

## The Microstratigraphy of Two Peat Sequences from Northeastern Newfoundland

## La microstratigraphie de deux séquences de tourbe dans le nord-est de Terre-Neuve

## Die Mikrostratigraphie von zwei Torfsequenzen von Nordost-Neufundland

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Résumé de l'article

Les tourbes ombrothropes de Terre-Neuve présentent d'ordinaire des couches nettement définies. Chaque couche comporte une partie inférieure claire et une partie supérieure foncée. Les couches sont séparées par des surfaces de récurrence abruptes. La régularité des couches suppose l'existence d'un phénomène cyclique. Les micro et macrostratigraphies physique et celles des éléments de deux coupes de deux profils rubanés de la région de Wesleyville ont été étudiés en vue d'en observer les différences et de déterminer les causes de ces différences. Les teneurs en cendres et en fibres, le poids volumétrique, la teneur en eau et la rétention d'eau ont été mesurés. Les trois dernières propriétés ont montré des changements uniformes dans chacune des coupes. Aucune configuration évidente n'est ressortie des valeurs des éléments biologiquement actifs qui ont été mesurés (Mg, Cl, Ca, Na, Mn et I), mais les courbes de Br, V et U, biologiquement inertes, ont montré des variations systématiques qui semblaient refléter les variations du taux d'accumulation de la tourbe. Les stratigraphies du pollen, des spores et des macrofossiles étaient dans l'ensemble insensibles, bien que la représentation des macrofossiles et des spores de Sphagnum variait de façon régulière, tout comme les concentrations de pollen et de spores. Chacune des séquences claire-foncée semble correspondre à un cycle de changements hydrologiques autogénérateurs impliquant des modifications dans la composition de l'association végétale et dans les taux d'oxydation et d'accumulation, plutôt que dans le climat. Les cycles, qui s'étendent à l'ensemble du système, semblent durer environ 700 ans, mais avec des décalages variables.

# THE MICROSTRATIGRAPHY OF TWO PEAT SEQUENCES FROM NORTHEASTERN NEWFOUNDLAND

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**ABSTRACT** Commonly, the ombrotrophic peats of Newfoundland have a well-defined banded appearance. Each band consists of a light-coloured lower section and a dark upper component. The bands are separated by abrupt recurrence surfaces. The regularity of the bands implies cyclicity. The physical, elemental, micro- and macrostratigraphies of two banded profiles from the Wesleyville area were examined in an attempt to document the differences and to provide insight into cause. Ash content, fibre content, bulk density, water content and water retention were measured. The latter three showed consistent changes through each profile. There were no obvious patterns in the values for the biologically active elements that were measured (Mg, Cl, Ca, Na, Al, Mn and I), but the curves for Br, V, and U, biologically inert elements, showed systematic variations that appear to reflect variations in peat accumulation rate. The pollen, spore and macrofossil stratigraphies were generally complacent, although the representation of *Sphagnum* macrofossils and spores varied regularly as did pollen and spore concentrations. Each light-dark sequence appears to reflect a cycle of self-sustaining hydrologic changes involving changes in community composition, and in oxidation and accumulation rate, rather than climate. The cycles appear to be ca. 700 years in length, and are system-wide, but with variable lag times.

**RÉSUMÉ** La microstratigraphie de deux séquences de tourbe dans le nord-est de Terre-Neuve. Les tourbes ombrotrophes de Terre-Neuve présentent d'ordinaire des couches nettement définies. Chaque couche comporte une partie inférieure claire et une partie supérieure foncée. Les couches sont séparées par des surfaces de récurrence abruptes. La régularité des couches suppose l'existence d'un phénomène cyclique. Les micro et macrostratigraphies physique et celles des éléments de deux coupes de deux profils rubanés de la région de Wesleyville ont été étudiés en vue d'en observer les différences et de déterminer les causes de ces différences. Les teneurs en cendres et en fibres, le poids volumétrique, la teneur en eau et la rétention d'eau ont été mesurés. Les trois dernières propriétés ont montré des changements uniformes dans chacune des coupes. Aucune configuration évidente n'est ressortie des valeurs des éléments biologiquement actifs qui ont été mesurés (Mg, Cl, Ca, Na, Mn et I), mais les courbes de Br, V et U, biologiquement inertes, ont montré des variations systématiques qui semblaient refléter les variations du taux d'accumulation de la tourbe. Les stratigraphies du pollen, des spores et des macrofossiles étaient dans l'ensemble insensibles, bien que la représentation des macrofossiles et des spores de *Sphagnum* variait de façon régulière, tout comme les concentrations de pollen et de spores. Chacune des séquences claire-foncée semble correspondre à un cycle de changements hydrologiques autogénérateurs impliquant des modifications dans la composition de l'association végétale et dans les taux d'oxydation et d'accumulation, plutôt que dans le climat. Les cycles, qui s'étendent à l'ensemble du système, semblent durer environ 700 ans, mais avec des décalages variables.

