Nuphar variegatum*, and *Sparganium angustifolium* (*Carex aquatilis*–*Sparganium angustifolium* Nodum) (Allington 1961, Sjors 1961a, Bjorkback 1965, Vitt *et al.*, 1975) This sparse cover in pools is especially interesting at Leech Lake Peatland where the process of hydrarch succession has been conspicuous along the lake shore and around the tarns The instability of the flocculent and degrading peat bottom, erosion by wind and ice, low pH and limited nutrient availability may all prevent the extensive colonization of pools by plants

The *Carex limosa*–*Carex oligosperma* Nodum occurs in shallow pools (water depth 5–15 cm), and is dominated by a discontinuous cover of *Carex limosa*, *C. oligosperma*, and *Menyanthes trifoliata* Around the margins *Andromeda glaucophylla*, *Betula michauxii*, and *Chamaedaphne calyculata* contribute a more luxuriant cover Shallow pool bottoms may become exposed during lengthy summer droughts The peat surface then becomes hardened in the sun and dries, forming a network of desiccation cracks

The *Carex aquatilis*–*Sparganium angustifolium* Nodum occurs in pools more than 20 cm deep Water-table fluctuations seldom result in the complete exposure of the pool bottom The vegetation generally covers less than 5% of the water surface and occurs as widely scattered patches of the three prominent species *Nuphar variegatum* and *Sparganium angustifolium* are most common in deep water and are often found in the centre of pools, whereas *Carex aquatilis* generally occupies shallower areas and may form a narrow band near the shrub fringe that borders the upslope margins of strings

Tarns

The tarns at Leech Lake Peatland—Lower and Upper Ponds (Table 1, Fig. 2)—are large, open bodies of water extending down to ice-block depressions in the mineral substratum Two metres or more of lake sediment overlies glacial silt and suggest continued existence of the tarns throughout the post-glacial period The original margins of these basins are now obscured by extensive sedge and *Sphagnum* mats, which at Lower Pond cover 60% of the basin (Fig. 2) On a transect from the water's edge, peat deposits of increasing thickness and consolidation are located between the mat and the lake sediment

At Lower Pond the vegetation of the open water is limited to scattered colonies of *Nuphar variegatum* and, increasingly towards shallower parts of the basin, *Sparganium angustifolium* Jutting irregularly out into the open water is a discontinuous mat 0.5–3.0 m wide of *Carex rostrata* intermixed with *Nuphar variegatum*, *Sparganium angustifolium*, and *Utricularia intermedia* (*Carex rostrata* Nodum, Table 2) The mat produced by this vegetation is submerged and only loosely maintained by an open network of sedge rhizomes

Behind the *Carex rostrata* fringe the mat becomes more consolidated through a surface network of *C. limosa* and *Menyanthes trifoliata* rhizomes, although overlying a fluid and extremely flocculent peat detritus The surface of this floating mat lies at or just above the

water surface. Away from the open water, hummocky areas coalesce to provide a firmer and drier surface that is occupied by many more species. On low hummocks *Sphagnum angustifolium* and *S. lindbergii* are associated with *Carex limosa* and *Menyanthes trifoliata*, whereas the mud surfaces bear a scattered vegetation of *Cladopodiella fluitans*, *Drosera anglica*, and *Juncus stygius*. The moss *Aulacomnium palustre* may be locally important and forms monospecific carpets adjacent to the *Sphagnum lindbergii*.

Twenty metres or more from the water's edge low shrubs are prominent, including *Andromeda glaucophylla*, *Chamaedaphne calyculata*, and *Kalmia polifolia*. These species add further to the consolidation of the mat. With the presence of *Carex exilis* and *Scirpus cespitosus*, the firmest portions of this area assume the composition of the *Scirpus cespitosus*–*Carex exilis* Nodum that is frequently found on low ridges (Table 2).

Mire margin hummocks

Along the upland borders of the fens and extensive lawns, are large hummocks 3–12 m or more wide, composed of *Sphagnum fuscum* and *S. nemoreum* and partially wooded with stunted *Larix laricina* and *Picea mariana*. This landform is best developed to the north-west of Lower Pond, where numerous hummocks have coalesced to form extensive raised areas that are readily discernible from the air by the orange-red colour of the dominant *Sphagnum* species. The hummocks are underlain by peat 75–150 cm thick and are 20–50 cm above the surrounding fen surface.

The plant community on hummocks (*Sphagnum fuscum* Nodum) is similar to the mire margin community of Sjors (1948) and the *Fuscetum* assemblage described by Du Rietz (1948), both of which form similar raised areas. This nodum is differentiated by species indicative of oligotrophic conditions: *Carex pauciflora*, *Dicranum undulatum*, *Empetrum nigrum*, *Myrica anomala*, *Sphagnum fuscum*, and *S. nemoreum*. In addition there are a few cryptogams that prefer the tops of hummocks and other dry or exposed microhabitats—*Cetraria islandica*, *Cladonia rangiferina*, *C. cornuta*, and *Pleurozium schreberi*. Numerous species that are found in the *Abies balsamea*–*Sphagnum girgensohnii* Nodum or are common to a variety of string communities comprise the remainder of the assemblage.

Although these mire margin communities are differentiated from the other fen communities by a group of species characteristic of ombrotrophic sites, they are distinguished from true bog communities by numerous obligate fen species (Sjors 1948, Nordqvist 1965, Wells 1981). Their location at the margins of fens, and consequently away from the direct influence of soligenous water moving across the mire, enables the hummock-building *Sphagnum* to expand and thereby raise the hummock surface (Nordqvist 1965, Damman 1979). Hummock surfaces are ombrotrophic, or at least extremely oligotrophic, and this favours the oligotrophic cryptogams and shallow-rooted bog species. The deeply rooted vascular plants may have a more nutrient-rich environment within the lower depths of the hummocks, at or below the water table (Bjorkback 1965). Meanwhile the height of hummocks relative to the water table may result in greater aeration of the peat, which would favour tree growth (Jeglum 1974).

Ordination of the vegetation

A principal components analysis of the forty-three relevés and forty-four species from the mire nodum, but excluding the two relevés and fourteen species from the ice-push ridge (*Abies balsamea*–*Sphagnum girgensohnii* Nodum) is shown in Fig. 4. The first two principal components account for 60% of the total variability in the data, and provide a

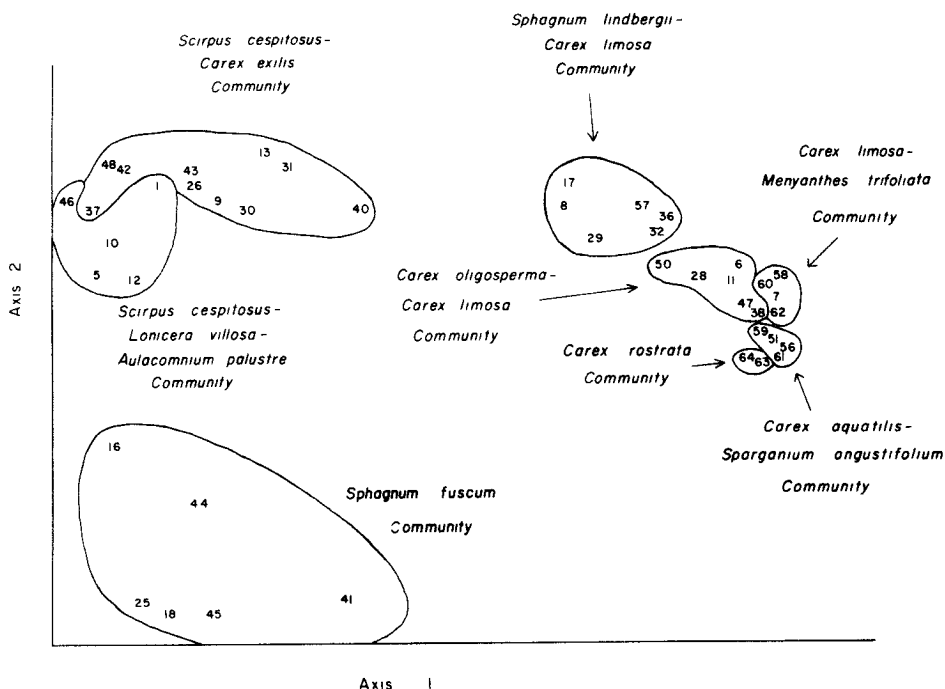


FIG 4 Principal components analysis of vegetation relevés from Leech Fen, Labrador. The first principal component (axis 1) accounts for 41% of the total variation in the data, the second (axis 2) for 19%. Numbers refer to relevés in Table 2.

good graphical representation of the relationships among the stands and between the various noda.

The first principal component separates those stands on raised hummocks and firm peat above the water table (twenty-one relevés), and those occurring near the water surface and occupying water-filled depressions. The separation closely parallels the arrangement of noda in the phytosociological table, where they are arranged in order of increasing moisture and decreasing height above the water table. Along the second principal component, stands of the *Sphagnum fuscum* Nodum are widely separated from the closely grouped relevés in the *Scirpus cespitosus-Carex exilis* and the *Scirpus cespitosus-Lonicera villosa-Aulacomnium palustre* Noda. Similarly, the relevés from the *Sphagnum* carpets (*Sphagnum lindbergii-Carex limosa* Nodum) are separated from those relevés taken in shallow pools, mud bottoms, deep pools and tarns.

Water chemistry

The water chemistry of the mires in Leech Lake Peatland is characteristic of poor fen conditions. At Leech Fen, pH ranges from 4.7 to 5.5, conductivity is approximately $5 \mu\text{S cm}^{-1}$, and the major cations each have average concentrations less than 0.5 mg l^{-1} (Table 3). The extremely base-poor nature of the bedrock, dilution by abundant precipitation and low rates of decomposition due to the short, relatively cool growing-season undoubtedly contribute to the low nutrient status of the minerotrophic mires.

The tarns (Lower and Upper Ponds) have higher pH and conductivity, and greater cation concentrations than those found in the fen pools. As the tarns occupy natural basins

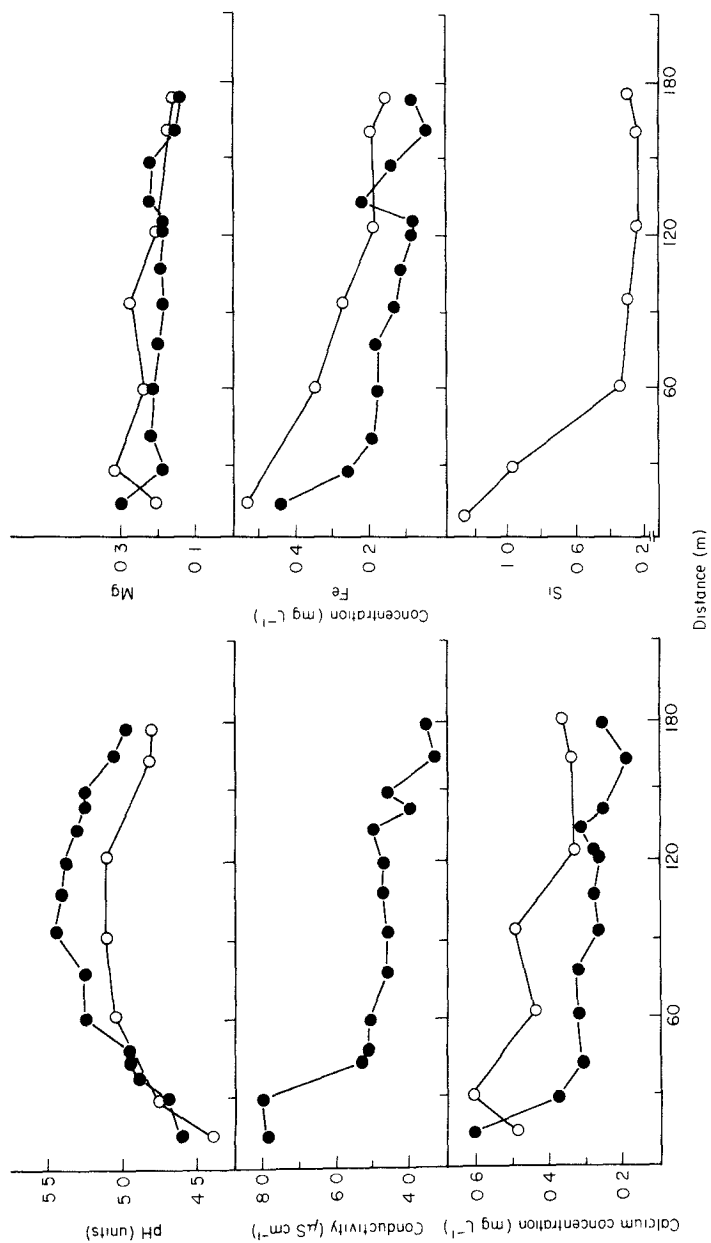


FIG 5 Analysis of water from Leech Fen, Labrador along a transect from the upslope edge (left) towards the lake. Samples were taken from open water in pools (O) samples taken in 1980, (●) samples obtained in 1981

in the mineral substratum and are underlain by lake sediment rather than peat, the influence of mineral-soil water may be greater here than in pools. Upper Pond is closely bordered on two sides by mineral uplands, which may explain the greater nutrient status recorded there.