**ZUSAMMENFASSUNG** Die Mikrostratigraphie von zwei Torfsequenzen von Nordost-Neufundland. Im allgemeinen treten die ombrotrophen Torfe Neufundlands in gut erkennbaren Streifen auf. Jeder Streifen besteht aus einer leichtgefärbten unteren Schicht und einem dunklen oberen Teil. Die Streifen werden durch plötzlich zu Tage tretende Grenzhorizonte getrennt. Die Regelmäßigkeit der Streifen setzt Periodizität voraus. Die Mikro- und Makrostratigraphie des physikalischen und elementaren Aufbaus zweier Streifenprofile aus der Gegend von Wesleyville wurden untersucht, um die Unterschiede aufzuzeichnen und um die Ursachen zu ergründen. Gehalt an Asche und Fasern, spezifische Dichte, Wassergehalt und Wasserzurückhaltungsvermögen wurden gemessen. Die drei letzteren wiesen konstante Wechsel in jedem Profil auf. Keine deutlichen Muster in den Werten der biologisch aktiven Elemente konnten gemessen werden (Mg, Cl, Ca, Na, Al, Mn und I), aber die Kurven von Br, V und U, den biologisch inaktiven Elementen, zeigten systematische Variationen, welche die Variationen von Torfansammlungsraten wiederzuspiegeln schienen. Die Pollen-, Sporen- und makrofossilen Stratigraphien waren im allgemeinen unverändert, wenn auch das Vorkommen von *Sphagnum*-Makrofossilen und Sporen genauso wie Pollen- und Sporenkonzentrationen regelmäßige Veränderungen aufwies. Jede hell-dunkel Sequenz scheint einen Zyklus sich selbsttragender hydrologischer Veränderungen in der pflanzlichen Zusammensetzung, der Oxydierung und der Akkumulationsrate zur Folge hatten als klimatische Veränderungen. Die Perioden scheinen etwa 700 Jahre gedauert zu haben, betreffen das ganze System aber mit variablen Verzögerungen.

## INTRODUCTION

In northwestern Europe, pollen and macrofossil stratigraphies of ombrotrophic peats have long been basic to the reconstruction of Holocene vegetation and climatic changes. The Blytt-Sernander scheme of climatic episodes was in part dependent on the recognition of recurrence surfaces (MOORE and BELLAMY, 1974). The latter are abrupt changes from dark, well-humified peat to light unhumified peat. Commonly, several of the light-dark sequences are recognizable at each peat exposure. They are characteristic of *Sphagnum*-dominated peatlands in northeast Europe and northeastern North America.

The association of these stratigraphic features with the climatic changes of the Holocene implied direct climatic control. The major recurrence surface common to most ombrotrophic peatlands was designated as the "grenzhorizont" by WEBER (1900) and dated by archaeological association with the Sub-Boreal/Sub-Atlantic transition of the Blytt-Sernander scheme. In Sweden, GRANLUND (1932) recognized five recurrence surfaces. NILSSON (1964) identified nine. More recent work supported by  $^{14}\text{C}$  dates shows that many of these surfaces are local in extent, and are considerably time-transgressive (MOORE and BELLAMY, 1974). Explanations involving autogenic, hydrologic and vegetation changes rather than direct climatic control have been suggested (see BARBER, 1981).

In Newfoundland, the light-dark sequences have a regular banded appearance that suggests cyclicity. In this research, the physical, chemical and micro- and macrofossil characteristics of two banded profiles from the Wesleyville area were examined. Each profile consisted of a series of cycles. Each cycle contained a light-coloured lower unit, and a darker upper unit. The boundaries between successive cycles were abrupt. Two cycles from each profile were examined. It was assumed that such analyses might allow determination of the causes of the distinctive stratigraphies.

Although peatlands in eastern North America are morphologically and floristically similar to those of northwestern Europe, until recently there have been few investigations of their stratigraphies and paleoecologies (WELLS, 1981; DAVIS, 1984; FOSTER, 1984; FOSTER and KING, 1984; COUILLARD and PAYETTE, 1985; ZOLTAI and JOHNSON, 1985). Banded profiles have been noted by FOSTER (1984) and by GLASER and JANSSENS (1986). The work presented here complements those studies.

## THE STUDY SITE

Geologically, northeastern Newfoundland is within the Gander zone, which consists of early Paleozoic sediments and numerous granitic intrusions (ROGERSON, 1981). Throughout much of the region, peat has developed directly over granite with no intervening accumulation of mineral soil.

The climate of the area is wet, cool and cloudy. Its mean annual precipitation is ca. 1000 mm. Snowfall averages 200 cm. Mean daily temperatures are 14°C to 16°C in July and -4°C to -6°C in February (BANFIELD, 1981). Sea-ice commonly persists into June. Cloud cover averages  $\frac{7}{10}$  to  $\frac{8}{10}$ . Fogs are common.

Although ROWE (1972) classifies the area as part of the boreal forest region, it has few trees. Over half of it is treeless peatland. Trees have been largely eliminated from the remainder by cutting and burning, and by the effects of exposure. *Abies balsamea* and *Picea glauca* persist in sheltered locations. *Picea mariana* occurs in dwarf form across the peatlands. DAMMAN (1983) classifies the area in his eastern hyper-oceanic barrens ecoregion which also includes the blanket bog area of the southern Burin and Avalon Peninsulas.

The peatlands of coastal northeastern Newfoundland are commonly plateau raised bogs (WELLS and POLLETT, 1983). Their surfaces are generally flat. Pools are frequent, but lack obvious orientation, except around the margins, where there may be slopes of 20-30%. Low interfluves between the deep peats may have a blanket-like peat cover.