The water chemistry on a transect down the axis of Leech Fen, from the upper margin to the lake, shows a trend of decreasing conductivity and cation concentrations and a convex curve for pH that has a maximum approximately in the middle of the slope (Fig. 5). The 1980 samples were taken following a week of heavy rainfall and the high values for silicate probably represent the inwash of materials from the mineral upland. Silicate (as Si) concentrations from 1981 were uniformly low, approximately $0.1\text{--}0.2\text{ mg l}^{-1}$ or lower.

The trend in pH may reflect water movement and drainage patterns on the fen surface. The flow from two narrow seepages that enter on the upper flanks of the fen (Fig. 2) converges approximately 60 m downslope. Upslope of this point the pH is lower, and water movement is slower. Towards the upslope margin of the fen the vegetation is more oligotrophic with small hummocks of *Sphagnum fuscum*. Stagnation of water movement in this area may result in greater acidity because of a long period of active exchange of H^+ ions between *Sphagnum* and pool water. Similarly, stagnation may contribute to the concentration of cations by evaporation, and displacement by H^+ of ions absorbed on organic matter. Downslope the pH may rise because of the increased influence of flow from the upslope peatland and cation concentrations drop because of greater dilution. The mineral status and pH continue to drop further downslope where the fen becomes isolated from mineral soil influence by the intervening lake sediment (Fig. 3).

Stratigraphic analysis of Leech Fen

Leech Fen was chosen for intensive stratigraphic study to unravel the developmental history of a small patterned mire as well as to investigate the stratigraphic evidence for the process of pattern development. Twelve cores were taken, ten of which were located along a transect up the fen slope (Fig. 6). Four sediment types are recognized in the cores: lake sediment, peat detritus (*sensu* Sernander 1905), sedge peat and shrub peat. The lake sediment consists of olive-green gyttja containing scattered sedge remains. In the peat detritus the proportion of sedge remains increases significantly, with a corresponding decrease in the lake component. The sedge peat consists largely of sedge leaves, rhizomes and rootlets, while the shrub peat is fibrous and coarse-textured, containing numerous wood fragments in a matrix of shrub rootlets and sedge leaves. Bryophyte fragments are rare in both the sedge and shrub peat.

The vertical and horizontal distribution of these sediments in Leech Fen is shown in a cross-section of the fen (Fig. 3). Cores from the lower third of the fen have basal lake sediment, succeeded by peat detritus, sedge peat and then shrub peat, indicating that this portion of the fen developed through hydrarch succession of a shallow bay of Leech Lake. The original shoreline of the bay that was overgrown by a sedge mat is 80–100 m inland from the present shoreline of the lake (Figs 2 & 3). In the upper two-thirds of Leech Fen, the lake sediment and peat detritus zones are absent, and a thin sedge peat forms a narrow zone between the mineral substratum of glacial till and a thick shrub peat zone that extends to the present surface. This general stratigraphy of sedge and shrub peat overlying till or lake sediments was consistently found in the other cores from the Leech Lake Peatland (Fig. 2). Subsequently 'downslope' refers to the lower third of Leech Fen that is underlain by lake sediment, and 'upslope' refers to the area above the original shoreline of Leech Lake.

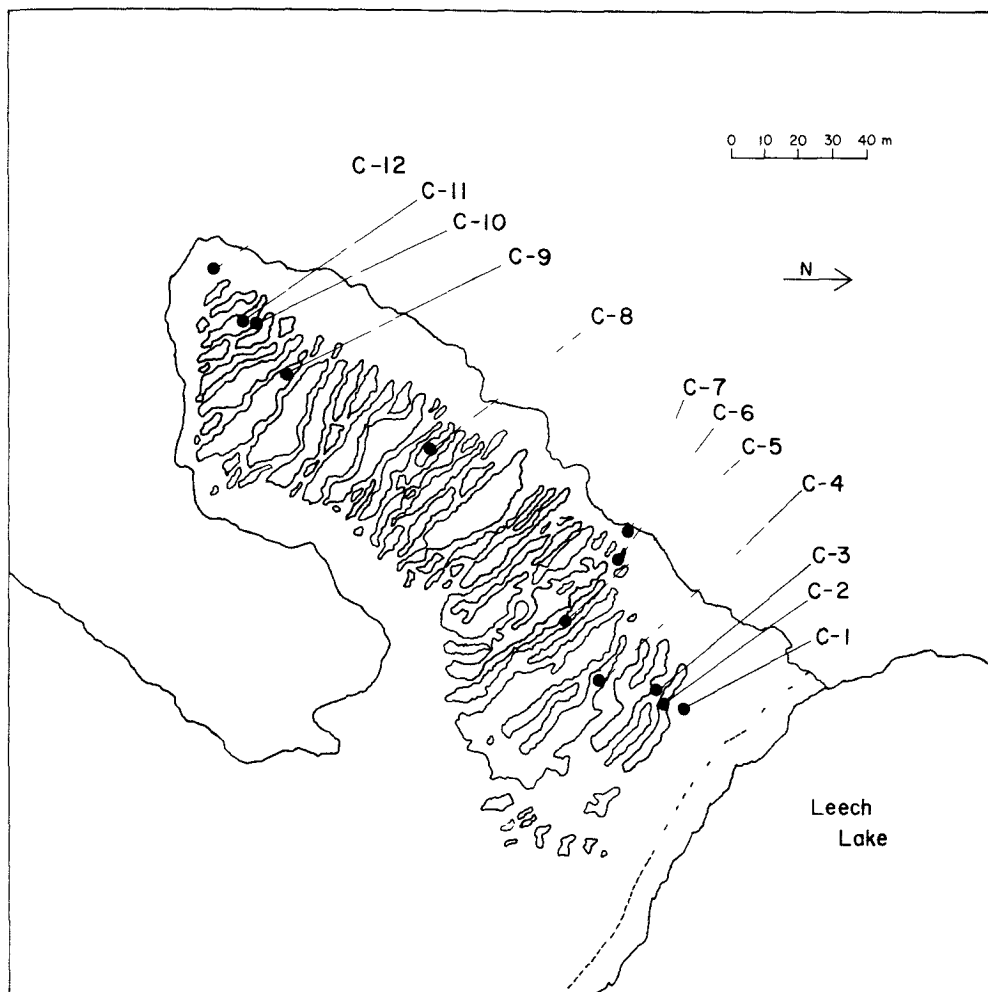


FIG 6 Map of Leech Fen, Labrador, showing core locations (C1-C12) Map drawn from aerial photograph taken from an altitude of 150 m

Development of the downslope region of Leech Fen

Cores 2 and 3 from the first pool and string in Leech Fen, respectively, were analysed in detail for pollen and macrofossils. Pool 1 is relatively small and shallow, averaging less than 1 m in width and 10–20 cm in depth. The adjacent core was taken from the middle of the adjoining string, within 2 m of the pool core (Fig 6)

Pool 1

Lake sediment comprises the basal 81 cm of the pool core, at a depth of 67–148 cm below the water surface (Fig 7). Sedge leaves are present to the base of the core, which was dated at 7100 ± 80 B P (Table 4). Above the lake sediment is a layer of peat detritus 5 cm thick, overlain by sedge peat 8 cm thick. In these two layers the loss-on-ignition increases sharply from 30% to 90%. The upper portion of the core consists of shrub peat 44 cm thick. No pool sediment has been deposited over the shrub peat layer, which is loose and flocculent at the surface.

Leech Fen Labrador 53° 10' N 58° 27' W

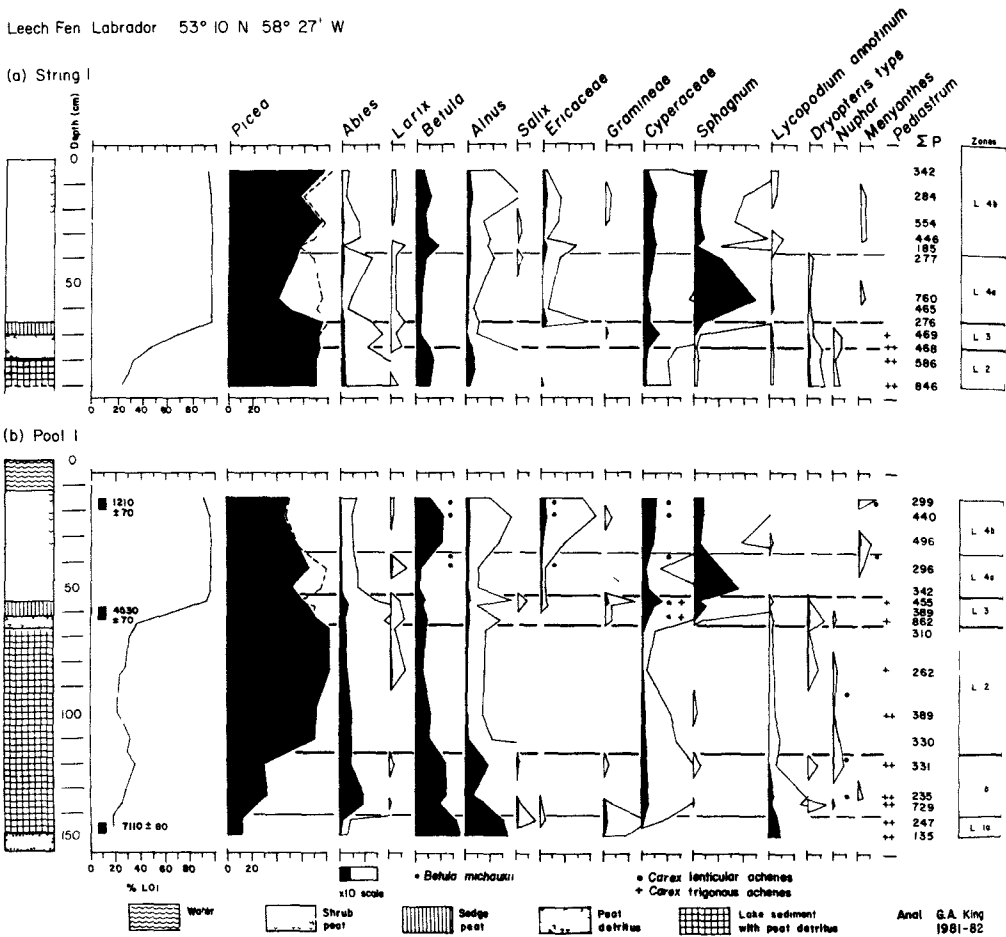


FIG 7 Summary pollen percentage diagrams from (a) core 3 (string 1) and (b) core 2 (pool 1) at the base of Leech Fen, Labrador (---) percentages in which *Sphagnum* spores were excluded from the pollen sum Presence of macrofossils indicated by dots Conifer needles are present throughout the peat, and are not indicated in the diagram ΣP indicates total number of pollen grains counted % LOI is per cent loss-on-ignition at 550 °C

TABLE 4 Radiocarbon dates from Leech Fen, Labrador, cores

Core number	Laboratory number	Depth of sample (cm below water or peat surface)	Radiocarbon date (years B P)
2	WIS-1353	15-19 (3-7 cm below water- peat interface)	1210 ± 70
2	WIS-1354	58-63	4530 ± 70
2	WIS-1357	144-148	7110 ± 80
8	WIS-1404	31-36 (1-6 cm below water- peat interface)	410 ± 70
8	WIS-1355	73-76	4440 ± 60
11	WIS-1356	75-79	2900 ± 70
12	WIS-1403	27-32	760 ± 70