The peatlands are dominated by *Sphagnum*, although heaths are common on drier sites. Hummocks are usually comprised of *Sphagnum fuscum* and *S. rubellum*, although *S. flavicomans* and *S. imbricatum* may be present. The latter may completely cover hummocks in coastal areas (WELLS, 1981 and pers. comm. 1986). Other bryophytes include *Dicranum undulatum* and *Polytrichum strictum*. Hollows are dominated by *Sphagnum rubellum* and *S. tenellum* with *S. pulchrum* and *S. cuspidatum* in patches. Lawn communities are dominated by *S. rubellum*, *S. flavicomans* and *S. magellanicum*, with scattered patches of *S. tenellum*, *S. cuspidatum*, *S. pulchrum* and *S. papillosum*.

*Empetrum nigrum* is the most common heath, although *Vaccinium oxycoccus*, *Andromeda glaucophylla*, *Chamaedaphne calyculata* and *Kalmia polifolia* occur in all communities. *Cladonia* spp. are prominent on drier sites. *Scirpus cespitosus* is widespread. *Eriophorum spissum* is common except in lawn communities.

The profiles used in this study were taken from peats exposed in the shoreline ca. 1 km west of Newtown (Fig. 1; Lat. 49° 12' N, Long. 53° 32' W). Up to 3 m of peat is exposed here. The basal date, 10,290 ± 380 (WAT-888) on birch wood, implies that peat accumulation began early after deglaciation/emergence. The *Sphagnum* peats in the middle and upper parts of the exposures are clearly banded and have well-defined recurrence surfaces. At the site of Profile A, surfaces are obvious at 115 cm, 122 cm, 132 cm, 139 cm, 157 cm, 171 cm, 177 cm, 183 cm. Twigs were common in the darker sections, but absent from the light coloured peat. At the site of Profile B, recurrence surfaces occurred at 140 cm, 150 cm, 163 cm, 182 cm, and 197 cm. Each of the cycles had twigs in the dark areas. Mean twig diameter increased with depth from 1 cm at 140 cm to approximately 2 cm at 197 cm.

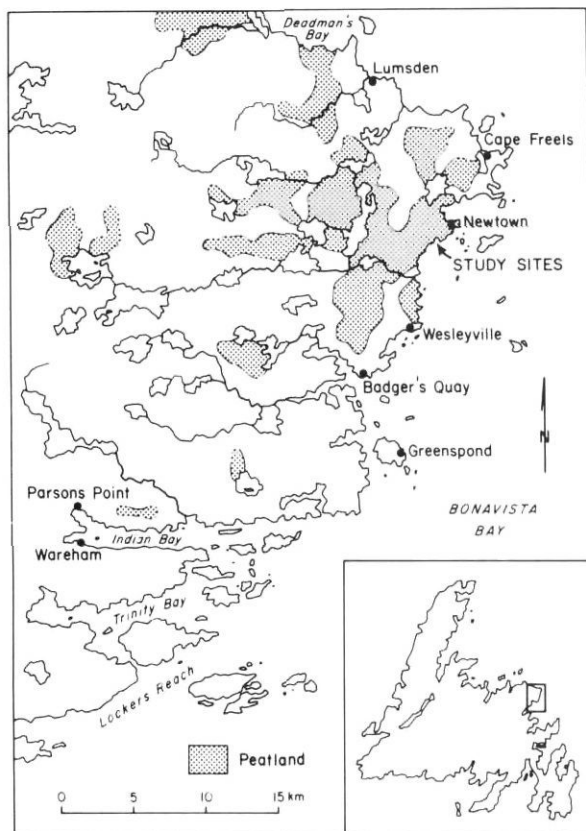


FIGURE 1. Map of northeastern Newfoundland indicating location of the study sites.

Carte du nord-est de Terre-Neuve montrant la localisation des sites à l'étude.

## METHODOLOGY

### 1. FIELD COLLECTION

The exposed faces were cutback approximately 50 cm prior to sampling to minimize the effects of exposure on the physical and chemical properties of the peat. In Profile A, samples were taken between the 139 and 171 cm levels to include the two most prominent cycles. Each cycle was sampled on three blocks; top, middle, and bottom. Each was ca. 10 × 8 × 6 cm. Profile B was sampled between 150 and 182 cm. Two cycles were included. Two blocks were cut from each. A vegetation inventory of the bog surface was made. Plants were collected for reference material. Samples are stored in the Department of Geography, University of Toronto.

### 2. LABORATORY ANALYSIS

Several physical parameters were determined. These included ash content, fiber content, bulk density, water content and water retention. It was assumed that these measurements would provide insight into the degree of decomposition and into behaviour with respect to water storage, yield and conductivity. Ash content, fiber content and bulk density are considered good indicators of degree of decomposition (see BOELTER, 1966, WALMSLEY,

1977). Ash content was measured *via* loss on ignition at 375°C for sixteen hours. Fiber content was determined by the half-syringe procedure proposed by LYNN *et al.* (1973). Bulk density, the dry weight of a given volume of peat, was calculated on a wet volume basis.

Although bulk density reflects water storage capacity, the latter can be expressed directly by water content (on a weight basis) or as total porosity, usually total volume of water at saturation expressed as a percentage (WALMSLEY, 1977). The former is used here. Water retention characteristics were measured using a pressure cell (DAY *et al.*, 1979). This was suitable for suctions of 0.1 bar; sufficient to illustrate the differences in water retention between undecomposed and moderately decomposed peats. Values are shown as percent volume.

pH was determined in the laboratory after samples had equilibrated in distilled water for thirty minutes (STANEK, 1973).