Four pollen zones have been distinguished in the pool pollen percentage diagram (Fig 7) Zones L-1 and L-2 in the lake sediment of the core closely correspond with two contemporary zones in a core from Eagle Lake, 15 km north west of Leech Lake (Lamb 1980) and record development of the upland forest in the region after deglaciation Zone L-1 corresponds to Lamb's *Alnus-Abies-Picea* zone in which a shrub tundra surrounding Leech Lake at 7100 B P was later colonized by *Abies balsamea*, *Betula papyrifera*, and *Picea glauca*, *P. mariana* The initial forest was probably a park tundra with scattered clumps of *Abies balsamea*, *Betula papyrifera* and *Picea* spp (Lamb 1980) Zone L-2, corresponding with Lamb's *Picea* zone, has *Picea* pollen percentages increasing to over 70% and is interpreted as representing the closure of the spruce-dominated forest around Leech Lake, although the relatively high percentages of *Abies* pollen indicate that it was a common component of this forest

Zones L-3 and L-4 are located in the peat section of the pool core, and hence their pollen spectra have a higher proportion of locally produced pollen than the zones in the lake sediment For example, *Picea* pollen percentages fall as values of mire species such as sedges, grasses and *Sphagnum* increase In zone L-3, Cyperaceae and Gramineae pollen become much more common than in lower zones, reaching peaks near the top of the zone of 16% and 2%, respectively *Sphagnum* spores and Ericaceae pollen first appear in this zone, whereas *Pediastrum* decreases in frequency Trigonous achenes similar to reference material of *Carex rostrata* and lenticular achenes of other *Carex* spp are commonly found in this zone The middle of this zone was dated at 4530 ± 70 B P (Table 4)

The rapid rise in *Sphagnum* spore values, beginning at 53 cm, distinguishes subzones L-4a from zone L-3 *Sphagnum* spores reach a maximum of 35%, followed by a gradual decline to 4% at the top of subzone L-4a Cyperaceae pollen values decline from zones L-3, and *Alnus* and *Betula* pollen values remain low to the top of the subzone, where they increase Gramineae pollen was not found, whereas *Menyanthes* pollen and seeds first appear in this subzone Ericaceae and *Betula michauxii* leaves are present at the top of this subzone, where their pollen also increases Subzone L-4b is distinguished from subzone L-4a by lower *Sphagnum* percentages and higher *Alnus*, *Betula* and Ericaceae pollen values *Betula michauxii* and Ericaceae leaves are common, and Cyperaceae pollen percentages increase slightly The top of this subzone at the water-sediment interface was dated at 1210 ± 70 B P (Table 4)

String 1

The string core has a stratigraphy very similar to that of the pool (Fig 7) Lake sediment comprises the basal 66 cm of the core, and is overlain by a thin peat detritus zone, a thin layer of sedge peat, and then shrub peat that extends to the surface of the string The similarity to the pool core is reflected in values for loss-on-ignition, which rises sharply from 30% to 95% in the transition from lake sediment to peat As the lake sediment in the string core contains pollen assemblages reflecting the regional pollen collected by Leech Lake, it was assumed that these assemblages would be identical to those of the pool core Hence, pollen and macrofossil analyses were not completed for the lower sections of the lake sediment zone, but only for the top 90 cm of the core, beginning 10 cm below the contact of the lake sediment with the overlying peat detritus.

Pollen zones in the string diagram are labelled with the numerical code corresponding to that in the pool core, because of the overall similarity of the pollen assemblages *Picea* pollen dominates zone L-2, reaching 70%, while *Betula* pollen is the next most common type with 10% In zone L-3 Cyperaceae pollen has a peak at 13%, *Nuphar* pollen

disappears, *Pediastrum* abundance decreases, *Sphagnum* spore percentages begin to increase and Ericaceae pollen first appears

As in the pool core, *Sphagnum* spore percentages increase sharply to a peak value of 48% in subzone L-4a followed by a gradual decline *Menyanthes* pollen is first found in this zone, and *Betula* percentages remain less than 10%

Slight differences between the cores are noted in zone L-4b *Sphagnum* spore percentages remain low in both, but *Betula* and Ericaceae pollen values do not increase sharply to the same values Other taxa have pollen percentages similar to those in the pool subzone, except for *Picea*, which has higher values These differences probably reflect the variation in the local pollen rain caused by the scattered distribution of each species in the fen, they may not reflect major differences in the pool and string communities at the time

Interpretation of the downslope stratigraphy of Leech Fen

The stratigraphy of the downslope cores clearly indicates that peat accumulation in this portion of the mire began by encroachment of a sedge mat over a shallow bay of Leech Lake The presence of sedge macrofossils throughout the lake-sediment section of the downslope cores suggests that sedges were growing in the shallow bay by 7100 B P when lake sediment was first deposited at this location Some aspects of the development of this sedge mat may be inferred from zone L-3 of pool 1 and string 1 cores The lower portion of the zone is distinguished by a rise in loss-on-ignition, an increase in Cyperaceae pollen, and the first appearance of *Carex rostrata* achenes, which probably reflect the development of a loose floating mat *Carex rostrata* often forms a loose floating mat in open water of oligotrophic lakes throughout the region The continued rise in loss-on-ignition, increase in sedge pollen and macrofossils, and change to sedge peat in the middle of the zone reflect the gradual consolidation of the mat Towards the upper part of the zone, the appearance of Ericaceae pollen and *Sphagnum* spores indicates a continued change in composition and increased stabilization of the mat Lake water must still have influenced the mat environment, however, as *Pediastrum* is still present in these horizons and only disappears at the boundary of zones L-3 and L-4 where the loss-on-ignition curve reaches a maximum, this may signal the final isolation of the sedge mat surface from the direct influence of lake water The middle of zone L-3, where peat detritus changes to sedge peat, is dated at 4530 ± 70 B P (Table 4)

The *Sphagnum* spore peak in subzone L-4a is interpreted as representing the rapid expansion of *Sphagnum* spp on the consolidated and slightly drier mat *Menyanthes* seeds in the peat however suggest that parts of the peatland surface were not raised far above the local water table Shrubs, though present, were not important in the sedge and *Sphagnum* vegetation as pollen percentages remain low and ericaceous and *Betula michauxii* leaves are not common

Subsequently, in subzone L-4b, shrub pollen and the frequency of shrub leaves (e.g. of *Betula michauxii*, *Chamaedaphne calyculata*, *Kalmia polifolia*, and *Ledum groenlandicum*) increase, indicating the expansion of shrubs on the fen The decline of *Sphagnum* spore percentages in subzone L-4a and continued low values in L-4b are difficult to explain Changes in species composition or spore production caused by environmental change, or a decrease in the abundance of *Sphagnum*, are possible explanations for the decrease The vegetation then present was probably similar to the raised string community (*Scirpus cespitosus*-*Lonicera villosa*-*Aulacomnium palustre* Nodum) present in the fen today After the decline in percentage of *Sphagnum* spores and the expansion of shrubs, no major stratigraphic changes are apparent until the start of pattern formation

Development of the upslope region of Leech Fen

The surface patterns and vegetation present today in the upslope region of Leech Fen are almost identical to those downslope, although the upslope peat overlies a very irregular surface of glacial till—whereas the downslope area developed on a relatively flat sedge mat. Of interest then is a comparison of the developmental history of these two regions. To make such a comparison, the stratigraphy of the cores from the upslope region was analysed in detail, particularly the basal peat of cores 8–11 located at 130, 175, 193 and 195 m upslope from Leech Lake (Fig. 6).

Peat depth in the upslope area generally ranges from 50 cm to 100 cm, although it decreases towards the extreme upper end of Leech Fen to less than 20 cm. In all but one of the four cores analysed in detail, sedge peat or sandy sedge peat overlies the mineral substratum (Fig. 8). Wood fragments are not common in this basal peat, and only a few conifer needles are present. Bryophyte remains are also rare, and where found consist only of branches devoid of leaves. Other macrofossils include a few leaves of *Betula michauxii* and lenticular *Carex* achenes.

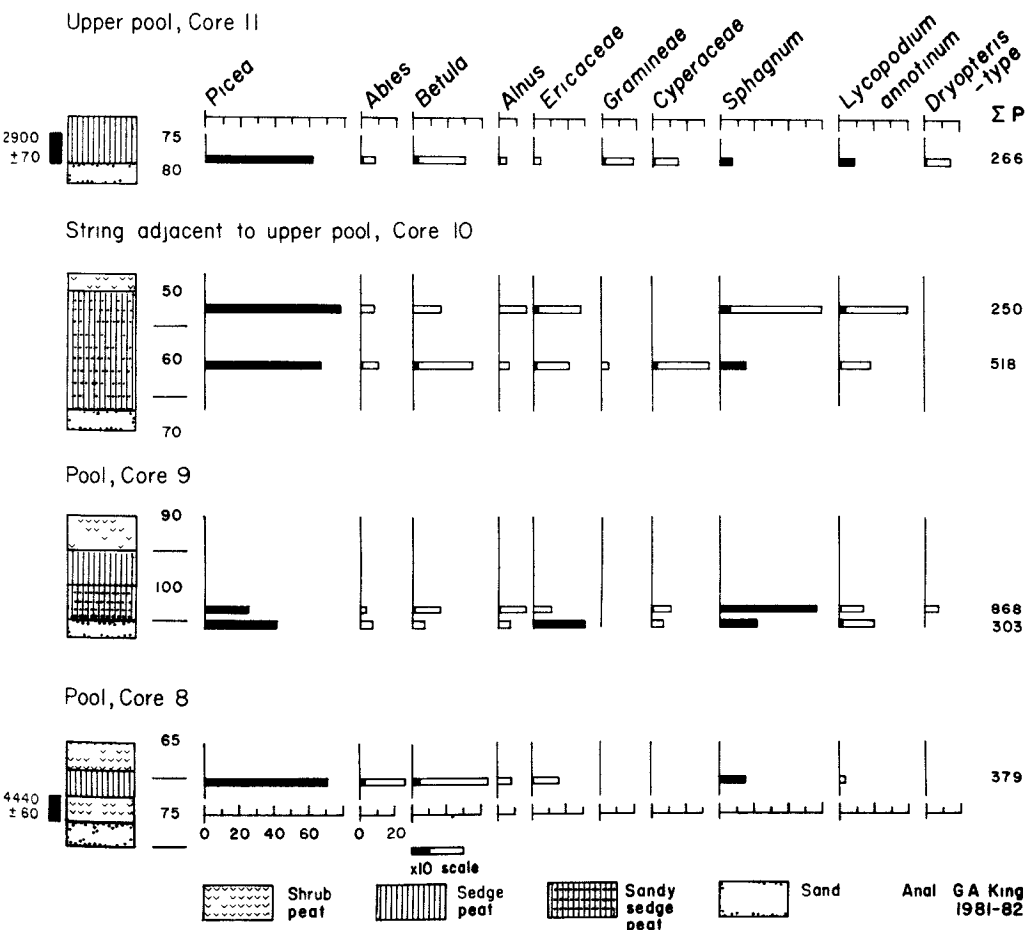


FIG. 8 Stratigraphic summary of the basal peat layers of four upslope cores (8–11) from Leech Fen, Labrador, located at 130, 175, 193 and 195 m upslope from Leech Lake, respectively. ΣP indicates total number of pollen grains counted.

The exception to this generalization is core 8, in which wood was found in the basal peat (Fig. 8). Sedge leaves are common in this zone, as in the other basal peat layers, and few conifer needles are present. This woody zone is 5 cm thick and is overlain by a thin sedge peat zone in which wood is rare, followed by shrub peat to the top of the core.

Pollen assemblages from the basal peat zones are quite variable, both between and within cores (Fig. 8). For instance, core 9 has a basal Ericaceae pollen of 31%, by far the highest Ericaceae percentage of any sample in the fen, and a *Sphagnum* spore percentage of 22%. The sample only 2 cm higher has a much lower Ericaceae value and a much higher *Sphagnum* percentage. This variability of the pollen spectra probably reflects the high proportion of locally produced pollen in the pollen rain on the fen (Janssen 1966) and the variable distribution of fen species with time.

In spite of the variability of the pollen assemblages between and within cores, they are useful in inferring the composition of the plant community present at the time of the initial peat accumulation. The high percentages of *Sphagnum* spores and Ericaceae pollen, together with the macrofossil information, indicate that this community was dominated by sedges and *Sphagnum* spp., with ericaceous shrubs and *Betula michauxii* present but rare and scattered throughout the area. Also, basal *Picea* percentages over 40% indicate that peat began accumulating in the upslope area of Leech Fen only after trees invaded the area approximately 6500 B.P. (Lamb 1980).

After establishment of the sedge-*Sphagnum* community, shrubs increased in importance as indicated by the shrub peat overlying the basal sedge peat of all the upslope cores. Pattern formation did not begin until after establishment of the shrub peatland, as all the pools are underlain by shrub peat.