Chemical analyses of dry peat were done by instrumental neutron activation analysis using the University of Toronto's SLOWPOKE reactor (HANCOCK, 1976). Mg, Cl, Ca, Na, Al, Mn, I, Br, V and U were measured. These are a combination of biologically active and inert elements (BROOKS, 1973). The former, the first seven, provide data on the rate and character of biogeochemical cycles. The latter, Br, V and U, appear to be useful indicators of accumulation rate.

### 3. MACROFOSSIL ANALYSIS

The methodology generally followed was that of DICKSON (1979). Approximately 5 g of fresh peat was sieved through 80, 110 and 120 mesh sieves to separate the macrofossils into size classes. The plant remains were identified under the dissecting and compound light microscopes. Each taxon was expressed as a percentage of volume. Identifications of bryophytes were made by comparison to reference material provided by the Herbarium, University of Toronto, and by Dr. L. Ovenden, and the keys of WATSON (1981) and CRUM and ANDERSON (1981).

### 4. POLLEN AND RHIZOPOD ANALYSIS

Approximately 1 ml of each sample was prepared for pollen analysis using a modified version of the technique proposed by FAEGRI and IVERSEN (1975). Prior to processing, two tablets containing approximately 27,000 *Eucalyptus* pollen grains were added to each sample (STOCKMARR, 1971). This allowed calculation of pollen concentrations. Percentages were calculated on a pollen sum of at least 200 grains. Trees and shrubs were included in the sum. *Sphagnum*, Cyperaceae and the rhizopods, *Amphitrema* and *Assulina*, were excluded from the sum.

## RESULTS

### 1. PHYSICAL AND CHEMICAL ANALYSIS

The physical variables were measured for four replicate samples from each block. The relationships between the



physical parameters and position with the profile were tested by linear regression (BLALOCK, 1979). Correlation coefficients and significance levels were calculated. The results were summarized in Figure 2. For Profile A, the ash content is lowest in the blocks immediately above each recurrence surface and is highest in the dark upper section of each cycle. There was a significant correlation between position and ash content in Profile A ( $r = .654$ , 95 % level), but no significant correlation in Profile B.

The unrubbed fiber contents are illustrated in Figure 2. Only the lower cycle of Profile A shows any dramatic difference between blocks, but trends are not significant in either profile.

The bulk density data show a consistency not apparent in the previous two indicators. The upper sections of all cycles have higher values than do the lower parts. These differences in bulk density are significant ( $r = .84$ ; 95 % level). Saturated water content was highest in the lower portion of each cycle. For both profiles, water content is significantly correlated with position in the cycle ( $r = .480$ ; 95 % level); water content decreases with height in the cycle. However, even under small suctions (0.1 bar), the relationship is reversed (Fig. 2). Little water is retained by the peats in the lower section of each cycle. The upper sections retain much of their original water ( $r = .75$ ; 95 % level). pH varied little and there are no significant trends.

Concentrations of the ions detected in the dry peat samples are shown in Figure 3. The ions in order of abundance (highest to lowest concentrations) are Mg, Cl, Ca, Na, Al, Br, I, Mn, V and U. There are few consistent relationships between ionic concentration and position in a cycle. Ca, Al, V, Br and U have highest concentrations in the upper darker positions, and lowest concentrations at the base of each cycle.

## 2. MACROFOSSIL AND MICROFOSSIL ANALYSIS

The taxa identified in Profiles A and B are shown in Figure 4. The open bars show 10x exaggeration. The identification of macrofossils was rarely made to species level, in part because of preservation. The amount of identifiable organic matter was greatest in the lower section of each cycle. The materials in Profile A were better preserved than those in Profile B. Identification of the *Sphagnum* was based largely on the shape and size of branch leaves, and on the morphologies of their hyaline cells, fibrils and pores. Unfortunately, there were few stems or stem leaves present. Cross-sections of leaves, often critical to identification (VITT and ANDRUS, 1977) could not be made. OVENDEN (1985) found similar difficulties with the separation of *Sphagnum*, particularly section *Acutifolia*.

The other bryophytes are poorly represented. *Polytrichum* is identified as *P. strictum* on the basis of cell structure and awn size, although no complete leaves were found. *Drepanocladus* is probably *D. fluitans*. Leaves were fragmented, but the few tips had the lightly toothed margins characteristic of the species. *Dicranum* is probably *D. bergeri*. Lichens are usually underrepresented in peat (MOORE

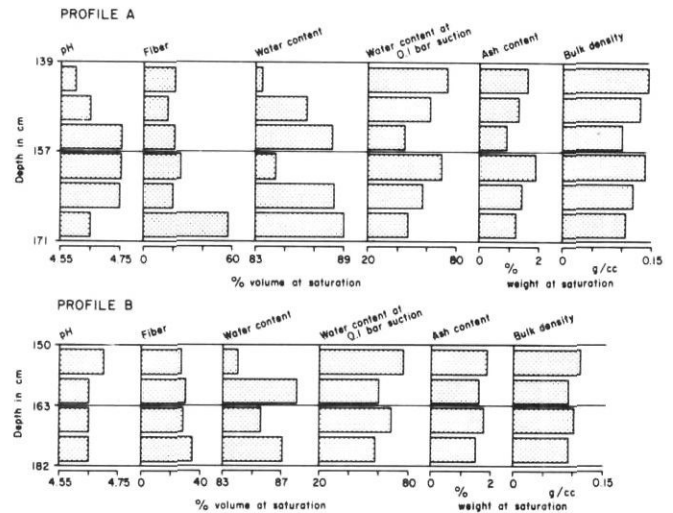


FIGURE 2. Physical variables for Profiles A and B.

*Les variables physiques des profils A et B.*

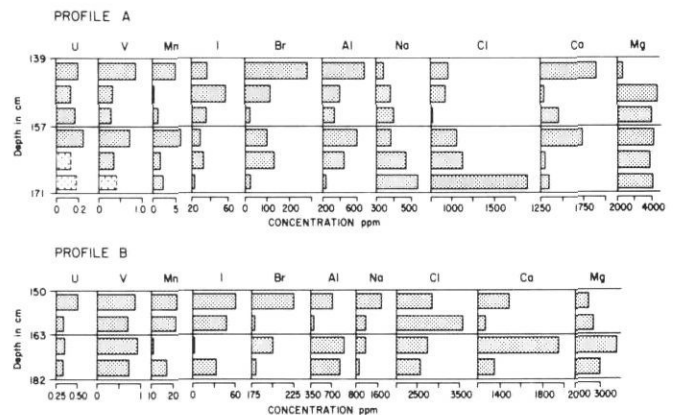


FIGURE 3. Concentrations of ions. Bars with light shadings give maximum values. Correct value is less but could not be accurately determined.

*Les concentrations d'ions. Les colonnes dont le gris est plus léger représentent les valeurs maximales. La valeur réelle est moindre, mais n'a pas pu être déterminée avec précision.*

and BELLAMY, 1974), so the small amounts of highly fragmented *Cladonia* are not unusual.

Because of a lack of bark and the difficulty of preparing cross-sections, much of the wood could not be identified. Longitudinal sections made it possible to distinguish between gymnosperm and angiosperm wood. The fossils in the dark upper portions of each cycle were more decayed than those in the lower levels of the cycles.

The major genera of pollen grains identified are shown in Figure 5. The two rhizopod genera, *Assulina* and *Amphitrema* are also included in the diagrams. There were no clear patterns in the percentages of the tree and shrub taxa, but the representation of *Sphagnum* is consistent from cycle to cycle as is the pollen concentration. In both profiles, the *Sphagnum* spore concentrations are highest in the lower, lighter portion of each cycle. The rhizopod, *Amphitrema*, is

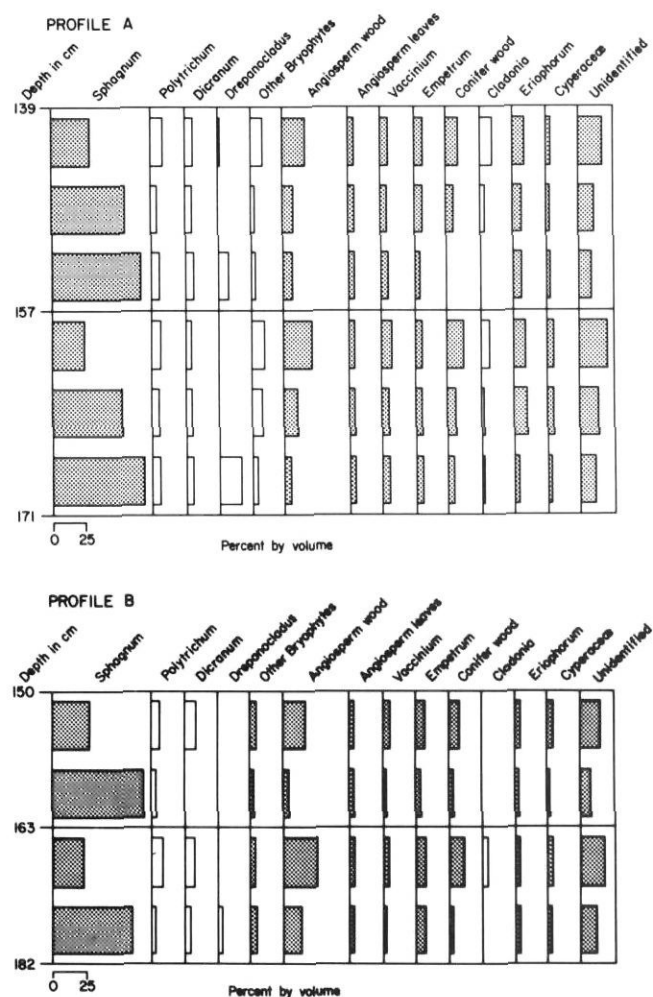


FIGURE 4. Macrofossil diagrams. Values are % of dry weight. White bars indicate 10x exaggeration.

*Diagrammes macrofossiles. Les valeurs sont en pourcentage du poids sec. Les colonnes sans grisé représentent une exagération de 10x.*

also highest in the lower portions for all cycles. *Assulina* is inconsistent.