The vegetation on most of the upslope area of Leech Fen prior to the start of peat accumulation probably was not upland forest. If it had been, one would expect to find more large pieces of wood and conifer needles than were found in the basal peat layers of the upslope cores. Only in Core 12, from the 20-m wide transition area between the upper end of the fen and upland forest, were abundant wood and needles found in the basal peat, suggesting that perhaps some forest has been destroyed at the upslope end of Leech Fen by paludification.

Radiocarbon dates were obtained from the basal peats of three upslope cores to determine more precisely when peat began accumulating upslope and to describe the spatial development of the fen. The basal date at 130 m upslope from Leech Lake is 4440 ± 60 B.P., at 195 m, 2900 ± 70 B.P., and at 210 m, the extreme upper end of Leech Fen (Core 12), 760 ± 70 B.P. (Fig. 3, Table 4). These dates clearly indicate that the fen has gradually encroached upslope from the original shoreline of Leech Lake—a vertical rise of 1.5 m.

Peat accumulation probably began at the original shoreline sometime before 4500 B.P., initiated by impeded drainage along the shoreline. Drainage is likely to have slowed near the shoreline after the sedge mat began growing out over the bay. The initial peat accumulation further impeded drainage, resulting in a rise in the local water table. Conditions favourable for peat accumulation may thus have extended upslope.

The initial peat accumulations cannot be attributed to a climatic change to a cooler, moister regime favouring such accumulations, as the climatic history of south-eastern Labrador is one of continual warming since deglaciation until maximum warmth was reached at 4000 B.P. Only after 2500 B.P. did the regional climate cool significantly (Lamb 1980).

Development of surface patterns at Leech Lake Peatland

The evidence for the developmental sequence and processes responsible for the formation of surface features is provided by the stratigraphic analysis and the study of analogues in the present mire landscape. Observations from elsewhere in south-eastern and western Labrador suggest that the sequence outlined below is applicable to patterned fens throughout the region.

Stratigraphic evidence

Stratigraphic analyses of the cores from Leech Fen show that development of the patterned fen has proceeded from an initial sedge-dominated community to a community in which shrubs and *Sphagnum* have increased in prominence. The differentiation of surface features, pools and strings, occurred after the formation of the shrub peatland. The shrub peat at the peat-water interface in pool 1 dates to 1210 ± 70 B.P., indicating that pool formation occurred at least 3000 years after the establishment of a shrub-dominated peatland at this location. An additional sediment-water interface date of 410 ± 70 B.P. (Table 4) from core 8 corroborates the timing of pool formation. Once initiated, the pools are stable and persistent, an observation supported by work on Swedish fens (Lundqvist 1951) and on raised bogs in Great Britain (Boatman, Goode & Hulme 1981).

Stratigraphically, the transition from shrub peat to open water in the pools is extremely abrupt, and there is a complete absence of autochthonous pool sediment suggesting a strongly degradative environment in which all allogenic and autogenic materials are completely broken down and decomposed. Active decomposition of the peat lining the pools is the most probable explanation for the abrupt change from woody peat to pool water, and the absence of any peat derived from transitional phases in pool development (see below). Thus, pool 1 probably began forming more recently than 1200 B.P. and gradually deepened through the degradation of the underlying peat, to the level that had accumulated at 1200 B.P.

The stratigraphic evidence also indicates that several of the frequently-cited hypotheses that attempt to explain pattern formation are not applicable at Leech Lake Peatland. Closely spaced cores on two transects—from the crest of one ridge across the intervening pool to the next ridge, and in a transect along the length of a pool—do not exhibit any unconformities in the stratigraphic relationships that would suggest the downslope slippage of peat (Andersson & Hesselman 1907, Auer 1920, Schenk 1966). The topographic survey demonstrates the complete lack of correlation between the subsurface topography and the distribution of surface features. This contradicts those theories that predict a correlation (as cited in Sakaguchi 1980), and differs from observations made on some raised bogs (Osvald 1928, Boatman *et al.* 1981).

At Leech Fen, identical surface features, supporting very similar vegetation, have developed in peat overlying lake sediment and in peat that formed directly on mineral soil. This demonstrates that the underlying lithology exerts little influence on the differentiation of strings and flarks. The presence of patterns in peat overlying lake mud also argues against any role of permafrost or gelifluction.

The stratigraphy indicates that the important developmental processes in pattern formation may be operative in analogous situations at present. The present-day mire landscape provides analogues for the major stages in pool and string formation.

Evidence from the modern mire landscape

Pattern development in Leech Lake Peatland is an active process. Flarks and pools in various stages of formation and expansion are common in Plain Fen, Incipient Fen, and Marginal Fen, and suggest a biological and physical mechanism for pattern development. The proposed process includes three parts: (i) development of an irregular mire surface of hummocks and hollows; (ii) gradual expansion and merger of depressions across a slope as controlled by differential rates of peat accumulation; and (iii) expansion and coalescence of water-filled pools through active peat degradation.

An unpatterned shrub community on Incipient Fen provides an analogue for the first stage. A characteristic feature of this community is the irregular hummock-hollow topography that results from the natural growth form of the sedges and *Sphagnum*. The *Scirpus cespitosus*-*Lonicera villosa*-*Aulacomnium palustre* Nodum occupies the raised hummocks and drier peat, whereas depressions often lack continuous vegetation cover or have a thin carpet of *Cladopodiella fluitans*, with scattered individuals of *Carex limosa*, *Chamaedaphne calyculata* and *Menyanthes trifoliata*. The two plant assemblages have different peat-building capabilities, and in time the depressions deepen and increase in size (Plate 2).

The small hollows may gradually merge across the slope of the mire through a process for which analogues are found on the lower flanks of Incipient Fen. Fluctuations in the water table occasionally fill the depressions, and decrease peat production of the vegetation lining the depressions. As the general peat surface rises in time, the water table rises, the duration of standing water in depressions increases, and adjacent hollows may merge across the slope by the gradual swamping of the intervening hummocks (Boatman *et al.*



PLATE 2. Shallow mud-bottom on Incipient Fen, Labrador. These small hollows coalesce across the slope to form continuous pools. Photograph by D. R. Foster.

1981) As intervening hummocks are submerged, their vegetation changes to more hydrophytic assemblages. The original vegetation is replaced by a carpet of *Sphagnum angustifolium* or *S. lindbergii* associated with *Andromeda glaucophylla*, *Betula michauxii*, *Chamaedaphne calyculata*, *Menyanthes trifoliata* and *Scirpus cespitosus*. As the water table rises relative to the peat surface of the hummock, first *Sphagnum lindbergii*, then the shrubs and finally *Scirpus* are eliminated. Relict hummocks are scattered throughout many shallow flarks and pools, and extend just above the water surface with a broken vegetation cover of *Cladopodiella fluitans*, *Drosera anglica* and *Juncus stygius*. These features are underlain by firm shrub peat and may be a typical by-product of flark formation.