## DISCUSSION

### CHANGES IN THE VEGETATION

The pollen, spore, rhizopod and macrofossil data imply that each light/dark sequence represents a cycle of vegetation change in response to altering hydrologic conditions. The upper, dark layer of each cycle is commonly woody, although the matrix is predominantly *Sphagnum*. The lower, light areas are dominated by *Sphagnum* and contain very little woody material. Only *Sphagnum* macrofossils show consistent changes through each profile, although these changes are in amount rather than species composition. The lack of reliable indicator species limits the value of *Sphagnum* macrofossils for paleoenvironmental reconstruction. *Sphagnum rubellum* dominates both profiles. Presently the species occupies a wide range of microhabitats. AN-

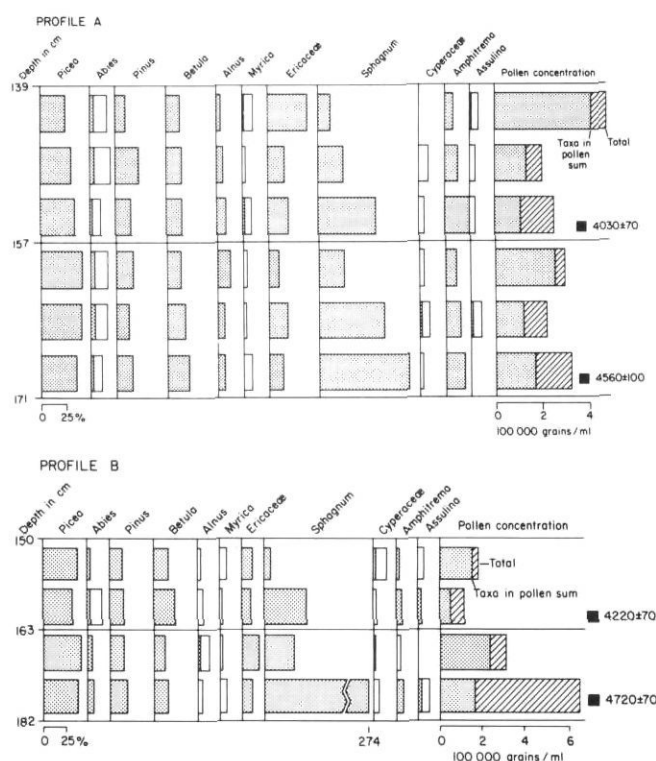


FIGURE 5. Pollen, spore and rhizopod diagrams. White bars indicate 10x exaggeration.

*Diagrammes sporolliniques et des rhizopodes. Les colonnes sans grisé représentent une exagération de 10x.*

DRUS (1986) suggests that it shows unusual adaptability in coastal environments.

Although the combinations and abundances of the other taxa suggest some community differences between different parts of each cycle, these are not marked.

The pollen and spore spectra for the trees and shrubs are complacent. *Picea* and *Abies* percentages have little variability. There is no indication of extra input in the upper sections of each cycle even though an increase in conifer wood implies stronger local representation of spruce and/or fir. Presently, dwarf spruce is common on hummocks, but does not appear to be producing male or seed cones. DAVIS (1980) has shown that *Picea* values are high in ombrotrophic bogs in northern Newfoundland even where there is no local input of spruce. This is in part a function of the paucity of local pollen production from shrubs and herbs. Only the percentages of *Sphagnum* show consistent changes through each cycle (Fig. 5). Values are always highest in the basal section of each cycle, above the recurrence surface. The concentration data indicate that the differences are independent of fluctuations in the values of the other taxa. Spore and macrofossil records for *Sphagnum* are remarkably similar. Here, *Sphagnum* spore production appears to be a reliable indicator of the importance of the moss in the community. TALLIS (1964) noted that in banded peat profiles in the southern Pennines, England, spore production was proportional to the *Sphagnum* content

of the peat, and was highest in the zones of light-coloured, unhumified peat.

The pollen and spore concentration curves (Fig. 5) indicate that the highest concentrations of those taxa included in the pollen sum occur in the dark upper sections of each cycle. Concentrations of taxa outside of the sum (*Sphagnum* is by far the largest contributor) are largest in the lower part of each cycle. Usually, these variations can be attributed to changes in the size and character of the pollen source, or to changes in the rate of accumulation. In the former, local environmental changes may induce a different vegetation association. However, it is likely that the relative values of the taxa would change as well as their influxes. This is not obvious in the pollen spectra. Thus, the high pollen concentrations in the dark layers are probably related to changes in accumulation rate, the balance between productivity and humification. The environmental implications are considered later.

The rhizopod curves generally complement the pollen and macrofossil data. In the past, rhizopods have been little used as indicators of paleoenvironment (BARBER, 1981). As with other types of protozoa, their ecology is not well understood, although VAN GEEL (1978) indicates that *Amphitrema* and *Assulina* species prefer wet environments. AABY and TAUBER (1975) consider them reliable indicators of humidity at the time of peat formation. In their study at Draved Mose, strong representation of these rhizopods was coincident with other indicators of surface wetness, and was negatively correlated with degree of humification (AABY and TAUBER, 1975). In this study, only *Amphitrema* is consistently high in the lower, wetter parts of each cycle (Fig. 5).

#### CHANGES IN BIOCHEMISTRY

Little is known about the input, uptake and release of nutrients in peat. Most research has been confined to the living layers above the permanent water table (see DAMMAN, 1978, 1986; CLYMO, 1983). The distribution of elements in peat profiles has received little attention. Recently, there has been interest in the cation, heavy metal and radioisotope contents of peats primarily as indicators of atmospheric pollution, and as measures of productivity and accumulation (see PAKARINEN and TOLONEN, 1977; CLYMO, 1983).

*Sphagnum* is well-known for its high cation exchange capacity, high productivity under low nutrient conditions, and its conservative nutrient regime (CLYMO and HAYWARD, 1982). In ombrotrophic bogs like those of the study area, elements are derived from the atmosphere and by recycling. Those elements active in the biogeochemical cycle are useful indicators of the local environment. Those biologically inert can serve as a surrogate dating tool; a guide to accumulation rate, as can pollen concentration (MIDDEL-DORP, 1982).

The vertical distribution of elements in the peat profile are largely determined by supply, uptake and retention, and by removal and relocation (DAMMAN, 1986). Uptake and

retention are related to pH, community composition and redox potential (determined by water level). The pattern of elements varies with community and, thus, peat type (CLYMO, 1983).

In most peat sequences, elements have their highest concentrations in the acrotelm, the zone above the water table (DAMMAN, 1986). In the underlying catotelm, concentrations are considerably less; elements have been biologically relocated or leached from the system. Once peat enters the anaerobic catotelm, where hydraulic conductivity is minimal, its elemental pattern is essentially fixed.

In this study some elements show little pattern in their distributions. Of those with large concentrations only calcium (Ca) has consistency, being higher in the upper sections of each cycle (Fig. 3). Ca is lost rapidly in anaerobic conditions. It is normally found in an extracellular exchangeable form and is rarely taken up by plants (BROWN, 1982). If Ca values are related to surface wetness, then this pattern here implies greater wetness in the lower section of each cycle.

Aluminum (Al) availability is related to water table. It is immobile where there is poor drainage (DAMMAN, 1978). Al has its highest concentrations in the darker, upper portion of each cycle. This pattern suggests lower water table at this stage.

U, Br and V are biologically inert elements, although their retention may be related to their affinity for *Sphagnum* and peat (HEMOND, 1980). All show higher concentrations in the darker sections of the cycles. This pattern may be indicative of slower growth rates in the dark, upper section of each cycle, if a constant input of the elements can be assumed.

BROWN (1982) has suggested that differences in nutrient concentration may be attributable to differences in the ecologies of the *Sphagnum* species. He concluded that faster growing hollow species had higher concentrations of Mg and lower concentrations of Ca and Mn than hummock species. Here, only the pattern for Ca supports his contention.

Despite inconsistencies, the distribution of ions throughout the profiles appears to be a good indicator of past bog conditions. It suggests that in each cycle the bog passes from an assemblage of fast-growing species adapted to wet, relatively high nutrient conditions, to a group of slow-growing species adapted to drier, more nutrient deficient conditions.

#### ACCUMULATION RATE

Accumulation of peat is determined by the difference between plant growth and losses by decay, compression and consolidation (CLYMO, 1978). It may vary between half to one tenth the rate of primary production (READER and STEWART, 1972; FENTON, 1980).

DAMMAN (1986) has suggested that peat accumulation is due to slow decomposition rather than high productivity, although CLYMO (1983) has demonstrated that the productivity of *Sphagnum* in pools may be twice that of lawns and



5x that of hummocks. Decomposition is accomplished largely by oxidation, which is temperature and water dependent (CLYMO, 1983). It is at a maximum in the acrotelm and minimal in the anaerobic catotelm (DAMMAN, 1986).

It might be assumed that decay would be largest in the wettest, but not anaerobic parts of the bog surface, represented in the peat stratigraphy by the lowest sections of each cycle, but this is not supported by the physical and elemental data (Figs. 2 and 3). The fiber percentage is highest in the lower portion of each cycle. If, as JOHNSON (1977) has suggested, fiber percentage is negatively correlated with degree of decomposition, then more decay has occurred in the later, upper part of each cycle. This agrees with the bulk and water retention data, and with the observations made on the condition of the macrofossils. Pollen concentrations for those taxa within the pollen sum, the regional producers, are highest in the upper sections of each cycle (Fig. 5). These differences do not appear to be attributable to increased local pollen production. Perhaps high water tables and fast *Sphagnum* growth in the stage immediately above the recurrence surface caused rapid consignment of the peat to the catotelm.

#### MECHANISMS FOR CYCLIC CHANGES

The preceding evidence indicates that the light/dark cycles reflect changes in community composition, habitat moisture, nutrient availability and rates of peat accumulation. The light areas appear to be formed from remains of plants adapted to living in a wet, relatively nutrient rich environment. *Sphagnum* productivity was probably high and decomposition rate low. Peat accumulation was rapid. Slowly these wet areas became drier and poor in nutrients. Peat accumulation decelerated because of greater aeration and increased oxidation and lower productivity in the biomass. *Empetrum* and Ericaceae were the most likely dominants, though *Sphagnum* was still common. At the recurrence surface there was an abrupt change from a dry, slow-growing community, to a wet, fast-growing community. The cycle appears to be ca. 700 calendar years (Fig. 5, Table I). Cyclic patterns similar to those identified above has been attributed to a number of mechanisms:

##### A. Hummock-hollow succession

This theory, also known as the regeneration cycle theory, was proposed by Swedish researchers early this century, and had general acceptance by the 1930's. BARBER (1981) has provided a history of its development and demise. In hummock-hollow succession, it is proposed that hollows accumulate peat rapidly, but that accumulation on hummocks is low. The slow growth on hummocks may be attributable to low productivity, or to oxidation, subsidence or erosion (BARBER, 1981). MALMER (1986) notes that pH is lower, redox potential higher, and decomposition more complete on hummocks, than in adjacent hollows. The hollow accumulates material so rapidly that the growing surface rises above that of the hummock, until the latter becomes a hollow.