Hollows which were originally small and nearly circular gradually become elongated across the slope as they grow larger and coalesce into pools (Gorham 1957). If a higher and lower pool are connected by erosion, the higher will drain and tend to be colonized by vegetation. As pools join across the slope on the same water level, however, they will be maintained as a single pool elongated perpendicular to the slope.

Once the differential accumulation of peat has led to formation of water-filled depressions, expansion of pools in size and depth is promoted by peat degradation. The evidence for this process is ubiquitous and compelling. The great age of, and absence of modern sediment at, the peat-water interface in pools demonstrate that decomposition is active and may be attacking the walls of the peat basin itself. Cores taken in pools show that the peat becomes progressively darker towards the water interface, an indication of increasing humification. The peat in the bottom of a pool is a highly unconsolidated ooze underlain by a layer of twigs and other woody material, which suggests that the decomposition of the less resistant sedge and *Sphagnum* matrix of the shrub peat results in the concentration of the refractory woody materials. In many pools, pieces of wood, principally the root crowns or main stems of shrubs and small trees, jut from the mud surface.

Conditions within pools certainly provide an environment favourable for decomposition. Dissolved oxygen concentrations ranging from 3.5 mg l⁻¹ to 9 mg l⁻¹ have been measured in the water of numerous pools on a patterned fen in western Labrador. Mixing by wind, as well as, algal photosynthesis (Sjors 1961) is probably responsible for oxygenating the water column. Large gas bubbles (probably primarily of methane and carbon dioxide) form across the bottoms of pools and buoy up the algal mat or other unconsolidated material. The bubbles, which may extend 1 m or more in diameter and 30 cm in height, eventually burst, suspending the flocculent plant debris and increasing its exposure to the warm, oxygenated water. Other physical processes, such as wind and, in winter, ice action may serve to churn the surface layers of peat that line the pools. Shallow pools undergo a wet-dry (pool-mud bottom) cycle through the growing season as the water table fluctuates. Longitudinal cracks appear in the mud bottom surface and these introduce air into the surface peats.

Evidence of the coalescence of adjacent pools is found throughout the peatland, and helps explain the shape and orientation of these features on the mire surface. Two processes are operative—gradual swamping and degradation of the intervening strings, and erosion of an open channel to form a narrow connection between pools. If two pools are on very nearly the same level within the mire, the first process may occur if the intervening string across the slope grows more slowly than the damming string downslope. This currently is occurring at three locations on Beautiful Fen. As the water level rises in the downslope pool, the vegetation on the slower-growing string upslope becomes more hydrophytic and there is a gradual loss of mesic species and decrease in plant cover (Plate 3). Strings have an



PLATE 3. Degradation of strings by swamping results in the formation of a series of small peat islands, Leech Fen, Labrador. Photograph by D. R. Foster.



PLATE 4. Final stages in string degradation consist of scattered peat islands with mud bottom vegetation and parallel strips of *Carex limosa* and *Menyanthes trifoliata*, in Leech Fen, Labrador. Photograph by D. R. Foster.

undulating surface topography and slowly break up into lines of small peat islands as they are flooded. Eventually the entire string becomes submerged and only a line of scattered shoots of *Betula michauxii*, *Carex aquatilis*, or *C. limosa* and a few relict islands mark the previous position of the string (Plate 4).

Photographs taken over a 23-year period on Brishie Bog, S W Scotland (Boatman & Tomlinson 1973) document a similar process of peat island formation through flooding of a strip of vegetation between the island and the confluent pool. These islands, similar to those in pools in Labrador, have steep eroded sides and are undoubtedly slowly degrading. Identical processes have been seen on raised bogs along the south-eastern coast of Labrador and suggest that analogous mechanisms operate on both ombrotrophic and minerotrophic peatlands.

The role of water erosion in cutting and enlarging channels between pools has been discussed previously (see Water movement, p. 121). If there is a great height difference between adjoining pools, upon channel formation the upper one may drain, with the consequent exposure of an extensive mud bottom. The mud bottoms are frequently invaded by a carpet of *Sphagnum lindbergii*, or if they are very close to the water table they may be maintained by fluctuating water levels as open communities of *Carex limosa*, *Cladopodiella fluitans*, and *Menyanthes trifoliata*.

If the bottom of the upper pool is lower than the water level in the lower pool, channel cutting results in the connection of the two pools by a narrow neck. The water level of the composite pool will be determined by the level of the lowest outflow (cf. Boatman & Tomlinson 1973). The depth of water in the two basins will remain different however, and fluctuations of the water table may expose the mud bottom in one part of the pool and not the other. In time, and with continual erosion and degradation, the floor of the composite pool eventually becomes level, an observation recorded at Brishie Bog (Boatman & Tomlinson 1973).

Both processes of pool coalescence are active throughout Leech Lake Peatland, and are especially prevalent on Beautiful Fen. The irregular and sinuous shape of many pools, the narrow constrictions between two or more larger pools, and the difference in water depths between connected basins substantiate the historical importance of these mechanisms in the formation of the existing pools. Aerial and field observations in south-eastern Labrador, as well as literature reports and air photographs (Ruuhijarvi 1960, 1970, Allington 1961, Sjors 1963, Boatman & Tomlinson 1977) suggest that pool expansion and coalescence explain many of the attributes of pools in patterned mires.

ACKNOWLEDGMENTS

We thank Professor N. Malmer and Dr P. Pakarinen for informative discussions, Drs P. Glaser, E. Gorham, M. Henselman, and H. E. Wright for critical reviews of the manuscript; Dr R. Ireland for identifying the bryophytes; Dr J. Janssens for assistance with sub-fossil bryophytes, Dr C. Wetmore for assistance with lichen taxonomy, D. Engstrom and S. Fritz for consultation on water chemistry, and Dr J. Kingston for diatom analyses of sediment cores. Support was given by the Smithsonian Institute (through W. Fitzhugh), National Geographic Society, National Science Foundation, and U.S. Department of Energy (through T. Webb). This paper is Limnological Research Center Contribution No. 274.

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(Received 3 March 1983)