TABLE I  
*Radiocarbon Dates*

Profile A :	
<sup>14</sup> C	Adjusted dates
Base of upper cycle : 4030 ± 70 BP (Beta-6830)	4614 BP
Base of lower cycle : 4560 ± 100 BP (Beta-6831)	5302 BP
Profile B :	
<sup>14</sup> C	Adjusted dates
Base of upper cycle : 4220 ± 70 BP (Beta-6832)	4824 BP
Base of lower cycle : 4720 ± 70 BP (Beta-6833)	5542 BP

All samples were peat. Prior to benzene synthesis and counting each was subjected to hot acid to remove carbonate, then rinsed to neutrality, dried, and combusted. Adjusted dates from KLEIN *et al.* (1982).

This succession should result in a series of lenticular structures although compaction of the horizons may reduce the resolution of these features. GLASER and JANSSENS (1986) report interlocking layers rather than continuous horizons in bogs from Labrador to Maine, but those in eastern Newfoundland seem to be continuous over large areas. The planar, continuous horizons in the peat faces are not compatible with hummock-hollow theory. Similar stratigraphies in northwest Europe and extensive studies of the ecology of *Sphagnum* contradict the theory (RATCLIFFE and WALKER, 1958 ; WALKER and WALKER, 1961 ; CLYMO, 1965, 1970, 1973).

##### B. Climatic fluctuations

The Blytt-Sernander scheme for the climatic episodes of the Holocene, based largely on the peat record, inevitably tied climatic change to peat stratigraphy. WEBER (1900) recognized a "grenzhorizont" (boundary horizon) at the Sub-Boreal/Sub-Atlantic transition. GRANLUND (1932) identified five recurrence surfaces. Both attributed the stratigraphic changes to climate. Light horizons represented cool and wet conditions, while dark, humified peat was the product of warm, drier conditions. The sharp boundary of the recurrence surface was attributed by Granlund to active peat accumulation in response to rapid climatic deterioration. This implies progressively cooler and wetter conditions. It also invokes a general rapid response. Unidirectional climatic change is untenable. Recent studies have shown that recurrence surfaces are considerably time-transgressive (MOORE and BELLAMY, 1974). However, a strong relationship between peat stratigraphy and climate has been demonstrated by BARBER (1981), and DICKINSON (1975) has claimed to recognize two of Granlund's recurrence surfaces in peat sequences from Cumbria.

The apparent cyclicity of the stratigraphic changes at the study sites eliminates catastrophic, episodic causes. Droughts are rare, non-periodic occurrences. The response of *Sphagnum* to drought is not well-known (CLYMO and



HAYWARD, 1982), although KATZ (1926) noted a die-off of *Sphagnum* over thousands of square kilometres when water tables dropped during prolonged drought.

Fire may be catastrophic in peatlands. *Calluna* is fire adapted (KEATINGE, 1975) as is *Empetrum*. Few charcoal fragments were found in the samples from the study area. Although WILTON and EVANS (1974) have estimated a fire rotation of 480 years for Newfoundland, it is more likely to be over 1000 years as WEIN and MOORE (1977, 1979) have calculated for fir-dominated forests in New Brunswick and Nova Scotia.

If direct climatic control is invoked, the apparent periodicity of the stratigraphic changes implies a periodic climatic forcing function. AABY (1976) has suggested that cyclic climatic variations with a 260 year periodicity are evident in the humification, macrofossil and pollen data from Draved Mose, but this is not supported by other proxy data. There is no evidence for a 700 year periodicity in climatic variability to explain the Newfoundland cycles. Recurrence surfaces in northwest Europe are time-transgressive. Those in north-eastern Newfoundland appear to be similar, although the chronology is presently only tentative. The lack of a synchronous, system-wide response, would appear to negate the concept of an exogenic forcing function, although FOSTER (1984) suggests that the regional scale of recurrence surfaces in Labrador implies climatic control.

#### C. Community effects on water table

As indicated earlier, each light to dark sequence appears to represent succession from wet habitat to dry habitat species. WALKER and WALKER (1961) suggested that such changes had a periodicity related to the life history of the dominant plants. GLASER and JANSSENS (1986) suggest that the banding may be related to the different dynamics of *Sphagnum* and lichens on the surfaces of bog hummocks. Similarly, DAMMAN (1978) attributes the cycle to the abilities of the wet habitat species to elevate the growing surface faster than the water table can rise. The dry habitat species that replace those that favour wet conditions have a more decomposed residue with high water retention capability. Thus, hydraulic conductivity declines, surface wetness increases, and wet habitat species are reestablished (RYCROFT *et al.*, 1975; DICKINSON, 1975).

The cycling of vegetation is dependent on the impact of communities on the physical properties of the surface, and independent of exogenic influences. DICKINSON (1975) has used this explanation to account for the extensive recurrence surfaces encountered in Cumbria.

### CONCLUSION

The cycles of light to dark peat appear to reflect differences in community composition at the growing surface. The light peat was formed in a wet, relatively high nutrient environment. It is dominated by *Sphagnum* macrofossils and spores. The dark peat at the top of each cycle was formed in a drier environment. Although *Sphagnum* was dominant, heath was important. Accumulation rates were

relatively low, probably because of high humification, although productivity is likely to have been less than that of wet sites.

The cycles appear to have a periodicity of ca. 700 calendar years with variable lagtimes dependent on position on the bog, although presently this must remain highly conjectural. The periodicity supports a formative mechanism involving endogenous changes related to community composition, life cycles and associated hydrologic responses, rather than exogenic, climatic stimuli.

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